Types of Audio Amplifiers

By SYLVAN HARRIS

An exceptionally valuable article covering the characteristics of all existing forms of audio frequency amplifiers, together with a technical explanation of their operations.

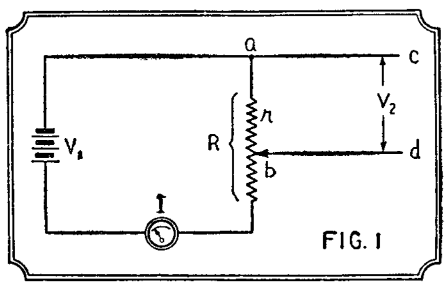
THUS far in this series of articles dealing with amplifiers (which began in the June, 1926, issue of RADIO NEWS) we have not considered the nature of the amplifiers themselves, but have devoted our attention solely to what amplifiers are supposed to do and what they are supposed *not* to do. The present article, therefore, begins the second part of our study of amplifiers. We will now consider the amplifiers in a general manner, indicating the reasons for the various elements of which they are composed, and for the several circuit arrangements; and we will point out the extreme similarity of operation in all the different types.

Surprising as it may seem at first to the uninitiated reader, we begin the discussion with what is commonly known as the "potentiometer," but which, it is recommended by the Institute of Radio Engineers (Report of Committee on Standardization for 1926), should preferably be termed the "voltage divider." In accordance with this recommendation, this instrument is so designated here.

RESISTANCE AND VOLTAGE

The most common form of voltage divider is illustrated in Fig. 1 as a simple resistance connected in series with a source of electrical energy. A current, of the value I, flows through this resistance, which has a value R, so that by *Ohm's law* the voltage drop across the resistance is RI. In other words if the current is 0.2 ampere and the resistance is 1,000 ohms, the voltage drop in the resistance is 0.2 x 1,000, or 200 volts.

It is evident that the voltage drop between any two points (a, b) on the resistance R is proportional to the value of the resistance between these two points, with a given current flowing. In other words, if the resistance between points a and b is half the total resistance of R, then the voltage drop between a and b is half the voltage drop across the total resistance R. In the above example, if the resistance, between a and b, is 500 ohms, and the current in R is 0.2 ampere, the drop between a and b is 0.2 x 500 or 100 volts.



In this simple circuit the current in the resistance R is measured by the ammeter, I. The variable resistance or "voltage divider" permits the voltage, V2, across C and D to be varied.

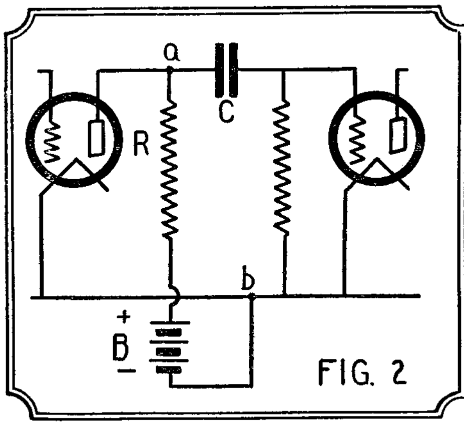
In other words we can start out, with a battery having a voltage V, of 200 volts, and get any voltage we want by simply moving the variable contact on the resistance. The voltage V_2 would then be related to the original voltage V_1 by

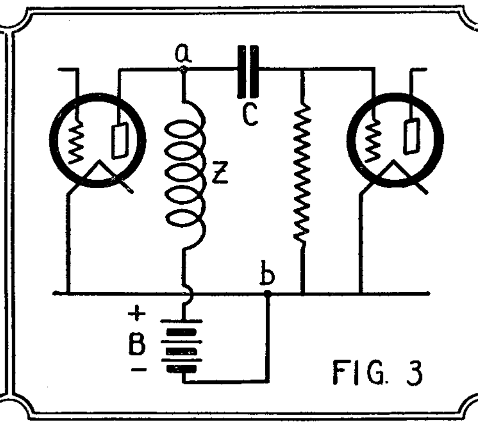
$$V_2 = \frac{r}{R} V_1$$

There is a very important point that must not be forgotten, however, and that is that the circuit to which the terminal points c and d are connected should not take any current from the system, for the above relation to hold. If current *is* taken by a circuit connected to c and d, the voltage relations become more complicated; in any case, however, the general rule applies, *viz.,* by increasing the resistance between a and b the voltage delivered by the voltage-divider is likewise increased.

On the other hand, if the circuit to which c and d are to be connected takes an appreciable amount of current, the voltage drop will not be as high as if no current at all were taken by this circuit. This can be easily understood by remembering that the greater the current through the resistance R, the greater will be the voltage drop between any two points on it. Any current taken away from R, therefore will cause this voltage drop to be lowered.

(*Continued on page* 418)





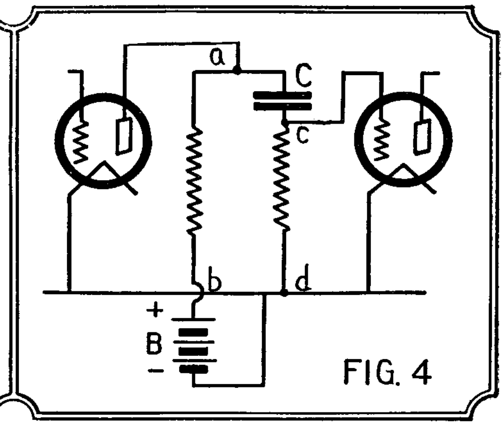
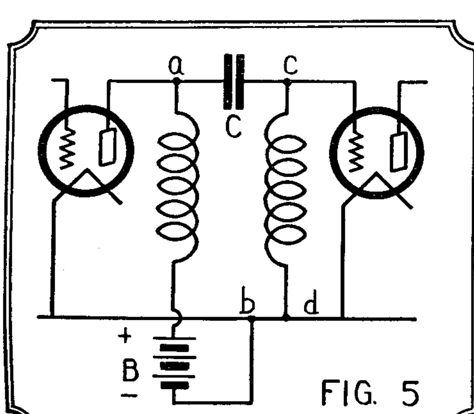
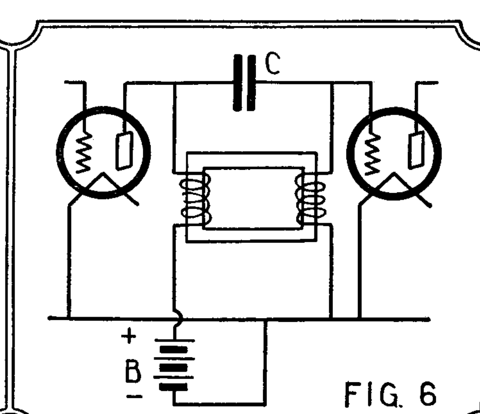
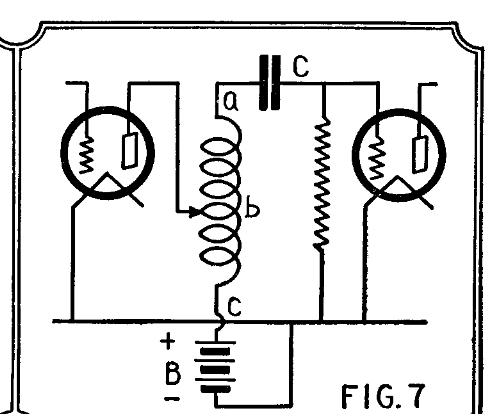


Fig. 2. An audio amplifier of the resistance-coupled type. The voltage drop across the resistance R is large. The voltage drop across the impedance Z in Fig. 3 is considerably less and the potential on the plate of the first tube is consequently higher. The same is true of the grid voltages as applied across the resistance c-d (Fig. 4).







The impedance amplifier of Fig. 5 employs also an impedance in the grid circuit. This is superior to a resistance in that high voltages cannot accumulate on the grid and block the action of the tube. The arrangement of Fig. 6 is the same as that of Fig. 5 except that both impedances are on the same core. An "auto transformer" coupling arrangement is shown in Fig. 7.

Radio News for October, 1926

Types of Audio Amplifiers

(*Continued from page* 364)

AUDIO COUPLING DEVICES

Now, let us consider what is required in an audio-frequency amplifier. We have two electron tubes to be joined together in such a way that the voltage developed in the output (or plate) circuit of one is transferred with as little loss as possible to the input (or grid) circuit of the other tube. The voltage developed in the output of a tube can be utilized only by causing part of it to appear in some resistance or impedance external to the tube. Thus in Fig. 2 we have shown a resistance R connected in the plate circuit of a tube in series with the "B" battery. A current I flows in this circuit so that, in accordance with our study above, the voltage drop across the terminals of this resistance is RI.

But this is not the total voltage developed in the plate circuit of the tube. It must not be forgotten that there is a high resistance existing *within* the tube between the plate and filament, which is determined by the design of the tube, and which we cannot change. Suppose this resistance is r_p. The voltage drop in *it* will then be r_pI, for the same current flows through it as flows through the external resistance R. The total voltage developed in the plate circuit is, therefore, the sum of the internal and external voltage drops, of which the only portion we use is the external drop. The voltage between the points a and b (Fig. 2) is a fraction of the total voltage, and this fraction is

$$\frac{R}{R + r_p}$$

In other words, this fraction expresses the part of the total voltage in the plate circuit which is available, and it is to our interest to make it as large as is practically possible. This is done by using large values of R, that is, by making the external resistance as large as possible. We can never hope to transfer the *total* voltage developed in the plate circuit of the tube to the points a and b (or to the input of the succeeding tube), for this would require that the resistance be infinite.

RESISTANCE-CAPACITY COUPLING

The next point we have to consider is the manner of connecting the points a and b to the succeeding amplifier tube. The connections cannot be made directly to the grid and filament of the latter tube; for in that case there would be impressed on the grid of the second tube a very large positive bias, due to the "B" battery. This bias must be removed; otherwise there would be a large grid current in the second tube which would cause distortion and other ill effects. It is removed by placing before the grid a blocking condenser C, which presents infinite impedance to the continuous (or direct) voltage, but which allows the alternating signal voltages to go through.

However, by adding this condenser to the circuit we have allowed the grid of the second tube to "hang up in the air." In other words, the grid is "free" to collect a considerable number of electrons and acquire quite a large negative bias. This is not a good thing; it is almost an axiom in radio that a tube should never be operated with a "free" grid, as the circuits become unstable and almost anything is likely to happen.

To avoid the "open" or "free" grid we must provide a "grid leak"; in other words, we must place a leakage path in the circuit, over which these electrons trapped on the grid may flow away from the grid to the filament whence they came. The addition of this leak resistance to the circuit completes what is generally known as the resistance-capacity-coupled amplifier, and is shown in full in Fig. 2. This is the simplest type of amplifier, from all viewpoints; it is simple to construct, the cost is relatively low, and the electrical analysis is much simpler for this than for any other known type of amplifier. The detailed analysis of the circuit will be undertaken in a succeeding article of the series.

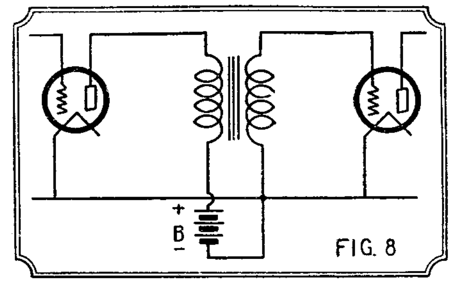
IMPEDANCE COUPLINGS

The most general type of amplifier coupling device (other than the transformer type) may be represented by the circuit of Fig. 2, in which the various paths of the amplifier network may include complex impedances rather than pure resistances. In other words, it is possible to vary the amplifier circuit of Fig. 2 by replacing the pure resistances with certain combinations of resistances, inductances and capacities.

For instance, if we replace the resistance in the plate circuit external to the tube (R in Fig. 2) by an impedance coil (Z in Fig. 3) we will have what is generally known as the impedance-coupled amplifier. The same general principles apply to this type of amplifier as to the resistance-capacity coupled amplifier, as far as the voltages are concerned, with the following exception: in the resistance-capacity coupled amplifier the voltage ratio (defined in previous articles of the series) is practically independent of the frequency, provided the blocking condenser C is sufficiently large.

In the impedance-coupled amplifier the effect of the blocking condenser remains as before, but added to this is the effect of the varying impedance at various frequencies. At low frequencies the blocking condenser, in both types of amplifiers, tends to reduce the voltage ratio; at the lower frequencies, from about 200 cycles per second down, producing the effects studied in our previous articles. In the impedance-coupled amplifier, the impedance in the plate circuit acts in the same manner, thereby accentuating the effect if the impedance is not large enough. The use of the impedance, however, permits smaller "B" battery voltages to be used; as the impedance generally has relatively low resistance to the direct voltage, but of course has an impedance to the alternating signal voltages which depends upon the frequency of these voltages.

We have said before, that it is necessary to make the resistance R of Fig. 2 as high as practically possible, in order to make the voltage ratio as high as possible. The same is true of the impedance Z in Fig. 3. There is a practical limit to which R may be increased, however, for very large plate-circuit resistances require "B" batteries of rather high voltage. The impedance Z, of Fig. 3, however, has relatively low direct-current resistance, so that it may not be necessary to use such high voltages; provided, of course, that the *resistance* of the impedance coil is kept low. The inductance of the coil must be kept as high as practically possible, for a high inductance will keep the voltage ratio high throughout the greater part of the range of acoustic frequencies.



The typical transformer-coupled audio-amplifier circuit arrangement.

GRID-LEAK EFFECTS

By examining the diagrams on page 364 it will be easily understood that the grid-leak resistance represents a partial short-circuit across the input of the second tube; in other words, the lower this resistance is, the smaller will be the voltage drop across it, in comparison with the voltage drop available, which is that across the points a and b.

To be explicit, the circuit of Fig. 4 is exactly the same as that of Fig. 2, as can be proven by comparing the two circuits. The voltage drop across the points c and d is only a portion of the voltage drop across the points a and b. The fraction, of the voltage across a and b, which is available across c and d, is represented by the ratio of the resistance, cd, to the reactance of the blocking condenser C.

To keep this fraction as high as possible, the impedance between c and d must be kept as high as possible. If the impedance, cd, is a *pure resistance*, the grid of the tube will be blocked, or become "free". Therefore there is a practical limit to increasing its size, beyond which we may not go. In one type of amplifier, shown in Fig. 5, the grid-leak resistance is replaced by a grid-leak *impedance*. This impedance is high to the alternating signal voltage, but has a relatively low resistance, allowing the grid charges to leak away easily so that overloading does not generally occur on strong signals. This system was described in the June, 1926 issue of Radio News by Fred A. Jewell.

INCREASING THE VOLTAGE RATIO

As a further change in the circuit arrangement, H. P. Donle (see Radio News for June, 1926) has arranged the two impedances on a single iron core, as illustrated in Fig. 6. The two windings have a turns-ratio of 1 to 1, and a coupling or blocking condenser is used as in the other types of amplifiers. The reason for this will be studied in a later article, but we may indicate it here.

It has been said before that the highest voltage ratio possible with an amplifier, using a circuit arrangement like those in Figs. 2, 3 and 5, is unity. That is, the highest theoretical voltage, that can be impressed on the input of the second tube, is the voltage drop in the impedance or resistance in the external plate circuit of the first tube. Practically the voltage ratio is less than unity, so that there is not only no increase in voltage, as the signals pass through the coupling device, but there is an actual attenuation, or decrease of voltage. To prevent this attenuation Mr. Donle introduces into the leak impedance an electromotive force, through the mutual inductance between the plate coil and the impedance coil. This is accomplished by placing them on the same iron core. At the same time they are so arranged that the capacity between the coils is very small. As a result of this, the system has many of the advantages of the ordinary impedance-coupled amplifiers, with the additional advantage of giving higher voltage ratios.

Radio News for October, 1926

There is another variation of this type of amplifier which must be considered. We have pased from the simple voltage-divider to the resistance-capacity coupled amplifier; from this to the impedance-capacity coupled type and then to various combinations of these. It will be noted that the Donle amplifier bears considerable resemblance to the transformer type, although differing considerably from the latter in its action. We shall now pass from the foregoing types to the transformer-coupled amplifier. It is interesting to note this transition from the one type to the other, since by doing so it is possible to understand many things about amplifiers which have heretofore troubled us.

THE AUTO-TRANSFORMER

The impedance coil is generally considered merely as an *impedance* coil, or, as it is termed in telephone parlance, a "retardation coil." It may very easily and properly be considered as an auto-transformer, or as a transformer of two windings, in which the two have merged together, forming a single winding.

Let us then, take an impedance coupled amplifier, such as that shown in Fig. 3, and arrange it so that the plate current of the first tube flows through only part of the coil winding, as shown in Fig. 7. The general characteristics of the circuit have not been changed, but now, on account of the electromagnetic effects, the voltage ratio may become higher than unity. We therefore have the impedance coil acting as a transformer rather than as a voltage-divider; and the voltage ratio of this auto-transformer is, very approximately, the same as the turns-ratio. That is, if the tapping point, b, is one-third the way up the coil, the voltage between a and c will be, very approximately, three times the voltage between b and c.

The circuit now possesses the features of a circuit employing a two-winding transformer, except that the blocking condenser C, is still required in the grid circuit of the second tube. We will not now go further into the discussion of this type of amplifier, except to say that the writer does not believe that the full merits of the auto-transformer have been generally recognized. It is a well-known fact that auto-transformers can be built, with much less wire and smaller core, to handle the same power and to have the same ratios as two-winding transformers. There are other things to consider, however, and we will study these in a future article.

STANDARD TRANSFORMER COUPLING

It is but another step from the one-winding transformer, or auto-transformer, to the two-winding transformer. This is shown in the circuit of Fig. 8. The circuit appears entirely different from that of Fig. 7, but a glance will show the reasons why. In the first place, since the grid (or input) circuit of the second tube is not *conductively* connected to the plate circuit of the first tube, in which the "B" batteries are connected, there is no longer any fear of an excessive grid bias in the second tube due to the "B" batteries. This means, therefore, that we can remove the blocking condenser. Furthermore, since the secondary winding of the transformer, which is connected to the input of the second tube, has relatively low resistance, there is likewise no longer any fear of a "free" grid in the second tube. Consequently we can eliminate the grid-leak resistance. And there you are.

We have now pointed out the similarities existing between all of the popular types of audio frequency amplifiers; and have considered the reason for the particular arrangements used. We have not, however, gone very deeply into the subject, for there remains to be studied the effects of varying the many different elements of these circuits. In other words, although we have the fundamental circuit arrangements, we know nothing as yet about the *values* of the resistances, impedances, capacities, etc. We want to get as much amplification as possible. This means we want the voltage-ratio of the coupling device to be as high as possible. At the same time we wish to avoid all effects that lead to distortion.

In other words, all this requires that the separate systems be studied in detail; we shall proceed to do so in the succeeding articles, which will deal mainly with the resistance-capacity-, impedance-capacity-, and transformer-coupled types of amplifiers. We shall determine what value of capacity to use, how high to make the external plate resistance, what turns-ratio to use in the transformer, and many other important things.