NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

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LESSON TEXT No. 42

CONSTRUCTION AND OPERATION OF POWER AMPLIFIERS

Originators of Radio Home Study Courses
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Washington, D. C.

An aim in life is the only fortune worth the finding; and it is not to be found in foreign lands, but in the heart itself.—ROBERT LOUIS STEVENSON.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

INTRODUCTION

The term "Power Amplifier" is applied to radio-frequency and to audio-frequency amplifiers, in radio transmitting and receiving equipment. In this text we are only concerned with audio-frequency amplifiers. We will consider their design, construction, and theory of operation, starting with the so-called "Low Power Amplifiers" and ending with the units that are termed "High Power Amplifiers," as far as audio-frequency amplification in the course of radio reception is concerned.

A power amplifier, for audio-frequency amplification in a radio receiving installation, is an amplifier which employs one or more power tubes.

A power tube is a tube that is used in an audio-frequency amplifier to obtain greater amplification without distortion than can be obtained with a receiving tube of the UX-201-A type. In other words, a power tube is one that can produce 100 milli-watts, or more, of undistorted audio-frequency output, when employed under normal operating conditions.

You will observe that the definitions given in the preceding paragraphs are relative, that is, a 100 milli-watt tube would hardly be called a "Power Tube" if it were to be used in a radio transmitting system, but it could be so called when employed in a receiving set. Therefore, it is well to bear in mind the fact that the preceding definitions, and those that follow, are given with the understanding that they are applicable, primarily, to audio-frequency amplifiers which are used in connection with radio receiving systems.

The UX-201-A is an excellent receiving tube for amplifying the small electric currents that enter the input circuit of the receiver, for changing these high-frequency currents into audio-frequency currents, (detector action), and for effecting a small amount of audio-frequency amplification. However, you cannot supply a loud-speaker with enough volume from the output circuit of a UX-201-A to cause that unit to produce a great amount of volume without distortion. It might be well to mention the fact that the UX-201-A was not designed for supplying more than 55 milli-watts of audio-frequency energy in an undistorted form.

The chief reason for the poor quality output signals that are heard from the output units in more than 50 per cent of the radio installations today is that the tubes used are being overloaded. The reason that you get distortion when you use tubes of the UX-201-A type to drive a loud-speaker is that you are overloading one or more of your tubes in trying to get plenty of volume.

When we say that a tube is overloaded we mean that the potential variations on the grid of the tube in question are of such a magnitude that they cause values of plate current which are off the straight line part of the characteristic curve of the tube used, hence you effect non-linear amplification which is manifested in the loud-speaker output by distortion.

Now, as long as the potential variations on the grid of an amplifier tube are kept within the range of the straight line part of the characteristic curve of the tube used, it will be possible to get linear amplification and undistorted output signals. If, in the course of following the path of the signals through an audio-frequency amplifier, we come to a stage where the grid voltage swing is too great for the tube used in this stage, we should substitute a tube having the proper characteristics to handle a grid swing of this magnitude, hence the use of the "Power Tube" in the "Power Amplifier".

The "Power Tube" is so designed that the straight part of its plate current-grid voltage characteristic curve covers a greater range of grid voltage than in the case of the UX-201-A, hence it will allow for greater grid voltage swings before the values of plate current reach points that are off the straight part of the curve.

Just as we have our 7.5 watt (UX-210) transmitting tube; our 100 watt (UV-203-A); and our 250 watt (UV-204-A) Radiotrons for radio-frequency amplification; so do we have in receiving, our 15 milli-watt, (UX-201-A); our 330 milli-watt (UX-171-A); and our 1.5 watt (UX-210) Radiotrons, etc., for audio-frequency amplification. You will note the difference in the rating of the UX-210 at radio and audio-frequencies, namely, 7.5 watts at radio-frequencies and 1.5 watts at audio-frequencies. It might be well to note the fact that the audio-frequency ratings given above are the power outputs for undistorted audio-frequency signals and that higher outputs may be obtained at audio-frequencies, with the tubes mentioned, but with some distortion along with it.

The term "Power Amplifier", you see, is really a relative term. In transmitting it is usually applied to the last stage of radio-frequency amplification. In receiving it is applied, in many instances, to the last stage of audio-frequency amplification. In the latter case we can be more specific and say that the term is applied, in general, to any amplifying unit which employs a tube of greater power output at audio-frequencies than the UX-210-A.

AMPLIFIER TUBE CONSTANTS

Before discussing the details concerning different types of power amplifiers, let us first consider some of the constants of the different types of power tubes that will be mentioned in the following text, as well as the receiving tubes that are used ahead of these power tubes. We shall bear in mind the fact that we are primarily interested in the amount of undistorted signal output which the tubes in question can supply, due to the fact that one of the prime reasons for using a power tube is to effect great volume without distortion. The following is a list of the tubes in which we are interested, together with some of their constants:

TABLE I

Type	Filament Voltage	Plate Voltage	Grid Voltage	Plate Current	Voltage Amp. Factor	Maximum Undistorted Output In Milli-Watts
UX-199	3.0	90.0	— 4.5	2.5	6.6	7.0
UX-201-A	5.0	90.0	— 4.5	2.5	8.0	15.0
		135.0	— 9.0	3.0	8.0	55.0
UX-120	3.0	135.0	—22.5	6.5	3.3	110.0
UX-112-A	5.0	135.0	— 9.0	7.0	8.0	120.0
		157.5	—10.5	9.5	8.0	195.0
UX-171-A	5.0	135.0	—27.0	16.0	3.0	330.0
		180.0	—40.5	20.0	3.0	700.0
UX-210	7.5	350.0	—27.0	16.0	8.0	925.0
		425.0	—35.0	18.0	8.0	1540.0
UX-245	2.5	250.0	—50.0	30-35	3.5	1600.0
UX-250	7.5	350.0	—63.0	45.0	3.8	2350.0
		450.0	—84.0	55.0	3.8	4650.0

LOW POWER AMPLIFIER

Figure 1 is the schematic diagram of a power amplifier, which produces good quality audio amplification and volume.

It is to be remembered that although the use of power tubes in an audio-frequency amplifier circuit is what produced the term "Power Amplifier" as used in connection with radio reception, the elements of the amplifier circuit must be of good quality and have the proper design to allow for good quality output signals.

In this particular amplifier the three different fundamental types of audio-frequency amplifier circuits are employed. The first stage is resistance coupled; the second stage is transformer coupled; and the third stage is resistance coupled, with an impedance leak across the grid filament terminals of the last amplifier tube.

Resistance coupled amplification possesses the inherent characteristics that all frequencies in the audio-frequency band in which we are interested in the course of the reception of radio broadcast signals, are amplified equally. The amplification is not as great as in the case of transformer coupled circuits. In the latter, voltage amplification is effected in the transformer itself, due to the step-up ratio between the primary and secondary windings. Whereas in the former the resistance coupling unit affords no inherent amplification. All the voltage step-up is attainable due to the amplification factor of the tube used.

Transformer coupled amplification produces the greatest step-up in signal voltage, but some audio-frequency interstage transformers show partiality to certain frequencies. While this might not be detected in the use of one transformer, if you use two stages of transformer coupling the chances are considerably greater. Unless you use transformers of extremely careful design and construction, which amplify the low frequency notes in the same proportion that the high frequency notes are amplified.

In the use of resistance coupling, you have a duplicate of the input circuit of a detector tube, (condenser in series with the grid and grid leak between grid and filament), with the exception that different constants are used and the frequency of the signals under consideration are different, e. g., in a resistance coupling unit the condenser has a value of the order of .05 mfd. as against .00025 mfd. in a detector circuit; the grid leak in a resistance coupling unit is usually a fraction of a megohm whereas in a detector circuit it is of the order of several megohms; in a resistance coupled unit such as we are considering we are concerned with audio-frequencies in the band between 50 and 5,000 cycles, whereas in the detector input circuit it is with radio-frequency currents that we are concerned.

Just as we get rectification in a detector circuit, so would we get rectification in a resistance coupled amplifier circuit, with subsequent distortion in the output signals, if we didn't keep the grid leak resistor of a low enough value so that electrons would leak off to the filament as fast as they collected on that plate of the coupling condenser connected to the grid terminal of the tube. This can be done without much trouble in the first stage of amplification, but in the last amplifier stage the grid swings through such a large potential difference that a great number of electrons are attracted to the grid of the tube when its potential is swinging through that half of its

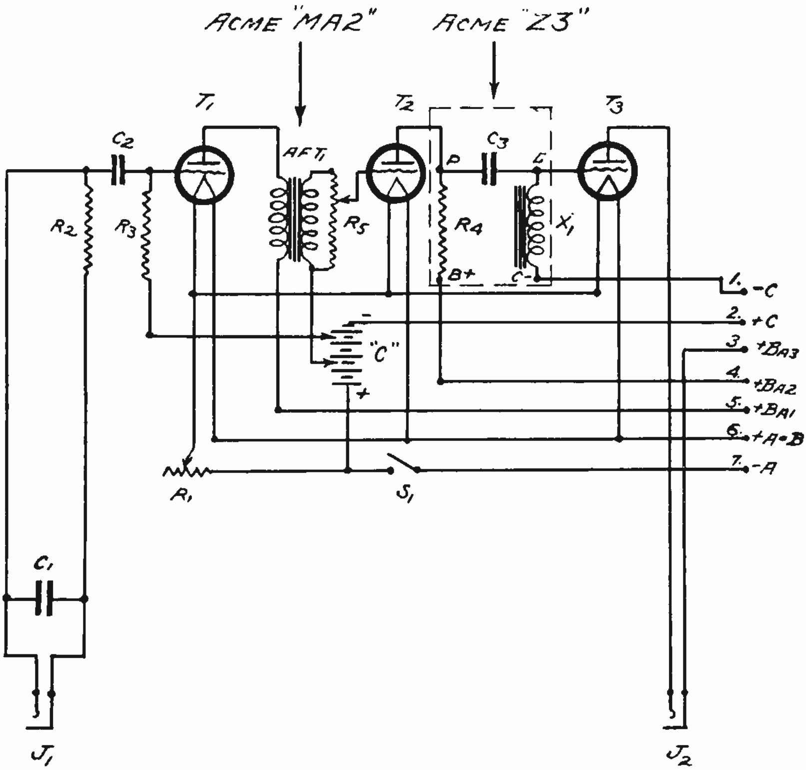

Fig. 1—Circuit Diagram of Low Power Amplifier.

cycle which is in the positive direction. Hence the value of grid leak must be made quite low or rectification will occur, and when the leak is decreased to that value which obviates the possibility of rectification, the value in question is usually so low that it greatly impairs the output volume.

What we want, then, in the grid circuit of the last stage amplifier, is a leak that will offer a low resistance to direct current flow, but a high resistance to alternating current flow. The impedance leak is the answer, hence its use in this circuit.

The following is a list of the apparatus used in this power amplifier together with the circuit constants:

AFT_1—Audio-frequency interstage transformer.
X_1—200 henry reactor.
C_1—.002 mfd. radio-frequency by-pass condenser.
C_2—.05 mfd. by-pass condenser.
C_3—.05 mfd. by-pass condenser.
R_1—6 ohm rheostat.
R_2—50,000 ohm coupling resistor.
R_3—50,000 ohm coupling resistor.
R_4—200,000 ohm resistor.

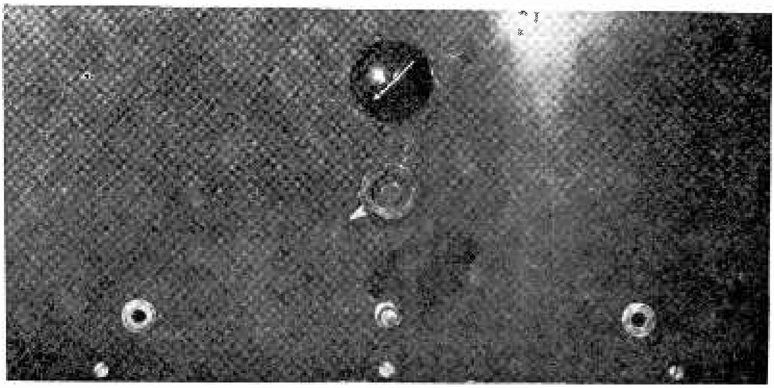

Fig. 2—Panel Arrangement of Amplifier.

R_5—500,000 ohm potentiometer.
T_1—UX-201-A.
T_2—UX-201-A.
T_3—UX-171-A.
3 —UX tube sockets.
J_1—Open circuit jack.
J_2—Open circuit jack.
S_1—Filament switch.

You will note that there are seven power supply terminals in this amplifier unit, which are numbered 1 to 7 on the schematic diagram of figure 1. The following is a list of the proper voltages to use:

No. 1—C for T_3 .... -19.5 volts.
No. 2—Positive terminal of external 19.5 volt "C" battery for T_3.

No. 3—"B" battery plus for T_3 . . . 135.0 volts.
No. 4—"B" battery plus for T_2 . . . 135.0 volts.
No. 5—"B" battery plus for T_1 . . . 90.0 volts.
No. 6—Positive 6 volt battery and negative "B" battery.
No. 7—Negative 6 volt battery.

There is a 7.5 volt "C" battery within the amplifier assembly which is designated as "C" on the diagram in figure 1. You will note that this 7.5 plus the external 19.5 volt battery gives a total bias of 27 volts on the grid of the last stage amplifier tube which has 135 volts on its plate. It is well to use a negative bias of -4.5 volts on the grid of T_1 and -1.5 volts on the grid of T_2.

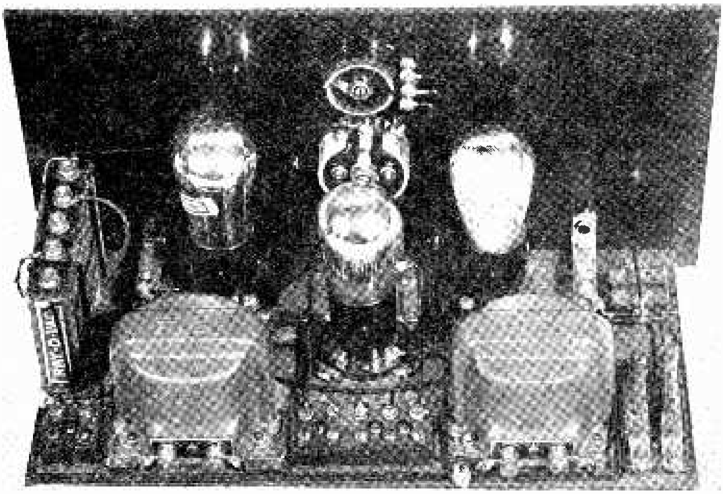

Fig. 3—Rear View of Amplifier.

If you want to push this amplifier a bit, you can increase the "B" supply for T_2 to 157.5 volts with a 3.0 volt bias on the grid of this tube, and raise the plate supply for T3 to 180 volts, putting a bias of 40.5 volts on the grid of this tube.

It is well to draw your attention to the fact that this power tube UX-171-A draws considerable plate current as compared with tubes of the UX-201-A type. For instance, with 135 volts on its plate and a 27 volt bias, this tube draws 16 milli-amps. of plate current, while with 180 volts on its plate and a 40.5 volt bias it draws 20 mils. In view of these facts, you can see that it is not wise to put more than 135 volts on the plate of this tube when you are using dry cell "B" batteries due to the rapidity with which they will be used up. However, if you have a "B" eliminator capable of supplying 180 volts, it is possible to use the higher voltage.

From a consideration of the facts contained in the preceding paragraph, and with the added knowledge that the standard loud-speaker should not have its field coil windings subjected to the flow of a direct current of greater than 10 milli-amps., you can see that when using the type of circuit shown in figure 1 with a UX-171-A in the last stage, it is not desirable to plug the loud-speaker right in the output jack of the last stage but rather, to couple the loud-speaker to the amplifier through the medium of an output transformer or a choke coil-condenser coupling unit.

Figure 2 is a front view of this amplifier. Figure 3 is a rear view, and figure 4 is a top view.

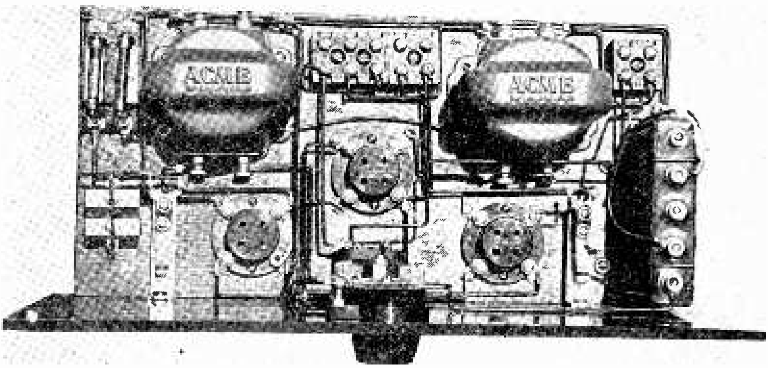

Fig. 4—Top View of Amplifier.

DOUBLE IMPEDANCE COUPLED AMPLIFIER

Figure 5 is the schematic diagram of an audio-frequency amplifier which uses two small power tubes. In this amplifier circuit there are two stages of impedance coupling, each employing the impedance leak, and one stage of transformer coupling.

In the previous discussion of a power amplifier, the point was brought up as to why resistance coupled amplifiers of the past had been modified, during the present era, by the application of the impedance leak, to prevent rectification with subsequent distortion. In the circuit now under discussion, two stages of impedance coupling have been also modified by the application of the desirable impedance leak.

In the amplifier, Figure 1, there are two stages of resistance coupled amplification, one of them modified, and one stage of transformer coupled amplification. In the "Double Impedance" amplifier there are two stages of impedance coupled amplification, both of them modified, and one stage of transformer coupled amplification.

Although Figure 5 gives quite a detailed idea of this type of amplifier, it might be well to list the component parts, as follows:

2—General Radio type 373 double impedance couplers.
1—General Radio type 285-D audio-frequency transformer.
1—General Radio type 387-A speaker filter.
1—General Radio type 410 rheostat, 6 ohms.
3—General Radio type 349, UX tube sockets.

SCHEMATIC DIAGRAM
FOR COMBINATION 2 STAGE DOUBLE IMPEDANCE COUPLED
AND 1 STAGE TRANSFORMER COUPLED AMPLIFIER WITH SPEAKER FILTER

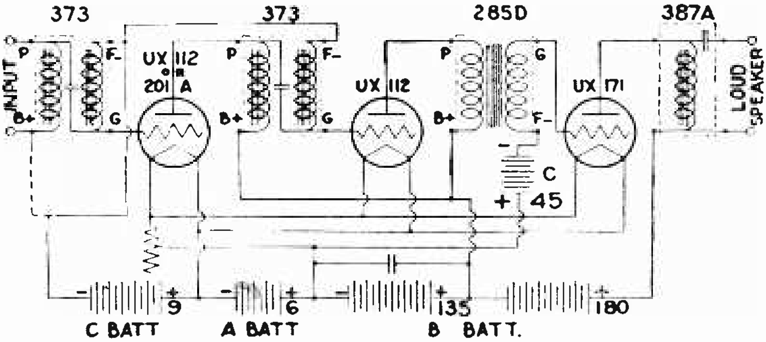

Fig. 5.

You will note that either a UX-201-A or a UX-112 can be used in the first stage; a UX-112 is used in the second stage; and a UX-171-A is used in the last stage, with a coupling unit between the amplifier output and the field coil windings of the loud-speaker.

Either an output filter, as it is termed here, or an output transformer is recommended for use wherever the direct current flow to the plate of the last stage amplifier tube is more than 10 milli-amperes. This is due to the fact that currents of greater value are quite apt to burn out the speaker field coil windings which are usually made of very fine wire. Also, the flow of this relatively high value of direct current through the field coil windings of the speaker is quite apt to demagnetize the permanent magnet in the field coil assembly, which will cause the speaker to decrease in sensitivity. The prime function of the output transformer, or the output filter, then, is to keep direct current of abnormal value out of the loud-speaker field coil windings.

ECONOMICAL HIGH POWER AMPLIFIER

We have termed this unit an "Economical High Power Amplifier," because the relative cost of the component parts for its construction is quite low.

The schematic diagram is shown in Figure 6 and the parts used in its construction, as well as the circuit constants, are given in the following list:

(1) —Power transformer.
One 450 volt plate winding.
Two 8 volt filament windings, one being center-tapped.
X_1—30 henry filter choke.
X_2—30 henry filter choke.
AFT_1—Audio-frequency transformer (2 to 1.)
AFT_2—Output transformer (1 to 1.)
C_1—750 volt, 2 mfd. filter condenser.
C_2—750 volt, 4 mfd. filter condenser.
C_3—750 volt, 6 mfd. filter condenser.
C_4—200 volt, 1 mfd. by-pass condenser.
C_5—200 volt, 1 mfd. by-pass condenser.
R_1—7 ohm rheostat.
R_2—7 ohm rheostat.
R_3—2,000 ohm variable resistor.
R_4—200 ohm potentiometer.
R_5—500,000 ohm potentiometer.
R_6—Heavy duty resistor, 20,000 ohms.
R_7—Heavy duty resistor, 4,500 ohms.
R_8—Heavy duty resistor, 7,500 ohms.
R_9—Heavy duty resistor, 9,000 ohms.
J_1—Open circuit jack.
J_2—Open circuit jack.
S_1—Filament switch.
—Overall size of amplifier, 21″x7″x10″ deep.

Considering the schematic diagram, you will note that 110 volts AC is supplied to the primary winding of the power transformer, through the single pole, single throw switch (S_1), which functions to turn the amplifier on or off, due to the fact that it supplies or removes the supply current to the plate and the filament of the power amplifier tube.

The high voltage secondary winding of the power transformer is the source of the AC which is to be rectified for application to the plate of the power amplifier tube. What we really do is to connect one side of this winding to the amplifier filament circuit, through the biasing resistance (R_3), and we connect the other end of this winding to the plate of the rectifier tube, through a rectifier tube (which only allows current to pass in one direction), through a filter circuit, and thence through the primary winding of an output transformer. The rectifier tube functions to change the AC to DC and the filter circuit functions to smooth out the ripple in the rectified AC.

The filament winding for the rectifier filament supply must be insulated for voltages of the order of 1.41x450, or, 635 volts due to the fact that the peak voltages at this point in the circuit are of the order of 635 volts, the rectifier filament winding being the source of the positive lead for the DC supply.

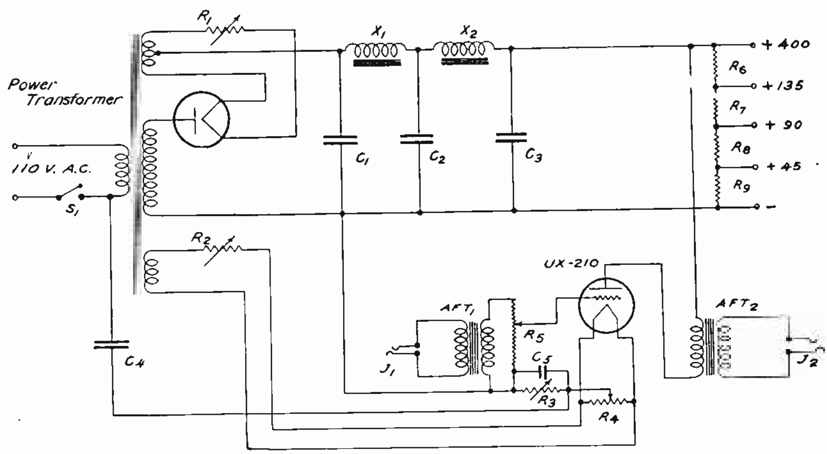

Fig. 6

Two 30 henry chokes are used in the filter circuit, together with 12 microfarads of capacity.

The filament of the power amplifier tube is energized from one of the low voltage windings on the power transformer. The filament current is limited to its normal value, 1.25 amps., by means of the 7 ohm rheostat (R_2).

The audio-frequency signal to be amplified is supplied to the primary winding of the input transformer through the medium of the jack (J_1). The secondary winding of this transformer is shunted by a 500,000 ohm potentiometer, the variable contact arm of which is connected to the grid terminal of the amplifier tube. Since maximum signal voltage is apparent across this 500,000 ohm resistor, as the movable contact arm is moved from the filament end of the resistor in question to the high voltage end, the signal voltage applied to the grid of the amplifier tube is varied through wide limits, thus affording a very convenient volume control.

The low side of the secondary winding of the input transformer is connected to the mid-point in the filament supply, through the 2,000 ohm biasing resistor (R_3). This resistor is shunted by an audio-frequency by-pass condenser (C_5) which increases the output volume and is a great aid to quality. The mid-point of the filament supply is effected through the medium of a 200 ohm potentiometer whose extremities are connected across the filament supply leads, it being possible to adjust the movable contact arm to the exact neutral in the filament supply.

It is desirable that the grid-return lead of the amplifier tube be brought to the electrical mid-point in the filament supply, due to the fact that this point remains at zero potential. In other words, there is no fluctuation in voltage at this point. For instance, let us consider the fluctuation in voltage at one end of the 200 ohm potentiometer that we have connected across the filament supply leads. The voltage at this point rises from zero to maximum in the positive direction, then decreases to zero, rises to its maximum negative value and again decreases to zero. This is called one cycle. If we move to a point, half way between the end of the resistor and the electrical mid-point of the coil, the voltage passes through the same cycle, but the peaks are now only half as high. Now, if we move to the center of the resistor we will find that there are no fluctuations in voltage.

If we brought the grid-return to one end of this potentiometer, an alternating e.m.f. would be applied to the grid of the amplifier tube, due to the fluctuations in filament supply voltage at the point in question. However, we can see how we would eliminate these fluctuations on the grid of the tube if we brought the grid-return to a point in the filament supply which was at zero potential.

You may wonder how it is possible to use pure A.C. on the filament of a power amplifier tube and not successfully on the filaments of the preceding D. C. tubes in a radio receiving system. The reason is that the power amplifier tube is the last tube in the system, and if you do create a slight hum by using A.C. on its filament, you have to worry only about the amplification effected by this tube itself. If A.C. were used on the filament of the D.C. tube preceding the power amplifier, the disturbance that it effected would be amplified through the medium of the amplification factor of this preceding tube, plus the amplification effected by the coupling transformer, as well as the amplification of the last amplifier tube. Thus, in the first case, you can see where the hum might not be appreciable. In the latter case, due to the greater degree of amplification, it is quite likely to be excessive.

The variable resistor (R_3) controls the bias on the grid of the tube by virtue of the plate current that flows through this resistor. To see this clearly, we had better trace the plate circuit of the power amplifier tube. We start at the source of the positive lead which is at the mid-point in the rectifier filament supply winding. We then pass through the two filter chokes (X_1 and X_2), through the primary winding of the output transformer AFT_2 to the plate of the power amplifier tube; through the interior of the tube in question, from plate to filament, to

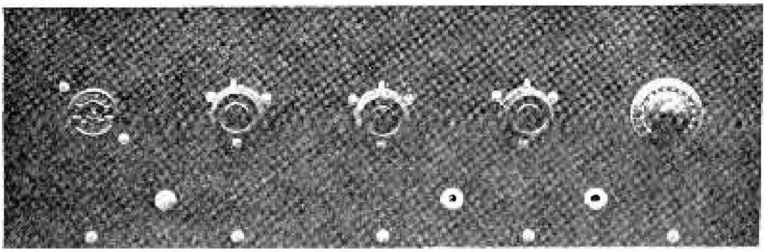

Fig. 7—Panel Arrangement of Power Amplifier.

the center point of the potentiometer (R_4), through the biasing resistance to the low side of the secondary winding of the signal input transformer, thence to the negative DC supply lead, through the high voltage secondary winding of the power transformer, to the plate of the rectifier tube, and through the interior of this tube, from plate to filament, and thence to the mid-point of the rectifier filament supply winding.

Bearing in mind the fact that we have just traced the path of the current flow through the plate circuit of the power amplifier tube, you will note that this current flowed through the biasing resistor in such a direction as to make the end nearest the filament positive and the end nearest the grid of the amplifier tube, negative. Thus the amount of bias applied on the grid of the amplifier tube depends upon the value of the resistor (R_3) and the amount of current flowing through this resistor. From a consideration of the foregoing facts, you can see how it is possible to vary the bias on the grid of the amplifier tube by changing the value of the effective resistance cut in the circuit at (R_3).

The output transformer AFT_2 is used to keep the high value of direct current flowing to the plate of the amplifier tube, out of the field coil windings of the loud-speaker. The normal amount of direct current to pass through the field coil windings of the standard loud-speaker is 10 milli-amperes. This applies to the better grade of speakers which use a very fine wire in their field coil construction. It is not advisable to pass more than 10 milli-amperes through the field coil windings of a loud-speaker due to the fact that you are liable either to burn out the delicate windings, or demagnetize the core on which the field coils are wound.

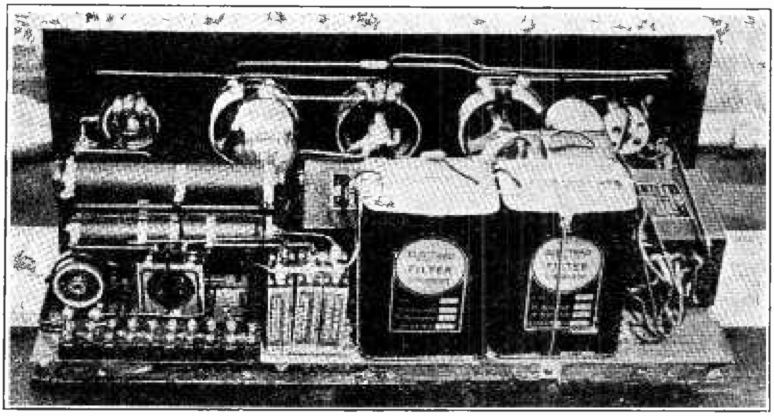

Fig. 8—Rear View of Power Amplifier.

Four resistors (R_6, R_7, R_8 and R_9) are connected in series across the rectifier output to afford "B" potential supply points of the proper value for the tubes in a radio receiver.

Figure 7 is a front view of the "Economical High Power Amplifier," and Figure 8 is a rear view of this unit.

HIGH POWER AMPLIFIER WITH FULL WAVE RECTIFIER SYSTEM

Figure 9 is a schematic diagram of a power amplifier which employs a full-wave rectifier system capable of supplying 500 volts D.C. to the plate of the power amplifier tube. The following is the list of parts and the circuit constants:

(1)—200 watt power transformer.

One 110 volt primary winding.

One 1,500 volt secondary winding with a mid-tap. This high voltage secondary winding has taps which effect 550 volts on either side of the mid-tap, hence a 1,100 volt output.

One 10 volt rectifier filament winding center tapped.

One 10 volt amplifier filament winding center tapped.

AFT_1—Audio-frequency transformer. (2:1.)

AFT_2—Output transformer. (1:1.)

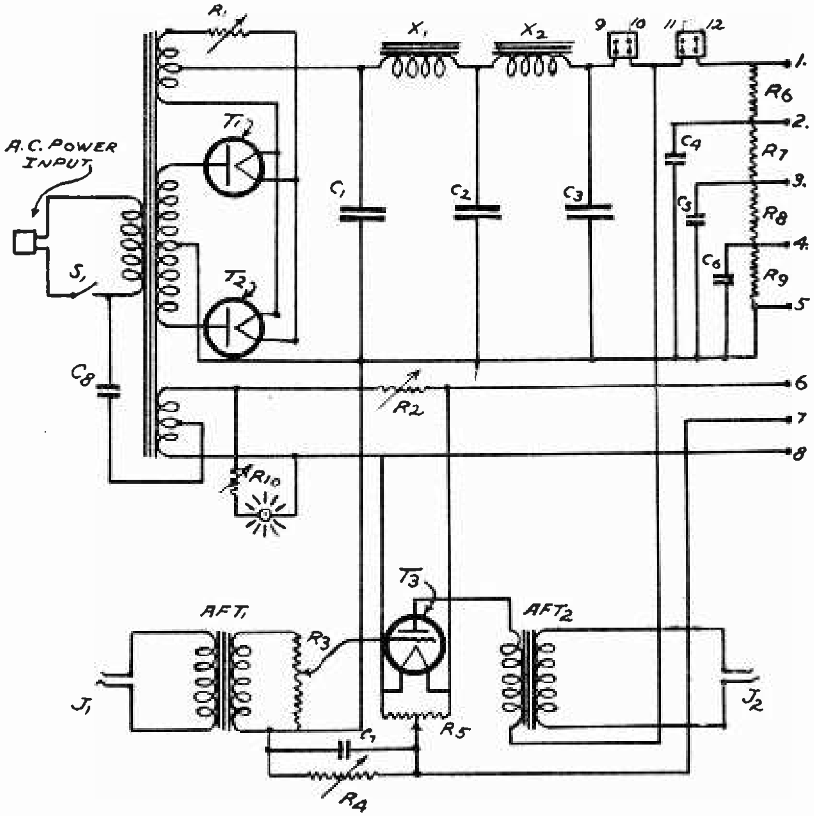

Fig. 9—Power-Amplifier Circuit and B-Eliminator with Full Wave Rectification.

X_1—30 henry choke.

X_2—30 henry choke.

C_1—1,000 volt, 2 mfd. filter condenser.

C_2—1,000 volt, 4 mfd. filter condenser.

C_3—1,000 volt, 6 mfd. filter condenser.

C_4—200 volt, 1 mfd. by-pass condenser.

C_5—200 volt, 1 mfd. by-pass condenser.

C_6—200 volt, 1 mfd. by-pass condenser.
C_7—200 volt, 1 mfd. by-pass condenser.
C_8—200 volt, 1 mfd. by-pass condenser.
R_1—2 ohm rheostat.
R_2—7 ohm rheostat.
R_3—500,000 ohm potentiometer.
R_4—2,000 ohm variable resistance.
R_5—400 ohm potentiometer.
R_6—11,500 ohm resistor.
R_7— 3,500 ohm resistor.
R_8— 1,500 ohm resistor.
R_9— 1,500 ohm resistor.
R_{10}—25 ohm variable resistor.
J_1—Open circuit jack.
J_2—Open circuit jack.
S_1—Filament switch.
3 —UX tube sockets.
T_1—UX-281 Rectifier tube.
T_2—UX-281 Rectifier tube.
T_3—UX-210 Radiotron.
8 —Bakelite binding posts.
—Overall dimensions of cabinet 20″x12″x9½″.

From a consideration of the schematic wiring diagram shown in Figure 9 and the list of circuit constants and parts given above, there is probably not much question in your minds as to the fact that the amplifier in question is a real amplifier.

In this power amplifier unit, two UX-281 rectifier tubes are used for restifying both halves of the A.C. cycle. Each of these tubes is rated at 65 milli-amps. thus it is possible to draw 130 milli-amperes from this rectifier without overloading the tubes used. There are other limiting factors which also have a bearing in the amount of direct current drain allowable from this type of rectifier, such as, filter chokes, whose inductance varies with the amount of current passed through them (the greater the current flow the less the effective inductance of the choke.) In this case, the chokes specified have an inductance of about 30 henries each when passing 40 milli-amperes. If you should attempt to pass a current of the order of 100 milli-amperes through these chokes their effective inductance would go way down, and you would stand a pretty good chance of burning them out.

A little tell-tale lamp is connected across the amplifier filament supply, in series with a variable 25 ohm resistor, and is mounted in the front panel to indicate whether the amplifier is on or off. This is quite a practical idea.

A UX-210 tube is used for a power amplifier tube in this unit and is fed with signal energy through the medium of a low ratio, audio-frequency interstage transformer, AFT_1. The potentiometer method of volume control is used here, and the variable bias resistor is used to control the negative voltage on the amplifier grid. An artificial neutral is effected in the amplifier filament supply by means of the 400 ohm potentiometer R_5. An output transformer AFT_2 is used to keep the high value of direct current out of the loud-speaker field coil windings.

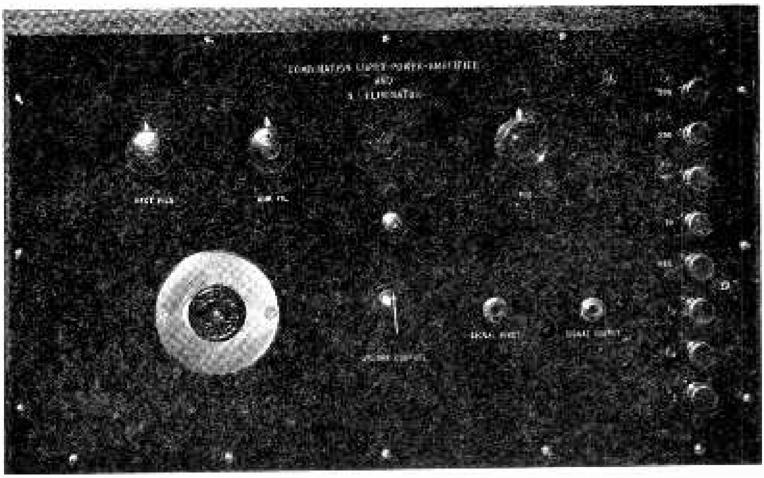

Fig. 10—Panel of Super-Power-Amplifier, Showing the Various Controls and Binding Posts.

Intermediate potentials for plate supply for a radio receiver are effected by means of the four fixed resistors connected across the 500 volt D.C. supply. These resistors allow for output voltages of the order of 135 volts at tap No. 2; 90 volts at tap No. 3; 45 volts at tap No. 4; remembering that we have 500 volts available at tap No. 1. The by-pass condensers (C_4, C_5, C_6) are connected between the different potential output taps to afford audio and radio-frequency by-pass paths in the case where an adjacent receiver is connected to these taps. If the receiver is located at some remote point, necessitating long leads between the potential output taps on the power amplifier unit and the radio set, it is quite obvious that the by-pass condensers must be at the radio receiver in that case. You will note in the diagram of the "Economical High Power Amplifier," Figure 6, no by-pass condensers were included across the output taps, due to the fact that they are superfluous in cases where the radio set is located at a distance from the amplifier, which is often the case. Hence, whether by-pass condensers are to be included in the power amplifier "B"-eliminator unit is strictly a question of installation conditions.

Three leads are also brought out, in this unit, from the extremities of the amplifier filament winding and the artificial

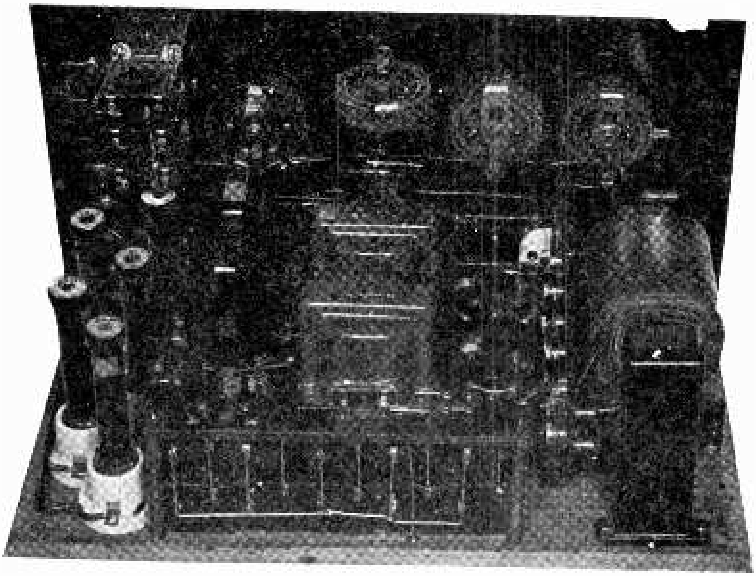

Fig. 11—Rear View of Amplifier.

mid-point, so that they are easily accessible in case it is desirable to feed filament heating energy to some other local unit.

Figure 10 is a front view of the amplifier. Figure 11 is a rear angle view of the amplifier, giving an idea of the arrangement of the component parts.

TWO STAGE AMPLIFIER

Figure 12 is the schematic diagram of a two stage power amplifier circuit which employs UX-171-A in the first stage, and a UX-210 in the second stage, the plates of these two power tubes being fed with direct current at high voltage from a half wave rectifier system, and the filament of the last amplifier tube (the UX-210) being fed with filament heating energy from a low voltage winding on the power transformer of the rectifier system, while the filament of the first stage amplifier tube is connected to a storage battery, or "A"-eliminator source of direct current supply.

The following is a list of parts used in the construction of the amplifier to be described herewith, and the circuit constants:

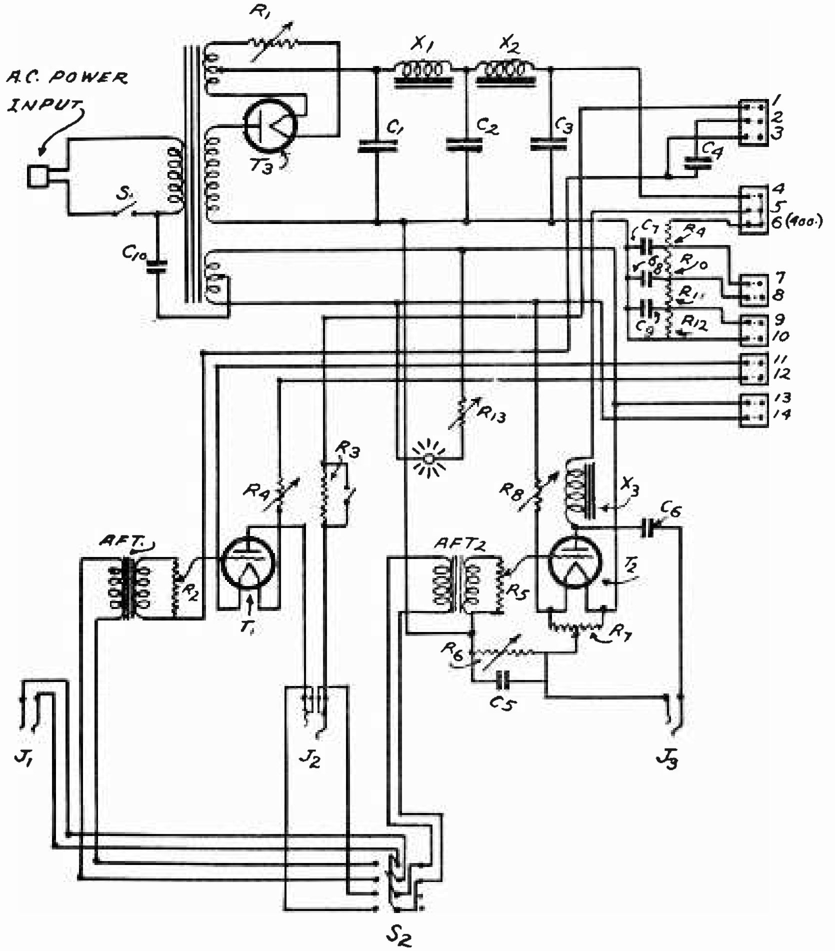

Fig. 12—Circuit Diagram of Two-Stage Power Amplifier and B-Eliminator.
*NOTE— The resistances to the right of condensers C7, C8 and C9 are R9, R10, R11 and R12.

(1)—Power Transformer.
 One 110 volt primary winding.
 One 450 volt secondary winding.
 Two 8 volt secondaries with mid-taps.

X_1—60 henry choke coil.

X_2—60 henry choke coil.

X_3—60 henry choke coil.
AFT_1—First stage transformer.
AFT_2—Second stage transformer.
C_1—2 mfd., 750 volt filter condenser.
C_2—4 mfd., 750 volt filter condenser.
C_3—6 mfd., 750 volt filter condenser.
C_4—1 mfd., 200 volt by-pass condenser.
C_5—1 mfd., 200 volt by-pass condenser.
C_6—2 mfd., 750 volt blocking condenser.
C_7—1 mfd., 200 volt by-pass condenser.
C_8—1 mfd., 200 volt by-pass condenser.
C_9—1 mfd., 200 volt by-pass condenser.
C_{10}—1 mfd., 200 volt grounding condenser.
R_1—7 ohm rheostat.
R_2—500,000 ohm potentiometer.
R_3—10,000 ohm resistor, capacity 20 milliamps.
R_4—7 ohm rheostat.
R_5—500,000 ohm potentiometer.
R_6—2,000 ohm variable resistor.
R_7—400 ohm potentiometer.
R_8—7 ohm rheostat.
R_9—20,000 ohm heavy duty resistor.
R_{10}— 4,500 ohm heavy duty resistor.
R_{11}— 7,500 ohm heavy duty resistor.
R_{12}— 9,000 ohm heavy duty resistor.
R_{13}—25 ohm resistor.
J_1—Open circuit jack.
J_2—Double circuit jack.
J_3—Open circuit jack.
S_1—Filament switch.
S_2—Anti-capacity switch.
T_1—UX-171-A Radiotron.
T_2—UX-210 Radiotron.
T_3—UX-281 Rectron.
(3) —UX tube sockets.
(1) —Power input receptacle.
—Overall dimensions of cabinet, 20″x10″x12″.

In this particular type of amplifier equipment, the audio-frequency signal to be amplified is fed into the circuit at (J_1) by means of an ordinary radio plug. The terminals of (J_1) are connected to two of the poles of a four pole double throw switch, termed an "anti-capacity" switch. The function of this switch is to pass the input energy, either to the primary winding of the interstage transformer AFT_1, in which case the signals pass through two stages of amplification, or to the primary winding of the second interstage transformer AFT_2, in which case the signals only pass through the final amplifier stage.

A biasing resistor (R_6) is used to control the negative potential on the grid of T_2, hence the negative D.C. supply lead is connected to the low side of the secondary winding of AFT_2, rather than directly to the filament circuit of (T_2), which would be the procedure if a "C" battery were used instead of a biasing resistor. It is important that you shunt the biasing resistor with a by-pass condenser such as (C_5), to improve the quality and increase the output volume.

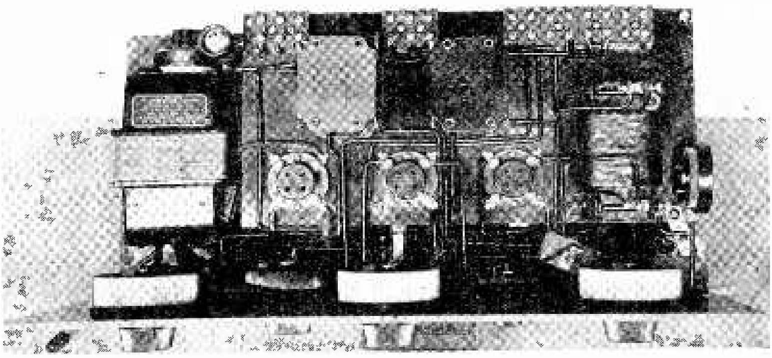

Fig. 13—Top View of Amplifier.

The filament of T_2 is heated from an A.C. source, namely, a low voltage secondary winding on the power transformer in the rectifier circuit. The leads from the secondary winding in question are brought out to terminals No. 13 and No. 14, to provide low voltage A.C. for any other device for which it is required.

Plate voltage is supplied to T_2 through the choke coil (X_3) which passes D.C. but chokes off the signal energy, the latter being by-passed through the condenser (C_6) and the field coil windings of the loud-speaker, by way of the output jack (J_3), to the filament circuit of T_2. The by-pass condenser (C_6) keeps direct current out of the field coil windings and offers very little impedance to the flow of audio-frequency signal current.

The entire design of this unit, as you will perceive, is along the lines of flexibility. Leads are brought out to terminals so that they can be connected in different ways. For instance, the filament of the first stage amplifier tube (T_1) can be connected to storage battery source of supply or it can be connected to a rectified source of supply, or still again, it can be connected to the same winding on the power transformer as the filament of T_2 by connecting terminals No. 11 and No. 12 to terminals No. 13 and No. 14.

A "C" battery or a biasing resistance can be used for biasing the first stage amplifier grid. External "B" batteries can be used on the plate of T_1 or plate current can be drawn from the output circuit of the high voltage rectifier for T_2. In fact, this type of amplifier affords you an opportunity to find out just what you can get away with and just what you can't get away with, at the present time, in the elimination of batteries from your audio-frequency amplifier system, as well as your radio receiver, which is connected ahead of your amplifier.

UX-245 PUSH-PULL AMPLIFIER AND PLATE SUPPLY

A power amplifier built around the Thordarson Power Compact is very easy to assemble since, through use of this compact, there are but few parts required for the complete assembly.

The Thordarson R-245 Power Compact is a specially designed power unit to supply plate, filament and grid voltages for a power amplifier using the 245 type power tubes in push-pull arrangement and also plate supply for the balance of the receiver.

This compact contains a high voltage supply of 350 volts (no load) each side of center and a 5 volt (center tapped) filament supply for a 280 type full-wave rectifier tube.

The 2.5 volt filament winding will supply two 245 type power tubes. It is tapped at the exact electrical center for the grid-return of the power tubes.

Two chokes with an inductance of 30 henries each are included in the compact. Chokes and high voltage winding have a capacity of 100 milliamperes. They are designed for 110 volt, 60 cycle alternating current and should never be used with any other power supply.

The voltage-divider Resistor supplies external voltages of 22½, 45, 90 and 135 volts when used with a receiver of normal drain. If heavier drain receivers are used, these voltages will drop somewhat but not beyond the point of practicable operation.

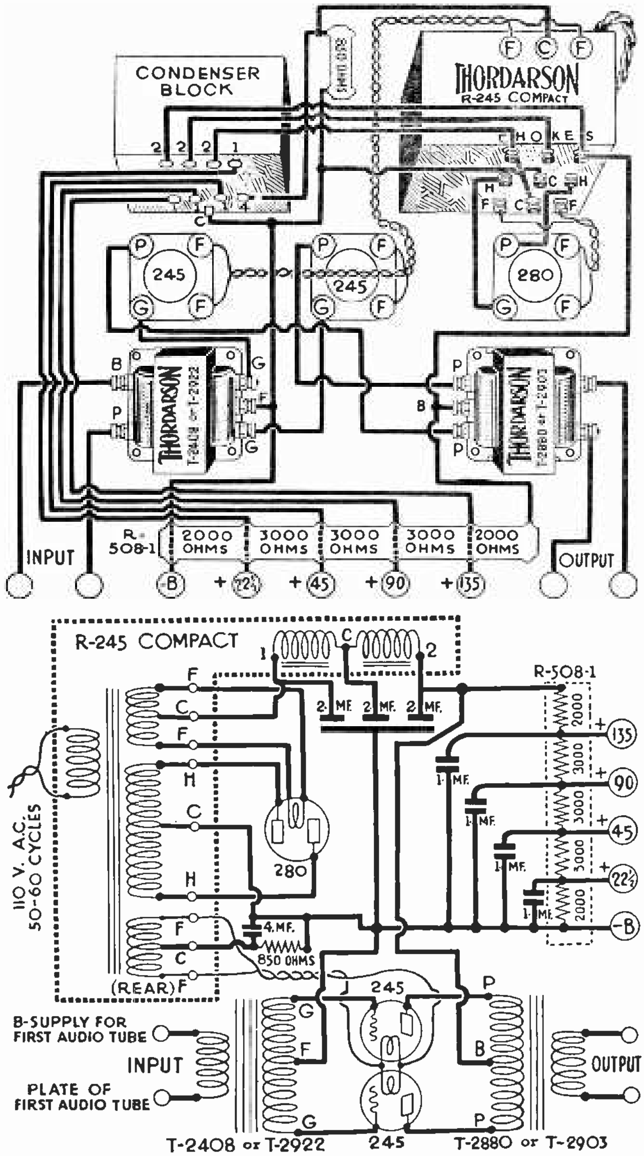

Fig. 14—Circuit Diagram of UX-245 Push-Pull Amplifier.

The voltage-divider also serves as a ballast to steady the voltages delivered to the receiver. It has a relatively low resistance with a high current carrying capacity and, when placed across the output of the filter circuit, serves as a ballast to compensate for variations in receiver current drain. Excellent regulation is thus secured.

In some cases, where comparatively large currents from the 45 volt tap are required, it is necessary to lower the value of the resistance between the 45 and the 90 volt taps. It is impossible to make the change in the divider itself but it may easily be accomplished merely by connecting a 10,000 or 15,000 ohm potentiometer with one side connected to the 45 volt tap, the other side connected to the 90 volt tap, the variable voltage being obtained from the binding post connected to the movable arm which is now the 45 volt tap. This arm is adjusted for desired results. In this case, the variable tap should be by-passed to B- with a 1 mfd. condenser.

In the event that the plate supply for the receiver is not taken from the amplifying unit, it is necessary nevertheless to see that the minus B of the amplifier is connected to the minus B of the receiver.

The plate terminal of the input push-pull transformer should be connected to the plate of the first audio-frequency tube, the second audio tube being removed when using this amplifier. The B terminal is connected to either the 90 volt terminal or the 135 volt terminal of the voltage-divider depending on which voltage is desired on the plate of the first audio tube.

Thordarson type T-2880 is used as an output transformer for a high impedance speaker (horn or cone.) If a dynamic speaker be used, the output transformer included with it should be changed for the Thordarson type T-2903 speaker coupling transformer. When this transformer is used, the output transformer in the dynamic speaker should be disconnected and the movable coil of the speaker connected directly to the output or secondary terminals of the T-2903. If high frequency cut-off is desired, two small fixed condensers, about .02 mfd. should be used across the plate winding or primary of the T-2903 transformer.

A condenser should be connected from each outer or plate terminal to the center or plus B terminal.

Because of the limited output of the rectifier tube, there is no provision for supplying the field of the dynamic speaker from the amplifier. The dynamic, if used, should either have a six volt field or a field operating direct from alternating current.

This assembly with the first audio tube in the set makes an excellent phonograph amplifier when used with a good electrical pick up. The pick up should be connected either by using the plug which is furnished with the pick up and plugging into the detector socket or by connecting across the primary of the first audio transformer with a single throw double pole switch. If an electric motor operates the turntable, the case of the motor should be grounded.

The following is a list of parts used for UX-245 Push-Pull Amplifier and Plate Supply.

1 Thordarson R-245 Compact.
1 Thordarson T-2922 Push-Pull Input Transformer.
1 Thordarson T-2880 Push-Pull Output Transformer (for High Impedance Speakers), or T-2903 Push-Pull Transformer (for Dynamic Speakers.)
1 Thordarson R-508-1 Resistance Unit (or Electrad type IT.)
1 R-245 Condenser Block (Dubilier PL 1429, Potter, Tobe, Acme, Aerovox.)
1 Fixed Resistance 850 ohms (Electrad type B 8.5, Ward-Leonard.)
3 UX Sockets
9 Binding Posts (2-Input, B-, +22, +45, +90, +135, 2-Output or Speaker.)
1 Pc. Bakelite 3"x11"x3/16".
1 Wood Baseboard 1"x11"x14".
Hardware, Solder, Wire.

Tubes Required:
2 UX-245 or CX-345 Amplifier Tubes.
1 UX-280 or CX-380 Rectifying Tube.

TWO STAGE AC AMPLIFIER WITH *UX-210 OR UX-250 TUBES IN PUSH-PULL

Figure 15 shows the schematic diagram of a two stage A.C. amplifier and power supply with UX-210 or UX-250 tubes push-pull in power stage for 110 volts 60 cycles A.C. The plates

Note: All AC filament leads must be twisted in with return and kept clear from plate and grid leads, otherwise excessive hum will result.

*This layout applies equally well for two UX-210 tubes push-pull if Hvs is reduced to 1,100 volts. Chokes may be reduced to 100 mills.

of the tubes are fed with direct current at high voltage from two UX-281 tubes full-wave rectifier system.

The following is a list of parts used in the construction of this power amplifier.

PT Power Transformer.
Pri Primary 110 volts, 60 cycles.
Hvs High voltage secondary 1,200 to 1,300 volts, 150 to 250 mills with center tap.
FS-1 Secondary 7.5 volts for two 250 tube filaments with center tap.
FS-2 Secondary 2.4 volts for 227 tube filament with center tap.
FS-3 Secondary 7.5 volts for two 281 tube filament with center tap.
X-1 Choke coil 30 henrys 150-200 mills.
X-2 Choke coil 30 henrys 150-200 mills.
C-1 Condenser, 2mf., 1,000 to 1,500 volts according to safety factor desired.
C-2 Condenser, 4 mf., 600 to 1,000 volts according to safety factor desired.
R Rectifier tubes two UX-281.
RV-1 Resistor, wire wound, 60,000 to 70,000 ohms, 25 mills with adjustable tap.
RV-2 Resistor, wire wound, 40,000 to 50,000 ohms, 50 mills with adjustable taps used only when desired for B & C supply for radio set (preferable to use separate supply for set.)
R-1 Resistor, 1,000 ohms, 200 mills.
R-2 Resistor, 10,000 ohms.
R-3 Resistor, 20,000 ohms.
R-4 Resistor, 2,000 ohms, 20 mills.
R-5 Resistor, 10,000 ohms.
R-6 Resistor, 250,000 ohms required only for AF-3c and AF-5c
R-7 Resistor, 250,000 ohms required only for AF-3c and AF-5c
R-8 Resistor, 20,000 ohms.
C-3 Condenser, 2 mf., 200 volts.
C-4 Condenser, 2 mf., 200 volts.
C-5 Condenser, 2 mf., 200 volts.
C-6 Condenser, 4 mf., 200 volts.

T-1 Audio transformer, AF-3, AF-4 or AF-5, from instructions.

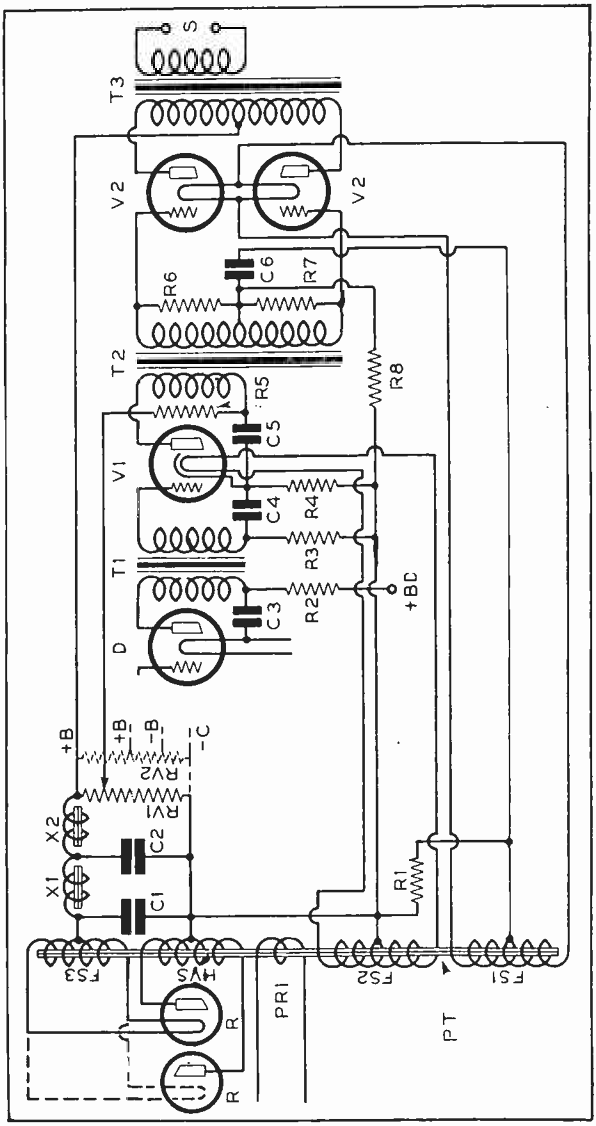

Fig. 15—Circuit Diagram of Two-Stage A. C. Amplifier and Power Supply With 210, 250 or 245 Tubes Push-Pull in Power Stage of 110 Volts, 60 Cycles A. C. (Courtesy Ferranti. Inc.)

T-2 Audio transformer, AF-3c, AF-4c, or AF-5c from instructions.

T-3 Output transformer, OP-8c for magnetic speakers, OP-4c or OP-4cc for dynamic speakers.
V-1 Tube UY-227.
V-2 Tube UX-250.

TWO STAGE AC AMPLIFIER WITH UX-245 TUBES IN PUSH-PULL

The same circuit arrangement can be used in building a two stage AC amplifier and power supply with UX-245 tubes push-pull in power stage for 110 volts, 60 cycles AC, as shown in Figure 15, except some of the apparatus must be changed. The following is a list of parts used in the construction of this amplifier:

PT Power Transformer.
Pri Primary 110 volts, 60 cycles.
Hvs High voltage secondary 750 volts 100-150 mills with center tap.
FS-1 Secondary 2.5 volts for UX-245 tube filament with center tap.
FS-2 Secondary 2.4 volts for UY-227 tube filament with center tap.
FS-3 Secondary 5 volts for UX-280 tube filament with center tap.
X-1 Choke coil 30 henrys 100-150 mills.
X-2 Choke coil 30 henrys 100-150 mills.
C-1 Condenser, 2 mf., 600 volts.
C-2 Condenser, 4 mf., 400 volts.
R Rectifier tube UX-280.
RV-1 Resistor, wire wound 30,000 to 35,000 ohms with adjustable tap.
RV-2 Resistor, wire wound 15,000 to 20,000 ohms with adjustable taps used only when desired for B and C supply for radio set (preferable to use separate supply for set.)
R-1 Resistor, 700 ohms, 100 mills.
V-1 Tube UY-227.
V-2 Tube UX-245.

All other components same as for UX-250 push-pull.

It is always preferable to build a power amplifier on a metal base which insures grounding all components. If a base of insulating material is used, all component cases, frames.

or cores should be connected to a common lead and joined to B negative. The negative must be connected to a good ground. Use gas pipe or water pipe where possible.

When amplifiers are built in accordance with diagram, Figure 15, if motor-boating or oscillations occur, a condenser of 4 mf. capacity should be connected across RV-1. It is desirable to add a 4 mf. condenser connected between the detector plus B tap at the resistor and the negative B if the power supply is designed to also supply B and C for a Radio set.

The various power amplifier units described in this text include some of the most modern and most efficient types of power equipment. It seems difficult to imagine a very great improvement over the equipment described in this text, but probably in the course of a few years we will have many modifications to consider.

TEST QUESTIONS

Number Your Answers 42 and add your **Student Number**

1. What is the chief reason for the poor quality of signals heard from many receiving sets?
2. Name 3 tubes that can be used as power amplifying tubes in a receiving set.
3. What is the disadvantage in using transformers for coupling the tubes in an amplifier?
4. Is it possible to cause distortion in a resistance coupled amplifier? If so, what is the cause?
5. Why is it best to use an output filter, or transformer, in the plate circuit of a power tube?
6. Draw a diagram of a high power amplifier, using a UX-210 tube, and show the method of obtaining the correct plate voltage for the receiver.
7. In figure 6 how is the power obtained for lighting the filament of the UX-210 tube?
8. What is the purpose of the variable resistance R_3 in Fig. 6?
9. What is the purpose of the resistors R_9, R_{10}, R_{11} and R_{12}, Figure 12?
10. Why is the condenser C_6, Figure 12 used?

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