AUTOMATIC VOLUME CONTROL

Lesson RRT-10

DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois

RRT-10

Radio Reception and Transmission

LESSON RRT-10

AUTOMATIC VOLUME CONTROL

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1906—Dr. Lee DeForest announced the development of his 3-electrode vacuum tube, to be used as an amplifier of weak-signal pulses. A patent was granted in 1907.

1906—The first high frequency alternator built by Alexanderson at the General Electric Company. The machine gave a great impetus to long-distance and overseas radio communication.

1906—Fessenden constructed his first transatlantic wireless station, which differed considerably from the systems employed by Lodge and Marconi.

1913—Radio beacons were installed on all important lighthouses and lightships under the supervision of Frederick Kolster, prominent American Radio Engineer.

DE FOREST'S TRAINING, INC.

2533 N. ASHLAND AVE., CHICAGO 14, ILLINOIS

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-10

AUTOMATIC VOLUME CONTROL

INDEX

Rectifier Action .... Page 4

Action of AVC Filter .... Page 6

AVC Circuit .... Page 10

Time Delay .... Page 12

Series-Feed AVC .... Page 15

Shunt-Feed AVC .... Page 15

Delayed AVC Systems .... Page 16

Number of Tubes Controlled by AVC .... Page 19

Automatic Volume Expansion .... Page 20

* * * * *

An education may be obtained in a high school or a college. It also may be obtained in an office, the home, or a factory. It is willingness to learn; a desire to acquire a knowledge; a determination to advance that gives one an education.

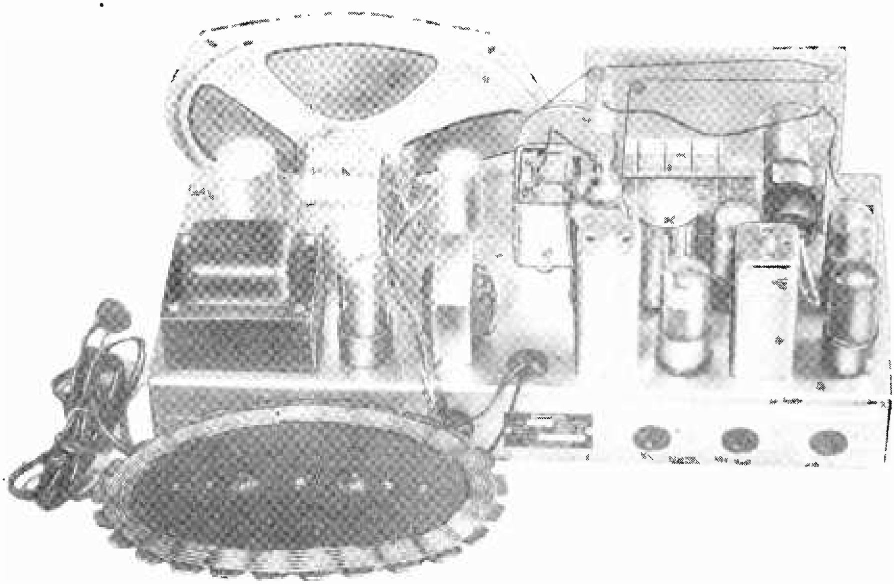
—Selected

AUTOMATIC VOLUME CONTROL

Automatic volume control, commonly abbreviated "avc", was explained briefly in the earlier lessons; but because of its application to practically all present day commercial superheterodyne receivers and other electronic devices, we want you to have a more complete understanding of its action. Therefore we will devote this entire lesson to the subject.

Considering the usual conditions of signal input, it is not difficult to understand why "avc" has been so universally applied to radio receivers. The many electromagnetic carrier waves cutting the antenna of most any radio receiver installation, will be of various amplitudes, depending on the power of the transmitters and their distance from the receiving station. In the case of weak carriers, the signal strength may be as low as 2 or 3 microvolts, whereas with a powerful local transmitter it may be as high as 1 volt.

Therefore, without avc, tuning the receiver from a weak to a strong signal, without changing



Chassis view of modern radio receiver that is equipped with automatic volume control. The chassis can also be employed for reproducing phonograph records as well as for recording purposes.

Courtesy Wilcox-Gay Corporation

the gain or volume control, will result in a loud and probably distorted sound from the speaker. However, this difficulty, which is commonly referred to as blasting, can be minimized with automatic volume control.

Then also, as explained in an earlier lesson, a change in the Kennelly-Heaviside layer produces a variation of signal strength, the effect of which, commonly called "Fading", can be reduced considerably by applying avc.

Referring to the earlier lessons on vacuum tubes, you will remember that an increase of the negative bias voltage applied to the control grid, reduces the plate current and likewise reduces the gain or available amplification. This means that an increase in negative control grid bias, applied to the r-f and i-f stages of a receiver, reduces the sensitivity of the complete system.

Thus, if we devise some method by which the negative control grid bias on the r-f and i-f stages of a radio receiver will be changed automatically in proportion to the incoming signal strength, an automatic control of the sensitivity is secured. This will provide an approximately constant signal level at the detector, which in turn will result in a more constant audio output, although there is a change of signal voltage in the antenna. This is the general method employed in present avc circuits, and the following explanations will show you how it is possible to obtain this "automatic" control of the negative grid bias voltage.

RECTIFIER ACTION

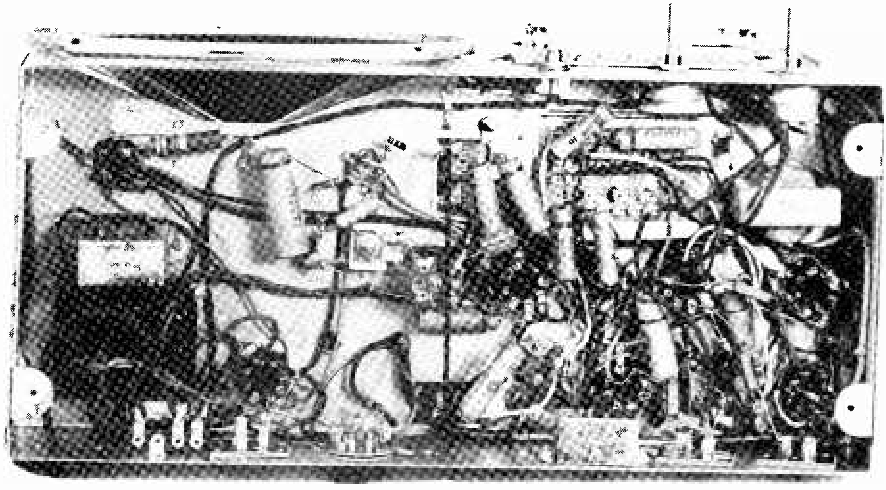
Due to the amplifying action of the radio and intermediate-frequency stages of a receiver, the carrier wave has its greatest amplitude at the demodulator or 2nd detector. Therefore, we will investigate its action to determine if it is possible to obtain a d-c voltage which will vary with the applied signal and be available as a negative bias for the control grids of the r-f and i-f stages.

Looking at Figure 1, we want you to think of the circuit as that of the last i-f stage of a superheterodyne receiver, coupled to a diode second detector "V_2" by the i-f transformer consisting of a tuned primary and secondary. As you know, the diode detector is really a rectifier, and perhaps it will help you to follow this explanation by considering the secondary of the i-f transformer as that of a power transformer. The tube and load resistance R complete the circuit of a conventional half-wave rectifier system.

Since we are interested in obtaining a fairly high-d-c voltage, and to reduce detuning and damping of the circuit it is essential to apply a minimum load on the i-f transformer, R has a comparatively high value, usually several hundred thousand ohms. The bypass condenser C is installed to prevent intermediate-frequency variations of voltage drop across resistor R.

sistor R. Thus, if the strength of the carrier increases, the d-c voltage output increases also.

However, from your study of the diode detector you know that with a modulated i-f input, the voltage appearing across R will vary with the modulation, and thus must be considered as a pul-



Lower view of chassis shown on the previous page.
Courtesy Wilcox-Gay Corporation

From the earlier lessons you know that a diode detector is essentially a linear rectifier, which means that an increase in input results in a proportionally greater output. For simplicity of explanation, we will assume a 2 to 1 ratio between the carrier voltage and the rectified a-c. That is, with a 10 volt carrier across the secondary L, 5 volts of d-c will appear across the load re-

sating d-c. In this form it is not possible to employ it as the control voltage for avc, because its variations are at an audio rate, representative of the modulation component of the carrier. This would be the equivalent of applying an audio signal to the control grid circuits of the r-f and i-f stages.

This pulsating d-c can be considered as being made up of two parts or components. One part is the modulation component and the other is the steady d-c voltage. The next step, therefore, is to separate these components so that the steady d-c can be made available for the avc voltage.

The method by which these are separated is exactly the same as in any other system wherein we wish to remove the a-c component from a pulsating d-c voltage. You will notice that the network used for this purpose, as shown in Figure 2, is very similar to the conventional type of filter found in the common plate power supply systems. In comparison, resistors R_1 and R_2 occupy a position similar to that of the usual filter chokes while C_1 and C_2 occupy the normal filter condenser positions. Thus, the filter system employed to secure a pure d-c output in an avc circuit is basically the same as the filter employed in a conventional power supply system.

ACTION OF AVC FILTER

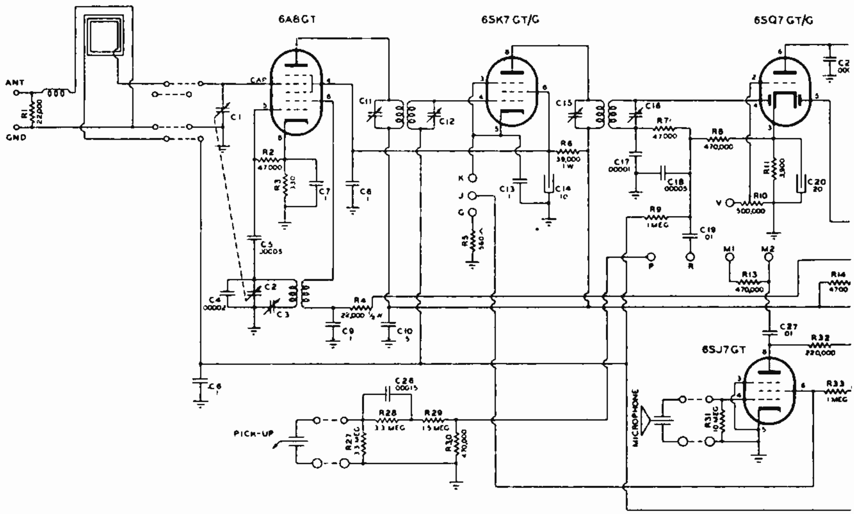
The action of the avc filter network is not hard to understand, and we want you to imagine that the circuit of Figure 2 is connected across the output load resistance R of Figure 1.

Point A is connected to the junction between L and R, with point B connected to ground. Thus, between points A and B there will be a steady d-c voltage plus an a-c signal voltage, but in analyzing the action, we will consider each of them separately.

Since we are interested in the steady d-c voltage as a source of control grid bias, an examination of Figure 2 shows no d-c path between A-B or XY. Suppose we assume a 5 volt d-c source is connected across A-B, and terminals X-Y are unloaded or open. Condensers C_1 and C_2 block d-c, consequently there is no d-c voltage drop across R_1 and R_2. Under such conditions, the voltage between X and Y is also 5 volts.

Still comparing the circuit of Figure 2 with a conventional power supply filter network—only d-c voltage is necessary across X and Y for negative bias control; whereas, to supply the plate and screen grid circuits of vacuum tubes with proper energy, both voltage and current must be avaliable at the output terminals of the filter. Just as the voltage divider and the tube circuits form a load across a power supply, the grid circuit of a controlled tube is connected across X and Y of Figure 2. However, there is one big difference, and that is the fact that avc circuits do not draw current from the source of voltage. Therefore R_1 and R_2 can be high resistance values compared to the low d-c resistance values of the chokes in a power supply filter.

To further clarify the fact that the d-c voltage across X-Y, Figure 2, is almost identical with that across A-B, assume R_1 and R_2 each have a value of 500,000 ohms. Consider also that the grid circuit connected across X-Y has a d-c resistance of 99 megohms. Thus the total series resistance between A-B is .5 megohm plus .5 megohm plus 99 megohms, or 100 megohms. As the voltage drop across a portion of a series circuit is proportional to the resistance of that part, the drop across the 1 megohm of R_1 plus R_2 is 1/99 of the total. With 5 volts d-c across A-B, the voltage across X-Y = 99/100 x 5 = 4.95 volts. This loss of .05 volt is negligible and for all practical purposes, the d-c voltage across points A-B and X-Y is the same.

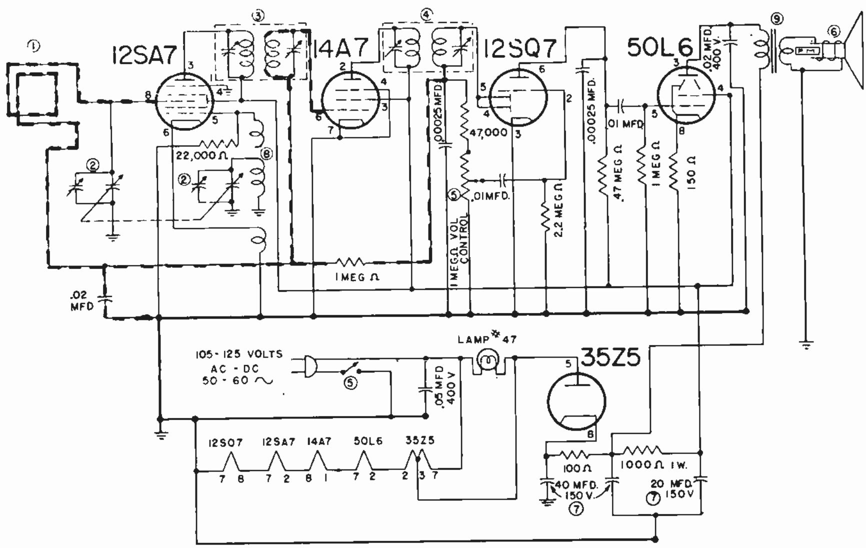


Portion of circuit employed in the chassis shown on the previous pages. The avc line is tapped off at the left end of resistor R8, and leads through resistor R9 to the control grid of the 6SK7 i-f amplifier as well as to the signal grid of the 6A8 mixer tube.

Courtesy Wilcox-Gay Corporation

To eliminate the a-c component of the pulsating d-c voltage, the capacitances C_1 and C_2 are chosen so as to provide a low reactance at audio frequencies. This means that only a small a-c voltage will be developed across the first filter condenser C_1 because of its relatively low impedance with respect to the first resistance R_1. This small a-c voltage across C_1 is reduced further by the same action in the R_2-C_2 combination, with the result that very little a-c voltage appears across C_2, which is the output of the filter.

To offer greater detail on the removal of the a-c component, the circuit of Figure 2 has been re-arranged to that of Figure 3, the 318 cycles. Because its value is low, in comparison to that of the resistors, we will consider this reactance as a resistance, and also assume that the signal input to the filter is composed of a 5 volt a-c component plus a 5 volt d-c component.



5-tube superheterodyne receiver with the avc distribution system shown in heavy broken lines. The avc filter consists of a 1-meg resistor and .02-mfd condenser. (1) is the loop assembly, (2) two-gang variable tuning condenser, (3) & (4) i-f transformers, (5) volume control, (6) p-m speaker, (8) oscillator coil, (9) output transformer.

Courtesy Garod Radio Corporation

connections, however, remaining the same. To make use of some definite quantities, for this example we will assume R_1 has a value of 1 megohm, R_2 is 500,000 ohms, and the condensers C_1 and C_2 each have a capacitance of .05 mfd which provides a reactance of 10,000 ohms at a frequency of

With a 5 volt a-c signal applied across A-B of Figure 3, there will be a 5 volt a-c drop across R_1-C_1. In a series circuit the voltage drop across the different parts is proportional to their resistance. As R_1 with 1,000,000 ohms is 100 times the 10,000 ohms of C_1, the drop across R_1

will be 100 times that across C_1. The total resistance of the circuit is 1,000,000 ohms + 10,000 ohms = 1,010,000 ohms and in proportion,

$$R_1 = \frac{1.000,000}{1,010,000} = \frac{100}{101}$$
$$= .99+ = 99\% \text{ (approx.)}$$
$$C_1 = \frac{10,000}{1,010,000} = \frac{1}{101}$$
$$= .0099 = 1\% \text{ (approx.)}$$

With a 5 volt a-c supply, the drop across R_1 will be 5 x .99 = 4.95 volts and that across C_1 will be 5 x .0099 = .0495 volt which, for simplicity, will be considered as .05 volt.

As resistor R_2 and condenser C_2 are connected in series across C_1, the voltage impressed across them will be the same as that across C_1 which, for this example is .05 volt. With the assumed values of R_2 = 500,000 and the reactance of C_2 = 10,000 ohms, the total resistance across C_1 = 500,000 + 10,000 = 510,000 ohms. Following the former plan, in proportion,

$$R_2 = \frac{500,000}{510,000} = \frac{50}{51}$$
$$= .98+ = 98\% \text{ (approx.)}$$
$$C_2 = \frac{10,000}{510,000} = \frac{1}{51}$$
$$= .0196 = 2\% \text{ (approx.)}$$

With an .05 volt supply, the drop across R_2 will be .05 x .98 = .049 volt and that across C_2 will be .05 x .02 = .001 volt. Thus, the filter system has attenuated the a-c component so that at the output of the filter, the a-c voltage is equal to about 1/5000th of that present at the input.

To continue the explanation, the filter has no effect upon the d-c of the detector output, which is the part we seek for automatic volume control purposes. Inasmuch as we have stated that there is no direct current path through the filter, the d-c voltage across the output is approximately equal to the d-c input which in this case is 5 volts.

Although the above explanation is suitable for the assumed conditions, in actual practice the filter system must be capable of separating the a-c and d-c components for all audio frequencies. You know the reactance of a condenser varies inversely with the frequency, and therefore, at the lower values of audio frequency, the efficiency of this filter will decrease because the ratio of the reactance to resistance will be reduced. That is, the reactance of the filter condensers will increase while the ohmic value of the resistors will remain approximately the same. For example, the .05 mfd condensers mentioned above provide a reactance of approximately 64,000 ohms at a frequency of 50 cps—therefore, the drop across them will allow a greater a-c voltage at the output of the filter.

However, at the higher frequencies, the efficiency of the filter will be increased, due to the reduction of the capacitive reactance of the filter condensers. This causes a lower voltage drop across C_1 and C_2 of Figure 3, and therefore a lower a-c voltage at the output of the filter.

In analyzing this variable situation, it appears that the values of the filter components should be chosen to give good efficiency at the lowest audio frequency. This would mean increasing the capacitance of C_1 and C_2 or increasing the values of the resistances R_1 and R_2. A design of this type would give the desired d-c component, but at the same time would slow up the "speed of action" of the avc system. In other words, the time delay of the system would be too great for efficient avc action and therefore, in the practical design of a complete network, a compromise between filtering efficiency and time delay must be made. An explanation of the "time delay" action will be given a little later in this lesson.

The addition of the filter of Figure 2 to the output of Figure 1, provides a d-c voltage which varies with the average value of the applied modulated i-f voltage. So far, we have said nothing about the polarity of this voltage, but by checking the circuit of Figure 1 and following the path of the electrons, the voltage drop across R will be positive at the cathode and negative at the end connected to the i-f transformer. Therefore, with the filter of Figure 2 connected as before, point X will be negative with respect to point Y or ground.

Considering a 10 volt i-f signal aplied to V_2 in Figure 1, and assuming a 2 to 1 ratio between the applied voltage and d-c output, there will be a 5 volt drop across R. With the filter properly connected and no d-c current, point X of Figure 2 will be 5 volts negative with respect to point Y. If the i-f signal is increased to 50 volts, then point X will be 25 volts negative with respect to point Y.

Thus, if the control grid return of an amplifier tube is connected to terminal X and its cathode connected to terminal Y, its negative grid bias voltage will increase or decrease with the average amplitude of the i-f voltage and its sensitivity or gain will be controlled automatically.

AVC CIRCUIT

To follow the action in detail, the circuits of Figures 1 and 2 are combined with the grid and cathode circuits of tube V_1 to complete the circuits of Figure

4 which can be considered as the last i-f and detector stages of a superheterodyne receiver. From the control grid, there is a circuit down through coil L, resistors R_2, R_1 and R to ground and from ground through R_3 to the cathode.

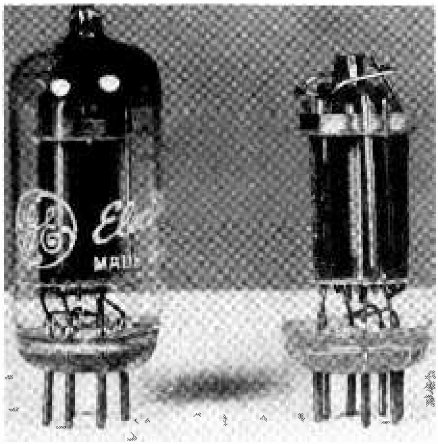
An electronic voltmeter with a high input resistance is needed to measure the voltages operative in an avc system.
Courtesy Electronic Instrument Company

Thus, with no signal, there will be a bias voltage on the control grid due to the voltage drop across R_3 caused by the plate and screen grid currents of tube V_1.

With adequate capacitance provided by C_3, the voltage drop across R_3 can be assumed as constant, and therefore the negative bias on the control grid of V_1 will not be less than the voltage drop across R_3. This may bring to your mind a question as to the necessity of this minimum bias, but you must remember that most tubes operate at their maximum sensitivity with a definite bias voltage. Therefore, the ohmic value of R_3 is chosen to develop the required voltage drop for maximum sensitivity of the stage. When used in this way, the voltage drop across R_3 is commonly referred to as the "initial" bias voltage. To illustrate with definite values, we will assume this drop to be 3 volts, giving an initial negative bias of 3 volts on the control grid of V_1.

When an i-f voltage from the secondary L is impressed on the control grid of V_1, the signal will be amplified and appear in the plate circuit primary L_1 of the i-f transformer. Because of the inductive coupling, the signal voltage will appear across the secondary L_2 and be impressed on the detector V_2 and resistor R. Assuming this signal has an amplitude of 10 volts, with a 2 to 1 a-c/d-c ratio, there will be a 5 volt d-c component across R.

As the avc filter and resistor R are in the control grid return circuit of tube V_1, this 5 volt drop will make the grid potential 5 volts negative with respect to ground. However, the cathode is the reference point for tube element voltages, therefore the voltage drop across resistor R_3 must be considered also. Checking the previous explanations and the polarities indicated in the diagram, you will find the voltage drops across R and R_3 are series aiding and thus the total negative grid bias voltage is $3 + 5 = 8$ volts. This increase above the



A type 12AT6 miniature duodiode high-mu triode used in modern superheterodyne receivers as 2nd detector, avc rectifier, and 1st audio amplifier.

Courtesy General Electric Company

initial bias of 3 volts, causes a reduction in the gain of the i-f stage.

According to the previous explanations, the d-c voltage across R will vary with the average amplitude of the i-f voltage therefore, an increase of signal will cause an increase of negative grid bias and the gain of the stage will reduce. A reduction of signal will reduce the negative bias and the gain of the stage will increase.

Therefore the avc action tends to maintain a uniform output from the detector, regardless of the signal strength at the input of the receiver. The action of an avc circuit is not perfect, and the output of the detector is not the same for all values of input. However, a receiver equipped with avc is far superior in operation than one without this feature. By distributing the d-c voltage output of the avc filter to the control grids of several tubes, the desired degree of control over the amplification in the r-f and i-f systems can be obtained.

TIME DELAY

In our explanations so far, we have mentioned that the purpose of an avc system is to provide substantially constant output regardless of changes in the signal input. As far as the changes of received signal intensities are concerned, they may be either rapid or slow, but whatever the condition, the control voltage must be able to increase or decrease as the occasion demands.

Earlier in this lesson we told you about the difference in the efficiency of the avc filter with respect to changing frequencies, and also that the values of filter resistance and capacitive reactance had a great influence upon the ability of the control voltage to follow rapid changes in receiver output voltage. This action is known as the "time delay"; but before going into detail, it will be of benefit to review the actions which take place when a condenser is charged and discharged through a resistor.

As a general rule, if the voltage is changed in one part of a circuit, there is an instantaneous change in every other part. However, when a circuit contains large values of capacitance and resistance, there is a definite and appreciable time between the instant that the initial voltage change is made at one point and the instant the corresponding effect appears at other points of the circuit.

It has been found that if a condenser is connected in series with a resistor and the combination connected across a d-c supply, the condenser will be charged gradually to the full potential of the source. A definite amount of time is required for the flow of electrons necessary to charge the condenser.

When in series with a resistor, the exact amount of time required for a condenser to reach 63% of its final charge is known as the "time constant", and this percentage holds true for any combination of resistor and condenser values. From a practical standpoint, however, the time constant in seconds is equal to the product of the resistance in megohms and the capacitance in microfarads.

Written as an equation,

$$t = RC,$$

when

t = time constant in seconds
R = resistance in megohms
C = capacitance in microfarads

There is no voltage term in the equation, as the magnitude of the source of voltage will have no effect on the time constant and the condenser will charge to 63% of its final value in the same time regardless of whether the source is 1 volt, 5 volts, 75 volts or 1000 volts.

When speaking of time constant, it is also necessary to mention the discharge of a condenser through a resistor. Just as a certain amount of time is required to charge a condenser when in series with a resistor, it is also necessary for a certain amount of time to elapse to permit it to discharge. As far as the discharge is concerned, the time constant RC as explained above, is the time required for a condenser, in series with a resistor, to discharge to 37% of its initial or fully charged value.

Going back to the circuit of Figures 2 and 3, it contains combinations of resistors and condensers in series and therefore will cause a definite time lag between changes of applied voltage across A-B and output voltage across X-Y. Using the values of a previous example, $R_1 = 1$ megohm and $R_2 = .5$ megohm for a total of 1.5 megohms, with C_1 and C_2 of .05 mfd each for a total of .1 mfd. Tracing the condenser charging circuits,

$$t = R_1 (C_1 + C_2) + R_2C_2$$
$$= 1 (.05 + .05) + .5 (.05)$$
$$= .125 \text{ second}$$

which is the time required for a change of input voltage to cause a corresponding change of output voltage. Intervals of .125 second correspond to a frequency of 8 cps, thus, in effect, the output voltage will vary only at frequencies below this value. Changes of input voltage, occurring at higher frequencies, will not affect the output voltage and thus no audio signal voltages developed across resistor R will appear at the filter output.

The action of condenser C connected across resistor R can be explained in much the same way. Due to the rectifying action of tube V_2, the current in R is in the form of pulses which occur at the intermediate frequency and vary in amplitude with the modulation. When the tube is nonconductive, the condenser discharges through R and therefore the circuit has a definite time constant or time delay. Quite common values for this circuit are R = .5 megohm and C = .0001 mfd for a time constant of,

$$t = RC = .5 \times .0001 = .00005 \text{ second}$$

which corresponds to a frequency of 20,000 cps. Thus, audio frequency voltages below this value appear across R while the higher intermediate frequencies do not.

Referring again to the avc filter circuit, its time constant should be large enough to provide adequate filtering yet small enough to allow the output voltage to follow rapid changes of input voltage due to fading or tuning. By employing smaller values of R and C, the time delay can be reduced but the filtering efficiency is impaired, therefore, a compromise must be made.

For broadcast receivers, the optimum value of the time constant is approximately .1 to .3 second. For high fidelity receivers, suitable time constants range from .25 to .5 second while multi-wave receivers employ values between .1 and .2 second. A shorter time delay is desirable for short wave reception due to the more rapid fading characteristics of higher frequency carriers.

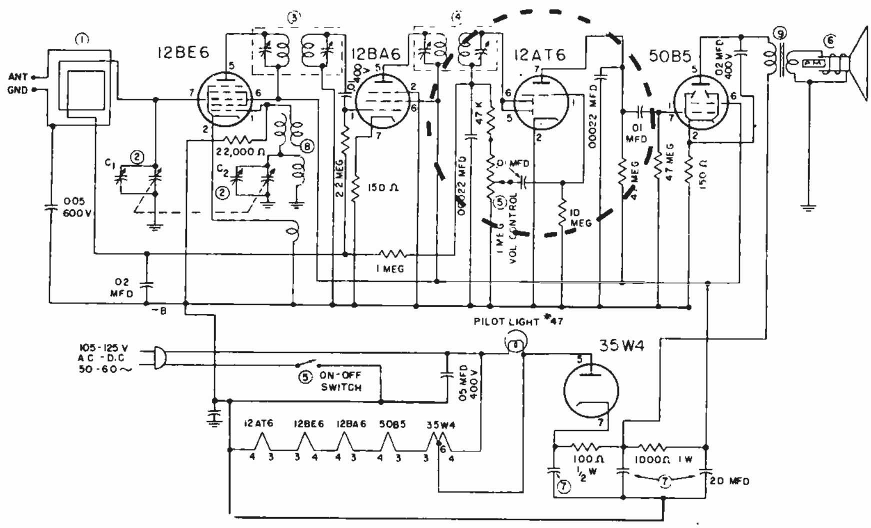
SERIES-FEED AVC

As in any electrical network, there are two basic types of avc circuits, series and parallel. An arrangement of series-feed avc is shown in Figure 4, in which the d-c grid circuit from the control grid of tube V_1 is completed through L, R_2, R_1, R and R_3 to the cathode, all components being connected in series.

In a controlled r-f stage, where the tuning condenser is grounded, a blocking condenser of relatively large capacity is placed between the coil and ground to prevent shorting out of the avc voltage. The tuned grid circuit of V_1, Figure 4, need not be grounded as condenser C_2 provides sufficient bypass for i-f currents.

SHUNT-FEED AVC

Shunt-feed avc is an arrangement whereby the d-c control voltage is fed directly to the control grid, usually through a one-half megohm resistor connected to the filtered avc voltage source. However, a blocking condenser must be connected between the control grid of the tube and the tuned circuit to prevent shorting out of the avc voltage. The 500,000 ohm grid resistor mentioned above, is the usual value of resistance to use for the grid leak, as greater values have a tendency to cause grid blocking.



Commerciol 5-tube superheterodyne circuit illustrotroting the use of o type 12AT6 duodiode triode os 2nd detector, ovc rectifier, ond 1st oudio omplifier. See port of circuit enclosed within lorge broken-line circle.

Courtesy Gorod Rodio Corporotion

It is therefore possible to use combinations of series and shunt-feed avc circuits to provide any desired characteristic action with minimum damping or detuning of r-f and i-f circuits.

DELAYED AVC SYSTEMS

The simple avc circuit of Figure 4 acts to reduce the gain of the controlled r-f and i-f amplifier stages as soon as a signal voltage is developed in the detector circuit and therefore, is undesirable at low input signal levels. To overcome this disadvantage, circuits have been developed to delay the avc action until the signal voltage rises to some predetermined value. Because of the action, this is known as "delayed avc" and the signal strength at which the action starts is called the "threshold" voltage.

With delayed avc, all signal inputs below the threshold voltage allow the receiver to operate with maximum sensitivity as only the optimum initial negative bias voltage is applied to the grids of the controlled amplifier tubes. At signal inputs above the threshold voltage, the action is the same as explained for the circuit of Figure 4.

For example, if the threshold voltage is set at 50 microvolts input, the receiver will operate at maximum sensitivity for all inputs below this value to provide the best possible reception of weak signals. For higher inputs, the avc will be operative and provide the advantages explained for the circuit of Figure 4.

The details of the "delay" action can be followed in the circuit of Figure 5, which is similar to that of Figure 4, but tube V_2 is a duo-diode. Modulated i-f voltages developed across coil L are impressed across the grid circuit of amplifier tube V_1, and, as explained previously, appear in amplified form across plate coil L_1. As coils L_1 and L_2 are coupled inductively, the amplified voltage is impressed across the D_1 section of the duo-diode tube V_2. The rectifying action of the tube causes a pulsating d-c across R_4 and the filtering action of C_4 removes the i-f pulses so that the modulation or audio frequency voltages can be coupled to the audio amplifier.

So far, the action duplicates that of the circuit of Figure 4 but there is no provision to apply the voltage across R_4 to the grid circuits of preceding tubes. Tracing from the control grid of V_1, there is a circuit through coil L, avc filter resistors R_2 and R_1 and through resistor R to ground. From ground, the circuit is completed through R_3 to the cathode. Thus, as far as the grid return is concerned, resistor R of Figure 5 replaces resistor R of Figure 4.

From the ungrounded end of resistor R, Figure 5, there is a connection to the D_2 plate of tube V_2 and a circuit is completed through the tube to the cathode and through resistor R_5 to ground. Resistors R_6 and R_5 form a voltage dividor across the plate supply and thus, the junction between them is positive with respect to ground. As the cathode of the D_2 section of V_2 is connected to this junction it will be positive with respect to ground. With no current in resistor R there will be no voltage drop across it and thus diode plate D_2 will be at ground potential. Under these conditions, the cathode will be positive with respect to the plate or, with the cathode as the reference point, the plate will be negative with respect to it to make the tube nonconductive.

The diode plates are coupled by condenser C_5 and thus the modulated i-f voltages impressed across the D_1 circuit appear also across the D_2 circuit and resistor R. Because diode D_2 is nonconductive, there is no current in its circuit. Current in resistor R is at the intermediate frequency, but as explained for Figures 2 and 3, the avc filter prevents the passage of these frequencies. Under these conditions, there is no avc action and tube V_1 operates with only the initial bias voltage provided by the drop across R_3.

When the signal voltage impressed across tube V_2 increases to a value slightly greater than the drop across resistor R_5, diode D_2 becomes conductive during positive input peaks and the current in its circuit, carried by resistor R, develops a voltage drop similar to that across R_1. As resistor R is in series with the control grid return of tube V_1, the D_2 current it carries provides the automatic bias control as explained for R of Figure 4.

Thus, in the circuit of Figure 5, the avc action is delayed until the signal rises to the threshold voltage which is equal to the drop across resistor R_5. At lower input voltages there is no avc action to permit maximum receiver sensitivity and at higher input voltages the avc operates to maintain constant output.

In modern radio receivers, it is common practice to employ a duo-diode-triode type of tube which operates as a demodulator or detector, delayed avc rectifier and first audio amplifier. An arrangement of this kind is shown in the circuit of Figure 6 which, in many respects, is similar to those of Figures 4 and 5.

To simplify the drawing, only the plate circuit of tube V_1 is shown in Figure 6 but, as explained previously, the i-f signal will appear across the secondary coil L_1 and be impressed across the upper diode circuit of tube V_2. During the signal voltage alternations that drive the diode plate positive, there will be current in resistor R_2 and coil L_1. As before, this current will cause the modulation or audio signal voltages to appear across potentiometer R_2.

Thus, with respect to the signal voltages across it, resistor R_2 is the equivalent of the plate resistor in a resistance coupled stage of an a-f amplifier. Here the circuits are completed by coupling condenser C_3 and grid resistor R_4 with the triode grid of V_2 connected to the junction between them. The movable contact makes it possible to impress any portion of the drop across R_2 on the triode grid circuit and therefore it serves as a volume control.

Remember here, avc does not eliminate the need for a manually operated volume control. It acts only to maintain a constant output, the desired level of which is selected by manual adjustment of the volume control.

Going back to the circuits of V_2, the cathode is grounded through resistor R_3 and the plate current it carries develops the negative bias for the grid of the triode section. This action is like that explained for R_3 of Figure 5. Thus, the detector diode of tube V_2 is resistance-capacitance coupled to the self-biased triode section which operates as the first stage of the audio amplifier.

The circuit of the other diode is through resistor R_1 to ground and through resistor R_3 to the cathode. As the drop across R_3 is of a polarity which causes the cathode to be positive with respect to ground, this diode plate will be negative with respect to the cathode. Thus, the drop across resistor R_3 of Figure 6 serves the same purpose as the drop across resistor R_5 of Figure 5.

Going back to Figure 6, the lower diode is coupled to L_1 through condenser C_1 and, when the impressed signal voltage exceeds the drop across R_3 there will be current in its circuit with a corresponding drop across resistor R_1. This voltage is impressed across the avc filter which here is a single section made up of resistor R and condenser C. However, it serves the same purpose as those explained previously and its output, marked "AVC" is connected to the grid return circuit of the controlled tubes. Therefore, the lower diode circuit provides the desired delay in the application of the avc voltage.

In a circuit of this kind, the delaying voltage will be determined by the required negative bias voltage on the control grid of the triode section. If we assume this negative bias to be 9 volts, the i-f signal must exceed this value before there will be any avc action. With signals below this value, the receiver will operate at maximum sensitivity.

The avc circuits of Figures 4 and 5 are basic, and in practice there have been many variations. However, if you fully understand the principles explained in this lesson you should not have difficulty following the actions of any automatic volume control circuits.

NUMBER OF TUBES CONTROLLED BY AVC

In our previous explanations we told you that the tubes controlled by avc were in the r-f and i-f stages. However, we said nothing about the number which were to be controlled, and can add now that there is no definite set rule. In some receivers of low sensitivity, only one tube will receive the control voltage, while in others of high sensitivity, as many as four tubes may be controlled automatically.

This variation is due to a definite relationship between the number of tubes automatically controlled and the performance of the avc system with respect to a uniform audio output.

Portable phonograph and sound amplifier equipped with automatic volume expander circuit.
Courtesy Stromberg-Carlson Company

To show you this relationship, we will assume a certain receiver in which only one tube is controlled by avc. In this case we will say that a 2 to 1 increase in voltage output will be accompanied by an avc voltage that will decrease the sensitivity of the receiver by a definite amount. The exact amount of reduction depends upon how much the gain of the controlled stage is influenced by the control voltage

Now, if two tubes in this same receiver are controlled, then the increased signal input required to produce the same 2 to 1 voltage increase in output will have to be much greater. This is because the sensitivity of the receiver is less than in the first case, as the gain of two tubes has been reduced.

As a general rule, you will find the larger receivers with higher sensitivity employ avc on several stages; while in the smaller receivers with lower sensitivity, only one or two stages are controlled.

AUTOMATIC VOLUME EXPANSION

Basically, automatic volume control is an arrangement by which an external or input voltage controls itself. When the input voltage increases, the sensitivity of the receiver is lowered and the output is reduced, while a reduction of input voltage allows an increase of receiver sensitivity and output. In this case, the input voltage works against itself and reduces the effects of its amplitude variations.

This basic action has many applications for automatic control in electronics and can be reversed so that changes of input voltage amplitude will be exaggerated in the output of a device. For example, if a conventional voltage amplifier stage has a gain of 20, with a 1 volt input there will be a 20 volt output, with a 2 volt input there will be a 40 volt output and so on up to the maximum output. However, if an increase of input from 1 to 2 volts causes an increase of output from 20 to 60 volts, the changes of input have been exaggerated or expanded.

Thinking along the same lines, with the avc action explained earlier in this lesson, an increase of input from 1 to 2 volts might allow an increase of output from 20 to 25 volts and thus the changes of input would be decreased or compressed. Compression and expansion of this kind are necessary in the popular field of disc recording and reproduction of music.

When music is being recorded, some passages may be so low as to be barely audible, while other portions of the same selection may be loud enough to vibrate the walls of a building. This is especially true in the case of symphonic music. However, the range of sound level that can be recorded is much smaller than that which is necessary for the faithful reproduction of orchestral music. This is because the ratio of the maximum to the minimum amount of cutting stylus swing which it is practical to use, is much less than the power ratio corresponding to the strongest and weakest sounds produced by an orchestra.

If, during loud passages, the power supplied to the cutting head is too great, the stylus excursions will be so large that it will break through the walls of the groove and jump into the next track. If this happens, the record is ruined. On the other hand, during the very soft passages, the stylus excusions may be so small that they are comparable to the record material irregularities which cause "needle scratch". That is, all sound intensities which are below some definite level will be lost in the scratch noise.

To avoid either of these conditions, the recording level is varied from time to time during the cutting of the wax master record; the gain of the recording amplifier being decreased during the loud passages and increased during the soft passages.

Monitoring of the music is accomplished either manually by the recording operator "riding" the volume control, or electrically by means of an arrangement, called "audio avc" or "volume compression".

The result of this recording procedure is to "compress" the dynamic range of the sound intensities. This greatly affects the reproduction of a symphonic selection, and if a well monitored symphonic record is played back through a high-quality amplifier, it cannot sound real because the peaks have been depressed and the valleys have been raised. Devoid of its normal dynamic volume range, the recorded music sounds flat and lifeless compared to that actually produced by the orchestra.

To compensate for the effects of the volume compression methods employed when the recording is made, a circuit arrangement called a "volume expander", can be used in conjunction with the phono input circuits of a p-a amplifier. The expander acts to increase the volume during the loud passages, thereby producing the effect of making the low passages softer.

A three tube volume expander circuit is shown in Figure 7 where the signal input from the phono pickup is applied across the two parallel connected potentiometers R_1 and R_2. From the slider on R_1 the signal is coupled to grid number 1 of the "controlled tube" V_1, the output of which appears across plate load resistor R_6 and is coupled to the input of a regular audio amplifier. From the slider on R_2 the signal is applied to the grid of expander amplifier tube V_2 the output of which is coupled to the plate of diode tube V_3. The voltage developed across diode load resistor R_4 (and condenser C1) is couped through filter R_5-C_2 to grid number 3 of tube V_1. The various tube elements obtain their d-c operating voltages through the voltage divider shown at the lower right. The voltages indicated along this divider are all measured with respect to the V_1 cathode, which is maintained at a-c ground potential by condenser C_3.

The input signal, amplified by V_2, causes V_3 diode current which varies directly with the amplitude of the input signal. Carried by resistor R_4, the current causes a voltage drop which charges the parallel connected condenser C_1. Thinking of R_4-C_1 as a filter, the values are chosen so that the individual audio frequency pulses are removed and the drop across them varies with the average amplitude of the diode current. As indicated, the polarity of this voltage is the same as that of the usual cathode bias resistor. The signal voltage and the drop across R_4-C_1 vary with the "loudness" of the recorded music.

Tracing the circuit of resistor R_4, it extends from the "-13 v" point on voltage divider resistor R_7, up through resistors R_4 and R_5 to grid No. 3 (G_3) of tube V_1, through the tube to the cathode and back to the "0 v" point on the divider. Checking polarities, any voltage drop across R_4 will be in series opposition with the 13 volts across the divider.

Thus, with no signal input, there is no drop across R_4, and the bias on G_3 is -13 volts. When a signal is present, the resulting drop across R_4 opposes the -13 v supply value so that the net bias on G_3 is reduced. However, as explained, the drop across R_4 varies with changes in signal level and, therefore, the bias voltage on G_3 will be caused to vary likewise.

Since G_3 is in the electron stream between G_1 and the plate, variations in voltage on G_3 will affect the mutual conductance of tube V_1. If the value of the load resistor R_6 is made small, compared with the V_1 plate resistance, the voltage amplification of the tube will be proportional to its mutual conductance. Thus, an increase in signal volume increases the drop across R_4, which in turn causes a decrease of the negative bias on G_3. This increases the mutual conductance and, therefore, the amplification of V_1. Conversely, a decrease in the volume of the input signal results in a reduction in the voltage amplification provided by the tube. Thus, at any instant, the amplification provided by tube V_1 is directly proportional to the amplitude of the signal input voltage and the desired automatic volume expansion is obtained.

Resistor R_5 and condenser C_2 serve as a time delay coupling circuit between V_3 and V_1, so that the changes in volume level will not be too abrupt during speech passages. However, the delay must not produce an objectionable lag when music is being played.

The signal input to tube V_1 is applied to G_1 which is a remote-cutoff type grid and prevents excessive distortion when, during soft passages, the mutual conductance of the tube is reduced to a low value by the high negative bias on G_3. The need for a high gain-control voltage is avoided because grid G_3 is of the sharp cutoff type.

While R_1 acts a manual volume control for V_1, control R_2 makes it possible to regulate the effectiveness of the expander circuits, V_2 and V_3, regardless of the setting of R_1. For example, if no expansion action is desired, control R_2 can be set at minimum position. Thus, if the expander circuit is well-designed and its controls properly set, the recorded version of a symphonic selection may be a reasonably exact replica of the original rendition.

With a slight change, the expander circuit of Figure 7 may be converted to a volume compressor circuit for use with recording equipment. Since one process is the reverse of the other, all that is necessary is that the gain of the controlled tube be reduced during the loud passages and vice versa. This can be done by reversing the connections to the elements of tube V_3 so the voltage across R_4 will be of opposite polarity to that indicated and thus add to rather than subtract from the −13 v supply. Then an increase of signal input increases the G_3 negative bias, reduces the amplification by tube V_1 and amounts to a system of audio avc or volume compression.

Some volume expander circuits incorporate a switch so that the diode connections may be reversed easily, and the same circuit made to operate as a compressor during recording and as an expander during playback. Another advantage of this switch arrangement is that when a p-a system is used to play records where the ambient noise level is high, such as in large dance halls, a constant volume output is desirable, and the circuit may be operated as a compressor to provide a more uniform output regardless of fluctuations in recording levels.

IMPORTANT WORDS USED IN THIS LESSON

AUTOMATIC VOLUME EXPANSION—An audio-frequency circuit arrangement that increases the volume range of an audio amplifier by expanding the volume of loud passages.

DELAYED AVC—A system of automatic volume control which operates only when the incoming signal strength exceeds a certain value. This delay action prevents avc from operating on weak signals and permits maximum receiver sensitivity.

DELAY VOLTAGE—A fixed bias voltage, acting in series with the avc rectifier circuit, which must be neutralized by the signal voltage before avc is initiated.

INITIAL BIAS—The bias established on the control grid of an r-f or i-f amplifier tube by the receiver circuit itself, without avc action.

MICROVOLT—A unit of electric pressure or voltage, equal to one millionth of a volt. The carrier signal strength at a given point usually is expressed in microvolts per meter, that is, the signal strength at the receiving antenna divided by the effective height of the antenna in meters.

SENSITIVITY—The ability of a radio receiver to respond to weak signals. It is usually expressed as the minimum input signal strength required to produce a desired signal output.

THRESHOLD VOLTAGE—As applied to delayed avc circuits, is the signal voltage amplitude required to initiate avc.

TIME-CONSTANT—The length of time required for the voltage or current in a resistor-capacitance circuit to reach 63% of its final value. The time-constant in seconds is numerically equal to the product of the resistance in ohms times the capacitance in farads (or the resistance in megohms times the capitance in microfarads).

TIME-DELAY CIRCUIT—An electric circuit or network in which the voltage or current is delayed a definite time interval before it attains a certain value.

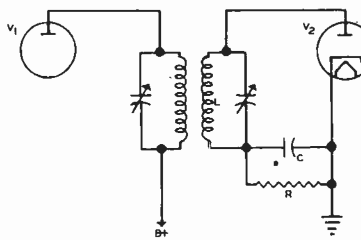


FIGURE 1

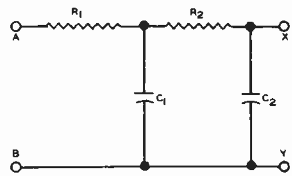


FIGURE 2

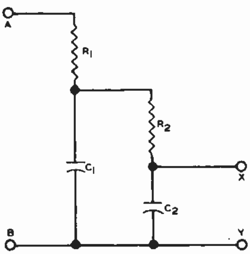


FIGURE 3

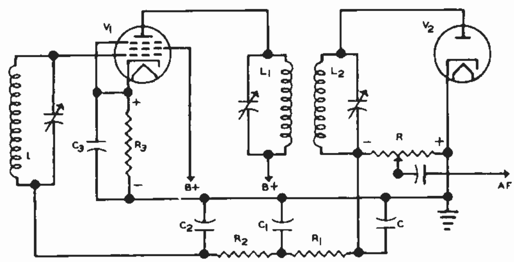


FIGURE 4

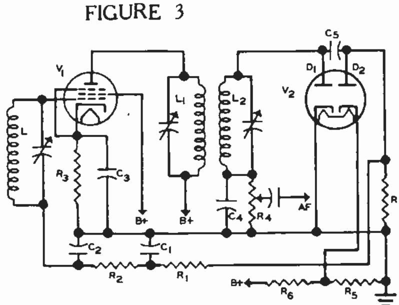


FIGURE 5

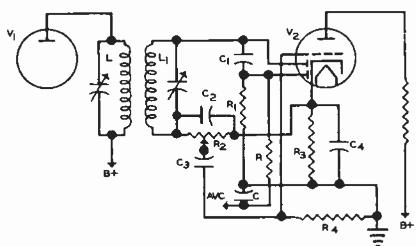
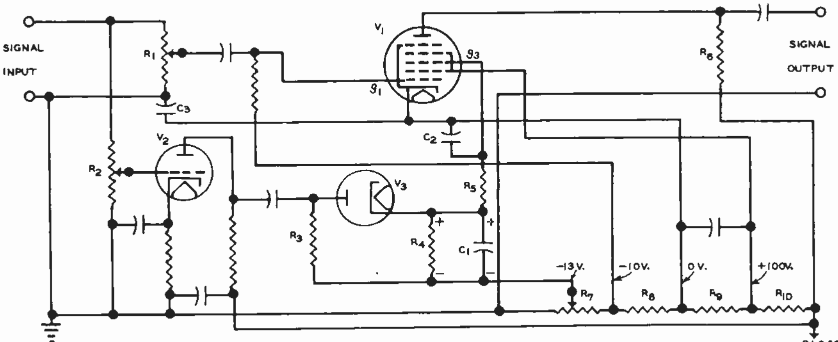


FIGURE 6



RRT-10

FIGURE 7

FROM OUR *President's* NOTEBOOK

THERE ARE NO SHORT CUTS

The sooner a man is convinced that there are no short cuts in life, the better for him. Some men, however, never seem to realize it. To the end of their lives they have a notion that there exists a short cut to success, a short cut to reputation, a short cut to happiness—if they could only find it.

They walk along the high road with a continual sense of grievance. Every now and then they deviate to the right or to the left, hoping to be able to cut a corner; but we always find them returning to the main road, and invariably a little way behind the spot at which they left it.

Yours for success,

PRESIDENT

PRINTED IN U.S.A.