

**RADIO FREQUENCY AMPLIFIERS
FOR SOUND AND TELEVISION
COMMUNICATION**

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STUDY SCHEDULE NO. 16

For each study step, read the assigned pages first at your usual speed, then 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 specified for that step. Study each other step in this same way.

1. What R.F. Amplifiers Do; Resonance Curves Pages 1-9

T.R.F. Receivers; Superheterodyne Receivers; Side Bands; Fidelity; R.F. Amplifiers in Transmitters; What Is a Resonance Curve; Typical R.F. Amplifier Stage; How a Resonance Curve Is Secured; Defining Selectivity; Amplifiers in Cascade; Ideal and Practical Ratio Resonance Curves. Answer Lesson Questions 1, 2, 3 and 4.

2. Simple Tuned R.F. Amplifiers; How Tube Capacities Affect R.F. Amplifier Circuits Pages 9-14

Amplifier Loads; Coil-Condenser Loads; Coil-Condenser Load Connections; Tuned Transformer Circuit; Inter-Electrode Capacities; Practical Considerations. Answer Lesson Questions 5 and 6.

3. Getting Rid of Feed-Back; The Screen Grid Tube; The Suppressor Grid Tube Pages 15-20

Grid Suppressors; Neutrodyne Circuits; The Performance of a Screen Grid Tube; purpose of the suppressor grid; suppressor grid circuits; characteristic curves for tubes using suppressor grids. Answer Lesson Question 7, 8 and 9.

4. Variable-Mu or Super-Control Tubes; Practical R.F. Pentode Circuits Pages 20-24

Cross-Modulation; Modulation Distortion; grid construction in a variable-mu tube; mutual conductance and plate current curves; r.f. amplifier circuits using pentode tubes. Answer Lesson Question 10.

5. Band-Pass R.F. Circuits; Fixed R.F. Amplifiers; Power R.F. Amplifiers Pages 24-28

Problems of flat response; double-peak response; band width; purposes of fixed r.f. amplifiers; power r.f. amplifiers for transmitters; Efficiency; class A amplifier; class B amplifier; class C amplifier; Self-Biased R.F. Amplifier Circuits; Power Amplification; Push-Push Power R.F. Amplifiers.

6. Mail your Answers for this Lesson to N.R.I. for Grading.

7. Start Studying the Next Lesson.

Radio Frequency Amplifiers for Sound and Television Communication

WHAT R. F. AMPLIFIERS DO

IN sound or television receivers the modulated R.F. carrier current in the antenna circuit is usually not strong enough to be fed directly to the detector (where the sound or picture signals are separated from the carrier). Weak modulated carrier voltages must often be amplified as much as a million times before they can be satisfactorily demodulated by the detector; this can be done by an *R.F. amplifier* consisting of one or more stages.

This R.F. amplifier must not only *amplify* the desired incoming carrier signal, but must also be able to reject all undesired carrier signals which are present in the antenna circuit; the R.F. amplifier must have *selectivity*. Furthermore, the R.F. amplifier must be able to select, when the receiver controls are adjusted, any one of the many carriers which may be present in the antenna circuit; it must be possible to *tune* the R.F. amplifier to a desired carrier frequency.

T.R.F. Receivers. In one very common type of R.F. amplifier, all of the R.F. stages can be tuned to the frequency of the desired incoming carrier signal. A receiver using this type of R.F. amplifier is commonly known as a tuned radio frequency receiver, or simply as a *T.R.F. receiver*.

Superheterodyne Receivers. The most widely used R.F. amplifier is that in which only the first stage (or first two stages) is tuned to the frequency of the incoming carrier. The amplified carrier signal from the first stage then enters a mixer-first detector tube, where it is mixed with an R.F. signal from a local oscillator in such a way that the frequency value of the R.F. carrier is reduced to a lower R.F. value which is known as the intermediate frequency (I.F.). This intermediate radio frequency, still modulated with either the sound or picture signal, is then amplified by I.F. amplifier stages having fixed tuning and therefore giving maximum amplification at one particular frequency. This is the so-called superheterodyne (or super) principle of R.F. amplification, in which the tuning action takes place before frequency conversion and most of the amplification takes place after frequency conversion (in the I.F. amplifier stages, which are also known as low R.F. amplifier stages). Each R.F. and I.F. stage contributes something to the selectivity of the receiver, with the greatest amount of selectivity being secured in the fixed tuned stages (the I.F. amplifier).

Side Bands. Let us review briefly the characteristics of a modulated radio frequency carrier current. As you know, the process of modulating a carrier introduces side frequencies which are above and below the carrier frequency value. The greater the frequency range of a sound or picture signal being transmitted, the farther off from the carrier frequency will be the extreme side frequencies. The frequency range extending from the lowest to the highest side-band frequency is known as the *band width*;

this naturally varies with the nature of the intelligence being transmitted. In addition to the carrier frequency, then, the R.F. amplifier must therefore handle all of these side frequencies.

Fidelity. The R.F. amplifier in a receiver must be able to reject all signals except the desired R.F. carrier and its side bands, but at the same time it must not be so selective in its operation that it completely or partially rejects any of the side frequencies associated with the desired R.F. carrier frequency.

The fidelity (quality of reproduction) of an R.F. amplifier is impaired when the carrier frequency is amplified more than the side frequencies; distortion likewise occurs if the side frequencies higher than the carrier are amplified more than the side frequencies which are lower than the carrier.

The R.F. amplifier in a sound or television radio receiver must therefore be able to do these four things: 1, tune to the desired carrier frequency; 2, amplify the desired carrier frequency; 3, contribute selectivity by rejecting undesired carrier frequencies; 4, give uniform amplification for all side frequencies when high fidelity reproduction is required.

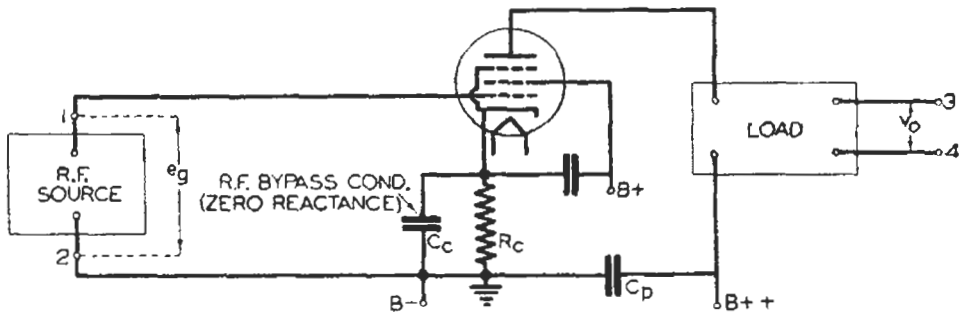


FIG. 1. Simplified schematic circuit diagram of a typical R. F. amplifier stage.

R.F. Amplifiers in Transmitters. In any radio transmitter, regardless of whether sound or picture signals are handled, the R.F. amplifier can be divided into two sections: 1, the section handling only the unmodulated R.F. carrier currents; 2, the section handling the modulated R.F. carrier current. The point of division is therefore the stage in which modulation takes place.

The first section of a transmitter creates, by means of an oscillator stage, an R.F. carrier which is amplified by succeeding R.F. stages until the R.F. carrier current is at the power level required for modulation purposes. Since only a single frequency passes through this first section, the R.F. stages may be very selective.

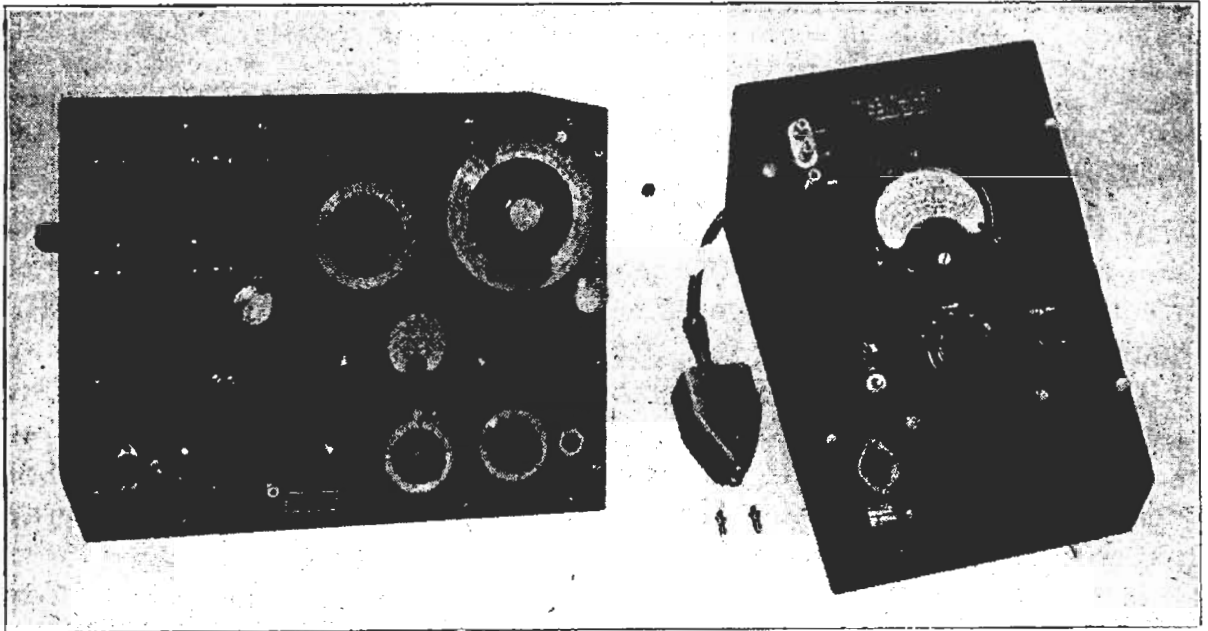
The process of modulation introduces side frequencies as well as harmonics. The second section of a transmitter must therefore pass a definite band width, amplifying all frequencies in this band equally well while raising the power of the modulated R.F. carrier to the desired value.

RESONANCE CURVES

What Is a Resonance Curve? The manner in which the amplifying ability of a tuned R.F. amplifier stage varies for the different frequencies between the lowest and the highest side frequencies is of great importance;

with this information at hand, we can tell how much the stage amplifies, how well it rejects undesired signals, how it amplifies desired signals, and how it amplifies some frequencies more than others in the side bands associated with the desired carrier. All this information about a tuned R.F. amplifier can be presented with a *frequency response curve* which shows in graphical form *the manner in which the amplifier handles or amplifies the various frequencies in its operating range*. Since tuned R.F. amplifiers always contain at least one resonant circuit, this frequency response curve is often called a *resonance curve*.

Typical R.F. Amplifier Stage. The diagram in Fig. 1 presents in simplified form a typical tuned R.F. amplifier stage; after reviewing briefly the



Courtesy General Radio Co.

FIG. 2A (left). General Radio type 605-A signal generator, which consists fundamentally of an R.F. oscillator having a frequency range of 95 kc. to 30,000 kc., and means for varying and measuring the output voltage. There are also provisions for modulating the R.F. signal with an audio note of fixed frequency or with an external modulating signal when a modulated carrier is required; the meter on the panel indicates percentage modulation in this case.

FIG. 2B (right). General Radio type 726-A vacuum tube voltmeter, a multiple-range instrument designed to measure R.F. voltages from .1 to 150 volts with a high degree of accuracy. It is calibrated to read r.m.s. (effective) values of sine wave voltage.

operation of this stage, I will show you how a resonance curve for it can be obtained.

The R.F. source in Fig. 1 feeds to the grid-cathode of the tube (between points 1 and 2) an R.F. voltage which we will call e_g . As a result of the amplifying action of the tube and the effects of the load, there appears across the output terminals of the load an R.F. output voltage which we will designate as v_o . The net or true voltage amplification of this R.F. amplifier stage (expressed as A) is the output voltage v_o divided by the input voltage e_g . The type of tube used, the operating voltages and the type of load applied determine to a great extent the behavior of this stage as an amplifier.

How a Resonance Curve Is Secured. Although an R.F. amplifier must handle many frequencies (the carrier frequency and the side-band frequencies) simultaneously in actual practice, it is obvious that we cannot study the performance of the amplifier while all these frequencies are pass-

ing through; the practical way is to send through only one frequency at a time, a simple sine wave R.F. signal, and measure how much it is amplified. The frequency of this test signal is then changed to other values, and the amplification is measured at each frequency.

Radio engineers use a signal generator like that shown in Fig. 2A to supply a sine wave R.F. signal whose frequency can be adjusted to the various values required when testing an R.F. amplifier. The large dial in the upper right corner of the panel controls the frequency of the output, the dial at its left changes the frequency range, and other dials change the strength and the modulation percentage of the R.F. output signal when a modulated signal is desired.

To measure the input and output voltages of an R.F. amplifier, engineers use a special voltmeter which employs a vacuum tube as a detector; a typical laboratory type vacuum tube voltmeter (abbreviated V.T.V.M.) is shown in Fig. 2B. The voltage being measured is applied to the wedge-shaped probe (at the left of the cabinet) in which is an acorn-type tube connected as a rectifier. A shielded cable connects the probe unit to the cabinet on which is mounted a multi-range voltmeter and the control switches. The amplification produced by an R.F. stage at any frequency can be determined simply by dividing the measured output voltage v_o by the measured input voltage e_r .

If the R.F. amplifier stage in Fig. 1 is set to amplify a 1,000 kc. signal, and we desire to obtain a resonance curve for the amplifier at this resonant frequency, we would connect the signal generator in place of the R.F. source and set it in turn at 980, 985, 990, 995, 1,000, 1,005, 1010, 1,015 and 1,020 kc., and for each setting connect the vacuum tube voltmeter across terminals 1 and 2 to measure e_r (if its value is not already known) and across terminals 3 and 4 to measure v_o . We would then compute the amplification A obtained at each frequency, and plot our information on graph paper in the manner shown in Fig. 3 to secure the resonance curve for the R.F. amplifier at 1,000 kc. Notice that as the frequency is increased from the lowest value, the amplification increases and reaches a maximum value at 1,000 kc., the resonant frequency of the stage. Further increases in frequency beyond 1,000 kc. give decreasing amplification, the amplification dropping to zero at about 20 kc. above the resonant frequency. A curve of this nature is called a *single-peaked resonance curve*, for it gives maximum or peak amplification at a single R.F. value.

When a 1,000 kc. R.F. carrier is modulated with a sound signal having a maximum frequency of 5 kc., you know that the side-band frequencies will extend from 995 to 1,005 kc. The amplifier represented by the response curve in Fig. 3 would amplify the carrier frequency about 65 times, but would amplify the lowest side frequency (f_1 in Fig. 3) only 50 times and the highest side-band frequency (f_2) 58 times.

An amplifier which has a single peaked resonance curve distorts a modulated carrier in two ways. If the corresponding upper and lower side frequencies are amplified equally well *but less than the carrier frequency*, the result after demodulation is comparable to frequency distortion (where the extremely high frequencies in the modulation signal are eliminated). If the corresponding upper and lower side frequencies are, in addition, *amplified unequally*, as is the case in Fig. 3, there is amplitude distortion as well.

Defining Selectivity. Since the U. S. A. radio stations in the broadcast band are only 10 kc. apart in frequency, it is essential that a receiver

tuned to one station does not also pick up the stations 10 kc. away on either side; insufficient selectivity in an R.F. amplifier therefore results in station interference. If the tuned R.F. stage whose performance is represented by Fig. 3 is the only one in a receiver, and it is tuned to a 1,000 kc. station, its carrier signal would be amplified about 65 times, while the carrier signals of adjacent stations (at 990 kc. and 1,010 kc.) would be amplified 15 times and 28 times respectively; this is clearly poor selectivity, for all three stations, if received with nearly equal signal intensity, will be heard at once. What, then, constitutes good selectivity?

Selectivity was formerly found according to the following procedure: The two frequencies at which amplification was 70% of the maximum amplification (the value at resonance) were found; the difference between these frequencies was determined, and the resonant frequency divided by this difference in frequency was said to be a measure of the selectivity of

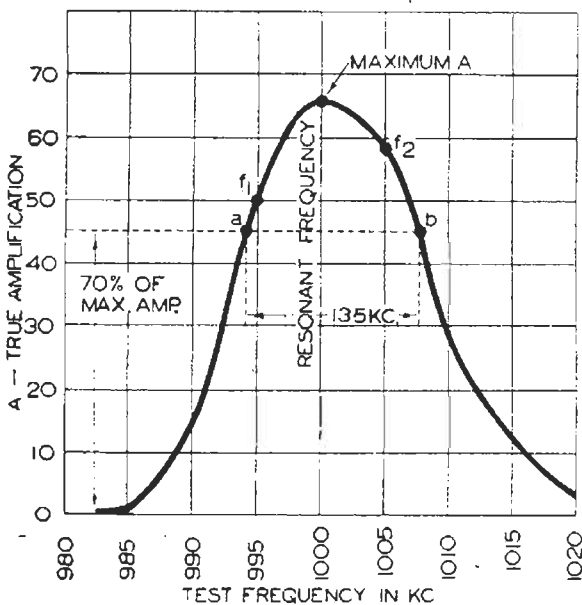


FIG. 3. Conventional resonance curve at 1,000 kc. for an R.F. amplifier stage.

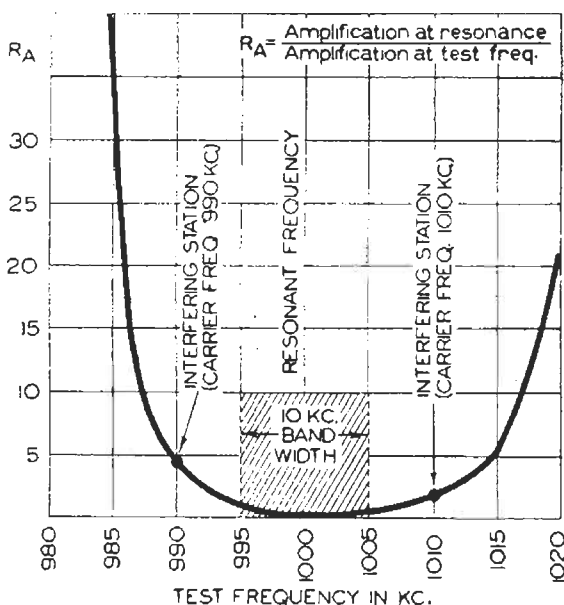


FIG. 4. Ratio resonance curve at 1,000 kc. for an R.F. amplifier stage. R_A is 1 at 1000 kc.

the amplifier. Points *a* and *b* in Fig. 3 correspond to the two frequencies at which *A* is 70% of its maximum value. The difference in frequency between these two points is 13.5 kc., hence the selectivity value for this particular amplifier stage would be 1,000 (the resonant frequency) divided by 13.5, or 74. Incidentally, this value is also the *Q* factor for the resonant circuit of this amplifier stage.* This older definition for selectivity and *Q* factor is perfectly satisfactory when applied to simple or single resonant circuits, since all such circuits have essentially identical resonance curve shapes. The response curves of complicated or multi-resonant circuits have widely varying shapes, however, making this old definition of selectivity unsuited for present day use.

The modern definition for receiver selectivity is based upon the fact

* In a series resonant circuit which is tuned to resonance, the ratio of the voltage across the coil or condenser to the applied circuit voltage is the *Q* factor of the circuit; *Q* factor is also the reactance of the coil divided by the circuit resistance. In a parallel resonant circuit the ratio of the coil or condenser current to the line supply current at resonance is the *Q* factor; *Q* factor is also the resonant resistance divided by the coil or condenser reactance at resonance.

that we are *primarily* interested in how much better the amplification is at resonance than at the nearest undesired frequencies. *For good selectivity, the desired signal frequency and its side frequencies must be amplified at least 1,000 times more than the nearest undesired signal and its side bands.* For fair selectivity this ratio (which we shall designate as R_A) can be about 100, and for excellent selectivity the ratio must be higher than 10,000.

Fidelity is now defined in much the same way as selectivity. *For good fidelity the desired carrier frequency must not be amplified more than 1.25 times the highest side frequency desired with that signal;* in other words, amplification at the highest side frequency must be at least 80% of the amplification at resonance. These figures are by no means fixed, for they are based upon opinions rather than upon precise data, and in addition will vary with the purpose of and use to which an R.F. amplifier is put.

A better picture of the frequency response characteristic of an R.F. amplifier can be obtained by computing R_A , the ratio of amplification at resonance to amplification at the test frequency, for each value of test frequency and plotting these ratios against frequency in the manner shown in Fig. 4.* A curve like this (called a *ratio resonance curve*) gives us both the fidelity and selectivity characteristics of an amplifier; for example, in Fig. 4 the highest side frequency (for a 5 kc. modulating signal) has a ratio of about 1.1 (at 1,005 kc.), which indicates excellent fidelity since it is considerably less than the maximum allowable value of 1.25. At 1,010 kc. however, the ratio is only about 2.3, indicating that the desired carrier frequency signal will be amplified only about 2.3 times more than the carrier signal of an undesired station at 1,010 kc. if both carrier signals have equal signal strength at the location of the receiver. Thus, fidelity is good but selectivity is very poor in the amplifier represented here.

Amplifiers in Cascade. If one R.F. amplifier stage raises the voltage at the resonant frequency 10 times, another similar stage connected in cascade will amplify the voltage 10 times further, giving a total amplification of 100; the addition of a third identical amplifier stage will boost the voltage 10 times further, giving a total amplification of 1,000. The amplification (gain) of an R.F. amplifier is therefore the product of the gain of each individual stage (the gains are multiplied together).

Resonance curves for two and three tuned R.F. amplifier stages in cascade are given in Fig. 5, with the curve for a single stage shown for comparison. The addition of stages makes the resonance curve sharper and higher in peak value. *Cascading of R.F. amplifier stages thus boosts the amplification and improves the selectivity of an R.F. amplifier.*

The resonance curve for perfect fidelity and ideal selectivity should be flat throughout the desired band width and should have straight vertical sides; adding stages makes the sides of the resonance curve more nearly vertical, giving better selectivity, but lowering fidelity (by making the resonance curve sharper in the band width).

* Laboratory engineers sometimes measure R_A directly. At each test frequency they increase the output of the signal generator until the measured amplifier output voltage v_o is the same value as it was at the resonant frequency; the signal generator output at the test frequency divided by the signal generator output at resonance gives the value of R_A .

Fidelity and selectivity characteristics of amplifiers in cascade are more clearly presented by plotting R_A against frequency, as was done in Fig. 4; this is done in Fig. 6. Let us analyze these three ratio resonance curves; for convenience I will set down again the practical definitions for selectivity and fidelity.

Good fidelity: R_A is lower than 1.25 at the *highest* side frequency.

Good selectivity: R_A is higher than 1,000 on both adjacent-channel carrier frequencies.

Checking fidelity first, we find that good fidelity is secured with one stage (R_A is less than 1.15 at 1,005 kc.) and with two stages ($R_A=1.25$),

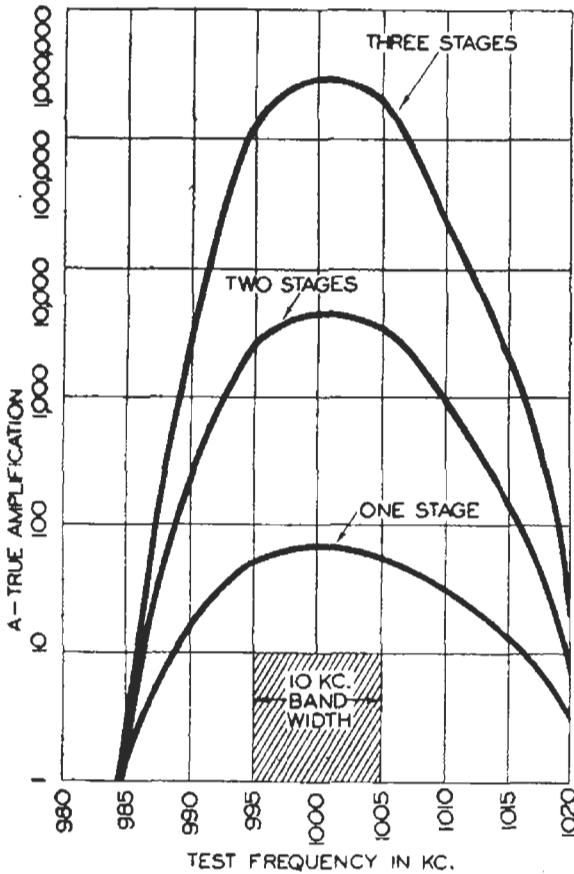


FIG. 5. Resonance curves at 1,000 kc. for one R.F. amplifier stage and for two or three similar stages connected in cascade. Amplification A is here plotted on a special condensed scale which corresponds to the response of the human ear. Resonance is at 1,000 kc.

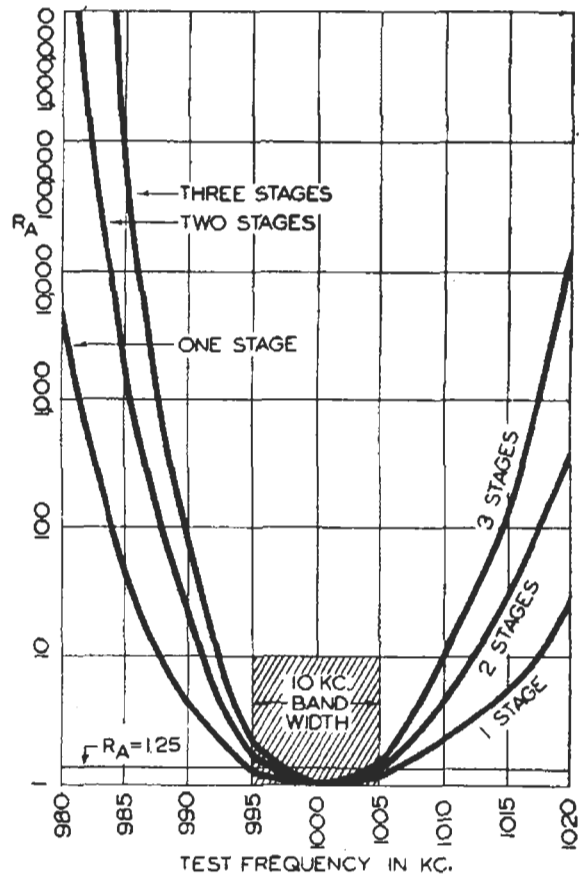


FIG. 6. These three ratio resonance curves give the fidelity and selectivity characteristics of one, two and three of the R.F. amplifier stages in Fig. 1. The scale at the left gives values of R_A (amplification at resonance \div amplification at test frequency). Resonance is at 1,000 kc.

but three stages give poor fidelity (R_A is higher than 1.25). As to selectivity, R_A for three stages is about 100 at 990 kc. and is about 10 at 1,010 kc., these being the adjacent-channel carrier frequencies in the broadcast band. The lowest value governs, and hence selectivity is poor. For one and two stages, the values of R_A at these undesired carrier frequencies are lower, so selectivity is even poorer than for three stages.*

* When peaked R.F. amplified stages have symmetrical response curves, several stages may be connected in cascade to give good selectivity, and the attenuation of the higher modulation frequencies (the poor frequency response) can be compensated for by using an audio (or video) amplifier which will give greatest amplification at the higher frequencies. This fact makes it possible to equalize (adjust) a receiver for high fidelity even though individual stages in it do not have ideal characteristics.

You will notice that the vertical scales in Figs. 5 and 6 are arranged in a different manner from those in Figs. 3 and 4; this "condensing" was done in order to cover a wide range of values while still showing the nature of the curves clearly at the lowest values, around the resonant frequency. These condensed scales are known as logarithmic scales; they also tell us more clearly what the ear is going to hear, for our ear has this same logarithmic response.

Complete R.F. amplifiers, regardless of whether they are of the super-heterodyne or the T.R.F. type, are measured in exactly the same manner as the single stage shown in Fig. 1, and the results are plotted exactly as is done in Figs. 5 and 6. The resulting curves allow the radio engineer to study the amplification, selectivity and fidelity characteristics of the entire R.F. amplifier.

Ideal and Practical Ratio Resonance Curves. Ratio resonance curves for four different R.F. amplifiers, each of which contains several stages in cascade, are given in Figs. 7A and 7B. These curves give the value of the ratio R_A for different frequencies up to 20 kc. above and below resonance. You can consider R_A in two ways, as the ratio of the amplification at resonance to the amplification at various off-resonance frequencies, or as how much stronger the signal must be off resonance to produce the same output as at resonance. The higher the value of R_A for frequencies off resonance, the more selective is the amplifier.

Before you can study the ratio resonance curve for a particular R.F. amplifier, you must know at least two facts: 1, the frequency separation in kc. between the stations which are to be picked up by that amplifier; 2, the R.F. band width in kc. which is required to handle the entire range of frequencies for the audio or video signal being transmitted.

Stations in the broadcast band in the United States, radiating sound signals, are located 10 kc. apart and always have a frequency value ending in zero; thus you may receive stations at 570, 580, 590 kc., etc. For sound signals having a maximum range of 5,000 cycles, the side frequencies will extend 5 kc. above and below the carrier frequency. For good selectivity, then, the value of R_A should be greater than 1,000 at frequencies more than 5 kc. off the desired carrier frequency. To secure good amplification of the side frequencies, however, R_A should be as close to the value 1 as possible throughout the band width of 10 kc.

Curve 1 in Fig. 7A (the dash-dash curve) represents the ideal ratio resonance characteristics for an R.F. amplifier designed for use with broadcast band apparatus; all frequencies in the band width are amplified equally, while all other frequencies are completely cut off. Curves 2 and 3 in Fig. 7A and curves 4 and 5 in Fig. 7B progressively approach this ideal response, curve 5 being about the closest approach to the ideal which can be secured in practice. A radio expert would label curve 2 as "fair fidelity but very poor selectivity"; curve 3 would be designated as "poor fidelity and good selectivity" (this particular response curve might be satisfactory for radio-telegraphy work, where the side frequencies extend very little off resonance). In Fig. 7B, curve 4 represents an amplifier having good

selectivity and fair fidelity, while curve 5 has excellent fidelity and good selectivity.

Resonance curves very similar to those just studied are used in portraying the abilities of R.F. amplifiers designed for television purposes. Remember, however, that the resonant frequencies here will be in the range extending from 40 to 90 megacycles, the band width will be 5 to 10 megacycles wide and stations will be separated as much as 15 megacycles. The same resonance curves can be used to portray the behavior of R.F. amplifiers which follow the modulated stages in transmitters.

Now we are ready to consider R.F. amplifier circuits in detail; you will learn how their desired features are obtained. A knowledge of how their operation is affected by changes in circuit parts will be of great value when you have to make repairs on incorrectly operating receivers.

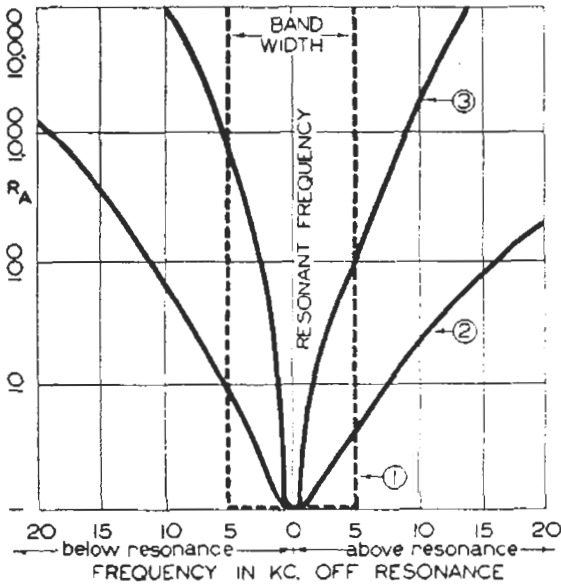


FIG. 7A. Ideal (1) and typical (2 and 3) ratio resonance curves for R.F. amplifiers.

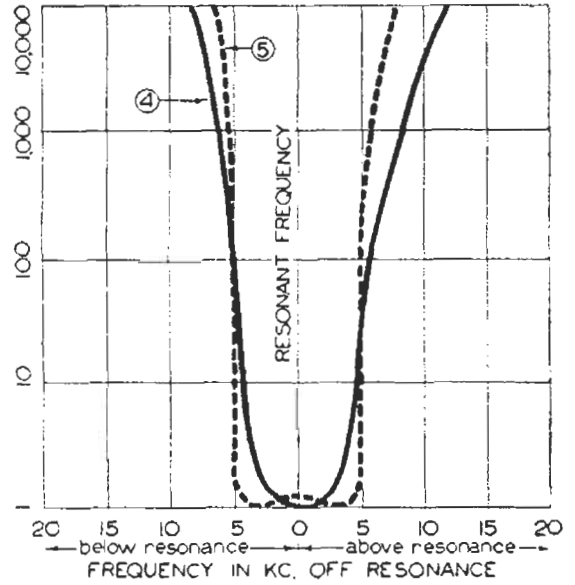


FIG. 7B. Ratio resonance curves of R.F. amplifiers designed to have 10-kc. selectivity. Vertical scale gives values of R_A .

SIMPLE TUNED R. F. AMPLIFIERS

Amplifier Loads. Almost any circuit which uses a vacuum tube having a control grid can be used as an R.F. amplifier provided that the proper plate load is used. If a simple resistor or coil is made to serve as the plate load, we have an untuned R.F. amplifier circuit which will amplify R.F. signals over a *very wide band*; this poor-selectivity characteristic is highly desirable in those cases where other radio devices are used for signal selecting and tuning purposes. If a reasonable amount of voltage amplification is to be secured, the ohmic resistance (or the reactance in the case of a coil) of the plate load (which is untuned) should be greater than the A.C. plate resistance of the tube.

Coil-Condenser Loads. You are already familiar with the fact that a coil and condenser connected in parallel, as in Fig. 8, behave exactly like a resistor of high ohmic value at the resonant frequency (the frequency at which the coil reactance exactly balances the condenser reactance), but offer a lower reactance at other frequencies. Changing the value of either

the coil or the condenser changes the resonant frequency. Thus this parallel coil-condenser resonant circuit is a very desirable load for an R.F. amplifier, giving high amplification of the desired signal, giving low amplification of other frequencies and permitting tuning to a desired frequency.

If coil L in Fig. 8 has an inductance of 250 microhenrys and a resistance R of 20 ohms, and condenser C is adjusted to 100 micro-microfarads (mmfd.), this circuit will act like a 125,000 ohm resistor at its resonant frequency (this can be proved by actual test or by computation with a formula given later in this book). Thus, when this circuit is used as a plate load, a high value of A.C. voltage is produced across terminals 1 and 2 at the resonant frequency, but the circuit acts either as a condenser or coil of low reactance to other frequencies (off-resonance frequencies), with a resulting low A.C. voltage for these frequencies; the circuit therefore possesses selectivity characteristics. Decreasing the inductance of the coil or decreasing the capacity of the condenser *raises* the resonant frequency of the circuit. Another advantage of this coil-condenser tuned load circuit is that it is not seriously affected by capacity between the electrodes of the tube; a high plate-to-cathode capacity simply means C can be smaller.



FIG. 8. A coil-condenser load (a parallel resonant circuit) acts as a resistor of high ohmic value at the resonant frequency of the circuit.

Coil-Condenser Load Connections. There are a number of different ways of connecting a coil-condenser resonant circuit into the plate circuit of a tube; four of the most important of these are shown in Fig. 9. Remember that a small resistance (that of the coil) is always present in a resonant circuit (it is usually neglected when preparing diagrams, in order to simplify the presentation of resonant circuits).

In Fig. 9A, resonant circuit $L-C$ (often called a tank circuit) is connected directly into the plate circuit, with D.C. plate supply current flowing through coil L . The A.C. voltage which is developed across the tank circuit terminals is impressed upon the grid of the next R.F. amplifier stage through coupling condenser C_K , which has negligible reactance to signal currents. This condenser also prevents D.C. plate current from flowing to the grid of VT_2 , the next tube. Resistor R_g has an important function, that of connecting the grid to ground in order that the C bias voltage developed by cathode circuit resistor R_c can act upon the grid of the tube. Obviously the ohmic value of R_g must be much higher than the resonant resistance of the tank circuit if it is not to affect the plate circuit. (Since R_g is in parallel with the plate circuit, a low value of R_g would absorb power, lowering the resonant circuit resistance and thus reducing the net plate circuit resistance; the result would be a reduction in the amplification of the amplifier and a broadening of the resonance curve. This broadening improves fidelity, and is therefore desirable in some cases.)

In Fig. 9B, choke coil CH is used in place of grid resistor R_g . The reactance of this choke coil at any frequency to which the tank circuit may be tuned should be many times greater than the resonant resistance of the tank circuit, in order to secure a large A.C. voltage drop across the tank circuit.

In Fig. 9C the positions of the choke coil and the tank circuit are interchanged as compared with Fig. 9B; this arrangement, where the choke coil is in the plate circuit, is known as a shunt fed circuit, for the D.C. power is fed in parallel or in shunt with the L - C circuit. When the resistance of R_p in Fig. 9A and the reactance of CH in Figs. 9B and 9C are many times greater than the resonant resistance of the tank circuit, the values of L and C in the tank circuit control the R.F. signal output; the resonant circuit thus becomes the plate load. The following important facts apply to all three circuits:

1. *The values of L and C determine the resonant frequency of the tank circuit.* For practical reasons it is customary to tune the condenser; decreasing the capacity of the condenser increases the resonant frequency of the tank circuit. Coil L is still shunted by a capacity, however, when condenser C is set at minimum capacity; this residual capacity consists of: a , the distributed capacity of coil L ; b , the minimum capacity of the condenser; c , capacities between the tube electrodes and between the leads in the circuit. In a well designed practical circuit the minimum or residual tank capacity is about one-ninth of the maximum tank capacity; this means that the maximum frequency to which the tank circuit can be tuned is about 3 times the lowest frequency. An example of this is the average broadcast band receiver, which tunes from about 500 to 1,500 kc. with a single set of coils.

2. *The effective resistance of the tank circuit at resonance is determined by the inductance of the coil, the capacity of the condenser and the inherent tank circuit resistance.**

3. *If the tank circuit at resonance has a coil of high inductance and a condenser of low capacity, the resonant resistance will be high.* Radio men say that a tank circuit with large L and low C has a high L/C ratio. The lower the inherent resistance of the tank circuit, the greater will the resistance of a tank circuit be at resonance.

4. In a single-tube tuned R.F. amplifier stage which uses a parallel resonant circuit as a plate load, the maximum possible amplification is the μ of the tube, and this value is obtained when the resonant resistance of the plate load is many times greater than the A.C. plate resistance of the tube. Triode tubes have relatively low A.C. plate resistances and hence this condition is quite easy to secure, but with tetrode and pentode tubes the load ordinarily cannot be made high enough in value to give maximum amplification.

5. When the tank circuit is tuned to higher frequencies in the usual manner by reducing the value of capacity C , the L/C ratio increases, raising the resonant resistance of the load.

Tuned Transformer Circuit. In Fig. 9D is perhaps the most widely used R.F. amplifier circuit, the so-called tuned transformer circuit. The power required for tank circuit L - C must be supplied to the primary coil L_p by the tube. When the L - C tank circuit acts like a resistor, as at resonance, the reflecting properties of the transformer make coil L_p act like a resistor (the

* There are two formulas for securing the resonant resistance of a tank circuit like that in Fig. 8; the radio engineer uses whichever is more convenient. The

formulas are: $R_r = \frac{L}{RC}$, and $R_r = \frac{\omega^2 L^2}{R}$, where R_r is the resonant resistance of the tank circuit in ohms, R is the inherent tank circuit resistance in ohms, ω is 6.28 times the frequency in cycles, L is the inductance of the coil in henrys and C is the capacity of the condenser in farads.

leakage inductance of primary L_p affects this condition, but this inductance is so small that it can be neglected). Facts 1, 2, 3 and 5 brought out in connection with the first three circuits in Fig. 9 hold true also for this circuit, and the following additional facts apply to this circuit only:

1. Increasing the number of turns on primary winding L_p or increasing the coupling between L_p and L raises the reflected resonant resistance appearing between terminals 1 and 2. We are actually increasing the mutual inductance M of the coils when we add turns or move the coils closer together; thus we can say that increasing the mutual inductance increases the effective resonant resistance of the plate load.

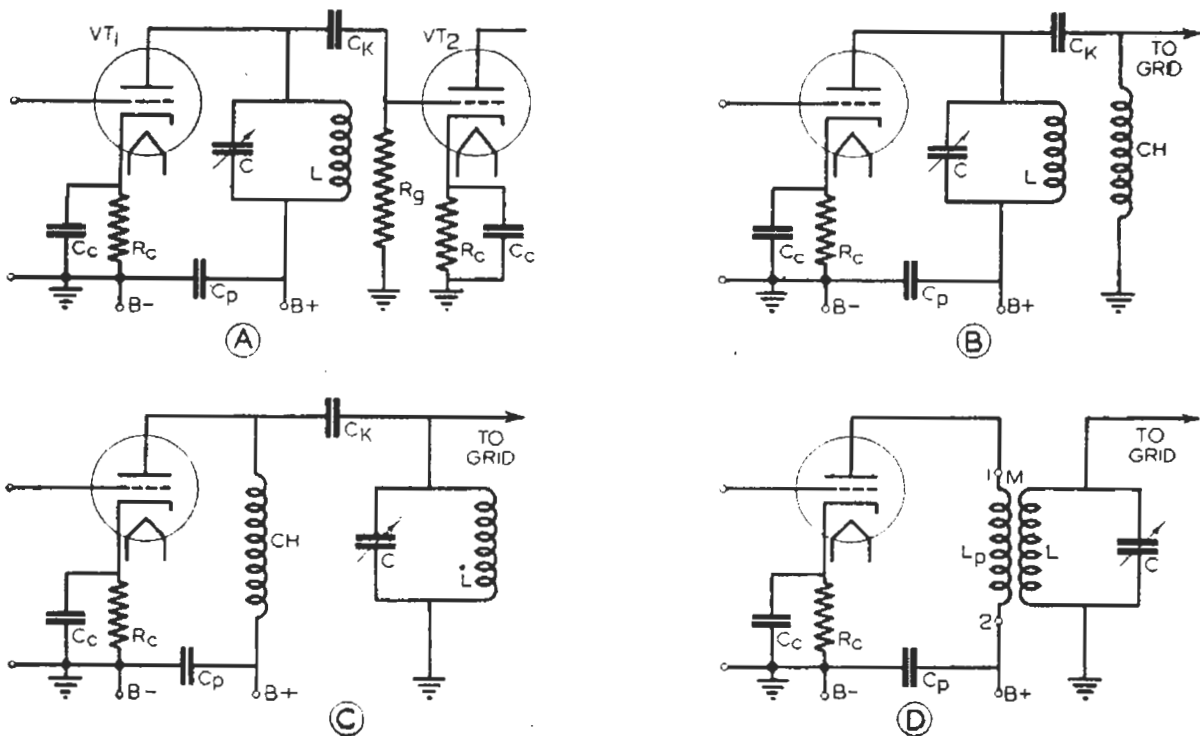


FIG. 9. Four ways of connecting the resonant L - C load circuit into an R.F. amplifier stage so it will act as a plate load. These circuits apply also to screen grid and pentode tubes; triodes are shown here merely for simplicity.

2. When a tuned transformer load is used, maximum voltage amplification is obtained *when the resonant resistance of the tuned load (as it appears in the plate circuit) is equal to the A.C. plate resistance of the tube*, for the tank circuit then absorbs the greatest amount of power.

3. Circuit L - C in Fig. 9D is a *series resonant circuit* (because the voltage induced in it acts in series with L and C), and hence acts as a coil when tuned below resonance and as a condenser when tuned above resonance. The effects at terminals 1 and 2 are opposite, however, because of transformer action.

HOW TUBE CAPACITIES AFFECT R. F. AMPLIFIER CIRCUITS

Inter-Electrode Capacities. When we study an ordinary triode tube in detail, we realize that the grid, plate and cathode are tiny condenser plates which introduce into the tube circuits the three capacities shown by dotted lines in Fig. 10. These inter-electrode capacities are: 1, the grid-to-cathode capacity, C_{gk} ; 2, the plate-to-cathode capacity, C_{pk} ; 3, the grid-to-plate capacity, C_{gp} . It is the grid-to-plate capacity, C_{gp} , which prevents the grid and plate circuits from being entirely independent of each other.

In the R.F. amplifier circuit in Fig. 10, the grid-to-cathode capacity C_{gk} acts simply as if it were an extra condenser connected in parallel with C_1 ; the plate-to-cathode capacity C_{pk} acts as a condenser connected in parallel

with C_2 . By-pass condensers C_0 and C_p in Fig. 10 are of such high capacity that they act as low reactance paths for A.C. currents, and therefore need not be considered in this discussion.

In Fig. 11 the R.F. amplifier circuit of Fig. 10 has been modified to include only those parts which affect the tube as an amplifier; C_{gk} and C_{pk} have been placed in their effective positions. Capacity C_{gp} can, according to a complicated mathematical analysis which need not be taken up here, be considered as *equivalent* to an extra resistor R_R and an extra condenser C_R , both in parallel with the grid tank circuit C_1-L_1 . Remember that R_R and C_R are present *as effects only*, not as actual devices; their exact equivalent values vary greatly with circuit conditions, being dependent upon the capacity of C_{gp} , upon the resonant frequency and nature (resistive, inductive or capacitive) of the plate circuit load, and upon the over-all amplification of the stage.

Coil L_2 in Fig. 11 acts with C_2 and C_{pk} to form a parallel resonant tank circuit which is the equivalent of a high resistance at resonance. When this parallel resonant circuit is tuned below resonance (to a frequency *lower*

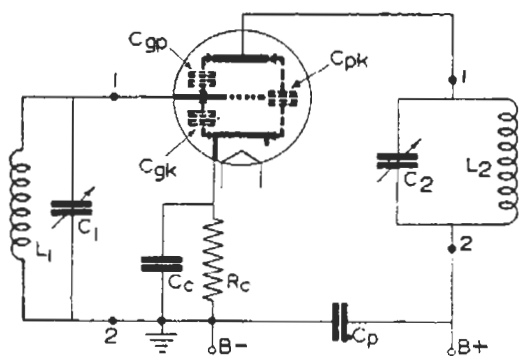


FIG. 10. The three inter-electrode capacities which enter into the operation of an R.F. amplifier are here indicated by dotted lines.

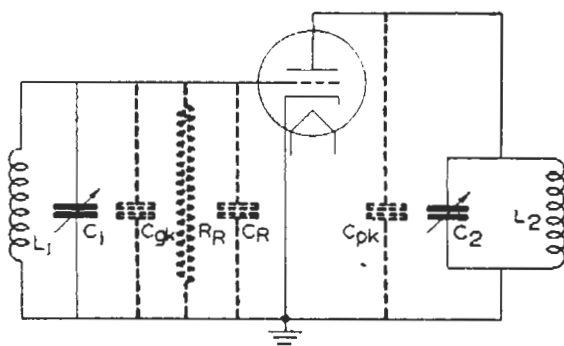


FIG. 11. The circuit of Fig. 10 is here modified to include only those parts which affect the tube as an amplifier. The effects of the grid-to-plate capacity C_{gp} are represented by R_R and C_R .

than that of the incoming signal), the tank circuit will act as if it were a condenser. (This is because decreasing the resonant frequency by increasing the capacity of C_2 lowers the reactance of the condenser but does not affect the reactance of the coil; in a parallel circuit such as this it is the lowest reactance [the reactance of L_2 or C_2] which governs the nature of the tank circuit off resonance.) Likewise, when this parallel resonant circuit is tuned above resonance (to a frequency *higher than* that of the incoming signal), the tank circuit acts as a coil.*

* When a resonant load circuit is loosely coupled inductively to the plate circuit of a tube, as is done in Fig. 9D, the tuned secondary ($L-C$) is purely resistive when tuned to resonance. Because of the leakage inductance of primary L_p , however, the effect of the load in the plate circuit (as measured between points 1 and 2) will be *inductive*. When the $L-C$ circuit is tuned off resonance, the reactance which it reflects into primary L_p will always be opposite in nature to the reactance which the $L-C$ circuit itself appears to have. Thus, when series resonant circuit $L-C$ is tuned above resonance it acts as a capacity and is reflected as an inductance; when tuned below resonance it acts as an inductance and reflects as a capacitance. In order to make the effect of the load purely resistive across terminals 1 and 2, then, it is necessary to tune the load slightly below resonance, so it reflects a capacitance which will balance out the leakage inductance of the primary; in doing this we are really using the secondary $L-C$ circuit to tune the primary L_p (which is in effect the load) to resonance.

The circuit in Fig. 11 possesses a number of interesting and important characteristics, some of which are portrayed by the curve in Fig. 12. These facts are listed here, for they mean a lot to any one who will work with R.F. amplifiers. The following facts apply equally well to the circuits in Figs. 9 and 10 (if points 1 and 2 in Fig. 9D are considered as the load terminals).

1. When the load is tuned exactly to the frequency of the incoming signal, the capacity of C_R is a maximum and is equal to the capacity of C_{RP} plus a value equal to the capacity of C_{RP} multiplied by the true amplification of the stage. When the load is tuned either above or below the signal frequency, the true amplification of the stage is greatly reduced and the capacity of C_R therefore decreases rapidly, as is shown in Fig. 12.

2. When the load is tuned exactly to the incoming signal, the equivalent ohmic value of R_R is so high that it can be neglected.

3. When the load acts as a condenser, the equivalent ohmic value of R_R is greatly reduced. The selectivity response curve of the amplifier is consequently broadened and the amplification of the stage is reduced.

4. When the load acts as a coil, the tube is actually feeding power back into the grid circuit, thus increasing the amplification of the stage and improving selectivity. For convenience this is often explained by saying that the ohmic value of R_R becomes *negative*; a negative resistance in shunt with a real resistance will actually increase the net resonant resistance of L_1-C_1 , clearly indicating that the circuit is capable of producing a greater resonant voltage.

5. If the load acts as a coil of sufficiently high reactance, the tube will feed sufficient energy back to the grid to make the circuit oscillate at a frequency determined essentially by the values of L_1 , C_1 , C_{RP} and C_R .

Practical Considerations. The curve in Fig. 12 also contains the answers to some very practical questions concerning the operation of amplifiers in general, including audio or video amplifiers. Keep the following facts in mind when you work with amplifiers and you will have no difficulty in finding causes and cures for annoying squeals or for poor fidelity.

1. In an audio or picture frequency amplifier, a high plate load resistance or reactance will give high amplification and make C_R very high in capacity. The higher frequencies in the audio or picture signal will therefore be attenuated (by-passed to ground before they reach the grid). A low-impedance load gives less attenuation.

2. If high plate load impedance in an audio or picture frequency amplifier stage is accompanied by an inductive plate load condition, undesirable oscillation may take place.

3. In an R.F. amplifier using a triode tube, any stage having plate and grid circuits arranged as in Fig. 10 will go into oscillation whenever the plate tank circuit is made sufficiently *inductive* by tuning it above the signal frequency. Two R.F. signals, the incoming signal and the oscillating frequency, will then reach the grid and be amplified by the tube; these two frequencies will be mixed together by the detector stage, and if the difference in their frequencies is in the audio range, an annoying squeal will be heard in the loudspeaker.

4. Oscillations can take place even without an incoming signal if the resonant frequency of L_2-C_2 , the plate load, is considerably higher than the resonant frequency of L_1-C_1 in the grid circuit, for under this condition the plate tuned circuit will be *inductive* at the resonant frequency of the grid tuned circuit. These being R.F. oscillations, they will not ordinarily be heard in the loudspeaker. If, however, this condition for R.F. oscillation exists in two different stages, two R.F. signals may go through the system and beat with each other at the detector, producing an A.F. note which will be heard as a squeal. This explains why some receivers produce squeals even when not tuned to a station; the remedy simply involves adjusting one or more of the tuned circuits.

GETTING RID OF FEED-BACK

When triode tubes are used in amplifier circuits, it is the grid-to-plate capacity which is of vital importance; the other two inter-electrode capacities, C_{gk} and C_{pk} , simply reduce the tuning range of the amplifier slightly at the highest frequencies.

Grid Suppressors. The oscillation or regeneration caused by the grid-to-plate tube capacity in a triode tube is an especially serious problem in single dial receivers, for these have no provisions for tuning out an annoying squeal at a particular setting of the tuning dial. Since only triode tubes were available in the early days of radio, engineers were compelled to develop a number of solutions for this regeneration or feed-back problem. One of these involved loading the grid tank circuit (L_1-C_1 in Fig. 10) with a resistor which made the resonant resistance of the grid tank circuit less than the ohmic value of the equivalent negative resistance R_R . (Engineers have proved that R_R , in addition to being negative must be lower in ohmic value than the resonant resistance of the grid tank circuit before oscillation can occur.) Another feed-back-killing scheme involved inserting a re-

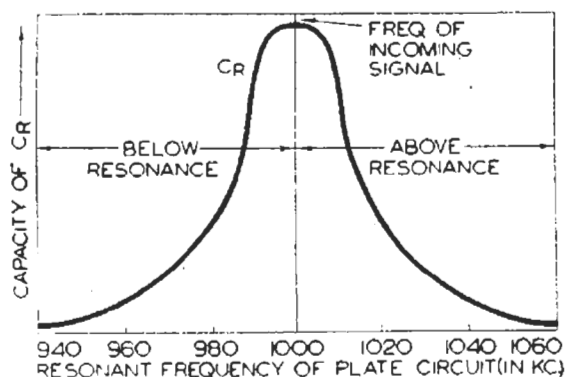


FIG. 12. This curve shows how the equivalent capacity C_R of the circuit in Fig. 11 varies when the plate tank circuit of an R.F. amplifier is tuned to, above and below the frequency of an incoming signal.

sistor in the grid lead, as at point 1 in Fig. 10; the resistor was in this case known as a *grid suppressor*. Lowering the amplification of the stage, such as by using a low L/C ratio in the plate tank circuit, was another way of preventing regeneration.

Neutrodyne Circuits. In the early days of radio, neutrodyne receivers were "all the rage"; these used an ingenious method of preventing regeneration while retaining all of the amplification of a stage. An A.C. voltage taken from the plate circuit of the R.F. amplifier was fed back into the grid circuit out of phase to balance out, buck out or *neutralize* the undesirable feed-back voltage caused by grid-to-plate capacity.

Figure 13A is an example of one of these early neutrodyne circuits; regeneration occurred here because the A.C. voltage across coil L_1 fed back to the grid tank circuit through inter-electrode capacity C_{gp} . To offset this, coil L_2 was coupled with and connected to coil L_1 in such a way that the voltage which it fed through neutralizing condenser C_N to the grid was out of phase with the undesired feed-back voltage; the two voltages therefore bucked each other and, when C_N was adjusted to make the two voltages equal, they exactly cancelled each other and eliminated regeneration effects.

Figure 13B gives another neutrodyne circuit; no additional coil winding was needed here, for the required out-of-phase A.C. voltage was secured

by tapping the secondary winding of the R.F. transformer. There were many variations of these two neutrodyne circuits, but all were essentially the same in their operation. Neutrodyne circuits were not entirely practical, for they were easily thrown out of adjustment. Any changes in the circuit parts, or the installation of a new tube, made it necessary to readjust neutralizing condenser C_N .

Engineers realized that the grid-to-plate capacity in the tube was the real cause of all their regeneration troubles, and finally called in vacuum tube engineers to design a tube which had negligible grid-to-plate capacity. The screen grid or shielded grid tube, which you know as the tetrode, was the result; we will consider this tube next.

THE SCREEN GRID TUBE

As you know, it is current flowing from the plate through inter-electrode capacity C_{gp} to the grid which results in regeneration in amplifier circuits. If an additional grid is placed between the control grid and plate of a triode, and this new grid, which we call the *screen grid*, is connected to

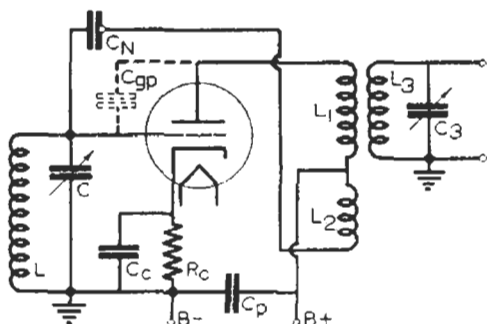


FIG. 13A. Early neutrodyne R.F. amplifier circuit, in which a special coil L_2 provides the required neutralizing voltage.

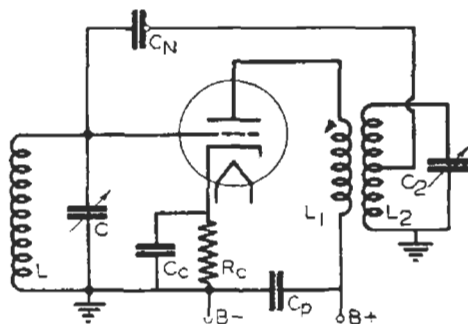


FIG. 13B. A tap on coil L_2 in this neutrodyne circuit gives the required out-of-phase feed-back voltage.

ground, the feed-back current will flow to the screen grid and then to ground, and will not reach the control grid at all. Tube engineers also realized that this new grid could be made to aid the plate in pulling electrons out of the space cloud near the cathode. The resulting circuit arrangement, in which the screen grid is at zero potential for A.C. and at a high positive potential with respect to the cathode for D.C., can be seen in Fig. 14A. The screen grid is connected directly to one terminal of the power supply, and the plate is connected to a higher voltage terminal ($B++$), while by-pass condenser C_2 is placed between screen grid and ground to provide a path to ground for the A.C. feed-back currents. The capacity of C_2 must be much higher than the capacity existing between screen grid and control grid in order to make the feed-back current take the desired path to ground.

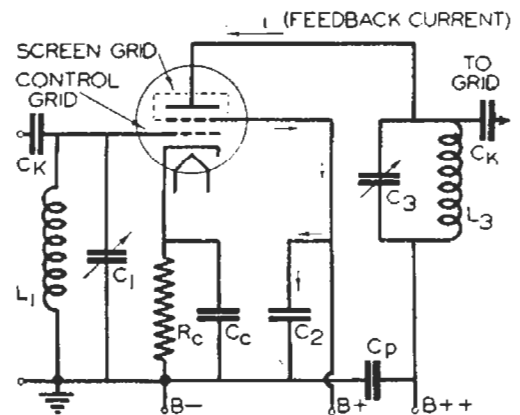
Now you can readily see that if the screen grid by-pass condenser in an R.F. amplifier (such as C_2 in Fig. 14A) should open, as it often does in radio equipment, the feed-back current will flow past the screen grid to the control grid, and *oscillation will occur*, resulting in a squeal in the loud speaker output. Replacement of the screen grid by-pass condenser (C_2) will eliminate the squeals.

The effect of the screen grid in reducing the grid-plate capacity of a tube can be determined from any tube chart. A comparison of the inter-electrode capacity values for a typical triode and a typical tetrode tube is given below:

Type 27 (triode) — $C_{gp} = 3.3$ mmfd.; $C_{gk} = 3.1$ mmfd.; $C_{pk} = 2.3$ mmfd.
 Type 24A (tetrode) — $C_{gp} = .007$ mmfd.; $C_{gk} = 5.3$ mmfd.; $C_{pk} = 10.5$ mmfd.

Observe that in the tetrode the introduction of the screen grid has reduced the grid-to-plate capacity about 470 times, an amount which is more than sufficient to prevent regenerative feed-back. C_{gp} cannot be entirely eliminated, however, for there is always a little leakage current from plate to grid. Surrounding the plate completely with the screen grid eliminates a great deal of this leakage, at the same time increasing the plate-to-cathode capacity, but increasing C_{pk} does not appreciably affect the performance of a tuned R.F. amplifier; it simply means that less capacity will be needed in the plate circuit variable condenser, and a reduction in the highest frequency to which the T.R.F. amplifier can be tuned.

FIG. 14A. R.F. amplifier circuit using a screen grid tube. In such screen grid tubes as the 24A, the screen grid completely surrounds the plate, as indicated by the light dotted lines, but the schematic diagram for a screen grid tube generally shows only the heavy lines here indicated.



With the troublesome grid-to-plate capacity out of the way, radio tube engineers proceeded to build greater amplification into the screen grid tube by moving the control grid closer to the space cloud and moving the plate farther away from the cathode. While this did not materially increase the electron flow to the plate, it did increase the A.C. plate resistance. The screen grid tube therefore has a high amplification factor, a high A.C. plate resistance and an average value of mutual conductance; the following table gives a comparison of these values, together with rated plate current values for a triode and a tetrode:

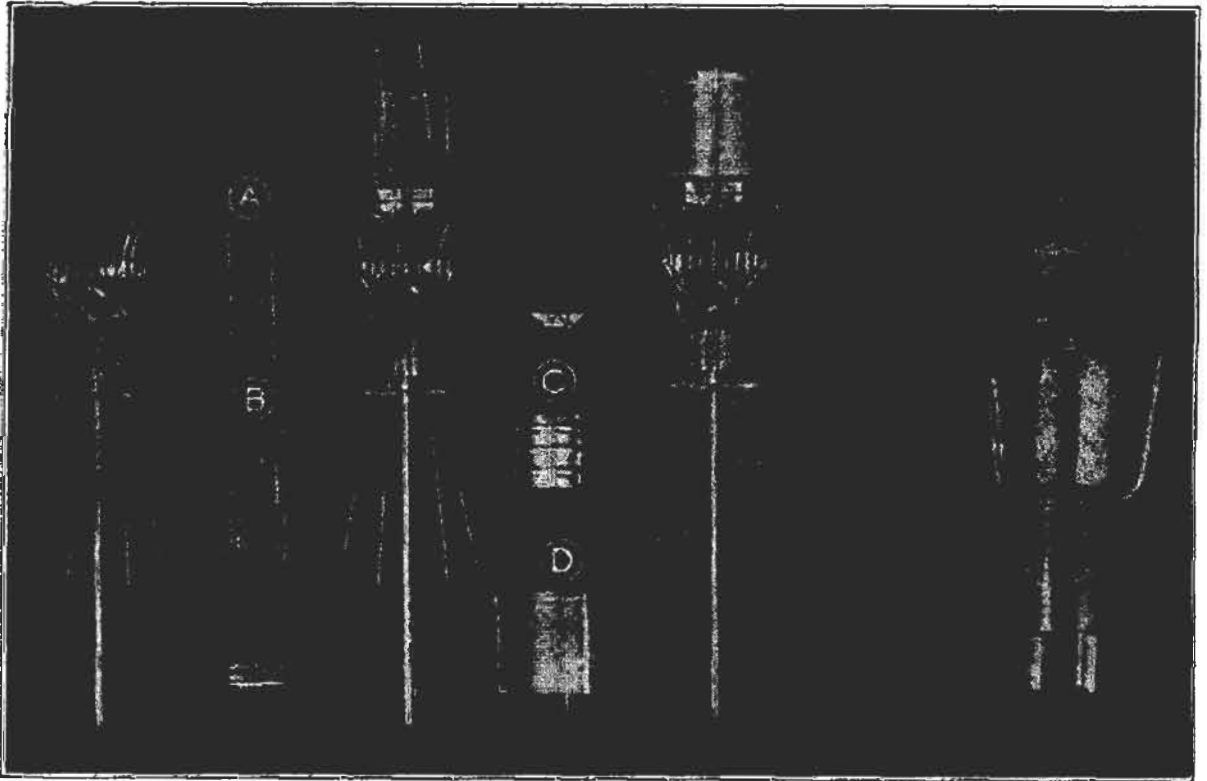
Type 27 (triode): $\mu = 9$; $g_m = 1,000$ micromhos; $r_p = 9,000$ ohms; $I_p = 5.0$ ma.
 Type 24A (tetrode): $\mu = 400$; $g_m = 1,000$ micromhos; $r_p = 400,000$ ohms; $I_p = 4.0$ ma.

Details of construction of a typical screen grid tube, the type 32, are shown in Fig. 14B; note how completely the plate is surrounded by the screen grid.

The Performance of a Screen Grid Tube. The behavior of a tetrode or screen grid tube as an amplifier is expressed by the family of $E_p - I_p$ curves given in Fig. 15; these curves give average characteristics for the RCA Radiotron type 24A screen grid tube. Notice that plate current is referred to as I_b instead of I_p . In securing data for these curves, the tube was operated at a normal filament voltage of 2.5 volts (either A.C. or D.C.) and normal screen grid voltage of 90 volts D.C., and the plate voltage was

varied from zero to a maximum for each value of D.C. control grid voltage (for 0, -1.5, -3.0, -4.5 and -6.0 volts).

For any one value of control grid voltage, plate current rises quite rapidly at first, as the plate voltage is gradually increased from zero. The screen grid has such tremendous electron-pulling power, however, that electrons approach it at very high speeds, pass right through its widely spaced wires and hit the plate with terrific impact, knocking electrons out of the plate; this effect is known as *secondary emission*. Some of these secondary electrons return to the plate, but a great number of them are attracted to the screen grid, which also is at a high positive D.C. voltage.



Courtesy Hygrade Sylvania Corp.

FIG. 14B. Construction of a typical screen grid tube, a type 32 tetrode. The control grid is at A. The inner part of the screen grid (mounted between the plate and the control grid) is at B, while the outer part of the screen grid (which surrounds plate C) is at D. At the right is the completed tube.

Curve I_{c2} , representing screen grid current, shows you that for low plate voltages the screen grid current is actually higher than the plate current, indicating that the screen grid collects a high proportion of the electrons which "bounce" off the plate and also attracts electrons directly (the screen grid is at a higher potential than the plate in the region to the left of line AA). It is for these reasons that in the region between zero and 90 volts (labeled "VALUES UNSTABLE" in Fig. 15), increases in plate voltage actually cause the plate current to go down. For plate voltages above 90 volts, plate current rises and screen grid current decreases gradually to a very low value.

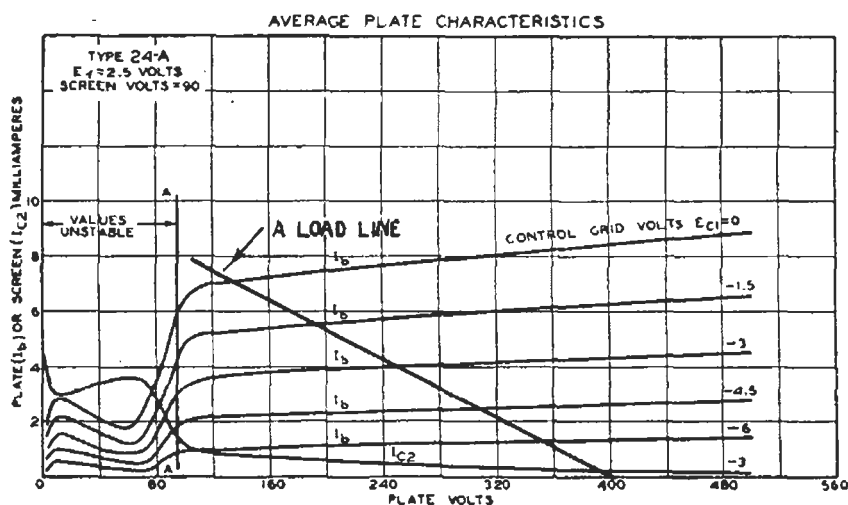
When the plate tank circuit in an R.F. amplifier contributes its resonant-produced A.C. voltage to the D.C. plate voltage, it makes the plate-to-cathode voltage swing from high to low values. In order to show how plate current varies under this condition, we can use the load line in Fig. 15; this load line gives us plate current and plate voltage values directly, making it unnecessary to compute the voltage drop across the load.

The plate voltage of the screen grid tube in Fig. 15 cannot be allowed to swing below the screen grid voltage (90 volts in this case) if distortion is to be prevented. Incidentally, if the plate voltage in an R.F. amplifier circuit like Fig. 14A should swing down to about 40 volts, the circuit will act as an oscillator instead of an amplifier; under this condition the screen and plate possess a negative resistance characteristic and supply power to the plate tank circuit. A screen grid tube gives better results than a triode in an R.F. amplifier provided that we limit the plate voltage swing to the linear portion of the E_p-I_p characteristic curve.

THE SUPPRESSOR GRID TUBE

Tube designers quickly realized that some means of forcing secondary electrons to return to the plate in a screen grid tube instead of going to the screen grid would greatly improve the amplifying characteristics of the tube at low plate voltage. One scheme for accomplishing this, actually tried in the type 48 power tetrode tube, involved attaching thin metal fins

Courtesy RCA Mfg. Co., Inc.
 FIG. 15. Family of E_p-I_p characteristic curves for a typical screen grid (tetrode) tube, a type 24A tube. (I_p is here designated as I_b .)



around the inside of the plate electrode, as shown in Fig. 16A. These fins exert control over the secondary electrons for a considerable distance after they have bounced off the plate. The fins attract far more secondary electrons than does the screen grid, and these electrons then travel back along the fins to the plate. The chief objection to this method is that the fins are expensive to construct; electrical means for accomplishing the same results have been developed.

The introduction of an extra grid between the plate and the inner section of the screen grid proved to be the electrical answer to the problem of driving secondary electrons back to the plate. This extra grid is known as the suppressor grid, for it actually *suppresses* the effects of secondary emission.

Here is how a suppressor grid acts: First of all, it is connected to the cathode or to a terminal which is more negative than the cathode. When an electron bounces off the plate and tries to flow to the positively charged screen grid, it is repelled just enough by the suppressor grid to be forced back to the plate. Even when the suppressor grid is at zero or cathode potential, its action is sufficient to make secondary electrons prefer the plate to the screen grid.

Why is it that the suppressor grid has very little effect upon the electrons flowing from the cathode to the plate, but a great deal of control over those which reverse their direction at the plate? *Speed* is the answer; an electron moving from the cathode through the control grid and the screen grid to the plate has developed so much speed by the time it reaches the suppressor grid that it goes right through the coarse wire mesh without slowing up at all, but secondary electrons coming from the plate have very little speed. We might compare the suppressor grid to a thin sheet of steel, which is easily pierced by a bullet from a high powered gun but which is able to stop a slow speed bullet from a small rifle. This one-way action of the suppressor grid is so efficient that it is even possible to operate the screen grid at the same potential as the plate, improving the electron flow to the plate without affecting secondary emission.

Figure 16B shows a typical circuit for a suppressor grid or pentode tube. Notice that the suppressor grid is connected directly to the cathode. The screen grid is often connected to the same power supply terminal as the plate; thus terminals 1 and 2 may be connected together in some circuits, as they usually are when power pentode (suppressor grid) tubes are used.

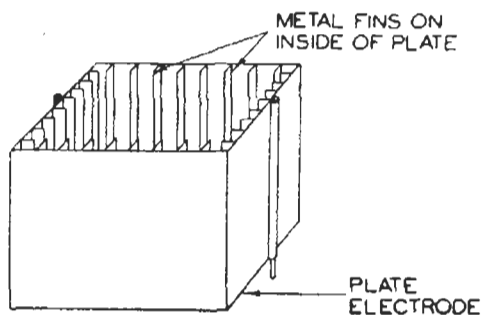


FIG. 16A. Sketch of plate electrode in a type 48 tube, showing metal fins used to limit screen grid current.

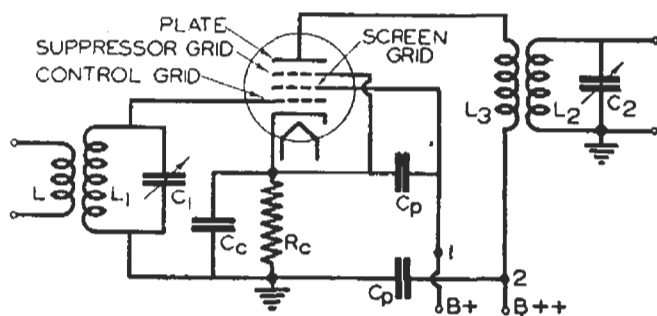


FIG. 16B. R.F. amplifier circuit using a suppressor grid tube. In most pentode tubes like this, the screen grid does not cover the outside of the plate.

The quality of a radio tube is judged entirely by its characteristics. A family of E_p-I_p characteristic curves for a pentode tube designed for R.F. amplification is given in Fig. 17; notice that the suppressor grid has eliminated the unstable region below the screen grid voltage value which was present in the screen grid tube characteristic curves in Fig. 15. The plate current of this pentode tube practically reaches its full value at low plate voltages, indicating that secondary emission is not depriving the plate of its current. A tube with characteristics like this can be made to swing over wide plate current and plate voltage values, giving maximum amplification and maximum power output for the tube.

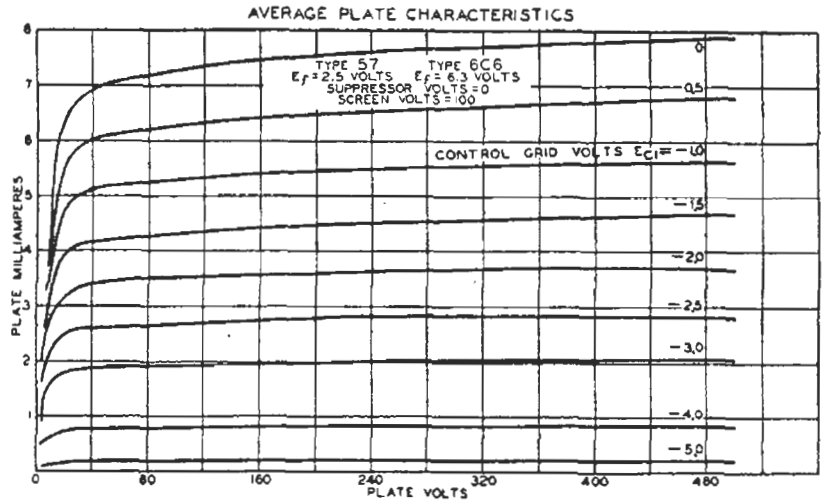
VARIABLE-MU OR SUPER-CONTROL TUBES

You may already have heard of *variable-mu tubes*, also called *super-control tubes*, for they are quite commonly used in amplifier circuits where the gain (the amplification) is varied by varying the C bias voltage of the tube. These tubes solve the problem of controlling volume by providing a mutual conductance (and therefore an amplification factor μ) which can be varied by *changing the setting of the C bias voltage*. But let us first see what happens when we try to control volume in this way with ordinary tubes.

Cross-Modulation. When two stations are heard at the same time on a radio receiver, one being a weak station to which the receiver is tuned and the other being a powerful local station, and this is observed for a number of other desired weak stations as well, *cross-modulation* exists.

Courtesy ROA Mfg. Co., Inc.

FIG. 17. Family of E_p-I_p characteristic curves for a typical suppressor grid (pentode) tube, the type 57 and its equivalent in the 6-volt series, the 6C6.



Here is what happens: The weak signal is amplified in the normal manner by the first R.F. amplifier stage, but because of poor selectivity the strong signal also reaches the amplifier tube and is demodulated *because it swings the grid of the first tube beyond the linear region of the E_g-I_p characteristic curve*. Plate current thus varies at the modulation frequencies of the strong station, just as in any detector, and these A.F. variations serve to modulate the desired R.F. carrier. This carrier, now having both the desired and the undesired modulation signals, goes through the receiver in

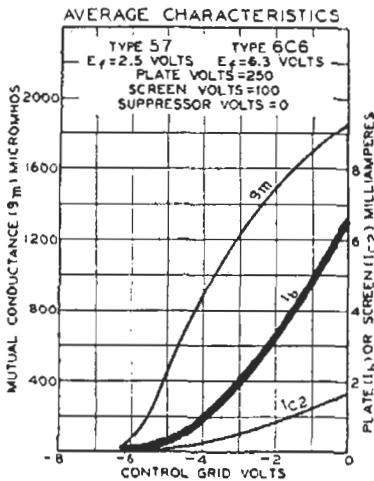


FIG. 18A. Characteristic curves for a type 57 or 6C6 pentode tube having both screen and suppressor grids.

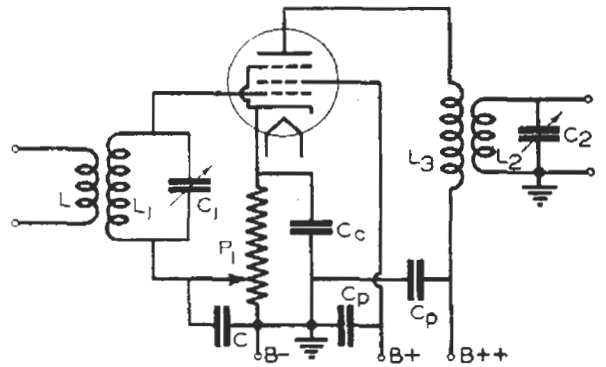


FIG. 18B. R.F. amplifier circuit using a pentode tube. Volume control P_1 varies the automatic C bias value.

the normal manner and both modulation signals are demodulated together.

The characteristic curves for a typical R.F. amplifier tube are given in Fig. 18A; let us consider an actual example of cross-modulation, where the tube represented by these curves is placed in the R.F. amplifier circuit of Fig. 18B. A normal C bias of -3 volts can be obtained for this tube by adjusting P_1 . If the desired signal has a peak voltage of one-half volt, it will swing the grid over a linear portion of the grid voltage-plate current characteristic curve (I_b) and the signal will be amplified in a normal man-

ner. If any undesired signal greater than 3 volts gets into this stage, however, it will swing the grid down beyond the bend in the I_p curve or even beyond the plate current cut-off point. The resulting rectification of the undesired signal causes cross-modulation.

Modulation Distortion. The E_g-I_p curve (curve I_p in Fig. 18A) for an ordinary screen grid tube has a very pronounced bend in the region of cut-off; the result is that signal voltages which swing the control grid *more positive* cause *large changes* in plate current, whereas signal voltages which swing the grid *more negative* give only *very small changes* in plate current. The harmonics produced under this condition can be partially filtered out by resonant circuits, but the more serious effect, distortion of the wave form of the modulation accompanying the carrier, is difficult to remedy; *modulation distortion* is the term applied to this operating defect of a screen grid tube.

In order to eliminate cross-modulation and modulation distortion effects yet still control volume by means of the C bias voltage, we need a tube which will reduce its mutual conductance as the C bias is made more negative, but which will not have a *sharp* bend in its E_g-I_p curve at low current values; we need a tube which requires a very high negative C bias to produce plate current cut-off.

An ordinary screen grid tetrode or pentode tube has a sharp plate current cut-off and, since the control grid wires are close together and near the cathode, only a small negative C bias is needed to drive the plate current to zero. This construction, as you know, gives a high amplification factor. If, now, we modify the construction so that some of the control grid wires are farther away from the cathode than others or so some of the control grid wires are closer together than others, we get a tube which has the desired characteristics. The variable spacing scheme is illustrated in Fig. 19A; this is the arrangement commonly used for variable-mu tubes, since it simplifies construction problems.

This variable spacing of control grid wires gives to the tube two distinct characteristics, one for each spacing, as you would expect. At small negative C bias voltages the action of the tube is essentially the same as if all grid wires were uniformly spaced at the maximum distance, but at high negative bias values the closely wound turns block electron flow; electrons continue to pass through the widely spaced grid turns to the plate until the highly negative cut-off bias is reached, and thus we obtain the desired remote cut-off characteristic.

The mutual conductance and plate current curves for a representative variable-mu tube are given in Fig. 19B, with the plate current curve (E_g-I_p curve) for an ordinary screen grid tube (the type 57) shown for comparison. If you compare the plate current cut-off points and the bends in the two I_p curves, you can verify the statements just made concerning variable-mu tubes.

Ordinarily screen grid and pentode tubes are quite satisfactory for those circuits where the C bias is such that the A.C. signal swings over a linear part of the E_g-I_p characteristic, but only a very limited variation in g_m is permissible if cross-modulation and modulation distortion are to be

eliminated. Variable- μ screen grid tubes and variable- μ pentodes (often called super-control pentodes) permit considerable variation in their values of g_m ; these tubes are well suited for those stages of a well designed amplifier where a C bias type of gain control is used, for they will reduce cross-modulation and modulation distortion.

PRACTICAL R. F. PENTODE CIRCUITS

Amplifier circuits containing ordinary pentode tubes or super-control pentode (variable- μ) tubes are basically the same as the triode amplifier circuits shown in Fig. 9. Remember, however, that pentode tubes have a very high A.C. plate resistance; this means that the conditions for maximum amplification (a load resistance many times higher than the A.C. plate resistance if an ordinary resonant circuit is used as load, or a load resistance equal to the A.C. plate resistance in the case of a tuned trans-

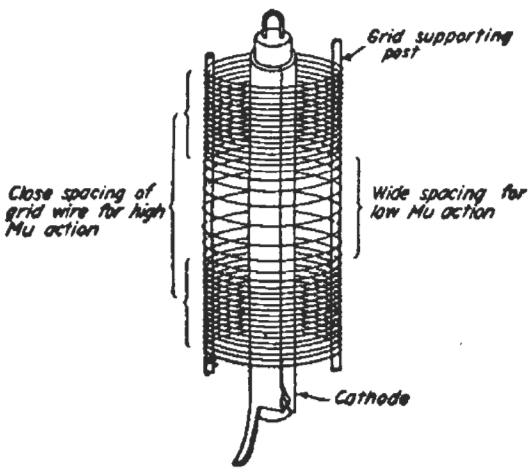


FIG. 19A. This sketch shows the variable spacing used for the control grid wires in a variable μ tube.

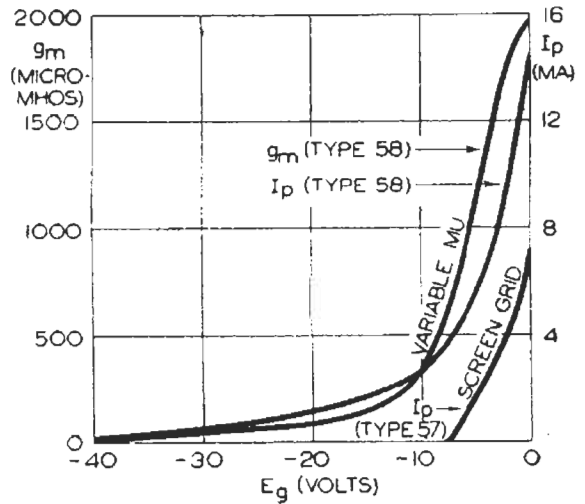


FIG. 19B. Characteristic curves for a variable μ pentode tube (type 58), with plate current curves for ordinary pentode (type 57) shown for comparison.

former load for a single-tube stage) are seldom if ever secured. A tank circuit load which is designed for a triode tube is purposely given a low resonant resistance, so obviously a triode load will not be satisfactory in a pentode circuit.

A two-stage R.F. amplifier using pentode tubes and containing a number of different types of R.F. circuits is shown in Fig. 20. The first tube is an ordinary pentode; a 1,500 ohm cathode-to-ground resistor supplies it with an essentially constant automatic C bias. Condensers marked .1 (.1 mfd.) serve as low-reactance paths for A.C. currents. The second R.F. amplifier stage, containing a super-control pentode tube, is coupled to the first stage by condenser *C*, which is used both as a D.C. blocking condenser and as an A.C. coupling condenser. The capacity of *C* is quite low, being about 10 mmfd.; this capacity generally is secured simply by twisting two insulated wire leads together once or twice.*

* When the R.F. choke and the tank coil are constructed as a single unit (but with no inductive coupling between them), a stiff wire is sometimes connected to the upper end of choke *RFC* and looped partly around the grid end of the tank coil *L₂* to provide the required low coupling capacity *C*.

The type 58 super-control pentode tube feeds into its load through a transformer having a tuned primary. The gain of this R.F. amplifier is controlled by varying the negative C bias which is applied to the type 58 tube; potentiometer *P* in the voltage divider network provides a means of varying this C bias. Choke coil *RFC*₁ in the plate supply lead of the super-control pentode prevents A.C. signal currents from entering the power supply circuit.

Pentode R.F. amplifiers of the type just described are used for all frequencies. With R.F. values between 100 kc. and 20 megacycles it is simply necessary to design the resonant circuit to respond to the desired frequency and to have a resonant resistance which gives sufficiently high amplification for desired results. By-pass condensers and choke coils must, of course, be of the proper values to keep A.C. signals in their proper paths. At the ultra-high frequencies, however, such as those used in television systems, the grid-to-cathode, grid-to-plate and plate-to-cathode capacities in the tubes become appreciable in value, especially in stages which are designed for high voltage gain; in these cases acorn-type tubes, which have no bases and are so designed that leakage and inter-electrode capacities are a minimum, are used.

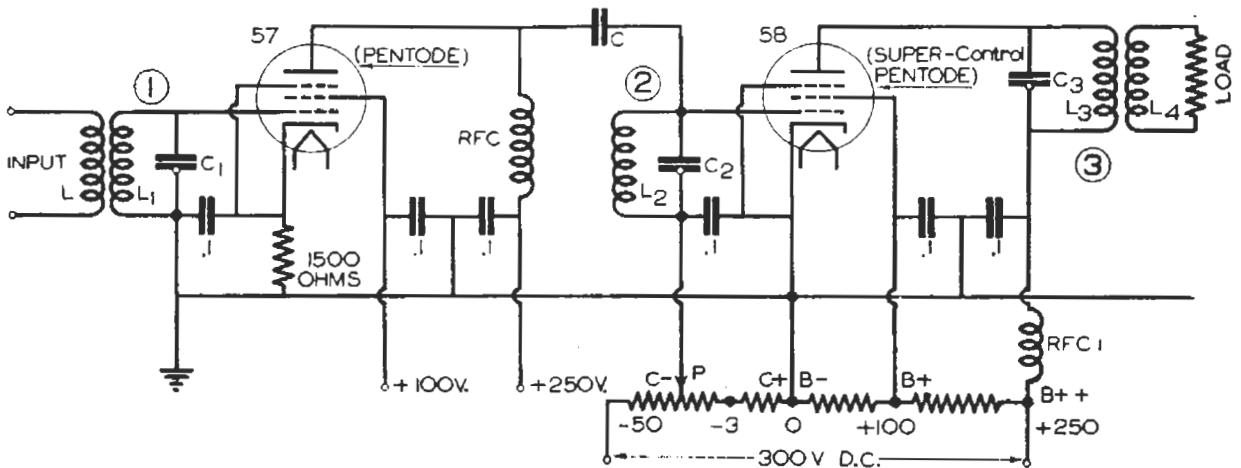


FIG. 20. Circuit of a two-stage R.F. amplifier using pentode tubes. The small circle on a condenser symbol indicates that the condenser is adjustable. Numerals alongside a condenser represent its capacity in microfarads. All .1 mfd. condensers are by-pass condensers.

BAND-PASS R. F. CIRCUITS

All of the R.F. circuits which you have just studied have had single peak frequency response curves like that shown in Fig. 7A; these are, of course, perfectly satisfactory where the side-band frequencies involved are within narrow limits. In order to approach the ideal flat response curve shown in Fig. 7B, multiple resonant circuits are required. It is possible to flatten the curve produced by a single tuned circuit if the tank circuit is shunted by a resistance, but this reduces the gain considerably and simply gives an approach to the ideal response.

When a number of tuned circuits are used in cascade, as they are in Fig. 20, it is possible to secure an approach to an ideal response curve by tuning one or more circuits off the incoming signal frequency. For example, circuit 2 could be tuned to the desired 1,000 kc. signal, circuit 1 could be tuned to about 995 kc., and circuit 3 could be tuned to about 1,005 kc. The over-all

response curve is the product of the responses of each stage. By careful adjustment, very nearly ideal response, with three more or less pronounced peaks, like those shown in Fig. 21, can be obtained. Considerable gain is of course sacrificed in order to secure this response; another disadvantage is that two tubes are required to provide the three tuned circuits.

It is possible, however, to obtain flat response with only a single R.F. stage; several such stages can be used to give the desired amount of amplification, for the gain of the stages is cumulative. Double and sometimes triple tuned circuits are used in place of single resonant circuits; a typical double tuned circuit which is widely used in the I.F. amplifiers of superheterodynes is shown in Fig. 22. Circuits L_1-C_1 and L_2-C_2 are usually identical circuits, coupled to each other by mutual inductance M . When both resonant circuits are tuned to give maximum output, a single peak response curve is obtained; if each tuned circuit has low circuit resistance, the frequency response curve will be pointed or peaked, whereas high circuit resistance gives a broad, rounded curve. When circuit L_1-C_1 is tuned to a frequency *above* the incoming signal (by reducing the capacity of C_1) and circuit L_2-C_2 is tuned *below* the incoming signal (by increasing the capacity of C_2), the resulting resonant curve will have a double hump. The

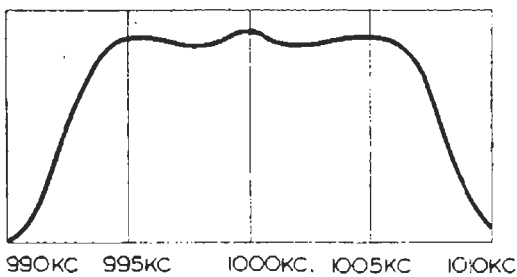


FIG. 21. When the three tuned circuits in the amplifier of Fig. 20 are properly adjusted for band-pass operation, the over-all response characteristic will be as shown here.

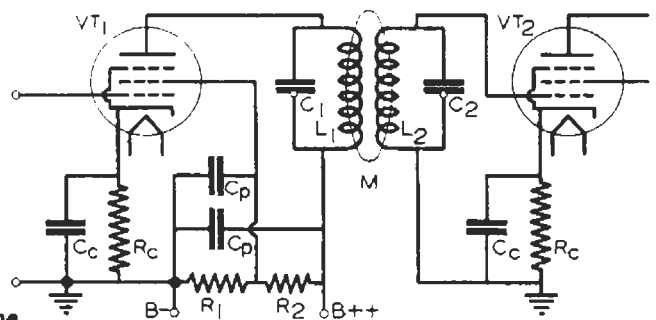


FIG. 22. A double-tuned band-pass radio frequency amplifier circuit, with inductive coupling between the two tuned circuits.

primary could just as well be tuned *below* resonance and the secondary *above* resonance for band-pass results.

The use of three resonant circuits, each coupled to the next and each adjusted to a different frequency, as the load of an R.F. amplifier gives a triple hump response curve. Of course, each extra coil wastes a certain amount of power, lowering the effective value of plate load resistance and consequently reducing the gain, but this loss in gain can be compensated for by using several such R.F. stages in cascade. A tuned amplifier having two or three tuned circuits obviously cannot give as much amplification, even when each circuit is tuned to resonance, as a single tuned circuit because of the losses in the extra coils. Single tuned circuits are therefore often referred to as high gain R.F. amplifiers.

Figure 23 shows another way of using two resonant circuits to give a double peak response curve; capacity C here couples the two circuits together, for the voltage developed across C by the L_1-C_1 circuit becomes the source voltage for circuit L_2-C_2 . Coil L_1 is tuned by condensers C_1 and C in series, while coil L_2 is tuned by condensers C_2 and C in series. Since condenser C is usually fifty to one-hundred times as large as either C_1 or C_2 , its tuning effect is negligible.

Condenser C can be replaced with a coil if desired, giving an inductively coupled circuit; the inductance of coils L_1 and L_2 should then be fifty to one-hundred times that of the coupling coil. The band width of a double tuned coupled circuit like this is roughly dependent upon the reactance of the coupling device; this reactance increases with frequency when inductive coupling is used, but decreases with frequency when capacitive coupling is used. Thus, in Fig. 22, where inductive coupling is used, the frequency response curve will be broadest when the circuit is tuned to the higher frequencies, while for the circuit in Fig. 23, which has capacitive coupling, the frequency response curve will be broadest at the lower frequencies to which the circuit is tuned. Quite often both inductive and capacitive coupling are used in order to secure a constant band width, especially when a circuit is to be tuned over a wide range of frequencies.

The question of band width is highly important in high fidelity sound receivers and especially in television receivers. In high fidelity sound receivers the band width is generally between 10 and 20 kc., while in television receivers the band width may be as much as 6,000 kc. The greater the band width of an amplifier, the less attenuation there is of the higher side frequencies, and the better is the fidelity of response.

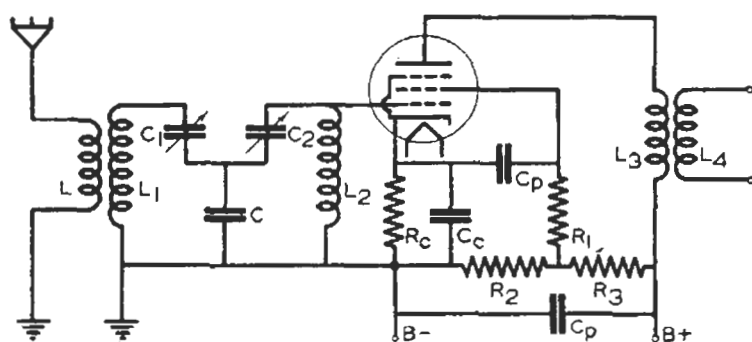


FIG. 23. The resonant circuits here couple the antenna circuit to the grid circuit of the first R.F. amplifier stage, giving a double-peak response characteristic.

FIXED R. F. AMPLIFIERS

At one time in the development of the radio industry, the tuned radio frequency amplifier patents were available only to a few radio manufacturers. This compelled other manufacturers to develop fixed R.F. amplifiers in order to get around these patents; tuning was accomplished with a resonant circuit placed ahead of the amplifier. In fixed R.F. amplifiers it was possible to use resistance-capacity coupled circuits, especially with triode tubes which had a low A.C. plate resistance; if screen grid tubes were used, however, a high plate load resistance and extremely high plate supply voltage were required.

A more practical solution to the problem of designing a fixed R.F. amplifier was found in the untuned air core transformer having a primary and secondary which were tightly coupled together; in fact, primary and secondary were wound simultaneously on a single coil form. The resulting circuit, shown in Fig. 24, gave excellent results with triode tubes. The coupling between the primary and secondary windings in the transformer was sometimes made even closer by using pulverized iron cores. Fixed R.F. amplifiers are seldom used today, as patents on tuned R.F. amplifier circuits, which give much better results, are available to practically all receiver manufacturers.

POWER R. F. AMPLIFIERS

Maximum power amplification in any single-tube R.F. amplifier stage is obtained when the A.C. plate resistance of the tube is equal to the resonant resistance of the plate tank circuit. When maximum power is desired in the tank circuit, the tubes should have a high mutual conductance. In power R.F. amplifiers, especially those used in transmitters, the circuit must be designed to make maximum use of plate power; since it is ordinarily not feasible to design tank circuits which will have resonant resistances comparable to the A.C. plate resistances of ordinary tetrode and pentode tubes, special power R.F. amplifier tubes have been designed, these having a low A.C. plate resistance which is secured by reducing the amplification factor of the tube and by raising the cathode emission. The use of special tubes is the essential difference between power R.F. amplifiers used in transmitters and those used in receivers. Some power amplifier circuits are designed for peak response at a single frequency, while others (such as circuits handling modulated R.F. currents) are designed for band-pass operation.

Efficiency. In high power R.F. amplifiers such as are used in transmitters, the A.C. power in the tank circuits may be hundreds or even thousands of watts; in cases like these the efficiency of operation of the tube is of vital importance.* When

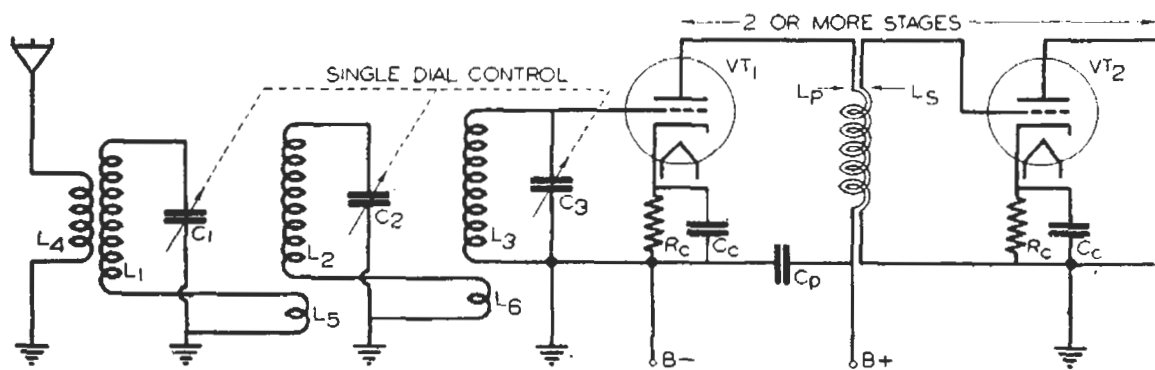


FIG. 24. A fixed R.F. amplifier circuit, with tuning being accomplished by the three resonant circuits which precede the first triode tube.

the C bias of an R. F. amplifier is set to make the input signal swing over a linear portion of the dynamic E_g-I_p curve, so the tube is operating as a *class A amplifier*, an efficiency of about 30 per cent is obtained even if the grid is driven positive for a part of each cycle.

The plate resistance of the tube is to blame for the greatest part of this wasted power, for all plate current must flow through this plate resistance. Greater efficiency can be obtained by cutting down the time during which plate current flows; by setting the C bias for plate current cut-off, no plate current will flow at normal plate voltage when there is no excitation, and plate current will flow only for one-half of each cycle when grid excitation is applied; this condition, where the tube is operating as a *class B amplifier*, is shown graphically in Fig. 25. Efficiencies of 50% are possible with this circuit. Observe that although the grid excitation voltage e_g is a perfect sine wave in form, the plate current i_p is a half sine wave; thus power is being supplied to the plate load circuit for only half of each cycle.

Engineers have proved, both by calculation and experiment, that the half sine wave plate current i_p in Fig. 25 is made up of a direct current component and an A.C. component having *even* (second, fourth, sixth, eighth, etc.) *harmonic components*; all these components are trying to flow through the $L-C$ plate tank circuit. The D.C. component readily flows through coil L to the power supply, but the fundamental A.C. component encounters a high resonant resistance; part of this A.C. component is absorbed by the tank circuit, and the remainder by the tube.

* The efficiency of an R.F. amplifier is the A.C. power output (in the tank circuit) divided by the D.C. power supplied to the plate circuit; multiply this ratio by 100 to get per cent efficiency. The power supplied to the plate circuit is, of course, the D.C. plate voltage multiplied by the D.C. plate current.

The harmonic components find condenser C to be a low reactance path; since only the tube is offering impedance to the harmonic currents, the entire harmonic power is wasted in the tube. A tank circuit having a high Q factor will have an unusually high fundamental A.C. component flowing through both L and C .

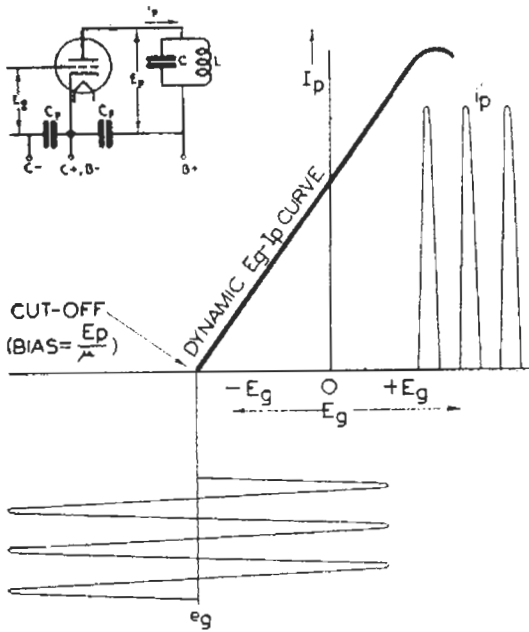


FIG. 25. Circuit diagram and characteristic curve for a typical triode tube operating as a class B amplifier.

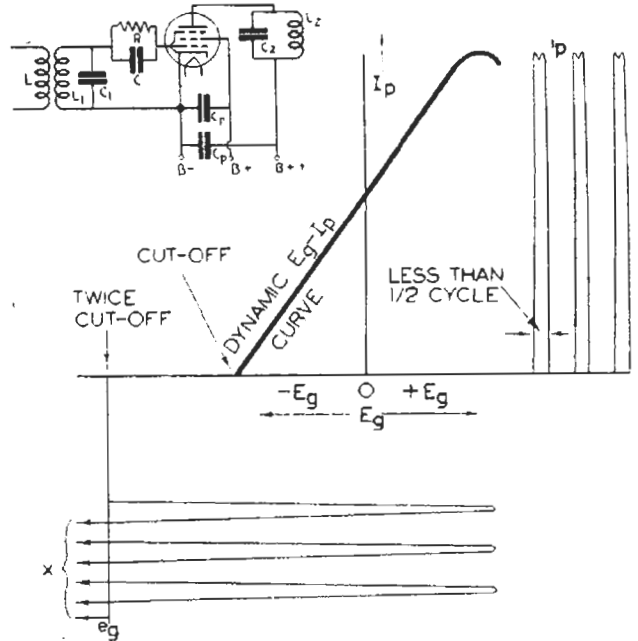


FIG. 26. Circuit diagram and characteristic curve for a typical pentode tube operating as a class C amplifier. The negative half-cycles at x have been omitted to conserve space on the drawing.

Even greater operating efficiencies (as high as 85%) can be obtained by making the C bias more negative than the cut-off value (usually about twice the cut-off value, as in Fig. 26) and increasing the grid excitation until the maximum possible plate current is obtained; the tube is here operating as a *class C amplifier*. Notice that the resulting plate current pulses in Fig. 26 are almost rectangular in shape, and flow for considerably less than a half cycle. Experiments have shown that

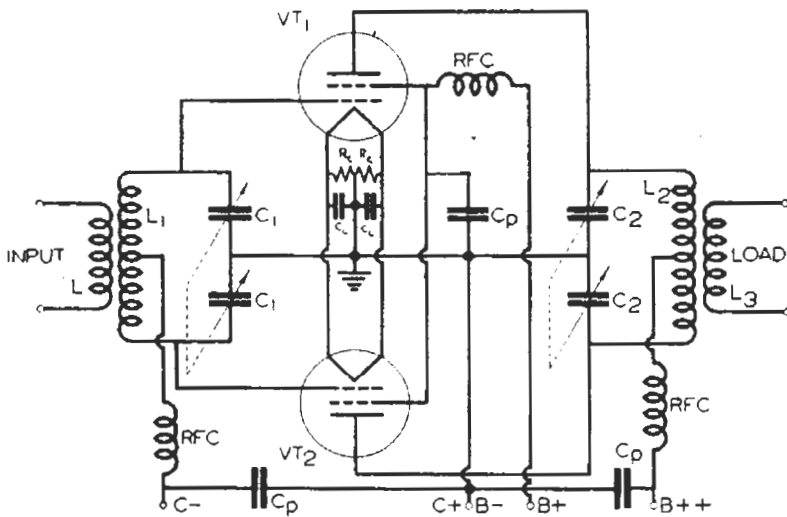


FIG. 27. Typical push-push power R.F. amplifier circuit.

with this wave form, more of the desired A.C. power is absorbed by the tank circuit.

Class C operation is widely used in power R.F. amplifiers where high efficiency and a large amount of power are desired. With both class B and class C operation, coupling the load to the tank circuit coil insures that the load will be fed with power at the fundamental frequency.

Self-Biased R.F. Amplifier Circuits. Although a separate C bias supply (like that in the circuit of Fig. 25) is generally used in power R.F. amplifiers, a self-

biased circuit like that in Fig. 26 is occasionally used. Here a pulsating rectified D.C. grid current flows through grid resistor R when the grid is driven positive by the excitation, thus making that resistor terminal negative which is closer to the grid. Condenser C in Fig. 26 provides a low reactance path for the A.C. excitation being applied to the grid and at the same time smooths out the pulsating direct current flowing through R , making the C bias voltage constant in value.

Power Amplification. Since the grid in the circuit of Fig. 26 is drawing current, power is being absorbed by the grid-cathode path in the tube; this power must be supplied by the grid excitation source. The power delivered to the plate tank circuit divided by the power fed to the grid gives what is known as the *power amplification* of a high-power R.F. amplifier stage. The power amplification value is usually about 10, which means that in order to get 1,000 watts out of a power R.F. amplifier, you must furnish about 100 watts of power to its grid.

Push-Push Power R.F. Amplifiers. In *audio frequency* amplifiers, a circuit containing two tubes arranged for push-pull or push-push operation is widely used to secure large power outputs, as you already know. These same two-tube circuits can, with slight modifications, be used to deliver high power output as R.F. amplifiers. A typical push-pull or push-push R.F. amplifier circuit is shown in Fig. 27. Split-stator condenser C_1 divides the input voltage between the two tubes. A fixed C bias voltage is applied to the grids through an R.F. choke and coil L_1 . Each tube feeds into the resonant load circuit made up of center-tapped coil L_2 and split stator condenser O_2 .

TEST QUESTIONS

Be sure to number your Answer Sheet 16FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What four things must the R.F. amplifier do in a sound or television radio receiver?
2. What does a frequency response curve (or resonance curve) for a tuned R.F. amplifier show?
3. In the modern definition for good selectivity, how many times more should the desired signal frequencies be amplified than the nearest undesired signals?
4. How does the cascading of R.F. amplifier stages affect the amplification and selectivity of an R.F. amplifier?
5. When a tuned transformer load is used in a single-tube R.F. amplifier stage, under what condition is maximum voltage amplification obtained?
6. Of the four circuits shown in Fig. 9 (A , B , C and D), which one uses a series resonant circuit?
7. Which inter-electrode capacity in a triode tube causes regeneration or oscillation?
8. In an R.F. amplifier like that shown in Fig. 14A, what happens when the screen grid by-pass condenser C_2 opens?
9. What does the suppressor grid do in a vacuum tube?
10. Will variable- μ (super-control) pentode tubes reduce cross-modulation and modulation distortion?