

# AERONAUTIC RADIO

*A MANUAL FOR OPERATORS, PILOTS,  
RADIO MECHANICS*

*By*

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## PREFACE

Radio has become part and parcel of aeronautics. Many pilots and ground men are now required to hold radio operators' licenses. Aeronautic radio offers splendid opportunities for interesting and worthwhile employment.

"Aeronautic Radio" is for all persons interested in any phase of the subject—students, mechanics, operators, pilots, and air transport operations executives. All should be benefited by familiarity with the contents of the volume.

In preparing this manual the author has been guided throughout by two considerations: (1) the requirements of the Federal Communications Commission as to aviation radio operators' licenses and the regulations of the Civil Aeronautics Authority as to radio in aeronautics, especially its use by pilots, both commercial and private; and (2) the actual approved usage of existing aeronautic radio equipment for both communication and special purposes, such as course guidance and instrument landing.

The first eleven chapters, carefully studied, should prepare the average person to pass the theoretical part of the examination for an aviation radio operator's license. The next five chapters explain the special applications of radio to aeronautics. Those thoroughly covering the book should be well prepared to acquire quickly skill in the operation of radio equipment and to understand readily manufacturers' instructions for the installation and maintenance of apparatus.

Only by drawing on the knowledge of many specialists identified with aeronautic radio in one way or another has it been possible to prepare a book presenting a complete picture of this field in aspects both of manufacture and operation. Fortunately "all hands" have given unstinted help in supplying essential information. For their assistance I am deeply grateful. Names of the companies follow:

Aero Digest, Aeronautical Radio Company, Aeronautical Radio, Inc., Aerovoice, Inc., Air Associates, Inc., Air Radio,

Air-Track Mfg. Corp., American Airlines, Aviation, Bendix Radio Corp., Boeing School of Aeronautics, Breeze Corporation, Bureau of Air Commerce, Civil Aeronautics Authority, Dallas Aviation School and Air College, Eclipse Aviation, Fairchild Aviation Corp., Federal Communications Commission, Lear Radio Developments, Inc., International Telephone Development Co., Inc., Parks Air College, Inc., Pioneer Gen-E-Motor Corp., The Prest-O-Lite Battery Co., Inc., Radio Navigational Instrument Corp., Radio Receptor Co., Radio Corporation of America Manufacturing Co., Inc., Titeflex Metal Hose Co., Western Electric Co., Willard Storage Battery Co.

I wish also to make special acknowledgment of the help of Major C. R. Johnson, United States Army, whose strict criticism has set a high standard of aspiration in preparation of the book.

MYRON F. EDDY

March, 1939

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# AERONAUTIC RADIO

# CHAPTER 1

## AVIATION RADIO COMMUNICATIONS

Radio is the art of communication by means of radio waves. Radio, in its many applications, is a large subject. The expression "radio communication" or "radio communications" is legally defined as meaning any intelligence, message, signal, power, pictures, or communication of any nature transferred by electrical energy from one point to another without the aid of any wire connecting the points from and at which the electrical energy is sent or received, and any system by means of which such transfer of energy is effected.

Contained in this coldly phrased definition lies the promise of big things to come. But to be of greatest value, radio must be understood and it must be controlled.

No other nation in the world affords its citizens as many privileges in the use of radio as does the United States. It is in order that this may be so and that all of the benefits of radio may be enjoyed by all of the people, with proper considerations for individual rights, that the Federal Communications Commission (F.C.C.) exists. The rules and regulations of this commission, together with the provisions of the Communications Act of 1934, have all the weight of law and apply to the use of radio in aviation as well as elsewhere.

Some of these governing factors are of particular importance to airmen, and are presented in this first chapter so that their effect on airline operation may be understood from the start. Do not think of these provisions of law as merely tiresome rules to memorize; rather, come to understand their object and the necessity for carrying out their spirit at all times. This attitude about "radio regs" is invaluable indoctrination for any airman dealing with radio because communications in aviation must be conducted in a legal manner if the fine traditions of aviation are to be maintained.



## Radio Services

There are three different radio services utilized in aeronautics. These services are defined by the F.C.C. in the paragraphs which follow :

*Fixed Service.* The term "fixed service" means a service carrying on radio communication of any kind between fixed stations.

Airlines maintain facilities for communicating between airports by radiotelegraph and radiotelephone and therefore maintain a fixed service; however, it is of a special nature. See "Aviation Service."

*Mobile Service.* The term "mobile service" means the radio communication service carried on between mobile stations and land stations, and by mobile stations communicating among themselves.

Airplanes in flight maintain mobile service by communicating with ground stations and with other airplanes by radiotelephone and radiotelegraph.

*Special Service.* The term "special service" means the radio communication service of radio beacons, radio direction finders, transmission of time signals, notices to navigators, standard frequencies, transmissions having a scientific object, and others not herein defined.

The Civil Aeronautics Authority maintains a special service particularly suited to persons who use the civil airways.

*Aviation Service.* The term "aviation service" means a radio communication or special service carried on by aircraft stations, airport stations, aeronautical stations, or aeronautical point-to-point stations.

It is this service, together with the mobile and the special service defined above, with which this book aims to deal.

## Radio and the Pilot

The important function of radio to the airman—especially the private pilot—is to keep him out of trouble. Airline pilots

know this; the itinerant pilot soon learns it to be true. Unforeseen dangerous flying conditions should be minimized by an exact knowledge of weather and fields. The pilot should know when to turn back, or not to attempt the flight in the first place. But once he finds himself in trouble, the only help outside the cockpit must come through his radio. He must know exactly what it will do. He must have confidence based on experience with radio. In the process of gaining this confidence he will learn that to make full use of the radio is not so simple as some of the popular newspaper and magazine articles would indicate. He must know or have aboard his plane identifying signals, frequencies, and weather broadcast schedules. If he has a transmitter as well as a receiver he should know exactly what distance range to expect of it for the altitude and time of day, and should know the call letters and frequencies and distances of the stations which can give him the information that is desired.

The most important of all radio facilities is the broadcasting of weather information. The weather broadcast procedure follows a fixed pattern. It is desirable for the pilot to learn this form so that the reports can be more accurately understood under adverse conditions.

The second most important facility available to pilots is the "radio range." The same 200 to 400-kc receiver is used for both "range" reception and weather; this receiver must be operated correctly. There are 133 Range Stations located throughout the United States, generally along established airlines and almost never more than 200 miles apart. These stations transmit radio signals which are projected along a fixed path over the surface of the earth that the pilot may follow; it may be pictured as a widening searchlight beam stretching across the country. Most airmen are familiar with the type of signal sent out by these stations.

There are 84 marker beacon stations located throughout the country which serve as radio "lighthouses" or "foghorns." These are of two classes. One is the low power (5-mile range) transmitter which sends a nondirectional identifying signal. This helps the pilot locate his position along a major range course. Another type of marker beacon is the low-power radio range which not only acts as a radio "lighthouse," but also acts as a

special runway radio-range direction indicator for some of the intermediate fields.

He should know some of the "must nots" in connection with flying the radio range and in the use of his aircraft transmitting equipment. If he uses a direction finder—required equipment aboard air transports—he must have a knowledge of the geographical position of the transmitting stations heard on it.

Perhaps most important of all to the pilot flying from one point to another in the United States is a knowledge of existing facilities and the methods by which they may be utilized.

### Radio Stations

The different kinds of radio stations are defined as follows :

*Station.* The term "station" means all of the radio-transmitting apparatus used at a particular location for one class of service and operated under a single instrument of authorization. In the case of every station other than a broadcast or amateur station, the location of the station shall be considered as that of the radiating antenna.

Sometimes a station antenna is remotely controlled. When taking a radio-compass bearing which is to be plotted, the geographical location of the antenna must be known by the radio compass operator aboard the plane so that the line of bearing may be correctly plotted on his chart.

*Mobile Station.* The term "mobile station" means a station that is capable of being moved and ordinarily does move.

Ships and other vessels are licensed as mobile stations. An airplane equipped with two-way radio is a mobile aircraft station.

*Portable Station.* The term "portable station" means a station so constructed that it may conveniently be moved about from place to place for communication and that is in fact so moved about from time to time, but not ordinarily used while in motion.

A radio transmitter installed in a truck would be licensed as a portable station. (Certain blind-landing systems, discussed in Chapter 13, use truck-mounted equipment.)

*Aircraft Station.* The term "aircraft station" means a radio station on board aircraft.

Such a station always carries at least one receiver and one transmitter. A transport airplane usually carries three receivers; two transmitters are generally installed on large craft.

In all cases transmitters are quartz-crystal controlled and may be of the single or "two-frequency" channel variety. The output is approximately 50 watts. The total weight of the transmitter, including power supply, control box, control cables, microphone, etc., is about 75 lb.; the transmitter unit is about 10 in. square. The transmitters used by airlines and itinerants are described in Chapter 10.

Each plane carries a communication receiver, a beacon receiver, and an emergency or auxiliary receiver. The communication receiver is a multifrequency crystal-controlled superheterodyne receiver having an output of the order of 1 watt and arranged so that either the pilot or co-pilot, or both, can control it. The beacon receiver is of the continuously variable type of superheterodyne and generally contains a provision for quick switching, usually by means of a relay and pretuned circuits at 278 kc for traffic control so as to make it unnecessary always to tune the receiver off the radio-range frequency. This receiver likewise is arranged for dual output and at times for dual control. It is usually controlled through a rotating flexible shaft which may be as much as 30 ft. in length.

Radiotelephone on the overland routes in the continental United States utilizes frequencies between 2600 kc and 6500 kc for communication between ground and plane. Figure 64, page 180, illustrates in general the transmission characteristics of various radio-frequency signals. Because of these characteristics, day communication is generally carried on at frequencies between 4500 and 6210 kc and night communication at frequencies between 2600 and 3500 kc.

At least one day and one night frequency are used by each plane. If a plane is used over more than one route or in more than one division, it is sometimes necessary to utilize as many as eight crystals in both the aircraft receiver and transmitter. On a

transcontinental flight, if a receiver or transmitter is not to be retuned or replaced, approximately four day as well as four night frequencies would be required. Some airlines interchange the equipment at main division points and utilize only two-frequency receivers and transmitters on the plane. Others employ larger equipment with more pre-set frequency channels and do not resort to interchanging equipment at division points. A complete set of aircraft equipment includes power supply, remote control equipment, etc. The total weight of all this is approximately 150 lb.

*Aeronautical Station.* The term "aeronautical station" means a station used primarily for radio communication with aircraft stations, but which may also carry on a limited fixed service with other aeronautical stations in connection with the handling of messages relating to the safety of life and property in the air.

It is common practice to utilize 400-watt multifrequency transmitters on the ground, quartz-crystal controlled. Quick frequency change by switching is utilized both at the ground station and on the airplane. Reception is accomplished through the use of superheterodyne receivers with crystal-controlled oscillators and arranged for quick switching between the various frequencies.

*Aeronautical Point-to-Point Station.* The term "aeronautical point-to-point station" means a station used primarily for fixed services in connection with the relay of messages destined for or originating on aircraft and relating solely to the actual aviation needs of the licensees.

## Communications Systems and Regulations

Aeronautic radio, the subject covered in this book, includes all of the subjects connected with the operation of the radio gear carried aboard aircraft and at the ground stations which serve aircraft. Radio sets aboard aircraft are for :

- (a) Communication purposes, or
- (b) Navigational aid.

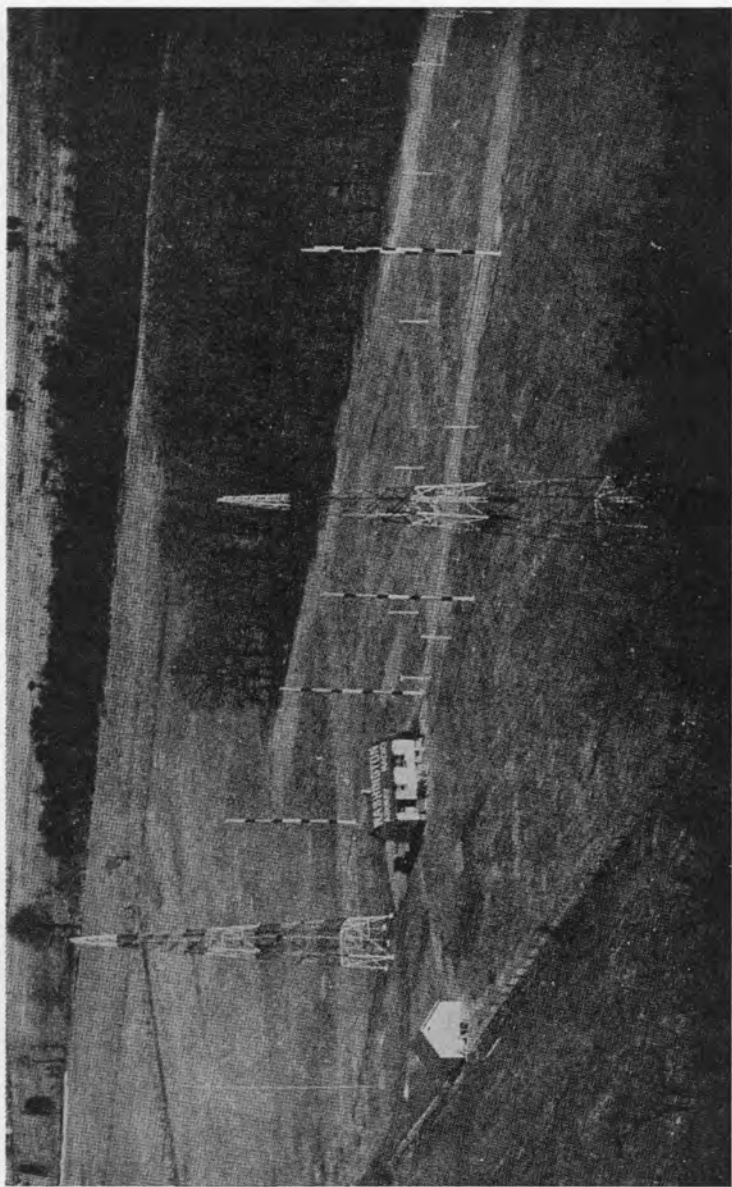


Plate I. Government Airway Radio Station

Federal ground stations have one or both of these two types of apparatus and in addition are on a teletype circuit. Private ground stations have radiotelephone transmitters and receivers and facilities for point-to-point communication.

### Aviation Communication Systems

In the aviation industry, radio plays its most important rôle, because in this field its chief purpose is to promote safety. It is not a cure-all and the men who handle radio in aviation must be competent if it is to perform its life-saving functions. All aviation communications systems are now functioning well; but all are subject to improvements. Systems will improve as the men who work with radio increase their proficiency. The student should learn as much as possible about existing networks and their administration first; then as much as possible about radio apparatus.

**Civil Aeronautics Authority.** The Civil Aeronautics Authority has general control over all (government) civil airway radio facilities. In addition, it regulates the use of radio by pilots and airlines. It issues an approved type certificate for radio equipment. The regulations of the C.A.A. pertaining to radio can be secured upon request.

The C.A.A. maintains a communication system along the federal airways for flyers without charge. Aviation messages are passed along from station to station by radiotelegraph, radiotelephone, and by teletypewriter. This Authority maintains radio range beacons and other aids to navigation. Messages between the ground and planes are sent by radiotelephone; course-guidance signals go out by radiotelegraph code. These U. S. government radio facilities are the finest in the world. Frequent revisions of airways maps are published by Civil Aeronautics Authority. Plate I shows an airways station.

**Airline Communication Systems.** Airlines also maintain communication systems between their fields and between the ground and airplanes. Practically all of the domestic transport companies use voice installations aboard aircraft. Radiotele-

phone, radiotelegraph, telegraph, and teletype link company stations in the United States. On Pan American and other foreign runs, radiotelegraph is much used both on planes and along the ground. On page 18 are shown the frequencies used by various airlines. (See Plates II and III.)

**Aeronautical Radio, Inc.** This is a nonprofit corporation having its main office at Washington, D. C., organized in 1929 from among a number of airline companies for the purpose of having a controlling body to which radio station licenses could be issued.

Aeronautical Radio, Inc., does not own any radio apparatus at the more than 250 ground stations and more than 350 aircraft installations licensed in its name. The ground equipment is owned by the respective airlines and leased to Aeronautical Radio, which arranges the licenses with the Federal Communications Commission for such frequencies as may be needed. The aircraft station is owned by and licensed to the air transport company operating the aircraft. The company does not dictate to the airlines their choice of radio apparatus or its servicing. Neither does it employ a single radio operator, on the ground or in the air. These, too, are provided by the respective airlines.

It does, however, through the lease agreement with the airlines, have unrestricted control over the use and operation of each station to the extent required by the F.C.C. license. It is responsible to the F.C.C. for proper mechanical and human operation of the equipment, though it does not own the radio apparatus, nor employ the operating personnel.

Cooperation necessary from the airlines is best manifested when a new operator requires radio services along an existing route or portions of several routes. Its mobile radio apparatus, installed in the airplanes, is licensed with the F.C.C. for the frequencies of the radio chain or chains where the new airline will operate. Before the license is obtained, Aeronautical Radio satisfies itself that the new airline's radio apparatus and personnel meet F.C.C. requirements. The new airline need not buy or operate its own ground stations; existing stations in the network extend their facilities and rearrange calling schedules. Similarly, private pilots are accommodated on any chain. All radio licenses





(Courtesy Western Electric Co.)

Plate II. Radio Ground Station of Eastern Air Lines at Atlanta, Georgia



(Courtesy Western Electric Co.)

Plate III. Radio Ground Station of Eastern Air Lines at Candler Airport, Atlanta, Ga.

for mobile equipment are taken out in the name of the operator, and for ground equipment in the name of Aeronautical Radio, Inc.

Established airlines meet Aeronautical Radio's expenses, less what is collected from feeder lines and itinerants. What they pay is apportioned on the basis of miles flown, not on the basis of radio contacts made. Thus, the pilots are not being discouraged from making as many contacts as may be needed for safe operation.

Similarly feeder lines which are neither stockholders in the company nor responsible for the perpetuation of its services, are charged on the per-trip basis.

Itinerant pilots, however, are charged \$1 per contact, or contacts, within a one-minute period, the charge including radio transmission of the message to the home base, if requested.

EXTRACTS FROM THE RULES AND REGULATIONS  
OF THE  
FEDERAL COMMUNICATIONS COMMISSION  
AVIATION SERVICE

(Revised May 10, 1937)

NOTE: These extracts which are supplied for information purposes should not be considered as giving all rules concerning these stations.

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247. The term "airport station" means a station of low power used only for communication with aircraft in the vicinity of an airport and/or for the transmission of radio range signals for the locating of the aircraft, and/or runways.

254. Airport stations will not be licensed to use more than 15 watts power for type A3 emission. Airport stations authorized to be used for the transmission of radio range signals may use power in excess of 15 watts for the transmission of these signals provided that the power is limited so as to not produce a field strength of more than 1500 microvolts per meter at one mile from the transmitter location, in the direction of the maximum field. An applicant desiring to base operating

power on the field produced must submit with the application for license requesting authority to transmit radio range signals a record of field intensity measurements made in sufficient number to insure accuracy in conformity with this rule. All data on the antenna resistance, complete description of the antenna system with dimensions and method of making field intensity measurements, and of relating these measurements to the operating power requested shall be submitted to and approved by the Commission before any license will be granted to operate by this method of power determination. If any change is made in the antenna system, or any change made which may affect the antenna system, the power of the airport station shall be immediately reduced to 15 watts until data are taken and approved by the Commission as provided in this rule.

255. Each licensee of airport, aeronautical and aeronautical point-to-point stations licensed only for non-public aviation service shall keep a record of the operation of each station, showing time of operation, frequencies used and stations with which communication was held.

The licensee of every station licensed to carry on aviation public service shall keep a record showing similar information and, in addition, a record of the messages handled.

An aircraft station not licensed for public service is not required to keep such records.

These records shall be made available upon request by authorized Government representatives.

256. In all cases herein where the word "day" occurs in connection with a specific frequency, such use of the word "day" shall mean that period of time included between 2 hours after local sunrise and 2 hours before local sunset. If, for any reason, it is impossible to shift from a day to a night frequency at the exact time required, such shift in frequency shall be made at the earliest possible moment. Under no circumstances shall the use of a day frequency be continued at night on an aircraft after such aircraft has once landed at one of the regular airports along its route, following the time when such shift is required to be made.

258a. The licensee of an airport station licensed to use the airport frequency shall without discrimination provide non-public service for any and all aircraft. Such licensee shall maintain a continuous listening watch on the aircraft calling frequency 3,105 kilocycles, and also be prepared to render a non-public communication service, during all hours of the day and night; provided, however, that upon application therefor the Commission may exempt any station from the require-

ments of this provision when it appears that in the preservation of life and property in the air the maintenance of a continuous watch by such station is not required. Except for test purposes radio range signals shall be transmitted only upon specific requests from aircraft desiring to use the airport served by the station and the transmission of radio range signals shall be discontinued immediately upon the landing of such aircraft. Before conducting tests the licensee shall determine that such tests will cause no interference on the assigned frequency or to other frequencies.

259. The Commission may, from time to time, designate certain airports at which the licensee of aeronautical chain facilities will be required to make arrangements for the installation and operation of a transmitter for the airport frequency, and maintain a listening watch on 3,105 kilocycles during hours to be specified. In cases of disagreement between various interests at an airport, as to the operation of the airport transmitter, the Commission will specify the arrangements.

260. Only one airport station will be permitted to an airport. Such station shall render a non-public safety service to any and all aircraft operators making use of the facilities of the airport. Communication between aircraft and airport stations shall be limited to the time when an aircraft is within 10 minutes' flight or 30 miles from the airport. Airport stations shall be used for safety purposes in the control of air traffic in the vicinity of the airport only. When airport stations are installed in adjacent airports arrangements must be made between the licensees for a system to prevent interference being caused by simultaneous operation. In the case of disagreement between the various interests as to the operation of airport stations the Commission will specify the arrangements.

262a. The frequencies assigned for aviation purposes are as follows:

*A. Distress, Calling and Navigation*

- 278 kilocycles, airport frequency: Calling and working frequency from ground stations to aircraft. Power not to exceed 15 watts.
- 3105 kilocycles: National calling and working frequency for all itinerant aircraft. It may also be assigned to transport aircraft in addition to the chain frequencies. Aircraft calling or working ground stations on this frequency will conduct a two-way communication by utilizing the 3105 kilocycles frequency for transmitting from aircraft to the ground and the 278 kilocycles frequency for the receiving from the ground to aircraft.

3120 kilocycles: National working frequency for all itinerant aircraft, this frequency to be used in lieu of 3105 kilocycles for working purposes on itinerant aircraft equipped for transmission on two frequencies; it shall not, however, be mandatory for aircraft not having a rapid means of frequency changing from 3105 kilocycles to 3120 kilocycles.

6210 kilocycles: Day only, for communication with stations of the C.A.A. under conditions when the frequencies 3105 and 3120 kilocycles are unsuitable.

**Other Channels for Aeronautical Use.** In addition to the foregoing frequencies allocated for aeronautical use, four channels in the 30-40 megacycle (Mc) band have been assigned for (flight) student instruction; six channels in the 129-132 Mc band for airport traffic control; and eleven channels in the 132-144 Mc band primarily for radiotelephone service with aircraft in flight.

The transmitter and receiver on an airplane constitute an "aircraft station" which is also classed as a "mobile" station; \* radio communication equipment used to communicate from the ground to aircraft or from one place to another constitutes a "fixed station" and is generally referred to as a "ground station." These aviation stations may use radiotelegraph, code, or voice or both, but are NOT broadcast stations as they do not handle commercial broadcasts.

Every station must be licensed. Every man who operates a station must be a licensed radio operator.

### Operators' Licenses

Pilots on domestic airlines are required to have a third class radiotelephone operator's license. Any person holding this license may also operate a ground station set as long as a second class operator is available if needed. However, most airlines require their ground station operators to hold a second class radiotelephone license, and a few airline companies in the United States hire only those who hold a second class radiotelegraph operator's license. Most foreign lines, including Pan American,

\* Unlike the sea-going vessel, which is also a mobile station, the airplane is not "open to international service of public correspondence."

## AIRLINE FREQUENCIES (KC)

Day	Night		Day	Night	
AMERICAN			NATIONAL AIRLINES SYSTEM		
5652.5	3232.5	{ New York—Boston—Montreal	5652.5	2946	Miami—Jacksonville
5612.5	3232.5	{ Cleveland—Boston	NORTHWEST		
5632.5	3257.5	{ New York—Buffalo—Chicago	5377.5	3005	Chicago—Seattle
		{ New York—Los Angeles	PENNA.—CENTRAL		
5602.5	3242.5	{ Cleveland—Nashville	5697.5	4335	Milwaukee—Washington
		{ Washington—Chicago	TRANS-CANADA AIRWAYS		
		{ Chicago—Fort Worth	5642.5	3212.5	
BOSTON MAINE AIRWAY			3105.0		
5887.5	2946	Boston—Burlington—Bangor	TWA		
BRANIFF			4967.5	3088	Pittsburgh—Chicago—Kansas City
5042.5	3452.5	Chicago—Brownsville	4947.5	3072.5	Kansas City—Los Angeles— San Francisco
CHICAGO & SOUTHERN			4937.5	3088	New York—Pittsburgh
5682.5	3485	Chicago—New Orleans	UNITED		
CONTINENTAL			5572.5	3162.5	New York—Chicago
5582.5	3172.5	Denver—El Paso	5662.5	3322.5	Chicago—Salt Lake
DELTA			5122.5	3147.5	Salt Lake—Oakland—Portland— Vancouver
5707.5	2854	Charleston—Dallas	5592.5	3182.5	San Diego—Oakland
EASTERN			WESTERN AIR EXPRESS		
4122.5	2922	New York—New Orleans	5692.5	2906	San Diego—Los Angeles—Salt Lake— Helena
		Chicago—Miami	PRIVATE FLYERS		
6590		New York—Miami	3105	6210	
HANFORD			Tulsa—Bismarck—Minneapolis		
5887.5	2994				

specify radiotelegraph, second, as minimum for any operating job on the ground or in the air.

As to the legal requirements, operator licenses are valid for the operation of radio stations as follows: †

**Radiotelephone Operator, Third Class.** Any station while using type A-3 or A-4 emission‡; provided that,

1. Such operator is prohibited from making adjustments that may result in improper transmitter operation.
2. The equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation.
3. Any needed adjustments of the transmitter that may affect the proper operation of the station are regularly made by an operator holding a first or second class license, either telephone or telegraph.

**EXCEPTIONS:**

1. The license is not valid for the operation of any of the various classes of broadcast stations other than a relay broadcast station.
2. The license is not valid for the operation of a coastal harbor station or a coastal telephone station.
3. The license is not valid for the operation of a ship station licensed to use types A-3 or A-4 emission for communication with coastal telephone stations.

**Radiotelephone Operator, Second Class.** Any station while using type A-3 or A-4 emission.

**EXCEPTIONS:**

1. The license is not valid for the operation of any of the various classes of broadcast stations other than a television, facsimile, high frequency, relay or experimental broadcast station.

† Extracts from Federal Communications rule 443 governing operator licenses, as amended to be effective April 1, 1938.

‡ Types of emission are defined on page 21.



2. The license is not valid for the operation of a ship station of over 100 watts power licensed to use type A-3 or A-4 emission for communication with coastal telephone stations.

**Radiotelegraph Operator, Third Class.** Any station while using type B, A-1, A-2, A-3, or A-4 emission; provided that, in the case of equipment designed for and using type A-3 or A-4 emission,

1. Such operator is prohibited from making adjustments that may result in improper transmitter operation.
2. The equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation.
3. Any needed adjustments of the transmitter, which may affect proper operation of the station are regularly made by an operator holding a first or second class license, either telephone or telegraph.

**EXCEPTIONS:**

1. The license is not valid for the operation of any of the various classes of broadcast stations other than a relay broadcast station.
2. The license is not valid for the operation of a ship station licensed to use types A-3 and A-4 emission for communication with coastal telephone stations.
3. The license is not valid for the operation of a radiotelegraph station on board a vessel required by treaty or statute to be equipped with a radio installation.
4. The license is not valid for the operation of any ship telegraph, coastal telegraph, or marine-relay station open to public correspondence.

In addition to the foregoing, there is a radiotelephone first class, and a radiotelegraph second and first class; the latter is attainable after one year of experience.

**Special privileges:**

1. An operator of any professional class may operate any station in the experimental service on a frequency above 30,000 kc in accordance with station license.
2. Subject to the limitations set forth above, the holder of any class radiotelephone operator license may operate a radiotelephone point-to-point station or a coastal telephone station while using A-1 or A-2 emission, for testing or other transmission entirely incidental to the service of such station.
3. The holder of a radiotelephone operator license of any class, when the license also certifies to his proficiency in International Morse Code (16 words per minute plain language, see Rule 436) may operate aircraft stations on *domestic* flights while using any type emission authorized by the station license.

**Types of Emission**

The various types of emission referred to above are as follows.

Waves of Class A include the following types:

Type A-1—Unmodulated continuous waves. Continuous waves, the amplitude or frequency of which is varied by means of telegraphic keying.

Type A-2—Continuous waves modulated at audible frequency. Continuous waves, the amplitude or frequency of which is varied in a periodic manner at audible frequency, combined with telegraphic keying.

Type A-3—Continuous waves modulated by speech or by music. Continuous waves, the amplitude or frequency of which is varied according to the characteristic vibrations of speech or music.

Type A-4—Television.

The term "radiotelegraph" as herein used shall be construed to include the following types of emissions:

A-1—C.W. (continuous wave) Morse telegraphy.

Printer.

Slow-speed facsimile.

A-2—Tone modulated I.C.W.

Special—High-speed facsimile, picture transmission, and special methods of keying and modulating not included in A-1, A-2, and A-3.

The term “radiotelephone” as herein used shall be construed to include the following emissions :

A-3—Commercial telephony, single and double side bands.

**How to Secure Operator’s License.** The applicant for a second class radiotelephone operator’s license will be examined in the following subjects :

1. Radio communication laws and regulations. (Rules and Regulations of Federal Communications Commission may be obtained from Superintendent of Documents, Washington, D. C.) The rest of this chapter is devoted to this subject.
2. General principles of electricity ; operation and care of storage batteries ; power supply apparatus. (These subjects are considered in Chapters 2 to 7.)
3. The theory, adjustment, operation, and care of radiotelephone transmitters ; receivers, including a diagram of an installation of both receiver and transmitter. (These subjects are covered in the chapters following Chapter 7.)

The examination for third class (radiotelephone) deals mostly with regulations.\* For third class radiotelegraph, a code test must be passed, otherwise this examination is much the same except that the diagram of a radiotelegraph transmitter must be drawn and the operation of the set explained.

Bear these things in mind as you go ahead : the basic theory in every case is the same ; knowledge of the regulations which apply to the various sets and services is very important.†

An applicant desiring to be examined for radio operator’s license reports in person to the nearest radio inspector and fills

\* Specifically, ten questions based on the radio provisions indicated in Title III, Part I, Title V and Title VI of the Communications Act of 1934, as amended.

† Aeronautics Bulletin No. 27, *Aeronautic Radio*, is an excellent and authoritative, yet simple, treatise on this subject. It is interesting, nontechnical, free. (Apply to C.A.A.)

out two application forms. He is then given a written examination in sections, each section consisting of from five to ten questions. A percentage of 75 constitutes a passing mark. In case of failure the applicant may not be reexamined for ninety days.

### Radio Regulations

The rules and regulations of the F.C.C. taken all together clearly indicate the proper way to conduct communications by radio. It is quite necessary for radio transmitters to be licensed, for if they were not, communication would be blocked continuously by interfering signals and there would be no agency having the power to prevent this.

Operators who man station transmitters also must be licensed, otherwise there would be no legal control over their activities.

Any one guilty of operating a licensed radio station without an operator's license is subject to a fine of \$500.

Only an American citizen may secure an operator's license.

Once secured, the license should be kept on the operator's person or posted in plain sight in the transmitter room where he is working.

The station license also must be conspicuously displayed in the transmitter room.

An operator holding a second class radiotelephone license is authorized to operate any radiotelephone station except a broadcast and an amateur station. A third class operator may operate an aviation radio station under ordinary circumstances where a second class man is in charge.

An operator may have his license suspended for any one of the following reasons: (a) Transmitting profane or obscene language; (b) maliciously interfering with other radio communications; (c) willfully damaging radio apparatus; (d) failing to carry out the lawful orders of his pilot; (e) violation of any of the conditions under which the radio license is granted, such as power, frequency, grade of license, etc.

If an operator violates any of the provisions of the Communications Act of 1934 he is liable for a maximum fine of \$10,000 and/or two years in prison. For violation of the Rules and Regu-

lations of the F.C.C., the maximum fine is \$500 for each and every day of offense.

It is unlawful to transmit not only indecent language, but also : propaganda against any department of this or any government, any fraudulent distress signal, any superfluous signal, any signals which maliciously interfere with other communications. There is a penalty of a fine up to \$10,000 and a prison sentence up to two years for divulging the contents or meaning of any message to any party other than the addressee or his agent.

All operators are obligated to adhere to the International Law pertaining to distress signals. Every station must keep watch for three minutes twice per hour beginning at the fifteenth minute and at the forty-fifth minute after each hour, Greenwich Mean Time, on 500 kc, the international distress frequency. Distress signals hold precedence over all other signals.

### **How to Learn the International Morse Radiotelegraph Code\***

It is the opinion of the author and of a great many other men who work with radio in aviation, that every radiotelephone operator should learn the radiotelegraph code early in his career. The pilot must be able to distinguish the designating call letters of the different beacons. Anyone listening in on a receiver ought to be able to "copy" code messages at a fair rate. It is for these reasons that the code is given here with the urgent advice that the reader attend some code class if possible; to learn the code by himself if necessary. It can be done; amateurs prove this constantly. Many different methods of learning to send and receive have been tried in the United States during the past twenty years. The Army has one system; the Navy another. Civilian schools having large classes in attendance naturally use methods that are different from those employed by small private schools which handle small classes and individual students.

To memorize the code, study the groups on page 27 in the order listed. Memorize each group, in turn, then send them. Do not attempt to memorize group (2) until you have proved to yourself

\* This section is from Lieut. Eddy's booklet, "How To Become An Amateur Radio Operator," included here by permission of the Publisher, *Short Wave Craft*.

**International Morse Code Signals**

LETTERS		NUMERALS
A .—	N —.	1 .— — — — —
B —....	O — — — —	2 .. — — — —
C —. — .	P —. — .	3 ... — — —
D —... —	Q — — — . —	4 .. — — — —
E .	R —. — .	5 ..... —
F .. — .	S ...	6 — — — . —
G — — .	T —	7 — — — . — .
H ....	U .. —	8 — — — . — .
I ..	V ... —	9 — — — . — .
J . — — — —	W . — — —	0 — — — — —
K — — .	X — . — .	
L — . — .	Y — . — — —	
M — —	Z — — . — .	

**PUNCTUATION AND OTHER SIGNS**

Full stop	(.) . . . . .
Semicolon	(;) — . — . — . — .
Comma	(,) . — . — . — .
Colon	(:) — — — . — . — .
Interrogation or REPEAT	(?) . — . — . — .
Exclamation	(!) — — — . — . — . — .
Hyphen or dash	(-) — — — . — . — .
Bar indicating fraction	(/) — . — . — .
ATTENTION (or call)	— . — . — . — .
UNDERSTOOD	.....
ERROR	.....
GO AHEAD	— . — .
END OF MESSAGE	— . — . — .
WAIT	— . — . — .
RECEIVED (acknowledgment of message)	— . — .
Double dash (separates preamble from address; address from text; text from signature)	(=) — . — . — .
FINISHED (end of work)	.....

The international signal of distress is .....  
(the letters **S O S** of the International Code)

by actual work on a practice set that you know group (1). You should react instantly and accurately without effort to each letter when it is sent to you before deciding that you know the entire group. When sending, each letter should register subconsciously, on sight, as a combination of dot-and-dash sounds. **E** should be reproduced as dit (the t in dit can be silent, if you prefer), **M** as dah, dah, etc.

Just as soon as you feel that you know all of the letters in each group as to their component sound parts, turn to your key. As you make **S**, for example, think of it so far as the key is concerned as dit dit dit—the sound which is **S**. Either pronounce the equivalent sound out loud in memorizing and sending each letter, or say it to yourself silently.

When you become tired while studying, rest a few minutes, then continue. It does not pay to concentrate to an extreme degree. Learn what you start out to learn perfectly, but you should not make hard work of memorizing the code because it is a simple, natural process, best accomplished when your mental attitude is the same as when playing a game.

**How to Learn to Send.** Learn to send by sending with a good practice set. Figure 74 is the circuit of an oscillator tube-type set which you should be able to construct with very little trouble or expense. If you prefer a buzzer set any of the simple practice sets on the market may be purchased.

Try to secure an adjustment of the set used which will give a fairly pleasing tone. In the tube set the amount of current regulates the tone; in the buzzer set, adjustments on the buzzer itself will change its tone.

**Directions for Keying.** First adjust the key by means of the set-screws until there is a small gap between contact points, and a medium tension on the spring. When manipulating the sending key, or "keying," you should hold down the key three times longer for a dash than for a dot. The time space to be allowed between the characters of each letter (the dots and dashes that make up the letter) should be the equivalent of one dot. Avoid a jerky manner of sending and do not try to send too fast.

MEMORIZING GROUPS

(1)

**T** dah  
**M** dah dah  
**O** dah dah dah

(2)

**E** dit  
**I** dit dit  
**S** dit dit dit  
**H** dit dit dit dit

(3)

**A** dit dah  
**N** dah dit  
**D** dah dit dit

(4)

**W** dit dah dah  
**J** dit dah dah dah  
**B** dah dit dit dit

(5)

**R** dit dah dit  
**F** dit dit dah dit  
**L** dit dah dit dit

(6)

**U** dit dit dah  
**V** dit dit dit dah  
**K** dah dit dah

(7)

**C** dah dit dah dit  
**G** dah dah dit  
**Q** dah dah dit dah

(8)

**Y** dah dit dah dah  
**Z** dah dah dit dit  
**P** dit dah dah dit  
**X** dah dit dit dah

(9)

**1** dit dah dah dah dah  
**2** dit dit dah dah dah  
**3** dit dit dit dah dah  
**4** dit dit dit dit dah  
**5** dit dit dit dit dit

(10)

**6** dah dit dit dit dit  
**7** dah dah dit dit dit  
**8** dah dah dah dit dit  
**9** dah dah dah dah dit  
**10** dah dah dah dah dah

(11).

**PERIOD** dit dit dit dit dit dit

**INTERROGATION** dit dit dah dah dit dit

**BREAK OR DOUBLE DASH (=)** dah dit dit dit dah

**ERROR** dit dit dit dit dit dit dit dit

(12)

**WAIT** dit dah dit dit dit

**END OF MESSAGE** dit dah dit dah dit

**END OF TRANSMISSION** dit dit dit dah dit dah

NOTE: You must remember the error sign from the start. You must learn to make this error sign every time you make a letter wrong.



The key should be held about as you hold a pencil—thumb on left side, second finger on right side, first finger mostly on top and on far edge. Keep your wrist limber; do not “grip” the key.

No one can actually teach you to become an operator. Almost any operator, however, can advise you as to good form in keying and you, yourself, must learn by listening to tell when you are sending “good clean stuff.”

It has been said that if any two amateurs would send the Bible to each other they would, by so doing, become operators. It will certainly help, in the beginning, if an experienced operator can be secured for sending to you and to listen to your sending. After learning the code, you can “copy” other amateurs on your receiving set; at first just a few of the simpler letters, then whole words and sentences.

Practice making dashes first. Try the letters **T**, **M**, and **O**. Then send the following series (Practice Exercise 1) over and over until your keying is smooth and effortless. Keep the letter close-coupled; that is, with proper spacing between the parts of each letter.

**PRACTICE EXERCISE 1.** This practice exercise contains the all-dash letters listed in memorizing group (1): **T** dah; **M** dah dah; **O** dah dah dah.

#### TWO-LETTER CODE GROUPS

TT	MM	OO	MO	OM	TT	MM	MT	MO	TM
TO	MO	TM	OT	MT	OM	TM	TO	OT	OM

#### THREE-LETTER CODE GROUPS

TOM	MOO	OTO	TOM	OMO	MOO
TTM	OMO	MMT	MMT	OTM	TMO
TOO	MTM	MOM	TOM	TMO	MTM
MOT	TMT	OTM	TOO	OMT	OOM
TMT	TOT	OOM	OOT	MTO	TOM

#### FOUR-LETTER CODE GROUPS

TOMO	TMTM	OTOT	MMOT	MOTO
MTMT	MOMO	TMOM	MOTT	OTOM
TMTO	MTTM	MTMO	TMOT	TOTO
OTMO	MTOM	TOTM	OMTM	TOOM
MOTO	OMTT	TOMT	OTMT	MOTM
OMOT	TOTO	TOMO	MOOT	OTTO

FIVE-LETTER CODE GROUPS

TOTOM	MTMOT	TOTTO	OTTOM
MOTMT	MMOOT	MTOMT	MTOMO
OOMTT	TOMTO	MTOTM	TOMOT
MOTTO	MTOTM	OTOMO	OMTTO
TOTMO	OMMOT	TOMOT	TMOTO
MOTOT	OTMTO	MOTTO	MTOMT
TMOTT	TMOTM	TOTOO	TOMMT
TOMOT	OTTOM	MTOMT	MOMOT
OTMOT	TOTOO	MOTOM	TOMOT
MOTTM	TOTOM	OMOTT	OMOTO

Watch your spacing in the above groups, both between letters and between groups. Notice that these groups can be sent from left to right, or backwards from right to left; also both up and down.

**PRACTICE EXERCISE 2.** Next send dots or dot letters such as **I, IS, E, EH, HI, HS, SI, and SE.** Prepare a drill exercise similar to the one which follows. As you write the letters in the drill exercise, say them mentally to yourself, using "dit" and "dah" instead of dot and dash. (Letter **E** is dit, **I** is dit dit, **S** dit dit dit, etc.)

This exercise is for sending and receiving the all-dot letters in memorizing group (2).

E I S H  
 . . . . .

TWO-LETTER GROUPS

EI	EH	SH	SI	IH
SS	II	HI	HS	EH
ES	IS	SE	IE	IE
HH	EE	HE	EI	ES

THREE-LETTER GROUPS

SIS	EIE	ESE	ISH	HIS
ESE	IEI	ISI	EIE	SIH
HSI	ISE	IHI	SHE	EIS
HEH	HSH	ESI	EHS	ISE
EHE	ISI	ESH	HIH	ESI
SIE				SEI

## FOUR-LETTER GROUPS

SISE	SHIS	HISH	HEHE	ISHE
ESHE	ISIS	SHIE	ISHE	SHEI
ISHE	SHEE	HSEI	SEIS	ISHI
HESE	HISE	HIHI	EHIE	EHIS
HISI	ESHI	SEHS	SISI	SISE
ISES	EIEI	SIES	HISH	HSIE
		SEHI		

The next combination to try is that of words made up of all-dot letters and all-dash letters. Try sending the following words :

It, set, hot, too, him, meet, totem, mites, items, met, home, his, he, me, mist, hot, test, net, sot, toes, some, mete, sim, miss, moss, sit, toss, tom, this, the, hem, otto, them, most, hoist, tee, motto, moist, stem, memo, theme, mess, smite, smote.

The next three letters to be added will be **A, N, D**. Try sending and receiving the following words : and, Dan, name, made, mad, man, hand, sand, an, tan, Nan, maid.

Now you can send and receive certain short sentences :

It is time to meet him. He is to see Tom at noon. Nan and Tom are Danish. She is a maiden. This time send the men. She met him one time. The man and maid seemed to see them.

**PRACTICE EXERCISE 3.** The following exercise contains the letters **EISHTMOAND** from memorizing groups (1), (2), and (3) on page 27.

## FIVE-LETTER CODE GROUPS

AISHD	DANAS	NINES	DISOM	SMITE
IDSNT	ANOMI	SAMES	DODOS	MISAD
NATID	DITES	MEDIN	OTDIN	DIDAN
ONSET	SNADS	TADAN	SEDNI	INISE
NADAT	MIDAS	MANDA	HDTAN	ADANE
NTMOA	NEADS	AIDIS	OTESA	DIDSN
ENTAH	NEATS	NANED	MADIN	HEOAD
ANADA	ADNAD	ODONA	OSTEA	SANDS

## Special Signals and Procedure

A mobile radio station (in this case an airplane) may call some other station, either airplane or ground even if their identity is not known by sending the letters **CQ**. This is followed by **de**

(from) and the call letters of the calling station, then followed by the letter **K** which letter means "go ahead."

The letters **P A N** by radiotelegraphy or radiotelephony are sent out from an airplane immediately preceding an impending forced landing—*not an impending crash landing*. In other words, when a pilot wishes to give notice of damage to the plane which compels the aircraft to land without requiring immediate assistance, these letters are sent.

The *distress* call which should be sent from an airplane by radiotelephone is *mayday*. This was originally adopted from the French *m'aidez* which means "help me." This should always be followed by the name or number of the plane or the call letters of the plane. If time permits, the approximate position of the plane should, of course, follow this broadcast distress signal. This is usually phrased in regard to what can be seen, as an example, "mayday mayday mayday trip nine over heavy timber beacon light dead ahead about 10 miles turning back turning back will try to make Platte Canyon both engines out."

The *distress signal* in radiotelegraphy consists of the letters **S O S**. This means that the airplane sending this signal is in grave and imminent danger and requests immediate assistance. A message should follow this call giving the name or number of the aircraft, its position, nature of its danger or its distress, and the kind of assistance desired. Airplanes usually attempt to include the line of action contemplated by the pilot in the impending emergency as "jumping" or "bailing out." The significance of these brief messages is readily understood by anyone receiving them. Any station hearing a distress signal shall first listen and NOT commence transmitting until it seems fairly certain that the distress transmission is complete; then take action unless some other station broadcasts acknowledgment and announces that it will take action. The action indicated is, of course, the securing of a promise by competent authority that help of a suitable nature will be dispatched to the scene of the expected crash. (Note that the radiotelegraph distress signals are sent on 500 kc which is the international calling and distress wave. The radiophone distress call "mayday" is sent on the frequency being used, not necessarily on 500 kc.)

The *urgent signal* consists of several repetitions of a group of **X**'s sent before the call letter of the station called; for example, **XXX XXX KFO de KFM**. This would be sent by telegraph to station Oakland by plane *K.F.M.* when the plane has a very urgent message to transmit concerning the safety of the plane or some other plane which he has in sight. This urgent signal has priority over all other signals except those of distress. All other planes stop transmitting and listen, after hearing this signal, whether they are addressed or not.

The *safety signal* consists of the letter **T** formed in a group of three, well-spaced, followed by the word **de** (from) and the call signal of the station sending it. It indicates that the sending station will immediately transmit a storm warning or message concerning the safety of navigation.

A pilot may order a distress signal sent at any time that he considers life or property to be in danger. If an airplane is following a maritime route, its transmitter must be adjusted to 500 kc. The order of priority of communication in mobile services is as follows:

1. Distress calls, distress messages, distress traffic.
2. Communications preceded by an urgent signal.
3. Communications preceded by the safety signal.
4. Communications relative to radio-compass bearings.
5. All other communications.

### Special Applications of Radio to Aviation

In the early days of commercial aviation, one-way and then two-way communication with aircraft was the first development. Then the government devised a system of navigation aids along the airways and commenced to broadcast weather messages while guiding transport and mail planes from one radio beacon to the next. In 1936 air traffic control by radio communication was established at several points and in Chapter 14 this system is explained. Blind landing of aircraft was first accomplished in 1932; in 1938 the government purchased and installed the first of a number of such systems, as explained in Chapter 9. Marker beacons of a new type also were installed during 1938 and many improve-

ments in other beacons were accomplished. The transmission of teletype messages by radio is under way; so also is facsimile transmission, and television is undoubtedly on the way.

The man who does not catch up with radio now and keep abreast of its developments will not be able to hold his own in aviation as he should, because the special applications of radio which are due to be incorporated far exceed the number of uses of radio at this time.

### QUESTIONS

1. What constitutes a radio station?
2. Must stations be licensed?
3. Who may legally operate a radio transmitter?
4. What authority licenses stations and operators?
5. May an alien secure an operator's license or a station license?
6. Where should an operator's license be kept? A station license?
7. If you secure a third class radiotelephone operator's license, will it authorize you to operate a broadcast station?
8. For what reasons may an operator's license be suspended?
9. If Rules and Regulations of the Federal Communications Commission are violated, what penalty may be imposed?
10. What is the penalty for: (a) Violation of the Radio Act of 1934? (b) Willfully damaging radio apparatus?
11. What matter is it unlawful to transmit by radio?
12. What is the law regarding secrecy of messages?
13. What is the penalty for transmitting obscene, indecent, or profane language?
14. What is the international law in reference to maintaining watch on distress frequency of 500 kc?
15. What communication holds precedence over all other communication by radio?
16. What is the (a) radiotelephone distress signal? (b) the radiotelephone urgency signal?
17. (a) Who has authority to transmit distress signals? (b) Under what conditions? (c) When may the signal be transmitted? (d) What transmitter adjustments are necessary for an aircraft following a maritime route?
18. (a) What are the regulations covering use of 278 kc airport transmitters? (b) What is the purpose of this transmitter?

19. What is meant by aircraft radio communication?
20. Explain the terms "special service" and "aviation service."
21. What kinds of radio stations are used in aviation?
22. Explain the function of the F.C.C.; of Aeronautical Radio, Inc.
23. What frequencies are available for aviation service?
24. What is meant by the term "aircraft station" and what is the rule governing the maintenance of a log by such stations?
25. What authority does the C.A.A. have in regard to aviation radio?
26. Why is radio along the airways important to the private pilot in good weather, in bad weather? (Note: If practicable, this question should be discussed with some pilot in connection with existing regulations governing "flight plans.")
27. List government airway radio facilities; private (airline) facilities.
28. What radio equipment is obligatory for an air transport?
29. What is the scope of examination an applicant must pass in order to secure a radiotelephone operator's license, third class? a radiotelegraph operator's license, second class?

#### TERMS TO BE STUDIED

Look up the definitions of these radio terms in Appendix II: 221, 255, 81, 191, 19, 9, 1, 25, 68, 90, 176, 213.

## CHAPTER 2

### FUNDAMENTALS OF ELECTRICITY

#### Introduction

As employed in this book, Aeronautic Radio includes all the applications of radio to aeronautics. The most common applications are the transmission of voice and the radio aids to navigation.

The approach to any technical subject is made easier if the fundamentals are thoroughly mastered. Radio is based on the principles of electricity. For this reason, the student of aviation radio should have a clear conception of the natural laws governing electricity. It is not necessary that electricity itself be defined in the mind, nor that the fundamental reason for its existence be known. It is necessary, however, that the principles governing its use be thoroughly understood.

This applies particularly to students who have had no previous instruction in elementary electricity; they probably will need a more complete text that will elaborate on the condensed information of this chapter. Instructors should advise them relative to supplemental texts that ought to be studied.

Readers who do not have the help of an instructor should make certain that they understand the different manifestations of electricity. Current electricity appears to flow or move through a circuit. Static electricity is stored in a condenser or circuit and is discharged as electrical energy. Current electricity is either unidirectional or alternating in its flow. Direct current from a battery is unidirectional, ordinarily of constant strength, but it can be made pulsating by certain apparatus.

Current that alternates rapidly in direction at different rates may properly be designated as radio-frequency, audio-frequency, or oscillating current. If oscillating, it may or may not be of constant amplitude. Alternations of low frequency, such as the



common 60 cycles per second of house lighting circuits, are quite different from the higher frequencies employed in radio. All of these terms must be familiar while thinking or reading about radio equipment. Associated with the forms of electricity are the units of pressure, flow, and resistance. Their relationship must ever be present in the mind in order to understand the action in a circuit.

In order to acquire basic knowledge of alternating current and how it is handled, it is necessary to understand capacity and inductance. In the study of alternating current circuits these two characteristics should be associated with condensers and inductors. Wire should be recognized as an electrical path; insulation as a bar to the flow of current, and resistance as a control of flow.

In taking up the study of vacuum tubes, bear in mind that they are the most important items of all radio apparatus. The tube is the most essential part of both the transmitter and the receiver. Retain a mental picture of the elements in a tube and their position in regard to each other. Know the action that takes place between these parts.

It is customary for the manufacturers to provide a circuit diagram with each set. Therefore, it is essential that students attain facility in interpreting these diagrams by frequent practice in tracing the component parts. Teachers are advised to require much of this on the part of their students. A variety of circuit diagrams are included in this book to be helpful in that direction. Every student should be required to memorize the basic radio circuits of receivers and transmitters.

The definitions of terms that are employed in radio engineering and the symbols that have been adopted for circuit diagrams and other illustrations pertaining to radio engineering will be found in the Appendix. When a raised number follows a word in the text, that word is listed and defined in Appendix II.

To most readers, this chapter will be a review of elementary electricity studied at some former time. The review will be brief in this case and should result in an added feeling of confidence in approaching the more technical chapters that follow. To one who has not studied electricity before, this chapter is more important.

It will be the foundation for everything that appears later in this book; therefore, it should be carefully studied as a whole and then reviewed by sections.

The "why and wherefore" of electricity is difficult to explain to the satisfaction of the ordinary person. Scientists seldom attempt to define electricity to the layman. If students understand the manifestations of electricity, that will be sufficient for practical purposes. Theories regarding the nature of electricity have changed as progress has been made in research. The most modern and the most useful is the electron theory. This is quite generally accepted at the present time and is presented here as the first subject. It is not within the province of this text to prove or disprove the electron theory. It is not essential that it be proved in order to have a proper understanding of aircraft radio. The electron theory provides an excellent vehicle for electrical thoughts, however, and should be grasped before the more conventional presentation of electrical facts is studied. It is the only theory that satisfactorily explains the action of the radio tube.

### Electron Theory

**Matter.** Matter is anything, solid, liquid, or gaseous, that is acted upon by gravity. Each kind of matter is composed of *molecules*, which are the smallest particles that can be identified as a part of any substance. Molecules are made up of one or more *atoms* which are the smallest particles of matter that can be obtained by chemical action. Molecules retain their identity as part of a known substance; atoms do not.

We know of 94 different kinds of atoms of varying weights and sizes, generally called the "chemical elements." All existing substances are these elements alone, such as mercury, or comprising some combination of them. For example, cane sugar will be found to be composed of 22 atoms of hydrogen, 12 atoms of carbon, and 11 atoms of oxygen. Hydrogen is the lightest atom in weight. The lead atom weighs about 216 times more than the hydrogen atom.

**Electrons.** An electron is a minute charge of negative electricity. It is not matter, but it exists as one or more portions of

each atom of matter while the remaining portion, or nucleus, may be considered as a minute charge of positive electricity.

In the normal atom, which shows no electrical properties, the electrons are conceived as revolving about the nucleus with inconceivable rapidity. The number of electrons in the normal atom is approximately equal to one-half the atomic weight of that element.

A negatively charged body is one which has obtained more than its normal number of electrons. An atom in this condition is called a negative ion.

A positively charged body is one that has lost some of its electrons. Atoms that have lost some electrons are called positive ions, or protons; they attract electrons.

Electrons that are lost from atoms do not remain free, but seek positive ions. Negative ions repel electrons. If an atom is changed to either a positive or negative ion, we say that it has been ionized.

**Emission of Electrons.**<sup>81</sup> Electrons can be produced by emission. To accomplish this, a suitable metal, such as tungsten, is placed in a vacuum and subjected to a high temperature. The metal may be heated by passing an electric current through it or by some other means. When the metal is sufficiently heated, electrons are emitted from the surface at an initial velocity which is proportional to the temperature of the heated metal. The average velocity of electrons so emitted is many miles per second but the distance traveled from the surface from which emitted is very slight. The number of electrons emitted from any metal (called a cathode) depends upon the kind of metal, the condition of its surface, and temperature. The more electrons emitted from the cathode, the more positively charged the cathode becomes. However, the positive charge on the cathode remains at all times equal and opposite in polarity to the sum of the charges on all electrons that have been emitted. Therefore, all electrons eventually return to the cathode. From this it will be seen that the function performed by a cathode as described is to make available in its near vicinity a supply of electrons, the emission continuing while the proper temperature is maintained in the cathode.

**Thermionic Currents.** If a plate of metal is placed near a cathode that is emitting electrons and a difference of potential is maintained from an outside source so that the plate (called an anode) remains positive with respect to the cathode, current will flow. The path of this current flow will be from the anode through space to the cathode, and from the cathode through the outside source back to the anode. This is called a convection current, or a thermionic current. It is carried by electrons in a high vacuum; by both electrons and ions when gas is present.

The positively charged anode attracts the electrons as they are emitted from the cathode. The extent to which electrons are attracted is governed by the degree of positive potential maintained on the anode. However, the anode attracts all electrons emitted when the electric field at the surface of the cathode is zero or negative. Each electron emitted overcomes a retarding potential as it leaves the surface of the cathode before it is carried to the anode.

The foregoing remarks are made here in connection with the electron theory. The complete action taking place within tubes is explained in Chapter 5.

**Electron Theory of Magnetism.** Electrons revolving about the nucleus of an atom constitute a magnetic action. If there are just as many electrons revolving in one direction as in the other, the atom will not be magnetizable. When this type of (non-magnetic) atom is in a magnetic field, it is diamagnetic, that is, a repelling action occurs. The atom is called paramagnetic when a greater number of electrons are revolving in one direction about the nucleus of the atom than the other. In this case it is believed that the rate of travel of the electrons and the planes of the electron orbits are changed. There is also an indication that the atoms themselves are rotated by the inducing field.

Ordinary bar magnets are considered as consisting of a number of tiny elementary magnets. Before the bar is magnetized, it is held that these elementary magnets form closed loops among themselves, similar to that of a horseshoe magnet with a "keeper" bar across the two poles. In this condition there is no magnetism exhibited externally. When partially magnetized, these elemen-

tary magnets are supposed to be partially straightened out. When the bar is fully magnetized, the elementary magnets theoretically are all turned in the same direction. The more elementary magnets that are turned in one direction, the more powerfully is the iron bar magnetized.

If a bar magnet is suspended in the middle, free to swing, it will point toward the general direction of the geographical north pole. This end of the magnet is referred to as the north-seeking pole, or more commonly as the north pole. The opposite end is known as the south pole. Unlike poles tend to attract each other; like poles repel.

A unit magnetic pole is one which, when placed at a distance of one centimeter in a vacuum from an equal and like pole, repels it with a force of one dyne. The laws of magnetism are closely akin to those of electricity. Magnetic fields have the same general manifestations whether produced by permanent magnets like the bar magnet, by electromagnets, or by wire circuits in which electric current flows.

**Static Electricity.** A charged body possesses static *electricity*. The space in which it exerts an electric force is called an *electrostatic field of force*. The amount of this force between small charged bodies varies inversely as the square of the distance between them and is a force of repulsion if both bodies are charged either positively or negatively; it is one of attraction if they are of opposite polarity to each other. The intensity of the electrostatic field is influenced by the medium through which the force is acting. This insulating medium is called a *dielectric*.

### Current Electricity

**Potential.** The force which tends to discharge a body is called *potential*. The more electrons present therein, the more potential. Potential is synonymous with electrical pressure. (Impressed or applied e.m.f., line e.m.f., and line voltage all mean the same.) If there is a difference in potential, the electrons will move to equalize this difference and we say that a current of electricity flows, liberating heat and causing chemical or magnetic effects. The current or electron path of flow is confined to conductors

having little resistance and great conductance; controlled by insulators having considerable resistance and little conductance.

**Units.** A *volt* is the unit of electromotive force (e.m.f.) or potential. (Symbol is *E*.)

An *ampere* is the unit of current flow. (Symbol is *I*.)

An *ohm* is the unit of resistance. (Symbol is *R*.)

The following prefixes are applied as indicated to the various electrical units:

Prefix	Abbreviation	Meaning
"deci"	d	one-tenth part of
"centi"	c	one-hundredth part of
"mil or milli"	m	one-thousandth part of
"micro"	$\mu$	one-millionth part of
"pico" or "micro-micro"	$\mu\mu$	one-millionth of one-millionth part of
"deka"	dk	10 times
"hekto"	h	100 times
"kilo"	k	1,000 times
"mega"	M	1,000,000 times

**Ohm's Law.** One volt will force one ampere through one ohm. From this law the following formulas are developed:

$$E = IR$$

$$I = E \div R$$

$$R = E \div I$$

Where  $E$  = volts,  $R$  = ohms,  $I$  = amperes.

**Electrical Power.** The watt is the unit of electrical power. (Symbol is  $W$ ). Volts multiplied by amperes equal watts. Or, using the symbols:

$$E \times I = W$$

But,  $E = I \times R$

Substituting, we have  $I \times R \times I = W$ , or  $I^2 R = W$ .

**Quantity.** When one volt forces one ampere through one ohm in one second, a quantity of electricity called one *coulomb* will flow (628 million-million electrons) and an amount of energy called one *joule* will be expended.

**Current.** When current flows through a wire, the conductor is heated; it has an electromagnetic field around it; it may retain a static charge (or field) after the current flow ceases and the wire has cooled. The propagation of radio waves is brought about by employing magnetic and static fields.

**Direct Current.** Current that flows through a circuit of conductors and apparatus continuously in one direction is called *continuous current* (c.c.) or *direct current* (d.c.).

**Alternating Current.** Current which flows through such a circuit, first in one direction and then in the opposite direction, is called *alternating current* (a.c.)

**Sources of D.C.** Aside from the d.c. generator, the primary cell is one of the most familiar sources of direct current. It cannot be recharged. The *storage* or *secondary* battery stores chemical energy which is liberated as a.c. electrical energy. Chapter 6 deals with batteries.

### Simple Circuits

**Series Circuit.** If the circuit contains apparatus connected in succession one to the other, it is called a *series* circuit and the

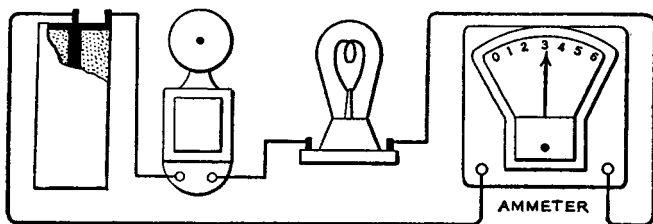


Figure 1. A Series Circuit

Ammeters are always connected in series as shown. Assume that the resistance of the lamp is 0.2 ohm and the bell 0.3 ohm. The voltage drop across the lamp would be the product of the ammeter reading, 3, multiplied by 0.2, which is 0.6 volt, while across the bell it would be  $3 \times 0.3$  or 0.9 volt. If two similar cells were connected in series for the source, the voltage drop in each case would be doubled, because the ammeter would read 6.

resistance is additive. (See Figure 1.) The difference in potential or voltage across any apparatus or any other portion of a series circuit equals the current multiplied by the resistance of that portion of the series circuit. ( $E = I \times R$ .) If cells are connected

in series (from positive to negative terminals in sequence), the total voltage of the source is the sum of the voltage of the cells so connected. If in parallel, the amperage is additive. Two or more cells constituting a source are called a *battery*, no matter how connected.

**Parallel or Shunt Circuits.** The two terms, parallel or shunt circuits, are synonymous. Voltmeters are always connected in shunt. (See Figure 2.) Here the same voltage is applied to two lamps. If their resistances are the same, each will take the same amperage. Assume that A has a resistance of 100 ohms. The current flow through it will be 1 ampere. The current through B

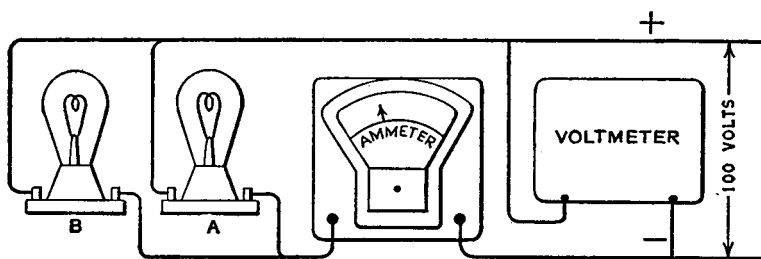


Figure 2. Parallel Circuit

will also be 1 ampere so that 2 amperes will register on the ammeter. In this case each lamp is a 100-watt lamp. Note, however, that as the current is 2 amperes, the combined resistance of both lamps in parallel must be less than the resistance of one. This is logical, for with two paths the combined resistance is naturally less than with one. This is expressed by saying that the *conductance* is greater. The conductance is always numerically the reciprocal of the number of ohms. Its unit is "ohm" spelled backward: *mho*. In this particular case the resistance of both lamps together is exactly half the resistance of one ( $100 \div 2 = 50$ ), and the conductance is, therefore,  $1/50$  mho. If another similar lamp was lit, the resistance of one lamp would be divided by three to find the combined total.

This is the rule for resistances in parallel: the total or joint resistance will equal the reciprocal of the sum of the reciprocals.



If the resistances are equal, their joint resistance will be found to be equal to that of one resistance divided by the number of resistances connected in parallel.

In the above circuit (Figure 2) assume that A has 100 ohms resistance and B 200. Then the reciprocals are  $1/100$  and  $1/200$ . Added, the sum of these reciprocals is  $3/200$  and the reciprocal of this is 66.66, which is, then, the ohms resistance in the circuit. This can be checked. By Ohm's Law (dividing the line voltage by each lamp's resistance), we can determine that A takes 1 ampere and that B takes 0.5 ampere. The line voltage, 100, divided by this total amperage, 1.5, also gives 66.66 ohms, which checks. What size lamps are they?

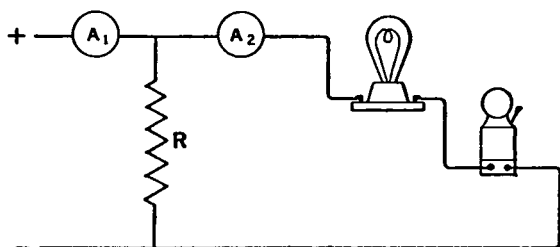


Figure 3. Series-Parallel Circuit

A takes 1 ampere and has a resistance of 100 ohms.  $1^2 \times 100 = 100$  watts. *Answer.*

B takes 0.5 ampere and its resistance is 200 ohms.  $0.5^2 \times 200 = 0.25 \times 200 = 50$  watts. *Answer.*

Assume that a 900-watt lamp takes 9 amperes. What is its resistance? ( $I^2R = W$ .)

In this case  $W = 900$  watts, as stated; also  $I = 9$  amperes; consequently,  $I^2$  becomes 81.  $81 \times R = 900$ . Therefore,  $900 \div 81 = R$ . Dividing 900 by 81 as indicated,  $R$  is found to be 11.11 ohms. *Answer.*

Also: If the wattage is 900 and the amperage 9, the voltage must be 100, because by algebra watts divided by amperes give volts. ( $W = EI$  or  $E = W \div I$ .) If the voltage is 100, that number divided by the 9 amperes will give the resistance resulting in the quotient, 11.11, which also checks.

**Series-Parallel Circuits.** (Also called *series-shunt*.) An example of a series-parallel circuit is shown in Figure 3. The resistance  $R$  is shunted across the source. The lamp and bell are in series with the line from the source and therefore with each other, but together they are in parallel or shunt with  $R$ . With a source of 100 volts, there will be this same voltage across  $R$  and also the same 100 volts across the lamp and bell together; but separately considered, the drop of potential across the lamp and bell will be the product of their combined resistance and the current flowing through them. If their combined resistance equals that of  $R$ , their current will also equal that through  $R$ , and if the resistance of the lamp and bell together is equal, the voltage across each will be half the total, in this case 50. In this circuit, ammeter  $A_2$  will not register the current passing through  $R$ .

If the lamp burns out, the bell will not ring; if the bell is removed and the circuit connected again, the lamp will get the full 100 volts. Disconnecting  $R$  will not affect either the bell or lamp.

**Drop of Potential in Line.** Referring to Figure 3, suppose that the conductors connecting  $R$  had a resistance of 1 ohm and that the line beyond had 0.5 ohm. With 4 amperes flowing in the first "leg," the loss up to  $R$  would be  $4 \times 1 = 4$  volts. ( $IR = E$ .)

There would also be a loss of power in the line up to this point of  $4^2 \times 1 = 16$  watts. (By the  $I^2R$  formula.) There would be a further line drop in voltage across the second leg (consisting of the lamp and bell) equal to the current flowing there, 2 amperes, multiplied by the second leg line resistance of 0.5 ohms which is 1 volt.

It becomes evident that loss in line voltage and wattage is to be avoided by using extremely low resistance conductors and this is done in wiring aircraft radio sets.

## Conductors, Resistances and Insulators

**Conductors.** The resistance of a conductor depends upon the material, its cross-sectional area, and length. With a uniform wire, the resistance increases directly in proportion to the length. Wire sizes are given in thousandths of an inch (mils) in

diameter, in circular mils or by reference to the American Wire Gauge which expresses the sizes in numbers—the larger the number, the smaller the wire. Three sizes of increase, by number, will halve the resistance. Six sizes increase will double the diameter; resistance will then be  $\frac{1}{4}$  that of the size in comparison. For ordinary uses, the resistance of wires will not increase unless overheated and they will not overheat unless made to carry more current than they are designed to carry. Aluminum wire is much used in radio sets because it is light and fairly rigid. Stranded phosphor-bronze antenna wire is popular because of its strength and low resistance.

**Resistance.** Resistance material should be cheap, durable (especially when heated in service), and of high ohmic resistance so that its bulk is not great. Iron is used where much power is handled; nickel-steel and German-silver wire are found in radio sets; also special alloys such as manganin and invar are gaining popularity. Resistance coils are called resistors.

**Insulators.** Slate, marble, wood, hard fiber, and phenolic material like bakelite are used as insulators rather than resistances because the resistance that they offer to current flow is very high. Humidity may permit a small surface leakage of current through or across these. Also, high voltages applied to these materials may “break down” their resistance. This fact is important in their use as dielectrics in condensers. Dry air is one of the best of insulating substances but its dielectric strength (the ability to withstand this breaking-down effect) is lower than many liquids and solids.

High frequency a.c. breaks down insulators more readily than low frequency at the same voltage.

There is no perfect insulating material, but if those found in radio sets are kept clean and dry they will function satisfactorily.

Variable resistances of large current-carrying capacity are usually called rheostats. “Resistors” are resistance units. A voltage divider is a form of variable resistance. A potentiometer is a variable resistance apparatus used for measuring a volt or so in small fractions.

The resisting, or insulating, or conducting, quality of any material is determined by the molecular composition of that material. In a conductor, this molecular structure is loose, so that a voltage applied will set the electrons therein traveling with facility, whereas, in an insulator, such activity is very slight—for practical purposes it may be considered nil.

Resistance increases with temperature except in the case of carbon and an electrolyte.

The resistance of air at high altitudes is greater than at low altitudes. When wiring-in plane radio installations, this factor must be considered.

**Protective Devices.** Circuits which carry power, whether for lighting, for dynamo-electric machinery, or radio sets, are always equipped with some form of protective device<sup>184</sup> to safeguard the apparatus connected into the circuit against short-circuits, overload as to voltage, and in the case of a.c., inductive effects. A short-circuit is simply a name given to a condition which arises in a circuit whereby the current flows through a low resistance, causing a dangerous rush of current. A screw-driver accidentally dropped across the blades of a switch would cause a "dead short." Fuses, made up of some easily melted metal, either in a plug form or cartridge, protect against this *current* overload. On big switch panels, automatic circuit-breakers open up like a switch when the voltage or the current in the circuit rises to a dangerous value.

Condensers (to be discussed in the next chapter) and in some cases specially wound coils are used in a.c. circuits to prevent surges of current under certain conditions.

**Meters.** The commonest forms of meters used in radio are voltmeters and ammeters. In both instruments a pointer is made to move over a graduated dial by an electromagnetic effect (explained in the following paragraph). The voltmeter is always placed across the line in shunt as in Figure 2; the ammeter in series with one leg of the circuit as in aerials. The thermocouple ammeter works on a different principle; in this instrument there are two dissimilar metals, crossed and connected to a shunt coil carrying current. As each metal has a different resistance, the two together can be made to deflect the meter's needle.

### Electromagnetism

**Magnetic Induction.** The magnetic field around a single straight wire carrying current is circular. If the wire carrying a current is wound in a loop, it will be found that all the lines of force about the wire will combine and pass through the loop in the same direction. A magnetic field then exists both inside and outside the loop; consequently the coil acts as a magnet. If an iron core is inserted, it becomes magnetized by *induction* and we have an *electromagnet*; the coil of wire is called a *solenoid*.

The total number of lines of force induced in the iron is called the *magnetic flux*. The force which creates this flux is *magneto-motive force* (m.m.f.).

The relation between flux density and magnetizing force is a measure of the magnetizability of the iron and is called the *magnetic permeability*. The permeability of a vacuum is 1.

There is no insulator for magnetism, but if sheets of iron are placed around apparatus that needs protection, the iron will provide such an easy, permeable path for the magnetic lines of force that they will not continue further to disturb the sensitive equipment. Such apparatus is referred to as being "shielded" or "iron-clad."

*Reluctance* is the opposite of permeability and takes the same relationship with flux and m.m.f. as resistance does with current flow (which is analogous to flux), and e.m.f., which is analogous to m.m.f. (See Ohm's Law, page 41.)

**Induced E.M.F.** If a circuit carrying current is brought near to a closed circuit that is not, the flux of the first (primary) will "link" or sweep across the second. At the instant of linkage or coupling, an e.m.f. will be set up in the secondary circuit. This linkage or cutting of flux can be brought about by:

1. Moving either the primary or secondary circuit.
2. Switching on and off the primary current which supplies the flux.
3. Having current flow through it first in one direction and then in the other, as alternating current.

In any case, the induced e.m.f. is directly proportional to the rate of cutting or linkage. The generator supplies the first

method, the induction coil the second, and the transformer the third.

It can be said that a radio transmitter propagates what amounts to a moving magnetic field which will induce a weak e.m.f. in a receiving antenna when linkage occurs with it, that is, when the moving field sweeps across it.

Plate II, page 12, shows a modern aviation radio transmitter as installed at an airline ground station.

### QUESTIONS

30. What is meant by electricity? a.c. electricity? d.c. electricity?
31. Define static electricity and explain how it differs from current flow.
32. Briefly, what is the electron theory and under what circumstances are electrons caused to be emitted?
33. State the mathematical relationship between the units of e.m.f., current flow, and resistance.
34. How much greater is a megacycle than kilocycle?
35. The current flow in a circuit is 10 amperes; the resistance is 12 ohms. How many kilowatts power?
36. Sketch a series and a parallel circuit and explain the difference between them.
37. Name five common insulators; two ordinary conductors.
38. Explain electromagnetism, defining magnetomotive force and magnetic flux.
39. What is meant by magnetic permeability; reluctance; what is the relation between them?
40. Sketch a series circuit; a shunt circuit.

## CHAPTER 3

### RADIO ELECTRICITY

#### Alternating Current

In this chapter some of the more common and most fundamental facts about electricity as applied to radio will be presented as an introduction to Radio Circuits in the next chapter. To understand radio it is first necessary to learn the nature of alternating current and how it acts.

**Nature of A.C.** Figure 4 shows the *instantaneous* values of the e.m.f. of an ideal a.c. generator, plotted against the time of

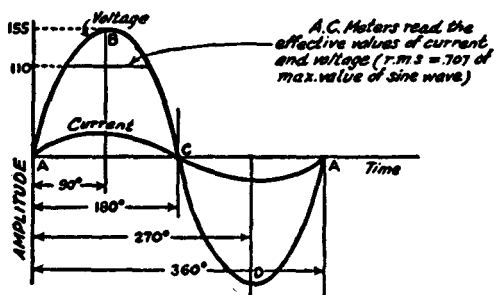


Figure 4. Sine-Wave Alternating Voltage and Current

one cycle of generation. This graph is conventionally known as a *sine* curve or sine wave. It represents a fundamental equation involving the action of a.c. expressed thus :

$$e = E_{max} \sin 2\pi f t$$

where  $e$  stands for the instantaneous voltage existing at any given instant,  $E_{max}$  represents the maximum voltage finally attained during the cycle,  $t$  is the time in seconds (or fractions thereof, as the time element is very small) from the beginning of the cycle,

and  $2\pi f$  is the angular velocity. (The action of an a.c. generator, explaining revolutions, is given in Chapter 7.)

**Effective Values of A.C.** From an inspection of Figure 4 it will be seen that the values of the current and voltage are constantly changing, but in the practical application of a.c. to radio and other circuits one *effective* ampere is considered to be flowing if the heat produced as it flows through a resistor is the same as when one ampere of d.c. is flowing through the same resistor. This *effective* value is, mathematically, the square root of the mean value of the instantaneous value of the current, squared, and is often referred to as the root-mean-square or r.m.s. value instead of effective value. It is a fraction more than 70% of the *maximum* value.

The *average* value of both the current and voltage, when generated in the pure sine curve or "wave" form shown, is 0.636 of the maximum (peak) value of current or voltage.

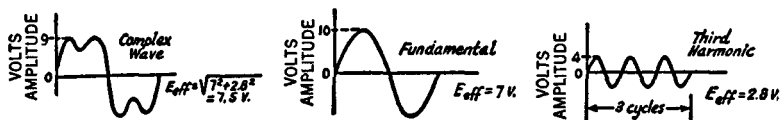


Figure 5. A Complex Wave and Its Sine-Wave Components

The mathematical relationship between the different values of a.c. voltage and of a.c. current is as follows :

$$\begin{aligned} \text{Maximum} &= 1.414 \times \text{Effective} = 1.57 \times \text{Average} \\ \text{Effective} &= 0.707 \times \text{Maximum} = 1.11 \times \text{Average} \\ \text{Average} &= 0.636 \times \text{Maximum} = 0.90 \times \text{Effective} \end{aligned}$$

Radio circuits handle high frequency ac. or radio waves which do not have perfect sinusoidal values. Instead, there are two or more components which are integrally related. This is shown in Figure 5. The principal frequency is known as the fundamental, which is the lowest frequency emitted from a transmitter. The additional frequencies are whole number multiples of this fundamental frequency; the second harmonic has double the fundamental frequency; the third harmonic, three times, etc. The effective value for a complex wave such as a harmonic will be the square



root of the sum of the squares of the effective values of the individual frequency components or,

$$E = \sqrt{E_1^2 + E_2^2 + E_3^2}$$

where  $E$  is the effective value of the complex wave whose effective value it is desired to compute,  $E_1$ ,  $E_2$ , and  $E_3$  are the effective values of the fundamental and harmonics.

Sometimes there are both a.c. and d.c. characteristics to be considered. This is the case where a.c. is rectified into pulsating d.c. Here we find a.c. superimposed on the d.c. circuit. For this reason rectified a.c. is generally "filtered" as explained under the paragraphs titled "Rectifiers" and "Filters" in Chapter 7.

**Inductance.** One of the chief properties of a.c. is inductance, the coefficient of self-induction, defined as that property of a circuit which opposes a change in the flow of current through it: its symbol is  $L$ . The practical unit of inductance is the *henry*. A circuit has an inductance of 1 henry when a current that is changing at the rate of 1 ampere per second induces an e.m.f. of 1 volt. (1 millihenry = 0.001 henry; 1 microhenry = 0.000001 henry). It is, therefore, true that inductance is basically a magnetic property that opposes any change in the flux and, therefore, any change in either the magnitude or the direction of the current. It can be said that inductance is the property of an a.c. circuit whereby electrical energy is stored up in the form of electromagnetic lines of force. The number of henries inductance in a circuit is numerically equal to twice the number of joules stored in the magnetic field when the current in the circuit is 1 ampere. It is quite aptly referred to as "electrical inertia," also sometimes as self-induction. These phrases are all beneficial in expressing a conception of this highly important property. All a.c. circuits possess inductance; they are said to be *inductive*. In a straight wire the inductance is distributed; if the wire is wound, the inductance is increased and concentrated; for this reason it is customary to refer to a coil introduced in a circuit to furnish inductance merely as an "inductance," rather than as an inductance coil. Also, the inductance of a circuit is usually considered as

being made up of these coils, the leads being ignored as of negligible inductive value in radio sets. The value of the inductance varies directly as the square of the number of turns and depends on the size of the wire and the permeability of the core. If the core is air, as in most radio circuits, the permeability is 1 and the amperage has no effect on the inductance.

**Inductive Effects.** The most familiar example of the action of self-inductance is shown by the opening of a switch in either an a.c. or d.c. circuit. The inertia or inductive effect of the circuit tends to carry the current on past the opening through the high resistance of the air, arcing the switch contacts in many cases. At the instant of arcing, the lines of force collapse around the wire; it is this stored energy that shows a counter e.m.f. existed as a result of them. This opposing e.m.f. which is induced has an instantaneous value equal to the time rate of change of the flux. The number of times the current stops or reverses per second gives the time rate. In the process of mutual induction we picture the reversals of current, natural to a.c., collapsing the flux of the primary and thereby causing a linkage into the secondary which produces an e.m.f. in the secondary. In self-induction this primary flux collapse causes a linkage across the primary which produces an e.m.f. in the primary, whether there is a secondary winding or not. As the effect of this self-induced e.m.f. opposes the applied e.m.f., it is termed *reactance*. As everything that opposes the flow of a.c. is termed *impedance*, inductive reactance can be computed as impedance and expressed in ohms. However, it is NOT directly additive to the resistance of the conductors; this is explained under the subject "Impedance."

**Mechanical Analogy.** The mechanical analogy of a combination of force, weight, and traction may help to present a comparable mental picture of the a.c. circuit containing inductance during any half cycle. If a tow-line and a large coil spring were connected to an auto, the towing car would exert a force on the line and the spring, creating tension before movement of the tow started. If the towing car moved 100 ft., the towed car might move more or less than that distance but, in any event, the latter would certainly start a short time after the towing car started, and

it would probably stop a short time after the towing car stopped. In this case, the towing car furnishes the equivalent of e.m.f.; the resulting motion is comparable to current flow; the traction to the ohmic resistance of the circuit; and the inertia of the towed car to inductance. This inertia causes a lag in time, or a difference in phase, between the applied force and the resultant motion. In the case of an electric circuit, the closing of the switch applies an e.m.f., but if inductance is present, then the resulting motion of electron or current flow will not take place without a measurable lag in time. In the induced circuit, the current actually flows for an instant after the applied e.m.f. has been switched off.

**Water-Pump Analogy.** Perhaps the action of a reciprocating water pump, connected to a closed piping system, gives a better example of the a.c. circuit. The friction of the pipes would be like the resistance of the wire. If the pipe is coiled, as in a hot-water heater, this coil causes a lag in water flow on both strokes of the pump. When the pump is stopped for an instant at the end of a stroke, water might continue to flow; in fact, it might continue in one direction after the pump started in the other, creating a back pressure. This back pressure would be like the counter e.m.f. in an inductive circuit. Its effect would be apparent in cutting down the water velocity like badly rusted pipes. It is well to remember that neither the frequency nor the voltage is changed by inductance, but that the current flow is decreased and that, as the e.m.f. and current are out of phase, the power-factor will be some percentage of 1.

**Practical Inductors.** One of the most common forms of inductance coil, or inductor, consists of a single layer of winding on an air-core cylinder shaped like a baking-powder can. This is called a solenoid type. The binocular coil consists of two solenoids placed side by side, resembling binoculars, and connected in series. In the single solenoid, the flux path is that of a bar magnet, from N to S outside, and from S to N inside the coils. In the binocular type, the inner flux from one acts through the inside of the other, linking at the ends of the coils. The flux field in this type is quite well confined to the coils as regards space, which is a great advantage in radio receivers. Flux does not flow, or move, however.

The so-called honeycomb and spider-web coils are now fairly familiar types. These derive the names from their shapes and construction; various advantages are claimed for each form.

A recent shape to be developed is called the "toroid," built like a circular life-buoy, or a washer with a section removed like the bite out of a doughnut. This coil also limits the flux to the center of the coil.

In order to get a concrete impression of the relation between the size of an inductance coil and the amount of inductance it furnishes, the following formula used for computing the inductance of Air Corps radio coils should be examined:

$$L = \frac{0.2 A^2 N^2}{3A + 9B + 10C}$$

$L$  = Inductance in microhenries

$A$  = Mean diameter of the coil in inches

$B$  = Length of winding in inches

$C$  = Radio depth of winding in inches

$N$  = Number of turns

(Note: In the case of a single layer of solenoid,  $C$  may be assumed to be zero.)

The amount of energy stored in an inductance coil is proportional to the inductance of the coil and to the square of the current; or, mathematically, the energy in joules or watt-seconds =  $\frac{L I^2}{2}$ .

When inductance coils are connected in series their inductances are additive if placed so the magnetic flux of one coil does not link with the turns of any other coil.

When coils are connected in parallel or series parallel, the total inductance is found by the same method used in computing the total resistance of resistors placed in parallel, page 43.

The *effective resistance* of a very high (radio) frequency circuit is determined by dividing the square of the maximum effective radio-frequency current in amperes into the power in watts. This is because of the "skin effect" (the tendency of high-frequency currents to concentrate on the outside of conductors) and may be several times greater than the pure ohmic resistance.

**Series Resonance.** A radio circuit which has inductance, capacitance, resistance, and the circuit source in series with each other is known as a series resonant tuned circuit. (See Figure 6.) In circuit S the current flow will be maximum at resonant frequency and the value of this maximum current will be governed by the resistance in the circuit. Curve A in Figure 6 indicates this value for minimum resistance, curves B and C indicating current values for resistance of higher values.

Parallel resonant circuits are used more generally than series. Note that in circuit P there is inductance, capacity, and resistance in series as in the series resonant circuit shown in S, but that the voltage of the source is shunted across the circuit. In this type circuit the variations of parallel impedance are shown by the same

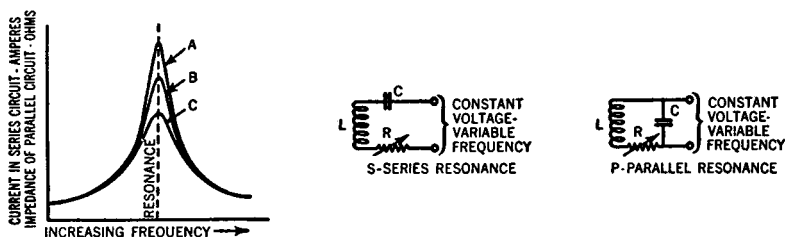


Figure 6. Characteristics of Series-Resonant and Parallel-Resonant Circuits

curves in Figure 6 that show the variation of current with frequency for circuit S.

In studying this graph again, notice that the curves become flatter for frequency near resonance frequency as the internal series resistance is increased, but are of the same shape for all resistances at frequencies further removed from resonance frequency. The relative sharpness of the resonance curve near resonance frequency indicates the sharpness of tuning, that is, the selectivity, or ability to discriminate between voltages of different frequencies in tuned circuits. The ratio of a tuning coil's reactance to its effective series resistance is a measure of the efficiency of the coil. This ratio is approximately the reciprocal of the power factor (page 151); the symbol of this sharpness of resonance is usually  $Q$ .

This value ( $Q$ ) for radio coils used in high frequency circuits runs to several hundred. The actual frequency width of the frequency curve for a high frequency circuit will be proportionately greater than for a low frequency circuit having an equal value of  $Q$ .

The impedance ( $Z$ ) of a parallel resonant circuit is actually only the ohmic resistance at resonant frequency as explained under Resonance, page 65.

**Coupling.** If the relation between voltage and current, as to time or phase, is the same in both primary and secondary, the most efficient coupling or transfer will result. For this reason, most tuning coils are made variable as to turns; also as to their position to each other, because the permeability of the magnetic medium influences the degree of mutual inductive effect. Iron cores are used in power transformers and for reactance or choke-coils. In radio coils the core is usually air. The magnetic field strength in air varies inversely as the square of the distance between coils. In the old-fashioned tuning coils the primary always slid into the secondary, or vice versa, and they were always cylindrical. Now they are of different shapes and take various positions with respect to each other, usually controllable by the operator. They are now called inductors.

In practice, the coupling between two coils is given in terms of their coefficient of coupling, symbol  $k$ . Maximum coupling (1 or 100%) is accomplished when all of the flux from one coil links all of the turns of the other coil. Looser coupling, that is, less than 100%, usually is employed in radio sets.

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

Where  $M$  is the mutual inductance,  $L$  is the self-inductance of one coil, and  $L$  that of the other coil. In the use of this formula  $k$  is expressed as a decimal less than one;  $M$ ,  $L$ ,  $L_1$ ,  $L_2$  must be expressed either as henries, millihenries, or microhenries.

Critical coupling is accomplished when the transfer of energy from the primary to the secondary coil is maximum. Under these conditions the sharpness of resonance ( $Q$ ) is NOT the maxi-

mum. Loose coupling makes for greater selectivity, decreased amplification. The coefficient  $k$  for critical coupling

$$= \frac{1}{\sqrt{Q_1 Q_2}}$$

where  $Q_1$  and  $Q_2$  are for the primary and secondary coils.

In designing radio sets, the engineer knows that many of the circuit constants are modified by the effect of elements which exist in other circuits in the set. In the operation of a set the manipulation of coupling coils which make up part of the process of tuning is best accomplished by trial and error but an understanding of the mathematical relations existing in circuits which indicate the controlling factors of selectivity and linkage proved to be a great help to the thoughtful operator, particularly when dealing with an unfamiliar set.

*Link Coupling* is explained on page 82.

**Choke-Coils.** There are two forms of choke-coils employed in radio circuits; audio-frequency and radio-frequency. Both are used as balancing elements in the circuit action, supplying inductance. Radio-frequency chokes usually are cylindrical in shape and have air cores. Audio-frequency choke-coils usually are wound on a steel core and have many turns of wire.

**Mutual Inductance; Transformers.** Mutual inductance is measured in henries and must be considered where mutual induction takes place, such as between two coils arranged for the transfer of energy in transformers or "tuning coils."

The primary and secondary coils of a transformer are placed so as to increase their mutual induction, usually being wound on top of each other on an iron core. The wattage output is never equaled by the wattage input so that although the secondary of a step-up transformer has a higher voltage and a lower amperage than its primary, it delivers less power. Some of the power lost is due to the iron core, but iron increases the mutual inductance of the coils by providing a more permeable flux path. If this path is partly through air, the transformer is said to have an "open core"; if not, the core is "closed." A straight iron rod would form an open core, and a hollow square piece would constitute a closed

core which would allow less flux leakage than the open core. Ordinarily, both primary and secondary windings are made up in flat coils called "pies," connected in series with each other. The primary and secondary are carefully insulated from each other and ventilation is provided by the method of spacing the pies on the core, which is built up of thin strips called laminations, of iron or silicon-steel or some similar metal. These iron-core transformers are used in radio circuits having frequencies up to 10,000 cycles per second and air-core transformers are used with higher frequencies. The iron causes too much heating at the higher frequencies, due to hysteresis.

**Transformer Ratio.** In transferring energy by inductively coupling or linking one coil to another, the frequency of the induced electricity remains the same as the primary source. The voltage induced in the secondary will be of the same proportion as the ratio of wire turns in windings of the primary and secondary transformer coils.

A 1-to-2 step-up transformer has twice as many turns in the secondary as in the primary; this same transformer would halve the voltage output if the secondary terminals were connected to a suitable primary source. In this case we would have to consider the secondary coil as having become the primary. This ratio rule holds true because of the basic law, that the value of e.m.f. produced depends on the relative amount of cutting of lines of force, or "linkage." A primary produces the same number of lines of force with any given current, but 1000 turns in a secondary will cut twice as many lines per alternation as 500 turns and so twice as much voltage will be induced in a 1000-turn secondary as in a 500-turn secondary with the same kind of a primary and source.

If the frequency of the primary was doubled, the frequency of the secondary current also would be doubled, but the voltage is controlled by the number of turns employed.

### Capacity

**Capacity, Farad, and Condenser.** Capacity is that property of an a.c. circuit which permits electricity to be stored within it in the form of electrostatic lines of force: its symbol is  $C$ .



The unit of capacity is the farad. Its symbol is  $F$  when employed with numerical values. When one coulomb will raise the potential of a condenser one volt, the capacity of that condenser is one farad. A microfarad (abbreviation mfd.) is one-millionth of a farad.

A practical condenser is a device designed to hold a charge of electricity. Electrically, a condenser consists of any conducting surface separated by an insulator from another conducting surface. Two telephone wires stretched from pole to pole may form a condenser, or even an inductance coil may act like one at high radio-frequencies. An antenna and ground form a leaky condenser. Ordinarily, these and similar arrangements are not considered condensers because they are not designed to receive a charge of electricity or to introduce capacity into a circuit. It is well to remember, however, that each pair of leads, the electrodes in a vacuum tube, etc., all have a condenser or capacity effect in the circuit. This effect is usually negligible but not always. The typical manufactured condenser is an arrangement of two sets of metallic or foil plates rigidly separated from each other by some insulating substance. Each set of plates is connected in series and, therefore, has the same effect as one plate having an area equivalent to their combined areas. Where one set of plates is movable, the condenser is "variable."

A condenser can be charged by d.c. The condenser also can be disconnected from such a source, after it is charged, and later on discharged. This is interesting from a theoretical standpoint. However, our consideration of capacity is in regard to its practical adaptation to radio and here we find that its use is carefully governed at all times by the design of the set and the proficiency of the operator.

The more skilfully capacity is utilized, the better will be the performance of the set.

The condenser, whether of fixed or variable design, is synonymous with capacity to the average radio operator because its function is to supply capacity. This association of the two is quite satisfactory from a practical point of view.

The insulating material between the plates of a condenser performs a function different from the ordinary insulator and so

these insulators are known as dielectrics. The capacity of a condenser depends on the nature of the material used as a dielectric, consequently dielectrics have been assigned a numerical constant which is a ratio to the basic constant of air, taken as 1. The dielectric constant or specific inductive capacity of paraffine is from 2 to 2.5; paper from 1.6 to 2.5; hard rubber from 2.0 to 3.5; mica from 3.0 to 7.0.

**Capacity Explained.** Capacity and capacitance are practically synonymous. When the two plates of a condenser are connected to the two leads of an a.c. source, current will produce the effect of flowing through the circuit. If a condenser is similarly connected into a d.c. circuit, current will not flow through that circuit even though the condenser may receive a charge of electricity. In the first case mentioned, the condenser charges and discharges with the alternate flow of current. In the case of the d.c. charge, no reversal of current occurs and so the condenser does not discharge. However, the theoretical explanation of the charging of the condenser is the same in both cases; that is, when an electric pressure is applied to conductors insulated from each other, a static strain is established between the conductors. This phenomenon is facilitated in a condenser (not equipped with a means for discharge) wherein the plates become charged bodies; using a.c., each plate is charged with one polarity during one alternation and with the other polarity during the next alternation. The static lines of force constituting the electrostatic field between the plates result from the charge impressed on them. If the plates of a charged condenser were separated sufficiently, the connecting lines would collapse, the charge existing on the plates would be dissipated and there would be no longer a condenser in a practical sense.

There is a definite relation between the amount of charge, or the capacity of a condenser and the following :

1. The size, position, and substance of the plates (the more surface exposed, the more capacity).
2. The strength of the dielectric (insulator) between them, i.e., the dielectric constant.
3. The applied voltage and its frequency.

Note that capacity changes with the frequency. This is important; and because of the high-frequency currents employed in radio, condensers are necessarily designed for certain stipulated frequencies.

When voltage is applied to the plates, the electrons tend to become displaced, but because they cannot move through the intervening medium, they establish a static stress. This tendency toward displacement is referred to as a "displacement current" (in the electron theory) and while it is occurring, an actual current is flowing through the conductors and from one plate to the other, charging one negative and the other positive. The static field "passes" the current from one plate to the other. The amount of energy stored up in farads is equal to twice the number of joules in this field when the potential difference is 1. If the charge is doubled, the difference in potential between the plates (static voltage) will be doubled. In fact, there is a definite relation between the charge, the voltage, and the capacity:

- (a) The capacity equals the charge divided by the voltage.
- (b) The charge equals the capacity multiplied by the voltage.
- (c) The voltage equals the charge divided by the capacity.

Irrespective of the value of the applied voltage, a condenser does not accumulate its charge instantaneously. When the voltage of the plates equals the applied voltage, the charge is complete, but not until then. A certain amount of work is done in charging a condenser and this equals the charge times the voltage.

The same amount of energy will be liberated from a perfect condenser on discharge as was received on charge. When discharged, the plates have the same potential and no current flows. The discharge itself supplies a voltage to the circuit opposite in polarity to the applied voltage.

In a spark transmitter, a condenser—charged by a suitable source—is discharged through an inductance across a spark gap. This energy is radiated as waves, which are detected at the receiving station.

**Capacity Effect.** Capacity must be understood in two lights; as a property which permits electricity to be stored as a charge;

and as to its effect on the circuit—because of this storage of electricity—and its release. By upsetting the phase, or time, relations between the applied voltage and current flow, capacity decreases the power-factor of the circuit and Ohm's Law does not apply. Capacity introduces a reactance which can be expressed in ohms.

The most important point about capacity is that it can be used in a circuit to neutralize inductance. Capacity is analogous to elasticity, which is just the opposite in its effect from the inertia effect ascribed to inductance.

**Mechanical Analogy.** In a water-pumping system consisting of a reciprocating pump and closed pipe-line, with a double-acting spring valve mounted in the line, tension is put on the valve-spring before the valve head is displaced. At the end of the stroke, this tension comes into play and the reverse stroke adds to its effect. In an a.c. condenser circuit, current flows to one condenser plate on one alternation and puts a tension or charge on that plate before the effect of the current passes through; then completes the alternation, and on the next—opposite alternation—this strain comes into play. The charge is placed during the first half alternation and is released during the second. Thus, in effect, current appears to flow.

Comparing capacity to the auto-towing case mentioned in discussing inductance, we must assume that the auto representing capacity is pushed, instead of towed, and that the spring connection between the cars is compressed at first, before motion begins, so that when the pushing car stops, the tension of the spring will tend to continue the motion. If this action can be conceived as taking place in conjunction with that of towing (in the inductance analogy), this conclusion will be reached: that an adjustment could be made between the towing car and the pushing car so that the car being pushed and pulled would travel exactly the same distance as the other two. This shows that inertia and elasticity neutralize each other.

### Reactance

**Inductive Reactance.** Inductive reactance opposes an alternating current in passing through an inductance. Its symbol is  $X$  or  $x$  and it is expressed in ohms.

$x = 2\pi fL$  where  $\pi = 3.1416$

$f$  = the frequency of the current in cycles per second

$L$  = inductance in henries

As  $2\pi$  equals approximately 6.28, the above formula is often presented as :

$$x = 6.28fL$$

**Capacitive Reactance.** Another reactance is the limitation placed upon the flow of a.c. by capacity. Its symbol is also  $x$  and it is expressed in ohms. (The sub letters L and C are often used to indicate that the reactance is due to inductance or capacity.) In this case  $x = \frac{1}{2\pi fC}$ , or,  $x = \frac{1}{6.28fC}$ , where  $C$  = capacity in farads, the other symbols being the same as given above in the inductive reactance formula.

**Effect of Reactance on Current.** With a given value of applied voltage and inductance, the amperage will DECREASE as the frequency is INCREASED.

With a given value of applied voltage and capacity, the current will INCREASE as the frequency is INCREASED.

From these two statements it is seen that the effect of inductance in limiting the flow of current is least at those frequencies where the limiting effect of capacity is GREATEST. (See table on page 66.)

**Impedance.** Impedance is the total opposition to the flow of an alternating current in a circuit containing both resistance and reactance, and is expressed in ohms. Its symbol is  $Z$ .

$$Z = \sqrt{R^2 + \left[ 2\pi fL - \frac{1}{2\pi fC} \right]^2}$$

$Z$  takes the place of  $R$  in Ohm's Law:  $E = IZ$ ;  $\frac{E}{I} = Z$ ;  $\frac{E}{Z} = I$ . It is customary to represent resistance and reactance graphically as the two legs of a right triangle, the resultant impedance being the hypotenuse. (See A, Figure 7.)

*Susceptance* is the reciprocal of reactance.

*Admittance* is the reciprocal of impedance.

With resistance represented by the base line, inductive reactance would be opposed to capacitive reactance as shown in B, Figure 7. Note that if these two reactances are numerically equal to each other, the impedance will be numerically equal to the resistance.

*Example.* Assume resistance to be 10 ohms, inductive reactance 4 ohms, and capacitive reactance 6 ohms. Draw the base line to scale, 10 in. in length, one right-angle leg 6 in. in length, and the other, opposite in direction, 4 in. The resultant of the two legs gives one leg of 2 in. Scale this distance off on the longer

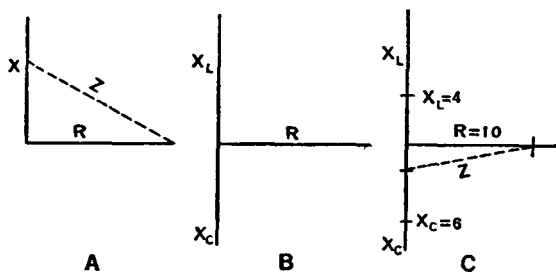


Figure 7. Graphical Illustration of the Relation Between Reactance  $X$ , Resistance  $R$ , and Impedance  $Z$

leg and draw a hypotenuse from this point on the leg. The length of the hypotenuse in inches will represent the impedance in ohms. (See C, Figure 7, as a guide for this graphical example.)

Check the results obtained by substituting the values given in the formula given for  $Z$ . (6 for  $2\pi fL$  and 4 for  $\frac{1}{2\pi fC}$ .) Notice in this case that the following simplified formula applies:  $Z = \sqrt{R^2 + X^2}$ . In using this formula, the two reactances equal their numerical difference.

**Resonance.** A circuit is said to be in tune, or in resonance,<sup>206</sup> when the inductive reactance equals the capacity reactance. The voltage across the inductance due to the counter e.m.f. built up therein is then opposite and equal to that across the capacity, and

this counter e.m.f. may be many times greater than the applied voltage. In this case Ohm's Law will apply because the circuit will act as if it contained nothing but resistance. When this condition exists, the frequency of the circuit corresponds to the frequency of the current supplied to and flowing in the circuit. The frequency at which this occurs is called "resonance frequency." Every combination of capacity and inductance has its reactance equal to each other at some frequency and by having variable inductance and capacity, one circuit can be "tuned" to another. In the following table, results are shown when using a 500 microhenry inductance with a 0.005 microfarad capacity in series, at the frequencies shown:

<i>F</i> Cycles per second	<i>L</i> Reactance of Coil in Ohms	<i>C</i> Reactance of Condenser in Ohms	<i>Z</i> in Ohms
60	0.188	530,000.00	530,000.00
1,000	3.142	31,840.00	31,837.00
100,000	314.20	318.40	4.20
100,700	316.23	316.23	0.00
1,000,000	3,142.00	31.84	3,110.00

Notice that the inductive reactance increases and that the capacitive reactance decreases as the frequency increases. Resonance occurs with the above combination at a frequency of 100,700—the resistance being considered negligible. It is necessary for the coupled circuits in radio sets to be in resonance in order that energy may be transferred between them, and without this efficient transfer of energy, as from transmitter to receiver, and from one circuit in a receiver to another, there would be a decrease of operating efficiency, or complete failure.

In practical terms, since at resonance the inductive reactance must equal the capacitive reactance, then

$$X_L = X_C \text{ or } 2\pi fL = \frac{1}{2\pi fC}$$

The resonant frequency is, therefore,

$$f = \frac{1}{2\pi \sqrt{LC}} \times 10^6$$

where  $f$  is the frequency in kilocycles per second  
 $2\pi$  is 6.28  
 $L$  is the inductance in microhenries  
 $C$  is the capacitance in micro-microfarads

In Figure 8,  $L$  is a variable reactance or choke-coil, being an inductance coil with an iron core which increases its inductive effect.  $C$  is a variable condenser.

With the key closed, current will be induced by  $P$  into  $S$  and will tend to flow through  $L$ ,  $C$ , and the lamp. The induced current will have the same frequency as the alternator. The voltage in  $S$  will be the same as delivered by the alternator if the number of turns in  $P$  and  $S$  are the same.

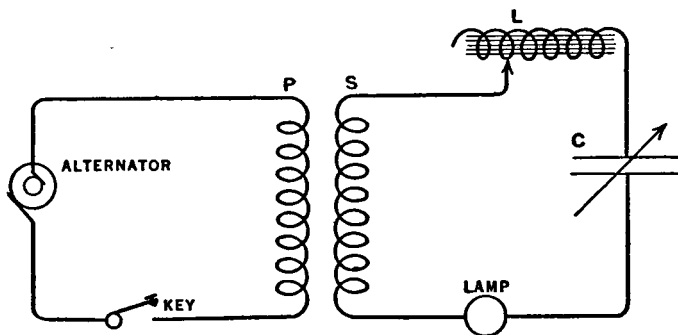


Figure 8. A Simple Circuit with Which to Illustrate Tuning

The inductive reactance can be decreased in two ways: by decreasing the number of turns in  $L$  or by pulling out the iron core. The opposite action will increase the reactance.

The capacity can be decreased by turning one set of the plates of the condenser away from the other and increased to maximum by fully exposing each set to the other.

By experiment it will be found that an increase or decrease of either capacity or reactance may result in the lamp burning at its maximum brilliance, indicating that the circuit is tuned into resonance.

Suppose that this resonant condition was reached with half the inductance and half the capacity tuned in, and that when all the capacity was tuned in, the lamp went out, indicating that the



circuit was badly out of resonance. The condenser need not be readjusted to its former capacity to tune the circuit—an adjustment of the inductance alone may tune it.

When tuning a radio receiver, this sort of adjustment is accomplished by the operator in tuning the received signals; maximum sound instead of maximum light being the effect obtained by perfect tuning. Figure 9 is a typical resonance curve for a tube transmitter.

As explained in the chapter on transmitters, certain crystals are incorporated as a part of the circuit in such a manner that

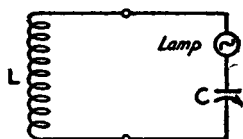


Figure 8A. Absorption Frequency-Meter Circuit

The variable condenser, *C*, should have a maximum capacity of about 350 mmfd. The meter should be arranged so that the coils are readily interchangeable. The lamp acts as a resonance indicator when the absorption meter is used with a transmitter; its use is not essential, although it is a convenience.

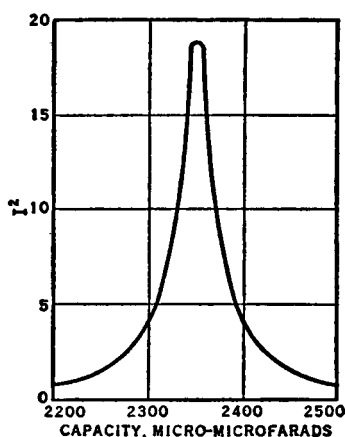


Figure 9. Resonance Curve

the frequency of the set is held at the value for which the crystal is ground. The radio inspector will test a transmitter as to frequency; in fact, if there is complaint on the part of other operators that interference is being caused by a transmitter being off frequency, the inspector will call of his own accord to fix the fault.

Amateurs (and sometimes others) check transmitter frequency by hooking up a receiver nearby, the tuning dial of which has been changed to indicate frequency from listening to stations of known frequency and marking values on the dial. This sort of a receiver is called a "monitor," for when the transmitted signals

cannot be heard on the monitor while it is set on the transmitter's frequency, the transmitter is obviously off frequency.

Sometimes an absorption frequency-meter is used. This consists of a coil and condenser connected as shown in Figure 8A. Maximum current will flow in the lamp when exactly on frequency. A heterodyne frequency-meter is somewhat like the monitor but with refinements that make for accuracy. There is also an electron-couple frequency-meter but this and other types ought to be studied at first hand; the important thing to remember is that it is an extremely serious error on the part of an operator to allow his transmitter to get off frequency. In receiving, if it gets off frequency, the operator does not get the messages or calls intended for him. Plate III shows a transmitter which has ten fixed frequencies.

*Frequency Tolerance* is the maximum permissible deviation (plus or minus) between the frequency assigned to the station and the actual frequency of operation. This deviation is slight in aircraft transmitters and is due to the different characteristics of the equipment under different conditions of temperature and humidity.

### QUESTIONS

41. Explain the relation between effective and average value of a.c. Which is read on the voltmeter?
42. Define inductance and explain inductive action.
43. Where are inductors and choke-coils used and why?
44. Define capacity and explain the nature of capacitance.
45. How may circuits be coupled?
46. Define reactance, impedance, susceptance, admittance.
47. Explain resonance and how a circuit is made resonant.
48. What is resonant frequency? a resonance curve?
49. How does an operator determine a transmitter's frequency?
50. Explain what is meant by frequency tolerance.

# CHAPTER 4

## RADIO CIRCUITS

### Electrical Characteristics

Radio circuits are made up into transmitter sets, receiver sets, radiobeacon transmitters, radio compasses, etc. They are all designed to handle high-frequency currents; all possess capacity, inductance, resistance. Each performs a different function as indicated by their names.

**Receiving Circuits.** The receiver must have inductance and capacity so arranged that the frequency of its circuit may be adjusted to that of the transmitter; in addition it must rectify these high-frequency currents and make them audible to the human ear. Figures 25 and 27, pages 105 and 107, illustrate basic receiving circuits.

**Transmitting Circuits.** A radio transmitting circuit, whether telegraph or telephone or radio range beacon, must consist of a source of high (radio) frequency, means of controlling this type current (as to both power and frequency), and a means of emitting the energy as radio waves.

**Oscillatory Circuit.**<sup>171</sup> Consider Figure 10. In this circuit, when C is charged sufficiently, it discharges across the spark gap.

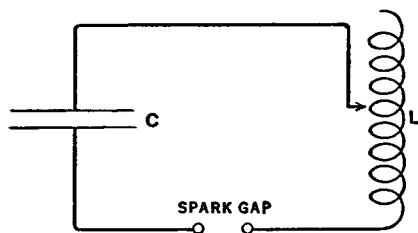


Figure 10. Oscillatory Circuit

The rate of charge is twice the number of cycles-per-second frequency of the charging source. The rate of discharge is controlled by L, and is considerably greater than the rate of charge. The discharge is *oscillatory*. If each succeed-

ing discharge is weaker than the first one, the condenser emits what is called a damped electric wave-train. If the oscillations do not die down, they have a "constant amplitude" and are called undamped, continuous, or sustained, oscillations. (The periodic motion of a clock pendulum is that of sustained oscillations.) In the circuit shown, the resistance of the spark gap would "damp" the discharge; that is, the amplitude would be decreased in each of the several succeeding discharges following each charge. Spark transmitters emit damped wave-trains; tube transmitters emit undamped wave-trains. Spark transmitters make use of condenser capacity as the source of oscillations, whereas in tube transmitters a heated tube is employed instead. Spark transmitters are now obsolete, but oscillatory circuit effects should be understood before studying tube sets.

**Frequency,<sup>94</sup> Wavelength, and Waves.** Frequency is defined as the number of cycles or periods per second. The symbol for frequency is  $f$ .  $f = \frac{1}{2\pi\sqrt{LC}}$ , where  $L$  is given in henries and  $C$  in farads. Audio-frequencies range from 16 to 10,000 cycles per second. These are audible to the human ear. Radio-frequencies are those above 10,000. The upper limit of this "band," as ranges of frequency are called, is about 3,000,000.

In discussing the alternator, Chapter 7, it is stated that the frequency of its generated current depends on its design as to poles, and its speed. The wave-train frequency of an oscillatory circuit depends on the frequency of its source (such as an alternator), capacity, inductance, and resistance. The "natural frequency" of an oscillatory circuit is the frequency at which it will oscillate if it is not acted on by some external frequency. The frequency of oscillations in radio sending and receiving circuits depends primarily on the capacity and inductance tuned into these circuits.

Aircraft radio transmitters are now all of the tube type, emitting a pure continuous wave of the desired frequency with greater efficiency than any other type. These waves are radiated by the antenna circuit, which, like all other a.c. circuits, contains capacity, inductance, and resistance. Because of the physical properties

of the material (length, size, etc.), it is impossible to reduce the electrical properties below a certain sum. In other words, there is a "natural" or fundamental frequency for every such circuit. The quantity  $LC$  is called the oscillation constant and whether  $L$  is larger than  $C$ , or vice versa, so long as their product remains the same, the natural, or resonant frequency of a radio circuit will not be changed.

It was originally the practice to convert this natural period or frequency to the natural or fundamental "wavelength." Natural and tuned frequencies of radio sets are now usually expressed in kilocycles per second. A kilocycle is 1000 cycles. The frequency of a set, or circuit, can be measured by a frequency-meter. The relation between wavelength in meters and frequency in kc is as follows :

$$\lambda = \frac{v}{f}$$

$$\begin{aligned} \text{where } \lambda &= \text{meters} \\ v &= 300,000 \\ f &= \text{kc} \end{aligned}$$

If the resistance is considered negligible, the natural frequency of a radio circuit can be found by the following formula :

$$\lambda = 1885 \sqrt{LC}$$

$$\begin{aligned} \text{where } \lambda &= \text{wavelength in meters} \\ L &= \text{inductance in microhenries (1 microhenry =} \\ &\quad \text{0.000001 henry)} \\ C &= \text{capacity in microfarads (1 microfarad =} \\ &\quad \text{0.000001 farad)} \end{aligned}$$

The fundamental wavelength<sup>257</sup> of an ordinary four-wire flat-top antenna is about 4.3 times its length in meters; wavelength being always expressed in meters. The wires act as one condenser plate and the ground as the other. This fundamental wavelength can be decreased by inserting a capacity in series with it, and can be increased by inserting "loading coils" of inductance at its base. The natural capacitive effect in aircraft antennas varies some-

what with the size of the craft. The aircraft itself takes the place of the ground capacity effect, and at ground stations antenna capacity varies with the distance above ground, the shape, number and size of wires and the lead-in. Usually, the higher the antenna from the ground, the more efficiently the energy of the transmitter is radiated and the more collective is its effect in receiving. Aircraft antennas, or aerials as they sometimes are called, are described in Chapter 15. Although the waves radiated may differ in lengths (frequencies) it is well to recognize the fact that they are otherwise identical in their electrical properties, being made up of two parts: electromagnetic and electrostatic lines of force. These are propagated from a straight-wire aerial in all directions, the magnetic lines of force parallel to the earth and the electrostatic lines perpendicular to the earth, constituting a moving field which reverses its direction every half wavelength but traveling with the speed of light, nevertheless, through a theoretical medium called the ether. Radio waves have often been referred to as "ether waves," "electric waves," "magnetic waves," and "electrostatic waves" but they are really all the same thing. Their motion is the result of fundamental laws of nature which have made radio communication possible.

The action of certain short waves now being used in radio is described in Chapter 8, and "directional waves" in Chapter 9.

### Circuits

**Condensers in Series.** In Figure 11,  $C_1$ ,  $C_2$ , and  $C_3$ , are condensers connected to a charging source  $E$ . Referring to the charge received by the right-hand plate of  $C_3$  as  $+Q$ , then the left-hand plate of this condenser receives a charge of  $-Q$ , being equal in value and opposite in polarity; the next plate connected to it (the right-hand plate of  $C_2$ ) has the same polarity, the next is positive, and the left-hand plate of  $C_1$  is negative. The charge  $Q$  is expressed in coulombs.  $Q = CV$  where  $V$  is voltage, and  $C$

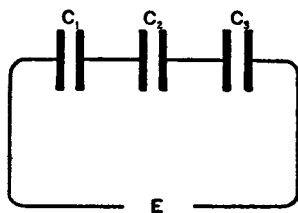


Figure 11. Condensers in Series

is capacity in farads. The voltage of each condenser is equal to the charge divided by the capacity of the condenser. Calling  $V_1$  the voltage across  $C_1$ ,  $V_2$  that across  $C_2$ , etc.,

$$V_1 = \frac{Q}{C_1}, V_2 = \frac{Q}{C_2}, \text{ and } V_3 = \frac{Q}{C_3}$$

However, the sum of  $V_1$ ,  $V_2$ , and  $V_3$  is equal to the charging voltage  $E$  and where  $C$  is the total capacity of the three condensers it is also equal to  $Q$ .

Therefore :

$$\begin{aligned} \frac{Q}{C} &= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \\ \frac{1}{C} &= \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \end{aligned}$$

From this it is seen that when condensers are connected in series, their joint capacity will be the reciprocal of the sum of the reciprocals of the individual capacities; the voltage across any one of the condensers is in inverse ratio to its capacity.

It is evident that the total capacity of condensers in series is never as great as the capacity of the smallest condenser in the circuit.

If it is desired to find the capacity  $C$  of two or more equal condensers in series, the following simple formula applies :

$$C = \frac{C_1}{n}$$

where  $C_1$  = capacity of any one of the condensers  
 $n$  = the number of condensers

The capacity of condensers in parallel is found by adding their individual capacities.

**Inductance and Resistance in Series.** The impedance due to inductance coils in series is additive as with resistances in series, but when an inductance and a resistance are in series together, the resulting impedance is the square root of the sum of the resistance

squared and the reactance squared. This is expressed in the formula,

$$Z = \sqrt{R^2 + X^2}$$

where  $X$  = reactance  
 $X = 2\pi fL$

Therefore  $X$  increases with  $f$  and so a few turns of wire which might have merely ohmic resistance at low frequencies act as a high reactance at frequencies above 10,000 (radio-frequencies). As a matter of fact, the impedance due to the inductance coil or coils is apt to be greater than the resistance when the two are connected in series in a radio circuit. The inductance takes on a large reactive value at radio-frequencies because of the extremely rapid rate of flux change (linkage) across the coil. The resistance also increases at high frequencies by reason of what is termed the *skin effect*. High-frequency currents flow along the outer surface of their conductors.

In the following table, the resistance  $R$  of an inductance coil of  $1.88 \times 10^{-4}$  henries was measured at the various frequencies  $f$  given in the first column. The reactance is given in ohms in the column headed  $X_L$ .

$f$	$R$	$X_L$
60	0.2	0.068
10,000	0.3	11.3
100,000	1.0	112.8
300,000	2.5	339.0

It can be seen from this table how important it is to have capacity in a circuit of radio-frequency, for without capacity to neutralize the inductive reactance, the inductive effect tends to prevent the circuit from functioning as a path of easy travel for current. Under neutralized conditions of no reactance, a radio-frequency current flowing in the circuit is impeded only by the radio-frequency resistance of the circuit. This *resonance* is the condition that every operator tries to maintain constantly.

**Inductance, Capacity, and Resistance in Series.** These characteristics are discussed as an "Oscillatory Circuit" on page 70. The power ( $W$ ) supplied to this type circuit at resonant fre-



quency is  $W = I^2R$ , where  $I$  is the radio-frequency (r.f.) current measured between the inductance and capacity and  $R$  is the r.f. resistance of the circuit. To obtain the current strength, the ammeter should be inserted in the inductance lead—not in the coil—and the circuit should be grounded.

To find the reactance of this circuit, it is necessary to determine both the capacity reactance and the inductive reactance at the frequencies to be employed. The two reactances can be combined with the resistance of the circuit as explained under the paragraph entitled "Inductance and Resistance in Series" on page 74, or the impedance can be calculated at any desired frequency by using the formula for impedance explained on page 75. The capacity reactance is considered negative in combination with inductance reactance, which is considered positive. The resultant or combined reactance is negative at less than resonant frequency and positive above this frequency, being neither negative nor positive at resonant frequency, but zero, as previously explained. The value of impedance is always positive because it cannot be eliminated due to the fact that its resistance component is always present.

**Antenna Circuits.** The antenna circuit is a good example of the practical application of the simple oscillatory circuit as shown in Figure 10. The action of the circuit shown would be the same whether the condenser is charged (1) from some outside source not shown in the diagram, (2) from a source connected at the spark gap, or (3) from a source induced into  $L$  from another coil.

For an antenna circuit, case (3) would apply. The circuit would be modified by replacing the condenser shown with an aerial and ground connection. The spark-gap would not be needed to discharge this condenser because its charge would rapidly leak away in the form of radio waves.

For any given antenna, the more current input, the more power will be expended and presumably the stronger the signal and greater the range. When it is considered that the strength of field set up varies inversely as the square of the distance from the antenna, it will be realized that an extremely small amount of

power reaches the receiver. But there are certain limiting factors to the antenna current input. The formula for this current is :

$$I = 2\pi fVC$$

where  $C$  = capacity of the antenna in farads

$V$  = antenna voltage

$I$  = antenna amperage

As there is a practical limit to  $f$ ,  $V$ , and  $C$ , the radiation necessary to assure received signals of maximum strength at maximum distances must be secured by employing the properly designed antenna as to capacity. Certain ground stations have antenna masts over 800 feet in height. Height increases radiation but as the distance between the antenna and ground is increased, the capacity effect between them decreases. When the maximum capacity commensurate with the greatest radiating efficiency has been reached, the highest voltage that can be applied without troublesome "corona" (discharge) effect must be employed. This seems to be at the present time about 120,000 volts. (Obviously it is an excellent idea for aircraft to keep well clear of all ground stations.)

In aircraft installations, the capacity of the antenna circuit is supplied by the antenna and the bonded metal parts of the plane such as the engine and brace wires. Where a network of wires replaces the ground connection at ground stations, this network, called a counterpoise, is designed for a certain capacity. It is not so easy to do this on an airplane, but the capacity of the bonded plane can be determined and the aerial designed accordingly, to some natural frequency. The antenna circuit can then be "loaded" by inserting either capacity or inductance in the "lead-in" of the aerial; condenser loading decreasing the capacity and therefore the natural frequency; inductance loading adding reactance and increasing the natural frequency, or fundamental wavelength, as it is sometimes expressed. Sometimes the aerial is loaded to several times its natural frequency, but its final frequency can be computed or determined in advance by reference to  $LC$  tables similar to the one shown on page 66.

If the antenna is used unloaded, the maximum voltage will be at the trailing or open end of the trailing-wire type, while the

minimum voltage will be at the end that is led into the plane. Loading will disarrange this distribution, as loading tends to equalize the value of the voltage at both ends.

**Parallel Circuits.** Figure 12 illustrates a typical radio circuit having a capacity and an inductance shunted across the same source of voltage—this voltage acting simultaneously on each. The applied voltage in this case, where neither leg of the circuit contains extra resistance, is balanced by the reactive voltage of both legs. At resonant frequency, the reactive voltage of one

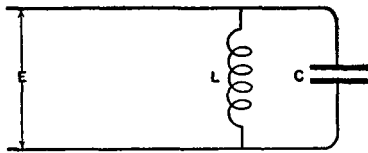


Figure 12. Inductance and Capacity in Parallel

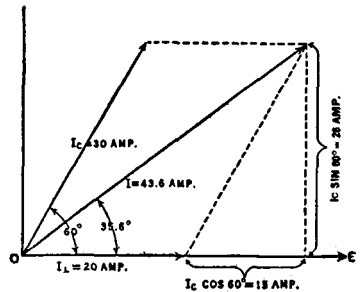


Figure 12A. Vector Diagram for Circuit Shown in Figure 12

leg balances that of the other; the reactance in ohms being zero, as for series circuits. (See table, page 66.)

The circulating current is the amperage necessary to produce the counter e.m.f. of the reactances. The larger the capacity of a parallel combination, the greater will be the value of the circulating current. Although the reactive voltages are neutralized, the voltage across C is equal and opposite to the applied voltage. If the applied voltage is increased, more current will flow within the two legs and the required counter e.m.f. will be built up.

Suppose that one of the legs shown contains resistance in series with the reactance. In this case the supply circuit will have a current flow as follows:

$$I = \frac{E}{Z} = \frac{E}{\sqrt{R^2 + X^2_L}}$$

where  $R$  represents the ohmic resistance of the  $L$  leg,  $IR$  the in-phase voltage component, and  $IX_L$  the inductive counter e.m.f., which is exactly equal to the e.m.f. of the capacitive leg. As the circuit resistance increases, the current decreases due to the applied e.m.f. being reduced by the  $IR$  voltage drop of the circuit. This current component, in phase with the applied e.m.f., is the line current (that which flows in the supply circuit). The out-of-phase current due to the reactance of  $X_L$  will be equal to the capacity current in value, but  $180^\circ$  out of phase with it.

The impedance or effective resistance  $R$  which the parallel circuit offers to the supply current at resonant frequency is given by the formula:  $R = \frac{L}{rC}$ , where  $C$  is the capacity,  $L$  the inductance of the combination, and  $r$  the circulating resistance.

The calculation of the line current can be accomplished by determining both the magnitude and phase of the different leg currents and then adding them vectorially. This, as a graphic method similar to that indicated in Figure 12A, takes into account the phase displacement in degrees of arc; values can be computed by trigonometry.

Suppose that in a circuit made up as shown in Figure 12, the current  $I_L$ , through  $L$ , is 20 amperes, in phase with the line voltage called the active component, and current  $I_C$ , through  $C$ , is 30 amperes, leading the line voltage by  $60^\circ$ . The graphic way of showing the vector sum, which is 43.6 amperes, is illustrated in Figure 12A.

The reactive component of a current is one that is  $90^\circ$  out of phase. The angle of lead is found by the active and reactive components of the line current.  $I_L$  has no reactive components, so the 10 amperes are added to the line current only.  $I_C$  has a reactive component which is equal to the 30 amperes times the sine of the angle of  $60^\circ$  which is 26 amperes. The active component of  $I_C$  is 30 times the cosine of the same angle, or 15 amperes. Adding the two active line amperages, the sum is 35; the angle of lead can be found by the following relation between this value and the 26 amperes reactive component: the angle whose tangent is  $26/35$  equals  $36.6^\circ$ . (Found in Table of Trigonometric Natural Functions.)

The impedance  $Z$  of the circuit would result from dividing the line voltage by the 43.6 amperes, found to be the vector sum of the current.

If it is desired to replace this circuit with an equivalent resistance, this could be computed from  $Z \cos 36.6^\circ$ , and the equivalent reactance would be  $Z \sin 36.6^\circ$ , but the same frequency would have to be used.

### Coupled Circuits

When two circuits are placed in a position relative to each other so that a transfer of energy takes place between them, they are said to be coupled. Circuits may be coupled inductively or by capacity or resistance. Furthermore, they may be coupled direct or "indirect." Direct coupling is shown in Figure 13A and B. Note that the coupling element is common to both circuits.

In indirect coupling the transfer of energy between circuits is accomplished either by two condensers or two coils. This method is shown in Figure 14A and B.

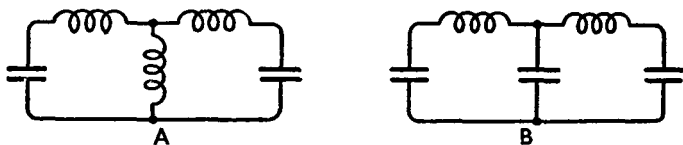


Figure 13. Direct Coupling: A, by Inductance; B, by Capacity

In the circuits shown coupled in Figure 14, electromagnetic induction takes place. The power induced will be greater when the coupling of either coils or condensers is close or "tight" and least when the distance between the coupling elements is a minimum, in which condition they are "loosely coupled."

When the coupling is small, or loose, the two circuits will be resonant to one frequency, but an increase in coupling will increase the mutual inductance and they will then be resonant to two frequencies. One of these frequencies will be higher, and the other will be lower than the original (resonant) frequency. That is why a spark transmitter, tightly coupled, has two wavelengths. Loose coupling is employed to eliminate interference in a receiving set and tight coupling is employed when listening over a small

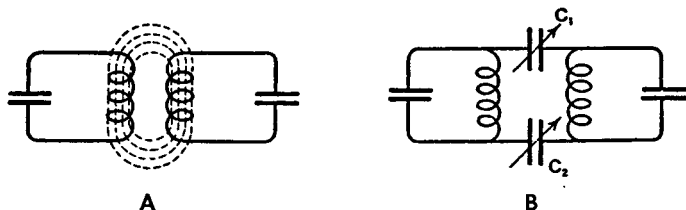


Figure 14. Indirect Coupling: A, by Inductance; B, by Capacity

band of frequencies when it is desired to hear several stations of slightly different frequency.

**Impedance Matching.** When the internal resistance of a generator is the same as that of its load, maximum power will be delivered to the load circuit, the internal and external circuits in this case being “matched” as to impedance. Because this holds true, the term “impedance matching” as applied to the design of

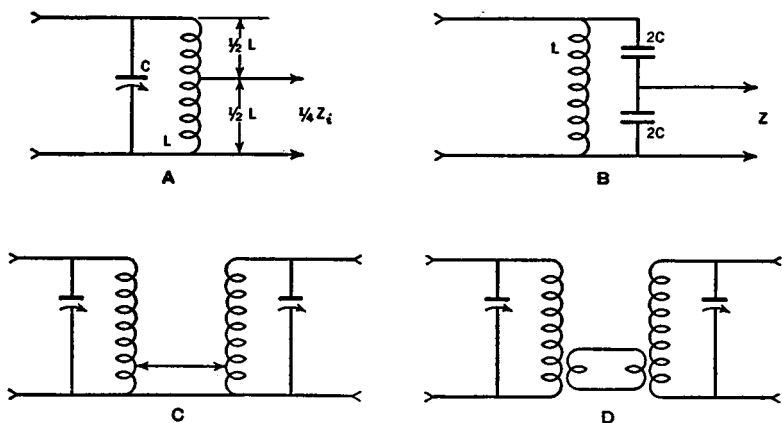


Figure 15. A and B, Methods of Tapping the Parallel Impedance of Resonant Circuits for Impedance Matching; C, Low Impedance Link Coupling; D, High Impedance Link

transmitter circuits means that the load impedance presented to the source is transformed to suit given requirements—which may NOT be matching impedances numerically, but DOES mean matching to best advantage.

**Matching by Tapped Circuits.** In addition to the custom of impedance matching by inductive coupling with tuned circuits, tapped resonant circuits are frequently used. (See Figure 15.) In both cases shown in circuits A and B the impedance between the tapped points will be the total impedance (practically) as the square of the reactance between the tap points is to the total reactance of the branch in which the tapping is done.

**Link Coupling.** Another coupling arrangement used for impedance matching radio-frequency circuits, known as "link coupling," is used for transferring energy between two tuned circuits separated by space. Two such methods are shown in Figure 15C and D. Compare A with C; such study will be a helpful training in the study of actual radio set circuits.

**Wave-Trap Circuits.** Wave traps are employed as part of a radio receiving set in order to eliminate an undesirable signal. Wave-trap circuits are of three classes: the rejector circuit, the acceptor circuit, and the by-pass filter circuit. The rejector circuit opposes the undesired signal; the acceptor circuit accepts and absorbs the energy of the undesirable signal so that it does not actuate the receiver; the filter circuit provides a low impedance path to ground for the objectionable signal. A practical illustration of the use of the rejector and acceptor circuits is furnished in the radiobeacon circuit shown and described on page 361. The shunt rejector consists of an inductor (inductance coil) and capacity in parallel. This type of trap prevents signals that are above and below the wavelength to which it is tuned from being received. The series rejector has a condenser and an inductor in parallel with each other placed in series with the antenna, receiver, and ground. This circuit can be tuned to reject any one specific wavelength.

In the filter circuit, either a variable condenser or an inductance coil that can be tuned is placed in series with the ground and antenna. The receiver is shunted around this capacity or coil. As the receiver offers an impedance to the interfering signal which is greater than the impedance offered to the signal it is tuned for, the undesired signal passes to ground instead of to the receiver.

**Filter<sup>93</sup> Circuits.** Although any resonant circuit is useful for selecting energy of a desired frequency and rejecting energy of undesired frequencies, certain hook-ups are better adapted to transmitting or rejecting more or less uniformly over a band of frequencies. Rejecting action is known as attenuation; accomplished by filters. Filter combinations are basically of three types, as illustrated in the simple forms of Figure 16. A is a low-pass filter, used to transmit energy below a given frequency limit, and

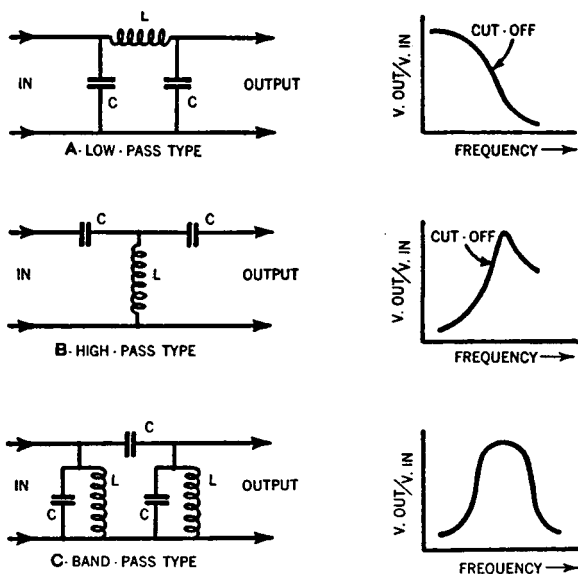


Figure 16. Filter Circuits

to attenuate energy of higher frequencies. Filters of this type are generally used with iron-core coils or filter chokes in plate power-supply systems for transmitters and receivers. A combination of inductance and capacitance elements of the arrangement of A is known as a "pi" section because its appearance resembles that of the Greek letter  $\pi$ . B is of opposite character to that of A, passing frequencies above a designated cut-off limit and attenuating lower frequencies. It is therefore called high-pass. The one shown is called a "T" section, because its form resembles that letter.



C is a type of filter for transmitting over a band of frequencies and attenuating outside this band. It is termed a band-pass filter.<sup>28</sup>

**Bridge or Neutralizing Circuits.** Another special type of circuit widely used is the bridge or neutralizing circuit, made up of capacitance and inductance so as to neutralize the undesired coupling effects. Such circuits are generally used for neutralizing the capacitance between the elements of tubes (Chapter 5) in transmitters. Figure 17 shows typical bridge circuits, and the balancing effects between parts therein.

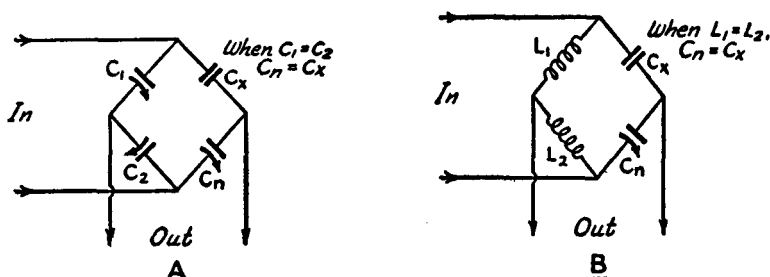


Figure 17. Capacitance and Inductance-Capacitance Bridge Circuits  
In both A and B the capacitance  $C_x$  is to be neutralized.

## Antennas

A transmitter consists of two major parts: (1) a transmitter circuit in which radio-frequency currents are set up, and (2) an antenna circuit into which these currents are fed and out of which radio waves are radiated. At the receiving station the antenna (or aerial as it is often called) is acted upon by the waves radiated from the transmitter in such a manner that the transmitted intelligence can be made audible through the receiver. The waves that are transmitted are also modulated. These waves are demodulated or detected by the receiver. An aerial at any radio station can be made to act both as a transmitting antenna and a receiving antenna. Since the action of a receiving antenna is simply that of a conductor which is cut by a moving magnetic field of force in the form of a radio wave, only the functioning of a transmitter antenna will be considered at this time.

**Types of Antennas.**<sup>10</sup> There are very many types of antennas used in broadcast and other services. There are also several types of aircraft antennas which are described in Chapter 15. Two of the most common basic types of ground station antennas are the Marconi and the Hertz.

A Marconi antenna can be a single wire, either vertical or part vertical and part horizontal. It is connected through coupling and tuning apparatus to the ground. The antenna wire acts as one plate of a leaky condenser—the ground as the other plate—energy being dissipated into the (air) dielectric.

The Hertz antenna is a single conductor suspended above the earth. The earth plays no part in the mechanism of radiation

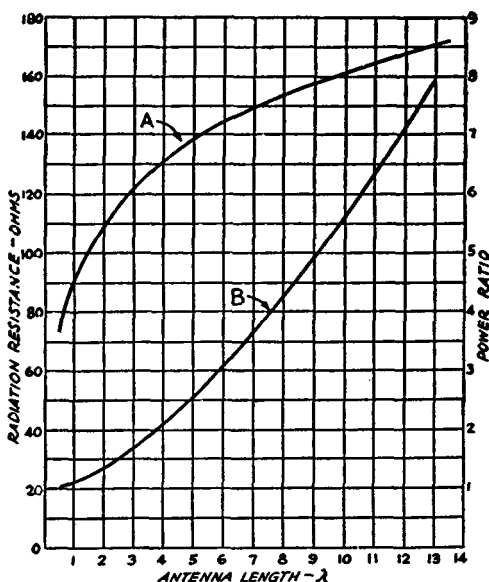


Figure 18. The Important Curves for Harmonically Operated Horizontal Antennas

Curve A shows the variation in radiation resistance with antenna length. Curve B shows the power in the lobes of maximum radiation for long-wire antennas as a ratio to the maximum of a half-wave doublet antenna.

although it affects the practical performance of this type. The Hertz is used almost exclusively for short-wave transmission. One form of the Hertz is the Zepp, used on Zeppelin airships.

**Antenna Lengths.** Antennas that are tuned (those of the resonant type) are cut to proper electrical length in accordance with the working frequency assigned to the radio station in order that the maximum amount of power may be fed into them without undue loss. The circuit of the transmitter which feeds power into the antenna during transmission is generally tuned. Antennas are designed as to length for any fundamental frequency desired; that of the Hertz is between 2.07 and 2.01 times its actual length. For a simple half-wave antenna, length (in feet) is equal to 468 divided by frequency in megacycles.

**Radiation Characteristics.** An antenna does not radiate equal amounts of power in all directions. The radiation pattern of any antenna is determined by its length in wavelengths, its effective height above ground, and its angle with respect to the ground. Vertical antennas radiate uniformly in a horizontal plane.

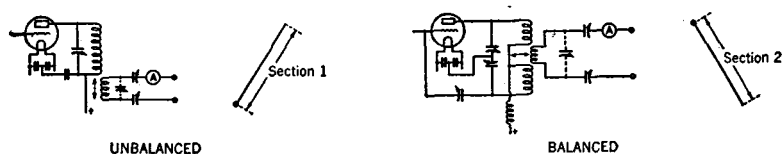


Figure 19. Directly Excited Antenna

Center-fed with suitable coupling arrangements. Antenna sections 1 and 2 are each quarter wavelength.

**Radiation Resistance.** Radiation resistance varies with the length of the antenna, its position with respect to surrounding objects, and the character of the ground. A Hertz antenna 1 half-wave in length has a radiation resistance of about 70 ohms, measured at the center of the antenna. Study Figure 18 briefly.

**Antenna Excitation.** When antennas are supplied with power from a transmitter by keying or speaking into the microphone, the antenna is "fed" or excited. Directly-excited antennas (those fed with a tuned feeder line) are generally either "voltage fed" or "current fed." Voltage-fed means that the exciting power is introduced into the antenna at a point of maximum voltage. Current-fed antennas are those where the feeder line delivers power at a point of maximum current.

Figure 19 shows a common form of directly-excited Hertz antenna fed at the center. When operated at its fundamental frequency, sections 1 and 2 should be one-quarter wavelength; the total length, section 1 plus section 2, should be one-half wavelength.

Figure 20 shows a directly excited antenna of the end-fed type. Its length is determined by measuring from the remote end to the point at which it is attached to the antenna feeder circuit. Its length should be one-half wavelength for the lowest frequency at which operation is desired.

**Transmission Lines.** Radio-frequency power is often fed from a transmitter to a somewhat distant antenna. In this case the impedance of the untuned transmission must be matched to that of the antenna at the point of connection. (A "transmission



Figure 20. Showing How Coupling for an End-Fed Antenna May Be Accomplished

line" antenna, referred to as a T.L. antenna, is used at radio range beacon stations.)

A resonant transmission line is simply an antenna that has been folded so that the currents flowing in the two parts are opposite in phase (page 151) but of the same magnitude so that the radiation from one wire is offset by that from the other.

*Standing Waves* are said to exist in a radio transmission line (or antenna) when there are electrical reflections from the point of termination in a line back to the source of excitation. This effect exists in an unmatched type of transmission line or in a line improperly matched. The impedance connected into a line to prevent standing waves is referred to as "surge impedance."

The highest voltage in an antenna exists close to the end.

Antennas which swing with the wind do not radiate a wave of fixed frequency.

**Field Intensity.** The field intensity of a transmitting antenna is expressed in *microvolts per meter*, and refers to the distribution of electrical energy in the field pattern of a transmitter. The study of field patterns becomes very important when handling any type of directive antenna such as the loop for radio-compass operation described in Chapter 12 and the radiobeacon transmitter antenna described in Chapter 9.

A *counterpoise*,<sup>55</sup> as used at some ground stations, consists of a network of wires strung above the ground below the antenna. It is a "false ground" and supplies capacity to the antenna system when the earth is not used. The airplane acts as a counterpoise when in flight.

**Tuning Antenna Circuits.** A radio-frequency ammeter is generally connected in the antenna circuit. The frequency of the exciting circuit (as L in Figure 10) is determined by a wavemeter (or frequency-meter) and then the capacity and inductance of the antenna circuit is adjusted until maximum current registers on the ammeter, indicating that the circuits are in resonance.

### QUESTIONS

51. Draw a workable receiving circuit and label parts.
52. Sketch an oscillatory circuit and explain its action.
53. What is the relation between frequency and wavelength?
54. Condensers in series: is their capacity additive?
55. Inductance in series: how is impedance calculated?
56. How may a circuit containing L and C in parallel be tuned?
57. Sketch two types of coupled circuits.
58. What is meant by the term "impedance matching"?
59. Describe a wave-trap circuit; a filter circuit.
60. Describe two common types of antennas.

NOTE. Look up following terms in Appendix II: 13, 16, 17, 18, 78, 80, 255, 257.

## CHAPTER 5

### RADIO TUBES

Vacuum tubes are now considered the most important part of all radio apparatus. They may be either glass or metal but an understanding of the basic principles of their operation is absolutely essential; their functioning in aircraft radio receiving and transmitting sets must be carefully studied.

#### Fundamental Phenomena

Extremely hot bodies discharge electricity; for example, a white-hot platinum wire will *emit negative ions*, called *electrons*, and these negative ions will negatively charge any nearby electrode. This phenomenon occurs in all radio tubes. A *cathode* emits electrons which pass to an *anode*.

#### Structure of Tubes

Tubes used in transmitters and receivers consist of a cathode and from one to three additional electrodes, mounted in an evacuated enclosure. The material employed for the enclosure or "envelope" or bulb is either glass, metal, or a combination of glass and metal. The function of the cathode is to emit electrons; the function of the other electrodes is to control and collect the emitted electrons. Suitable electrical connections are provided on the base of the glass bulb or metal shell containing these elements designed so as to plug into the circuit of the radio set for which they are designed. As the function of the cathode is to emit electrons with the greatest possible effectiveness, different materials are used in their manufacture, the materials selected depending upon the manner in which the cathode is to be heated. The directly-heated cathode, called a filament-type cathode, is of pure tungsten wire. High-power high-voltage tubes have this

type cathode. There is also a coated filament type of cathode. This is usually a nickel-alloy wire or ribbon coated with a mixture which contains certain alkaline earth oxides. A heater cathode consists of a number of thin metal sleeves which have been similarly coated, together with a heater element inside the sleeve and insulated from it. This heater is either tungsten or tungsten-alloy wire. The coated indirectly-heated cathode is often referred to as a unipotential cathode because it has no voltage drop as does the filament-type cathode.

The efficiency of the tungsten filament-type cathode as an electron emitter is relatively low; that of the coated cathode is high. Also, the coated cathode, of either filament or heater type, has a lower operating temperature than the tungsten filament cathode; is therefore not going to burn out as soon as the uncoated cathode. The unipotential (indirectly-heated-coated) cathode has the further advantage of a comparatively low hum level, a tube operating characteristic obviously essential to quiet performance of a receiver. Coated cathodes are found in many of the smaller, low-voltage tubes.

Thoriated-tungsten cathodes are made up from tungsten impregnated with thoria, having a surface of thorium. This type cathode emits electrons when heated at a medium temperature—to a bright yellow glow. Their efficiency as emitters is not as high as that of the coated cathodes, but higher than the tungsten cathode. Thoriated tungsten filament tubes are much used with a fairly high voltage. When used in circuits having extremely high voltages, or when overloaded, the surface layer of thorium may sputter off as the result of positive ion bombardment, thereby decreasing emission.

The *emission efficiency* of the cathode is largely dependent on its material and construction. The emission efficiency of any cathode is the electron space current in amperes per watt of filament or heater power. For convenience it is usually expressed in milliamperes per watt.

**Anodes.**<sup>9</sup> Anodes (plates) are made of tungsten, molybdenum, nickel, tantalum, or graphite. These have been selected mostly because of their high thermal emissivity and mechanical

properties. The anode is bombarded by electrons emitted from the cathode. It must dissipate the heat of bombardment. In the common type of tube this heat is radiated by the tube envelope—generally a glass bulb. The more effectively this is accomplished, the more power the tube will deliver. The larger the anode, the more electrostatic capacitance it will have. It is desirable to keep this capacity at a minimum in tubes used in high-frequency radio sets in order that the losses involved may be held down to a minimum.

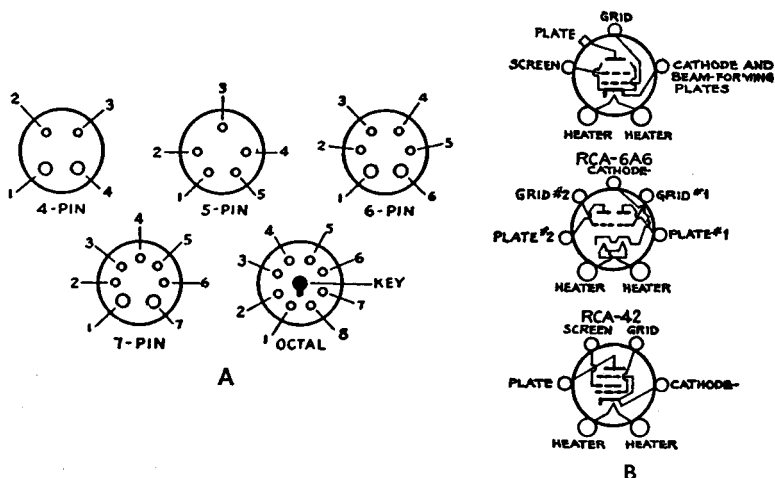


Figure 21. Tube-Base Pin Numbering System

A, showing the pins looking at the bottom of a tube base or socket; B, bottom view of sockets of tubes used in RCA-7B transmitter.

**Grid Structure.** Grids are of the same materials used in the manufacture of anodes and in addition certain alloys of molybdenum, nickel, and tungsten. Some grids are coated with carbon, this material tends to reduce the secondary emission of electrons and to increase thermal emissivity. The function of the grids is to control the plate current, that is, the flow of electrons between cathode and anode.

**Bases.** Bakelite, a *plastic*, is much used in making tube bases. Certain *ceramics*, such as porcelain, are also used. Some bases consist of metal shells with an insulating bottom disc. A good



porcelain insulator will prevent radio-frequency losses between base pins to a greater degree than will bakelite, but the latter is cheaper and easily shaped and is therefore more generally used.

Tube bases are built with from four to eight pins for element connections; except in the five- and eight-prong types, the two cathode pins are heavier than the others. The pins of all except the eight-pin or octal base are numbered according to the following system. Looking at the bottom of the base or the bottom of the socket, the left-hand cathode-pin is No. 1, and the others are numbered consecutively in the clockwise direction, ending with the right-hand cathode pin. In the octal (eight-pin) base, No. 1 pin is to the left of the key. (See Figure 21.)

In indicating which element is connected to which base pin, it is customary to use the letters, *F*, *F*, or *H*, *H* for filament or heater, *C* or *K* for cathode, *P* for plate, etc.

**Bulbs.** So-called "soft" glass is used in tubes which do not generate extreme heat. Small tubes which must dissipate much heat and large air-cooled transmitting tubes are made of "hard" glass which will not commence to soften from heat up to a temperature of 750° C., whereas soft glass will start to melt at 625° C. Hard and soft glass must not be confused with hard and soft tube *characteristics* which have to do with gas content as explained on page 96.

### Manufacturing Methods

In manufacturing a filament-type glass tube, a flanged glass cylinder serves as the main support of the elements. The supporting posts and lead-in wires are sealed into the top of the flanged tube by fusing the glass. A smaller exhaust tube also is fused into the side.

The filament—usually shaped like an inverted V—is next welded to the supporting posts and then the grid is mounted. This wire either is welded to, or embedded in, the supporting frame upon which it is wound. The wire may be wound up cylindrically or it may be flatly looped around a rack of two or more upright frames. If cylindrical in shape, the grid surrounds the filament; if of a flat "rack" type, it is placed between the filament and plate,

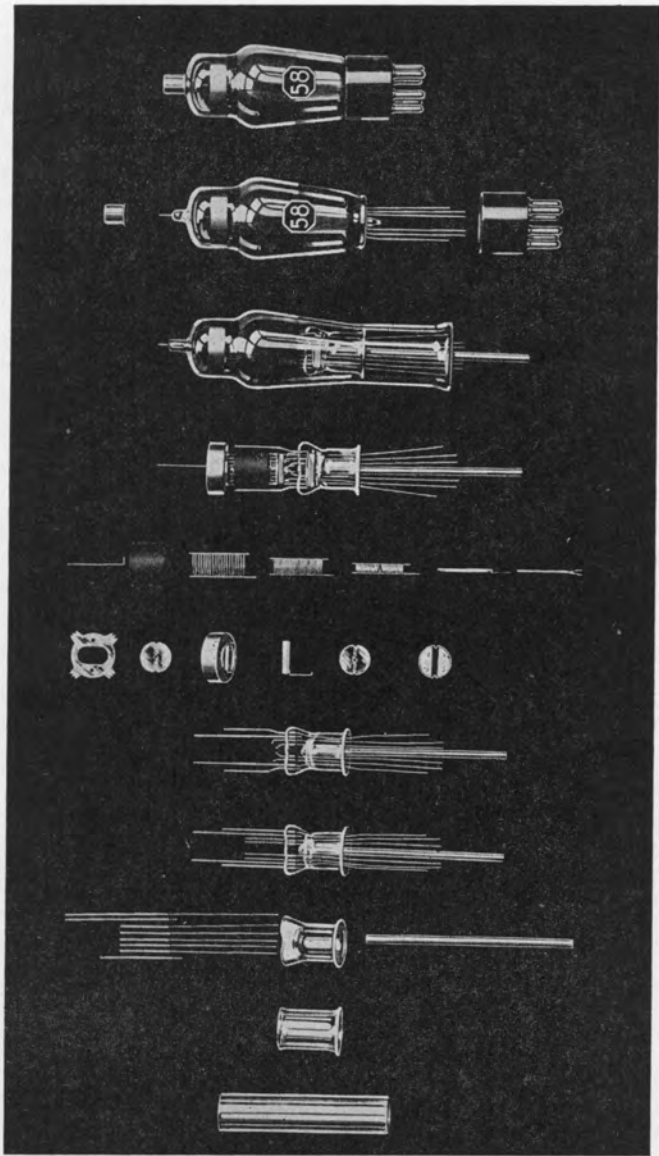


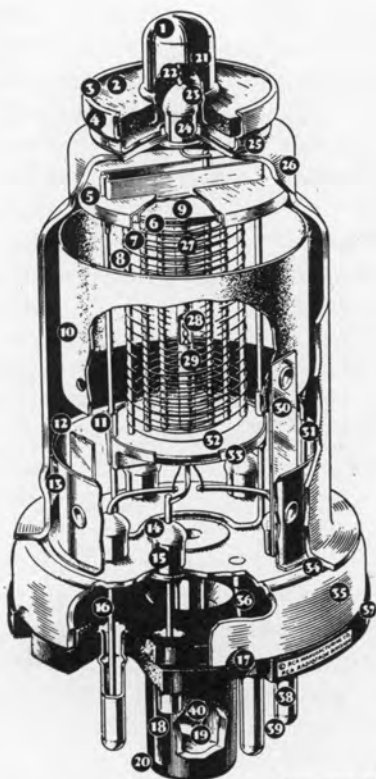
Plate IV. Showing Successive Steps in the Manufacture of an RCA Tube

which is made in several shapes, varying from a wire-wound type to heavy sheet metal. The plate is usually made of nickel, but sometimes molybdenum or tungsten is employed.

The final step in building the tube is to enclose the elements in a glass bulb, fuse it to the flange of the flanged tube and exhaust the atmosphere through the small tube previously fused into the side for that purpose. If the oxygen of the atmosphere remained, the elements would burn. The removal of the air is accomplished by a vacuum pump with the tube hot and the elements electrically connected. When the desired degree of vacuum has been obtained by the pump, corresponding to a few hundred thousandths of a millimeter of mercury, the small exhaust tube is melted off, permanently sealing the radio tube. Usually, the hotter the tube while exhausting it, the greater the vacuum, and as plain tungsten will stand more heat than oxide-coated filaments, more gas and air can be pumped out of a tungsten-filament tube than out of an oxide-filament tube. However, all tubes release some gas from their inner parts when placed in service and to absorb these gases a small quantity of magnesium, phosphorus, sulphur, or arsenic is left inside. These substances create a silvery film on the inner surface of the bulb which attracts the gas that remains inside, sealing it into the glass walls of the bulb. After pumping out, the bulb is always cemented to an insulated base containing four or five small hollow rods which are connected to the contact prongs; two for the filament, one each for the plate and grid. Rigidity of all parts is necessary to prevent vibration, which causes "microphonic" noises in the receiver. Each tube is tested when finished, to determine its fitness for the service for which it is designed.

Plate IV is an illustration of an RCA tube during various stages of its fabrication.

As a perfect vacuum is impossible to obtain, all tubes contain a small number of gas atoms. If these gas atoms are broken up, there will be two parts—a free or negative ion and a positively charged nucleus or ion. These atoms, so broken up, are said to be *ionized* and become conductors instead of insulators as they were before the ionization. The freed electrons break up additional atoms by collision and all the electrons are attracted to the



(Courtesy RCA Manufacturing Co.)

- |                     |                             |                              |
|---------------------|-----------------------------|------------------------------|
| 1—Solder            | 14—Glass Bead Seal          | 28—Helical Heater            |
| 2—Cap Insulator     | 15—Eyelet                   | 29—Cathode Coating           |
| 3—Rolled Lock       | 16—Lead Wire                | 30—Plate Insulating Support  |
| 4—Cap Support       | 17—Crimped Lock             | 31—Plate Lead Connection     |
| 5—Grid Lead Shield  | 18—Aligning Key             | 32—Insulating Spacer         |
| 6—Control Grid      | 19—Pinched Seal             | 33—Spacer Shield             |
| 7—Screen            | 20—Aligning Plug            | 34—Shell-to-Header Seal Weld |
| 8—Suppressor        | 21—Grid Cap                 | 35—Header                    |
| 9—Insulating Spacer | 22—Grid Lead Wire           | 36—Shell Connection          |
| 10—Plate            | 23—Glass Bead Seal          | 37—Octal Base                |
| 11—Mount Support    | 24—Eyelet                   | 38—Base Pin                  |
| 12—Support Collar   | 25—Brazed Weld              | 39—Solder                    |
| 13—Getter Tab       | 26—Vacuum-Tight Steel Shell | 40—Exhaust Tube              |
|                     | 27—Cathode                  |                              |

Plate V. Structure of an All-Metal Tube

plate, while all the positively charged nuclei, or ions, move toward the filament. This movement produces an increase of current flow through the tube by neutralizing the electric charge in the space between the plate and filament, known as the "space charge." If this ionization continues, the surface of the filament breaks down. If a too high plate voltage is applied, a "blue glow" discharge may result and in this condition the plate current is not affected by the grid voltage, consequently the tube becomes insensitive. The more gas in a tube, the more danger of ionization; the "harder" the tube, the less danger.

While exhausting the tube during its manufacture, a high-frequency voltage is connected to the elements; the color and distribution of the resulting arc will indicate the approximate amount of gas not yet exhausted.

If a tube has a perfect vacuum, negative voltage applied to the grid will not reverse the grid current. Therefore, in a tube having less than a perfect vacuum, when negative voltage is applied to the grid, the *amount* of reversed grid current will serve as an indication of the approximate amount of gas present in the tube.

A "hard" tube contains practically no gas; a "soft" tube contains a little more gas than a "hard" tube. A soft tube will require an adjustment of voltage to best fit it for the use to which it is put. The softer tubes are usually chosen for detectors because they are most sensitive.

Plate V shows the component parts of an all-metal RCA tube.

## Diodes

**Operation.** The two-element tube or diode<sup>68</sup> consists of a vacuum glass or metal tube containing a cathode, often in the form of a filament heated directly or indirectly by electricity, and a metal electrode called a plate or anode which usually surrounds the filament. The plate and filament do not touch each other. If a high positive potential is applied to the plate, this relatively cold plate will be bombarded by the negative ions that the hot filament emits. This bombardment charges the plate negatively. Then current will flow in one direction only—from the plate to the filament.

If one wire of an alternating current source is connected to the filament and the other to the plate, the a.c. will be rectified into direct pulsating current by means of the one-way action of the tube.

Note that there is no material connection between the plate and the filament; also that because of the fundamental laws governing electron emission, the electrons emitted are negative and pass from the filament to the plate; therefore, the positive flow of *current electricity* is opposite in direction—from the plate to filament. The space between becomes a one-way conductor because of the presence, in steady passage, of negative ions only. The filament current does nothing but heat the filament so that it will emit electrons. This fundamental conception of how a rectifying tube functions is necessary to the understanding of rectifiers and detectors.

**Characteristic Curve.** The easiest and most common way to discuss the action of a tube in operation is by reference to a graph

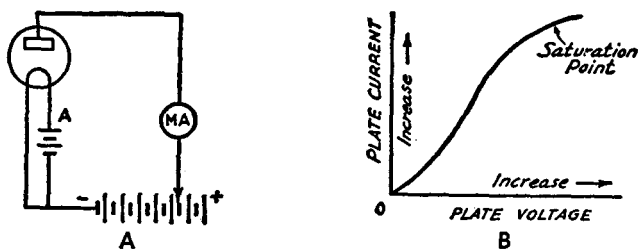


Figure 22. A, Diode Tube; B, Curve Showing Its Characteristics

which indicates its performance under the varying conditions to which it is normally subjected in the service for which it is designed. Such a graph is called a tube characteristic curve as shown in Figure 22B; 22A indicates the diode circuit hook-up from which the readings were taken to plot the curve B. Characteristic curves such as this are used to show not only the current flowing between the plate (anode) and cathode as in B, but between the cathode and other electrodes present in other forms of tubes having three or more electrodes. However, as the plate current is of chief interest in determining the output of a tube, the simple

curve shown should be studied carefully. It shows that with fixed cathode temperature, the plate current increases as the voltage between cathode and plate is raised. For any specific tube, the values of plate current and plate voltage would be plotted along their respective axes.

With the fixed cathode temperature, the total number of electrons emitted is always the same regardless of the plate voltage. The simple curve of Figure 22B shows, however, that less plate current will flow at low plate voltages than with high plate voltage. With low plate voltage only those electrons nearest the plate are attracted to the plate. The electrons in the space near the cathode, being themselves negatively charged, tend to repel the similarly charged electrons as they leave the cathode surface and cause them to fall back on the cathode. This is called the *space-charge* effect. As the plate voltage is raised, more and more electrons are attracted to the plate until finally the space-charge effect is completely overcome and all the electrons emitted by the cathode are attracted to the plate, and a further increase in plate voltage can cause no increase in plate current. The point at which practically all electrons are attracted to the plate is called the *saturation point*.

*Static characteristics* are the values obtained with different d.c. potentials applied to the tube electrodes, while *dynamic characteristics* are the values obtained with an a.c. voltage on the control grid under various conditions of d.c. potentials on the electrodes. The dynamic characteristics, therefore, are indicative of the performance capabilities of a tube under actual working conditions.

*Dynamic characteristics* include amplification factor, plate resistance, control grid-plate transconductance, and certain detector characteristics, and may be shown in curve form for variations in tube operating conditions.

*Plate resistance* ( $r_p$ ) of a radio tube is the resistance of the path between cathode and plate to the flow of alternating current. It is the quotient of a small change in plate voltage by the corresponding change in plate current and is expressed in ohms, the unit of resistance. If a change of 0.1 milliamperes (0.0001 ampere) is produced by a plate voltage variation of 1 volt, the plate resistance is 1 divided by 0.0001 or 10,000 ohms.

*Maximum peak inverse voltage* characteristic of a rectifier tube is the highest peak voltage that a rectifier tube can safely stand in the direction opposite to that in which it is designed to pass current.

*Maximum peak plate current* is the highest peak current that a rectifier tube can safely stand in the direction in which it is designed to pass current.

### Triodes

**Grids.**<sup>104</sup> Besides the filament and plate, the triode contains a third electrode, or element, called a grid. This is a metallic mesh so placed that the electrons emitted by the cathode must pass through it to reach the plate. This grid actually controls the flow of electrons. The sensitiveness of a receiving tube depends largely on this controllability. By imposing positive (or negative) potential on the grid, the amount of current flowing between plate and filament is controlled. This plate current can be increased greatly by a very small increase in the grid potential and the power released by the plate circuit is often greater than the power expended in the input circuit. For this reason, amplification can be increased by "feeding back" part of the plate circuit power to the input circuit. By this means, a tube can be made to produce sustained oscillations, a phenomenon which will be discussed later (page 181).

**Filament Current.**<sup>91</sup> Both d.c. and a.c. are used to heat filaments and (in the indirectly-heated cathode type) the heater element. Alternating current is generally preferred because it permits a more even distribution of current, but it may produce a hum in the directly-heated filament. One advantage of the indirectly-heated cathode is that a.c. hum is practically eliminated. If d.c. is used, that part of the filament which conducts current back to the B battery will carry more current than the other, tending to shorten the life of the filament. If the B battery circuit is traced through the tube in Figure 25, it will be seen that one leg of the filament is in the B circuit as well as in the A circuit.

As a tungsten filament deteriorates from heat, its resistance increases, consequently the current drops—then emission de-



creases. As a higher voltage is applied, the filament temperature rises and this shortens the life of the filament.

As a surface of an oxide-coated filament volatilizes, the resistance of the current-carrying core remains constant, but the impact of positive ions heats the filament in spots and these spots burn out, ending the life of the tube.

Most receivers use a.c. tubes requiring 6.3 volts for the cathodes, although some battery-operated sets use 2 volts connected to the cathodes which are generally of the directly-heated (filament) type.

**Plates.**<sup>176</sup> *The plate resistance* depends on the size of both the plate and filament, being inversely proportional to their combined area. It also depends on the voltage used and is affected by the *amplification factor*. (See page 112.) To make the amplification factor large and the plate resistance small, the grid is placed close to the filament.

The *plate current* depends on four factors :

1. The distance between the elements.
2. The area of the elements.
3. The shape and size of the grid.
4. The grid and plate voltages.

**Action of Three-Element Tube.** Figure 23 illustrates a symbol recently proposed by a standardization committee of engineers as the standard symbol of a three-element tube. The filament is heated by an A battery or other source of current. The grid is placed between the filament and the plate, but is closer than the plate to the filament and influences it more. The grid usually is charged negatively with respect to the filament, but not always. The plate current varies with the filament temperature and plate voltage; also it is varied by the electrostatic charge on the grid which is obtained from an additional source, usually a C battery.

A negatively charged grid tends to turn back to the filament the electrons emitted therefrom before they hit the plate. This effect is helped by the "space charge" reducing the plate current. If the negative grid charge is reduced, the number of emitted electrons reaching the plate is increased and vice versa down to the point where there is no plate current.

A *positive* grid charge will offset the space-charge effect and so the plate current will increase as the positive grid charge increases. The grid-circuit voltage should be adjustable. The grid current, which is small, is measured in microamperes, and its value becomes important when a grid leak or grid condenser is used. (See Figure 27, on page 107.)

**The Tube as a Circuit.** The input circuit is from grid to filament; the output circuit is from plate to filament through a battery and external load. The elements of a tube all have capacity known as interelectrode capacitance, as do the lead-in wires and the base. Between grid and filament of a triode there are about

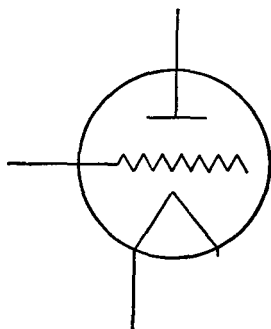


Figure 23. Three-Element Tube with Directly Heated Cathode

The filament leads are shown entering from the bottom, the plate lead from the top while the grid is shown between these two elements.

5 micro-microfarads, and between grid and plate about twice that capacity. In a tetrode these values are much decreased. There is an inter-capacity or "coupling" effect between all elements which introduces reactance, with resulting impedance. The whole tube can be conceived as functioning as a variable impedance, or resistance; the higher the grid resistance, the lower the tube resistance and vice versa. If a.c. is used in the input circuit, the grid and filament both act as condenser plates permitting current flow in the circuit which will set up a plate current by induction. The mutual conductance of a tube should be as large as possible. Also, the amplification factor, commonly represented by the Greek letter  $\mu$ , should be as great as possible when used as an amplifier.

Control-grid plate *transconductance*, or simply transconductance ( $g_m$ ), is a factor which combines in one term the amplification factor and the plate resistance, and is the quotient of the first by the second. This term is also known as mutual conductance. Transconductance may be more strictly defined as the ratio of a small change in the plate current (amperes) to the small change in the control-grid voltage producing it, under the condition that all other voltages remain unchanged. Thus, if a grid-voltage change of 0.5 volt causes a plate-current change of 1 milliamper (0.001 ampere) with all other voltages constant, the transconductance is 0.001 divided by 0.5, or 0.002 mho. (Mho is defined on page 43.) For convenience, a millionth of a mho, or a micro-mho, is used to express transconductance. So, in the example, 0.002 mho is 2000 micromhos.

**Overheating.** If the plate or filament voltage is too high, ionization will occur, decreasing the effectiveness of the tube and shortening its useful life. Increased voltage also subjects the elements to an increased temperature which will deteriorate all the elements, especially the filament. Electron bombardment of the plate may make it so hot that sagging will result. For this reason, many high-power tubes are cooled by a water circulating system around their outer surface, which surface is in many cases the plate. Heat radiates poorly in a vacuum, consequently blacking, sand-blasting, and oxidizing of the plates are often resorted to by manufacturers to increase the heat radiating characteristics.

### Tetrodes and Pentodes

Tubes containing four elements are tetrodes,<sup>237</sup> those with five elements are pentodes. The effect of grid-plate capacitance in causing excess regeneration can be eliminated in a number of ways. One scheme known as neutralization (page 109) requires the use of a special circuit arrangement which sets up counter-acting effects to balance out the action of the grid-plate coupling. A preferable method is to reduce the grid plate capacitance in the tube itself to a negligible value. This is accomplished by employing a fourth electrode in the tube, known as the screen. This screen is placed between the plate and the grid.

The screen is constructed so that although the flow of electrons to the plate is not materially obstructed, it establishes an electrostatic shield between the plate and the grid. The screen is usually operated at some positive voltage lower than that of the plate and is by-passed to the cathode through a condenser having low impedance at the operating frequency. The by-pass condenser effectively grounds the screen for high-frequency currents and assists in reducing the effective grid-plate capacitance. This permits tetrodes to provide a high order of stable amplification with relatively simple circuits. The 865 and 860 are typical tetrodes, or "screen grid" tubes.

In all radio tubes, electrons striking a positive electrode may, if moving at sufficient speed, dislodge or "splash out" other or

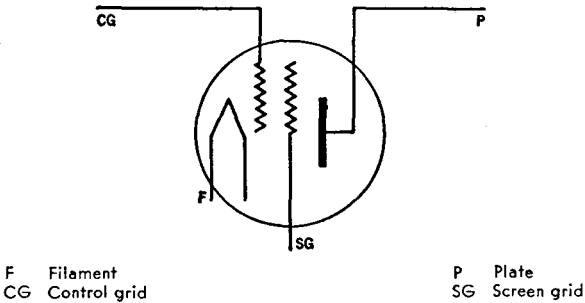
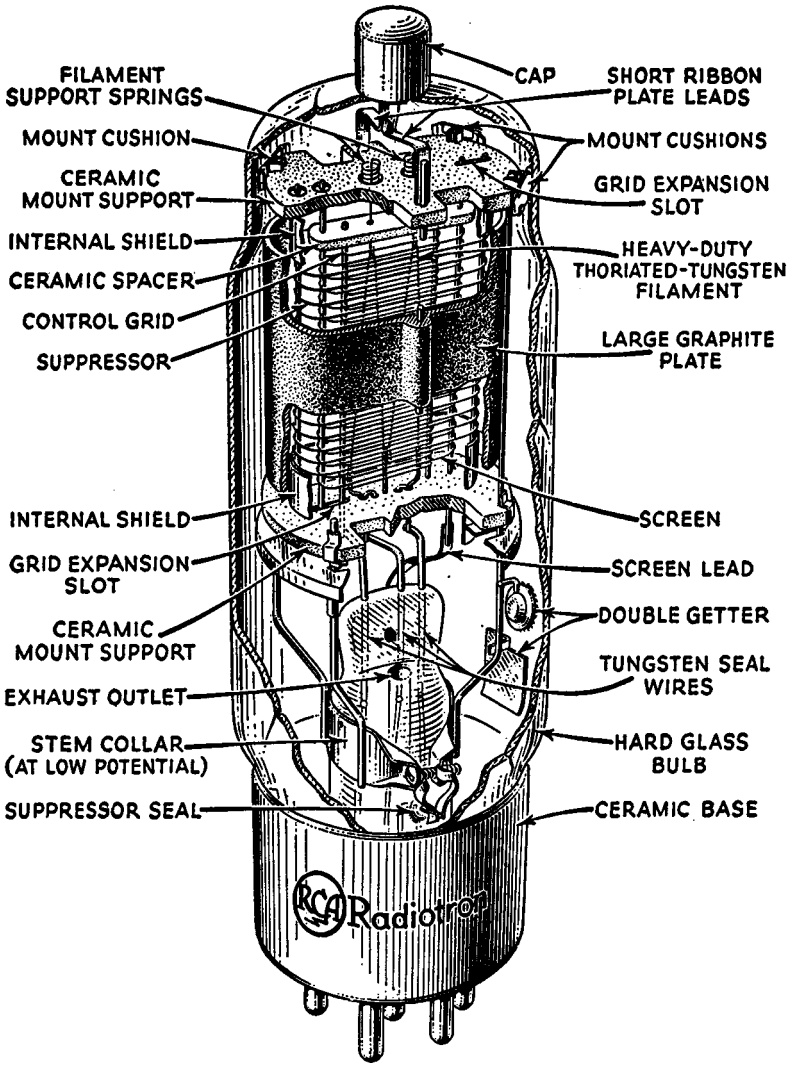


Figure 24. Conventional Representation of a Screen-Grid Tube

secondary electrons. In diodes and triodes such secondary electrons produced at the plate usually do not cause any trouble, because no positive electrode other than the plate itself is present to attract them. These electrons, therefore, are eventually drawn back to the plate. In tetrodes, the screen (operating at a positive potential) offers a strong attraction to secondary electrons when the plate voltage swings lower than the screen voltage. This effect limits the permissible plate swing for tetrodes because the major portion of the space current then goes to the screen rather than to the plate. The plate-swing limitation can be substantially removed when a fifth electrode, known as the *suppressor*, is placed in the tube between the screen and the plate. Such five-electrode types are called pentodes.



(Courtesy RCA Manufacturing Co.)

Plate VI. Structure of Transmitting Pentode RCA-803

The suppressor in a pentode is usually connected to the cathode or to a low positive or negative voltage, depending on the tube application. Because of its negative potential (in any case) with respect to the plate, the suppressor retards the flight of secondary electrons and diverts them back to the plate, where they cause no undesirable effects. Thus, in pentodes, the plate voltage may swing below the screen voltage. 6F6, 33, and 42 are pentodes.

The four-element tube is generally used as a radio-frequency amplifier in receivers with a positive tap from the B battery connected to the screen grid. It is the most successful radio-frequency amplifier yet developed, and when so used will supply the detector tube with a radio signal of several volts. It has also been employed with success in transmitters and can be used as a detector. When used as a detector, the first stage of audio-frequency amplification can be dispensed with as this type tube gives an amplification of from 40 to 75 per stage. (See Figure 24.)

Plate VI shows the construction of a pentode<sup>173</sup> in detail.

## Detectors

**The Function of a Detector.**<sup>67</sup> The primary function of a detector is to convert (radio) a.c. to pulsating d.c. This rectification

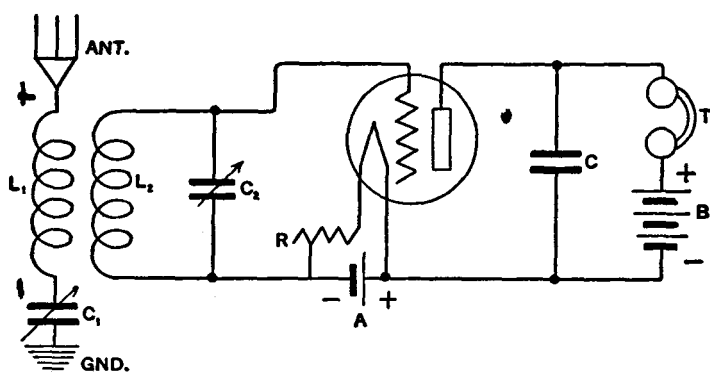


Figure 25. Non-Oscillating Tube Detector in Simple Receiving Circuit

process is absolutely essential in receiving because d.c. is necessary for the functioning of the headphones; the radio transmitter emits a.c. It is accomplished by either the grid or plate, according

to the type of tube and circuit that is used. The detector also converts radio-frequency currents, which are not audible in the phones, to audio-frequency currents which can be heard in the phones. Furthermore, the detector amplifies or increases the loudness of the incoming signals.

**Action of a Detector.** (See Figure 25.) The filament rheostat R, in the lead from the A battery to the filament, controls the filament voltage. The negative terminal of the A battery and also the grid are shown negative with respect to the negative terminal of the filament. This negative voltage applied to the grid is called the *grid-bias* and the amount of the *biasing voltage* is also controlled by R. The B battery insures direct current through the phones; the condenser C by-passes the radio-frequency from the plate circuit.

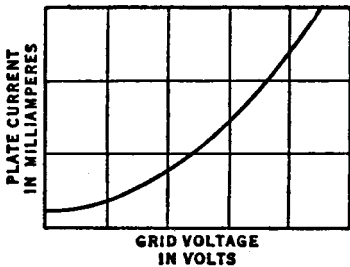


Figure 26. Characteristic Curve of a Typical Detector Tube

By putting the filament rheostat R in the positive lead from the A battery, the grid bias could be made to equal the voltage of a C battery; or, the rheostat R could be so connected as to vary the grid-bias from positive to negative. This grid-biasing is done in order to operate the tube with a specific relationship between the plate current and grid

voltage (see Figure 26); the object being increased efficiency.

**Plate Rectification.** Assuming that the receiving circuit (Figure 25) is in tune with some transmitter, the waves emitted from that transmitter will induce a radio-frequency current in the receiving antenna circuit. As it reverses back and forth from antenna to ground through  $L_1$ , it induces a radio-frequency current in  $L_2$  which is reduced to audio frequency, half of each cycle of which passes through the detector and is made audible in the headphones. In this particular circuit, detection is by *plate rectification*.

**Grid Rectification.** Examine Figure 27. The grid leak is indicated by the symbol  $R_2$  and the grid condenser in parallel as  $C_3$ .

Both are in series with the grid. The grid return lead is connected to the positive side of the A battery. The resistance of the grid leak is small, being from 1 to 10 megohms. The small "blocking" condenser  $C_3$  has a capacity of from 100 to 600 micro-microfarads. Electrons from incoming waves are "trapped" by the grid ( $C_3$ , the grid condenser, blocking their release), which becomes more negative as the incoming oscillations become stronger. The negative grid opposes the flow of electrons to the plate, decreasing the plate current. The grid condenser also decreases the average value of the plate current. (In a soft tube, leakage occurs from the grid to the filament through the gas present so that a grid leak is not needed.)

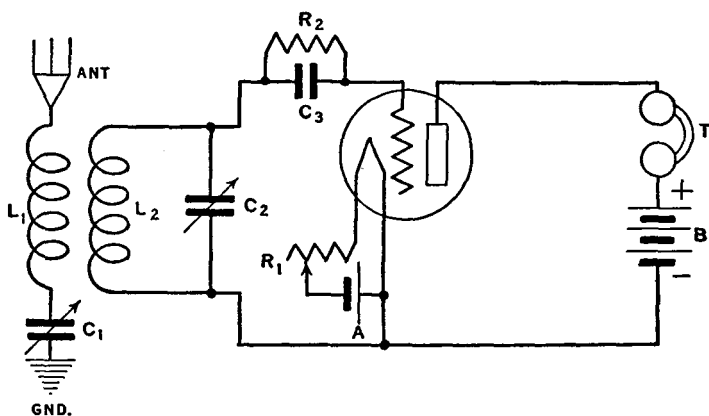


Figure 27. Non-Oscillating Tube Detector in Receiving Circuit with Grid Leak and Condenser

The resistance of the grid leak is maintained such that the rate of leakage is proportional to the *period* of the *audio-frequency* variations of the *radio-frequency oscillations* and not to the *period* of the *radio-frequency oscillations*.

This detection process (with grid leak and condenser) is referred to as *grid rectification*. Radio-frequency voltage is reduced to audio-frequency in the grid circuit; the plate circuit amplifies the audio-frequency variations. This is a better method than the plate rectification detection when the input voltage is small, because it is more sensitive to weak signals. When the input voltage



is large (signals loud), distortion is liable to result from overloading and under these circumstances the plate rectification method is best because, the output being greater, the tube is less liable to overload.

**Regenerative Detector.** Study Figure 28. Either plate or grid rectification can be accomplished with the regenerative detector, a feed-back or *tickler* coil inserted in the plate circuit being inductively coupled to the secondary coil of the receiving circuit. The object of this circuit is to produce amplification without using an

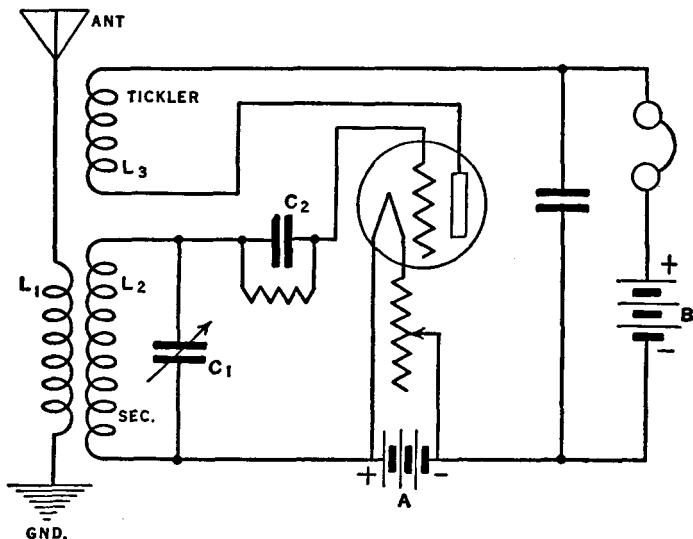


Figure 28. Regenerative Detector

additional (amplifying) tube. Larger radio-frequency voltage is produced by the feed-back and this creates a louder audio-frequency signal in the headphones. At a certain point in the feed-back process, the tube will commence to oscillate and the received note will become mushy.

**Oscillating Tube Detector.** The oscillating tube detector is also called the *autodyne* and is a type of regenerative detector with a large enough feed-back coil to keep it oscillating. It is used for

the reception of signals from a continuous oscillation arc or tube transmitter. (The arc transmitter is not used on aircraft but the tube transmitter is.) The frequency of oscillations in this tube will be governed mostly by the capacity and inductance of the secondary circuit of the receiver. If this circuit is not quite in tune with the transmitter, there will be two sets of oscillations in the receiver—a new “beat” will be heard and the received note will change with tuning. The current actuating the headphones in this case is the resultant of the two currents of different oscillations. The frequency of this resultant current is lower than the two that produce it.

**Avoiding Oscillation.** Two methods of stabilizing to avoid oscillation are known as the “Rice method” and “The Hazeltine

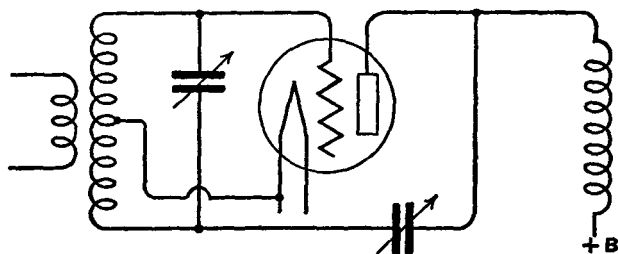


Figure 29. Rice Stabilizing Circuit

method.” In both methods, the capacity of the tube is neutralized by another capacity.

The Rice method is shown in Figure 29. The center of the input coil is grounded, therefore the coils must be carefully spaced or shielded or else the capacity coupling between them may destroy the balance being sought. The use of this method may decrease the sensitivity to a certain extent, but it prevents “mushiness” of tone in the headphones.

**Heterodyne Detector.** Two tubes are used; one as an oscillating detector and another to superimpose a second set of oscillations. This makes a very sensitive detector, but the circuit supplying the imposed oscillations must be kept carefully tuned. The so-

called *superheterodyne* or *multiple-heterodyne* system is a name given to a series of heterodyne circuits comprising one receiving circuit.

In the superheterodyne receiver, radio-frequency a.c. is lowered into "beat" frequency by superimposing a locally generated current. The resultant "beat" current is "filtered," amplified, and rectified and then passes through the usual stages of an audio-frequency amplifier. In this connection, see also page 325.

**Detector Tube Efficiency.** The detecting efficiency is the ratio of *audio-frequency output power* to *radio-frequency input power*. The actual power in watts used in the radio-frequency input circuit is not readily measured. For this reason, it is preferable to express the detecting efficiency as a relation between the radio-frequency input voltage and the resistance of the external output circuit. A detection coefficient is used; this factor squared and then multiplied by the ohms resistance in the output circuit will give the detecting efficiency of any tube.

In general, with a non-oscillating detector, if the received signal is weak, its strength will be directly proportional to the *square of the radio-frequency voltage applied to the detector*.

If the received signal is strong, or if an oscillating detector is used, its strength will be directly proportional to this radio-frequency voltage, **NOT** squared.

When an oscillating detector can be used, markedly superior results can be obtained in detecting modulated continuous-wave signals.

A good tube, properly handled, should operate for 500 hours in average service.

## Amplifiers

**Process of Amplification.** In an amplifier<sup>8</sup> receiving tube, the voltage impressed by incoming oscillations on the grid circuit produces oscillations of greater power in the plate circuit than the same voltage would produce if impressed directly on the plate circuit. This occurs because the small voltage coming into the grid circuit is used to release current from the B battery to the plate circuit. The advantage of this amplification process is obvi-

ous in the headphones where the signals sound louder. It can be accomplished *before* rectification of the incoming radio-frequency oscillations, when it is called radio-frequency amplification, or, *after* the rectification, when it is called audio-frequency amplification.

Amplifiers may be divided broadly into two general types, those whose chief purpose is to give a greatly magnified reproduction of the input signal without regard to the power delivered, and those which deliver a relatively large amount of power to a load such as a loud-speaker, in the case of an audio amplifier, or an antenna, in the case of a radio-frequency amplifier. The former is known as a *voltage amplifier*, the latter a *power amplifier*.

In audio circuits, the power tube or output tube in the last stage usually is especially designed to deliver a considerable amount of audio power, while requiring but negligible power from the input or exciting signal. The *power amplification* (ratio of output power to power supplied the grid circuit) is consequently very high. Such tubes generally require a large grid-voltage swing for full-power output, consequently the *voltage amplification* (ratio of output voltage to signal voltage) is quite low. To obtain the voltage swing required for the grid circuit of such a power tube, it becomes necessary to use voltage amplifiers, employing tubes of high amplification which will greatly increase the voltage amplitude of the signal. Although such tubes are capable of relatively-high voltage output, the power obtainable from them is small. Voltage amplifiers are used in the radio-frequency stages of receivers as well as in audio amplifiers.

If a weak radio-frequency signal is amplified 20 times and then rectified, it will be as loud as if it had been rectified first and then amplified 400 times. For this reason, from one to three radio-frequency amplifiers usually are connected ahead of a detector tube with two or three audio-frequency stages after the detector. Too many audio-frequency stages are apt to cause distortion, howling, and other noises when used in aircraft. In an aircraft receiver, the headphones are connected into the plate circuit of the last audio-frequency stage and the entire unit is "shielded" by a metallic enclosure to reduce noise.

**Amplification Factor.**<sup>7</sup> The extent to which the amplification, or increase in signal strength, can be carried constitutes an *amplification factor* (designated by the Greek letter mu) and depends almost entirely on the design of the tube. It is equal to the change in plate voltage divided by the change in grid voltage. Also it can be shown that it equals the electrostatic capacity of the grid and filament divided by the electrostatic capacity of the filament and plate. (Remember that capacity varies with the distance between the electrostatic elements.)

The amplification factor depends on the spacing and size of the grid wires, and increases with greater distance between the grid and plate. It varies directly as the distances between the plate and filament, and between the grid and filament. A fine grid, mounted closer to the filament than the plate, will produce a large amplification factor. This factor becomes a constant (except at very low operating voltages) for each tube manufactured and is a measure of the maximum voltage amplification obtainable from that tube.

Sometimes the amount of amplification<sup>6</sup> is expressed as a voltage amplification of a certain number per stage. This number is a ratio of increase between the grid and filament voltage of one stage and the voltage delivered by it to the next stage ahead. An amplification of ten simply means that the strength of signal is increased ten times more than it was originally. By "overall gain" is meant the increase in amplification accomplished by the entire receiver.

### Coupling of Amplifiers

If connected through a resistance, the stage becomes a resistance-type amplifier; if through a transformer, a transformer type; and if through an inductance coil or coils, it is known by three names: inductance, reactance, or impedance type. If the proper value of capacity and inductance is used, any type can be employed for either radio- or audio-frequency amplification.

**Resistance Type Amplifier.** In Figure 30  $R$  and  $R'$  are resistance coils of from 50,000 to 200,000 ohms, being greater than the internal resistance of the tube between plate and filament;  $E$

is the input voltage; it causes d.c. to flow in the plate circuit of No. 1 tube and through  $R$ . The voltage across  $R$  is applied to the input of the No. 2 tube through the coupling condenser  $C$  to the grid and through the  $A$  and  $B$  batteries, which are common to both tubes, to the filament of No. 2 tube.  $C$  prevents practically all positive plate voltage in No. 1 tube from being applied to the grid of No. 2 tube, but does not stop a.c.;  $r$  is the grid leak and helps to steady the grid voltage at the same value as that of the negative filament. As the reactance of  $C$  varies with the frequency, its capacity must be nicely calculated for aircraft receivers working on prescribed frequencies. Its impedance must

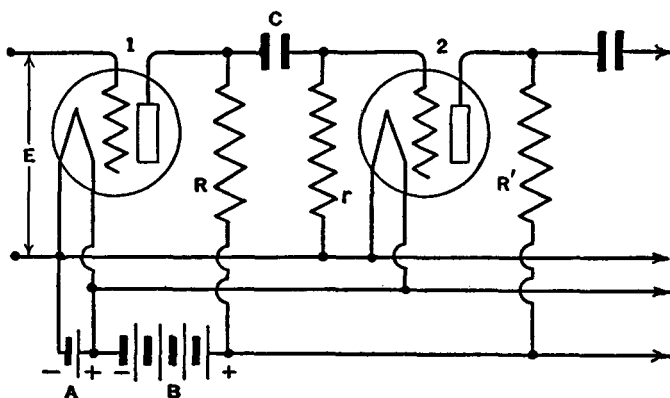


Figure 30. Resistance Coupled Amplifier

bear a precise relationship with  $R$  and  $R'$  for most efficient amplification.

The maximum voltage amplification per stage which can be obtained with a resistance-coupled amplifier depends almost entirely on the amplification factor of the tubes used. This type amplifier is not very efficient on the aircraft wavelengths of from 400 to 600 meters. The high plate voltages required for coupling through  $R$  and  $R'$  call for large heavy batteries which are objectionable in airplanes, particularly in military aircraft. Before pentodes were developed, one stage of audio-frequency using UX-240 type tubes (triodes) effectively amplified the received signal about 20 times; two stages,  $20 \times 20$  or 400 times, and as

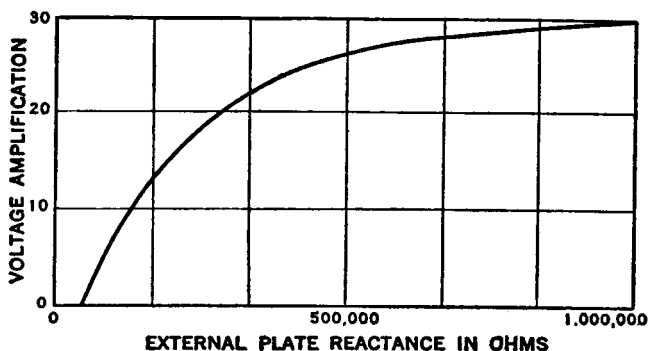


Figure 31. Theoretical Relation Between Voltage Amplification and Load Resistance (Old UX-240 tube)

three stages were used, the total amplification was  $20 \times 20 \times 20$ , or 8000 times.

Figure 31 shows that the increase in amplification factor for the old UX-240 (triode) tube is small at plate resistance above 500,000 ohms. In a UX-201A tube, the amplification gain is small at resistances greater than 50,000 ohms. Tetrodes and pentodes are now preferred as amplifiers, being much more efficient.

**Impedance Coupled Amplifier.** (See Figure 32.) Coils and condensers give an impedance coupling in this arrangement, instead of the resistance coupling furnished by  $R$  and  $R'$  in Figure 30, otherwise it functions much the same. The combined reactance of the coils and condensers must be high at the frequency

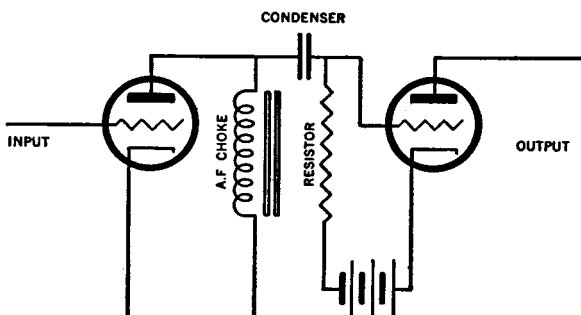


Figure 32. Impedance Coupled Amplifier

for which the amplifier is designed and yet have a low resistance to d.c. It requires a much lower voltage on the plate coupling coils than the resistance-type amplifier. The resistance of the coupling unit is so small in the impedance-type amplifier as to be negligible. At 30,000 ohms, a coupling coil has about 100 henries inductance at 50 cycles. The coupling coils for audio-frequency amplifiers have an iron core with low internal losses and capacity.

The size of the blocking condenser must be as small as will give good results, and the grid leak should have a large inductance and a small resistance. This amplifier has a tendency to oscillate; it requires considerable tuning. The amount of amplification obtained in a stage of this type depends on the amplification factor of the tube, not of the circuit.

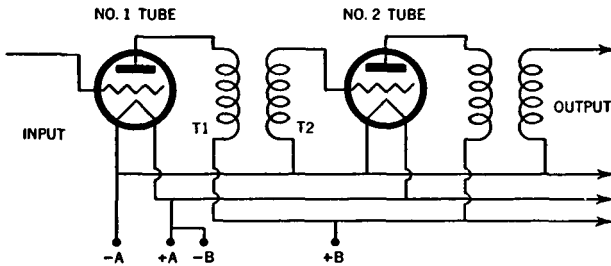


Figure 33. Transformer-Type Amplifier

**Transformer Type Amplifier.** In Figure 33, T1 is the high-impedance primary of the coupling transformer connected into the plate circuit of No. 1 tube, while T2 is the secondary of the same transformer connected to No. 2 tube. In a radio-frequency amplifier of this type, a 1-to-1 ratio air-core transformer is used in aircraft sets designed for normal wavelengths; for extra-long wavelengths, a step-up ratio is used. For audio-frequency amplification, a step-up ratio of from 1 to 3, up to 1 to 10 is used; the core is of finely laminated iron having a low internal capacity with little flux leakage.

**Tuned Radio-Frequency Amplifier.** This is a transformer-type amplifier for radio-frequency. It has a variable condenser connected across the secondary of the transformer. By tuning



this coupling circuit, maximum amplification can be obtained over a wide range of frequencies, or wavelengths. Aircraft amplifiers are usually designed for a rather narrow wavelength band, but the introduction of this additional tuning feature will increase the effectiveness of the amplifier on other than aircraft wavelengths. This is of advantage to the flyer who wishes to tune in stations off the aircraft band, which will include most broadcast stations.

**Parallel Connected Amplifiers.** When it is necessary to obtain more power output than one tube is capable of giving, two or more tubes may be connected in parallel, in which case the similar elements in all tubes are connected together as shown in Figure 34. When this is done the power output will be in proportion to

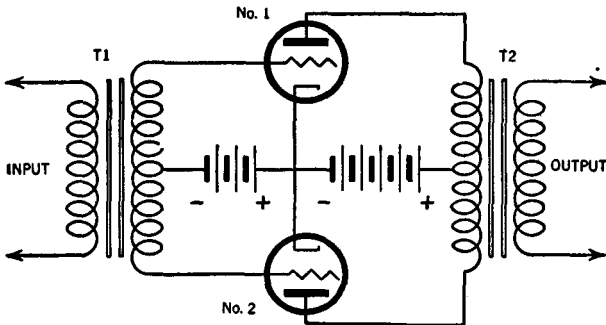


Figure 34. Push-Pull Amplifier

the number of tubes used; the exciting voltage required, however, is the same as for one tube.

**The "Push-Pull" Amplifier.** This is an arrangement of matched tubes intended to reduce distortion in radio-frequency amplification. One of the grids is positive when the other is negative, balancing the distorting components so that they are not effective. This hook-up also increases the power output of an amplifier.

A "balanced" circuit, in which the cathode returns are made to the midpoint of the input and output devices, is necessary with push-pull operation. (See Figure 34.) An alternating current

flowing through the primary of the input transformer will cause an alternating voltage to be induced in the secondary winding since the ends of the winding will be at opposite potentials with respect to the cathode connection; the grid of one tube is swung positive at the same instant that the grid of the other is swung negative. The plate current of one tube therefore is rising while the plate current of the other is falling. In push-pull operation the second-harmonic distortion is cancelled in the symmetrical plate circuit, so that for the same output the distortion will be less than with parallel operation. It follows, of course, that for a given degree of distortion, the push-pull amplifier is capable of delivering somewhat more power than a parallel amplifier.

**Reflex Amplification.** The "reflex" system of amplification passes the radio signal through radio-amplifiers, a detector, and then through the same radio amplifiers for audio amplification, making this set of tubes do double duty.

### Action of Amplifiers

Aside from the various coupling connections which identify amplifiers, such as impedance-coupled, transformer-coupled, etc., there are four classes of amplifier service recognized by engineers and covered by definitions standardized by the Institute of Radio Engineers (I.R.E.). This classification depends primarily on the fraction of input cycle during which plate current is expected to flow under rated full-load conditions. The classes are Class A, Class AB, Class B, and Class C. (The term, "cut-off bias," used in the following definitions, is the value of grid bias at which plate current is some very small value.)

A Class A amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

A Class AB amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half, but less than the entire electrical cycle.

(NOTE: To indicate that grid current does not flow during any part of the input cycle, the suffix 1 may be added to any of

the above letters of class identification and the suffix 2 may be used to denote that grid current flows during some part of the cycle.)

For radio-frequency amplifiers which operate into a selective tuned circuit, as in radio transmitter applications, or under requirements where distortion is not an important factor, any of the above classes of amplifiers may be used, either with a single tube or a push-pull stage. For audio-frequency amplifiers in which distortion is an important factor, only Class A amplifiers permit single-tube operation. In this case, operating conditions are usually chosen so that distortion is kept below the conventional 5% for triodes and the conventional 7% to 10% for tetrodes or pentodes. Distortion can be reduced below these figures by means of special circuit arrangements such as that discussed after *inverse feedback* on page 123. With Class A amplifiers, reduced distortion with improved power performance can be obtained by using a push-pull stage for audio service. With Class

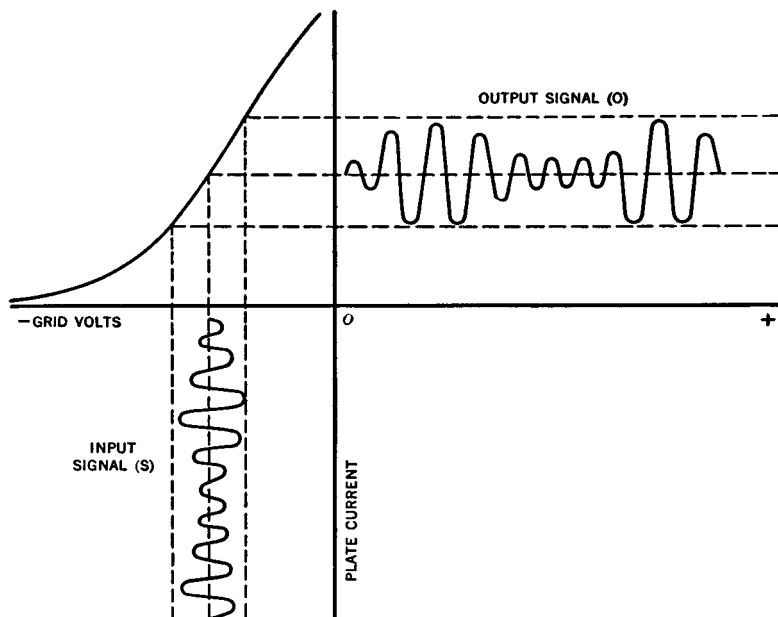


Figure 35. Amplification Graph

AB and Class B amplifiers, a balanced amplifier stage using two tubes is required for audio service.

As a Class A voltage amplifier, a radio tube is used to reproduce grid voltage variations across an impedance or a resistance in the plate circuit. These variations are essentially of the same form as the input signal voltage impressed on the grid, but of increased amplitude. This is accomplished by operating the tube at a suitable grid bias so that the applied grid-input voltage produces plate-current variations proportional to the signal swings. Since the voltage variation obtained in the plate circuit is much larger than that required to swing the grid, amplification of the

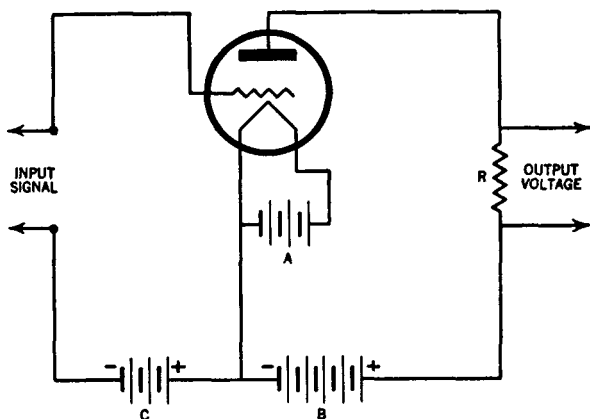


Figure 36. Class A Voltage Amplifier

signal is obtained. Figure 35 gives a graphical illustration of this method of amplification and shows, by means of the grid-voltage vs. plate-current characteristics, the effect of an input signal ( $S$ ) applied to the grid of a tube.  $O$  is the resulting amplified plate-current variation.

The plate current flowing through the load resistance ( $R$ ) of Figure 36 causes a voltage drop which varies directly with the plate current. The ratio of this voltage variation produced in the load resistance to the input signal voltage is the voltage amplification, or *gain*, provided by the tube. The voltage amplification due to the tube is expressed by the following convenient formulae:

$$\frac{\text{Voltage}}{\text{Amplification}} = \frac{\text{Amplification}}{\text{factor}} \times \frac{\text{Load resistance}}{\text{Load resistance} + \text{Plate resistance}}$$

The output wave form of a Class A amplifier is sinusoidal as illustrated in Figure 4, page 50.

The chief characteristics of the Class A amplifier are low distortion, low power output for a given size of tube, and a high power-amplification ratio. The plate efficiency—ratio of a.c. output power to steady d.c. input power—is relatively low, being in the vicinity of 20% to 35% at full output, depending upon the design of the tube and the operating conditions.

Class A amplifiers of the power type find their chief application as output amplifiers in audio systems, operating loud speakers in radio receivers and public-address systems, and as modulators in radiotelephone transmitters. Class A voltage amplifiers are found in the stages preceding the power stage in the same applications, and as radio-frequency amplifiers in receivers.

A *super-control amplifier* tube is a modified construction of a pentode or a screen-grid type and is designed to reduce modulation-distortion and cross-modulation in radio-frequency stages. *Cross-modulation* is the effect produced in a radio receiver by an interfering station "riding through" on the carrier of the station to which the receiver is tuned. *Modulation-distortion* is a distortion of the modulated carrier and appears as audio-frequency distortion in the output. This effect is produced by a radio-frequency amplifier stage operating on an excessively curved characteristic when the grid bias has been increased to reduce volume. The offending stage for cross-modulation is usually the first radio-frequency amplifier, while for modulation-distortion, the cause is usually the last intermediate-frequency stage. The characteristics of super-control types are such as to enable the tube to handle both large and small input signals with minimum distortion over a wide range. The super-control action is due to the structure of the grid which provides a variation in amplification factor with change in grid bias. The grid is wound with coarse spacing at the middle and with close spacing at the ends. When weak signals and low grid bias are applied to the tube, the effect of the non-uniform turn spacing of the grid on cathode emission and tube

characteristics is essentially the same as for uniform spacing. As the grid bias is made more negative to handle larger input signals, the electron flow from the sections of the cathode enclosed by the ends of the grid is cut off. The plate current and other tube characteristics are then dependent on the electron flow through the coarse section of the grid. This action changes the gain of the tube so that large signals may be handled with minimum distortion due to cross-modulation and modulation-distortion. Figure 37 shows a typical plate-current vs. grid-voltage curve for a super-control type compared with the curve for a type having a uniformly spaced grid. It will be noted that while the curves are similar at small grid-bias voltage, the plate current of the super-control tube drops quite slowly with large values of bias voltage. This slow change makes it possible for the tube to handle large signals satisfactorily. Since super-control types can accommodate large and small signals, they are particularly suitable for sets having automatic volume control. Super-control types also are known as remote cut-off types.

An interesting type of special tube is illustrated in Plate VI.

The Class B amplifier is primarily one in which the output current, or alternation component of the plate current, is proportional to the amplitude (or square) of the exciting grid voltage.

The distinguishing operating conditions of Class B service are that the grid bias is set so that the plate current is very nearly zero or cut-off; the exciting signal amplitude can be such that the entire linear portion of the tube's characteristic is used. Figure 38 illustrates Class B operation. Plate current flows only during the positive half-cycle of excitation voltage. Since the plate current is set practically to zero with no excitation, no plate current flows during the negative swing of the excitation voltage. The shape of the plate current pulse is essentially the same as that of the positive swing of the signal voltage. Since the plate current is driven up toward the saturation point, it is usually necessary

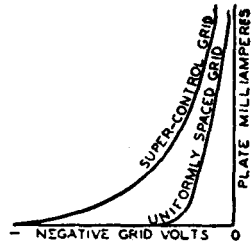


Figure 37. Plate-Current Plotted Against Grid-Voltage for a Super-Control Type Tube

for the grid to be driven positive with respect to the cathode during part of the grid swing, as indicated in Figure 38. Grid current flows, therefore, and the driving source must be capable of furnishing power to supply the grid losses.

Class B amplifiers are characterized by medium power output, medium plate efficiency (50% to 60% at maximum signal), and a moderate ratio of power amplification. They are used for both audio- and radio-frequency amplification. As radio-frequency amplifiers, they are used as *linear amplifiers* to raise the output power level in radio telephone transmitters after modulation has taken place.

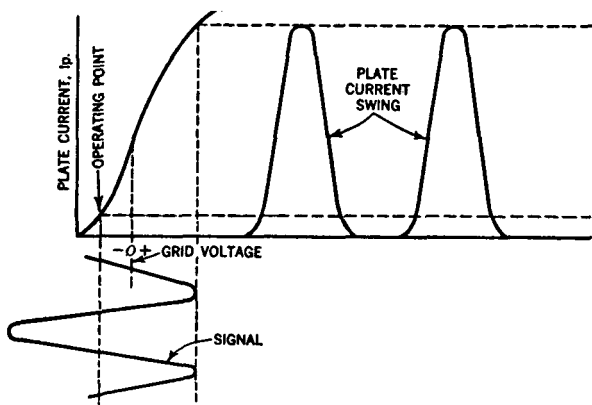


Figure 38. Operation of the Class B Amplifier

For audio-frequency amplification, two tubes must be used to permit Class B operation. A second tube, working alternately with the first, must be included in the amplifier circuit, so that both halves of the cycle will be present in the output. A typical method of arranging the tubes and circuit so that this end is achieved is shown in Figure 34, the circuit resembling that of the push-pull Class A amplifier, the difference being in the method of operation. The signal is fed to a transformer T1, whose secondary is divided into two equal parts, with the tube grids connected to the outer terminals and the grid bias fed in at the center. A transformer T2 with a similarly-divided primary is connected to the plates of the tubes, the plate voltage being fed in at the center-tap.

When the signal swing in the upper half of T1 is positive, Tube No. 1 draws plate current while Tube No. 2 is idle; when the lower half of T1 becomes positive, Tube No. 2 draws plate current while Tube No. 1 is idle. The corresponding voltages induced in the halves of the primary of T2 combine in the secondary to produce an amplified reproduction of the signal waveshape with negligible distortion. The Class B amplifier is capable of delivering much more power output, for a given tube size, than is obtainable from a Class A amplifier.

There are several tube types designed especially for Class B amplification. The characteristic common to all these types is high amplification factor (high "mu"). The plate current is small when grid voltage is zero. These tubes, therefore, can be operated in Class B at a bias of zero volts, so that a bias supply is not required. A number of the Class B amplifier tube types consist of two triode units mounted in one tube. The two triode units can be connected in push-pull, so that only one tube is required for a Class B stage. Examples of the Class B twin triode types are the 6N7, 6A6, and 19.

*Inverse feedback* is used in audio amplifiers to reduce distortion in the output stage where the load impedance on the tube is a loud-speaker.

A *corrective filter* is sometimes used to improve the frequency characteristic of an output stage using a pentode, when inverse feedback is not applicable. The filter consists of a resistor and a condenser connected in series across the primary of the output transformer. The resistance to be used in the filter for a push-pull stage is 1.3 times the recommended plate-to-plate load resistance; or, for a single-tube stage is 1.3 times the recommended plate load resistance. The capacitance in the filter should have a value such that the voltage gain of the output stage at a frequency of 1000 cycles or higher is equal to the voltage gain at 400 cycles.

**Class C Amplifiers.** The third type of amplifier is that designated as Class C. Fundamentally, the Class C amplifier is one operated so that the alternating component of the plate current is directly proportional to the plate voltage. The output power is



therefore proportional to the square of the plate voltage. Other characteristics inherent to Class C operation are high plate efficiency, high power output, and a relatively low power-amplification ratio.

The grid bias for a Class C amplifier is ordinarily set at approximately twice the value required for plate current cut-off without grid excitation. As a result, plate current flows during only a fraction of the positive excitation cycle. The exciting signal should be of sufficient amplitude to drive the plate current to the saturation point, as shown in Figure 39. Since the grid must be driven far into the positive region to cause saturation, consid-

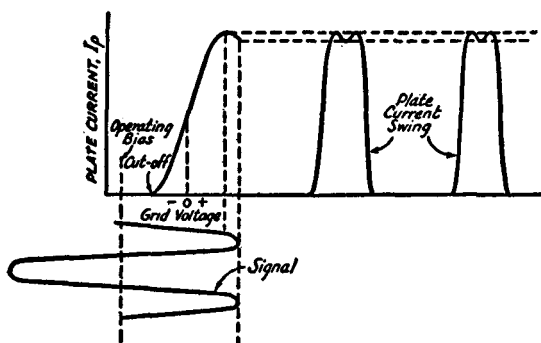


Figure 39. Class C Amplifier Operation

erable numbers of electrons are attracted to the grid at the peak of the cycle, robbing the plate of some that it would normally attract. This causes a droop at the upper bend of the characteristic, and also causes the plate current pulse to be indented at the top, as shown. Although the output wave-form is badly distorted, at radio-frequencies the distortion is largely eliminated by the filtering or flywheel effect of the tuned-output circuit.

Class C amplifiers are used principally as radio-frequency power amplifiers, since the Class C type of operation has very little audio-frequency application. Although requiring considerable driving power because of the relatively large grid swing and grid-current flow, the high plate efficiency of the Class C amplifier makes it an effective generator of radio-frequency power.

Characteristics desired : low driving power ; high output for given plate loss.

**Class AB Amplifiers.** As previously stated, a Class AB amplifier is one in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

The Class AB amplifier is also occasionally called Class A-Prime. The efficiency and output of the Class AB amplifier lie between those obtainable with pure Class A or Class B operation. Class AB amplifiers tend to operate Class A with low signal voltages and Class B with high signal voltages, thus overcoming the chief objection to Class B operation—the distortion present with low-input signal voltages. The Class AB amplifier is widely used where it is necessary to obtain a power output of considerable magnitude with a minimum of distortion.

**Linear Amplifiers.** By linear amplifier is meant a radio-frequency power-amplifier which is adjusted so that the voltage developed across the load is proportional to the voltage fed to the grid of the linear-amplifier tube.

These amplifiers are used to amplify modulated waves ; they do not distort the modulation envelope. The tube is normally operated with a fixed bias that approximates cut-off. This grid bias is a little less than for Class C amplifiers.

### How Tubes Are Selected

There are so many different kinds of tubes on the market that the selection of the correct tube for the service desired becomes a matter for thought. Transmitting tubes are basically larger versions of the small receiving tubes ; in fact, sometimes receiving tubes are used in low-power transmitters. The designer of an aircraft set usually develops specifications which call for the very best tube available on the market for the job he wants done, irrespective of price. For this reason it is not advisable for an operator to substitute one type of tube for another in the set he is operating. If the matter of designation numbers and letters proves confusing, go back to the section describing the bases of tubes

TUBE DATA  
6.3-VOLT GLASS

Type	Name	Base	Socket Connections	Cathode	Fil. or Heater		Use
					Volts	Amps	
6A6	Twin Triode Amplifier	7-pin M.	T	Htr.	6.3	0.8	Class-B Amplifier
42	Pentode Power Amplifier	6-pin M.	M	Htr.	6.3	0.7	Class-A Amplifier
6B7	Duplex-Diode Pentode	7-pin S.	Q	Htr.	6.3	0.3	Pentode R.F. Amplifier Pentode A.-F. Amplifier

## 2.5-VOLT RE

Type	Name	Base	Socket Connections	Cathode	Fil. or Heater		Use
					Volts	Amps	
58	Triple-Grid Variable-Mu. Amplifier	6-pin S.	J	Htr.	2.5	1.0	Screen-Grid R.F. Amp. Mixer
57	Triple-Grid Detector Amplifier	6-pin S.	J	Htr.	2.5	1.0	Screen-Grid R. F. Amplifier Bias Detector
59	Triple-Grid Power Amplifier	7-pin M.	N	Htr.	2.5	2.0	Class-A Triode Class-A Pentode Class-B Triode
6K7	Triple-Grid Variable-Mu. Amplifier	7-pin O.	G	Htr.	6.3	0.3	Screen-Grid R.F. Amplifier Mixer

\* Metal.

## TETRODE AND PENTODE

Type	Max. Plate Dissipation Watts	Cathode		Max. Plate Voltage	Max. Screen Voltage	Max. Screen Dissipation Watts	Interelectrode Capacitances (Mufd.)			Base	Socket Connections
		Volts	Amps.				Grid to Fil.	Grid to Plate	Plate to Fil.		
865	15	7.5	2.0	750	125	3	8.5	0.1	8.5	4-pin M.	I
807	21	6.3	0.9	600	300	3	11.6	0.2	5.6	5-pin M.	H
803	125	10.0	3.25	2000	600	30	15.5	0.15	28.5	5-pin J.	L

CHART  
RECEIVING TUBES

Plate Supply Volts	Grid Bias	Screen Volts	Screen Current Ma.	Plate Current Ma.	Plate Resistance, Ohms	Mutual Conductance Micromhos	Amp. Factor	Load Resistance Ohms	Power Output Watts
250 300	0 0	—	—	Power output is for one tube at stated load, plate-to-plate				8000 10000	8.0 10.0
250	-16.5	250	6.5	34.0	100000	2200	220	7000	3.0
250 250	- 3.0 - 4.5	125 50	2.3 —	9.0 0.65	650000 —	1125 —	730 —	— —	— —

RECEIVING TUBES

Plate Supply Volts	Grid Bias	Screen Volts	Screen Current Ma.	Plate Current Ma.	Plate Resistance, Ohms	Mutual Conductance Micromhos	Amp. Factor	Load Resistance Ohms	Power Output Watts
250 250	- 3.0 -10.0	100 100	2.0 —	8.2 —	800000	1600	1280	—	—
Oscillator peak volts = 7.0									
250 250	- 3.0 - 1.95	100 50	0.5 —	2.0 —	exceeds 1.5 meg.	1225	exceeds 1500	—	—
Cathode current = 0.65 ma. Plate resistor = 250000 ohms									
250 250 300 400	-28.0 -18.0 0 0	— 250 —	— 9.0 —	26.0 35.0 —	2300 40000	2600 2500	6.0 100	5000 6000 4600 6000	1.25 3.0 15.0 20.0
Power output for 2 tubes at stated load, plate-to-plate									
250 250	- 3.0 -10	125 100	2.6 —	10.5 —	600000 —	1650	990	—	—
Oscillator peak volts = 7.0									

TRANSMITTING TUBES

Typical Operation	Plate Voltage	Screen Voltage	Suppressor Voltage	Grid Voltage	Plate Current Ma.	Screen Current Ma.	Grid Current Ma.	Screen Resistor	Approx. Grid Driving Power Watts	Approx. Carrier Output Power Watts
Class-C Amp. (Telegraphy)	750	125	—	- 80	40	—	5.5	45000	1.0	16
Class-C Amp. (Telephony)	500	125	—	-120	40	—	9	20000	2.5	10
Class-B Amp. (Telephony)	750	125	—	- 30	22	—	—	45000	—	4.5
Class-C Amp. (Telegraphy)	600	250	—	- 50	95	9	2.5	35000	0.18	30
Class-C Amp. (Telephony)	400	250	—	- 75	80	9	1.5	15000	0.15	25
Class-C Amp. (Telegraphy)	2000	500	40	- 30	160	42	16	36000	1.6	210
Grid-Modulated Amp.	2000	600	40	- 80	80	15	4	—	2	53
Suppressor-Modulated Amp.	2000	500	-135	- 50	80	55	15	27000	1.6	53
Class-B Amp. (Telephony)	2000	600	40	- 40	80	15	3	—	1.5	53

## RECTIFIERS—RECEIVING AND TRANSMITTING

Type No.	Name	Base	Socket Connections	Cathode	Fil. or Heater		Max. A.C. Voltage Per Plate	Max. D.C. Output Current Ma.	Max. Inverse Peak Voltage	Max. Peak Plate Current Ma.	Type
					Volts	Amps.					
83	Full-Wave Rectifier	4-pin. M.	B	Fil.	5.0	3.0	500	250	1400	800	M

## TUBE SELECTION CHART

Descriptions	Metal Octal	Glass 6.3 V. Octal	Glass 6.3 V. Old	Glass 2.5 V. Old	Glass 2.0 V. Octal	Glass 2.0 V. Old
General Purpose Triode.....	6C5	6C5G 6J5G	76	56	1H4G	30
High-Mu Triode.....	6F5	6F5G 6K5G	...	...	...	...
R. F. Amplifier, sharp cutoff.....	6J7	6J7G 6U7G	6C6	57	1E5G	1B4
R. F. Amplifier variable-Mu.....	6K7	6K7G	6D6	58	1D5G	1A4
Twin Diode.....	6H6	6H6G	...	...	...	...
Duplex-Diode Pentode.....	6B8	6B8G	6B7	2B7	1F7G	1F6
Duplex-Diode G. P. Triode.....	6R7	6R7G 6V7G	85	55	1H6G	1B5
Duplex-Diode High-Mu Triode.....	6Q7	6Q7G 6B6G	75	2A6	...	...
Pentagrid Converter.....	6A8	6A8G 6D8G	6A7	2A7	1D7G 1C7G	1A6 1C6
Pentagrid Mixer-Amp.....	6L7	6L7G	...	...	...	...
Pentode Power Amp.....	6F6	6F6G 6K6G	42 (41)	2A5	1F5G 1E7G	1F4 33
Triode Power Amp.....	....	6B4G 6A5G	6A3	45 2A3	...	31
Twin Triode Power Amp.....	6N7	6N7G 6Y7G	6A6	53	1J6G	19
Direct-Coupled Power Amp.....	6N6MG	6N6G	6B5	...	...	...
Beam-Type Power Amp.....	6L6	6L6G 6V6G	...	...	...	...

(page 91). Then secure a tube manual giving specific data on some tubes which are available to you for inspection. (Much of the tube data presented here is from RCA Tube Manuals.) Practically all the glass tubes on the market can be secured with octal bases and these carry the suffix G attached to their type number. If the glass tube is a duplicate of some metal tube it will carry the same number. Example: 6K7 is a metal tube; in glass it is 6K7G.

The tube chart on page 129 is presented as an example of how the amateur (and to a certain extent the engineer) selects tubes for use.

The tube data chart on pages 126–127 supplies characteristics on a number of tubes used in aviation radio sets that are described in later chapters.

### QUESTIONS

61. What are the essential parts of a diode? of a pentode?
62. Explain the action of a diode as a rectifier.
63. How does a triode function as a detector? as an amplifier?
64. What is meant by the static characteristics and the dynamic characteristics of a tube?
65. What is the difference between plate rectification and grid rectification?
66. Describe the principle of a heterodyne detector.
67. Define the various classes of amplifiers; a linear amplifier.
68. What is the essential difference between a receiving tube and a transmitting tube?
69. Sketch the base connections and number the pins of a five-pin tube base.
70. Define: audio-frequency, C power supply, control grid, emission characteristic, grid bias, input impedance. (See Appendix.)

## CHAPTER 6

### BATTERIES

Batteries and generators are the two most generally used sources of electrical power found aboard airplanes and at ground radio stations. Batteries furnish a direct current source of supply which is entirely free from voltage fluctuation.

#### Primary Batteries

**Primary Cells.** Primary cells generate direct current by an electrochemical process. Any two dissimilar conductors immersed in an acid or salt solution constitute a primary cell. A difference of potential is set up between these "electrodes," one of which eventually is consumed, "wearing out" or "using up" the cell. A primary cell cannot be recharged.

The value of the e.m.f. depends mostly on the materials utilized as electrodes; to a lesser extent on the nature of the solution in which they are immersed (known as electrolyte) but not at all on the size or arrangement of electrodes.

A simple form of primary cell consists of a strip of copper and a strip of zinc suspended in a solution of sulphuric acid. When the electrodes are connected to an external circuit, zinc will pass into solution and bubbles of hydrogen gas will appear on the copper strip. The current flow is from the copper strip through the external circuit to the zinc strip, and from the zinc strip through the electrolyte to the copper strip. The copper is the plus electrode and the zinc is the minus electrode.

*Local action* is the process involved in the wasting of the zinc when the cell is *not in use*. This action is decreased when mercury is amalgamated with the surface of the zinc, which retards the formation of bubbles of hydrogen gas.

*Polarization* is the effect caused by the film of gas bubbles which is deposited on the copper electrode when the cell is connected to its load, the external circuit. Here, an opposing voltage

is generated which increases the resistance. Polarization can be offset by the addition of certain chemical substances.

The *internal resistance*  $R$  of a cell is resistance offered by the two electrodes and the electrolyte; it increases as these elements become affected by use. Internal  $R$  must be added to the resistance of the external circuit to which the cell is connected if the overall resistance of the entire circuit is to be accurately computed. If the voltage at the terminals of the cell is  $E_1$  when the current  $I_1$  is flowing, and  $E_2$  when current  $I_2$  is flowing, then (by Ohm's Law) the resistance  $R$  can be found as follows:

$$R = \frac{E_1 - E_2}{I_2 - I_1}$$

The desirable qualities of a primary cell are large voltage, large current capacity, freedom from local action, low internal resistance.

### Dry Cells

**Description.** The dry cell is the commonest form of primary cell used in aviation. The larger manufacturers have developed this cell to a very high standard of performance and it is used in connection with both receivers and transmitters on airplanes. However, it is extremely important that men dealing with aviation radio sets thoroughly understand the limitations. The typical dry cell consists of a zinc container which acts as the minus (—) electrode and an electrolyte of sal ammoniac and zinc chloride combined with a depolarizing mixture of manganese dioxide in contact with the positive (+) electrode which is carbon. The manganese dioxide is often mixed with ground carbon. Each cell has a pulp-board lining which acts as an absorbent for the electrolyte and prevents direct short-circuit contact between the manganese dioxide mixture and the zinc container-electrode. The electrolyte is mushy wet but the container top is sealed so the cell is a "dry cell."

**Voltage.** A good dry cell when new will give 1.5 volts. The voltage is additive when a battery of cells are connected in series—the normal hook-up. (A single cell is often called a battery.)



One of the chief advantages of a dry cell battery as a d.c. source of energy is that it gives a constant voltage under the normal working conditions for which it is furnished.

Other advantages are: small size, light weight, and the range of voltage and current they can be made to furnish. Also, they are quite rugged, of a uniform standard as to electrical characteristics, available in any town, and relatively cheap.

Small, light, battery packs are made up by a number of manufacturers for aviation radio use and usually consist of enough cells to give any required voltage. As an example, there is a Burgess battery of 96 cells which weighs only  $9\frac{1}{2}$  lb. This is naturally much favored by owners of small planes. The Burgess Company also makes a battery of this same weight (5996 Series) having length of 10 in., height  $12\frac{3}{4}$  in., and width 3 in., with taps provided for a source of 9,  $22\frac{1}{2}$ , 45,  $67\frac{1}{2}$  and 135 volts. Such batteries may be connected in parallel when used on apparatus imposing a heavy current drain. (Fifty milliamperes is a "heavy" drain. In this case the ampere-hour rating is 0.35 for a 24-hour-a-day service.) Two of these batteries will operate a low-power radiophone transmitter.

**Current.** Usually a large current capacity is desirable and a large momentary current flow indicates a fresh cell. A "flash" short-circuit test (with an ammeter connected dead across the cell's terminals) shows from 20 to 30 amperes of current flow. When the cell is old, the voltage during this short circuit will drop to about 1.1. Cells as low as this must not be used on aircraft flights; each airline company specifies the "dead low" at which dry batteries are discarded.

The normal current drain on a dry battery used with aircraft radio sets is usually less than 1 ampere; for receivers it may be less than 0.1 ampere. A record or "log" of current drain in ampere hours is usually maintained for all batteries used in flight operations so their fitness for service at any time may be computed.

**Rating.** The life of a battery varies with the current drain and the life rating is expressed as *service hour capacity*. The curves shown in Figures 40 and 41, furnished by the Burgess

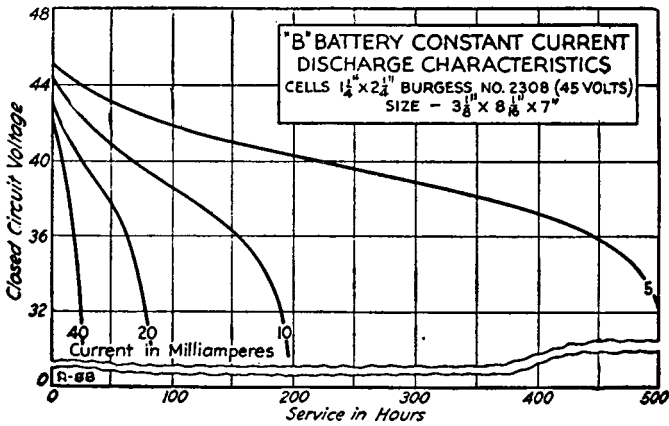


Figure 40. Constant-Current Discharge Characteristics for Dry Battery

Battery Company, show characteristics of a typical high service-hour-capacity type dry battery.

No matter what the rating assigned to it by the manufacturer, a battery should be periodically checked as to voltage while in service. Also, if it is found that the filaments of receiver tubes must be burned above normal brilliancy, this may be because the

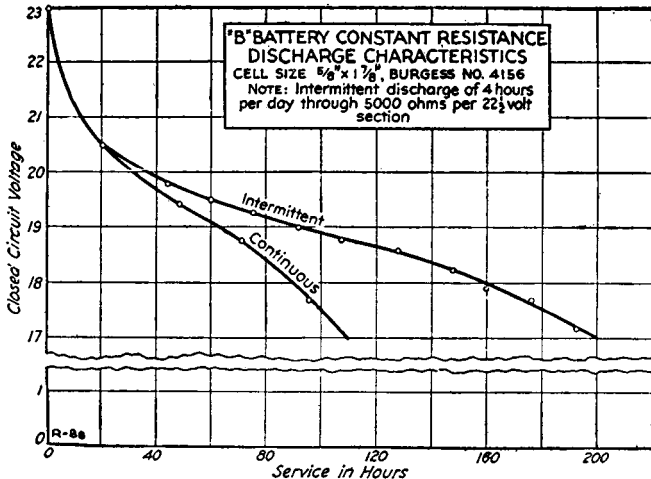


Figure 41. Constant Resistance Discharge Characteristics for Dry Battery

B battery is weak. One particular 22.5-volt dry battery much used in the Navy for plate (B) voltage supply delivers 4.3 milliamperes steadily for over a month, at which time its voltage has dropped to 17 volts. The aviation radio specialist will do well to learn the actual service life of batteries used by various airlines.

**Care.** The care of dry cells is a simple procedure, but important. Batteries will deteriorate even while not in use, depending somewhat on the conditions under which they are stored. They should be kept in a cool, dry place, top side up. Heat decreases their internal resistance; cold lowers their voltage; freezing badly deteriorates any battery. When handled, they should be kept upright and not squeezed or dropped. Contacts should be kept bright. They should *not* be frequently tested by the short circuit ("flash") method. It is better to impose the normal load and note voltage. Batteries recuperate when disconnected from their load, but old batteries, which seem to "come back" while "resting" between flights should be viewed with suspicion. To send out a defective battery on an airplane flight is to commit something very much akin to a major crime. In case of doubt it is best to use a new battery. It is cheaper than a human life.

Transport planes use storage batteries; however, *the emergency power provided is a dry battery*, kept sealed until needed, capable of supplying four hours of service. Dry batteries are IMPORTANT.

### Storage Batteries

Storage batteries, sometimes called secondary batteries, or "accumulators," are much used aboard aircraft for radio and other purposes and at aviation ground stations. Unlike primary batteries they may be recharged again and again, this being one of their chief advantages over the dry batteries just described. They cost more, weigh more and must have more care, but they are designed to furnish more electric power than dry batteries, being often used to drive dynamo-electric machines, as explained in Chapter 7 titled "Power Supplies." In these cases they are known as the primary source of power; in other cases a generator is the primary source, the batteries carried being auxiliary

sources. Aboard some planes storage batteries are charged while in flight, either by a wind-driven generator or an engine-driven generator. There are two types of batteries used in aviation, the lead type and the Edison. The 6- and 12-volt lead battery is most common, but both lead and Edison types will be discussed in turn.

### Lead Storage Batteries

**Component Parts.** The positive plate of the lead storage battery is lead peroxide; the negative plate is pure "sponge" lead. For this reason this type battery is often referred to as a lead-plate, lead-lead or a lead-acid battery. There are different ways of manufacturing these plates but in every case the positive lead-peroxide plate is brownish in color and its terminal is marked + ; the negative plate is gray and its terminal is marked — . In addition, the positive terminal or "lug" is quite often marked with a daub of red paint, or has a red bushing around it. In some cases the letters POS are stamped in plain sight, the important thing being that proper connections be made in connecting the battery to its load or to the charging source. (In case of doubt, use a voltmeter to discover correct terminals.)

The containing case for most portable storage batteries—the kind used in aircraft—is a rubber compound, tough, water- and acid-proof but breakable. This case contains a sulphuric acid solution which serves as the electrolyte. The plates are held suspended mechanically, almost rigid in this solution, the positive plates alternating with the negative plates in sequence. Thin sheets of wood or some composition insulating material are mounted between each pair of plates to prevent contact, for if a positive and a negative plate touch, an internal short circuit results, eating away the parts which touch; these sheets are called *separators*. Special vent holes (capped) are built into the top, to be opened only when adding distilled water or when the battery is gassing while on charge.

Practically all large manufacturers of storage batteries turn out light-weight, highly efficient batteries for aviation use. Some of the special features stressed are self-ventilation, non-spillable cases and vents, tough, almost non-breakable cases.

Plate VII is an illustration of desirable features of construction.

**Theory of Operation.** A storage battery stores chemical energy, *not* electrical energy. But it delivers electrical energy. No action takes place in the battery until the terminals are connected to complete the circuit; but as soon as the circuit is closed, chemical action occurs which generates sufficient electrical potential to cause a current to flow. During this time, the peroxide of lead is being changed into lead sulphate. When the change is complete, the action ceases and the battery is called "discharged." By passing a current in the reverse direction, the chemical action is reversed, changing the lead sulphate into peroxide of lead. When this is completed, the battery is in condition to deliver current and is called "charged."

During *discharge* there is a decrease in the specific gravity of the electrolyte in a storage battery. Charging causes a reversal of these conditions. Because of this, it is possible to learn the condition of a battery by testing the specific gravity and reading the voltage. A hydrometer reading of 1300 indicates (usually) *full charge*; 1260 is *three-fourths charge*; 1215–1225, is *one-half charge*.

When a battery is completely discharged, the lead sulphate in the plates has such a high resistance that it is almost impossible to recharge it without causing the generation of so much heat that the paste would be forced out of the grids. For this reason, a battery should never be completely discharged.

**Electrical Characteristics.** The overall voltage of a storage battery is, of course, the total of the cells connected in series—the only way portable batteries are normally connected. A "6-volt battery" is actually a 3-cell battery and will give about 2.2 volts per cell or 6.6 volts overall when in a new, fully-charged condition. At this time the specific gravity of the electrolyte will be from 1.280 to 1.300, depending somewhat on the nature of the service it is to render. (Heavy-duty batteries, such as starting batteries, have a heavier electrolyte than do radio batteries with a light current drain.) When the voltage of this battery drops to about 1.8 per cell and the electrolyte has dropped 100 points

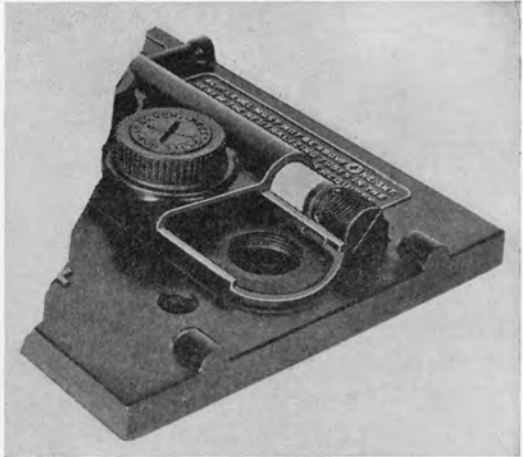
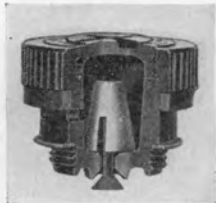


Plate VII. Showing How the Nonspillable Vents Work on a Prestolite Battery

(to 1180 or 1200 as the case may be, for the decimal point is not generally used in work-a-day reports) the battery is considered discharged and should be put on the charging line. The internal resistance decreases during charge; it increases while discharging. It is always low and the flash (dead short) test should never be used.

**Discharging.** The actual capacity of the battery to deliver power (the *output*) is computed in *ampere-hours*. This is the product of the amperes drawn from it in actual service, multiplied by the time of this service in hours. The ampere-hour capacity depends on the total area of all plates. A normal discharge period is set by the manufacturer. As an example, if a 60-ampere-hour battery is discharged over a specified period of 8 hours its current

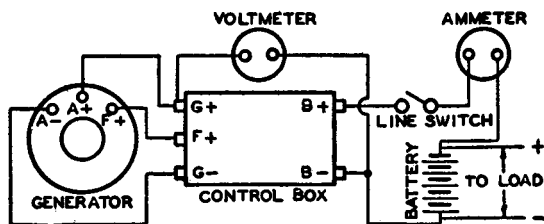


Figure 42. Eclipse Generator Charging System for Storage Cells

output during this period will be  $7\frac{1}{2}$  amperes. The efficiency of a battery becomes a ratio of its delivered output, to the input while charging it.

**Charging.** The battery must not be charged at too high a rate. An 8-hour battery usually requires more than that time to charge due to its efficiency always being less than 100%. Batteries CAN be discharged and also charged in less than the "normal" time recommended by the manufacturer. In aviation it is good practice to learn the best rates for the different batteries used; each is designed for the service to which it is put.

Figure 42 shows a typical charging outfit.

It is not possible arbitrarily to specify any certain charging rate for batteries which are on the planes. The best rate is that rate which keeps the battery well charged but without overcharg-

ing it. High charging rates will cause excessive gassing and overheating in a battery which damages both plates and wood separators. Do not allow the temperature of the electrolyte to get above 110° F.; decrease charging rate if this occurs because high temperatures injure the plates. Consistent undercharging results in a gradual deterioration of the cells. The plates sulphate excessively and harden under this condition. Abnormal sulphation damages the plates and in some cases they cannot be put back into working order.

*Constant potential* battery charging is a method whereby the rate of charge varies automatically with the requirements of the battery. The generator used has a voltage slightly above that of the battery. When the discharged battery is first connected to the generator there is little electrical counter pressure in the cells; therefore the current flows freely. As the charging progresses, the voltage rises in the battery; this causes a decrease in the rate of flow from the generator, until finally, when the battery voltage has reached that of the generator, no current flows. (See page 156.)

### Battery Chargers

**Charging from a 110-Volt D.C. Line.** Many methods of charging batteries are available, the desirability of each depending on the circumstances under which the charging is carried out. At ground stations where a d.c. source of 110–120 volts is available, it is only necessary to arrange a circuit having sufficient resistance to reduce this voltage to the required charging value. Assume that the charging rate of a 6-volt battery is 5 amperes. Apply the following application of Ohm's Law (page 41) :

$$I = \frac{V - E}{R}$$

$E$  in this case is the voltage of the battery;  $V$ , the voltage of the charging line;  $R$  is the resistance of the circuit and can be found by substituting as follows :

$$5 = \frac{110 - 6}{R} \quad \text{or} \quad R = \frac{104}{5} = 20.8 \text{ ohms.}$$



This must be the total resistance of the circuit including the internal resistance of the 6-volt battery. A lamp-bank placed in series with the charging line as shown in Figure 43 can be very easily arranged to supply approximately this resistance; the ammeter will tell when it has been accomplished if the resistances of the lamps are not known ahead of time. If they are, their combined resistance can be computed as explained on page 43.

The circuit shown in Figure 44 will allow the charging rate to be varied at will by the manipulation of the variable resistance

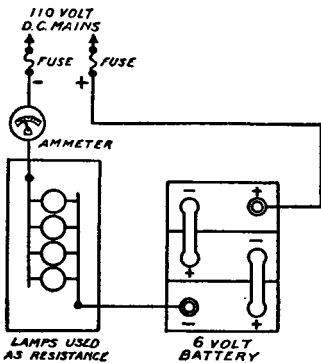


Figure 43. Charging a 6-Volt Storage Battery from a D. C. Line; Using Lamps for Resistance to Regulate Charge Rate

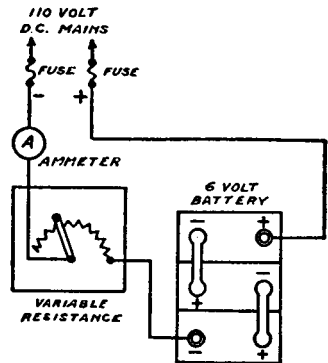


Figure 44. Charging a 6-Volt Storage Battery from a D. C. Line by Using a Variable Resistance to Regulate the Charge Rate

used here instead of the lamp-bank in the circuit shown in Figure 43.

**Charging from an A.C. Source.** In order to charge a battery from an a.c. source, some method must be employed which will change or rectify the a.c. into d.c. A chemical or electrolytic rectifier can be used. A (positive) plate of aluminum and a (negative) plate of lead in a solution of ammonium phosphate constitutes one form of rectifier. This is not nearly as popular in aviation as the vacuum-tube type. At some ground stations motor-generator sets are used for battery charging; this is probably the best method of all. At other stations commercial 60-cycle power is rectified by two-electrode tubes (diodes), then passed through

a filter system which converts the rectified a.c. into d.c. for feeding the plates of the tubes in the station's radio sets.

A simple diode like tube 866 only rectifies one-half of each cycle and this tube is therefore called a half-wave rectifier and is used on voltages above 500. A full-wave rectifier tube consists of two diodes in one envelope with their plates opposed, as receiving tubes 5Z3 and 83; these operate in circuits of 500 volts and less. Both half-wave and full-wave rectifiers are of two general types: (1) high vacuum thermionic; (2) mercury vapor, such as the 83 and 866. These are characterized by a very low and approximately constant internal voltage drop, amounting to about 15 volts. This drop is practically independent of d.c. load current, but depends to some extent upon the temperature of the mercury vapor within the bulb. Mercury-vapor rectifiers, in operation, have a characteristic bluish glow which fills a considerable portion of the bulb. The extent of the glow depends on the value of the d.c. load current.

Due to their low and relatively constant internal voltage drop, mercury-vapor rectifiers are very useful in applications where excellent voltage regulation of the d.c. power supply is desired.

High-vacuum rectifiers have an internal voltage drop which is proportional to the d.c. load current being drawn. With varying d.c. load currents, they do not, in general, provide the good voltage regulation obtained from mercury vapor rectifiers. Some high-vacuum rectifiers, such as the 836, are designed with close-spaced electrodes, so that a voltage regulation almost as good as that of a mercury-vapor type is obtained.

*Rectifier circuits* are shown in Figures 45 and 46. Figure 45 shows the widely used, single-phase, full-wave rectifier using two half-wave rectifier tubes. Figure 46 shows a single-phase bridge circuit employing two half-wave rectifier tubes in series on each side of a single-phase transformer secondary. This circuit is capable of giving twice the d.c. output voltage for the same total transformer voltage and d.c. output current as Figure 45. Since the total peak secondary voltage is also the same as that for Figure 45, tubes of the same peak inverse voltage rating can be used. When the bridge circuit is used, it may be necessary to reduce the load current in order to avoid exceeding the power

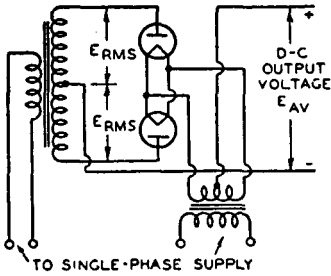


Figure 45. Full-Wave Rectifier

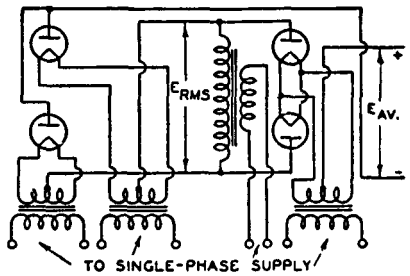


Figure 46. Half-Wave Rectifier

rating of the high-voltage transformer. "Filters" are used in connection with rectifiers. These are discussed in the next chapter.

Another form of rectifier much used aboard aircraft is the vibrating (mechanical) type. This rectifier consists of a contactor operated in synchronism with the alternating current to be rectified. When the contactor is allowed to make-and-break the circuit at the proper point of the wave, pulsations of current occur in the same direction. With a single contact as shown in Figure 47, half-wave rectification is obtained; with a double contact as

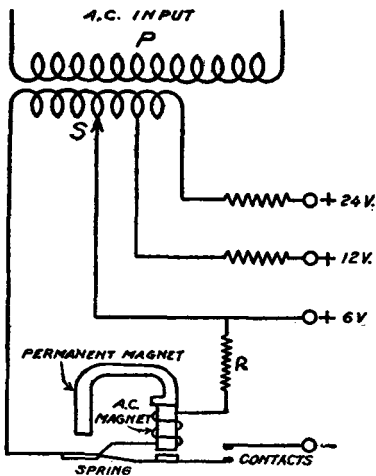


Figure 47. Circuit of a Vibrating Battery Charger (Half-Wave Type)

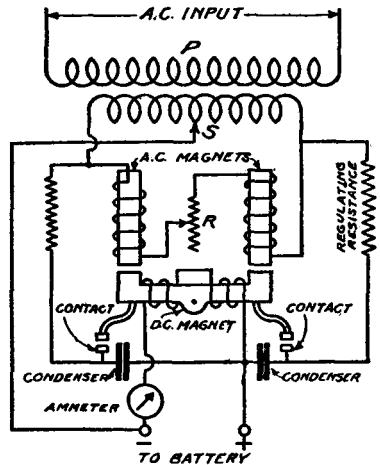


Figure 48. Circuit of a Vibrating Battery Charger (Full-Wave Type)

shown in Figure 48, full-wave rectification is obtained. When the current from the supply line is of the correct polarity to charge the battery in Figure 47, the contacts close and the current flows through the battery, but when the supply line reverses its polarity, the contacts open so that the battery cannot be discharged. On this diagram taps are shown for charging the battery at several voltages.

The vibrator rectifier circuit shown in Figure 48 is built in such a way that the connections of the charging line to the battery are automatically reversed with the reversal of current flow in the power line. This reversal in the rectifier is brought about by a combination of two electromagnets and a spring. When the current flowing in the power line passes through the a.c. electromagnet in one direction, this electromagnet attracts one end of the d.c. electromagnet. When the current in the power line reverses, the other end of the d.c. electromagnet is attracted. When the magnets are acting together, they overcome the tension of the spring and close the vibrator contact permanently so that charging current flows through the battery. At the instant of reversal of current flow, the magnets balance each other and the spring opens the contact so that a reversal of current cannot flow through the battery and discharge it.

Some vibrating rectifiers have a spring whose tension must be adjusted so that it vibrates in step with the alternations of the power line or supply line. With this adjustment correctly made, the spring will open the circuit at the proper time. The spring adjustment on certain vibrating chargers is critical and the least movement of the regulating screw one way or the other will start or stop the charge. Other chargers of the same type are not at all critical and are easily handled. The adjustment should be made to give the greatest possible current in amperes without making the vibrator contact spark excessively. The vibrating contact rectifier is fundamentally a vibrating reed, whose frequency is the same as that of the current to be rectified, carrying a contact which engages the second contact for each vibration of the reed. The contacts complete a circuit from the secondary of a step-down transformer through the storage battery each time they touch.

The armature is polarized either by using a permanent magnet or by using an electromagnet energized by the battery being charged. The result of using a polarized armature whose period of vibration is the same as the frequency of the a.c. line is that the contacts touch at the point of each succeeding cycle and remain in contact for a portion of the half wave so that the resultant current through the battery is shown in Figure 58(2), page 170.

**Precautions While Charging.** The routine procedure in charging a battery is generally furnished by its manufacturer and is always supplied by air transport companies to men assigned to the duty of battery upkeep. These instructions are based on certain fundamental principles of their construction and internal operation. Batteries must not be over-discharged. They should not be left in a discharged condition. A complete and continuous record of their performance, both during charge and discharge, should be kept, as this perpetual and up-to-the-minute case history provides the one most intelligent method of properly maintaining the working unit.

During the charging period, hydrometer tests should be made every hour. After there is no longer any increase in the specific gravity, the battery should be left on the charging line for 3 hours and then tested again. If there is no increase in the specific gravity, the battery is completely charged.

In using the hydrometer, the temperature should be taken, as the instrument is graduated for 70°. For each 3° above 70, 0.001 should be added to the specific gravity as shown on the hydrometer and for each 3° below 70, 0.001 should be subtracted.

**Care and Maintenance.** The normal servicing of aircraft batteries can be successfully accomplished by the use of a little common sense and careful handling. In disconnecting terminal leads, a properly-fitted wrench should be used so as not to burr the threads of the connection bolts. The battery connection lugs should be kept greased with vaseline. Batteries should be carried about with battery carrying straps and should not be bumped or turned over.

The voltage of the fully-charged cell should not fall below 2. After charging, the battery should be left standing for 2 hours

and the voltage again tested. Any drop in voltage denotes an internal short circuit, generally caused by accumulated dirt or sediment in the bottom of the case. One of the most serious conditions to be guarded against is sulphation. This is caused by the chemical action on the plates due to the breaking up of sulphuric acid molecules  $H_2SO_4$ , which combine with the active materials  $PbO_2$  and  $Pb$  to form  $PbSO_4$  (lead sulphate). This action takes place even though no current is being drawn from the battery, and is greatly increased when the battery is discharging. Some causes of sulphation are :

1. Discharging cell at too high a rate.
2. Cell leakage due to moist top covers.
3. Allowing cell to remain idle for too long a time.
4. Failure to keep cell on trickle charge when not in use.
5. Wrong specific gravity of original electrolyte.
6. Extremely rapid sulphation will occur if cells are charged with reverse polarity, or with alternating current.

In case a lead-acid cell shows signs of sulphation, the entire battery should be subjected to a long heavy charge. If the sulphation is not serious, this will restore the affected plates to normal condition. If one or more cells still appear abnormally sulphated, while the remainder of the battery is still in good condition, it is best to remove the defective cells, treating them separately by giving a charge at a high rate. If the specific gravity of the electrolyte of a cell under treatment for sulphation rises above the normal level, remove some of the electrolyte and replace by pure water until the proper density is secured. If a long charge at a high rate fails to raise the specific gravity above 1.200, new electrolyte should be mixed to replace the old. The new electrolyte should read between 1.275 and 1.300. This "doctoring" of a cell by juggling with the electrolyte values should be done carefully. Distilled water should first be placed in a lead or earthenware vessel, then the sulphuric acid poured slowly into the water. Soda and lime neutralize this acid ; if acid is spilled, prompt action is necessary to avoid painful burns and destroyed material.

All the cells of a battery should be tested at least once a month and preferably every two or three weeks. If any of the cells are

below 1.170 on any test, the battery should be charged up to full value.

Only approved (distilled) water should be added to the battery, and only enough of this to bring the level of the electrolyte up to a point slightly above the top of the plates, just making up for the amount of water that has been lost by evaporation. This is best done just before charging begins. Remember, the acid part of the solution does not evaporate, therefore sulphuric acid should never be added to any cell except when being "doctored" by an expert battery man during a rebuilding job, or to replace spilled electrolyte. (Rebuilt batteries are not used by commercial airlines.) Also, it is bad practice to remove any part of the electrolyte from one cell and put it in another cell. Keep connections and filler plugs tight. *Keep batteries clean.* Learn how to do this. Also, learn how to use a hydrometer correctly. Never use a hydrometer in a lead acid battery after it has been used in an Edison battery.

**Commercial Types.** The EXIDE, the PRESTOLITE, and the WILLARD batteries are much used in aviation, not only for radio sets but for lighting, instruments, and as a power source. All of these companies issue excellent manuals of instruction relating to their batteries. Plate VII shows certain details of construction of Prestolite batteries.

### Edison Batteries

The Edison cell differs from the lead cell in both construction and material. The two plates of the Edison are made of iron oxide and nickel, immersed in a solution of caustic potash. The positive plate of the Edison cell consists of a nickel-steel grid or frame which supports 30 perforated steel tubes filled with alternate layers of pure flake nickel and nickle-hydrate. The negative plate consists of a nickel-steel grid which supports 24 steel pockets filled with iron oxide and a small quantity of metallic mercury. The electrolyte is a solution of 21% potassium hydrate (caustic potash) and a small amount of lithium hydrate. Alternate plates are connected to different terminals. The specific gravity of the electrolyte of an Edison cell does not change as in the lead cell,

consequently a hydrometer reading does not indicate the condition of the cell. The voltmeter is the only means of testing. The voltage per cell is much less than that of the lead type, being about 1.2; also the water per cell is much less.

## QUESTIONS

*Primary Batteries:*

71. What is a primary cell? Describe a common dry cell.
72. How many dry cells are required to make a six-volt battery?
73. Where are dry cells used in aviation?
74. How may the fitness of dry cells for aviation use be determined?
75. What determines the internal resistance of a dry cell?
76. What is meant by local action?
77. In continuous service, about what current flow may be maintained from a dry cell?
78. What sort of atmospheric conditions increase the useful life of dry cells?

*Storage Batteries:*

79. What is the chief difference between a primary and a secondary cell?
80. Give structural details of (a) lead storage cell, (b) Edison; name parts and electrolyte.
81. What is the unit of capacity of a secondary cell?
82. What is the normal voltage of (a) lead storage cell, (b) Edison cell, charged and discharged?
83. How is the state of charge of (a) lead type cell and (b) Edison type cells determined?
84. How does the internal resistance of cells affect the battery output?
85. What is meant by "rate of charge" and "rate of discharge" of a storage cell or battery?
86. List essential precautions in the care of a lead-acid type battery.
87. Name two common chemicals which will neutralize the acid in storage cells.
88. What causes sulphation in a lead-type battery?
89. How should a lead cell be treated to correct sulphation?
90. State precautions in handling sulphuric acid.



## CHAPTER 7

### POWER SUPPLIES

#### General Considerations

On modern aircraft the need for electrical power to operate radio and other essential equipment is growing continuously. The extensive electrical and radio installation aboard the DC-4 is an example of this increasing need for power units, or power-packs, as they are often called—especially when related to radio alone.

The nature of the equipment to provide a source of power for radio sets in aviation—except at ground stations where commercial power is available—comprise two general classes: (a) batteries, described in Chapter 6, which can furnish only d.c. power, and (b) dynamo-electrical machinery, from which either d.c. or a.c. may be obtained. The most common of these, especially aboard airplanes, are the generator, the motor, and the dynamotor. At ground stations will be found motor-generator sets and rotary converters.

#### Dynamo-Electric Machines

**Parts.** The principal parts of a dynamo-electric machine are as follows: The *yoke*, *pole-pieces*, *field coils*, *armature core*, *armature winding*, *commutator (or slip rings)*, *brushes*, *shaft*, *bearings*, and mechanical *frame* or housing.

The *yoke* serves a double purpose; that of a mechanical support for the pole-pieces and as a path for magnetic flux. It is made of steel (sometimes cast; sometimes forged), shaped in a cylindrical form, and welded to form a homogeneous magnetic ring.

The *pole-pieces*, of forged or assembled sheet steel, are generally bolted to the yoke and are formed with flaring projections at their inner ends to spread the flux over a considerable area of the armature and also to serve as a mechanical support to the field coils.

The pole-pieces may be of solid steel or (preferably) built up of laminations (sheets of steel about 0.025 in. in thickness) and assembled together by insulated bolts passing through holes larger than the shanks of the bolts.

The *pole-pieces* are usually wider at the face next to the air-gap than in the main body, in order to spread the flux over a greater area where it crosses the air-gap in the armature. This enlarged section is called the *pole-shoe* and may be integral with the pole-piece or a separate part bolted to it. The arc subtended by the pole-shoe is usually from 60% to 70% of the arc from the center of one pole to the center of the next pole.

The *field coils* consist of insulated copper wire wound upon a form which fits upon the pole-piece. A current in these turns is the cause of the magnetomotive force which produces a flux in the magnetic circuit consisting of the yoke, pole-pieces, and the armature.

The armature core is a hollow cylinder made up of many pieces of sheet steel, punched to shape, and usually having slots punched around its outer periphery. The steel of the armature serves to carry the flux from one pole to the next; the slots hold the various moving turns-of-wire known as the armature winding. The motion of this winding in the magnetic field is the cause of the generated e.m.f.; a current in this winding is the cause of the force on the conductors which makes the armature move when the machine is used as a motor.

**Rating.** The rating of a d.c. machine is the output, together with such other characteristics as speed and voltage, assigned to it by its manufacturer. The continuous rating defines the load which can be carried for an unlimited period without exceeding any of the limitations, such as temperature, established by the Standardization Rules of the American Institute of Electrical Engineers (A.I.E.E.). Machines are classified in commercial practice as high-speed, moderate-speed, and slow-speed.

## Alternators

**Theory of Operation.** The power-driven generator, usually called an alternator, is the most common source of a.c. A radio

tube (see Chapter 5) can be used to change d.c. to a source of a.c. for a transmitter, but the only machine which changes mechanical power into electrical power is termed a generator. All generators produce a.c. within themselves. Those that deliver a.c. are called a.c. generators or alternators; those that deliver d.c. from a rectifying commutator are known as d.c. generators. The principles of generation (and operation) are the same, being based on the phenomena described as the linkage of conductors by flux. Besides the required conductors (armature), and the electromagnets to supply the flux (field), rubbing brush contacts are needed to lead the current to an external circuit in rotating armature types. In an a.c. generator, the brushes bear on revolving collector-rings.

An easy generator to describe and understand is one having a north and south magnetic pole with an armature revolving between the poles. The flux is of uniform intensity; its path is straight from one pole face to the other. The armature coils sweep past these faces, linking the flux at right angles to its path. At this instant maximum e.m.f. is generated in that particular conductor; when it is midway between pole faces, a minimum e.m.f. is generated. The resulting current flows in one direction, called positive, when in front of the north pole, and in the other direction, called negative, when in front of the other pole. Convention has prescribed the use of these signs for some time and so the electron theory will not be referred to in connection with this relative direction of current flow. The value of the voltage produced in any generator will depend on three factors:

1. The intensity of the magnetic flux. This depends on the number of the wire windings, the kind of core of the field coil, and the strength of current flowing through this coil.
2. The number of armature windings.
3. The r.p.m. of the machine.

Factors 1 and 3 can be controlled within certain limits by the radio operator; 2 cannot, being a matter of design. As a matter of fact, the r.p.m. of air-driven aircraft radio generators usually is controlled by an automatic governor to deliver a constant voltage as this is desired ordinarily.

One hundred million lines of force cut in 1 second will produce 1 volt. The amount of amperage that can be secured from a generator is theoretically governed by the application of Ohm's Law to the external circuit, but of course the size, or ampere-carrying capacity of the armature coils themselves, governs the electrical output in a practical way up to the point of "burning out." Likewise, friction will limit the r.p.m. Alternators are sold on a rating of wattage output.

**Frequency.** In the simple two-pole generator mentioned, the current will *alternate* at each pole. Two *alternations* make 1 *cycle*. The *frequency* of a.c. is expressed as the number of cycles per second. A two-pole alternator would deliver 60-cycle a.c. at 60 revolutions per second (3600 r.p.m.); likewise a four-pole generator at 1800 r.p.m., etc. This relation between r.p.m. and frequency also indicates why generators for radio sets should operate at their rated speed; if not, the transmitter supplied with their current would be out of adjustment as to frequency; consequently all receivers tuned for their specified wavelength (frequency) would never hear them. Radio alternators are made to deliver one certain frequency; usually from 60 to 500. Frequency-meters read in cycles (per second).

The values of e.m.f. generated and the resulting current in each alternation varies through this half cycle or circle of  $180^\circ$  so that besides a maximum value at  $90^\circ$  and a minimum at  $180^\circ$ , an *average* and an *effective* value can also be computed. The a.c. voltmeter and ammeter read effective values; the ammeter operates on the heating effect. Because the e.m.f. generated varies sinusoidally in accordance with the angular rotation of the armature coil, it is called a *sinusoidal* e.m.f. or is said to have a *sinusoidal wave form*. The current is also sinusoidal and will have the same frequency. If the voltage and current are in *phase* (time), the volts multiplied by the amperes give watts as in d.c. and the *power-factor* is said to be 1 (100% efficient); but if one *lags* or *leads* the other, the power-factor is less than 1 and this percentage must be applied to the product of volts and amperes to get the effective watts. It should be noted that the time element in a.c. circuits is highly important. (Review pages 50 and 51.)

**Eclipse Alternator.** Eclipse Aviation, a division of Bendix Aviation Corporation, at East Orange, N. J., manufactures an alternator (Type KA-215) to be driven from the airplane engine by a flexible-drive coupling between the driving-shaft and armature. This drive arrangement is designed to absorb torsional vibration and power impulses from the engine which would otherwise tend to affect the electrical operation of the alternator and cause excessive wear on the shaft and bearings of the engine. Different combinations of driving members and mounting flange are available to fit the different types and makes of airplane engines. Also, a cooling fan is made an integral part of the installation.

This alternator delivers 15 amperes at 32 volts, 60 cycles. A separately mounted regulator unit is furnished by the manufacturer to be used in conjunction with the alternator. The purpose of this is to maintain a practically constant value of voltage in spite of slight variations in the airplane engine speed.

### D.C. Generators

**Commutation.** The direct-current generator is basically an alternator which has been provided with an automatic reversing device called a commutator, in place of the usual collector rings. The main difference is the manner in which the alternating e.m.f. induced in the armature windings is permitted to pass into the external circuit. In the case of the alternator, the e.m.f. is allowed to act first in one direction and then in the reverse direction, while the d.c. generator is arranged in such a way that the e.m.f. can act only in one direction in the external circuit, that is, the e.m.f. acts continuously in the same direction, being rectified by the commutator.

**Field Windings.** After the alternating e.m.f. induced in the armature of a d.c. generator has been rectified, it is used in energizing the field magnets. (Practically all d.c. generators are of this self-excited type.) Various methods of connecting the field coils to the armature are employed, depending upon the operation characteristics desired. These methods are as follows:

1. **SERIES FIELD.** When all the current flowing in the armature windings also passes through the field winding, the latter must be connected in series with the armature terminals and the load. This type of field is called the *series field*. Since the armature current is usually large, the field winding consists of only a few turns of heavy wire. The number of ampere-turns to produce the required flux is thus obtained by passing a large current through a few turns.

The characteristics of the series generator at constant speed are such that the e.m.f. generated varies with every change in the load. Figure 49 shows the series field method of self-excitation.

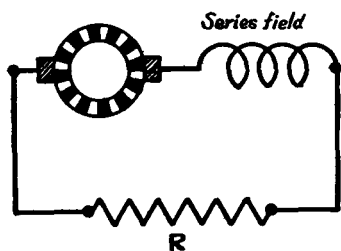


Figure 49. Circuit of a Series Wound Generator

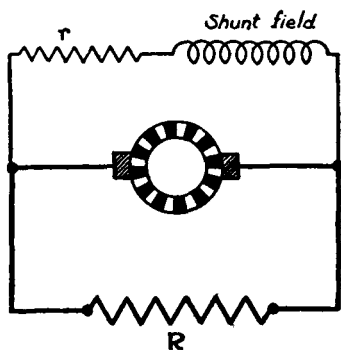


Figure 50. Circuit of a Shunt Wound Generator

2. **SHUNT FIELD.** When only a part of the current in the armature winding is used to energize the field magnets by connecting them in parallel with the brushes, the shunt-field method of excitation is employed. (See Figure 50.) Since the field is connected across the armature windings, it receives the full e.m.f. induced in the armature, consequently it must have a sufficiently high resistance to limit the current drawn to a predetermined value. The required flux is obtained by passing a small current through a large number of turns.

The characteristics of a shunt-wound generator at constant speed are such that, at zero load, the terminal voltage is a maximum. This is the kind most used on airplanes.

3. COMPOUND. The simple series and shunt-field methods of excitation with their opposing characteristics are usually combined in large generators such as at ground stations where a practically constant terminal voltage is required irrespective of any variations of the load. (Every dot and dash made by the radio key varies the transmitter load.) The contribution of each of the field windings to the total flux can be so proportioned that the terminal voltage will remain constant from no-load to rated full-load. Such a generator is said to be flat-compounded. The proportions of the two fields may also be such that the terminal voltage will rise slightly with increase in load. This is the overcompounded condition. Figure 51 is a diagram of the connections of

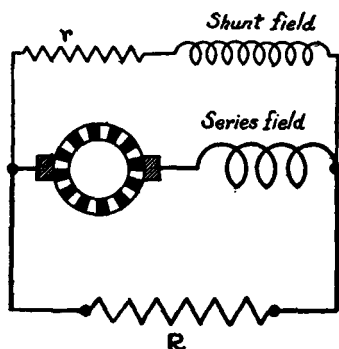


Figure 51. Circuit of a Long Shunt, Compound-Wound Generator with Terminal Voltage Control

a long shunt, compound-wound generator. It will be seen that the shunt field is connected across both the armature and the series field. In the short shunt, compound-wound generator, the shunt field is across only the armature.

### Eclipse Generators

Eclipse generators are available in a range of capacities to supply a wide variety of service requirements. Plate VIII shows an Eclipse generator. The mounting flange and drive member on all standard models are designed in accordance with the S.A.E. and U.S. Army-Navy Standards.

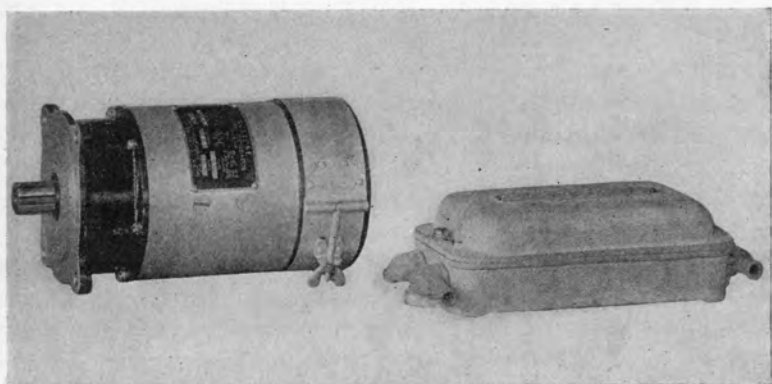


Plate VIII. Eclipse Engine-Driven Generator

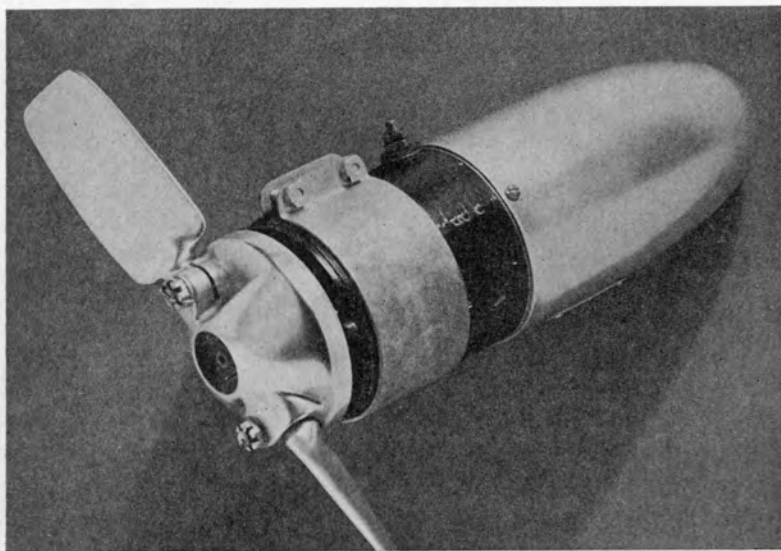


Plate IX. Air Associates Wind-Driven Generator, Model GE-20



The generators (with exception of the Type AL-1) are provided with flexible couplings between the driving-shaft and the armature. The purpose of this device is to absorb torsional vibration and power impulses from the engine, thereby preventing damage to the generator and excessive wear to the driving members of the engine.

**Purpose of Voltage Regulation.** The operation of generating equipment in aircraft, due to the constancy of the comparatively high cruising r.p.m. of the engine, necessitates utilizing a means of regulating the output of the generator so that overcharging of the battery does not occur. The generator-driven speed when cruising is sufficiently high to provide maximum rated output; to maintain this output without overcharging of the battery has led to the adoption of the voltage-regulated feature of Eclipse generators. The indispensability of voltage regulation is particularly evident in the generator models of larger capacities where the rated output is necessary because of intermittent load requirements but would cause damage to the battery if allowed to charge without being regulated in accordance with the state of charge of the battery. One form of voltage-regulation unit (not the Eclipse) is shown in Figure 61, page 173.

The Eclipse regulating mechanism is contained in a separate cushion-mounted control box. Its operation is automatic and the output of the generator unit is held at a predetermined constant voltage. The voltage-regulating unit within the control box is normally adjusted for a constant voltage of either 14.2 or 28.4 volts, which are values most suitable for use with 12- or 24-volt battery systems. The current output of the generator is automatically varied in accordance with the state of charge of the battery and, in addition, the amount of current which is being drawn from the battery and generator at that time. The combination of these conditions is the basis upon which the generator charging rate is automatically varied by the control box. Thus the proper charge is delivered to the battery at all times without danger of overcharging. A discharged battery will receive the maximum charging rate and as the charging proceeds (providing external load requirements do not equal or exceed the generator capacity) the

charging rate is reduced proportionately, tapering off to a trickle charge when the battery has become fully replenished.

To preclude the possibility of the generator's becoming overloaded with resultant overheating due to abnormal or excessive load requirements, a current limiter unit is provided within the control box; its function being to limit the maximum current output to a value slightly in excess of the generator's capacity.

In addition to the other features of regulation and control performed by the control box, there is included a unit termed a reverse-current cut-out. This device prevents the battery from discharging through the generator when the generator is at rest or operating at a speed at which it is not developing its normal voltage. The cut-out automatically connects and disconnects the generator to and from the battery at the proper time.

**Control Boxes.** Three types of control boxes are available for use with the generator units and differ mainly in the method of mounting on the airplane. All types, however, are in themselves cushion-mounted to prevent interruption of service due to excessive vibration. The first type is provided with a mounting base for installation in a permanent manner and is particularly adaptable in private aircraft or installations wherein ample space is provided for inspection and servicing of the unit. In order to meet the requirements of various installations, this particular type is available with regulator, current limiter, and cut-out, or with regulator and cut-out, or a combined regulator and cut-out unit. The latter unit is not cushion-mounted and is designed primarily for use with the third-brush generator.

The second type is designed so that the mounting base is permanently installed in the aircraft with the upper portion containing all three regulating units "plugged" in place and held by a quick releasing clamp. The mounting base also contains, in addition to all wiring connections, a filtering means to eliminate radio interference developed within the generator and control box.

### **Air Associates Wind-driven Generator Model GE-20**

Air Associates GE-20 wind-driven Battery Charging Generators are designed to charge aircraft batteries at their normal

charging rate. These generators are connected and operate in the same manner as an automobile generator, being connected across the battery with a reverse current cut-out in series with the generator to automatically disconnect the generator when its voltage falls below that of the battery. The standard generator is made for 12-volt operation, but 6-volt generators are furnished on special order.

The output of the generator is only sufficient to furnish charging current for the battery; therefore voltage regulators, current limiters, etc., are unnecessary. The reverse current is mounted in the streamline tail of the generator so that no separate relay or control box is required. A by-pass condenser also is mounted in the tail to reduce radio interference. Plate IX is an illustration of the GE-20 generator.

### Motors

At radio stations motors are used as prime movers and as one end of motor-generator sets. Aboard aircraft they are also used to reel antennas in and out, and for many other purposes: retractable landing gear, wing flaps, rudder and aileron tabs, and parachute release mechanism. The Dumore Company at Racine, Wisconsin, has supplied many such motors to the aviation industry. Nearly all large radio concerns supply special motors suitable for operation with their sets.

A motor is a machine which converts electrical energy into mechanical energy in the form of rotary motion, the amount of electrical energy converted into available mechanical energy being dependent upon the efficiency of the motor. Most generators and motors are so similar that often they can serve interchangeably with only slight adjustments.

Much of the theory of the generator, such as the generation of e.m.f., armature reaction, sparking, commutations, field connections, etc., therefore applies to the motor. It is well known that a force of attraction or repulsion is developed when different magnetic fields are acting in parallel directions in the same space, depending, respectively, upon whether the flux lines are acting in opposite directions or in the same direction. When a wire carry-

ing current is placed at right angles to the direction of a magnetic field, a force will be developed which will act on the wire to move it. If a very flexible wire in loop form is placed in a strong magnetic field, and a current then passed through it, the loop will form itself into a circle, in which case it would include the greatest number of flux lines possible. This gives the rule that a circuit always tends to move in a direction so as to include the maximum number of flux lines.

When the direction of the magnetic field is reversed, the direction in which the wire carrying current tends to move also is reversed. Likewise, if the direction of the current through the wire is reversed, the direction in which the wire tends to move also will be reversed.

**D.C. Motors.** The simplest form of a d.c. motor consists of a single loop with a two-segment commutator, arranged to revolve in a bipolar field. Current is supplied to the loop by an external source, through a commutator to the loop. The position of the loop at the instant of connecting the source is such that it includes the minimum number of flux lines. One side of the loop tends to move upward, and the other side downward. This direction of motion is the reverse of that necessary to induce a current in the conductors having the same direction as that supplied by the source. Therefore, the direction of rotation of the armature of a generator, when operating as a motor, will be reversed.

As the loop continues to revolve, it reaches a position where it embraces the maximum number of flux lines. In the case of this simple machine, the loop will stop in this position unless it has acquired sufficient momentum to carry it past this dead center, in which case the commutator operates to cause current to continue to flow in the conductors and the rotary motion of the loop continues as long as current is supplied.

When a d.c. motor is rotating, the field poles and the armature are both being supplied with electricity from the power-supply wires. If the power supply is suddenly cut off, a motor will act as a generator, supplying its own field and generating electricity until the friction and load cause it to stop. This shows that while it is operating and taking electric power from the supply lines,

it is also developing a *counter-electromotive force*. The voltage supplied from the line tends to cause a current to flow in one direction through the armature. The counter-voltage, in opposition to the supply voltage, tends to cause a current to flow in the opposite direction. The resultant voltage acting on the armature is the difference between the voltage of the current which is supplied and the counter-electromotive force. It is the resultant voltage which determines the actual current flowing through the armature.

The speed of a motor depends on the counter e.m.f. developed—the voltage of the power supplied to the motor remaining constant. By inserting a resistance—generally variable—in the field winding, the armature speed can be increased by cutting in resistance. This increase will continue until the counter e.m.f., which

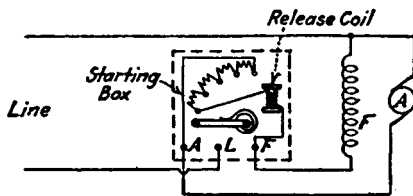


Figure 52. Starting-Resistance Box

will also increase because of the increased speed, reduces the armature current. The variable field resistances used to control motor speeds are known as rheostats.

When a motor is operating at full speed, the counter e.m.f. is almost equal to the applied voltage. At standstill or at low speeds, however, the counter e.m.f., which depends on the speed of rotation, is very small, so that the resultant voltage, acting on the low resistance of the armature, tends to cause a heavy current to flow. In order to limit this current, a *variable starting resistance* or *rheostat* is placed in series with the armature. As the motor comes up to speed, this resistance is gradually cut out of the circuit. Figure 52 shows the connections to an ordinary starting-box.

In order to prevent the starting resistance from being left out of the circuit after a motor has been shut down, due to the failure

of the supply line to furnish current or some other reason, the starting handle usually has an attached spring which returns it to the starting position, except when held up by a magnet which is energized only when the motor is running properly. This magnetic device may be operated by loss of field current, or by overload, loss of line voltage, overspeed, or some other factors. The terminals of motor-starting rheostats must be marked to indicate the part of the circuit to which each terminal is to be connected, as, for example, "line," "armature," and "field." To provide protection to the operator handling a motor-starting rheostat, frequently it is entirely enclosed in a metal box with only the operating handle on the outside. Sometimes it is operated by an automatic remote-control relay, arranged to advance the contact arm of the starting rheostat after successive time intervals.

D.c. motors are classified in the same manner as are d.c. generators: series, shunt, and compound.

The *series* motor is used where a large starting torque is required. After having started, if the load is suddenly increased, the armature speed decreases very rapidly, and the reduced counter e.m.f. allows a larger current to flow, the torque again increasing. The series motor will develop a variable torque at a variable speed.

The *shunt* motor is wound in exactly the same manner as the shunt generator, that is, the field is in shunt across the supply mains. It will not start on full load. If an overload is placed on it, the motor will slow down and probably stop.

The shunt motor develops a variable torque at a constant speed. Care must be exercised *never* to start a shunt motor with its field *open*, as it will race and probably wreck itself.

The *compound* motor combines the characteristics of both the series and shunt motor, and is the type most frequently encountered in aviation radio. It is used in most motor-generator sets.

By reversing the direction of either the field current or armature current on any type of d.c. motor, the direction of rotation may be reversed.

**Synchronous Alternating-Current Motors.** Some types of alternating-current motors are similar to alternating-current gen-

erators in principle. The synchronous motor, for example, has a field winding which is excited by direct current usually supplied by a small generator on the same shaft with the motor. The armature, however, is supplied with current from an a.c. line.

The synchronous motor has the disadvantage that it does not have sufficient starting torque, which means that it will not start without some special starting motor on the same shaft (a starting winding consisting of short-circuited copper bars built into the field poles, or some other means).

**Induction Motors.** The most rugged and common type of alternating current is the squirrel-cage induction motor. This type has a stationary armature winding somewhat like that of a synchronous motor. The rotor, however, consists of heavy bars of copper which are short-circuited at the ends by rings. The current flowing in the stationary winding, called the stator, induces a current in these loops of copper on the rotor by the principle of transformer action (page 58). The current induced in the rotor sets up a magnetic field which, combined with the magnetic field of the stator, causes the rotor to turn.

The single-phase squirrel-cage induction motor, like the single-phase synchronous motor, has very little starting torque; therefore it requires some starting device. If started by hand in either direction, it will continue to run in that direction. The three-phase squirrel-cage induction motor has a large starting torque, however, which makes this motor particularly applicable for driving machines which must be started under heavy loads.

Single-phase squirrel-cage motors when equipped with a starting device are very commonly used because of their uniform speed, simplicity, and ruggedness.

For small motors a shaded pole winding is frequently used, consisting of a single loop of heavy wire around one-half of the face of each field pole. This shaded pole winding distorts the field magnetism enough to start the motor turning in the correct direction. To reverse the direction of rotation the loop must be placed on the other side of each pole.

For motors rated at one horsepower or less, a split-phase winding is common, which may consist of small field poles wound with

fine wire between the main poles. This arrangement gives the effect of a moving magnetic field and thus causes rotation. A centrifugal switch is used to cut this split-phase winding out of service when the motor attains the rated speed. On the larger motors of this type, a clutch is sometimes used to pick up the load after the motor has reached full speed. Other methods of starting single-phase induction motors use combinations of resistance, reactance, and condensers to give an effect similar to that of a three-phase power supply while starting.

Both the synchronous and squirrel-cage induction motors are constant-speed types. The former maintains a constant speed from no-load to full-load if the frequency of the supply voltage is constant. There is a slight falling off of the speed of the squirrel-cage motor from no-load to full-load. Both of these types will be found at aviation radio stations. Motors, as parts of motor generator sets, may be either a.c. or d.c.; in many cases this depends upon whether a.c. or d.c. is available commercially.

### Dynamotors

**Construction and Purpose.** Dynamotors are dynamo-electrical machines employed for the purpose of changing d.c. at one voltage to d.c. at some other voltage. There are two armatures mounted on one shaft which rotate between one set of field magnets. One armature receives current from an outside source and acts as a driving motor. The other armature delivers a more desirable voltage. Dynamotors are much used on airplanes.

Two of the most important requirements of any dynamo-electric machine operated in the vicinity of receivers is the delivery of ripple-free voltage (if a d.c. machine) and the freedom from sparking at the commutator. In the case of dynamotors the commutated d.c. is smoothed out by filters. Sparking must be kept down to a minimum by good design and proper upkeep; otherwise there will be much "static" in nearby receivers.

Figure 53 shows the connections of a dynamotor.

**"Pinco" Dynamotor.** The "Pinco" Silver Band dynamotors are made by the Pioneer Gen-E-Motor Corporation, Chicago, Ill., in several sizes suitable for airplane installation.



Due to the use of electric iron of highest quality, correct brush material and large size wire, exceptional voltage regulation is obtained. The large number of commutator bars reduces a.c. ripple in the output to a minimum. The dynamically balanced armature runs on grease-sealed bearings which insure smooth, quiet operation. Pincos are compact, light weight, completely enclosed in dust-tight case and are furnished with or without filter.

In the type "E," a steel welded center ring is used with light-weight brackets in which armature ball bearings are mounted. There are dust-tight end covers which are easily removed to per-

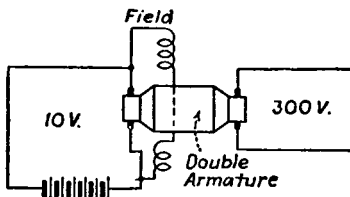


Figure 53. Wiring of Dynamotor

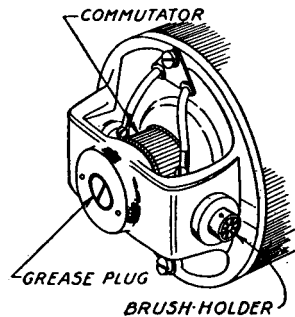


Figure 54. Type "S" Series Brushholder and End Bracket of Pinco Dynamotor

mit instant inspection of brushes and commutators. These power supply units are unaffected by vibration, and deliver d.c. with negligible ripple. For data on Type "O.S.," see following table.

#### CAPACITIES

Frame	Length	Min. Volts Input	Max. Volts Input	Max. Volts Output	Max. Output Watts Cont. 40 C Rise	Max. Output Watts Int. 50 C Rise	Weight
OS-100	5 $\frac{7}{8}$ "	6	32	350	10	15	2 lb 14 oz.
OS-175	6 $\frac{3}{8}$ "	6	32	350	18	25	3 lb 13 oz.

These are conservative ratings intended as a guide. Figure 54 shows one end of a Pinco Dynamotor.

**“Eclipse” Dynamotors.** “Eclipse” dynamotors, manufactured by Bendix Aviation Corporation, are available for operation from either 12- or 24-volt batteries. The electrical characteristics of these dynamotors are as follows:

Type	Input	Output
AD-2	3 Amps. — 14 volts	.080 Amps. — 220 volts
AD-5	5 Amps. — 14 volts	.100 Amps. — 360 volts
AD-7	8 Amps. — 14 volts	.163 Amps. — 425 volts
AB-3	14 Amps. — 12.5 volts	.154 Amps. — 520 volts
AA-2	57 Amps. — 11.5 volts	.400 Amps. — 1050 volts

The Type AD dynamotor can be furnished either with or without a mounting base. The Type AD mounting base consists of a two-piece aluminum box, containing units for the filtering of high frequency interference which may be developed within the dynamotor. The filter box, or mounting base, is so designed that the upper half, to which the dynamotor is attached, contains the filtering units. The lower half is mounted in a permanent manner in the plane and all electrical connections are made within this portion. The upper half, with dynamotor attached, is electrically connected to the lower half by plugging in place and is held in position firmly by means of a quickly-opened snap clamp. This method of mounting is particularly advantageous in that it affords quick removal for examination.

The Type AB dynamotor is furnished with a “cradle” type of mounting bracket and integral filtering means; the filtering units being enclosed within the dynamotor head. All wiring connections are made to an enclosed, compact terminal panel which is mounted on the side of the dynamotor unit. The terminal panel cover is provided with an outlet suitable for the attachment of metallic conduit for radio shielding.

Type AA dynamotor can be furnished with or without a “cradle” type of mounting bracket. Filtering units for this type are normally furnished by the radio set manufacturer. For this type dynamotor, there is available a 12-volt starting solenoid switch which eliminates the necessity of conducting heavy cable to the pilot cockpit for the control of the unit. The employment of this switch, in conjunction with the microphone switch,

provides for the starting of the dynamotor from a remote point.

The Eclipse dynamotor consists of a ball-bearing-mounted armature shaft supported at either end by the high- and low-voltage heads. The heads, which contain the high- and low-voltage brush rigging, are in most cases doweled to the yoke and held in place by through bolts. However, in late model dynamotors the heads are provided with slots, to permit staking over of the yoke, thereby eliminating the dowel pins. Field coils and pole-shoes are held in the yoke by means of four screws. Removable end covers facilitate inspection of commutator and brush rigging.

The dynamotors are of bi-polar construction with a single field winding, shunt connected. The armature assembly consists of a core into which are placed the high- and low-voltage windings, which terminate in their respective commutators. When the low-voltage side of the dynamotor is connected to the battery circuit the windings are energized, causing the armature to rotate, thereby producing current in the high-voltage winding.

The dynamotors vary slightly with respect to mounting features and method of bringing out high- and low-voltage leads. Units which have the leads brought out through a single rubber grommet are intended for mounting directly on a filter unit. Dynamotors which have leads brought out at each end through threaded nipples are intended for flush mounting.

**Esco Dynamotors.** The Electric Specialty Company, Stamford, Connecticut, manufactures a specially-designed, light-weight (aluminum) type of airplane dynamotor in various classes as to voltage output and power. They are all designed to operate from the 12-volt airplane battery. Some types deliver high voltage d.c. ; some a.c.

### Ground Station Power Equipment

**Rotary Converters.** Where an a.c. power source can be tapped—most cross-country transmission power lines carry a.c.—and a d.c. source is required at the radio station, a rotary converter is generally installed. This is equally true when only d.c. power

can be purchased and a.c. is desired for the radio transmitter. In every case the armature has connections to the external circuit attached to both ends. The usual form is driven as an a.c. motor and delivers d.c. Because the a.c. motor is generally a synchronous motor, the machine is often called a synchronous converter. When used to change d.c. into a.c. the frequency of the delivered a.c. of course depends on the r.p.m. and this type converter is called an "inverted rotary." Figure 55 shows the wiring of one form of rotary converter.

**Motor-Generators.** A motor-generator set consists of a motor and a generator, the shafts of which are direct-coupled mechanically. Each machine is complete within itself although the end of

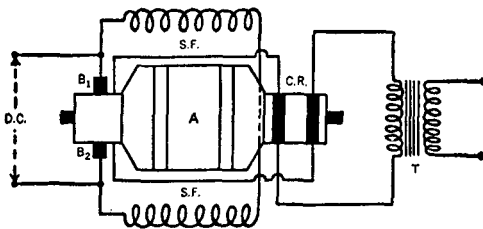


Figure 55. Fundamental Circuit of Rotary Converter

It has a single winding on one armature for both alternating and direct current. Direct current from an external source enters the armature A through the brushes B<sub>1</sub> and B<sub>2</sub> and also flows through the shunt field SF, causing the armature to revolve in the usual way. Taps are taken off the commutator segments directly underneath the brushes and are connected to collector rings CR on the opposite ends of the shaft, the circuit continuing through the primary of an a.c. transformer T.

the generator shaft may be part of the end of the motor shaft and one housing covers both machines.

The typical motor-generator used at aeronautic radio stations consists of a d.c. motor (generally compound or differential compound wound) and an a.c. generator.

Figure 56 is a schematic diagram of such a machine. In this set the d.c. supply is 110 volts; the delivered a.c. has a frequency of 500 cycles. The field coils of the alternator are supplied from the 110-volt source. The r.p.m. of the d.c. motor is controlled by the rheostat R1 which, in series with F1, is also tapped across the d.c. source. F2 controls the voltage of the alternator as long

as the speed of the driver is not varied. The frequency of the delivered a.c. depends on the r.p.m.

Servicing and maintenance of dynamo-electric machines are discussed in Chapter 16.

**Power Line Transformers.** *Power line* transformers are used at ground stations in connection with primary sources of power such as a commercial power line. Where the commercial source is 2200 volts, this is generally stepped down to a three-wire system at the radio station supplying 220 volts across the two outside legs of the circuit and 110 volts between either outside leg

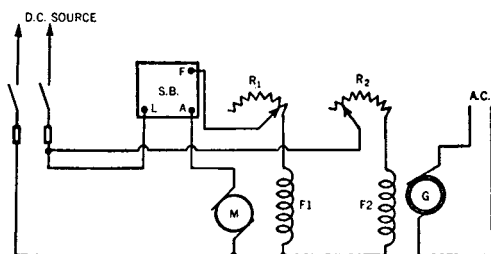


Figure 56. Wiring of Motor-Generator

- |  |   |
|--|---|
| M = Motor Armature                       | R <sub>1</sub> = Motor Field Rheostat     |
| G = Generator Armature                   | R <sub>2</sub> = Generator Field Rheostat |
| F <sub>1</sub> = Motor Field Winding     | S.B. = Motor Starting Box                 |
| F <sub>2</sub> = Generator Field Winding |   |

and the middle (neutral) conductor. The 110-volt circuits are customary for lighting; the 220 for dynamo-electric machinery although rotary converter sets are built for either 110 or 220 volts.

All transformers which deliver considerable power, either from a power line or as a part of a transmitter or receiver, are called *power* transformers and are classified according to their construction as open core and closed core. The cores are made of laminated iron. In the open-core type this core is incomplete as a magnetic circuit—some of the magnetic flux being forced to pass through air. The object in building a closed-core transformer is to confine this flux as much as possible to the core. Figure 57A and B illustrate these two types of iron-core power transformers.

“Core legs” are the parts of the core on which the primary and secondary coils are wound. The coils are usually made up of either enamelled or cotton-covered wire.

Figure 57C shows another form of core-type transformer known as a shell type. Notice that primary and secondary windings are wound one over the other on a single leg of the core. This type of construction is designed to reduce magnetic leak-

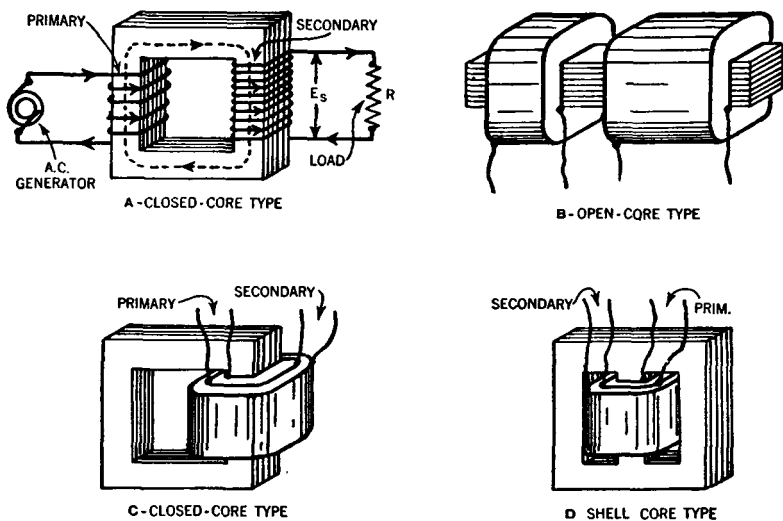


Figure 57. Various Types of Transformer Core and Winding Arrangements

The shell type is used most on account of its lower magnetic leakage.

age. It is much used as an inductor (inductance coil) or choke-coil in filter systems (page 83) of radio receiver systems.

Figure 57D is that of the shell-type transformer. Because it has a center leg and two outside legs, two outside parallel paths are provided for the magnetic lines of force indicated by the dotted lines. The chief advantage of this design is that it has very little magnetic leakage. It is used on power lines; also, in both radio-frequency and audio-frequency circuits in radio sets.

The principles of transformers used in radio sets are described in Chapter 3 (page 58).

### Power System for Radio Sets

With 110 volts a.c. available, it is possible to operate radio sets without using "B" batteries as a source of voltage for the tubes. In some cases the a.c. is stepped down and rectified. In other cases it is stepped up. A typical B-power<sup>25</sup> unit system (that which supplies power to the plate of a tube) would consist of the following four units:

1. A step-up power transformer, the primary of which is connected to a 110-volt a.c. line.
2. A rectifier which changes the a.c. to pulsating d.c.
3. A filter which changes pulsating d.c. to smooth d.c.
4. A voltage divider which enables various voltages as required, to be obtained for the various tubes.

These are connected in the order named.

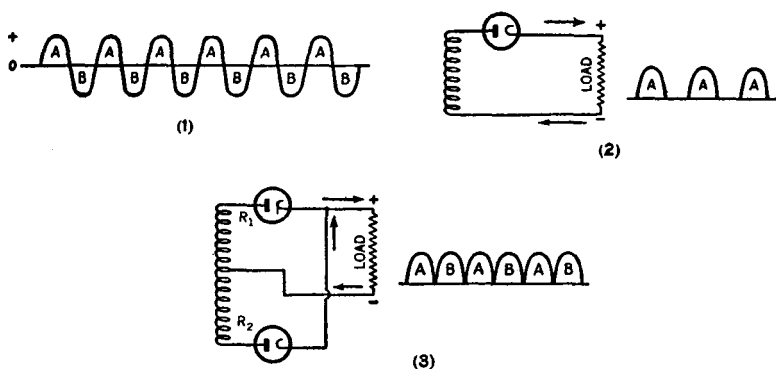


Figure 58. Rectification of Alternating Currents

**Rectifiers.**<sup>201</sup> The rectifier is a device, wired in series with the power supply, that changes alternating current to pulsating unidirectional current. This change is accomplished by the valve action of a radio tube. Radio tubes used as rectifiers are described in Chapter 5. However, at this time it will be well to learn how a rectifier functions. To do this, study Figure 58: (1) is a typical wave. Here the polarity of the current and voltage completes a reversal during each cycle. In rectification, this

wave is transformed into one in which the polarity is always the same; however, the amplitude of the current and of the voltage may vary continuously. The resulting voltage is often called "ripple" voltage (page 163).

(2) shows the result of connecting the secondary of a power transformer to a single rectifier element which permits the current to flow through it in one direction only (from the plate to the cathode) of the radio tube. Because of the valve action of the tube, the resistance of the tube considered as a circuit is zero in one direction but infinite in the other. Then during the period while the upper end of the transformer winding is positive, corresponding to A in (1), current can flow to the load unimpeded. When the current reverses, however, as at B, it cannot pass through the rectifier, consequently nothing flows to the load. The drawing shows how the output from the transformer and rectifier appears. Only one-half of each cycle is useful in furnishing power to the load, consequently this arrangement is known as a "half-wave" rectifier system.

In order to utilize the remaining half of the wave, two schemes have been devised. At (3) is shown the "full-wave center-tap" rectifier, so called because the transformer secondary winding must consist of two equal parts with a connection brought out from the center. In (3), when the upper end of the winding is positive, current can flow through rectifier  $R_1$  to the load; this current cannot pass through  $R_2$  because its resistance is infinite to current coming from that direction. The circuit is completed through the transformer center-tap. At the same time the lower end of the winding is negative and no current can flow through rectifier  $R_2$ . When the current reverses, however, the upper end of the winding is negative and no current can flow through rectifier  $R_1$ , while the lower end is positive and therefore rectifier  $R_2$  passes current to the load, the return connection again being the center-tap. The resulting wave shape is shown at the right—Figure 58 (3). All of the wave has been utilized, and the amount of power which can be realized at the load is doubled. However, in order to maintain the same output voltage (instantaneous, not average) as at (2), each half of the transformer secondary must be wound for the same voltage as that furnished by the whole



winding in (2); or, conversely, the total transformer voltage with the connections shown in (3) must be twice the desired output voltage.

Although the rectifier output is direct current in the sense that the polarity is always the same, the amplitude is not uniform but varies continually as shown in Figure 58. Before the power can be supplied to the transmitting tube plates the "humps" must be smoothed out by a filter.

**Filters.** Filters were first mentioned on page 83 in connection with receiving circuits. A filter used in conjunction with rectifiers is known as a ripple filter (page 165), the object of which is to deliver to the plates of the transmitting tubes pure d.c.

From a rectifier-filter system pure d.c. voltage is obtained, and in addition, a superimposed a.c. voltage called a ripple voltage.

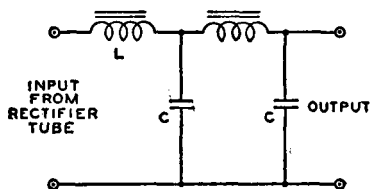


Figure 59. Choke-Input Type Filter  
(L = Filter Choke)

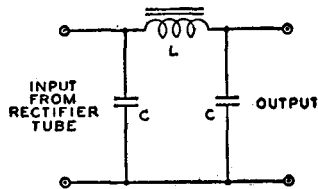


Figure 60. Condenser-Input Type Filter  
(C = Filter Condenser)

The percentage of ripple is determined by dividing the effective ripple voltage by the d.c. voltage. In a well-designed system for use in continuous-wave radiotelegraphy a ripple of less than 5% is satisfactory. For radiotelephony this ripple must be reduced to half this percentage. (See percent ripple<sup>174</sup> in Appendix II.)

A filter circuit must have a combination of inductance and capacity. Suitably designed inductors (page 54) or choke-coils (page 58) provide inductance; condensers (page 59) furnish the necessary balancing capacity. These are connected in several different ways, two of which are shown in Figures 59 and 60. The design of a filter influences the voltage-regulation, that is, the change in terminal voltage of a B power unit system ("power-

pack”) with different load currents. Figure 91 shows a rectifier-filter power supply circuit worth memorizing (page 222).

The windings of transformers and filter chokes used in plate supplies all have some resistance; as the current drawn from the power supply is increased, the voltage drop in the transformer and chokes also increases, with the result that the terminal voltage drops. Besides the ohmic effects, there may be other causes contributing to the decrease in terminal voltage with load, such as the behavior of the filter.

In an engineering sense, the term “voltage regulation” refers to the increase in voltage resulting when the load current is de-

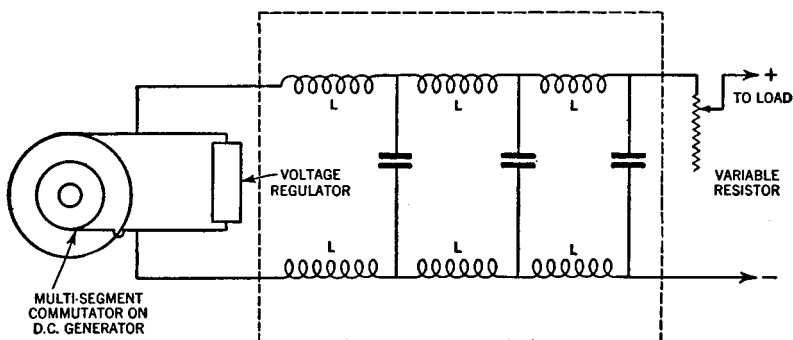


Figure 61. Generator Circuit with Voltage Regulation Unit and Filter Circuit

Dotted lines enclose the filter circuit; (L indicates iron core “chokes” or inductance coils).

creased from the rated value to zero, expressed as a percentage of the terminal voltage at full-load current. It is sometimes more convenient, in speaking of plate-supply systems, to use the terminal voltage at no load as a base, in which case the percent regulation will be the decrease in terminal voltage from the no-load value to the value of load at which the power supply is to be worked. Assume the measured terminal voltage of a power supply is 1000 volts at no-load (no current being drawn by the transmitting tubes); then with the transmitter in operation, the voltage is measured and found to be 750 volts. The percentage voltage regulation will be :

$$\frac{1000 - 750}{100} = 0.25, \text{ which is } 25\%$$

The voltage regulation will be found to vary with the load and with the type of filter used. Good B supplies will have a regulation of 10% or less; this is highly desirable.

Figure 61 shows a circuit designed to insure good voltage regulation of a generator supply together with a filtering arrangement which works in conjunction with the voltage regulator.

**Voltage Dividers.**<sup>254</sup> Different tubes require different plate voltages. Therefore, at the terminals of the filter, leads contain-

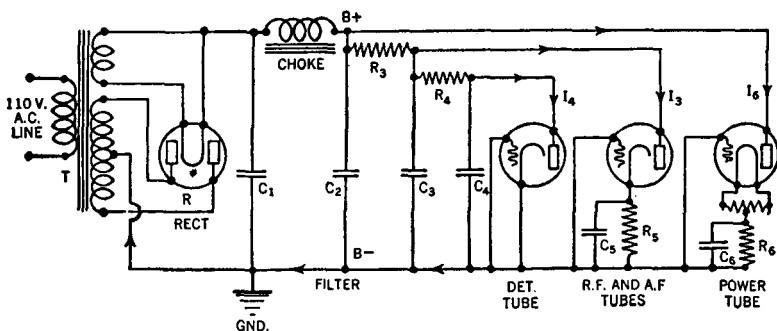


Figure 62. The Voltage Divider

If only one value of plate voltage were required by all of the tubes in a radio receiver, the power supply unit would now be complete, but since the various tubes require different plate voltages, provision must be made to supply them. This is the function of the *voltage divider system*. The fundamental principle involved in all voltage divider systems is that whenever current is made to flow through a resistance connected in the circuit, a certain amount of the e.m.f. applied to the circuit is used up in forcing the current.

ing suitable resistances to reduce the voltage as required, are connected to the various plates. How this is done in a receiver is shown in Figure 62.

## QUESTIONS

91. Name and describe the essential parts of a dynamo-electric machine.
92. Explain how a.c. is generated; upon what does the voltage and frequency depend?
93. Sketch diagrams of the field connections for a series, shunt, compound, generator.

94. Discuss voltage regulation in the case of an aircraft generator.
95. What is the theory of operation of a d.c. motor ; of an induction motor ?
96. Describe how a starting rheostat operates.
97. Where are dynamotors used aboard airplanes and why ?
98. List the power equipment used at aviation radio stations.
99. What constitutes an electric power system for radio sets ?
100. Describe the operation of a rectifier-filter system.

## CHAPTER 8

### RADIOTELEGRAPH TRANSMITTERS

#### General Considerations

**Employment.** There is no practical way of communicating with aircraft in flight except by radio. Two-way communication is desirable in every case and on passenger airlines is a flight requirement. Radiotelegraph sets provide the most reliable means of two-way communication as to distance, the effective range of a radiotelegraph transmitter being much greater than a radiotelephone transmitter of the same weight. However, the choice of radio communication equipment is not determined by this fact alone. Knowledge of the Continental Morse Code is required by

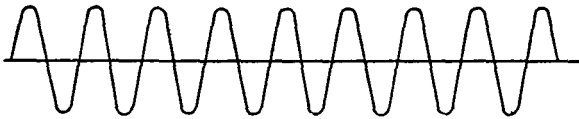


Figure 63. Conventional Representation of a Continuous Wave

the operator of a radiotelegraph set, therefore a radiotelephone set may be chosen instead for some particular route where its range is deemed sufficient. For a number of years, the U. S. Navy has used radiotelegraph sets in its planes while the Army has used both telegraph and telephone sets. As both kinds are suited to transport plane and ground station use, they should both be studied, especially as to circuits.

**CW Transmission.** When continuous oscillations of a constant amplitude are emitted by a set, it is called continuous-wave (CW) transmission.<sup>51</sup> These oscillations may be generated in a radio tube having a d.c. plate supply either from a d.c. generator, from a source of rectified and filtered a.c., or from a battery.

Figure 63 is a conventional representation of a CW wave train showing the characteristics of a continuous wave. It is the only kind of wave emitted by the modern aircraft sets described in this book.

**ICW Transmission.** At some ground radiotelegraph stations it is sometimes desired to interrupt the transmitted dots and dashes at an audio rate. This gives interrupted-continuous-wave (ICW) transmission. Such signals can be received on the ordinary aircraft receiver. ICW transmission is used at radio range stations. ICW transmission in the short-wave band carries well, does not "fade" seriously.

Types of emission are given on page 21.

**Design Requirements.** All of the apparatus described in this book are of careful design. Technical familiarity with these sets, combined with a fundamental knowledge of design requirements will help very greatly in an understanding of the radio equipment that will be marketed in the future. (Special applications of radio to aviation such as blind-landing systems are discussed in the last two chapters.) Remember this: the adaptation of radio to commercial aviation is mostly a matter of container forms—not of new design principles. Another note of warning: radio sets are not yet fool-proof; actual experience in handling them should be acquired after the theory of operation has been mastered.

The most important requirement of plane apparatus is reliability. Both transmitter and receiver should function consistently and effectively over their rated working range. If they work well one day up to 200 miles and the signals fade the next day, over a different territory at 100 miles, the set is not reliable; its effective range is certainly something less than 100 miles and it may not be anything. No matter how skilfully a set is designed nor how spectacular the results obtained by engineers on test flights, its value is less than nothing if it is unreliable in performance under service conditions, operated by aircraft personnel.

The entire set should be simple and rugged. Unless the average pilot, radio operator, or mechanic can readily learn to operate the set with good results, its value is questionable. It should be designed to withstand the normal usage incident to airplane travel

—landings, change of temperature, dust, inclement weather, etc. It should be accessible to facilitate testing and repairing. The receiver should be both sensitive and selective as to tuning.

All apparatus should be as light and compact as possible and neither the original cost nor the upkeep should be too great. Manufacturers' costs will go down as the engineering expenses originally incurred in research are absorbed by quantity production. Skilled operation will decrease maintenance costs.

Almost every set being manufactured today can be viewed with confidence from the standpoint of operation, and an increased knowledge of these sets will strengthen this confidence. All aviation sets are designed to operate on frequencies that are legal for this service.

The specifications for an airport transmitter are given in Chapter 14.

### Theory of Transmission

**Radio Waves.** The transmission of both voice and code is accomplished by the use of the energy of radio waves.<sup>255</sup> A radio wave is one, the period of which is a radio-frequency. It is the function of transmitters to generate and propagate radio waves; that of the receiver to intercept them and utilize their energy by converting it into sound. Radio waves are a combination of electromagnetic and electrostatic fields of force at right angles to each other and to the direction of travel. They travel partly along the ground; partly through the sky. The frequency of radio waves is that of the radio-frequency circuit of the transmitter. The wavelength is the distance in meters in space which is occupied by one cycle. Frequency is expressed both in kilocycles and megacycles. When frequency is expressed in cycles and wavelength in meters, the commonly used formula is:

$$\text{Meters} = \frac{300,000,000}{\text{cycles}}$$

The approximate velocity of light is 300,000,000 meters per second; it is assumed also to be the rate of travel of radio waves. The frequencies employed commercially range from about 15 kc

to 100,000 kc; those used in aviation as well as in other services are fixed by the F.C.C. as shown on pages 16–17.

The intensity of the field of force which comprises a radio wave is expressed in microvolts per meter.

**Propagation of Waves.** Radio waves of one frequency behave differently from those of other frequencies. As the entire spectrum of wavelengths must be utilized, the characteristics attending propagation are a matter of considerable interest and concern. The time of day and the season of the year also affect propagation. The received signal strength from various transmitters is affected by different factors; the earth absorbs some of the energy radiated from the transmitting antenna; there is a natural attenuation<sup>18</sup> which increases with the distance travelled by the

TABLE OF RADIO WAVE CHARACTERISTICS

Class	Chief Characteristics	Principal Uses
Low frequency: Below 100 kc	Low attenuation all times of day and of year	Long-distance transoceanic service requiring continuous operation
Medium frequency: 100 to 1500	Attenuation low at night; high in daytime; greater in summer than winter	Airplane radio, direction finding, etc. 550 to 1500 kc for broadcasting
Medium high frequency: 1500 to 6000	Attenuation low at night and moderate in daytime	Moderate-distance communication of all types
High frequency: 6000 to 30,000	Transmission depends upon ionization of the upper atmosphere; varies greatly with the time of day and season. Attenuation extremely small under favorable conditions.	Long-distance communication of all kinds; airplane radio
Very high frequency: above 30,000	Waves travel in straight lines; are not reflected by ionized layers, therefore can travel only between points in sight of each other	Short-distance communication, television, airplane landing beacons



waves; and there is a certain amount of attenuation and refraction caused by the ionized regions of the upper atmosphere, called the ionosphere, or the Kennelly-Heaviside layer of atmosphere.

There are several interesting and plausible theories which explain "bending," "fading," the "skip-distance effect," etc., all of which are of considerable value to the designer, the engineer, and the physicist. The inherent characteristics of aviation frequency

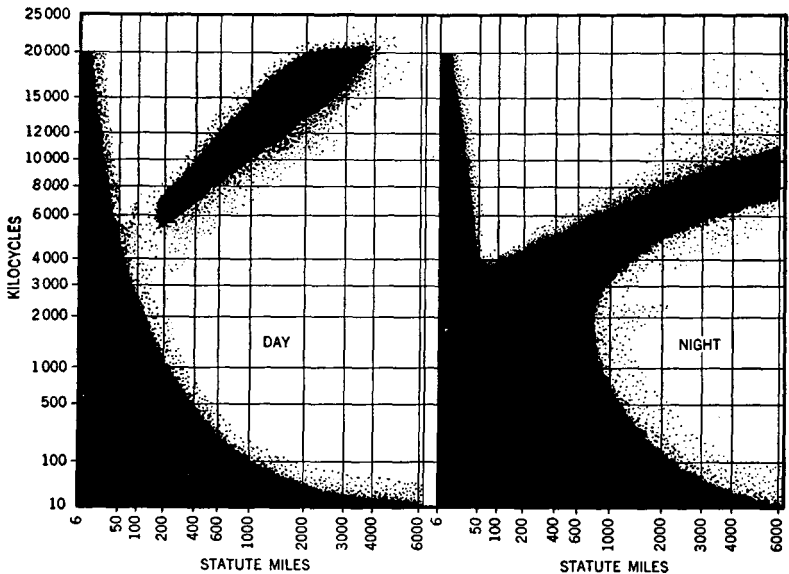


Figure 64. Transmission Effectiveness of Various Radio Frequencies

Approximate distance ranges of radio waves, 1 kw nondirectional radiation; useful ranges lie within black areas.

waves are now quite well established, consequently the technique of design and operation of aviation transmitters can be handled accordingly. The table of radio wave characteristics on page 179 at different frequencies may be studied as a summarized guide of how waves behave when employed for various forms of radio communication service.

The chart of transmission effectiveness, Figure 64, shows day and night distance range of certain radio waves.

In Appendix II will be found definitions for modulated wave, carrier wave, tone-modulated waves, marking wave, telegraph modulated waves, spacing wave.

### Oscillator Circuits

**The Oscillator Tube.** Any three-element detector or amplifier tube will oscillate under certain conditions. But if it is desired to establish and maintain a.c. oscillations of constant frequency, a tube designed for this purpose called an *oscillator tube* is used. With the proper electrical constants, an oscillator tube circuit can be made to supply any frequency of from one to several hundred million cycles per second. This tube, then, becomes the source of oscillations for *continuous-wave* transmitting sets and these sets can be designed for practically any desired frequency or wavelength. The production of a.c. within this tube depends upon the control which the grid voltage exerts on the plate current, that is, the valve action whereby a small amount of energy applied to the grid releases *a large amount from the plate battery* or an equivalent source. The tube is NOT the original source of energy, but it is the source of a.c. oscillations necessary for the emission of radio waves. A certain amount of each oscillation produced in the plate circuit is admitted to the grid circuit at such a time interval that pulsating current waves are continuously generated into the plate circuit. The time interval is controlled by the electrical constants of the circuit, the condensers and inductances used being variable for this reason. (Review Oscillatory Circuit, page 70, at this time.)

**Elementary Oscillator Circuit.** (See Figure 65.)  $L_2$  and  $C_2$  constitute an oscillating circuit adjusted for a certain frequency.  $L_1$  is coupled to the circuit  $L_2C_2$  and therefore receives some energy from that circuit, the oscillations in the grid circuit assisting those in the plate circuit.

When the A and B batteries are switched on and the circuit is tuned, weak oscillations will induce a.c. in  $L_1$  which acts on the grid and produces variations in the plate current which flows through the oscillating circuit  $L_2C_2$ , reinforcing the originally weak oscillation. Each succeeding cycle increases the amplitude

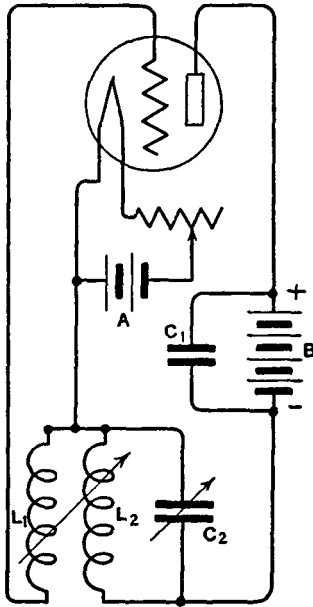


Figure 65. Elementary Oscillator Circuit

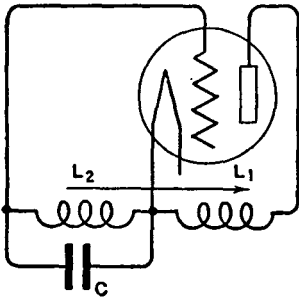


Figure 66. Tuned-Grid Oscillator Circuit

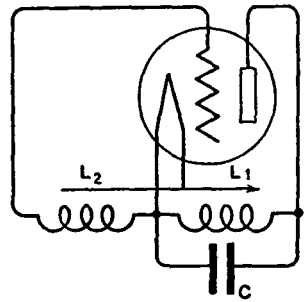


Figure 67. Tuned-Plate Oscillator Circuit

of the resulting wave until a continuous a.c. wave is established in  $L_1$ .  $L_1$  is often used to transfer further these waves externally, as in the case of a transmitter. If a sensitive radio ammeter is connected into the oscillatory circuit  $L_2C_2$ , current flow will be shown by it when oscillations are established.

Once established, continuous oscillations will be maintained if the voltage induced in the grid circuit produces variations in the amplitude of the plate current sufficient to maintain the voltage in the grid circuit. The necessary feed-back action can be brought about by electrostatic or inductive coupling or by direct coupling from the plate back to the grid circuit.

In Figure 66,  $L_2$  and  $L_1$  are coupled together in order that the voltage applied from the plate circuit will maintain the oscillations. To allow tuning,  $C$  must be variable.

In Figure 67, the coupling is necessary in order to control the grid voltage because in this case  $L_2$  is not in the oscillatory circuit. Tuning is possible if  $L_1$  is made variable.

In all oscillating-tube circuits, the varying plate circuit can be considered as partly a.c. and partly d.c.

The frequency of oscillations and the control of frequency are discussed in the chapter on radio circuits.

**Efficiency of Oscillator Tubes.** The efficiency of oscillator tubes is the ratio of output power to input power. (The power expended in heating the filament is not included.) For low-power tubes, it is about 20% to 35%; medium-power tubes, about 40% to 60%; and for high-power tubes it may be as high as 85%. Current in the oscillating circuit is brought up to a maximum by varying the capacity and inductance until the load in the plate circuit is just right for the tube to handle. By tuning in a large inductance or tuning out capacity (or using an antenna that is too small), the load resistance may become too high for obtaining maximum current flow. In general, the power output is maximum when the equivalent resistance is equal to the plate resistance of the tube. Maximum output may not insure maximum efficiency. The two factors which determine the power put into a tube are the plate voltage and the filament emission; efficiencies below 50% depend upon the tuning of the circuit.

**Types of Oscillators.** There are two types of oscillator circuits classified according to oscillation frequency control:

1. Circuits in which the oscillation frequency is determined by the tuning constants of the circuit. These circuits make up what are known as self-controlled oscillators such as shown in Figures 65, 66, and 67.
2. Circuits in which the frequency of oscillation is principally determined and kept constant by a piezo-electric crystal, an electro-mechanical device. These circuits constitute "crystal-controlled" oscillators.

### Basic Transmitting Circuits

There are three good basic circuits much used in aeronautic transmitters: the Meissner, the Colpitts, and the Hartley. They will be described in the order named. The application that has been made of these circuits to aircraft sets will be more readily understood if the reason for their arrangement is made fairly obvious. Note carefully the Colpitts and the Hartley; their individual characteristics, and how they differ.

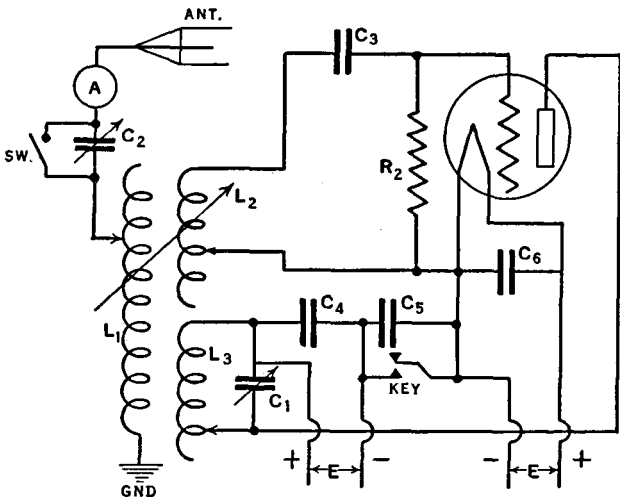


Figure 68. Meissner Circuit; Series Plate Feed

**The Meissner Circuit.** The circuit as shown in Figure 68 is a typical example of the simplified 3-coil Meissner circuit. (It will be found helpful in understanding this circuit if it is compared to that shown in Figure 65, page 182.)

Note that the Meissner circuit has a tuned antenna circuit and that there is no other tuned circuit. The electrical constants of any aircraft antenna circuit vary with the motion of the antenna; therefore, in the case of a trailing antenna of any sort that sways in such a way as to change its capacity, this method of maintaining frequency is unreliable. As a transmitter that goes off frequency while in operation may not be received at all, the Meissner circuit is not considered as desirable in aeronautics as the Hartley and Colpitts circuits.

Referring again to the diagram, it will be noted that the plate circuit is tuned by  $C_1$ , a condenser made variable for that purpose. It does not tune any other circuit, but its capacity does act as a control of the load taken by the tube.

By closing the key, voltage is applied to  $L_3$ , which induces an e.m.f. in  $L_1$  and that coil induces an e.m.f. in the grid coil  $L_2$ . The grid voltage produces a corresponding change in the plate current and this pulsating plate current flowing through  $L_3$  induces an e.m.f. in  $L_1$ , creating radio-frequency oscillations at a frequency determined by the tuning of the antenna circuit as previously stated. As soon as radio-frequency voltage is induced in the grid circuit, correspondingly greater variations of the plate current are brought about, and this continued action is the process of generation of radio-frequency currents emitted as continuous waves. Plate current is regulated by using the proper number of turns in the plate coil. The grid also has a coil to regulate the grid current, although suitable variable condensers could be used instead, in both cases, and the arrangement would still be known as a Meissner circuit.

There is also a four-coil Meissner circuit, but this has not been adapted to any commercial aircraft transmitter.

**The Colpitts Circuit.** The Colpitts circuit (Figure 69) is directly coupled by capacity between the tube circuits and the oscillatory circuits; that is, the grid is "capacitively excited."

Capacity coupling is described and illustrated on page 80. The Colpitts is the only one of the three basic circuits under consideration that is so coupled; this feature is one of the fundamental differences between this circuit and the other two. By examining Figure 70, it will be seen that the Hartley circuit is indirectly coupled, by inductance. The Hartley circuit is also sometimes directly coupled to the antenna circuit by inductance, but it is never coupled by capacity anywhere within the circuit. It could not be so coupled and still be rightly called a Hartley circuit.

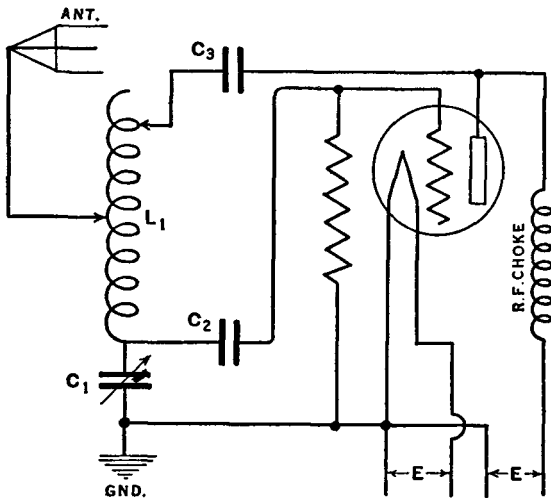


Figure 69. Colpitts Circuit; Direct Antenna Coupling; Parallel Plate Feed

It seems appropriate to state here that any of these basic transmitter circuits can have an arrangement of internal circuits whereby the tube-generated radio-frequency current emitting the radio wave is fed into the radiating (antenna) circuit by either an inductive coupling, or a direct coupling, or a capacity coupling. Also, the radio-frequency current may, or may not, feed through a radio-frequency "power amplifier." Remember, the method employed to excite the grid is an important distinguishing feature.

Referring again to Figure 69, by varying condenser  $C_1$ , the charge stored in it can be made just right to excite the grid. Fixed

condenser  $C_2$  will then control the frequency of oscillation. As these two condensers are in shunt, they are designed to withstand the voltage supplied to them, which is fairly high. The grid-leak resistance is always connected directly across the filament in the Colpitts circuit, rather than across the grid condenser as in certain other circuits. This is necessary to provide a d.c. path for proper grid bias.  $C_3$  is not always included in the Colpitts circuit, but where it is a part of the circuit, d.c. would not pass through  $C_1$  if a resistance was shunted across  $C_3$ .

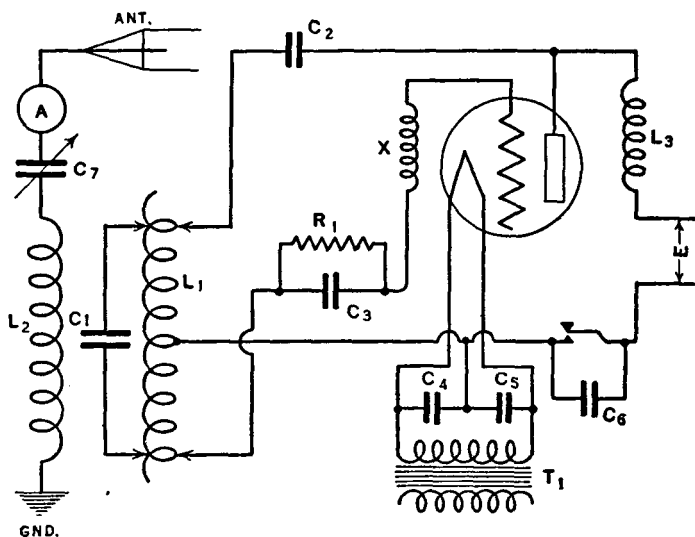


Figure 70. Hartley Circuit; Inductive Antenna Coupling

**The Hartley Circuit.** (See Figure 70.) In the Hartley circuit, as in the Meissner circuit, use is made of an inductive grid feedback in establishing and maintaining radio-frequency oscillations.

The grid and plate turns are made variable in the Hartley circuit in order that the proper number of turns can be introduced into the circuit to excite the grid properly. There is a connection near the middle of the inductance for the filament. If there is a greater number of turns between filament and grid than between



filament and plate, the plate current will be increased by reason of the greater feeding-back action that this arrangement will cause. The "plate coil" is that portion between the filament clip and the plate clip; the "grid coil" is that part between the filament clip and the grid clip. If the plate current becomes too high, the plate lead can be moved farther away from the filament to lower the plate current to its normal rating.

The frequency in this transmitting circuit is controlled by the condenser  $C_1$ . Also, if the grid is moved away from the filament, there will be a drop in frequency, or if moved closer, there will be an increase in frequency.

This circuit offers an interesting example of the action of a condenser with low- and high-frequency voltage.  $C_2$  prevents the high-voltage low-frequency generator from being short-circuited through  $L_1$ , but passes the radio-frequency currents from plate to inductance.  $C_3$  likewise stops the high negative voltage from the plate supply generator from reaching the grid, but passes radio-frequency voltage.

$R_1$  makes possible a correct negative grid voltage which reduces the grid current, saving power otherwise lost by dissipation.

$C_4$  and  $C_5$  by-pass radio-frequency currents across the secondary of  $T_1$ , the filament transformer.  $C_6$  is used when the negative supply line is above 1000 volts, to decrease the tendency of the key contacts to arc. The choke  $X$  is an impedance coil which is inserted to hold back the radio-frequency currents from the generator used as a source where they, of course, would cause damage.

### Components of Transmitting Circuits

Besides a suitable power supply, discussed in Chapter 7, and an antenna system described in Chapter 15, a radiotelegraph transmitter is made up chiefly of an oscillator, audio-frequency and radio-frequency amplifiers, and controls. In addition there is usually a frequency multiplier, a tank circuit, and protective devices.

**Tank Circuits.** The name "tank" has been given the tuned circuit connected between the cathode and plate of the radio-

frequency oscillator tube, probably because it stores electrical energy in its inductors and capacitors. Using a mechanical analogy, considering inductance as inertia and capacity as elasticity, as in Chapter 3, the tank circuit has a flywheel effect on the radio-frequency (r.f.) circuit, smoothing out the oscillating pulses of energy supplied by the tube and thereby producing a radio wave of purer form; specifically, harmonics are reduced. It is obvious that to accomplish this effect it must supply a proper impedance. It must not, however, consume too much of the power output of the tube.

The efficiency of a tank circuit is the output power of the tube delivered to the tank circuit divided into the power delivered by the tank circuit.

A filter network between the tank circuit and the antenna helps to suppress harmonics.

**Piezo-Electric Crystals.** By the term piezo-electricity is meant the electricity or electric polarity due to pressure, especially in a crystallized substance. It can be assumed that any crystalline body whose atomic structure is unsymmetrical and which has double refracting properties from an optical standpoint also possesses piezo-electric properties. Rochelle salts, tourmaline, and alpha quartz are the three most commonly known piezo-electric crystals. Beta quartz is not piezo-electrically active, being of symmetrical (hexagonal) atomic structure. Rochelle salts is too hard to handle under ordinary conditions to be of any practical value in radio apparatus. Tourmaline is too expensive. Alpha quartz, therefore, is the only one to be considered. This quartz is mined in the United States and several foreign countries. If it is free from structural and optical flaws it can be cut so that it will manifest excellent piezo-electric properties.

Such a crystal can be used to control the output of a vacuum tube oscillating circuit at one definite frequency and with maximum output. It furnishes the best means yet discovered for such control. For this reason, it becomes an important part of all tube transmitters containing this feature; such a transmitter can be set at a very precise frequency and held at that frequency in spite of voltage fluctuation and other disturbing factors for a period

of months without the necessity of calibrating the set with a frequency-meter.

The frequency of a crystal depends on its physical dimensions, being cut and ground as desired. These dimensions will be retained if the quartz is kept at a definite temperature. The method of cutting the quartz in the manufacture of radio crystals is based on the geometrical properties of the crystal. Besides the usual X and Y axes (geometrically speaking), there is an optical axis referred to as the Z axis. The X and Y axes are known as the electrical axes. As the crystal is hexagonal in shape, there are three X axes and three Y axes. Z axis is always at right angles or perpendicular to the electrical axes. The crystal is cut so that the sides are parallel to one of the Y axes and at right angles to one of the X axes. This is called a "Curie cut" or "zero angle cut." There are three normal frequencies to which the ordinary crystal of "Curie cut" will resonate. One frequency corresponds to the X dimension, one to the Y dimension, and the other, termed the coupling frequency, is between the X and Y frequency; it depends on the X and Y dimensions. There is a definite relationship between the dimensions in millimeters and the frequency in kilocycles. This ratio is well known to the cutter and grinder who works accordingly. If a crystal is ground down to one-half its original thickness, the original frequency will be thereby doubled. The crystal must be properly mounted, held, and housed. Various types of holders are in use, depending to a great degree on the conditions under which the transmitter functions. In order that the crystal may be kept free from moisture and dirt, it has been found best to seal it within a suitable container. It is necessary that capacities other than between the plates holding the crystal be kept as small as possible. These plates, between which the crystal is held, should have lapped surfaces and should maintain intimate contact with the crystal. The weight of the upper plate should be a minimum and free to move up and down. Brass pegs or a ring of bakelite can be used to prevent sideways motion of the crystal.

A change in temperature of  $10^{\circ}$  C. in the 4000 kc range will change the frequency as much as 1 kc. For this reason, a thermostatic heat control which will maintain the temperature of the

crystal at the constant temperature for which it has been cut, is advisable.

Briefly, it is extremely important that radio transmitters maintain constant frequency. At broadcast stations an operator is assigned to the duty of observing the frequency of the emitted wave, using a special control panel to compensate for any variation. This is called *monitoring*; the apparatus used to control both frequency and the degree of amplification is a *monitoring system*.

**Crystal-Controlled Oscillators.** Because of their general use in controlling the frequency of aviation radio transmitters, a knowledge of crystal-controlled oscillators is of considerable importance. Due to the fragile nature of crystals, especially those ground for high-frequency operation, and to the small amount of power they are capable of handling, it is general practice to use them in conjunction with oscillator tubes of relatively low power. Triodes, tetrodes, and pentodes can be used as crystal-controlled oscillators. In the case of a triode, such as the 801, the plate voltage should be reduced to about one-third of its normal value, to prevent overloading the crystal by excessive feedback and heavy r.f. currents. Pentodes, such as the 802, are especially suitable for crystal-oscillator service, causing relatively little loading of the crystal in properly designed circuits, even when operated at full plate voltage. They will deliver considerably more power output than triodes of similar size. In the case of tetrodes and pentodes, which have efficient screening between the control grid and the plate, it is usually necessary to introduce some external grid-plate capacitance in circuits where oscillation depends upon the feedback produced by this capacitance. The external feedback may be obtained by means of a small adjustable condenser (usually not larger than 2 or 3 mmfd.) connected between the grid terminal and the plate terminal. The extra capacitance should not be made larger than necessary, because an excessive value may cause sufficient feedback to overload and destroy a crystal.

An elementary crystal-oscillator circuit is shown in Figure 71. This uses a triode tube. In this simple circuit the tank circuit is

first tuned to a frequency slightly higher than the natural frequency for which the crystal has been cut. Under these conditions the feedback through the grid-plate capacity of the triode excites the grid circuit. The crystal then oscillates at approximately its natural frequency.

The power which can be obtained from a crystal-controlled oscillator will depend upon the tube, its plate voltage, and the amplitude of the r.f. voltage developed as the result of the (mechanical) vibrations of the crystal. The limit of plate voltage that can be used without endangering the crystal in the crys-

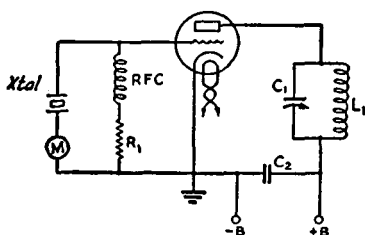


Figure 71. Elementary Crystal-Controlled Oscillator, Using Triode Tube

The tank condenser  $C_1$  would have a capacity of about 100 mmfd., the tank inductance  $L_1$  having a value such as to tune the circuit to about crystal frequency.  $C_2$  should be 0.001 mfd. or larger. If a high- $\mu$  tube is used, the grid leak  $R_1$  should have a resistance of from 2,500 to 10,000 ohms. With low- $\mu$  tubes  $R_1$  should be from 15,000 to 25,000 ohms. THE STUDENT CAN BUILD AN OSCILLATOR LIKE THIS.

tal oscillator shown in Figure 71 is about 255 volts when an X- and Y-cut crystal is used. In this circuit the r.f. crystal current can be measured by an r.f. galvanometer or low-range r.f. ammeter connected as shown at A. Assuming that this current is a maximum of 100 milliamperes, the power output would be about 5 watts.

A typical commercial type crystal oscillator is shown in Figure 72. Aside from the circuit arrangement, this oscillator is of interest because it uses a beam power tube (described on page 128), a type of tube especially designed to be used as an oscillator or a transmitting power amplifier. The most notable design feature is that the screen does not absorb appreciable power. Efficient suppressor action is supplied by space-charge effects produced

CHARACTERISTICS OF RCA-802 TUBE

Heater Volts (a.c. or d.c.).....	6.3
Heater Amperes .....	0.9
Transconductance (For plate current of 20 ma.) Micromhos....	2250
Grid-Plate Capacitance (With external shielding).....	0.15 max. $\mu\mu\text{f}$
Input Capacitance .....	12 $\mu\mu\text{f}$
Output Capacitance .....	8.5 $\mu\mu\text{f}$

AS R. F. POWER AMPLIFIER AND OSCILLATOR—CLASS C TELEGRAPHY

Key-down conditions per tube without modulation

	Pentode Connection	Tetrode Connection	
D.C. Plate Voltage.....	500 max.	500 max.	Volts
D.C. Supp. Volt. (Grid No. 3)	200 max.	—	Volts
D.C. Screen Voltage .....	250 max.	200 max.	Volts
D.C. Grid Volt. (Grid No. 1)	-200 max.	-200 max.	Volts
D.C. Plate Current.....	60 max.	60 max.	Milliamperes
D.C. Grid Current.....	7.5 max.	7.5 max.	Milliamperes
Plate Input .....	25 max.	25 max.	Watts
Suppressor Input .....	2 max.	—	Watts
Screen Input .....	6 max.	6 max.	Watts
Plate Dissipation .....	10 max.	10 max.	Watts

Typical Operation:

D.C. Plate Voltage.....	500	500	400	500	Volts
D.C. Suppressor Voltage...	0	40	—	—	Volts
D.C. Screen Voltage .....	200	250	100	100	Volts
D.C. Grid Voltage.....	-100	-100	-60	-60	Volts
Peak R.F. Grid Voltage...	155	155	90	90	Volts
Internal Shield .....	Connected to cathode at socket				
D.C. Plate Current.....	45	45	45	45	Milliamperes
D.C. Screen Current.....	22	12	15	15	Milliamperes
D.C. Grid Current (Approx.) .....	6	2	7	6	Milliamperes
Screen Resistor .....	13,600	20,800	20,000	27,000	Ohms
Grid Resistor .....	16,200	50,000	8,600	10,000	Ohms
Driving Power (Approx.)..	0.9	0.25	0.7	0.5	Watt
Power Output (Approx.)..	14	16	10	12	Watts

between the screen and the plate of the tube shown in Figure 72, an RCA-807. (This tube, 807, is used as a power amplifier in the RCA Transmitter AVT-7B, which uses an RCA-42 as an oscillator.)

The pentode tube 802 is often used as an oscillator and its characteristics and rating are given as an example of the infor-

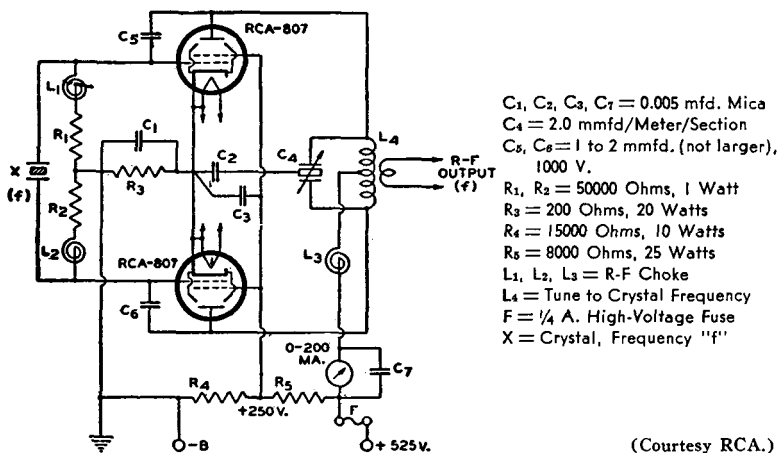


Figure 72. Push-Pull Crystal Oscillator; Power Output, about 30 Watts

mation available to manufacturers of transmitters. It is a heater cathode type. (See page 193.)

The suppressor and the special internal shield are connected to individual base pins. The 802 may be operated at maximum rated input at frequencies as high as 30 Mc.

**Transmitting Tubes.** There are so many power tubes for use in transmitters that proper selection can only be made after a number of design factors have been considered. In every case the tube selected for r.f. power amplification is important, as this is the tube which develops useful r.f. energy and supplies it to the radiating system. Therefore, in selecting power tubes for the final amplifier stages the following factors should be considered:

1. Power capability
2. Frequency capability
3. Design suitability
4. Costs

As to (1) the tubes used in the r.f. power amplifiers should be capable of delivering the desired power output when operated within the maximum ratios.

Regarding frequency capability (2), the final amplifier tube or tubes should be capable of operating at the desired radio-frequency with sufficient d.c. plate input so that with a practicable value of efficiency, the required output can be obtained.

Under (3) are included a large number of miscellaneous factors which the designer considers :

(a) The factor of *power supply* is important in the choice of tube types. For aircraft it may be necessary to use tubes which can be economically operated from a heavy-duty, low-voltage battery supply. At ground stations where a source of a.c. power is available, the problem of furnishing d.c. voltage is greatly simplified through the use of suitable rectifiers and filters as explained in Chapter 7.

(b) *Power sensitivity*. In those cases where the total number of stages in a transmitter must be kept to a minimum, tubes having a high power sensitivity should be employed. Power pentodes and beam power tubes, such as the 802 just discussed, require very little driving power compared to triodes of equivalent power output. For low-power frequency multipliers and intermediate amplifier stages, the 802 pentode and the 807 beam power amplifier are very useful.

(c) *Circuit flexibility*. Where a transmitter must be capable of operating on a number of widely different frequencies with a minimum of time required for changing frequencies, the use of tetrodes or pentodes (in preference to triodes) is indicated. Because tetrode and pentode amplifiers do not, in general, require neutralization, the problems that are sometimes encountered with neutralized triode amplifiers are avoided.

(d) The *size and shape* of the tube may be important in some transmitter designs because of space and weight requirements. The arrangement of the electrode terminals is sometimes of importance because it affects circuit wiring and the mounting of circuit components.

(e) It is frequently convenient to use certain tube *types together* because they can be operated from a common filament



supply or from a common plate-voltage source; or because they make practical certain other simplifications in design and maintenance.

In regard to costs (4), this factor includes not only initial tube cost but also the costs of auxiliary equipment, maintenance, and operation. An analysis of these costs will often indicate that it is desirable to modify the design to meet the requirements of a particular installation.

It is well to note at this time that in oscillator service for telegraphy, a tube is operated with an unmodulated d.c. plate voltage. The control grid is supplied with a negative bias voltage and is

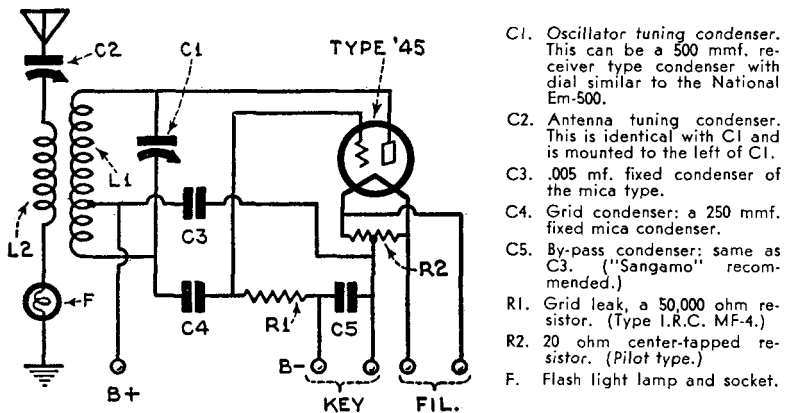


Figure 73. Simple Transmitting Circuit Showing Where Key Is Connected

excited by an unmodulated r.f. voltage. The screen of a tetrode or a pentode is supplied with a positive d.c. voltage. The suppressor of a pentode may be operated with a small positive d.c. voltage or it may be tied to the cathode and thus operated at zero potential. In the former case, the power output of a pentode is slightly increased.

Figure 74 shows a one-tube transmitter set used for sending practice only.

Characteristics of a few transmitting tubes are shown on pages 126 and 127 for reference. Most of these tubes are used in aviation transmitters. The advanced student is advised to se-

cure additional data from tube manufacturers. R.C.A. Manufacturing Co. publishes tube manuals which can be studied with profit by operators.

**Frequency Multipliers.** Because the plate-current waves of a Class C amplifier contain a relatively high percentage of harmonics,<sup>117</sup> an amplifier of this type can readily be employed to double or triple the frequency of the r.f. exciting voltage. The harmonic output can be increased by using a bias voltage higher than for Class C amplifier service. It is common practice to employ a low-frequency crystal oscillator, whose frequency has a sub-multiple relation to the desired operating frequency, in conjunction with one or more Class C frequency multipliers. A 3500 kc crystal oscillator can be used with several frequency doublers to provide an r.f. voltage having a frequency of 7000 kc, 14,000 kc, 28,000 kc, etc. The plate circuit of a frequency multiplier is tuned to the frequency of the harmonic which is to be amplified. Triodes, tetrodes, and pentodes can be used in this class of service. Pentodes as frequency multipliers generally provide more output for a given input than triodes or tetrodes; high- $\mu$  triodes are somewhat better than low- $\mu$  triodes.

### Radio Telegraph Transmitter Circuits

The purpose of any transmitter, whether radiotelegraph or radiotelephone, is to produce, from power supplied to it, radio waves, and to radiate these waves. This can be accomplished by using a single tube, the waves emitted being of the CW type. When keyed, it is a radiotelegraph transmitter; if the carrier wave is modulated by having impressed upon it another voltage, a radiotelephone transmitter is created and a microphone wired instead of the key.

**A One-Tube Amateur Transmitter.** For the experimenter who wishes to build a simple, inexpensive one-tube radiotelegraph transmitter, the circuit \* shown in Figure 73 is recommended for operation on amateur band-A frequency (1715–2000 kc).

\* This circuit is taken from "How To Become An Amateur Radio Operator," wherein Lieut. Eddy explains how to build the set.

**The Master-Oscillator Power-Amplifier Circuit.** A tube transmitter having the oscillation generating circuit directly connected to the antenna system, as in the case of the Meissner circuit, will radiate both the fundamental wave and harmonics of the fundamental wave. The fundamental wave will be propagated on the frequency as established. The harmonics will be propagated on some multiple of this wavelength and will cause objectionable interference that should not be tolerated. Radiation of harmonics is greatly suppressed when the master-oscillator

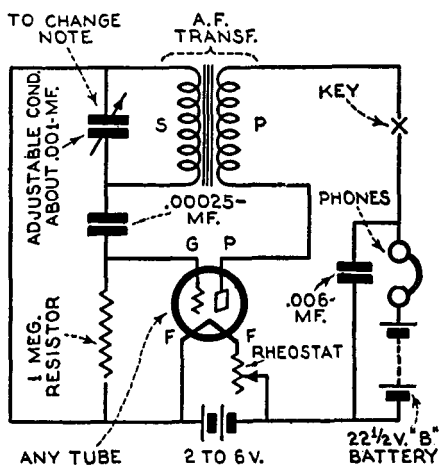


Figure 74. Simple Code Practice Circuit

A pair of phones are used, together with an a.f. transformer, a vacuum tube, batteries and condensers, and a key, all arranged in the simple manner shown.

power-amplifier circuit is used; a constant frequency is also assured.

Figure 75 is a simplified diagram of this type circuit. The oscillation-generating circuit is enclosed by dotted lines. Compare this oscillation-generating circuit with the Meissner circuit (Figure 68, page 184), noting the great similarity. It will be seen that the antenna system of the Meissner circuit is replaced by a condenser,  $C_4$ , in the master-oscillator circuit. This is of small capacity, although shunted around a rather large inductance,  $L_3$ . Condenser  $C_5$  couples the oscillation-generating circuit to an

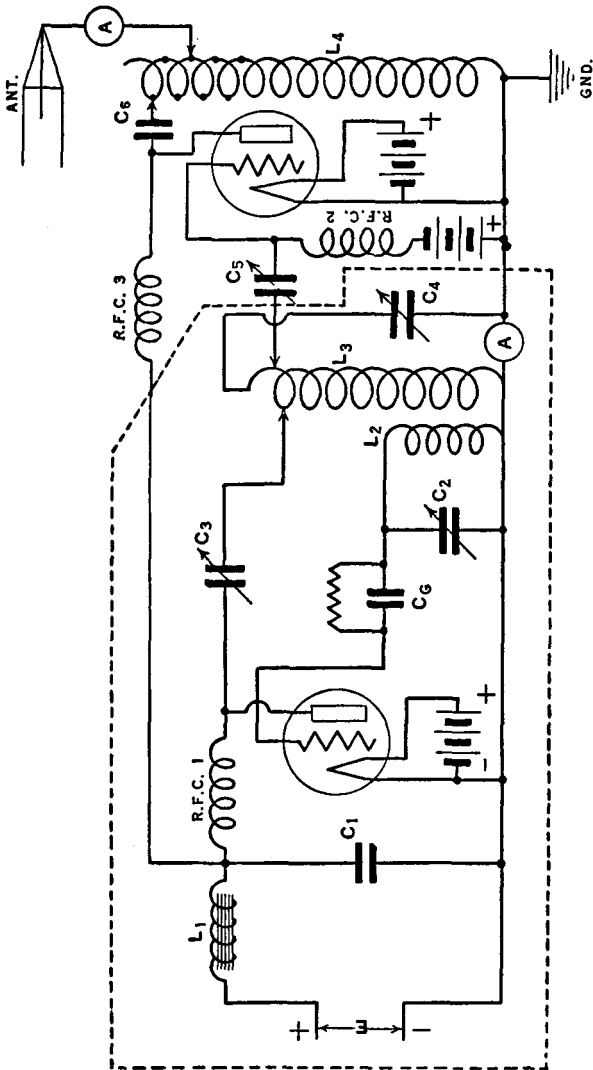


Figure 75. Master-Oscillator Power-Amplifier Circuit

amplifier. (The coupling could be accomplished by a coil instead, and a coil will be found in some transmitters of this type at this point in the circuit.) The output of the oscillation-generation circuit transferred to the amplifier is amplified as to the currents of the fundamental frequency, but little or no amplification of the harmonics occurs. This is because the oscillation-generation circuit is a "stiff circuit" (one having a large inductance-to-capacity ratio, as stated above, for  $L_3$  and  $C_4$ ) and because the antenna, or output circuit, of the amplifier is tuned to the fundamental frequency of the oscillation-generation circuit. The inductance-capacity portion, or "tunable" portion, of the oscillation-generation circuit is often called a "tank" circuit (page 188).

The "chokes" (r.f.c.) are inductance coils of the honeycomb, pancake, or banked-winding type. These absorb all damaging surges of radio-frequency currents. They have a very small distributed capacity. The natural period (fundamental wavelength) of each choke is the same as the specified working wavelength of the transmitter. When coupling by capacity, as in this circuit, it is essential to use a negative potential on the grid. This reduces the amplifier tube plate current to one-half the rated current capacity when no radio-frequency controlling voltage is being received from the oscillation-generating circuit. This makes for greater efficiency in the amplifier. To place this negative potential on the grid, and at the same time prevent the short-circuiting of radio-frequency currents through the battery, the inductance coils shown are required as chokes.

**Operation of Master-Oscillator Power-Amplifier Transmitter.** In the transmitter set, the oscillation-generating circuit is referred to as the master oscillator. In operating this set, it is first adjusted to the working frequency by using a frequency meter and varying  $C_2$  and  $C_4$ . The plate coupling of the generator is then changed turn by turn, until ammeter A reads maximum. This indicates maximum output from the master oscillator. By next adjusting  $C_3$  and  $L_3$  correctly, maximum voltage will be transferred to the grid of the amplifier tube. Maximum antenna current will then result when proper adjustment of  $L_4$  is made. During this process of tuning each circuit in sequence, the wave-

length may change slightly. If this occurs, it will be indicated on the frequency-meter. In this case,  $C_4$  and  $L_4$  must be readjusted until the meter indicates the correct frequency. If this readjustment causes a decrease of antenna current,  $C_2$  must be varied and the plate coupling changed until maximum antenna current is again obtained.

An important thing to know about the master oscillator is that, when its frequency is set, the swinging of the antenna does not change the length of the radiated wave. This is a highly desirable characteristic when the use of the trailing-wire antenna is contemplated. The master oscillator maintains the wave at a fixed value; the amplifier merely amplifies the output of the master oscillator, thereby increasing the power supplied to the antenna.

Porcelain, and kiln-dried wood which has been boiled in paraffin, are preferred for use as insulating material in the master-oscillator circuit. There is less fire risk involved if porcelain is used. These materials have low dielectric losses.

No metal fasteners should be used in this circuit, which ought to be clear of all closed metallic loops. The capacity effect of nearby leads should be kept to a minimum by supporting high-voltage leads at a maximum distance from the bonded part of the plane; otherwise losses will occur.

If the plate of the master-oscillator tube shows by its color that it is overheating, it indicates that the grid coupling is incorrect and the number of turns in the plate circuit should be varied until normal coloring is obtained. If overheating cannot be stopped in this manner, the amount of capacity in the grid-tuning condenser should be changed. If these changes do not reduce the heating of the plate, the antenna should be inspected for grounds or an open circuit.

Purity and constancy of the emitted wave are assured in the use of a master-oscillator power-amplifier transmitter.

**Transmitter with Harmonic Generator.** By taking advantage of the fact that the pulses of plate current have appreciable harmonic content, a Class C amplifier can be used to generate output power that is a harmonic of the signal voltage applied to the control grid. It is merely necessary to tune the tank circuit to the

desired harmonic and adjust the length of the plate-current pulse to a value that is favorable for generating the harmonic involved. Neutralization is unnecessary, since the grid and plate circuits are tuned to widely different frequencies. Harmonic generators of this character are frequently used in radio transmitters and for other communication purposes.

Most modern short-wave radiotelegraph transmitters are ordinarily designed around some form of oscillator having high-frequency stability. Crystal oscillators are usually employed, although master-oscillator power-amplifier arrangements, as well

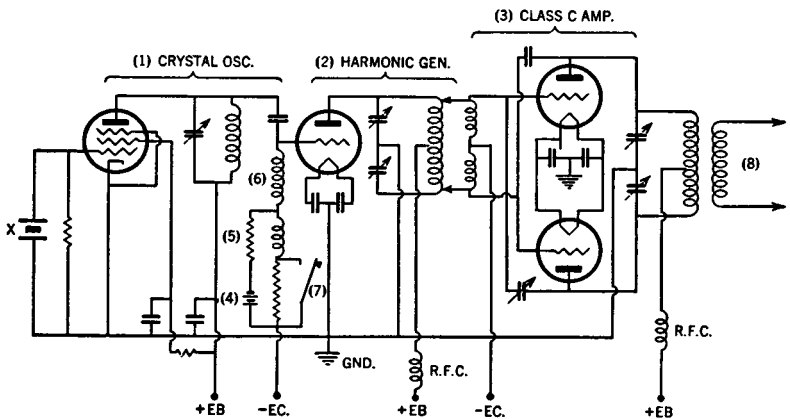


Figure 76. Transmitter with Harmonic Generator

X, crystal; (1) crystal oscillator; (2) harmonic generator; (3) Class C amplifier; (4) keying battery; (5) lag circuit; (6) R.F. choke; (7) key; (8) to antenna.

as electron-coupled and resonant-line oscillators, are used to a limited extent.

When a quartz crystal is used to control the frequency, the oscillator power output obtainable under commercial conditions is only a few watts, and the highest practical crystal frequency is of the order of 5 Mc. To obtain greater power, Class C amplifiers are required and higher frequencies necessitate the use of harmonic generators. The circuit of a simple crystal-controlled short-wave transmitter is illustrated in Figure 76. Here the crystal oscillator is followed by a harmonic generator that drives a push-pull Class C amplifier. This represents a typical amateur

design for a transmitter developing an output of from 50 to 200 watts of power.

### Keying Transmitters

When the operator sends (keys), using a master-oscillator power-amplifier transmitter such as shown in Figure 75, both the master oscillator and power amplifier are cut on and off by the action of the key, which is that of a single-pole switch.

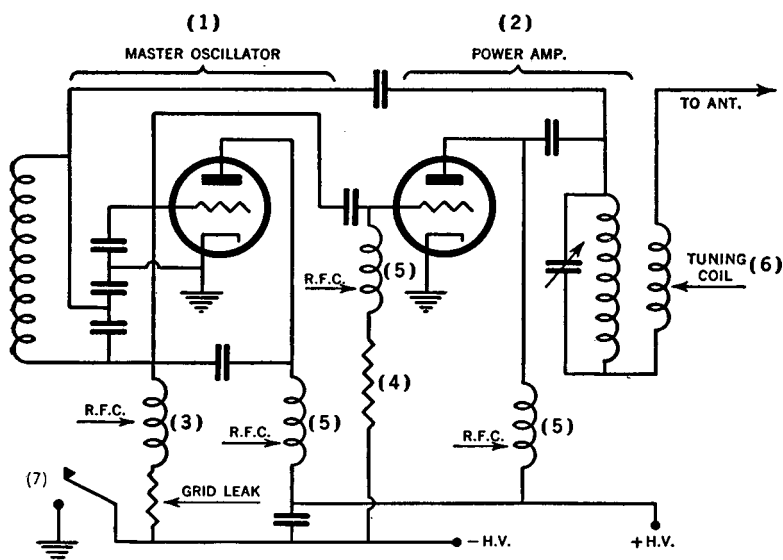


Figure 77. Parts of Master-Oscillator, Power-Amplifier, Transmitter Circuit

(1) Master oscillator; (2) power amplifier; (3) r.f. choke; (4) grid leak; (5) r.f. choke; (6) tuning coil; (7) key.

The output of a crystal-controlled type radiotelegraph transmitter is controlled by the key in one of the stages following the crystal oscillator, the oscillator being allowed to oscillate continuously. This method of keying improves frequency stability—one of the advantages of a crystal-controlled transmitter.

In Figure 76 the harmonic generator is made inoperative because a large negative bias is applied to the grid when the key is in the open position.



In Figure 77 the key opens the plate leads and also the grid return leads to the cathode.

In some circuits the key is placed between the center-tap cathode connection and the ground; in other transmitters the plate supply system is opened and closed by the key, either in the primary of the power transformer or in the output of the filter system.

The object of every operator handling a key is to send out clean-cut dots and dashes which have a constant carrier frequency and which produce a minimum of interference. Sometimes listeners in nearby receivers complain of hearing "key clicks" as the key makes and breaks contact. These are caused by high-order side-band frequencies produced by the sudden starting and stopping of oscillations. A "time delay" or "lag circuit" (shown in Figure 76) remedies this keying fault. Shielded circuits also help to suppress high-order side-bands.

Another so-called keying trouble occurs when the transmitter goes off frequency. "Transient" waves in the power supply system of the transmitter sometimes cause distortion of the dots and dashes made by the operator's key. Such frequency shifts are the result of insufficient isolation of the oscillator from those amplifier stages which carry keyed currents. Such frequency "drift" (or "phase shift") often occurs in master-oscillator power-amplifier transmitters as the set becomes heated.

(WARNING: Until you have learned to manipulate a key correctly, do not blame equipment for the poor transmission caused by sloppy sending.)

### Aerovoice Transmitters

Aerovoice aircraft transmitters are manufactured by AERO-VOICE, INC., Islip, New York, and supplied in two models: D-30 and D-40. The D-30 weighs  $18\frac{1}{4}$  lb. complete and takes 15 amperes; the D-40 weighs  $22\frac{1}{4}$  lb. and takes 19 amperes. The size of each transmitter is  $8\frac{1}{2}$  by 7 by  $4\frac{1}{2}$  inches; the weight of each transmitter is  $6\frac{1}{4}$  lb., which makes installation aboard light planes an easy matter. (Size, weight, and cost of radio equipment are important considerations to the private pilot.)

Although designed to furnish phone type of emission, they are particularly interesting as examples of transmitters where the operator changes from phone to radiotelegraph transmission by merely pulling the microphone out of its jack and inserting the sending key which is connected to a cable that also carries a jack plug. To send on MCW the operator throws a double-pole double-throw toggle switch. Keying is accomplished from an electrical point of view by opening the cathodes of both oscillator and amplifier. A relay is used in conjunction with this keying circuit. This relay also permits the transmitting antenna to be used for receiving. A fixed trailing-wire antenna is used.

The two models have similar circuits. In each set a 6L6 metal tube is used as an oscillator, connected in a stabilized crystal circuit. In the D-30 the output of the oscillator drives an RK25, a screen-grid transmitting tube, which is the power amplifier. This tube not only operates as a straight amplifier on 3105 and 3120 kc, but also operates as a doubler for 6210 and 6240 kc. Approximately 80% of the transmitter output is obtained on 3105 and 3120 kc. The average modulated output of the D-30 is 27 watts.

The D-40 uses the same oscillator tube but it drives an RK39. Its average modulated output is 36 watts, the carrier wattage being estimated at 29.

One hundred percent high-level modulation is obtained. Two 6L6 tubes act as modulators, supplying the necessary audio power to modulate the plate and screen of the power amplifier. Two separate AT-cut low-temperature-coefficient crystals are a part of the circuit. One is ground for a fundamental of 3105 kc; the other for 3120 kc.

A high-gain anti-noise type microphone is used. This feeds directly to the grids of the 6L6 tubes, a specially designed microphone input transformer being used in this circuit.

Both models operate from a dynamotor which is equipped with a filtering system. The filter compartment contains a relay operated from the transmitter panel which shuts the dynamotor off while the set is in a "stand-by" condition. Connections between the dynamotor and the transmitter are made by the use of removable cables with plug-connector ends.

### The TBK Transmitter

The TBK transmitter, designed by the Bureau of Air Commerce (now C.A.A.), manufactured by the Western Electric Company, and installed at many government ground stations along the civil airways, is an ideal type to study. Three methods of transmission are employed in this set :

1. CW radiotelegraphy
2. ICW radiotelegraphy
3. Radiotelephony

It is used for three purposes :

1. Point-to-point communication
2. As a radio range beacon transmitter
3. To broadcast weather by radiotelephone

The entire transmitting equipment is remote-controlled, generally from an airport.

The radio-frequency unit contains a crystal and two buffer stages, two radio-frequency intermediate power-amplifier (I.P.A.) stages and a radio-frequency power-amplifier (P.A.) stage. The crystal and the two buffer stages include six quartz plates, an oscillator, two buffer amplifiers, a self-contained power supply, and means for maintaining the quartz plates at a constant temperature. A voltage regulator on the a.c. supply line to the rectifier power unit insures constant output voltages from the power unit. The crystal unit is used for transmitting on six pre-determined frequencies in the 190-350 kc band.

As there are no means for crystal control of the transmitter above 350 kc, the first I.P.A. stage is converted for master-oscillator operation when used at higher frequencies. (Refer to Figure 78.) The crystal unit is taken out of the circuit as shown in this Figure by closing switch 34 which transfers the circuit from the 6-volt supply to the field coil of relay 20. This relay in turn connects the grid of the first I.P.A. from the output of the second buffer amplifier to the junction of condenser 6C and variometer 42A located in the plate circuit of the first I.P.A. This procedure converts this stage into a Colpitts oscillator circuit.

The buffer amplifiers serve to supply sufficient excitation to the first I.P.A. stage without permitting reaction on the crystal circuit. The buffer amplifiers are operated as Class A, while the I.P.A. and P.A. stages are Class C. The plate circuits of the crystal oscillator and first buffer amplifier are untuned. Plate variometer tuning is provided for the second buffer amplifier, the I.P.A. stages and the P.A. stage. Wave-change switch 36A, with five taps, serves to adjust the total inductance in the plate circuit of the P.A.

Used with the directional antennas required in radio range beacon transmission, the output terminals X-X feed directly into a goniometer (explained in Chapter 9). If a conventional open-type antenna is used, a variometer (43) and wave-change switch (36B) are provided for antenna tuning to an open-type antenna for ordinary transmission.

Plate and screen-grid power for the power-amplifying stages is furnished by a modulator-rectifier unit. The first I.P.A. stage is self-biasing by means of resistor 23A, while rectifier unit 33 supplies a 110-volt bias to the second I.P.A. and P.A. stages. To understand the manner in which the radio-frequency unit is keyed for use in continuous-wave radiotelegraphy or in radio range beacon transmission, it is necessary to study in detail the d.c. plate and screen-grid return circuits for the power-amplifying stages. Starting from center taps 4, 7, and 10 of the filament transformer secondary windings, the plate currents flow through the individual plate meters 18A, 18B, and 19, and thence jointly through keying choke-coil 3, and through the contacts of relay 21 (if the relay is closed) to the ground lead (which is also the negative terminal of the high-voltage supply). The d.c. path is then through the high-voltage supply to the respective plates and screen grids of the tubes.

Note that the 1500-volt supply to the I.P.A. stages (terminal 29) also connects to a voltage divider made up of five 10,000-ohm resistors in series (30A, 30B, 30C, 30D, and 30E). With the contacts of relay 21 closed, one of these, 30E, is short-circuited (shunted) by choke 3. The field coil of relay 21 is excited from the 6-volt d.c. supply only when transmitter test key 35 or the main key (connected in parallel) is closed. With both keys open,

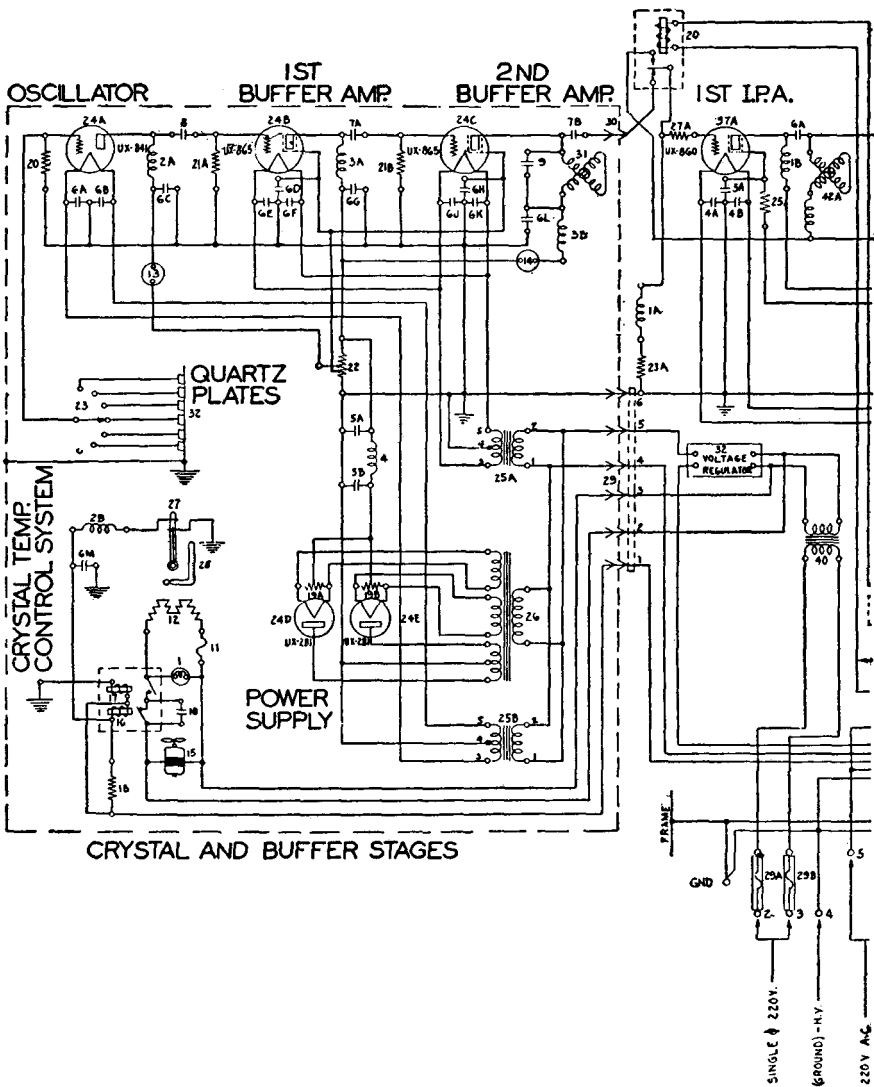
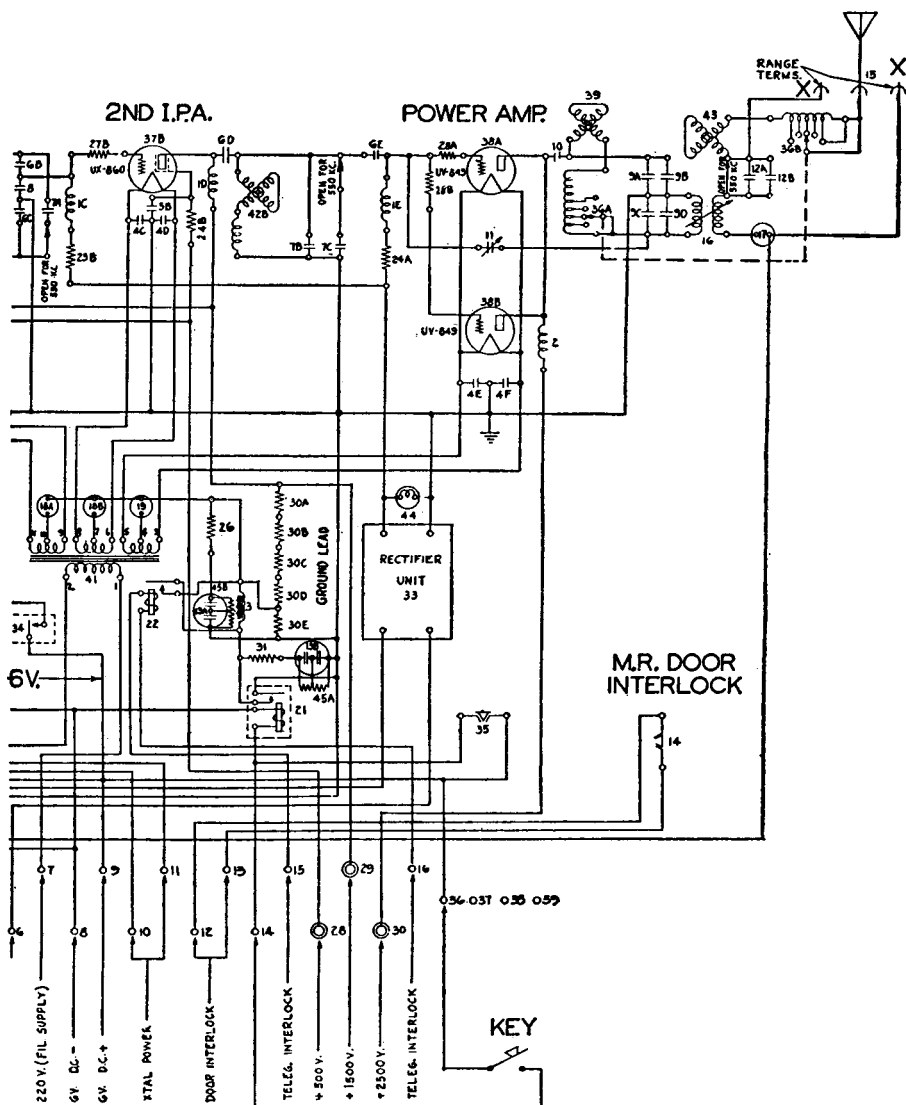


Figure 78. Circuit of Radio Frequency Unit and Crystal Box of the Department C.A.A. as a Phone Station for Weather Broadcasts and



of Commerce Type TBK Radiotelephone and Telegraph Transmitter, Used by the as an I.C.W. Transmitter for the Aural Range Beacon

relay 21 opens and the short on resistor 30E is removed. The d.c. path is then from the ammeters through resistor 30E to the ground lead and then through the high-voltage supply to the various tube plates and screen grids. But note that one-fifth of the 1500-volt high-voltage supply, or 300 volts, appears across resistor 30E; this places the filaments of the power-amplifying tubes 300 volts positive with respect to the ground and hence with respect to their grids, and the grids become highly negative. At the same time, the plate and screen grid supply voltages to the I.P.A. stages are reduced by 300 volts. The combination of high negative bias and reduced plate voltage prevents the amplifiers from passing any of the radio-frequency energy received from the last buffer amplifier. The transmitter is thus keyed.

Certain auxiliary parts in the keying circuit require explanation. Resistor-condenser combination 26, 45B, and 13A prevents high voltage surges from breaking down the insulation used in mounting resistor 30E when the short is removed, while resistor-condenser combination 31, 45A, and 13B serves to prevent arcing across the relay contacts. When the transmitter is used for the I.C.W. or phone operation, keying choke-coil 3 is automatically short-circuited by relay 22 to prevent wave-form distortion in the modulated output of the transmitter. The operation of this relay and the manner in which the transmitter is modulated will now be taken up, in connection with a study of the modulator-rectifier unit.

**Modulator-Rectifier Unit.** This unit contains the power supply, audio-amplifying system and auxiliary control circuits for the transmitter. (See Figure 79.) A voltage-regulator provides constant voltage, three-phase, 220 volt, 50 to 60 cycle a.c. power to a three-phase step-up transformer—unit 54, at the upper right in this figure. The output of this transformer is rectified by means of six mercury-vapor rectifier tubes, then properly filtered and fed to a voltage divider from which the various plate and screen-grid voltages of the transmitter are taken. The positive lead of each high-voltage supply is filtered by a choke-coil-condenser combination; in each case two condensers are in series, with resistors in parallel to distribute the voltage equally.

The audio input circuit (fed from terminals 34 and 35) is designed to operate from a 500–600 ohm line. A suitable transformer (51) couples the line to the speech input stage, which is operated as a Class A speech amplifier. The audio-frequency voltage applied to the primary of speech input transformer 51 is controlled by a constant impedance, continuously variable volume control (62).

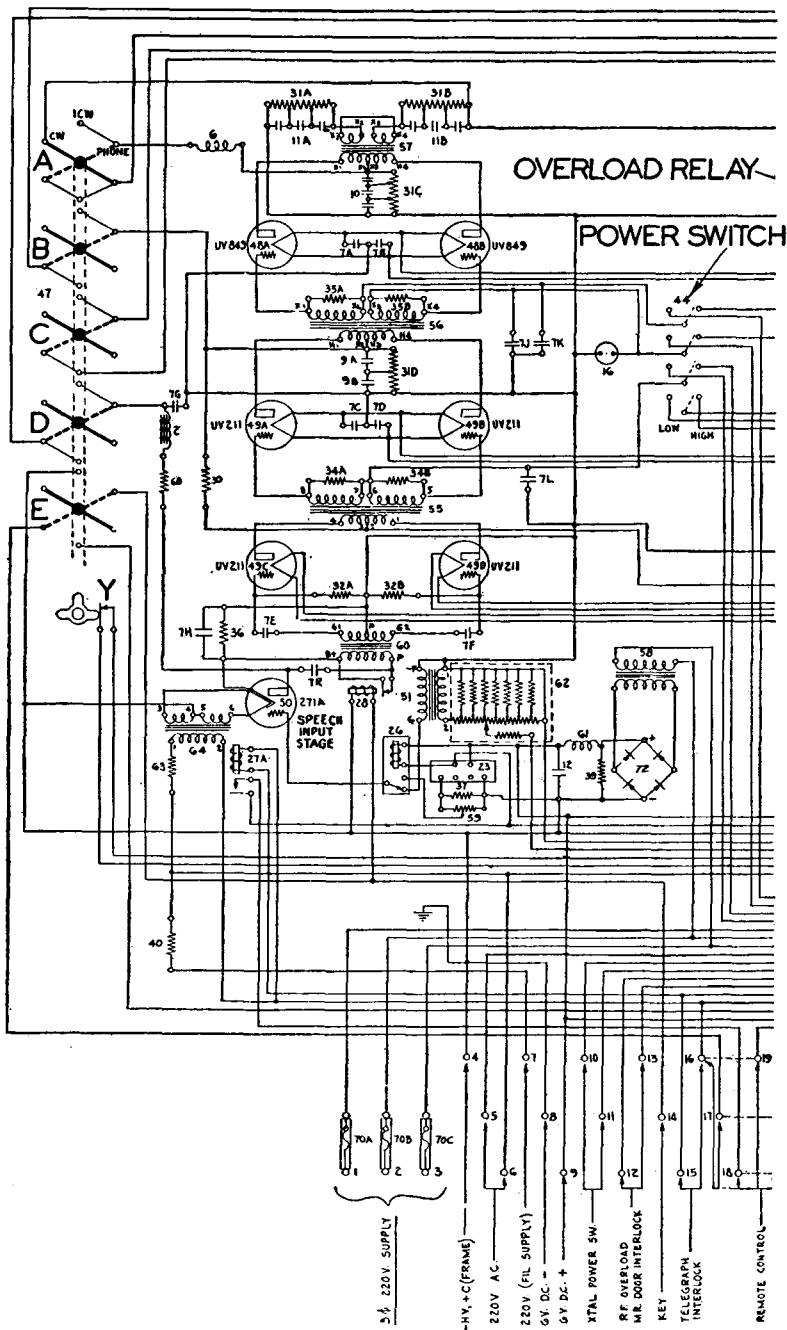
The speech input stage feeds a push-pull Class A stage using two tubes, and these in turn feed a second push-pull stage using the same tubes operated as Class B amplifiers. The output of the latter stage is then fed into a final push-pull stage containing a pair of tubes operated as Class B amplifiers. The final stage feeds into output transformer 57, which connects through combinations of condensers and resistors across modulation choke 1. This choke-coil is inserted in the plus lead from the 2500-volt high-voltage supply (coming from terminal 30). The audio output is thus superimposed upon the d.c. plate supply to the r.f. power amplifier, giving plate modulation of the r.f. transmitter output.

The interlock switch, shown at the left in Figure 79, serves to select the type of transmission employed. This switch has five contact blades (A, B, C, D, E) which may be thrown to the left, as shown, for CW transmission, up for ICW transmission, or to the right for phone transmission. This interlock switch controls the power to the modulation system and to the relays which perform certain necessary functions for the particular type of transmission selected. When in the CW position, blade A serves to route the 2500-volt lead from the high-voltage supply directly to the r.f. power amplifier. The remaining blades are open so that the modulation equipment is not in operation.

When in the phone position (with blades in positions indicated by dotted lines), blade A applies 2500 volts to the plates of the output stage of the audio amplifier; blade B applies 1500 volts to the plate circuits of the first and second push-pull stages; blade D applies a reduced voltage (obtained from voltage divider 38) to the plate of the speech input amplifier. The closing of blade C applies single-phase, 220-volt power (obtained from points 1 and 2 just above the relay 21) across the primary of



INTERLOCK SWITCH



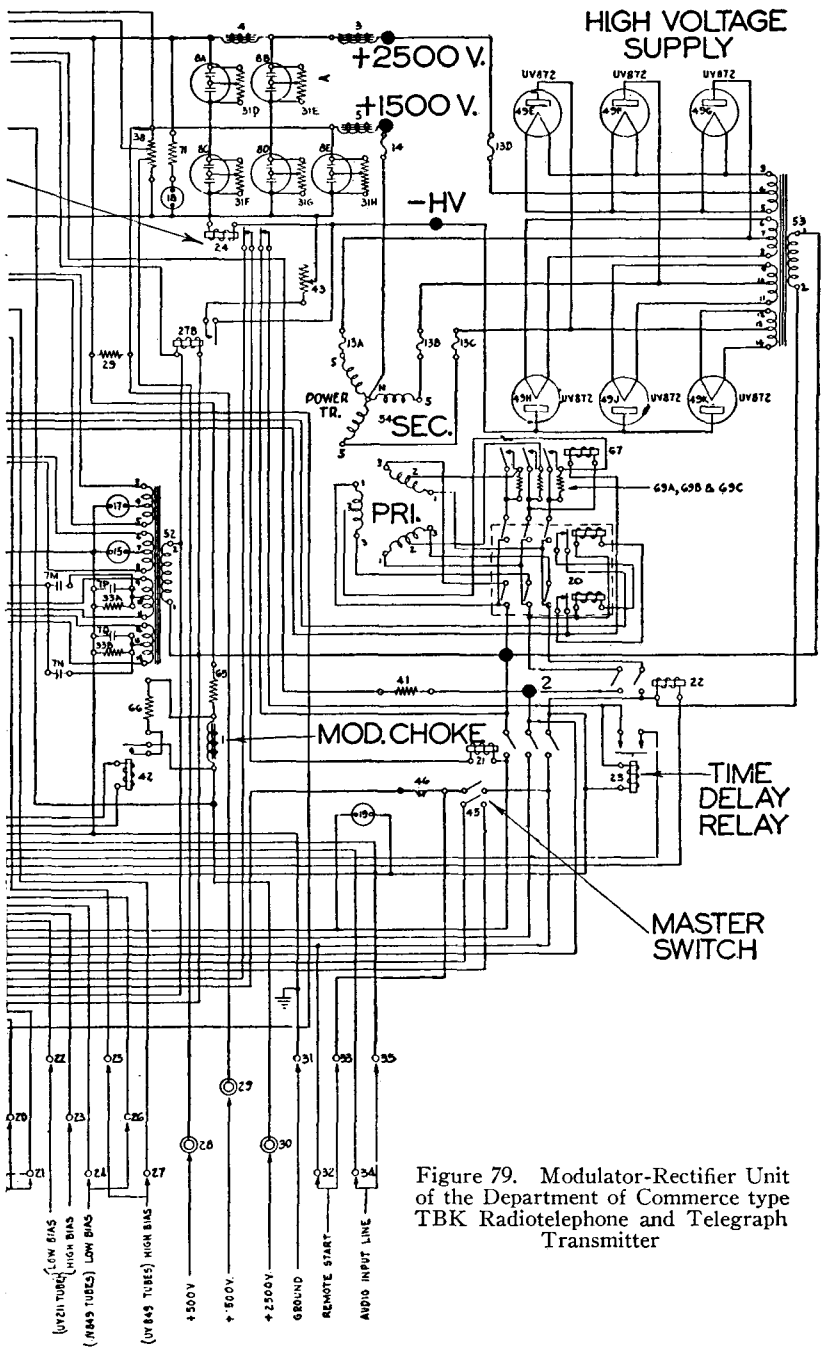


Figure 79. Modulator-Rectifier Unit of the Department of Commerce type TBK Radiotelephone and Telegraph Transmitter

filament transformer 52, across the field coils of relays 27A and 27B in the modulator-rectifier unit, and across relay 22 in the r.f. unit through telegraph interlock terminals 15 and 16. The closing of relay 27B places rheostat 43 across the field coil of overload relay 24, to prevent this relay from operating when the heavier current required for phone transmission is drawn from the rectifier. The contacts of relay 27A are in a control circuit which will be explained in connection with ICW operation of the transmitter.

When the interlock switch is in the ICW position, blades A, B, C, and D perform exactly the same operation as in the phone position. Blade E completes a circuit through the contacts of relay 27A (and also through terminals 18 and 21) to make copper-oxide rectifier 72 apply 6 volts d.c. to the input terminals of tuning fork 23 (a 1020-cycle tone oscillator) and to the field coils of relays 26 and 42. Relay 26 serves to connect the output of the tone oscillator to the input of the first speech amplifier, and disconnects the audio input line from this circuit. Relay 42 connects a 50,000-ohm resistor (66) across modulation choke 1 to prevent surges in this choke during keying. As a further precaution against surges in the ICW position, relay 28 (the field coil of which is connected in parallel with the field coil of the main keying relay) short-circuits the output of the first speech amplifier during each instant that the key is opened (i.e., when the r.f. unit is nonoperative). Contacts Y, as operated by a cam on the shaft of the interlock switch, open relay 22 while the interlock switch is being changed from one position to another, thus cutting off power to the high-voltage supply during switching operations.

Remote control of the transmitter is obtained by removing the three connector straps between terminals 16 and 19, 17 and 20, and 18 and 21 in Figure 78. The necessary operations for starting the transmitter, selecting the type of antennas, etc., are all carried out from the operator's position at the airport by means of a single leased telephone line. A special control system connected to the line is employed which permits the carrying out of many operations (previously set up) simply by dialing an automatic selector.

### Circuits to Study

The following circuits, Figures 80 to 91, should be studied as to construction, purpose, and function. They will be referred to both in the latter part of this book and in manufacturers' descriptions of airplane transmitters.

A Hartley circuit is shown in Figure 80. The battery A heats the filament of the tube, causing it to emit electrons. Battery B puts the plate at a positive potential with respect to the filament and electrons are drawn to the plate. Any minute disturbance in the circuit will cause a change of potential between the grid and plate, resulting in an instantaneous change in the electron stream to the plate. Because of the high reactance of the choke-coil, RFC, the change in plate current does not appear in the B-battery circuit but causes a potential to develop between the plate and filament through the condenser  $C_2$  and the part of the coil L included between  $C_2$  and the filament tap. Since this part of L is magnetically coupled to the part between the filament tap and the grid condenser,  $C_3$ , there is an induced potential between the grid and filament. This potential acts in a way to increase the change in plate current. The process continues, being reinforced by the amplifying properties of the tube, and when the power transferred to the grid circuit from the plate circuit is great enough to overcome the grid-circuit losses, a state of continuous oscillation is reached. The frequency of oscillation is determined by the constants of L and  $C_1$  to a very close approximation. (The purpose of the grid condenser,  $C_3$ , and grid leak, R, is to keep the average potential of the grid negative with respect to the filament. When the instantaneous grid potential is positive, electrons are attracted to the grid and current flows in the grid-filament circuit.

This current is unidirectional and cannot flow through  $C_3$  but is made to flow through R, and the voltage drop resulting is utilized as grid bias.  $C_3$  offers practically no impedance to the flow of r.f. currents. The direction of grid-current flow is such that the grid becomes negative with respect to the filament.)

A push-pull tuned-grid tuned-plate circuit is shown in Figure 81. As in the preceding explanation, the filament battery heats the

filaments of the tubes and causes electron emission; the "B" battery puts a positive potential on the tube plates and attracts electrons, causing plate current to flow. The circuits  $L_1C_1$  and  $L_2C_2$  are tuned approximately to the same frequency. Any slight disturbance in the grid circuit will cause the potentials of the grids to change with respect to the filament; since the grids are connected to opposite ends of the tuned circuit  $L_1C_1$ , a potential which causes the plate current  $V_1$  to increase will cause the plate current of  $V_2$  to decrease. These changes in plate current cause a potential to develop across the circuit  $L_2C_2$ ; the potentials developed by each tube separately add together across the circuit because of the push-pull connection. The change in instantaneous plate potential is larger than the originating potential in the grid circuit because of the amplifying properties of the tubes. Because of the electrostatic capacity existing between the grid and plate of each tube, the change in plate potential causes a change in grid potential which is in such a direction as to reinforce the original change in grid potential; the amplifying process is repeated and when the power returned to the grid circuit from the plate circuit is sufficient to overcome the grid losses a continuous oscillation ensues. The frequency of oscillation is determined by the constants of  $L_1C_1$  and  $L_2C_2$ . The purpose and operation of the grid leak,  $R$ , and condenser,  $C_3$ , are the same as described in the discussion of Figure 80. Condenser  $C_4$  is a radio-frequency by-pass condenser, across the source of plate power supply.

A representative antenna feed circuit is shown in Figure 82. The antenna or feeder system is inductively coupled to the transmitter tank circuit,  $L_1C_1$ , by the coupling coil,  $L_2$ . The radio-frequency current flowing in  $L_1C_1$  causes magnetic lines of force to be set up above  $L_1$ ; these lines are intercepted by  $L_2$ , causing a voltage to be induced in  $L_2$  which in turn causes current to flow in the antenna system. The condensers  $C_2$  and  $C_3$  are used to tune the antenna or feeder system to resonance with  $L_1C_1$ .

An oscillator circuit using series plate feed is shown in Figure 83. In series feed, the plate power is introduced in series with the radio-frequency circuit, and the direct plate current therefore flows through the tank inductance coil. The condenser,  $C_4$ , by-passes the r.f. across the power supply.

An oscillator circuit using shunt plate feed is shown in Figure 80. In shunt feed the plate power is introduced in parallel to the radio-frequency circuit. To prevent short-circuiting the r.f. voltage developed across the tank circuit, a radio-frequency choke-coil, RFC, must be connected between the power supply and the oscillator. The radio-frequency plate current of the tube flows to the tank circuit through the blocking condenser,  $C_2$ , which prevents short-circuiting the d.c. plate supply voltage through the tank coil,  $L$ , and the filament tap.

The circuit of Figure 84 shows a grid-return connection to center tap of filament transformer. Since filament-heating power is supplied by alternating current, an alternating potential appears across the terminals of the filament transformer winding. If the grid return is connected to one side of the winding, the alternating potential will cause the plate current of the tube to vary at the power-line supply frequency and will introduce modulation on the output of the oscillator. When the grid return is connected to the center of the winding, however, the instantaneous potential on one side of the center-tap is balanced by an opposite potential on the other side, hence there is no variation in grid potential and the filament-heating source introduces no modulation. The by-pass condensers,  $C_1$  and  $C_2$ , provide a low-impedance path for r.f. currents flowing to the filament.

In the circuit shown in Figure 85, a resistor,  $R$ , having an ohmic value sufficient to limit the current flow through it to a reasonable value, and tapped at its midpoint, is connected across the filament circuit. The grid return is made to the midpoint of the resistor. The voltages across the two halves of the resistor are equal and opposite, therefore the resistor performs the same function as the center-tapped transformer winding described in discussing Figure 84. The by-pass condensers serve the same purpose.

In the circuit shown in Figure 80, a grid-leak bias is employed. The operation is as follows: During the part of the radio-frequency cycle when the grid voltage is positive with respect to the filament, electrons are attracted to the grid, causing a flow of current. This d.c. current cannot flow in the external grid-filament circuit through the grid condenser,  $C_3$ , because the condenser

will not pass direct current. Therefore, the current must flow through the grid-leak resistor  $R$ . As a result of the current flow, a d.c. voltage is impressed across the terminals of  $R$ , the value of which is equal to the product of the resistance of  $R$  in ohms by the grid current in amperes. The direction of current flow is such that the grid assumes a negative potential or bias with respect to the filament.

In the diagram shown in Figure 86, the voltmeter,  $V$ , reads the actual voltage at the plate-supply terminals of the oscillator while the milliammeter,  $M$ , reads the plate current in milliamperes. The plate power input is then the product of the plate voltage multiplied by the reading of  $M$  divided by 1000. The milliammeter must be placed as shown and not between the plate power supply and the voltmeter because in the latter case the milliammeter would read the current taken by the voltmeter as well as that taken by the tube, consequently the calculated power would be greater than the true value.

In the diagram shown in Figure 87, the iron-core choke-coil,  $L$ , is placed in series with the key that breaks the plate current to the oscillator tube. Because of its self-inductance,  $L$  opposes any sudden change of current in the circuit; therefore when the key is closed the plate current does not reach its full value instantly, but rises at a comparatively slow rate. As a result, the power output of the oscillator rises at a similar slow rate, therefore shock excitation of the antenna, which causes key clicks, is avoided. Since  $L$  stores energy in magnetic lines of force, it also tends to keep the current flowing when the key is opened; this similarly causes the amplitude of oscillation to decrease slowly. Arcing would occur at the key contacts when the key is opened were it not for the condenser  $C$ , which is connected across the key to absorb the energy released by  $L$ .  $C$  retains its charge while the key is open, but discharges through the resistor  $R$  when the key is closed. If  $R$  were not in the circuit, the discharge of  $C$  would again cause arcing at the key contacts at the instant of closing. When  $L$ ,  $R$ , and  $C$  are properly proportioned, key clicks will be prevented and sparking at the key contacts will be minimized.

In a circuit of the type shown in Figure 88, when the filament of the tube is lighted and plate voltage applied, any small disturb-

ance in the grid circuit will cause a change in the potential of the grid with respect to the filament and thus cause the plate current to change. Since the plate current flows through  $L_2$ , which is inductively coupled to  $L_1$ , a voltage will be induced in  $L_1$ . If the two coils are correctly poled, the induced voltage will reinforce the original change in grid potential and the process will repeat itself, being amplified each time by the amplifying properties of the tube and building up to a continuous oscillation whose amplitude is limited by the tube and circuit characteristics and the operating voltages. The frequency of the oscillations is determined chiefly by the constants of  $L_1$  and  $C_1$ . The grid condenser  $C_2$  and leak  $R$  set the operating grid bias, and condenser  $C_2$  by-passes the radio-frequency currents around the source of plate power.

Examine Figure 83 again: a tuned-grid, tuned-plate oscillator. When the filament of the tube is lighted and the plate voltage applied, any small electrical disturbance in the grid circuit will cause the change in the potential of the grid with respect to the filament and thus cause the plate current to change. Since the plate current flows through  $L_2$ , the change in current will cause a voltage to be induced in  $L_2$  which appears between the filament and plate of the tube, since by-pass condenser  $C_4$  has negligible impedance for radio frequencies. Because of the amplifying action of the tube, the voltage so induced is larger than the original disturbance which caused it. Because of the electrostatic capacity existing between the grid and plate of the tube, the voltage existing between the plate and filament causes a further voltage to be induced on the grid which reinforces the change caused by the original disturbance. The process repeats itself and a continuous oscillation builds up, the amplitude of oscillation being limited by the tube and circuit constants and the operating voltages. Grid condenser  $C_3$  and leak  $R$  set the operating bias. The frequency of oscillation is determined to a close approximation by the constants of the two circuits,  $L_1C_1$  and  $L_2C_2$ , which are tuned approximately to the same frequency.

Consider the circuit shown in Figure 89. When radio-frequency current flows in the circuit  $L_1C_1$ , electromagnetic lines of force are set up about  $L_1$ . These lines of force cut through the turns of  $L_2$ , causing a voltage to be induced in  $L_2$  which in turn



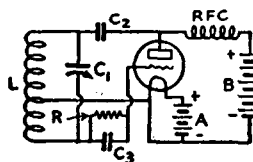


Figure 80. Self-Excited Oscillator Using a Single Vacuum Tube

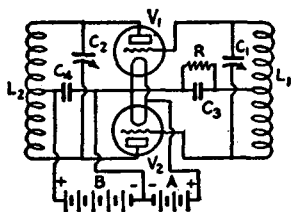


Figure 81. Self-Excited Oscillator Using Two Vacuum Tubes in Push-Pull Arrangement

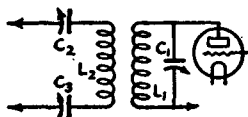


Figure 82. A Satisfactory Method of Coupling the Output of a Transmitter to an Antenna System

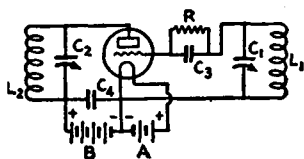


Figure 83. Series Plate Feed to a Vacuum-Tube Oscillator

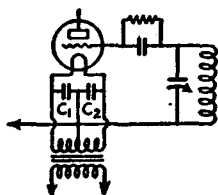


Figure 84. Grid-Return Connection to the Center-Tap of the Filament-Heating Transformer

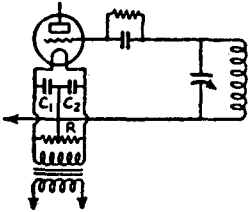


Figure 85. Grid-Return Connection to the Electrical Center of a Filament Circuit Where the Filament-Heating Transformer Has No Center Tap

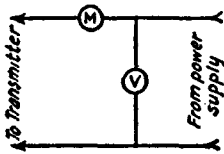


Figure 86. Method for Measuring Plate Power Input to a Vacuum-Tube Oscillator

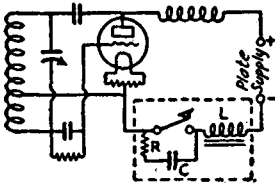


Figure 87. Method of Preventing Key-Clicks When Keying a Simple Vacuum-Tube Oscillator

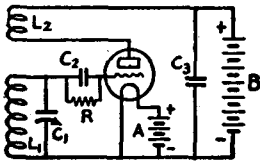


Figure 88. Electromagnetic Feedback in a Simple Vacuum-Tube Oscillator

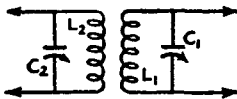


Figure 89. Electromagnetic Coupling Between Two Tuned Circuits to Transfer Energy from One to the Other

causes current to flow in the circuit  $L_2C_2$ . The transfer of energy will be maximum when the two circuits are tuned to the same frequency.

See Figure 90. A dummy antenna<sup>15</sup> preferably should have a resistance equal to that of the normal antenna or feeder system at the point at which it is to be fed. Several methods of connecting a dummy antenna are shown in Figure 90. That shown at A would be used when the dummy has comparatively low resistance (up to 50 ohms, approximately); that at B is used when

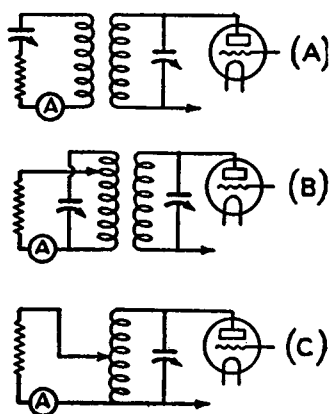


Figure 90. Dummy or Phantom (Non-radiating) Antenna, Coupled to a Transmitter Output Circuit for Testing Purposes

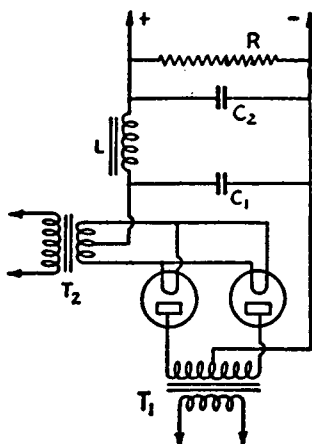


Figure 91. A Satisfactory Rectifier-Filter Power Supply

the dummy resistance is high (50 ohms or more); the arrangement at C also is suitable for use with dummy antennas of 50 ohms or more resistance. The purpose of the dummy antenna is to dissipate the power output of the transmitter without radiating it; relative power output can be measured if the resistance of the dummy is constant for the range of currents used, and absolute power output can be measured if the resistance of the dummy is known accurately. Artificial aerials are useful during tuning adjustments when it is necessary for the transmitter to deliver power but actual radiation of power is not essential.

In the diagram of Figure 91, power from the supply line is stepped-up in voltage by the transformer  $T_1$ , whose secondary winding is tapped at the center. The outside ends of the secondary winding are connected to the plates of the rectifier tubes, whose filaments are heated by means of the step-down transformer  $T_2$ . As the ends of the secondary winding of  $T_1$  alternately become positive with respect to the center-tap, current flows through the respective rectifier tubes; since the tubes will pass current only in one direction, the output of the rectifier is unidirectional but rapidly varying in voltage. The rectified voltage is applied to the filter, which consists of condensers  $C_1$  and  $C_2$  and the iron-core choke  $L$ . Because the choke and condensers possess the property of storing electrical energy, the pulsations in the rectified current are smoothed out, in much the same way as the flywheel on an engine smooths out the pulsations of the driver by mechanical storage of energy. If the values of  $L$ ,  $C_1$  and  $C_2$  are properly chosen, the output of the rectifier-filter system will be continuous direct current, for all practical purposes. A satisfactory value for  $L$  would be 30 henries, and for  $C_1$  and  $C_2$ , 2 fd. each, for a supply-line frequency of 60 cycles. The bleeder resistor  $R$  aids in stabilizing the load on the plate supply, and discharges the filter condensers when the power is turned off.

#### TYPICAL EXAMINATION QUESTIONS ON TRANSMITTERS, WITH ANSWERS

101. Why does a high ratio of capacity to inductance in the tank circuit of a self-excited transmitter improve the frequency stability?

*Ans.* Because the relatively large tank capacity tends to minimize those variations in frequency caused by changes in the inter-electrode capacities of the vacuum tube with heating. A high ratio of capacity to inductance in the tank circuit also minimizes the frequency variations caused by changes in plate voltage.

102. What are the advantages of an oscillator-amplifier type transmitter as compared to a self-excited oscillator?

*Ans.* The efficiency of an oscillator-amplifier transmitter is greater than that of a self-excited oscillator because the amplifier's grid losses are supplied from a separate source. The frequency stability is better because the oscillator is isolated from the antenna system and therefore is little affected by changes in the antenna or feeder

constants; changes in the amplifier plate-supply voltage have negligible effect on the frequency of the oscillator, so that plate-supply ripple does not result in frequency modulation or "wobulation," and a key filter with a large time constant can be applied, if the amplifier tube only is keyed, without causing a keying chirp.

103. What precautions ought to be taken in the adjustment of a transmitter to prevent the emission of harmonics?

*Ans.* The antenna coupling should be loose and the plate power input to the last stage should not be excessive. Harmonic output also can be reduced by limiting the excitation and reducing the grid bias.

104. If your self-excited transmitter erratically shifts frequency during operation, name at least three possible causes.

*Ans.* (1) A tube or other apparatus may be defective. (2) A connection may be loose. (3) Antenna or feeder system may be swinging, causing capacity changes which affect the oscillator frequency. Also, antenna coupling may be too tight.

105. Explain how you would determine whether a transmitter is radiating harmonics.

*Ans.* This can be determined by having a receiving station located at some distance from the transmitter listen on the frequencies that are harmonics of the transmitter frequency.

106. What are the relative merits of a crystal-controlled transmitter as employed in aviation sets, compared to a self-excited transmitter?

*Ans.* The crystal-controlled transmitter has greater frequency stability than the self-excited transmitter, and can be depended upon to stay upon one frequency unless through maladjustment it is permitted to operate as a self-excited oscillator. The efficiency and power output also can be higher than is possible with the self-excited transmitter. Except for very low powers and relatively low-frequencies, however, more apparatus is required for the crystal-controlled transmitter, especially for operation on the higher-frequency aircraft bands, where doubling amplifiers are usually necessary. The number of frequencies on which the crystal-controlled transmitter can work is limited by the frequencies of the crystals available, usually "day" and "night."

#### QUESTIONS

107. Explain the difference between CW and ICW transmission, stating which form is used in radiotelegraphy.

108. How does a radio transmitter develop and propagate radio waves?

109. Describe some of the peculiar characteristics of high frequency waves and how these affect aircraft communication.
110. Sketch a simple oscillator circuit and describe its operation.
111. Where and how are crystals used in radio transmitters?
112. What are the most desirable characteristics in power tubes?
113. Sketch a master-oscillator power-amplifier transmitter circuit and explain its operation.
114. In what part of a transmitter circuit is the telegraph key connected?
115. List the uses of the TBK transmitter and the types of transmission possible with this equipment.

NOTE: Questions have been found to be of great value to the reader who wishes to prepare himself to pass an operator's license examination. This is particularly true if care is taken in the wording of the answers. (The answers given to questions 101 to 106 inclusive are considered satisfactory as examples.)

An understanding of circuits will be found to be of even greater (and more lasting) benefit. For this reason the reader is urged to go over "circuits to study" again and again until adequate proficiency is attained in tracing and analyzing circuits.

## CHAPTER 9

### RADIO RANGE BEACONS

#### Radio Aids

The radio communication stations maintained along the Federal Airways System are in themselves an important aid to the navigation of aircraft. So are the light beacons which have been installed by the government. Various ground radio stations managed and operated by Aeronautical Radio for the airlines that contribute to the maintenance of this company also assist the pilot in navigating his plane from take-off to safe landing. The traffic control towers at various airports and at other points along the airways further aid the pilot in taking off, landing, and flying a safe course. Instrument-landing systems permit blind landings at airports.

In this book, radio aids to air navigation are classed as to the nature of service they render, as follows:

1. Radio range beacon stations (radiobeacons). These are TRANSMITTERS and as their name indicates they are located at ground stations, and include radio marker stations.
2. Radio direction finders (radio compasses). These are essentially RECEIVERS and are installed both on the ground and on board planes.

All radio range beacon stations in the United States are installed and maintained by the Civil Aeronautics Authority. A few radio compasses have been installed by some airports and airlines, but most of those in service are aboard planes. It is interesting to note that Pan American Airways do not have the advantage of radiobeacon service on their South American and overseas runs, but have installed radio compasses at all of their ground stations and aboard all their planes with remarkably fine

results as to navigation. It should also be noted that both the Army and Navy (especially the Navy) have used radio compasses both aloft and on the ground for years. It must be remembered, however, that the radio range service is free to flyers over thousands of miles of airways; that radio-compass installations cost money, a controlling factor in many cases in the selection and adoption of equipment for commercial aviation. All transports now carry radio compasses. It is more than probable that many radio compasses will be installed along the airways in the future. Certain it is that the Federal Airways System is the finest and best equipped in the world and probably always will be. The student should therefore know all types of radio aids, consequently all types are described. Radio compasses, instrument landing systems, and traffic control are included in Chapters 12, 13, and 14 respectively.

### Airway Radio Range

**Purpose.** The purpose of all radiobeacons, except marker beacons, is to emit radio waves of fixed intensity in a fixed direction like a beam, as a course for aircraft to follow. The path of travel of an airplane from one radio range beacon to another along an established airway is the path of the radio beam from or to a radiobeacon.

The aural system is received by headphones; the visual system by observing the amplitude of vibrating reeds in the receiving box that is usually mounted on the airplane instrument board.

The airway radio range is an *aid to dead reckoning navigation*.

**Designations of Radio-Range Stations.** Government radio-beacon stations are designated, according to the class of service they furnish, as follows:

RA—Range (Adcock, vertical radiators), power greater than 150 watts.

MRL—Range (Loop radiators), power 50 to 150 watts.

RL—Range (Loop radiators), power greater than 150 watts.

ML—Directive or loop-type marker, power less than 50 watts.



MRA—Range (Adcock, vertical radiators), power 50 to 150 watts.

M—Nondirective radio marker.

The letter S preceding a designation symbol means that there is simultaneous transmission of voice and range signals, as SMRA. D means distantly controlled. Z indicates an ultra high-frequency (station location) marker. In addition to this type marker, there is a "fan" marker. When B precedes a designation, it indicates that the radiobeacon is operated in conjunction with a scheduled broadcast station. V indicates that there are facilities for voice communication with aircraft; W indicates that the radio-range station has no voice facilities. T means teletype; X means that it is a principal teletype station. P is used to designate any station which has point-to-point radio.

RA and RL class radio-range stations may be received at distances up to 100 miles, and are located approximately 200 miles apart along the airways. Radio stations of these types are in operation on most of the airways.

The medium-powered MRA and MRL radio stations have a smaller range; they may be heard for distances up to about 50 miles. Although they have to be installed at closer intervals to furnish continuous radio range guidance, requiring more stations, the medium-powered installations are less adversely affected by a difficulty known as multiple courses which occur at some of the higher powered stations in mountainous country, and they therefore have been installed on the Northern Transcontinental Airway and several other routes on the Federal Airways system. Medium-powered stations also are used on some other airways to supplement the service of the higher-powered stations.

Still another type is the directional marker or miniature radio range station, with a range of about 15 miles. These stations are used to mark important intermediate landing fields and to serve as homing devices, assisting pilots to reach these fields.

Most of the RA and RL stations and some of the MRA and MRL facilities operate in conjunction with radio broadcasting stations which announce weather reports on regular schedules.

The communications and directional units may be housed in a single building, which is the newer type of installation, or they may be in separate buildings at a distance from each other. In either event, they are located at a distance from the airport so that the antennas will not constitute obstructions to landings and take-offs, and generally are operated by distant control from a C.A.A. office on the airport or intermediate field.

A combined station providing both directional signals and weather broadcasts normally transmits both on the same frequency. This is necessary because of the limited number of channels available, and has the advantage that the pilot flying the radio range does not have to retune his radio receiver to get the weather information. However, the radio range signals have to be silenced while broadcasts are being made. These periods never exceed 3 minutes and usually are less, but they may occur at the very moment when a pilot flying on instruments is approaching the end of his run and wants the assistance of the radio range station in locating the landing area.

To avoid this difficulty, some of the radio stations are equipped for radiophone transmission on an alternate frequency of 236 or 278 kc. At RA or MRA stations so equipped (the fifth tower in the vertical radiator antenna system is a part of the equipment for this purpose) the operator, upon request, will use the 236-kilocycle frequency for his weather broadcast. When he does so, he makes an announcement on the regular frequency that the weather broadcast will be given on the alternate frequency. The directive signals are silenced only for the few seconds needed for this brief announcement and then are resumed immediately. Thus, the pilot who needs continuous directional service gets it, and others listening to the station may retune their receivers for the weather, if they wish to do so.

At the SMRA stations (one of the newest developments) course guidance signals and voice transmission are accomplished simultaneously.

### Principles of Operation

In 1936, the Bureau of Air Commerce issued instructions, in regard to the airway radio range, prepared by Ward D. Davis,

instrument flying instructor for the Bureau. A portion of these instructions dealing with underlying principles follows.

Begin by comparing a radio range which controls the intensity of its signals in certain directions with a conventional broadcast station which normally radiates its energy with substantially the same intensity in every direction. Figure 92 illustrates the circular shape of the pattern covering the area over which a broadcast station would be heard with an ordinary receiver. Signals

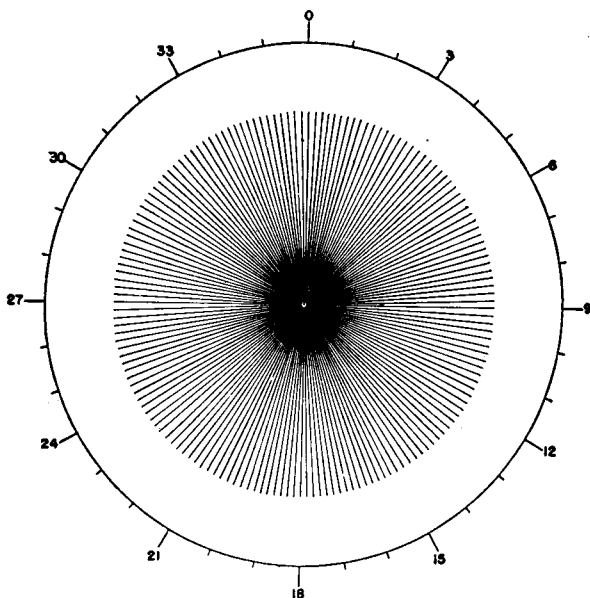
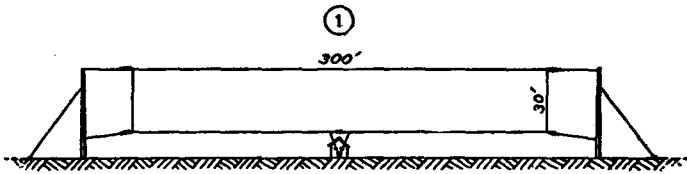


Figure 92. Omni-Directional Broadcast Antenna

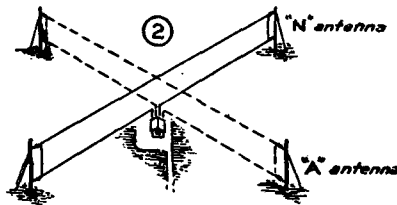
are strong near the transmitter and grow weaker gradually as they spread out in all directions until they fade out entirely. The radius of this circular area could be considered greater or less as the receiver volume is advanced or retarded, or the transmitter power is increased or decreased.

The shape of the pattern in which signals are audible can be controlled to some extent by use of specially designed transmitting antennas, one type of which is the loop illustrated in Figure 93.

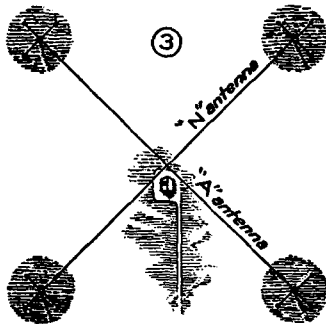
Comparing the pattern of the loop with the pattern of the broadcast antenna it will be found that radiation from the loop is suppressed in both directions at right angles to the loop, and maximum radiation is obtained in the directions in line with it.



Side view of single loop transmitter antenna



Cross loops No. 1 & 2 as used for range transmission



As viewed from above

Figure 93. Beacon Antennas

The loop is represented at the center of Figure 94 as it would appear if viewed from directly above. Note the directions in which it points by reference to the aircraft compass-rose drawn around the figure. For identification purposes the signals radiated by this loop are broken up into a succession of dots and

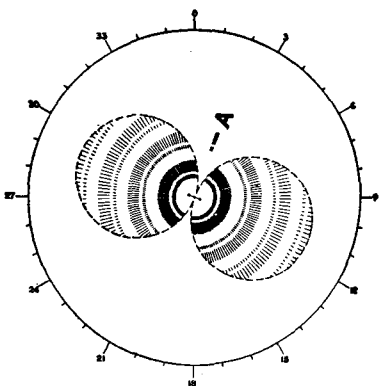


Figure 94. Single Loop, Bearing  $100^{\circ}$  and  $290^{\circ}$

dashes corresponding to the letter "A" (dot dash) and so represented by blocking in the areas covered by the signals. Figure 95 represents the areas which would be covered by another identical loop at the same location but rotated  $90^{\circ}$  (at right angles) and transmitting a succession of letter "N" (dash dot).

Two such loops radiating alternately would cover the areas shown in Figure 96. It is obvious, however, that only in the zones in which adjacent areas overlap would both the A and N signals be audible.

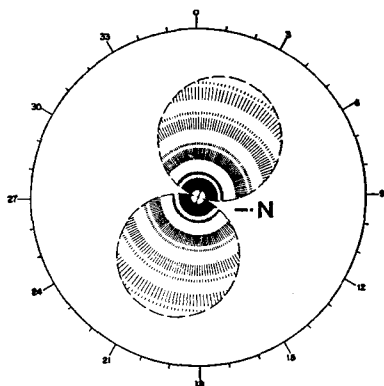


Figure 95. Single Loop, Bearing  $20^{\circ}$  and  $200^{\circ}$

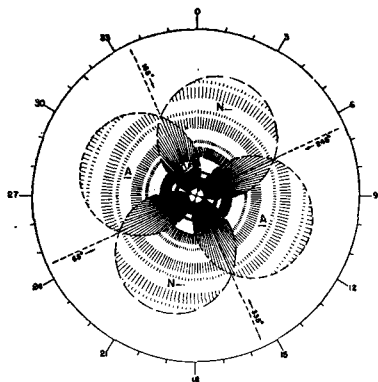


Figure 96. Loops A and N Combined

At the landing field represented by F in Figure 96, both A and N signals would be heard with exactly equal strength, resulting in a steady monotone. The same would be true at any other point on a line drawn through the center of each of the four zones of overlapping signals.

An airplane taking off from the field, flying away from the transmitter and following the line along which the A and N signals continue to be received with equal strength, would start with the receiver volume near minimum. The signal strength would drop off rapidly at first, making it necessary to advance the manual volume control at frequent intervals. (Automatic volume control is unsuitable for range navigation.) As the signal becomes progressively weaker with distance, the volume control would have to be advanced less frequently. Eventually the limit of receiver sensitivity would be reached or accompanying atmospheric noises and interfering stations become louder than the desired signal. This occurs under ordinary conditions and with normal transmitter powers at approximately 100 miles from the station.

At this distance it is possible to fly several miles before a noticeable change in signal strength is apparent to the ear. It is likewise possible to deviate a considerable distance to either side before the ear can detect a change in relative signal strength of the N and A. The limits between which a plane may range to either side before a change in relative strength of the signals is apparent can be represented by a line radiating from the transmitter approximately  $1\frac{1}{2}^{\circ}$  each side of the center line. This is actually the way in which courses are plotted on aeronautical charts. The true bearing of each course in degrees *towards* the station is published by the Bureau of Air Commerce (now C.A.A.) for all stations. The magnetic declination is specified in each case. The use of flying charts on which all courses are plotted with magnetic bearings is explained in detail in Special Publication No. 197 of the Coast and Geodetic Survey.

It is now obvious that radio-range courses are merely narrow wedge-shaped zones in which two signals of equal strength are received as a monotone. The degree of accuracy with which the ear judges relative signal strength (particularly station identifi-

cation signals), determines the accuracy with which the pilot can fly a radio-range course.

Like the entertainment broadcast band, the aeronautical radio-frequency spectrum (200–400 kc) must accommodate a great number of stations, and some interference is unavoidable. To eliminate all danger of mistaken identity, each station is assigned an individual one- or two-letter identification. Approximately every half-minute the course signals are interrupted and the station identification signals are transmitted twice in code, once from each loop, whereupon the course signals are resumed. Each radio-range station operates on a designated frequency. This means that only one range station will be received at only one place on the dial. Therefore, there are two means of identifying a radio-range station—first, by the radio-frequency or dial setting; second, by the identification signals. For instance, the pilot wishes to tune-in the radio range at Los Angeles. He knows that the radio frequency is 260 kc and that the identification signals are B U (—... ..—). He turns the radio dial to 260 and receives a signal. He waits until the station identification signals are transmitted and reads them as B U. This has definitely established the fact that he is listening to the Los Angeles range.

When a pilot is flying *away* from a range, the farther he progresses the less accurately does he know his position, but if he follows any of the four courses *towards* the station he will be led to a definite point. That point can be identified aurally by what is usually termed the “cone of silence.” It is an area, normally directly above the transmitting antennas, in which all signals fade out when the airplane passes directly through it. It should not be confused with momentary fade-out of signals sometimes found along airways, resulting from other causes, since it will be observed that just before reaching the cone of silence the signal volume builds up rapidly, drops off suddenly for a few seconds depending upon the speed and altitude, then surges back with still greater volume before it gradually begins to diminish as the station is left behind. Unless the receiver volume is kept at a minimum value and the airplane is exactly on-course when passing over the station, the signal will not fade completely out. The

airplane receiving antenna should be as nearly vertical as possible for best results. The reasons for these precautions will be evident from a study of Figure 97, which shows the normal position and shape of the cone of silence.

The pilot should have a complete understanding of the inherent limitations of radio ranges before attempting to fly them during inclement weather. Range courses which theoretically should be perfectly straight may be found to have kinks or bends in them. This is most likely to occur where they pass close to or

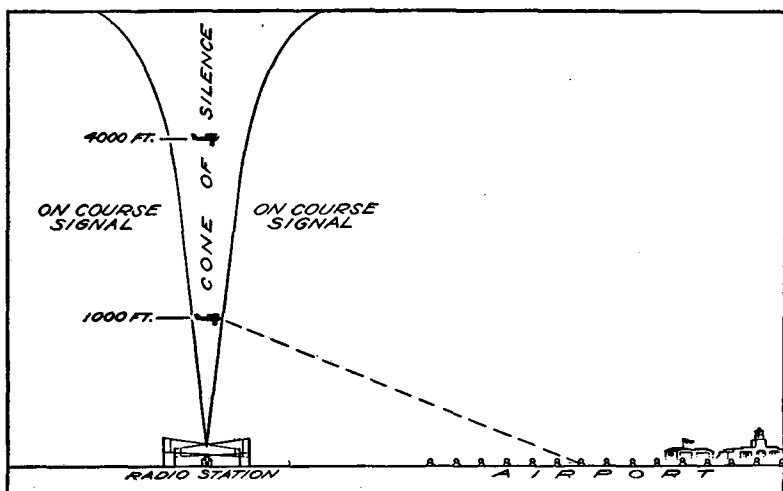


Figure 97. Cone of Silence Pattern

over hilly or mountainous terrain, large bodies of water, or over mineral deposits. Under such conditions a course is sometimes broken up into several parallel courses, usually referred to as "multiple courses." Bent courses are usually of little consequence since the bend is generally small and away from and around the obstruction that causes it. (However, in mountainous country, bends have frequently been found that necessitated a change of compass heading of  $45^\circ$  or more in order to stay "on course.") Several such bends may occur on a range in a short distance. Obviously, such a range would be hazardous to a pilot who was not entirely familiar with that particular range. These



conditions may be found anywhere, but are generally confined to hilly or mountainous terrain. A bent course creates the impression that the course is swinging, if the airplane proceeds on a straight path. The only time that courses actually do swing from their fixed position is usually for a short period at sunrise and sunset. This has been almost entirely overcome by substituting for the loop antennas a system of four steel tower radiators, located at the four corners of a large square plot and fed from a transmitter in the center through underground transmission lines.

“Course shifting” is illustrated in Figure 98. The theoretical explanation of shifting (sometimes called “squeezing”) of the

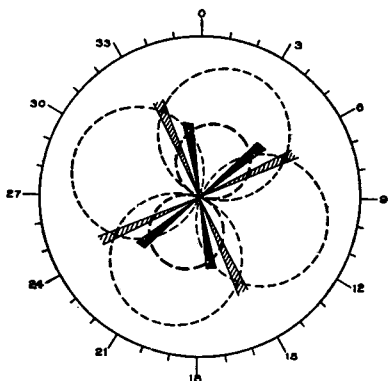


Figure 98. Illustrating Course Shifting

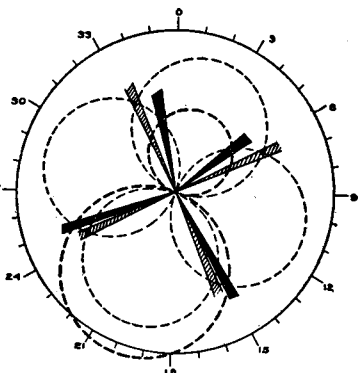


Figure 99. An Altered Pattern

courses may be visualized by plotting the pattern of the areas covered by signals from each loop and noting the resulting displacement of the on-course zones when the relative size of adjacent patterns is changed. The size of these areas is, of course, governed by the power radiated from the corresponding loops. The heavy dotted lines represent the pattern after adjusting the transmitting equipment for this purpose. It will be noted, incidentally, that any displacement of the course is achieved at the expense of a corresponding reduction of the distance over which the displaced courses may be used.

After shifting courses in the manner described above, opposite or reciprocal courses remain  $180^\circ$  apart. Occasionally circum-

stances demand a bend in reciprocal courses. This is accomplished by altering the relative size of the patterns in such a manner as to produce the desired alignment. (An example is illustrated in Figure 99.) This alteration is obtained not by a reduction of current in the loop, but by cancellation of a portion of the radiated energy.

**Shifting Courses.** The method of shifting courses that emanate from the beacon antenna will be explained by reference to the field patterns as illustrated by Figures 100 to 105 inclusive. All of this information relative to transmitting stations has been abstracted from data supplied by the Bureau of Air Commerce (now C.A.A.).

Figure 100 shows the field pattern of a four-course range, all four courses displaced  $90^\circ$  from each other. The distance from the center of the diagram to any point on the circles is proportional to the field strength in that direction for the modulation frequency. The widths of the courses have no significance as they depend to a great extent on the observer and the receiver that is used.

Figure 101 shows the field pattern where the courses are "shifted." Although both courses go straight over the range station, they are no longer  $90^\circ$  from each other. This "shifting" is very simple, being done by introducing resistance that reduces the plate voltage and consequently the amplitude of one channel.

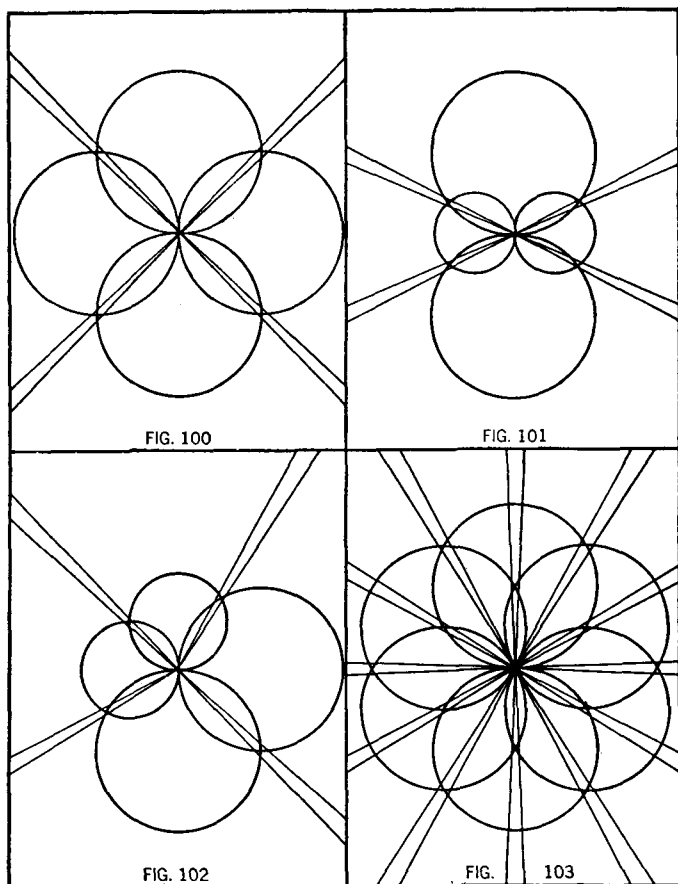
Figure 102 shows the field pattern where a course is "bent," that is, it does not go in a straight line over the range station. This is the condition under which most ranges will operate. It will be noted that one lobe is larger than the other for both modulation frequencies, this being obtained by the use of a vertical antenna that is placed close to the intersection of the  $90^\circ$  crossed loops.

Figure 103 shows a field pattern when operating as a twelve-course radio range. It will be seen that there are six weak courses and six strong courses. When operating in this condition, all three channels of the transmitter are used. The preceding explanations of "shifting" and "bending" apply also when operating

as a twelve-course range. As yet, none of the beacons in the United States are operating more than four courses.

In the diagrams that have just been discussed, the average diameter of any pair of opposite lobes is proportional to the output current of the corresponding channel.

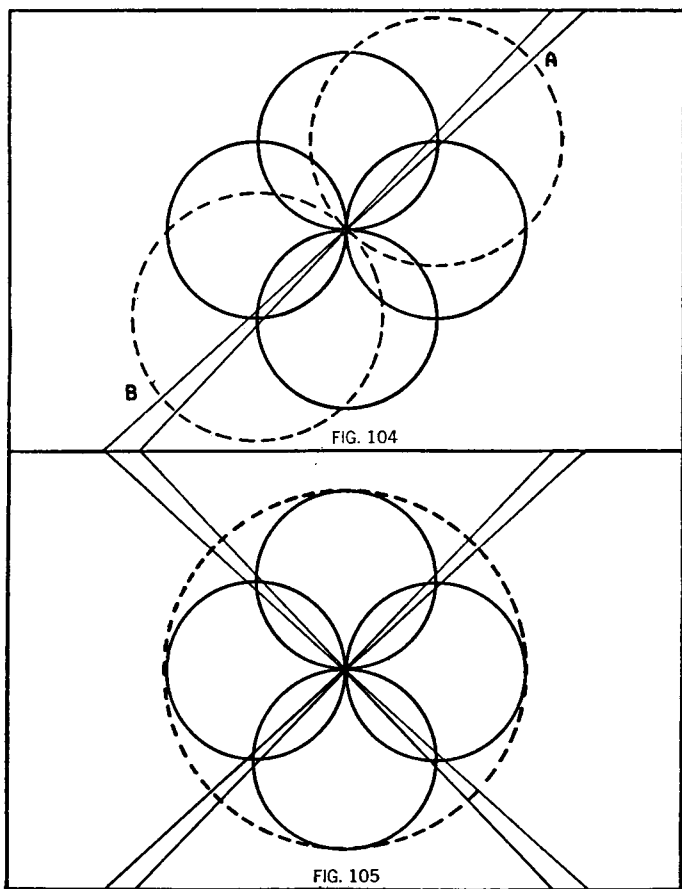
The actual means of rotating the field patterns, as illustrated by Figures 100 to 103, is accomplished by the movable coils (goniometer) in the transmitter circuit that increases or de-



Figures 100-103. Polar Diagrams Representing Radio Range Beacon Antenna Field Patterns

creases the current characteristics by inductive linkage or resistance, thus shifting or splitting the phase to different components of the antenna system.

**Theory of Phase Shifting.** Modulated radiation may be considered as consisting of three components—a carrier and two sidebands. As the carriers radiated by the two channels are of the same frequency, they combine in space and form a single



Figures 104–105. Polar Diagrams Representing Radio Range Beacon Antenna Field Patterns

resultant carrier. The sidebands radiated by the two channels, however, are of different frequencies and consequently must remain entirely independent. When the carriers radiated by the two channels are in phase, they combine to form a large figure 8 pattern as shown by the dotted lines in Figure 104. As it is necessary that a receiver combine both carrier and sidebands to reproduce a signal, it can be seen that if no phase-shift occurs, only two courses are usable, these being along the line AB.

When the carriers radiated are  $90^\circ$  out of phase, the resultant which they form is a large circle as shown by the dotted line of Figure 105. The phase of the carrier varies for different points on the circle, but this is of no great significance. For the arrangement shown in Figure 105, all four courses are usable. Although some of the transmitters when installed will serve only two courses, they will all be adjusted with a  $90^\circ$  phase-shift so that there is a circular carrier. This is done because the courses established by a four-course radio range are sharper than those obtained from the two-course range.

The use of a goniometer to modify the shapes of the field patterns, and thus the directions for the radio beams, is the same in principle for both the aural and visual beacon transmitters. However, there are minor structural and electrical differences in the goniometers that are employed for the two systems.

The following are a few simple rules that should be memorized by all pilots who anticipate flying the radio ranges:

**RULE 1.** The northern N quadrant is the one in which True North lies. Since the N quadrants are diametrically opposite, this rule immediately establishes which are the A and N quadrants. When the bearing of the northern range course happens to be True North the quadrant to the west of this north course will be the N quadrant.

**RULE 2.** The first identification signal is transmitted in the N quadrants, the second in the A quadrants. (Figure 106.)

**RULE 3.** If two station identification signals are heard, one being louder than the other, and the weak one starts to fade out, it is obvious that the pilot is flying away from the nearest on-course signal. If the weak station identification signal gets louder, the pilot is flying towards the nearest on-course signal.

Remember that when the airplane is on-course both station identification signals are heard with equal intensity. This information is particularly valuable when the volume is increasing and

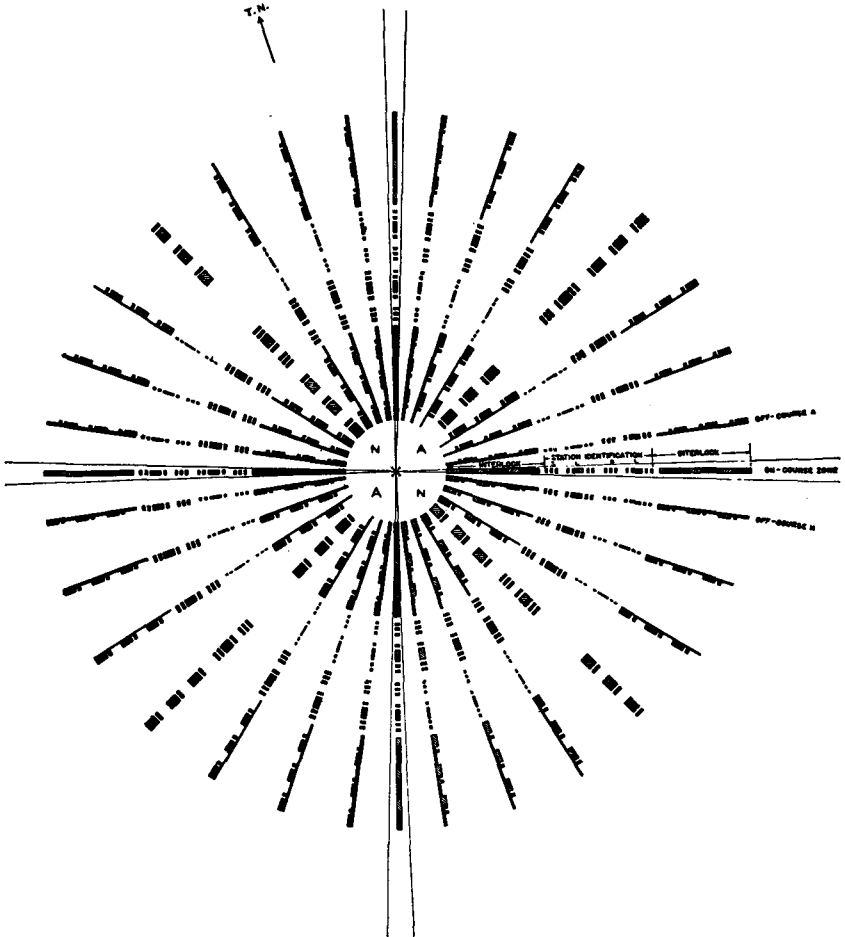


Figure 106. A and N Quadrants

fading so as to make it difficult to tell by sound whether the pilot is flying towards or away from a station. Also when static conditions make the signals most unreadable, the volume will not

change sufficiently fast to disrupt the relative intensity of the two station identification signals. Normally, rain and snow static will cause all signals to be blanketed out. Many airline pilots use the relative intensity of the station identification signals almost entirely as a means of following a given course.

*It must be remembered that radio range stations are to be used strictly as an aid to dead reckoning. The pilot should not*

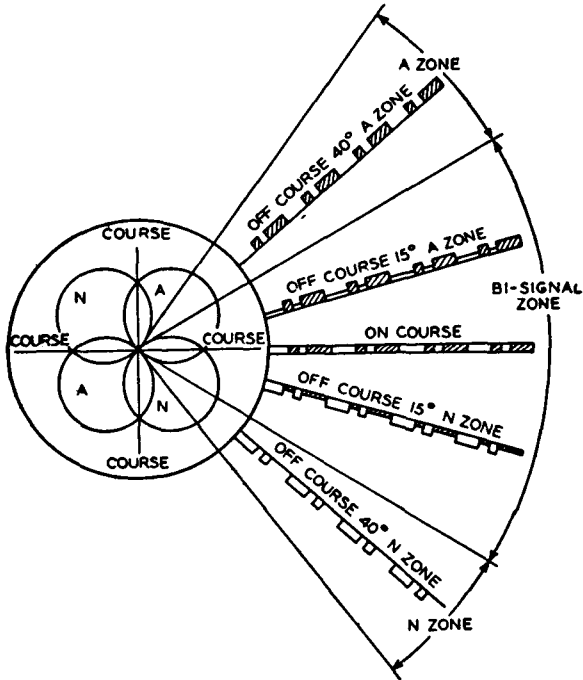


Figure 107. Diagram of Radio-Range System

*rely on the range alone, ignoring the compass and other instruments, because there always is the possibility that the range may be turned off because of mechanical difficulties, or may be unintelligible due to static or other conditions such as receiving equipment being in poor condition.*

**Orientation.** An excellent orientation procedure for the pilot who gets off the radio range has been developed by Mr. Davis;

this and other methods are used by pilots. All are based on an understanding of the quadrants and their designation. Figure 107 indicates this "quadrant system."

### **TMH Model Airway Radio Range Beacon Transmitter**

Much of the information concerning the TMH model radio-beacon, the SMRA set, described on page 256, and the U.H.F. Marker transmitter has been furnished by Radio Receptor Company, Inc., New York City. The TMH Radio Beacon Transmitter has been designed for both 150 watts and 400 watts of keyed telegraph power and continuous-wave power into any antenna whose characteristics are specified. This type is now being used on the airways of the United States and other countries to operate satisfactorily with an antenna or transmission line whose characteristics are given below. The frequency range is from 190 to 400 kc. The TMH Model delivers 150 watts of keyed telegraph pure CW power. It can also be used to transmit a 100% modulated signal. The modulation may be speech or a 300-cycle audio tone.

**Construction.** Component parts of the transmitter are assembled in a heavy duralumin angle frame. Good ventilation is insured by placing the tubes in a shielded compartment in the center of the transmitter, insuring a good draft by isolating the heated air in the center and drawing cold air through the bottom without distributing the high temperatures throughout the remainder of the transmitter.

The bottom shelf contains the high-voltage plate-rectifier transformer, the filter chokes and the filter condensers. On the terminal board, as shown in the illustration of the left front view showing tubes and remote control relays, are mounted the filament and plate contactors and all the control relays, with the exception of the antenna transfer relays, the side view of which can be seen on the left side of the upper shelf. Plate X shows all component parts.

The second shelf contains the three audio stages. On the front panel of this shelf is the filament rheostat, the local remote switch, the overload relay, and the various control switches and pilot



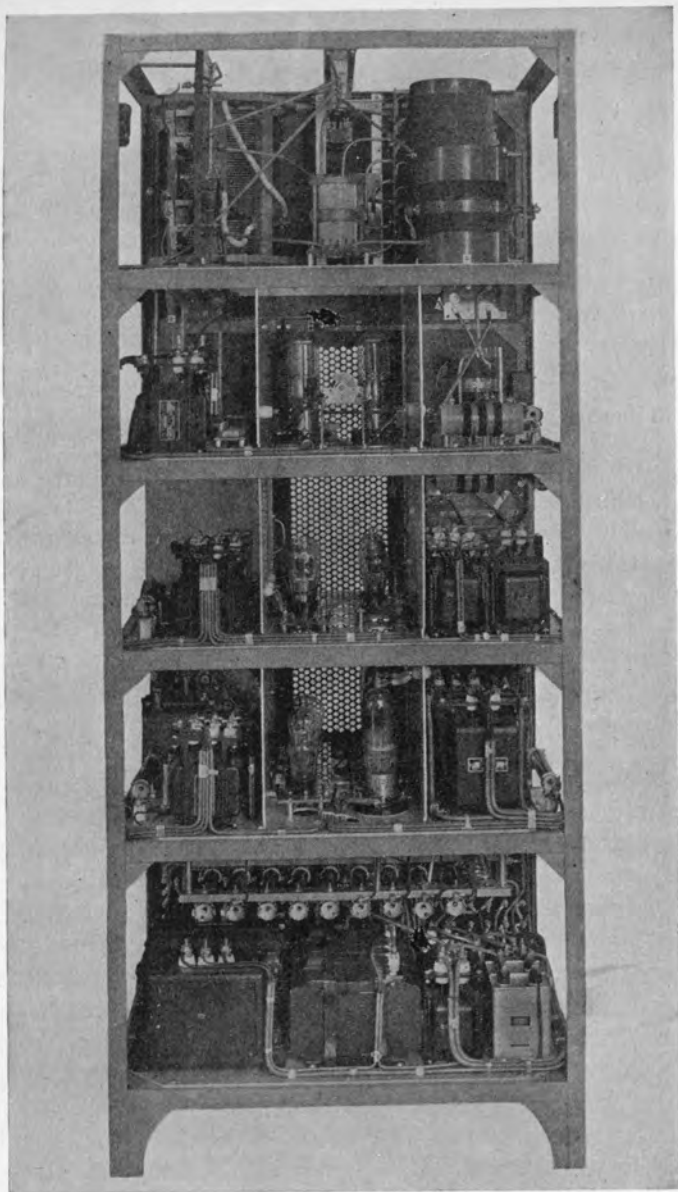
lights. The first and second audio tubes, the modulator tubes, and the high-voltage rectifier tubes are mounted in the tube compartment of this shelf.

The third shelf contains the bias and control rectifier, the coupling impedance for the untuned buffer stages, the filament transformer for the exciter stages, and the potentiometers for the bias and low-voltage plate rectifiers, the tuning elements for the master oscillator, the plate transformer, and choke of the low-voltage plate rectifier. The front panel carries the volume control, crystal switch, master oscillator, tuning dial, buffer-band switch, and the crystal master switch. There is also mounted on the right side the oscillator plate-current meter, and on the left side the buffer plate-current meter. On the shelf of the tube compartment there are mounted the crystals, the crystal oscillator and two untuned buffer tubes, the master oscillator, and the rectifier tubes for the control and low-voltage plate rectifiers.

On the fourth right shelf are mounted the tuning elements for the power-amplifier stage, the filament transformer for this stage, and the intermediate power amplifier stage. There are also mounted the tuning elements for the intermediate power-amplifier stage. The front panel carries the tuning controls for these two stages. In the tube compartment are contained the intermediate power amplifier and power-amplifier tubes, and neutralizing condenser.

The fifth shelf contains the antenna tuning elements. This includes the adjusting coupling transformer and the antenna transfer relays. It also includes the antenna loading coil and the auxiliary variometer for tuning the goniometer primary. The front panel carries the antenna coupling control, the tuning control, the tap switch, and the range tuning control with the band switches for the I.P.A. and P.A. stages. It also contains the filament, I.P.A., modulator plate-current, P.A. plate-current, and antenna-current meters. These are mounted at the top of the panel.

Two hinged interlocked doors are provided, one at the bottom exposing the terminal board and remote control relays, and one in the center permitting quick and convenient access to the vacuum tubes.



(Courtesy Radio Receptor Company, Inc.)

Plate X. TMH Airways Radio Range Transmitter Showing Component Parts as Installed on Shelves

Plate XI shows the control panel on front of transmitter compartment.

**POWER AND OTHER REQUIREMENTS.** 150-watt transmitter: 1700 watts, 60 cycle, 110 or 220 volts, as specified. 400-watt transmitter: 2700 watts, either 110 or 220 volts, 60 cycle or other frequency, as specified.

**ANTENNA.** The antenna characteristics for which these units have been designed have an effective capacity of 0.006 mfd. to 0.00085 mfd. The effective resistance is 4 ohms.

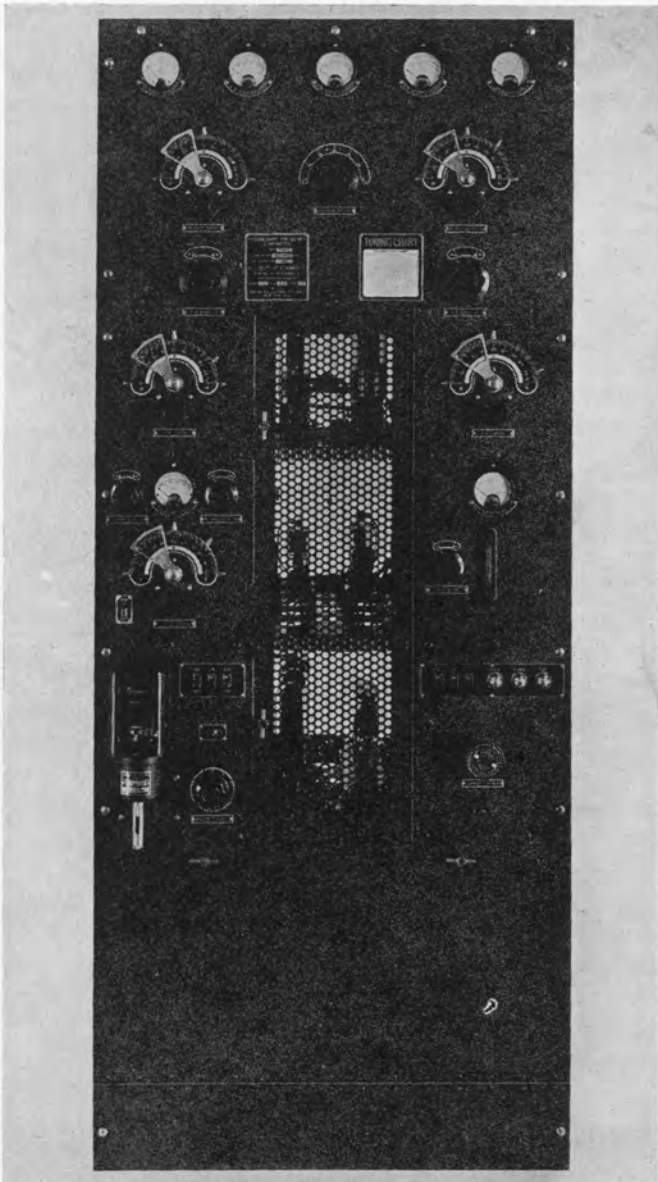
**TRANSMISSION LINE OPERATION.** From 70 to 135 ohms have been used in the past, or the transmitter can be designed for any other specified resistance.

For telephone and telegraph communication, the transmitter can be operated into a single tower having the characteristics mentioned above, or into an "L" or "T" type antenna having similar characteristics. The transmitter is capable of delivering full power into an antenna of this type, also into any power resistance load up to 150 ohms, including transmission lines whose characteristic impedance does not exceed 150 ohms.

**PHYSICAL DIMENSIONS.** Total Height, 76 in. Total Depth, 24 1/16 in. Total Width, 30 in.

**Goniometer.** The purpose of the goniometer is to transfer radio-frequency power from the transmitter to the transmission lines of a tower radio range beacon installation, or to a pair of loops.

The function of the goniometer is two-fold. First, if properly designed it will reflect a constant load upon its primary as the primary is rotated, although the power is being transferred from one secondary to the other. It is so designed that its coupling characteristics are sinusoidal. Second, it controls the phase relation between any pair of towers or antennas. The goniometer provides for two types of operation—beacon and phone. One antenna circuit connects through to the goniometer primary where it is transferred to the goniometer secondary, and through the artificial lines which in turn conduct it to the antenna tuning house. The other antenna circuit is connected to the primary of the hybrid coils and utilizes them as transformers to the trans-



(Courtesy Radio Receptor Company, Inc.)

Plate XI. Front View of TMH Airways Transmitter Showing Panel Controls

mission lines and the antenna tuning house. A contactor is provided which shorts out the hybrid coils for range operation. These coils are utilized so as to secure the proper phasing on the various towers for the two types of emission. The link circuit relay, which is mounted on the goniometer, transfers the energy from one goniometer primary to the other. In addition to the link circuit relay, the keying unit is also mounted on the goniometer. Its sole function is to operate the link-circuit relay and the transmitter key for identification signals.

The upper section contains the link-circuit relay, the condensers for tuning the goniometer secondaries, and the course-shifting resistors. The center section contains the goniometer proper and the two goniometer secondary meters. It also contains the 360-degree scale for indicating the angle of rotation.

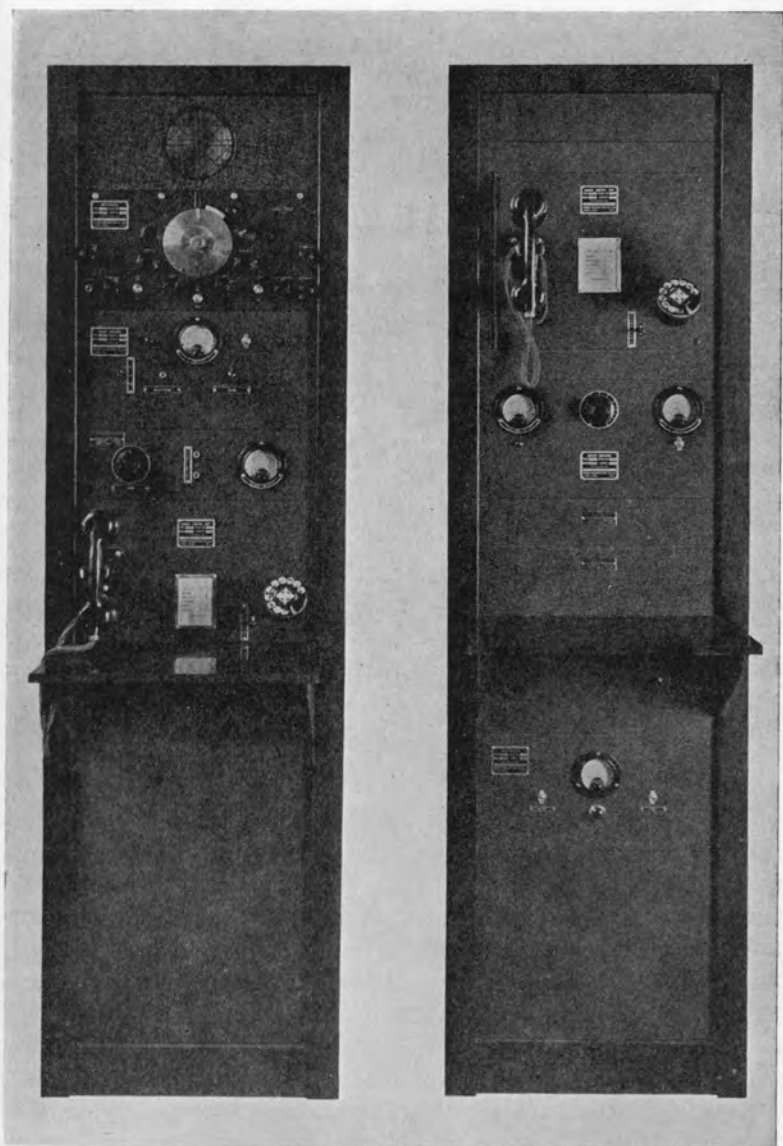
The primary windings of the goniometer are directly driven and its position indicated by directly-connected dial, insuring no errors due to lost motion.

The goniometer unit is assembled in a heavy dural angle frame reinforced with gusset plates and spot welding. The front panels and shelves are bolted directly to the angles and cross members.

As the TBK circuit is analyzed in Chapter 8, that of the TMH will not be given here. Plates X and XI are views of the TMH. (A visit to the C.A.A. stations will be found helpful.)

### **Marker Beacons (Class M)**

A marker beacon (M) is a low-powered, omnidirectional radio station which transmits a characteristic signal, such as H (....) about every ten seconds. It is also equipped for voice communication with aircraft. Marker beacons have a range of from three to ten miles, depending on the weather conditions and the type and conditions of receiving equipment being used. Marker beacons normally are placed at the intersection of two radio ranges, indicating when to tune to the next station. In such a case the characteristic signals are transmitted on the same frequency as the adjacent ranges so that they can be heard if tuned to either range. Also, marker beacons may be placed on or near some prominent landmark. Usually there is a C.A.A. intermedi-



(Courtesy Radio Receptor Company, Inc.)

Plate XII. Remote Control Rack with Monitor Receiver and Local Control Rack for SML Radio Range Beacon

ate landing field located adjacent to the marker beacon, and there are personnel on duty at all times.

A marker beacon does not operate continuously, but is turned on when the local ceiling is less than "unlimited" and the visibility is less than two miles, or at any time on request. This is because a marker beacon is used by the pilot to check his position when flying with reduced visibility or when flying "over the top" when the ground cannot be seen.

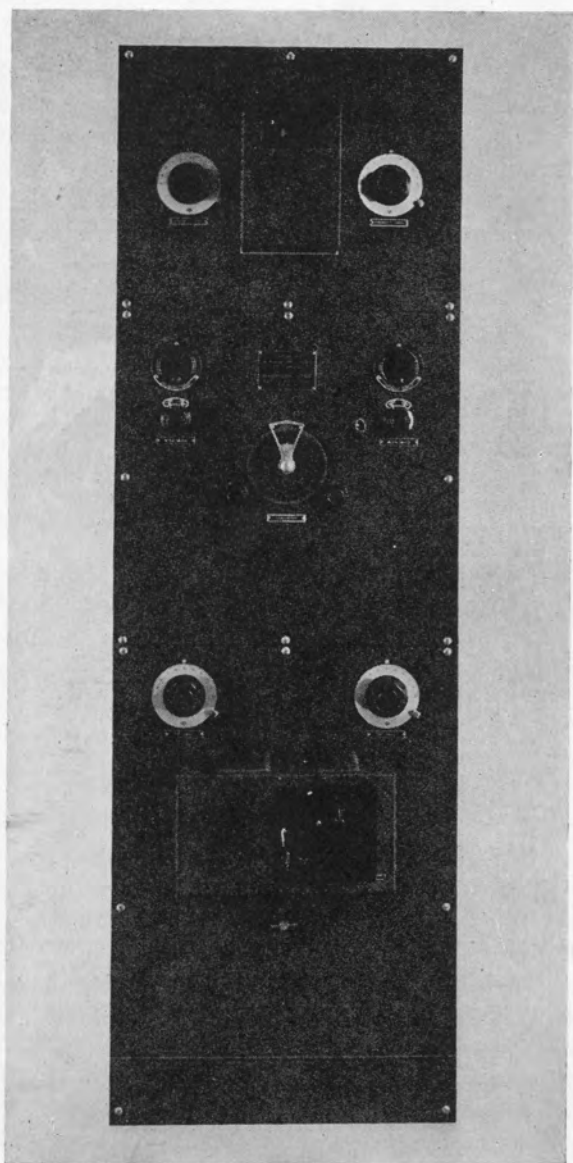
Plates XII and XIII show this type equipment.

### **Marine Radio Beacons**

The C.A.A. maintains a group of 81 Marine Radiobeacons along the coasts and Great Lakes. These stations transmit identifying signals with a nondirectional transmitter in the same frequency band as the airways weather and radio-range stations. They transmit continuously during bad weather and 15 minutes out of the hour in good weather. Ships as well as planes make use of these in obtaining their positions by use of the radio compass. Bearings taken on two or more determine the ship's location by triangulation.

### **Radio Range Beacon Antenna Systems**

For a long period of time the only type of directional transmitting antenna that was considered for producing the figure-of-eight characteristics required in radio range beacon work was the loop antenna. During the past few years, however, loop antennas have been replaced in a large number of stations by a transmission line (T.L.) type antenna. (Not to be confused with an "L" type. T.L. is abbreviation for transmission line.) This is because, with the loop type, horizontal portions of the loops produced sky radiations which made the beacon course "swing" irregularly and often violently at night. This "swinging," known as night errors, was also found to be dependent upon the nature of the terrain, the season of year, and other factors. It is produced by the sky component of the indirect wave, which reaches the receiving point by reflection from the ionized layers above the earth's atmosphere. The horizontal portions of the loop trans-



(Courtesy Radio Receptor Company, Inc.)

Plate XIII. Goniometer for SML Radio Range Beacon



mitting antennas were found to be responsible for the radiation of this undesired component of the indirect wave, and so were replaced by the T. L. shown in Figure 108.

This antenna system eliminates the radiation of the undesired sky component. The complete antenna system used at a radio range beacon station consists of four steel towers insulated from the ground and about 125 ft. in height. The four towers are placed at the corners of a square, with diagonally opposite towers 1 and 2 working together in place of one loop antenna; towers 3 and 4 serve in place of the other loop antenna. The spacing between the two towers or vertical elements of a pair is usually 600 ft. To insure a fixed low ground resistance for each vertical

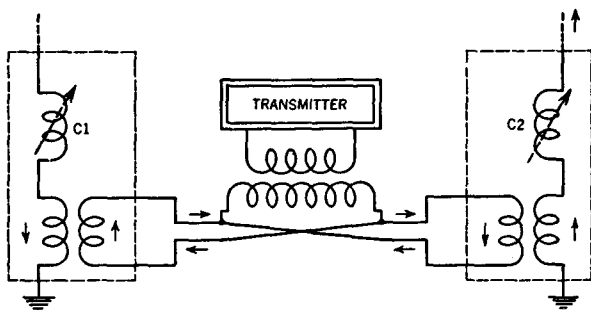


Figure 108. Simplified Diagram of T.L. Antenna System

antenna, an individual buried ground wire system is provided at the base of each tower.

As indicated in the foregoing, each pair of towers or vertical antennas or diagonal corners of the square (such as 1, 2, or 3, 4) are designed to produce the same figure-of-eight characteristic as a conventional loop antenna system, while at the same time eliminating the radiation of undesired components from the horizontal wires such as are produced by the horizontal members of the loop antenna. The means shown diagrammatically in Figure 108 for feeding power from the transmitter to each vertical element without having radiation from the horizontal wires consists of a two-wire parallel conductor transmission line which by its nature does not radiate at all. In actual installations, the transmission

line consists of ordinary two-wire armored r. f. power cable buried 18 in. below the ground surface, the armor providing mechanical protection as well as shielding. The antenna towers are often called Adcock type.

The important constant of the transmission line is its surge impedance. If one end of the transmission line is terminated by a resistor whose ohmic value equals the surge impedance of the line, and a voltage is applied to the other end, an electrical wave will be transmitted along the transmission line and will be en-

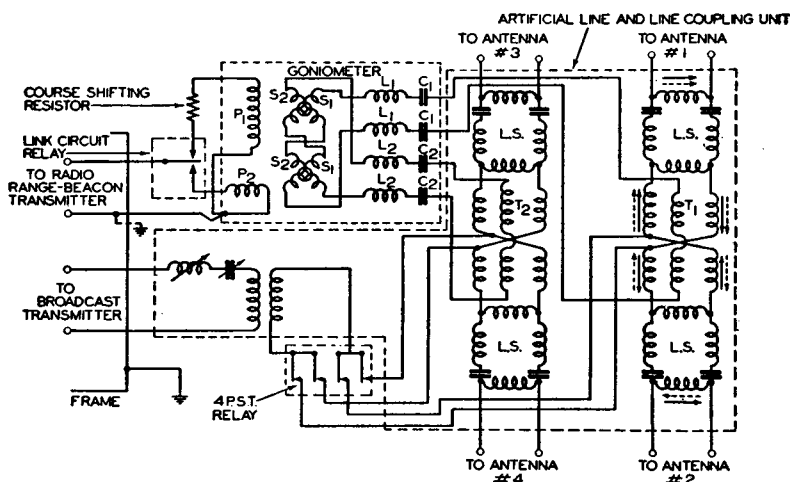


Figure 109. Schematic Circuit of Essential Units in a Radio Range Beacon Station Using TL Antennas

tirely absorbed by the terminating resistor ; no radiation from the transmission line will occur. If the terminating resistance is not equal to the line-surge impedance, part of the wave reaching the resistor will be absorbed by it and part of the wave will be reflected back along the line. This in part sets up standing waves and causes radiation from the line. The surge impedance of the transmission line employed is about 80 ohms. The radio-frequency transformers employed for coupling the transmission lines to the vertical antennas are designed so that the input impedance of each is exactly matched. (Review page 87.)

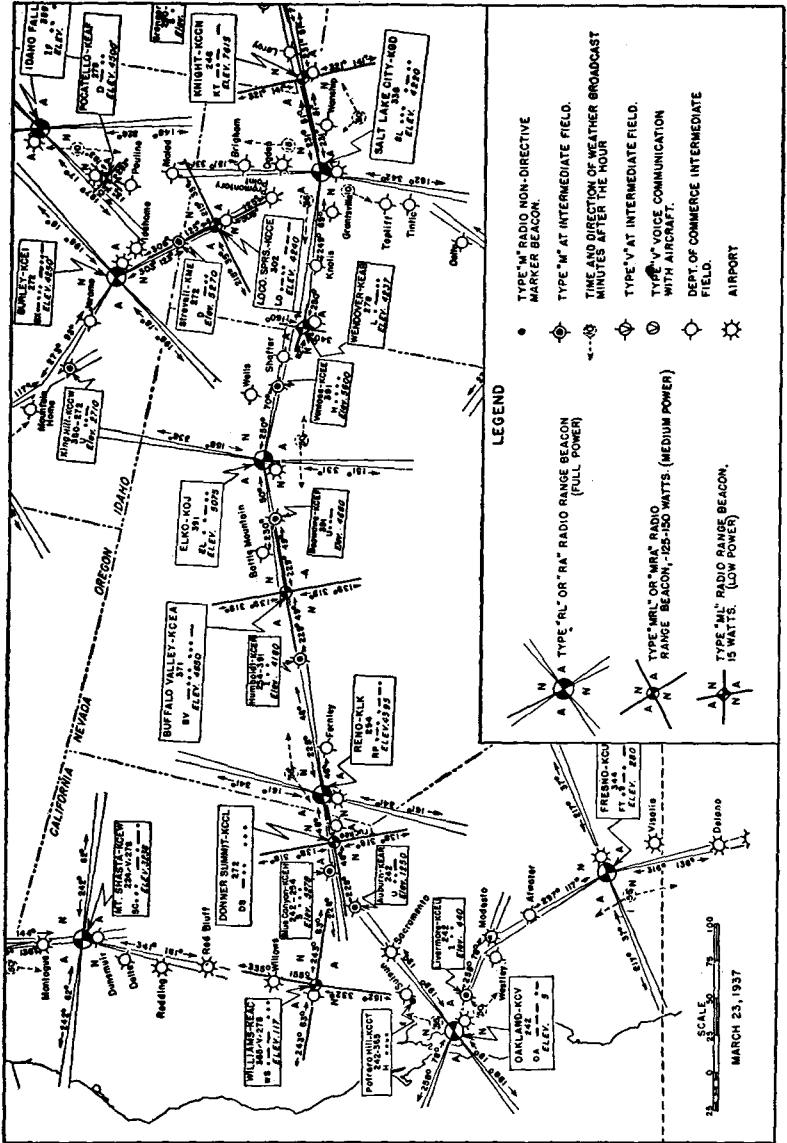
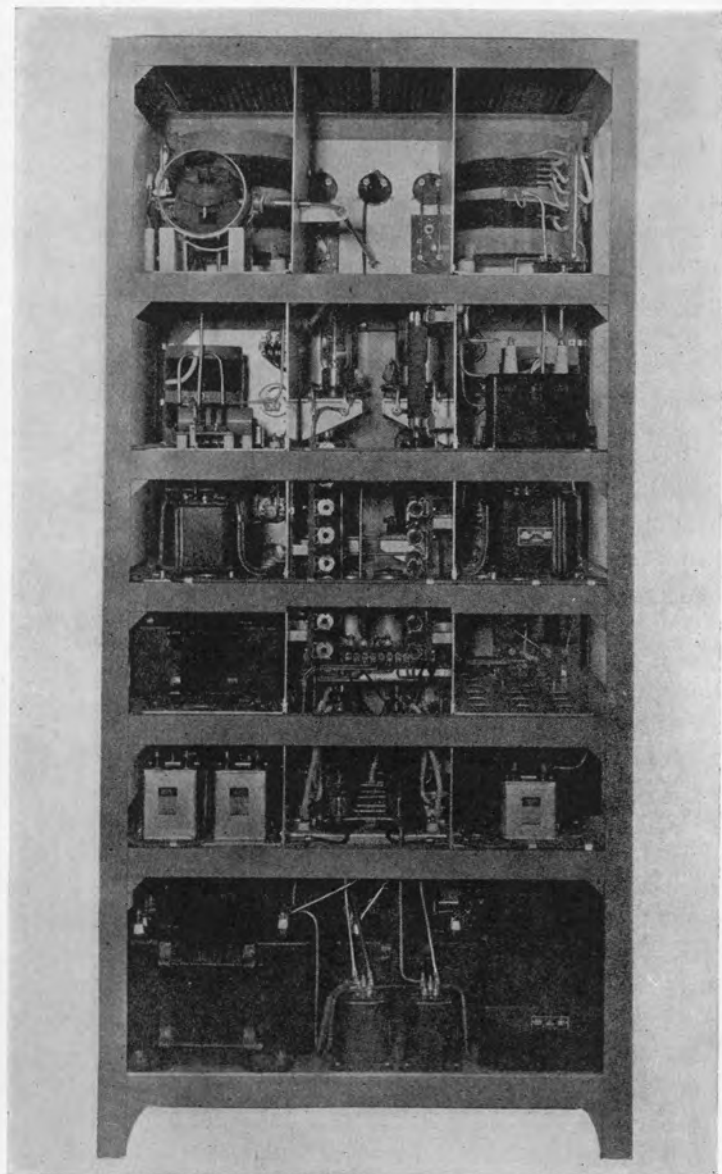


Figure 109A. Portion of Radio Facility Map—Northwest Quadrant  
 All azimuths magnetic-computed at station (elevation applies to adjacent airport or field)  
 (Courtesy Bureau of Air Commerce)



(Courtesy Radio Receptor Company, Inc.)

Plate XIV. SMRA Transmitter, Rear View

The variable inductors C1 and C2, shown in series with each vertical antenna, serve for tuning the antennas to the carrier frequency of the transmitter. In connection with alignment of the beacon courses with airway routes at arbitrary angles, very accurate tuning of the vertical antennas is required.

The schematic circuit of the component units utilized at a range beacon and weather broadcast station which employs T.L. antennas is shown in Figure 109. The transmitter, the link circuit (containing the lead from the transmitter, the link-circuit relay, and the primary windings,  $P_1$  and  $P_2$ , of the goniometer) are the same as when using loop antennas. The keying system is also the same. Secondary windings  $S_1$  and  $S_2$  of the goniometer, instead of being in series with the loop antennas, are now in series with local tuned circuits,  $S_1 L_1 C_1 T_1$  and  $S_2 L_2 C_2 T_2$  respectively, as shown in Figure 109.  $T_1$  and  $T_2$  are radio-frequency transformers each having two primaries and two sets of secondary windings. The secondary windings of each transformer are arranged to feed a pair of artificial line sections L.S. which connect to the transmission lines feeding the vertical radiators of the T.L. antenna system. The windings of  $T_1$  (and  $T_2$ ) are so arranged that the current flow is as shown by the solid arrows (shown for  $T_1$  only). Hence the input voltages to each pair of transmission lines are in phase. However, by reversing the connections of one line (say No. 1) with respect to the other (No. 2 in this case), the currents induced in the two vertical radiators of a pair (No. 1 and No. 2) are  $180^\circ$  out of phase.

The Radio Facility Map on page 254 can be studied at this time.

### **The (SMRA) Simultaneous Radio Range Beacon**

The policy of the Civil Aeronautics Authority provides for installation of the simultaneous transmission equipment through the Federal Airways System. Plates XIV and XV illustrate such equipment, an actual installation should be inspected.

**Operation.** To accomplish simultaneous transmission of voice and radiobeacon signals, advantage is taken of the modulation characteristics of radiotelephone transmission. Two separate

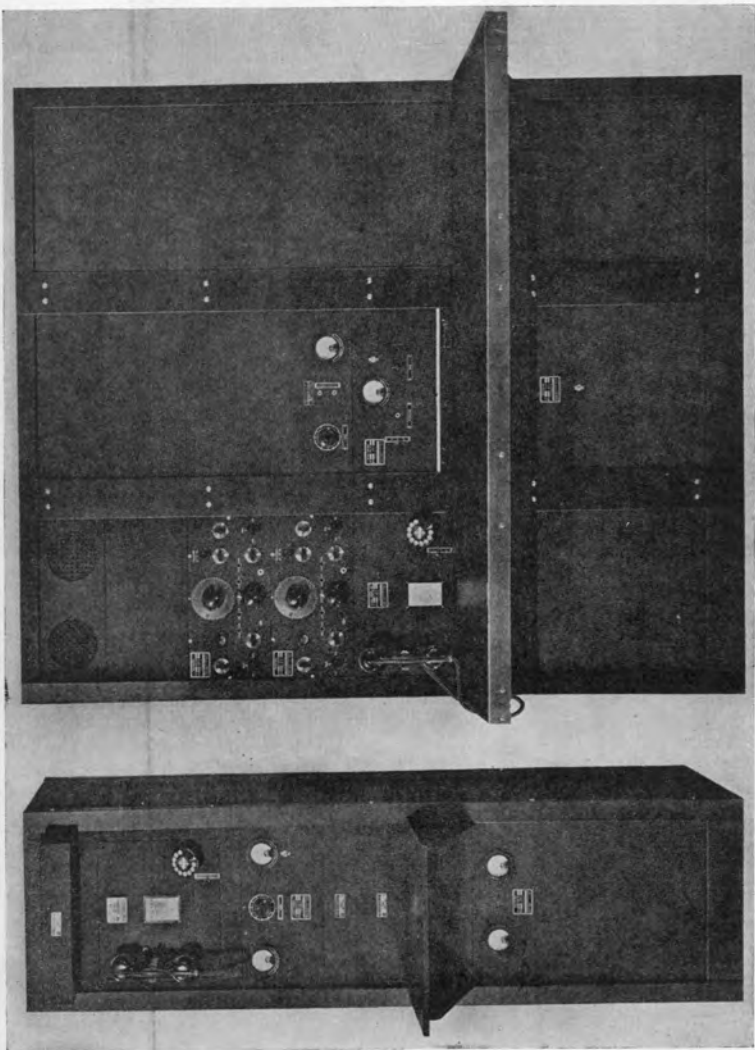


Plate XV. Remote Control Rack with Monitor Receivers and Local Control Rack for SMRA Radio Range Beacon  
(Courtesy Radio Receptor Company, Inc.)

transmitting antenna systems are generally used—the four-mast system described on page 252 and a fifth Adcock radiator in the middle of the four. The middle tower continuously radiates a circular radio-frequency field-pattern which is modulated by speech *only* during the weather broadcast. This carrier at all times forms a sideband to heterodyne the frequency of the radio range signals. The frequency of these latter signals is separated from the carrier frequency by 1020 cycles and radiated in an interlocked A-N manner from the four towers symmetrically dis-

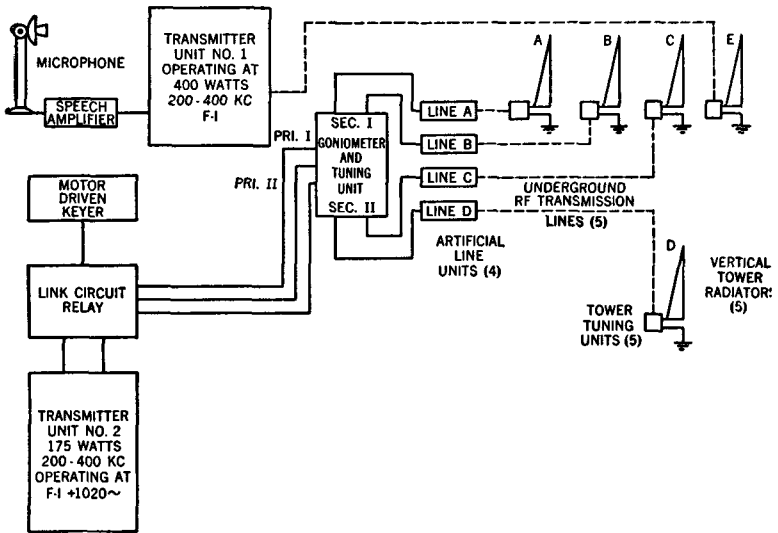


Figure 110. Schematic Layout of SMRA Radio-Range Installation

posed about the broadcast tower, so as to produce the radio range courses. Figure 110 shows an SMRA installation plan.

Fundamentally, the system used at Pittsburgh calls for transmission of all voice modulation frequencies from 50 to 4000 cycles, with the exception of 1020 cycles, which is the radio-range frequency at that station. Practical limitations make it necessary to eliminate the band of frequencies from approximately 830 to 1252 cycles from the speech transmissions. This can be done without noticeable loss of intelligibility, being accomplished with

filters in the speech input circuit to the modulator of the carrier transmitter. Voice is transmitted on 254 kc, modulated in the frequencies from 50 to 829 and from 1253 to 4000. Radio-range signals are transmitted on 254 kc with 1020 cycle modulation.

Filters are required in the airplane receiver as well—one to admit the radio-range signals and reject the voice, the other to admit the voice and reject the signals. (See page 360.)

The pilot selects his method of reception by means of a switch. With the switch in one position, he receives both voice and radio-range signals, in another he gets voice only, and in the third, radio-range signals only.

Ordinarily the pilot will have headphones connected, so that both voice and radio-range signals will be heard. Most of the time only the directional signals will be on the air, and he will be following the course by reference to them. At the same time, he will be sure of knowing whenever any voice broadcasts go on the air because these will be heard along with the range signals.

When a voice broadcast is heard, he may wish to pay close attention to it; therefore if he does not need the directional signals at the moment, the switch will be moved to the appropriate position so that he can concentrate on the spoken broadcast. On the other hand, if he is more interested in the directional signals and does not need information about the weather, he will change the switch to that position. Later, after the voice broadcast has been completed, he will change to the original position, so that he can continue to follow the range signals and in addition be aware of later broadcasts.

In flight tests it has been found that under ordinary atmospheric conditions the simultaneous station can be received satisfactorily even with the ordinary receiver not having filters. By concentrating on voice, or on directional signals, the pilot can listen to either one he chooses, even when both are heard together, just as the listener can hear music and the words of an announcer at the same time in a home radio receiver.

**Equipment.** The SMRA Beacon consists of a transmitter, a goniometer, five tuning units, a remote control unit, coaxial transmission lines, and five steel towers 125 ft. in height.



The four outside steel towers form the corners of a square having a diagonal of 600 ft. The ground plot required for such an installation is about 650 ft. square, and is situated about 3 miles from the airport. The extended center line of the most frequently used runway coincides, as a rule, with one of the diagonals of the square. The transmitter house is placed in the proximity of the center tower.

The purpose of the SMRA type of transmitter and its associated accessories is to emit beams in four directions, and simultaneously therewith permit broadcast of speech without interruption of the beam signal. To accomplish this, there are four units:

1. Power supply
2. Radio-frequency carrier channel
3. Modulator for carrier channel
4. Radio-frequency sideband channel

The transmitters, consisting of two radio-frequency channels, modulator, and rectifiers, are constructed in one unit—36 in. in width; depth of 30 in.; and height of 76 in. The frame is fabricated of aluminum angles 2 in. by 2 in. by 3/16 in.

The ventilation of the transmitter is by natural draft. The difference in temperature between the incoming and outgoing air, as measured at the tube chimney, is not more than 30° F., the transmitter operating at full rated output.

All tubes are made visible from the front of the equipment through a large transparent glass panel door. Interlock switches are used on the tube access door and terminal board.

In addition to switches, fuses, relays, and other control elements, eighteen meters are located on the front of the panel for indication of current and voltage in the various circuits of the transmitter.

**Power Supply and Rectifier.** The standard transmitter is designed to operate from a 200-volt, 50/60-cycle, single-phase supply. Other voltages and frequencies can be furnished. Two mercury-vapor type rectifiers are furnished, capable of supplying all power necessary for the proper and continuous operation of the transmitter. Separate power supplies are furnished for each channel to avoid cross-modulation.

The carrier channel can deliver not less than 400 watts of unmodulated radio-frequency power to any load between 50 and 200 ohms resistance when operating on any frequency within the band of 200 to 400 kc. The sideband channel can deliver not less than 275 watts of radio-frequency power on the same load as the carrier. Coupling is provided so that load may be varied from nearly 0 to 275 watts.

**R.F. Carrier Channel.** The carrier channel is used to feed radio-frequency power continuously to a single vertical radiator. This channel can be modulated with voice signals from the modulator. Simultaneously the sideband channel feeds power at a frequency 1020 cycles higher than the carrier-frequency into four vertical radiators symmetrically disposed about the voice broadcast radiator through suitable coupling to produce the conventional A-N radio range signals.

**Frequency Range.** The transmitter has a frequency range of from 200 to 400 kc; the settings are easily obtained between these limits when the transmitter is operating into a suitable load. These frequencies are continuously variable by means of dials on the front of the panel and three band-change links within the transmitter frame.

**Crystal Oscillator.** The carrier and sideband channels are crystal controlled. Crystals are of the low-temperature coefficient type and are mounted in holders similar to the U. S. Navy Type-C air-gap holders. Provision is made within the transmitter for mounting a spare pair of crystals.

**Buffer and Intermediate Amplifier.** The buffer and intermediate amplifier stages are designed to provide sufficient excitation for the power amplifier for efficient operation. The buffer stages are untuned. Power amplifiers are designed for efficient and stable operation.

**Modulator.** The modulator can modulate the carrier channel up to 70% peak when the audio input level to the transmitter is minus 6 db. The input transformer is designed to operate from a 600-ohm output of an amplifier.

**The Goniometer.** The unit consists of a single-section goniometer, a pad for cross-shifting, artificial lines, contactors for connecting this unit to the transmitter (space is left for an additional contactor in case the standby unit is desired), a keying device, a link circuit relay, and copper-oxide rectifiers for energizing the link-circuit relays. The goniometer includes provisions for resonating both its primary and secondary circuits.

It is mounted with its shaft horizontal. The scale mounted on the front of the panel reads from  $0^{\circ}$  to  $360^{\circ}$ .

Ammeters are inserted in each goniometer secondary, provided with shorting switches. They are carefully matched so that the ratio of the currents in the two secondaries may be accurately determined through windows in the front of the panel.

**Keying Device.** A keying device is mounted on the front of the panel and a link-circuit relay is provided for switching power from one set of antennas to the other, in accordance with Bureau of Air Commerce (now C.A.A.) Specification No. 673.

This link relay is operated by a full-wave copper-oxide rectifier unit.

Dimensions: Height, 76 in.; width, 30 in.; depth, 30 in.; weight, 1040 lb.

The antenna tuning units are designed to couple radio-frequency energy from a 70-ohm transmission line of the coaxial type to a tower radiator. In each tuning unit house, there is also equipment for feeding a 115-volt, 60-cycle power to the tower lights, and if necessary, sleet-melting resistors.

### **“Fan” Type Ultra-High-Frequency Radio Markers**

With the advent of a scheduled airline operation, particularly with the adoption of the present traffic-control system by the Civil Aeronautics Authority, there came the need for a positive means of accurately checking the position of aircraft when flying by instrument along the airways. The first and the most obvious method of determining position adopted by the airlines was that of locating the intersections of radio-range beams.

Flight tests of “Fan” type ultra-high-frequency radio markers for use along the airways as an aid to navigation and for utiliza-

tion in traffic control showed characteristics of the patterns that may be summarized as follows:

1. A vertical fan-shaped wall of signal with an elliptical cross-section, suitable for marking on radio-range courses and for the proper control of airway traffic, can be produced reliably by an array of four half-wave doublets in line, spaced  $\frac{1}{4}$  wavelength above ground and excited in phase.

2. The shape of the pattern in cross-section at 5000 ft. altitude is elliptical and has dimensions in the horizontal plane approximately 12 by 3 miles. Larger patterns of proportional dimensions are obtainable through the use of more transmitter power or greater receiver sensitivity.

3. A transmitter power output between 100 and 150 watts will cover all ordinary fan marker requirements.

4. Marker signals can be received properly in aircraft through the use of a half-wave belly antenna and a receiver having a sensitivity of 1400 microvolts.\*

5. The antenna system can be placed as close as 100 ft. to an airway beacon light or similar metallic structure without causing serious distortion to the pattern. Less than 100 ft. spacing is being investigated at a new installation at New Brunswick, N. J.

6. These markers have not yet been installed in mountainous terrain; however, knowledge at hand would indicate that no difficulty would be encountered if these markers were properly located, that is, located away from deep ravines and placed where the antenna is well within the line of sight of an airplane within the area to be served.

7. Proper spacing of these markers from the range station for air traffic control purposes will depend upon terrain and traffic operating conditions, and will vary from 10 to about 40 miles.

8. The keying of the signal in dashes to identify the particular leg of the range and to differentiate this marker from the Z marker is highly desirable.

9. The cost for each complete fan-type marker installation in quantities of 23 with an automatic standby transmitter and shelter is approximately \$3,500.

\* Measured by direct connection to a Ferris Microvolter, type 18B, 30% modulation.

This marker equipment has dual transmitters capable of automatically transferring to standby position in case of failure of the regular transmitter, and a special type of antenna and counterpoise designed to reduce the detuning effects of changing weather conditions such as rain, ice and snow.

### Ultra-High-Frequency Marker Transmitter

The Ultra-High-Frequency Marker Beacon is a transmitter supplied with additional equipment for the purpose of projecting an ultra-high-frequency pattern vertically. This gives the pilot flying over the course an indication, either visually or aurally, that he is over a particular location.

These beacons are located from 10 to 30 miles from an airport or hazard, and approximately on the center line over the route usually flown. The pattern projected into the air is so arranged that at from 3000 to 5000 ft. elevation, a field in the shape of an ellipse having a length of about 15 miles on its major axis and 3 miles on its minor axis is thrown directly across the course. The minor axis is usually on the course, thus enabling the pilot to fly 4 or 5 miles to the right or left of the course and still locate his position.

The station consists of : two transmitters, a shielded transmission line, an antenna array, counterpoise, tubes, crystals, spare parts.

The transmitters operate at a frequency of 75 Mc with a 100-watt output, 100% modulated. Each transmitter has a monitoring circuit which starts the standby transmitter when for any reason the output of the transmitter which has been running drops to 70% of its normal operation, thus insuring continuous service.

The antenna consists of hard copper tubing,  $\frac{3}{4}$  in. outside diameter, supported at seven points. The antenna is placed  $\frac{1}{4}$  wavelength above the counterpoise. Receiving antenna is shown on page 441.

Dimensions of each transmitter : Height, 76 in. ; width, 24 in. ; depth, 24 in. ; weight of transmitters, 1500 lb. ; weight of counterpoise, 1340 lb.

### Cone of Silence (Z) Marker

A reliable beam of radio energy directed skyward and supplementing the familiar "cone of silence" of a radio range beacon was developed by the Bureau of Air Commerce (now C.A.A.) and was designated as "Z" type. The present equipment is capable

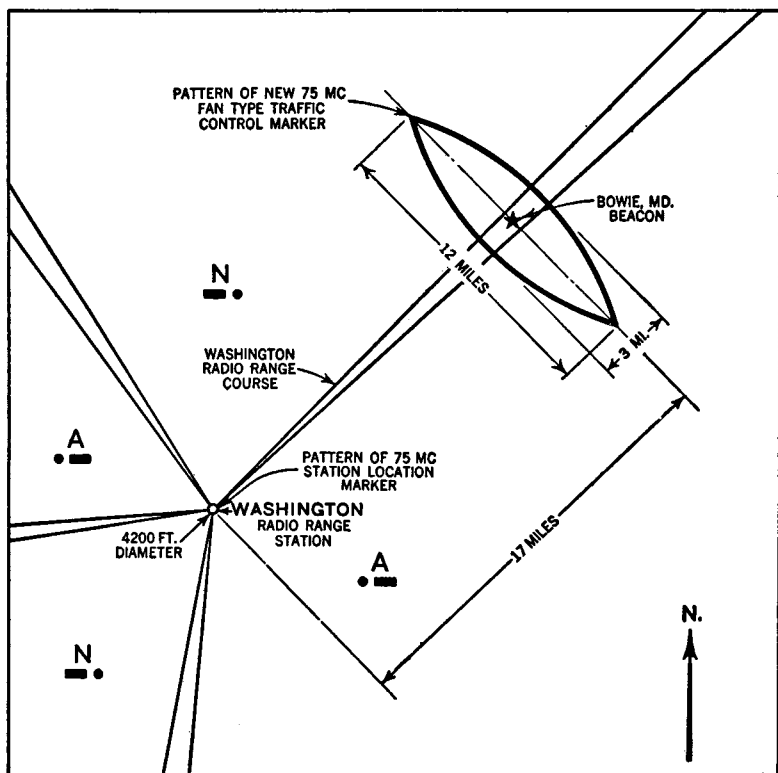


Figure 111. Relative Patterns at 5000 ft. Altitude of Z Marker at Range Station and Experimental Fan Type Marker at Bowie, Md.

of a power output of about 5 watts. This can be increased so that the pattern will extend upward to about 9000 ft.

**Antenna Arrangement.** The transmitting antenna array consists of four horizontal half-wave doublets supported one-fourth

wave above ground and pointing in four directions from a common center. These four antennas are excited at the common center through a special arrangement of down leads that provides balanced currents in all four antennas and a phase difference of 90 electrical degrees between the currents in adjacent antennas. To properly monitor the operation of this antenna and transmitter, some of the radio-frequency signal is rectified, filtered and coupled to the control line leading from the range station to the control station at the airport. At the control station the signal is used to operate a meter which clearly indicates to the operator the condition of the transmitting equipment. (See Figure 111.)

Adjacent fan markers along the airways probably will have differently keyed signals. The "Z" markers, which are being installed at radio-range stations as a supplement to the cone of silence and which operate on the same frequency as the fan markers, will not be keyed. They will have a steady signal to differentiate them from fan markers. All markers will be received on a pretuned marker receiver. The characteristic tone of each as heard in the pilot's headphone also will be alike (3000 cycles), the only difference being in the keying.

#### QUESTIONS

116. Clearly explain the essential difference as to purpose between radio range beacons and radio direction finders.

117. Name and give the designations of four different kinds of radio-range stations.

118. Describe in considerable detail the principles of operation of a radio range beacon.

119. What is the function of the goniometer?

120. Describe the most modern antenna system used at radio range stations.

## CHAPTER 10

### RADIOTELEPHONE TRANSMITTERS

**Elementary Principles.** Radiotelephone transmitters operate on the same basic principles as CW radiotelegraph sets, the essential difference between them being that the sending key is replaced by a microphone in order to transmit voice.

Speech modulation of radio-frequency currents radiated and received through space constitutes radiotelephony. An alternating current is said to be modulated when the amplitude of its oscillations is varied by suitable control. The voice, when impressed to vary the amplitude, or modulate the current, does so at an (audio) frequency equivalent to from 300 to 2000 cycles per second. As the power radiated from a simple antenna increases with the square of the frequency, a much higher (radio) frequency of from 25,000 to 200,000 or more cycles per second is used as a "carrier" of the sound waves caused by speech. This carrier frequency multiplies the modulating audio-frequency waves. As the strength of the received voice tones depends not only upon average radio-frequency amplitude, but also upon the degree of modulation, the voice should produce the greatest feasible \* change in the antenna circuit for best results. When this occurs, 100% carrier current modulation has been accomplished.

The simplest form of theoretical radiotelephone would comprise a ground terminal, microphone, source of high frequency, with an inductance coil and antenna, all connected in series. Considering the capacity of the ground and antenna as fixed quantities, the circuit would be tuned by the inductance so that its natural frequency would be equal to that of the power source. The antenna current would then be of constant amplitude.

**Practical Considerations.** In addition to a suitable power source and antenna system, a workable transmitter must have

\* The bad effect of *overmodulation* is described on page 269.



a method of modulation, a speech input circuit, audio-frequency amplifiers, and radio-frequency amplifiers. The speech amplifier circuit includes all of the audio amplifier stages between the microphone and the stage whose output actually modulates the r. f. output of the transmitter. These audio stages may all operate as Class A amplifiers unless a Class B modulator is used, in which case all of the stages preceding this Class B modulator may be of the Class A type amplifier service. (Amplifiers, as to classification, are explained on page 177.

If a Class B modulator is selected by the designer, one or two of the stages preceding the modulator may be Class AB. When the Class B modulator develops 100 watts or more (audio-frequency) they are usually excited by Class AB amplifiers because the grids of Class B amplifiers used as modulators require considerable power.

A stage from which power is taken to excite a following stage is called a *driver*.

## Modulation

**Principles.** Amplitude modulation for voice transmission is defined as the process by which the amplitude of the transmitted r. f. wave is varied in accordance with the sound waves (of the voice) which actuates the microphone.

The degree of modulation is usually expressed as a percentage. The modulation factor, expressed in percentage, is 100 times the maximum departure (positive or negative) of the envelope of a modulated wave from its unmodulated value, divided by its unmodulated value.

Modulation is called *linear*, or is said to be undistorted, when the average amplitude of the modulated wave is the same as its unmodulated value as long as the modulating signal is also symmetrical. This is because the increase in amplitude during the first half of the modulation cycle is offset by an equal decrease in amplitude during the second half of the modulation cycle.

**Sidebands.** The transmitted radio-frequency wave is the *carrier wave*. When the carrier wave is modulated, additional radio-frequencies in pairs are produced at a frequency slightly above

and below that of the carrier frequency. As these waves occupy a position in the frequency band, or spectrum, numerically adjacent to the frequency of the carrier wave (as 13 and 15 are adjacent to 14) they are called *sidebands*. The frequency of one sideband is numerically equal to that of the carrier wave plus the frequency of audio (voice) modulation frequency; that of the other sideband is the carrier frequency minus the modulation frequency. There is one pair of sidebands for each frequency component in the modulating signal. Therefore the frequency band occupied by the transmission is equal to two times the highest

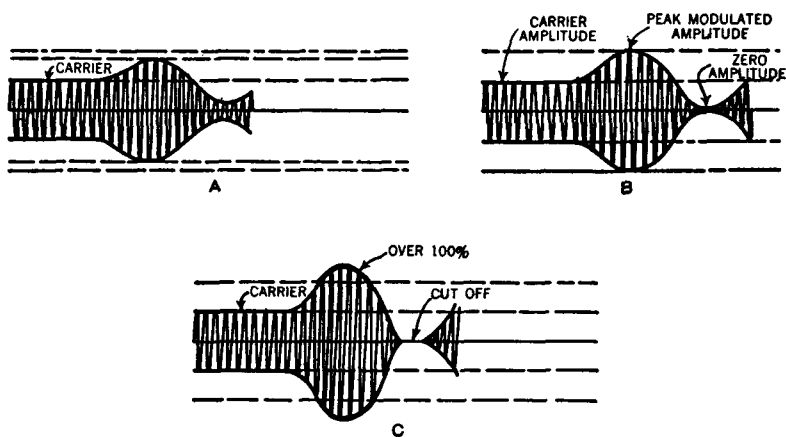


Figure 112. Wave Forms: Amplitude Modulated Waves

A, under-modulated (less than 100%). B, exactly 100% modulation. C, overmodulated.

modulation frequency used. More than 100% modulation creates high harmonics as a result of the distortion of the carrier wave form or envelope; this spurious radiation will broaden the wave, causing illegal interference. (Overmodulation is prohibited for this reason by the Federal Communications Commission.)

It is important to note that all of the speech conveyed by the modulated wave is contained in the sideband components.

**Wave Forms.** Figure 112A illustrates the conventional way of picturing modulated waves. In discussing modulated waves the wave envelope is the outline of the radio-frequency cycle

peaks. It probably will pay the reader to study Figure 112 and other similar illustrations together with the phraseology used in referring to them. Notice that there are two peaks, one for the maximum amplitude (the positive peak); the other for the minimum amplitude (the negative peak). In C the *positive* percentage is more than 100; the *negative* percentage can never be more than 100 because the amplitude can never be less than zero. This condition C is what is known as distortion of the wave envelope.

**Amplitude and Power.** Power is proportional to the square of the current. With 100% modulation, the amplitude is doubled; therefore the instantaneous *peak power* is four times the unmodulated power. The *average* power will be 1.5 times the unmodulated power in the case of continuous modulation by a single pure tone imposed on the microphone. The additional power which is equal to half the power in the carrier alone is divided equally in the two sidebands. An ammeter would show 22.5% greater current with 100% modulation than with the carrier alone. This is because the current is proportional to the square root of the power in the circuit. As pure tone or pure sine wave modulation is not obtainable in practice, these mathematical power relations cannot be attained.

**Modulation Capability.** In some sets distortion occurs at less than 100% modulation, as in a transmitter whose output power could not be quadrupled instantaneously on the modulation peaks. Modulation capability is defined as the maximum percentage modulation that can be attained without objectionable distortion. This must be high for the set to be efficient. Example: a 10-watt carrier, 100% modulated, is almost as effective as a carrier having four times the power, 50% modulated.

As with CW radiotelegraph sets, frequency stability is extremely important. Distortion, and the resulting radiation of abnormal sidebands, cause worse interference than the key clicks discussed on page 204.

Most aircraft radio transmitters use a radio-frequency system whose carrier frequency does not vary while modulation is taking place. These transmitters are adjusted so that overmodulation, or "lop-sided" modulation, does not occur.

**Basic Modulation Systems.** There are four different methods of modulation which have been successfully used :

1. Absorption method
2. Grid-bias modulation
3. Suppressor grid modulation
4. Plate modulation

Although plate modulation is most widely used, all systems will be explained.

**Absorption Method.** In applying this method, a microphone is connected in series with the antenna circuit. The antenna current flows through the microphone, its amplitude depending partly on the resistance of the microphone. The resistance of the microphone is changed by the effect of a sound wave and so the antenna is modulated as shown in Figure 112. The form of the modulated current is alike or symmetrical on each side of the zero (reference) line, because both halves of the cycle of current are affected by the microphone. This method is called *absorption method* because modulation is accomplished by absorbing power from the antenna. The amount of absorption varies with the intensity of the sound impressed. In using this method the microphone may be coupled directly across a few turns of the antenna inductance or it may be coupled inductively. Inductive coupling has this advantage: it is possible to match the resistance of the microphone to that of the antenna; however, the absorption method is used only with small outputs and the degree of modulation possible is low. This method is not approved for amateur purposes because it causes frequency "wobulation."

**Grid-Bias Modulation.** This is simple in application but somewhat unstable in action and so is used mostly in transmitters of low power. In the grid-modulation method, the speech frequencies are introduced into the grid circuit of the vacuum tube through a modulation transformer which serves to isolate the high voltages and also to match the impedance of the circuits. This method utilizes a variation of the grid-bias voltage of the oscillator tube in a self-excited system, or the modulation of the output current of the exciter in a separately excited system.

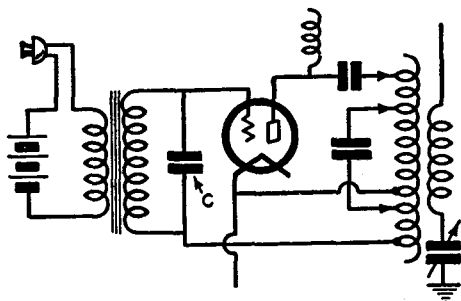


Figure 113. Telephone Transmitter, in Its Elemental Form, Arranged for "Grid" Modulation

See Figure 113. This shows one arrangement for grid-circuit modulation applied to a Hartley oscillator. When sound waves strike the microphone, the voltage induced in the secondary winding of the modulation transformer varies the grid voltage at an audio-frequency rate. This produces corresponding variations in the antenna current. One disadvantage of this method is that the output current is not affected to any considerable extent by changes in the grid voltage over the range in which stable operation takes place; also, the carrier frequency varies with the grid voltage. If the grid voltage is reduced below this range the tube

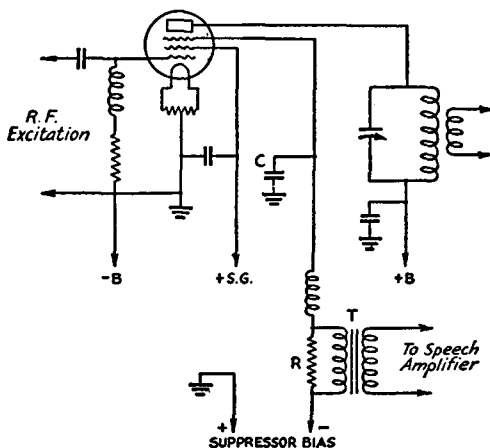


Figure 114. Suppressor-Modulated R.F. Amplifier

stops oscillating and the antenna current drops to zero. A fair degree of modulation is possible, however, by fine control of the grid lead and the load on the tube. This method of modulation is also frequently used in operating the tube as a Class C amplifier, supplying both carrier and audio to its grid input.

**Suppressor Grid Modulation.** In this system the pentode operates, essentially, as a Class C amplifier, and when properly adjusted the output current varies directly with the suppressor-grid voltage. In comparison with the grid-modulated system, it takes much less audio-frequency voltage for excitation. Figure 114 shows a circuit for suppressor grid modulation, using a pentode type tube. As in control-grid modulation, the modulating signal is applied to a grid. However, the r.f. excitation and modulation signals are applied to separate grid elements, one of which is the suppressor grid. It is probably a better system than the control-grid circuit and has a similar operating technique.

**Plate Voltage Modulation.** This is used mostly in large transmitters; more audio-frequency amplification is required than with the grid-voltage method. Modulation is possible by this method because the value of the oscillating current is proportional to the plate voltage over a wide range. The method may be applied in any oscillator or amplifier using a tuned-circuit coupling, providing there is sufficient excitation in the grid circuit.

In the simplest application of this method, the microphone circuit is coupled through a modulation transformer to the plate circuit of an oscillator tube. In operation, the audio-frequency voltage induced in the secondary winding of the transformer varies the plate voltage, and consequently the antenna current. This arrangement, however, is applicable only to low-power circuits, because a microphone circuit is not designed to provide the power necessary for the plate circuit of the tube, as a complete fluctuation of the plate current from zero to double current requires an amount of power which is equal approximately to that supplied to the oscillator. The modulating device must either provide this power or control its supply, as the microphone circuit is inadequate in this respect; its effect must be amplified by another tube called a modulator tube.

The action of this modulator tube may be regarded either as a speech-controlled amplifier or generator of speech-frequency power or as a speech-operated resistance which, when inserted in series with the plate source and the oscillator tube, causes the voltage of the latter to vary. Usually these are classified as separate methods, the first being called *constant current* or the Heising system, and the second *constant voltage*, while another term sometimes used is that of *transformer method*.

Refer to Figure 115. In this modulation method the tube O is an oscillator with its associated circuit, M is a *modulator tube*, B is the source which provides power to both tubes through a large

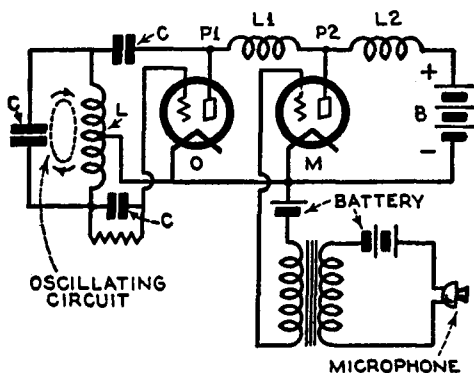


Figure 115. Radiotelephone Transmitter Circuit, Arranged to Utilize the Heising System of Modulation

choke-coil L2, while L1 is a choke-coil which is used to prevent radio-frequency currents from entering the modulator-tube circuit. The modulator tube does not supply any radio-frequency power to the oscillating circuit LC. The plate current of the modulator tube is controlled by means of the grid-bias voltage, so that it has a value equal to the plate current of the oscillator tube when it is in oscillation.

In operation, if the negative grid-bias voltage of the modulator tube is increased, the plate current is reduced and there is a small decrease in the battery current. Then when the current flowing in the choke-coil L2 is decreased, an induced voltage is set up which tends to maintain a constant flow of current; this induced

voltage is in the same direction as the voltage of the battery; as a result, there is an increase in the voltage on the plates of the two tubes, also an increase in the oscillating current in the circuit LC.

If the negative grid-bias voltage on the modulator tube is decreased, because the grid-bias voltage becomes more positive, the plate current from the battery increases, and a voltage is induced in the choke-coil  $L_2$ , which is in a direction to oppose the voltage of the battery. Therefore, the voltage on the plates of the two tubes is decreased, and the oscillating current is reduced.

The Heising method of plate voltage modulation is employed in the transmitter, the circuit of which is shown in Figure 116. The part of the diagram enclosed by the dotted line is the master-oscillator circuit shown in Figure 75, page 199. The remainder of the circuit is called the modulating system. B is a 6-volt battery. It furnishes power for the modulating system through the microphone M and the primary  $T_1$  of the step-up transformer. The action of the microphone, influenced by sound waves, causes variations in the current flow in the modulating circuit. These variations in turn cause large voltage variations in the secondary  $T_2$  of the transformer. The voltage variations are impressed on the grid of tube No. 1. They correspond to the vibrations of the microphone diaphragm. They also control the voltages impressed on the plates of tubes Nos. 1 and 2 through the action of the choke. Both tubes should be of the same size and characteristics. Coated-filament tubes are preferable for transmitters. The choke should have maximum inductance combined with minimum resistance.

**How to Check Modulation.** The percentage of modulation may be determined by connecting an a.c. voltmeter calibrated in microvolts and used in conjunction with a specially designed transformer in the plate circuit of the modulator tube. The use of an oscillograph is recommended in checking modulation.

**High and Low-Level Modulation.** When the final r.f. stage is modulated, the modulation system is called a high-level system, so named because modulation takes place at the highest power level in the transmitter.



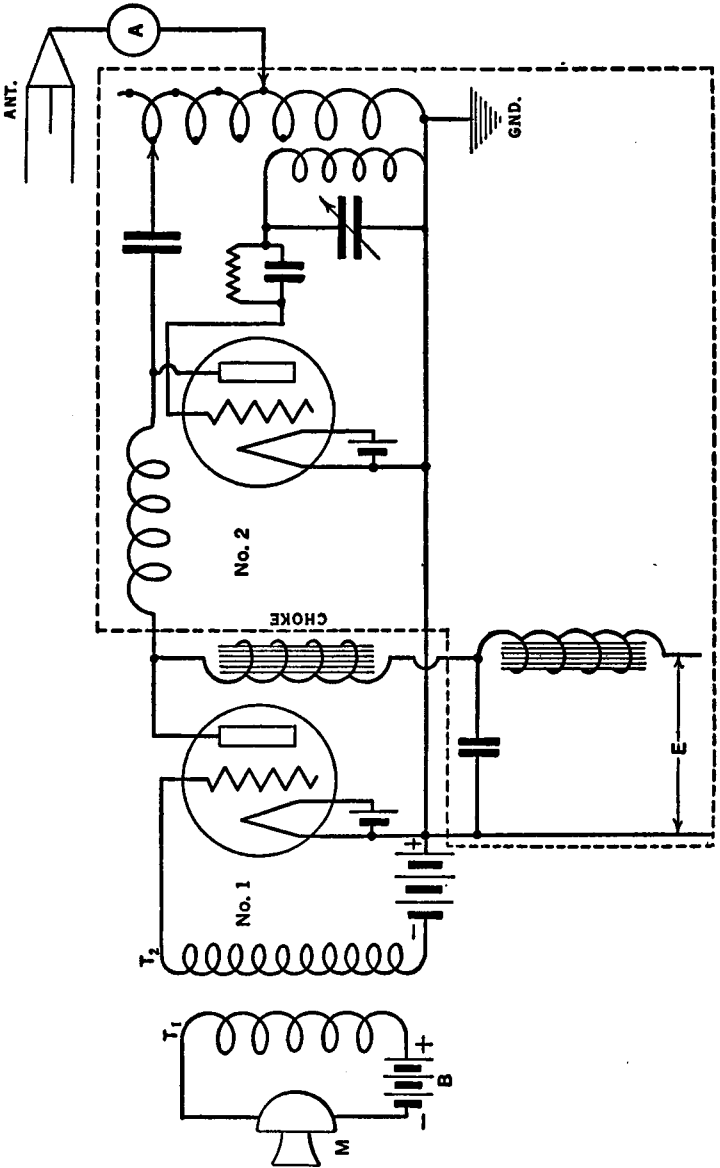


Figure 116. Radiotelephone Transmitter; Heising Circuit

When the modulation takes place in the intermediate (i.f.) stage, the system is termed low-level. Amplifiers which are used to increase the power output from a low-level stage are operated as linear amplifiers (defined on page 122), which are operated under Class B conditions. (See Figure 117.) R is a "load" resistor. It tends to improve the r.f. voltage regulation of the modulated exciter's plate circuit. The plate efficiency is about the same as with grid modulation.

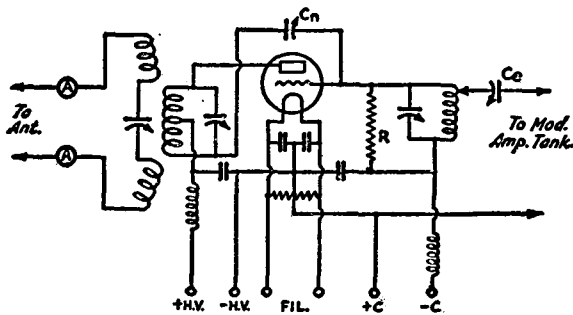


Figure 117. Circuit of a Single-Ended Class-B Linear R.F. Amplifier

The grid-regulation resistor, R, should be capable of dissipating a fair proportion of the exciting amplifier's power output. The excitation can be regulated by the coupling condenser,  $C_e$ , or by adjustment of the regulating resistor, or a tap on the exciting amplifier tank coil. The circuit values can be as usual for the frequency and power.

## Speech Input Circuits

**Single-Button Carbon Microphone.**<sup>152</sup> A microphone consists of an elastic diaphragm (usually thin steel) bearing against a mass of carbon globules, both suitably enclosed. It is actuated by sound vibrations, producing corresponding variations in an electric current. The carbon granules are a fixed resistance in the circuit while at rest. Sound waves, impinging on the diaphragm, delicately vary the resistance, thereby modulating the natural or carrier frequency of the circuit. (See Figure 118.)

Sound is produced by a body in a state of vibration. A vibrating body will set up longitudinal waves in the surrounding medium. The motion of each particle in the medium is the same as that of the wave. The periodic movement of these particles produces alternate regions of compression and rarefaction. When

sound waves impinge upon the face of a diaphragm, it will be set into a state of vibration by the alternating compressions and rarefactions of the air, which is the surrounding medium. The compressions tend to displace it; the rarefactions tend to return it to its state of rest. If its natural period of vibration is of the same frequency as the impressed sound waves, the amplitude of vibration will be a maximum. If it does not resonate to them at all, it will not be very sensitive but it will react just the same. As

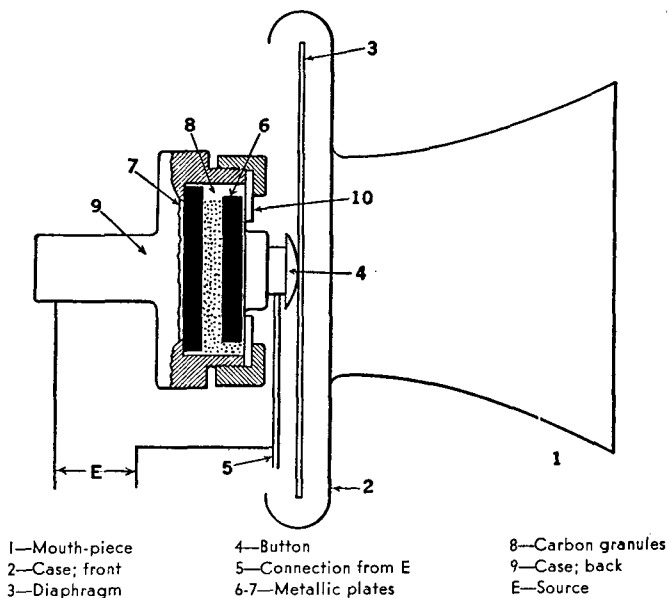


Figure 118. Microphone Transmitter

a matter of fact, a highly resonant diaphragm is not desirable for radio purposes, as it tends to produce distortion. Within ordinary limits, the vibratory motion of the diaphragm is practically in synchronism with the impressed sound waves. This vibratory motion may be imparted to another body in contact with the diaphragm or the diaphragm itself may serve as a secondary source of sound.

In the microphone transmitter, the motion of the diaphragm alternately unites and separates the carbon granules slightly. The

electrical resistance of these granules is higher when they are loose—not under compression. When in this state, a slight increase of pressure will cause a decrease of electrical resistance. In this way, the current flow will be easily varied by the sound waves of the voice striking the diaphragm when a microphone transmitter is supplied with a direct current. Figure 118 illustrates the arrangement of the component parts of a typical microphone transmitter. When the sound waves strike 3, the resulting motion is imparted to 6. The motion of 6, back and forth, varies the pressure on 8 and the resistance across E is varied.

If the average resistance of a microphone transmitter is between 10 and 15 ohms, it is classed as a low-resistance transmitter; if from 30 to 60 ohms, it is called a high-resistance transmitter. They are also classified as to their current-carrying capacity. If the current carried is much more than 0.2 amperes, there is a tendency for the carbon granules to arc. In this case, a frying noise is heard and the carbon becomes red hot.

**Double-Button Carbon Microphone.** Figure 119 shows how a double-button microphone is connected. These buttons, which are cups of carbon granules, located on each side of the diaphragm, are connected to the two ends of the primary winding of the microphone transformer. The diaphragm is connected in series with a battery to the center of the winding, shown in the circuit. In the better grades of "mikes" the diaphragm is stretched so that its natural resonance frequency will be well above the normal audio-frequency range. However, unstretched metal or graphite diaphragms are actually more often used than the stretched diaphragm—the latter having improved frequency characteristics which in most cases are more desired than sensitivity. RCA transmitter AVT-1 (page 291) has a double-button mike.

**Condenser Type Microphone.**<sup>50</sup> In this type microphone there is a condenser consisting of one fixed plate, the other plate acting as a diaphragm. Several hundred volts d.c. are applied between the plates of the condenser. As the capacity of this condenser is varied by the vibrations of the sound waves impinging on the diaphragm, a corresponding voltage drop is produced in the high

resistance which is placed between the d.c. voltage source and the microphone. (See Figure 120.)

**Moving-Coil Microphone.**<sup>159</sup> In this type microphone there is a coil attached to the back of the diaphragm and located in the field of a permanent magnet. As the diaphragm is made to vibrate by the speaker's voice, the turns of the coil cut across the magnetic flux, causing a voltage to be induced in them. This mike is comparatively sensitive, quite rugged, and generally free from hiss.

**Piezo-Electric Microphone.** Rochelle salt crystals cemented together are used in this type microphone. There is a pair of these

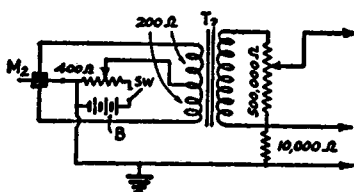


Figure 119. Double-Button Carbon Microphone

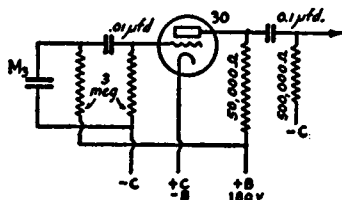


Figure 120. Condenser Microphone

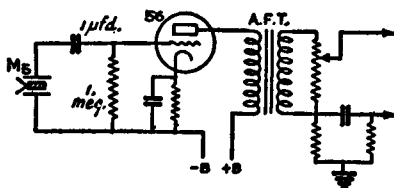


Figure 121. Crystal-Type Microphone

Figures 119 to 121 show speech input circuit arrangements for three generally used types of microphones:  $M_2$ , double-button carbon;  $M_3$ , condenser;  $M_5$ , crystal.

crystals, with plated electrodes. Figure 121 shows the crystal mechanically coupled to a diaphragm. The sound waves which actuate the diaphragm cause the crystal to vibrate mechanically, thereby generating a corresponding alternating voltage between the electrodes. Notice that these electrodes are connected across the grid circuit of an amplifier tube.

**The Microphone Circuit.** In Figure 138, page 329,  $M$  is the microphone transmitter,  $T_1$  the primary and  $T_2$  the secondary of

an iron core step-up transformer, while  $R$  represents the load.  $B$  is the source of a steady e.m.f. While the diaphragm is motionless, very little steady current will flow in this primary circuit because the resistance is fairly high; consequently no e.m.f. will be induced in the secondary  $T_2$ . When the transmitter resistance is varied by a voice, the primary current varies which induces an e.m.f. in the secondary, causing a.c. to flow there. This a.c. varies in amplitude, frequency, and wave form with the sound waves from the voice. Unless distorted, the variation of the amplitude will be in proportion to the intensity, the variation of the frequency to the pitch, and the variation of the wave form to the quality.

This alternating e.m.f. in the secondary circuit is suitable to be impressed into a radiotelephone transmitter and amplified.

**Speech Amplifier System.** The voltage variations in the secondary of the modulation transformer,  $T_2$  of Figure 116, is not usually enough to produce sufficient modulation of the master oscillator. One hundred percent modulation can be obtained when the antenna current is varied from zero to the maximum value. At least 60% modulation is required for satisfactory results. To increase modulation, speech input amplifiers are employed. A single-stage speech amplifier system is shown in Figure 122.

$M$ ,  $B_1$  and  $T_1$  comprise the microphone circuit.

$T_2$ , the grid of No. 1 tube, and  $B_2$  constitute the amplifier input circuit.

$B_3$ , CHOKE 1, and the filament-plate of No. 1 tube make up the output circuit of the amplifier.

The variations of current through CHOKE 1 produce a varying e.m.f. across this coil which is impressed on the grid of the modulator tube (No. 2) through condenser  $C_1$ . A certain negative voltage is placed on the grid of No. 2 tube to produce the best voice reproduction. This is accomplished through CHOKE 2 which permits the negative d.c. voltage to be impressed on the grid while preventing the audio or amplified voice-frequency voltages from being short-circuited through the battery  $B_4$ . The

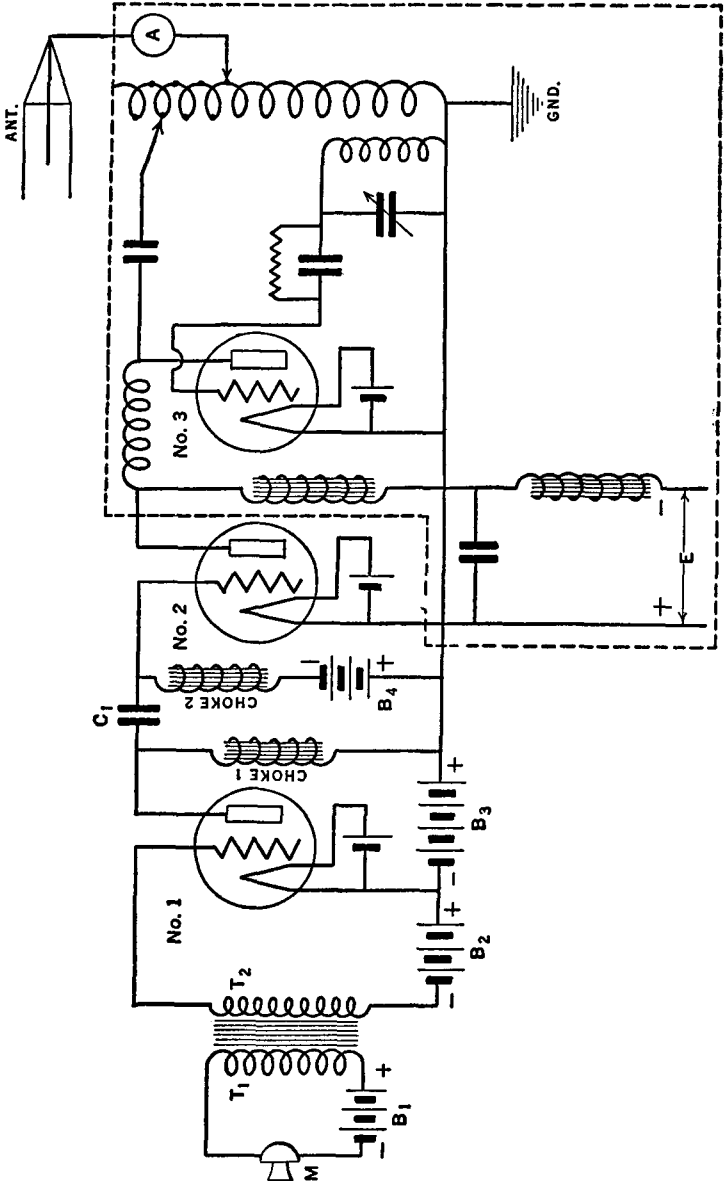


Figure 122. Single-Stage Speech-Amplifier System

inductive values of the chokes shown will be different for each type tube that is used.

**Microphone Characteristics.** The sensitivity of a microphone is really the electrical output for a definite speech input intensity. This characteristic governs the amount of amplification required between the microphone and the modulator. Of course, the output from any microphone depends somewhat upon the characteristics of an individual's voice. Another thing which affects microphone output is the speaker's distance from the mouthpiece. Microphone performance is adversely affected by engine noises.

Assuming a normal speaker's lips to be within 6 in. of a good quality single-button mike, its output will be from 0.1 to 0.3 volt

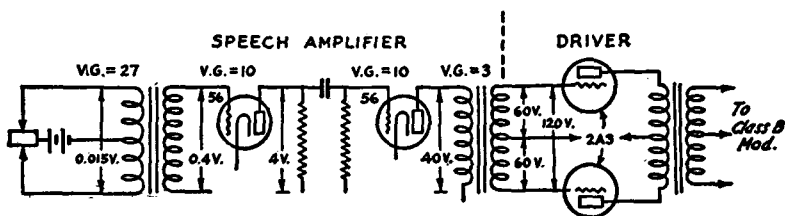


Figure 123. Simplified Diagram of Speech-Amplifier and Driver Stages, Showing Approximate Voltage Gain and Peak Voltage per Stage

across a resistance of from 50 to 100 ohms, which is the normal resistance of the primary winding of the microphone transformer. With the step-up of the transformer, a peaked voltage of between 2 and 3 volts across about 100,000 ohms can be assumed available at the grid of the first tube.

The two-button microphone has less sensitivity than the single-button type. There will be a peak voltage of from 0.4 to 0.5 volts (across 100,000 ohms) available at the grid of the first speech amplifier tube.

The sensitivity of the other type microphones discussed here varies widely. In every case the operating conditions recommended by the manufacturer should be followed if the best possible performance of the mike is to be secured.



Figure 123 is presented for the purpose of showing the typical voltage gain of a model, but not necessarily an actual speech-input hook-up. Notice how a driver, defined on page 283, is used.

### **The Western Electric Airport Transmitter No. 10A**

The Western Electric Airport Radio Telephone Equipment is used to transmit landing instructions, weather, and general information to airplanes in the vicinity. It comprises the radio transmitting apparatus necessary at an aeronautical ground station to provide means for communicating with airplanes by radio telephone in the frequency range 230 to 500 kc.

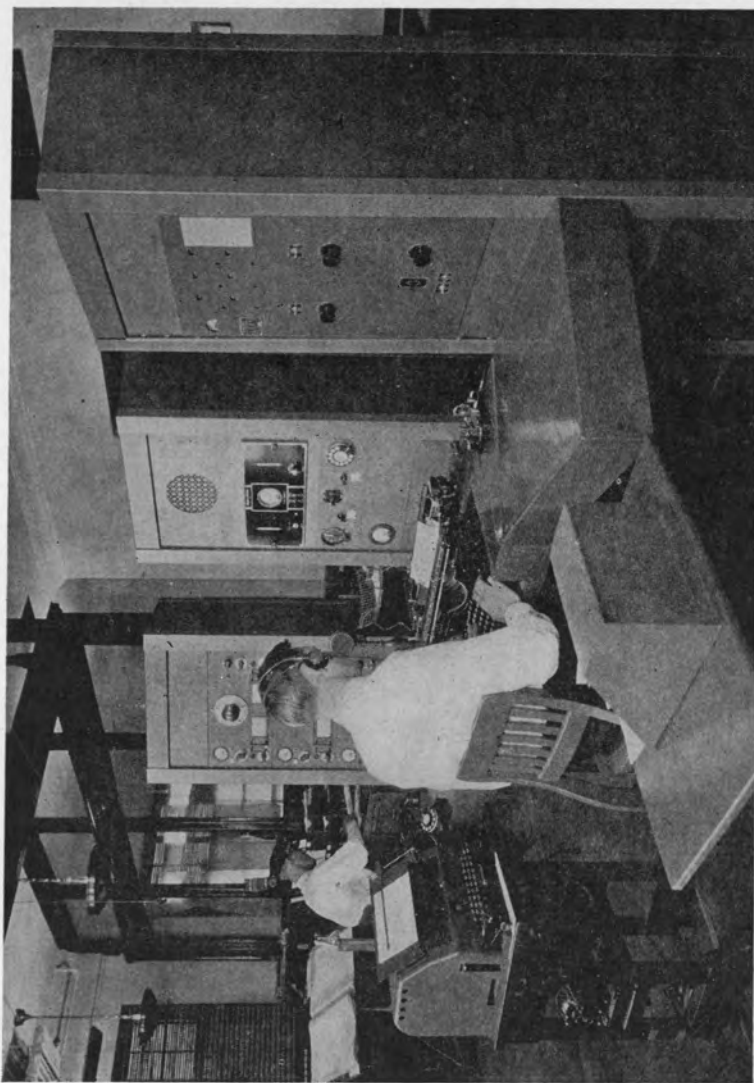
The equipment consists essentially of a Western Electric No. 10A Radio Transmitter and associated power and control equipment. The radio transmitter is capable of supplying to a suitable antenna 10 watts of carrier power. When speech signals of normal value are applied to the input of the radio transmitter, they cause substantially complete modulation of the carrier. For this condition the peak power input to the antenna is approximately 40 watts. Power for the radio transmitter may be obtained from a 100 to 120-volt, 50 to 60-cycle supply circuit. Speech signals are obtained from the No. 1120DA Desk Stand. The transmitter current for the desk stand is supplied by a dry-cell battery.

Figure 124 shows the circuit. Plates III and XVI illustrate a portion of this equipment. Complete information for the adjustment and operation of each unit is given in the separate instruction bulletin supplied with that unit by the Western Electric Company.

The transmitter employs five Western Electric vacuum tubes in the following manner: one No. 268-A vacuum tube as a crystal-controlled oscillator, one No. 254-A vacuum tube as a modulating amplifier, one No. 252-A vacuum tube as an audio amplifier, two No. 253-A vacuum tubes as rectifiers for the plate supply of the other tubes.

**Description of Circuits.** The circuits of this transmitter may be divided into three groups: radio-frequency circuits, audio-





(Courtesy Western Electric Co.)

Plate XVI. Western Electric Transmitting Equipment

frequency circuits, and power-supply circuits. These circuits are shown on the schematic diagram, Figure 124.

**RADIO-FREQUENCY CIRCUITS.** The radio-frequency part of this transmitter is of the Oscillator-Modulating Amplifier type. It makes use of two vacuum tubes, one as a quartz-crystal-controlled oscillator and one as a modulating amplifier. These circuits appear in the upper right-hand portion of the schematic diagram (Figure 124).

The oscillator tube (V1) with associated apparatus, including the quartz plate (Y1), is the source of radio-frequency oscillations. The frequency of these oscillations is very accurately controlled by the quartz plate. A variometer (L1) in the plate circuit of V1 is so adjusted that the reactance of this circuit is highly inductive at the operating frequency of the transmitter. Condenser C16 is of the proper value to provide optimum coupling between the plate and grid circuits.

The plate d.c. supply for V1 flows through L1. A resistor (R12) is connected in series with the plate supply lead to the oscillator tube to reduce the plate voltage to the proper value to insure long life to both the tube and the quartz crystal. A by-pass condenser (C17) permits the radio-frequency component of the plate current to flow around this resistor. A choke-coil (L8) and resistor (R2) are connected across the crystal to provide a path for the rectified grid current and, with the voltage drop across R7 in the power circuit, to determine the operating grid-bias potential of V1.

The oscillations from V1 are amplified and modulated in the modulating amplifier tube (V2). Radio-frequency voltage from the oscillator circuit is supplied to the grid through condenser C4. The grid bias is determined by the voltage drop across R3 through which the rectified grid current of V2 flows, and also by the voltage drop across R7 in the power circuits. A choke-coil (L2) limits the radio-frequency current flowing through this path. The screen grid of V2 is maintained at the proper d.c. potential by the filter circuit R5, R4, and C8. The plate of V2 is connected to a tuned circuit made up of L4, C6, and C7. This circuit is adjusted to be anti-resonant during operation. The antenna circuit is connected across C7 and is thus coupled to the

plate circuit. This condenser is made variable by steps to govern the amount of coupling obtained.

The antenna is tuned by the continuously variable and tapped inductance L5 which will resonate antennas with effective capacities as low as 0.0004 mf. at 230 kc and as high as 0.0009 mf. at 500 kc.

**AUDIO-FREQUENCY CIRCUITS.** A single-stage audio-frequency amplifier furnishes the power which modulates the carrier wave generated in the radio-frequency circuits just described. The degree of modulation secured, which is a measure of the effectiveness of the radiated wave, is determined by the output power of this amplifier. In order that the radiated wave be as effective as possible, the audio-frequency amplifier has been designed to furnish sufficient power to completely modulate the carrier wave during loud passages of speech. The input power to the audio-frequency amplifier is supplied directly from the microphone.

The detailed operation of this amplifier may be best understood by referring to the upper left-hand portion of the schematic diagram. A Western Electric No. 1046-A Desk Stand is to be connected to jack J1. This desk stand contains a microphone and a switch. One terminal of the microphone is connected through the cord and plug to the sleeve of the jack. The other terminal of the microphone is connected to the blade of the switch. As the switch blade is closed, it first makes a contact which connects to the tip of the plug and thence through the jack to the retardation coil L6, completing a circuit through the battery to the microphone. As the microphone switch is further closed, a second contact is made with the switch blade which completes a circuit through the plug and jack to condenser C9 and thence to the primary of the input transformer T1. By this arrangement direct current for the microphone flows through the retardation coil while audio-frequency current flows through the transformer primary. Because the d.c. circuit is closed before the audio-frequency circuit, the surge of voltage caused by the sudden rise of current through the microphone does not affect the input transformer. The secondary of the transformer T1 is connected to the grid of the audio-amplifier tube (V3). The plate current of

V3 flows through the primary winding of the modulation transformer (T2). Variations in this current, caused by the audio-frequency voltage impressed on the grid, induce an a.c. voltage in the secondary winding which is connected to the plate circuit of the modulating amplifier. Thus audio-frequency power, controlled by the sound waves striking the microphone, is supplied to the modulating amplifier, where it modulates the radio-frequency output.

The polarity of the windings in the modulation transformer T2 are opposed so that the flux in the core due to the direct current is reduced to a minimum, thus making possible a transformer of small size.

**POWER SUPPLY CIRCUITS.** The remaining equipment in the set is used to provide power for the apparatus just described. It consists of a full-wave, single-phase rectifier for plate and grid-bias supply, a transformer for filament heating, and a transformer for heating the quartz plate, together with the necessary switches, relays and fuses for the control and protection of the transmitter. This apparatus is shown in the lower portion of Figure 124.

A 100 to 120-volt 50 or 60-cycle power line is connected to terminals 1 and 2 from where the power passes to the "heater" switch (D3) and the "transmitter" switch (D4).

D3 is connected through fuses F3.1 and F3.2 to the primary of the crystal heater transformer (T3), the secondary of which supplies power at 11 volts a.c. to the heater of the quartz plate. A thermostat in this unit controls the relay S1 which in turn controls the heater power, and maintains the crystal at a constant temperature.

D4 connects through fuses F1.1 and F1.2 and door switches D5.1 and D5.2 with the primaries of the filament and plate transformers, T4 and T5, respectively. A separate fuse (F2) is connected in series with the filament transformer primary. A tap switch (D6) is connected with this winding so that correct filament voltage may be secured from any line voltage between 100 and 120 volts. The filament voltmeter (M4) is connected to the center tap of this switch and indicates a voltage which is proportional to the filament voltages of the vacuum tubes. There are

three secondary windings on T4, one for the audio-amplifier tube filament, one for the radio-frequency tube filaments, and one for the rectifier tube filaments.

A thermal time delay relay (S2) is connected to one of the filament windings on T4 and consequently starts to close as soon as power is connected to T4 by switch D4. When this relay closes, after 15 or 20 seconds, relay S3 is energized which in turn connects the primary of the plate transformer to the line and at the same time closes its own holding circuit after opening the circuit to S2. An external plate power control switch may be inserted in the primary circuit of T5 to allow the plate voltage to be removed without opening the filament supply. The primary of T5 is tapped so that the secondary voltage can be regulated to take care of + or - 10% variations from 110 volts in the line voltage. The secondary of T5 supplies high voltage to the rectifier tubes V4 and V5 through fuses F4.1 and F4.2. A retardation coil (L7) and a bank of condensers (C13) act as a filter in the output of this rectifier. The d.c. voltage appearing across C13 is about 520 volts and its exact value is indicated by the plate voltmeter (M5).

Resistors R4 and R5 act as a voltage divider which supplies 175 volts d.c. to the screen grid of the modulating amplifier tube (V2). A condenser (C8) connected across R4 maintains this voltage practically constant during modulation.

Grid bias for the audio-frequency amplifier tube is provided by the potential drop across resistor R8 through which the plate current of this tube flows. This bias voltage is normally 60 volts. Resistor R6 and condenser C10 act as a filter to attenuate any a.c. voltage caused by a ripple in the plate current. The grid bias of V3 is thus kept practically constant and free from any a.c. component.

The space current from the tubes V1 and V2 flows through resistor R7. The voltage thus obtained serves as bias to protect these tubes if their circuits are so improperly adjusted that no grid-leak current occurs. The radio-frequency portion of the space current from these tubes is by-passed around this resistor and the filament transformer through condensers C14 and C15. During normal operation the potential across R7 is 20 volts.

### **RCA Airport Transmitter AVT-1**

The RCA Victor Model AVT-1 is an airport radio traffic control transmitter. It operates on one fixed specified frequency within the band of 200 to 410 kc.

It is a crystal-controlled, 15-watt, fixed-tuned unit, capable of 100% modulation when used with the double-button microphone supplied as part of the equipment. Provision is made for mounting two crystals in the crystal-cover, so that, if desired, a spare crystal may always be available. Operation is entirely from 115 volts, 50-60 cycles, no batteries of any kind being required. An operator's control box is provided as part of the equipment so that remote control of the transmitter from a distant point can easily be obtained. The control box is equipped with a double-button microphone of excellent quality. This microphone is "normaled" through a three-circuit jack suitable for plugging in a "press-to-talk" microphone of standard type, so that this type of control can be readily used if desired. Provision is also made for MCW telegraph keying of the transmitter so that it may be used for runway localizing as well as for telegraphic communication.

The r.f. section of the transmitter uses the following tubes: one RCA-865 as a crystal oscillator, two RCA-865's as power amplifiers, and one RCA-83 as a rectifier.

The a.f. section uses one RCA-57 as an audio amplifier and oscillator, one RCA-59 as an audio amplifier (driver), two RCA-59's as Class B modulators, and one RCA-83 as the rectifier.

The AVT-1A is a later model than the AVT-1, having a somewhat greater working range and several refinements in the circuits. The AVT-2 and the AVT-4 in this series of models are both 25-watt, three-channel communication transmitters operating on the 2000-6500 kc band.

### **RCA Aircraft Transmitter Model AVT-7B**

This model has been developed, in accordance with the most up-to-date practices in design, to supersede the RCA Model AVT-7 and 7A transmitters long used aboard aircraft. Model AVT-7B is widely used on privately-owned airplanes.



The entire set including its power supply unit weighs 30 lb. The overall dimensions of the transmitter are a little less than 8 by 9 by 8 in. Figure 125 gives the circuit diagram.

**Electrical Specifications.** The following radiotrons are used: RCA-42 as crystal oscillator, RCA-42 as speech amplifier, RCA-6A6 as Class B amplifier modulator, RCA-807 as r.f. power amplifier. The frequency range is 2600 kc to 6500 kc (2.6 Mc to 6.5 Mc). Frequency control: low temperature coefficient V-cut crystal. Power supply: synchronous vibrator, rectifier; fuse rating, 20 amperes; input voltage, 12 volts d.c. Power consumption: standby, 1.8 amperes; transmit, 14.5 amperes.

### **Circuit Description.**

**R.F. CIRCUIT.** The r.f. circuit arrangement affords a number of combinations, namely: (1) two-frequency operation from one low-frequency crystal (fundamental and second harmonic; crystal frequency must be between 2600 kc and 3250 kc); (2) two-frequency operation from two crystals not harmonically related (one frequency between 2600 kc and 4000 kc and second frequency between 4000 kc and 6500 kc); (3) three-frequency operation from one low-frequency and one high-frequency crystal, provided that the frequency separation of the second harmonic of low-frequency crystal and fundamental of the high-frequency crystal is not greater than 2%, and (4) four-frequency operation from two low-frequency crystals (crystal frequencies between 2600 kc and 3250 kc).

For four-frequency operation with two low-frequency crystals, the lead to tap of oscillator coil (31) (high-frequency coil) must be removed and resoldered to the proper tap of coil (33) (low-frequency coil), the crystal oscillator r.f. coil (33) remaining connected regardless of position of relay (10).

The action of relays and circuit components, in a standby condition, will be described for operation with two low-frequency crystals. When selector switch (15) is set to position "1" (with "press-to-talk" button closed), neither relay No. 10 nor No. 11 is energized and crystal No. 1 is connected to the crystal-oscillator grid-circuit by the back contacts of relay No. 10. The low-frequency oscillator tuned circuit (33), self-tuned by the tube and coil capacitance, is connected to the crystal-oscillator tube-plate; and the back contacts of relay No. 11 connect the low-frequency power-amplifier tuned circuit (67) and (35) in the

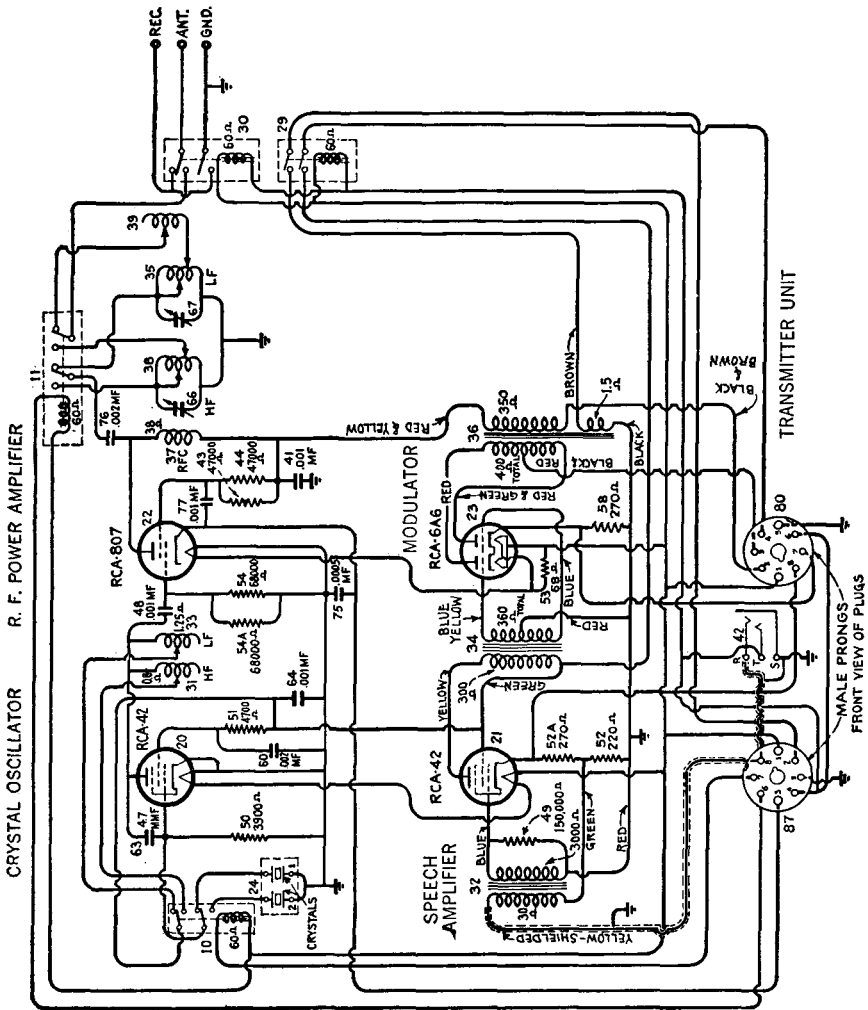


Figure 125. RCA Model AVT-7B Transmitter

power-amplifier plate-circuit and also connect the antenna lead through loading coil (39) to the antenna tap of coil (35). These relay positions result in the connecting of a low-frequency crystal, low-frequency oscillator-plate circuit coil and low-frequency power-amplifier tuned circuit.

When the selector switch is set to position "2" (with "press-to-talk" button closed) relay No. 10 is energized, connecting crystal No. 2 in the grid circuit of the crystal-oscillator tube, and even though the relay is in the forward position, the high-frequency coil (31) is not connected, inasmuch as the lead to the contact of coil (31) has been transferred and resoldered to the proper terminal of coil (33). Relay No. 11 is not energized and the low-frequency coil (35) and condenser (67) remain connected to the power amplifier plate. The antenna connection through coil (39) remains as it was with selector switch in position "1."

When the selector switch is set to position "3" (with "press-to-talk" button closed), relay No. 10 is not energized, placing crystal No. 1 in operation, but relay No. 11 does become energized, selecting the high-frequency tuned-circuit condenser (66) and coil (38) to be placed in the plate circuit of the power amplifier. With such connections, the crystal oscillator operates at the fundamental frequency of crystal No. 1, while the power amplifier is tuned to the second harmonic of the frequency of crystal No. 1. Thus the power amplifier acts as a frequency doubler and power amplifier.

When the selector switch (15) is set to position "4" (with "press-to-talk" button closed), relay No. 10 is energized, selecting crystal No. 2 and connecting it to the grid circuit of the crystal oscillator, while relay No. 11 remains energized and the high-frequency power amplifier tank condenser (66) and coil (38) remain in the circuit. Thus, in position "4" the power amplifier again acts as a frequency doubler and power amplifier.

An alternate method of operation is the use of one low-frequency crystal and one high-frequency crystal, in which case the lead from relay No. 10 to the low-frequency coil (33) is unsoldered and reconnected to the proper tap of the high-frequency coil (31). Coil (31) is then connected to the crystal-oscillator plate-circuit and relay No. 10 is closed when the selector switch (15) is in position "4," connecting with high-frequency crystal and high-frequency coil (31).

The coils of relays (29) and (30) are electrically connected in parallel and are energized when the "press-to-talk" button on the "anti-noise" aviation microphone is depressed. Relays (29) and (30) serve

to transfer the antenna lead to the receiver when the transmitter is not being operated and to open or close the high voltage, "B" plus lead to the crystal oscillator and first audio-amplifier tube. The second set of relay contacts serves to disconnect the inter-phone facilities and connect the side-tone signals so that the operator may listen to the speech-amplifier output while transmitting.

The RCA-807 power-amplifier tube (22) receives its grid excitation through the coupling capacitor (48). Bias for this stage is obtained from the grid lead (54). Tuning of the low-frequency power-amplifier tank circuit is effected by condenser (67), while tuning of the high-frequency tank circuit is effected by condenser (66). Coils (35) and (38) are tapped to permit adjustment of antenna coupling. The antenna loading coil (39) is located within the transmitter, and may be connected in series with the antenna to provide proper loading. The plate circuit of the crystal oscillator is series-fed, while the plate circuit of the r.f. power amplifier is shunt-fed and an r.f. choke (37) is provided to isolate the r.f. circuit from the power supply.

The power amplifier operates as a plate-modulated amplifier for radiotelephone operation and receives its modulated energy from the RCA-6A6 modulator tube (23). The modulation transformer (36) secondary is connected in series with the plate return of the power amplifier RCA-807. The side-tone winding is incorporated in the modulation transformer.

**AUDIO CIRCUIT.** Direct current for the microphone is obtained from cathode resistors (52A) and (52) of the RCA-42 (20) speech amplifier tube. The microphone current passes through the primary of transformer (32) and then through resistor (14) if inter-phone is used, and to the plus 12-volt battery or direct to ground if radio transmission is accomplished, depending upon the position of switch (15). The speech voltage developed across the primary of the step-up microphone transformer (32) is amplified by the RCA-42 (21). The output of this stage is connected to the grids of the modulator tubes 6A6's (23), connected "push-pull" through the step-up transformer (34). The output of the modulator RCA-6A6 (23) is connected directly to the "push-pull" primary connection of the modulation transformer (36), while the secondary of this modulation transformer is directly in series with the plate feed of the power amplifier RCA-807 (22).

**VIBRATOR POWER UNIT.** The power supply is a conventional synchronous vibrator (78) which plugs into the socket (79). The vibrator "hash" filter consisting of (R-55), (R-56), (C-71), and (C-71-A),

connected directly to the vibrator sockets, is used to reduce surge voltages and vibrator sparking. The rectifier filter system consists of four sections of 4 mfd. each, (C-69) and (C-70) with the filter choke (L-40). In parallel with (C-69) and (C-70) are two mica capacitors, (C-72) and (C-73), which are low power-factor units.

The by-pass units for the RCA-42 and the RCA-6A6 (condensers (68) and (59), 25 mfd. each) are located within the power unit, as is the "on-off" relay (12), fuse (91), and capacitor (74).

### **RCA Aircraft Transmitter Model AVT-12B**

The AVT-12B Aircraft Transmitter is crystal-controlled, shock-mounted to reduce effects of vibration. Complete remote control of the equipment is accomplished electrically by switches on the control panel.

It is designed to operate on four transmission frequencies within the 2600 to 6500-kc range. Two transmission channels within the range may be selected; each channel provides two closely associated transmission frequencies. The four transmission frequencies are specified by the customer at the time of purchase, and the crystals are ground to these frequencies. Final tuning of the transmitter is required after installation, the last adjustments being made during flight. The total weight of this set complete is 80 lb. The transmitter is (about) 12 by 10 by 10 in.

**ELECTRICAL SPECIFICATIONS.** The following radiotrons are used: RCA-837 as crystal oscillator; RCA-42 as speech amplifier; RCA-803 as r.f. power amplifier. The frequency range is 2600 to 6500 kc (2.6 to 6.5 Mc). The frequency control: low temperature coefficient V-cut quartz crystals. Power-output rating: phone, 50 watts, CW telegraph, 90 watts. Power supply: 1725-volt dynamotor. Fuse ratings: battery lead, 125 amperes; control box lead, 15 amperes. Power consumption (total): 62 amperes at 12 volts.

It will be good practice to trace out this circuit in Figure 126: Plate XVII illustrates the assembly of a companion receiver.

**R.F. CIRCUITS.** Referring to the schematic circuit diagram (Figure 126), the following action takes place: the frequency-selector switch (103) on the control panel operates to place the desired quartz crystal (LF-1), (LF-2), (HF-3), or (HF-4) in the circuit and to connect the proper oscillator and power-amplifier tuned plate circuits.

When this switch (103) is in position "1," none of the three relays (10), (11), or (12) is energized and both crystals (LF-1) and (HF-3) are connected to the crystal-oscillator grid circuit by the back contact of relay (11). The low-frequency oscillator tuned circuit, condenser (41) and coil (63), is connected to the crystal-oscillator tube plate through the back contact of relay (10). Relay (12) connects the low-frequency power-amplifier tuned tank, condenser (49) and coil (67), in the circuit and also connects the antenna lead to antenna load coil (73) which in turn is connected to the antenna-tap of 67.

When selector switch (103) is in position "2," relay (11) is energized, connecting crystals (LF-2) and (HF-4) to oscillator grid circuit. The low-frequency oscillator plate coil (63) and tuning condenser (41) remain connected to oscillator plate circuit, while PA low-frequency tank circuit coil (67) and condenser (49) remain connected to PA tube plate.

Thus in positions "1" and "2" of selector switch (103) low-frequency resonant circuits remain connected to oscillator and PA tube. Relay (11) functioning to select either low-frequency crystal (LF-1 or LF-2).

When the frequency-selector switch (103) is in position "3," both relays (10) and (12) are energized and crystal (HF-3) is placed in the circuit. Relay (10) connects the high-frequency oscillator tuned circuit, condenser (42) and coil (62) to the crystal-oscillator plate. Relay (12) connects the high-frequency power-amplifier tuned circuit, condenser (48) and coil (66), and also connects the antenna lead to the antenna-tap of (66).

When the frequency-selector switch (103) is in position "4," all three relays (10), (11), and (12) are energized. Relay (11) acts to place crystal (HF-4) in the circuit. The remainder of the circuits remain as for position "3," of the frequency selector switch, since these two frequencies are closely associated. No other operations are necessary for shifting transmission frequencies after the transmitter has been properly tuned.

The RCA-803 radio-frequency power-amplifier (21) receives its excitation through coupling capacitor (44). Bias for this stage is obtained from the grid-leak (83). Tuning of the low-frequency power-amplifier tank circuit is effected by condenser (49) while tuning of the high-frequency tank circuit is effected by condenser (48). Coils (66) and (67) are tapped to permit adjustment of antenna coupling. The antenna loading coil (73) is located within the transmitter, and normally is connected in series with the antenna in the two low-frequency

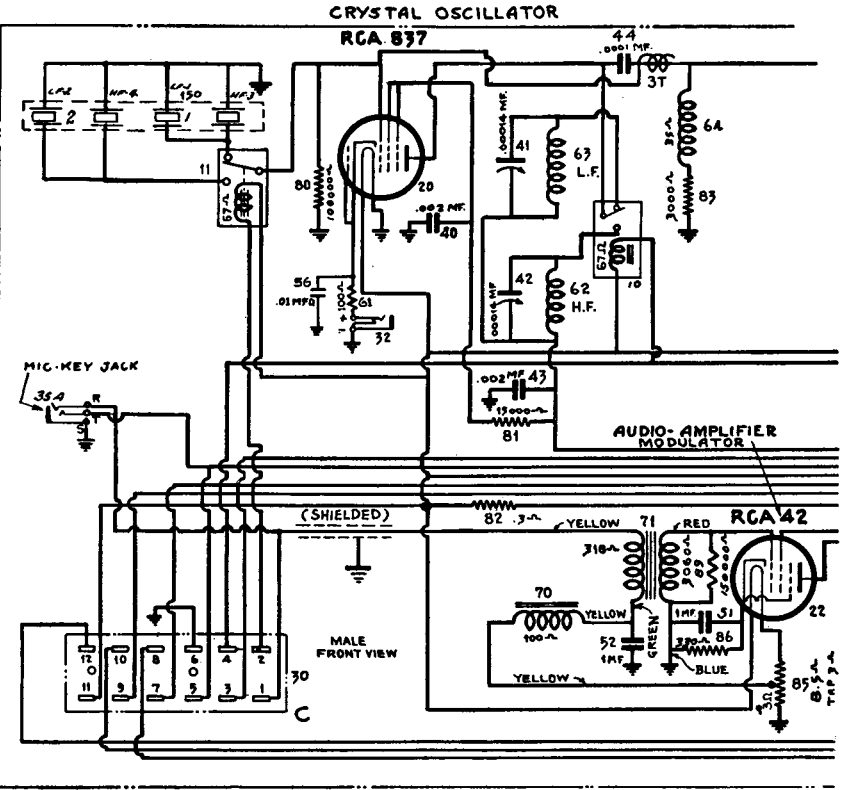
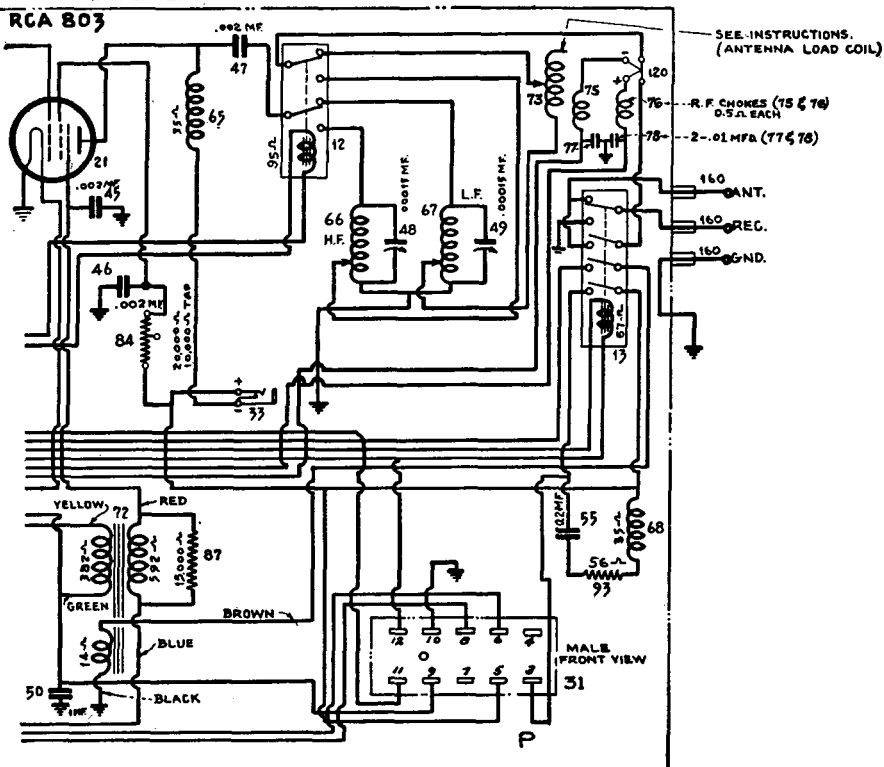


Figure 126. RCA Aircraft

RF POWER AMPLIFIER

RCA 803



Transmitter Model AVT-12B



(L.F.) positions of the frequency-selector switch, to provide proper loading. The plate circuit of the crystal oscillator is series-fed through either coil (63) or (62) while the plate circuit of the r.f. power amplifier is shunt-fed and an r.f. choke (65) is provided to isolate the r.f. circuit from the power supply.

The power amplifier operates as a suppressor grid-modulated amplifier for radiotelephone operation and as a Class C amplifier for radiotelegraph (CW) operation. The suppressor grid is connected to a negative bias voltage, obtained across a portion of the power voltage divider (92), for telephone operation. The modulation transformer secondary (72) is connected in series with the suppressor bias connection and this winding is loaded with a 15,000-ohm resistor (87) providing a more steady load on the RCA-42 amplifier-modulator as well as developing a negative bias when the suppressor grid swings from negative to positive potentials.

**AUDIO CIRCUITS.** Direct current for the microphone is obtained from the 3-ohm tap on the heater resistor (85) of the RCA-42 speech-amplifier-modulator tube. The microphone current passes through filter choke (70), the primary of the microphone transformer (71) thence through the microphone. The filter (70) and (52) serves to remove ripple from the microphone voltage supply. The speech-frequency voltage developed across the primary of the step-up microphone transformer (71) is amplified by the RCA-42 (22). The output of this stage modulates the suppressor grid of the RCA-803 r.f. power amplifier (21) through the modulation transformer (72). A tertiary winding on the modulation transformer provides side-tone for headphones.

Inter-phone transmission is provided when the "Fil.On - Fil.Off" switch (100) is in the "Fil.Off" position. Audio voltage is built up across resistor (109) which is connected in series with the microphone and 12-v. supply when the microphone button is pressed. This voltage reaches the phones through capacitor (110) and the side-tone lead.

**DYNAMOTOR POWER UNIT.** The dynamotor, filter capacitors, filter-reactors, and starting relay are contained in the power unit. The starting relay (14) is operated by the "press-to-talk" button on the microphone for telephone transmission or by the "Phone-CW" switch when in the CW position and permits remote starting of the dynamotor. One male plug for attaching cable from the 12-volt battery to the dynamotor and two cables (with female plugs attached) for connection between transmitter and control unit, and between transmitter and power supply are provided. The A battery negative lead, connected to

plug (38-B), acts as ground-return for all units of the equipment. The A battery positive lead, connected to plug (38-B), supplies the power required to operate the dynamotor. This connection should be protected at the battery by a 125-ampere fuse. The white A positive lead connected to terminal No. 7 of the control-cable female plug (39) supplies the necessary power for the filament circuits and for operating the various relays.

**CONTROL PANEL AND CABLES.** The control panel contains a jack (35) for microphone or key, a power "Fil.On - Fil.Off" switch (100), a frequency-selector switch (103), a "Phone-CW" switch (102), and an antenna-current meter (121). The jack (35) is a two-circuit type for a W.E. type 109A plug and carries connections for the microphone and "press-to-talk" circuit. The microphone connection is made between the ring contact (R) of the jack and the sleeve (S), while the "press-to-talk" switch connects from the tip contact (T) to the sleeve (S). When a telegraph key is used, it is connected between (S) and (T). The "Fil.On - Fil.Off" switch (100) controls power to the tube heaters and to one side of the relay circuits. This permits the tubes to be heated and ready for operation before plate power is applied. When the "press-to-talk" switch is depressed after the "Phone-CW" switch has been placed in "Phone" position, the ground-return circuit for relays 13 and 14 is completed. When the "Phone-CW" switch is in the CW position, the ground return for relay 14 is made through switch 102 and the "press-to-talk" switch then controls only relay 13. During CW operation the dynamotor runs continuously; during phone operation the dynamotor runs only when the "press-to-talk" button is pressed. The key-antenna relay (13) operates to connect the high-voltage supply to the transmitter, to connect the receiver headphones to the modulation transformer for side-tone, to ground the receiver antenna during transmission, and also connects the transmitter to the antenna when the same antenna is used for both transmitting and receiving.

Arcing at the high-voltage contacts is prevented by the absorption circuit (55, 93, and 68).

The control-box meter (121) is connected to a thermo-couple (120) located in the antenna circuit in the transmitter and indicates approximately the antenna current.

The control cable (140) interconnects the control panel with the transmitter; the power cable (141) interconnects the transmitter with the power unit; and the battery cable, furnished by the customer at time of installation, supplies power for the dynamotor unit and ground

return for all parts of the equipment. The power cable and control cable are shielded, and insulated by braid to stand reasonable wear.

### Western Electric Aircraft Transmitter No. 13C

Western Electric radio equipment of one kind or another is in use on most of the major airlines and many of their connecting lines where modifications have in some cases been successfully incorporated. The Bell Telephone Laboratories design and develop W.E. sets.

In presenting descriptions of a specific model, it is felt that the studious reader will acquire practice in analyzing the electrical action within circuits and gain a detailed knowledge of the various circuits.

Where a schematic diagram of a circuit is given, this can be referred to in connection with operating, installation, and adjustment instructions issued by the manufacturer and available wherever a W.E. set is installed. Students, operators, and pilots are advised to go over some W.E. radio installation with an attendant operator or competent instructor, learning how to operate both transmitters and receivers. In the meantime refer to Figure 127.

The No. 13C radio transmitter is a light, compact radiotelephone transmitter developed by Bell Telephone Laboratories for use in Western Electric communication systems. It provides facilities for three carrier frequencies, any one of which may be selected by means of a single mechanical control which may be extended to a remote point if desired. The transmitter contains antenna tuning equipment of ample flexibility to permit efficient adjustment for a wide variety of antennas, and also contains a remotely controlled antenna relay.

More than 50 watts of carrier power are delivered to the antenna circuit by the last radio-frequency amplifier stage in this transmitter. If the antenna has a resistance greater than about 4 ohms, approximately 50 watts will be delivered to the antenna itself. The transmitter is quartz-plate controlled and will maintain the carrier frequency within 0.025%. It is capable of substantially complete modulation.

The high-voltage supply for the transmitter may be a dynamotor or other source capable of furnishing 0.350 amperes at 1050 volts d.c. Neither side of the supply can be grounded. The commutator ripple

is attenuated by the filter choke L11 and condensers C17 and C19. The negative side is connected through resistor R7 to ground, the voltage drop across this resistor being used for grid bias. The positive high voltage is routed through a vacuum type relay (S5) which closes the circuit when the antenna relay is operated. Voltage dividing resistors, (R10, R9, and R8), furnish reduced plate voltage for the No. 205D vacuum tubes and screen bias for the No. 282A vacuum tubes.

Communication systems using this transmitter are arranged for push-button control. A button is pressed while transmitting and released while receiving, all switching operations being performed by relays. In the transmitter, S4 is the control relay. The positive 12-volt supply to this relay is routed through switch D1. D1 is arranged to prevent energizing S4 unless the frequency-change switches are centered on one of the three operating positions; it also furnishes 12 volts to terminal 12 when it is off-position to operate a remote signal. D9 is a safety switch on the transmitter cover to protect the operator while he is adjusting the tuning coils. It is connected in series with the coil of the high-voltage relay S5. When the microphone button is pressed, grounding terminal 7 or the tip of the microphone jack (J11), the control relay closes two sets of contacts. One contact operates the antenna relay (S6) and also places 12 volts on terminal 8, which is used to start the dynamotor. The other contacts close the microphone circuit and connect the speech input to the audio amplifier in proper sequence. The high-voltage relay (S5) is operated by a contact on the antenna relay and drops out as soon as the microphone button is released. This sequence of operation protects the antenna relay contacts from arcing. The copper oxide rectifier (Y4) prevents sparking at the contacts of the control relay.

In the following description the numbers in parentheses refer to apparatus designations on the schematic, Figure 127.

**RADIO-FREQUENCY CIRCUITS.** The quartz plates, interstage transformers, and antenna tuning coils and condensers are all plug-in units. Space is provided for three complete sets of this apparatus, any one of which may be selected for use by a single mechanical control operating a ganged switch. The transmitter may therefore be set up for any three frequencies within its range, each of which is immediately available for use.

The radio-frequency circuits in the transmitter consist essentially of a quartz-plate controlled oscillator and two stages of radio-frequency amplification. The quartz plate oscillates at one-half the desired output frequency and is connected in the grid circuit of the No. 205D vacuum

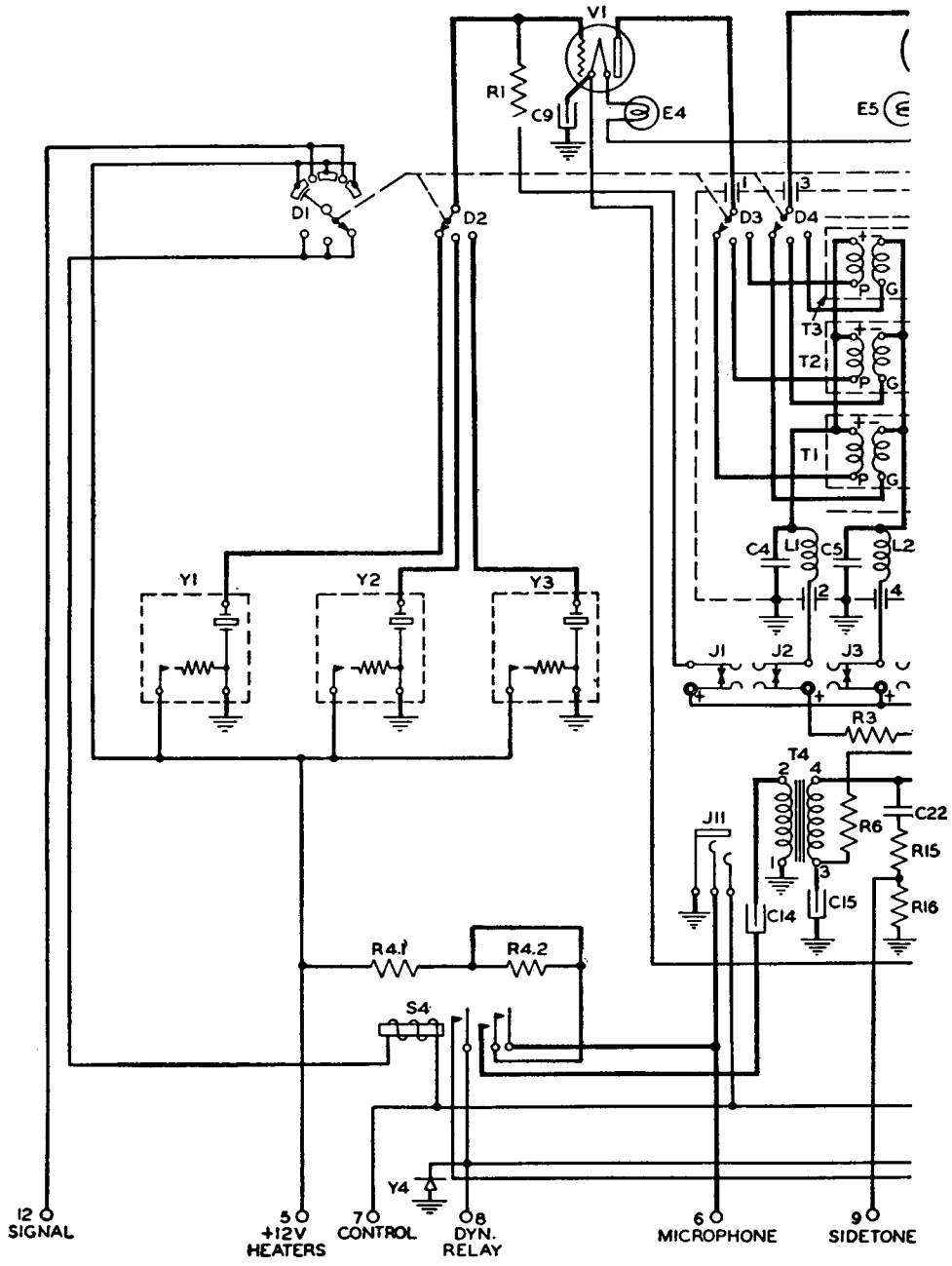
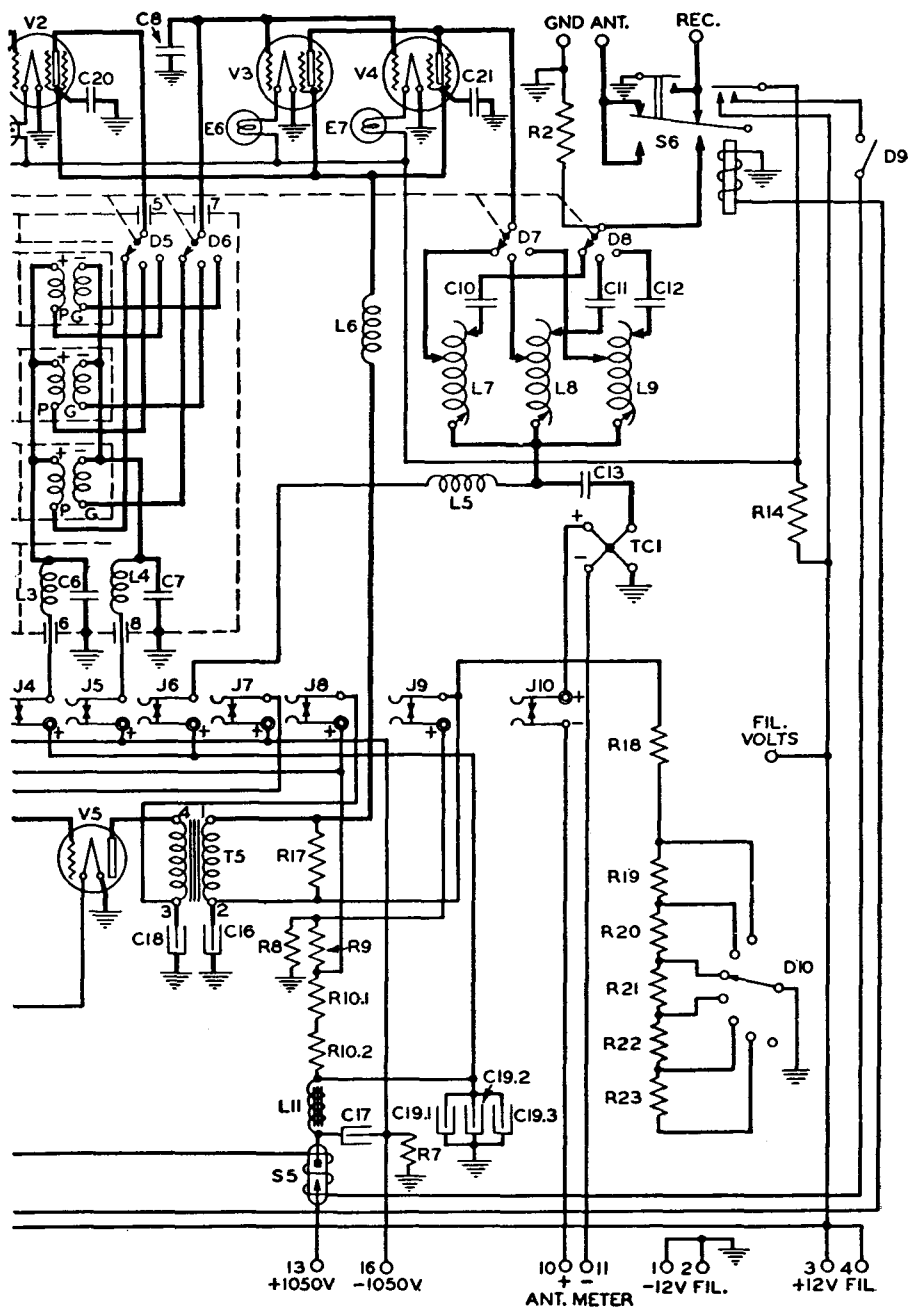


Figure 127. Schematic Diagram of W.E



Aircraft Transmitter No. 13C

tube (VI) used as the oscillator. The oscillator is coupled to the first amplifier by means of a radio-frequency transformer which in conjunction with the tube and wiring capacities forms a band-pass filter. The primary of this transformer presents a high inductive reactance to the plate of the oscillator tube at the quartz plate frequency and thus causes the No. 205D tube to oscillate. As this transformer freely passes the second harmonic of the quartz plate frequency, it drives the first amplifier at the output frequency, or twice the quartz plate frequency.

The first amplifier is a No. 282A vacuum tube (V2) and is coupled through another radio-frequency transformer to the grids of the second amplifier. This transformer in conjunction with condenser C8 and the stray capacities also forms a band-pass filter which freely passes the output frequency and drives the second amplifier.

For convenience, the two radio-frequency transformers are mounted together as a single plug-in unit (T1, T2, or T3) and designated a No. 271 type input transformer. The band of output frequencies over which the transformer will operate is given on the nameplate.

The second amplifier consists of two No. 282A vacuum tubes (V3 and V4) connected in parallel. The plate circuit of these tubes is coupled to the antenna by means of a No. 7A, 7B, or 7C tuning coil (L7, L8, or L9) and an antenna series condenser.

**AUDIO-FREQUENCY CIRCUITS.** The No. 13C radio transmitter contains a single stage of audio-frequency amplification using a No. 205D vacuum tube (V5). The microphone series resistor (R4) and stopping condenser (C14) are included in the transmitter. R4 is in two sections, one of 500 ohms and the other of 1595 ohms. For use in quiet locations (ground stations, boats, etc.) the large section can be short-circuited to increase sensitivity if desired. The stopping condenser prevents direct current from flowing in the input transformer (T4) and also modifies the frequency characteristic to a more desirable form when intense low-frequency noise is present.

The output of the audio amplifier is passed through transformer (T5) and modulates the screen bias on the first and second radio-frequency amplifiers. The resistor (R17) across the transformer secondary stabilizes the load on the audio tube and thereby improves the speech quality.

**POWER SUPPLY AND CONTROL CIRCUITS.** The low-voltage circuits in the No. 13C radio transmitter are arranged to operate on a 12-volt storage battery supply, the negative side of which may be grounded. The filament current is approximately 10.6 amperes, and the maximum

current demand from the battery is about 15 amperes. A series resistor (R14) in the filament circuit permits the tubes to heat under reduced current when the external filament switch is closed. The filament resistor is short circuited by the antenna relay, bringing the tubes up to normal current during the actual transmitting interval.

The filament of each No. 282A vacuum tube is in series with an individual No. 112A ballast lamp (E5, E6, or E7). The tips of these ballast lamps are painted red for identification and the corresponding sockets in the transmitter are marked with a red dot. The filaments of the two No. 205D vacuum tubes are in series with a No. 113A ballast lamp (E4) which is identified by a green tip. The socket for this lamp is marked with a green dot.

The three quartz plates (Y1, Y2, Y3) employ crystals with very low temperature coefficients. No heating is required with ambient temperatures down to zero Centigrade. The No. 5A quartz plate may be used where the temperature never drops below zero. The Nos. 5B and 5C quartz plates may be used interchangeably in installations where lower temperatures are encountered. They contain a thermostat and heater which operates automatically to maintain the crystals above zero.

### **Western Electric Ground Station Transmitter 14C**

**General Description.** This radio transmitting equipment has been developed by Bell Telephone Laboratories for use at ground stations. It is a multi-frequency crystal-controlled radiotelephone and telegraph transmitting equipment which may be pre-adjusted to any ten frequencies within the range 2 to 18.1 Mc. It will deliver a carrier power of 400 watts between 2 and 12 Mc and 300 watts between 12 and 18.1 Mc, with capability of substantially complete modulation for telephone or modulated CW transmission. Any one of the ten predetermined frequencies may be selected and made available for use by operating a single-digit telephone dial located on the front panel, or a similar dial which may be installed at a remote location. Likewise to change from one frequency to another it is only necessary to dial a single-digit number and that predetermined frequency is made available within the short space of time required for the dial to return to its normal position, approximately  $\frac{1}{2}$  to  $1\frac{1}{2}$  seconds. Primary power supply is derived from a 200–240-volt three-phase 50–60-cycle source capable of supplying 4.5 KVA.



The following notation will be used for various items throughout the following description. Symbol T, R, KP, or CU following an item number denotes that the item is located in the No. 14C transmitter, No. 9C rectifier, No. D-98888 keying panel, or No. 15C control unit, respectively. Thus relay S17R is relay S17 in the No. 9C rectifier.

**Methods of Carrier Control.** Three methods are available for controlling the carrier output of the No. 14C radio transmitter. They are "Push Button" carrier control, "Key" carrier control, and "Voice Operated" carrier control, and may be used to provide the following three radio transmission services:

1. "PUSH BUTTON" OPERATION ON TELEPHONY ONLY (LOCAL CONTROL). This service requires a No. 1120DA Desk Stand which controls the carrier by means of a "Press-to-Talk" key provided on the microphone.

2. CW TELEGRAPHY AND "PUSH BUTTON" OPERATION ON TELEPHONY. These services require a No. D-98888 keying panel which provides "key control" of the carrier for telegraph transmission and permits "break-in" service at all hand-keying speeds. Carrier control is accomplished over d.c. circuits between the transmitter and the technical operator's location. Dialing also is accomplished over a d.c. circuit when the technical operator is located at a remote point.

3. CW AND MCW TELEGRAPHY AND "VOICE OPERATION" ON TELEPHONY. This service requires a No. 15C control unit which provides "voice operated" control of the carrier on telephony and keyed tone control of the carrier on telegraphy. This feature is obtained by means of voice (or tone) operated relays which automatically turn on the carrier in the presence of impressed speech *or tone* and turn off the carrier in its absence. The tone source may be located at the remote point in the form of an auxiliary tone generator which is keyed for *both* CW and MCW telegraphy. Thus carrier control for both telegraph and telephone is normally accomplished over an ordinary telephone line between the remote point and the transmitter. Dialing may be effected over a d.c. circuit as before, or over the telephone line if a D-97098 selective dialing unit is used.

**ANTENNA CIRCUITS.** The output circuit of the No. 14C radio transmitter is designed to terminate in 500 ohms effective resistance. There are eleven output terminals provided on the unit, ten of which are asso-

ciated with the ten channels while the remaining one is common to all. This arrangement provides for connecting the output of one or more channels directly to the 500-ohm point on one or more half-wave antennas or, through the use of suitable No. 100-type coupling units, to one or more 500-ohm two-wire balanced transmission lines such as would be required by directional antennas. In addition to these possible terminations, one or more channels may be connected directly to a No. 10B tuning unit which provides the correct coupling to one or two suitable vertical wire antennas. Any combination of the foregoing antenna arrangements may be used.

**Transmitter Cabinet.** The No. 14C radio transmitter includes all of the radio-frequency elements of the equipment. It is of cabinet construction, with the approximate dimensions 83 by 24 by 29 in., and has its various radio-frequency stages arranged in chasses which may be readily detached and removed through hinged doors provided on the front. Each vacuum tube is plugged in the chassis associated with its particular stage, with the exception of the power amplifier tube which is located between the modulating amplifier and output chassis and is accessible through the glass panel door on the front of the unit. The power regulating resistor for the modulating amplifier, which determines the amount of carrier power, is likewise accessible through this door.

Five removable chasses are located in a vertical arrangement from bottom to top as follows: Oscillator chassis, first buffer chassis, second buffer chassis, modulating amplifier chassis, and output chassis. Each of the five removable chassis is equipped to accommodate as many as ten individual plug-in units which may be selected and adjusted to produce any carrier frequency within the specified range.

In addition to these removable chasses, the transmitter houses in its base the mechanism, actuated by the telephone dial, which selects one of ten elevator rods located at the back of the set. Each rod actuates a series of bell-cranks which close switches in the various chasses completing all the necessary circuits for setting up a particular frequency. Intermediate in position between the modulating amplifier chassis and the power amplifier chassis are located the power amplifier tube (No. 251A) and a tapped re-

sistor R12T. This resistor, or a portion thereof (predetermined for each channel by making appropriate connection between terminals 1 to 10 on the resistor panel and the tapped resistor R12T), is automatically placed in series with the plate supply to the modulating amplifier tube, which then furnishes the correct amount of drive to the grid of the power-amplifier tube for each of the ten predetermined frequencies. The first and second buffer stages are sometimes used to amplify the crystal frequency and at other times are used as frequency doublers, depending upon the desired carrier frequency and the particular No. 11-type tuning units chosen. In this way crystal frequencies ranging between 2000 and 4525 kc serve to yield a range in output frequencies between 2 and 18.1 Mc.

**Radio-Frequency Circuits.** The radio-frequency circuits employed in this equipment are of the crystal oscillator-intermediate amplifier or frequency doubler (two successive stages)-modulating amplifier-power amplifier variety. When MCW telegraph or telephone transmission is employed, modulation is applied to the plate and screen-grid of the modulating amplifier which immediately precedes the final or power amplifier stage.

NOTE: As considerable space is devoted to similar transmitter circuits further detailed explanation of the 14C circuit is not considered essential.

### **Bendix Radio Corporation Type TG-6A Radio Transmitter**

The TG-6A transmitting equipment is a multichannel crystal-controlled radio transmitter designed for aviation ground station and police communication use.

A power output of 1000 watts on telegraph transmissions or 900 watts on telephone transmissions may be obtained on any one of ten pre-selected channels in the frequency range between 1500 kc and 20,000 kc. Frequency selection may be effected locally by means of a manual control on the transmitter or remotely by the use of the MT-14 control unit, which is optional. Individual crystal-controlled exciter units for each channel, employing low temperature-coefficient crystals, maintain the transmitter frequency constant within 0.025%.

High-level Class B modulation is used. Complete modulation of the carrier can be secured with an input level of  $-40$  decibels (db), zero level being considered as 0.006 watts. The overall audio-frequency characteristic of the transmitter is flat within  $\pm 2$  db from 60 to 5000 cycles. The r.m.s. audio-frequency harmonic voltage of the rectified carrier, at 85% modulation, is less than 5% of the fundamental voltage, at 400 cycles.

**Radio Frequency.** In the exciter units a Type 42 vacuum tube is used as a pentode crystal oscillator with a plug-in fixed-plate inductance. The output of this stage is capacity-coupled to the grid of a Type 807 vacuum tube which is operated either as a "straight" amplifier or as a frequency multiplier, depending on the relation of the crystal frequency to the output frequency of the channel. All frequency multiplying is effected in this stage, subsequent stages operating as "straight" amplifiers.

A second amplifier, employing a Type 807 vacuum tube, provides the exciter output. Both amplifiers are equipped with plug-in coils and tuning capacitors adjustable from the front panel of the exciter unit.

Low impedance inductively-coupled link circuits transfer the output of the exciter units to the corresponding grid tank circuits of the intermediate amplifier, which employs a type 803 power pentode tube. A "pi" network is used in the plate circuit of this tube and is coupled to the grid of the power amplifier through a capacitor. The power amplifier, using a Type 251-A vacuum tube, as a neutralized triode, operates into a "pi" section antenna matching network. (Figure 16A, page 83, shows a pi filter.)

**Audio Frequency.** The audio input to the transmitter may be supplied either from a local single-button carbon microphone or remotely over a balanced telephone line. All amplifier stages are of the push-pull type for harmonic reduction, and transformer coupling is used throughout. The two voltage-amplifier stages employ a Type 53 vacuum tube and two Type 56 tubes. The driver stage uses four Type 2A3 tubes in push-pull parallel, and in the Class B modulator four Type 805 tubes are similarly connected. (A driver is a stage that feeds power to another. A circuit with both speech-amplifier and driver stages is shown on p. 293.)

For continuous-wave telegraph operation, the modulator tube filament supply is disconnected and the secondary of the modulation transformer is shorted out.

**Frequency Selection.** All frequency selection functions are effected by a vertical straight-line sliding-switch mechanism driven by a reversible capacitor-type a.c. motor. The switch, through its several slider rods, renders the appropriate exciter unit operative by supplying screen voltage, selects the proper grid and plate circuits for the intermediate and final power amplifiers, and makes the necessary circuit changes for telephone or telegraph operation as predetermined for the channel selected.

**Power Supply.** Four individual rectifier systems are used for plate and bias supplies. Six Type 872-A tubes in two 3-phase half-wave circuits supply 2250 volts d.c. for the final amplifier and 1500 volts d.c. for the intermediate amplifier and modulator tubes. The third and fourth rectifier systems each employ two Type 866 tubes in a single-phase full-wave circuit, one rectifier providing all bias voltages and the other furnishing plate potentials for the exciter units and for the audio amplifier.

A heater and forced-air cooling system maintains the temperature of all rectifier tubes within safe limits.

The equipment is usually supplied to operate from a 220-volt, 60-cycle, 3-phase supply, but may be arranged for operation from other power sources. Power transformers are provided with taps to compensate for  $\pm 10\%$  line voltage variation in 5% steps.

The power consumption of the transmitter under fully-loaded conditions is approximately 4 kw.

### QUESTIONS

121. What is meant by the carrier?
122. What is modulation? Modulation capability?
123. What is overmodulation in radiotelephony and what undesirable effects does it produce? Is it illegal?
124. What device is employed to convert sound waves into electrical variations for radiotelephony?
125. What is a speech amplifier? A microphone?
126. Describe a microphone and explain its operation.

127. What are sidebands? What are their frequencies?

128. What is radiotelephony and how is radiotelephone communication accomplished?

129. Draw a diagram of the circuit of some radiotelephone transmitter and tell how it works.\*

130. What radiotelephone transmitters are much used at airline ground stations? At airports?

\* Warning: Do not apply for an examination for a radiotelephone operator's license until you can answer this question.

## CHAPTER 11

### RECEIVERS

#### Preliminary Discussion

A radio receiver is a device for converting radio waves into perceptible signals. Many names have been coined and applied to the various receivers designed for broadcast reception. These names are usually descriptive of some basic principle, but not always. Broadcast and aviation receivers operate on the same principles and their function is the same: In each case radio-frequency current waves must be intercepted by an antenna, rectified by a detector, and amplified. Loud-speakers are not used on aircraft. The receptivity of the aircraft antenna system is usually greater than that of the ordinary house antenna system, but not always. The aircraft radio operator is obliged to contend with engine and other noises. The entire problem of reception aboard an airplane is greater than in a home or at a ground station; but the same basic circuits are used in all three cases. Figures 25, 27, and 28 (pages 105, 107, 108) show basic receiving circuits which are actually single-tube receivers. Figure 30 (page 113) shows an amplifier that can be combined with basic one-tube receiving circuits to increase the strength of signals as received in the one-tube set.

Figure 128 shows a complete five-tube receiver. A phone plugged into jack No. 2 will make audible the same signals that are heard when it is plugged into jack No. 1, but they will be many times greater at the jack No. 2 position. A loud-speaker could be connected at the No. 2 jack with good results but probably not at No. 1 jack. A five-tube set does not necessarily assure more volume than a four-tube set. The amplification factor and the efficiency of the sets are governing factors. Three tubes having a high amplification factor will produce more volume than four with a low amplification factor. In studying receivers, the

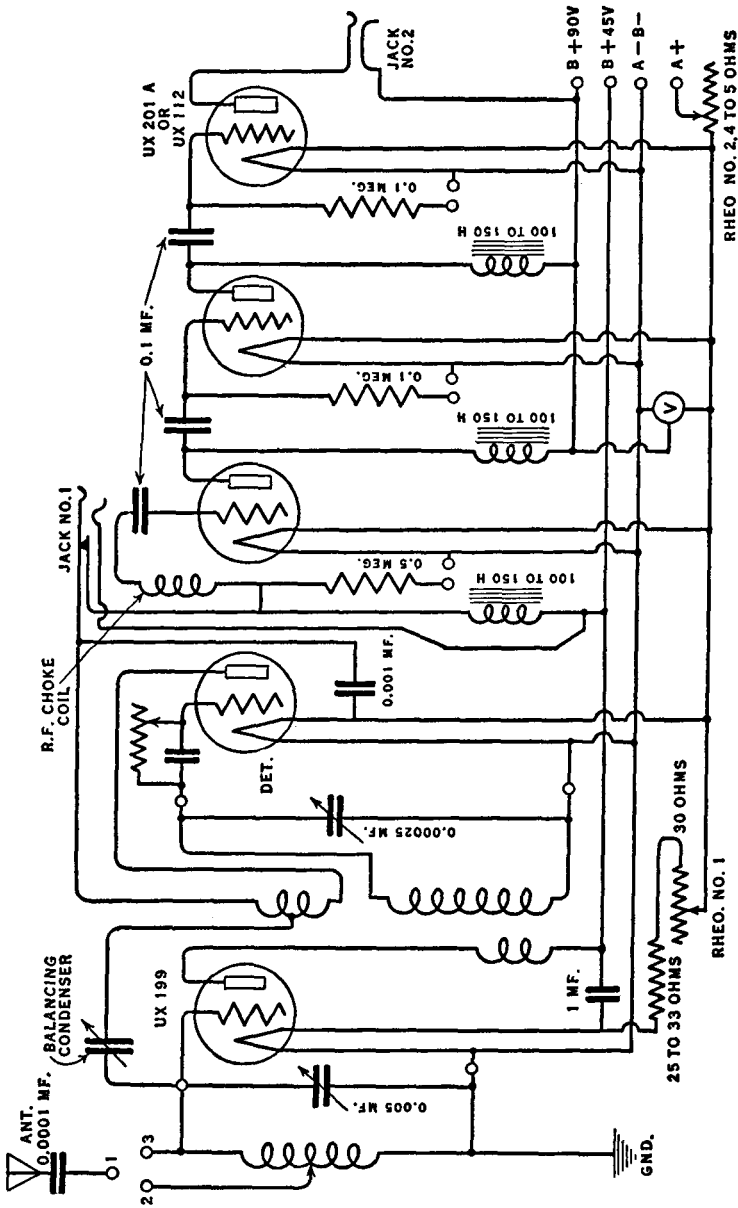


Figure 128. Impedance-Coupled Amplifier Type Receiver



important points to note are : how many radio-frequency amplifier tubes; how many audio-frequency tubes; and how well the circuit is tuned. There is always at least one detector tube.

### **Types of Aircraft Radio Receivers**

Aircraft radio receivers are broadly classified as high frequency (short wavelength), and low frequency (long wavelength). Sometimes the prefix, medium, is used to qualify these descriptive terms. All waves under 50 meters are short waves; below 5 meters, "ultra short." Medium waves are considered to be those from 50 to 1500 meters. All waves above 1500 meters are known as long waves. The use of wavelengths as descriptive of frequency is an old custom, difficult to discontinue, although liable to cause confusion. If it is noted that the higher the frequency, the lower the wavelength, this confusion can be avoided.

**Design Requirements of Receivers.** The known conditions under which radio receivers are used when installed on aircraft influence the designer in decisions regarding construction methods and materials, frequency and performance.

The receiver complete with its source of power should be light in weight, small in size, and accessible as to parts. It should be rugged, self-contained, and easily installed, with a shock mounting. The shielding should be as complete as possible. Non-inflammable materials should be used throughout the set. Special tubes that do not introduce microphonic noises are recommended. All plug contacts should be well secured; also all wiring contacts.

The frequency required to be used in aircraft radio is fixed by the Federal Radio Commission. If a set is to receive beacon signals and weather broadcasts, it should be designed for reception on frequencies from 285 to 315 kc as these are the frequencies assigned to the government stations along the civil airways for these purposes, as explained in Chapter 1. These are usually called "beacon receivers."

If a set is to receive "company messages," it is called a communication receiver and it must be capable of tuning to a frequency of from 315 to 350 kc as this band has been reserved for the use of the various air transport companies. If a set is to

“work” both beacon and communication bands, its frequency range must be from 285 to 350 kc. As there are other frequencies available for the use of aircraft, some sets are designed to cover frequencies other than these, but in every case the receiver should be designed for a specified frequency range. A receiver having a frequency range of from 230 to 500 kc is considered to be well designed as to frequency range; the range from 1600 to 6500 kc also can be well handled by one receiver. In some cases plug-in coils can be used on a receiver to make reception possible on the other frequency range.

The receiving range desired is about 100 miles. A receiver that will pick up signals consistently from this distance will be able to “copy” the government airways stations now operating and those to be installed. This means that the sensitivity and also the selectivity must be high. A trailing antenna is not as practicable as a 6 to 10 ft. mast type. With an input into this short antenna of 10 microvolts, in the form of received waves, a set which develops an output into the phones of about 6 milliwatts will be found to be sufficiently sensitive. The selectivity should be such that if the set is detuned from resonance on any certain signal, by 5 kc, the overall amplification of that signal will not be less than 10% of the amplification at resonance. A good set will develop an undistorted power output. The sensitivity of all the receiving equipment used on aircraft is limited by circuit noise. The beacon receiver has a sensitivity of about 3 microvolts for a signal-to-noise ratio of two to one. Automatic volume control is always used in the communication receiver but has never been employed in beacon receivers because of the fact that it would “iron” out the A and N signals and give the pilot a steady signal even if he was flying off course. Communications receivers have a sensitivity of 1 to 2 microvolts for a signal-to-noise ratio of two to one. (Automatic volume control is explained on page 326.)

If the set is to be capable of operating a visual radiobeacon indicator, an output of from 6 to 10 volts from the audio-frequency stage will be needed for delivery into this device, which imposes a load impedance of from 4000 to 7000 ohms.

An output transformer or filter should be used, as this eliminates the possibility of receiving a shock in the headphones. The

audio amplifiers and the output circuit are best designed to provide a nearly uniform amplification over a frequency range of 40 to 3000 cycles; above 3000 cycles it is better to provide a complete cut-off. A remote-control system is considered necessary in most cases. Some airlines use radiobeacon receivers having a Selsyn motor-tuning indication although most airlines employ direct indication through the medium of gears and dials. The tachometer shaft usually has a ratio of 264 to 1 to the tuning condenser. The crank, which is operated by the pilot, usually is geared 4 to 1 to the tachometer shaft. The emergency receiver is usually of the 2-band or 3-band type and may be used either on the beacon band or on the communication bands.

**PERFORMANCE CHARACTERISTICS.** The most important characteristics of a receiver for radiotelephone signals are sensitivity, selectivity, and fidelity.

*Sensitivity.* This is the ability to respond to signals of the frequency (wavelength) to which the receiver is tuned.

*Selectivity.* This is the ability of the receiver to differentiate between signals of different frequencies. See Fig. 141, page 340.

*Fidelity of Reproduction.* This is, in voice reproduction, absence of distortion and is determined by the response of the receiver to the frequency range of the sidebands. See page 360.

*Stability* is the capability of a receiver having a constant signal input to maintain a constant output.

These characteristics are interdependent. Selectivity affects sensitivity. Selectivity is affected by the frequency characteristics of the a.f. circuits following the detector. Audio-frequency can be quite affective where tuned audio combinations are used for CW radiotelegraph reception.

The performance of any receiver can be determined by feeding to it an artificial signal from a standard signal generator which consists of a shielded oscillator coupled to an attenuated (dummy) antenna system and producing known voltages. Curves such as shown in Figures 141 and 145 are usually prepared for each aircraft receiver. The decibel (db) is the unit of measurement of electrical or acoustic or logarithmic scale. A standard reference level is 0.006 watts (6 milliwatts). Gain and loss are expressed as plus db and minus db.

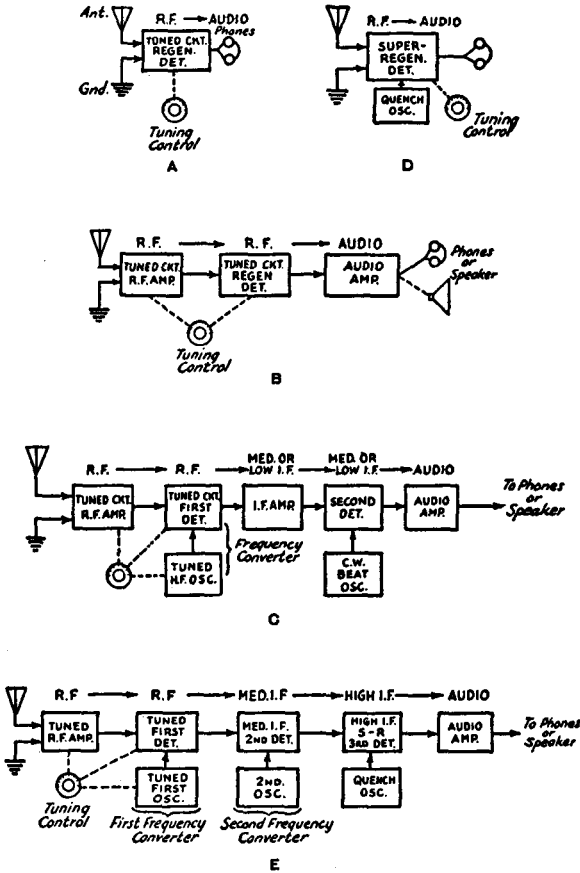


Figure 129. Essential Units of Basic Receiver Types

A, simple regenerative; B, tuned R.F. regenerative; C, superheterodyne; D, super-regenerative; E, super-infragrenerative. The last two are ultra-high-frequency types.

Figure 129 should be considered at this time and referred to later as the various types of receiver circuits are studied.

### Theory of Reception

**Modulated Waves.** The modulated waves which sweep across the antenna represent oscillations of varying amplitude; they consist of a number of waves of different frequencies superimposed upon each other. When the modulation is different from that of a simple sine wave amplitude variation, sideband components are introduced although the carrier wave form remains always the same. As an example, assume a radiotelephone transmitter is modulated by a complex sound wave containing pitches of 1000 and 1500 cycles. In this case the waves which must be "received" will contain one pair of 1000-cycle sideband component and in addition 1 pair of 1500-cycle sideband components. (See page 268 for review of sidebands.) The amplitude of sideband components is always one-half the amplitude of that particular frequency component which is contained in the modulation envelope. Therefore, in receiving, a band of frequencies must be used, not a single frequency. Speech transmission can produce sideband components extending to more than 10,000 cycles on each carrier frequency; that is why a high-frequency radiotelephone transmitter utilizes a frequency band of about 20,000 cycles. In the case of radiotelegraph signals, the essential sidebands are comparatively narrow. This is because the amplitude of the radio-frequency oscillation is varied only a few times a second although a definite frequency band is still required.

**Skip Effect.** One of the distinctive receiving characteristics identified with short-wave radio is what is termed the "skip effect." The result of this skip effect is more easily explained than the reason for it, although there are several commonly accepted theories which tend to explain satisfactorily this phenomenon. The skip effect as repeatedly noticed in recent years manifests itself in the following way. A short-wave transmitting set located, we will say, in New York will be clearly received in Nebraska, Kansas, and Oklahoma, Nevada, and California, Hawaiian Islands and London, but not elsewhere. The waves

have apparently skipped or hopped over all intervening areas.

Figure 64, page 180, shows certain wave characteristics.

This skip effect varies for different waves and apparently is different over mountainous and prairie regions. This inconsistency in the propagation of short waves has been a source of considerable trouble where different air transport companies have attempted to use the short waves assigned by the Federal Radio Commission for point-to-point radio transmission. It constitutes a great disadvantage in the use of short waves for comparatively short distances. This is particularly true where it is desired that messages from one airport to another a thousand miles or so away, be copied by intermediate airports. One of the tremendous advantages of short-wave transmission lies in the fact that low-power sets can be made to skip a long intervening distance, thereby causing no interference in this intervening area and still be received at the desired receiving station with great volume. As an example, the United States Naval Radio Stations on the coast of California have repeatedly transmitted to Samoa on low power without interfering with the handling of traffic in the Hawaiian Islands. Furthermore, the transmitting station was able to "bend" the radio waves propagated to a certain extent. This means that in the event reception in Samoa began to fade out, the Samoan station quickly indicated this by transmitting a prearranged signal, following which the transmitting station slightly varied the directive angle of the transmitting antenna, resulting in improved receptivity at Samoa.

It seems apparent that some such system as this can be developed for long-range radio transmission between widely separated airports resulting in the expeditious handling of company messages with low power and little resulting interference.

The ultra-high-frequency marker beacons described in Chapter 9 typify the most recent attempt to utilize these short waves to advantage for radio range operation. Receivers for this new type beacon are described on page 364.

**Methods of Reception.** In order to receive radio signals, it is first necessary to provide suitable means for abstracting energy

from passing radio waves. The antenna system of the receiving station accomplishes this. Next, the radio receiver must separate the desired signal wave from other undesired signal waves. To accomplish this there are tunable circuits, within the receiver, having high selectivity. Also, the information originally transmitted must be reproduced in the receiver (as dots and dashes in radiotelegraphy; sound, as speech or music in radiotelephony). To do this, detection, or demodulation, must be accomplished. The remainder of the work done by the receiver is the amplification of the received energy. Radiotelegraph receivers generally operate on the heterodyne principle mentioned on page 109). The National SW-5 receiver, described on page 329, used for the reception of both radiotelegraph (radio beacon) signals and voice, has a heterodyne circuit; most of the other aviation receivers use a superheterodyne circuit.

**Methods of Detection.** Two methods of detection are described on pages 106 and 107, a triode (3-element tube) being used in both cases.

A *diode-detector* circuit is shown in Figure 130. The action of this circuit when a modulated r.f. wave is applied is illustrated by Figure 131. The r.f. voltage applied to the circuit is shown in light line, the output voltage across the condenser C is shown in heavy line. Between points *a* and *b* on the first positive half-cycle of the applied r.f. voltage, the condenser C charges up to the peak value of the r.f. voltage. Then as the applied r.f. voltage falls away from its peak value, the condenser holds the cathode at a potential more positive than the voltage applied to the anode. The condenser thus temporarily cuts off current through the diode. While the diode current is cut off, the condenser discharges, from *b* to *c*, through the diode load resistor R. When the r.f. voltage on the anode rises high enough to exceed the potential at which the condenser holds the cathode, current flows again and the condenser charges up to the peak value of the second positive half-cycle at *d*. In this way, the voltage across the condenser follows the peak value of the applied r.f. voltage and thus reproduces the a.f. modulation. The curve for voltage across the condenser, as drawn in Figure 131, is somewhat jagged. However, this jag-

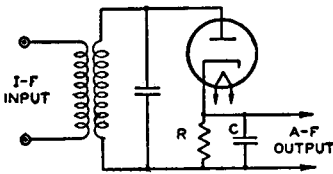


Figure 130. Diode Detector

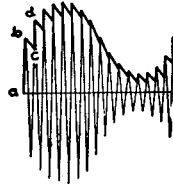


Figure 131. Voltage Across Condenser

gedness, which represents an r.f. component in the voltage across the condenser, is exaggerated in the drawing. In an actual circuit the r.f. component of the voltage across the condenser is negligible. Hence, when the voltage across the condenser is amplified, the output of the amplifier reproduces the speech or music originating at the transmitting station.

It is helpful, in order to understand the diode detector better, to consider the circuit as a half-wave rectifier (page 170). Considered this way, the diode is the half-wave rectifier tube, the r.f. signal voltage is the a.c. input, the r.f. by-pass condenser C is the filter condenser, and the resistor R is the load resistance. Be-

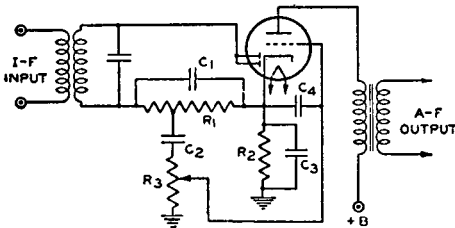


Figure 132. Diode Detector; Triode Tube

cause the d.c. output voltage of a rectifier depends on the voltage of the a.c. input, the d.c. voltage across C varies with the amplitude of the r.f. carrier and thus reproduces the a.f. signal. On the basis of this analogy, it can be seen that the condenser C should be large enough to smooth out r.f. or i.f. variations, but should not be so large as to affect the audio variations. Also, on the basis of this analogy, it can be seen that two diodes can be connected in a circuit similar to a full-wave rectifier to give full-wave detection.



However, in practice, the advantages of this connection generally do not justify the extra circuit complication.

The diode method of detection has the advantage over other methods in that it produces less distortion. The reason is that its dynamic characteristic can be made more linear than that of other detectors. It has the disadvantages that it does not amplify the signal, and that it draws current from the input circuit and therefore reduces the selectivity of the input circuit. However, because the diode method of detection produces less distortion and because it permits the use of simple AVC \* circuits without the necessity for an additional voltage supply, the diode method of detection is most widely used in broadcast receivers.

A typical diode-detector circuit using a duplex-diode triode tube is shown in Figure 132. In this circuit,  $R_1$  is the diode load resistor. A portion of the a. f. voltage developed across this resistor is applied to the triode grid through the volume control  $R_3$ . In a typical circuit, resistor  $R_1$  may be tapped so that five-sixths of the total a. f. voltage across  $R_1$  is applied to the volume control. This tapped connection not only reduces the voltage output of the detector circuit but also reduces audio distortion and improves the r. f. filtering. D. c. bias for the triode section is provided by the cathode-bias resistor  $R_2$  and the audio by-pass condenser  $C_3$ . The function of condenser  $C_2$  is to block the d. c. bias of the cathode from the grid. The function of condenser  $C_4$  is to by-pass any r. f. voltage on the grid to cathode. A duplex-diode pentode may also be used in this circuit. With a pentode, the a. f. output should be resistance-coupled rather than transformer-coupled.

**Heterodyne Detection.** When two signals of different frequencies are superimposed, the envelope of the resulting oscillation varies in amplitude at a frequency which is mathematically equal to the difference between the frequencies of the two signal currents. As the amplitude of one swings into phase with the other, the envelope increases; as it swings out of phase, the envelope decreases. The rate at which the amplitude of the envelope varies is called the beat frequency, and this variation is referred to as heterodyning. Because, when rectified by a de-

\* Automatic Volume Control, page 326.

detector, rectified current results which varies in amplitude at the beat frequency, it should be noted that heterodyne action provides a means for changing the frequency of the incoming a.c. signal current.

In a heterodyne receiver, a local oscillation is imposed on the incoming signal. Local oscillations may have either a higher or a lower frequency than the incoming signal current. The combined wave is then applied to a detector.

**Superheterodyne Receivers.** In the superheterodyne receiver the incoming signal frequency is first converted to a fixed intermediate radio-frequency and is then amplified at the intermediate frequency prior to audio-frequency detection. Special tubes and methods have been devised for performing the frequency-changing operations. The heterodyne detector for such purposes,

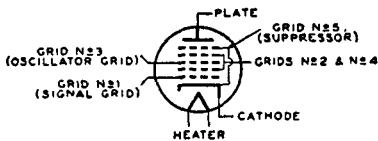


Figure 133. Pentagrid Mixer

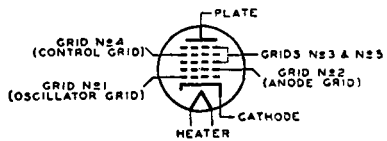


Figure 134. Pentagrid Converter

commonly referred to as first detector, converter, or mixer, is required to develop a different frequency. The principal arrangements employed to do this are plate detection, the pentagrid mixer tube and the pentagrid converter.

The 6L7 is used as a pentagrid mixer tube. It has two independent control grids and is used in connection with a separate oscillator tube. Radio-frequency signal voltage is applied to one of these control grids; oscillator voltage to the other. Variations in the plate current are then a combination of the oscillator and signal frequencies. This arrangement is shown in Figure 133.

The 6A8 and 1C6 are pentagrid converter tubes. By using either one of these tubes, coupling between the oscillator and mixer circuits can be obtained by means of the electron stream within the tube and therefore no oscillator tube is required. (See Figure 134.)

**Automatic Volume Control. (AVC)** Many ground station receivers have loud-speakers. Automatic volume control is especially desirable in these cases because such a circuit regulates the receiver's r.f. and i.f. (intermediate frequency) gain so that this gain is less for a strong signal than it is for a weak signal. This is usually accomplished by increasing the negative bias of the r.f., i.f. and frequency-mixer stages when the signal increases.

A simple AVC circuit is shown in Figure 135. On each positive half-cycle of the signal voltage, when the diode plate is positive with respect to the cathode, the diode passes current. Because of the flow of diode current through  $R_1$ , there is a voltage drop across  $R_1$  which makes the left end of  $R_1$  negative with respect to ground. This voltage drop across  $R_1$  is applied, through the filter  $R_2$  and  $C$ , as negative bias on the grids of the preceding stages. Then, when the signal strength at the antenna increases, the signal applied to the AVC diode increases, the voltage drop across  $R_1$  increases, the negative bias voltage applied to the r.f. and i.f. stages increases, and the gain of the r.f. and i.f. stages is decreased. Thus the increase in signal strength at the antenna does not produce as much increase in the output of the last i.f. stage as it would produce without AVC. When the signal strength at the antenna decreases from a previous steady value, the AVC circuit acts, of course, in the reverse direction, applying less negative bias, permitting the r.f. and i.f. gain to increase, and thus reducing the decrease in the signal output of the last i.f. stage. In this way, when the signal strength at the antenna changes, the AVC circuit acts to prevent change in the output of the last i.f. stage, and thus acts to prevent change in loud-speaker volume.

The function of the filter,  $C$  and  $R_2$ , is to prevent the AVC voltage from varying at audio-frequency. This filter is necessary because the voltage drop across  $R_1$  varies with the modulation of the carrier being received. If AVC voltage was taken directly from  $R_1$  without filtering, the audio variations in AVC voltage would vary the receiver's gain so as to smooth out the modulation of the carrier. To avoid this effect, the AVC voltage is taken from the condenser  $C$ . Because of the resistance  $R_2$  in series with  $C$ , the condenser  $C$  can charge and discharge at only a comparatively slow rate. The AVC voltage therefore cannot vary at a

frequency high enough to be in the audio range. However, the AVC voltage can vary at frequencies below the audio range and, at these frequencies, can compensate for most fading. Thus the filter permits the AVC circuit to smooth out variations in signal due to fading, but prevents the circuit from smoothing out audio modulation.

**Band Spreading.** By band width is meant the range between the minimum and maximum frequency limits which can be received. In the case of certain aircraft receivers, the band width is small. Tuning condensers used in these sets are of rather low capacity and so cover such a wide frequency range, or band, that

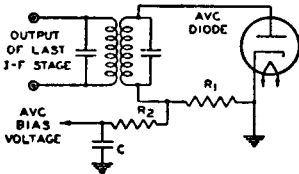


Figure 135. Automatic Volume Control Circuit

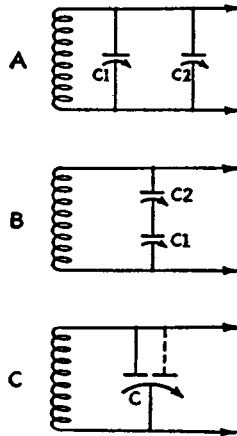


Figure 136. Band-Spread Tuning Systems

tuning becomes difficult. Figure 136 shows several circuit schemes used for band spreading. A is called the parallel condenser method,  $C_1$  being the tuning condenser,  $C_2$  the band-setting condenser. The setting of  $C_2$  will determine the minimum capacity of the circuit; the maximum capacity will be the capacity of  $C_2$  as set plus the total capacity of  $C_1$  at its maximum setting. With each setting of  $C_2$ , a new range of tuning control becomes possible through a manipulation as to the settings of  $C_1$ . In B,  $C_1$  is the tuning condenser. C shows a "split-stator"—one with two separate stationary plate sections and a single rotor.

**The Telephone Receiver.** A schematic drawing of the type of telephone receiver used in radiotelephone and telegraph sets is shown in Figure 137. This receiver provides a means whereby variations of current are made to produce sound.

M is a permanent horseshoe magnet attached to C.

I indicates the poles of M.

D is a thin soft-iron diaphragm, usually varnished on one side and enameled on the other.

C is a hard rubber ear-cap holding D.

L, L are the windings on I, usually of No. 40 B & S gauge wire having a total resistance of from 1000 to 4000 ohms.

E, E are the ends of windings L, L.

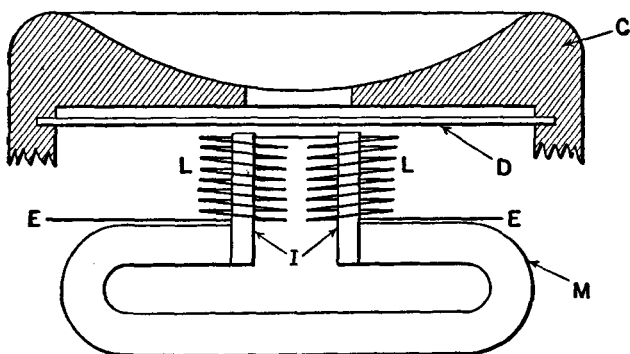


Figure 137. Telephone Receiver

The permanent magnet M pulls the diaphragm D in toward I. The current through L varies, which causes variations in the magnetic field around I. This varying field vibrates the diaphragm D, causing a sound to be set up and heard by the ear. If this receiver should be connected in the place of R in Figure 138, any sound impressed on M in that figure would be reproduced in the receiver while so connected. The intensity of the sound would be amplified by MBT, additional power being supplied by B. The diaphragm is very light in weight in order that its movement may be facilitated. It is placed close to the poles I so that the reluctance of the magnetic circuit will be low. L should be

of many turns of wire in order that it may produce a strong magnetic effect from a weak current. The sensitiveness will be greater if the moving parts are resonant to frequencies between 800 and 1000 cycles. The ear is also most sensitive to these frequencies. The impedance of telephones is from 23,000 to 30,000 ohms. Usually it is approximately the same as the plate circuit of any tube used in the same receiving set.

Two telephone receivers, suitably mounted and connected by a telephone cord, constitute a headset. The cord is really a special type conductor, very flexible, having cotton- or silk-braided insulation. Tinsel cord wrapped over the telephone leads and then covered with insulation makes a very good shielding. Shielded telephone cords tend to eliminate the objectionable howl caused

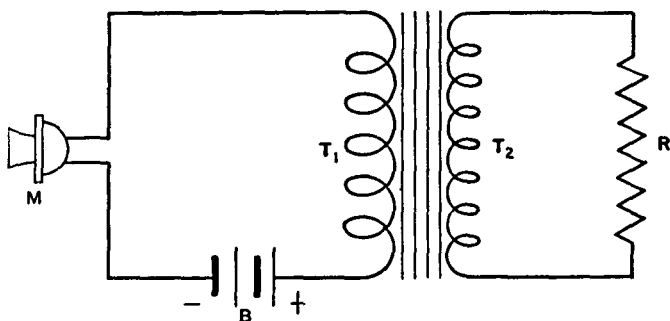


Figure 138. Elementary Microphone Transmitter

by the electric coupling between the output and the input circuits of amplifiers.

Headsets must be capable of reproducing very loud sounds without rattling; they must withstand temperature changes of from as much as 60° to 30° in short order, as when a quick climb follows the take-off. Also, they must be abnormally durable, yet comfortable.

### The National Short-Wave Receiver

The National Short-Wave Receiver was developed in the Jackson Research Laboratories during 1930. It has been successfully used by several air transport companies both as aircraft

equipment and as ground station equipment for the reception of radiophone transmission on wavelengths from 15 to 150 meters. There are embodied in this set several distinctive features of design. It is an a.c. set and the original idea of the manufacturers was to produce a set that would satisfactorily receive the broadcasting stations of the world within the range of 12 to 150 meters. The design requirements of such a set were held to be:

1. Absolute humless a.c. operation.
2. Single dial control.
3. Loud-speaker reception from foreign broadcasting stations.
4. Good tone quality.
5. Non-critical tuning.
6. Neat appearance and reasonable cost.

The set has evidently met the popular demand and its adaptation to the needs of aviation communication systems justifies a brief description of the circuit involved and a discussion of some problems overcome in attaining the ideals desired. This seems particularly true in view of the fact that ultra short-wave sets (those under 50 meters) are extremely efficient in long-range service.

Figure 139 is a diagram of the circuit employed in the National SW-5 Receiver. This circuit shows that the radio-frequency stage is a tuned circuit using a screen-grid tube. A regenerative detector is employed (page 108), the detector also being a screen-grid tube. There are two stages of audio amplification, both stages being transformer coupled. Note that a push-pull arrangement, with two tubes, is employed in the second stage of audio amplification, also that the phones can be plugged into the first stage when desired. The output of the second audio stage marked LS (loud-speaker) could be delivered to headphones if desired. This, of course, will result in considerable increase in signal strength. The push-pull (two-tube) arrangement in the second audio-stage assures a more balanced drain from the power source. Otherwise, the fluctuation in the supply of power would adversely influence the action of the bias resistors resulting in the introduction of hum in the detector and first audio-frequency stages.

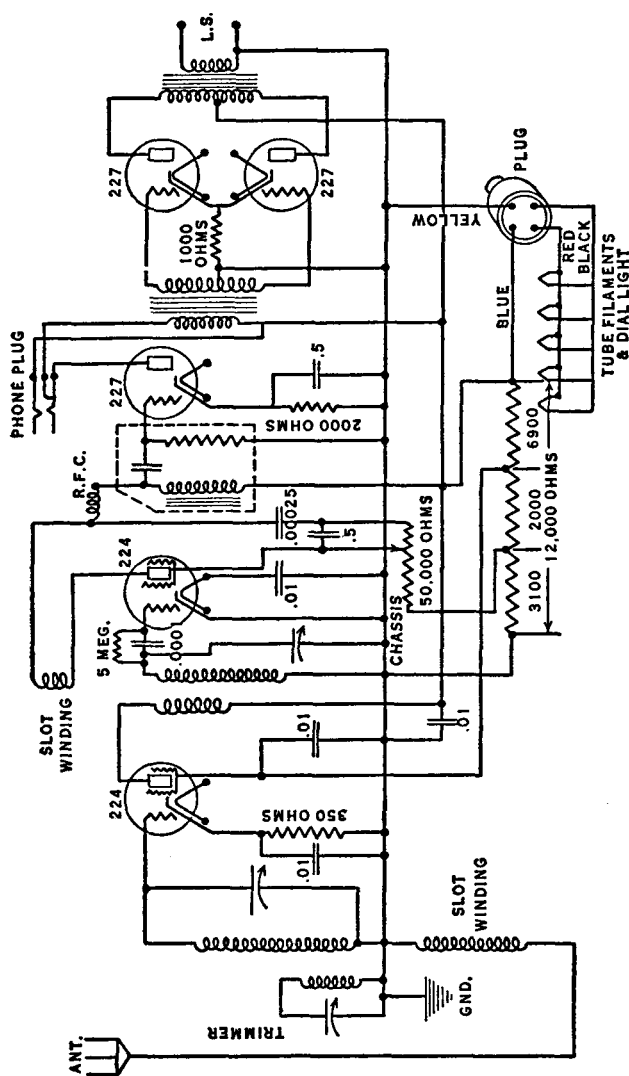


Figure 139. Circuit of National Receiver



The elimination of hum is the critical problem in both the design and construction of short-wave a.c. receivers. One of the most important methods of controlling hum is in the location and arrangement of the wiring.

There is furnished with the National Receiver a specially designed power-pack which supplies the necessary A and B voltages.

The receiving range of the set is varied by the introduction of different tuning coils. These are as follows:

- "Black" (No. 11) Range 14 to 25 meters.
- "Red" (No. 12) Range 23 to 41 meters.
- "White" (No. 13) Range 38 to 70 meters.
- "Green" (No. 14) Range 65 to 115 meters.

**Operation.** Manufacturers always issue detailed instructions telling the operator just how to use a set. It is believed that in most cases it is better for the student operator to learn to follow these instructions, especially as the operator in charge who instructs a new assistant is certain to refer to the operating instructions. However, the following information is given here as an example of the step-by-step procedure involved in making a receiver operative—in this case the SW-5.

On the front panel there are three knobs. The left-hand one is the regeneration control (a variable resistor of 50,000 ohms in the screen circuit of the detector). The center knob and dial control both the r.f. circuits (two 0.0001 mfd. variable condensers in gang). The right-hand knob is the trimmer for matching the antenna to the approximate frequency of incoming signal. This is a small variable condenser in parallel with the antenna coil and is adjusted to maximum signal for each individual set of coils.

To operate the receiver, turn on power with toggle switch located on power unit, allowing 10 to 20 seconds for heater to come up to operating temperature. First be sure the antenna is tuned. To do this, rotate antenna trimmer back and forth until a spot is found where the detector oscillates with the least amount of screen voltage. This point is where antenna and receiving circuits are in resonance and best results are obtained.

Now turn regeneration control clear to left and then slowly to right until detector oscillates. This will be indicated by a soft thud or sudden rush in the speaker or headphones.

The detector is now set at maximum sensitivity. Next turn center knob until a carrier or a CW note is heard and by carefully tuning, set the dial where the CW note has good audibility. Or, if a modulated carrier is heard, tune to dead-beat and return regeneration control to left until detector just stops oscillating and signal will be most easily readable and the detector is acting most efficiently as a detector. This procedure is only for the weaker signals. If a particularly strong CW signal is heard, the antenna may be detuned. Or, if the signal is modulated, turn regeneration control to left until desired volume level is obtained.

**Trouble-Shooting.** Trouble-shooting, like operating, should be learned at a radio station (or in school) but the following routine for checking the SW-5 is given as typical trouble-shooting procedure. If this receiver suddenly became inoperative, the trouble should be located by starting with the antenna, and coming down through the receiver and power-pack. This sequence would be logical only in case the detector could still be heard to come into oscillation but signals were much weaker than usual. In this case the antenna and ground connections should be checked at the binding-post strips. Then the antenna, lead-in, and connections should be investigated for an open circuit, or contact with other wires, or poor insulators. Vary the trimmer condenser from maximum to minimum with the detector in oscillation. If there is no place where the background noises are much louder, or if, with the detector barely in oscillation, there is no change when the trimmer condenser is varied from maximum to minimum and back, check the trimmer coil and condenser for an open or a short circuit. If the trouble has not been located so far, try changing radio-frequency amplifier tubes.

### **The National AGS Receiver**

The National AGS receiver employs a superheterodyne circuit. Plug-in coils are used, giving a tuning range of 1500 to 20,000 kc. The set consists of:

- One T.R.F. amplifier or pre-selector circuit using 36-Type tube.
- First detector or mixer circuit using a Type 36 tube.
- High-frequency oscillator circuit using a Type 36 tube.
- Two i.f. amplifier stages using two Type 36 tubes.
- Second detector circuit using a Type 37 tube.
- Power audio-amplifier circuit using a Type 89 tube.
- Automatic volume control (AVC) circuit using a Type 36 tube.
- Beat-frequency oscillator circuit using a Type 36 tube (for code reception and aid in tuning).

### The Western Electric Receiver No. 12D

**General Description.** The W.E. 12D receiver is found on many airlines. It is a superheterodyne type, so arranged that a quick shift may be made between two fixed frequencies. The frequencies are controlled by Western Electric No. 5 Type quartz plates. This receiver covers the frequency bands of 2750 to 4300 kc and 4300 to 6500 kc, with a suitable overlap. It may be adjusted to any one frequency in each of the two bands, the desired frequency being selected by means of a mechanical control which may be extended to a remote point. Reception of both modulated and CW signal is provided for.

The beating oscillator in the No. 12D radio receiver is designed for crystal-control operation in order to insure that the receiver is always adjusted to the proper frequency.

The plate supply for this receiver may be obtained from a dynamotor operated by a 12-volt storage battery, while the filament supply may be obtained directly from the same 12-volt battery. The plate circuit drain is approximately 40 milliamperes at 200 volts, while the filament drain is approximately 3.2 amperes at 12 volts. The heater current for each of the No. 5B or 5C quartz plates used in the crystal oscillator circuit is approximately 0.5 amperes at 12 volts, when the temperature drops below 32° F.; this current may also be supplied by the storage battery.

The component parts of the receiver are assembled on a chassis which is fastened in a ventilated metal box to provide mechanical protection and overall shielding. The larger pieces of equipment

such as vacuum tubes, quartz plates, intermediate-frequency filter units, radio-frequency coils, and the relay are mounted on the top of the chassis. Smaller parts such as tuning condensers, resistors, choke-coils, and certain by-pass condensers are mounted on the bottom.

**Antenna and Radio-Frequency Circuits.** A schematic circuit of the No. 12D radio receiver is shown in Figure 140. As the radio-frequency circuits are arranged in pairs, a suitable mechanical switching mechanism is employed to select the desired circuits for either tuning range.

The antenna circuit is series tuned and provides a considerable voltage step-up between the antenna and the grid of the first tube. The antenna tuning coils are tapped to provide for reasonably wide variations in antenna constants.

Each of the antenna coils is provided with a tap for use with a transmission line whose impedance is approximately 50 ohms. The leads from these taps are taped and bent over on the bottom of the chassis under L1. Parallel tuning is used when a transmission line couples the antenna to the radio receiver, and requires slight changes in the wiring of the antenna coil; these changes are given in the installation instructions.

Tuned impedance coupling is employed between the radio-frequency amplifier and the modulator tube in order to simplify the coil construction and to reduce the number of circuits which must be switched.

The beating oscillator voltage is introduced into the screen circuit of the modulator tube through a small condenser connected directly to the plate of the oscillator tube. The plate of the modulator tube is connected directly to the input terminals of the intermediate-frequency amplifier.

**Oscillator Circuits.** The quartz plate is placed in the grid circuit of the oscillator tube and the tuned circuit in the plate of the oscillator is adjusted so that it appears as an inductive reactance which is the condition necessary for oscillation.

**Intermediate-Frequency Amplifier.** The intermediate-frequency amplifier which contains two stages of highly-selective

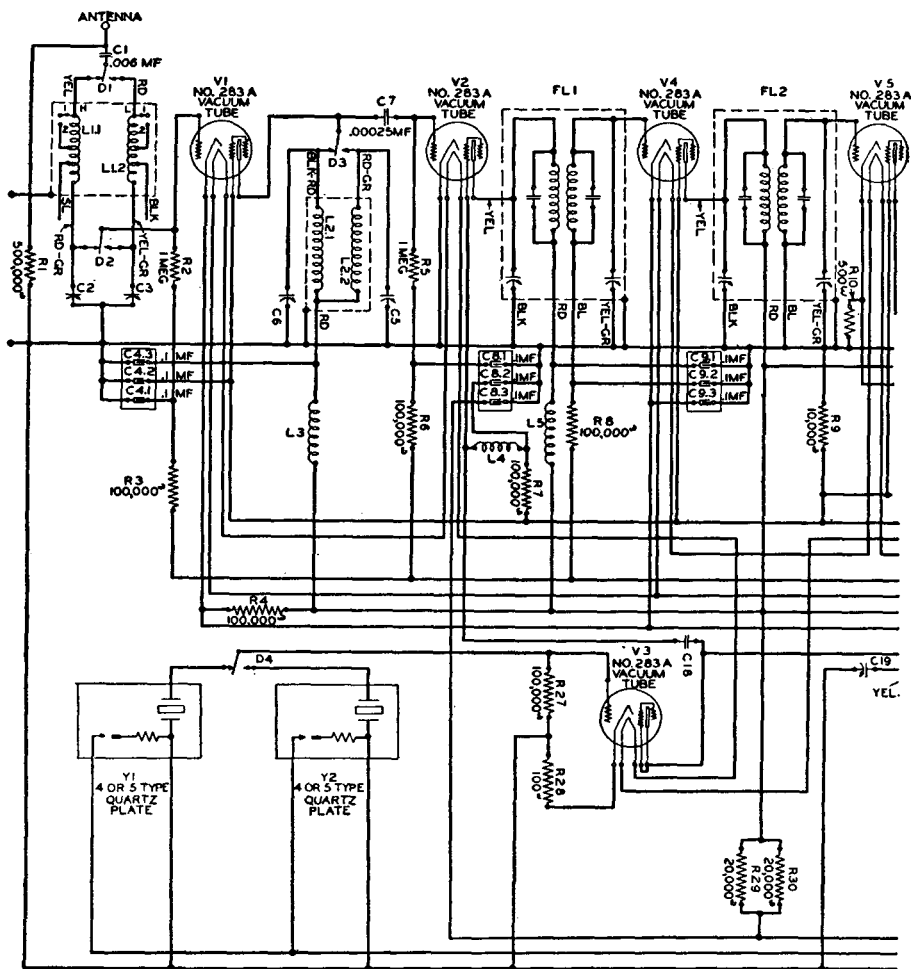
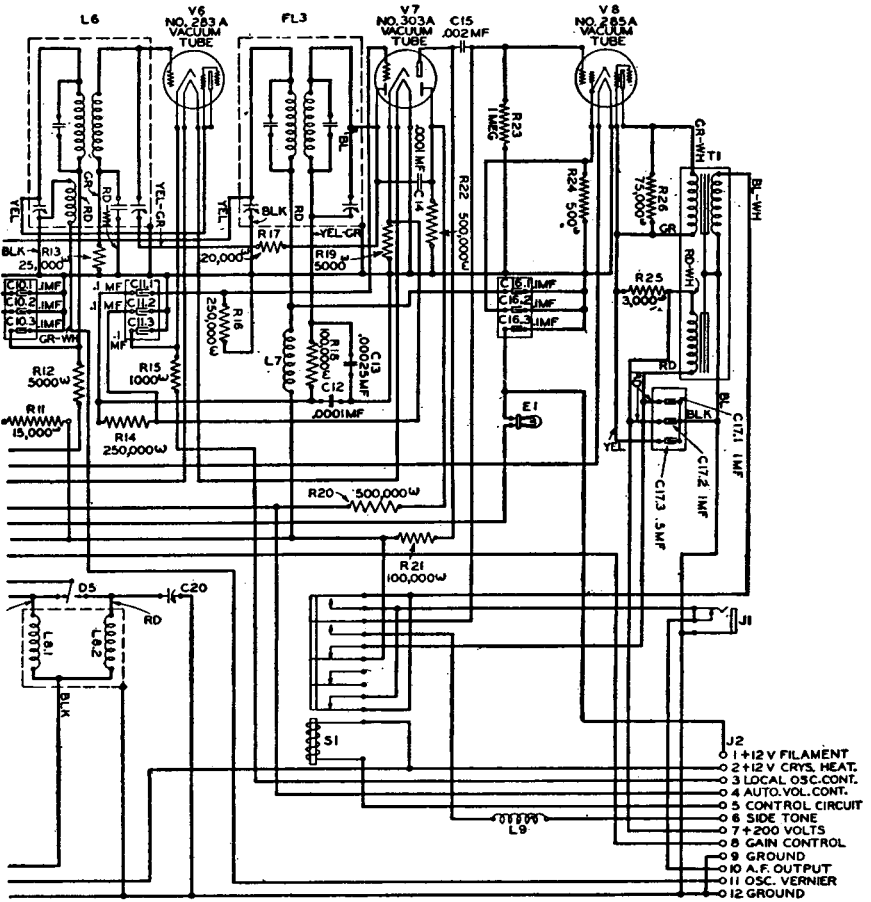


Figure 140. Schematic of Western Electric



No. 12D Radio Receiver

amplification operates at a frequency of 385 kc. Three i.f. filters are used as coupling elements between the modulator, the two i.f. stages, and the detector circuit. Each of these filters contains two tuned circuits which are inductively coupled to constitute a band-pass filter having a band width of approximately 6 kc with a mid-band frequency of 385 kc.

**CW Oscillator.** The CW oscillator is a self-excited oscillator coupled to the detector diode and tuned to give an audible beat note when an unmodulated carrier is received. This oscillator consists of a No. 283A vacuum tube with the screen and plate connected together and the No. 9P unit designated L6 on Figure 140. The frequency of this oscillator is 385 kc plus or minus an audible frequency, the amount depending on the setting of the oscillator control unit.

**Detector Circuit.** The No. 12D radio receiver employs one of the diodes of the duo-diode-triode tube as a detector and the other diode to furnish automatic gain control which allows the removal of the automatic gain control from the receiver when the CW oscillator is in operation without disturbing the detector circuit. The detector diode is resistance-capacity coupled to the triode section which functions as the first stage of audio amplification.

**Audio-Frequency Amplifier.** Two stages of audio-frequency amplification are used with a triode for the first stage and a pentode tube for the output stage. Resistance-capacity coupling is used between the detector and first audio stage as well as between the two audio stages. An output transformer is used which has the proper impedance ratio for low-impedance headsets. Adequate output is obtained for the operation of two headsets connected in parallel.

When the transmitter is in operation, the output tube functions as an amplifier to raise the side-tone to the desired level. Control relay S1, which is operated from the microphone button, makes the proper changes in connections.

**Automatic Gain Control Circuits.** Automatic gain control is obtained by permitting the incoming signal to readjust the grid

bias of the radio-frequency amplifier, the modulator, and one of the intermediate-frequency amplifiers by an amount proportional to the strength of the received carrier. When a signal is applied to the automatic gain control diode of the detector tube, a rectified voltage proportional to the carrier amplitude appears across a resistance in the diode circuit. This voltage is of the proper polarity to increase the negative bias as the strength of the incoming signal increases. Additional bias reduces the gain of the entire receiving system and tends to hold the audio-frequency output at a constant value regardless of the strength of the received signal.

**Level Control and Manual Gain Control.** The level controls are not a part of the No. 12D radio receiver but are a part of the control unit. This control unit will usually be located at some distance from the radio receiver in a location convenient to the pilot or radio operator.

The level control is a potentiometer (variable resistance) connected in the output circuit of the receiver, by means of which the output level may be varied to bring the signal to the desired loudness. This control is so arranged that it does not affect the output level of any other receiver, such as a weather and beacon receiver, which may be connected to the headset in parallel with the output of the No. 12D radio receiver.

When operating under conditions of severe atmospheric interference or when receiving an extremely strong signal it may be desirable to reduce the gain of the radio receiver. This may be accomplished by means of the manual gain control. This control consists of another potentiometer which applies a variable positive bias to the cathodes of the radio-frequency and first intermediate-frequency amplifier tubes, thereby reducing the gain of the receiving system.

**Frequency-Changing Mechanism.** The frequency-changing mechanism employs a series of single-pole double-throw toggle switches, all of which are coupled to the same shaft by means of mechanical links. These switches may be operated by means of a lever located on the mounting if the No. 2B radio receiver mounting is used, or they may be operated from a remote point



by means of a No. 9A control unit and the necessary length of flexible shaft and casing.

**Performance Characteristics.** Figure 141 shows a selectivity curve of the No. 12D radio receiver. As most of the selectivity of this receiver is obtained in the intermediate-frequency amplifier, the selectivity is practically constant over the entire tuning range. It will be noted that in spite of the broad, flat top of this curve, the signal is reduced approximately 50 db at a point 10 kc from the mid-band frequency.

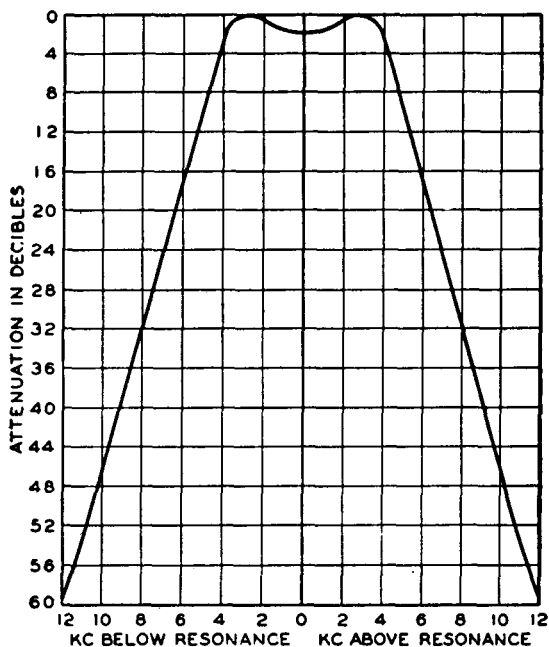


Figure 141. Selectivity Curve of W.E. No. 12D

### RCA Receivers

The RCA Manufacturing Company, Camden, N. J., has been making aircraft and aviation radio sets for some time, and keeps its line up to date. The following two types will be described:

AVR-7 series of Aircraft Receivers.  
AVR-11 Airport Receivers.

**The AVR-7 Series: AVR-7 and 7A.** These are both 4-tube superheterodyne sets designed primarily for the itinerant flyer. The amplifier tube is a 6D6; the detector and oscillator tube is a 6A7; a 6B7 is used as an i.f. amplifier and detector (in number 3 position) and a 6F7 tube is in number 4 position as an a.f. amplifier and power output tube. Both receivers have a power output of 600 milliwatts; both use two pairs of 600-ohm headphones. The overall dimensions are  $7\frac{1}{2}$  by  $6\frac{3}{4}$  by  $9\frac{1}{8}$  in. The circuit of the AVR-7A is shown in Figure 142.

These two receivers are alike in the majority of details, the only difference being in the higher frequency tuning range. The AVR-7 is adapted to reception of the standard Broadcast Band and the aviation Beacon Band, whereas the AVR-7A responds to the aircraft Communication Band and the Beacon Band.

Each receiver is compactly constructed into a complete metal housing. Operating controls are located on a control head, supplied with the receiver. A shockproof mounting is provided with the receiver for eliminating effects of vibration.

The circuit used in these receivers is of the superheterodyne type. A total of four radiotrons are employed, three of which function in a dual manner. Such a combination of functions causes the receiver to be equivalent in operation to one having seven tubes.

Beginning at the antenna and tracing through the circuit to the output, the first element encountered is the special transmission line. This line consists of a twisted-pair lead, thoroughly shielded. One conductor connects directly to the shield and ground at its outer end, and the other is attached to the antenna connector. The dimensions of this line are critical in respect to transmission efficiency and noise induction. They should therefore be left unchanged. Between the antenna transmission line and the first r.f. tube there is included a filter circuit for each of the tuning ranges. These filters are designed for band-pass operation, their action being such that they tend to suppress the residual interference caused by the ignition system of the plane.

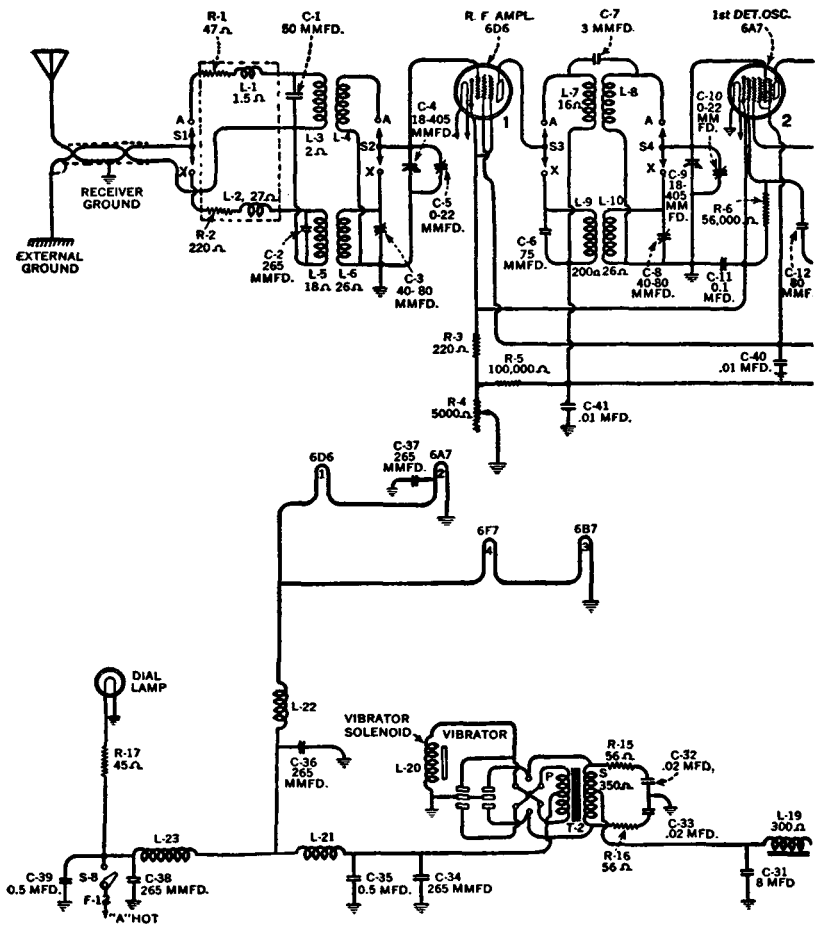
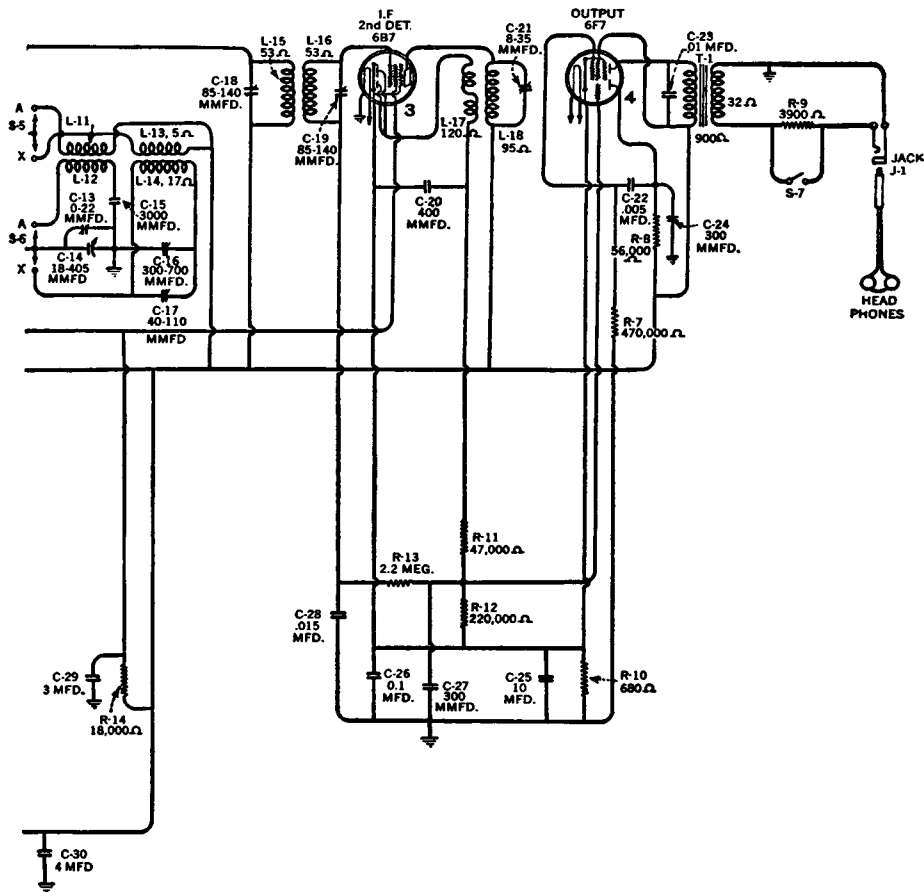


Figure 142. RCA Type AVR-7A Four-Tube



(Courtesy R.C.A. Manufacturing Co.)

Superheterodyne Receiver for Private Aircraft

An RCA 6D6, triple-grid, super-control amplifier tube is used in the first r.f. position, coupling into the first detector through an untuned primary-tuned secondary transformer. The RCA-6A7, which serves as the first detector, also operates as the local oscillator. Two sets of coils are provided in the oscillator circuit as well as for the r.f. transformers. Coils of one set are in operation for each of the two tuning ranges.

The intermediate frequency system consists of a single-stage, transformer-coupled amplifier. The RCA-6B7 employed for i.f. is also used as a diode second detector, and in addition, furnishes an automatic amplitude limiting action on the grid of the i.f. stage. This assists in reduction of static crashes.

Audio amplification and power output are handled by the double function RCA-6F7 tube. The output transformer matches the tube into the 600-ohm headphone circuit.

A "static limiting" circuit is incorporated in the output system for use in improving reception during periods of high atmospherics. It is controlled by a resistor (R-9) in series with the headphones with a shorting switch for cutting it in or out of the circuit. For ordinary reception, when static level is not bothersome, the resistance is allowed to remain shorted, the headphones receiving normal volume at low settings of the volume control. When the static level increases and the resistor is placed in the circuit by opening of the switch, the signal energy to the phones (and static) is reduced. It will then be necessary to advance the volume control in order to bring the signal level back to normal. In so doing, however, the limit of output of the power stage is reached and further increase is not possible. Under these conditions, the output tube is operating at its maximum limit. The intensity of the static therefore can never exceed that of the signal and a marked improvement in reception is obtained.

Filament voltage to the tubes is supplied through a carefully filtered system from the battery of the plane. There are two groups of two filaments in series. Plate current for the various tubes is also supplied by the storage battery of the plane, by inversion and rectification in the vibrator-rectifier unit of the receiver.

The sensitivity of this receiver is 3 microvolts input for 6 milliwatts audio output in the beacon band, and 12 microvolts

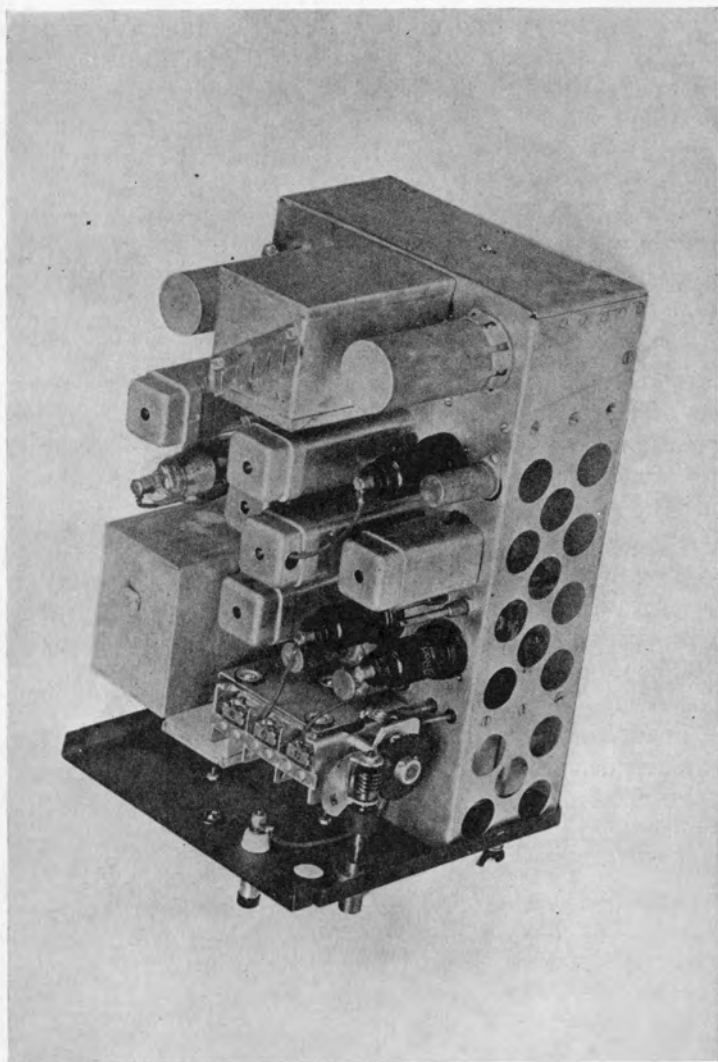


Plate XVII. RCA Model AVR-7G Aircraft Receiver

input for the same audio output in the communication band. The selectivity in the beacon band is such that an interfering signal 14 kc off resonance suffers a loss of 60 db (1000-to-1 voltage ratio) as compared to the signal being received. In the communication band, the loss is 60 db (1000-to-1 voltage ratio) for an interfering signal 40 kc off resonance. The total current drawn from the 12-volt storage battery is 1.4 amperes.

**AVR-7 D, E, F, and G.** The AVR-7 G is the latest of this series. All sets employ a 5-tube, 3-band, superheterodyne circuit, enclosed in a metal container of suitable design. Operating controls are located on a control panel, supplied with the receiver. A shockproof mounting is supplied with the receiver for reducing effects of vibration. The sensitive 5-tube chassis is dependable in operation and durability. Care has been taken in the use of the lightest materials available to keep the receiver weight at a minimum. The AVR-7G is illustrated in Plate XVII.

The AVR-7D is a compact 5-tube, 3-band superheterodyne receiver with self-contained vibrator power unit (Powertron) and a separate panel for operation by remote control. It provides for reception of either Beacon (195 to 420 kc), Broadcast (495 to 1400 kc), or Communication Signals (2300 to 6700 kc).

The AVR-7E has all the features of the AVR-7D and provides, in addition, crystal control of the high-frequency oscillator on two frequencies in the communication band by means of a crystal oscillator assembly installed within the receiver, with its control switch mounted on the control panel.

The AVR-7F is similar in all respects to the AVR-7D and includes in addition a CW beat oscillator, thus providing for CW reception. The CW oscillator assembly is installed within the receiver with its control switch mounted on the control panel.

The Model AVR-7G aircraft radio receiver is the complete model of AVR-7D, E, and F series, incorporating both the crystal control and CW oscillator. These units are installed within the receiver and their control switches mounted on the control panel.

All AVR-7D, E, F, and G models are constructed so that those on which the crystal and CW oscillator are not installed have pro-

vision for easily making the necessary additions and modifications on both receiver and control panel. Also, complete kits of parts are available for the addition of a loop antenna if desired.

### Electrical Specifications.

#### Frequency Ranges:

Beacon and weather (X)	195 to 420 kc.
Broadcast (A)	495 to 1400 kc.
Communication (B)	2300 to 6700 kc.

#### R.F. Alignment Frequencies:

Beacon	200 to 400 kc.
Broadcast	550 to 1200 kc.
Communication	2700 to 6000 kc.
Intermediate Frequency:	460 kc.

The radiotron complement is as follows: RCA-6K7, r.f. amplifier; RCA-6A8, detector and oscillator; RCA-6K7, intermediate frequency; RCA-6R7, second detector and first a.f.; RCA-6F7, CW oscillator and audio output. Receiver power unit; synchronous vibrator rectifier. Current consumption, 2.1 amperes at 12 volts. Power output, 700 milliwatts. Output impedance, 600 ohms.

The total weights of these receivers are: for the AVR-7D, 30 lb. 14 oz. The AVR-7E, 31 lb. 14 oz. The AVR-7F, 31 lb. 2 oz. The AVR-7G, 32 lb. 2 oz. The overall dimensions of the receivers are  $9\frac{1}{8}$  by  $8\frac{7}{8}$  by  $15\frac{5}{8}$  in.

**The Circuit.** The basic receiver circuit in all four models is the same, consisting of a tuned r.f. stage, dual-purpose first detector and heterodyne oscillator stage, intermediate-frequency amplifier stage, a dual-purpose second detector and first audio-frequency amplifier, and a dual-purpose output tube of which the triode section is used as a CW beat oscillator in the AVR-7F and AVR-7G. The use of multi-purpose tubes allows compact construction and gives performance equivalent to an 8-tube circuit.



## The RCA Model AVR-11 Series

The AVR-11's are 16-tube, 4-band, superheterodyne airport receivers. The 11 is a cabinet model, the 11A and 11B rack-mounted, otherwise the models in this series are the same.

### ELECTRICAL SPECIFICATIONS

#### FREQUENCY RANGES

"Long Wave" (X) .....	150- 410 kc
"Standard Broadcast" (A) .....	530- 1,800 kc
"Medium Wave" (B) .....	1,800- 6,400 kc
"Short Wave" (C) .....	6,400-23,000 kc
Intermediate Frequency .....	460 kc

#### ALIGNMENT FREQUENCIES

"Long Wave" (X) .....	175 kc (osc.), 350 kc (osc., det., r.f., ant.)
"Standard Broadcast" (A) .....	600 kc (osc.), 1,500 kc (osc., det., r.f., ant.)
"Medium Wave" (B) .....	6,000 kc (osc., det., r.f., ant.)
"Short Wave" (C) .....	20,000 kc (osc., det., r.f., ant.)

#### RADIOTRON COMPLEMENT

(1) RCA-6K7 .....	First R-F Amplifier
(2) RCA-6K7 .....	Second R-F Amplifier
(3) RCA-6L7 .....	First Detector
(4) RCA-6J7 .....	Heterodyne Oscillator
(5) RCA-6K7 .....	First I-F Amplifier
(6) RCA-6K7 .....	Second I-F Amplifier
(7) RCA-6H6 .....	Second Detector
(8) RCA-6J7 .....	Beat-Frequency Oscillator
(9) RCA-6C5 .....	First Audio Amplifier
(10) RCA-6J7 .....	Noise Suppressor
(11) RCA-6R7 .....	Automatic Volume Control
(12) RCA-6C5 .....	Audio Driver Amplifier
(13) RCA-6F6 .....	Power Output
(14) RCA-6F6 .....	Power Output
(15) RCA-5Z3 .....	Full-Wave Rectifier
(16) RCA-6E5 .....	Tuning Tube
Pilot Lamps (5) .....	Mazda No. 46, 6.3 volts, 0.25 ampere
Power Supply Rating .....	105-125 volts, 50-60 cycles, 120 watts
Power Supply Fuse Rating .....	3 amperes

Power output: undistorted, 5 watts; maximum, 8 watts.  
Loud-speaker type: electrodynamic; impedance, 2.2 ohms at 400 cycles. Headphones: 600 ohms impedance. The circuit is shown in Figure 143.

## General Description

**Circuit.** The conventional type of superheterodyne circuit is used. It consists of two r.f. amplifier stages, a first-detector (converter) stage, a separate oscillator stage, two i.f. amplifier stages, a diode-detector—noise-limiter stage, a beat-frequency oscillator stage, a noise suppressor stage, an automatic volume control stage, a push-pull power-amplifier stage, a tuning indicator "Magic Eye," and a full-wave rectifier.

"MAGIC BRAIN." The new "Magic Brain" is constructed as a separate, self-contained, completely shielded, four-band, oscillator, detector, r.f., antenna-tuning unit, which plugs into the main chassis.

A single-wire antenna, or a doublet antenna, when connected to the proper input terminals of the receiver, is coupled to the control grid of the RCA-6K7 first r.f. amplifier tube (see Figure 143) through the tuned r.f. transformer, consisting of L6, L5, L4, L3, and L2. A unique method of switching is used. In the long-wave band, L6 becomes the primary with L5, L4, L3, and L2 as secondary. In the standard broadcast band, L5 becomes the primary with L4, L3, and L2 as secondary (L6 shorted out). In the medium-wave band, L4 becomes the primary with L3 and L2 as secondary (L6 and L5 shorted out). In the short-wave band, L3 becomes the primary with L2 as secondary (L6, L5, L4 and tap on L4 shorted out). The tap on L4 is provided to prevent interaction with L3 and L2 when operating receiver in short-wave band. This method of switching reduces the total number of coils and leads, and results in having a low-loss primary and secondary winding for each band, with high efficiency of operation.

The band switching of the second r.f. amplifier and first-detector is similar to that of the antenna circuits. Coils L11 and L17 act as high-frequency primaries which resonate slightly above 20 Mc and improve the gain at the high-frequency end of the short-wave band.

Separate windings are employed in the oscillator stage for each position of the range selector. The inherent stability of this circuit provides minimum frequency drift which is especially advantageous for high-frequency reception. The locally-generated signal is capacitance coupled to grid No. 3 of the RCA-6L7 first detector.

The output of the "Magic Brain" is fed to the i.f. amplifier through a plug-in cable. This cable also supplies all power required by the "Magic Brain" unit.

This phrase "magic brain" was coined by The RCA Company.

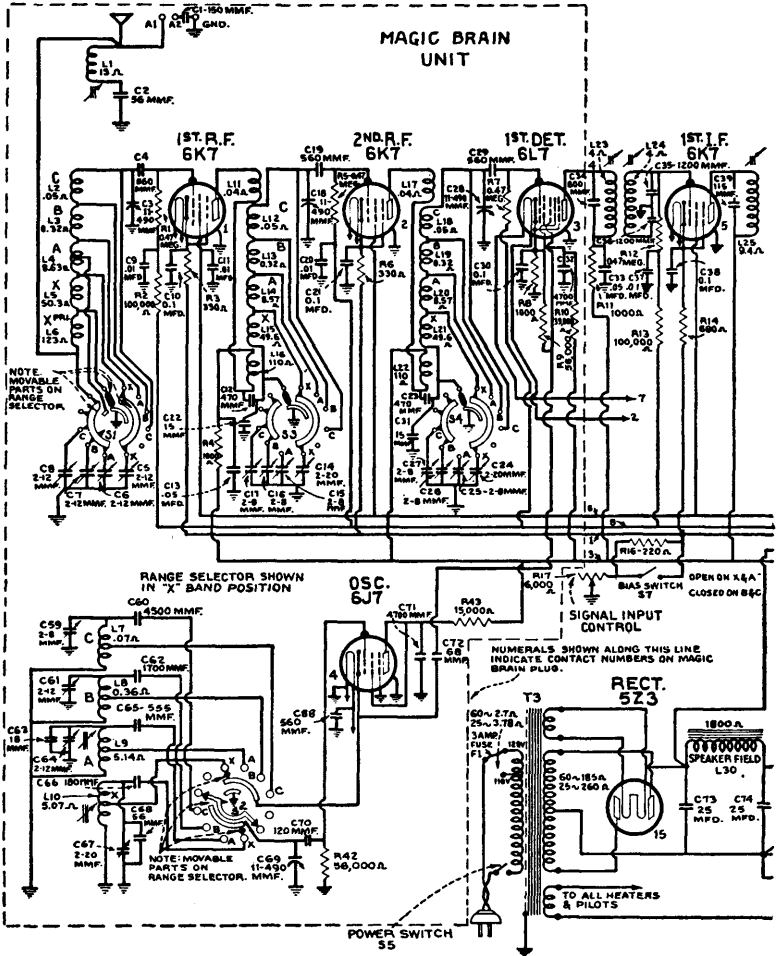
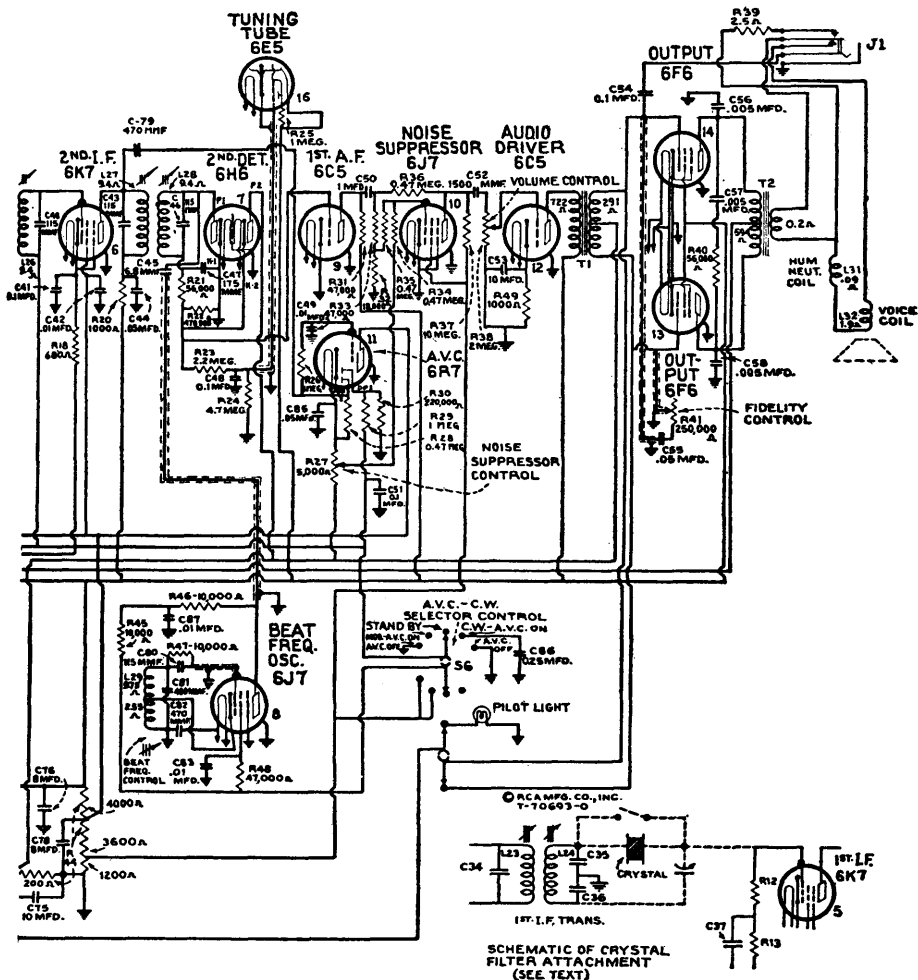


Figure 143. Schematic Circuit Diagram



RCA Model AVR-11 Airport Receiver

**I.F. AMPLIFIER.** The intermediate-frequency amplifier consists of two RCA-6K7 tubes in a two-stage, transformer-coupled circuit. The windings of all three i.f. transformers are resonated by fixed capacitors, and are adjusted by molded-magnetite cores (both primary and secondary) to tune to 460 kc. Provision is made for the addition of a crystal filter between the first i.f. transformer secondary (L24) and the control grid of RCA-6K7 first i.f. amplifier tube.

**DETECTOR AND NOISE LIMITER.** The signal, as obtained from the output of the last i.f. stage, is detected by an RCA-6H6 twin-diode tube (No. 1 diode), the useful audio-frequency (a.f.) and direct current (d.c.) components appearing across resistor R22. The No. 2 diode of this same Radiotron is effectively placed in shunt with R22 with its anode biased approximately 20 volts (in opposition to components across R22) negative with respect to the cathode by means of the bleeder resistor R44. Excessive signals, or bursts of static, of magnitude great enough to cause the voltage across R22 to exceed 20 volts will cause the No. 2 diode to draw current, or present a low impedance across R22, thereby acting as a noise limiter.

**AUDIO SYSTEM.** The control grid of the RCA-6C5 first audio amplifier is connected directly to R22, the tube functioning as a diode-biased voltage amplifier. The output of this tube is resistance-capacitance coupled to the control grid of the RCA-6C5 audio driver, potentiometer R38 functioning as the volume control. The output of the driver stage is transformer coupled through T1 to the control grids of the RCA-6F6 push-pull power-output tubes. The output of this stage is transformer-coupled, through T2, to the voice coil of the electrodynamic loud-speaker. Insertion of a telephone plug in the headphone jack J1 disconnects the voice coil from the secondary of T2 and substitutes a dummy resistor R39 in its place. The tip and sleeve of the plug are connected across the input circuit of one of the RCA-6F6 power tubes, through capacitor C54, for headphone reception.

The "Fidelity" or tone control comprises the combination of capacitor C55 and variable resistor R41 shunting the secondary of T1.

**AUTOMATIC VOLUME CONTROL.** The operation of the RCA-6R7 automatic-volume-control tube and associated circuits is as follows:

Under condition of no signal, the cathode current flowing through resistor R27 develops a voltage across R27 of approximately 29 volts. This is in opposition to the approximate 20 volts drop across the bleeder resistor R44, thereby making the cathode approximately 9 volts positive with respect to chassis-ground, or to the anode DP-1. When signals

are present, a portion of the i.f. voltage is applied to anode DP-2, through capacitor C79, for rectification. The d.c. voltage which develops across resistor R28 is applied to the control grid of the RCA-6R7 through a resistance-capacitance filter, making the grid more negative with respect to cathode; in turn reducing the cathode current or voltage drop across R27, and consequently making the cathode less positive with respect to anode DP-1 than under the condition of no signal. Sufficient signal will cause the cathode to become negative with respect to diode DP-1; current will flow through resistor R30 causing a voltage drop across R30, which is applied as automatic control-grid bias to the r.f., first-detector, and i.f. tubes through suitable resistance-capacitance filters.

**NOISE SUPPRESSOR.** The noise suppressor consists of an RCA-6J7 whose plate circuit effectively shunts the input circuit of the audio-driver stage, and a means of making the shunting plate impedance very high for desired signals, and very low for undesired noise impulses of short duration and amplitude greater than the desired signal. The plate impedance will be very high for control-grid bias value sufficient to cause plate-current cut-off, and low for bias values which will permit plate current to flow. The audio signal appearing across resistor R37, and consequently across the RCA-6C5 audio driver input circuit will, therefore, depend upon the ratio of the plate impedance of the noise suppressor tube to the resistance of R36; the series combination being essentially a voltage-dividing network. When the plate impedance is high, the ratio will be high, and practically the total audio voltage appearing across resistors R33 and R32 will appear across the plate circuit. The converse will occur with a low plate-impedance. In operation, the bias is adjusted just below the point of plate current cut-off by means of the movable arm on R27. Noise impulses of short duration, tending to make the grid more positive, will cause the plate impedance to be low during these impulses with a consequent reduction of input to the audio driver during these intervals.

**"BEAT-FREQUENCY" OSCILLATOR.** The frequency generated by the "Beat-Frequency" beat-oscillator (457 to 463 kc) for CW reception is applied to the No. 1 diode plate of the RCA-6H6 second-detector through capacitor C45. This frequency mixes with the incoming intermediate frequency to produce an audio-frequency note which can be readily heard in the loud-speaker or phones. The movable magnetite core, adjusted by the "Beat-Frequency" control, provides a variable inductance which acts as a vernier control for adjustment of the oscilla-

tor frequency over the required a. f. range on either side of the intermediate-frequency signal. The plate and screen-grid voltage supply to this oscillator is turned on and off by means of the "AVC—CW" selector switch.

**"AVC—CW" SELECTOR.** A five-position switch is provided to adjust the receiver for modulated or CW reception, either with or without automatic volume control, according to requirements. The time constants of the AVC circuits will be such that they will hold for the intervals between characters for high-speed CW reception. For slow-speed CW reception, however, the time constant will not hold and the switch should be turned to "CW—AVC Off." The secondary of the audio transformer T1 is short-circuited in the "Stand-by" position.

**"MAGIC EYE."** An RCA-6E5 cathode-ray tuning tube is used as a means of visually indicating when the receiver is accurately tuned to the incoming signal. This tube consists of an amplifier section and a cathode-ray section built in the same glass envelope. A portion of the voltage developed across resistor R22 is used to actuate the grid of the amplifier section. Maximum voltage is applied to this grid when the receiver is tuned to resonance with an incoming carrier. This condition is evidenced by minimum width of the dark sector on the fluorescent screen.

**AVA-8 Crystal Attachment Unit.** Because most aircraft transmitters are crystal-controlled, RCA has developed the same means for controlling the frequency of receivers, the AVA-8 being especially suitable for use with the AVR-11 airport receiver. It provides for the control of any two frequencies in the aviation communications band of 2000 kc to 6500 kc. The crystals used are of the "V"-cut low-temperature coefficient type, mounted in RCA Model AVA-10 crystal holders. The two crystals will be supplied, ground for the frequencies requested by the customer. Additional crystals may be had when desired.

When operating with this Model AVA-8 unit, the receiver may be pre-tuned to one frequency, thus allowing for three-frequency operation with two frequencies being crystal controlled. Or, the receiver may be used as a conventional receiver. Two controls on the front panel of the AVA-8 serve for complete control of the unit; one being a filament on-off switch, the other a four-position switch controlling: (1) remote operation;

(2) day frequency; (3) night frequency; (4) conventional receiver.

Where desired, an RCA remote receiver control equipment is available for remote control operation. This is particularly recommended wherever there is severe electrical disturbance around the local field. This remote control equipment allows for switching from day to night frequencies.

The RCA Model AVA-8 unit consists of a duo-radio frequency amplifier, duo first detector with crystal oscillator combined, and a common intermediate-frequency amplifier. Any pair of frequencies within the frequency range of 2000 kc to 6500 kc may be used by obtaining the proper crystals and making the necessary tuning adjustments. The unit receives its plate-voltage supply from the receiver chassis, but the tube heaters are energized by a built-in transformer. The additional 110-volt a.c. power required is 12 watts. Special interconnecting cables are supplied for wiring this unit to the receiver and complete instructions for application to the RCA Models AVR-5A and AVR-11 airport receivers are included with the equipment.

**RCA Operating Manuals.** The RCA Company supplies very clearly written instructions for the installation, maintenance, and operation of all their sets, consequently that information will not be repeated here.

### **The Western Electric Receiver No. 14B**

The W.E. receiver 14B is for weather and beacon signals in the band of 200 to 400 kc. An automatic gain-control circuit is provided for use with the beacon transmission system employing a low percentage of modulation to keep the output of the radio receiver essentially constant regardless of the strength of the received signal.

**Description of Circuits.** A superheterodyne type of circuit is employed consisting of one stage of tuned radio-frequency amplification, an oscillator, a modulator, two stages of intermediate-frequency amplification, a diode detector, and two stages of audio-frequency amplification. The functions of oscillator and



modulator are combined in a single converter tube. The detector and first audio-frequency tube are combined in a double diode-triode type of tube. The schematic of this receiver is shown in Figure 144.

A set of fixed condensers shunted by "trimming" condensers are provided which may be connected in place of the variable tuning condensers by means of a solenoid-operated switch. This provides a convenient method of quickly tuning the receiver to the airport frequency of 278 kc without disturbing the setting of the variable condenser.

**Radio-Frequency Amplifier.** The antenna is directly connected to the first tuned circuit. This method of coupling provides a maximum voltage set-up between the antenna and the grid of the first tube. A trimming condenser (C1) is provided to compensate for different antenna capacities. A fixed condenser in parallel with a trimming condenser is located in the same assembly with the antenna circuit coils, and this assembly is coded as the No. 9L tuning unit. These condensers are used to tune the antenna circuit to the airport frequency of 278 kc when the relay is operated.

The plate circuit of the radio-frequency amplifier tube is coupled to the grid of the converter tube by means of the tuned transformer L2. This transformer, in conjunction with the condensers used for tuning the fixed frequency, constitutes the No. 9M Tuning Unit.

**Converter Circuit.** A converter tube of the "hexode" type combines the functions of oscillator and modulator. The two inner grids of this tube are connected in a conventional oscillator circuit while the remaining elements of the tube constitute the modulator circuit. A screening grid is located between the oscillator section of the tube and the modulator section, so that there will be no coupling between these circuits.

The oscillator tuned circuit is inductively coupled to both the grid and anode of the oscillator. The plate of the converter tube is connected directly to the input of the two-stage intermediate-frequency amplifier.

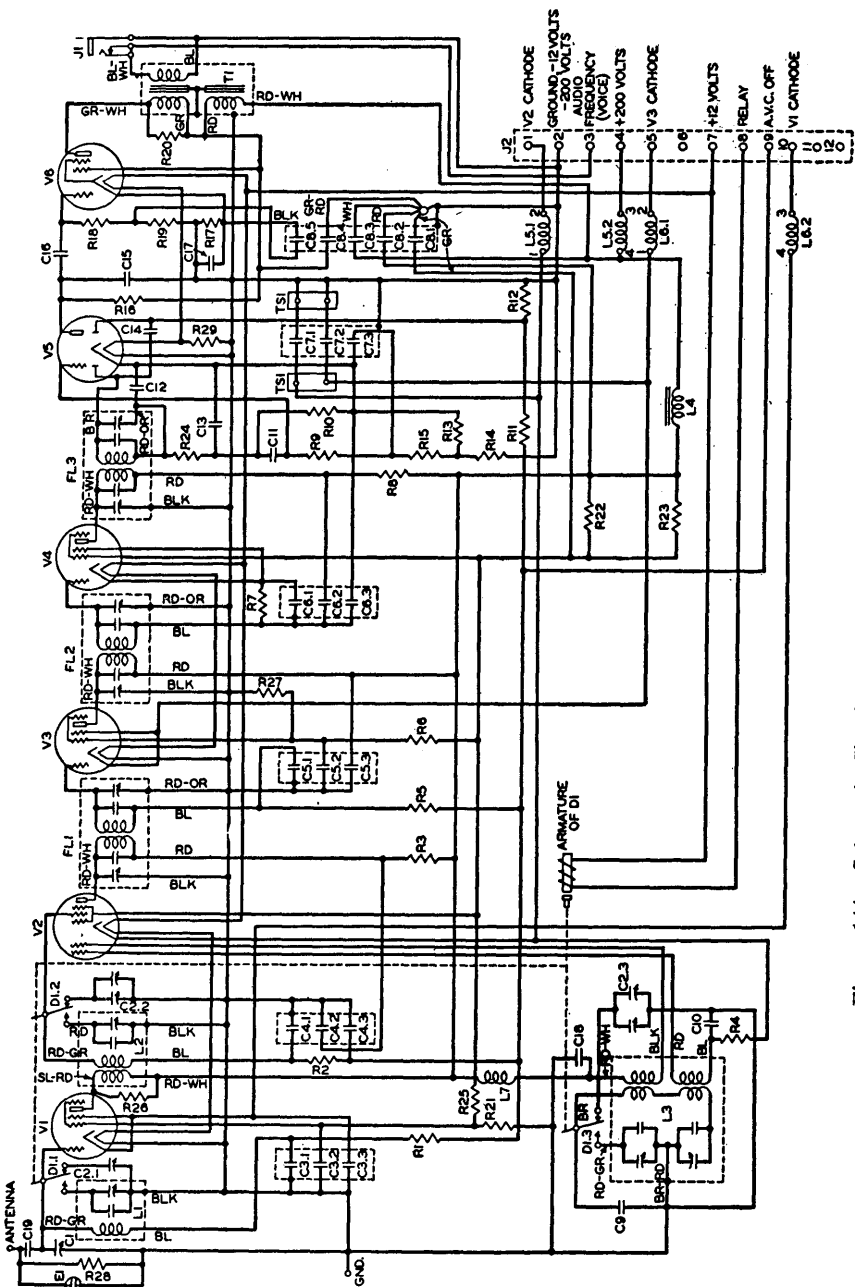


Figure 144. Schematic Circuit of Western Electric Receiver No. 14B

**Intermediate-Frequency Amplifier.** The intermediate-frequency amplifier, which contains two stages of selective amplification, operates at a frequency of 96 kc. Three i.f. filter units are used as coupling elements between the modulator, the two i.f. stages of amplification, and the detector. Each of these filters contains two tuned circuits which are inductively coupled to constitute a band-pass filter having a band width of approximately 4 kc with a midband frequency of 96 kc.

**Detector Circuit.** The output of the i.f. amplifier is connected directly to the diode used as a second detector. This diode is one of the elements of tube V5, which contains another diode to provide automatic volume control for use with radio range transmissions employing a low percentage of modulation. This tube also contains a triode which is used in the first stage of audio-frequency amplification. Resistance-capacity coupling is employed between the detector and the first a.f. stage.

**Audio-Frequency Amplifier.** The two-stage audio-frequency amplifier employs resistance coupling between the first and second stages. A pentode tube is used in the output stage. The output transformer has the proper impedance ratio for the use of either one or two pairs of low-impedance headsets.

**Automatic Volume Control Circuits.** A separate diode provides automatic volume control. The circuit is so adjusted, however, that this diode operates only when receiving signals from transmitters which employ a much lower percentage of modulation than do the present aural radio-range transmitters.

The automatic volume control diode is biased by a voltage in the detector cathode circuit, so that it cannot draw current until the intermediate-frequency voltage fed to the detector exceeds approximately 10 volts. When receiving from a station which employs a high percentage of modulation, as certain aural radio-range transmitters now in use, less than 3 volts of intermediate-frequency signal is required at the detector to give the full output which the receiver can deliver. If the sensitivity control is retarded until the receiver gives the desired output, the voltage which is available at the detector is insufficient to make the auto-

matic volume control diode draw current and affect the gain of the receiver. The receiver therefore operates as a manual gain control receiver.

When a received signal employs a low percentage of modulation, a correspondingly higher intermediate-frequency voltage is required at the detector to give the desired output. When receiving this type of signal, the sensitivity control will usually be left at maximum. Then, as the voltage at the second detector exceeds 10 volts, the automatic volume control diode begins to draw current and supplies bias to the r.f. amplifier, the modulator and the first i.f. amplifier tubes. When receiving a signal of this type, a level control may be used in the output of the receiver to reduce the output to the desired value. The output signal will then remain practically constant regardless of the strength of the received signal.

**Manual Gain Control Circuits.** The manual gain control is not a part of the No. 14B radio receiver but is located in the 8C control unit. This control is a potentiometer which supplies a variable bias to the cathodes of the radio-frequency amplifier, the modulator and the first i.f. amplifier tubes, thereby controlling the gain of these tubes. Separate leads are brought out from the cathode of the r.f. amplifier, the converter, and the first i.f. amplifier. These three leads are connected together in the control unit where they are attached to the gain control potentiometer. By bringing these leads out separately, a switch inserted in the cathode of the radio-frequency amplifier will act as a "local-distance" switch, and a meter inserted in the cathode of the first intermediate amplifier will act as a rough distance indicator when signals are received from radio range beacons employing continuous carrier. The two radio-frequency circuits contribute considerably to the selectivity of the receiver. Approximately 60 db suppression is supplied by these circuits at the image frequency, which is 192 kc above the signal frequency.

Fidelity <sup>89</sup> curves taken at 220 and 365 kc are shown in Figure 145.

The attenuation of the higher frequencies is due almost entirely to the selectivity of the r.f. and i.f. circuits. The r.f. cir-

cuts are considerably sharper at the lower frequency, which explains the difference in the fidelity curves taken at 220 and 365 kc.

The sensitivity <sup>216</sup> of this receiver is sufficient to get full output with a signal input on the antenna of only a few microvolts. Sufficient step-up is provided in the antenna circuit so that with a signal of one microvolt at 40% modulation, the output with unmodulated carrier present is at least 6 db below the output obtained with the modulated carrier present.

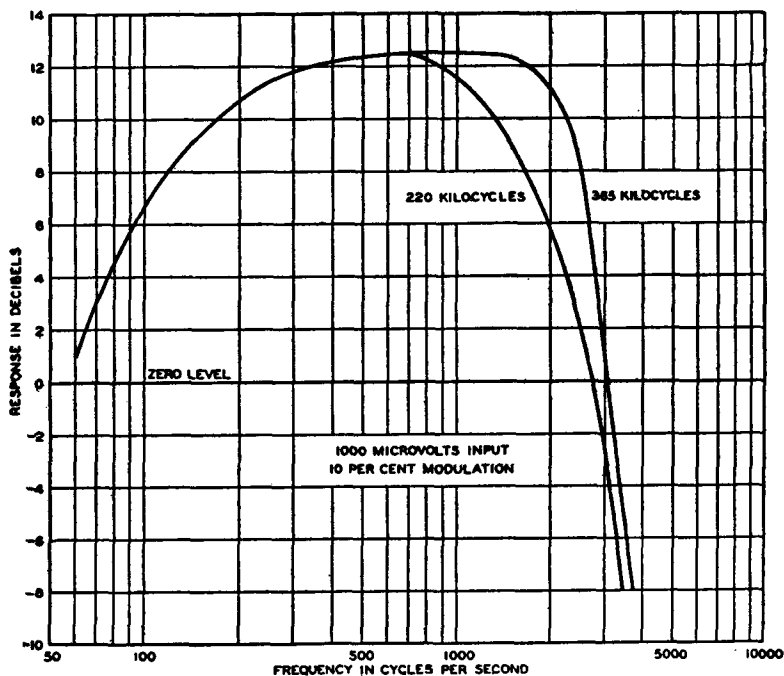


Figure 145. Fidelity Characteristics Graph

### Beacon Receiver Filter

The radio-frequency carriers of all the new simultaneous radio range stations are modulated with a 1020-cycle tone. To make it possible for the pilot to secure clear reception of either the range signals or weather announcements when they are both being transmitted at the same time, Bell Laboratories, following a

design of the Department of Commerce, has developed a small filter, known as the 724A. This really consists of two filters: a band-pass filter that passes only a narrow band centered at 1020 cycles, and a band-elimination filter that eliminates a narrow band centered at 1020 cycles. The band-pass filter passes the range signals and eliminates the weather announcements, while the band-elimination filter eliminates the range signals and passes the announcements. The connection of these two filters into or out of the circuit is controlled by a three-position switch. In one position of the switch both range and weather signals are heard; in the second position, only the range signals; and in the third position, only the weather announcements. The method of connecting is indicated in Figure 146.

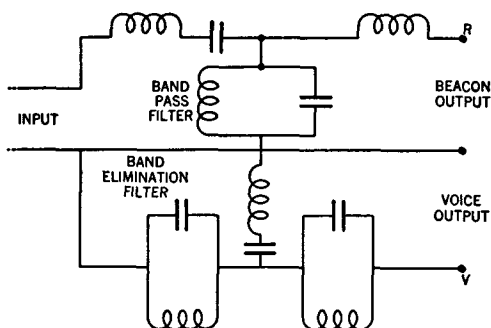


Figure 146. Western Electric Beacon Receiver Filter Unit 724A

When flying the range, the pilot will normally have his filter switch turned to the range-and-voice position, and thus will hear the weather announcements as soon as they come on. If at that time the range signals are more important to him than the weather announcements, he will turn his switch to the range position, which will cut out the voice announcements, and leave the range signals clear. If, however, he wants the weather announcements and can get along without the range signals for a short time, he will turn the switch to the voice position, which will eliminate the range signals and leave the voice clear.

A schematic of the two filters is given in Figure 146, and their characteristics in Figure 147.

### Antennas for Beacon Receivers

The standard beacon antenna system initially consisted of a vertical streamline mast projecting some 6 ft. in height outside the aircraft fuselage and insulated from metal parts of the ship. Due to the drag of such an antenna, however, it has largely been superseded by a "Vee" type of antenna along and across the

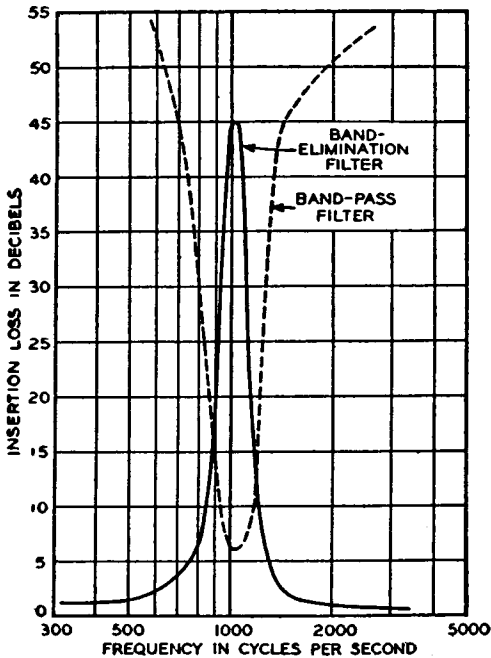


Figure 147. Characteristics of the W.E. 724A Band-Pass and Band-Elimination Filters

belly of the ship. The horizontal portion of such antennas are effective only in reducing the antenna impedance and only the vertical portion of the antenna is effective in signal pick-up. Considerable care has been necessary in this construction of antennas for beacon reception to prevent false cone of silence indications. Inasmuch as the radio beacon signals are vertically polarized it is general practice to locate the receiver directly at the end of a verti-

cal lead-in rather than drape the antenna along the inside of the fuselage of the ship.

Another type of antenna for beacon reception which has been popular with some airlines is the so-called sloping fin antenna. This antenna was suspended from the tail-fin to a point forward along the fuselage, with the receiver installed near the tail of the ship. The objection, however, to this type of antenna was that when flying into the cone of silence the output of the beacon receiver varied as shown in Figure 148. Thus the output of the receiver increased considerably when flying into the cone of silence, dropped to zero when directly over the cone, and rose when flying out of the cone of silence. Beacon receivers do not utilize automatic volume control action for the obvious reason that it would level off the A-N signals so as to give pilots the indi-

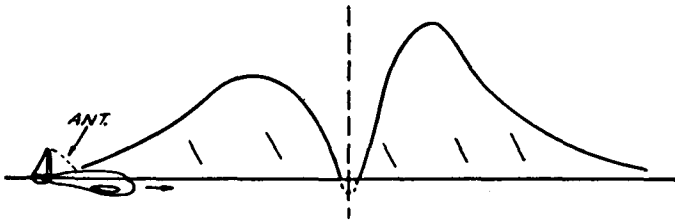


Figure 148. One Form of Beacon Receiver Antenna, Its Receiving Characteristics Indicated

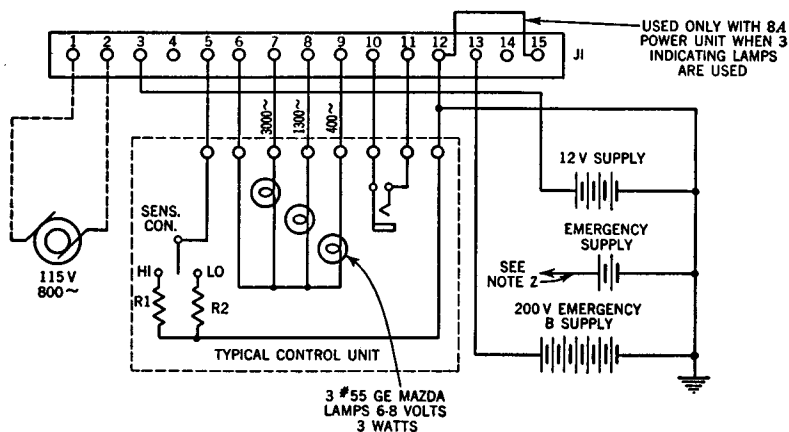
cation that they were flying down the course even if they were off course.

Antennas of various types are described more in detail in Chapter 15; some of these are especially designed for use with receivers.

### Ultra-High-Frequency Marker Beacon Receivers

The essentials of the receiver developed by the government for the reception of signals aboard aircraft of the fan type ultra-high-frequency marker beacons described in Chapter 9 are described in Vol. 8, No. 8, February 1937 issue of the Air Commerce Bulletin. It consists of a grid-leak condenser and audio





Note 1—R1 and R2 shall be determined by test after antenna installation.

Note 2—When emergency supply is 12 v. connect to terminal 4 of J1.

When emergency supply is 6 v. connect to terminal 14 of J1 and gnd. terminal 4 of J1.

Figure 149. Wiring Diagram for Western Electric U.H.F. Marker Beacon Receiver, No. 27A. (Receiving antenna is shown on page 441.)

amplifier with an output band-pass filter, a diode rectifier, and a sensitive d.c. relay.

The Western Electric Company has supplied these extensively both for the government and most airline companies. They are crystal-controlled superheterodyne type; weigh about 20 lb. No tuning or other attention on the part of the pilot is required. An indicator lamp lights when the plane passes over the marker; a signal is also heard. Figure 149 shows the wiring circuit.

### Bendix Radio Corporation Type RA-1 Series Aircraft Receiver

The Bendix RA-1 may be employed for the reception of continuous-wave telegraph, modulated continuous-wave telegraph, and radiotelephone signals within two frequency ranges: from 0.15 to 1.5 Mc, and from 1.8 to 15.0 Mc (166–20 meters).

The receiver is designed to be operated locally, through the controls mounted on its front panel, or from any remote point within the airplane, through the use of a remote-control unit which includes duplicate operating controls.

Plate voltage for the receiver is obtained from a dynamotor designed to operate from the airplane 12-14-volt (6-cell) storage battery. The filament voltage is supplied directly from the same source.

**Radio-Frequency Circuit.** The input energy is fed into a high-gain antenna coil working into another high-gain r.f. stage which is arranged to produce a high-image ratio. Separate tubes are used for the converter and high-frequency oscillator, resulting in freedom from circuit interaction and permitting a high order of conversion gain. All coils in the antenna, r.f., and oscillator assemblies are wound on isolantite forms. Trimming and padding condensers are made of invar metal and isolantite insulation. These coils have been developed to produce great stability with regard to humidity and wide-range temperature variations.

**Intermediate-Frequency Circuit.** The intermediate frequency is 1630 kc. This receiver employs two such stages. The first stage incorporates a band-pass filter, designed for improved i.f. selectivity. All i.f. filters employ iron core i.f. coils with isolantite tuning condensers. These i.f. assemblies have been designed for the greatest possible stability and selectivity characteristics.

**Automatic Volume Control.** The receiver uses separate diode plates for signal and automatic-volume-control rectification.

**Tube Complement.** The tube complement is shown in the following chart:

Designation	Type	Circuit
V1	6K7G	Radio-Frequency Amplifier
V2	6K7G	High-Frequency Oscillator
V3	6L7G	Converter
V4	6K7G	1st I.F. Amplifier
V5	6K7G	2nd I.F. Amplifier
V6	6R7G	2nd Detector-1st Audio Amplifier
V7	6K6G	Audio-Output Stage
V8	6K7G	Beat-Frequency Oscillator

**Audio Circuits.** The audio amplifier combines a relatively low-gain resistance-coupled triode with a standard 6K6G output pentode. Special control of power output automatic volume control is arranged by means of a dual volume control. This method permits the omission of any high-level grid leads running through the remote cable.

### **Bendix Type RG-2 Series Receiver**

The Bendix type RG-2 Radio Receiver is a rack-mounted, multichannel receiving equipment designed for fixed-frequency applications at ground stations.

The receiver is designed to operate from a 110-volt, 25- or 60-cycle supply.

Separate r.f., i.f.-a.f., and power supply units are used, and provision has been made for either local or remote control of the equipment.

A maximum of eight channels may be equipped in the frequency range between 1900 and 21,000 kc (158–13.3 meters). One i.f.-a.f. unit is required for four r.f. pre-selectors. Each channel may be selected individually or all channels may be monitored simultaneously if desired.

A carrier-operated noise-suppression circuit renders the receiver inoperative during periods when no signals are being received.

The inclusion of a variable-beat frequency oscillator permits reception of continuous-wave telegraph as well as modulated transmissions.

All units are of the recessed chassis type construction with removable front panels finished in black crackle enamel, and are provided with individual dust-covers finished in satin cadmium plate.

The input of the amplifier unit is designed for connection to a 72-ohm doublet antenna. A maximum of four r.f. amplifier units may be used with a single antenna, the inputs of the amplifier units being connected in series. The input terminals are located in a small junction box on the left of the chassis deck.

The circuit includes a stage of radio-frequency amplification, a high-frequency oscillator and a mixer stage.

The oscillator is designed to use either a crystal or a coil-and-condenser combination for frequency control, a plug-in arrangement permitting easy change-over from one type of control to another when desired.

The output of the mixer tube is run to the i.f.-a.f. amplifier unit through a concentric conduit, which is attached to the r.f. amplifier unit at one of two holes in the center of the chassis deck.

### QUESTIONS

131. How are aircraft receivers described and classified?
132. Name and define three performance characteristics.
133. What are modulated waves and how are they demodulated?
134. Explain what is meant by "skip effect."
135. Describe heterodyne and superheterodyne reception.
136. How is a telephone receiver constructed and how does it work?
137. Sketch a simple receiver circuit and trace its action.
138. Describe a typical aircraft receiver.
139. Describe an automatic volume control.
140. Name some commercial receiver and tell how you would operate it.

## CHAPTER 12

### DIRECTION FINDERS

#### Principles of Various Types

Radio direction finders, generally called radio compasses, provide a means whereby an airplane can navigate along courses which do not coincide with the radio range beacon courses, by permitting the pilot to take radio bearings on distant transmitters. The apparatus consists essentially of a receiver connected to a loop antenna. It also serves as a means of orientation for an airplane which has deviated materially from the "on course" path formed by a radio range beacon; the pilot takes a bearing on a range beacon station and so determines which way he must fly in order to get back to on-range course. *Transport planes must carry radio compasses.*

Radio direction finders employ the directive characteristics of a single loop antenna, a combination of loop antennas, or a combination of a loop antenna with a vertical antenna. To facilitate the use of a radio direction finder on an airplane, it is considered necessary that the bearing of the ground station (to which the receiving equipment is tuned) be indicated visually.

**Types.** There are two types of radio compasses for aircraft. One has a fixed loop and is used as a homing device. This is apt to be referred to as a direction finder. The other type uses a rotatable loop, allowing the pilot to take bearings without deviating from his flight course. Air transports carry this type and call it a radio compass. The receiving apparatus used may require aural reception of the directional bearing signals received from the distant transmitter or it may possibly operate a visual indicator. In addition to airplane radio compasses of these two general types, there are ground installations. All will be described in this chapter.

**Navy Shore Stations.** The Navy system consists of about 50 shore radio-compass stations located at advantageous points along hazardous coast lines of the Atlantic, the Pacific, and the Great Lakes. These stations were originally established to take radio bearings of vessels. With the advent of seaplanes, this service has been extended to furnish seaplanes and other aircraft with similar service. The operating wavelength for shore stations is 800 meters (375 kc).

When two or more stations are located near each other, two or more simultaneous bearings of a plane may be taken. These are plotted on a chart at one station, called the master station. The master station receives from the other stations, by land telephone, the bearings obtained by them. The "fix" or position is then radioed by the master station to the pilot by giving the airplane its latitude and longitude. The only requirement is that the plane request by radio that this be done. The plane then transmits for a short interval a prearranged sequence of signals, usually the letters **M O**, repeated over and over. If the time of transmission is noted, and a number of fixes are received aboard the plane in sequence, the line of flight will be clearly indicated by plotting this series of fixes. They are truly fixes and are usually quite accurate.

On flights over water this system is especially valuable, as both land stations and vessels can furnish positions. This is particularly true when a radiotelegraph operator is carried aboard the plane, as required by the C.A.A. for certain water flights. Pan American Airways uses ground radio-compass stations.

**Purpose.** The purpose of the radio compass is to permit the determination, by radio, of the absolute direction and geographical position of a radio transmitter. Two or more bearings must be plotted to determine the geographical position. The principles involved are the same whether the radio compass installation is on shore, aboard ship, or on an airplane.

**Directional Effects.** The simple antenna of moderate horizontal dimensions is not directional. This is shown to be true by experiment. If a transmitter is moved around such an antenna in a circle and the e.m.f. induced in the antenna is plotted against

the angular position of the transmitter, the resulting diagram will be a circle. This diagram, called a polar diagram, shows that the e.m.f. induced in the antenna is the same for reception from all directions. The signal will not vary in strength, therefore the direction of the transmitter from the antenna cannot be determined.

Consider the loop antenna (which is directional) shown in Figure 150, with the other parts of the radio compass installation.

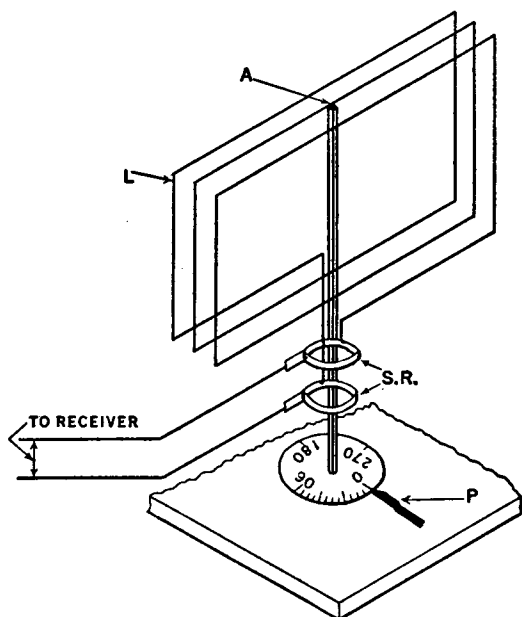


Figure 150. Elementary Loop Antenna

This loop, when rotated on its vertical axis, will make a varying angle with the waves from a fixed radio transmitter. By plotting the e.m.f. induced in this loop against its angular position, a curve similar to that shown in Figure 151 will be obtained. This polar diagram, a figure-8 pattern, represents the bilateral characteristic curve of the loop. Figure 151 shows a top view of the loop, and the dial which is permanently fastened to the vertical shaft of the loop. The pointer is shown in this figure set on the north-

south line. The position of the figure-8 curve indicates that maximum strength signals will be received from a transmitter that is either due east or due west of the loop. The plane of the loop coincides with the east-west line. A transmitter on the north-south line would not be heard. Therefore, if the loop is rotated through an arc of  $360^\circ$ , a maximum signal would be heard twice,  $180^\circ$  apart, and no signal—or a signal of minimum strength—would also be heard twice,  $180^\circ$  apart.

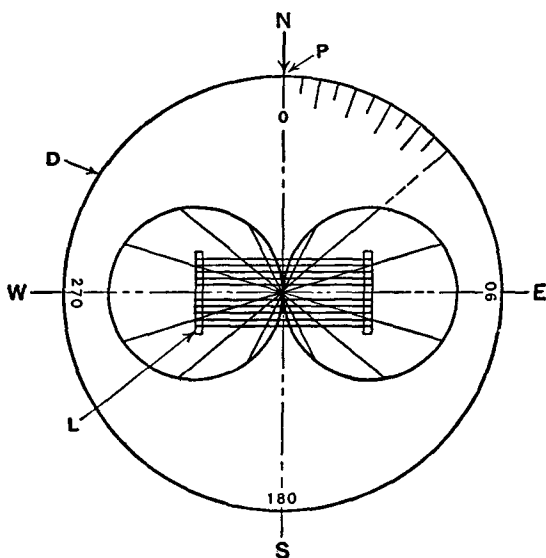


Figure 151. Top View of Loop Antenna

The explanation of this phenomenon is as follows. The wave from the transmitter passes through the loop and induces an equal e.m.f. in each side of the vertical part of the loop. These two voltages are slightly out of phase. The resultant small e.m.f. sets up a weak flow of current in the loop which is  $90^\circ$  out of phase. This current either lags behind or leads the electrical component of the wave by  $90^\circ$ .

**Maximum and Null Methods.** The maximum signal will be heard when the plane of the loop coincides with the line of bear-



ing of the transmitter. When the loop is rotated from this position, the signal strength will gradually decrease until at a point  $90^\circ$  from the position of maximum strength, the signal is not as easily detected as is the point of minimum signal; consequently, this latter point is the one that is best found in the actual use of the compass. This is called the null method. Also, in the practical application of the theory of the radio compass it has been found that the radio waves impinging on the loop are often distorted due to re-radiation, reflection, and diffraction. Therefore, the polar diagram is not always the same as the one shown in Figure 151, and certain defects in the apparatus introduce errors. Each radio compass is calibrated after installation and these errors are then noted.

When the radio compass is installed in a plane, the maximum method, not the null method, is usually used on account of the noise of the engine. If a point can be found, by detuning the receiver, where no signal is heard, both methods can be used. This point, called the null point, usually covers several degrees of arc, but the center is taken as the point.

**Circuits.** The circuit of a practical land radio-compass installation is shown in Figure 152. The Faraday cage, which is metallicly screened, houses the operator and his receiver. The terminal from the vertical side of the loop antenna,  $L_A$ , connects to the filament of the detector tube while the other side of the loop,  $L_B$ , is connected to the grid. An electrical dissymmetry exists on account of the unequal capacity to ground  $C_F$  of the filament and of the grid,  $C_G$ . This unbalancing of the circuit is caused mainly by the proximity of the filament battery to ground and is often referred to as the "antenna effect." It permits the loop antenna to function as a simple antenna or open oscillator. Therefore, when the plane of the coil is at right angles to the direction of the propagation of the radio wave, and the current induced as a result in the loop is zero, there is a weak current induced in the circuit due to the loop antenna acting both as a loop and as a simple antenna. The result of this is that the null point is obscured by a residual signal. Condenser  $C_2$  can be regulated to compensate for this effect and this condenser is called

the compensator, for that reason. (In the German air-transportation system, an auxiliary antenna is used, instead.)  $C_2$  is thoroughly shielded and has an air dielectric. When an adjustment is made of  $C_2$ ,  $C_1$  must be readjusted also to keep the circuit in tune. The loop antenna should have a low radio-frequency resistance when a non-oscillating detector is used; especially if audio- or radio-frequency amplification is employed.

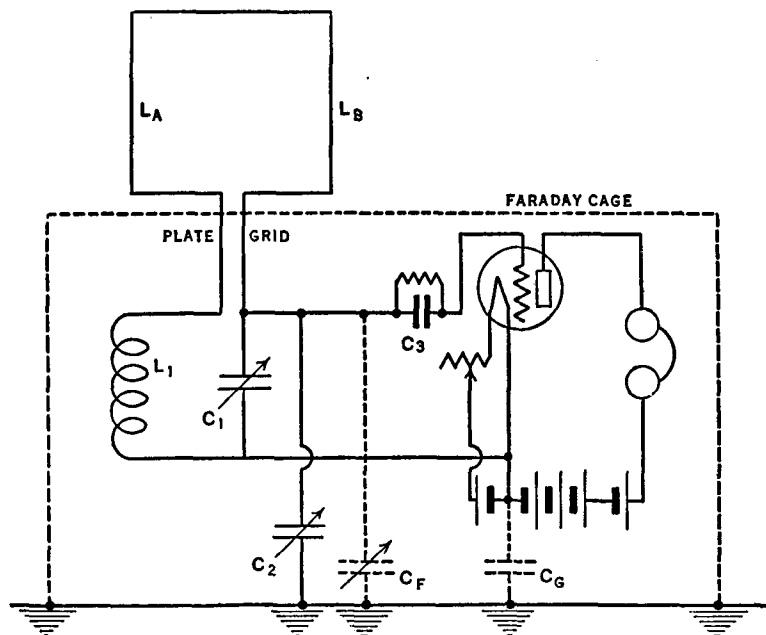


Figure 152. Circuit of Radio-Compass Receiving Set

### Aircraft Radio Compass

To understand the manner in which the basic principles of the "ground" radio compass have been successfully applied to aircraft use, it is necessary that the characteristics of antennas be thoroughly understood, after which the apparatus associated with radio-compass antennas must be studied.

**Theory of Operation.** The adaptation of the single-loop antenna to direction-finding purposes utilizes the field-intensity

pattern which results when the loop antenna is not symmetrical with respect to the ground. In this pattern the positions of minimum received voltage are displaced, and a difference is introduced in the amplitudes of the maximum received voltages.

The field-intensity pattern for the reception of a transmitted wave by a loop antenna is normally in the form of a figure 8. (See Figure 153A.) Lack of symmetry of the loop antenna with respect to ground may result in any of the various forms shown in patterns B, C, and D of Figure 153. The cause of these changes

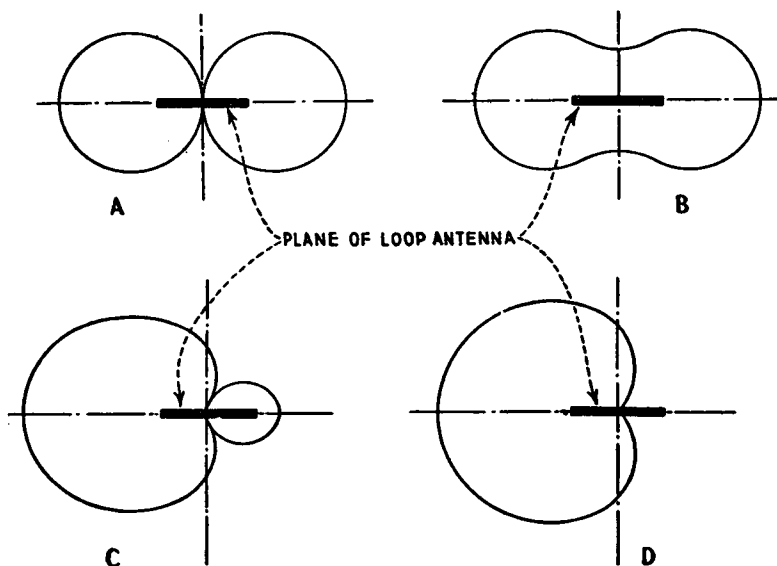


Figure 153. Field Patterns for Loop Antennas

is the presence of vertical effect (that is, the loop antenna operating as a vertical antenna) and the phasing of this current with the normal loop-antenna current.

When the loop antenna is tuned to resonate at the frequency of the signal being received, and the ground is displaced so that vertical effect is present, the current due to this vertical effect is  $90^\circ$  out of phase with the current of the loop antenna. This gives the pattern shown in Figure 153B.

If, however, the loop antenna is not resonated, the current due to the vertical effect is in phase with the current of the loop antenna, and the pattern shown in C or D of Figure 153 results, depending on the relative amplitude of the current due to the vertical effect and that due to the loop antenna. This latter form of field intensity pattern, C or D of Figure 153, is utilized to provide direct-reading indication of the direction of the transmitting station.

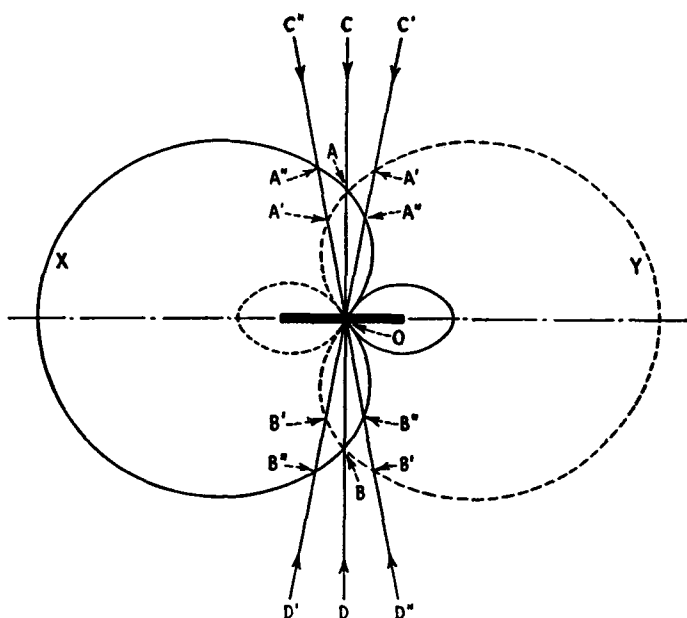


Figure 154. Two Field Patterns; One Loop Antenna

**Field Patterns.** It is possible to obtain two field patterns, X and Y, Figure 154, from the same loop antenna in rapid succession. The means for accomplishing this will be described later. In this figure it may be shown that when the signal being received comes from direction C, the voltage induced in the loop antenna will be the same,  $OA$ , for each field pattern. If, however, the signal comes from direction  $C'$ , the voltage received by the loop antenna for pattern Y will be  $OA'$ , which is greater than

that for pattern X, namely OA". Suppose, now, that the signal comes from direction C". The received voltage for pattern Y, namely OA', will be much less than that for the pattern X, or OA".

Therefore, with a device for measuring the relative intensity of these two signals, not only can the direction of the transmitting station be determined, but also the sense of deviation of the line of flight of the airplane from the direction of the transmitting station. In the Kruesi, Lear, and Western Electric Radio compasses, this is accomplished by means of an output device which tends to deflect a zero-center type course-indicating meter in one direction when voltage corresponding to one field pattern is present, and in the other direction when voltage corresponding to the other field pattern is present. When the voltages corresponding to the two field patterns are equal, the currents through the course indicator are equal, and since they oppose each other, the meter is at zero in the center of the scale. When the one received voltage is greater than the other, the meter reading is at one side of zero; and when the one received voltage is less than the other, meter reading is at the other side of zero, the amount of deflection depending on the relative amplitudes of the two rectified currents through the course indicator.

**The 180° Ambiguity (Error).** This device, in combination with the special single-loop antenna arrangement, also eliminates the so-called "180° ambiguity." In most direction finders it is necessary to provide a special "sense" antenna to permit the navigator to determine whether the station being received is ahead of him or behind him. Reference to Figure 154 will indicate how this "directional sensing" is accomplished in this particular set. Assume that the radio wave is coming from D' instead of C'. In this case the field pattern X gives the greater induced voltage and tends to deflect the course-indicating meter in a corresponding direction, opposite from that when the direction of the incoming radio wave was from C' and the field pattern Y gave the greater induced voltage. To determine whether the incoming station is at C' or D', it is necessary only to rotate the loop antenna according to a definite standard rotation, say clockwise. For direc-

tion  $C'$ , the pointer of the course-indicator will swing, say, from left to zero-center, then to right as the loop antenna is rotated through course, while for direction  $D'$ , the pointer will swing from right through zero-center, then to left. If clockwise rotation of the loop antenna is adopted as standard, it is preferable to use the orientation of the loop antenna so that the radio wave comes in from direction  $C$ , since with the loop antenna fixed, deviation of the line of the airplane to right or left of the direction of the incoming station will result in corresponding deflection of the point of the course-indicator. The direction-finder scale is therefore calibrated so that the scale reading corresponds to this orientation of the loop antenna. Zero-scale reading corresponds, of course, to the position of the loop antenna when the plane containing it is perpendicular to the longitudinal axis of the airplane.

This direction finder is not dependent on any exact balancing of the amount of current due to vertical effect with that due to the normal loop antenna field-intensity pattern; as long as sufficient vertical effect is present to distort the normal figure-8 pattern in the manner described, the direction finder operates satisfactorily. Balancing devices to secure any relative balance of currents are unnecessary.

A further advantage of this type of radio compass is that it does not work on the loop-antenna *minimum*. This makes the loop antenna a much more efficient receiving device, and the direction finder is capable of being operated over greater distances than a similar radio compass using the loop-antenna minimum method.

### Radio-Compass Indicators

To understand how a radio compass can be made to work as a course indicator, examine Figure 155. The field pattern of the loop antenna (its directivity) is both modified and reversed by rectifier tubes  $T_1$  and  $T_2$  which operate alternately. Equal alternating voltages, opposite in phase, are applied to the plates of these rectifiers by an audio oscillator. When one of the rectifiers passes current, its resistance is low, and the loop antenna is effectively grounded at that end. When the other rectifier passes cur-

rent, the loop antenna is effectively grounded at the other end. The loop antenna is tuned to the homing transmitter. The voltage developed in the loop antenna by an incoming radio wave is fed first to the grid of a radio-frequency amplifier and then to the input of a radio receiver. The output of the radio receiver is fed to the indicating instrument.

The zero-center course-indicating meter, shown as C.I. in Figure 155, is connected both across  $R_1$ , by using a variable

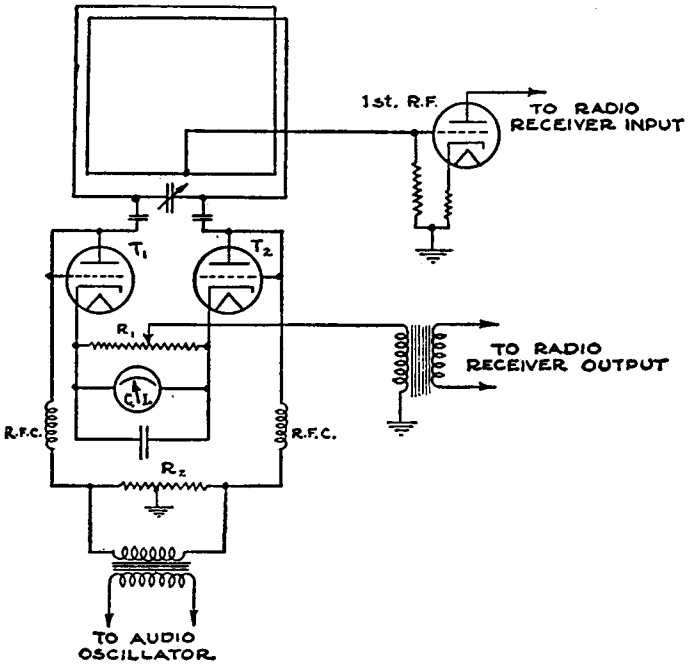


Figure 155. Radio-Compass Indicator

center-tap, and between the cathodes of the rectifier tubes. The tap of resistor  $R_1$  furnishes the ground return for the rectifier tubes through the secondary of the audio-output transformer of the receiver.

The currents of  $T_1$  and  $T_2$  (Figure 155) produced by the voltage of the audio oscillator pass through the course-indicator C.I. in opposite directions. Since the voltage of the audio oscillator

is applied equally to these rectifiers, the currents are equal, and the course indicator reads zero. When  $T_1$  passes rectified a.f. current, the loop antenna picks up the radio signal from one direction and a current passes through the course indicator in one direction, depending on the strength of the signal in that direction; when  $T_2$  passes rectified a.f. current, the loop picks up a signal from the opposite direction, and its output current passes through the course indicator in the other direction.

Since the currents through the course indicator due to the audio oscillator voltage are equal and opposite, they cancel. Currents deflecting the course indicator right and left are then directly proportional to the difference between the signals due to the difference created by the radio wave when the directivity of the loop is rapidly changed. Zero-center indication is only obtained when the loop picks up equal radio signals from both directions—when the plane is on course.

There are two points at which the receiving field patterns are equal. These two points are at right angles to the plane of the loop antenna and are  $180^\circ$  apart. It can be shown that the action of the course indicator for one course is the reverse of its action for the other course, giving automatic direction "sense."

The adjustment of the potentiometer  $R_1$  enables the determination of the exact course, since this resistor permits balancing with the audio frequency supplied to the loop. Should the signal received from one direction be greater than the other, the setting of the potentiometer can be used to cause a balance to be had in any direction.

The pointer then swings left or right as the airplane heading swings to the left or right of the direction of the station. The pointer then swings in a direction *opposite* to the change of heading of the airplane. There is thus no  $180^\circ$  ambiguity. This general system is used in the Kruesi radio compass.

### Bureau of Air Commerce Type

Several years ago the Bureau of Air Commerce developed a radio-compass outfit which is presented here for study as to circuits. See Figure 156.



A is the input unit of the direction finder and comprises the loop-antenna tuning and switching arrangement. B is a radio receiver used for amplifying and detecting the signal received on the loop antenna. C is the output unit which is synchronized with the input unit A. Zero-center course-indication is obtained by means of meter M. D is the synchronizing unit and supplies synchronizing voltage to input unit A and output unit C properly phased to secure proper reversal of the meter of Unit C as the field pattern of the loop antenna is reversed.

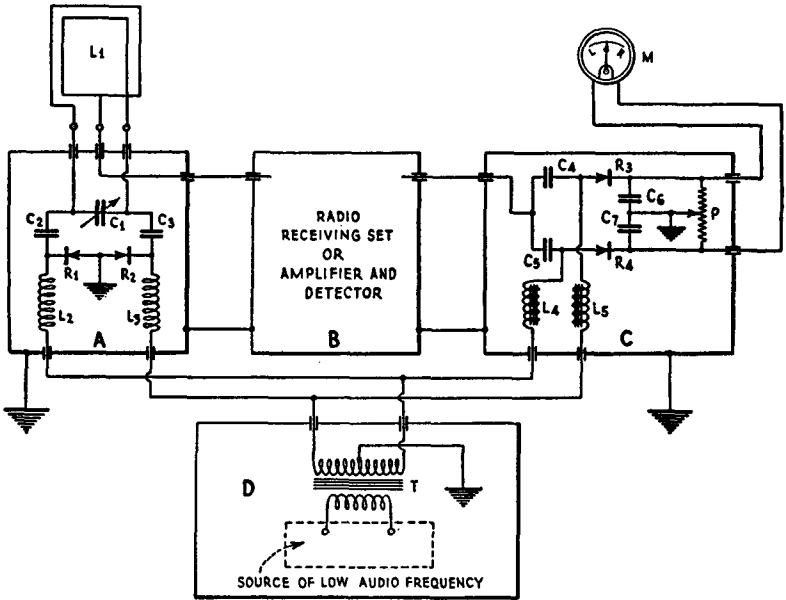


Figure 156. Circuit Arrangement of Airplane Radio Direction Finder

**A, The Input Unit.** Referring to A of Figure 156, loop antenna  $L_1$  is connected at each terminal through blocking condensers  $C_2$  and  $C_3$ , to rectifier tubes  $R_1$  and  $R_2$ , the filaments of which are connected together and grounded. Two equal alternating voltages, of the same frequency but opposite in phase, are applied from ground to the plates of  $R_1$  and  $R_2$  through equal radio-frequency inductors  $L_2$  and  $L_3$ . Consequently, when a positive voltage is applied to the plate of  $R_1$ , a negative volt-

age is applied to the plate of  $R_2$ , and vice versa. It is well known that when a positive voltage is applied to the plate of a suitable rectifying device, the resistance of that device is relatively low, but when a negative voltage is applied to the plate, its resistance is relatively high. For this reason the ground is effectively placed at each end of the loop antenna, alternately (once for each cycle of the alternating voltages supplied by the synchronizing unit D), and the normal field pattern of the loop antenna is altered as previously explained. The voltage developed in the loop antenna is applied to unit B, the radio receiver, between the center of the loop antenna and ground.

The tuning condenser  $C_1$  is not strictly necessary for the operation of this device. However, if  $C_1$  is not used, the loop antenna is untuned, and its pickup will vary considerably with the tuning of the radio receiver. When  $C_1$  is used, the loop antenna is always tuned to a point off resonance, in a predetermined manner so that the circuit  $L_1 C_1$  is either always capacitive or always inductive for any given frequency in the frequency range of the receiving set. This may be accomplished by coupling  $C_1$  to the tuning unit of the radio receiver.

It is not necessary that  $R_1$  and  $R_2$  be carefully matched to have the same resistance, but they should be normal rectifiers of the same type. An ordinary three-element triode may be used, with the grid and plate connected together as the anode, or a full-wave rectifier tube may be used to serve for both rectifiers.

**B, The Radio Receiver.** Unit B of Figure 156, the radio receiver, requires no explanation, being any of the usual types comprising essentially a radio-frequency amplifier, a detector, and an audio amplifier. It must, of course, be capable of receiving the frequencies for which the loop antenna is designed. (Western Electric receivers are much used. See page 392.)

**C, The Output Unit.** The circuit arrangement of output unit C is shown in Figure 156.  $C_4$  and  $C_5$  are two equal capacitors, one terminal of each being connected to the output of the radio receiver, and the other terminal of each connected to half-wave rectifiers  $R_3$  and  $R_4$  respectively, which pass current only when a positive voltage is applied to them. The other terminals of  $R_3$

and  $R_4$  are connected one to each side of voltage divider P, to zero-center meter M, and to condensers  $C_6$  and  $C_7$  as shown.  $C_6$  and  $C_7$  are each connected to ground at one terminal and the center-tap or movable arm of voltage-divider P is connected to ground.  $R_3$  and  $R_4$  are supplied with equal alternating voltages of the same frequency, but opposite in phase, through inductors  $L_4$  and  $L_5$ . Thus, when a positive voltage is applied from ground to one side of  $R_3$ , a negative voltage is applied to one side of  $R_4$ , and vice versa, so that during one-half cycle of the applied alternating voltage,  $R_3$  passes current tending to deflect meter M in one direction, and during the other half cycle  $R_4$  passes current tending to deflect meter M in the other direction. These currents are equal and opposite, and meter M remains at zero in the center of the scale.

**Current Path.** The current path is traced from the source through  $L_4$ , through  $R_4$  to P and M. Here the current divides, part passing through one-half of P to ground, and part passing through M and the other half of P to ground, ground being the return to the source of the low audio-frequency. Voltage-divider P is used to compensate for any slight mismatch of parts in the output unit, so that currents due to the applied audio-frequency cancel in M and cause no deflection. Let an audio signal be applied between the common point of  $C_4$   $C_5$  and ground: then, if this signal is greater or less during one-half cycle, meter M will deflect in a given direction.

**D, The Synchronizing Unit.** The output unit may be readily synchronized with input unit A by applying as its low-frequency alternating voltage the same voltage that is applied to unit A. Unit D accomplishes this. Transformer T is necessary for proper phasing of the voltages, but any source of supply may be used, preferably a low-frequency audio oscillator.

In choosing the source of supply, it should be remembered that the radio receiver used for direction finding has high amplification, and its operation will be seriously disturbed by any source of supply which creates radio interference by sparking of contact or brushes. A low-frequency power source is used; an exact frequency, or a constant frequency, being unnecessary. The fre-

quency should, however, be sufficiently low to be readily isolated from any audio signal received by the direction finder.

**Uses.** This direction finder was designed primarily for use on aircraft, where dependability, ease of operation, sensitivity and compactness are of primary importance, but it is also adaptable to marine use. It may be operated on the received waves from any radio transmitting station and may be used as a homing device or for position finding by means of cross bearings. Tests indicate an accuracy of from  $1^\circ$  to  $2^\circ$ . The possibility of error due to a change in the component parts is remote, since neither the input nor the output unit depends for accuracy upon the amplification of a vacuum tube or the balance of the amplification of two tubes. A failure in the radio receiver cannot introduce a course error. There are no mechanical rotating parts, which if used would decrease the dependability and increase the cost.

The most advantageous feature of this direction finder is its almost completely automatic operation. The loop antenna does not require any careful tuning or phasing operations, since it constitutes the sole means for reception of the transmitting stations.

### The Dieckman and Hell Radio Compass

Figure 157 shows the circuit for the Dieckman and Hell Radio Compass developed in Germany. The circuit is of interest for purposes of comparison with American apparatus.

The split-loop antenna is connected in a push-pull arrangement with respect to the input switching tubes  $T_1$  and  $T_2$ . These tubes are biased to cut-off by the C battery, passing current only when successive half cycles of the switching frequency alternately make the grids less negative. Because of the push-pull connection of the two halves of the loop antenna to the switching tubes, the r.f. voltage applied to the grid of  $T_1$  is  $180^\circ$  out of phase with the r.f. voltage applied to the grid of  $T_2$ . Therefore, as  $T_1$  and  $T_2$  are alternately made conducting by the audio switching voltage, the r.f. voltage passed on from coil  $L_1$  (in their common plate

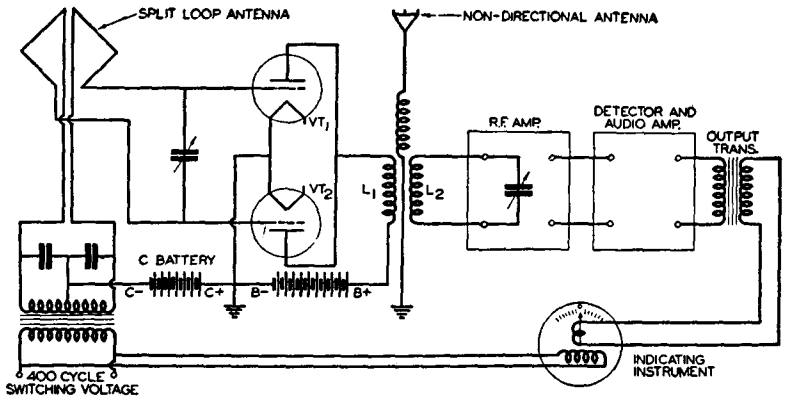


Figure 157. Simplified Circuit Diagram of Dieckman and Hell Radio Direction Finder

circuit) to coil  $L_2$  (connected to the input of a conventional receiving set) is thus alternately reversed.

### Cathode Ray Types of Radio Compasses

Figure 158 shows the layout of the component parts of a cathode ray direction finder. This type does not have course errors due to dephasing. The elimination of this type of error is brought about by amplifying the directional and nondirectional received voltages and then combining them at the cathode ray indicator where the pattern permits visual adjustment of the phasing to the proper value.

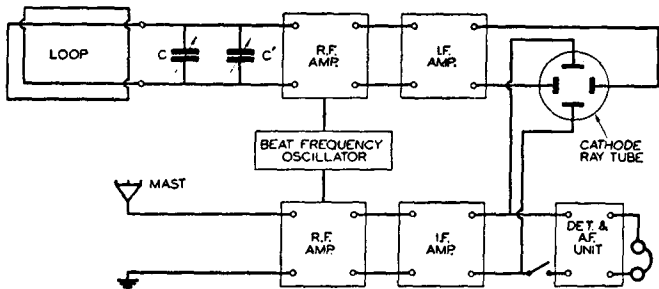


Figure 158. Arrangement of the Cathode Ray Direction Finder

The voltage from MAST (the vertical antenna) is amplified both at the radio-frequency and at an intermediate frequency, and this amplified voltage is applied to the vertical deflecting plates of the cathode-ray tube. The voltage from the loop antenna is similarly amplified and is applied to the horizontal deflecting plates of the cathode-ray tube. This, operating alone, would produce a horizontal trace or image on the screen, the amplitude of which depended upon the position of the plane of the loop antenna with respect to the direction of the ground transmitting station. With the loop antenna at right angles to this direction, its received voltage is zero and hence the horizontal trace becomes a point. With the plane of the loop antenna along the direction of the ground station, maximum received voltage is obtained and the horizontal trace expands to its maximum length. Intermediate positions of the loop antenna result in intermediate lengths of the horizontal trace.

### **The Simon Radioguide**

The Simon Radioguide is a radio compass made up of three units: (1) two electrostatically-shielded loops crossed at a  $60^\circ$  angle; (2) a twin-channel superheterodyne receiver; (3) a specially designed course indicator. When the airplane veers from its right heading, the resulting induced voltage increases in one of the loop antennas and decreases in the other. The two induced voltages are separately amplified by the receiver; this signal voltage then actuates the two moving coils of the signal course indicator. Means are provided in the receiver for accurately balancing the gains of the two amplifiers so that the final signals applied to the course indicator are directly proportional to the voltages induced in the two loop antennas.

### **The Kruesi Radio Compass**

The Kruesi Compass consists of four main units: (1) the compass receiver; (2) the bearing indicator; (3) the remote-control box and (4) the fixed or rotatable loop. The radio-compass receiver apparatus is concentrated in one complete unit. This apparatus weighs 45 lb.; requires 1000 cu. in. of space for

installation. It has a frequency range of 150 to 1500 kc; two bands.

The tuning dial, the frequency band, all headphone switches, and the headphone's jack are mounted on the remote-control box. All adjustments are made by remote control.

The loop has a streamline cross-section with a diameter of 21 in. and is so designed that it has a drag of only 8 lb. at a speed of 250 m.p.h. The rotatable loop mechanism includes a handwheel and a 360° scale to facilitate readings. Power is supplied by a dynamotor and a storage battery. The loop is used in conjunction with a standard mast antenna projecting no more than 6 to 8 ft. from the fuselage or a fixed wire antenna between 9 and 19 ft. in length.

The receiver is of conventional design, sensitive, selective, and ruggedly constructed. Plate XVIII shows a typical installation diagram of the entire unit.

To use the Kruesi Radio Compass, the pilot tunes in on a station along the course or at his destination with headphones. Then he switches from the headphones to the indicator. By holding the pointer on the indicator (mounted on the instrument board) centered at zero, he is able to fly direct to the selected station. A deflection of the needle to the left of zero indicates instantly that the airplane is heading to the right of the course. A deflection to the right indicates the airplane is to the left of the course.

To determine his position along the course it is necessary only for the co-pilot to turn the rotatable loop and secure bearings on any two stations to one side of his course, or for the pilot, in case the fixed loop is used, to train the plane on two off-course stations long enough to secure the required bearings for plotting a "fix."

### **Lear Radio-Compass Receiver**

The Lear (Model L) radio-compass receiver can be used as a visual radio compass and also as a radio receiver, either separately or together. There are three frequency ranges: radio range beacons, 195 to 415 kc; broadcast stations, 550 to 1500 kc; air-line reception, 2800 to 7700 kc (this latter being for receiver operation only).

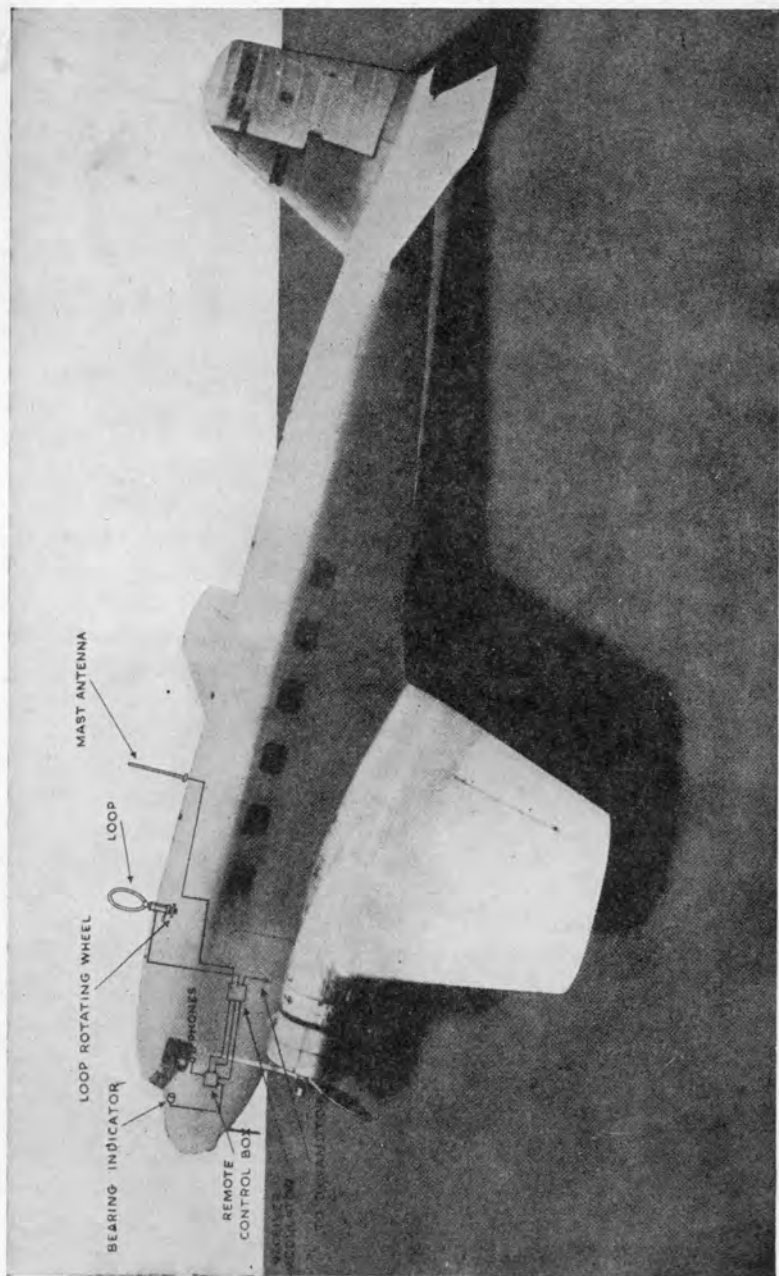


Plate XVIII. Typical Installation of Fairchild-Kruesi Radio Compass in Douglas Transport



A superheterodyne circuit is employed. The input to the balanced modulator is connected to a radio-frequency amplifier through an intermediate buffer stage. At the output of this buffer, the amplified modulator output is combined with the amplified output of the nondirectional auxiliary antenna and this combined output is coupled through a selective circuit to the first detector. The signal frequency is converted to 487.5 kc in this tube, and amplified by a highly selective two-stage 487.5 kc amplifier. The intermediate frequency output is detected by a diode detector; the resulting audio-frequency signal is amplified by a two-stage audio amplifier.

One tube in the power output stage feeds into the telephone headset through a wide response coupling transformer, and the other tube is fed to the indicating meter through a sharply-tuned coupling transformer. The output level from each channel is separately controlled by a manual adjustment on the remote-control panel.

The balanced modulator stage consists of a double triode. The audio-frequency oscillator is a push-pull circuit using a double triode tube. The output of the balanced modulator is amplified, and is combined with the output from the first r.f. amplifier stage.

The antenna circuit is inductively coupled to a tuned circuit, so designed that ordinary variations in the antenna will not affect the tuning of the circuit. The tuned circuit functions to furnish selectivity, and also to give the required phase-shift between the nondirectional antenna and the loop antenna output. The tuned circuit is connected to the grid of the amplifier tube, which is a pentode and serves to amplify the signal to the required level. It also prevents stray coupling of the vertical antenna to the balanced modulators. The screen voltage is variable to suit the antenna installation characteristics.

The converter tube is of the pentagrid type, and combines the function of the beating oscillator and the modulator. This circuit is provided with air trimmers to facilitate tuning.

The intermediate frequency amplifier contains two stages, operating at a frequency of 487.5 kc. The output of this amplifier is connected to a diode, which functions as a detector.

There are two parallel output channels. The output transformer for one stage has a wide frequency response with the proper impedance ratio to match the headphone impedance value. The other output transformer has its primary tuned sharply to the compass modulator frequency. Attenuation of all frequencies, other than that of the audio oscillator, prevents "meter jiggle" from station modulation.

The remote-control panel carries two audio controls, one of which is required to set the level for the headphones. The other is to set the sensitivity of the course meter indicator.

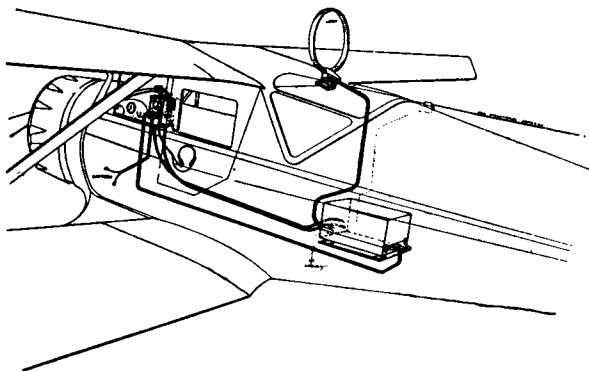


Figure 159. Installation Plan for Lear Radio Compass

The loop antenna used is 20 in. in diameter. Its winding is weatherproofed, and the core is grounded to maintain its balance at its electrical center. It is mounted on a special aluminum pedestal. The loop should be rigidly mounted. Figure 159 is the installation plan furnished by Lear Developments, the manufacturer of this equipment. Other radio-compass installation plans are shown in Chapter 15.

### RCA Radio Compass

The RCA (Model AVR-8D-E) radio compass is a combination of a navigating instrument and a high-grade radio receiver. Figure 160 shows all circuits.

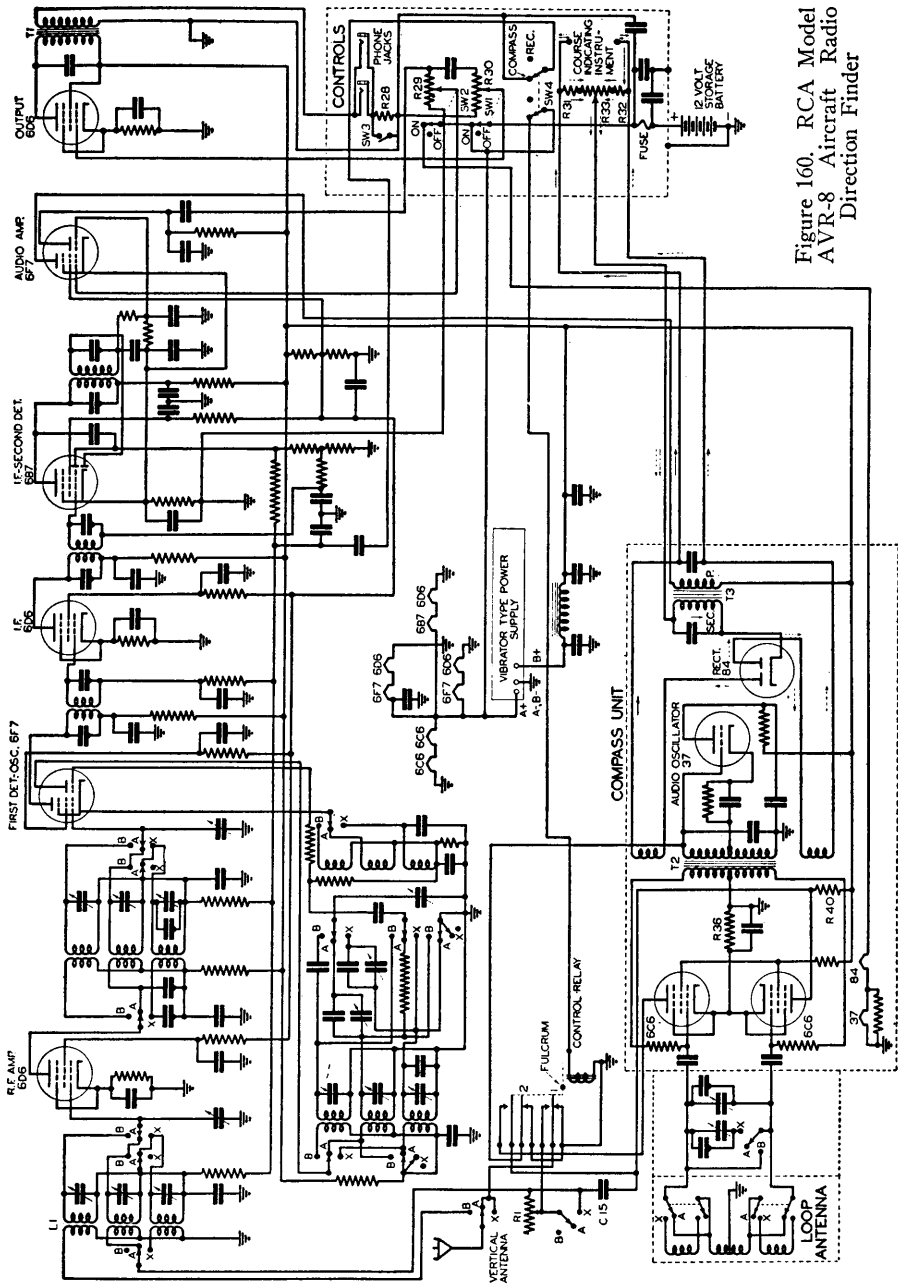


Figure 160. RCA Model AVR-8 Aircraft Radio Direction Finder

The principal specifications for this direction finder are outlined briefly as follows:

1. Power supply—airplane 12-volt storage battery with vibrator (of synchronous rectifier type) transformer and filter system to provide plate and grid-bias voltages.
2. Power output—0.7 watt maximum.
3. Current consumption—radio compass, 2.8 amperes; receiver (compass "off") 2.5 amperes.
4. Circuit—superheterodyne with automatic volume control and direction-finder loop with controls.
5. Tuning ranges—200–410, 550–1500, and 2200–6700 kc.

There is a fixed loop designed for operation in the radio-compass circuit which also serves as a receiving antenna.

There is also a fixed antenna used in conjunction with the loop. This may be any conventional type of aircraft antenna.

The receiver unit itself is usually located toward the rear of the plane, remotely controlled.

Plate and grid voltages are provided by a vibrator, transformer, and filter system.

The control heads or boxes, electrical control panel and indicating meter, are in easily accessible locations near the pilot, generally on or near the instrument panel.

The loop is usually mounted on the outside surface of the ship, although occasionally it is mounted inside, just below the skin. When used inside, the loop housing is removed. This housing is of streamline design to reduce air friction or "drag" when mounted outside.

The loop-coupled receiver provides operating conditions, through electrostatic shielding of the loop, which give a materially reduced effect of "rain static." In this condition the antenna is disconnected and reception is by means of the loop which then acts like the conventional direction-finder loop with aural indication, on X and A bands. The reception on B band is then through the vertical antenna only. In the X and A bands under this condition, if the ship is headed towards the station, either the ship or loop must then be turned from  $5^{\circ}$  to  $15^{\circ}$  "off course," in order to equal the pickup obtained with the vertical antenna.

With the fixed loop, when the ship is "off course," the indicating meter will show by its indication the direction in which the ship should be turned to fly "on course" toward the station. The indicator meter operates only at the time of signal reception and the pointer movement may, therefore, be confusing unless interpreted by simultaneous listening. The deflection amplitude or sensitivity of the indicating meter is controllable by adjustment of the indicator-movement control. This control is independent of the voice-volume control and therefore does not affect the headphone signal intensity.

Plate XIX shows the entire layout of units. This direction finder is designed around the Dieckman and Hell circuit, Figure 157. Figure 174 shows an installation plan.

### **Western Electric Radio-Compass Attachment**

The Western Electric radio-compass attachment (No. 6004A) was designed primarily for use with Western Electric 14 and 20 type receivers, the ES198, and other radio receivers having similar input circuits.

This assembly consists of a new simplified type of shielded "anti-static" loop antenna (which can also be rotated for direction-finding service), a mounting, a control unit, a flexible shaft and cable, and an input transformer. Each unit is sturdily built and extremely light in weight and has been designed for ease and convenience of installation.

The electrostatic shield around the radio-compass loop enables the pilot to fly through atmospheric disturbances such as rain, snow, sleet or dust static which ordinarily paralyze his receiver when used with a simple wire antenna. Utilizing an entirely new idea in loop construction, this important unit is waterproof, a feature that those who have used radio compasses heretofore will appreciate. This is but one of the many advantages which this equipment offers.

**Control Unit.** Since the loop also projects beyond the surface of the plane and is subject to all the stresses set up by the ship's movement through the air, extreme care has been given to the

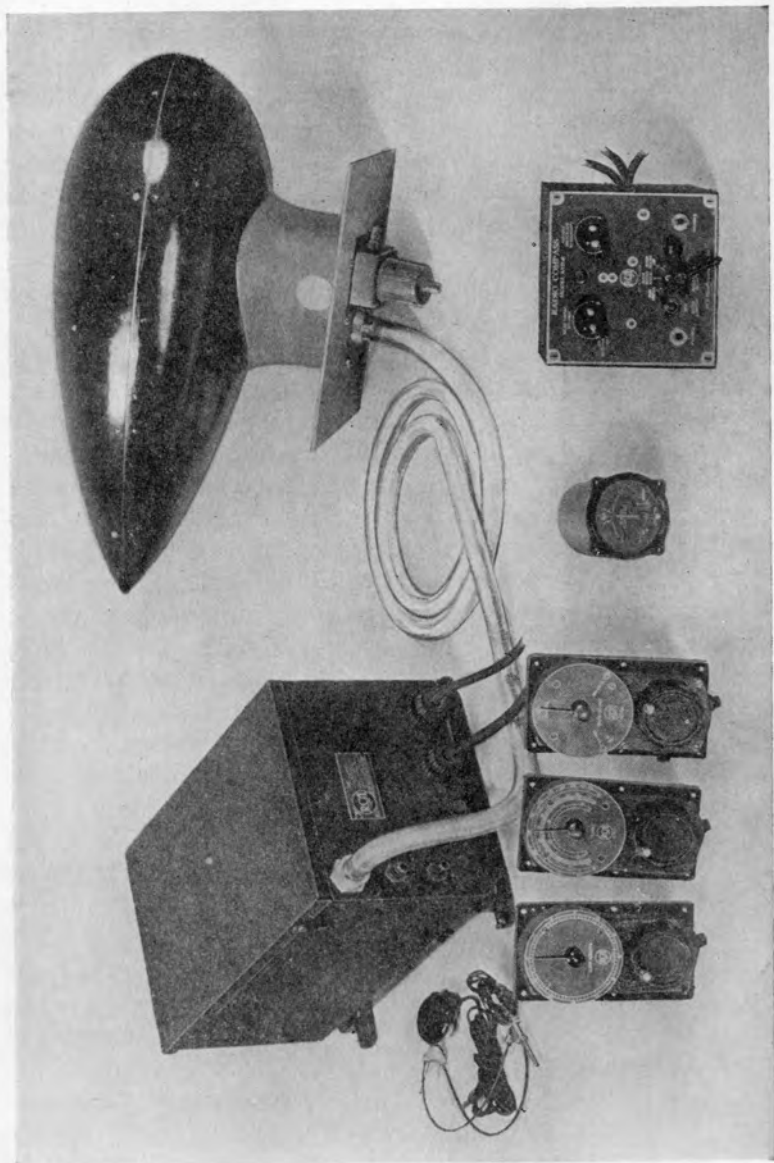


Plate XIX. RCA Model AVR-8E Radio Compass

design of the entire structure so as to prevent end-play and rocking of the loop.

The mounting provides for the rotating of the loop and has a plug connector for the cable and a bayonet-type connection for the flexible shafting. The loop is assembled on the mounting with a gland nut which has a positive indexing keyway, allowing all loops to be completely interchangeable both mechanically and electrically.

The loop rotating mechanism is driven by a control unit which is geared to the turning mechanism by the finest of concentric spring flexible shafts. The gear ratio between the control unit and the loop is 264 to 1, permitting extremely accurate adjustment of the loop. The position of the loop is indicated on the face of the control unit by the position of the needle and a removable card is supplied, enabling the user to correctly calibrate the control unit for his particular plane. The concentric spring flexible shaft may be taken off at any angle to the control unit within an arc of  $180^\circ$ . This makes for further ease of installation.

An excellent method of tuning and coupling the loop to a radio receiver is made possible by a special Western Electric input transformer. The radio receiver may be located up to 25 ft. from the loop and excellent operation can be secured.

Figure 161 shows the general layout of the system. The No. 3A loop consists of a winding placed inside of a moulded fabric covering which is metallically shielded. The continuity of the shield is broken at the top by an insulated section. This insulated portion is then covered with a moisture-proof paint. The loop is clamped at the bottom and secured to the No. 50A Antenna Mounting by a key and a gland-nut.

Referring to Figure 162, which is a schematic diagram of the No. 6004A radio-compass antenna outfit, it will be seen that one side of the loop is connected to the No. 50A antenna mounting at the point at which the loop is attached. The No. 50A mounting is in turn bonded\* to the plane. The bond conductor is continued to the shell of the No. KS-7908 plug and jack which is insulated from the mounting. This single-point ground in the antenna mounting is continued through the insulated shield of the transmission line (No. 719 cable) to the radio receiver.

\* Bonding is discussed in Chapter 15.

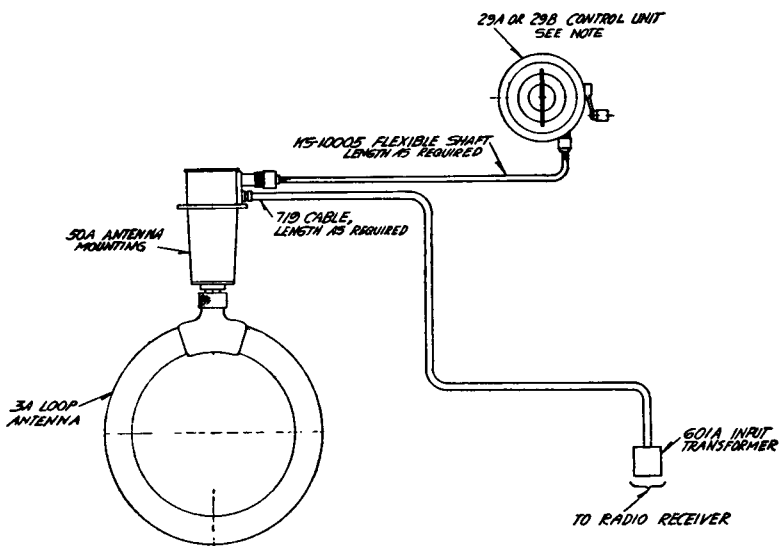


Figure 161. Assembly Scheme for the Western Electric Radio-Compass Attachment No. 6004A

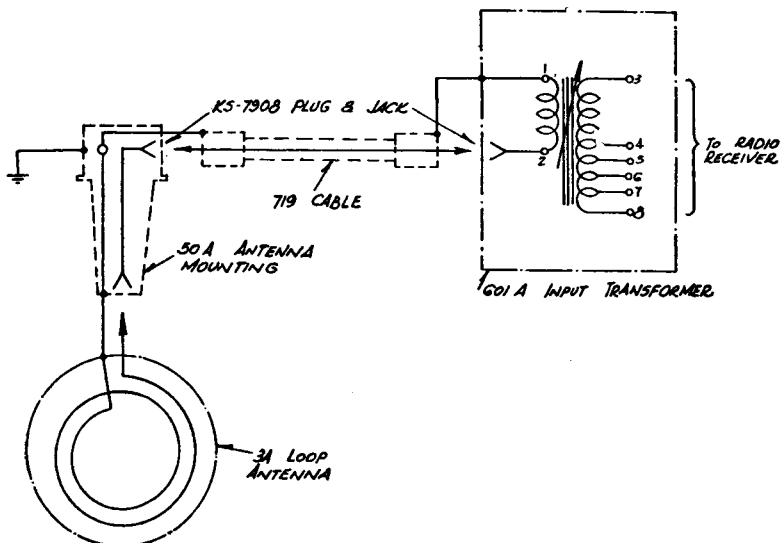


Figure 162. Western Electric No. 6004A Radio-Compass Attachment



### Radio Frequency Laboratories Radiobeacon Compass Receiver

Radio Frequency Laboratories Inc., of Boonton, New Jersey, manufacture a radiobeacon receiver which operates in conjunction with a direction-finding loop. The receiver is model CB-3. It is intended primarily for private aircraft. It covers airways radio ranges and marine radiobeacon frequencies in a single band, 194–420 kc. The receiver is a direct-control 5-tube, superheterodyne of high sensitivity. There are tuning and volume controls, and a toggle antenna selector switch is provided which permits change-over from the conventional receiving antenna for radio-range navigation to the loop antenna for direction finding. The dial is 3 in. in diameter and is divided into 5-kc graduations for ease in tuning.

The loop is 6 in. in diameter, is electrostatically shielded, and is intended to be mounted on the cabin roof. Direct-drive loop rotator and course indicator are integral with the loop base, and are within comfortable reach above the pilot's head. The course indicator is divided in  $10^\circ$  divisions, from  $0^\circ$  to  $180^\circ$ , left and right; divisions from  $0^\circ$  to left are in red figures, those from  $0^\circ$  to right are in black. Station bearings are read in degrees off bow.

It is the lightest direction finder now on the market; the individual weights are: receiver, 4 lb. 3 oz.; dynamotor, 4 lb.; loop, 29 oz.

#### QUESTIONS

141. What is a direction finder; upon what principle does it work?

142. Why do you suppose air transports are required to carry radio compasses?

143. What two types of radio compasses are used aboard aircraft and what are the advantages of each?

144. Describe the maximum and null methods of receiving by radio compass.

145. What is meant by a field pattern? (Use a sketch with answer.)

146. What is the principle of a cathode-ray type radio compass?

147. Of what units does the Simon Radioguide consist and how does this radio compass work?

148. Describe the Kruesi radio compass.

149. Compare the Lear radio-compass receiver with the Bureau of Air Commerce radio direction finder.

150. Describe either the RCA radio compass or the W.E. radio compass attachment.

## CHAPTER 13

### INSTRUMENT LANDING SYSTEMS

A "landing system" as referred to here means a method by which a pilot is enabled to land his plane by use of instruments alone without seeing the ground at all; the term is synonymous with "blind landing system." It is because radio is such a vital part of the systems used in this country that an entire chapter is devoted to this subject; it is becoming increasingly evident that the operation and upkeep of instrument landing equipment will be a required part of the duties of all those connected with Aeronautic Radio. There may be eventually as many different systems as there are different makes of radio sets. Or, because of engineering and economic reasons, one system may become standard as far as the Civil Aeronautics Authority is concerned. In that case airlines may install this standard system or some cheaper system at their airports. Certain it is that instrument landing systems will be developed and installed rapidly and that all will utilize radio. It is only the question of expense that may delay their universal adoption as regular equipment, for the feasibility has been definitely established. Furthermore, the major airlines of the United States have reached an agreement with the F.C.C., the C.A.A., and the Radio Technical Committee for Aeronautics as to what the fundamental elements are which should be incorporated in a practical system.

**Importance of Blind Landings.** Instrument, or "blind" flying is perfectly feasible, as has been demonstrated under actual service conditions by all of the airlines for several years. If a plane is properly equipped as to radio and other instruments, the radio-range system along the civil airways provides a very satisfactory means of navigating aircraft from one airport to another under conditions of reduced visibility, or "totally blind" (zero visibility). Such flights are now authorized. As a matter of fact, if

commercial flying was not carried out under adverse weather and visibility conditions, there would be little air transport business to be had; therefore, blind flying, especially when over the top of clouds, is common. But when such flights terminate at an airport which is completely obscured a grave danger develops in connection with the landing of the plane.

One radio engineer in the C.A.A. says on this subject:

“Another point to be considered is that with the increasing number of aircraft being dispatched to and from airports under conditions of restricted ceilings and visibility, the air traffic problem is becoming more acute. Under present conditions, at a well regulated traffic control center, each airplane is allowed a maximum of 15 minutes for landing under the worst possible conditions. It is believed that an instrument landing system would contribute to the solution of the airways traffic control problem by reason of the fact that more ships could be landed and dispatched per hour at a busy terminal during bad weather conditions. An instrument landing system would relieve the present ‘bottle neck’ by reducing the time required for landings, as it would furnish the pilot with precise indications of the proper course and glide path down to the point of contact with the runway.”

There is no element entering into the business of safe commercial flying more important than that of blind landing. There is no other application of radio to aviation so essential. Because of these two fundamentals, it is very necessary that past developments along this line, together with the basic principles underlying current design and installation practices, be thoroughly understood and thoughtfully considered.

**Basic Types of Landing Systems.** There are two basic types of radio landing systems:

1. Those which employ radio transmission merely as a means of enabling an airplane pilot to orient himself in a horizontal plane, after which he must depend on altimeter in making his actual landing contact;
2. Those in which radio transmission supplies the pilot with both lateral and vertical guidance.

NOTE: In every case, various instruments are used for flying blind. Nowhere in this book does the author wish to create the impression that radio can take over and replace the need of skilled flight personnel and all the instruments carried. (Probably too much has been published already along the lines that radio constitutes the "cure-all" for troubles inherent with blind flying and blind landing.)

**Early Developments.** Early developments of blind landing systems have clearly shown the possibilities and limitations of these systems. An understanding of how the problems incidental to perfecting an acceptable system will provide the student-reader with the ability to appreciate the difficulties which are of necessity overcome in successful present-day design.

**Development History.** The Bureau of Standards developed experimentally a system in 1919. A direction finder on the airplane was used in conjunction with a marker beacon on the landing field which effectively "marked" the landing field.

In 1928 this Bureau developed a system utilizing a radio range in conjunction with marker beacons, sometimes called a radio approach system. Using it, successful landings were made; non-radio instruments such as the artificial horizon were developed. In 1929 a complete three-dimensional system was undertaken by the Bureau of Standards and installed at College Park, Maryland, soon after. To the equisignal runway-localizer and the marker beacons was added a beam in the vertical plane which provided a constant-intensity glide-path of convenient shape for easier landing. Many blind landings were successfully made with this system between 1931 and 1934 at various airports.

From these early tests the requirements of the system seem to be:

1. A minimum of manipulation of radio controls by the landing pilot.
2. Simplicity of interpretation of the received radio signals (such as a visual runway-localizer and landing-beam course indicator in the form of a single cross-pointer instrument).

3. Elimination of slight bends in the runway-localizer course caused by such things as railroad tracks and power lines.
4. An increased slope landing-path.
5. Reduction of cost of ground station equipment.

These requirements, broadly speaking, must still be met if a system is to be generally acceptable.

**Army Development.** In 1932 and 1933, the Air Corps at Wright Field under the direction of Captain Hegenberger developed an instrument landing system which was unique in its simplicity of operation and the flexibility with which it could be used under varying wind conditions. This system was adopted by the Bureau of Air Commerce and installations were begun at 36 airports throughout the United States. This program was never completed, due primarily to the fact that a majority of the airlines felt that it did not give sufficiently precise indications for safe commercial use. This system is described in the Air Commerce Bulletin, Vol. 6, No. 5. The major disadvantage of the Army approach system was that it did not give a precise absolute altitude indication, since that furnished by the Kollsman sensitive altimeter could only be relied upon within plus or minus 40 ft. under all practical conditions. Furthermore, it did not provide a well-defined lateral path, but gave a radio-compass heading which would continually change with any cross-wind component. The major advantage of the Army system was that it was simple to fly, which made it possible for the pilot to quickly orient himself and placed no extra burden on the pilot as he followed the radio-compass indicator.

### The Air-Track System

In 1933 the Washington Institute of Technology was originated by engineers from the Bureau of Standards; action was taken to develop and market the system they had initiated while in the Bureau. An improved system, named the AIR-TRACK system, as installed at College Park, Maryland, is the result of this development. It provides the pilot with a constant and automatically defined three-dimensional gliding path from a point in space to a selected runway within the airport limits.

There are three elements in Air-Track : a narrow radio beam directed along the airport runway ; a curved beam laid on top of the first beam, running together with it for some distance and then curving up into the sky ; and one or more radio beams directed straight up like fans, one placed at the end of the runway, others, as required, at distances from the airport. These three devices are called respectively, the "runway-localizer," the "glide path," and the "marker beacons"; they are terms to remember. The transmitters and antennas for the runway-localizer and glide path are contained in an automobile trailer that can be towed quickly to any runway end, if the wind changes. The marker-beacon transmitters and antennas are permanently fixed at their positions.

In the airplane itself are three receiving sets, one for each of the three beams. (One of these is the receiver used for receiving 75 Mc beacons.) The runway-localizer set actuates a vertical-pointing needle on the dial. When the ship is off the runway beam to right or left, the needle moves right or left. When the ship is on the beam, the needle stays at center. The glide-path receiver controls a horizontal-pointing needle on the same dial. When the ship is above or below the glide path, this needle moves above or below or stays at center in the same way. And when the two needles, horizontal and vertical, cross each other at right angles in the center of the dial, the ship is headed directly along the runway beam and down the glide path. The marker-beacon set, instead of registering on the dial, gives the pilot two simultaneous signals when he crosses the beacon. One is the shrill high-pitched p-e-e-p that comes through the pilot's earphones, the other the flashing light he sees on the instrument board. When he receives the two signals, the pilot knows that he has arrived at the edge of the airport. Distinctive signals identify markers where more than one are used.

The entire ground equipment, including antenna arrays for directional and vertical guidance, is compactly mounted in an automobile trailer. Each trailer station is equipped with a metal trough for trailer wheels, and a trailer locking device, assuring constant and stable alignment of the transmitting antennas. Coupling the trailer's electrical conduits to the underground

power and control cables through weatherproof outlets at the station automatically connects the corresponding marker beacon at the opposite end of the runway. The system's monitoring equipment is located in the trailer, operated by time-relay switches.

The three transmitters (localizer, glide path, and marker) are controlled from the central control board, a green light for each transmitter indicating that the equipment is functioning. After

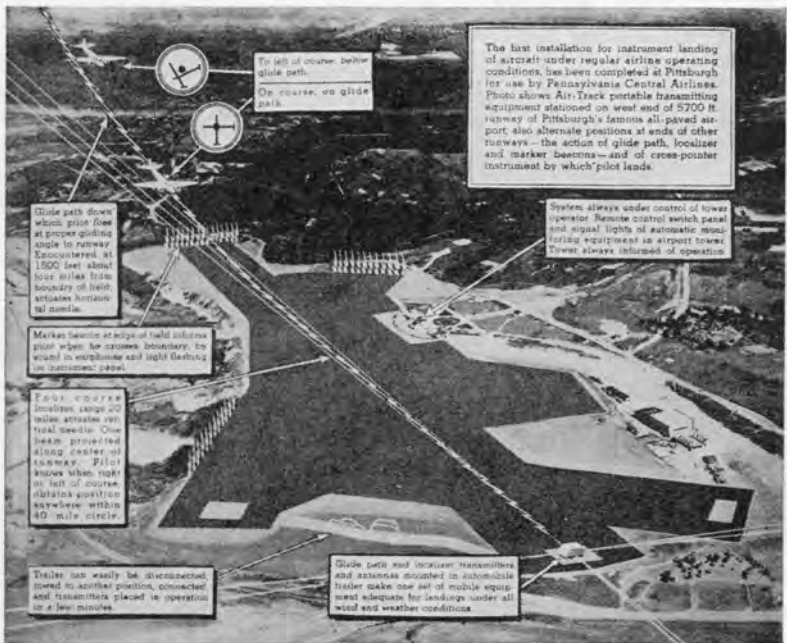


Figure 163. The Air-Track Instrument Landing System

a short interval the monitors are automatically cut in, and if the transmitting equipment is functioning correctly, an appropriate green light flashes on the control board. Any irregularity in transmission (in excess of predetermined limits) causes the monitoring equipment to shut off power and flash the warning to the control board by means of a red light.

Landing information is transmitted by a 4-course localizer beacon operating at 109.9 Mc; an ultra-high-frequency glide-



path beacon at 93.9 Mc; and a field-boundary radio marker beacon or beacons operating on 75 Mc.

The localizer beacon for directional guidance is similar in principle to the familiar radio range beacon, but instead of interlocking A and N signals, it employs two different modulation frequencies: 65 and  $86\frac{2}{3}$  cycles respectively. The equisignal zone, or "beam" is interpreted visually by a reed converter actuating the vertical pointer of the landing instrument. This permits a sharper definition of the directional path than is possible aurally, as the human ear is normally sensitive to a difference in sound of not less than 2 decibels, giving an apparent breadth to the beam.

Vertical guidance is provided by an ultra-high-frequency transmitter radiating a pear-shaped pattern directed slightly upward; the pear-shaped lines of constant field intensity provide a number of glide paths of varying steepness, converging at the runway. The horizontal pointer of the landing instrument is preadjusted to assume a horizontal position when the ship follows the optimum lane of constant field intensity. This adjustment would hold valid for any airport, or any approach to a given airport, as the necessary variations in the glide path, to clear obstructions, are made on the ground by setting the glide-path transmitter control to a predetermined value for each runway.

Longitudinal guidance is provided by a low-power ultra-high-frequency marker beacon at the edge of the runway, with radiation directed sharply upward and modulated by a suitable audio-frequency note which forms a "wall of sound" through which the airplane must pass. At this point the airplane's horizontal receiving antenna is 15 to 25 ft. above the ground, and the actual landing of the airplane can be accomplished without difficulty by the pilot.

The steepness of the gliding path may be regulated at will, to allow for obstructions. To suit the optimum gliding angle of the craft involved in making an instrument landing, the receiver in the airplane is adjusted.

The diagram of this system, shown in Figure 163 on the preceding page, should be studied in connection with the foregoing description.

### The Lorenz System

In 1934 and 1935 Dr. E. Kramar of the Lorenz Company in Germany developed a unique and simplified blind-landing system. This system consisted of the same elements originally used by the Bureau of Standards, that is: glide path, runway radio-range localizer, marker beacons, and monitor system. The glide path and the localizer were combined into one transmitter and radiating system. The transmitter was operated on 33.3 Mc, and excited a vertical half-wave radiator. On each side of the vertical radiator, a reflector was located with a relay at its center. One reflector was keyed by dots while the other reflector was keyed by dashes. By interlocking the dots and dashes, two elliptical patterns were obtained, the major axes of which were parallel to the on-course. Only one pattern was present at a time, inasmuch as a single source of energy is used to supply the energy in both patterns. These alternately-keyed patterns produced an equisignal zone, which gave two courses. The carrier energy was modulated at 1150 cycles, and the usual type of aural radio-range courses was obtained with an interlock signal. Visual indication was obtained by means of a rectifier circuit and amplifier which produced off-course indications either to the right or the left, depending upon whether dashes or dots were the predominant off-course signal. This indicator, however, gave a kicking needle indication. The glide path was produced by the presence of a field pattern in the vertical plane. A field intensity line of constant amplitude was selected and followed directly to the airport. The outer marker was located approximately 1.9 miles from the airport. The inner marker was located approximately 0.19 miles from the airport. Each of the markers transmitted on a frequency of 38 Mc. The outer marker was modulated at a frequency of 700 cycles and keyed with dashes four-tenths of a second in duration. The inner marker was modulated at a frequency of 1700 cycles and keyed with dots one-fifteenth of a second. Each marker gave an aural indication in the headphones of the pilot in addition to lighting an individual light on the instrument panel. A complete remote-control apparatus was provided which constantly checked the operation of all units.

**Tests of Lorenz System.** Through the courtesy of the International Telephone & Telegraph Company,\* one complete set of equipment was installed at the Indianapolis airport for test purposes. Receiving equipment was also furnished to the Bureau of Air Commerce and to several of the airlines. These tests indicated that approaches could be made to the field under conditions of low visibility and low ceilings with good reliability. However, there were several limitations to the use of this equipment. First, it was found that the radio range could be flown better aurally than visually. This was attributed to the fact that the needle indications were of the kicking type rather than of the smooth visual type, which was originally used in the Bureau of Standards installation. It was also found that if the transmitter was keyed with the N and A, pilots who were familiar with this form of keying could fly the radio-range localizer much better than with the dot-dash signals. When the equipment was originally installed, the course was approximately  $6^{\circ}$  broad, which it is understood is the width desired in Europe. However, the consensus among all the pilots in this country who flew this equipment was that the courses were too wide and a considerable amount of work was done in an effort to sharpen the course.

### **International Telephone Development Company Instrument Landing System**

This system, developed for the C.A.A. by the International Telephone Development Co., Inc. (a subsidiary of the I.T.T. Corp.), should be studied intensively. Although the problem of "blind" flying along predetermined routes has been solved satisfactorily by the use of radiobeacons and other standardized aids to air navigation, the problem of "blind" landing, or bringing a plane down safely by the use of instruments only, has not yet advanced to a uniformly standardized stage. Various schemes have been devised to accomplish this task: Infra-red radiation, artificial fog dissipation, high-powered visible light beams. Also, certain methods involving radio waves have been utilized in blind-landing experiments. Some of these methods involving the use

\* Study the description (in following paragraphs) of the system later developed by this company for the C.A.A.

of radio, generally based on the research started in 1929 by Diamond and Dunmore of the Bureau of Standards, have already been described.

With a view toward establishing blind landing as a definite and reliable aid to air navigation, engineers of the Bureau of Air Commerce, after studying the situation in great detail, prepared complete performance specifications for a radio instrument landing system incorporating the most desirable features of all previous systems. The complete equipment was then developed and manufactured by the International Telephone Development Co., Inc., in accordance with these specifications, to be installed at the Indianapolis Municipal Airport. It is the plan of the C.A.A. to apply this system to the Civil Airways to provide an aid for the safe landing of aircraft at fields and airports under conditions of restricted ceiling and visibility.

Landings may be made from any one of four directions. There are three fundamental elements in this system of instrument landing:

1. A runway-localizer beacon. This will provide horizontal guidance to the plane, aligning it properly with whatever runway is to be used for landing.
2. The glide path or landing beam to indicate the line to be followed in making a proper descent to earth.
3. Two successive marker beacons with rather sharply defined vertically-directed radiation patterns, to provide spot indications to the pilot as to his location and distance relative to the airport.

**The Localizer Equipment.** The localizer equipment consists of a transmitter and antenna system installed at the airport, together with the receiver and its antenna system installed in the plane.

The transmitter is controlled by a 4579.17 kc crystal. A succession of multiplying stages raises the frequency to 109.9 Mc. The output power—300 watts—is divided into two equal parts, each modulated at its characteristic audio frequency.

The radiation pattern of the runway-localizer antenna will be similar to that shown in Figure 164. As illustrated, two over-

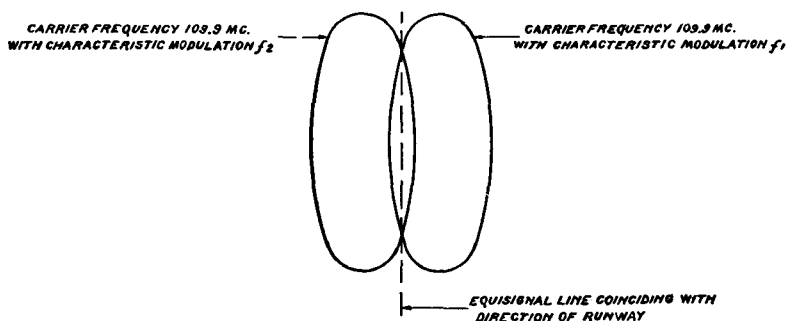


Figure 164. Runway Localizer Radiation Pattern

lapping directional diagrams are produced. These radiation diagrams have the same carrier, but different modulation frequencies. Along one direction only, the amplitude of the two modulation frequencies will be equal. This direction coincides with the direction of the runway.

If the airplane is too far to the left of the runway, it will receive a preponderance of the characteristic modulation  $f_1$ . This will cause the vertical pointer of the cross-pointer instrument, associated with the receiver in the plane, to incline toward the left



Figure 165. Typical Cross-Pointer Instrument Indications

(Figure 165B). When the airplane is too far to the right, it will be receiving mostly characteristic modulation  $f_2$  which will incline the vertical pointer to the right (Figure 165C). When the airplane is exactly in line with the desired runway, the received signal will contain equal amplitudes of  $f_1$  and  $f_2$ , therefore the pointer will be exactly vertical as in Figure 165A.

The general blind-landing layout at the Indianapolis Municipal Airport is shown in Figure 166. The localizer transmitter and antenna set up at  $L_1$  guides the incoming plane to the north-east-southwest runway (with plane approaching from the north-

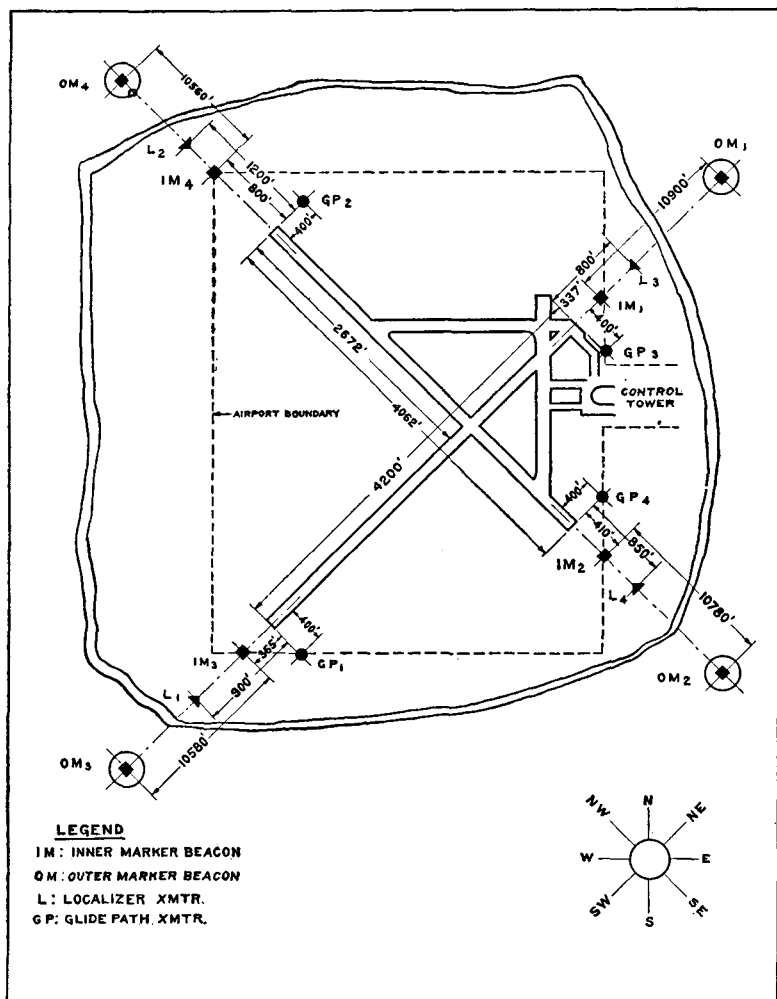


Figure 166. Instrument Landing System, Indianapolis Airport (as specified by C.A.A.)

east direction). The other localizers act in a similar fashion to guide planes into their respective runways.

The receiving apparatus for the localizer transmitter consists of a crystal-controlled superheterodyne operating at 109.0 Mc. Connection from the airplane antenna to the receiver is made by means of 70-ohm flexible coaxial line.

The audio output of the receiver, consisting of the two characteristic modulation frequencies  $f_1$  and  $f_2$ , is fed into two band-pass filters. These in turn operate the visual indicator (the vertical pointer of the cross-pointer instrument) in a manner previously described.

**Glide-Path Equipment.** The glide-path equipment also consists of a transmitter and antenna system installed at the airport, together with the associated receiving apparatus in the plane. The glide-path transmitter is controlled by a 3912.5 kc crystal. The succession of multiplying stages following the crystal oscillator raise the frequency to 93.9 Mc. At this frequency the output stage of the transmitter delivers a modulated output of 300 watts. The modulation frequency is 60 cycles.

The antenna system to be used will be such as to radiate horizontally polarized waves. The radiation from the antenna will be predominantly in the forward direction. This minimizes the possibility of wrong-way approach from the airplane and also gives a maximum amount of field strength in the forward direction, where it is most needed.

The actual glide path, or the line of descent, to be used by the plane is obtained in the following manner. If there exists a source of radiation from an antenna array close to the earth, there exist an infinite number of lines of constant field strength all of which, starting in space, terminate on the ground near the radiation source. These lines of constant field strength are essentially parabolic in shape. (See Figure 167.)

It is one of these lines of constant field strength which is made use of by the plane making a blind landing. As the plane approaches the airport, the glide-path receiver is turned on. The output of the receiver operates the horizontal needle on the cross-pointer instrument (Figure 165). At first this horizontal needle

will be pointing very low. As the airplane approaches the airport at its normal altitude, the field intensity increases, and the horizontal cross-pointer will rise up. When it reaches a horizontal position, it indicates to the pilot that he must begin the descent. If he loses altitude too fast, the pointer will again drop below the horizontal level (Figure 165B). If he does not lose altitude fast enough, the pointer will be above the horizontal position (Figure 165C). Therefore the pilot has definite information as to his position relative to the glide path he is to follow in making a landing.

The glide-path receiver, like the runway-localizer receiver, is a crystal-controlled one. It operates at the fixed frequency of 93.9 Mc. The audio output of the receiver, which is 60 cycles, is

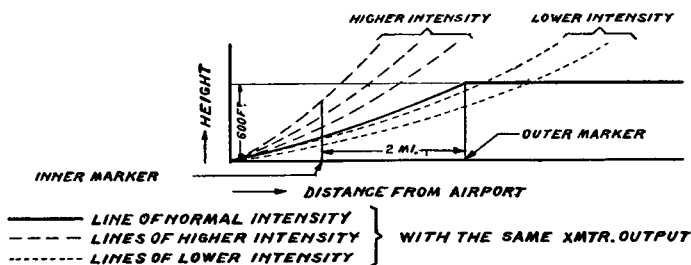


Figure 167. Airplane Glide Path Landing

rectified and applied to the cross-pointer instrument, which in turn indicates the line of descent in a manner previously described. A separate antenna, independent of the localizer-receiver antenna, is used to pick up the glide-path transmitter signals.

Coaxial lines of 70-ohm impedance are used to connect antenna to the receiver input.

**The Marker Equipment.** The marker equipment consists of two transmitter and antenna systems at the transmitting end, together with a receiver and its antenna in the airplane. One of these transmitters with its antenna is located approximately two miles from the airport boundary, in line with the particular runway whose path it is marking. This is called the Outer Marker Beacon. The other transmitter, with its antenna, is located at the boundary of the airport in line with the runway. This is called



the Inner Marker Beacon. The locations of these various Marker Beacons are shown in Figure 166 ( $OM_1$ ,  $IM_2$ , etc.).

These transmitters are controlled by a 4166.7 kc crystal oscillator. The third harmonic from the oscillator is passed through two multiplying stages, giving a final frequency of 75 Mc. At this frequency the power amplifier delivers 5 watts of carrier power, modulated at 400 cycles in the case of the Outer Marker and 1300 cycles in the case of the Inner Marker. The 400-cycle audio tone is keyed at the rate of two each second, each pulse having a duration of four-tenths of a second. The 1300-cycle audio tone is keyed at the rate of six per second, each pulse having a duration of one-fifteenth of a second.

The antennas of these marker beacons are mounted directly above screen counterpoises 20 ft. square. In the case of the Outer Marker, the counterpoise is located 6 ft. above ground and one-quarter wavelength below the antenna. In the case of the Inner Marker, the counterpoise is located 2 ft. above ground and one-eighth wavelength above the counterpoise. The antenna, in both cases, consists of two co-linear half-wavelength radiators. The projected radiation will be an elliptically-shaped directional space pattern having a major axis amplitude approximately three times that of the minor axis, measured in a plane parallel to ground.

The receivers to be used for these markers will be the same type that are used for Fan and Cone of Silence Marker beacons. They are crystal-controlled superheterodyne, operating at the fixed frequency of 75 Mc. The receiver output is fed to three audio-frequency band-pass filters at 3000, 1300, and 400 cycles. The output of each of these filters in turn operates a light located on the pilot's instrument board. The 3000-cycle output operates a white light which indicates the location of Cone of Silence and Fan Marker beacons. The 400-cycle output operates a blue light, indicating the Outer Marker location. The 1300-cycle output operates an amber light, indicating the location of the Inner Marker. A phone jack is also provided at the output of the receiver, so that the pilot may listen to the various marker signals with his headphones.

The antenna used in connection with this receiver is a half-wave conductor placed under the belly of the airplane, parallel to

the axis of the airplane. A coaxial line of 70-ohm impedance is used to connect the antenna to the receiver input.

**Monitor and Control Equipment.** Each of the transmitters above described is monitored at the transmitter site. The detected, filtered output of the monitor is fed to the control lines which go to the control tower of the airport. From here provision is made for turning on and off each of the localizer, glide-path and marker transmitters.

In the case of the localizer transmitter, the monitor is located on a pole about 50 ft. in front of the localizer antenna array, from which it picks up its energy. By this means both the power output and course alignment may be checked.

The glide path transmitter is monitored by means of a vacuum-tube rectifier coupled to the transmission line adjacent to the output tank circuit. The marker transmitter is monitored in a similar fashion, by means of a rectifier coupled to the output circuit.

**Operation of Complete Instrument Landing System.** Figure 166 gives a complete picture of the location of the various units of the International Telephone Development Company Instrument Landing System at Indianapolis Municipal Airport. It is seen that four each of localizer, glide-path, inner and outer marker transmitters and their respective antenna arrays are provided. By this means four wind directions may be accommodated.

In actual operation, under conditions of poor visibility, one lineup of localizer, glide-path, inner and outer marker beacons will be turned on from the control tower. Suppose the wind was from the southwest; then  $L_1$ ,  $GP_1$ ,  $IM_1$ , and  $OM_1$  will be turned on. The pilot in the incoming airplane will then, while still 20 or more miles away, turn on his localizer and glide-path receiver, the marker receiver being on continuously. He will pick up the localizer signal and reach the equisignal zone, thus aligning himself with the correct runway, as indicated by the vertical pointer of his cross-pointer instrument.

He will then maintain this course by always retaining the pointer vertical. As he nears the airport, the pilot will bring the plane down and proceed in flight at an altitude of 600 ft., as indicated by altimeter. In the meantime the horizontal needle of the

cross-pointer instrument, operating from the output of the glider-path receiver, will start rising from a maximum downward indication. Approximately two miles from the airport this indicator will have reached a perfectly horizontal position, and the two pointers will intersect exactly at the center of the instrument. At this point the blue light on the instrument board will begin to flash at the rate of two flashes per second. This will indicate that the airplane is directly over the outer marker beacon. The pilot will now reduce speed and begin his descent, always maintaining the needles of the cross-pointer instrument crossed at the center.

Continuing the glide to earth, a few moments later the amber light on the instrument board will begin to flash at the rate of six times per second, indicating that the airplane is above the inner marker beacon, at the boundary of the airport. Everything being carried out successfully, the airplane will contact the airport at approximately the middle of the runway, about 200 ft. from the glide-path transmitter.

### **Bendix Radio Corporation Type TG-12A Transmitting Equipment**

**Description.** The TG-12A transmitting equipment is intended for use as the transmitter in an instrument landing system for aircraft. The frequency of the carrier is stabilized at 93.9 Mc by means of a low temperature coefficient quartz crystal. The 300-watt carrier output of the transmitter is unmodulated, keying of the radiated wave being accomplished in the antenna array.

The circuit employs the following tubes: 5 Eimac 35T, 4 Eimac 100TH, and 6 RCA-866A.

The crystal-controlled oscillator drives, through three stages of harmonic amplifiers, the final stage consisting of 2 Eimac 100TH tubes in push-pull arrangement. The radio-frequency system is divided into three separate units.

The first unit contains the crystal oscillator and quadrupler. The oscillator employs a triode tube in a conventional circuit and is inductively coupled to the quadrupler. The quadrupler uses two triodes with the grids in push-pull and the plates in parallel.

High grid bias is employed to give a maximum harmonic content in the plate tank circuit. Cathode bias in addition to excitation bias is used in both the oscillator and quadrupler.

The second unit contains the doubler and tripler stages. The two tubes used in the doubler stage are connected with their grids in push-pull and plates in parallel, while the tripler stage uses conventional push-pull connections. Inductive coupling is used throughout. The plate tank circuit of the tripler is in the form of two rods, each one-quarter wave in length. Plate voltage is applied at the electrical center of the circuit. The plate rods are copper, silver plated for low r.f. resistance. A condenser is also provided for fine tuning adjustments.

The tripler circuit is employed because it provides symmetrical coupling to the push-pull grids of the final amplifier.

The third unit contains the final amplifier and antenna coupling circuit. This stage is inductively coupled to the tripler, and one-quarter wavelength rod tank circuits are used in both the grid and the plate circuits. Both tanks are provided with condensers, which are mounted directly on the rods. Means are provided to remove the plate voltage when neutralizing the amplifier. This is accomplished through the use of a 110-volt plug in the rear of the chassis which controls the high-voltage plate relay.

**Power Supplies.** Three separate power supplies are used and all employ two type 866A tubes in single-phase full-wave rectifier circuits. No. 1 supply provides 1000 volts d.c. plate voltage for the oscillator, quadrupler and doubler. No. 2 supplies 2000 volts d.c. plate voltage for the tripler, and No. 3 supplies either 2000, 2500 or 3000 volts d.c. plate voltage for the final amplifier.

A voltage regulator is mounted in the bottom of section No. 1 of the cabinet. This unit is essentially an auto-transformer with a motor-driven contact-arm actuated by a sensitive solenoid-type relay. The regulator will maintain the output voltage constant at a value between 112 and 118 volts plus or minus 1%, for a variation in supply line of 200 to 250 volts. Adjustment of secondary voltage is available, and is provided with a lock-nut to prevent accidental change. The regulator supplies primary voltages for the entire transmitter.

The equipment is normally supplied to operate from a 220-volt a.c. single phase, but can be supplied for other voltages on special order.

**Remote Control Unit.** A remote-control unit Type MT-58-A is supplied which provides a remote start-stop switch, with indicating pilot light, and two monitoring meters which indicate the relative power in each of the two antenna arrays.

#### QUESTIONS

151. What is an instrument landing system and why is such a system an important radio aid to flying?

152. Distinguish between the two basic landing systems now in vogue.

153. Define the terms runway localizer, glide path, and marker beacon (as applied to a radio landing system).

154. What equipment is utilized at the C.A.A. installation at the Indianapolis airport?

155. What special equipment is required aboard aircraft for use in connection with the Air-Track system?

## CHAPTER 14

### RADIO TRAFFIC CONTROL

Traffic along the airways often is directed by radio. Also traffic control has come into use at municipal airports in order to bring the ever-increasing number of aircraft arriving at these ports to safe landings. Traffic control of airplanes constitutes the most pressing present-day safety problem in connection with the operation of airlines. The C.A.A. frequently is inaugurating new facilities to improve the situation at congested points.

It is necessary that aircraft around or over an airport be brought speedily to the landing field in order to eliminate hazard to the next arrival. This is especially true at municipal airports, where private craft and commercial airlines intermingle in the use of the port's facilities. Strict control of the traffic at such ports is an absolute necessity. In order to provide adequate control, the municipal airport must utilize the following radio equipment:

- (a) A low-powered radio transmitter; also a stand-by set and an emergency source of power.
- (b) One or more high-frequency receivers; sometimes six or eight. These are usually installed in a glass-enclosed tower which affords excellent visibility for the control officer and his associates. Several receivers are required at large airports.

**Radio Transmitters.** The Western Electric 10A radio transmitter is a typical example of a set designed specifically for use at airports. A complete description of this transmitter is given in Chapter 10. The RCA-AVT-4, described on page 291, is also used for traffic control at airports.

The 10A transmitter operates, by direct assignment of the Federal Communications Commission, on a frequency of 278 kc. Its range is purposely limited, by restricting the power, to prevent

interference with similar transmitters at other airports. The frequency of 278 kc falls in the center of the so-called "Weather and Beacon Band." Practically all aircraft employ a Beacon Receiver to receive weather and beacon broadcasts in the 200- to 400-kc band; this same receiver picks up all the transmissions from the municipal airport transmitter. See also specifications for such sets, pages 422 and 423.

**Radio Receivers.** The radio receiver recommended by the W.E. Company for municipal airports is its ES-192 with accessories. This instrument is described fully in Chapter 11. The RCA-AVR-11 described on page 348 is also used in conjunction with traffic. Since all aviation communication in the United States is handled on the frequencies between 2900 kc and 6300 kc the frequency range of such a receiver should be limited to this band. In order to eliminate the possibility of missing calls due to improper tuning, the radio receivers should be controlled by means of quartz crystal oscillators. With such a control, the operator cannot do anything which will cause his receiver to be detuned from the specific frequency for which the crystal oscillator is adjusted. All transport aircraft flying in this country utilize this principle and municipal airports that endeavor to use a radio receiver which does not employ crystal-control oscillators are not taking full advantage of the possibilities of radio and are not offering to the transport users of their field the same high-grade service which the airplane itself affords.

The radio receivers may be either locally or remotely controlled. If the man-made static and the electrical noises about the airport are of high intensity, then it is very desirable to have the receiver located at a remote point several miles from the airport and the resultant signals fed, by means of a telephone line, into a loud-speaker at the control tower. The description of this remote-control equipment is given on page 425.

The radio transmitter is usually located in the same building with the airport traffic control offices and very often in the same room. Because of the frequency of 278 kc, the transmitting antenna should be of the maximum permissible height and have as much wire in the clear as possible. This antenna should be 50 or

60 ft. in height and should be at least 200 ft. in length in the form of a symmetrical T and preferably twice as long if it can be reasonably located. The preliminary survey can determine the location of this antenna and how to provide facilities for a reasonably good ground system. More complete information on this is presented in the section below entitled, "Extracts from Aeronautics Bulletin No. 27." In the traffic control tower may be located the radio receivers, provided a preliminary listening watch on the frequencies to be covered shows the noise level to be within reason. Assuming local control radio receivers will be used, the space for a relay rack to house the necessary number of radio receivers or cabinets to allow their mounting must be provided. The radio receiver together with its power-pack takes up approximately 14 in. of panel space on a standard relay rack. These radio receivers can be located in the control room if they are to be locally controlled, or if remote-controlled this equipment may be located at the remote point together with the accessories.

The frequencies at present used by airports and by the airlines are given in Chapter 1. A check must be made at the municipal airport to ascertain what radio frequencies are used by the airplanes of the transport companies using the airport so as to determine what frequencies must be provided for in the radio receivers. Each ES-192 radio receiver will accommodate 2 frequencies, one between 2400 and 3700 kc and the other between 4800 and 6300 kc. These are termed NIGHT and DAY frequencies respectively, and each receiver accommodates one pair. In addition to the frequencies used by the transport companies, provision must be made for constant listening watch on the frequency of 3105 kc (itinerant fliers' frequency) and on 6210 kc (the new daytime frequency for itinerant fliers).

### Extracts from Aeronautic Bulletin No. 27

The following are extracts from *Aeronautic Radio*, issued by the Bureau of Air Commerce, July 1, 1937.

**Antenna System.** All transmitting is conducted on the national airport frequency of 278 kc. An antenna to resonate at this



corresponding wavelength should be approximately 200 ft. in length. Although transmitting antennas are ordinarily placed as high above ground as practicable, it is necessary to sacrifice some efficiency in the radiating system where located at or adjacent to an airport. Lofty towers near a landing area are, of course, an obstruction and constitute a hazard to aircraft in flight. Most commercially available airport transmitters are designed to give satisfactory results when operated into a low single-wire antenna having an electrostatic capacity to ground of from 0.0005 to 0.001 microfarads, and almost any resistance from 4 to 40 ohms.

**The Transmitter.** A transmitter capable of delivering at least 15 watts of r. f. power to the antenna is recommended. This is the maximum antenna power permissible under the regulations governing airport stations.

Good speech quality is desirable and a high percentage of voice modulation of the carrier an important consideration, as the resulting improvement in signal-to-noise ratio is a decided advantage.

Efficient harmonic suppression is a necessity since usually several receivers on different frequency channels are operated in the immediate vicinity, even in the same room. (There are always two—generally three—tower operators.)

It is entirely practicable to design and build or purchase from any one of several reputable commercial concerns a transmitter which will meet the above specifications and which will operate from the conventional 110-volt, 60-cycle, single-phase electric supply lines. The power consumption is so small as to be negligible. The transmitter may be installed in the traffic-control room or located at some remote point convenient to an antenna so situated as to minimize its potential hazard as an obstruction. Floor space required for the transmitter is ordinarily not more than 6 or 8 sq. ft. If the transmitter is installed remotely, only the microphone, amplifier, and control equipment need be located in the traffic-control tower. There may, in fact, be several control stations, and this is frequently the case, for reasons which will be discussed later.

**Equipment Design.** The design features of one of the several commercial models of airport transmitters on the market will be described as representative. The output circuit is arranged for either feeding into a conventional quarter-wave antenna and ground system, or to give the proper impedance relations for working into an r.f. transmission line. The final power amplifier utilizes two Type 865 tubes excited by the output of another Type 865 which acts as the oscillator. The oscillator is quartz-crystal controlled since frequency stability is becoming increasingly important with the advent of pretuned 278-kc aircraft receivers and the consequent demand for precise and permanent adjustment. Two Type 59 tubes in parallel modulate the power amplifier 100%. The first audio amplifier tube is arranged so that it can be made to function as an audio oscillator by simply throwing a single switch to the "ICW" position. Thus is made available a signal source for a runway-localizer or other such navigational aids.

Plates and bias potentials, even microphone current, where required, and direct current for operating control relays are rectified and filtered a.c. from the 110-volt supply line; no batteries of any kind are necessary.

Microphones of the carbon type should be designed for operation in any position for portable use. Probably the moving-coil magnetic type is best suited in this respect because this type is more rugged and less affected by moisture and weather changes. It is true it requires more preamplification as its output is lower, but it gives excellent quality capable of great amplification, with complete freedom from the noises inherent in the carbon type. It has the advantage also of not requiring a microphone battery.

**Receivers.** Usually several radio receivers are required, two at least: An intermediate frequency receiver for airways radio range signals and weather broadcasts in the 200- to 400-kc band, and a high-frequency receiver for guarding the national aircraft frequency of 3105 kc. The airport station guards all of the several aeronautical chains operating in the vicinity. This entails a multiplicity of receivers—at some airports as many as eight or nine—one for each transport chain frequency. H.f. aeronautical

radio-transmitting stations are usually operated on the airport, frequently in the same building. For this and other reasons both low and high-frequency receiving equipment should be the best obtainable. A sensitivity of 5 microvolts per meter and minimum selectivity that will permit discrimination between stations of equal strength 10 kc apart in frequency is recommended as a minimum requirement. Complete shielding is important; stability of operation and freedom from frequency drift, a consideration; and, of course, adequate ventilation to prevent overheating under continuous service is essential. An efficient and quick-acting automatic gain control is a desirable feature, especially on the receivers used for guarding the frequencies used by local transmitters.

Several reputable manufacturers now offer receivers especially designed for airport use. Most of them are of multiband design covering airway frequencies from 200 to 400 kc; entertainment broadcasts, 500 to 1500 kc; and that portion of the high-frequency spectrum which includes all aeronautical channels.

### **Specifications for Airport Traffic-Control Transmitter**

Transmitter must be of a type designed primarily for airport service for control and direction of air traffic by means of radiotelephone only and should not include any extraneous circuits or apparatus not essential for such use. It must be of a type now in use at other major airports in the United States and must have sufficient output to guarantee communication with planes within a radius of 15 miles under normal operating conditions.

Transmitter to provide radiotelephone transmission on any carrier frequency between 230 and 500 kc per second. Apparatus to be contained in one unit and shall operate from 100- to 120-volt, 50- to 60-cycle single-phase lighting circuit. It shall consume not more than 250 watts of power from this line. It is to be enclosed in a metal case, which is to be as nearly dustproof as consistent with satisfactory ventilation. This metal case to be fitted with a lock and key to prevent unauthorized tampering with the transmitter. All external tuning controls to be of such type that changes in tuning adjustments cannot readily be made

without a special tool which shall be provided for that purpose. Transmitter to be so designed as to require no additional control equipment for its satisfactory operation, other than a suitable desk stand microphone of the "press-to-talk" type which is to be supplied with this equipment. Transmitter to be so designed as to be either fastened to the inside wall of a building or to the top of a bench or table or other support.

The radio-frequency circuits part of the transmitter to be of oscillator modulating amplifier type, with a low temperature quartz-crystal controlled oscillator, holding the carrier frequency to within 0.01% plus or minus of assigned frequency, under all temperature conditions from 32° to 140° F. A variometer shall be installed in the plate circuit and so adjustable that the reactance of this circuit is highly inductive at the operating frequency of the transmitter. The antenna is to be tuned by continuously variable and tapped inductances which will resonate antennas with effective capacities as low as 0.0004 microfarad at 230 kc and as high as 0.0009 microfarad at 500 kc.

The audio-frequency circuit must be designed to furnish sufficient power for substantial 100% modulation of the carrier wave during loud passage of speech.

Transmitter to be equipped with proper line fuse, power-circuit fuses and proper protection to cut power circuits when door of transmitter is opened.

Transmitter to be equipped with visual tuning meters in order that operator may adjust circuits without using external meters or other devices.

A full set of vacuum tubes of the proper type for the transmitter, to be furnished.

Complete information to be furnished covering operation, care and maintenance of the equipment.

### **Specifications for Airport Traffic-Control Radio Receiver**

As an example of what is desired in a certain type receiver, the following specifications should be studied as an ideal.

The radio receiver must be designed primarily for aviation and airport service. It must be of a type now in use by other municipal

airports and by major transport lines as the main radio-receiving equipment for reception of radiotelephone signals from aircraft. The frequency range is to be divided into two bands, one of the bands being from 2400 to 3700 kc, while the other band shall be from 4800 kc to 6300 kc. Each of these bands shall be provided with a complete radio-frequency amplifier and detector oscillator circuit with provision made within the receiver and controlled by means of a switch located on the front panel to shift from one of these bands to the other simply by the operation of this switch on the front panel. The output of one or the other of these separate radio-frequency amplifier detector units shall be supplied to a common intermediate-frequency amplifier.

The frequency of the heterodyne oscillator in each of the two radio-frequency bands shall be controlled by means of a quartz-crystal oscillator. This quartz-crystal oscillator shall be of the low temperature frequency coefficient type commonly known as the AT or BT type of quartz plate. These quartz-crystal oscillators are to be of the plug-in type and are to be ground specifically for use in this radio receiver, the frequency of the quartz plate to be specified by the purchaser at the time of placing the order. The heterodyne oscillator shall be so constructed that the fundamental frequency of oscillation of the quartz plate shall be the carrier frequency in kilocycles per second which is desired to be received minus the intermediate frequency of 385 kc per second.

Each of the two radio-frequency bands shall be provided with antenna-coupling transformers. Each antenna-coupling transformer shall be capable of being attached to an open or simple antenna, a two-wire 70-ohm transmission line, a 500-ohm transmission line, or a concentric transmission line.

The output of one or the other of the radio-frequency channels shall be supplied to a common intermediate-frequency amplifier. This i. f. amplifier shall be 385 kc. Two stages of i. f. amplification at 385 kc per second shall be provided. Automatic volume control shall be applied to the grids of the first radio-frequency tubes and to the intermediate frequency tubes. Audio automatic volume control shall be provided to prevent overloading and blocking of the audio-amplifier tubes on very strong signals. A manual sensi-

tivity control shall be provided on the front panel to adjust the sensitivity of the radio receiver.

The radio receiver shall be provided for relay rack mounting and the panel height occupied by the radio receiver on this standard relay rack shall not exceed  $8\frac{3}{4}$  in. When installed on a relay rack, the receiver shall be equipped with a dust-cover which shall completely enclose the vacuum tubes, transformers, and other apparatus mounted on the top of the chassis except for the necessary holes provided for ventilation.

The power supply for the radio receiver shall be external and shall be mounted on a relay rack panel. It shall not occupy more than  $5\frac{1}{2}$  in. panel height in a standard relay rack. This power supply shall be sufficient to provide the plate current necessary for the operation of the radio receiver.

The radio receiver together with its power supply shall be provided for local control. The radio receiver and its power supply, however, shall be capable of being controlled remotely over a pair of metallic telephone wires by the simple addition of the necessary remote-control equipment. (A description of this remote-control equipment with photographs is presented at the time bids are offered on these radio receivers, together with the approximate apparatus costs of such remote-control units.)

The radio-receiver circuit shall provide one stage of tuned radio-frequency amplification before the detector, a crystal-controlled heterodyne oscillator, two stages of i.f. amplification, second detector, automatic volume control, and two stages of audio-frequency amplification. The output of the radio receiver shall be such that it can be fed directly into 500 ohms or into 250 ohms. All external connections to the radio receiver other than the antenna circuit shall be through filters, such filters to prevent the introduction to the radio receiver of noises originating from the 110-volt, 60-cycle a.c. line, microphone relays, or power supply equipment associated with the radio receiver.

### **Western Electric Remote-Control Equipment for Airport Receivers**

The Western Electric Company, which has devoted considerable time to research (through the Bell Telephone Laboratories)

in the development of airport communication equipment, has this to say :

When the general man-made static or electrical disturbances at an airport interfere with the operation of aviation radio receivers located at the airport, a very serious situation exists. Heretofore the only escape was to place the operator at a remote point together with the radio receiver. While this insured satisfactory reception, it interfered with the normal operation of the airport inasmuch as the operator could not observe conditions on the port itself, and was not within direct control of airport or airline authorities.

With the introduction of radio receivers employing quartz-crystal oscillators, the Western Electric Company overcame this tremendous difficulty. It was then possible to locate the radio receiver at a distance from the airport and because of the temperature-controlled quartz-crystal oscillator, the receiver would not drift away from the assigned frequency. By utilizing Western Electric equipment, the remote control of such a radio receiver over telephone lines is possible. With this apparatus, it is possible then to turn the receiver off and on, change the sensitivity and to shift between one of the two frequencies. All these functions correspond with those which could be effected, were the operator at the receiver controls.

The equipment for remotely controlling a radio receiver such as the W.E. ES-192 radio receiver comprises in general the D-97778 selector panel which goes with the radio receiver at the remote location and the D-97779 control panel which is located at the airport within reach of the operator. Between these two units is a single pair of telephone wires.

### **Airport and Airways Traffic Control Procedure**

The C.A.A. promulgates regulations as to procedure in controlling both airway and airport traffic by radio. It is not within the province of a book of this nature to detail any operating procedure, whether in aircraft, at airline ground stations, or airports and airways stations controlled by C.A.A. It is, however, within the province of any text to advise as to supplementary reading ; in the case of radio traffic control, the reading should be confined almost entirely to official publications whenever issued. In the meantime the equipment now installed and being installed should be inspected if this is practicable ; in any case the requirements of such equipment can be learned from study of this chap-

ter. The chapter which follows this will add to the reader's knowledge of equipment and how it is installed.

## QUESTIONS

156. What is a control airport?

*Ans.* It is an airport which has been so designated by the Authority to provide for the safety of aircraft moving in interstate or foreign air commerce.

157. What is an airway traffic-control station?

*Ans.* It is a station operated by the Authority for the purpose of air traffic control on Civil Airways within the jurisdiction of such station.

158. Describe an airport control tower.

*Ans.* It is an establishment properly situated and equipped to allow an operator thereof to adequately control air traffic in the immediate vicinity of the airport on or adjacent to which such airport control tower is located.

159. What control tower operator ratings have been authorized?

*Ans.* Junior, associate, senior (airport control tower operator rating).

160. What is meant by a control zone?

*Ans.* A control zone is the air space above an area within a circle with a radius of three miles drawn from the center of the control airport: provided, however, that if a radio directional aid station designed to direct air traffic to the control airport is more than three miles from the center thereof then the control zone is extended above an area one-half mile on each side of a line projected from the center of such airport to such radio aid.



## CHAPTER 15

### INSTALLATION OF EQUIPMENT

#### General Considerations

Proper installation and maintenance of radio apparatus requires a comprehensive knowledge of radio on the part of the mechanic. Correct installation methods have already been prescribed by radio and aeronautical engineers; only the supplementary principles will be given here. The care and maintenance which do not involve overhaul and repair of radio equipment are the responsibility of the operator, consequently the methods followed by a radio operator in maintaining equipment operative under normal service conditions also will be explained. But the procedure in detail of a radio technician who must remove a set from service and subject it to tests by special instruments cannot be described in a book of this kind nor should the work be undertaken by a radio operator holding any junior license unless he has proper supervision.

The watchful radio operator can—and does—frequently learn what has gone wrong with his set; some of the faults may be remedied easily by replacement of a part. In such cases either the operator or a “repairer” is able to remedy the fault discovered, but this sort of simple trouble-shooting usually is a small part of the work done by a radio mechanic. Only a few tools are needed to substitute an old part for a new one: a couple of pairs of pliers, two or three screw-drivers, a pocket knife, a small soldering outfit, and a few small wrenches. The reader is advised to get a few tools of this kind and, if he is to become an operator or any kind of an aviation mechanic, *learn to use them*. Messrs. Moser and Krenz, radio instructors at the Boeing School, estimate that “75% of radio maintenance work is mechanical.” If the reader is not a student at some good school, he should be reminded that an excellent way to become a radio operator and

learn to work on sets is to build his own set and become an amateur.

This book is mostly for the person already engaged in—or entering—aviation who desires to qualify for a radio operator's license. This chapter is for the newly licensed operator or mechanic who must actually deal with radio apparatus, for it must be remembered that all airlines have a very carefully organized maintenance department with a routine for the inspection, cleaning, testing, repair, and replacement of all radio gear at periodic intervals. The important consideration is that the orders pertaining to servicing be understood and carried out. For this reason it is advisable for the reader now to turn back and review Chapters 6 to 10 inclusive, making certain that the terms and phraseology are understood, that circuit diagrams can be traced with ease, and that they add to the reader's theoretical knowledge of equipment as given in the text.

The general scheme of installing radio apparatus on airplanes will be explained first because a knowledge of where and how such apparatus is best placed constitutes an important part of both installation and maintenance work, the installing of ground station equipment usually being accomplished by an electrical contractor.

In considering the general subject of the installation of radio apparatus in aircraft, it is necessary to bear in mind certain fundamental requirements: the plane must first be bonded, the engine should be shielded, the type of antenna desired must be decided upon, and the size and weight of the different pieces of radio equipment must be known. Then the location of the apparatus and the best method of installation can be determined.

### **Bonding**

By bonding is meant the interconnection of all metal parts of the aircraft by means of good electrical conductors. Aside from the necessity of bonding in order that the metal parts of the plane may collectively constitute a suitable counterpoise of a capacity value to make it a proper substitute for the "ground" in the antenna circuit, bonding is necessary for the elimination of certain

causes of noises in the radio receiver and as a prevention against fire. If the plane is not bonded, or is ineffectively bonded, objectionable noises may be heard in the receiver caused by sparks occurring between two metal members having a difference of potential due to having collected charges of static electricity. Varying resistances between vibrating or rubbing parts also will cause noises in the receiver.

Bonding of airplanes is best accomplished during their manufacture or assembly at the factory. Both the Army and Navy have issued technical orders specifying the correct and most effective manner of bonding.

Electrical connections of approximately the same or less resistance than those of the metal parts joined, are made by soldering, bolting, or clamping connecting strips between them. Small masses of metal are bonded by a single strip of metal braid or ribbon. Shielded cables, piping, tubing, brace wiring, and any long metal members are bonded at intervals of 36 in. or less, at each end, and at any point where there is rubbing or vibrating contact with another member. An exception to this rule occurs in certain instances where bonding is impracticable, as in the case where diagonal brace wires cross one another. In jobs like this, rubbing contact is avoided by suitably insulating the parts from each other, preferably at, or near, the point of natural contact. If two long members run parallel and in contact with each other, they should be held firm by clamping, or taping, between bonding strips. In using bonding braid, care should be taken to prevent fraying; if a hole is to be drilled in it, the braid first should be dipped in solder. All braid-to-braid contacts should be soldered. All joints should be flexible enough to prevent being broken by expansion and contraction; in every case the metal parts must be joined before any protective coating is applied. Rosin solder flux is used except in soldering to a steel member, when paste may be used, but this paste should be cleaned off immediately. In wings of wood-and-wire construction, a strip of copper is placed along each spar; all internal and external wires, fittings and conduits of the wing are connected to this. All control surfaces, control wires, tanks and pipes must make a proper contact to the main metal part of the plane.

Government and factory inspectors examine all this work as it is done. During subsequent overhaul or repairs incident to service, the bonding system is maintained intact or replaced according to the original requirements, and then tested to see that every portion of the bonding system is of equally good conductance. The following detailed instructions for bonding have been issued by the Western Electric Company.

**Wooden Wings.** Wooden wings are to be metallized and bonded in the following manner. A metal strip  $\frac{1}{4}$  by  $\frac{1}{64}$  in. or larger shall be fastened along the front and rear spars from fuselage to wing tips. These strips shall be interconnected to the "ground," to the internal brace wires at each drag brace, to the external brace wires and fittings wherever these wires and fittings come into the wing, and to each other by similar strips which run from front to rear strips along each drag brace. The front and rear strips shall also be connected together at the wing tip. If the wing carries a metal entering edge, the front metallized strips may be dispensed with and connection made to the edge. The same is true of any metal wires or sheets in the trailing edge or other parts of the wing which are of sufficient size to be used in place of the metallized strip. The metal shielding which covers any electrical wires in the wings such as landing-light leads, etc., shall be grounded at least every 14 to 20 in. to the metallizing strips at each drag brace.

**Brace Wires, Etc.** Wherever control or brace wires, or other movable or semi-movable parts come into casual contact with each other, or with other metal parts of the ship, it is necessary either to furnish insulation at the point of uncertain contact or else to bond the parts together. Crossed wires may be insulated from each other by passing one wire through a hole at one side of a flat insulating washer and the other through a similar hole in the opposite side of the same washer. Small button or egg type insulators (such as micarta spacer wrapped with tape) may be used to hold the wires apart instead of the washer. This method of insulating the wires where they cross is to be preferred to bonding by means of a soldered lead as the flux used in soldering has a corrosive action.

It has been found that turnbuckles and tie-rod terminals sometimes offer considerable resistance to the flow of high-frequency currents. Such equipment therefore should be tested with the test-rigs described on page 433; also wherever a high resistance is found it should be by-passed by a copper bond.

**Wooden Fuselages.** A wooden fuselage is to be bonded and metallized as follows: A metal strip equivalent to that used in the wings is to be fastened along each longeron. This strip shall extend from the engine to the tail surface, making good electrical contact with the engine base and with each metal part and fitting along its length, branch strips being used if necessary. These longeron strips must also be connected to the wing strips. All water, gasoline, and oil lines should be grounded to the frame at frequent intervals. Rubber hose joints should be by-passed by copper braid bonds.

**Control Surfaces.** The metal hinges of rudder, elevators, ailerons, etc., must be bonded across and the control wires attached to such parts must be bonded to the hinges. The whole is to be connected to the ground—which means making one electrical circuit of all metal parts.

The method generally used is to place braid about 2 in. in width on the control wires near the thimble and wrap with waxed and shellacked cord, then pigtail a piece of braid to an effective ground contact. If soldering is attempted, it must be done with due care on account of possibility of weakening control wires.

**Metal Airplanes.** In metal airplanes metallizing strips are, of course, unnecessary, but it is quite essential that the various parts of the ship be connected by low-resistance paths and a certain amount of bonding will sometimes be required in order to achieve this. The resistance between metal parts which are in contact may be rendered high by a protective shellac or other coating or by oxide films. Contact surfaces between each of the parts should be scraped bright and clean and after having been forced into tight contact, a new protective coating applied along the outside of the joint. Wherever there is any uncertainty as to a satisfactory connection at a contact, it should be by-passed by a copper

bond. Parts that are welded together need no attention, as welded joints are of low resistance. Lighting wires which are shielded should be bonded every 14 in. to 20 in.

**Tests for Efficiency of Bonding.** The best test of bonding is to try it out with a radio receiver. However, a test-rig consisting of a 2-volt storage battery, a low-resistance rheostat or variable resistance, and an ammeter having a low-reading scale of from 0 to 2 amperes connected in series with leads of about No. 14 copper wire, can be used to determine the efficiency of bonding. In making a test, short-circuit the terminals of the test leads and adjust the rheostat until the ammeter registers 1 ampere. Then separate the terminals and close the circuit by applying the terminals to various different metal parts of the airplane, noting the ammeter reading. If at any time the ammeter reads less than 0.9 amperes, the bonding is considered unsatisfactory. Fluctuation in the reading when testing the moving control surfaces will also indicate an unsatisfactory connection in the bonding system.

Frequently the source of receiver noise can be located by means of a probe antenna used in conjunction with one of the radio receivers. Such an antenna consists of a length of flexible wire shielded its entire length except for a distance of approximately 1 ft. at one end. The opposite end is connected to the input of the radio receiver and the shield at this end grounded to the receiver mounting. By probing with the unshielded portion of the wire, the source of disturbance frequently can be localized.

Another circuit tester often used consists of a battery-operated buzzer, with or without headphones. When connected between any two parts of the airplane to be tested, the circuit is completed through the bonding circuit and if the buzz is weak, it can be assumed that the resistance of the bonded section is too high. It is customary to test across all bonds and joints in this way.

### Shielding

Whenever a spark discharge occurs in an electrical circuit, high-frequency oscillations are set up and create an electromagnetic effect which is appreciable at some distance from the circuit.

If the discharge is highly damped, as in the case of spark ignition circuits, the oscillations involve a very wide range of frequencies and a tuned radio receiving set will pick out and amplify those frequencies to which it is resonant. For this reason the ignition circuit can be responsible for a prohibitive amount of noise in the receivers.

The low tension wire systems on the plane may also be responsible for radio noise. Radio-frequency interference from sparks at the commutator of the generator may be transmitted along the low tension systems and unless the wires of this system are effectively shielded, this interference will be audible in the receiver. Furthermore, unshielded lighting and instrument wires may pick up high-frequency energy from the ignition or generator circuit due to the fact that the shielding of these circuits is never perfect. This energy is then distributed over the whole low-tension wiring system and may cause serious trouble. Consequently the only satisfactory practice is to completely shield *all* wires on the ship. In addition, a 4 mf condenser across the regulator and a can-cover for the generator field lead on the voltage regulator will eliminate noise from these sources.

**Shielding Explained.** Ignition shielding consists of so confining the electrical fields of the ignition system that no interfering "signal" or electrical disturbance can be set up by induction in the radio-receiving circuit or heard in the receiver. Shielding constitutes an important installation problem due to the increased use of highly sensitive receivers. The difficulty of the problem lies chiefly in the electrical and mechanical design of the arrangement for shielding that must be employed to be effective both ways between the ignition circuit or circuits and the radio set. The use of a rod or fixed-pole antenna also increases the difficulty of shielding.

All manufacturers of airplanes, engines, spark plugs, magnetos, and ignition cable are interested in the development of shielding equipment. Complete shielding assemblies may now be purchased intact for most airplane engines. Air transport companies in many cases have developed the most satisfactory shielding equipment now available.

**Requirements of Shielding Assembly.** In the design of a safe and practicable shielding assembly, the following factors govern:

1. Reliability of engine performance is the first consideration. The shielding must prevent insulation breakdown of any of the component parts of the ignition system. Full provision for the protection of the component parts from the effects of oil, gasoline, and water should be made. Mechanical protection of the ignition cable and other parts is necessary.

2. Shielding of an effective and permanent nature is next in importance. The effectiveness of the shielding should not decrease with service. This requires a mechanically sturdy assembly.

3. The shielding assembly must be satisfactory from an operating point of view. Servicing of the spark plugs and magnetos should be possible with a minimum of effort on the part of the operating staff. Replacements of individual leads or groups of leads should also be possible. Ordinary replacements should in no way affect the efficiency and completeness of shielding.

4. In addition to the above considerations, it is important that the component parts of the shielding be simple to manufacture in order that the cost of radio shielding shall not be prohibitive.

**Method of Ignition Shielding.** Shielding of the ignition system is accomplished in the following manner. A metallic ignition manifold is employed with high-tension cable drawn through it in the usual way. The leads from the manifold to the spark plugs and the groups of leads from the manifold to the magneto outlets are enclosed in liquid-proof flexible aluminum tubing with copper braid on the outside to insure effective shielding. Each flexible tubing is suitably fitted to the ignition manifold and to the magnetos or spark plugs, as the case may be. The magnetos are provided with covers which completely enclose the distributor blocks. A single outlet permits the use of an elbow fitting for connection to the large flexible metal tubing. This elbow fitting differs for different types of engines. Outlets are provided in the elbows for the booster and ground leads. The spark plugs are of a type in which the shield is an integral part and are provided with elbows for connection to the smaller flexible metal tubing. The



ignition switch is totally enclosed in a metal cover, the booster magneto is also covered, and the leads from the magnetos to the ignition switch and booster magneto are enclosed in flexible metal tubing. The complete assembly insures electrical safety, mechanical sturdiness, liquid-proofing of magnetos, spark plugs, and ignition cable; also ease of installation and servicing.

**Shielding Harnesses.** Complete shielding harnesses for any type of aircraft engine can be purchased from any one of several firms. The Titeflex Metal Hose Co., Newark, New Jersey, has this to say of its product, "Our complete harnesses include shielded manifolds, magneto leads, spark-plug leads, ignition wire and elbows for attaching to shielded spark plugs, as well as with spark-plug cans for shielding unshielded plugs.

"The complete harness is pressure-tight in all respects, insuring freedom from dust, dirt and moisture. A slight amount of moisture, however, may condense within the shielded manifold. This is taken care of by providing drain holes at the lower portion of the manifold.

"An effort to insure the use of only similar metals in the complete harness is made, eliminating any undue corrosion from the use of dissimilar metals. Manifolds and harnesses have normally been mounted in two points on radial aircraft engines, either in front or behind the push-rods. The former method has been conceded to be the most practical from a service standpoint, inasmuch as the harness can be removed without disturbing the push-rods and valve assembly. Somewhat longer lengths of leads are required by this method of mounting, but this has been compensated for by the recent development of lighter weight shielding leads.

"A point which has not as yet been particularly stressed is that a pressure type of conduit such as supplied by our organization might be super-charged for flying at high altitudes. We believe that this factor will be extremely important when sub-stratosphere flying becomes more common.

"In addition to offering complete shielding against interference as it pertains to radio reception, the harness being pressure-tight, liquid and moisture proof, prevents any outside agent detri-

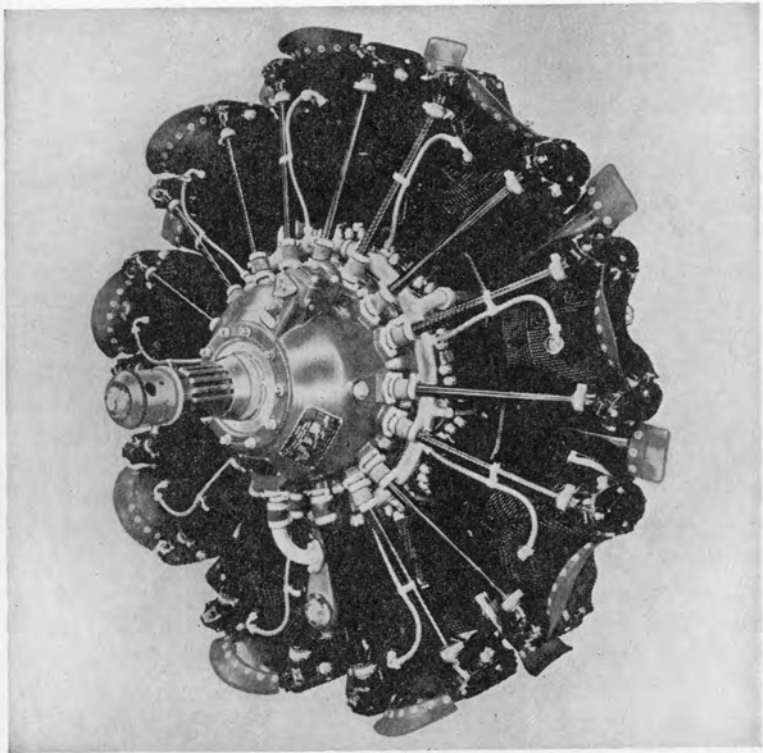


Plate XX. The Breeze Radio Ignition Shielding

mental to ignition wire, such as gasoline, oil, kerosene, etc., from coming in contact with the ignition cable, causing premature break-downs."

Breeze Corporations, Inc., Newark, New Jersey, also make a complete shielding harness which is well known among engine manufacturers. Plate XX shows this harness.

## Antennas

**Choosing the Correct Antenna.** As certain factors affect performance, a compromise must be made in the choice of the antenna or radiating system to be used on various craft. The final selection is limited. It is affected by both the electrical and physical limitations as well as the specific conditions under which the plane is to operate in the air and the circumstances under which it is handled on the ground. All types should be understood; therefore, the principal forms will be described.

In general, the same antenna is used by both the transmitter and the communication receiver on airliners. Some airlines employ a fixed-length trailing-wire antenna which is not reeled in. This antenna usually employs a tuning unit located in the tail of the ship. As a rule, these antennas consist of stranded-steel control cable and are about 30 ft. in length. Other airlines employ a similar length of wire, usually stranded copper, supported between a stub mast directly over the pilot's cab and the top of the vertical fin of the ship. Antennas for reception of radio-range signals are usually mounted on the belly of the ship. Sometimes they take the form of a symmetrical V with a vertical lead-in, the beacon receiver being located directly at the point to which the lead-in enters the fuselage. Other operators employ symmetrical T antennas suspended on the belly between stub masts. Still another antenna, which has been more popular in the past for beacon reception, is a sloping wire stretched between the tail fin and a point on the fuselage near the tail so that the antenna makes an angle of approximately  $30^{\circ}$  to  $45^{\circ}$  with the fuselage.

Rain, snow, sleet, and thick dust clouds produce what is called "rain static," apparently caused by the high potential charge picked up by the surface of the plane and the antenna from elec-

trically charged particles in the atmosphere. Rain static can be considerably reduced by using a shielded loop antenna. The Western Electric (radio compass) loop described on page 392 has been installed on a number of air transports. The United Air Lines in addition to this loop use six or eight gossamer-like wires, each about 12 ft. in length, attached to the trailing edge of the wing. Figure 168 shows the loop antenna circuit that is used. T2 is adjusted to make the loop-circuit impedance equal that of the regular antenna.

On small planes, a 3- to 5-ft. mast, tapered and streamlined, is generally used for all reception purposes. This may be of wood with a wire up the middle, or all metal. There is little

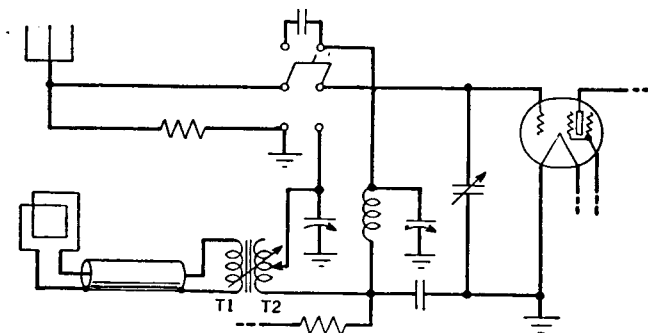
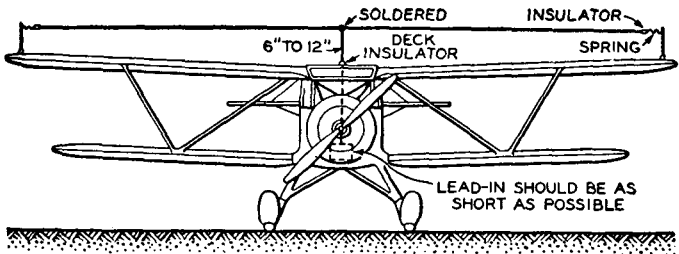


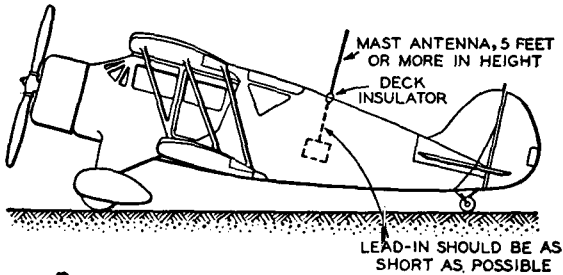
Figure 168. Anti-Static Loop Circuit

choice from a radio viewpoint. The problems are mainly aerodynamical. Another excellent form of receiving antenna is a wire T. (See Figures 169A and B.) It consists of a flat top section with a centrally located lead-in which may be above or below the ship. Such an antenna should extend as far above or below the airplane as the owner is willing to tolerate it from the consideration of drag. The separation of the flat top from the fuselage should not be less than 10 in.; from 1 to 2 ft. is desirable.

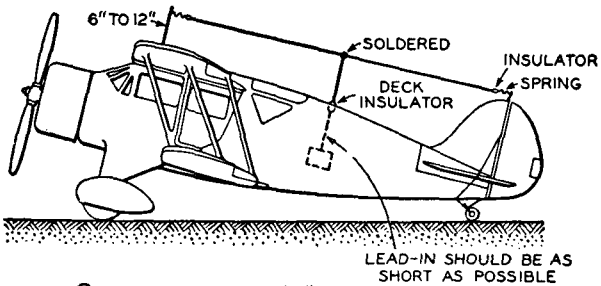
For transmission, a fixed antenna is the only practical type for the private flyer. A wire strung fore and aft above the entire fuselage at a height of at least 2 ft. and having a down-lead anywhere along its length makes a fair radiating system. (See Fig-



A - TRANSVERSE "T" ANTENNA



B - VERTICAL-MAST TYPE ANTENNA



C - LONGITUDINAL "T" ANTENNA

Figure 169. Typical Antennas for Small Aircraft

ure 169C.) No practicable antenna on an airplane is perfect, and whatever is used is a compromise between radiating efficiency and what seems a reasonable drag on the airplane. Wire from wing tips to tail with a down-lead near the tail makes a fair antenna, but has the disadvantage of greater drag than the fore-and-aft antenna; is more apt to be damaged in the hangar. The transmitting antenna may be used for receiving in any frequency band if it is essentially a flat top T with a central down lead; but if it is in the shape of an L, it must not be used for radio range reception.

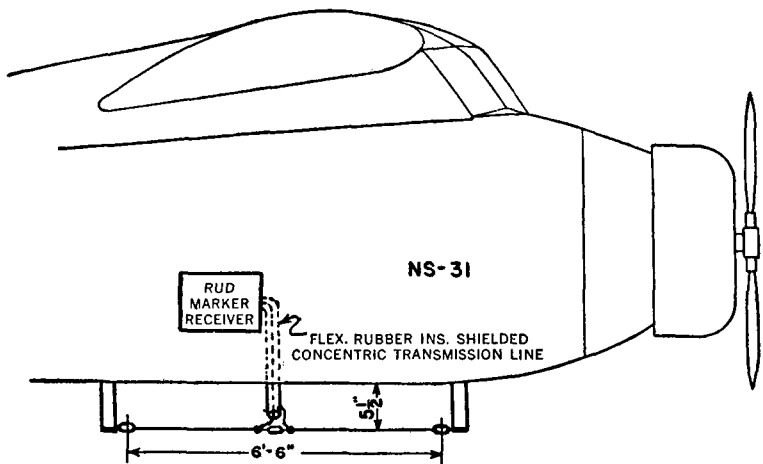


Figure 170. Receiving Antenna for U.H.F. Type Marker Beacon

Figures 169A, B, and C all show antenna installations popular with small plane owners.

Figure 170 shows correct installation plan of receiver antenna for reception of the ultra-high-frequency marker beacons.

**Overhead.** Overhead or belly antennas may be of either the T, L, or V type (originally named from their shape). The overhead antenna is mounted from the vertical stabilizer or stabilizers in the rear to stub masts forward on the fuselage or on the wing tips as the case may be.

Belly antennas are installed from short streamlined mounts. Any of the above types may be used for receiving. Each has its own individual characteristics as to signal pickup and directional properties.

The decision as to the kind to be installed rests with both communication and design engineering personnel, who base their choice on the latest information available from cooperative civilian and government research groups and from operating data continually being gathered under flight service conditions. The actual position of any of the above antennas in the particular craft will materially affect their operation electrically. A correct decision can only be reached by the consideration of much more data than can be presented here.

For transmitting purposes, a large overhead V can be used with considerably reduced range as compared to the fixed or retractable trailing wire; however, such an antenna presents a physical problem in storing the airplane.

**Trailing.** A trailing antenna may be either fixed, of a specified length; or retractable. Whether fixed or retractable, this type of aerial is the most efficient for transmitting. This is also true for receiving in certain cases where the receiver is NOT to be used for range flying, but is for long-distance weather-reception on low frequencies and company communications on high frequencies.

The length of the trailing antenna may either be of some odd multiple of the wavelength being transmitted, or of some more convenient length provided a loading or resonating coil is inserted between the antenna and the transmitter. In the case of a transmitter using many different frequencies, such loading coils are sometimes incorporated in the switching facilities of the transmitter.

The fixed trailing-wire antenna has the disadvantage of requiring frequent replacement due to wear from being dragged while taking off or landing, also due to whipping in the air at high speeds. Such trailing wires last from twenty to perhaps over a hundred take-offs and landings, depending on the material (usually stranded steel control cable, either bare or covered with cloth or rubber).

Retractable types are of the electrically or manually-controlled varieties, either of fixed or variable lengths.

Manually operated trailing antennas may be the direct-control form, as those mounted under the pilot's seat or somewhere on the sides of the cockpit, or have a remote cable and housing which in turn rotate gears operating the reel on which the antenna wire—phosphor-bronze multistrand or steel—is wound. Certain forms of these antenna-controlling devices have indicators showing the length of wire reeled out while others simply have the required length of wire on them.

When the lead is brought out from the rear of the ship, a rubber "snake" or wind-sock can be used instead of the streamlined lead weight (which is necessary where the lead is brought out under the forward part of the ship to prevent it from whipping the belly). In metal transports where it becomes desirable to use a shorter length than called for by resonance, a loading unit such as the widely known Cannon unit is employed.

**Vertical Antennas.** This antenna had its birth in the original tapered streamlined metal type, of chrome-molybdenum steel, which is still widely used by the C.A.A. and military. Present variations of the vertical antenna are of the "whip" type similar to those used on automobiles. These have the advantage of less resistance with resultant less objectionable vibration and they do not accumulate ice.

The virtual nondirectional characteristics of this antenna make it extremely desirable for range flying and cone-of-silence reception.

**Fin.** If the vertical stabilizer is of sufficient height, it is possible to install a semi-vertical antenna from the top of it to a point several feet forward of the base of the fin, which gives an antenna of very good performance for range operation.

**Loop.** The loop antenna is finding popularity both as a direction-finding device and as an electrostatic shielded antenna for the reduction of static. When used as a direction finder on transports, the loop is made rotatable to permit bearings to be taken. For operation on privately-owned planes the loop is sometimes



mounted in a fixed position at right angles to the axis of the plane and used in conjunction with a short fixed or sense antenna. The rotatable type of loop can be used either as a direction finder or as a compass.

Seldom, if ever, is the vertical, fin, or loop antenna used as a transmitting radiator; however, at times the L, T, or V antenna used for reception is switched (either manually or electrically by relay) to the transmitter through a suitable loading coil to allow transmission on the ground without subjecting the transmitter to unresonant operation (such as is done when the trailing antenna is dragged on the ground and the transmitter is operated at that time. This unresonant operation has a damaging effect on tubes and power equipment).

Whatever antenna is used, proper installation is an essential factor which should always be given the utmost consideration. Especially in receiving antennas is the matter of stability and rigidity of the installation an important item. Attempts to use insulated wire in the construction of antennas have given no tangible increase in efficiency or effectiveness in the operation of the sets.

**Antenna Assembly.** Numerous forms of masts may be employed, depending upon the conditions to be met in each case. Generally the construction will be of a tapered streamlined chrome-molybdenum steel either cut to the desired length and mounted to a base, or run through the fuselage and mounted internally to some of the ship's structure with suitable metal or fabric seal. These masts should be rustproofed and plated or finished as desired. It is important that whatever mounting is used mechanically, it must conform with the rules and regulations covering such alterations as governed by the C.A.A.

While in most cases stranded wire either of copper, phosphor-bronze, or steel is used in antenna construction, there has been some use of special strong solid wire not having the faults of the usual solid copper wire. A phosphor-bronze wire consisting of several strands is the most popular, having flexibility and strength with a minimum stretching quality. Special compression types of antenna springs, either the open or enclosed forms,

are often used to take up any slack in the antenna due to stretching, thus keeping the antenna from oscillating while the craft is in flight (which in some cases would cause variations in the strength of the signal received).

To decrease the leakage path from the antenna proper to the fuselage, several of the small, streamlined, compression type antenna insulators may be used, fastened at intervals from several inches to several feet apart. This increased insulation is desirable because when grease, moisture, or ice adheres to the insulators the small amount of signal energy or transmitter radio-frequency power is quite liable to be lost.

Unless exceptionally strong insulators are available of the long, narrow kind with fastening holes at either end, the smaller compression types are to be preferred as they minimize the danger of breakage.

In fastening the wire to the various component parts, such as insulators, springs, etc., great care must be exercised that the job is done neatly; and when the bound section of the fitting is soldered, no solder must get out on the single antenna strand, as that tends to stiffen the otherwise flexible wire, making a point which will fray and finally break. Only a resin-core solder should be used—not an acid flux—as the latter will contribute spurious noises as the connection corrodes.

Several different kinds of insulating materials are available, such as isolantite, glazed porcelain, and linen-base pabelite, etc. As the quality of insulating materials and their tensile strengths are being improved all the time, it is recommended that data be obtained from manufacturers in order that the most suitable materials can be chosen for the particular job.

The most popular form of the feed-through type of insulator is that which only requires a single hole for mounting, thus simplifying the sealing problems. The exact shapes vary; some have a corrugated surface which tends to increase the total length of the insulating path; some are of the smooth variety.

Unless special low-capacity transmission-line type of shielded wire is available Do NOT use shielding over an antenna lead-in either for the receiver or transmitter. Improper shielding of a higher capacity adds to the losses of signal and transmitting

energy; consequently a well-insulated wire of the nature of ignition cable (not shielded) must be used. It is imperative in locating the lead-in about the ship that it not be placed parallel to metal parts of the fuselage for any distance. Bakelite insulating mounts can be used to hold the wire off the metal fuselage tubing.

**WARNING:** When assembling antenna on fabric planes, positively **NO CHANCES** should be taken in the handling of soldering irons, etc. **BE SURE** that the tip of the iron is well fastened and that in soldering in or out of the ship an asbestos cover or tarpaulin is spread to catch even the smallest bits of hot solder. The amount of radio-frequency energy usually present in aircraft transmitters is well able to burn fabric. Care must be taken in handling trailing-wire antennas, as when wrapping parts about the ship while it is on the ground. In mounting fixed trailing-wire antennas and whips, shear-pin plug-in arrangements are used to facilitate removal and in case the antenna may catch on some object.

**Installation of Antennas.** Antennas of the fixed type usually are supported by stub masts or horns about 10 in. in length; the antennas should be strung to these masts with strain insulators. The masts should be clamped to some rigid member of the plane. If the vertical-mast type of antenna is used, it should be rigidly mounted to the upper and lower longerons of the plane. If the mast is of metal, it should be suitably insulated at points of contact with the aircraft. The mast-type antenna is generally used for receiving, while the trailing or fixed type is more frequently employed for transmitting. It is possible to "guy" the vertical mast with the triangular (transmitting) antenna, and for this reason these two types are often used together. In the event that a trailing or depending type antenna is not of the sleeve type, the suspended weight should be in the shape of a pencil and weigh from 2 to 10 lb., depending on the length of antenna and the speed of the airplane. This weight should be securely fastened to the antenna by means of a swivel attachment which is usually a part of the weight. It is good practice to pass the antenna around the weight and securely fasten it to a thimble of suitable size, after which a long tapering splice can be made.

When a trailing type antenna is part of the equipment, a spare antenna and weight are usually carried. Every plane equipped primarily with a trailing-wire antenna should carry in addition thereto some form of fixed auxiliary antenna; also some form of emergency antenna. The auxiliary antenna is desirable in maintaining communication while approaching for a landing after the trailing antenna has been reeled in. The emergency antenna is desirable in the event of a forced landing. The antenna reel used with the trailing antenna must be insulated from the metal part of the aircraft. This is usually accomplished by mounting the reel on an insulating panel.

If a metal reel is employed, the bolts used to secure it should be separated by at least 2 in. from the bolts which secure the panel to the aircraft. The reel should be ruggedly mounted and provided with a ratchet stop and a locking arrangement which will permit it to be secured in any position desired. The entire reel should be well shielded from any possible contact with high-voltage leads.

A fair-lead is used to guide the antenna from the reel through the bottom of the fuselage. It also provides electrical contact between the antenna and the transmitter or receiver. There should be an air space of 2 in. between this fair-lead and any metal part of the aircraft. The inside diameter of the fair-lead must be sufficient to allow the antenna weight to be drawn entirely through it into the fuselage of the plane.

**Efficiency of Antennas.** The efficiency of the entire transmitter is affected by the efficiency of the antenna circuit; that is, the greater the ratio of power output to power input in this circuit, the more effective will be the range of the transmitter. The power delivered to the antenna is equal to the square of the antenna current multiplied by the effective resistance of the antenna.

The effective resistance is the total or combined resistances<sup>13</sup> existing in the antenna. These are known as ohmic resistance, radiation resistance, and dielectric absorption. Ohmic resistance is offered by the antenna wires, ground wires, condensers, coils, etc., in the antenna circuit. This ohmic resistance is governed by the physical properties of the circuit. The length and position

of an antenna and the bonding system of the plane, together with the frequency, determine the radiation resistance. At the fundamental frequency (page 51), the radiation resistance is maximum. This resistance is decreased as the antenna is loaded. Dielectric absorption is caused by any metal part of the plane being between the antenna and the bonding system. It increases as the circuit is loaded.

The effective antenna resistance, usually referred to simply as antenna resistance, can be determined by substituting a dummy antenna (made up of a suitable inductance, capacity, and a calibrated variable resistance) for the antenna of the airplane.

### Artificial (Dummy) Antennas

To facilitate the adjustment of the radio transmitter prior to its installation in an airplane or other type of station, an adjustment on a test-bench using an artificial antenna will be helpful in reducing the time required for the final adjustment with the real antenna.

The usual antennas encountered on commercial airplanes may be simulated by a 250-mmf., 2000-volt variable condenser connected in series with a 5-ampere radio-frequency ammeter and a two to ten-ohm non-inductive resistor capable of dissipating 50 watts. The artificial antenna should be adjusted to simulate the characteristics of the antenna with which the transmitter is to be used. This may be done by substituting the artificial antenna for the real antenna after the transmitter has been tuned to operate properly with the latter. This substitution process should be repeated for each frequency on which the transmitter may be operated. The variable condenser should be adjusted for maximum antenna current in each case and the resistor adjusted to make the current the same magnitude as the antenna current.

The artificial antenna so calibrated may then be used for testing the transmitter or for preliminary tuning without using the real antenna.

### Antenna and Ground Systems

**W.E. 10A Airport Transmitter.** The range obtained with most ground radio equipment is approximately proportional to

the effective height of the antenna. It is highly desirable not to locate the antenna in close proximity to the side of tall buildings or towers constructed with metal framework. Such locations result in a decrease in efficiency for the station and cause the antenna to have a distorted radiation pattern.

A suitable antenna for the No. 10A radio transmitter consists of a symmetrical T type antenna with a flat top 250 ft. in length, and raised to an elevation of approximately 60 ft. No. 12 B & S gage hard-drawn bare copper or phosphor-bronze wire may be used. A 6-in. Pyrex entering insulator or its equivalent is suitable for the lead-in insulator. The entire construction of the antenna and lead-in should be based on a radio-frequency voltage

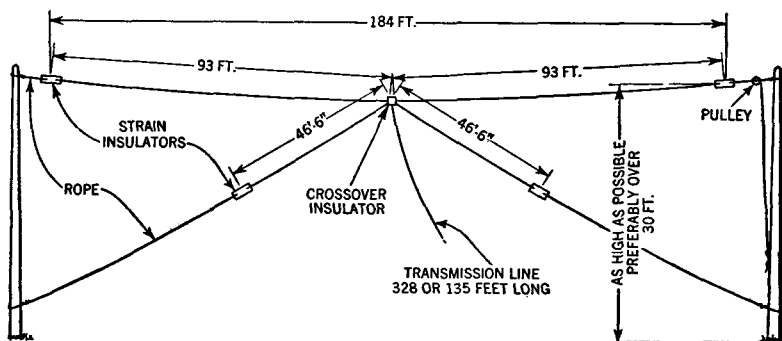


Figure 171. RCA Antenna Kit

of 5000. Care should be taken to keep all parts of the antenna circuit at a distance of several feet from where gasoline is stored or handled.

The distance from the radio transmitter to the lead-in on the antenna should be as short as possible. It is suggested that a copper tube be used to make the connections between the antenna lead-in, the antenna switch and the radio transmitter. This conductor should not be run parallel to or within 1 ft. of other conductors.

The ground connection to the radio transmitter should be made with a No. 10 B & S gage wire. The lead should be short and terminate on as extensive a ground system as possible. A

good low-resistance ground system can be obtained by bonding together water and steam pipes as well as any metal parts of the building. If a ground system of this kind is not readily accessible, ten to twenty No. 12 B & S gage bare copper wires may be buried in the ground spreading radially under the antenna and on either side a distance approximately equal to the height of the antenna.

**The RCA Antenna Kit Model AVA-4.** This unit consists of a double-doublet antenna for the reception of aircraft at ground stations. Figure 171 illustrates how it should be installed.

### Installation Methods

The manufacturers of aircraft radio sets usually try to determine the detailed plan of installation for each type of set that is put on the market. These plans are modified by the user of the set as circumstances warrant. Radiotelegraph apparatus should be housed aboard the plane in a manner that allows the operator free access to most of it. When radiophone sets are installed aboard mail-planes carrying but one pilot, the set is often quite inaccessible to the pilot, usually being located in the fuselage back of the cockpit and remotely controlled.

In every installation, due regard must be given to securing the set to the plane properly, to securing the leads firmly, and to protection from fire hazards. Sponge rubber of some sort is employed to cushion the sets, which usually are bolted to a framework permanently attached to the fuselage structural members. Tubing of aluminum or aluminum alloy is generally used as conduits for all wires not part of some shielded cable. The source of power, as the generator, power transformers, and any other possible source of trouble from sparking or overheating, should be enclosed in such a way that damage to the plane cannot result from overheating. Switches should be enclosed in flameproof boxes. Fuses are inserted in power lines. The entire installation should be easy to inspect.

### Installation Procedure

The first installation of radio in aircraft must be supervised by a person holding the proper C.A.A. mechanics authority. If

additional equipment is installed afterwards, the aircraft must be checked by a Federal Inspector before taking flight again. Inspection may not be passed if weight is wrongly distributed, cables are improperly fastened or holes are drilled where no holes should exist.

A form must be submitted to the inspector showing in detail the nature of the proposed work. For this reason, a good point to remember in aircraft radio installation or maintenance is: Never drill a hole or drive a nail or screw unless you have positive approval of the C.A.A. to do so.

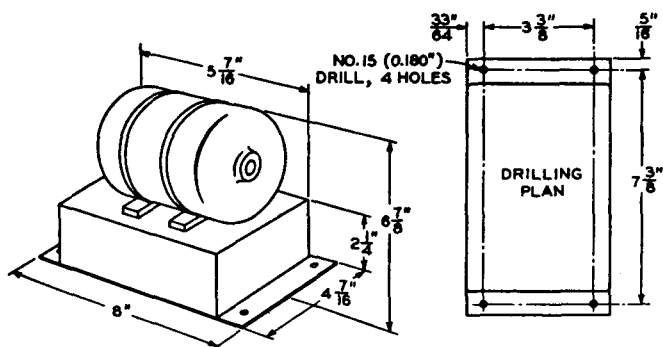


Figure 172. Mounting Dimensions for W.E. No. KS 7543 Power Unit

Be sure remote-control and electrical cables are completely clear of all aircraft controls, and so rigidly fastened that they can never foul.

Use lock washers under every nut and, where possible, safety wire or safety pin bolts to prevent nuts backing off.

The details of actual installation and maintenance can be obtained from instruction books from manufacturers. As an example of an approved plan of power equipment installation, Figure 172 shows the working drawing of a Western Electric power unit supplied by this company for the guidance of the mechanic installing it.

In the case of a wind-driven generator, such as the GE-20 described in Chapter 7, choose a location where the driving fan will be in the slipstream. Then prepare a plan and drawing that will show the clamp ring supplied with this machine welded to a suit-



able mounting bracket, so it will fit the location chosen. Submit this plan to the inspector.

### Wiring the Airplane

**Wiring.** Power leads are "electric wiring" and the best methods of installing electric wiring are definitely established. Large air transport companies have prescribed general rules for their radio mechanics which can be summarized as follows:

1. All wires should be placed in conduit so that new wires may be readily pulled in; all ignition wiring must be in separate conduit.
2. Solid conduit is to be used in place of flexible conduit wherever possible. All conduit should terminate in junction boxes and all junction box covers should be protected by sheet fiber. Shielded wire should be used from junction boxes to instruments, generators, magnetos, etc., where conduit is not practicable. Shielded wires are to be grounded at the extreme end.

**Wiring and Conduit.** All wiring should be installed in a thoroughly workmanlike manner and should be sufficiently insulated to comply with the voltage requirements.

All wires should be provided with an outside covering of sufficient strength to protect them from mechanical injury. House-wiring practice has indicated that conduit wiring results in the lowest possible fire hazard. However, since the consideration of weight and easy accessibility is involved, the use of conduit or armored cable should be optional except where specifically required in the Wiring Chart. Particular care should be taken with the load from the transmitting set to the antenna. This load should be made as short as practicable, insofar as the convenient installation of the transmitting set and the antenna lead-in insulator permit.

Aluminum or aluminum alloy is much employed aboard airplanes as conduit, because of its light weight. However, you may find that in certain instances a flexible conduit is necessary, and in this case armored cable can be employed to good advantage. Of

course, all wiring should be exposed to view in order that it may be of easy accessibility.

The following Electric Wiring Chart, based on standards adopted by the American Institute of Electrical Engineers and accepted by insurance underwriters, will be useful as a reference.

FOR CAMBRIC INSULATION ONLY

Packard Cable B & S Gage	Resistance Ohms per Foot	Capacity in Amperes	Length of Wire at Max. Load before Voltage Drop Exceeds 5% at 12 Volts
18	.006385	5	19 ft.
16	.004016	10	15 "
14	.002525	20	12 "
12	.001588	25	15 "
10	.0009989	30	20 "
8	.0006289	40	24 "
6	.0003951	60	25 "
4	.0002485	75	32 "
2	.0001563	125	30 "
0	.00009827	200	30 "

Where any circuit calls for long leads, computation must be made to insure adequate voltage for satisfactory operation being received by the unit.

If the proper size wire is selected for the load that is to be carried, it can safely be assumed that the insulation is sufficient. This is because all electric wire on the market today has passed the Fire Underwriters' specifications.

### Installation of Power Supply Units

On aircraft operating over land, sufficient power supply should be available, when the aircraft is at rest with the airplane engine not running, to permit the intermittent use of the transmitting equipment for a minimum period of two hours. On aircraft operating over water, sufficient power supply for intermittent operation should be provided for six hours.

All electrical machinery should be installed in suitably reinforced locations and as far away from the fuel lines as practicable. Voltage regulators should be totally enclosed in metal cases, so

that sparking contacts are not exposed. The electrical wiring of the power supply should be run in metal conduit or armor. The possibility of accidental short-circuiting of the component parts of the system should be minimized by the use of suitable insulating terminal blocks, etc. The system should be properly protected with relays and fuses. The method of connecting the leads to the component parts of the system should not permit exposed terminals.

The storage battery should be of the non-spillable type. It should be completely enclosed in a metallic box, provided with an inner lining of sheet-lead along the bottom and sides of sufficient size to hold the entire liquid content of the battery in case of breakage. Suitable clamps for holding the battery firmly in place should be provided. The metallic box should be properly vented to permit the escape of acid fumes from the battery.

### **Installation of Transmitters**

Figure 173 is a detailed plan furnished by The RCA Company for the installation of their AVT-7B transmitter; it is self-explanatory.

### **How to Install the RCA Radio-Compass Loop**

In the installation of the AVR-8E aircraft radio compass it is desirable, from an operation standpoint, to arrange the loop and the azimuth control in such a manner that the following conditions are fulfilled:

1. The loop should rotate in the same direction as the pointer on the azimuth scale and the control knob.
2. The pointer on the azimuth scale should always point in the direction of the station being received or the station from which a bearing is being taken.
3. The zero heading on the azimuth scale should coincide with the line of flight of the airplane.
4. The bearings as read from the azimuth scale should increase from left to right in the same manner as magnetic compass bearings increase.

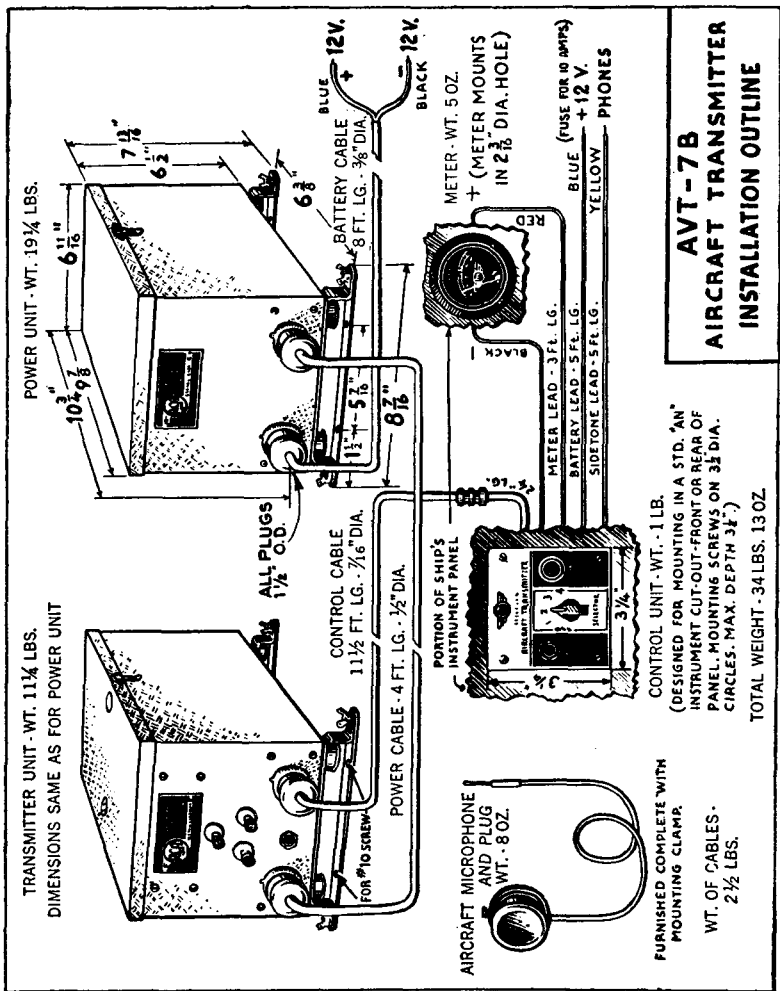


Figure 173, Installation Plans for RCA Model AVT-7B Transmitter

The control box is normally supplied with a right-hand worm gear as shown in Figure 174, together with a clockwise azimuth scale. (If desired, the left-hand worm gear and the counter-clockwise azimuth scale can be obtained from the RCA Manufacturing Company, Inc., Camden, N. J.)

The general scheme of installation for this equipment is shown in Figure 174. Radio compasses should be calibrated in flight after installation.

### Installation of Receivers

Most manufacturers of transport planes determine very carefully an installation plan of all equipment to be carried aboard, being in some cases guided by the ideas and specifications of the airline company which is to use the plane. Itinerant pilots have their own ideas, generally based on available space. There are certain fixed factors which govern the radio engineer in allocating space for receivers. Plane manufacturers are guided by these; itinerants ought to be influenced in their plans by the experience of air transport operators. First, the receiver should be mounted as near the antenna as possible to avoid long connecting lines which will attenuate (or fade out) the received signals in the case of the high-frequency receivers, and when beacon receivers are used (especially on smaller, non-metal planes) cause a directional effect. Also, excessive capacity set up between lead-in and receiver ground (the bonded fuselage) will reduce the voltage step-up normally secured in the tuned antenna circuit.

The optimum value of antenna capacity for the two lower frequency bands is 100 micro-microfarads and for the two higher frequency bands 50 micro-microfarads. If a single antenna of approximately 100 micro-microfarad capacity is used, it may be connected directly to the low-frequency antenna binding post and through a series 100 micro-microfarad mica condenser to the high-frequency antenna terminal.

In certain cases it may be desirable to use a short antenna on the two lower frequency bands for the reception of beacon and broadcast signals and the longer transmitting antenna on the two higher frequency bands for air-ground communication. If this



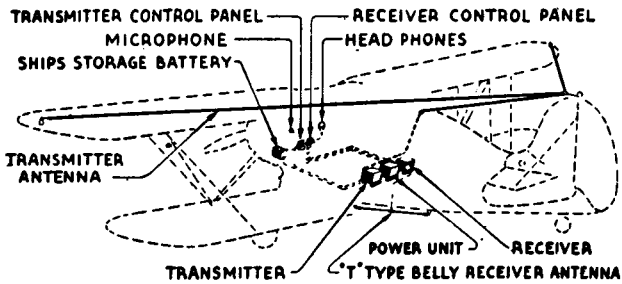


Figure 175. Installation Scheme for RCA Radio Equipment

arrangement is used, the approximate capacities of the antennas must be known in order that appropriate series capacities may be chosen to make the total antenna capacities approximately 50 and 100 micro-microfarads. Typical construction of three types of short antenna for airplanes is shown in Figure 169. Additional information on the construction of antennas for radio range beacon reception may be obtained from U. S. Department of Commerce, Aeronautics Branch (now C.A.A.), Air Commerce Bulletin of May 1, 1933, pages 528 and 529. If any antenna is connected to the receiver through a series condenser without a direct connection in addition, a 0.5 megohm resistor should be connected in parallel with the series condenser to drain off any static charges which may be built up on the antenna.

Figure 175 shows a detailed plan for the installation of RCA equipment on a small plane.

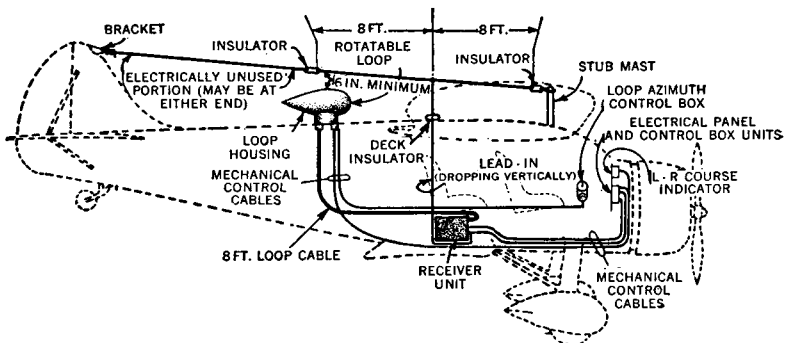


Figure 176. A Complete Radio Installation Aboard an Airplane

After the receiver is installed it will be necessary to trim the antenna tuned circuits for the particular antenna capacity. This is accomplished by tuning in a station near the high end of each frequency band in turn and adjusting the trimmer condensers for maximum output from the receiver.

Figure 176 shows an installation of loop and T antenna with associated radio-compass equipment.

### QUESTIONS

161. What is bonding, why necessary and how accomplished?
162. Sketch a bond-testing outfit and explain how used.
163. Explain shielding, state the advantages of shielding ignition, and describe the construction of a shielding harness.
164. Name and describe four types of aircraft antennas.
165. What type of antenna would you select for installation on a Taylor Cub for both transmitting and receiving? Explain reasons for choice.
166. Why and where is a loop antenna used?
167. Give the purpose and use of dummy antennas.
168. State basic rules governing wiring aboard aircraft.
169. What general rules govern the installation of receivers?
170. What hand tools would you like to have in order to do the work of a radio mechanic?



## CHAPTER 16

### MAINTENANCE

#### General Considerations

Maintenance is a broad term. As applied to aeronautic radio it covers the care and preservation of sets by the operator, the inspection and cleaning of equipment by service crews, the testing, repair, and replacement of entire sets and their component parts.

An operator can only hope to become a radio mechanic by working as one. The procedure laid down by the various airlines applies to this type of mechanic, not to the reader of this book. Even so, there are certain basic principles involved in a sound maintenance routine, and certain examples are available which should be studied as a guide in acquiring a knowledge of this line of work.

Equipment normally removed from an airplane for servicing consists of transmitters, receivers, direction finders and loops, keys, microphones, headphones, etc. Power-packs, antennas, mechanical remote controls, and other fixed equipment are serviced on the plane. There is generally a twenty-hour check which applies to removable equipment during which tubes and circuits are tested. About once every fifty hours the bonding and shielding are checked. At longer intervals the antenna is removed and probably replaced by a new one.

Care should be taken at these times in handling equipment. The most important consideration to remember in maintenance work is: **BE SURE; CHECK AND DOUBLE CHECK ON EVERY JOB THAT IS DONE.** One successful maintenance chief puts it this way: "Trust no one. Check it yourself; then check it again." This is particularly true as to soldered connections, nuts, screws, bolts, and contacts. Figures 177 and 178 show two check-off forms. Similar forms are used to check other items of equipment.

### Routine Inspection of Radio Equipment

All airlines require that operating radio equipment be inspected by a radio mechanic appointed to that duty both before and after each flight. When an airliner lands at an intermediate airport, a quick check is made of the radio equipment; any troubles are remedied.

The American Air Lines require at this time what they call a Turn-Around Inspection. Here are the instructions covering

<i>INSPECTION AND SERVICE REPORT No. 1</i>			
<i>PLANE</i> _____ <i>OAKLAND</i> _____ <i>19</i> _____			
<i>TRANSMITTER</i>			
<i>Report of plane operator</i>			
<i>Operating frequency</i> _____		<i>Transmitter No</i> _____	
<i>Range of last communication</i> _____ <i>miles (approx)</i>		<i>Make</i> _____	
<i>Report of other station, if any</i> _____		<i>Type</i> _____	
<i>Probable fault</i> _____			
<i>CHECK</i>	<i>CHECK</i>	<i>PERFORMANCE</i>	
<i>FIL. VOLTS</i>	<i>CONDENSERS</i>	<i>FREQUENCY OF OSC.</i>	<i>Kc.</i>
<i>PT. VOLTS</i>	<i>RESISTORS</i>	<i>FREQUENCY OF OUT.</i>	<i>Kc.</i>
<i>PT. CURRENT</i>	<i>CHOKES</i>	<i>CARRIER OUTPUT</i>	<i>W</i>
<i>CRYSTAL</i>	<i>TUBES</i>	<i>MOD. CARRIER OUTPUT</i>	<i>W</i>
<i>COILS</i>	<i>TRANSFORMERS</i>	<i>MOD. PERCENTAGE</i>	<i>%</i>
<i>CLIPS</i>	<i>METERS</i>	<i>HARMONIC CONTENT</i>	<i>%</i>
	<i>RELAYS</i>	<i>COMMUNICATION TESTS</i>	
<i>Remarks:</i> _____			
<i>Signed</i> _____			

Figure 177. Transmitter Check Sheet

this inspection, given as a typical example of the nature of work done by an operator or radio mechanic assigned for radio maintenance duty.

1. As the period of time that an airplane remains at a station may be brief, it is essential that inspection and tests be made immediately upon arrival. Tools and spares should be available and the work will be a continuation of the preliminary inspection.

2. Inoperative equipment shall be inspected at once and the cause of the trouble investigated. Repair or replacement of the unit should be

made. If the cause is not immediately apparent, substitution of a unit known to be in operative condition will aid in determining the location of the fault. Use a logical and orderly procedure, examining first the most obvious and probable sources. Blown fuses, open tube filaments, broken headset and microphone cords, plug and jack connections, broken antenna connections, poor relay contacts, and similar troubles head the list. Failure of the radio wiring in the airplane is one of the rarest cases of trouble.

INSPECTION AND SERVICE REPORT No. 2										
PLANE _____ OAKLAND _____ 19 _____										
GENERATOR AND DYNAMOTOR										
GENERATOR No. _____ MAKE _____ TYPE _____ RATED R.P.M. _____										
VOLTAGE TESTS				CHECK			CHECK			CHECK
CONDITION	RATED R.P.M.	50% OVER	50% UNDER	CLEANED	COMMUTATOR	COUPLING				
NO LOAD	V	V	V	OILED	REGULATOR	FILTER				
FULL LOAD	V	V	V	BRUSHES	BRACKET					
25% OVER	V	V	V	BEARINGS	PROPELLOR					
Remarks, other work done: _____										
DYNAMOTOR No. _____ MAKE _____ RATED R.P.M. _____										
VOLTAGE TESTS				CHECK			CHECK			CHECK
CONDITION	RATED V INPUT	50% OVER V INPUT		CLEANED	COMMUTATOR-1	REGULATOR				
NO LOAD				OILED	COMMUTATOR-2					
FULL LOAD				BRUSHES	BRACKET					
				BEARINGS	FILTER					
Remarks: other work done: _____										
Temperature one hour, 20% overload run _____ Signed: _____										

Figure 178. Power-Pack Check Sheet

3. Visual inspection of antennas, receiver, and transmitter mounts, condition of headsets and microphone, volume control panel, power unit and connections shall be made.

4. An operating check of transmitters and receivers shall be made, testing by calling a company station. Listen to the company receiver, checking both day and night frequencies. Listen to several radio-range stations on standard beacon and auxiliary receivers.

After the inspection outlined above is completed, there are two forms to be filled out and signed; these show just what was done and why.

### Maintenance of Generators

Periodically all parts should be cleaned and bearings properly packed with a good grade of neutral grease of high melting point. New oil-sealing washers should be installed at this time and the generator given a run at about 400 r.p.m. over a period of one hour on a test bench, before reinstallation on the engine.

Grease and oil should not be permitted to collect on the commutators. If dirt, oil, or grease is present, it should be removed and the commutators wiped with a clean cloth. *Do not sandpaper* the commutators unless absolutely necessary to remove roughness. In time the commutators *should* be covered with a dark semitransparent film which should be preserved thereon.

The natural wear of the brushes causes carbon dust to collect on the interior of the generator; and this accumulation mixed with oil vapor will form a gummy paste which readily adheres to the brushes, causing the latter to stick. The brushes should be kept free in their respective boxes and when necessary may be washed in gasoline and thoroughly dried before reassembling.

It is of extreme importance that the generator brushes make FULL contact with the commutator surface. Reseating of the brushes may be quickly accomplished by inserting a strip of No. 00 sandpaper (sanded side against the brush) between the brushes and commutator, then withdrawing sandpaper against the rotation of the armature. Sand particles must be blown out of the generator after this operation. This should be carefully and thoroughly done.

Before reassembling the generator, the oil-seal washers should be examined and if found to be damaged or worn, they should be replaced at once. No difficulty with engine-oil seepage should be experienced if oil seals are properly assembled.

### Maintenance of Transmitters

At airline terminals it is common practice to arrange for quick removal of the transmitter (and receivers) for service or replace-

ment. Inasmuch as only a few minutes are allowed for receiver and transmitter check while the plane is on "the apron" preparatory to flight, no service work can be done on the radio equipment without it being removed from the plane. Consequently, defective apparatus is removed for service at a later time and is replaced with properly tested and operating equipment.

The following instructions for locating trouble on a Western Electric transmitter are furnished by this company; they should be studied as an example of correct step-by-step maintenance procedure and as a review in circuit study.

**TEST BENCH.** All large users of mobile radio equipment have found it convenient to establish test benches at strategic points for routine checking of their apparatus at regular intervals. It is recommended that accurate records be kept of the performance of the transmitters on the test bench in order that any depreciation of the tubes or other apparatus items may be detected. By this means it should be possible to anticipate failures and avoid interruptions in service.

The Western Electric company furnishes a diagram of a circuit which is suggested for use on the test bench. The circuit contains apparatus representing other parts of the system which depend for their operation on the correct performance of the No. 13C radio transmitter. A lamp is used to represent the dynamotor relay, and another lamp to represent the signal lamp in the control unit. A high impedance headset may be plugged into the side-tone jack to check that circuit. The apparatus provides facilities for testing every circuit within the transmitter. If it is desired to make the artificial antenna<sup>15</sup> exactly equivalent to the actual antenna it will be necessary to have a continuously variable resistor which can be adjusted to obtain the same value of antenna current. The setting of both the resistor and condenser will be different for each frequency. To simulate a very large antenna it will be necessary to use a continuously variable inductance instead of the variable air condenser.

**Trouble-Shooting the Western Electric No. 13C.** The test bench will be invaluable in case trouble occurs in the No. 13C radio transmitter. The test jacks provided in the transmitter make it possible to quickly isolate the trouble. The general procedure should be to check the radio-frequency circuits progressively from the quartz plate to the antenna and then test the audio-frequency modulation. In case it is necessary to trace any of the

wiring, an ohmmeter should be used for this purpose. Never use a buzzer or test lamp for this purpose, as serious damage may result. The method of locating some specific troubles is described in the following paragraphs.

**No R.F. OUTPUT.** In case no radio-frequency output is obtained when the control button is pressed, be sure that all tube filaments are lighted and that the low and high-voltage power sources are of the normal voltage. Measure the oscillator grid and plate currents. No plate current indicates an open in that circuit which may be located by referring to the schematic diagram and testing with an ohmmeter. No grid current indicates the quartz plate is not oscillating, which in turn may be due to a defective quartz plate or oscillator tube or an open circuit. Replace the tube and quartz plate and check the circuit with the ohmmeter.

If the oscillator stage is working properly, check the first amplifier and then the second amplifier by a similar procedure.

**Low R.F. OUTPUT.** Measure the screen voltage, using a voltmeter of not less than 1000 ohms per volt. If the voltage is low, and cannot be brought up by adjusting D10 (Fig. 127), one of the No. 282A vacuum tubes is probably drawing an abnormally large screen current. As only one screen current jack is provided, it will be expedient to substitute three new tubes and then replace the old ones, one at a time, until the one causing the trouble has been found. If it is a second amplifier tube and is not in too bad condition it may give additional service in the first amplifier stage.

Other possible causes of low output may be a defective quartz plate, oscillator tube, or interstage transformer.

**NORMAL OUTPUT BUT NO MODULATION.** This indicates an open circuit or defective apparatus in the audio amplifier. It may be progressively checked in the following manner. Plug a low range milliammeter into the audio grid jack and make a loud sustained sound in the microphone. If the input circuit and transformer are correct it should be possible to draw a fraction of a milliampere grid current on the audio tube. The audio-amplifier plate current should be normal if the tube and circuit are correct. It should change little in either direction when the microphone is spoken into. A large change indicates a defective output transformer.

**ABNORMALLY HIGH R.F. OUTPUT AND POOR MODULATION.** Check the adjustment of the antenna coil. Measure the screen voltage. If it is high and cannot be made normal by adjusting D10, the cause is probably that one or more of the No. 282A vacuum tubes are drawing very low or reversed screen current. Replace them one at a time until the one causing the trouble is located. If it is a second-amplifier tube it may give additional satisfactory service in the first amplifier.

**ABNORMAL HEATING OF VACUUM TUBES.** If a ground should occur at any point in the system on the negative high-voltage lead, the bias would be removed and all tubes would draw abnormally large plate currents.

If only one of the second amplifier tubes is abnormally hot, the trouble is due to the two parallel tubes refusing to divide the load. Check the wiring to be sure both tubes are connected. Interchange tubes until two are found which will divide the load. The tube removed may operate satisfactorily in the first amplifier.

### **Maintenance of Receivers**

The combination multi-range ohmmeter and high resistance voltmeter is the most useful instrument for checking receivers. Never connect the ohmmeter across a circuit in which current is flowing. All resistance checks are made with receiver power off. The voltmeter is used for checking d.c. voltages at the power supply terminals and tube sockets and other points in the circuits. If an ohmmeter is not available, a low-range high-resistance voltmeter connected in series with a battery and two insulated prods can be used for checks on continuity of circuits (opens, grounds and shorts). An a.c. voltmeter is necessary for checking heater or filament voltages and line voltage on an a.c. operated receiver.

If tubes do not light, check the filament or heater supply (battery or transformer) and connections. Some a.c. tubes heat very slowly and do not always show a strong light. Check a.c. supply to power transformer. If a single tube fails to light, check voltage at the socket terminals for defective contact; check tube.

Excessive hum in an a.c. receiver usually indicates an open filament center-tap resistor or open connection on center-tap of supply secondary. Leakage between heater and cathode causes hum, and tube should be replaced. Infrequent causes of excessive hum are open filter or by-pass

condensers in supply circuits. An open grid circuit sometimes causes hum accompanied by weak output and distortion. A periodic clicking with poor sensitivity in regenerative receivers indicates open detector grid leak or leak with too high resistance. Replace the leak with one of lower resistance.

If filaments light but receiver is dead, check B supply voltage and connections to output stage. With no signal there should be strong clicks when the speaker or headphones are connected and disconnected. If output stage is O.K., check each circuit component (condensers, resistors, and coils or transformers) for opens, grounds, and shorts, going through each stage in receiver.

Shorted filter condenser in power supply is indicated by no B voltage and a very hot rectifier tube. In the 80 type rectifier, a blue glow will show inside plates when a filter or plate by-pass condenser is shorted. In mercury-vapor rectifiers the blue glow is characteristic of the type but will be more green in color when overloaded by shorted condensers.

Open audio transformer or choke windings will cause weak signals. Open or inadequate cathode resistor by-pass condensers on audio tubes will cause poor bass note response or a "tinny" quality.

If a tube tester is available, all tubes should be checked before making any checks on receiver circuits. After tube trouble is eliminated by replacing any defective or microphonic tubes, proceed to check all connections and circuit components.

Keep in mind these facts: that circuit components consist of resistors, condensers, and coils (inductances), and that there is no d.c. continuity through a condenser, but that in some circuits condensers are paralleled by resistors or coils which will indicate continuity of such a circuit unless disconnected.

Single-dial control on tuned r.f. receivers of two or more stages necessitates trimmer condensers parallel with tuning condensers to compensate for inequalities and differences in wiring of such circuits. This type receiver will show considerable lack of sensitivity when T.R.F. stages become misaligned.

Poor sensitivity and broad tuning in superheterodyne receivers also indicate misalignment of r.f. and i.f. stages. Do not attempt the aligning of circuits unless the proper tools are available consisting of a good modulated signal generator, an output meter, and insulated screw-driver. This is no job for a novice without expert advice.



Service methods, available tools, and receivers which are serviced vary in different commercial radio shops. Familiarity with schematic diagrams and servicing equipment is necessary for efficient servicing of receivers.

### Maintenance of the National SW-5 Receiver

The circuit comprises a stage of tuned screen-grid r.f., using plug-in coils, employing especially designed coupling transformer and a screen-grid detector. The two-stage audio amplifier uses push-pull in the second or output stage. A jack is provided in the output circuit of the first stage for headphone reception when desired.

The power-pack is in a separate unit, so as to avoid any possible hum resulting from location inside of the tuning cabinet, and is furnished with a cable and connector plug to facilitate connection. A UX-280 is used as the power rectifier.

If all sound has ceased in the headphones, the first thing to check is the phone plug. If the dial light went out at the same time that the receiver became inoperative, observe the tube filaments. It takes between 5 and 10 seconds for the heaters to cool below a red glow when alternating current supply is taken from them. If this has happened, trace the 100- to 110-volt alternating current supply from the plug through the switch and the primary of the power transformer. If the rectifier tube remained lighted when the other tubes went out, the 2.5 secondary circuit should be traced through the power plug to the tube filaments, looking for an open or a short circuit.

If the set went completely dead but the tubes remained lighted, a test set should be used with its plug in the detector socket. The plate voltage of this stage should be about 130 volts positive when the volume control is varied from minimum to maximum. If no voltage is shown at all, check the rectifier tube, and look for an open filter choke or short-circuited filter condenser. A weak rectifier tube may be discovered by taking it out of the socket and holding it upside down. If an excess of the white oxide collects in the bottom of the bulb, the tube is weak in emission and should be replaced. The sudden weakening of the tube may have been due to a short-circuited filter condenser taking an excessive load from the tube.

The above remedies having failed, the various circuits of the receiver should be tested with a continuity meter for open or short circuits.

## Aircraft Radio Servicing

At a number of the major airports, servicing aircraft radio facilities are maintained (by specially trained mechanics) as a business, their customers being itinerant pilots and in some cases airlines. The problems met in the conduct of such a business should be understood by the pilot and radio operator. For this reason Mr. H. T. Sagert of *Air Radio* at the Municipal Airport in Chicago, Illinois, has prepared a statement covering this special phase of maintenance.

“Our observations for the past several years in the installation and maintenance of both transport and itinerant radio communication equipment show that the quality of the original installation is of prime importance to the reliability and stable performance of the apparatus, it being understood, of course, that the equipment has been properly designed and manufactured to an approved quality.

“Beyond the importance of a good installation lies the necessity for the proper maintenance of apparatus comprising the communication system. One method of insuring a maximum operating efficiency is to make an attempt to anticipate possible failure of wearable parts such as tubes, dynamotors, vibrators, switch contacts, relays, condensers and resistors, etc. All scheduled airline operators have adopted such a system of service by virtue of routine maintenance plans for all of their communication equipment. Various units permit different lengths of operating periods, dependent upon their reliability. Such items as headphones and microphones will perform reliably over much longer periods than dynamotors and other gear having movable parts, consequently they are only required to be serviced and checked perhaps semi-yearly as against monthly or quarterly periods for others.

“The itinerant flyer, during the development of the industry, has been required to pick up whatever information or service he may have come across in his travels, and within his capabilities to do has had to determine the good and bad. Even the manufacturers of the equipment he might have been using were not in a position to give positive solutions to his problems, as they

themselves were still in the process of conducting sufficiently extensive tests to determine the correct answers. (Their activities along this line have been far-reaching.)

"Now, however, enough data have been gathered under actual operating conditions to assure him of a reasonable knowledge of operating range and service reliability.

"Neither by law nor by his own volition has a pilot been inclined to permit the motor to operate until it fails, as the majority have been apt to do with their communication equipment. Today the picture has changed, with increased instrument flying and closer regulation, to the point where he now realizes that it also behooves him to anticipate a depreciation in his radio material and restore it to a serviceable, overhauled status as he does his powerplant.

"Operating, as we do, very closely with a large number of itinerant and non-scheduled operators, *Air Radio* has introduced a system of periodic and routine overhaul for all radio apparatus. This system has been rapidly accepted as the answer to why previously his equipment would function fine for a certain period of time after its installation, and then seem to require several radio service trips. The truth of the condition was that, after reliable operation for a certain time, the equipment would have become worn or depreciated in some respect, and at the time something failed, it alone would be restored to a serviceable condition, and some other item which should have been checked at that time will fail shortly thereafter, causing the pilot no little embarrassment if not placing him on the proverbial spot.

"Under our routine overhaul system for itinerant operators we completely check all apparatus as to sensitivity, calibration, etc., after all component parts have been very closely serviced. All tubes, dynamotors, vibrators, headphones, microphones, and similar parts are serviced with the idea in mind that there is a certain wear and tear on all parts either electrically or mechanically, and that each unit must be in condition to give reliable service until the next routine service period. The frequency measurement of the transmitter required by the F.C.C. is made at the time of the overhaul and is included in the cost of the routine service.

“An item of equal or even greater importance than maintenance to the itinerant in the operation of his radio communication equipment is that he have a full knowledge of the operating capabilities, as well as the limitations of the particular units he may be using, along with a complete appreciation and understanding of the problems confronting the ‘other end.’ The rapidly expanding facilities and the future plans of the C.A.A. undoubtedly will make radio of more value with each new feature.

“The education of the airline pilot with regard to radio can be accomplished through the communications department; however, the itinerant flyer, whose problems in some respects are even more complex, has had no such concentrated source of help and information, and it is the idea of this and similar organizations that this type of flyer can be materially helped so far as his radio is concerned.”

It is the opinion of the author that the aeronautic radio operator of today will be the aeronautic radio mechanic of tomorrow. Therefore, the reader is urged to qualify for a radio operator's license as early in his career as possible, then learn as much of the work of a radio mechanic as he can by actual field experience. Also, the author wishes to advise all men who now hold operators' licenses to learn everything they can about short waves and about ultra-high-frequency equipment.

#### QUESTIONS

171. Distinguish between airline and private maintenance of aircraft radio methods and policy; outline basic procedure for both.

172. Who checks an air transport's radio equipment? Where is it checked? When? How?

173. Outline a system of generator maintenance.

174. Make up a check-off list to be used while inspecting an aircraft radio installation.

175. Give a step-by-step plan of trouble shooting a receiver.

176. Define inspection, servicing, installation, and maintenance (of aeronautic radio equipment).

177. List the jobs that are done by a licensed radio operator and by a radio mechanic in the maintenance of radio equipment.

178. List items on a transmitter check sheet.

179. Describe a test bench for transmitters.

180. Make up an inspection and service report for a power pack.

## GENERAL REVIEW QUESTIONS

181. Briefly indicate the scope of authority of C.A.A.
182. Outline the scope of authority vested in F.C.C.
183. Define aviation service.
184. Briefly describe a typical aircraft radio installation.
185. What station may a radiotelephone operator third class operate?
186. Define volt, ampere, ohm, and give Ohm's Law.
187. Show by a diagram sketch how to connect a voltmeter and ammeter in a circuit.
188. Discuss tuning in detail.
189. List the most important rules to be followed in the maintenance of lead batteries.
190. Describe the construction and functioning of a four-element tube.
191. Discuss modulation.
192. How are radio signals transmitted?
193. Draw a simple oscillator tube circuit.
194. How are radio signals received?
195. Sketch circuit connections for a diode detector.
196. Describe a superheterodyne receiver.
197. Which type of antenna is best for radiobeacon reception?
198. Before installing radio aboard aircraft who must approve plans and why?
199. Describe a container for lead batteries on aircraft.
200. What are some advantages of a shielded loop-type antenna?
201. How does a radio compass function?
202. Describe a transmitter for airport traffic control.
203. Draw a diagram of a radiotelephone transmitter.
204. Draw a diagram of a radiotelephone receiver.
205. How does one secure a radiotelephone operator's license?





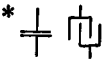





Answers to above questions may be determined by making reference to the following pages as indicated:

Question	Page	Question	Page	Question	Page
181	10	190	89-94	198	450
182	1			199	454
183	4	191	268-277	200	439
184	7	192	178-180	201	373
185	19	193	180	202	422
186	41	194	320-325	203	Ch. 10
187	43	195	323	204	Ch. 11
188	65-68	196	325	205	p. 22
189	144-146	197	443		



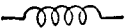
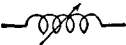


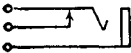
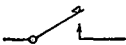
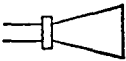


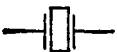

## APPENDIX I

### STANDARD GRAPHICAL SYMBOLS USED IN RADIO ENGINEERING

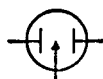
The following graphical symbols used in radio engineering have been abstracted from the 1938 Standardization Report of The Institute of Radio Engineers and reproduced by permission.

Ammeter	
Antenna	
Antenna, loop	
Battery (the positive electrode is indicated by the long line)	
Condenser, fixed	
Condenser, fixed, shielded	
Condenser, variable	
Condenser, variable (with moving plate indicated)	
Condenser, variable, shielded	
Counterpoise	

\* Preferred symbol for radio purposes.

Galvanometer	
Ground	
Inductor	
Inductor, variable	
Inductor, adjustable (by steps)	
Inductor, iron core	
Jack	
Key	
Loud-speaker	
Microphone (telephone transmitter)	
Phototube	
Piezoelectric plate	
Rectifier tube, half way (with cold cathode)	

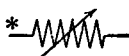
Rectifier tube, full wave (with cold cathode)



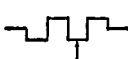
Resistor



Resistor, variable



Resistor, adjustable (by steps)



Telephone receiver



Thermoelement



Transformer, air core



Transformer, iron core



Transformer, with variable coupling



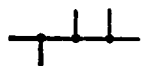
Transformer, with variable coupling (moving coil indicated)



Voltmeter



Wires, joined













Wires, crossed, not joined



\* Preferred symbol for radio purposes.

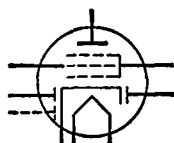


## Graphical Symbols for Tubes

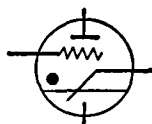
High-vacuum-tube envelope	
Gas-tube envelope (dot placed where convenient)	
Directly heated cathode or heater	
Cold cathode	
Indirectly heated cathode	
Photoelectric cathode	
Pool cathode	
Pool cathode with immersion ignitor	
Grid (either symbol may be used as is convenient)	
Plate	

## SAMPLE COMBINATIONS OF ELEMENT SYMBOLS

Indirectly heated cathode duodiodepentode with internal connection between grids 1 and 3. The diode plates may be placed on one or both sides of the indirectly heated cathode.



Grid-controlled mercury-pool-cathode gas tube with immersion ignitor.



Gas phototube



## APPENDIX II

### DEFINITIONS OF TERMS USED IN RADIO ENGINEERING

The following terms have been selected from the 1938 Standardization Report of The Institute of Radio Engineers, and published by permission.

1. **"A" power supply.** An "A" power supply is a power supply device which provides power for heating the cathode of a vacuum tube.
2. **Absorption.** Absorption is the loss of power in transmission of radio waves due to dissipation.
3. **Active transducer.** An active transducer is a transducer in which the power supplied to the second system is obtained from a local source and is controlled by the power from the first system.
4. **Aerial.** An aerial is the elevated conductor portion of a condenser antenna.
5. **Alternator transmitter.** An alternator transmitter is a radio transmitter which utilizes radio-frequency power generated by a radio-frequency alternator.
6. **Amplification.** Amplification is the process of increasing the amplitude of a signal through the control by signal input of power supplied from a local source to the output circuit. The amplification of a signal is the ratio of the signal output amplitude to the signal input amplitude, both expressed in the same terms.
7. **Amplification factor.** Amplification factor is the ratio of the change in plate voltage to a change in control-electrode voltage under the conditions that the plate current remains unchanged and that all other electrode voltages are maintained constant. It is a measure of the effectiveness of the control-electrode voltage relative to that of the plate voltage upon the plate current. The sense is usually taken as positive when the voltages are changed in opposite directions. *Note:* As most precisely used, the term refers to infinitesimal changes. Amplification factor is a special case of mu factor.
8. **Amplifier.** An amplifier is a device for increasing the amplitude of electric current, voltage, or power, through the control, by the input power, of a larger amount of power supplied by a local source to the output circuit.

9. **Anode.** An anode is an electrode to which a principal electron stream flows.
10. **Antenna.** An antenna is a conductor or a system of conductors for radiating or receiving radio waves.
11. **Antenna array.** An antenna array is a system of elemental antennas, usually similar, excited by the same source, for the purpose of obtaining directional effects.
12. **Antenna reflector.** An antenna reflector is a portion of a directional antenna array which serves to reverse the direction of propagation of radio waves.
13. **Antenna resistance.** Antenna resistance is the quotient of the power supplied to the entire antenna circuit by the square of the antenna current measured at the point where the power is supplied to the antenna. *Note:* Antenna resistance includes radiation resistance, ground resistance, radio-frequency resistance of conductors in antenna circuit, equivalent resistance due to corona, eddy currents, insulator leakage, dielectric power loss, etc.
14. **Arc converter.** An arc converter is a form of oscillator utilizing an electric arc for the generation of alternating or pulsating current.
15. **Artificial antenna.** An artificial antenna is a device having all the necessary characteristics of an antenna with the exception that it dissipates in the form of heat instead of in the form of radio waves substantially all the power fed to it.
16. **Atmospheric absorption.** Atmospheric absorption is the loss of power in transmission of radio waves due to dissipation in the atmosphere.
17. **Atmospherics.** Atmospherics are strays produced by atmospheric conditions. (In the United States the term static has come to be used quite generally as a synonym for atmospherics.)
18. **Attenuation.** Attenuation is the reduction in magnitude of a wave with increasing distance from its source, or from a specified point of reference.
19. **Audio frequency.** An audio frequency is a frequency corresponding to a normally audible sound wave. *Note:* Audio frequencies correspond roughly to from 20 to 10,000 cycles per second.
20. **Audio-frequency transformer.** An audio-frequency transformer is a transformer for use with audio-frequency currents.
21. **Autodyne reception.** Autodyne reception is a form of heterodyne reception using the same circuit elements to perform the functions of producing the locally generated wave, selecting the radio wave, and changing the frequency.
22. **Automatic regulator.** An automatic regulator is a device for regulating a system in such a manner that changes in its functioning are initiated by changed conditions and carried out without the intervention of an attendant.
23. **Automatic starter.** An automatic starter is a device for starting a system in such a manner that its functioning is initiated by changed conditions and carried out without the intervention of an attendant.

24. **Automatic volume control.** An automatic volume control is a device which automatically reduces the total amplification of the signal in a radio receiver with increasing strength of the received signal carrier wave.
25. **"B" power supply.** A "B" power supply is a power supply device connected in the plate circuit of a vacuum tube.
26. **Balancer.** A balancer is that portion of a direction finder which is used for the purpose of improving the sharpness of the direct indication.
27. **Band of frequencies.** A band of frequencies is a continuous range of frequencies between two specified frequency limits.
28. **Band-pass filter.** A band-pass filter is a filter designed to pass currents of frequencies within a continuous band, limited by an upper and a lower critical or cut-off frequency, and substantially reduce the amplitude of currents of all frequencies outside of that band.
29. **Banked winding.** A banked winding is a compact multilayer form of coil winding, for the purpose of reducing distributed capacitance, in which single turns are wound successively in each of two or more layers, the entire winding proceeding from one end of the coil to the other, without return.
30. **Beat.** A beat is a complete cycle of pulsations, in the phenomenon of beating.
31. **Beat frequency.** Beat frequency is the number of beats per second.
32. **Beating.** Beating is a phenomenon in which two or more periodic quantities of different frequencies react to produce a resultant having pulsations of amplitude.
33. **Broadside directional antenna.** A broadside directional antenna is an antenna array directional substantially at right angles to the line along which its elements are arrayed.
34. **By-pass condenser.** A by-pass condenser is a condenser used to provide an alternating-current path of comparatively low impedance around some circuit element.
35. **"C" power supply.** A "C" power supply is a power supply device connected in the circuit between the cathode and grid of a vacuum tube so as to apply a grid bias.
36. **Capacitive coupling.** Capacitive coupling is the association of one circuit with another by means of capacitance common or mutual to both.
37. **Carbon microphone.** A carbon microphone is a microphone which depends for its operation on the variation in resistance of carbon contacts.
38. **Carrier.** Carrier is a term broadly used to designate carrier wave, carrier current, or carrier voltage.
39. **Carrier current.** A carrier current is the current associated with a carrier wave.
40. **Carrier frequency.** A carrier frequency is the frequency of a carrier wave.
41. **Carrier suppression.** Carrier suppression is that method of operation in which the carrier wave is not transmitted.

42. **Carrier wave.** A carrier wave is the unmodulated component of a signal wave.
43. **Cathode.** A cathode is an electrode which is the primary source of an electron stream.
44. **Cathode current.** Cathode current is the total current passing to or from the cathode through the vacuous space.
45. **Cathode heating time.** The cathode heating time is the time, in seconds, required after application of normal voltage to the heater of an indirectly heated cathode for the plate current to attain a value equal to 90% of its final value.
46. **Choke-coil.** A choke-coil is an inductor inserted in a circuit to offer relatively large impedance to alternating current.
47. **Communication band.** A communication band consists of the band of frequencies due to modulation (including keying) necessary for a given type of transmission.
48. **Compensator.** A compensator is that portion of a direction finder which automatically applies to the direction indication all or a part of the correction for the deviation.
49. **Condenser antenna.** A condenser antenna is an antenna consisting of two conductors or systems of conductors, the essential characteristic of which is its capacitance.
50. **Condenser microphone.** A condenser microphone is a microphone which depends for its operation on variations in capacitance.
51. **Continuous waves.** Continuous waves are waves in which successive cycles are identical under steady-state conditions.
52. **Control electrode.** A control electrode is an electrode on which a voltage is impressed to vary the current flowing between two or more other electrodes.
53. **Control grid.** A control grid is a grid, ordinarily placed between the cathode and an anode, for use as a control electrode.
54. **Corrected radio bearing.** A corrected radio bearing is an observed radio bearing to which all known calibration corrections have been added algebraically.
55. **Counterpoise.** A counterpoise is a system of wires, or other conductors, elevated above and insulated from the ground, forming the lower system of conductors of an antenna.
56. **Coupling.** Coupling is the association of two circuits in such a way that power may be transferred from one to the other.
57. **Coupling coefficient.** The coupling coefficient is the ratio of the mutual or common impedance component of two circuits to the square root of the product of the total impedance components of the same kind in the two circuits. (Impedance components may be inductance, capacitance, or resistance.)
58. **Cross modulation.** Cross modulation is a type of intermodulation due to modulation of the carrier of the desired signal by an undesired signal.

59. **Crystal microphone.** A crystal microphone is a microphone which depends for its operation on the generation of an electromotive force by the deformation of a crystal having piezoelectric properties.
60. **Current amplification.** The current amplification is the ratio of the signal output current to the signal input current.
61. **Cycle.** A cycle is one complete set of the recurrent values of a periodic phenomenon. A cycle, when used as a unit of frequency, is one cycle per second.
62. **Damped waves.** Damped waves are waves of which the amplitude of successive cycles, at the source, progressively diminishes.
63. **Decremeter.** A decremeter is an instrument for measuring the logarithmic decrement of a train of waves.
64. **Degeneration.** Same as negative feedback.
65. **Demodulation.** Demodulation is the process of modulation carried out in such a manner as to recover the original sound.
66. **Detection.** Detection is the process by which there is obtained, in response to a modulated wave, the signal imparted thereto in the modulation process.
67. **Detector.** A detector is a device having an asymmetrical conduction characteristic which is used for operation on a frequency or combination of frequencies to produce certain desired frequencies or changes in current.
68. **Diode.** A diode is a two-electrode vacuum tube containing an anode and a cathode.
69. **Diplex transmission.** Diplex transmission is the simultaneous transmission of two signals using a specified common feature, such as a single antenna or a single carrier.
70. **Direct capacitance.** Direct capacitance is the quotient of the charge, produced on one conductor by the voltage between it and another conductor, by this voltage, all other conductors in the neighborhood being at the potential of one of the conductors.
71. **Direct coupling.** Direct coupling is the association of two circuits by means of self-inductance, capacitance, or resistance common to both circuits.
72. **Direction finder.** A direction finder is a radio receiving device which permits determination of the line of travel of waves as received.
73. **Direction finder calibration.** A direction finder calibration is the determination of the direction and amount of fixed local wave-front distortion, to the end that the correct bearing may be obtained.
74. **Direction finder deviation.** The direction finder deviation is the difference between the observed radio bearing and the corrected radio bearing. (It is the algebraic sum of all known corrections to the indication of the direction finder.)
75. **Directional antenna.** A directional antenna is an antenna having the property of radiating or receiving radio waves in larger proportions

along some directions than others. (An antenna of this type used for transmitting is often called a directive antenna.)

- 76. Distortion.** Distortion is a change in wave-form occurring in a transducer or transmission medium. The principal sources of distortion are: (a) nonlinear relation between input and output at a given frequency; (b) nonuniform transmission at different frequencies; (c) phase shift not proportional to frequency.
- 77. Double modulation.** Double modulation is the process of modulation by which a wave of one frequency is first modulated by a signal and the resultant signal wave is then made to modulate a second wave of another frequency.
- 78. Doublet antenna.** A doublet antenna is an antenna consisting of two elevated conductors substantially in the same straight line, of substantially equal length, with the power delivered at the center.
- 79. Duplex operation.** Duplex operation is the operation of associated transmitting and receiving apparatus in which the processes of transmission and reception are concurrent.
- 80. Effective height of an antenna.** The effective height of an antenna is a term applicable only to simple non-directive antenna, and is the height  $h$  in the equation,

$$h = \frac{0.80 \epsilon d}{f I}$$

where,

$h$  is the height in meters,

$\epsilon$  is the measured radio field intensity in microvolts per meter,

$d$  is the distance in kilometers at which  $\epsilon$  is measured,

$f$  is the frequency in kilocycles, and  $I$  is the antenna current in amperes measured at the point where the power is supplied to the antenna, this point being ordinarily that at which the antenna current has its maximum value.

The field intensity  $\epsilon$  is measured at a distance small enough to avoid ground absorption, and  $d$  is usually greater than one wavelength, in all cases sufficiently great so that the induction field is negligible. (In some cases the effective height of an antenna is different for different frequencies or different distances.)

- 81. Electron emission.** Electron emission is the liberation of electrons from an electrode into the surrounding space. Quantitatively, it is the rate at which electrons are emitted from an electrode.
- 82. Electron tube.** An electron tube is a vacuum tube evacuated to such a degree that its electrical characteristics are entirely due to electron emission.
- 83. Emission characteristic.** An emission characteristic is a graph plotted between a factor controlling the emission (such as the temperature, voltage, or current of the cathode) as abscissas, and the emission from the cathode as ordinates.



84. **End-on directional antenna.** An end-on directional antenna is an antenna array directional substantially along the line in which its elements are arrayed.
85. **Equisignal radio range-beacon.** An equisignal radio range-beacon is a radio range-beacon which transmits two distinctive signals which may be received with equal intensity only in certain directions.
86. **Equisignal sector.** An equisignal sector is a region in which two distinctive signals from an equisignal radio range-beacon are received with equal intensity.
87. **Fading.** Fading is the variation of the signal intensity received at a given location from a radio transmitting station as a result of changes in the transmission path.
88. **Feedback.** Feedback in a transmission system or a section thereof is the returning of a fraction of the output to the input.
89. **Fidelity.** Fidelity is the degree with which a system, or a portion of a system, accurately reproduces at its output the essential characteristics of the signal which is impressed upon its input.
90. **Filament.** A filament is a cathode of a thermionic tube, usually in the form of a wire or ribbon, to which heat may be supplied by passing current through it.
91. **Filament current.** Filament current is the current supplied to a filament to heat it.
92. **Filament voltage.** Filament voltage is the voltage between the terminals of a filament.
93. **Filter.** A filter is a selective circuit network designed to pass currents within a continuous band or bands of frequencies, or direct current, and substantially reduce the amplitude of currents of undesired frequencies.
94. **Frequency.** Frequency is the number of recurrences of a periodic phenomenon in unit time. In specifying electrical frequency, the customary unit of time is the second.
95. **Frequency changer.** A frequency changer is a device delivering alternating current at a frequency which differs from the frequency of the supply.
96. **Frequency divider.** A frequency divider is a frequency changer used to divide by an integer the frequency of an alternating current.
97. **Frequency meter.** A frequency meter is an instrument for measuring frequency. (Frequency meters used in radio work are sometimes called wavemeters.)
98. **Frequency multiplier.** A frequency multiplier is a frequency changer used to multiply by an integer the frequency of an alternating current.
99. **Frequency tolerance.** The frequency tolerance is the extent to which the frequency of the emission may be permitted to vary on either side of the frequency assignment.
100. **Full-wave rectifier.** A full-wave rectifier is a double-element rectifier arranged so that current is allowed to pass in the same direction to

the load circuit during each half-cycle of the alternating current supply, one element functioning during one-half cycle and the other during the next half-cycle, and so on.

101. **Fundamental frequency.** A fundamental frequency is the lowest component of a phenomenon where all of the original components are present.
102. **Gas tube.** A gas tube is a vacuum tube in which the pressure of the contained gas or vapor is such as to affect substantially the electrical characteristics of the tube.
103. **Goniometer.** The term goniometer has two meanings: the first being a movable loop receiving antenna. (See Direction Finder.) The second use of the term applies to a mutual inductance arrangement that forms part of the range-beacon transmitter equipment, the purpose of which is to set the courses for any desired direction, by modifying the current characteristics that are impressed on portions of the sending antenna system. (Not I.R.E. definition.)
104. **Grid.** A grid is an electrode having one or more openings for the passage of electrons or ions.
105. **Grid bias.** Grid bias is the direct component of grid voltage.
106. **Grid characteristic.** A grid characteristic is the graph plotted between grid voltage as abscissas and grid current as ordinates, other electrode potentials being maintained constant.
107. **Grid condenser.** A grid condenser is a series condenser in a grid circuit of a vacuum tube.
108. **Grid conductance.** Grid conductance is the ratio of the change in the grid current to the change in grid voltage producing it, other electrode potentials being maintained constant.
109. **Grid current.** Grid current is the current passing to or from a grid through the vacuous space.
110. **Grid leak.** A grid leak is a resistor in a grid circuit, through which the grid current flows, to affect or determine a grid bias.
111. **Grid voltage.** Grid voltage is the voltage between a grid and a specified point of the cathode.
112. **Ground absorption.** Ground absorption is the loss of power in transmission of radio waves due to dissipation in the ground.
113. **Ground equalizer inductors.** Ground equalizer inductors are coils of relatively low inductance placed in the circuit connected to one or more of the grounding points of an antenna, to distribute the current to the various points in any desired manner.
114. **Ground system of an antenna.** The ground system of an antenna is that portion of the antenna, below the antenna loading devices or generating apparatus, most closely associated with the ground, and including the ground itself.
115. **Ground wire.** A ground wire is a conductive connection to the ground.
116. **Half-wave rectifier.** A half-wave rectifier is a rectifier which changes

alternating current into pulsating current, utilizing only one-half of each cycle.

117. **Harmonic.** A harmonic is a component of a periodic phenomenon having a frequency which is an integral multiple of the fundamental frequency. For example, a component, the frequency of which is twice the fundamental frequency, is called the second harmonic.
118. **Heater.** A heater is an electrical heating element for supplying heat to an indirectly heated cathode.
119. **Heater current.** The heater current is the current flowing through a heater.
120. **Heater voltage.** The heater voltage is the voltage between the terminals of a heater.
121. **Heptode.** A heptode is a seven-electrode vacuum tube containing an anode, a cathode, a control electrode, and four additional electrodes ordinarily in the nature of grids.
122. **Heterodyne reception (beat reception).** Heterodyne reception is the process of operation on radio waves to obtain similarly modulated waves of different frequency. In general, this process includes the use of a locally generated wave which determines the change of frequency.
123. **Hexode.** A hexode is a six-electrode vacuum tube containing an anode, a cathode, a control electrode, and three additional electrodes ordinarily in the nature of grids.
124. **High-pass filter.** A high-pass filter is a filter designed to pass currents of all frequencies above a critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies below this critical frequency.
125. **High-vacuum tube.** A high-vacuum tube is a vacuum tube evacuated to such a degree that its electrical characteristics are essentially unaffected by gaseous ionization.
126. **Homodyne reception (zero-beat reception).** Homodyne reception is a form of reception in which the carrier wave is locally supplied or reinforced relative to the sidebands.
127. **Hot-wire ammeter, expansion type.** A hot-wire ammeter, expansion type, is an ammeter dependent for its indications on a change in dimensions of an element which is heated by the current to be measured.
128. **Impulse excitation.** Impulse excitation is a method of producing damped oscillatory current in a circuit in which the duration of the impressed voltage is short compared with the duration of the current produced.
129. **Indirectly heated cathode (equipotential cathode, unipotential cathode).** An indirectly heated cathode is a cathode of a thermionic tube to which heat is supplied by an independent heater element.
130. **Inductive coupling.** Inductive coupling is the association of one circuit with another by means of inductance common or mutual to both. (This term, when used without modifying words, is commonly used for coupling by means of mutual inductance, whereas coupling by means

of self-inductance common to both circuits is called direct inductive coupling.)

131. **Input admittance of a vacuum tube.** The input admittance of a vacuum tube is the reciprocal of the input impedance.
132. **Input impedance of a vacuum tube.** The input impedance of a vacuum tube is the quotient of the alternating voltage impressed on the input terminals of the tube by the alternating current thereby produced.
133. **Interelectrode capacitance.** Interelectrode capacitance is the direct capacitance between two electrodes.
134. **Interference.** Interference is disturbance of reception due to strays, undesired signals, or other causes; also, that which produces the disturbance.
135. **Interference guard bands.** The interference guard bands are the two bands of frequencies additional to, and on either side of, the communication band and frequency tolerance, which may be provided in order that there shall be no interference between stations having adjacent frequency assignments.
136. **Intermediate frequency in superheterodyne reception.** An intermediate frequency in superheterodyne reception is a frequency resulting from a frequency change before detection.
137. **Intermodulation.** Intermodulation is the production, in a non-linear circuit element, of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies which are transmitted to that element.
138. **Interrupted continuous waves.** Interrupted continuous waves are waves obtained by interruption at audio frequency in a substantially periodic manner of otherwise continuous waves.
139. **Kilocycle.** A kilocycle, when used as a unit of frequency, is a thousand cycles per second.
140. **Lead-in.** A lead-in is that portion of an antenna which completes the electrical connection between the instruments or disconnecting switches and the main portion of the antenna.
141. **Linear detection.** Linear detection is that form of detection in which the output voltage under consideration is substantially proportional to the carrier voltage throughout the useful range of the detecting device.
142. **Linear rectification.** Linear rectification is that process of operation on a wave which produces a variation of rectified current or voltage proportional to variations of the input-wave amplitude, over a wide range of input-wave amplitude.
143. **Loading coil.** A loading coil is an inductor inserted in a circuit to increase its inductance but not to provide coupling with any other circuit.
144. **Logarithmic decrement.** The logarithmic decrement is the Napierian logarithm of the ratio of the first to the second of two successive amplitudes of the same sign for an exponentially damped alternating current. The logarithmic decrement can also be considered as a constant of a simple resonant circuit, being  $\mu$  times the product of the

resistance and the square root of the ratio of the capacitance to the inductance of the circuit.

145. **Loop antenna.** A loop antenna is an antenna consisting essentially of one or more complete turns of wire. (This is also called a coil antenna.)
146. **Low-pass filter.** A low-pass filter is a filter designed to pass currents of all frequencies below a critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies above this critical frequency.
147. **Magnetic modulator.** A magnetic modulator is one employing a magnetic circuit as the modulating element.
148. **Marking wave.** The marking wave, in telegraphic communication, is the emission which takes place while the active portions of the code characters are being transmitted.
149. **Master oscillator.** A master oscillator is an oscillator of comparatively low power so arranged as to establish the carrier frequency of the output of an amplifier.
150. **Megacycle.** A megacycle, when used as a unit of frequency, is a million cycles per second.
151. **Mercury-vapor tube.** A mercury-vapor tube is a gas tube in which the active contained gas is mercury vapor.
152. **Microphone.** A microphone is an electroacoustic transducer actuated by energy in an acoustic system and delivering energy to an electrical system, the wave form in the electrical system being substantially equivalent to that in the acoustic system.
153. **Modulated wave.** A modulated wave is a wave of which either the amplitude, frequency, or phase is varied in accordance with a signal.
154. **Modulation.** Modulation is the process by which some characteristic of a periodic wave is varied with time in accordance with a signal.
155. **Modulation capability.** Modulation capability is the maximum percentage modulation that is possible without objectionable distortion.
156. **Modulation factor.** The modulation factor is the ratio of the maximum departure (positive or negative) of the envelope of a modulated wave from its unmodulated value to its unmodulated value. *Note:* In linear modulation the average amplitude of the envelope is equal to the amplitude of the unmodulated wave provided there is no zero-frequency component in the modulating signal wave. For modulated signal waves having unequal positive and negative peak values, both modulation factors must be given separately.
157. **Modulator.** A modulator is a device to effect the process of modulation. It may be operated by virtue of some nonlinear characteristic or by a controlled variation of some circuit quality.
158. **Monitoring radio receiver.** A monitoring radio receiver is a radio receiver arranged to permit a check to be made on the operation of a transmitting station.
159. **Moving-coil microphone.** A moving-coil microphone is a moving-conductor microphone in which the movable conductor is in the form of a coil. (This is sometimes called a dynamic microphone.)

160. **Mu factor.** Mu factor is the ratio of the change in one electrode voltage to the change in another electrode voltage, under the conditions that a specified current remains unchanged and that all other electrode voltages are maintained constant. It is a measure of the relative effect of the voltages on two electrodes upon the current in the circuit of any specified electrode. *Note:* As most precisely used, the term refers to infinitesimal changes.
161. **Multielectrode tube.** A multielectrode tube is a vacuum tube containing more than three electrodes associated with a single electron stream.
162. **Multiple-tuned antenna.** A multiple-tuned antenna is an antenna with connections to ground or counterpoise through tuning reactances at more than one point, these being so determined that their reactances in parallel present a total reactance equal to that necessary to give the antenna the desired frequency.
163. **Multiple-unit tube.** A multiple-unit tube is a vacuum tube containing within one envelope two or more groups of electrodes associated with independent electron streams. *Note:* A multiple-unit tube may be so indicated; for example, duodiode, duotriode, diode-pentode, duodiode triode, duodiodepentode, and triode-pentode.
164. **Multiplex transmission.** Multiplex transmission is the simultaneous transmission of two or more signals using a specified common feature, such as a single antenna or a single carrier.
165. **Natural frequency of an antenna.** The natural frequency of an antenna is the lowest resonant frequency of an antenna, without added inductance or capacitance.
166. **Negative feedback.** Negative feedback is feedback which results in decreasing the amplification.
167. **Observed radio bearing.** An observed radio bearing is the angle between the observed direction of the line of travel of the received radio wave and an arbitrarily fixed line (such as the centerline of a ship).
168. **Octode.** An octode is an eight-electrode vacuum tube containing an anode, a cathode, a control electrode, and four additional electrodes ordinarily in the nature of grids.
169. **Ordinary rectification.** Ordinary rectification is the rectification taking place in an electrode circuit, as indicated by a change in the average direct current therein, when an alternating voltage is applied to the same electrode.
170. **Oscillator.** An oscillator is a nonrotating device for producing alternating current, the output frequency of which is determined by the characteristics of the device.
171. **Oscillatory circuit.** An oscillatory circuit is a circuit containing both inductance and capacitance, so that a voltage impulse will produce a current which periodically reverses.
172. **Parallel phase resonance.** Parallel phase resonance is a condition which exists in a circuit comprising inductance and capacitance connected in parallel, when the current entering the circuit is in phase with the voltage across the circuit.

173. **Pentode.** A pentode is a five-electrode vacuum tube containing an anode, a cathode, a control electrode, and two additional electrodes, ordinarily in the nature of grids.
174. **Percent ripple.** Percent ripple is the ratio of the effective (root-mean-square) value of the ripple voltage to the algebraic average value of the total voltage, expressed in percent.
175. **Percentage modulation.** Percentage modulation is the term applied when the modulation factor is expressed as a percentage.
176. **Plate.** Plate is a common name for the principal anode in a vacuum tube.
177. **Plate characteristic.** A plate characteristic is a graph plotted between plate voltages as abscissas and plate currents as ordinates. (See Grid Characteristic and Emission Characteristic.)
178. **Plate conductance.** Plate conductance is the ratio of the change in plate current to the change in plate voltage producing it, all other electrode voltages being maintained constant.
179. **Plate current.** Plate current is the current passing to or from the plate through the vacuous space.
180. **Plate voltage.** Plate voltage is the voltage between the plate and a specified point of the cathode.
181. **Positive feedback.** Positive feedback is feedback which results in increasing the amplification.
182. **Power amplification.** The power amplification is the ratio of the signal output power to the signal input power.
183. **Power detection.** Power detection is that form of detection in which the power output of the detecting device is used to supply a substantial amount of power directly to a device such as a loudspeaker or recorder, etc.
184. **Protective device.** A protective device is a device for keeping current, voltage, or power of undesirably large magnitude out of a given part of an electric circuit.
185. **Push-pull microphone.** A push-pull microphone is a microphone which makes use of two elements functioning  $180^\circ$  out of phase.
186. **Radiation efficiency.** The radiation efficiency of an antenna at a given frequency is the ratio of the power radiated to the total power supplied to the antenna.
187. **Radiation resistance.** Radiation resistance is the quotient of the power radiated by an antenna by the square of the antenna current measured at the point where the power is supplied to the antenna.
188. **Radio channel.** A radio channel is a band of frequencies of a width sufficient to permit of its use for radio communication. The width of a channel depends upon the type of transmission.
189. **Radio circuit.** A radio circuit is a system for carrying out radio communication between two points.
190. **Radio compass.** A radio compass is a direction finder used for navigational purposes.
191. **Radio frequency.** A radio frequency is a frequency at which radiation of electromagnetic energy, for communication purposes, is possible.

- 192. Radio-frequency alternator.** A radio-frequency alternator is a rotating type of alternating-current generator which generates radio-frequency power.
- 193. Radio-frequency transformer.** A radio-frequency transformer is a transformer for use with radio-frequency currents.
- 194. Radio range-beacon.** A radio range-beacon is a radiobeacon which transmits directed waves by means of which departures from a given course may be observed.
- 195. Radio receiver.** A radio receiver is a device for converting radio waves into perceptible signals.
- 196. Radio transmission.** Radio transmission is the transmission at radio frequencies of signals by means of radiated electromagnetic waves.
- 197. Radio transmitter.** A radio transmitter is a device for producing radio-frequency power, with means for producing a signal.
- 198. Radio wave-front distortion.** Radio wave-front distortion is a change in the direction of advance of radio waves.
- 199. Radiobeacon.** A radiobeacon is a radio transmitting station in a fixed geographic location which emits a distinctive or characteristic signal for enabling mobile stations to determine bearings or courses.
- 200. Rectification.** Rectification is a process of operation on a wave to produce a unidirectional component.
- 201. Rectifier.** A rectifier is a device having an asymmetrical conduction characteristic which is used for the conversion of an alternating current into a pulsating current. Such devices include vacuum tube rectifiers, gaseous rectifiers, oxide rectifiers, electrolytic rectifiers, etc.
- Note:* In dealing with rectification in the reception of radio signals the term detector is preferred to rectifier.
- 202. Reflex circuit.** A reflex circuit is a circuit through which a signal wave passes both before and after a change in its frequency.
- 203. Regeneration.** Same as positive feedback.
- 204. Relay.** A relay is a device by means of which contacts in one circuit are operated by a change in conditions in the same circuit or in one or more associated circuits.
- 205. Resistive coupling.** Resistive coupling is the association of one circuit with another by means of resistance common to both.
- 206. Resonance.** Resonance is a condition which exists in a circuit containing inductance and capacitance when its equivalent reactance is zero. When the inductance and capacitance are connected in series, the current in the circuit is a maximum. When the inductance and capacitance are connected in parallel the external current is approximately a minimum.
- 207. Resonant circuit.** A resonant circuit is a circuit containing both inductance and capacitance whereby it is capable of exhibiting resonance phenomena.
- 208. Rheostat.** A rheostat is a resistor which is provided with means for readily adjusting its resistance.



209. **Ripple filter.** A ripple filter is a low-pass filter designed to reduce the ripple current, while freely passing the direct current, from a rectifier or generator used as a source of power supply.
210. **Ripple voltage.** Ripple voltage is the alternating component of unidirectional voltage from a rectifier or generator used as a source of direct-current power.
211. **Screen grid.** A screen grid is a grid placed between a control grid and an anode, and usually maintained at a fixed positive potential, for the purpose of reducing the electrostatic influence of the anode in the space between the screen grid and the cathode.
212. **Screen-grid tube.** A screen-grid tube is a type of thermionic tube in which the capacitance between certain electrodes (ordinarily the control electrode and the plate) is substantially eliminated by the interposition of an additional electrode and suitable screening.
213. **Secondary emission.** Secondary emission is electron emission due directly to impact by electrons or ions.
214. **Selectivity.** Selectivity of a radio receiver is that characteristic which determines the extent to which it is capable of differentiating between the desired signal and disturbances of other frequencies.
215. **Sense finder.** A sense finder is an addition to a direction finder which permits determination of the direction without 180 degrees ambiguity.
216. **Sensitivity.** Sensitivity of a radio receiver is that characteristic which determines the minimum strength of signal input capable of causing a desired value of signal output.
217. **Series phase resonance.** Series phase resonance is a condition which exists in a circuit comprising inductance and capacitance connected in series, when the current entering the circuit is in phase with the voltage across the circuit.
218. **Service band.** A service band is a band of frequencies allocated to a given class of radio communication service.
219. **Side band.** A side band is a band of frequencies on either side of the carrier frequency produced by the process of modulation.
220. **Side frequency.** A side frequency is a frequency on either side of the carrier frequency, produced by the process of modulation.
221. **Signal.** A signal is the form or variation with time of a wave whereby the information, message, or effect is conveyed in communication.
222. **Signal wave.** A signal wave is a wave, the form of which conveys a signal.
223. **Single side-band transmission.** Single side-band transmission is that method of operation in which one side band is transmitted and the other side band is suppressed. The carrier wave may be either transmitted or suppressed.
224. **Space-charge grid.** A space-charge grid is a grid which is placed adjacent to the cathode and positively biased so as to reduce the limiting effect of space charge on the current through the tube.
225. **Spacing wave.** The spacing wave, in telegraphic communication, is the emission which takes place between the active portions of the code characters or while no code characters are being transmitted.

- 226. Spark gap.** A spark gap is an arrangement of electrodes used for closing a circuit (usually oscillatory) at a predetermined voltage. Among the types of spark gaps are plain gap, rotary gap, synchronous gap, and quenched gap.
- 227. Spark transmitter.** A spark transmitter is a radio transmitter which utilizes the oscillatory discharge of a condenser through an inductor and a spark gap as the source of its radio-frequency power.
- 228. Spurious radiation.** Spurious radiation is any emission from a radio transmitter at frequencies outside of its communication band.
- 229. Stopping condenser.** A stopping condenser is a condenser used to introduce a comparatively high impedance in some branch of a circuit for the purpose of limiting the flow of low-frequency alternating current or direct current without materially affecting the flow of high-frequency alternating current.
- 230. Strays.** Strays are electromagnetic disturbances in radio reception other than those produced by radio transmitting systems.
- 231. Subharmonic.** A subharmonic is a sinusoidal phenomenon having a frequency which is an integral submultiple of the frequency of some other sinusoidal phenomenon to which it is referred. For example, a wave, the frequency of which is half the fundamental frequency of another wave, is called the second subharmonic of that wave.
- 232. Superheterodyne reception.** Superheterodyne reception is a form of heterodyne reception in which one or more frequency changes take place before detection.
- 233. Suppressor grid.** A suppressor grid is a grid which is interposed between two electrodes (usually the screen grid and plate), both positive with respect to the cathode, in order to prevent the passing of secondary electrons from one to the other.
- 234. Swinging.** Swinging is the momentary variation in frequency of a received wave.
- 235. Telegraph-modulated waves.** Telegraph-modulated waves are continuous waves the amplitude or frequency of which is varied by means of telegraphic keying.
- 236. Television.** Television is the electrical transmission of a succession of images and their reception in such a way as to give a substantially continuous and simultaneous reproduction of the object or scene before the eye of a distant observer.
- 237. Tetrode.** A tetrode is a four-electrode vacuum tube containing an anode, a cathode, a control electrode, and one additional electrode ordinarily in the nature of a grid.
- 238. Thermionic tube.** A thermionic tube is a vacuum tube in which one of the electrodes is heated for the purpose of causing electron or ion emission from that cathode.
- 239. Thermocouple ammeter.** A thermocouple ammeter is an ammeter dependent for its indications on a change in thermoelectromotive force in a thermocouple which is heated by the current to be measured.

- 240. Thermoelement.** A thermoelement is a device consisting of a combination of a thermocouple and a heating element for measuring small currents.
- 241. Tone-modulated waves.** Tone-modulated waves are waves obtained by modulating at an audio frequency, in a substantially periodic manner, otherwise continuous waves.
- 242. Transducer.** A transducer is a device actuated by power from one system and supplying power in the same or any other form to a second system. Either of these systems may, for example, be electrical, mechanical, or acoustical.
- 243. Transmission level.** The transmission level is the radio field intensity of the signaling power amplitude at any point in a communication system expressed either in some absolute unit or with reference to an arbitrary base value.
- 244. Transmission loss.** Transmission loss is the loss of power in a wave in passing along a transmission path or through a circuit device.
- 245. Trickle charger.** A trickle charger is a device designed to charge a storage battery at a low rate continuously or during a major portion of the 24-hour day.
- 246. Triode.** A triode is a three-electrode vacuum tube containing an anode, a cathode, and a control electrode.
- 247. Tuned transformer.** A tuned transformer is a transformer whose associated circuit elements are adjusted as a whole to be resonant at the frequency of the alternating current supplied to the primary, thereby causing the secondary voltage to build up to higher values than would otherwise be obtained.
- 248. Tuning.** Tuning is the adjustment of a circuit or system to secure optimum performance in relation to a frequency; commonly, the adjustment of a circuit or circuits to resonance.
- 249. Vacuum tube.** A vacuum tube is a device consisting of an evacuated enclosure containing a number of electrodes between two or more of which conduction of electricity through the vacuum or contained gas may take place.
- 250. Vacuum tube modulator.** A vacuum tube modulator is a modulator employing a vacuum tube as a modulating element.
- 251. Vacuum tube transmitter.** A vacuum tube transmitter is a radio transmitter in which vacuum tubes are utilized to convert the applied electric power into radio-frequency power.
- 252. Vacuum tube voltmeter.** A vacuum tube voltmeter is a device utilizing the characteristics of a vacuum tube for measuring alternating voltages.
- 253. Voltage amplification.** The voltage amplification is the ratio of the signal output voltage to the signal input voltage.
- 254. Voltage divider.** A voltage divider is a device whose purpose it is to yield a fractional part of the applied voltage. (Devices employing mutual effects are not considered as voltage dividers.)

- 255. Wave.** A wave is: (a) a propagated disturbance, usually periodic, as an electric wave or sound wave; (b) a single cycle of such a disturbance; or (c) a periodic variation as represented by a graph.
- 256. Wave antenna.** A wave antenna is a horizontal antenna, the length of which is of the same or greater order of magnitude as that of the signaling wave, and which is so used as to be strongly directional.
- 257. Wavelength.** A wavelength is the distance traveled in one period or cycle by a periodic disturbance. It is the distance between corresponding phases of two consecutive waves of a wave-train. Wavelength is the quotient of velocity by frequency.

#### NOTE

The foregoing terms have been selected by the author as those most suitable for inclusion in a book of this nature. They have been furnished both for reference and for study. They are excellent examples of precise definitions. The student-reader will do well to memorize some, paraphrase some for practice in correct expression, and to refer often to others in connection with the reading of magazine articles and I. R. E. papers—a practice that is definitely recommended.

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