

HOW TUBES WORK IN TYPICAL RADIO STAGES

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STUDY SCHEDULE NO. 10

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

- 1. **How Radio Systems are Divided into Stages Pages 1-5**
Now that you have learned the characteristics of radio parts, you are ready to combine them with tubes into radio stages. This section gives an introduction to the names and purposes of radio stages as they are found throughout a radio system. Use this "map" as you go along, to understand just how each kind of stage fits into the over-all picture. Answer Lesson Question 1.
- 2. **More Facts About Tubes Pages 5-13**
Radio stages work because it is possible to arrange parts and voltages so that tubes will do certain things. The more you can learn about tubes, the easier you can understand stages. Answer Lesson Questions 2 and 3.
- 3. **Basic Amplifying Stage Pages 13-18**
All tube amplifying stages can be reduced to a simple, basic stage—an input device or signal source, a load to which the signal is delivered, and a power supply. Here are the details of how this basic circuit works; how changes in voltage or load value affect the operation; how signals are kept in their correct paths by by-pass condensers; how a tube can produce its own bias. This is a **VERY IMPORTANT** section. Read it over and over, until you feel you know everything in it. Then review it from time to time. Answer Lesson Questions 4, 5 and 6.
- 4. **Typical Amplifying Circuits Pages 18-22**
Now that you understand the basic stage, you are introduced to some of its variations. The major difference is in the type of coupling—that is, in the different ways of getting signals into and out of the stage.
- 5. **Tubes as Signal Generators and as Signal Mixers . . Pages 23-28**
Here is a brief introduction to radio stages which do other things in addition to amplifying signals. You are *not* expected to fully understand oscillators, modulated stages and frequency converters from this discussion, but you should learn what these stages do to the radio signal. Answer Lesson Question 7.
- 6. **The Diode in Radio Systems Pages 28-33**
Power supplies and demodulator stages commonly use the two-element (diode) tube. This introduction to these stages shows how it is used. Answer Lesson Questions 8, 9 and 10.
- 7. **A Complete Superheterodyne Receiver Circuit . . Pages 33-36**
A schematic diagram is used to show how radio signals progress through a superheterodyne receiver. This review of the lesson shows the manner in which all kinds of stages are brought together in a receiver—how each stage performs a necessary operation so that the reproducer can deliver the intelligence we want.
- 8. **Mail your Answers for this Lesson to N.R.I. for Grading.**
- 9. **Start Studying the Next Lesson.**

HOW TUBES WORK IN TYPICAL RADIO STAGES

How Radio Systems are Divided into Stages

THIS lesson is a milestone in your Course in Radio Fundamentals. Up to this time you have been learning the characteristics of *radio parts*. You will now begin to learn how these parts are combined into groups in which tubes are used—groups that are called *radio stages*.

In this lesson, we are going to do two things: 1, give you a preview of the radio stages you will study in detail in the next few lessons; and 2, give you a basic understanding of the requirements underlying ALL stages. Once you understand stages, it will be easy for you to combine them into *sections* and thus form a complete receiver or transmitter.

► To help you see the relationship between stages, we will first describe a complete radio system. Pay particular attention to the *names* and *functions* of the stages—and refer to this “radio map” from time to time so that you can keep these stages properly in mind. (Later in this lesson, we will give a description of a complete superheterodyne receiver in somewhat more detail.)

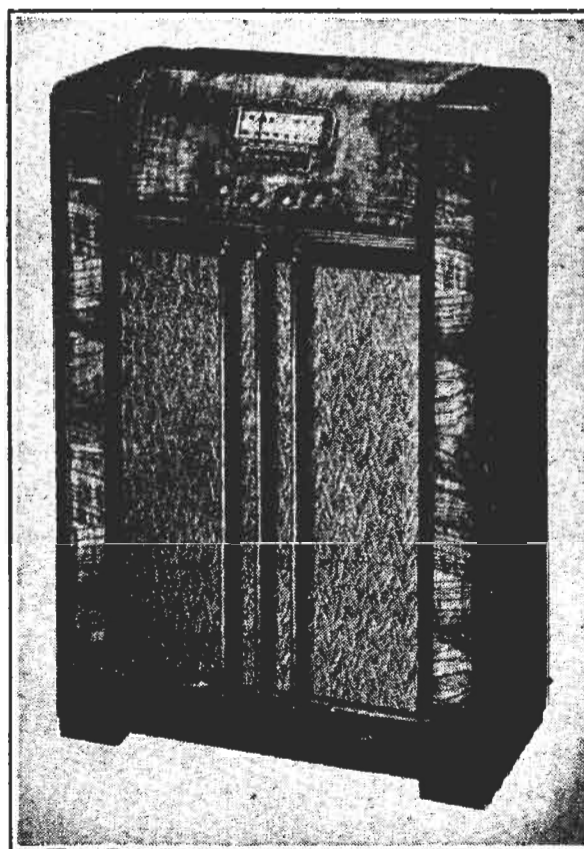
Naturally, we will not try to give *every detail* of the operation of radio stages in this one lesson. A preview of this kind is intended to give you enough basic facts to help you understand the full details to be found in later lessons.

RADIO SYSTEMS

All radio systems have one object—to convey intelligence from one point to another. The intelligence can be

anything—a sound or sight (television) program; commercial (voice or code) messages going from point to point; a guide-path for aircraft or ships; or messages intended for police or fire departments.

The original intelligence cannot be carried to distant points without some form of conversion or without the use of a carrier. Even the loudest sounds cannot be heard more than a few



Courtesy General Mfg. Corp.

This Motorola is typical of the console type radio receivers you are likely to meet if you become a serviceman. What is inside the cabinet? A superheterodyne receiver using the basic stages you are studying in this lesson.

miles and close-up details of a scene are visible for only a few feet. We can record sounds or take photographs, but these are not instantaneous methods of transmission. It is also true that by converting sounds or scenes into electrical impulses it is possible to carry them over wire lines. However, at best, wire circuits have limits, so radio steps in and provides a means of sending intelligence instantly to any desired receiving point.

Radio transmission is made practical by the fact that high-frequency signals will travel through space, and it is possible to make these signals "carry" the intelligence. At the receiving point, a *copy* of the original intelligence signal can be obtained from the "carrier" signal and used to operate a reproducer system. Fig. 1 shows just such a system in block-diagram form. Let's review the basic actions in each stage.

THE TRANSMITTER

The Carrier Signal. At the transmitter, the "carrier" signal is generated by a vacuum tube stage known as an *oscillator* (indicated at *A* in Fig. 1). The carrier is called an r.f. (radio frequency) signal since it is in the r.f. range. At each station, the frequency of this signal is set at the value assigned to that particular station. An American broadcast station using the amplitude modulation (a.m.) system will be assigned a frequency within the 550 kc.-to-1600 kc. broadcast band, while an f.m. (frequency modulation) broadcast station will be assigned a carrier frequency somewhere within the 88- to 106-mc. range.

Amplified copies of this r.f. signal are obtained from a series of vacuum tube amplifying stages (in section *B* of Fig. 1) which deliver the amount of power needed to make the proper com-

ination with the intelligence signal.

The Intelligence Signal. The intelligence (sound waves or visible scenes) is converted into a corresponding electrical signal by the pickup device at *D*. Amplified copies of this electrical signal are obtained from the amplifiers at *E*.

Modulation. At *C*, the carrier and the intelligence signals are combined. This process of combining is called *modulation*, because the intelligence signal *modulates* or varies the carrier signal. At present, two systems of modulation are in use: *amplitude modulation* (a.m.) and *frequency modulation* (f.m.). In amplitude modulation, the *amplitude* of the carrier signal is varied in proportion to the amplitude of the intelligence signal; in frequency modulation, the *frequency* of the carrier signal is varied in proportion to the amplitude of the intelligence signal. In either system, the rate at which variations in the carrier signal occur corresponds to the frequency of the intelligence signal.

► The modulated carrier signal may be, and frequently is, amplified before being applied to the transmitting antenna or radiator *G*. In later lessons, we'll go into the subject of antennas and find why they radiate—here, all we'll say is that the signal is radiated into space in the form of a varying electromagnetic field which is known as a radio wave.

THE RECEIVER

When the radio wave encounters receiving antenna *H*, it induces a voltage in the antenna. This voltage causes a varying current flow through the lead-in; this, in turn, induces a voltage in the r.f. preselector *I*. All radio waves striking the antenna—whether they come from the desired station or from other stations—induce voltages in the

r.f. preselector, so we use "tuned" or resonant circuits (coil-condenser combinations) in the preselector section to start the process of selecting the desired signal from all the others received. (Here you see the reason for assigning different frequencies to transmitters; only by frequency separation can we select the signals of the desired stations from among all others broadcasting at the same time.)

The preselector usually must tune over a wide range of frequencies, since, of course, we generally like to tune to different stations. Now, it is difficult to obtain the same amount of amplification and selectivity at different frequencies over wide ranges. It is far easier to obtain high gain and good selectivity from an amplifier operating at a *fixed* frequency, especially if this *fixed* radio frequency is in the lower r.f. range. These facts have led to the creation of the *superheterodyne* receiver, in which incoming signals, regardless of frequency, are converted into a fixed lower frequency for amplification.

The Superheterodyne. Briefly the fundamental principle of the superheterodyne circuit is: The incoming signal is combined with a "local" r.f. signal so that a lower frequency r.f. signal is produced.

Now, let's see what stages are used in a superheterodyne receiver to perform the action we have just described. In Fig. 1, preselector *I* is used to give an initial separation of the signals present in the receiving antenna *H*. The preselector is not required to give much amplification nor much selectivity; these are obtained after the frequency mixing has occurred. The mixer-first detector stage *J* is fed the modulated r.f. signal from the preselector and is also fed another (unmodulated) r.f. signal from the *local r.f. oscillator stage K*. (This is called a "local"

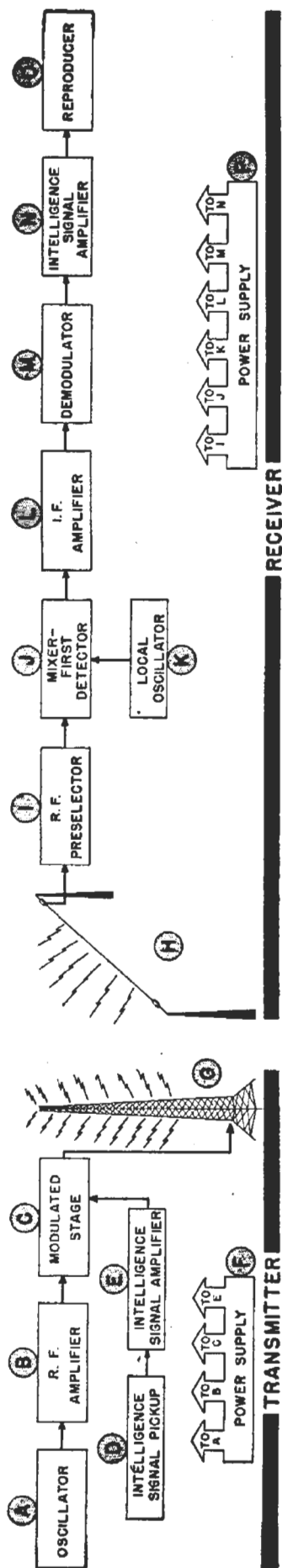


FIG. 1. A complete radio system. After the sound or picture signal is combined with the r.f. carrier at the transmitter, the combined signal is radiated through space by the antenna system G. At the receiving location, the radio wave is picked up by receiving antenna H. The superheterodyne receiver selects the desired signal, amplifies and demodulates it, then amplifies the intelligence signal further so as to operate the reproducer. This block diagram applies to both a.m. and f.m. sound systems as well as to television. The major differences are in the r.f. and intelligence frequencies handled and in the types of modulation and demodulation stages. Hence, this diagram can be applied to ALL radio systems.

oscillator to distinguish it from the oscillator in the transmitter.)

The result of the frequency combination (called "frequency conversion") is a new carrier which has a frequency known as the *intermediate frequency* (abbreviated i.f.) and which is modulated by the intelligence signal. The i.f. is usually equal to the difference between the carrier frequency and the local r.f.*

► The preselector and the local oscillator are tuned simultaneously by a single control which rotates their tuning condensers or varies their coil inductances in step. Thus, as we tune to a particular station, the local oscillator is automatically adjusted to the frequency necessary to produce the desired combination.

► The tuned circuits at the input of the i.f. amplifier (L in Fig. 1) tend to select the desired i.f. carrier (carrying the intelligence signal) from among all others offered by the mixer-first detector. Each stage in the i.f. amplifier makes an amplified copy of the desired signal, and the resonant circuits in each stage serve to further select the desired signal from among others.

When the modulated i.f. carrier signal has been amplified to the limits of the i.f. amplifier, it is fed into a *demodulator* stage. (This stage is another *detector*, and is called the *second detector* to distinguish it from the *mixer-first* detector.)

Demodulation. The demodulator M serves a very important purpose; it is here that the intelligence signal is

*Here is an example: If the local oscillator of a receiver generates a 1460-kc. signal when the r.f. section of the receiver is tuned to a 1000-kc. station, the i.f. will be 460 kc. ($1460 - 1000 = 460$ kc.). This is called the i.f. value because it is normally *intermediate* in value between the r.f. carrier frequency and the frequencies of the intelligence signal.

separated from the carrier. The carrier has been necessary to convey the intelligence signal through space. The intelligence signal must remain with the carrier until the desired carrier can be selected from among all others. Then, when the carrier has served its purpose, it is cast aside and a reasonably accurate duplicate of the original electrical intelligence signal is obtained.

► The intelligence signal is similar to that existing at D in the transmitter, and usually must be amplified further before it can operate the reproducer. The intelligence signal amplifier N is called an *audio* amplifier if the signal corresponds to sound, or is called a *video* amplifier if the signal corresponds to a television picture scene.

Reproduction. After the intelligence signal has been sufficiently amplified, it must pass through a *reproducer* O which will convert the electrical signal into the original form of the intelligence. For audio signals (voice or music), a *loudspeaker* is used. This device produces sound waves in accordance with the variations in electrical current. For television, an image reconstructor tube "paints" the television scene on a screen at one end of the tube. Code signals may operate a sounder or an automatic typewriter. Facsimile signals may operate a device which chemically reproduces a picture on special paper. And so it goes—whatever the original signal, a suitable device restores the original sound, scene, or impulse into a recognizable or usable form.

► This completes the journey of our intelligence signal. It has travelled through many radio stages at both the transmitter and the receiver. *Most of the stages made amplified copies, which in turn were amplified by suc-*

ceeding stages. Some stages did nothing but amplify, others performed specialized duties, while still others did both. This has been just a bare outline of the process of radio transmission and reception—we have not tried to show the *number* of stages in each section nor have we shown all that may be done in some of the more elaborate systems. Instead, we have given you a brief over-all picture to make it easier for you to see the relationships between the *stages* you are about to study.

Importance of Tubes. One important fact stands out about these stages: whatever their function, *vac-*

uum tubes are used in all of them, except possibly the intelligence pickup *D* and the reproducer *O*. (In a television system, special tubes are used at *D* and *O* too.)

Because of this widespread use of tubes, you must have a thorough understanding of fundamental tube operation before you study stages. We will now expand some of the information presented in your earlier lesson on tubes, thereby giving you a more complete picture of tube action under different operating conditions. Then we will be ready to study the operation of each *basic* radio stage.

More Facts About Tubes

There are many kinds of tubes—some designed for specific purposes and some for general purposes. Basically, they all operate over rather similar characteristic curves; the particular actions obtained depend upon the *operating* point chosen and upon the devices used as “loads.” Although tubes with two, three, and four grids are better than triode (single grid) tubes for certain purposes, we will consider only diode and triode tubes in this lesson. This will let you concentrate on the important features of the stages described without becoming confused by extra grids. (You will take up multi-grid tubes as you study each stage in detail in later lessons.)

HOW THE GRID CONTROLS THE PLATE CURRENT

From your earlier studies you know that, in a triode tube with a fixed plate voltage, the grid voltage determines the amount of plate current which will

flow at any particular instant. When no signal voltage is applied to the grid, the bias voltage (a d.c. voltage placed between the grid and the cathode) determines the amount of plate current flow; the plate current which flows under these conditions is often called the “operating” current. (This value is the initial or starting plate current which is then varied by the signal.)

In most receiver circuits the grid is not allowed to become positive with respect to the cathode, because this would cause an undesirable flow of grid current. (In transmitter r.f. power amplifier circuits and in oscillator circuits, the grid is allowed to go positive, as we shall see later.) Hence, we usually have a *negative* grid bias. The amount of bias depends on the point at which we desire to operate on the characteristic curve.

A typical characteristic curve is shown in Fig. 2. For a tube which has this characteristic, a negative bias of -3 volts places the operating point at

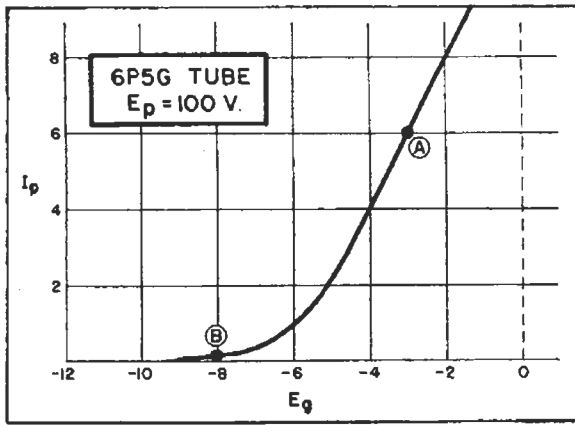


FIG. 2. The characteristic curve for a 6P5G tube. Although characteristic curves are similar in shape, the values apply to only one tube type and to one particular supply voltage value.

A (on the straight portion of the curve). A bias of -8 volts causes the operating point to move to B, while a bias of more than -9 volts will "cut off" the plate current. If a different plate voltage is used, then the curve will "move" so that other bias values will be required for these conditions. For this reason, curves must be labeled as to what plate voltage is being applied.

► Naturally, tubes differ in their plate currents and bias requirements, although the general *shape* of their characteristic curves may be very similar.

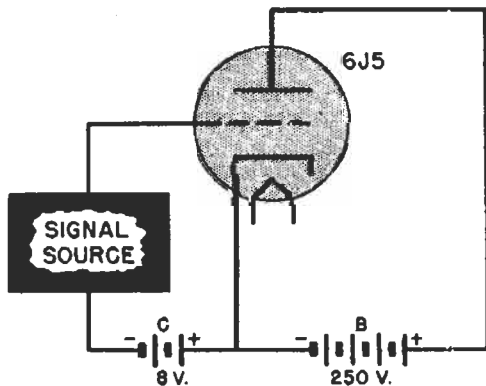


FIG. 3. Typical bias and plate voltage connections are shown here. However, the filament supply is NOT shown. Naturally it IS connected to the filament terminals and must be of the proper value to produce temperature saturation. Its omission on diagrams is purely to simplify the circuit so that you can concentrate on the actions being described.

Another tube may require a bias of -50 volts to operate at point A, and may then pass a current of 30 ma. instead of the 6-ma. value shown in Fig. 2. Thus, the same curve may fit both tubes, except that the *values* of current and voltage differ. Therefore, characteristic curves must be labeled also for the particular tube to which they apply.

► Now, with our operating point determined by some suitable bias, let's see what happens when we apply a sine-wave signal to the circuit shown in Fig. 3.

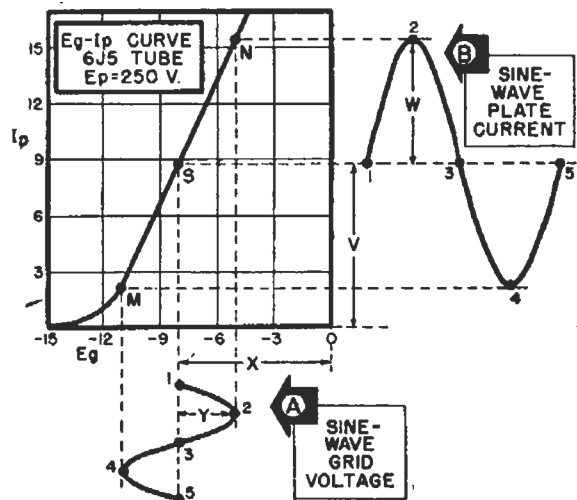


FIG. 4. The E_g-I_p curve for a 6J5 tube, with a plate voltage of 250 volts. It is assumed that the proper filament voltage is applied to the tube.

Fig. 4 is an E_g-I_p (grid voltage-plate current) curve for the triode tube used in Fig. 3. With the plate and bias voltages shown in Fig. 3 (which are typical for this tube), the operating point is at S, and the operating plate current value is nearly 9 ma. We know that the applied signal makes the grid voltage alternately more and less negative than the grid bias, so when the signal shown at A (in Fig. 4) is applied, the grid voltage will be made up of the bias value x plus or minus the value of the signal voltage y at that instant. Since the bias voltage is greater than the

largest value of the signal voltage, the grid remains negative at all times and there is no grid current flow. The grid is purely a *potential-operated device*—its *voltage* at any instant determines the plate current value.

Let's see how a change in the grid voltage affects the plate current. Suppose the grid voltage changes from point 1 to point 2 on curve A (making the grid less negative by 3 volts). Tracing vertically from each of these points up to the E_g-I_p curve, then horizontally over to curve B, we find that this grid voltage change causes a plate current change from point 1 to point 2 on curve B. The plate current changes from its operating value of 9 ma. (point 1) to a value of about 15.5 ma. (point 2)—an increase of about 6.5 ma.

Similarly, changes in grid voltage from point 2 to point 3, from point 3 to point 4, and from point 4 to point 5 on curve A cause plate current changes as shown by similarly-numbered points on curve B. Each grid voltage swing in a *less negative* direction causes an *increase* in plate current, while each swing in a *more negative* direction causes a *decrease* in plate current.

► Another important fact is that the plate current is a *pulsating d.c.*; that is, it is made up of a d.c. component v (equal to the no-signal operating current) and a sine-wave a.c. component w which causes the total plate current to vary above and below its no-signal operating value. (The plate current cannot reverse its *direction* of flow; hence, the a.c. variation can exist only as a *component* or part of the pulsating plate current. When we speak of an a.c. plate current, we mean *only* this varying component, not the total plate current.)

► The signal actually applied to an amplifier rarely has a sine-wave shape; it *usually* is more complex. However,

a complex signal is made up of many different sine-wave voltages in combination, so the tube response to a sine-wave signal corresponds to its response to that component of a complex signal. This makes it possible to use sine-wave signals when studying radio circuits. However, as Fig. 5 shows, if we know the exact wave shape of a complex signal, we can prove that the plate current has the same form as the grid voltage, provided that the E_g-I_p curve is linear (straight) over the operating region, as is the section M-N of Figs. 4 and 5.

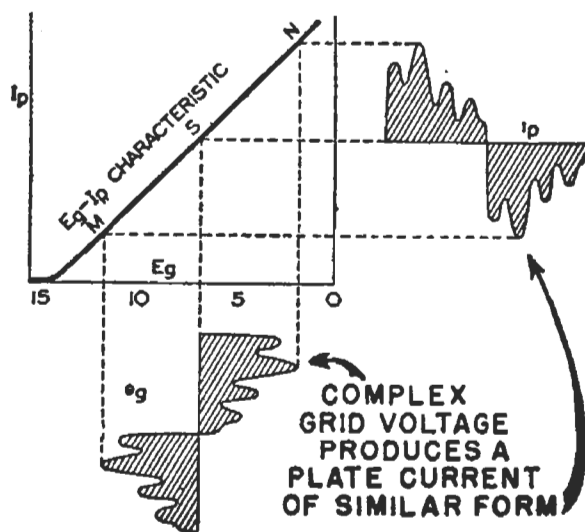


FIG. 5. The signal currents handled by most radio and television tubes have irregular wave forms much like that shown here for e_g . It can be proven by mathematics, however, that any wave, no matter how complicated, can be broken up into a number of simple sine waves. We can simplify our work by considering only sine-wave signals, for we know that radio circuits will behave the same for a particular sine wave as they do for this component of a complex wave.

CLASSES OF AMPLIFIERS

Not all amplifying stages operate on the straight portion of their characteristic curves; sometimes an exact "carbon copy" of the grid voltage is not wanted. This means that amplifiers must be classified according to the part of the characteristic over which they operate.

► When an exact duplicate of the *en-*

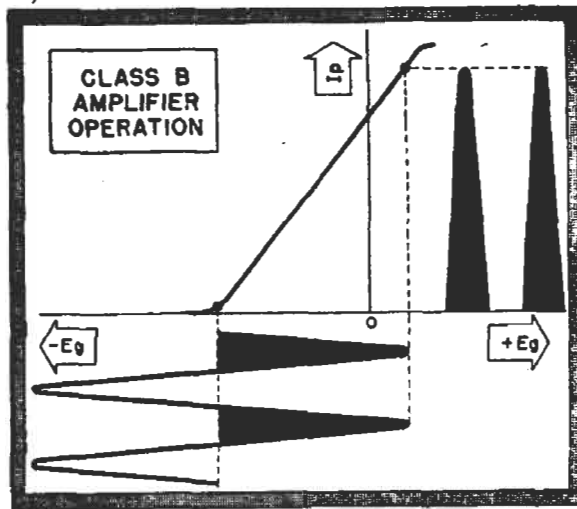


FIG. 6. In class B amplifiers, only half of the incoming signal is effective in producing plate current pulses.

entire input signal is wanted, the operating point is chosen near the center of the straight portion between the zero grid-voltage value and the lower bend or curved portion of the characteristic curve, and operation is confined to this straight portion. This is called class A amplification. Class A amplification is relatively distortionless (the output is practically proportional to the input at all times) provided: 1, that the signal voltage is not so large that some curved portion of the characteristic is encountered; and 2, that the grid never goes positive.

► For some purposes, we do not want the plate current variations to be exactly like the entire signal applied to the grid circuit. We may, for example, apply a bias sufficient to cut off plate current, as shown in Fig. 6. Now when we apply a signal, we will get half-wave pulses in the plate circuit—in other words, very little (if any) plate current will flow until the positive signal alternations overcome the bias. This is called class B operation and is very necessary for certain purposes.

► Going a step further, we may even apply a bias many times that required for plate current cut-off, as shown in

Fig. 7. Only the positive tips of the grid signal can cause plate current to flow. This is called class C operation.

► If we allow the grid signal to swing over into the positive region (Figs. 6 and 7), class B and class C amplifiers become far more efficient than class A (that is, they produce more output for the same plate supply power). However, the resulting distortion generally limits such operation to special stages where the distortion can be overcome or does not matter. We shall explain these uses in later lessons.

FAMILIES OF CURVES

In practical radio work, tables of tube characteristics furnish practically all the needed information, so curves are rarely used. However, characteristic curves are extremely valuable to you now as a student in helping you to understand just how tubes work—so let's take a few minutes to see how these curves are plotted and what they reveal.

Plotting Curves. To make curves, the tube manufacturer uses a circuit similar to that shown in Fig. 8. This circuit is arranged so that any desired C voltage can be applied, the plate voltage is variable, and the plate current can be measured. Normal fila-

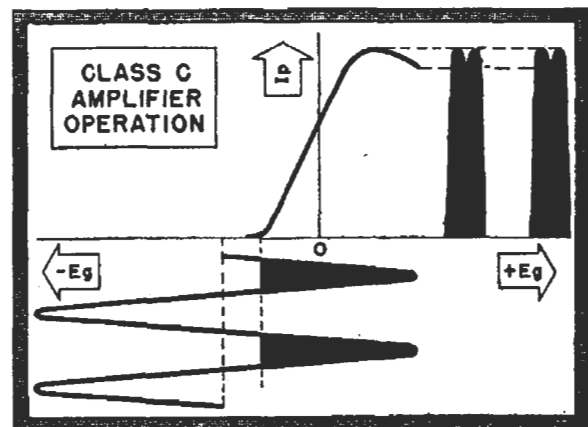


FIG. 7. In class C operation, even less than half of the incoming signal is used to produce plate current pulses.

ment voltage is applied.

To make E_g-I_p curves, the first step is to choose some value of plate voltage, by adjusting tap P_2 on the B battery. Then the grid voltage is varied in steps from zero to a maximum negative value by moving the slider from terminal 1 toward terminal 2 on the potentiometer P_1 in the grid circuit. The plate current is measured and plotted for each particular grid voltage value. The resulting curve is the E_g-I_p characteristic curve of the tube for that particular plate voltage.

This process is repeated for other values of plate voltage until a series or family of E_g-I_p characteristic curves is secured. They are similar to those shown in Fig. 9 (which are for a 6C5 tube).

▶ Although a family of curves can be made to tell almost everything about the behavior of a tube, radio men compress some of the most important information in characteristic curves into quickly usable forms. Ratings like horsepower, maximum speed, and gasoline consumption tell much about the performance of an automobile; tube performance is likewise expressed by the following ratings:

1. Amplification factor.
2. A.C. plate resistance.
3. Mutual conductance.

You've already met the first two of these in an earlier lesson. We'll review them briefly, then discuss the third rating (which is really a com-

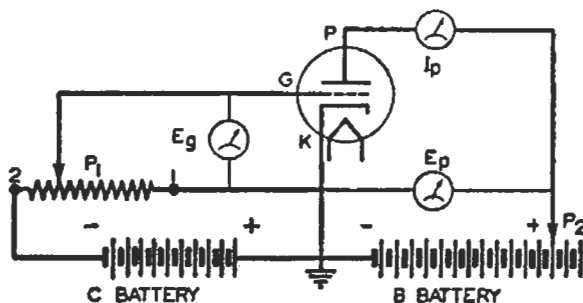


FIG. 8. A laboratory circuit used to determine the characteristics of tubes.

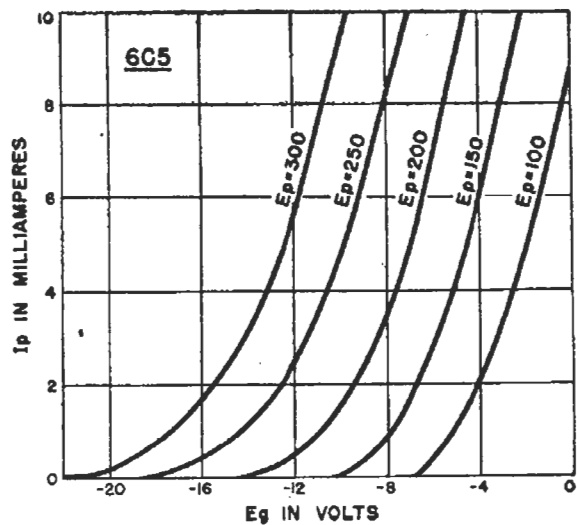


FIG. 9. A family of characteristic curves.

bination of the other two).

AMPLIFICATION FACTOR

This factor is important because it tells us how good a tube is as a voltage amplifier.

Suppose we use Fig. 10, showing two curves taken from Fig. 9, to illustrate this. If the 6C5 tube is operating at point a on curve B (for a plate voltage of 200 volts), then a plate current increase of 4 ma. can be obtained by changing the grid voltage 2.5 volts (from -8.5 to -6 volts); this moves the operating point to c . Similarly, with the bias voltage fixed at -8.5 volts, a 4-ma. change can be obtained by increasing the plate voltage 50 volts, from a on curve B to b on curve A . (Curve A is for 250 volts, which is 50 volts higher than curve B .) We can thus get a certain change in plate current either by leaving the plate voltage fixed and changing the bias, or by leaving the bias fixed and changing the plate voltage. However, notice that the plate voltage change is far larger than the grid voltage change needed to give the same plate current change.

If we now divide 50 (plate voltage change) by 2.5 (grid voltage change) we get 20. This means that the grid is *twenty times as effective* as the plate

(for this particular tube) in controlling the plate current. This value is called the *amplification factor*, and in plain language it means that, for this tube, a 1-volt grid change will affect the plate current just as much as will a 20-volt plate-voltage change. In other words, a 1-volt signal on the grid can act like a 20-volt variation in the plate circuit of this tube.

► The amplification factor *does not* tell directly how much the grid controls plate current, but it does express the relative effects of the grid and plate voltages on the plate current. The amplification factor can be defined technically as follows:

Amplification factor is equal to the plate voltage change which will produce a certain plate current change, divided by the grid voltage change which will produce the same plate current change.

Amplification factor, also called amplification ability, amplification number, or amplification constant, is generally designated by the Greek letter mu (μ), which is pronounced "mew." Amplification factor depends mostly upon the construction of the tube—particularly upon the position of the grid between the cathode and plate and upon the spacing between the meshes or turns of the grid wire. The closer the grid is to the cathode and the closer together are the grid wires, the larger will be the μ of the tube, because the grid then will have a greater control over the electron movements.

► The values of μ given in tube characteristics charts are only *averages*, as tubes of the same type may vary as much as 20% from the rated value. This deviation applies to other tube ratings as well, for radio tubes are delicate devices, made so compactly that errors of a few thousandths of an inch in the position of an electrode will greatly affect the tube ratings. These

differences in tube characteristics are permitted because close similarity is generally not necessary.

A.C. PLATE RESISTANCE

The opposition which the plate-cathode path of a tube offers to the flow of a.c. is expressed in ohms, just as is any other resistance, and is commonly abbreviated as r_p .

The value of r_p for a tube is found by applying to the plate-cathode an

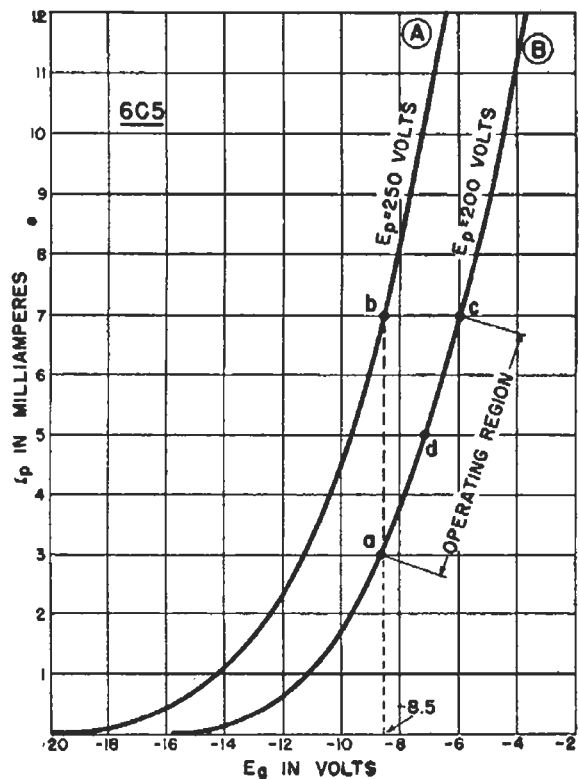


FIG. 10. Two of the curves taken from the family in Fig. 9.

a.c. voltage and measuring the resulting change in plate current, or it can be found from the characteristic curves. For example, referring to Fig. 10, a plate voltage change of 50 volts (a to b) produces a plate current change of 4 ma. when the tube is biased at -8.5 volts. As we can consider the change to be equivalent to an a.c. variation, we need only use Ohm's Law to find the a.c. resistance. In this case, then, r_p is equal to $50 \div .004$, or 12,500 ohms. Notice—this value applies only

to the particular operating point chosen (—8.5 volts bias). Other operating voltages would result in a different a.c. plate resistance.

D.C. Plate Resistance. A radio tube is peculiar in that it offers a different plate-to-cathode resistance to a steady voltage than it does to a varying voltage. When only d.c. voltage is applied to the grid and the plate, a definite amount of d.c. plate current will flow. By dividing the d.c. plate voltage by the d.c. plate current (Ohm's Law), we get the d.c. plate resistance of the tube for that particular grid bias value. Thus, at point *a* in Fig. 10, the d.c. plate voltage is 200 volts and the d.c. current is 3 ma., so the d.c. resistance is $200 \div .003$, which is about 66,000 ohms. (This is for the chosen value of grid bias only—since changing the grid bias changes the plate current and therefore changes the d.c. plate resistance, the bias must always be specified when a value of d.c. plate resistance is given.) This is quite different from the a.c. resistance.

► Strictly speaking, the designations "a.c." or "d.c." should always be given when the name "plate resistance" is used. However, for amplifiers, the *a.c. behavior* of a tube is the most important, for it tells us what the tube will do when signals are applied; d.c. resistance is seldom of interest. *Whenever you see the plate resistance of a tube mentioned, you can assume the a.c. value is meant, unless it is definitely marked "d.c."*

MUTUAL CONDUCTANCE

The third important tube rating, called mutual conductance or transconductance, is equal to the amplification factor divided by the a.c. plate resistance. This rating tells directly how much the grid voltage controls the plate current; it is defined as follows:

Mutual conductance of a tube is equal to the a.c. plate current divided by the a.c. grid voltage, when there is no load in the plate circuit.

Mutual conductance, abbreviated as g_m (or s_m), is expressed in *mhos* (pronounced "mose"). If we divide the a.c. plate current (the *varying* portion of the plate current) in amperes by the a.c. grid voltage in volts, we obtain mhos. However, the mutual conductance of tubes is but a small fraction of a mho, so, to avoid an awkward decimal number, the *micromho*, equal to one-millionth of a mho, is used in radio work. (Incidentally, "mho" is "ohm" spelled backwards.)

Mutual conductance (sometimes known as transconductance) shows *how much* a.c. plate current will be produced by an a.c. signal in the grid circuit. If the grid voltage in volts and the mutual conductance in mhos are known for a tube circuit, such as an amplifier tube circuit whose load has negligible resistance, the a.c. plate current in amperes is obtained simply by multiplying the two values together.

► When a tube ages, its electron emission is lowered and its g_m is reduced. This is why g_m is often measured when testing radio tubes, because it indicates the worth of the tube.

► Values of mutual conductance are given on tube charts. They can also be obtained from the E_g-I_p curves. In Fig. 10, a grid voltage change of 2.5 volts (from *a* to *c*) produces a plate current change of .004 ampere. Since a change corresponds to an a.c. value, the mutual conductance of the 6C5 tube (for operating point *d* in the middle of the operating region of curve *B*) will be $.004 \div 2.5$ or .0016 mhos. This is the same as 1600 micromhos.

► An example of a tube chart is given in Fig. 11. Note that r_p , g_m , and μ vary greatly among the tubes listed.

EQUIVALENT TUBE CIRCUITS

The tube ratings we have discussed so far are those of the tube alone, with no load in the plate circuit. These ratings are useful, but they do not tell directly how much amplification can be obtained in a practical stage, where a load must be used. When we wish to find the *actual stage gain*, it is far simpler to consider an equivalent circuit (such as was shown in an earlier lesson). This circuit deals only with the a.c. voltages and the a.c. currents in the plate circuit of the tube.

Equivalent A.C. Plate Voltage.

First, let us explain what is meant by *equivalent a.c. plate voltage*. You know

a.c. grid voltage in its effects.

We use the tube amplification factor to find this equivalent voltage. Since this factor shows how many times more effective is a change in grid voltage than is a change in plate voltage, the plate voltage change is equal to the grid voltage change multiplied by the μ of the tube. Hence, we say that the a.c. grid voltage e_g multiplied by the μ of the tube is the *equivalent a.c. plate voltage* μe_g . This equivalent a.c. plate voltage is used in calculations just as if it were an actual voltage; in fact, most engineers speak of it as the a.c. plate voltage.

The Circuit Without a Load. Now, let us draw the equivalent circuit of an

TYPE	CLASS	BASE	FILAMENT RATING		USE	PLATE VOLTS	NEGATIVE GRID VOLTS	SCREEN VOLTS	PLATE CURRENT MA.	SCREEN CURRENT MA.	r_p PLATE RESISTANCE OHMS	μ MICROMHOS MUTUAL CONDUCTANCE	μ AMPLIFICATION FACTOR	OHMS LOAD FOR STATED POWER OUTPUT	UNDISTORTED POWER OUTPUT MILLIWATTS
			VOLTS	AMPS											
6K9GT/6	TRIODE	5-U	6.3	0.30	AMPLIFIER	100 250	1.5 3.0	---	0.35 1.10	---	78,000 50,000	1,900 1,400	70	---	---
6K6GT/6	PENTODE	7-S	6.3	0.40	POWER AMP.	100	7.0	100	8.0	1.6	104,000	1,500	---	12,000	350
						250	18.0	250	32.0	5.5	68,000	2,300	---	7,600	3,400
						315	21.0	250	28.5	4.0	75,000	2,100	---	9,000	4,500
6K7GT/6	PENTODE	7-R	6.3	0.50	AMPLIFIER	90	3.0	80.0	5.4	1.3	300,000+	1,275	400	---	---
						250	3.0	100	7.0	1.7	800,000	1,450	1,160	---	---
6L56	TRIODE	6-Q	6.3	0.15	AMPLIFIER	100	3.0	---	4.0	---	10,000	1,500	15	---	---
						250	9.0	---	8.0	---	9,000	1,900	17	---	---
6L6	BEAM AMP.	7-AC	6.3	0.90	POWER AMP.	250	14.0	250	72.0	5.0	22,500	6,000	---	2,500	6,500
						350	18.0	250	84.0	2.9	33,000	5,200	---	4,200	10,800
6Q7	DUODIODE TRIODE	7-V	6.3	0.30	DET. AMP.	100	1.5	---	0.35	---	88,000	800	70	---	---
						250	3.0	---	1.1	---	58,000	1,200	70	---	---

FIG. 11. A section of a typical tube chart. Reading from left to right we find that the columns give: 1, the type number on the tube, assigned according to the RMA code; 2, the class of tube, whether a triode, pentode, etc.; 3, the base connections are given in another section of the chart (not shown here) but the key letter and number in column 3 refer to similarly-keyed base views; 4 and 5, the filament voltage and current; 6, the use to which the tube can be put; 7 through 11, the voltages and currents of the various plate, screen grid and control grid electrodes; 12, 13 and 14, the plate grid resistance, mutual conductance and amplification factor; 15, the proper load value; 16, the power output. This chart only shows the characteristics of a few of the many hundreds of different tubes used in modern radio receivers. Notice how even these tubes vary widely in characteristics.

that an a.c. grid voltage, or signal, acting in one circuit of a tube (the grid circuit) produces an a.c. plate current in another circuit (the plate circuit). Thus, we are dealing with two different circuits connected only by the action of a tube. It is always simpler to study a single circuit at a time. For this reason, we transfer the *effects* of the a.c. grid voltage to the plate circuit; we forget the grid circuit and assume that there is only a plate circuit containing an a.c. plate voltage *equivalent* to the

amplifier having no plate load. Considering only the a.c. actions, we find that the only opposition to the flow of current in the plate circuit is the a.c. plate resistance r_p , and that the only a.c. voltage acting in the circuit is the equivalent a.c. plate voltage μe_g .

Therefore, we can consider the a.c. plate circuit to be as shown in Fig. 12A—an a.c. source and a resistance r_p . The a.c. plate current flows through r_p and all the equivalent a.c. voltage is dropped in this internal tube resistance.

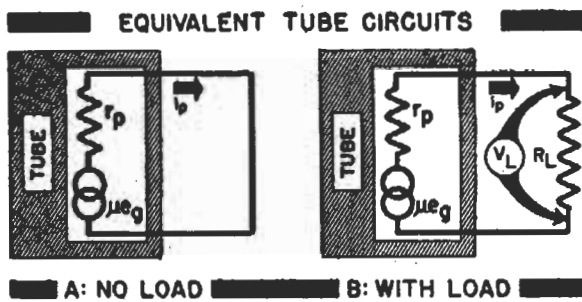


FIG. 12. Equivalents of plate circuits with and without a load.

Equivalent Tube Circuit With Load. The circuit without a load is useless, as all the signal energy is lost in the tube plate resistance. Hence, in a practical amplifier, we have to use a load in the plate circuit so that some of the signal energy can be developed outside the tube where it can be put to use. This load R_L is in series with the resistance r_p , as shown in the equivalent circuit of Fig. 12B. The insertion of this load will not change the operation of the tube, provided the same d.c. operating voltages are still applied to the tube. (If the load is a resistor and we want to operate the tube at a definite plate-to-cathode d.c. voltage, then the supply must furnish this plate voltage

plus the drop which occurs because of the d.c. plate current flow through the load resistor. The values of μ and r_p will then be those shown in the tube characteristics chart.)

With a load in the plate circuit, the equivalent a.c. plate voltage is divided between r_p and R_L .^{*} That portion of the a.c. plate voltage which is developed across R_L is the useful portion of the signal voltage and can be applied to other circuits.

^{*}For example, let's suppose e_g is 2 volts; μ is 10; r_p is 10,000 ohms; and R_L is 50,000 ohms. The voltage division will be in the ratio of R_L to the total ($R_L + r_p$) resistance, so the amplified signal voltage developed across R_L will be:

$$\begin{aligned}
 &= \mu e_g \times \frac{R_L}{R_L + r_p} \\
 &= (10 \times 2) \times \frac{50,000}{50,000 + 10,000} \\
 &= 20 \times \frac{50,000}{60,000} \\
 &= 20 \times \frac{5}{6} = 16.66 \text{ volts}
 \end{aligned}$$

Thus, in this case, the original 2-volt signal has produced a voltage of about 17 volts across the load resistor. With a μ of 10, the value of μe_g is 20, but we can never get all this as there is always some loss across r_p .

The Basic Amplifying Stage

Any amplifier, whatever its purpose, can be reduced to the simple circuit shown in Fig. 13. As shown here, the basic requirements for a tube amplifier are: 1, a signal source; 2, the proper operating voltages; 3, a load to which the signal is delivered.

Signal Source. The signal source which feeds into the grid-cathode terminals of a tube may be any device capable of supplying the desired signal voltage. The basic operation of a tube stage will be the same regardless of the

source—whether the signal source is a photoelectric cell, a microphone, or a television camera tube, or whether the signal is obtained from a preceding stage.

Amplifier Load. The load is the device to which the tube delivers a copy of the voltage applied to the grid. As there must be a path for the d.c. supply voltage to the tube, the load (or a coupling part) will be a resistor, a coil, or a transformer.

Supply Voltages. We have already

discussed the importance of supply voltages in this and other lessons. The plate voltage and grid voltage are chosen to cause operation at the particular point on the characteristic curve desired for that particular amplifier. Under those conditions, the applied signal will cause the proper variation in the plate current to give the desired output voltage across the load.

VOLTAGE AND POWER AMPLIFICATION

Amplifiers can have one of two purposes: 1, if an amplifier makes the signal *voltage* across its load as large as possible (much larger than the grid signal voltage), it is called a *voltage amplifier*; or 2, if an amplifier makes the signal power in the load as large as possible, it is called a *power amplifier*. In this latter case, the a.c. load current multiplied by the a.c. load voltage should be as large as possible.

Voltage amplifiers are needed to build up the strength of weak signals,

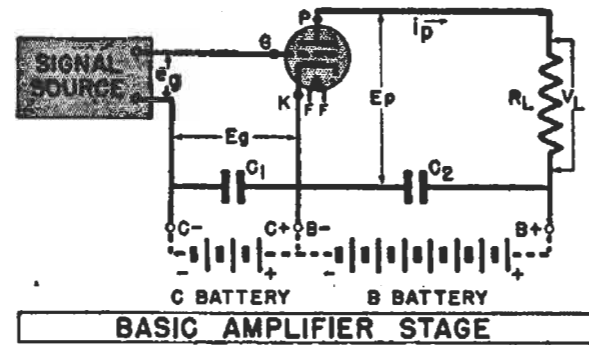


FIG. 13. By inserting the proper signal source, the proper load value, and the correct operating voltages, this basic circuit can be made to fit ANY AMPLIFIER USE!

while power amplifiers are needed to operate most reproducers and to build up the power at the transmitter to the desired level. The basic circuit shown in Fig. 13 will be the same in either case—we can get either maximum signal *voltage* or maximum signal *power* by the proper choice of a tube and by adjusting the value of the load.

To see just how the load can have this effect, let's go back to our equivalent circuit shown in Fig. 12B. To get the greatest *voltage* amplification, we

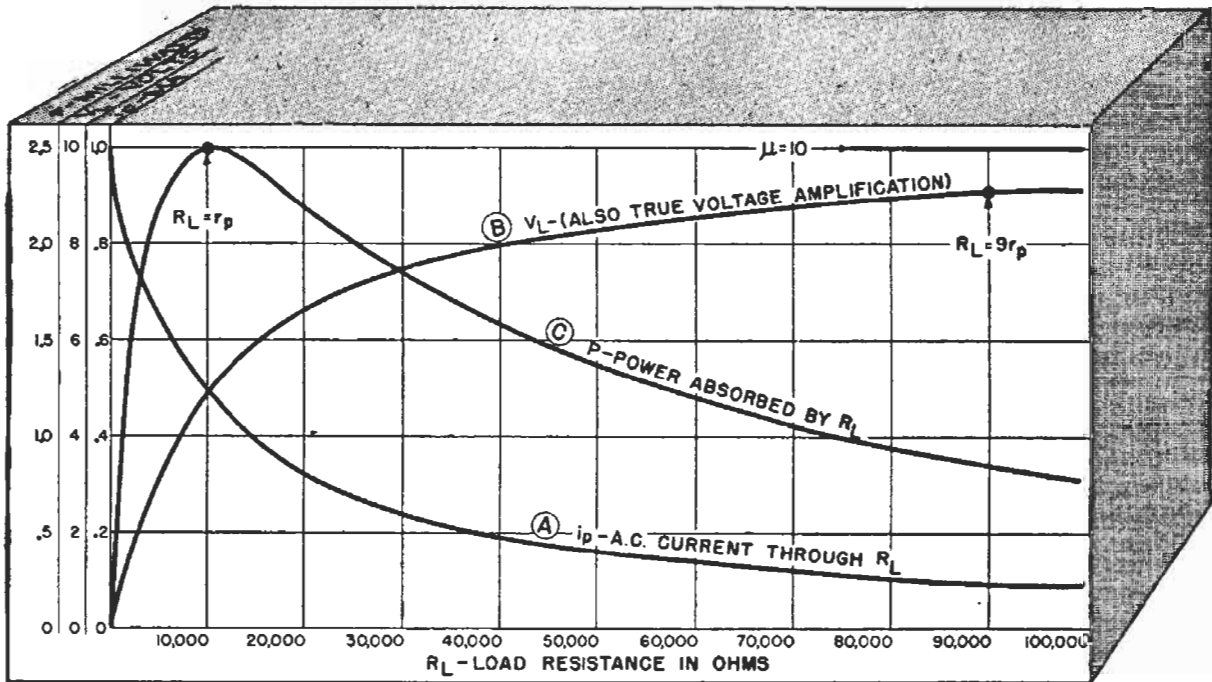


FIG. 14. These curves show the effect that various load values have on the plate current, load voltage, and power output. The higher the load value the greater the VOLTAGE gain. The load should equal the source impedance for greatest POWER output.

want V_L (i_p times R_L) to be as large as possible, while for power amplification we want the power absorbed by the load (V_L times i_p) to be as large as possible. To illustrate the effects of the load resistor, let's assume that r_p is 10,000 ohms, that μ is 10, and the a.c. grid voltage is 1 volt.

A.C. Plate Current. From Ohm's Law, the a.c. plate voltage divided by the total a.c. resistance in the plate circuit gives the a.c. plate current i_p . (This a.c. plate current is only a part of the *total plate current*—it is just the variation caused by the signal. We are not interested in the d.c. current, so we ignore it.) By assuming different values of R_L and plotting the resulting plate current* we would get the curve *A* of Fig. 14. As we expect, increasing R_L (that is, increasing the total resistance) causes i_p to be reduced.

A.C. Output Voltage. The load voltage is simply the product of i_p and R_L . By multiplying together these values for each size of load resistor, we will get curve *B* of Fig. 14. Although i_p is decreased by larger values of R_L , their product is increasingly larger—that is, R_L increases faster than i_p decreases.†

This voltage across R_L is the *output voltage*; the larger R_L is the larger the output voltage becomes. *The true stage gain is equal to the output divided by the input*, and since we chose an input

*The a.c. plate voltage is μe_g , and the total resistance is $R_L + r_p$, so

$$i_p = \frac{\mu e_g}{R_L + r_p}$$

†We could arrive at the same result by remembering that the a.c. plate voltage μe_g divides between R_L and the plate resistance r_p ; as R_L is increased, a greater part of the a.c. plate voltage is developed across it. In fact, we can calculate the load voltage for any particular input voltage from the relation:

$$V_L = \mu e_g \times \frac{R_L}{R_L + r_p}$$

grid voltage of 1 volt, in this particular case the voltage V_L is equal to the true voltage amplification.

Power Output. The load power is the product of i_p and V_L —the a.c. plate current multiplied by the a.c. voltage across the load. By multiplying together the values obtained on curves *A* and *B* of Fig. 14, we get curve *C*, which represents the load power for various values of load resistance. ► There are a number of very important facts revealed by the three curves in Fig. 14. These are the points you should remember:

1. Effect of Load on A.C. Plate Current: The insertion of a load in the plate circuit of an amplifier tube *decreases* the a.c. plate current; the greater the ohmic value of the load, the less the current.‡ When the plate load resistance is exactly equal to the a.c. plate resistance, the a.c. plate current will be reduced to exactly half its no-load value (the value when R_L is not in the circuit).

2. Effect of Load on Amplification: Increasing the plate load resistance increases the stage gain, so the maximum gain is obtained when R_L is many times larger than r_p . The maximum possible amplification is μ , the amplification factor of a tube, but this limit can never be reached in actual practice, since there is always some loss in voltage across r_p . When R_L is equal to r_p , only 50% or one-half the total possible amplification is obtained, and when R_L is nine times the value of r_p , about 90% of the maximum amplification is obtained. (Practical voltage amplifying stages using *triode* tubes usually have load values about 7 to 10 times the value of r_p .)

‡‡It is assumed that the supply voltage is adjusted so the d.c. plate-cathode voltage and the d.c. plate current do not change.

3. When Maximum Power is Delivered to the Load. The load in a triode tube amplifier gets the maximum power when the resistance of the load is equal to the a.c. plate resistance of the tube; the power then decreases gradually as R_L is further increased. Thus, maximum power output is obtained when the load resistance equals or matches the a.c. plate resistance. ► From this, you can see that the value of plate load resistance used in a stage is important. In your service work, you will be called upon many times to replace the part used as a load. Naturally, the replacement part should be approximately the same value as the original, although generally you can

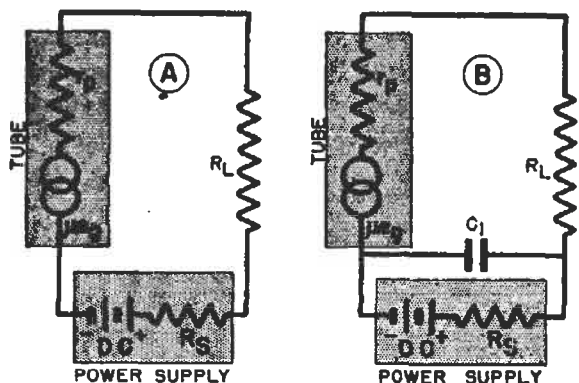


FIG. 15. How the effects of the power supply resistance are eliminated by a by-pass condenser.

use a somewhat higher value if an exact replacement part cannot be obtained.

► Incidentally, maximum *undistorted* power output is not obtained with the same load value as is maximum power, as we shall see later. With *triode* tubes, distortion is less when the load value is about twice the a.c. plate resistance. Tube charts give load values for maximum *undistorted* power output.

BY-PASS CONDENSERS

Returning to the circuit of Fig. 13, you will notice that condensers C_1 and C_2 are connected across the batteries. Now, batteries have some internal re-

sistance and, as they grow older, this resistance increases. Also, all power supplies (used in place of batteries) have considerable impedance. If the signal current has to flow through this impedance or resistance, several undesirable actions will occur.

► The equivalent circuit containing this added resistance is shown in Fig. 15A. Obviously, the added R_s increases the total resistance, thus reducing i_p and reducing the output voltage (i_p times R_L) across R_L .

We can minimize this effect by connecting a condenser C_1 across the power supply, as shown in Fig. 15B. By choosing a capacity large enough to have a very small reactance to the signal current, we find that the condenser will act practically as a short circuit for signals around R_s , so that little signal energy is lost in R_s . We can then ignore R_s and can consider the a.c. circuit to be r_p - R_L - C_1 , with the opposition of C_1 so low that the circuit is, for all practical purposes, the same as was shown in Fig. 12B. (Of course, the condenser, if in good condition, does not pass appreciable d.c., so the d.c. operating voltages are still supplied to the tube through R_L in the usual manner.) Because C_1 offers another path for a.c. around the undesired path, it is called a *by-pass* condenser.

► There is another reason for keeping the signals out of the power supply. Usually the power supply furnishes d.c. voltage to more than one stage. If we let signals get into the power supply, they may flow into the other stages powered by the supply. Such coupling is undesirable—it may cause squealing and howling, or it may reduce the gain; you will learn about this in later lessons.

► Finally, we don't want stray a.c. voltages to come from the supply, along with the desired d.c. The same

by-pass condenser helps here too. If we represent the unwanted a.c. in the supply by generator e in Fig. 16, you can see that there are two paths for its current; 1, through $R_S-R_L-r_p$; and 2, through R_S-C_1 . As C_1 has a low reactance, it forms a filter with R_S , such that most of the undesired a.c. is dropped in R_S . Thus, the condenser again acts practically like an a.c. short circuit, reducing the a.c. voltage between terminals 1 and 2 to the point

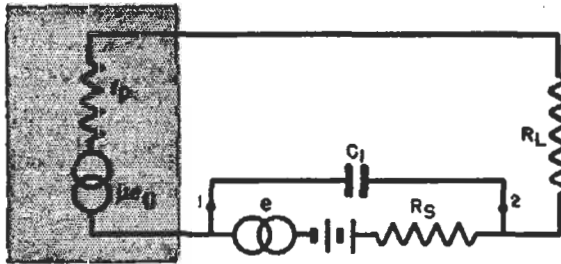


FIG. 16. Stray a.c. voltages from the power supply do not affect the rest of the circuit if the by-pass condenser C_1 is in good condition.

where very little undesired current will flow through R_L and r_p .

► These reasons for using a by-pass condenser across the power supply in the plate circuit also apply to the grid circuit, where a by-pass condenser generally is used across the d.c. bias supply. Condenser C_1 in Fig. 13 does not interfere with the d.c. bias supply, but does prevent a signal voltage drop across the supply; it also prevents any a.c. voltage in the bias supply from affecting the grid circuit.

► Thus, by-pass condensers across operating voltage supplies serve three important purposes:

1. They prevent an undesirable loss of signal.
2. They prevent undesirable coupling between stages.
3. They prevent undesired signals from the power supply from getting into the amplifying stage.

► Should a by-pass condenser become defective, the stage operation is certain

to be upset. If the condenser open-circuits (perhaps because a lead pulls away from a foil plate), then the condenser is in effect "not there." We will consequently get a loss of gain, undesirable coupling between stages, and perhaps hum or noise voltages from the power supply. On the other hand, if the condenser short-circuits, it will provide an unwanted path for d.c. This "short" would act like a direct wire connection between terminals 1 and 2 of Fig. 16, so it would remove all d.c. plate voltage and cause a "dead" stage.

SELF-BIAS

The amplifier circuit in Fig. 13 shows a C battery as the grid bias supply. However, if the radio is equipped

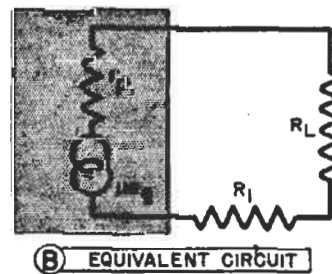
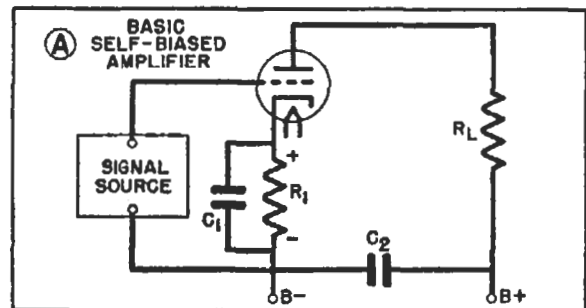


FIG. 17. The tube can furnish its own C bias when this circuit is used. Plate current moving from B+ to the cathode causes a voltage drop across R_1 . As this voltage is between the grid and the cathode, it acts as the bias.

with a power pack so it can operate from a power line (as most sets are today), obviously we don't want to have to use batteries too. While it is possible to obtain bias voltages from the power pack, it is not always convenient to do so, particularly if the pack must supply a number of different stages.

The circuit shown in Fig. 17A makes it unnecessary to use any external source to furnish the proper d.c. bias voltage for the tube. In this circuit, the electron flow in the plate circuit is from the cathode of the tube to the plate, through R_L , through the plate power supply ($B+$ to $B-$), and then through resistor R_1 back to the cathode. Thus, *the d.c. plate current must flow through R_1 .*

This current flow through R_1 produces a d.c. voltage drop across it. The polarity of this voltage drop will be as shown, because electrons enter the end of R_1 connected to $B-$; this end of resistor R_1 is, therefore, more negative than the other end.

This voltage is between the grid and cathode, because the grid return from the signal source connects to the negative end of R_1 , while the positive end of R_1 is connected to the cathode. In other words, the d.c. voltage across R_1 makes the grid more negative than the cathode. This is exactly what a C battery or other bias supply does.

Effectively, with this circuit, the tube biases itself—since its own d.c. plate current furnishes the bias voltage, which in turn sets the plate current! That's why such an arrangement is called *self-bias*.

► Service hint: the proper value of resistor R_1 is rather easy to determine, as the normal d.c. plate current and the required grid bias voltage are known from the tube chart characteristics. By dividing the grid bias voltage by the plate current (in amperes), we get the value of R_1 .

► If we did not use by-pass condenser C_1 , there would be an a.c. voltage drop across R_1 just as there was across R_s in Fig. 15. (The equivalent circuit in Fig. 17B shows this more clearly.) Such a drop is undesirable both because it will reduce the output across R_L and because it will be introduced into the grid circuit (since the voltage across R_1 acts on the grid). Therefore, R_1 is usually by-passed by a condenser such as C_1 in Fig. 17A.

If by-pass condenser C_1 open-circuits, the stage gain will be reduced. If it short-circuits, the bias voltage will be removed; this will cause a high d.c. plate current and operation on the wrong part of the characteristic curve. Compare this with what you just learned about the effects of an open or a short in the by-pass condenser across the plate supply. *Notice — although the two condensers serve much the same purposes, defects in them may have quite different effects on the set.*

Typical Amplifying Circuits

While all amplifiers are basically alike, there are differences between them — differences in the methods of coupling into the grid circuit, in the signal source used in the grid circuit, and in the types of plate loads. The exact circuit depends upon the use to which the tube is put; whether, for example, it is to amplify low-frequency intelligence signals or high-frequency

carrier signals, or is to be used in television or in sound systems. Suppose we now briefly introduce you to some typical amplifiers, which you will study fully in your next few lessons.

RESISTANCE-CAPACITANCE COUPLING

Fig. 18 shows an amplifier circuit that is frequently found in audio or

video frequency amplifiers (intelligence signal amplifiers similar to *E* or *N* of Fig. 1).

Resistors and condensers are used to couple (connect) this stage to the stages before it and after it, so it is called a "resistance-capacitance coupled amplifier." As you can see, the d.c. plate voltage is obtained from the B supply in the usual way. The stage is self-biased by resistor R_2 . By-pass condensers C_2 and C_3 have already been explained.

When an input signal is applied to terminals 1 and 2, the a.c. portion of this signal will pass through condenser C_1 and develop a voltage across resistor R_1 . If there is also a d.c. voltage between terminals 1 and 2, condenser C_1 will prevent this d.c. component from entering the stage. Thus, C_1 and R_1 form a filter, blocking any d.c. voltage which may be between terminals 1 and 2, but passing on the a.c. signal. (The d.c. blocking is necessary to prevent interference with the bias—the d.c. voltage from the previous stage could force the grid highly negative or highly positive, and thus cause operation at some undesirable point on the tube characteristic.)

The varying a.c. signal voltage across R_1 is alternately added to and subtracted from the bias voltage produced by R_2 . This produces an a.c. variation in plate current, which in turn produces an amplified copy of the signal voltage across the load resistor R_3 .

The voltage across R_3 is passed through another filter, C_4 - R_4 , which passes on only the a.c. signal and blocks the d.c. voltage in the plate circuit from the following stage.

Notice that condensers C_1 and C_4 serve to isolate the stage. On the input side, C_1 prevents any external d.c. voltage from interfering with the grid

circuit and, on the output side, C_4 prevents the plate operating voltage from causing an undesirable action in any following stage or device.

► In case you're not sure how an a.c. voltage gets across R_4 from R_3 , notice the ground connections. You can trace a complete circuit (for a.c. only) from R_3 to C_4 , C_4 to R_4 , R_4 to ground, ground to C_3 , and from C_3 back to R_3 .

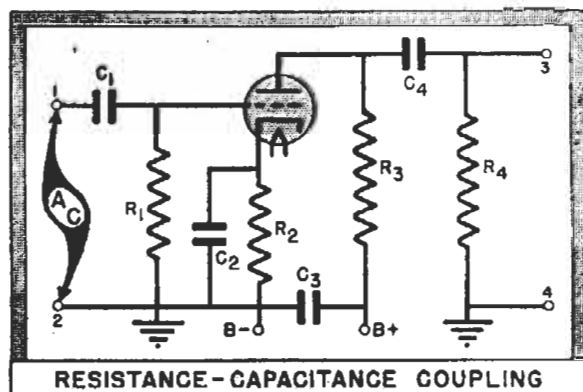


FIG. 18. This basic circuit is the most commonly used type of audio amplifier.

Thus, any a.c. voltage appearing across R_3 is applied to R_4 through condensers C_3 and C_4 . In effect, these condensers place R_4 in parallel with R_3 insofar as a.c. is concerned.

Very many radio circuits are completed in this manner through ground connections, so remember—when you are tracing a circuit, don't stop when you meet a ground connection; trace from the other end of the source until you come to ground again. You can consider that all grounded points are connected just as if wires were run between them.

► However, just because ground points are connected together, don't make the mistake of thinking of currents as wandering about aimlessly. Currents *only* flow in *complete* circuits because of the voltages in those circuits. Thus, in Fig. 18, the current flow from R_4 will be through C_3 ; it will *not* flow through R_1 as there is no path

from the grid end of R_1 to the $B+$ end of R_3 .

LOW-FREQUENCY (AUDIO) TRANSFORMER COUPLING

Another amplifying circuit is shown in Fig. 19. Here, resistor R_1 furnishes the self-bias and C_1 is the by-pass condenser preventing any appreciable signal voltage drop across this resistor. Condenser C_2 by-passes the B supply.

The grid circuit is completed through the secondary S of transformer T_1 , while the plate circuit of the tube is completed through the primary P of transformer T_2 .

When an a.c. signal is applied to terminals 1 and 2, the resulting current flow through primary P of transformer T_1 sets up a varying flux which induces an a.c. voltage in the secondary S of

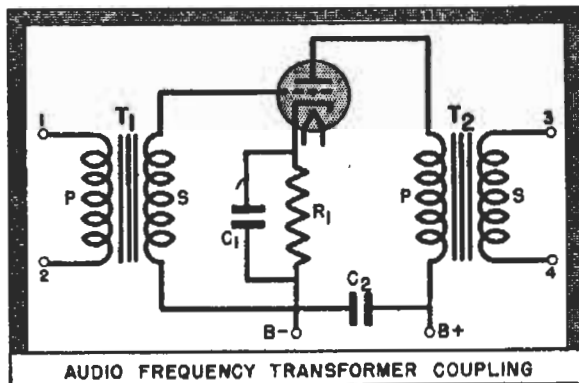


FIG. 19. Transformer coupling is employed when high gain is desired, as you will learn later.

this transformer. This a.c. voltage is between the grid and cathode of the tube, and produces a varying plate current.

The plate current variation must pass through the primary P of transformer T_2 . This produces a flux change in this transformer, and so induces a voltage in the secondary S which can be applied to a reproducer system or to another stage.

► Notice the voltage *changes* which take place. One voltage causes a current to flow in the primary of trans-

former T_1 . This current flow produces a flux change which induces *another* (but *similar*) voltage in the secondary winding. This acts as the input signal for the tube, which varies the plate current of the tube. In turn, this plate current flow through the primary of transformer T_2 causes a flux change which induces a *final voltage* in the secondary S of this transformer. Thus, while the *original voltage* applied to terminals 1 and 2 gets no farther than the primary of transformer T_1 , successive "carbon copies" are produced by each transformer and by the tube; finally, an amplified copy of the original signal can be obtained from terminals 3 and 4.

► The transformers act as "isolators" like the condensers C_1 and C_4 of Fig. 18, in that d.c. has no influence on their secondary circuits. Basically, therefore, we use d.c. to get proper tube operation, but then we usually separate the signal from the d.c. before passing it along.

R.F. AMPLIFIER STAGES

The low-frequency amplifier shown in Fig. 19 uses laminated iron-core transformers, which cannot be used at frequencies higher than about 15,000 cycles per second. R.F. carrier frequencies are far higher than this, so air-core or powdered-iron core transformers must be used in r.f. amplifiers. A typical circuit for an r.f. amplifier stage is shown in Fig. 20.

It is customary to tune radio frequency transformers so that the amplifier stage will give both amplification and selectivity. Condensers C_1 and C_4 in Fig. 20 are variable condensers which are used to tune L_2 and L_4 (respectively) to some desired radio frequency. Let's see what effect the addition of these condensers has on operation of the circuit.

An r.f. voltage applied to terminals 1 and 2 causes a current flow in L_1 which sets up a varying flux. This induces in coil L_2 a voltage which acts as if it were in series with this coil. Hence, the tuned circuit L_2-C_1 is series resonant (has minimum impedance) for the frequency to which the circuit is tuned.

If the voltage induced in L_2 is of the resonant frequency, it will undergo

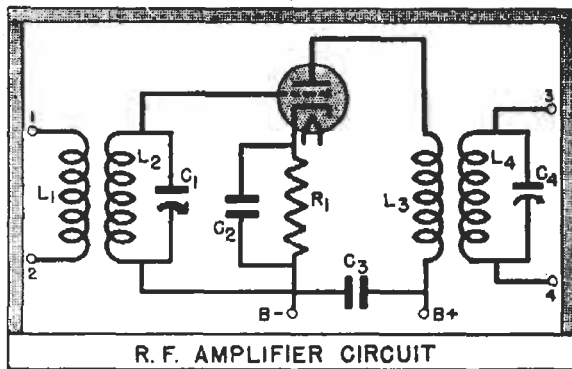


FIG. 20. This tuned amplifier circuit is known as a t.r.f. stage.

resonant voltage step-up and appear across C_1 in amplified form*; if it is not of the resonant frequency, it will appear across C_1 , but will not be much amplified by the action of the resonant circuit. Thus, if the signal applied to terminals 1 and 2 consists of a mixture of several frequencies, only the resonant-frequency voltage will appear across C_1 in greatly amplified form (though voltages with frequencies near

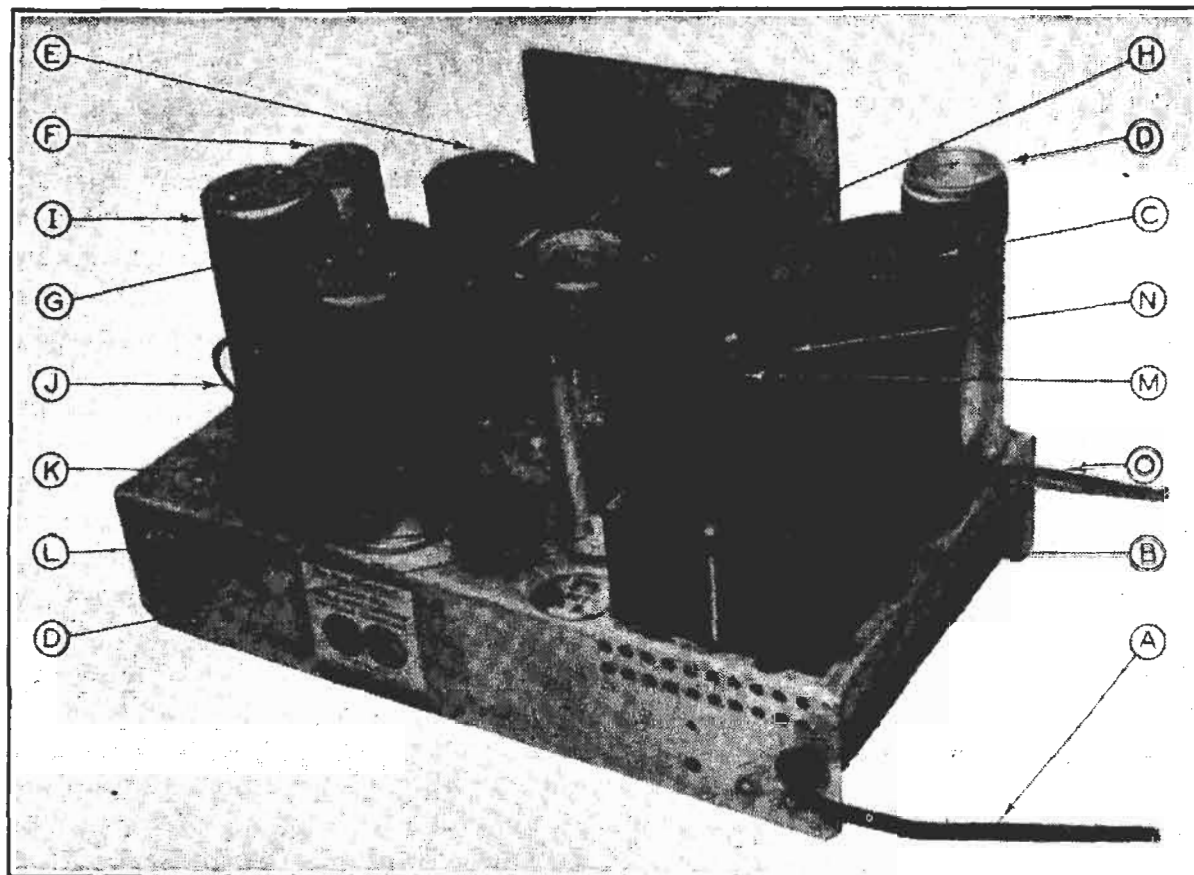
*Remember, the action of a series resonant circuit in stepping up a voltage is as follows: The coil and condenser together have a resonant frequency at which their reactances cancel each other; when the voltage induced in the coil is at this resonant frequency, a large a.c. current flows in the resonant circuit. This a.c. current naturally produces a large a.c. voltage drop across the coil and another across the condenser, as each one *alone* has a high a.c. reactance. The resulting voltage across either the coil or the condenser is therefore many times greater than the original induced voltage.

the resonant frequency may be slightly amplified).

The r.f. voltage developed across C_1 is between the grid and the cathode, so it causes a varying plate current through L_3 , which in turn induces a voltage in L_4 . Again there is a series resonant circuit (L_4-C_4); and again the resonant-frequency voltage will appear across the condenser (C_4) in amplified form. This voltage can be passed on to the next stage for further amplification. Thus, this r.f. amplifier has *variable gain*: it amplifies the resonant frequency signal much more than other signals. We can (and, in fact, do) use such a circuit as a *selector* as well as an amplifier. When we tune its two resonant circuits to some desired frequency, signals of that frequency will receive far more amplification than will signals of other frequencies which may be present in the input to the amplifier. In other words, the circuit will *select* signals of the desired frequency.

► Fig. 20 looks very much like Fig. 19. However, the use of air-core transformers (instead of laminated iron-core transformers) and the fact that tuning condensers are used tell us that this is an r.f. circuit exclusively; air-core transformers and tuning condensers are not used in a.f. stages.

► An interesting variation of this circuit can be had by using C_4 to tune L_3 instead of L_4 . This would form a parallel resonant circuit in the plate circuit which would offer maximum impedance at its resonant frequency but far less impedance at other frequencies. In other words, at the resonant frequency the load resistance is a maximum—which, as you have learned, means that the stage gain will be highest at this particular frequency. As a result, the greatest possible amount of the signal voltage will be



Here is a photograph of the chassis of a six-tube all-wave superheterodyne. The various stages can be recognized in two ways—by the types of tubes used and by their associated signal sources and loads. (You will learn more about this in other lessons.) In this figure, the following parts are identified: A, 110 volt a.c. line cord; B, power transformer; C, rectifier tube; D, filter condensers; E, antenna coil; F, frequency converter tube; G, oscillator coil; H, tuning condensers; I, first i.f. transformer; J, i.f. amplifier tube; K, second i.f. transformer; L, second detector (called the demodulator) tube; M, first audio tube; N, power amplifier tube; O, loudspeaker cable.

developed across L_3 at the resonant frequency. Again we have a *selective* circuit which provides maximum gain at the resonant frequency, but less gain at other frequencies.

► Naturally, the coil and condenser combination in each of these circuits must be properly chosen so that their L-C values will give resonance at the desired frequency. It is possible to

change the frequency to which the circuit is resonant (or, as radio men say, to “tune” the circuit) by varying the tuning condensers C_1 and C_4 in step.

► We have given you this brief introduction to amplifiers to show you how similar they are, even though they are designed to perform different jobs. You are going to study the details of these circuits in the next few lessons.

Tubes as Signal Generators and as Signal Mixers

The amplifying stages we have discussed so far have been purely relaying devices. Each has taken a signal from the signal source, made an enlarged copy of it, and passed it along to another stage. The signal itself has not been changed, except that it has been made larger.

There are stages which perform other functions instead of amplifying, or in addition to amplifying. We now will discuss several of these briefly, so you will see the important parts they play.

THE OSCILLATOR

The radio stage we call an oscillator is the stage in which an r.f. signal is generated. This signal is an a.c. voltage which varies between positive and negative values just like the a.c. voltage in your power line. In fact, the only differences between power line voltages and r.f. voltages are in their voltage values and frequencies.

Essentially, here is how an oscillator works. As you know, an a.c. grid voltage in an amplifier stage causes an a.c. plate current. This current produces an a.c. voltage drop across the load which is an amplified version of the grid signal voltage. To make such an amplifier into an oscillator, all we need do is to feed part or all of this a.c. load voltage back into the grid circuit with the proper phase. Then the a.c. load voltage will act as a grid signal, which in turn will cause more a.c. load voltage, and so on. An oscillator, in other words, is simply an amplifier which supplies its own grid signal from its plate circuit.

A typical oscillator circuit is shown in Fig. 21. Here, the a.c. plate current

flowing through the feedback coil L_T produces an a.c. flux. This flux links with L_1 , inducing a corresponding a.c. voltage in it (much as if L_T were the primary and L_1 the secondary of a transformer). The grid voltage thus developed is fed to the grid (through the parallel R_g - C_g combination, the function of which we will discuss shortly) and there produces a continuation of the plate current variations, which in turn keeps the grid voltage changing! Obviously, this action can keep on indefinitely, once it gets started. But how does it start?

Because of the L_1 - C_1 circuit, all we need do is to cause some change in plate current. The act of turning on the circuit (applying operating voltages) is sufficient. The rise in plate current as the tube warms up will cause a pulse to be induced in L_1 from L_T . From here, the resonant circuit takes charge and controls the oscillator.

The initial pulse of energy causes a current flow which charges the condenser C_1 . Then, when no further energy is induced, C_1 discharges through L_1 . Electrons flow from the condenser with a rush at first, then, as the condenser voltage drops, the discharge current decreases. In other

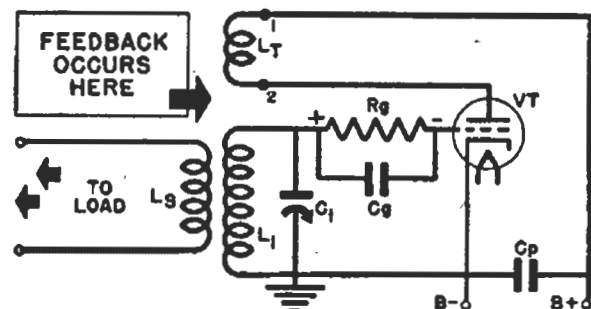
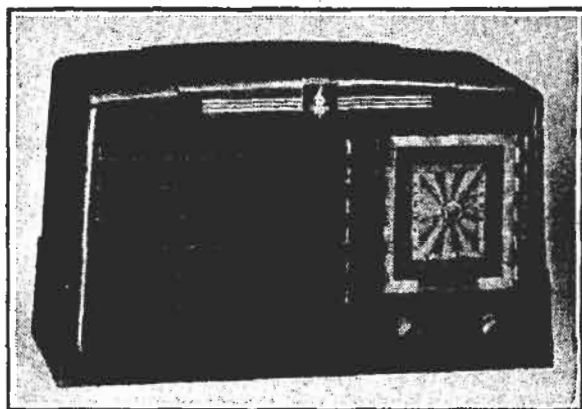


FIG. 21. A basic oscillator circuit.

words, the condenser discharge produces a varying current through the coil. And, as you know, a coil opposes changes in the current flow through it. Therefore, when the condenser tries to discharge through the coil, energy is stored in the magnetic field of the coil. When the electron movement has caused the condenser voltage to reduce to zero, the current flow would tend to stop. However, now, the coil field collapses and keeps the current flowing in the same direction as it was going. This results in the condenser being charged up again, this time with the opposite polarity.



Courtesy Emerson Radio and Phone Corp.

A typical midget receiver. It uses the same stages as a large console type. The main differences are: 1, a different power supply; 2, different tubes; 3, components smaller physically.

When the magnetic field is completely collapsed, the condenser will try again to make current flow through the circuit, this time in the opposite direction. Thus, if a pulse of energy is fed into the circuit, an oscillatory (back and forth) electron flow will take place in the L_1-C_1 circuit.

This oscillating current flow keeps reversing the polarity with which condenser C_1 is charged. In fact, it follows a sine-wave pattern, with a frequency which is equal to the resonant frequency of the L_1-C_1 circuit. Thus, our resonant circuit is able to convert the initial pulse of energy into a sine-wave

voltage.

If there were no resistance in the circuit, current oscillations would keep on indefinitely. However, any practical circuit always has resistance in the coil and leads. Current flow through this resistance produces power losses (I^2R) which rapidly reduce the amplitude of the current oscillations.

This is where the tube comes in. The sine-wave voltage across C_1 controls the plate current, which in turn induces pulses of energy from L_T into L_1 at just the right time to keep oscillations going. This feedback makes up for the power lost in the resistance of the resonant circuit, so the oscillations are maintained.

► We can make use of the a.c. power produced in the oscillator circuit L_1-C_1 by placing a coil L_s near coil L_1 . A sine-wave voltage will then be induced in L_s , which we can feed to other circuits, where it can be used as an input signal.

Automatic Bias. Perhaps the easiest way to see why R_g and C_g are used in the grid circuit is to imagine what would happen if they were not present and the C_1 voltage were fed directly to the grid. Then, when the a.c. voltage across the condenser went through its positive alternation, the grid would become highly positive and a large plate current would flow. In fact, under these conditions, a high-power tube could actually pass enough current to melt the tube elements. R_g and C_g supply a bias voltage which keeps the grid voltage low enough to prevent this action.

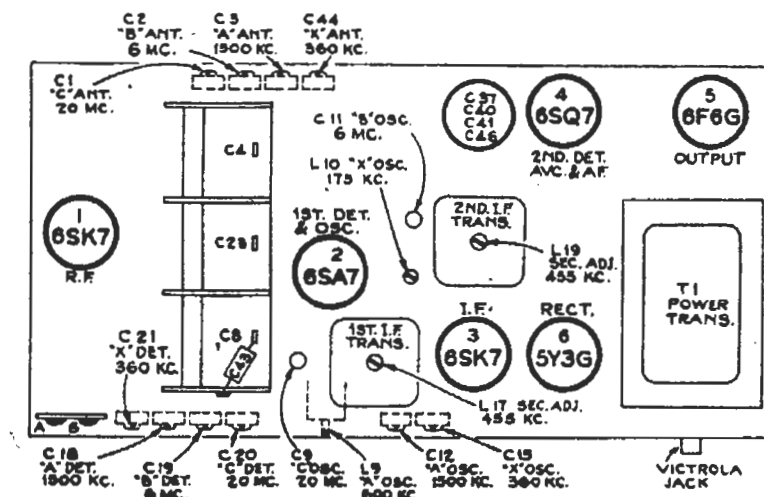
When the grid is driven positive by the voltage across C_1 , grid current will flow because the grid will attract some of the electrons emitted by the cathode. This grid current flow develops a voltage across R_g with the polarity shown in Fig. 21. This voltage charges up

condenser C_g .

When the L_1-C_1 circuit drives the grid negative, the grid electron flow stops, but condenser C_g now partially discharges through R_g . This discharge current replaces the grid current and maintains the voltage across R_g practically constant. Then, on the next positive swing, C_g is recharged, and events repeat themselves. This is called an *automatic bias*. It is another form of self-bias; here the *grid* current flow produces the bias, while in those circuits we studied earlier the *plate* current flow produced the bias.

(1) as the generator of the carrier wave in a transmitter; (2) as the local oscillator in a superheterodyne receiver; and (3) as a test signal generator used by servicemen. These are all r.f. oscillators. Audio oscillators are used mostly in test and measuring equipment.

► This is by no means the only oscillator circuit. You'll find many others in later lessons. But while these oscillators are different in some respects—some to the extent that they produce sawtooth or square waves instead of sine waves—they are alike in being



Many manufacturers furnish complete service information on their receivers in the form of service sheets and manuals. This layout of the top of a chassis is typical of the kind of information you can expect. This layout gives: 1, the positions of the trimmer condensers used for adjusting the circuits to track together; 2, the types of tubes; 3, the functions of the tubes. Thus: 1, a 6SK7 r.f. amplifier; 2, a 6SA7 first detector and oscillator combined (the frequency converter); 3, a 6SK7 i.f. amplifier tube; 4, a 6SQ7 second detector (demodulator) and first a.f. tube; 5, a 6F6G output tube; 6, a 5Y3G rectifier tube. The positions of the stages are different in each radio, but there will always be relatively short signal paths from stage to stage.

Oscillator Uses. With the oscillator we've described, we could produce sine-wave voltages of almost any frequency we desire—from audio to radio frequencies—merely by using the proper values of inductance and capacitance in the tuned circuit. The chief radio uses of oscillators are:

amplifiers which supply their own grid signals.

MODULATED AMPLIFIERS

Now that we know how a carrier signal can be generated, let us see how we can modulate it with an intelligence signal. (This is accomplished in sec-

tion C in Fig. 1.) At this point in your Course, we won't give a detailed discussion of the circuits used for modulation, but you should learn the essentials of the process. And, the method used determines the kind of demodulator necessary in a receiver. There are two systems now in wide use; we shall describe both briefly.

► In one important method of modulation, the amplitude (the strength) of the carrier is varied by the intelligence signal. This method—called amplitude modulation (or a.m.)—is used in the standard broadcast stations, in the majority of commercial stations, and for the video television signal.

► Another method is to have the intelligence signal vary the frequency of the carrier. This *frequency modulation* (f.m.) is used for the sound portion of a television program, and for broadcasts on the very high frequencies. In particular, it is used for some police radio and other special services where its unique freedom from atmospheric and man-made interference makes frequency modulation highly desirable.

Amplitude Modulation. Fig. 22A represents an unmodulated carrier which has a constant amplitude N . We want this carrier to be varied in amplitude by the audio signal shown in Fig. 22B. In other words, we want to produce an r.f. signal like that shown in Fig. 22C, where the amplitude of the carrier varies as the audio signal varies. (Actually there are hundreds of r.f. cycles to each modulation cycle. We can't show them all in this drawing.)

A simple way to get this action is to feed the carrier into the grid circuit of an r.f. amplifier, and to arrange the amplifier so that the intelligence signal can vary its plate voltage. With no intelligence signal, the plate current

pulses follow the r.f. variations; the amplitudes of these pulses are fixed by the operating voltages.

When an intelligence signal is applied, its positive alternations will add to the d.c. plate voltage, while its negative alternations subtract from the d.c. voltage. Thus, the plate voltage is varied up and down. You know that the amount of plate current depends on the plate voltage, so you can see that this variation forces the plate current to vary. Thus, the r.f. pulses are made larger and smaller, accord-

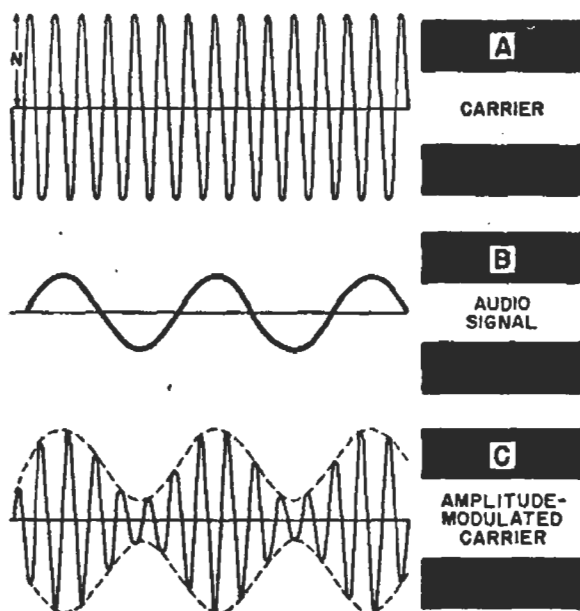


FIG. 22. When the carrier at A is modulated by the audio signal, B, the result can be represented by C.

ing to the intelligence signal variations.

Frequency Modulation. In frequency modulation, the amplitude of the carrier is unchanged, but its frequency is varied. This is quite different from amplitude modulation.

The carrier signal is just like the carrier used in an a.m. system, but the "carrier" frequency is known as the *resting* frequency; it is the frequency radiated when there is no modulation.

Suppose we modulate the resting signal with an intelligence signal. Our

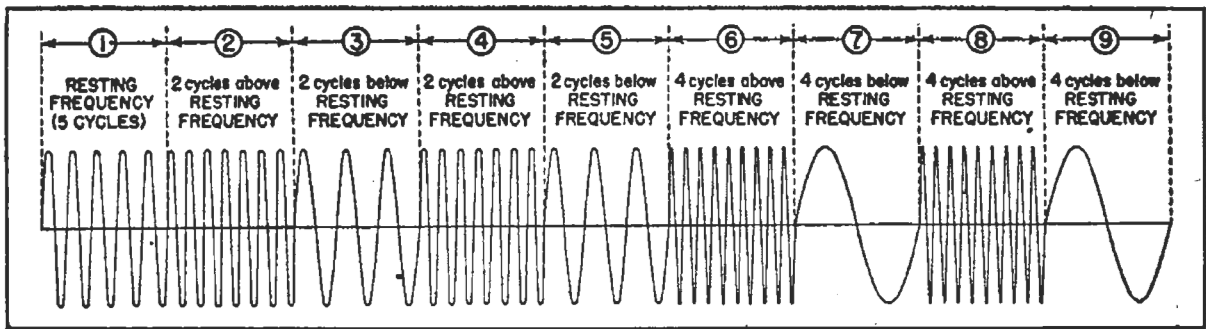


FIG. 23: A fundamental representation of a frequency-modulated wave.

f.m. circuit then produces an output which consists of a signal of constant amplitude that varies in frequency. The frequency increases when the intelligence signal cycle is positive, and decreases when it is negative; the amount of increase or decrease from the normal value depends upon the amplitude of the intelligence signal (the greater the amplitude, the greater the frequency change).

Fig. 23 shows this process in a simplified form. The resting frequency is represented at 1. When modulated by an intelligence signal of medium-strength, the frequency changes up and down as shown at 2, 3, 4, and 5. A stronger intelligence signal causes a wider frequency change, as shown by 6, 7, 8, and 9. (These represent peak values.)

► To sum up: in an f.m. system, the *rate* at which the carrier frequency changes corresponds to the intelligence frequency, while the *amount* of carrier frequency change depends on the amplitude of the intelligence signal.

► The actual circuits used for frequency modulation contain a number of stages and are rather elaborate. However, their fundamental operation can be shown by Fig. 24.

This is the circuit of an oscillator which generates a carrier signal at a frequency determined by the tuned circuit L_1-C_1 . Condenser C_1 is attached to a microphone so its capacitance can

be varied by movements of the microphone diaphragm. When no sound waves are striking the microphone diaphragm, the condenser has a normal or resting value, and the oscillator will produce an r.f. carrier at a frequency known as the "resting" frequency.

When sound waves strike the microphone M , the diaphragm is moved back and forth. This varies the capacity of C_1 and so varies the resonant frequency of the L_1-C_1 circuit. This, in turn, varies the output frequency of the oscillator—in other words, gives us a frequency-modulated carrier. This is a crude example, but it does show the essentials of this system of modulation.

FREQUENCY CONVERTERS

The frequency converter, which combines two different radio frequen-

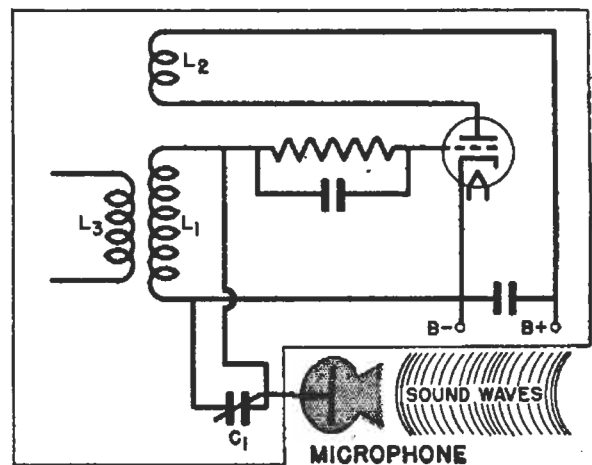


FIG. 24. This simple circuit shows one possible way of frequency-modulating an oscillator. Of course, practical circuits are far more complex

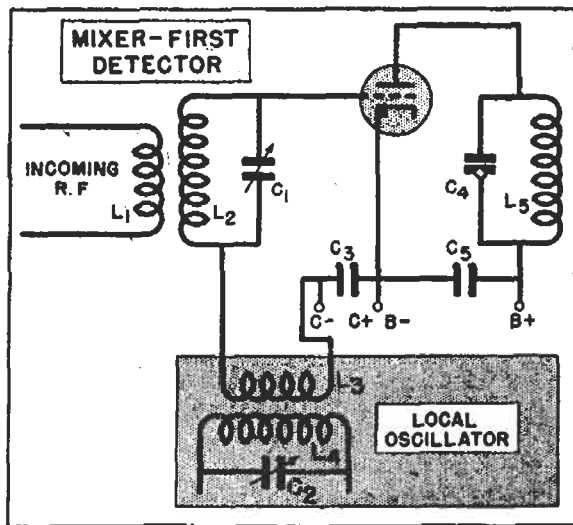


FIG. 25. In the mixer-first detector stage, the incoming signal is mixed and combined with the local oscillator signal. The result is a new carrier frequency known as the intermediate frequency.

cies to form a third frequency, is a very important section of a superheterodyne receiver. You will recall that this is the section which takes the incoming signal and combines it with a signal from a local oscillator so that they produce an intermediate frequency (i.f.).

This frequency conversion takes place in a mixer-first detector circuit like that shown in Fig. 25. The name

of the stage comes from the fact that two r.f. voltages (the incoming carrier and the output of the local oscillator) are fed into the grid circuit, where they *mix*, and from the fact that the C bias voltage is adjusted so it causes plate current cut-off, which makes this a special form of class B amplifier called a *detector*.

If the tube were a perfect amplifier, its plate current would be just a mixture of the signals fed to the grid of the tube. However, by using the characteristics of a detector (to be fully explained elsewhere), we find that the plate current pulsations contain not only the two original signals but also frequencies equal to the sum of, and the difference between, these two. This difference-frequency component is the i.f. we want, so we tune the resonant circuit L_5-C_4 in Fig. 25 to this difference frequency, thereby making the stage output consist almost solely of i.f. voltage. This same action occurs on both a.m. and f.m. signals, because the modulations are just transferred to the new i.f. carrier.

The Diode in Radio Systems

While all the circuits we have discussed so far use tubes with control grids, diode tubes (which have only a cathode and a plate) are also used widely in radio—particularly as rectifiers in power packs and as detectors for separating the intelligence signal from the i.f. signal. Let's touch briefly on each of these important uses.

POWER PACK CIRCUITS

The power pack of an a.c.-operated radio or television apparatus is used to convert the a.c. line voltage to the var-

ious a.c. and d.c. voltages required by the apparatus.

The power pack in the average superheterodyne receiver (as well as in the average transmitter) has four important components:

1. *The power transformer*, which changes the a.c. line voltage to a higher a.c. value for the rectifier tube, and to lower a.c. values for the filaments of all tubes in the apparatus.

2. *The rectifier tube*, which converts the stepped-up a.c. voltage into a pulsating d.c. voltage.

3. *The filter section*, which smooths out or filters the variations in the pulsating d.c. voltage.

4. *The voltage divider*, which divides the resulting d.c. voltage into the various values required by the grids and plates of individual tubes.

► A basic power pack, similar to those used in superheterodyne receivers, is shown in Fig. 26. Let us learn a little more about the purpose of each part.

windings are used for each voltage.

Thus, when 110 volts a.c. are supplied to primary P_1 in Fig. 26, secondary S_1 provides 440 volts a.c.; secondary S_2 provides 5 volts a.c. for the diode rectifier tube filament; secondary S_3 provides 6.3 volts a.c. across terminals x and y for the filaments of all other tubes in the receiver.

The Rectifier Tube. The simplest and easiest way of converting a.c. into

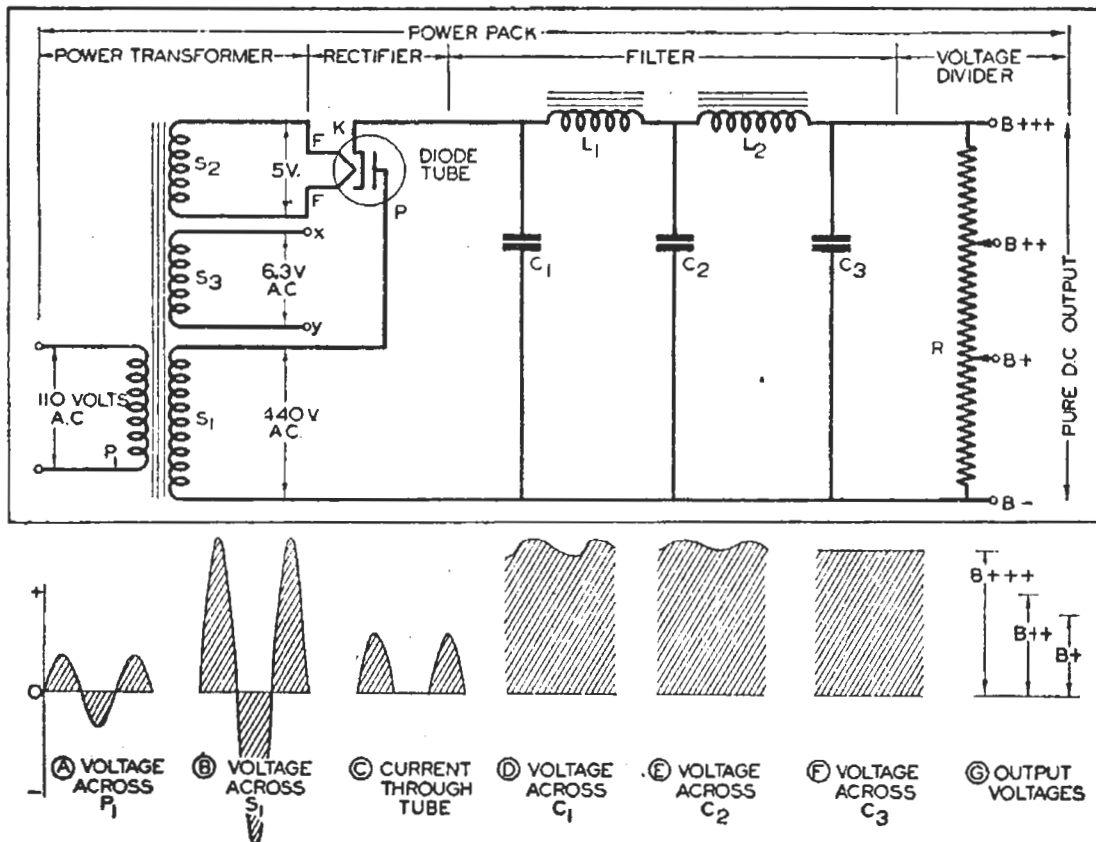


FIG. 26. A simple power supply using a diode tube as a rectifier.

(There is a complete lesson on power supplies later in your Course.)

The Power Transformer. The voltage induced in each secondary winding will depend upon the number of turns in the winding. If the secondary has more turns than the primary, its voltage will be higher than the primary voltage; if the secondary has fewer turns than the primary, its voltage will be lower. If different voltages are required, separate secondary

pulsating d.c. is by means of a diode, as you learned in a previous lesson. This tube allows electrons to flow from its cathode K to its plate P when the a.c. voltage makes the plate positive, but completely blocks the flow of electrons when the a.c. voltage reverses polarity. Thus, if the voltage across P_1 is represented by graph A and the voltage across S_1 is represented by B , the current through the diode tube is represented by C .

The Filter Section. The plate current flowing through the diode rectifier tube is varying or pulsating: as you have learned, this means that it contains a d.c. component plus one or more a.c. components. Since we want only the d.c. for our tube plates and grids, we use a low-pass filter to remove the a.c. components. The chokes offer little opposition to d.c., but L_1-C_2 and L_2-C_3 form voltage dividers for a.c., in which most of the a.c. is dropped across the high-reactance chokes rather than across the low-reactance condensers. The exact manner of filtering, and the special action of C_1 will be covered fully in later lessons on power supplies. However, notice that graphs *D*, *E*, and *F* show that the result is a progressive reduction in a.c., leaving a relatively pure d.c. voltage across C_3 .

The Voltage Divider. The output voltage at C_3 may be too high for many of the tubes, so a resistor, having taps or terminals along it, is sometimes connected across the output of the filter to divide the d.c. voltage. The arrangement is shown in Fig. 26 and the voltage division is represented at *G*. It is customary, when a power pack has several output voltages, to mark $B+$ on the circuit diagram at the terminal which has the lowest positive voltage; the next higher voltage is indicated by $B++$, the next by $B+++$, and so on.

AMPLITUDE DEMODULATORS

A typical a.m. demodulator stage is shown in Fig. 27A. This corresponds to the demodulator stage *M* in Fig. 1, and is the place where the intelligence signal is separated from the i.f. carrier. (You will recall that the intelligence signal was transferred from the original r.f. carrier to the i.f. carrier in the mixer-first detector stage.)

In an amplitude-modulated system,

the modulated i.f. fed into the demodulator stage has a form like that in Fig. 27B. The envelope of the high-frequency voltage — that is, the dotted lines drawn through the peaks of the i.f. voltage—represents the intelligence signal we want. There are actually two envelopes in this diagram, one drawn through the positive peaks and the other through the negative peaks. We want either one but not

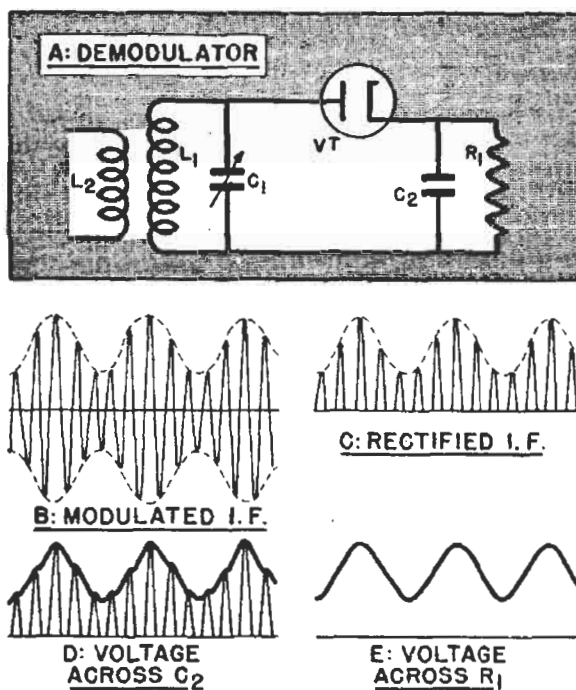


FIG. 27. The diode is also commonly used as a demodulator.

both, since the two are just opposite. If we attempted to send both into some reproducer they would cancel one another and produce no net effect.

Therefore, we apply the modulated i.f. to the diode circuit shown in Fig. 27A. The diode does not permit current flow during the negative alternations of the voltage, so the output of the tube consists of only half of the modulated i.f. (Fig. 27C).

Remember, now—what we actually want is just the *peak voltage* of these half-cycle pulses. Therefore, we feed the diode output into condenser C_2 . During each half-cycle that the tube

conducts, condenser C_2 charges rapidly to the full peak voltage of the pulse; during the rest of the cycle, when the tube is not conducting, C_2 discharges through resistor R_1 . However, R_1 is made so large that C_2 is able to discharge only a small amount before the next pulse comes along and charges it up again. Therefore, the voltage across C_2 (Fig. 27D) remains at or very near the peak voltage of the modulated i.f. pulses all the time. Since C_2 is in parallel with resistor R_1 , the voltage across R_1 (Fig. 27E) also remains just about at the modulation peaks—in other words, the voltage across R_1 is the intelligence signal we want.

FREQUENCY DISCRIMINATORS

The “detector” or “demodulator” for a frequency modulated signal has another function, in addition to that just described. As you learned earlier, frequency modulation changes the amplitude variations of the original intelligence signal into a frequency change. This produces a signal which varies in frequency but has a constant amplitude (Fig. 23). We must convert the frequency variation back into an amplitude change before we can reclaim the original intelligence signal. The processes of conversion and demodulation both occur in a single stage known as a *frequency discriminator*.

Before we study the circuit, let's review one more fact about resonant circuits.

Resonance Curves. You know that an L-C resonant circuit responds best to a signal that has the frequency to which it is resonant—in fact, it actually “amplifies” or steps up such a signal. However, this does *not* mean that a resonant circuit excludes signals of other frequencies. It responds *best* to the frequency to which it is tuned,

but it will respond somewhat to nearby frequencies, with its response becoming less and less the farther away from resonance we go.

This fact is shown by what is called a “resonance curve,” which shows the response of the circuit to the resonant frequency and to other nearby frequencies. A typical curve is shown in Fig. 28. The scale at the left represents the response of a circuit which is tuned to 100 kc. This is indicated by the fact that this is the highest point on the curve. In this case, 100 kc. signals would receive a step-up of 30. Other frequencies are also stepped up, though not as much: frequencies of 90 and 110 kc. are stepped up by a factor of 15, while frequencies of 80 and 120 kc. are stepped up only about 3 each.

Let's see how we can use this variable step-up effect of a resonant circuit

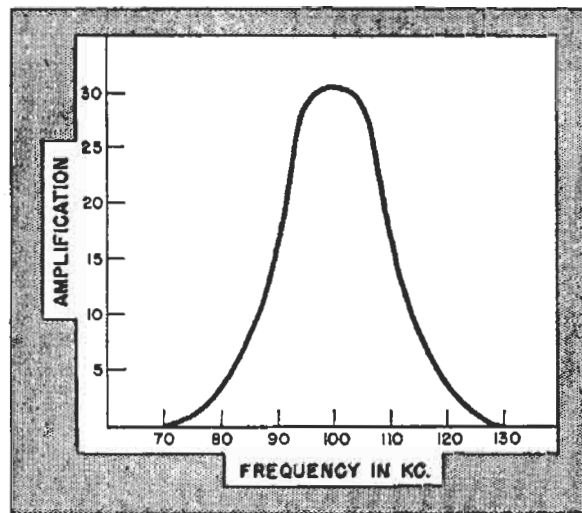


FIG. 28. The response curve of a resonant circuit.

to convert frequency variations into amplitude variations.

Frequency Discrimination. One kind of frequency discriminator circuit is shown in Fig. 29A. The circuit L_1-C_1 is tuned to the i.f. “carrier” or resting signal, but responds well to frequencies on both sides of this value. The input signal induces voltages in both L_2 and

L_3 , thus causing electrons to flow through diodes VT_1 and VT_2 .

Since electrons move only from the cathode to the plate, electrons flowing through VT_1 come upward through resistor R_1 , producing across this resistor a voltage drop with the polarity shown. Similarly, electrons flowing through VT_2 move downward through resistor R_2 ; the voltage drop across this resistor is therefore of opposite polarity from that across resistor R_1 .

The resonant circuit M (L_2-C_2) is

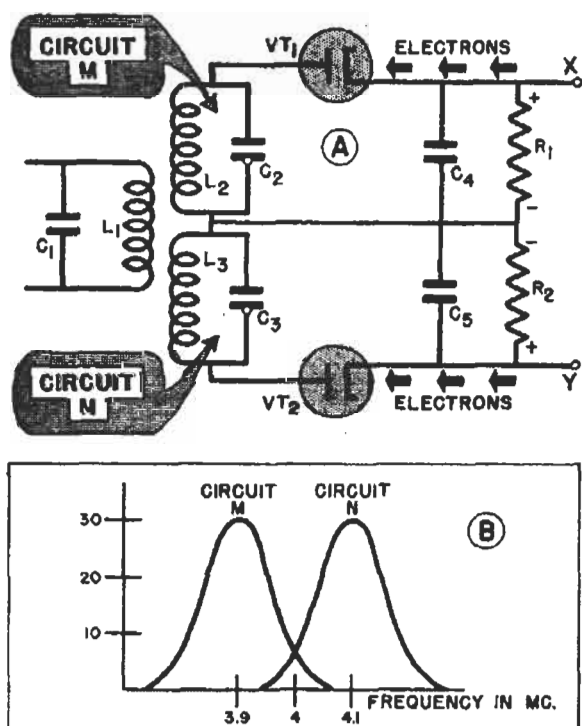


FIG. 29. One type of f.m. discriminator.

tuned to a frequency somewhat lower than L_1-C_1 , while N (L_3-C_3) is tuned to a frequency somewhat higher. If the frequency of 4 mc. in Fig. 29B represents the L_1-C_1 resonance frequency, then 3.9 mc. may represent the resonance frequency of M , and 4.1 mc. that of N . Hence, neither M nor N is tuned to favor the center frequency, although both pass it along to a certain extent.

The circuits are adjusted so that, at the resting frequency, the voltages ap-

plied to VT_1 and VT_2 are equal, and equal currents flow through R_1 and R_2 . As these are equal resistances, their voltage drops are equal, and, since their voltage drops are *opposite in polarity* (see Fig. 29A), there is NO VOLTAGE between terminals X and Y when only the resting frequency is fed into this stage.

► Now let us suppose the signal frequency is modulated so that it swings from 4 to 3.9, back through 4 to 4.1, then back toward 3.9, etc.

As the frequency approaches 3.9 more voltage will be developed by M . This causes larger voltages to be applied to VT_1 ; larger currents result and produce larger voltages across R_1 . At the same time, the signal is moving away from the resonant frequency of N , so less voltage is being applied to VT_2 . The resulting smaller current produces less voltage across R_2 . Hence, for this swing, the voltage across R_1 increases while that across R_2 decreases. The two voltages no longer cancel one another, so a *net voltage* (equal to the difference between them) appears between terminals X and Y.

For example, suppose the R_1 and R_2 voltages are initially 50 volts each, and cancel exactly. On the swing just described, the R_1 voltage may go up to 90 volts and the R_2 voltage may go down to 10 volts. The difference is 90 minus 10 or 80 volts, which will appear between X and Y. Terminal X will be positive, as the polarity will be that of the voltage across resistor R_1 .

► When the swing reverses toward 4.1 mc. exactly the reverse action occurs. Now, N develops the larger voltage, VT_2 passes the larger current, and the drop across R_2 is larger than that across R_1 . This reverses the polarity of the difference voltage existing across X and Y, since the polarity now is that of the voltage across R_2 .

Summary: A signal, shifting in frequency, is introduced into this stage. The frequency variations produce a varying voltage across terminals X and Y. Small frequency changes produce small voltages, as frequencies near 4 mc. do not "climb" as high on the L_2-C_2 and L_3-C_3 resonance curves. Larger changes, out to the limits set by the resonance points (3.9 and 4.1 in Fig. 29B), produce larger voltages. Thus, we have a circuit which produces an amplitude variation from a varying frequency signal.

This same circuit also gives us de-

modulation; in this, it is like the diode detector we just discussed for amplitude-modulated systems. The diodes VT_1 and VT_2 rectify the r.f. signal, while condensers C_4 and C_5 reproduce the modulation peaks. Thus, the original intelligence signal appears across terminals X and Y.

► Remember, we don't expect you to grasp all the details of operation of these circuits from the brief descriptions we've given! This has been just a preview of what you'll be studying in your coming lessons—we are introducing you to practical radio stages.

A Complete Superheterodyne Receiver Circuit

To show you how the stages you have studied are used in a modern radio receiver, we have sketched a basic amplitude-modulation type superheterodyne circuit in Fig. 30. (This same circuit would do for f.m. if the second detector were changed to a discriminator circuit and the resonant circuits were arranged for the proper frequencies. A television receiver is also similar, but there would be differences in the tuned circuits and in the output stage, as well as in the reproducer.) Let's go through its operation briefly, as a summary of what you've learned in this lesson.

► The antenna system intercepts many different modulated r.f. signals, causing modulated r.f. currents to flow in coil L_1 . A number of signals are induced in coil L_2 , but only the signal at the resonant frequency of L_2-C_2 will undergo the full resonance step-up.

Thus, the resonant circuit serves as a preselector which partially separates the desired signal from all others. The

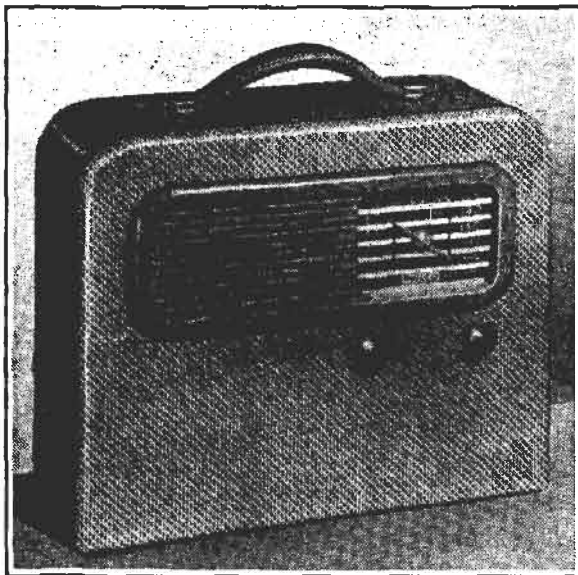
desired signal and such others as get through this resonant circuit then are applied to tube VT_1 . This tube is a class A amplifier, and its plate current variations through coil L_3 induce a voltage in L_4 . The whole stage acts as a combination preselector and r.f. amplifier.

Resonant circuit L_4-C_4 is tuned to the same frequency as L_2-C_2 and serves to separate signals further. Again resonance step-up occurs in this circuit at the desired frequency. (While other frequencies may be getting through, they are not being stepped up as much and so are rapidly being "swamped" or drowned out by the desired signal.)

► At the same time, tube VT_2 in an oscillator circuit is producing a frequency which is higher in value than the incoming carrier frequency. The oscillator tuning condenser C_{11} , which is operated by the same shaft as tuning condensers C_2 and C_4 , is adjusted so that the oscillator frequency always

differs from the desired incoming signal by a chosen amount—the i.f. value. The coil L_9 provides the necessary feed-back action in this oscillatory circuit. Then, coil L_{10} couples the oscillating circuit $L_{11}-C_{11}$ to the input or grid-cathode circuit of tube VT_3 .

► The oscillator and desired input signals are mixed in this mixer-first detector stage, producing the modulated i.f. signal (as well as signals of various other frequencies) in the plate circuit of VT_3 . The resonant circuit L_5-C_5 is tuned to the intermediate frequency,



Courtesy Radio

A typical portable receiver. Once again the standard superheterodyne circuit is used, this time with battery-operated tubes.

and so maximum voltage is induced in coil L_6 at this frequency.

Resonant circuit L_6-C_6 is also tuned to the i.f. value. It assists in separating this particular intermediate frequency from among any others that may be produced by the mixer-first detector tube.

► The i.f. amplifier tube VT_4 is a voltage amplifier, delivering maximum signals to the parallel resonant circuit L_7-C_7 , which is also tuned to the i.f. value; thus, maximum i.f. signals are transferred to L_8-C_8 .

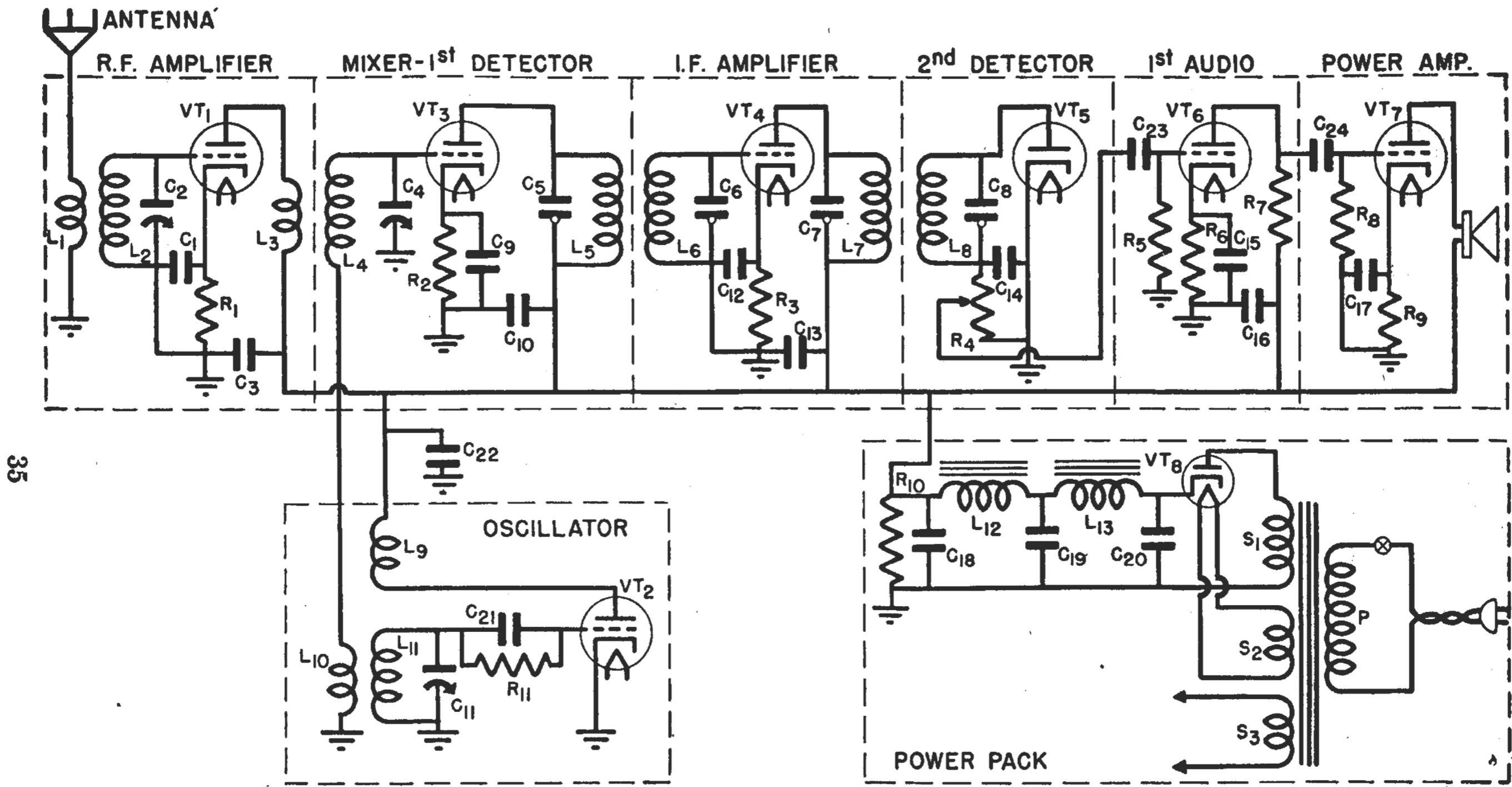
By now, the combined selective effects of all these circuits should have made the desired signal so much larger than any other signals that little or no interference can occur. We get most of our selectivity in the i.f. amplifier; earlier selector circuits are used principally to keep down certain kinds of interference caused by signals far removed from the one desired.

► The signal is now applied to the second detector; here it is rectified by diode VT_5 , which, together with condenser C_{14} , causes the intelligence signal to appear across resistor R_4 .

► The intelligence signal variations across R_4 are then passed through C_{23} , appearing across resistor R_5 in the grid circuit of VT_6 . This voltage amplifier then develops an amplified intelligence signal across R_7 , which is transferred to the grid of VT_7 through C_{24} . This last tube is arranged to deliver power to the reproducer, which is a loudspeaker in this diagram. (Of course, if this were a television set, the reproducer would be a television image-reconstructor tube.)

► A power supply circuit using tube VT_8 is also shown in this diagram. As you see, this power supply is exactly like the one previously discussed in this lesson.

Fig. 30 thus shows all the basic circuits you will find in a superheterodyne receiver intended for an amplitude modulated signal. Of course, *this is a simplified diagram*; actual sets usually have variations from these basic circuits which give certain desired actions. Furthermore, multi-element tubes are generally used in place of tubes VT_1 , VT_3 , and VT_4 , and sometimes in place of tube VT_7 . (In fact, unless screen grid or pentode tubes are used as VT_1 and VT_4 , these stages would have to be modified to prevent undesired oscillations from occurring



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FIG. 30. This is a simplified, basic circuit of a superheterodyne receiver. Of course, the actual circuit would use different tubes and would be somewhat more complex, as you will see later. Also, sometimes the r.f. stage might not be used, and more than one i.f. stage frequently is found. An a.c.-d.c. or battery receiver would use a different power supply. It is important to realize, however, that regardless of the "extras" on the receiver, all superheterodynes can be reduced to a basic circuit like this one. As you read the text, notice how this schematic diagram is drawn to show the orderly progress of the signal from the antenna to the reproducer. However, schematic diagrams are intended to show only the ELECTRICAL connections, not the PHYSICAL positions of parts. Compare this diagram with some of the layout sketches shown elsewhere in this lesson.

within them.) *However, this diagram shows you the relationships between stages and prepares you for the detailed discussions of separate stages that are coming in your next lessons.*

REVIEWS AND PRELIMINARIES

Looking back over the lessons you have studied, you will realize that we have gone over the complete radio system more than once. The first time, in an elementary form, we showed how certain radio *parts*—coils, condensers, resistors, and tubes — were found throughout the radio system.

We studied these parts individually, then in small groups and simple circuits. Finally, in this lesson, we have put these parts together into groups that we call *stages*. Now that you have learned the names and purposes of radio stages, and know the order in which radio signals progress from one to another, you are ready to learn the details of operation of each of them.

► Now, let's look at the lessons just ahead. Your next one will be on iron-

core choke coils and iron-core transformers. You have already been introduced to these devices, but they have a number of important characteristics which have much to do with the workings of intelligence frequency amplifiers and power supplies. Once these characteristics are understood, you will plunge right into a study of power supplies, and from there into other stages. Soon, you will have a complete "how and why-it-works" understanding of radio equipment.

Remember, once you understand fully how stages and sections work when *normal*, you will know what to expect when trouble occurs. As you go along, you will see that certain breakdowns produce certain easily recognizable effects. For example, the output of the radio device may be distorted in a special manner, or there may be noise or hum, etc., caused by certain particular breakdowns. This is vital knowledge—the kind that leads you right to the trouble, so you are going to find future lessons more and more interesting and valuable!

THE N. R. I. COURSE PREPARES YOU TO BECOME A
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Lesson Questions

Be sure to number your Answer Sheet 10FR-4.

Place your Student Number on every Answer Sheet.

Send in your set of answers for this lesson immediately after you finish them, as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.

1. Briefly state the fundamental principle on which the superheterodyne receiver operates.
2. Which one of the following amplifier classes duplicates the *entire* grid signal in its plate current variations: 1, class A; 2, class B; or 3, class C?
3. What important tube rating tells *directly* how much the grid controls the plate current?
4. When does the plate load in a tube amplifier absorb *maximum power*?
5. Name the three important purposes served by the by-pass condenser C_2 in Fig. 13.
6. If the by-pass condenser C_1 in Fig. 17A short-circuits, does the bias voltage: 1, increase; 2, drop to zero; or 3, remain the same?
7. In the oscillator circuit shown in Fig. 21, which two parts develop the automatic C bias?
8. What are the four important components of an average power pack?
9. Which component of the power pack converts a.c. to pulsating d.c.?
10. What two processes occur in the frequency discriminator stage of an f.m. receiver?