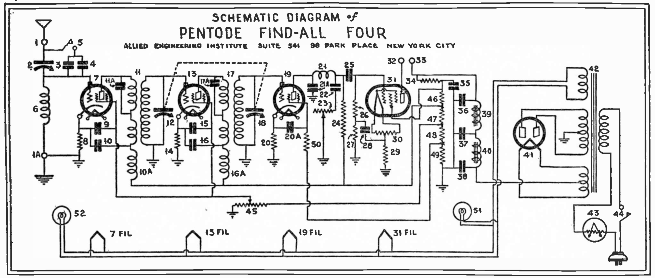
The Pentode Find All-Four

Among the new circuits designed to take full advantage of the new pentode tube is the Pentode Find-All Four which has been recently introduced to the set-building public. This receiver is extremely powerful, selective and sensitive, and includes features of design which combine to give excellent performance.

Parts required for the Pentode Find-All-Four are as follows:

1—Aerovox "Hi-Farad" Dry Electrolytic Condenser, type E5-8888 (35, 36, 37, 38) with mounting ring.
1—.00015 mfd. Aerovox Mica Condenser, type 1460 (4).
3—.0005 mfd. Aerovox Mica Condensers, type 1460 (3, 11A, 17A).
1—.001 mfd. Aerovox Mica Condenser, type 1460 (21A).
1—.006 mfd. Aerovox Mica Condenser, type 1455 (25).
2—.01 mfd. Aerovox Mica Condenser, type 1455 (22), (33A).
2—.1 mfd. (ea. section) Double Section Aerovox Metal Case Condensers, type 461-21 (9, 10); (15, 16).
2—1 mfd. Aerovox Condensers, type 261 (20A, 28).
2—10,000 ohm Resistor (20), (32A).
2—50,000 ohm Resistor (27, 50).
1—250,000 ohm Resistor (24).
1—1 meg. Resistor (26).
1—Find-All Impedance Coil (6).
2—Find-All Coils, type P-SG (11, 17).
3—R. F. Chokes (10A, 16A, 21).
1—Amperite Control, type 5-A-5 (43).
1—.00035 mfd. Cardwell Variable Condenser, type 171-C (2).
1—.00035 mfd. (ea. section) Cardwell Dual Variable Condenser, type 217-C (12, 18).
1—Electrad Royalty Potentiometer, type "C" (45).
1—Electrad Royalty Potentiometer, type "E", (23).
2—400-ohm Electrad Truvolt flexible Wire Grid Resistors (8, 14).
1—20-ohm Electrad Truvolt Center-tap Resistor, type V-20 (30).
1—Electrad Resistor, type B-4 (29).
1—Electrad Resistor, type B-12.5 (49).
1—Electrad Resistor, type B-15 (34).
1—Electrad Resistor, type B-22.5 (46).
1—Electrad Resistor, type B-25 (48).
1—Electrad Resistor, type B-50 (47).
1—Find-All 245-type Combined Power and Supply Compact (42).
2—30 Henry Chokes (39, 40).
3—Arcturus Screen Grid Tubes, type 124 (7, 13, 19).
1—Arcturus Pentode Tube, type PZ (31).
1—Arcturus Full-Wave Rectifier Tube, type 180 (41).

Further details and free diagrams of this receiver can be obtained by writing direct to the Allied Engineering Institute, 98 Park Place, N. Y. C., mentioning The Aerovox Research Worker.



Numbers on the above diagram correspond with those in parentheses given in list of parts.

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The Pentode and Its Use

By the Engineering Department, Aerovox Wireless Corporation

One of the latest tubes to be brought to the attention of the engineer and the experimenter is the pentode, a power output tube of rather unusual characteristics. Active experimental work on the power pentode was undertaken in this country about a year ago, but it is only recently that this type of tube became commercially available; a tube of this type is

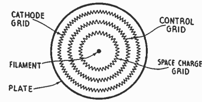

Fig. 1

now being made by all the prominent tube manufacturers. It appears likely that a number of set manufacturers will make use of this tube in their new receivers.

Since the power pentode is being given such serious consideration, it may be worth while to discuss in some detail the characteristics of the tube with special reference to its difference in comparison with ordinary types of power tubes. The power output pentode designed for use in a. c. receivers has the following characteristics:

Filament Voltage .... 2.50 volts
Filament Current ...... 1.5 amperes
Plate Voltage recommended .... 250 volts
Space Charge Grid Voltage recommended .... 250 volts
Control Grid Bias —16.5 volts
Plate Current .... 32 milliamperes
Space Charge Grid Current .... 7.5 milliamperes
Plate Resistance .... 38000 ohms
Mutual Conductance 2500 microhms
Load Resistance approximate .... 7000 ohms
Power Output .... 2.5 watts

The pentode is a five-element tube, the various electrodes being arranged as shown in Fig. 1. There are two additional grids in the tube besides the usual control grid found in the ordinary tube. Immediately surrounding the filament is the space charge grid. Outside of the space charge grid is the control grid and it is this grid which corresponds to the grid found in ordinary power tubes as, for example, the type 245. Surrounding the control grid is placed the cathode grid and around the outside of this grid is the plate. The manner in which the tube is connected into an actual circuit is illustrated in Fig. 2. The inner or space charge grid is connected to B plus 250 volts, the control grid is connected to the secondary of the input transformer, the cathode grid is connected inside the tube to the center point of the filament and the plate is used, of course, to supply the power to the loud speaker.

In an ordinary three-element power tube, the electrons emitted by the filament congregate about the filament and build up what is termed a space charge. In the pentode the space charge grid prevents the space charge from building up about the filament and in this manner a much larger number of electrons are subject to the control action of the control grid. The practical result is that the pentode tube has a much higher mutual conductance, i. e., a much larger change in plate current for a given change in grid voltage than can be obtained in ordinary three-element tubes.

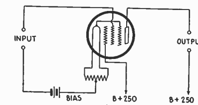

Fig. 2

The cathode grid located between the control grid and the plate serves to prevent secondary emission. The cathode grid is tied directly to the filament and in practical operation is therefore always somewhat negative with respect to the plate, being highly negative during those portions of the output cycle which result in low plate current. It is found in practice that the pentode tube shows but slight secondary emission effects except at very low plate voltages.

Besides having a very high mutual conductance, 2500 microhms, the tube also has a high amplification factor. Whereas, the 245, for example, has an effective voltage amplification (a. c. volts across the load divided by a. c. volts on the grid) of about 2.3, the pentode has an effective amplification of about 11. As a result of these two characteristics, we find that the pentode is a much more sensitive tube than ordinary three-element power tubes. By this we mean that for a given a. c. voltage on the grid it will supply a much greater amount of power to the loud speaker. If we compare it directly with the 245, we find that this tube requires 36 volts a. c. on the grid to deliver a power output of about 1.5 watts. The pentode, on the other hand, will supply 2.5 watts of power and requires only 11.5 volts a. c. on the grid.

But in the use of the pentode considerably greater care is required in the design and arrangement of the associated circuits than is required when using other types of power tubes. Whereas, the amount of distortion produced by a three-element tube is quite slight and decreases the higher the load resistance, the distortion produced by the pentode is low over only a small range in output load resistance and the distortion becomes greater if a load resistance is either greater or less than those values which give minimum distortion. Also in an ordinary three-element tube it is not difficult to eliminate the common coupling between input and output circuits which tends to occur because the grid bias resistance is common to both circuits. In the pentode, on the other hand, this type of coupling is quite severe and is not so readily prevented.

First let us examine in further detail the manner in which common coupling occurs in the C bias resistance and means by which it can be eliminated. When C bias is obtained by means of a resistance placed between ground and the center of the tube filament, we obtain a circuit arrangement as shown in Fig. 3. The pentode requires a bias of 16.5 volts obtained from the voltage drop across the grid bias resistance R, and it follows that since the plate current of the pentode is 32 milliamperes and the space charge grid current 7.5 milliamperes and both of these currents must flow through the C bias resistance, that the value in ohms of this resistance will therefore be

$$R = \frac{16.5}{0.032+0.0075}$$

$$= 418 \text{ ohms}$$

When an a. c. voltage is applied to the grid, a. c. currents are produced in the plate circuit of the tube and if the a. c. input voltage has a peak value equal to the bias on the tube, the peak a. c. value of the current in the plate

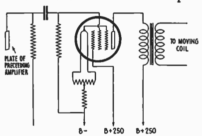

Fig. 3

circuit will be equal approximately to the normal d. c. current. In the case of the pentode we can assume, therefore, that with an a. c. voltage of 16.5 volts peak applied to the grid, the peak value of the a. c. plate current will be about 30 milliamperes. This a. c. current will flow through the load, through the B supply circuit, hence through the C bias resistance and back to the filament of the tube. As a result there will be an a. c. voltage drop across this C bias resistance which voltage drop will be equal to the r. m. s. value of the a. c. current multiplied by the resistance in ohms. In this case the drop across the C bias resistance would therefore be 0.03x418, or 12.6 volts a. c. peak value, and the r. m. s. value would be 12.6 divided by 1.4, giving 8.97 volts. This voltage would be reimpressed on the grid circuit and being exactly opposite in phase to the original a. c. voltage applied to the tube, it would result in a considerable reduction in overall amplification. If the tube is to give satisfactory performance the a. c. voltage drop across the grid bias resistance must be reduced to a very low value.

A method of accomplishing this is to shunt the C bias resistance with a condenser which lowers the impedance of the circuit and results in a lower voltage drop. In the case of ordinary types of power tubes, a capacity of one or two microfarads proves quite effective, but because of the much higher sensitivity of the pentode ordinary sizes of condensers do not give very effective results; this can be attributed to the fact that not only is the tube more sensitive but also because it requires a comparatively low value of C bias resistance and hence a much larger condenser is needed to produce a given reduction in the impedance of the circuit.

The impedance of a resistance shunted by a condenser is

$$Z = \frac{1}{\sqrt{\frac{1}{R^2} + (WC)^2}}$$

This formula can be simplified and the following expression then is obtained

$$Z = \frac{R}{\sqrt{1 + (RWC)^2}}$$

Using this formula and calculating the impedance of a 418 ohm resistance shunted by various capacities from 1 up to 25 microfarads, the following results are obtained, using a frequency of 60 cycles.

Shunting Capacity in Microfarads	Resulting impedance Z (R and C in parallel)	Peak a. c. volts across Z
1	415	12.4
2	398	12.0
4	355	10.7
8	260	7.8
15	163	4.9
20	130	3.9
25	103	3.1

These voltages (shown in the right-hand column) will not be exactly opposite in phase with the original voltage due to the fact that the voltage across the bias circuit will lag behind the current, the amount of lag depending upon the phase angle of the circuit. If Φ is the angle of lag then $\tan \Phi = RWC$ and the peak voltage exactly opposite in phase with the original grid voltage will be $\cos \Phi$ x peak a. c. volts across Z. Working out the angle Φ and multipling its cosine by the total volts given in the above tabulation, the following results are obtained:

Capacity	Peak-in-phase component of voltage across R and C	Percent of original peak a. c. grid voltage
1	12.25	74
2	11.4	69
4	9.15	56
8	4.83	29
15	1.92	11.6
20	1.17	7.1
25	0.536	3.2

Of course in an actual circuit the voltage fed back to the grid circuit, causes a reduction in a .c. plate current which in turn causes a reduction in the feedback voltage. The two preceding tabulations give, however, a good idea of the effects which occur and serve to indicate the need of a very large condenser across the bias resistor. To obtain 10 or more microfarads in a paper condenser would of course mean a unit too costly and requiring too much space. But the Hi-Farad Electrolytic condenser is ideally suited to the purpose, being low in cost and very compact; a 25 mfd, 100 volt electrolytic condenser requires only about 4 square inches.

The a. c. voltage across the bias circuit will of course be greatest at low frequencies where the condenser reactance is largest; it was for this reason that a frequency of 60 cycles was

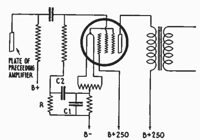

Fig. 4

used for the above calculations. At higher frequencies the condenser reactance is lower and the voltage across the bias circuit correspondingly less.

There are, of course, other methods of eliminating this feedback effect. For example, if the grid circuit is filtered as shown in Fig. 4 a much smaller condenser can be used across the bias resistance. In this circuit it would be satisfactory to use about 2 mfd. each for C^1 and C^2 and about 0.1 megohms for R. But when we consider that this circuit requires that three units be wired into the circuit it is doubtful that the circuit represents any real advantage, from a manufacturer's standpoint, over the use of a single high capacity condenser across the bias resistor.

A third method which can be used is to obtain the bias voltage not from a resistor in the cathode circuit but from some part of the power supply system. A resistor can be placed in the power supply for this purpose or part of the voltage drop across the loud speaker field winding (used as a filter choke in the negative side of the circuit) can be utilized to obtain bias for the tube. If such a circuit arrangement is used it is not difficult to decouple the bias circuit from the remainder of the receiver.

The circuit arrangement generally used when bias is obtained from some point in the power circuit is shown in Fig. 5. Sometimes an additional resistor and condenser are placed in the grid circuit to afford additional decoupling. The bias arrangement, besides having the advantage that fairly complete decoupling is not difficult, also has the advantage that no additional 2.5 volt filament is required for the pentode, whereas a separate filament winding is needed when bias is obtained from a resistor placed in the filament circuit of the pentode. Furthermore, when bias is obtained from the negative side of the filter circuit the hum voltage on the grid circuit is opposite in phase to the hum impressed on the plate circuit of the preceding amplifier tube so the circuit lends itself readily to hum balancing arrangements. For these reasons we find the circuit of Fig. 5 more generally used in receivers utilizing the pentode tube. Although the circuit of Fig. 5 shows a tapped loud speaker field coil it is of course possible to place a tapped resistor across the circuit if untapped field coils must be used.

In any case the effect of coupling between plate and grid circuits across the bias resistor is to decrease the gain at low frequencies. This effect is especially disastrous in the case of the pentode, for the rising impedance characteristic of the loud speaker tends to make the high audio frequencies predominate and the rise in gain at high frequencies is aggravated if degenerative effects occur at low frequencies across the bias resistor. Even without degenerative effects at low frequencies the highs tend to predominate and to be badly distorted. As French [1] has shown,

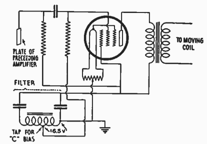

Fig. 5

this is one case where side-band cutting in the r. f. amplifier can be used to advantage. Side-band cutting operates to decrease the grid swing on the pentode at high audio frequencies, thereby compensating the rise in output which tends to occur and at the same time eliminating much of the distortion since at high load resistances the Ip Eg dynamic characteristic to fairly straight for limited grid swings.

Regarding the matter of output transformer ratio it appears that the impedance ratio should be such that the loud speaker looks like about 6000 or 8000 ohms to the tube at a frequency slightly about the resonant point of the speaker; the average dynamic mounted in a large baffle usually resonates in the neighborhood of 100 cycles.

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