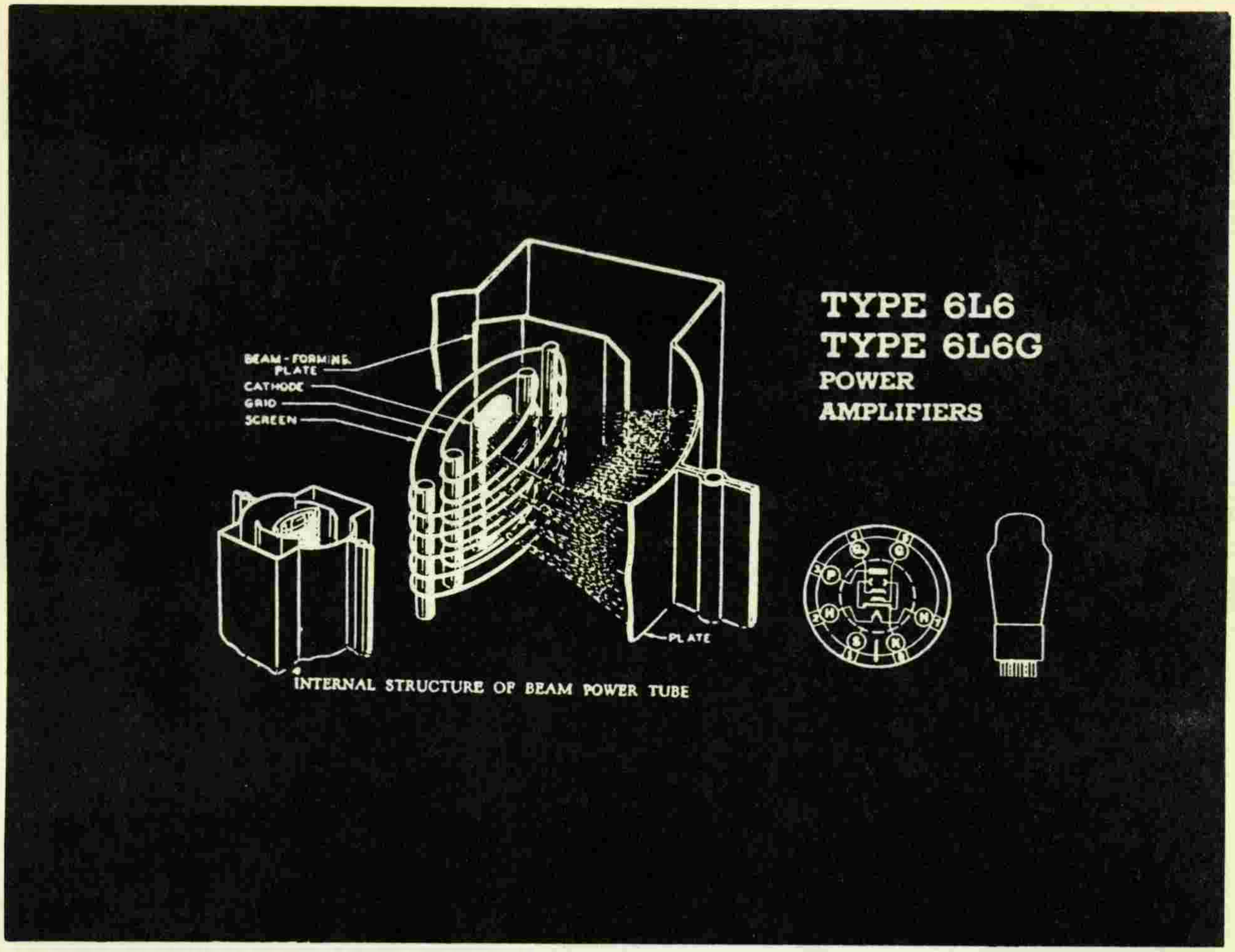


LESSON 32 R

POWER AMPLIFICATION

RADIO-TELEVISION TRAINING SCHOOL, INC. · LOS ANGELES · ESTABLISHED 1922

RADIO-TELEVISION TRAINING SCHOOL, INC.

5100 SOUTH VERMONT AVENUE • LOS ANGELES 37, CALIFORNIA, U. S. A.

POWER AMPLIFICATION

THE NEED OF POWER AMPLIFICATION. The operation of a loud speaker differs from that of the grid circuit of an amplifier tube in that the grid is purely a voltage operated device with no current drain, while actual power is required to operate a loud speaker. This electric power consumed by a speaker is converted into sound energy, and is radiated outward into space as voice or music.

Since these power requirements of a speaker are large compared to the power ordinarily expended in a radio circuit, and since this power must be supplied by the last audio stage, conditions here are quite different from those in any preceding stage. In other words, the tube or tubes in the last audio stage must be capable of supplying to the output circuit amounts of electric power proportional to the volume of sound desired. In ordsr that the proper tone quality will be maintained, the tubes must be able to furnish this power output without overloading and without distorting the signal voltages.

To meet these requirements, it is necessary to precede a speaker with a power amplifier. Ordinarily an amplifier stage serves purely to step up the signal voltage so that the grid of the next tube can be actuated more intensely, but in a stage of power amplification the aim is to release or render available the larger quantities of electric power required by the speaker or reproducer system. Also, such a power amplifier stage must generally be preceded by one or several stages of voltage amplification to build up the signal strength to the point where it can effectively swing the output power stage. The greater the power rating of the amplifier, the more preliminary voltage amplification is usually needed. It is also evident that for such purposes special power tubes must be used, as the ordinary amplifier tubes would be useless on account of their small power output. Power amplification can accordingly be defined as the process of imparting to the signal impulses as they pass through special tubes and circuit arrangements, sufficient electric power to enable them to operate the attached sound reproducing units with the desired output.

POWER TUBES AND POWER OUTPUT

It was explained in a preceding paragraph that it is the electric energy supplied by the last audio stage that is converted into sound energy by the speaker. It was also stated that the tubes in this last audio stage must be capable of handling this greater bulk of power without overloading. A review of the operating characteristics of the tubes suitable for use in such output power amplifiers is, therefore, well worth while at this time.

Every amplifier tube has a definite operating range on its grid voltage-plate current characteristic over which the curve is a straight line, that is, over which the amplifying action is linear. In other words, through this range changes in grid voltage always produce proportional changes in plate current flow. As long as the applied grid voltages do not extend outside of this linear range, no appreciable distortion results. But if the grid voltages extend beyond this range, unsymmetrical variations will occur in the plate current fluctuations, and distortion will result. This, it will be remembered, is commonly referred to as overloading, for the tubes are loaded with greater grid swings than they can safely carry.

It was to prevent such distortion due to overloading that the so-called power tubes were developed. These power tubes possess the important feature of being able to carry a wide grid swing before operation extends beyond the straight portion of the curve. When used in an amplifier, these power tubes are biased negatively by such an amount that the normal operating point falls midway on the straight portion of the curve between the lower bend and the zero bias axis, and consequently the maximum permissible grid swing is equal to the negative grid bias. In other words, in Table 1 the 71A tube is normally biased 40.5 volts negative, and, therefore, grid voltages up to this value could be applied to the tube before operation would extend beyond the straight portion of the curve and distortion set in. The 45 tube could carry a 50-volt grid swing, and the type 6A3 tube a 60-volt grid swing.

TABLE 1. SOME FAMILIAR POWER TUBES

Type Tube	Fil. Volts	Plate Volts	Grid Volts	Plate Mill's	Plate Resist.	Mut. Cond.	Amp. Factor.	Load Ohms	Power Output
31	2.0	135	22.5	6	4950	760	3.8	9000	150
71A	5.0	180	40.5	20	1850	1620	3.0	5350	700
45	2.5	250	50.0	34	1750	2000	3.5	3900	1600
6A3	6.3	250	45	60	800	5250	4.2	2500	3200

In the last column of the table is given the amount of power that these tubes can deliver to the output circuit. This power is given in milliwatts, a milliwatt being equal to one-thousandth of a watt. One watt equals 1000 milliwatts. This greater output capacity of power tubes is due to the use of larger elements in the tubes as well as to closer spacing of these elements. It can further be seen from the table that as the power output increases, the plate current drain of the tube is also more. This in itself calls for the use of larger elements with their greater heat radiating surface. Also, the closer spacing of the elements reduces the available amplification within the tube, and power tubes all have a low amplification factor.

LOAD RESISTANCE OF A TUBE

The load on a tube is defined as the amount of resistance or impedance that is connected into its external plate circuit. This load may be in the form of a speaker winding, the primary of a coupling transformer, a coupling resistor, etc., and it is across this load that the signal output of the tube is built up.

Now it can be proven mathematically, although a little too complex to be taken up here, that for a given signal input the greatest output will be obtained from the tube when the external load impedance is equal to the internal plate resistance. In other words, maximum transference will take place under these conditions. But it is not alone the actual power transference that is important, for the amount of signal distortion attending the process is also a vital factor. If it is assumed that up to 5 per cent distortion may be present in a signal train without its being detected by the average human ear, then it can be further proven experimentally that maximum undistorted power output is obtainable from a triode power tube for any given signal input voltage, if the external load impedance is equal to approximately twice the internal plate impedance.

The power actually built up or expended in the external load impedance, of course, must be supplied by the B + voltage section of the power supply unit, for the tube in itself is not a generator of power but rather only a control relay that regulates the amount of power that is to be released from the power unit.

If Table 1 is again reviewed at this time, it will be seen that in most cases the recommended load impedance as given in the ninth column is approximately equal to twice the internal plate resistance as given in the sixth column. The ratio is not exactly 2 to 1 in each case, but nearly so, for some of the other elements of the tubes also have a determining or influencing effect. But in any case, the applied grid voltage must not exceed the grid bias on the tube, for otherwise the operating point will travel beyond the straight portion of the curve. In selecting a power tube for any given purpose, not only must the power output be considered, but also the signal input voltage that will be impressed on the grid of the tube.

MATCHING THE LOAD TO A TUBE

Another problem encountered in the use of output power tubes is matching the speaker load to the plate circuit of the tube in use. The speaker winding or voice coil is generally in the form of a coil of wire and comprises an inductive load in the plate circuit of the tube. But since the audio output of the tube contains frequencies ranging from about 50 to 6000 cycles per second, the impedance of the speaker coil varies over wide limits. In such cases it is customary practice to decide upon some intermediate value that seems to represent fair average operating conditions, and then carry this value through the rest of the design calculations.

The greater number of speakers in use today are of the electro-dynamic type, with movable voice coils that range in impedance from 1 or 2 ohms up to about 12 or 15 ohms. It is at once evident that such a speaker could not be worked directly out of a power tube and a satisfactory transference of power expected. However, the problem can readily be solved with the aid of a so-called impedance matching transformer, commonly referred to merely as an output transformer. Such a transformer has a primary winding of sufficient turns to make up an impedance equal to about twice the A.C. plate resistance of the power tube with which it is to be used. This assures maximum undistorted power output from the tube to the transformer primary. By electromagnetic induction this power is then transferred to the secondary of the transformer, and this secondary in turn is designed so that its impedance approximates that of the voice coil of the speaker with which it is to be used. The important feature of the transformer design then is the relative number of turns in the primary and secondary windings, and this is commonly referred to as the turns ratio.

It can be proven mathematically that this turns ratio is equal to the square root of the ratio of the secondary to the primary impedances, or expressed in formula form:

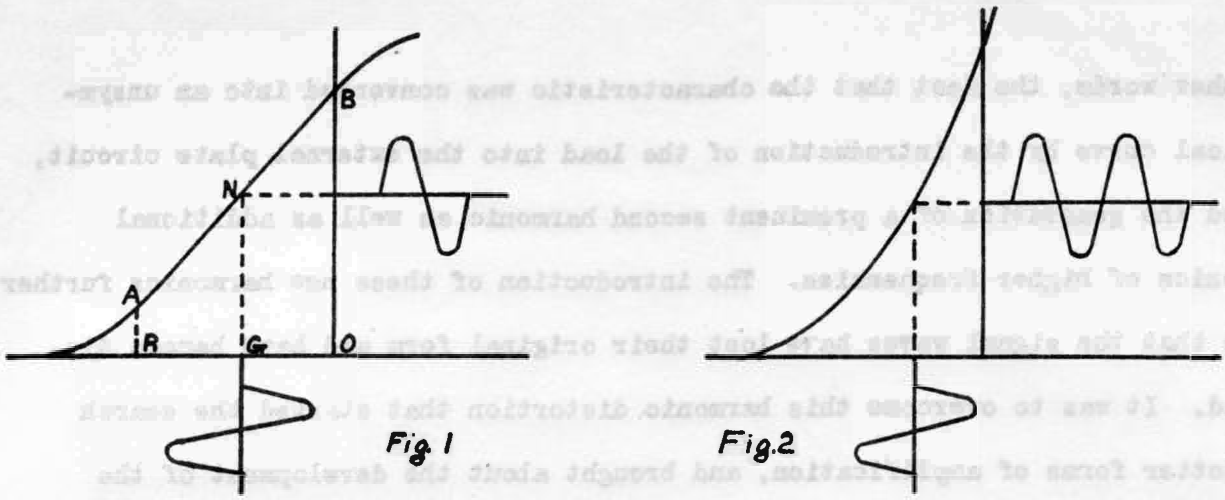
$$\text{Turns Ratio} = \frac{Ns}{Np} = \sqrt{\frac{Rs}{Rp}}$$

To illustrate the use of this formula, let it be assumed that a speaker having an 8-Ohm voice coil is to be operated from a single type 45 power tube. According to Table 1 the recommended load impedance should be 3900 ohms. In other words, "Rs" has a value of 8 and "Rp" a value of 3900, and the ratio of "Rs" and "Rp" is equal to 8 divided by 3900 or .00205. The turns ratio is then equal to the square root of .00205, which is equal to .045. Properly interpreted, these statements mean that the load matching transformer would have to use a primary built up with enough turns of wire to produce an impedance of 3900 ohms, the recommended load impedance. The number of turns used in the primary is then multiplied by .045, and the result is the number of turns that must be used in the secondary. The transformer is then used as an ordinary output transformer, with the primary connected into the plate circuit of the output power tube and the secondary connected to the voice coil of the speaker.

HARMONIC DISTORTION

The action of a vacuum tube as a distortionless amplifier depends upon the principle that changes in grid potential bring about proportionate changes in plate current flow. The action was described as a linear one, that is, any changes in grid potential are always accompanied by proportional or equivalent fluctuations in plate current flow.

In other words, the grid voltage-plate current curve of a tube was represented as being a straight line over a certain portion, with the grid bias set at such a value that the normal operating point fell at the middle of this straight line section as is illustrated in Fig. 1. As the grid potential then swung above and below this midpoint, uniform pulsations were set up in the plate current. As long as the grid swings did not extend beyond this straight portion, the action was linear and no deformation of the current waves (distortion) occurred.



In actual practice, however, such ideal conditions do not exist, for as soon as a load is placed upon the tube, that is a resistance or impedance is connected into the external plate circuit, the grid voltage-plate current characteristic becomes unsymmetrical, and the straight portion referred to previously becomes slightly curved. The shape of the curve turns out to be such that no matter where the operating point is placed, the portion of the curve above it is steeper than the portion below it. Consequently the positive fluctuations or loops in the plate current changes will be higher and more peaked than the negative portions. That is, the plate current waves will have higher and more peaked positive loops and flatter and lower negative loops. This situation is illustrated in Fig. 2.

According to one of the higher branches of mathematics known as Harmonic Analysis, it can be proven that such an unsymmetrical wave form as illustrated to the right in Fig. 2, is in reality a combination of a fundamental wave and several additional waves of double, triple or higher frequency. These waves of higher frequencies are known as harmonics, and it happens that of these harmonics the second (the one having double the fundamental frequency) is the most prominent.

In other words, the fact that the characteristic was converted into an unsymmetrical curve by the introduction of the load into the external plate circuit, caused the generation of a prominent second harmonic as well as additional harmonics of higher frequencies. The introduction of these new harmonics further means that the signal waves have lost their original form and have become distorted. It was to overcome this harmonic distortion that started the search for better forms of amplification, and brought about the development of the push-pull amplifier.

THE PUSH-PULL AMPLIFIER

The push-pull system is a form of audio frequency amplification designed for use in the output stage of a radio receiver, to supply energy to a loud speaker or reproducer unit. It was developed for two primary reasons, one being to render available a greater volume of power output from the power tubes and the other to eliminate the harmonic distortion resulting from the curvature of the grid-voltage plate current characteristic of the tubes.

These two effects really go hand in hand, for with part of the harmonic distortion eliminated, it is possible to use a somewhat lower load impedance and thus approach more nearly the plate resistance of the tube where maximum output is obtained. It will be remembered that this maximum output is obtainable when the plate impedance and external load impedance are equal, but that maximum undistorted output is obtained only when the load impedance is approximately twice the plate resistance. With the distortion wiped away, the load impedance can be lowered and the output increased to more nearly the maximum output of the tube. This also means that smaller power tubes can be utilized to provide a given output; and smaller power tubes require lower "B" voltages and thus afford greater economies in the B-power supply unit. The economies of the system are, therefore, readily evident. In addition to these important features, the push-pull amplifier offers a number of additional advantages as will be pointed out in the following paragraphs.

The fundamental circuit of the push-pull amplifier is illustrated at "A" in Fig. 3, while at "B" is given the same circuit adapted for A.C. operation.

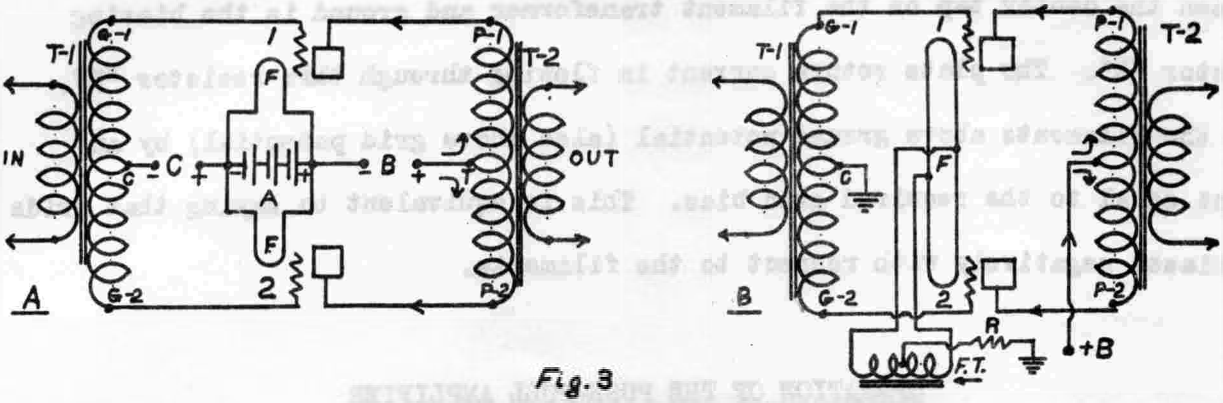


Fig. 3

As is illustrated, two tubes (1) and (2) of similar characteristics are used, with their filaments connected in parallel and their grids connected to the outer terminals of the secondary winding of a special input transformer T-1. This secondary winding also has a tap "C" brought out at its electrical center to which is connected the negative "C" or grid bias voltage. The transformer also has a primary or input winding which is connected into the plate circuit of the previous tube. The plates of the tubes are connected to the outer terminals of the primary winding of the output transformer T-2. This primary winding also has a center tap "T" to which is connected the plate "B" supply line. The secondary of the output transformer generally feeds directly into the voice coil of the loud speaker or reproducer. T-2 is really an impedance or load matching transformer, with the primary designed to fulfill the load requirements of the two tubes and the turns ratio and secondary designed to match the impedance of the loud speaker winding to which the amplifier is connected.

The A.C., circuit illustrated at "B" is very similar, except that the filaments are supplied with current from the secondary of a suitable filament transformer F.T. The center tap on the secondary of the input transformer T-1 is grounded, which, of course, puts the two grids also normally at ground potential. Between the center tap on the filament transformer and ground is the biasing resistor "R". The plate return current in flowing through this resistor "R", puts the filaments above ground potential (also above grid potential) by an amount equal to the required grid bias. This is equivalent to saying that grids are biased negatively with respect to the filaments.

OPERATION OF THE PUSH-PULL AMPLIFIER

Basically the action of the push-pull amplifier is such that the incoming signal swings the grid of one tube positive and that of the other tube negative, and in this manner sets up a plate current flow in each tube the magnetic effect of which is to produce a signal output as though the two tubes were acting in series. As long as no signal impulses are sent into the amplifier, the C-battery impresses a negative potential or bias on the grid of each tube. In the case of the A.C. circuit this bias is obtained from the "IR" drop in the biasing resistor "R". This bias when properly chosen, places the normal operating points of the tubes approximately midway on the straight portion of the characteristic curve.

At the same time the B-supply unit sends the normal plate current to each tube. This current enters the primary of the output transformer at the center tap and then divides, part flows through the upper half of the winding to the plate of tube (1) and the other part through the lower half to the plate of tube (2). If the two tubes are similar in their characteristics (as they should be), the two plate currents will be equal; and since they flow in opposite directions through the primary winding, they will produce equal and opposite magnetizing effects on the transformer core. In other words, the magnetizing effects neutralize each other, and no magnetization or magnetic flux is set up in the transformer core by the normal D.C. components of the plate currents.

Since no magnetic flux, or at least comparatively little, is set up in the transformer iron by the normal or residual plate currents, the iron core of the output transformer can be made much smaller without any danger of magnetic saturation. This is quite an important factor, especially if it is considered that the plate current of a power tube is in itself fairly large and would saturate an iron core of pretty good size. Here is the third important advantage of the push-pull amplifier, namely, the cost economy effected through the permissible smaller core construction of the output transformer.

When a signal wave train is sent into the amplifier, as when the primary of the input transformer is connected into the plate circuit of the preceding amplifier tube, a corresponding voltage is induced in the secondary winding; and since half of this secondary is connected across the grid input circuit of tube (1) and the other half across the grid input circuit of tube (2), each tube receives only one-half of the total signal voltage present in the secondary winding. In other words, the input signal is divided between the two tubes, which means that two tubes in push-pull can handle twice as great a signal input voltage (twice as great a grid swing) as any one tube alone can. This is a fourth important advantage of the push-pull amplifier.

The signal voltage in the secondary of the input transformer T-1 is alternating in nature, and during one-half of a cycle the upper terminal G-1 is positive and the lower terminal G-2 negative, and during the next half cycle the polarities are reversed. As this alternating voltage is impressed on the grids of the tubes, which are normally biased negatively a prescribed amount, during the first half cycle the grid of tube (1) will become less negative and the grid of tube (2) more negative. This will cause an increase in the plate current of tube (1) and a decrease in plate current of tube (2). This increased plate current of tube (1) through the upper half of the primary winding of the output transformer T-2, causes an increase in the magnetic flux in its direction. At the same time the equal decrease in the plate current of tube (2) through the lower half of the primary winding of T-2 causes an equivalent decrease in magnetizing effect in its direction. Since these two magnetic effects are in opposing directions, the increase in one and equal decrease in the other will each induce a voltage in the same direction in the secondary winding. In other words, the current changes are additive in effect, each current change producing the same result as to inducing a voltage in the secondary. The action is as though the two tubes were in series, for their inductive effects on the secondary are in the same direction.

During the next half cycle conditions reverse and the grid of tube (1) becomes more negative and that of tube (2) less negative. This time the plate current of tube (2) increases through the lower half of the primary winding of the output transformer, while the plate current of tube (1) decreases equally through the upper half. Each current change again has the same effect in inducing a voltage in the secondary winding, and the two tubes are again additive in their effects.

In each case the alternating voltage induced in the secondary of the output transformer by the two tubes is twice as great as that which one tube alone could produce, so that the effects are always additive and the two tubes have a series or tandem action. Due to the grid voltage variations, first the plate current of one tube increases and that of the other decreases, and the next instant the action reverses - therefore we use the term, push-pull, one tube pushing, the other pulling. In the same manner it can be reasoned that the internal plate resistance of the two tubes are in series.

HARMONIC DISTORTION ELIMINATED IN THE PUSH-PULL AMPLIFIER

In a previous paragraph it was explained how an impedance load connected into the external plate circuit of a tube causes the grid voltage-plate current characteristic to deviate from a straight line and assume the form of an unsymmetrical curve, and how this curved characteristic brings about a non-linear amplifying action in the tube. The fluctuations in plate current flow are then not uniform or symmetrical, and are not all proportional to the applied grid voltages. The upper or positive current loops are high and peaked while the lower or negative loops are more shallow and flat. These wave deformations are due to the introduction of harmonics, most prominent of which is the second harmonic. In other words, the signal current wave consists of the original fundamental with a second harmonic superimposed upon it. The meaning of harmonic is an overtone. When we speak of the second harmonic it simply means that the second harmonic is twice the fundamental frequency, the fundamental frequency being the original frequency tuned in. For instance, if we were to say that we were tuning in a 90-kilocycle note, which would be the fundamental, the second harmonic of this fundamental would be 180.

In a push-pull amplifier the plate current of one tube passes through a positive alternation while that of the other tube passes through a negative alternation, and at the same time the two currents are additive in their inductive effect on the secondary of the output transformer. With one current wave peaked and the other flattened, and the two current waves additive in their effect, it is readily evident that the peakedness of one will be counterbalanced by the shallowness of the other and the distorting elements or harmonics will be balanced out. The combined inductive effect on the output transformer secondary will be a higher voltage wave resembling the original fundamental and free of the second harmonic ripple.

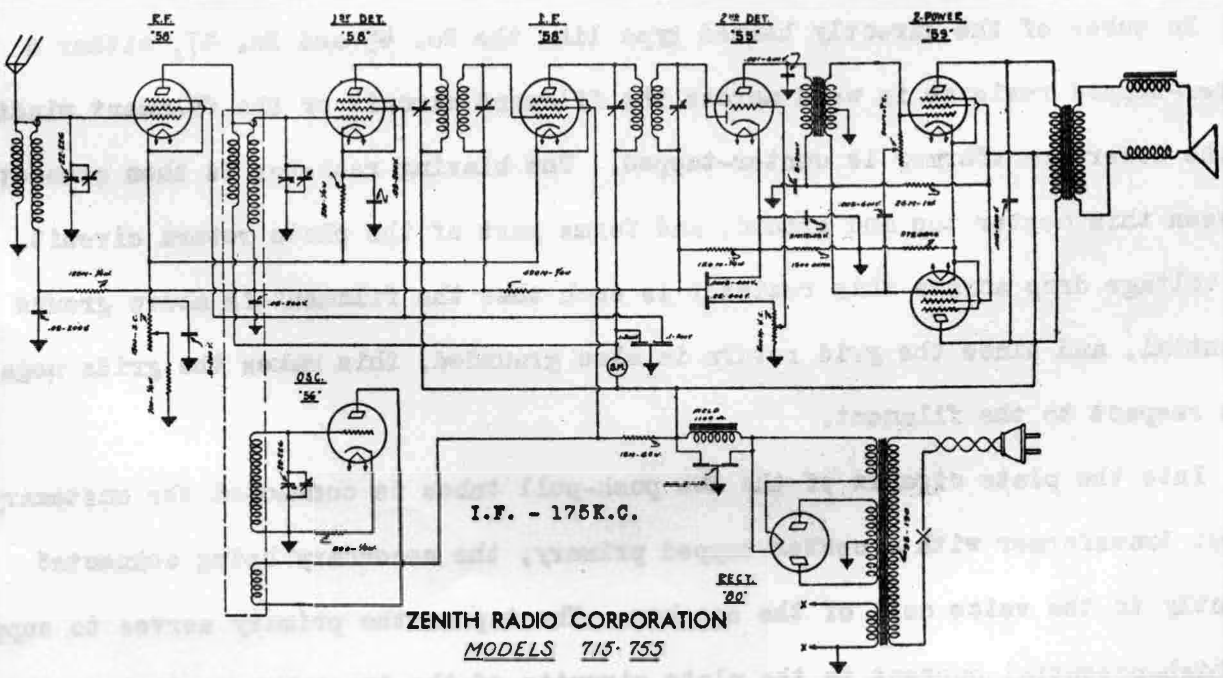
In other words, having the plate currents of the two tubes vary oppositely to each other, causes the distortion component of one to be neutralized by the distortion component of the other, with the net result that the final output is a more faithful reproduction of the original. In a push-pull amplifier even though the tubes in themselves introduce harmonic distortion, the circuit arrangement is such that these distortion components of the signals balance or neutralize each other, and the net output is an amplified reproduction of the signal impulses that were initially impressed on the grids of the tubes. An important point, however, is that the action of the push-pull amplifier will not eliminate any harmonic distortion that may already be present in the input signal, for that will pass through the amplifier unaltered. The push-pull circuit will balance out only that second harmonic distortion which originates within the amplifier tubes themselves.

GREATER STABILITY IN THE PUSH-PULL AMPLIFIER

Further consideration of the actions within the output transformer will reveal several additional important features regarding the push-pull amplifier. It was explained previously that as the plate current of one tube is increasing, that of the other is decreasing, and the sum of the two is constant or nearly so. The result is there is no audio signal current flowing through the B-power supply line and into the center tap of the output transformer primary. This prevents any stray audio coupling in the components of the B-power supply, and also avoids troublesome feed-back between the power output stage and any previous stages. The possibilities of motorboating are also greatly reduced. The net result of all this is greater operating stability.

A complete filtering system is not necessary in the plate supply for a push-pull stage, for any ripples that may be present in the plate current will automatically cancel out in the primary of the output transformer. That is why in most circuits the B-supply for a push-pull stage is generally tapped off between the first and second filter chokes, whereas the plate supply for the rest of the tubes requires additional filtering. This means that the push-pull amplifier is much freer from hum than a single tube or parallel tube arrangement would be. Similarly, if there is a ripple in the grid bias voltage or in the filament supply, the effects will be wiped out due to the balancing of the resulting plate current variations in the transformer primary. Also, since no appreciable audio component of the plate current flows through the grid biasing resistor, this resistor need not be shunted by a large by-pass condenser such as is needed with a single output power tube. This represents a further appreciable saving.

ZENITH MODELS 715 AND 755



ZENITH RADIO CORPORATION
MODELS 715-755

The Zenith Models 715 and 755 are 8-tube superheterodyne receivers that employ a typical push-pull output stage equipped with type 59 power amplifier tubes. The tuner and oscillator systems are explained in another lesson, at present we are interested primarily in the audio amplifier.

In the second detector stage a type 55 tube is used, the triode section of which is operated as a first audio amplifier. This is coupled through a standard push-pull input transformer to a pair of No. 59 tubes in which the suppressor (grid No. 3) is externally tied to the cathode, so that the tubes function as power pentodes. The center-tap on the secondary of the push-pull input transformer is the grid return for the two push-pull tubes and is grounded to chassis. The cathodes of the two tubes are also grounded to chassis, but through a 375-ohm resistor, and the drop across this resistor thus places the cathodes at a positive potential with respect to the chassis, and with respect to the grids. In other words, the grids are biased negatively.

In tubes of the directly heated type like the No. 45 and No. 47, either a center-tapped resistor is used across the filament circuit or the filament winding on the power transformer is center-tapped. The biasing resistor is then connected between this center tap and ground, and forms part of the plate return circuit. The voltage drop across this resistor is such that the filament is above ground potential, and since the grid return is also grounded, this makes the grids negative with respect to the filament.

Into the plate circuit of the two push-pull tubes is connected the customary output transformer with a center-tapped primary, the secondary being connected directly to the voice coil of the speaker. The tap on the primary serves to supply the high-potential current to the plate circuits of the two tubes, and since the currents through the two halves of the winding have opposite magnetizing effects on the iron core, the net magnetizing effect is nil. That is why the output transformer can be smaller in size,—for as was previously explained, there is no magnetic saturation of the iron core due to the normal plate current flow.

The output transformer must always be designed so that the impedance of the primary winding meets the requirements of the plate impedance of the tubes with which it is to be used. Also, the secondary winding must match the impedance of the voice coil in the speaker. When purchasing or ordering an output transformer, it is always necessary to specify the type of tube with which it is to be used, and whether a single tube is used or a pair of the tubes in push-pull. The impedance of the speaker voice coil must also be given. If this is not known, it can be obtained from the speaker manufacturer, or in case of a commercial set the data is usually given in the service bulletin issued by the maker of the set. When a defective output transformer is to be replaced in a receiver, it is always advisable to use an exact duplicate, preferably one offered by the maker of the set, so that optimum performance is obtained.

RESISTANCE-COUPLED PUSH-PULL

It is also possible to operate two power tubes in a push-pull stage and use resistance coupling in place of the usual input transformer with a center-tapped secondary. However, with resistance coupling it is necessary to provide some means of shifting the phase of the signal voltage so that the input to the grid of one tube is 180 degrees out of phase with the signal input to the other tube. That is, when the signal voltage input to a push-pull stage swings the grid of one of the tubes in the positive direction, it must also swing the grid of the other tube in the negative direction by an equal amount. When a coupling transformer is used, these phase relations are inherently established by the center-tapped secondary winding, for while one terminal of the secondary is positive with respect to the center tap, the other is equally negative.

In a resistance-coupled push-pull stage this signal phase displacement is usually obtained through the use of an additional tube known as a "phase inverter." The circuit is arranged so that while the signal voltage from the preceding audio stage is fed directly to the grid of one of the push-pull tubes, part of it is also supplied to the grid of the phase inverter, and the output of this inverter tube is then impressed on the grid of the other push-pull tube. Since the signal undergoes a phase reversal as it passes through the inverter, the signals supplied to the grids of the two push-pull tubes are 180 degrees out of phase, and the necessary conditions prevail for proper push-pull operation.

For example, in the skeleton circuit diagram in Fig. 4, tube T-1 is the preliminary audio amplifier, the signal output of which is built up across the load resistor R-1, and transmitted through condenser C-1 to the grid G-1 of one of the push-pull tubes. Also, as the signal builds up across resistor R-3, part of it is tapped off and sent to the grid of tube T-2, which is the phase inverter. The output of this tube in turn is built up across load resistor R-2 and transmitted through condenser C-2 to the grid G-2 of the other push-pull tube.

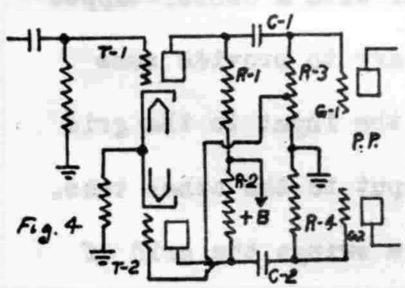


Fig. 4

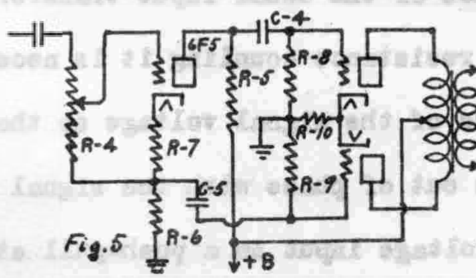


Fig. 5

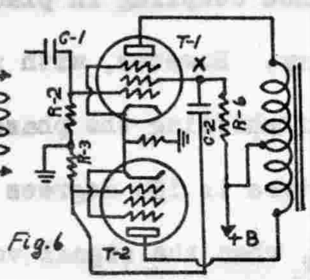


Fig. 6

When the voltage output of T-1 is positive and it swings the grid of T-2 positive, the plate current of T-2 increases, the drop across R-2 increases, and the plate voltage at T-2 decreases, that is, swings negative. In other words, the output voltage of T-2 is 180 degrees out of phase with the output voltage of T-1. This meets the requirements for push-pull operation, while one grid is swung positive, the other is swung-negative. Also, the voltage output of T-2 is made equal to the voltage output of T-1 by selecting the proper position for the tap on R-3. For instance, if the voltage amplification in T-2 is 20, then the tap on R-3 is placed so that one-twentieth or only five per cent of the audio frequency voltage built up across R-3 is supplied to the grid of T-2. This makes the signal voltage across R-4 equal to that across R-3. Through the aid of the additional phase inverter tube, two equal signal voltages are made available 180 degrees out of phase, and efficient resistance-coupled push-pull operation is established.

Another system of phase inversion is illustrated in Fig. 5. Here a type 6F5 high-mu triode is used between the audio frequency signal source and the push-pull stage. The plate of this tube is coupled through condenser C-4 to the grid of one of the push-pull tubes, while the grid of the other tube is coupled through condenser C-5 to resistor R-6 in the cathode return of the 6F5 tube. Since the lower end of R-6 is grounded, any change of current through it will vary the potential of its upper end.

When the signal voltage is such that the grid of the 6F5 tube is swung positively, plate current through this tube increases, and this in turn increases the voltage drop across resistors R-5 and R-6. This increased drop across R-5 subtracted from the B-supply decreases the potential at the plate, that is, the plate is swung negatively, as is also therefore the grid of the push-pull tube to which it is coupled. Also, the increased drop across R-6 makes the upper end of this resistor more positive, and the grid of the other push-pull tube to which it is coupled is also swung positive. Since resistors R-5 and R-6 are equal in value, the potential fluctuations are also equal. The two tubes in the push-pull stage are accordingly supplied with equal signal voltages 180 degrees out of phase, and effective push-pull operation is again set up.

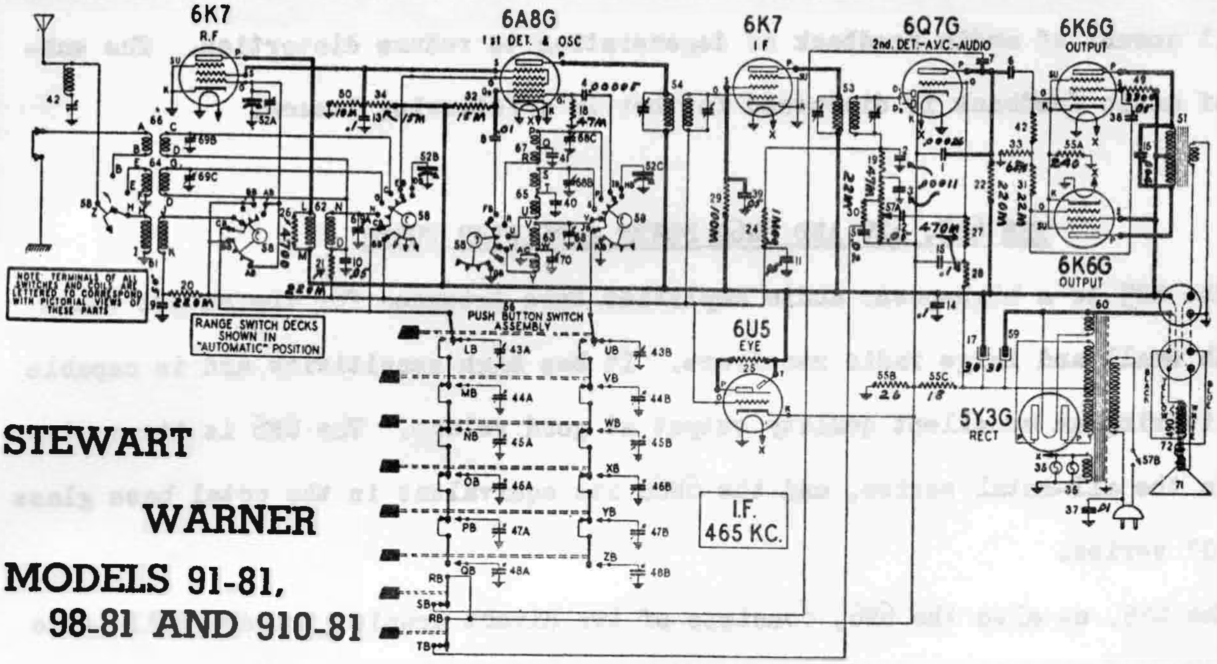
The 180 degree phase displacement needed for the signal input to a push-pull stage can also be obtained without the use of a separate phase inverter tube. For example, the system illustrated in Fig. 6 is used in a number of commercial receivers. Here a 6Q7 tube is used as second detector and the triode section operated as a first audio stage. The output signal is built up across the load resistor and transmitted through condenser C-1 to the grid of tube T-1, one of the two push-pull tubes.

Use is then made of the fact that as a signal passes through a tube it experiences a 180-degree phase displacement. In other words, the output signal appearing at point "X" at the screen terminal of tube T-1 is 180 degrees out of phase with the signal impressed on the grid of the tube. Therefore, part of the signal is picked off at point "X" according to the value of the load resistor R-6, and transmitted through condenser C-2 to the grid of tube T-2, the other tube in the push-pull stage. The resistance of R-6 is chosen so that the voltage built up across resistor R-3 is equal to that built up across R-2.

Again there are two equal signal voltages 180 degrees out of phase impressed on the grids of a pair of power amplifier tubes in a push-pull arrangement, and effective push-pull performance is had. Other circuit arrangements of resistance-coupled push-pull amplifiers and phase inversion may be encountered, but if they are analysed they will be found to be merely modifications of the three forms described and outlined previously.

THE STEWART-WARNER MODEL 91-81, 98-81 AND 910-81 CHASSIS

The Stewart-Warner Model 91-81 Chassis is built around an 8-tube superheterodyne receiving circuit that is designed for both manual and automatic tuning. These tuning systems will be discussed in detail in a later lesson; at present we are interested only in the audio system, that is, the portion of the circuit extending between the second detector and the speaker.



STEWART WARNER MODELS 91-81, 98-81 AND 910-81

A type 6Q7G tube is used in the second detector stage, the triode section of which functions as a first audio amplifier. Potentiometer No. 57A serves both as a load resistor on the diode rectifier system and as a manual volume control for supplying the signal to the grid of the triode.

The output of the 6Q7G triode is coupled through a network of resistors to a pair of 6K6G tubes in push-pull. The signal voltage is built up across the triode load resistor R-22 and transmitted through condenser 6 to the grid of the upper 6K6G output tube. The signal in passing through this tube experiences a 180-degree phase displacement, and use is made of this fact in that the signal is again picked up at the screen terminal and imparted through condenser 38 to the grid of the lower output tube. Resistor 49 serves as a load resistor across which this signal voltage is built up.

Two signal voltages equal in value but differing in phase by 180 degrees, are supplied to the output tubes and effective push-pull operation is established.

Resistors 31 and 42 function as grid-leaks, and resistor 33 is used to introduce a small amount of audio feedback or degeneration to reduce distortion. The subject of audio feedback is discussed further in a following lesson.

THE 6B5, 6N6 AND 6N6G POWER AMPLIFIER TUBES

The 6B5 is a high-power audio amplifier tube intended for the output stage of both small and large radio receivers. It has high sensitivity and is capable of delivering an excellent quality output at good volume. The 6N6 is its equivalent in the all-metal series, and the 6N6G its equivalent in the octal base glass tube "G" series.

The 6B5, as also the 6N6, consists of two direct coupled triodes built into one composite structure. It has a small input triode that serves as a driver for a larger output triode. The general arrangement of the internal electrodes and their connections are illustrated at "A" in Fig. 7. P-1, G-1 and K-1 comprise the input section and receive the incoming signal, either transformer or resistance coupling can be used. Similarly, P-2, G-2 and K-2 comprise the output section, the plate of which is connected to the primary of the output transformer. The cathode K-1 of the first or input section is internally connected directly to the grid G-2 of the output section.

With no signal voltage on the grid, plate current flows from the positive B-supply to the plate P-1 and on to K-1, then over to the grid of the second section G-2, and finally across the grid to cathode gap, and from K-2 to ground. The voltage drop from G-2 to K-2 is 15 volts, and the effective plate potential on the input section is the B-supply voltage minus this 15-volt drop.

Also, the voltage distribution through the tube is such that the grid of the output section G-2 is positive with respect to its cathode by the amount of drop from this grid to cathode or 15 volts. In other words, cathode K-2 is 15 volts negative with respect to grid G-2. Since the grid return of the input section is brought to K-2, and K-1 is connected to G-2, the grid of the input section G-1 is biased negatively with respect to its cathode K-1 by 15 volts.

When a signal is impressed on the grid of the input section G-1, the grid swings positive and negative, and this in turn causes the input section plate current to alternately increase and decrease. This pulsating plate current, corresponding to the signal potential, flows through the G-2 to K-2 resistance gap, and as a result varies the voltage drop across this gap. This voltage drop now acts as the signal input voltage and in turn swings the plate current of the output section in a similar manner, and the signal is carried to the primary of the output transformer and then to the speaker. Thus the grid-cathode (G-2 to K-2) resistance serves bothas a grid bias resistor and a plate load resistor for the input section, and no biasing or coupling resistors, transformers or condensers are needed.

Two 6B5 or 6N6 tubes can also be used in a push-pull output stage with either transformer or resistance coupling. For a single output tube a load resistance of 7,000 ohms is recommended by the tube manufacturers, but for a push-pull system the plate-to-plate load resistance should be 10,000 ohms. With 250 volts on the plates a single tube can deliver an output of 2.5 watts, and at 300 volts an output of 4 watts. Two tubes in push-pull operated at 250 volts can deliver up to 8.5 watts, and when operated at 300 volts up to 10 watts. In any case the percentage of distortion does not exceed five percent. Since practically no associated parts such as bias resistors, condensers, etc., are needed with these tubes, circuit systems designed for their use are comparatively simple and the cost also is greatly reduced.

THE 6AC5G POWER AMPLIFIER

The 6AC5G is a positive Grid Class A power amplifier triode that is similar to the output section of the type 6B5 tube. The 6B5, it will be recalled, is a composite power output tube that consists of two direct-coupled triodes. The 6AC5G also requires a driver tube, and is designed for direct coupling to a type 76. This tube then performs the same function as the input section of the 6B5. The circuit arrangement is also often referred to as dynamic coupling, and is illustrated in the accompanying sketch, Fig. 8.

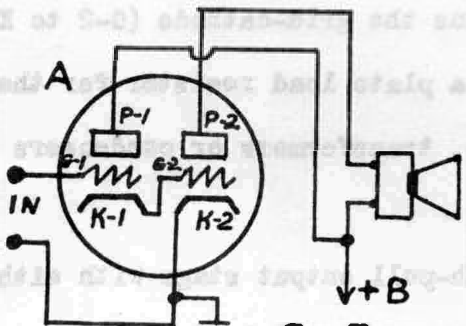


Fig.7

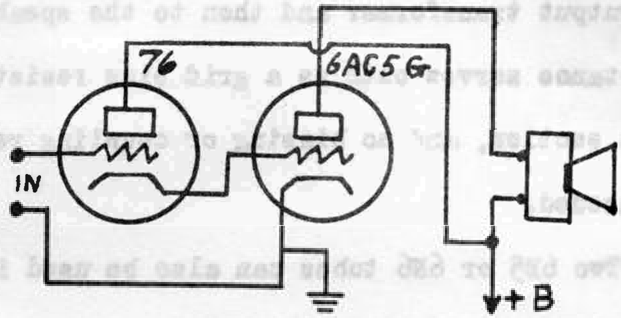
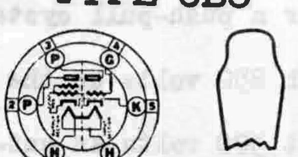
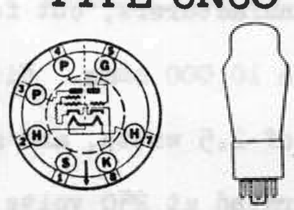


Fig.8

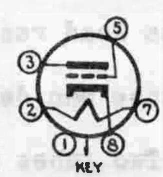
TYPE 6B5



TYPE 6N6G



BASE CONNECTIONS



The 6AC5G power amplifier is used in the output stages of A.C. operated radio receivers that would normally employ a type 41 output pentode. The important feature of the 6AC5G tube, however, is that it offers a low cost method of increasing the number of tubes in a set and at the same time improves the performance and tone quality. In place of a No. 41 pentode the 6AC5G-76 combination requires merely the addition of a 76 tube and socket, and eliminates the 41 grid bias resistors and filter condensers.

Two 6AC5G tubes can also be used in a resistance-coupled push-pull circuit system as is illustrated in Fig. 9. Type 6J5G tubes are illustrated used as drivers.

These are similar to the type 76 but have a higher amplification factor. A type 76 or 6J5G tube can be used as phase inverter. This arrangement is an excellent manner of using a greater number of inexpensive tubes in the audio output system of a larger receiver. The performance and tone quality are also of a very high standard.

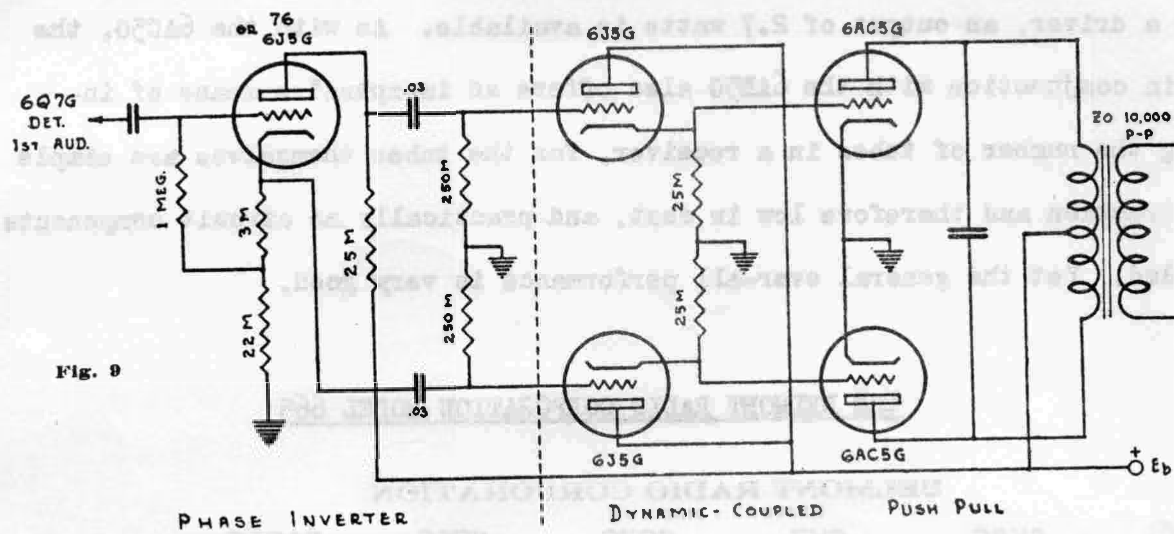


Fig. 9

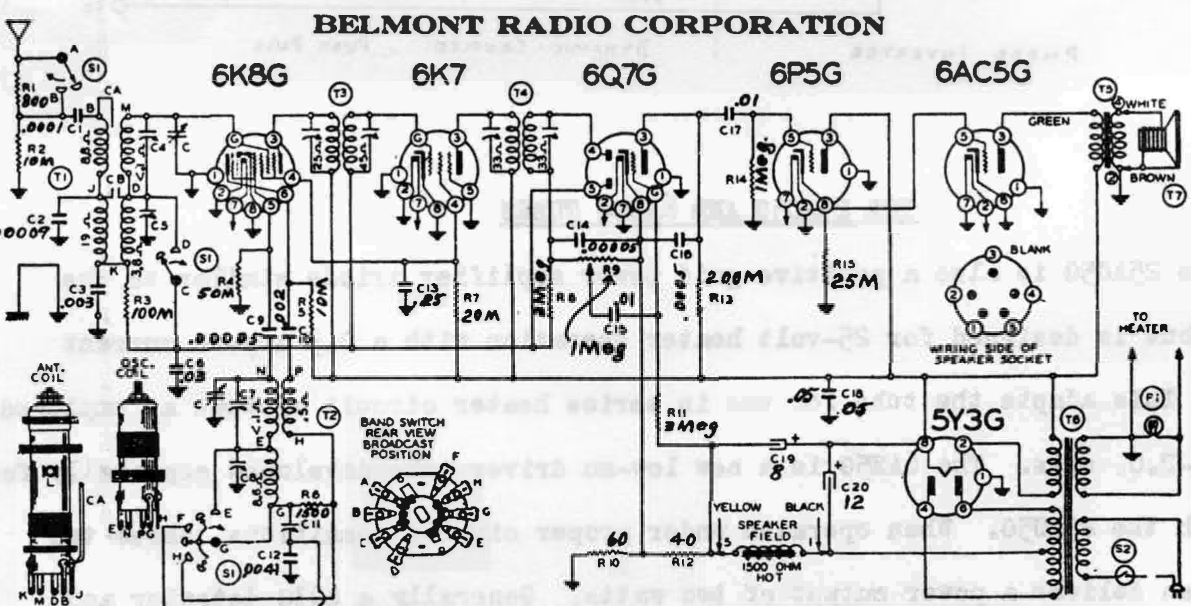
THE 25AC5G AND 6AE5G TUBES

The 25AC5G is also a positive grid power amplifier triode similar to the 6AC5G, but is designed for 25-volt heater operation with a 0.3 ampere current drain. This adapts the tube for use in series heater circuit systems as employed in A.C.-D.C. sets. The 6AE5G is a new low-mu driver tube developed especially for use with the 25AC5G. When operated under proper circuit conditions, these two tubes can deliver a power output of two watts. Generally a 6Q7G detector and first audio stage is used that is resistance-coupled to the 6AE5G driver through a 0.25-megohm plate resistor.

The 25AC5G can also be operated at 180-volts plate pressure, and in this way it offers an excellent solution to the problem of tube selection for low voltage A.C. operated receivers when it is feasible to operate the heaters in series.

An inexpensive transformer can then be used for the plate supply. Such an arrangement makes possible the design of a low cost A.C. operated receiver with good performance and satisfactory tone quality. A type 6P5G (the octal base G-tube equivalent of the 76) is commonly used as a driver. If a type 37 tube is used as a driver, an output of 2.7 watts is available. As with the 6AC5G, the 25AC5G in conjunction with the 6AE5G also offers an inexpensive means of increasing the number of tubes in a receiver, for the tubes themselves are simple in construction and therefore low in cost, and practically no circuit components are needed. Yet the general over-all performance is very good.

THE BELMONT RADIO CORPORATION MODEL 665



CHASSIS MODEL 665

The Belmont Radio Corporation (often abbreviated BRC on the chassis) Model 665 is a 6-tube, 2-band superheterodyne receiver employing a type 6AC5G power tube in the output stage. The tuner and I.F. amplifier are of conventional design, and in the second detector a type 6Q7G tube is used, which is a double-diode high-mu triode similar to the type 75.

Potentiometer R-9 is the diode load-resistor across which the A.V.C. and audio potential is built up. The slider is coupled to the grid of the triode through condenser C-15, and since moving this slider to the left or right increases or decreases the signal strength supplied to the grid, the potentiometer also serves as a manual volume control. Resistor R-11 is a filter resistor or grid leak, and the drop across R-12 serves as a biasing potential for the grid of the triode. The plate of the 6Q7G triode is coupled through resistor R-13 and condenser C-17 to the grid of the 6P5G.

The 6P5G is the octal base G-type equivalent of the No. 76 tube and functions as an input driver for the 6AC5G. The cathode of the 6P5G is biased through resistor R-15, and is approximately 10-volts above chassis potential. Since the grid of the tube is returned to chassis through the grid leak R-14, the grid is consequently biased 10 volts negative with respect to the cathode.

In the 6AC5G tube the cathode is grounded directly at the socket and is at chassis potential. The grid, however, is connected to the cathode of the 6P5G which is 10 volts above chassis potential. In other words, the grid of the 6AC5G is biased positively 10 volts with respect to its cathode. Although this might suggest Class "B" operation, the tube performs strictly as a high grade Class "A" amplifier in conjunction with the type 76 or 6P5G driver. The remainder of the circuit is of standard design and arrangement.

STATIC AND INTERFERENCE

Local interference or "man-made" static is a form of disturbance that is often confused with natural or atmospheric static. It is generally caused by electrical devices and appliances that, due to arcing or leakage, radiate the interfering waves into space.

The principle sources of "man-made" static are high voltage power lines, ignition systems of automobiles, brush-type motors, streetcar trolley lines, flasher signs and various household appliances. The noise from these sources is distributed over the entire frequency range used in radio broadcasting, and is always strong in cities and particularly in business and industrial areas.

In rural communities such local interference is not as common as in cities, but farm lighting plants, rural telephone systems and nearby high tension transmission lines often develop disturbances which make radio reception noisy. When the disturbance originates from power lines or associated equipment, the operating companies will always be found ready to cooperate in hunting down and eliminating such disturbances.

Static which is caused by atmospheric disturbances and lightning can be identified from man-made forms of interference by its characteristic crackling and frying noises. Such static is more prominent during the spring and summer months, and may even make distant reception almost impossible at times. So far no means have been developed that will eliminate this type of interference.

SIGNAL FADING

Fading is a peculiar phenomenon that is frequently encountered when distant stations are being received. It manifests itself as a periodic change of signal strength or as a periodic mushing or distortion of the signal. A program from a distant station may be tuned in loud and clear, and then without any change in the adjustment of the set, the reproduction becomes weaker and weaker and finally may die out altogether. Then the program reappears, increases in volume, and becomes normal again without any change in the receiver adjustments having been made.

Such fading is due to natural causes, and is an action over which the set designer or operator has no control. The automatic volume control incorporated in most receivers tends to overcome such fading and change of signal strength to an appreciable extent, but when the incoming signal falls below the sensitivity of the receiver, even the automatic volume control has no effect. Fading is more noticeable on some nights than others, and also is more pronounced with certain stations. It can be due only to some peculiar atmospheric conditions which have not yet been discovered, and therefore no means of combating such fading has as yet been developed.

THE BEAM POWER TUBE

The beam power tube is a power output tube of special design and superior operating characteristics. It is a form of tetrode and has incorporated in its structure a cathode, grid, screen and plate. It derives its name from the fact that the electrons liberated from the cathode reach the plate in the form of concentrated horizontal beams. The general arrangement of the inner electrode structure is illustrated in Fig. 10.

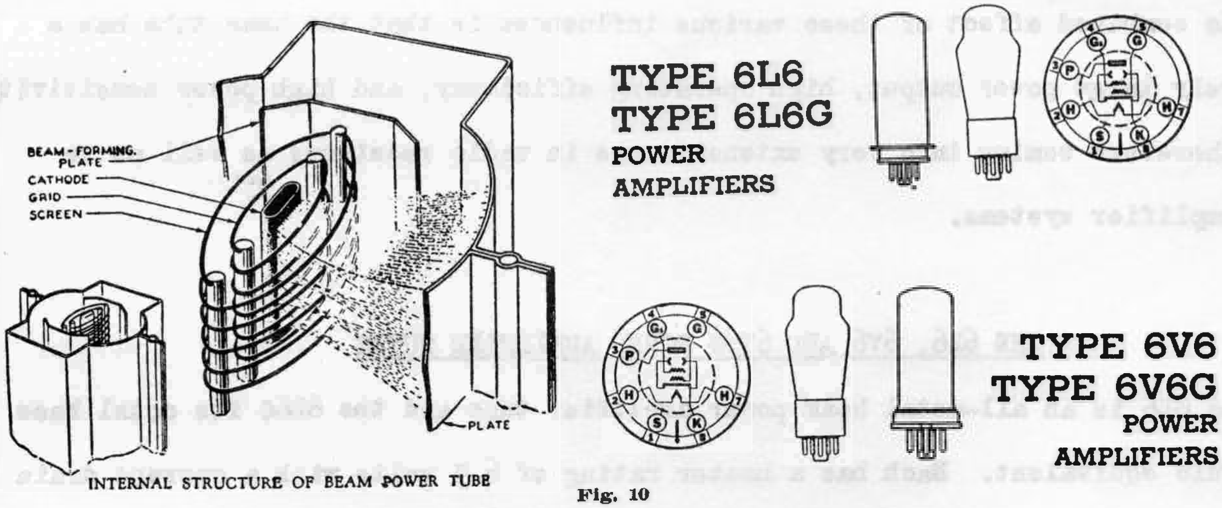


Fig. 10

The screen and grid are spirally wound so that each turn of the screen is shaded from the cathode by a grid turn. As a result of this alignment of the screen and grid wires, it is practically impossible for electrons to travel directly from the cathode to the screen, and very few actually reach the screen, which means that the current drawn by the screen is very low. Another result is that the electrons are caused to migrate toward the plate in horizontal sheets or layers. The curved beam-forming plates which are electrically connected to the cathode have a further effect of concentrating and directing the electron beams. They also keep the electrons away from the narrow ends of the grid and screen where the windings are less regular.

Although the beam power tube is essentially a 4-element tube, its performance is like that of an improved pentode. Suppressor action is obtained by virtue of the concentrated mass of electrons between the screen and plate. Since this distance between the screen and plate is rather large, the big volume of electrons always on their way to the plate creates a strong space charge here, that halts secondary emission and prevents the interchange of electrons between the screen and plate.

The combined effect of these various influences is that the beam tube has a relatively large power output, high operating efficiency, and high power sensitivity. It is therefore coming into very extensive use in radio receivers as well as in power amplifier systems.

THE 6L6, 6V6 AND 6Y6G POWER AMPLIFIER TUBES

The 6L6 is an all-metal beam power amplifier tube and the 6L6G its octal base glass-bulb equivalent. Each has a heater rating of 6.3 volts with a current drain of 0.9 ampere. Several of these tubes would therefore place quite a load on the power supply system of a receiver. The tubes are built along the lines described as illustrated in Fig. 10.

The outstanding feature of these tubes is the large power output that is available from them. For example, two type 6L6 tubes in push-pull and operated with only 250 volts on the plate and screen can deliver a power output of 14.5 watts when maximum signal is applied to the grids. Also, if two tubes in push-pull are operated in Class "B" (grid current flowing during part of the input cycle) with 400 volts on the plate and 300 on the screen, up to 60 watts are available at the output with maximum signal input. These tubes, therefore, find wide application in public address amplifiers and other installations where high power is required.

The 6V6 and 6V6G tubes are also beam power amplifier tubes similar in construction to the 6L6 tubes but with more moderate ratings. The 6V6 tubes have the same 6.3-volt heater rating but a current drain of only 0.45 ampere. They are consequently better adapted for service in the audio output stages of radio receivers, in that they do not throw such a heavy load on the power supply unit. When operated in push-pull with 250 volts on the plate and screen, two type 6V6 tubes can deliver an output of 8.5 watts. If 300 volts are applied to the plate and screen, up to 13.5 watts are available.

The 6Y6G tube is another beam power tube similar in construction to the 6L6 and 6V6. It has a heater rating of 6.3 volts and a current drain of 1.25 amperes. This tube was designed primarily for use in low voltage A.C. operated receivers in which economy in B-power consumption is essential. The maximum plate and screen voltages that can be used with the 6Y6G should not exceed 135 volts.

THE 25L6, 25L6G, 35L6GT AND 50L6GT TUBES

The 25L6 and 25L6G tubes are also beam power amplifiers similar in construction and operation to the tubes described above, but intended primarily for operation in the output stage of A.C.-D.C. receivers. Being rated at 2.2 watts, these tubes can supply high power output at the comparatively low plate and screen voltages that are available in such receivers. The heater is rated at 25 volts and the current drain at 0.3 ampere, and consequently these tubes can be used in series filament circuits with other 0.3 ampere heaters.

The 35L6GT and 50L6GT are beam power amplifiers that belong to the new miniature or bantam GT tube series. With a 35-volt and 50-volt heater rating the current drain is only 0.15 ampere, and the tubes are therefore especially adapted for use in midget receivers in which space and heat dissipating facilities are at a premium.

EXAMINATION QUESTIONS ON FOLLOWING PAGES