TONE CONTROL

Lesson RRT-4

DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois

Radio Reception
and Transmission

LESSON RRT-4

TONE CONTROL

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1835—Samuel Morse made and exhibited his first telegraph instrument at the University of the City of New York.

1841—Jas. Joule announced the electric power law named after him, namely, current in in a conductor develops heat directly proportional to the resistance and the square of the current intensity.

1849—Prof. Kirchoff announced his two laws concerning the voltage and current distribution in an electric circuit—a further application of Ohm's law to complex circuit analysis.

1855—Jean Foucault discovered eddy currents, that is, induced currents that circulate in a solid conducting body. To overcome the effects of these currents, transformers and other cores are laminated.

DE FOREST'S TRAINING, INC.
2533 N. ASHLAND AVE., CHICAGO 14, ILLINOIS

RADIO RECEPTION AND TRANSMISSION

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INDEX

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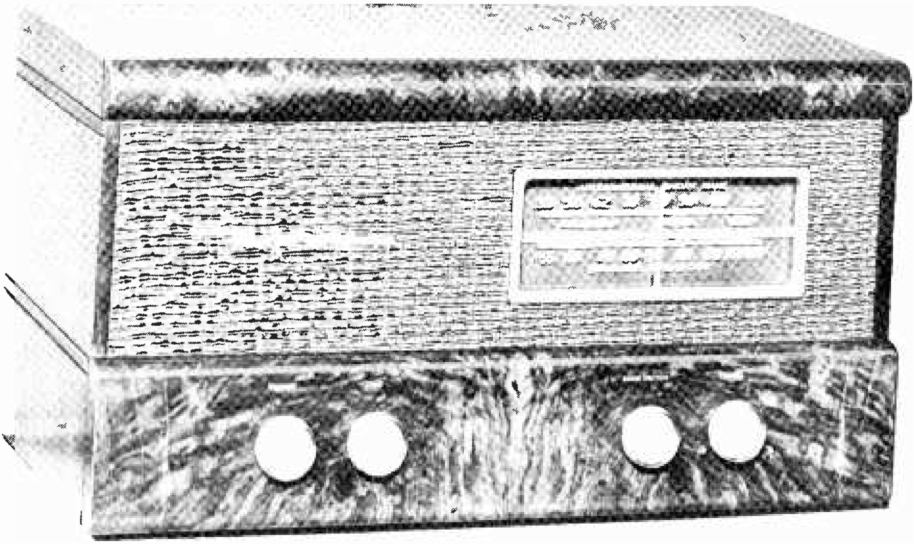
True progress never commands the human race to start over again from scratch. Civilization is an accumulation of living values, an organic thing. Without change, there can be no growth; but without tradition there can be no civilization.

—Dorothy Thompson

TONE CONTROL

Before starting our explanation of tone control circuits, we want to give you an idea of the various audio frequencies which affect the human ear. Like electricity, sound frequencies are measured in cycles per second, and in Figure 1 we show the standard piano keyboard with the frequencies of the "C" notes below.



Modern table model radio receiver equipped with separate volume and tone control knobs at the left, and a band switch and tuning knob at the right.

Courtesy Motorola, Inc.

Middle C has a frequency of 256 cycles per second, and when this note is struck, the string it operates vibrates at this frequency. Eight notes above is another C note and its frequency is just twice that of middle C or 512 cycles per second.

These eight notes are what we call an "Octave", and the point to remember here is that the frequency doubles for every octave. Starting over at the left of the keyboard, you can see that low C has a frequency of 32, the next C 64, the next 128 and so on, the valve doubling each time up to a frequency of 4096 cycles per second at the upper end.

In electrical work, the octaves are known as harmonics, and by starting with lower C as the fundamental frequency of 32 cycles, the next "C" is the second harmonic because its 64-cycle frequency is twice the fundamental of 32 cycles.

If you are at all familiar with written music, the notes shown below the keyboard will indicate where these frequencies are located on the bass and treble clefs. Middle C, you will find, is between them. The frequencies given here are based on the scientific scale with middle C tuned to 256 cycles. For the orchestral pitch, middle C is tuned to 264 cycles; or perhaps more common, A is tuned to 440 cycles.

Above the piano keyboard of Figure 1 we have listed various musical instruments and voices with their frequency ranges. The Piccolo, for example, has a range from 512 cycles to 5,000 cycles, the flute from 256 to 2048 and so on down. The lines marked "Woman" and "Man" show the frequency range of the average speaking voices.

Study these ranges carefully, as they will give you a good idea of the various frequencies and help you in much of your later work. The reason these frequency values are important is due to the fact that, from the time the sounds strike the microphone of the Broadcasting Station until the speaker coil of the receiver operates its diaphram, sound frequencies are transmitted, received and amplified as electrical energy. Therefore, as far as the receiver circuits are concerned, the various notes and tones are merely alternating currents of like frequency.

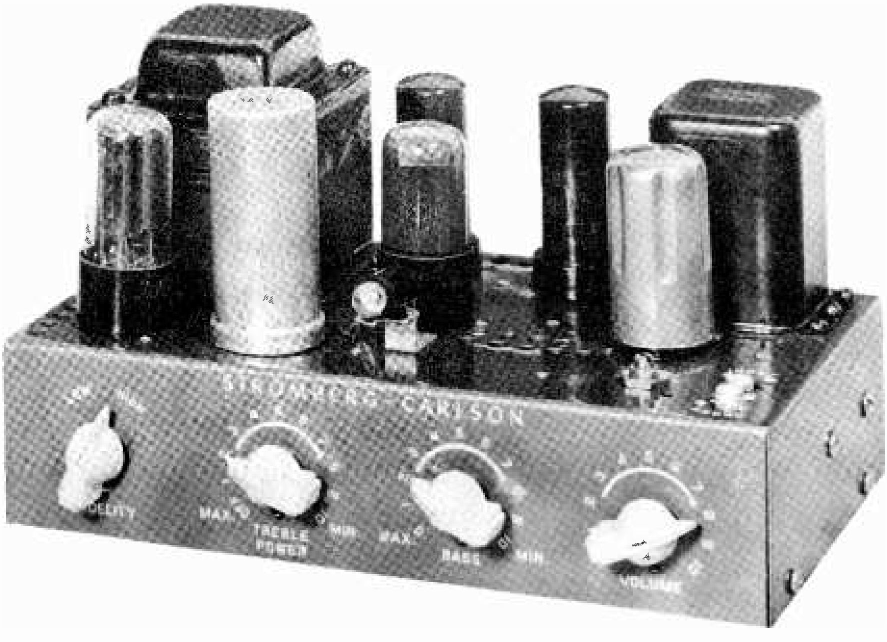
For example, if the voice coil of a dynamic speaker carries an alternating current with a frequency of 256 cycles, the diaphragm will vibrate at that frequency and produce a tone of the same pitch as middle C on the piano keyboard.

The common systems for the distribution of electric power are operated at some constant voltage and frequency, with the load, which may vary from 25% to 100% of the rating, as the only variable factor. To design a transformer for these systems, the amount of iron and size of the windings depend on the load to be carried, but both the primary and secondary circuits operate at one frequency only.

In comparison, the design of a transformer for music and voice is much more complicated. The frequency of an ordinary man's speaking voice varies from 128 to 213 cycles per second, while a woman's speaking voice varies from 192 to 384 cycles per second. For the various musical instruments, the range of fundamental frequencies is from 40 to 5000 cycles per second, while the harmonics, or overtones, are well up into 8000 cycles or more. These overtones are the first, second, third and fourth harmonics which represent the quality and timbre of the voice and music.

These higher frequencies must be amplified in the same way as the fundamental frequencies in order that the human ear can distinguish different instruments and voices. The circuits used to amplify voice and music should handle all frequencies from 40 to 8000 cycles equally well although the power may vary.

For talking pictures, public address systems and all similar electronic equipment, the amplification of power should be the same at all frequencies, yet very often one frequency, or group of frequencies, is overamplified.



A public address amplifier equipped with both a treble and bass tone control.
Courtesy Stromberg-Carlson Company

In this Lesson we will explain the circuits, give you formulas for tuning them to different frequencies, and then show you what effects they have on the operation of the amplifiers in which they are used. We will explain how to increase the impedance of a circuit for some definite frequency, and in other cases, how to reduce the impedance at the same frequency.

SIMPLE ACCEPTOR CIRCUIT

To describe these actions, we will follow the usual engineering practice and make a series of graphs or curves. For example, at the upper right of Figure 2 we have a simple series circuit made up of a choke coil or inductor, with a value of 159 millihenries and a condenser with a capacitance of 1.59 microfarads.

While these may seem to be odd values, they work out very nicely; and once you have the idea, it will be easy to substitute any other values in their places. Comparing this circuit with those of the earlier Lessons, you will recognize it as "series resonant", but for the purpose we are going to explain, it is commonly known as an "Acceptor" circuit.

To see just what takes place here, you must remember that when an inductor is placed in an a-c circuit, it becomes an inductive reactance measured in ohms, and its value is found by the formula:—

$$X_L = 2\pi fL$$

If you have forgotten how this formula is derived, go back and review the earlier Lesson on impedance. You will notice the inductive reactance varies with the frequency, and to find out what happens, we will substitute in the formula for different frequencies.

With an inductance of 159 mh, which is .159 Henry, and a frequency of 200 cycles, we have

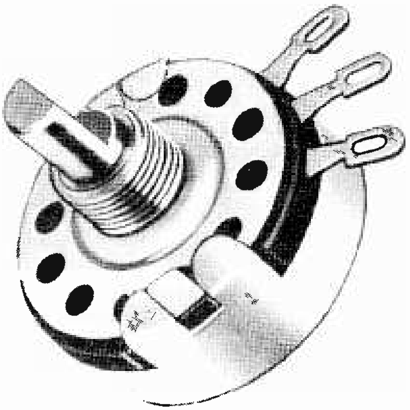
$$X_L = 2 \times 3.14 \times 200 \times .159$$
$$= 199.7 = 200 \text{ Ohms.}$$

When the frequency is 400 cycles,

$$X_L = 2 \times 3.14 \times 400 \times .159$$
$$= 399.4 = 400 \text{ Ohms.}$$

When the frequency is 600 cycles,

$$X_L = 2 \times 3.14 \times 600 \times .159$$
$$= 599.1 = 600 \text{ Ohms.}$$



A form of variable resistor such as is commonly used in conjunction with a fixed condenser for tone control purposes.
Courtesy Allen Bradley Company

In the same way, we can find the inductive reactance in ohms for any frequency, but of course, when the frequency is zero, the reactance will be zero also. At zero frequency the reactance of the choke coil is zero, but it will have the ohmic or d-c resistance of the wire. However, for this explanation we will imagine the d-c resistance is zero.

To show this change of reactance in the form of a curve, in Figure 2 we have laid off a horizontal "f" scale from 0 to 1000 cycles, and a vertical reactance scale from 0 up to 600 ohms and from 0 down to 800 ohms.

Going back to an earlier Lesson again, you will remember that inductive reactance causes the current to lag while capacitive reactance causes the current to lead, therefore we will plot the X_L curve above, and the X_C curve below the "O" reactance line or axis.

Taking the values we just worked out, at zero frequency there is zero reactance, therefore, the first point of the curve is located where the zero scale lines cross. With a frequency of 200 cycles the reactance is 200 ohms, and therefore the next point is at "P" where the 200 lines cross. At 400 cycles the reactance is 400 ohms, therefore point "S" is located where the 400 lines cross.

Plotting the other points in the same way and connecting them, we have the graph X_L which is a straight line and shows how the inductive reactance increases with the frequency.

CAPACITIVE REACTANCE

As the condenser "C" is in series with choke coil "L", we next find the capacitive reactance for various frequencies by substituting in the formula

$$X_C = \frac{1}{2\pi fC}$$

The C of the formula represents farads, and as the condenser of Figure 2 has but 1.59 mfd, it must be written as .00000159 Farad. When the frequency is 200 cycles:

$$X_C = \frac{1}{2 \times 3.14 \times 200 \times .00000159}$$

$$= \frac{1}{.001997} = 500.7 \text{ Ohms.}$$

When the frequency is 400 cycles —

$$X_C = \frac{1}{2 \times 3.14 \times 400 \times .00000159}$$

$$= \frac{1}{.003994} = 250.3 \text{ Ohms.}$$

At zero frequency the formula shows the capacitive reactance is equal to 1 divided by 0 which is infinity.

By following the plan explained for inductive reactance, curve X_C, Figure 2, is plotted below the frequency scale or axis.

Notice that here the graph is not a straight line, and at low frequencies the capacitive reactance is very great; but as the frequency is increased, the capacitive reactance reduces very rapidly at first and then more slowly. Saying it another way, at low frequencies the inductive reactance is low and the capacitive reactance is high, while at high frequencies the inductive reactance is high and the capacitive reactance low.

CIRCUIT REACTANCE

As both these values are present in the same circuit and act in opposite directions, the total reactance of the circuit must be equal to their algebraic sum. To add, the inductive reactance is thought of as being positive while the capacitive reactance is negative.

For example, at a frequency of 200 cycles, the inductive reactance has a value of 200 ohms positive while the capacitive reactance has a value of 500 ohms negative. Adding, the sum is 300 ohms negative. Adding in this way, we find 150 ohms positive at 400 cycles, shown by point "a" in Figure 2. At other frequencies, points "b", "c" and "d" are found by the same method, and by joining them we have the curve X which represents the total reactance of the circuit.

Checking up here, you will notice the curve starts with a large negative reactance at low frequencies and rises rapidly as the frequency increases, reading zero at about 317 cycles. In other words, at a frequency of 317 cycles, the inductive and capacitive reactances are equal and opposite to make their sum zero.

As we explained in the earlier Lessons, the circuit is resonant at this frequency, has zero reactance, and thus allows maximum current. Looking at it in a different way, if the circuit of Figure 2 were connected across a 317-cycle supply it would form a short.

SERIES RESONANCE

The subject of resonance seems to cause some confusion, and therefore we want to check up a little further at this time. The general formula for resonance is stated:

$$f = \frac{1}{6.28\sqrt{LC}},$$

and substituting our values of 159 millihenries and 1.59 microfarads, we find f is equal to 316.69 cycles per second. By following the explanations already given, at 316.69 cycles we have:

$$X_L = 6.28\ fL = 316.22\ \text{Ohms.}$$

$$X_c = \frac{1}{6.28fC} = 316.23\ \text{Ohms.}$$

Thus you see, at the resonant frequency of 316.69 cycles as found by the general formula, the values of inductive and capacitive reactance are equal. Our figures show a difference of .01 ohm, but had we carried the figures out further, the results would have been exactly equal.

For all practical purposes, both inductive and capacitive reactance represent an opposition or resistance to an alternating or pulsating current of electricity. Thus, curve X of Figure 2 can be redrawn with all points above the axis as shown in Figure 3. Check these two curves and you will find points "a", "b", "c" and "d" are exactly the same.

A form of fixed condenser such as is commonly used in conjunction with a variable resistor for tone control purposes.

Courtesy Sangamo Electric Company

At 200 cycles, Figure 2 shows a net capacitive reactance or negative value of 300 ohms, while Figure 3 shows this same value above the axis instead of below. In this way, Figure 3 is really easier to read as it shows the circuit reactance decreasing to zero at resonance and then increasing as the frequency is increased further.

The small sketch below Figure 3 is merely the graphical method of adding the values of capacitive and inductive reactance at different frequencies.

RESISTANCE IN ACCEPTOR CIRCUIT

So far we have considered the circuit of Figure 2 as having zero resistance, but in practice that is never true. For Figure 4, therefore, we have added a resistance of 200 ohms in series with the inductance and capacitance.

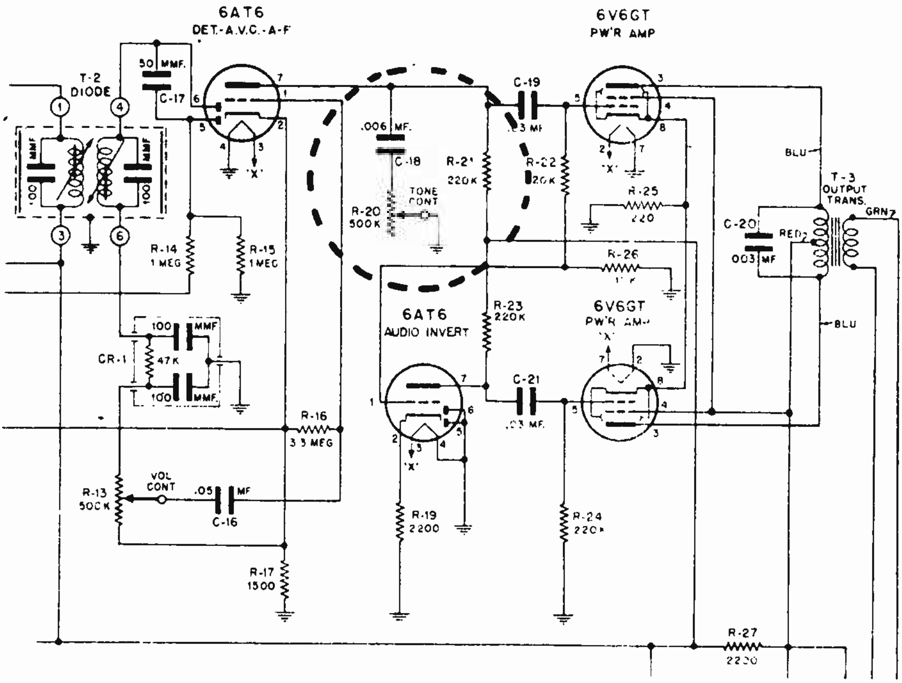
Once more, we will refer to the earlier Lessons and remind you that when adding resistance and reactance, it is necessary to find the square root of the sum of their squares. The same results can be obtained by graphs or vector diagrams if the resistance is represented at right angles to the reactance.

This is the plan we have followed in the small diagram below Figure 4. For example, at 200 cycles, according to Figures 2 and 3, X has a value of 300 ohms. To find the inpedance, with the 200 ohm resistance of Figure 4, we work like this:

$Z = \sqrt{R^2 + X^2} = \sqrt{(200)^2 + (300)^2}$

$Z = \sqrt{130{,}000} = 360$ ohms

The lower curve of Figure 4 is similar to that of Figure 3, while the upper curve is found by calculating the values as explained above for 200 cycles. The lower diagram of Figure 4 shows the work for points "a", "b", "c" and "d". The upper curve of Figure 4 thus represents the actual practical values more closely, and at the resonant frequency of 317 cycles, the reactance drops to zero but the impedance drops only to the 200 ohms of the resistance



Portion of a Motorola auto radio circuit. The tone control, shown within the broken line circle, consists of a .006-mfd. condenser in series with a 500,000-ohm variable resistor connected between the plate of the 1st audio amplifier and ground.

Courtesy Motorola, Inc.

PARALLEL CIRCUITS

Many circuits contain an inductor and a capacitor connected in parallel, and to find the reactance and impedance, we have to follow the general plan of simple direct current parallel circuits. In the earlier Lessons we showed you how to find the total reactance of a parallel circuit by adding the conductances of the branches. Conductance is measured in the unit MHO, and as a formula we can write: —

$$\text{MHOS} = \frac{1}{\text{OHMS}}$$

To find the total reactance of an inductor and capacitor in parallel, we can follow the same plan. That will give us a property known as the "Susceptance" of each branch which, like conductance, is measured in "MHOS". Compared to d-c circuits, a-c circuits have reactance instead of resistance, both measured in ohms, and susceptance instead of conductance, both measured in mhos.

For Figure 5, we have taken the units of Figure 2, connected them in parallel and now are going to draw curves for the susceptance of each. To make the difference easy to keep in mind, the curve for the susceptance of the inductor will be marked "Y_L", for the capacitor "Y_C", and their sum "Y".

By remembering the relation between mhos and ohms, if

$$X_L = 6.28\ fL \text{ in Ohms}$$

$$Y_L = \frac{1}{6.28\ fL} \text{ in Mhos}$$

And, in the same way, if

$$X_C = \frac{1}{6.28\ fC} \text{ in Ohms}$$

$$Y_C = 6.28\ fC \text{ in Mhos}$$

At a frequency of 200 cycles,

$$Y_L = \frac{1}{6.28 \times 200 \times .159}$$

$$= .005 \text{ Mho}$$

$$Y_C = 6.28 \times 200 \times .00000159$$

$$= .002 \text{ Mho}$$

$$Y = .005 - .002 = .003 \text{ Mho}$$

As explained for Figure 2, these points are located for different frequencies and connected to make the curves of Figure 5. Notice that here curve Y has the same general shape as curve X of Figure 2, and also crosses the axis at the resonant frequency of 317 cycles. However, susceptance represents the ease with which a reactive circuit will carry or allow current, and as this is zero at resonance, the reactance of the circuit must be very high.

If the frequency is reduced, the susceptance increases, which means the circuit will offer less resistance to current. In the same way, when the frequency is raised above resonance, the susceptance again increases, but where most of the current is carried by the inductor at frequencies below resonance, the capacitor carries more current as the frequency increases.

REACTANCE OF PARALLEL CIRCUIT

Perhaps it will be easier to follow the action here as we change the susceptance curve, "Y" of Figure 5 back to values of reactance. Remembering the relation between ohms and mhos, we can use the formula:

$$X = \frac{1}{Y}$$

At 200 cycles curve Y Figure 5 has a value of .003 mho, and substituting in the above formula:

$$X = \frac{1}{.003} = 333 \text{ Ohms}$$

By following this plan for frequencies from 0 to 1000 cycles, curve Y of Figure 5 becomes curve X of Figure 6. Notice that here at zero frequency, the reactance is also zero, but increases rapidly with the frequency, reaching infinity at the resonant frequency of 317 cycles.

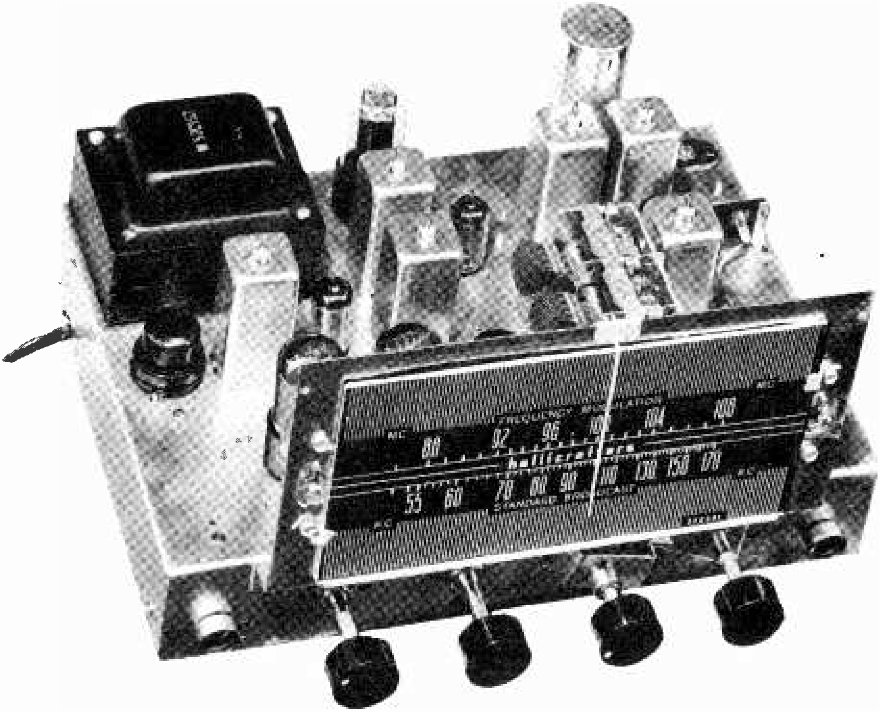
This may be a little hard to follow, but at resonance $X_L = X_C$ and, with "L" and "C" connected in parallel, both will have equal voltage across them which means equal current. However, the current in the inductor lags 90 degrees behind the voltage, while the current in the capacitor leads the voltage by 90 degrees. Thus we have two equal currents, 180 degrees out of phase which means they are opposite and neutralize each other. As a result, there will be no further current supplied to the circuit, even though there is a voltage across it, and therefore the reactance must have a value of infinity.

Above the resonant frequency the capacitive reactance drops rapidly and approaches zero, giving a curve which shows conditions opposite to those of the series circuit. Here again, for all practical purposes the values of reactance can all be thought of as positive, and by following the plan explained for Figures 2 and 3, the curve of Figure 6 can be redrawn as in Figure 7.

By following the curve here, and keeping the circuit in mind, it can be seen that at zero frequency there is zero reactance. All the current is carried by the inductor and none by the capacitor. As the frequency is increased, the reactance of the inductor increases while that of the capacitor is reduced. The total reactance, however, increases rapidly, and still there is more current in the inductive than the capacitive branch of the circuit.

At resonance, the reactances are equal and the currents are equal and opposite, making the total reactance rise to infinity.

Above resonance, the capacitive reactance reduces faster than the inductive reactance increases, making the total reactance less. Under these conditions most of the current is carried by the capacitive branch of the circuit.



Modern radio receiver chassis equipped from left to right with: volume control, tone control, selector switch, and tuning control.

Courtesy The Hallicrafters Company

REJECTOR CIRCUIT

Compare the curves of Figures 3 and 7 very carefully and notice their differences. At resonance, the circuit of Figure 3 has minimum reactance and thus will allow maximum current. At resonance also, the circuit of Figure 7 has infinite reactance and thus allows minimum current.

The series circuit offers a high reactance to all but the resonant frequency which it "Accepts", while the parallel circuit of Figure 7 offers a comparatively low reactance to all but the resonant frequency, which it "Rejects". For that reason, the parallel arrangement of Figure 7 is often called a "Rejector Circuit".

RESISTANCE IN PARALLEL CIRCUIT

As we explained for the circuit of Figure 3, there will always be some resistance, therefore, in Figure 8, we have added 200 ohms to the circuit of Figure 7. To plot a curve under these conditions, we follow the general plan explained for the series circuit curve of Figure 4 by using the formula,

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

or by vectors as shown below Figure 8.

For a frequency of 200 cycles, the curve of Figure 7 shows that the reactance has a value of 333 ohms, and we know that "R" of Figure 8 has a value of 200 ohms. Substituting in the formula:

$$Z = \sqrt{(200)^2 + (333)^2} = 388 \text{ Ohms}$$

By following this plan for frequencies from 0 to 1000 cycles per second, we are able to draw the curve of Figure 8 which approximates the actual conditions very closely. At zero frequency, the impedance of the circuit is equal to its resistance. As the frequency increases, the impedance rises rapidly, approaching infinity at resonance. At higher frequencies, just above resonance, the impedance first drops rapidly and then more slowly, approaching the value of the resistance again.

LOW PASS FILTER

Now that we have explained the electrical actions of these series and parallel resonant circuits, our next step is to show you how they are used to obtain practical results.

In Figure 9-A for example, we again have the circuit of Figure 2, but here have connected the load across the condenser. We want you to think of this load as the grid circuit of a tube. Imagine also a constant a-c voltage across the entire circuit with an arrangement to vary the frequency from 30 to 5000 cycles.

The choke coil and condenser are in series across the supply, and the load is in parallel with the condenser. As in any parallel circuit, the voltages across the branches are equal, and here the voltage across the load will always be the same as the voltage across the condenser. As the impedance of a grid circuit is extremely high, we will imagine it carries no current.

If we let L/2 and C/2 of Figure 9-A have the same numerical values as L and C of Figure 2, at a frequency of 100 cycles the condenser "C/2" has a reactance of approximately 1000 ohms, while the choke coil "L/2" has a reactance of 100 ohms. The total reactance is therefore 1000 − 100 or 900 ohms.

With 10 volts assumed across the circuit, the current will be .011 ampere which will cause a drop of 11 volts across the condenser and a drop of 1.1 volts across the choke coil. At this frequency, the voltage across the load will be a little higher than the supply voltage.

When the frequency is increased to 1000 cycles, the choke coil has a reactance of 1000 ohms while the condenser has a reactance of approximately 100 ohms. With a 10-volt supply, again there will be a current of .011 ampere in the circuit, but now there will be 11 volts across the choke coil and but 1.1 volts across the condenser and load.

If you figure the voltage drop at various frequencies, you will find the lower frequencies are passed on to the load with comparatively high voltage, while the higher frequencies reach the load at greatly reduced voltages. In other words, the circuit allows low frequencies to pass with little loss but greatly attenuates the higher frequencies, and therefore, it is known commonly as a "Low Pass Filter".

HIGH PASS FILTER

By using the same circuits, but connecting the load across the inductor as shown in Figure 9B, the opposite effect is obtained. For convenience, we will say that "2L" and "2C" of Figure 9-B are numerically equal to "L" and "C" of Figure 2, and following the explanation of Figure 9-A, with a 10 volt supply at 100 cycles there will be a drop of 1.1 volts across the inductor and load. At a frequency of 1000 cycles, there will be a drop of 11 volts across the inductor and load.

Thus, the higher frequencies are passed on to the load with little loss while the lower frequencies are greatly attenuated. The arrangement of Figure 9-B therefore is known as a "High Pass Filter".

When the load of Figure 9 is not infinitely large and carries a measurable current, at "A" the inductor is in series with the load and thus causes but a small voltage drop loss at low frequencies, but a large voltage drop at high frequencies. For Figure 9-B, the condenser is in series with the load and causes a large voltage drop at low frequencies with but small drop at high frequencies. Therefore, the explanation given for voltage of different frequencies also holds true when the loads carry current.

T-TYPE FILTER

The circuits of Figure 9 represent the simplest form of filters, and in practice you will usually find a number of inductors and capacitors arranged in different ways. The circuit of Figure 10-A is like that of Figure 9-A except a second inductor has been added and connected in series with the load. Since the layout of the units resembles the letter "T", this circuit is known as a T-type filter.

Because the inductors are in series with the load, the action will be similar to that of Figure 9-A and thus again we have a low-pass filter. The action of the inductor in series with the load will cause a sharper attenuation of the higher frequencies in the T-type than the simple type.

For a T-type high-pass filter, the same general layout is used, but the parts are connected as shown in Figure 10-C. Here we have the circuit of Figure 9-B with a second condenser connected in series with the load. This second condenser will cause a sharper attenuation of the lower frequencies, and for most purposes is an improvement over the simple type.

The circuits of Figure 10-A and 10-C are single section T-type filters, and a complete filter is often made up of two or more sections. Suppose two sections like Figure 10-A were connected in series. There would be a total of four chokes and two condensers. Two of the chokes would be in series between the condensers, and to save space, they could be combined into one unit with twice the inductance. Thus, a two-section T-type filter can be made of three chokes, and two condensers, the outer chokes with half the inductance of the center one.

In much the same way, two sections of the T-type high-pass filter of Figure 10-C would be made up of three condensers and two chokes, the outer condensers having twice the capacitance of the center one.

PI-TYPE FILTERS

Another common arrangement of a low-pass filter is shown in the circuits of Figure 10-B. Notice that here the choke is again in series with the load but has a condenser across the circuit on each side. Because the units here have a layout similar to the shape of the greek letter pi, "π", it is known as a "PI" type. Thus, the circuits of Figure 10-B represent a single-section, pi-type, low-pass filter.

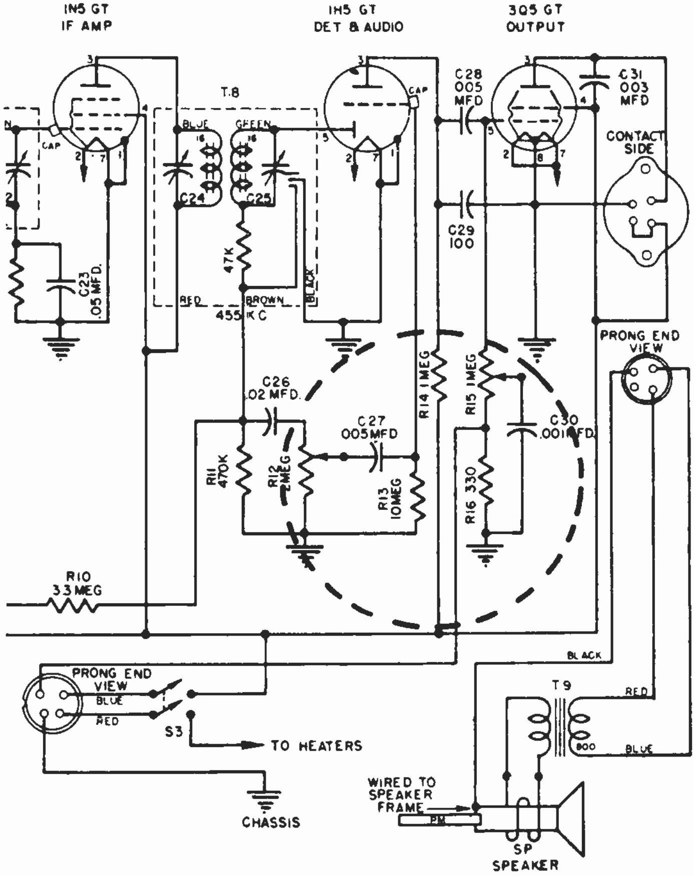
Using a similar arrangement, in Figure 10-D we have the circuits of a single-section pi-type, high-pass filter with a condenser in series with the load and two chokes across the line.

A two-section pi-type low-pass filter is made up of two chokes and three condensers, the outer condensers having one-half the capacitance of the center one, while a two-section, pi-type high-pass filter has two condensers and three chokes, the outer chokes having twice the inductance of the center choke.

FILTER CURVES

Another method of showing the action is by means of curves, and for Figure 10-E we have plotted the action of the low-pass filters of circuits A and B. With zero at the lower left, the frequency scale is along the bottom and the current scale at the left.

At zero and low frequencies the current is high, but at some particular frequency starts to reduce quickly. This is the "Cut Off" of the filter, and at frequencies above



Section of General Electric battery-operated receiver showing volume control in grid circuit of 1H5GT tube, and tone control in grid circuit of the 3Q5GT output tube.

Courtesy General Electric Company

the cut off the current reduces rapidly to a comparatively low value.

The curve of Figure 10-F is laid out in the same way and shows the action of a high-pass filter. At high frequencies the current is high, but as the frequency is reduced to the cut off point, the current reduces rapidly, and for all practical purposes there is zero current at the low frequencies.

LOW-PASS FILTER DESIGN

In the design of a low-pass filter section, it is general practice to consider the cut off value to be two times the resonant frequency of the circuit. Therefore,

$$f\ \text{cut off} = 2 \times \frac{1}{2\pi\sqrt{LC}} = \frac{1}{\pi\sqrt{LC}}$$

dividing π into 1 results in the constant .3183. For the low-pass filter, therefore, the formula becomes,

$$f = \frac{.3183}{\sqrt{LC}} \qquad (1)$$

In which

f = Cut off frequency in cycles per second.

L = The inductance in Henries.

C = The capacitance in Farads.

The value of the load connected to the filter is important and should be approximately equal to the impedance of the filter itself.

As explained in former Lessons, a transmission line has capacitance between its conductors, and any unit length will have a certain value of inductance even though it is not a coil. It is convenient to consider the electrical constants of a circuit "lumped" together, and for example, the low-pass filter circuit of Figure 10-B could represent a transmission line.

Any convenient length of a transmission line will have properties of inductance (L) and capacitance (C); and such a network connected to a source of voltage, will have what is known as a "characteristic impedance" which is entirely dependent upon the values of L and C.

When the values of L and C are known, the impedance of the line or filter can be found from the general formula

$$Z = \sqrt{\frac{L}{C}} \qquad (2)$$

At this point we want you to accept the correctness of the expression for characteristic impedance as the derivation of the formula is rather involved.

The values of L and C employed in the above and following design formulas are the same as those shown in Figures 9 and 10. However, you must take the figure "2" into consideration and use it as indicated. That is, if C in the formula is 10 mfd, the values of the condensers in Figure 10-B would each be 10/2 or 5 mfd.

For an illustrative solution, suppose we have a 200-millihenry choke coil and two 2-mfd condensers connected as in Figure 10-B. "C" will then be equal to 2 times 2 or 4 mfd, and on substituting in formula 1, the cut-off frequency will be—

$$f = \frac{.3183}{\sqrt{.200 \times .000004}} = \frac{.3183}{.000894}$$

$$= 356 \text{ cycles}$$

To find the proper impedance for this filter to work into, we substitute in the second formula and have:—

$$Z = \sqrt{\frac{L}{C}} = \sqrt{\frac{.200}{.000004}} = \sqrt{50{,}000}$$

$$= 223.6 \text{ Ohms}$$

Thus, we find the filter should work in a circuit with an input and output impedance of about 225 ohms and will have a cut-off frequency of 356 cycles.

Very often it is necessary to build a filter to work in a circuit with some definite impedance, and therefore we must find the correct values of L and C. To do this in a general way, we will work with equations (1) and (2).

By squaring equation (2), we have,

$$Z^2 = \frac{L}{C}$$

From which we can find,

$$C = \frac{L}{Z^2} \text{ and } L = CZ^2$$

Substituting this value of C in equation (1)

$$f = \frac{.3183}{\sqrt{L \times \frac{L}{Z^2}}} = \frac{.3183}{\sqrt{\frac{L^2}{Z^2}}}$$

$$f = \frac{.3183}{L/Z} = \frac{.3183\ Z}{L}$$

Transposing these values:

$$L = \frac{.3183\ Z}{f} \qquad (3)$$

Following the same steps, but substituting the value of L from equation (2), in equation (1),

$$f = \frac{.3183}{\sqrt{(CZ^2) \times C}} = \frac{.3183}{\sqrt{C^2Z^2}} = \frac{.3183}{CZ}$$

Transposing these values—

$$C = \frac{.3183}{fZ} \qquad (4)$$

Suppose now we want to use a low pass filter in a 200 ohm microphone circuit and have a cut-off at 350 cycles. For the proper values of L and C, we need only substitute in equations (3) and (4) like this—

$$L = \frac{.3183 \times 200}{350} = \frac{63.66}{350} = .1818 \text{ Henry}$$

$$C = \frac{.3183}{350 \times 200} = \frac{.3183}{70{,}000}$$

$$= .00000454 \text{ Farad}$$

Working this way, we find an inductance of 182 millihenries and capacitances of 4.54 ÷ 2 or 2.27 mfd, will produce a low pass filter, like Figure 10-B, to work in a 200-ohm circuit and have a cut off of 350 cycles.

Of course, the odd values found this way cannot be purchased readily; therefore you select standard sizes of the closest values, and substitute in equations (1) and (2) to determine what effect they will have on the filter. In our former explanation we found a 200-millihenry choke and 2-mfd condensers would make a filter with a cut-off at 356 cycles and an impedance of 223.6 ohms. This would be close enough to the above values for most practical applications.

HIGH-PASS FILTER DESIGN

In the design of high-pass filters, the cut-off frequency is considered to be one half the resonant frequency, therefore,

$$\text{f cut off} = \frac{1}{2} \times \frac{1}{2\pi\sqrt{LC}} = \frac{1}{4\pi\sqrt{LC}}$$

Dividing 4π into 1 results in the constant .07958, and the general formula for the cut off frequency becomes—

$$f = \frac{.07958}{\sqrt{LC}} \qquad (5)$$

The impedance of the filter remains as stated in Formula (2), and to find the proper values of L and C for a given load impedance, we follow the plan explained for low-pass filters.

Without repeating all the steps, for high-pass filters,

$$L = \frac{.07958Z}{f} \qquad (6)$$

$$C = \frac{.07958}{fZ} \qquad (7)$$

To show you how these work out, suppose we again take the 200-ohm microphone circuit with a cut-off frequency of 350 cycles.

Substituting in equations (6) and (7)

$$L = \frac{.07958 \times 200}{350} = \frac{15.916}{350}$$

$$= .0454 \text{ Henry}$$

$$C = \frac{.07958}{350 \times 200} = \frac{.07958}{70{,}000}$$

$$= .00000113 \text{ Farad}$$

Reducing these values to the more common units, the choke coil of Figure 10-C requires an inductance of 45.4 Millihenries and the condensers a capacitance of 2 x 1.13 or 2.26 mfd. Commercially we might have to use a 50-millihenry choke and 2-mfd condensers, and on substituting in formula (5) we find:

$$f = \frac{.07958}{\sqrt{.05 \times .000001}} = \frac{.07958}{.000223}$$

$$= 356.8 \text{ cycles}$$

which is very close to our required

value of 350 cycles. When substituting in equation (2), we get:

$$Z = \sqrt{\frac{.05}{.000001}} = \sqrt{50000} = 223 \text{ ohms}$$

These explanations will give you an idea of how the different values are found. The methods apply to all types of filters explained in this Lesson. As a general rule, the T-type filter is used for constant voltage circuits, while the Pi-type is used for constant current circuits.

TONE CONTROL CIRCUITS

The actions of series and parallel circuits containing inductance, capacitance and resistance are used in many ways for controlling or improving the tone of audio amplifiers. For example, a low-pass filter will reduce the higher frequencies and thus emphasize the lows, while a high-pass filter will reduce the lows and emphasize the highs. By making either or both of these adjustable, we will have a Tone Control.

Bass and treble tone controls installed on the panel of a sound system amplifier.
Courtesy Stromberg-Carlson Company

In Figure 11, we have the circuits of one of the simplest and perhaps the most common type of tone control. The complete circuit is a single stage of a resistance coupled audio amplifier made up of the grid load R, bias resistor R1 and the plate load resistor R3. However, in addition to these units, there is the condenser C and the variable resistor R2 which make up the tone control.

Without taking C and R2 into consideration we will assume that the frequency response of this stage is perfectly flat. That is, both high and low frequency voltages will appear across the load R3 with equal amplitude, provided the input voltages are equal. Now, let's assume that C and R2 are connected in the circuit with the movable contact at the upper end of R2. This, in effect, takes the resistance out of the circuit and places the condenser C from the plate of the tube to ground.

As the reactance of a condenser varies inversely with the frequency, it will tend to provide a comparatively low reactance path for the high frequencies. Under these conditions, the frequency response of the stage is no longer flat, but at the high frequency end there will be a dropping off in the amplitude of the voltage across R3. In other words, the high frequencies will be attenuated by an amount depending on the value of C.

Therefore, if condenser C were variable, the degree of the attenuation could be controlled. However, a variable condenser of the needed capacitance is impractical, but the same effect is obtained by using the variable series resistor R2. The action of R2 thus is to increase or decrease the total impedance of the plate circuit. This will have a greater effect at the higher frequencies due to the lower reactance of condenser C. In other words, R2 controls the authority of condenser C in the attenuation of the higher frequencies.

In the design of a tone control circuit of this type, R2 has a resistance value several times greater than the capacitive reactance of the condenser at the lowest frequency chosen, in order that when the moving arm is at the lower end of R2 in Figure 11, there will be very little attenuation of the higher frequencies.

You will also find the tone control of Figure 11 employed in the grid circuit, with the condenser C and resistance R2 connected in series from the grid to ground. The action, however, is exactly the same as that explained above.

The ohmic value of R2 will depend on the capacitance of the condenser C and the impedance of the circuit in which it is placed. The common values used vary between 50,000 and 500,000 ohms.

The value of the condenser C will depend on the maximum attenuation desired, and generally varies between .02 mfd and .006 mfd.

The circuit of Figure 11 will attenuate only the high frequencies, and to attenuate either the highs or lows, the circuit of Figure 12 may be employed. You will notice that the amplifier stage is exactly the same as that in Figure 11, while the tone control is made up of the condensers C, C1 and C2 together with the variable resistors R2 and R4. The two variable resistors are "ganged" or controlled by the same shaft, and the broken line below R2 indicates an "open" while the solid line above R4 indicates a direct connection.

To use definitive values, we will asume that R2 and R4 each have a resistance of 500,000 ohms, while C is .02 mfd, C1 is .05 mfd and C2 is .00075 mfd. With the movable arm in the position shown in Figure 12, the only active parts are the condensers C1 and C2 connected in parallel, to form the coupling condenser to pass the signal to the grid of the next stage. We will assume that the values of these condensers are such that a flat frequency response is obtainable with the movable contacts as shown.

Suppose now that the shaft of the control is turned so that the movable contacts are at the lower end of R4. Under these conditions we have added the 500,000 ohms resistance of R4 in series with condenser C1, and have thus increased the coupling impedance for a given frequency. However, we still have the condensers C1 and C2 in the circuit, and as C2 is very small, the reactance will be so large at the low frequencies that but little signal voltage will be carried over to the grid of the following tube. However, the capacitive reactance diminishes as the frequency increases and thus the high frequencies will be carried over to the next stage with but little attenuation. Therefore, with these connections the low frequencies are attenuated.

If the movable contacts are at the upper end of R2, condenser C will be connected directly from the tube plate to ground and give exactly the same action as explained for Figure 11, thus attenuating the high frequencies. By placing the movable contacts anywhere between the extremities we have explained, the desired degree of attenuation of either the high or low frequencies can be obtained.

The circuit of Figure 13 is another method of controlling both the high and low frequency response, but here we make use of tuned circuits containing resistance, capacitance and inductance.

On tracing the circuit, you will see a choke coil "L" is connected in series between the plate and transformer primary, while a potentiometer "R2" is connected in series with a condenser "C" across the primary. The movable contact of the potentiometer connects directly to the plate of the tube.

With the potentiometer arm P at the top or inductor end of R2, the choke coil L is shorted out of the circuit. All the resistance of R2 is in series with condenser C across the transformer primary. The value of R2 is high enough to prevent the condenser from attenuating the high frequencies, which are therefore carried over to the following stage by the transformer.

With the arm P at the bottom or condenser end of R2, condenser C is in parallel with the transformer primary and choke coil L, while R2 is across the choke. This arrangement places a tuned circuit in series with the plate, producing greater amplification at and near a low resonant frequency, while the added inductance of the choke tends to attenuate the higher frequencies. Thus, moving arm P one way will cut down the lows and increase the highs, while moving it the other way will attenuate the highs and increase the lows.

RESONANT PLATE CIRCUIT

Not all tone controls are of the adjustable type, and in Figure 14 we have a common circuit for increasing the amplification of the lower frequencies. We show only the circuits of the tube which feeds the push pull output stage, although there may be several stages in the complete amplifier.

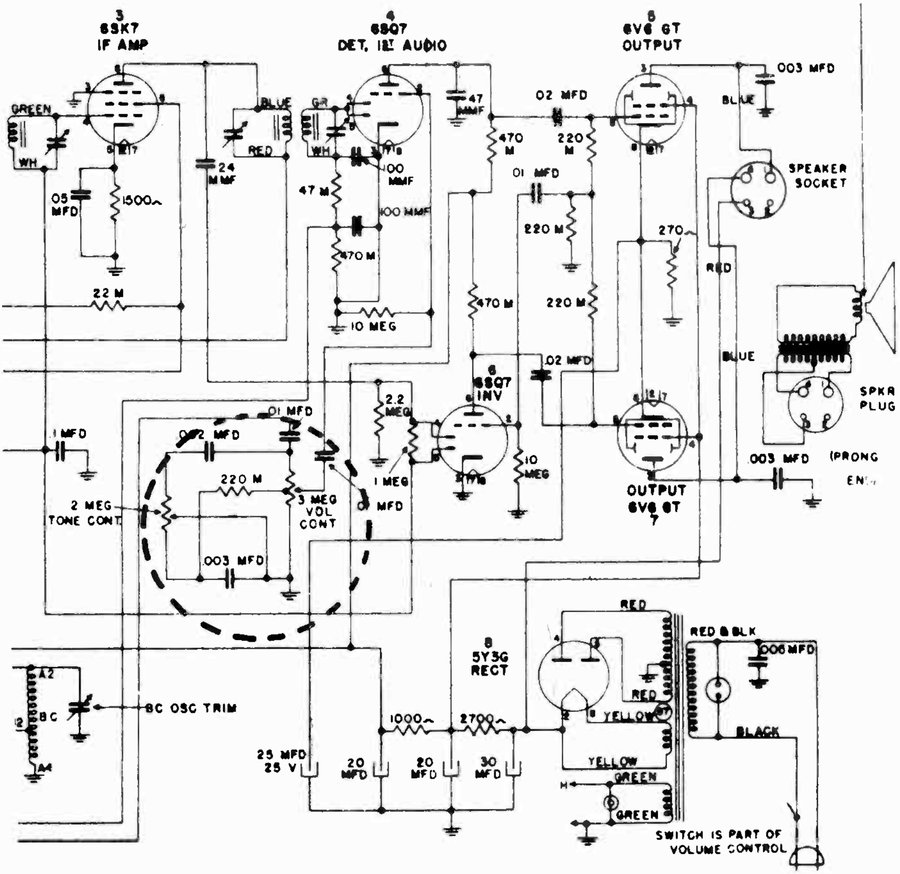
In the ordinary circuit of this type, the "B+" supply connects directly to one end of the coupling transformer primary, but here the condenser C has been added in order to make the circuit resonant at some low frequency.

The signal in the plate circuit of the preceding tube is carried over through the coupling condenser and appears as a voltage across the grid resistor R. This voltage is thus across the grid and cathode of the tube, and controls its plate current.

There also is a circuit from the plate of tube T1 through the transformer primary and condenser C to the cathode. This is like the circuit of Figure 2 and has values which make it resonant at some low frequency. For signals at or near this frequency, the reactance of the transformer primary and condenser C is very low, allowing a high current. This high current causes a greater voltage drop across the transformer primary, and thus tends to increase the amplification of the signals at or near the resonant frequency.

A similar high voltage appears across condenser C which is also in the circuit C, R2, C1 and R1. Condenser C1 has a large capacitance and is used to bypass high-frequency currents around the B supply, therefore R2 is necessary because the voltage drop across it keeps one side of the condenser C above ground potential.

The voltage across C therefore will cause current in the circuit made up of C, R2, C1 and R1; but as R1 is in the grid circuit, current through it will cause a



Section of a Farnsworth receiver circuit. Within the heavy broken circle can be seen the tone-compensated tapped volume control as well as the variable tone control.

Courtesy Farnsworth Television & Radio Corporation voltage drop which will also be applied to the grid of the tube. Thus, the signal voltages in the plate circuit are fed back to the grid in the correct phase, thereby increasing the signal voltage.

The reactance of condenser C will vary inversely with the frequency, and thus this feedback action will take place only at low frequencies. At high frequencies the reactance of C is low, there is but little voltage drop across it and therefore, no noticeable feedback.

The result of the action is a greater amplification of the lower frequencies with little or no effect on the higher frequencies.

BASS COMPENSATION

The characteristics of the human ear are such that when sounds are reproduced at lower than normal volume levels, the low notes appear to be abnormally weak, while when the sound is reproduced at greater than normal level, the low notes appear to be abnormally loud.

In order to correct for this peculiarity, an arrangement commonly referred to as "Bass Compensation" is used in many radio receivers and audio amplifiers. It causes the manual volume control to function so that at low levels the intensity of the low notes is not reduced as much as that of the higher pitched sounds.

In a typical circuit as shown in Figure 15, we have the potentiometer R which is tapped toward its lower end, and from the tap the condenser C and resistor R2 are connected in series to ground. The movable contact of the potentiometer, being connected directly to the grid of the tube, allows any value of voltage across R, from zero to full potential, to be applied to it. Due to this action, the potentiometer serves as a volume control.

With the movable contact at the upper end of R, the full signal voltage is applied to the grid, and the part above the tap is in series with the parallel combination made up of C and R2 and the lower section of the potentiometer. Controls of this type are usually tapped at 30% of the total resistance; and by using a 1-megohm control, the upper section would have a resistance of 700,000 ohms while the lower section would have a resistance of 300,000 ohms. Therefore, with the movable contact at the upper end of the volume control, there would be little attenuation of any frequency.

However, as the arm is moved towards the tap where maximum compensation occurs, the condenser forms a comparatively low reactance path for the high frequencies and thus they are attenuated. The resistance R2 is connected in series with C in order that there will not be too great a loss of the higher frequencies, and also to fix the output level when the volume control arm is set at the tap. In practice, using a 1 megohm control tapped at 300,000 ohms, with C having a capacitance of .01 mfd, a fairly high order of compensation will occur when R2 has a value of 10,000 ohms. To reduce the compensation, it is only necessary to increase the value of R2.

On summing up the action of this circuit, it is seen that at low settings of the volume control, the section of the potentiometer in use is shunted to ground through a resistance and capacitance combination which has a lower impedance to high frequencies than to low frequencies, and which thereby discriminates against the former. With the control set in the high position, there is little attenuation of any frequency.

COMPENSATED VOLUME CONTROL

If in Figure 15, we place an inductor L in series with C and R2 and make the circuit resonant at about 1000 cycles, where the ear has the greatest sensitivity, then the audio frequencies in this region are bypassed more than those at the higher and lower audio frequencies. This series resonant circuit is then a form of an acceptor circuit, sometimes called a "trap", and its effectiveness can be controlled by adjusting the value of R2. Larger values of R2 will decrease the attenuating effect of the tuned circuit.

As this circuit arrangement gives an apparent boost of both the high and low audio frequencies, it is called a "Compensated Volume Control", in contrast with the bass compensated circuit of Figure 15. Insertion of the acceptor circuit provides a "loss", and therefore the audio amplifier must be capable of supplying the needed additional amplification.

BASS BOOSTER

In Figure 16, we have the circuits of a simplified "Bass Booster". The name is derived from the fact that, instead of attenuating the highs in order that the low notes will be more pronounced, the low frequencies are amplified more than the highs to give a better control of the tone desired by the individual listener.

On checking the circuits of Figure 16, you will notice that the signal voltage is impressed across the volume control R. From here, however, it splits and one path is from the upper end of R to the grid of T1 while the other path is from the movable contact to the left hand grid of T2. Thus, we have what might be called a dual channel audio system.

Following the signal from the grid of T1, it will be seen to reappear in the plate circuit containing the tuned circuit L-C. From here it is carried over to the potentiometer R2 by condenser C1, and impressed on the right hand grid of T2. Let us assume that the combination L-C is resonated at 30 cycles. From your earlier Lessons you know that at this frequency the circuit will offer maximum impedance and thus develop maximum voltage drop. As the frequency increases or decreases from resonance, the voltage drop across the circuit will also decrease. Under these conditions, therefore, with the circuit resonated at 30 cycles, the low notes will be amplified to a much greater degree than the higher frequencies.

However, the original sound containing all frequencies, is impressed also on the left hand grid of T2, and thus in tube T2, we have not only the amplified bass notes but also the original sound. The next step is to "mix" the two, and this is done simply by connecting the two plates of T2 together. From these plates the resultant audio voltages can be amplified in the usual way.

TUNED PLATE BASS BOOSTER

A modified bass booster not requiring the use of a separate tube, may be an arrangement whereby an audio frequency tuned circuit is placed in the plate circuit of a tube. Looking at Figure 11, suppose the condenser C is replaced by the tuned audio L-C circuit of Figure 16. Imagine also that R3 of Figure 11 is removed, and instead of connecting the variable arm of R2 to ground, assume it is connected to B+. The plate load then consists of the tuned circuit and the used portion of R2.

In practice it is desirable to place a fixed resistor of about 50 thousand ohms in series with the variable resistor in order to prevent excessive amplification at the frequency of the tuned circuit and to provide greater stability. The value of the coil L and the capacitance of C will depend on the desired resonant frequency, and also on the plate resistance of the tube.

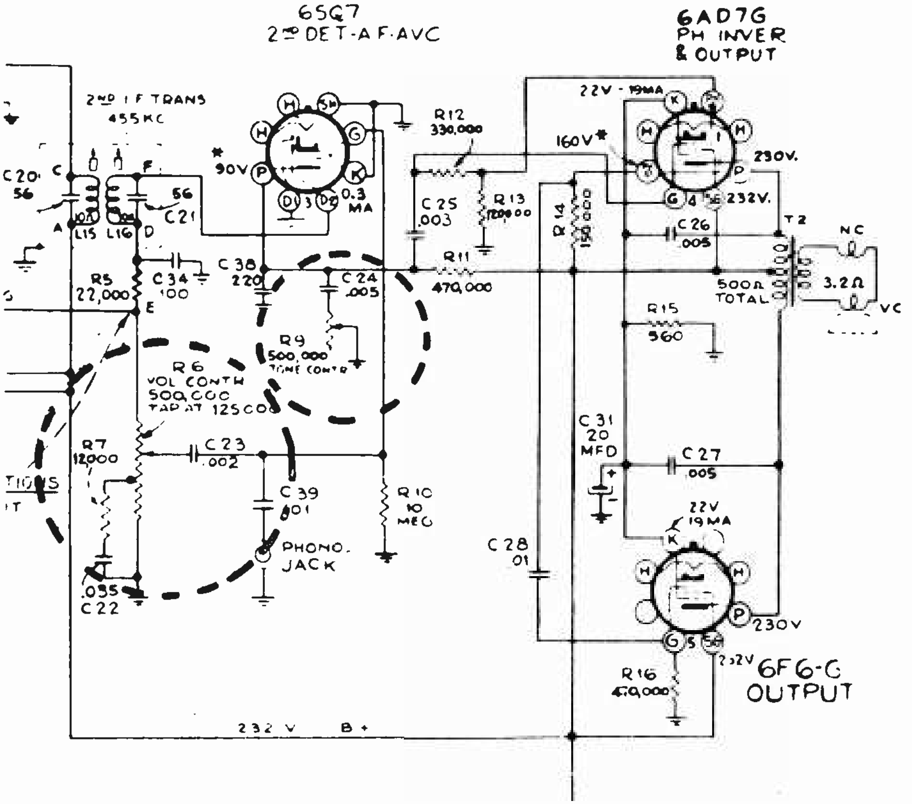
If a tube with a high resistance is used, such as a high mu triode or pentode, L should have a high value of inductance — say about 100 henries, and for an 80-cycle bass boost, C should be about .04 mfd, whereas 100,000 ohms resistance would be a satisfactory value of R2.

In operation, the audio frequencies at and near resonance of the tuned circuit will develop a greater voltage than frequencies above the resonant value, and thus the bass boost is accomplished. The desired amount of accentuation can be controlled by R2.

TREBLE — BASS BOOSTERS

It may be desirable to boost both the high and low frequencies in an audio system, particularly if the program is being operated at low level.

In Figure 17 we show a resistance-capacitance coupled stage which is basically conventional in that the audio-frequency voltages are applied to the control grid of the triode tube, and thus reappear with greater amplitude across the plate load resistor R5. From this point the proportion of the high and low frequency voltages appearing across the in-



Part of an RCA receiver circuit showing the 2nd detector and audio amplifier stages. Within the heavy circles are shown the tone control and the tone-compensated tapped volume control.

Courtesy Radio Corporation of America

put to the following a-f tube will depend on the respective positions of the arms on potentiometers R1 and R2.

If the tube is a low-mu triode and the grid load, plate load, and cathode resistor with its bypass condenser are of conventional values to give satisfactory high and low frequency boosting, the other circuit constants may be as follows:—

C1 – .25 mfd.
C2 – .0008 mfd.
C3 – .006 mfd.
C4 – .0005 mfd.
C5 – .004 mfd.
R3 – 250,000 ohms
R4 – 50,000 ohms
R5 – 30,000 ohms
R1 – 500,000 ohm audio control
R2 – 5 megohm linear control

We will assume that the indicated positions of the potentiometer arms R1 and R2 give "normal" operation of the circuit such that no tone control effect takes place.

If bass boost is desired, the arm of R2 is moved up which effectively shorts out the parallel network composed of C4 and part of R2, and therefore decreases the "opposition" to the low frequencies being applied to the following grid circuit.

Now assuming that R2 is returned to the normal position, if high boost is desired, control R1 is moved to the left to decrease the shunting of high frequencies to ground through C3.

With R1 in the normal position and bass attenuation desired, control R2 is moved down, which effectively provides a "loss" circuit for low frequencies, yet lets the high frequencies pass to the output terminal through C4 without appreciable attenuation.

High frequency attenuation is then provided by moving R1 to the right, which decreases the opposition to high frequencies through condenser C3.

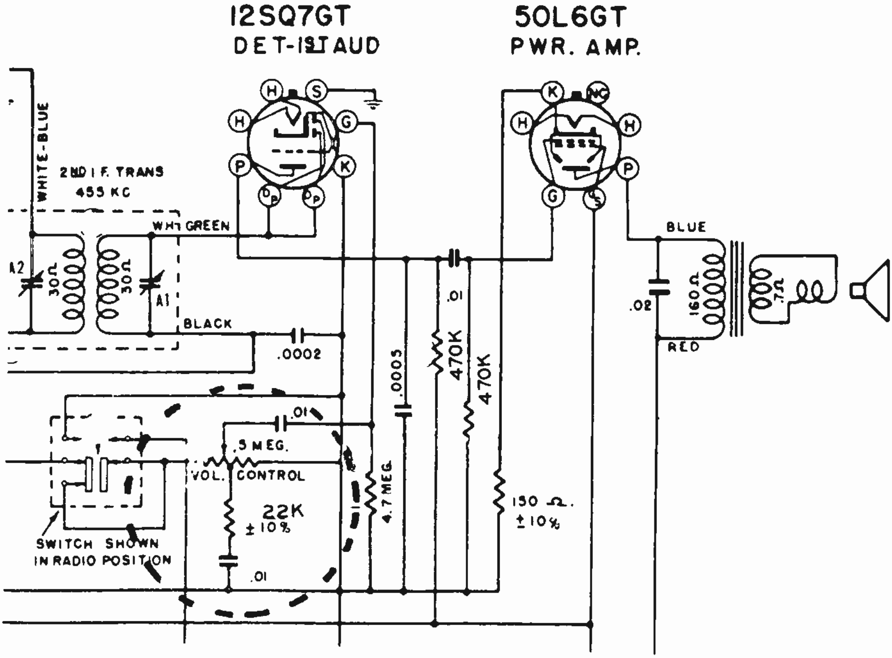
Resistor R5 is about 50,000Ω in order that the output voltage remains essentially constant irrespective of the change of impedance made in the tone control section of the circuit. R3 and R4 are selected to determine the "loss" at normal settings. As the circuit operates on the principle of introducing losses, sufficient amplification in the tube is required in order to compensate for them.

It will be noticed that the basic principles of attenuation in the above described tone control are to provide a low opposition path to high frequencies, and a high opposition path to the low frequencies.

Other types of treble-bass control circuits sometimes used in higher priced audio systems consist of two or more tuned circuits acting as a portion of a load in a tube circuit and desirable accentuation is accomplished by means of series or shunt variable resistors.

AUTOMATIC TONE CONTROL

As you will learn later, under certain conditions it is possible to make a tube exhibit the properties of a condenser or an inductance. A simple application of this feature is illustrated in Figure 18 where we show a tube and circuits which function as an automatic tone control.



Section of a Zenith a-c/d-c receiver circuit showing the use of a tone-compensating tapped volume control connected into the grid circuit of the triode section of the 12SQ7GT tube. See part enclosed in broken line circle.

Courtesy Zenith Radio Corporation

The principal object of the circuit is to provide changing capacitance effects across the portion of the volume control which supplies audio voltage to the succeeding a-f stage at varying volume levels. In other words, the circuit is designed to vary the high-frequency audio response automatically in accordance with the strength of the signal in the receiver. When a strong signal is being received, the higher audio frequencies are permitted to pass;

while in the case of a weak signal in which the noise level is high and it is composed largely of the higher audio frequencies, the action of the circuit is such that these frequencies are attenuated by the "condenser action" of the circuit.

The capacitance between the control grid and cathode of the tube acting as a conventional amplifier, is dependent on its mutual conductance. When the amplification of the tube is high, the input capacitance of the tube is correspondingly high. When the gain is low, the input capacitance is also low.

When a variable mu tube, which means one in which the amplification factor varies with d-c grid potentials as in a 6K7, is connected conventionally as shown in Figure 18, and it has a change of d-c bias applied from a suitable source in the receiver, then changing signal levels affecting the operating point of the tube will also vary its input capacitance in accordance with the strength of the signals being received. The input capacitance appears as a shunting condenser, shown by the dashed lines, and when the capacitance increases, the high audio frequencies are by-passed.

The condenser connected between the plate and control grid serves the purpose of broadening the range over which the input capacitance varies under the action of the d-c bias circuit. The purpose of the switch is to cut off the automatic tone control circuit if desired. When the switch is open, no audio signals reach the tube and therefore it will have no tone control effect.

In this Lesson, we have given you an explanation of various types of frequency controls, and although you may run into variations of these, the operating principles will be the same. Therefore, be sure that you are familiar with these principles so that you will not have any difficulty understanding the action of any other tone control.

IMPORTANT WORDS USED IN THIS LESSON

ACCENTUATE—To emphasize or increase the intensity of a series of sound or radio waves.

ACCEPTOR — A series resonant circuit that permits the free passage of an alternating current of the frequency at which the circuit is resonant.

ATTENUATE — To diminish or reduce the intensity of a series of sound or radio waves.

BASS BOOSTER — A circuit arrangement that causes the low-frequency response of an audio amplifier to be accentuated without affecting the higher frequencies.

BASS COMPENSATION — The process of emphasizing the low-frequency response of an audio amplifier to compensate for the decreased sensitivity of the human ear to weak low frequencies.

FLAT-TOP RESPONSE — The response characteristic of a circuit or device that uniformly transmits all frequencies within a certain band.

FUNDAMENTAL — The lowest component frequency of a periodic or recurring action. The fundamental of a vibrating string, as in a piano, is the frequency when the string vibrates as a whole, or in one segment.

HARMONIC — A note or tone that has a frequency which is an integral multiple of the fundamental or basic frequency.

HIGH-PASS FILTER — A filter that permits the free passage of alternating currents above a certain critical or cut-off frequency, and retards or attenuates all frequencies below this value.

LOW-PASS FILTER — A filter that permits the free passage of alternating currents below a certain critical or cut-off frequency, and retards or attenuates all frequencies above this value.

OCTAVE — The interval between two tones or notes that have a frequency ratio of 2 to 1.

OVERTONE — Same as harmonic.

REJECTOR — A parallel circuit that offers high opposition to an alternating current of the frequency at which the circuit is resonant.

RESONANCE — That condition in a circuit when the inductive and capacitive reactances are equal.

TONE CONTROL — A control used on some radio receivers and audio amplifiers for changing the frequency response by causing the bass or treble frequencies to be emphasized.

STUDENT NOTES

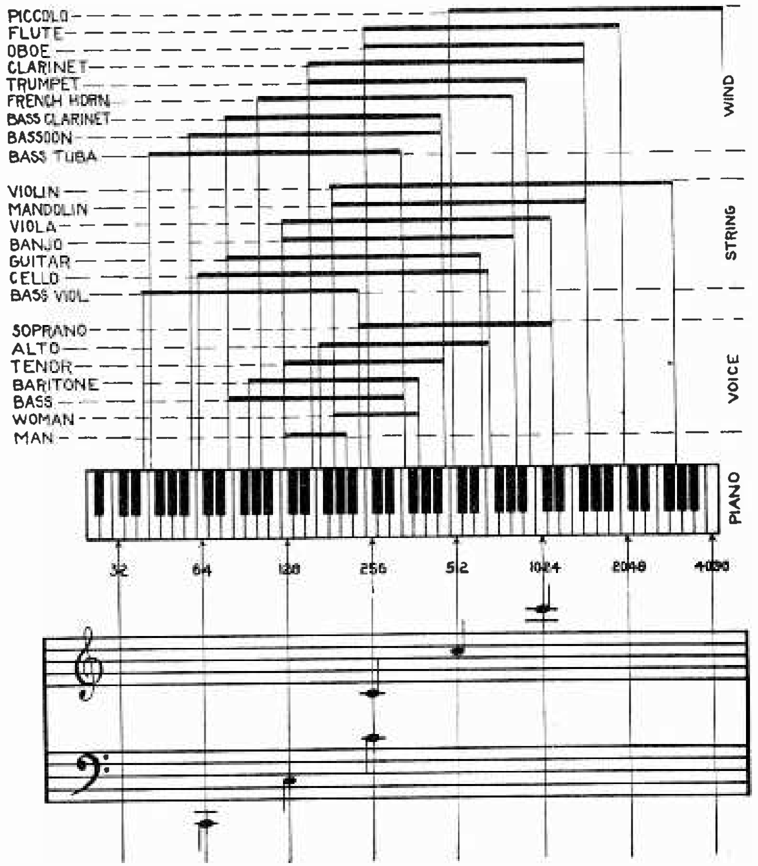
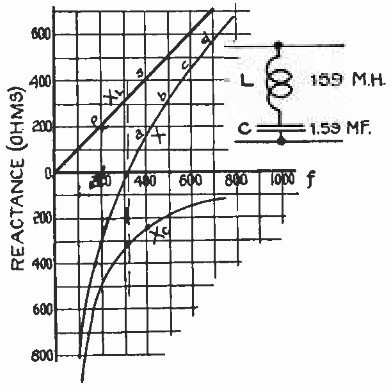


FIGURE 1



RRT-4

FIGURE 2

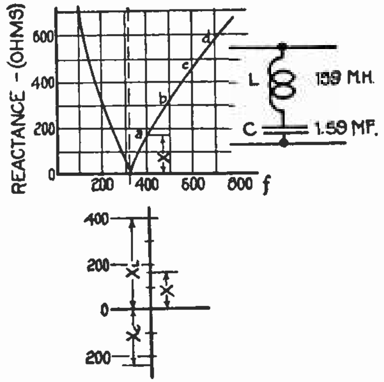


FIGURE 3

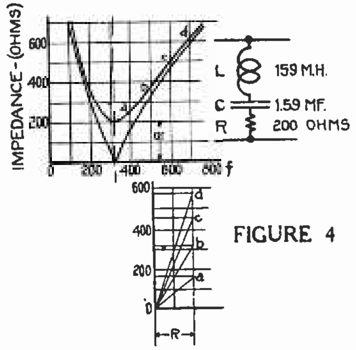


FIGURE 4

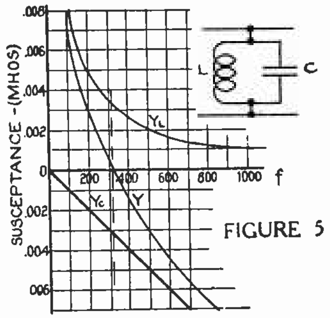


FIGURE 5

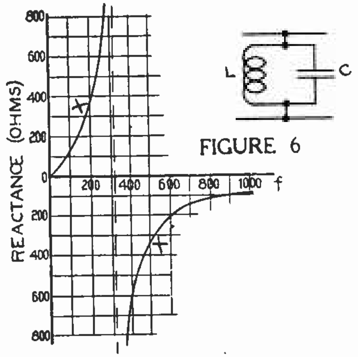


FIGURE 6

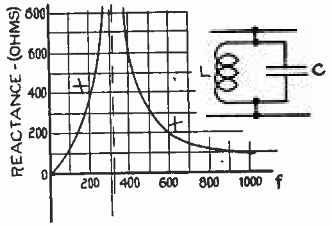


FIGURE 7

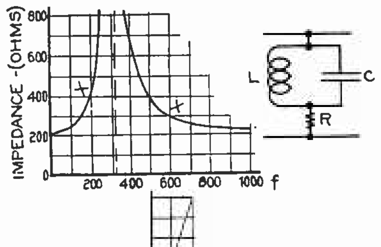


FIGURE 8

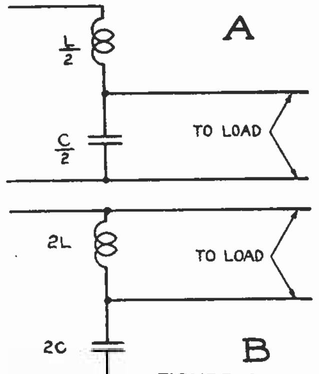


FIGURE 9

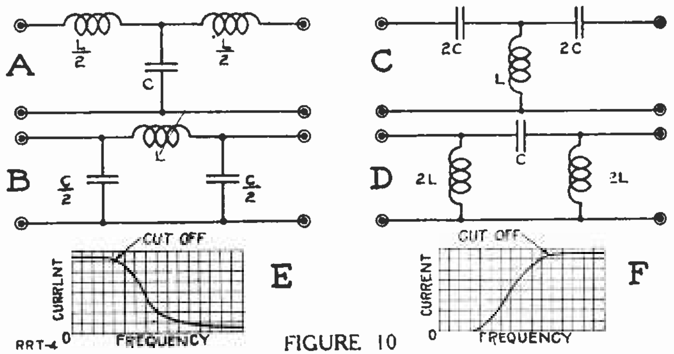


FIGURE 10

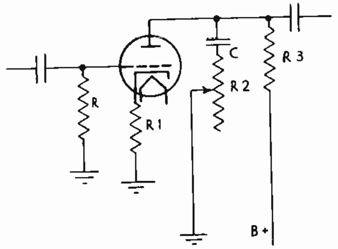
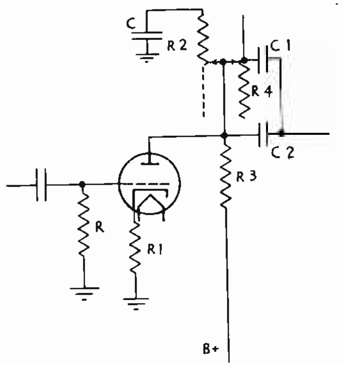


FIGURE 11



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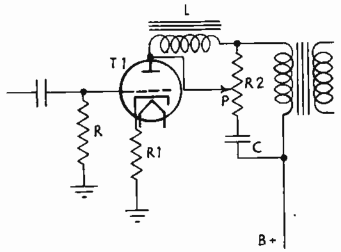


FIGURE 13

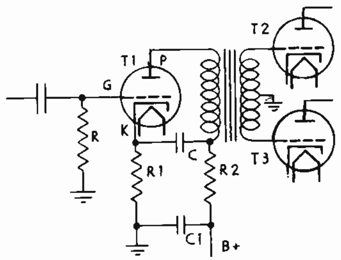


FIGURE 14

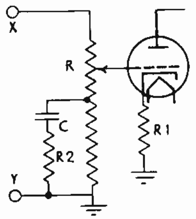


FIGURE 15

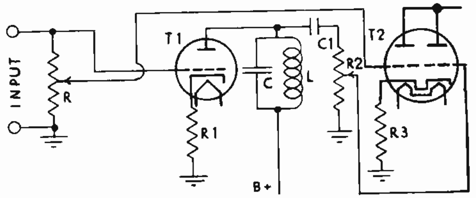
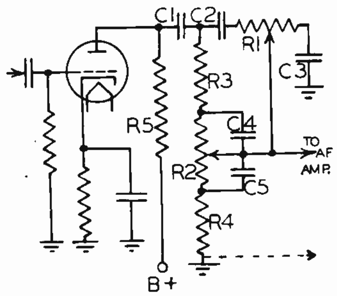


FIGURE 16



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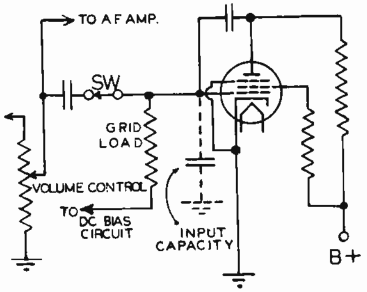

FIGURE 18

FROM OUR *President's* NOTEBOOK

THE MAN WHO GETS PROMOTED

The ordinary fellow does an ordinary task,
He's mighty fond of "good enough" and
lets it go at that;
But the chap who gets promoted, or the
raise he doesn't ask,
Has just a little something more than hair
beneath his hat.
The ordinary fellow lives an ordinary day,
With the ordinary fellow he is anxious to
be quit;
But the chap who draws attention and the
large weekly pay
Has a vision for the future, and is working
hard for it.
The ordinary fellow does precisely as he's
told,
But someone has to tell him what to do, and
how and when;
But the chap who gets promoted fills the job
he has to hold
With just a little something more than ordinary men.

—Edgar A. Guest

Yours for success,

E. B. DeVry

PRESIDENT

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