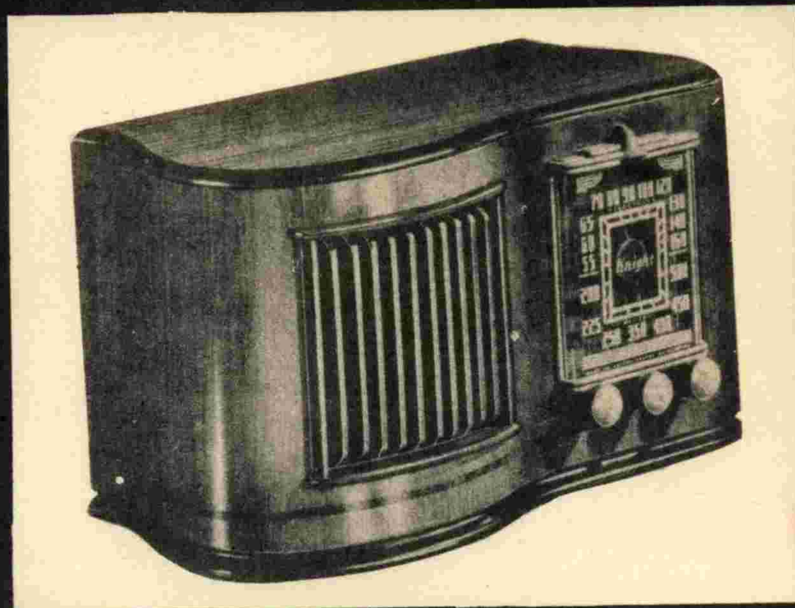

LESSON

29 R

METHODS OF AUDIO AMPLIFICATION

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METHODS OF AUDIO AMPLIFICATION

AMPLIFICATION IN RADIO RECEIVERS. Radio signals or programs as received over the antenna and reproduced in the plate circuit of the detector tube of a receiving set, can generally be heard comfortably if head phones are used; but if a loud speaker or large reproducing system is to be operated, the signals are too weak and must first be strengthened or amplified to be effective for such purposes.

These radio signals can be amplified in two ways in a receiver: First, while they are still at their high frequency and before they reach the detector, or second, after they have passed through the detector and have been demodulated or reduced to an audio frequency. In the first case the process is referred to as high frequency or radio frequency amplification, and in the second case as audio frequency or voice frequency amplification. Intermediate frequency amplification as used in superheterodyne receivers is a form of high frequency amplification.

Each of these two types of signal amplification serve a useful purpose in a radio receiver, and for best results a proper balance of the two is necessary. High frequency amplification aids in the reception of weak signals that under ordinary conditions might not operate the detector effectively. In other words, it builds up the signal before demodulation occurs so that a greater detector output is obtained. Of course, there is a practical limit to which high frequency amplification can be applied, for if too strong a signal is impressed on the detector, the quality of the signals will be ruined. In other words, the detector tube will be overloaded. A high frequency amplifier can also be tuned so that it will help greatly in increasing the tuning selectivity of the receiver.

After a signal has undergone demodulation in the detector and has been reduced to an audio frequency, it can be further amplified for loud speaker operation, and the process is now called audio or voice frequency amplification. It is at once evident that audio frequency amplification cannot aid a receiver in its reception of weak signals or its tuning selectivity, for these features depend upon what operations take place ahead of the detector, while the audio amplifier operates on the signal only after it has reached and actually passed through the detector. The audio amplifier accordingly is not really involved in radio reception, it operates on the signal only after it has already been received and renders it fit for loud speaker operation.

BLACK DIAGRAM OF RADIO RECEIVER

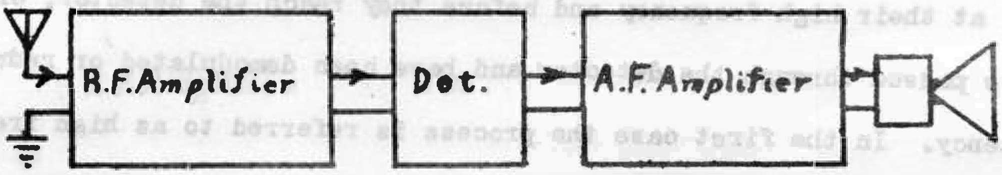

Fig. A - Typical Radio Receiving System. The incoming signal is amplified at its initial high frequency in the radio frequency (R.F.) amplifier, it is demodulated and reduced to an audio frequency in the detector, then further amplified in the audio frequency (A.F.) amplifier, and finally converted into sound in the speaker or reproducer.

OTHER APPLICATIONS OF AUDIO AMPLIFIERS

Besides being used in radio receivers to amplify the signal in the output circuit of the detector tube, audio amplifiers are also used for other purposes that are not concerned with radio reception. For example, they are used in electric phonographs in connection with a pickup for the electrical reproduction of phonograph records. They are also employed in public address systems to make a speaker's voice or music audible over a large area. In sound picture reproduction high-grade audio amplifiers are employed. Photo-electric cell devices involve the use of audio amplifiers for relay operation, etc. Television reproduction also requires special audio amplifiers.

Although all the audio amplifiers in the various fields of application mentioned operate on the same general principles, still they have special features that adapt them to their respective applications. Audio amplification as discussed in the following paragraphs will be particularly with respect to its application in radio receivers. The others will be taken up later on. High frequency amplification is also explained at length in a later text.

CHARACTER OF A GOOD AUDIO AMPLIFIER

Since it is the function of the audio amplifier to receive the detector signal output and amplify it for effective loud speaker operation, this must be accomplished without producing any noticeable change in the speech or music initially transmitted. Consequently a good audio amplifier must meet with the following two requirements: (1) It must transmit and amplify all tones (all frequencies) alike without showing preference for any; and (2) it must amplify all frequencies alike at high and low volume. In other words, there must be no frequency distortion or volume distortion. Distortion can be defined as a deformation or change in the wave form of a signal as it passes through the successive stages of a radio receiver.

Although no audio amplifier system operates at 100 per cent efficiency, modern audio amplification has been developed to such a high degree, that it is more perfect than the receiving abilities of the human ear. In fact, on account of certain peculiarities of the ear, it is actually necessary for most pleasing reproduction to introduce some distortion in audio amplifiers to counteract these aural deficiencies. For example, a tone control is merely a hand-operated distortion introducing unit, for it only serves to render the higher frequencies (higher tones) less prominent and to emphasize the lower notes. Then there is also the principle of acoustical compensation in audio amplifiers, for the human ear is less sensitive at low volume to the high and low frequencies, and therefore these frequencies must receive more amplification than the middle range frequencies when the volume is reduced.

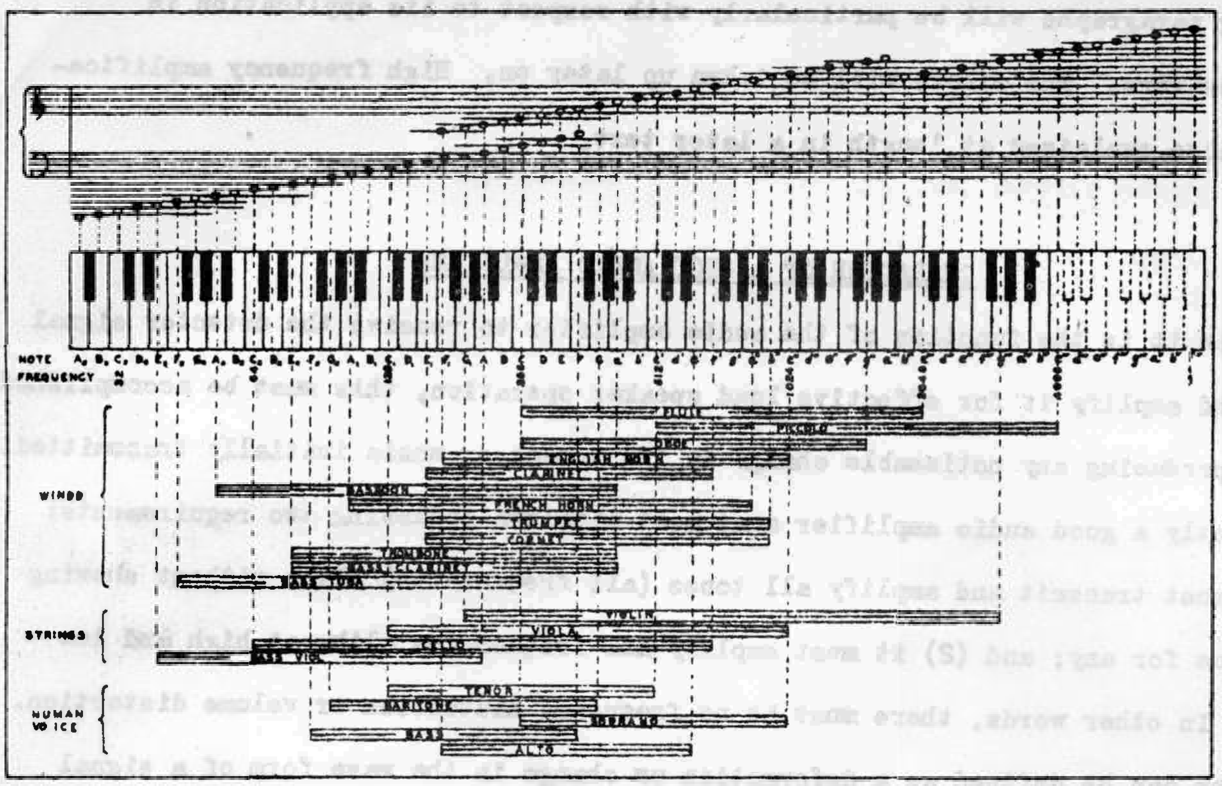

Fig. B. - The Audible Spectrum or range of frequencies covered by the various musical instruments. A good audio amplifier should amplify all frequencies between 50 and 5,000 cycles per second with equal uniformity. It will be noticed that this span includes practically all tones emitted by these instruments.

FREQUENCY RANGE OF AUDIO AMPLIFIERS

The frequency range of an audio amplifier, that is, the band of frequencies that will amplify without introducing noticeable distortion, depends upon the nature of the system and the design and quality of the parts employed. Very high grade amplifiers as used in some broadcasting stations and high quality receiving sets can amplify all frequencies from as low as 40 cycles per second up to 15,000 cycles per second.

This range would give high fidelity reproduction, but in actual transmission practice frequencies above 5,000 cycles per second are not broadcast. The reason

is that broadcasting stations have a 10-kilocycle separation, that is, there is a frequency separation of 10,000 cycles (10 kilocycles) between adjacent stations. If audio frequencies above 5,000 cycles were broadcast, adjacent stations would overlap. For example, if a station is transmitting at 700 kilocycles (700,000 cycles) per second and it is modulated with a 5,000 cycle audio frequency, it would be operating at frequencies ranging from 695,000 cycles to 705,000 cycles, 5,000 cycles above and below its fundamental frequency. The adjacent station operating at 710 kilocycles (710,000 cycles) would similarly extend from 705,000 cycles to 715,000 cycles. Now it is at once evident that if a 6,000 cycle audio note were used, the upper limit of the 700-kilocycle station would be 706,000 cycles and the lower limit of the 710-kilocycle station would be 704,000 cycles. The two stations would thus overlap by 2,000 cycles and that would never do.

THE VACUUM TUBE AS AN AMPLIFIER

Building up the signal strength in an audio amplifier involves the amplifying action of a radio vacuum tube, that is, the ability of a tube to receive a weak signal voltage on the grid and to relay it or cause it to reappear in the plate circuit with greater intensity, the additional energy being provided by the power supply unit. Since the grid is placed very much closer to the cathode or filament than the plate is, a very small potential on the grid will bring about the same change in plate current as a very much greater change in plate potential would. Therein lies the secret of the amplifying action of the vacuum tube, for very small grid potentials can be caused to produce quite appreciable variations in plate current flow.

The term "amplification factor" is merely a measure of the amount of amplification in signal strength actually taking place, and numerically is equal to the ratio of the change in plate potential to the change in grid potential required to bring about the same change in plate current flow. For example, if a variation of 10 volts in the plate potential applied to a tube produces a change of .6 milliampere in plate current flow, and the same change in plate current can be produced by a change of only 1¼ volts in grid potential, the amplification factor of the tube is 10 divided by 1¼ or 8. In other words, a signal in passing through the tube would be multiplied 8 times in strength. A great deal more is given about the amplifying action of a vacuum tube in a later lesson; the above few sentences are given here merely to present some idea of how and why amplification actually occurs in a vacuum tube.

The amplification factor of the 26 type tube is 8.3, of the type 27 it is 9, of the type 56 it is 13.8, of the type 45 it is 3.5, of the 71A it is 3, etc. These are the amplification factor values of some of the more common audio amplifier tubes. All this data can be obtained from the customary tube data charts or bulletins furnished by the tube manufacturers. In order to gain high amplification in a tube the grid is not only placed close to the cathode or filament, but also it is wound with a very close mesh, the principle being to make the grid potential as effective as possible on the electron movement.

AUDIO AMPLIFIER SYSTEMS

In an audio amplifier the signal output of the detector tube of a radio receiver is strengthened or amplified by being sent through one or several vacuum tubes in a cascade arrangement. The increase in signal strength will then depend upon the amplification gain in each tube, the number of such tubes used, and the means of coupling employed between the successive tubes.

The number of amplifier tubes required in any case will be determined by the signal strength available from the detector and the amount of power required to operate the loud speaker or reproducing system. In the earlier sets it was common practice to employ two stages of audio amplification, the term, stage, meaning an amplifier tube and the unit for coupling it to the previous tube. Some sets employed three stages, but more were never recommended, for the noise and distortion that developed greatly impaired the quality of the reproduction.

In many of the later sets, including those of the present time, greater high frequency amplification is employed ahead of the detector, and this combined with the higher gain available in some of the more recently developed audio amplifying tubes, made possible the use of only one audio stage to produce sufficient power output at the speaker. However, in many of the higher grade sets of today two and three stages of audio amplification are employed in order to develop ample output power for the speaker system.

When two audio stages are employed, the function of the first stage is different from that of the second stage, for the first is generally a voltage amplifier while the second is a power amplifier. That is, the first audio stage serves to step up the voltage or electrical potential of the signal, while the second or output stage serves both to step up the voltage of the signal and to impart to it greater energy so that it can operate the reproducing system more effectively. It is similar to saying that the first stage is like a pump that raises a very fine stream of water to a higher pressure, while the second stage also raises the pressure and at the same time pumps in additional water from a storage reservoir to increase the volume of the stream so as to give it greater power. In the radio circuit the power supply unit is the storage reservoir.

TYPES OF AUDIO AMPLIFIERS

Audio amplifiers are named or classified according to the method of coupling used between the successive stages. The earliest and for a long time the best system used was transformer coupling. Here a specially built transformer is used that receives the signal output of one tube and by induction passes it on to the next tube. At the same time it steps up the voltage of the signal so that it is capable of affecting the grid of the next tube with a greater strength. This method is very efficient, and when good transformers are employed, excellent amplification is obtained.

A second system is resistance coupling. In this a high resistance element is used in the plate circuit of the tube, and the signal current in flowing through this resistor sets up across it a corresponding potential that is transmitted through a suitable blocking condenser to the grid of the next tube. No signal gain is obtained with this coupling and a large portion of the supply voltage known as B + voltage is dissipated across the plate resistor, but the quality of reproduction is very good. Impedance coupling is similar to resistance coupling, except that a high impedance audio choke is used in place of the plate resistor. Reproduction is very good and only little of the B+ voltage is dissipated in the coil, but the coil is more costly and therefore the system is used only in the higher priced receivers.

Another system is "autoformer" coupling in which a tapped impedance coil of the auto-transformer type is used. This is an improvement over straight impedance coupling in that some signal gain is obtained in addition to providing the general advantages of impedance coupling. The so-called dual impedance system is another modification or improvement of straight impedance coupling. Here two choke coils are used, one in the plate circuit as a load and the other in the grid circuit as a leak. Although this system yields excellent reproduction it is rather costly and is not used much in commercial sets.

Some amplifiers use a combination of several coupling methods to produce the desired results. For example, it is very common practice in two-stage audio amplifiers to use resistance coupling between the detector and first stage and transformer coupling between the first and second stages. Often the second audio stage is referred to as the output stage.

TRANSFORMER COUPLED AUDIO AMPLIFIERS

Transformer coupling in audio amplifiers has probably been the most popular system, both on account of its simplicity of circuit arrangement, and reliability of operation. In the early days when nearly all radio communication consisted of code transmission, little attention was paid to the operation of a transformer as to its distortion or tone quality. But when modern broadcasting became popular and the listeners demanded more clear and undistorted music and voice reproduction, a need for better transformers arose, and as a result of much research work very high-grade transformers have been developed that will transmit practically all frequencies in the audible spectrum with nearly equal ease. Excellent tonal reproduction is thus possible with them.

An audio transformer consists essentially of a rectangular steel core, generally of the shell type, with two coil windings, one the primary and the other the secondary. The primary is connected as a load into the plate circuit of the tube, and the secondary is connected across the input or grid-filament circuit of the following tube. The pulsating plate current sets up a variable magnetic flux in the iron core, and this flux in turn induces a similar voltage in the secondary winding. If the transformer is well designed, this alternating voltage in the secondary will correspond in every detail to the current oscillations in the primary or plate circuit.

As the current in the plate circuit and primary coil increases, the magnetic flux in the core expands and induces a voltage in the secondary. When the plate current decreases, the magnetic flux collapses partially and induces a voltage in the opposite direction in the secondary. The pulsating direct current in the primary thus induces an alternating voltage in the secondary. This secondary voltage is then impressed on the grid of the next tube in which it undergoes further amplification and reappears as a variable current in its plate circuit.

In Fig. 1 is illustrated the symbol commonly used to indicate an audio transformer "T" in radio circuits. The transformer has four terminal connections, two for the primary and two for the secondary. The primary terminals are labeled "P" and "B". "P" is connected directly to the plate of the tube and "B" to the B + supply unit for furnishing the high D.C. potential to the plate. The secondary terminals are labeled "G" and "F". "G" is connected to the grid of the next tube and "F" to the grid return, that is, the filament or cathode. In battery operated receivers a C-battery is connected into this grid return line. Fig. 1 also illustrates how these various connections are made, including the C-battery. The C-battery, it will be remembered, serves to impress a negative bias on the grid of the tube. This reduces the B-battery drain and also improves the tone quality. In A.C. operated receivers the "F" terminal or grid return is commonly made directly to ground or chassis, for the necessary grid bias in these cases is generally obtained through a resistor connected into the cathode or filament plate return circuit.

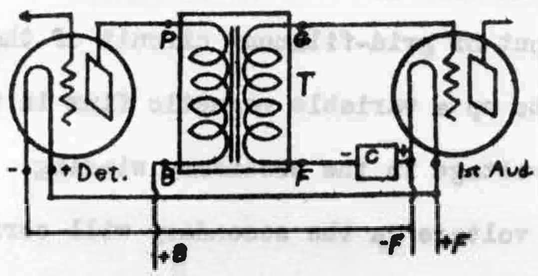

Fig. 1 - Typical Circuit Connections of a Transformer-coupled Audio Amplifier Stage.

A TYPICAL TWO-STAGE TRANSFORMER-COUPLED AMPLIFIER

In Fig. 2 is illustrated a typical two-stage transformer-coupled audio amplifier. The amplifier can be arranged either for battery operation, or for electric power operation as is shown in the diagram. The detector tube is of the indirectly-heated cathode type, such as the 27 or 56, and the first audio amplifier tube is also of this type. The filaments of these tubes, labeled "F" in the diagram, are supplied with current from a suitable secondary winding on the power transformer. The second audio amplifier tube is usually a power amplifier tube of the 45 type. The filament of this tube is heated from a separate secondary winding. A common power supply or B + unit is used for all three tubes.

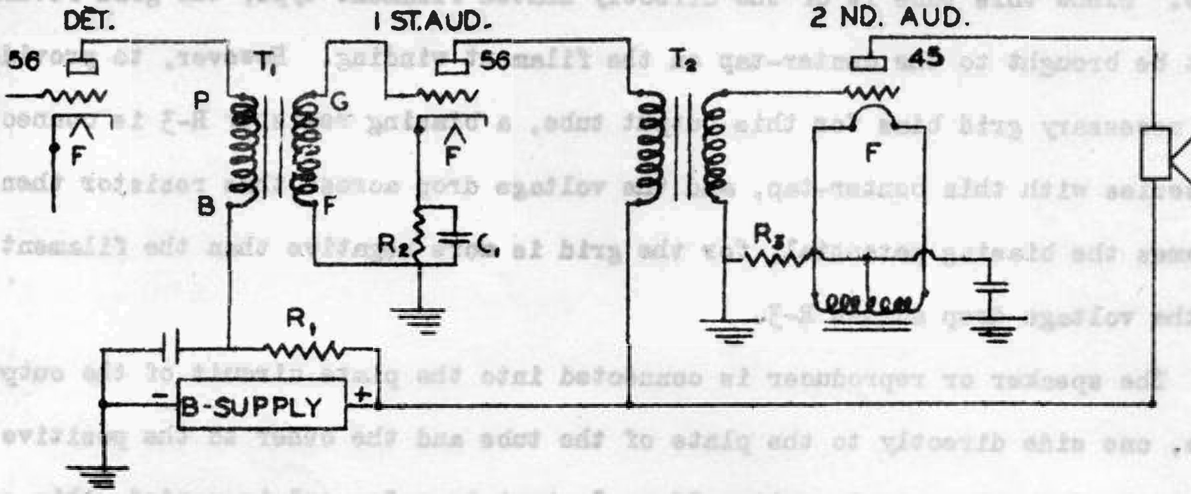

FIG. 2

The primary of the first audio transformer T-1 is connected into the plate circuit of the detector tube, "P" directly to the plate terminal of the detector and "B" through the voltage dropping resistor R-1 to the B + supply line. Since the plate voltage required by the detector generally is less than that required by the amplifier tubes, the plate current of the detector in flowing through resistor R-1 sets up a voltage drop (I x R) that reduces the plate voltage to the proper value. The secondary of the audio transformer is connected into the grid input circuit of the first audio amplifier, the "G" terminal to the grid of the tube and the "F" terminal to the cathode. Resistor R-2 serves to provide the proper bias for the tube, for the plate current in returning through this cathode resistor sets up a voltage drop across it, and this voltage drop then serves as the grid biasing potential. It is equivalent to connecting a C-battery into the circuit with a terminal voltage equal to the drop across the resistor.

The primary of the second audio transformer T-2 is connected into the plate circuit of the first audio amplifier tube, but here no voltage dropping resistor is employed, for the amplifier tube requires the full output of the B + supply unit. The secondary of T-2 is connected into the grid and filament circuit of the "output" tube. Since this tube is of the directly heated filament type, the grid return must be brought to the center-tap on the filament winding. However, to provide the necessary grid bias for this output tube, a biasing resistor R-3 is connected in series with this center-tap, and the voltage drop across this resistor then becomes the biasing potential, for the grid is more negative than the filament by the voltage drop across R-3.

The speaker or reproducer is connected into the plate circuit of the output tube, one side directly to the plate of the tube and the other to the positive terminal of the B + supply unit. If an "output transformer" is needed, this generally forms an integral part of the speaker, and the connections to the speaker would then be made in the same manner.

The operation of the entire amplifier is really quite direct and simple. The signals impressed on the grid of the detector tube reappear in the plate circuit as a variable direct current through the primary of the first transformer T-1. An alternating voltage is induced in the secondary winding and impressed on the grid of the first amplifier tube. In this tube the signal is amplified and again appears in the plate circuit as a variable current flow. In flowing through the primary of T-2 it induces an alternating voltage in the secondary. This voltage is impressed on the grid of the second amplifier tube. Here the signal is not only further amplified but receives additional energy so that the current variations in the plate circuit are of much greater intensity. This current is finally sent through the windings of the speaker and converted into sound.

TRANSFORMER DESIGN AND CONSTRUCTION

Although the details of transformer design cannot be taken up at this point (this is an engineering rather than a service problem), still there are a number of points that should be understood about transformer construction so that a good transformer can readily be distinguished and that service repairs can be made in an intelligent and practical manner.

An audio transformer consists essentially of two coil windings, a primary and a secondary, on a laminated magnetic core of silicon or nickel steel. In the better transformers the cores are of the shell type so that a closed core is formed and magnetic leakage reduced to a minimum. Each coil consists of several thousand turns of very fine enameled copper wire ranging from No. 38 to No. 44 in size. Some manufacturers have special winding schemes, but common practice is to wind the primary in several layers on a form that fits closely on the iron core, and then arrange the secondary in successive layers around the primary. The connecting leads are usually brought out and arranged so that the innermost lead is the plate connection and the outermost the grid. This is done to keep down the capacity effect between the grid and plate connections.

The relative number of turns in the primary and secondary windings depends upon the step-up ratio that is desired and the performance qualities that the transformer is to have. It will be explained in a later text that best results are obtained from a tube as to distortionless amplification if the plate circuit load is equal to about twice the internal plate resistance of the tube. This means that the transformer primary must have a high impedance, and to obtain this impedance a winding of many turns is necessary and a large iron core. A high turns ratio is thus impractical, for it would make the secondary too large and bulky, and inefficient electrically. Good audio transformers, therefore, seldom have a higher turns ratio than 2½ or 3 to 1. If a high ratio transformer is had, the primary winding must necessarily be small, meaning that the transformer is operating at a low efficiency. As a result, a good quality low-ratio transformer will generally give more and better amplification than a poorer high-ratio transformer.

The term "turns-ratio" denotes the number of times the turns in the secondary winding are as many as the number of turns in the primary. If the turns ratio in a good audio transformer is $2\frac{1}{2}$ to 1, there will also be a corresponding step-up in signal voltage, that is, the induced secondary voltage will be nearly $2\frac{1}{2}$ times as great as the signal voltage impressed across the primary. This is an important advantage of transformer coupling, it permits a gain in signal strength in the coupling unit as well as in the amplifying tube. If in Fig. 2 the transformers have $2\frac{1}{2}$ to 1 ratio and the amplifying factor of each tube is 8, the amplification gain through the two amplifier stages would be $2\frac{1}{2} \times 8 \times 2\frac{1}{2} \times 8$ or 400.

FREQUENCY RESPONSE OF AUDIO TRANSFORMERS

Since the impedance of an iron core coil like the transformer windings, depends upon the frequency of the current sent through it, and since the audio signal current through the primary varies from 50 to 5,000 cycles, it is evident that the amplification will not be uniform over the entire frequency range. At the higher frequencies the primary impedance is greater, and, therefore, more signal voltage is built up across it and greater amplification is had. This means that the low notes do not receive as much amplification as the higher tones do and that distortion results.

This condition is somewhat counterbalanced by the fact that on account of the greater number of turns in the secondary winding the distributed capacity is large enough to shunt some of the high frequency energy and thus reduce the amplification of the higher notes. The amplification of the lower notes can be brought up by increasing the number of turns of wire and using a core metal of higher magnetic permeability. Both of these factors increase the cost of the transformer, and a high-grade audio transformer costs considerable money. A good transformer can always be distinguished by a large iron core and a heavy coil winding.

The amplifying characteristics of an audio transformer at different frequencies are generally illustrated by a "performance curve." A number of such performance curves are illustrated in Fig. 3A where frequencies are plotted along the horizontal distances and amplification along the vertical. Curve "A" is that of a cheap transformer, for the shape of the curve shows that the amplification is small at the low frequencies and increases rapidly at the higher frequencies. Such a transformer would emphasize the higher tones and neglect the lower notes. As a result the music would sound thin and shallow and lack fullness and depth. It is evident that a small iron core and relatively small coil winding were used.

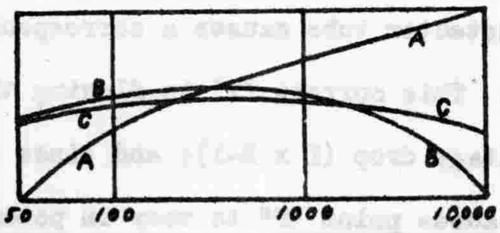

Fig. 3A - Audio Transformer Performance Curves.

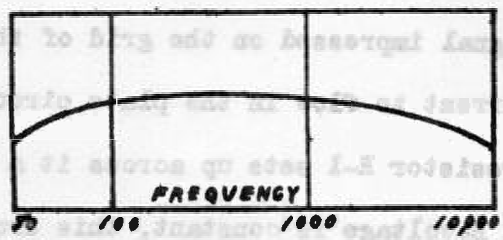

Fig. 3B - Resistance Coupling Performance Curve.

Curve "B" shows the performance of a transformer in which a high distributed capacity exists in the windings. This capacity effect shunts and suppresses the higher frequencies, and therefore the higher notes would lack amplification. Under such conditions music would lack brilliance and would create somewhat of the "boom-boom" effect. This fact makes it necessary to keep the distributed capacity of the transformer windings at a minimum.

Curve "C" illustrates the amplification characteristics of a high-grade audio transformer. A large iron core and high inductance primary winding are used, for good amplification of the low notes is indicated. Also, the transformer ratio was not very high, for the distributed capacity effect of the windings was not great enough to materially reduce the amplification of the higher frequencies. It is thus evident that the design and construction of a good audio transformer is not such a small or simple matter, and that more is involved than merely winding some turns of wire around an iron core.

RESISTANCE COUPLED AUDIO AMPLIFICATION

In resistance coupled audio amplification the successive tubes are coupled by means of high resistance elements. The general circuit arrangement of such a resistance coupled amplifier is illustrated in Fig. 4. Each coupling unit consists of a plate resistor (R-1, R-2 and R-3), a blocking condenser (C-1, C-2 and C-3), and a grid resistor R-4, R-5 and R-6.

The signal impressed on the grid of the detector tube causes a corresponding variable current to flow in the plate circuit. This current "I" in flowing through the plate resistor R-1 sets up across it a voltage drop (I x R-1); and since the applied B+voltage is constant, this drop causes point "P" to vary in potential in exact accordance with the signal voltage initially impressed on the grid of the tube. But point "P" cannot be connected directly to the grid of the next tube, for this would place the high positive potential of the power supply on the grid and render the amplifier tube inoperative. Consequently the blocking condenser C-1 is used. This protects the grid from the high positive potential, but permits the signal voltages at "P" to pass through to the grid. The grid resistor R-4 serves as an input resistor across which the input signal voltage is developed for the first audio amplifier, a type 6J5G triode. This tube is coupled to the second audio amplifier (also a 6J5G tube) in a similar manner. The same type of coupling is used between the second audio amplifier and the power output tube, a type 6F6G power pentode similar to the type 42.

The necessary grid bias for the two 6J5G amplifier tubes is developed across resistors R-7 and R-8 (each 900 ohms in value), and each resistor is bypassed by a condenser (C-4 and C-5, 1-Mfd. each) to maintain the cathodes at zero potential with respect to the audio signal voltage. The bias for the output pentode is developed across resistor R-9 (400 ohms) which is also bypassed by a 1 or 2-Mfd. condenser C-6.

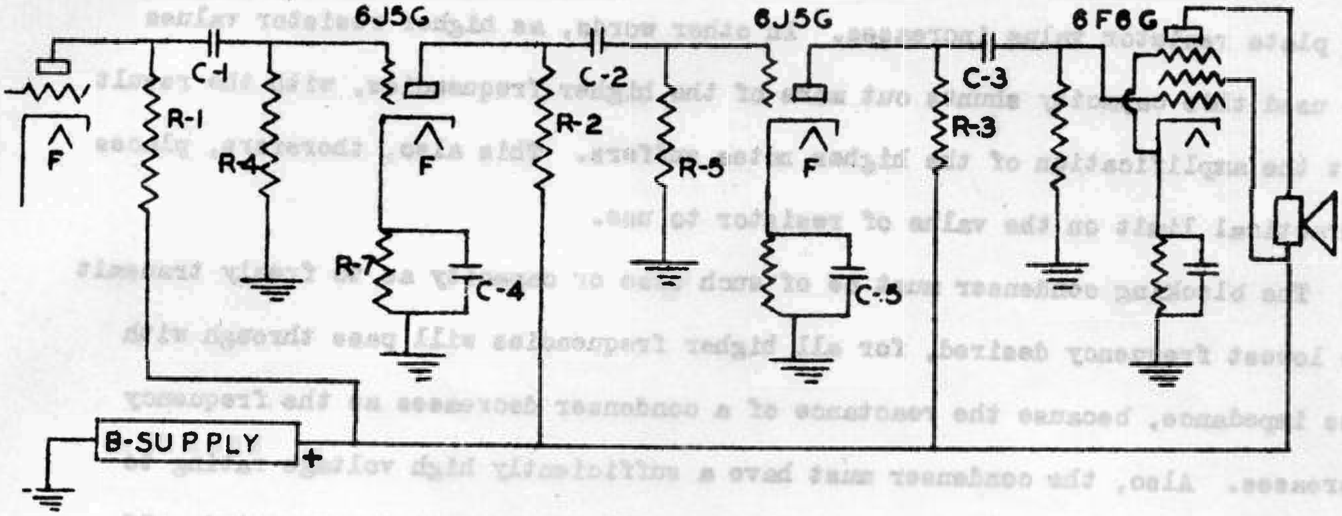

FIG. 4

The load resistors R-1, R-2 and R-3 usually are of 200,000 or 250,000 ohms, while the grid resistors commonly have a value of 500,000 ohms or 1 megohm. The B + supply unit can be made an integral part of the amplifier so that the power input transformer can also supply the filament current for the several tubes, or a separate power supply can be used.

RESISTOR AND CONDENSER RATINGS

The value of plate resistor to use depends very much upon the characteristics of the tube. Theoretically, the higher the resistor value the larger the voltage (IR drop) built up across it and the greater the amplification gain, but higher resistor values also require higher B+ voltages to overcome the "IR" drop and still supply the necessary potential to the plate of the tube. A practical rule to follow is to use a plate resistor equal from two to three times the plate impedance of the tube. Higher values, of course, are used in many cases. The values in most common use range from 200,000 to 250,000 ohms.

Another condition that requires consideration is the internal capacity effect existing between the plate and cathode or plate and filament of the tube. This acts as a shunt capacity across the plate resistor and becomes more prominent as the plate resistor value increases. In other words, as higher resistor values are used this capacity shunts out more of the higher frequencies, with the result that the amplification of the higher notes suffers. This also, therefore, places a practical limit on the value of resistor to use.

The blocking condenser must be of such size or capacity as to freely transmit the lowest frequency desired, for all higher frequencies will pass through with less impedance, because the reactance of a condenser decreases as the frequency increases. Also, the condenser must have a sufficiently high voltage rating to withstand the high potential of the plate circuit to which it is connected. If the condenser is too small, the low frequency response will suffer. A common value used in commercial receivers is .01 Mfd.

The grid resistor must be large enough to permit a high voltage to build up across it, and yet must not be too large to prevent the condenser from discharging rapidly enough and not to allow the tube to clog or block. Grid resistor values ranging from .5 megohm to 5 megohms are used in commercial receivers, the most common value probably being .5 megohm.

APPLICATIONS OF RESISTANCE COUPLING

Resistance coupled amplifiers can be used to amplify the detector output of any radio receiving circuit, and on account of the low cost of the resistors and condensers compared to the cost of audio transformers or chokes, it has become very popular in modern receivers. However, since no amplification takes place in the coupling units and the only amplification obtained is that in the tubes, two or three stages must generally be employed. In the case of some of the more recently developed detector tubes enough amplification can be built up so that only one stage of resistance coupled amplification is needed. These special purpose tubes are taken up later on.

The big feature about resistance coupled amplification, however, is the fact that nearly uniform amplification is had over the greater part of the audio frequency range, and the performance curve of such an amplifier is as illustrated in Fig. 3B. The curve is nearly horizontal over the greater part of the frequency range, and drops off at the very low and high frequencies. The drop off at the lower frequencies is due to the higher impedance of the coupling condenser at these frequencies, while the drop at the higher frequencies is caused by the shunting effects of the internal tube capacity and other stray capacity effects.

On account of the large potential drop across the plate resistor, higher B + voltages are needed with resistance coupling. The voltage needed in any case can be calculated by adding to the voltage needed at the socket plate terminal the drop (Ip x R) across the plate resistor. In general, resistance coupling has the advantages that it renders high quality amplification possible and is relatively low in cost. Its disadvantages are that the amplification per stage is less and therefore an additional stage is needed, and higher B + voltages are necessary. In a 3-stage amplifier such as is illustrated in Fig. 4, the first and second amplifier tubes are voltage amplifiers, while the third is a power amplifier and releases power from the B + supply system for operating the speaker or reproducer.

COMBINATION AUDIO AMPLIFIER

Both resistance and transformer coupling are sometimes employed in an audio amplifier, and very good results can be obtained in this way. Such a combination audio amplifier is illustrated in Fig. 5.

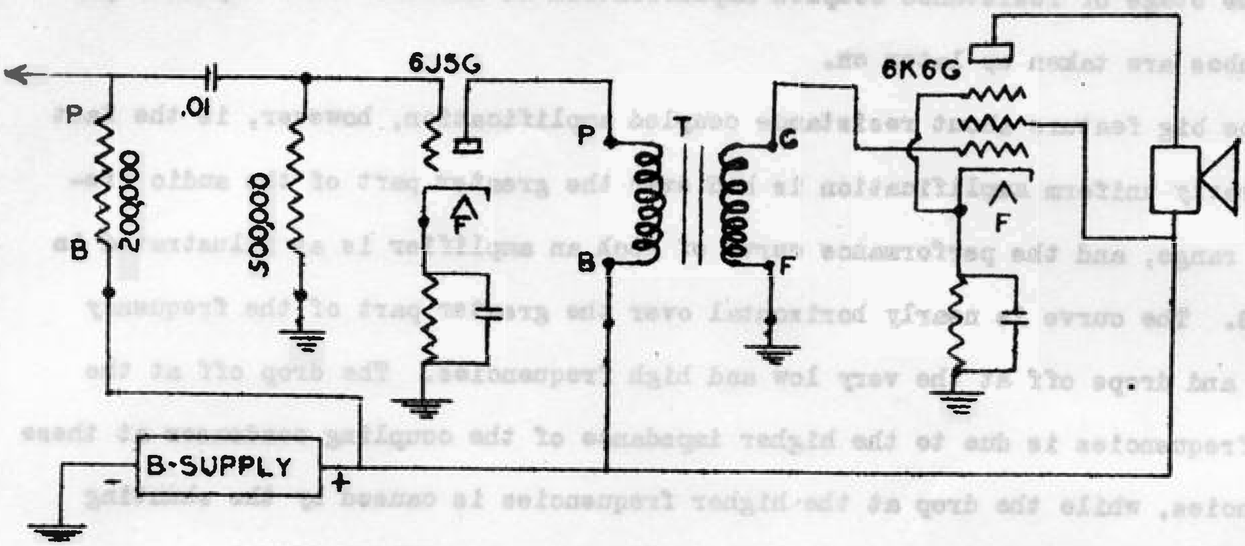

FIG. 5

Two stages are used, the first being resistance coupled to the detector and the second transformer coupled. The first tube is a voltage amplifier, and the second a voltage and power amplifier, for it not only aids in stepping up the signal voltage, but also serves to release power from the B + supply system for speaker operation.

The values of all parts are illustrated in the diagram, and the amplifier can be built as a separate unit or can be made an integral part of a receiver. If a high-grade transformer is used, the distortion will be well within acceptable limits, and at the same time sufficient amplification will be obtained for effective loud speaker operation. Another advantage of the circuit is that such high B+voltage is not needed as though the second stage were also resistance coupled. A similar arrangement is used in many modern A.C. operated sets, except that the last stage has two power tubes in push-pull. A later lesson is devoted entirely to audio power amplifiers, and amplifiers for all purposes are discussed there.

Impedance coupled amplification partakes of the characteristics of both transformer coupling and resistance coupling. In this system, which is also sometimes known as choke coil coupling, high reactance choke coils are used as coupling units. The general circuit arrangement of an impedance coupled amplifier is illustrated in Fig. 6. As illustrated, each coupling unit consists of three elements, a reactance coil "CH", a coupling condenser "C", and a grid leak "R". For effective performance it is necessary that each of these elements be of the proper design and have the correct value.

The coil "CH" is an iron core choke with a very high inductance, 200 henries or over, and a relatively low D.C. resistance. There is accordingly very little voltage drop across the coil due to the direct current component of the plate current, and therefore the high "B" voltages are not needed as with resistance coupling where the high voltage loss occurs across the plate resistor. Due to the high impedance of the coil, however, the signal component of the plate current builds up a very high signal voltage that is passed on to the grid of the next tube.

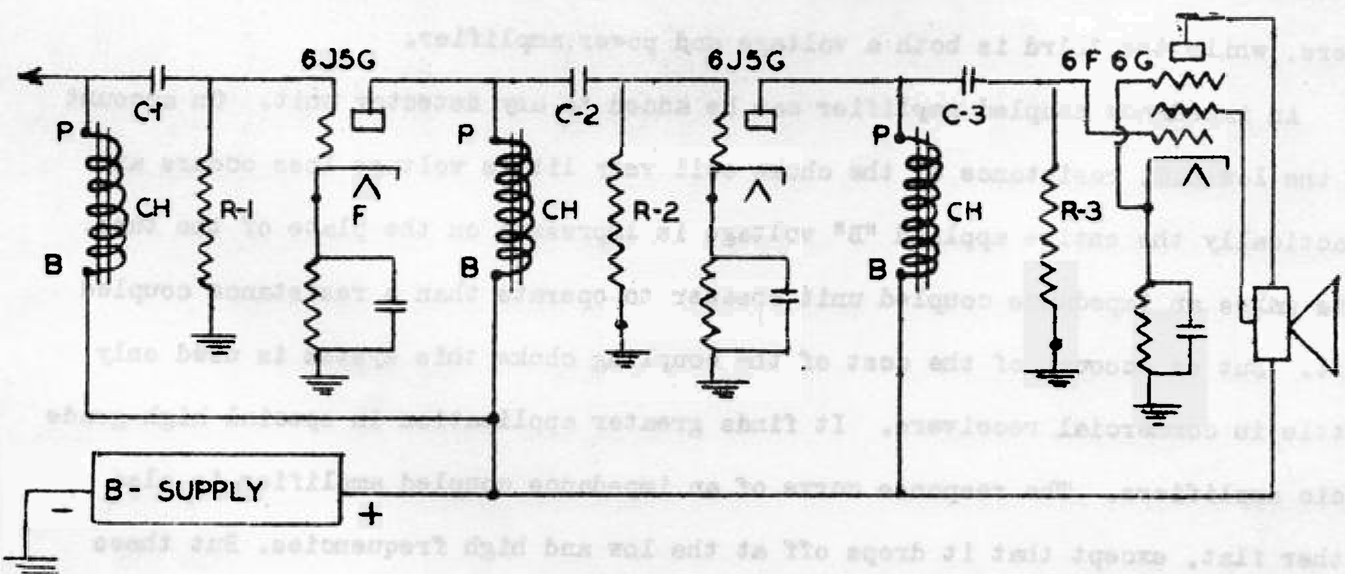

Fig. 6

The condenser "C" serves the same purpose as in resistance coupling, namely to protect the grid of the next tube from the high positive plate voltage and to transmit the signal voltage. It should have sufficient capacity (.01 Mfd. is a common value used) to pass on the lowest audio frequency desired, and have a high enough voltage rating so as not to break down under the plate pressure used. The grid leak "R" allows the negative charges to escape that would otherwise accumulate on the grid due to the presence of the condenser "C".

APPLICATIONS OF IMPEDANCE COUPLING

Impedance coupling is really a compromise between transformer and resistance coupling. Per stage it gives slightly greater amplification than resistance coupling, and at the same time the quality of reproduction is nearly as good. However, the amplification is less than with a stage of transformer coupling, and for sufficient output two or three stages are needed. A high impedance choke is more costly than a resistance element, yet somewhat cheaper than a good audio transformer. The first two tubes in a 3-stage amplifier are purely voltage amplifiers, while the third is both a voltage and power amplifier.

An impedance coupled amplifier can be added to any detector unit. On account of the low D.C. resistance of the choke coil very little voltage loss occurs and practically the entire applied "B" voltage is impressed on the plate of the tube. This makes an impedance coupled unit cheaper to operate than a resistance coupled unit. But on account of the cost of the coupling choke this system is used only little in commercial receivers. It finds greater application in special high-grade audio amplifiers. The response curve of an impedance coupled amplifier is also rather flat, except that it drops off at the low and high frequencies. But these conditions can be corrected by the use of equalizing condensers, etc.

The choke coil is the important unit in impedance coupling, and for best results only a high-grade coil should be selected. The coil should be built so that the plate current will not saturate the core and the winding should have a high inductance and minimum distributed capacity, for these two factors determine the response at the low and high frequencies. The core should be of a very high permeability. It is true that such units are costly, but if quality reproduction is wanted, cost should be of secondary importance.

THE NATURE OF DISTORTION

A radio receiving set at its best should be a real musical instrument, and reproduce all music and sounds in their true nature. But many receivers, both home-made and factory built, fall far short from this standard on account of various forms of distortion that take place in some part of the circuit.

Distortion is merely a deformation of the electric current waves as they travel through the successive parts of a radio receiver. This statement will mean more if we remember that all sounds are a form of vibratory motion. The higher the pitch of a sound the greater is the rate of frequency of vibration; and the lower the tone, the lower the vibrations. Also, all musical sounds are a rather complex form of vibration, in that they consist of a fundamental tone or vibration with a number of harmonics or overtones superimposed upon it. The nature and number of these overtones will determine the quality or timbre of the tone. It is this tonal quality that enables one to distinguish one person's voice from another, or to recognize notes as those from a violin, cornet, etc.

It is thus evident that the electric current waves corresponding to such sounds are themselves very complex. These complex current waves must pass through a receiver from tuner through detector, amplifier and loud speaker, without being in any way altered or impaired. All frequencies must be conveyed with the same

efficiency. If one piece of apparatus in a receiver is partial to the higher frequencies, while anotherpasses on the lower frequencies more readily, then the output current waves will be quite different from the input waves. In other words, the current waves have been deformed, and the sounds emanating from the speaker are more or less distorted.

Distortion can occur in several parts in a radio receiver - in the detector tube, in the audio amplifying tubes, in the audio transformer, or in the loud speaker. Let it be said at this point that when a receiving set is being built or repaired, only the best parts and apparatus should be used. Cheap parts are generally poorly designed and made only to sell and not so much to operate or perform. It is well worth while spending a little more money for good parts and feeling sure that when everything is done the set will work and work right.