# RADIO-FREQUENCY AMPLIFIERS.

By P. D. Lowell.

ABSTRACT.

Electron tube amplifiers may make use of either radio-frequency amplification or audio-frequency amplification, or both. Radio-frequency amplification consists in the amplification of the received radio-frequency current before it is detected. The use of radio-frequency amplification makes it possible to receive a very weak signal which can not be heard at all if only audio-frequency amplification is used. The coil antennas used in direction finding work receive only a very feeble signal, and for satisfactory reception with coil antennas it is necessary to use radio-frequency amplification.

There are three methods of coupling the output of one tube into the input of another tube, so as to provide a multistage amplifier of radio frequencies: First, resistance coupling, second, tuned-plate coupling, and, third, transformer coupling. The range of frequencies which may be successfully amplified by the first method usually has an upper limit at about 150 kilocycles per second. The second method can be made effective for frequencies as high as about 1500 kilocycles per second by using special tubes and careful design. The third method—transformer coupling—usually is most satisfactory and permits amplification at almost any frequency. This paper deals or the most part with the third method and gives circuits and constructional details for transformers with both air cores and iron cores. The iron-core transformer will usually operate satisfactorily over a much broader wave band than the air-core transformer. Although the construction of a successful radio-frequency amplifier is quite a difficult task, important advantages are gained because of the fact that with a good radio-frequency amplifier available an indoor coil aerial may be employed.

Electron tube amplifiers now form an essential part of all but the most simple radio receiving sets. By the use of a good amplifier a feeble signal may be made loud enough to be heard throughout a large room, and a signal which is so feeble as to be inaudible may be made loud enough to be clearly read. Amplifiers are in fact necessary to receive distant stations or when using coil antennas. The received radio-frequency current may be amplified before it is rectified by a detector tube. This is called radio-frequency amplification. The rectified output of the detector tube may be amplified. This is called audio-frequency amplification. Persons desiring an elementary discussion of amplification may refer to the Principles Underlying Radio Communication, Signal Corps Radio Communication Pamphlet No. 40.[1]

[1] A copy may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Price, $1.

An amplifier which has one tube used as a detector and two tubes used as amplifiers is said to have two stages of amplification. The simplest amplifiers have one or two stages of audio-frequency amplification. If it is desired to use four or more stages of amplification, it is necessary to use radio-frequency amplification, as well as audio-frequency amplification. If the attempt is made to use more than three stages of audio-frequency amplification, serious disturbances are likely to be caused, which will result in "howling" noises in the telephone receivers. These noises may be caused by regenerative effects. Audio-frequency amplification can cause extraneous noises by amplifying electrical disturbances of low frequency. It is often advantageous to use radio-frequency amplification even if only one stage of audio-frequency amplification is used. A certain minimum signal is required for good operation of a detector tube, and if only a very feeble signal is being received it is necessary that radio-frequency amplification be used in order that a signal of proper strength be delivered to the detector tube.

Radio-frequency amplification can make clearly audible a signal from a distant station which without such amplification is entirely inaudible. In a properly designed amplifier the use of radio-frequency amplification often improves considerably the ratio of signals to strays. Radio-frequency amplification alone will not, however, give a signal strong enough to operate a loud speaker, since the detector tube does not have sufficient output to operate a loud speaker. If a loud signal is desired audio-frequency amplification should be used.

The small coil antennas used in direction finding work receive only very feeble signals, and it is necessary to amplify these feeble signals many times if it is desired to do accurate direction finding work. This is particularly true if the minimum method of direction finding is used. Methods of direction finding are discussed in Bureau of Standards Scientific Paper No. 428, by F. A. Kolster and F. W. Dunmore, The Radio Direction Finder and Its Application to Navigation.[2]

A multistage amplifier consists of a number of electron tubes connected in suitable circuits. Each tube amplifies the signal impressed on its grid circuit and delivers the amplified signal from its plate circuit. The output or plate circuit of one tube

[2] A copy of this paper may be purchased from the Superintendent of Documents, Washington, D. C. Price, 15 cents.

is coupled to the input or grid circuit of the next tube by any one of several methods. It is important that efficient methods be used for transferring the signal energy from the plate circuit of one tube to the grid circuit of the next tube.

There are three methods by means of which the electron tubes may be coupled together so as to give amplification at radio frequencies: First, resistance coupling; second, tuned-plate coupling; and, third, transformer coupling.

A usual method of resistance coupling is to connect in the plate circuit of one tube a noninductive resistance of about 80 000 ohms, having a low capacity, and to connect a small condenser from the plate of this tube to the grid of the next tube. Figure 1 shows a circuit for one stage of resistance coupling. The radio-frequency variations of the current in the plate circuit of the first tube cause corresponding variations in the voltage across the resistance, and hence radio-frequency variations in the potential of the grid of the second tube. Therefore, a corresponding radio-frequency current flows in the grid circuit of the second tube through the condenser mentioned. The resistance chosen should be such as to make the voltage drop between the grid and filament in the latter circuit as high as possible. This method is, however, limited to amplification of relatively low radio frequencies and will not usually give satisfactory results on frequencies much above 150 kilocycles per second with the tubes at present ordinarily available.

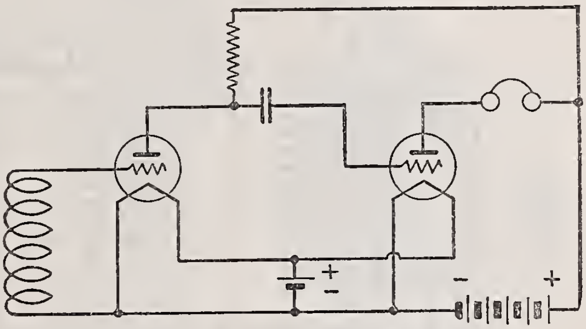

Fig. 1.—*Resistance-coupled amplifier.*

In the second method—tuned-plate coupling—the plate circuit of the first tube is actually tuned to the signal frequency either by means of an inductance shunted by a variable condenser or by a continuously variable inductor inserted in series with the plate circuit. The circuit is similar to that of Figure 1, except that the coupling resistance shown in Figure 1 is replaced by a continuously variable inductor or by an inductance coil shunted by a condenser. A condenser permits the radio-frequency currents to flow from this plate to the grid of the next tube, as in the resistance-coupled method. The tuned-plate method is more efficient than resistance coupling at frequencies above 150 kilocycles per second. With special tubes having low capacities between the elements and by careful design the tuned-plate method can be used for frequencies as high as about 1500 kilocycles. The effective range of a tuned-plate amplifier is rather narrow unless each stage is separately tuned, which requires a considerable number of additional adjustments.

The third method—transformer coupling—is the most effective and therefore most desirable, and it is this method for which circuits were developed and which is discussed in this paper.

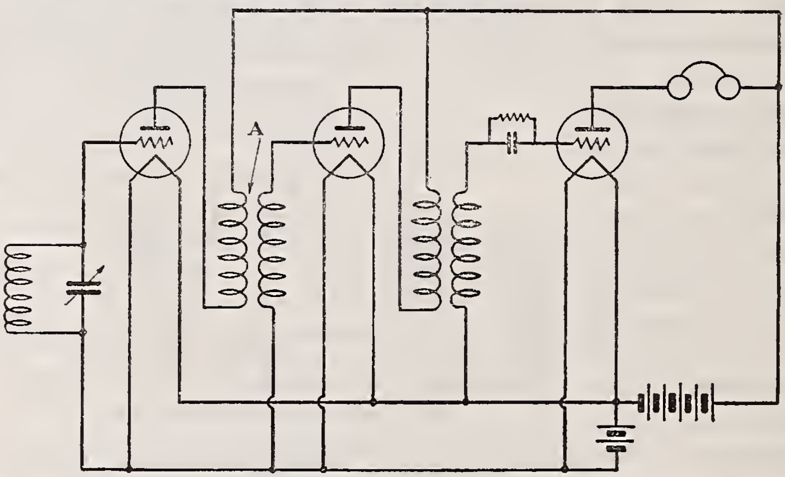


FIG. 2.—*Transformer-coupled amplifier.*

The prime requisite of all radio-frequency amplifying circuits is to keep all capacities as low as possible because of the fact that even a small capacity is a good conductor of high-frequency current and the reduction of capacities means the reduction of losses in the amplifier. It is therefore necessary for good operation to design a transformer which will have small capacities in the windings as well as between the windings, and, in connecting it in an amplifier circuit, to have all connecting leads as short as possible. It is also important that the electron tubes employed be designed so as to have a minimum allowable capacity between the various elements. This is necessary because of the fact that the grid-to-filament capacity is in parallel with the secondary transformer winding and tends to narrow the range of wave lengths over which the amplifier will operate. Capacity between the plate and grid tends to feed back the high-frequency emf in opposite phase into the grid circuit and thereby reduce the amplification.

It has been found that either air-core or iron-core transformers may be used for coupling the output circuit of one tube to the input circuit of the next. The air-core type gives more amplification per stage but, on the other hand, is responsive to only a narrow band of frequencies owing to the low effective resistance of the windings. The iron-core type, while not giving as much amplification per stage, will allow amplification over a much broader band of frequencies.

However, a special form of air-core transformer has been developed for radio compass work which will respond to signals on wave lengths from 600 to 1000 meters by means of a simple and quick adjustment. The coils of this air-core transformer were wound with No. 38 B. & S. gauge single silk-covered copper wire in the form of a pancake or flat doughnut, as it is sometimes called, and are impregnated with insulating varnish to make them self-supporting. The wire was wound in a manner similar to the so-called "honeycomb" coils or, as the British call it, a basket winding. The coils have an inside diameter of 1¼ inches, the outside diameter being approximately 1¾ inches, are 3/32 inch thick and wound with about 350 turns. They are wound continuously from the inside to the outside in the usual "honeycomb" fashion. Two of the coils coupled together constitute an air-core radio-frequency transformer, one coil being connected in the plate circuit of one tube and another connected in the grid circuit of the succeeding tube, in the usual manner as shown in Figure 2.

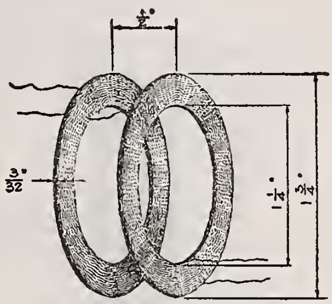

FIG. 3.—*Air-core radio-frequency transformer.*

It was found that when the primary and secondary transformers were placed about one-half inch apart the transformer allowed best amplification at 600 meters, and when the coils were placed close together the amplifier responded best at 1000 meters. This was due to the increase of the capacity between the coils when placed adjacent, thereby increasing the amplifier's peak from 600 to 1000 meters, intermediate degrees of coupling giving peaks at points between 600 and 1000 meters. Figure 3 shows the arrangement of the two coils which make up the transformer.

An amplifier was then constructed having three radio-frequency stages of amplification, a detector tube, and two stages of low or audio-frequency amplification, there being a mechanical arrangement whereby the coupling between the primaries and secondaries of the first two radio-frequency transformers could be varied simultaneously from about five-eighths inch to maximum coupling, the third radio stage having a fixed coupling. The two audio-frequency stages were of the ordinary type, employing ordinary audio-frequency iron-core transformers. Figure 4 shows the me-

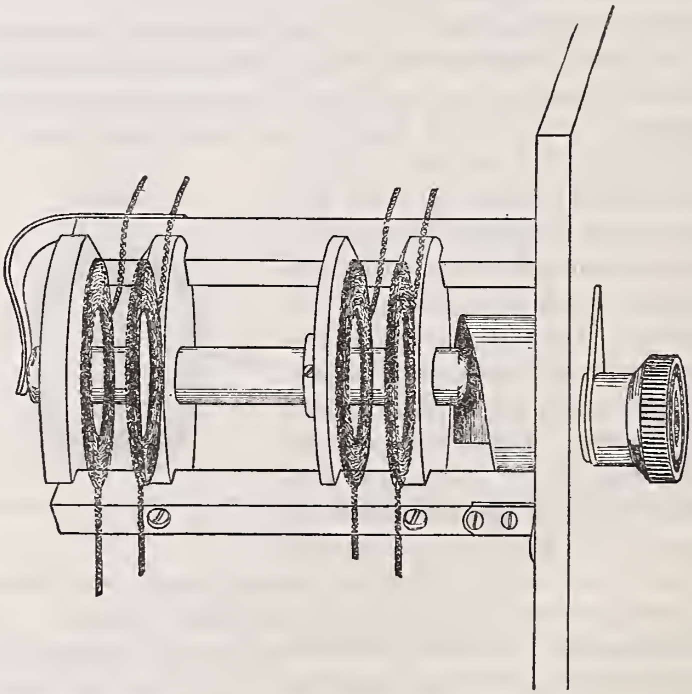

FIG. 4.—*Device for varying coupling of air-core radio-frequency transformers.*

chanical device used to vary the coupling of the radio-frequency transformers, and Figure 5 shows the circuit diagram for the amplifier described.

This diagram shows tubes *1*, *2*, and *3* as radio-frequency amplifiers, tube *4*, as detector, and tubes *5* and *6* as audio-frequency amplifiers, the telephones being in the plate circuit of tube *6*. Resistance (*R*) is known as a voltage divider or stabilizer, its sliding contact being connected to the grid circuits of tubes *1* and *2* so as to allow the normal voltage on the grids of these tubes to be varied for best amplification.

Several six-stage amplifiers have been made, utilizing iron-core radio-frequency coupling transformers and have given very good results. The construction of this type of transformer is shown

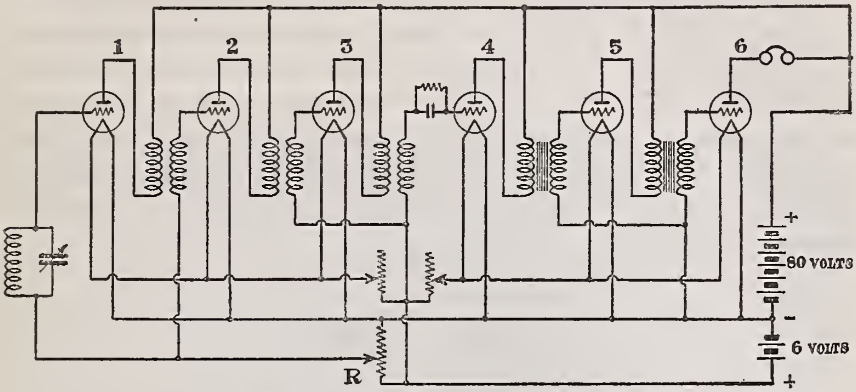


FIG. 5.—*Six-stage radio-audio-frequency amplifier.*

in Figure 6. *A* is a square tube of insulating material about one-half inch inside measurements, with a wall about one-sixteenth

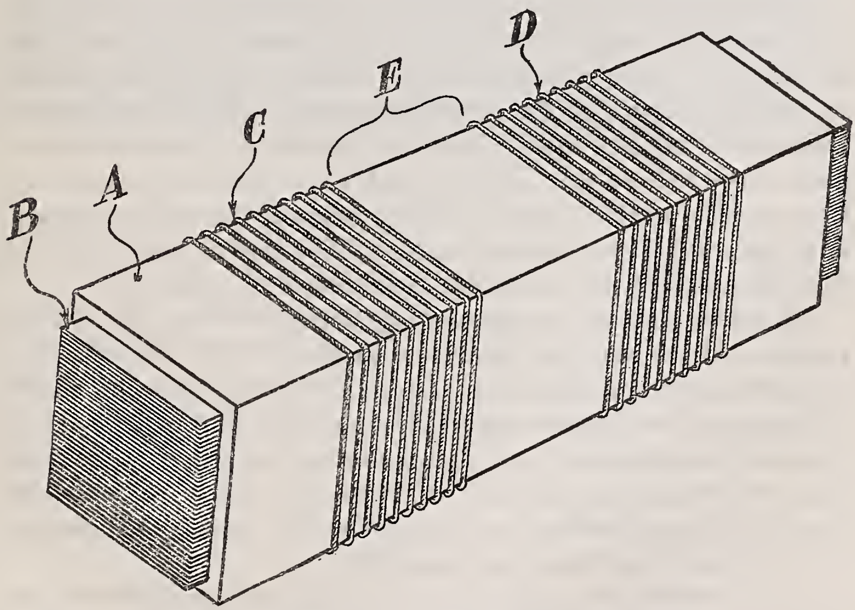


FIG. 6.—*Iron-core radio-frequency transformer.*

inch thick and about 4 inches long, the length depending on the winding space required. It is fitted with a core *B*, built up of silicon steel laminations, each lamination being not more than 0.001

inch thick for best results. A core of this fine steel has very low eddy current losses and is useful even at very high radio frequencies. *C* and *D* are the primary and secondary windings, respectively, wound in a single layer, so that distributed capacity of each coil may be small. The middle or inside ends are spaced about one-fourth inch apart, as shown at E. The windings are preferably made of No. 44 B. & S. gauge enameled copper wire, and the number of turns is determined by the frequency of the current to be amplified. This is determined exactly only by the "cut and try" method, but Table 1 indicates roughly the number of turns for various frequencies.

TABLE 1.

| Frequency (kilocycles per second). | Turns on each coil. |
|---|---|
| 1500–750 | 175 |
| 750–375 | 300 |
| 375–187 | 500 |
| 187– 94 | 800 |

In all cases the coils are wound in a single layer, one layer only. It is, of course, desirable to use electron tubes having a minimum of electrical capacity between the elements, and a high vacuum is also very desirable for amplifying tubes. When this type of transformer is used, it is desirable to connect the extreme outside ends of the coils to the grids and plates and the inside ends to the low-potential battery circuit, thereby keeping the grid-to-filament and plate-to-filament capacities low. The circuit used with this type of transformer is the same as that shown in Figure 5.

As before stated, all connecting wires between the various elements of the amplifier should be as short as possible to reduce capacities; but, on the other hand, the various elements should be separated somewhat, especially the plate and grid leads, to prevent radio-frequency oscillating and audio-frequency howling. The radio-frequency transformers especially should be quite well spaced from one another, so that there will be no inductive feeding back to cause oscillating and instability.

It is of interest to note the way in which the amplification produced by a given amplifier—i. e., a given combination of transformer and tubes—varies with the wave length. This may be pictured by a curve such as that shown in Figure 7. The amplification is greatest for current of a certain frequency, depending on the design of the transformer. The width of the frequency band over which amplification is obtained is shown by the broadness of this curve and also depends upon the transformer design.

It may be said in conclusion that the construction of a radio-frequency amplifier is quite a difficult task and requires no little amount of patience and resourcefulness, but when constructed

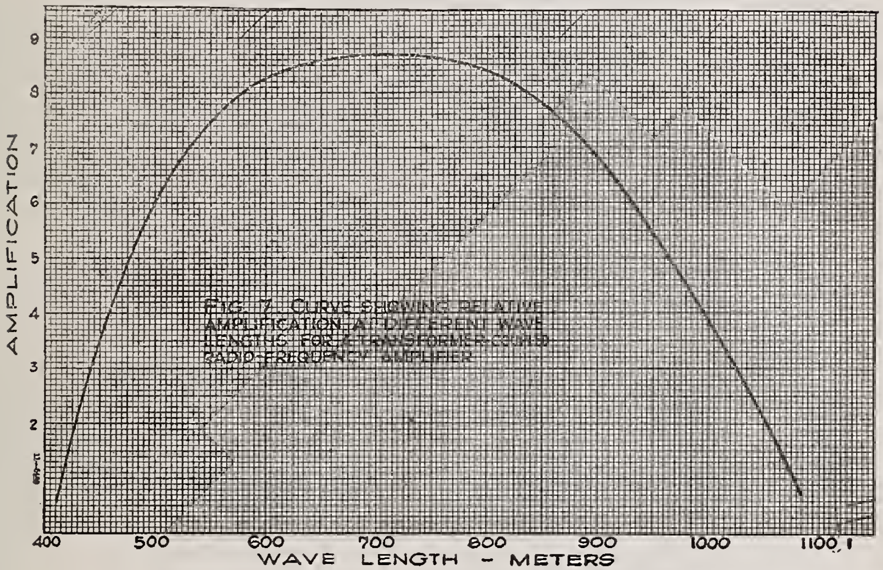


FIG. 7.—*Variation of amplification with wave length.*

properly is, of course, extremely useful for the reception of signals with a coil aerial. The coil aerial permits the elimination of undesired and interfering signals by rotation of the coil to the point where the unwanted signals drop out.

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