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The Essential Factors in the Design of Receiver and Amplifier Systems

Part II*

By the Engineering Department, Aerovox Wireless Corporation

IN this article we continue our "pencil and paper" investigation in receiver design, with particular emphasis this month on the design of audio amplifiers. Readers will recall that last month we gave a general summary of the problem of receiver design and worked out also the basis for the choice of power tubes. This month we consider the factors that effect the design of the circuits between the grid of the power tube and the plate circuit of the detector tube. Although in this series of articles special emphasis is placed on the design of radio receiver circuits, the data given below is applicable to all types of audio amplifiers, whether they are used as part of a radio receiver, public address system or talking movie installation.

Before beginning a detailed discussion of the subject we would like to point out that we are considering an audio amplifier to consist of all the apparatus from the source of audio frequency voltage up to the grid circuit of the power tubes. This is perhaps somewhat unusual since many of us think of the power tubes as part of the audio amplifier. If we do this however we are grouping under one name two groups of apparatus with entirely different functions. All of the apparatus up to the grid circuits of the power tubes functions as a voltage amplifier, whereas the power tubes are designed to supply power rather than voltage. For this reason the factors that influence the choice of the power tubes are altogether different from the factors that effect the design of the circuits preceding the power tubes. It seems advisable therefore to differentiate between these two parts of the circuit, and it was for this reason that the first part of this series discussed the considerations that determine what power tubes should be used.

The design of an audio amplifier depends upon a number of factors of which the most important are:

(1) The maximum a. c. output voltage required.
This is determined by the type, number and arrangement of the power tubes.

(2) The upper and lower limits of frequency which must be uniformly amplified.

(3) The maximum amplification required.
This is determined by the maximum required output voltage and upon the available input voltage.

(4) The available plate voltage.
Whether a resistance or a transformer-coupled amplifier is used may depend somewhat on this factor.

In normal circuits the maximum a. c. voltage which can be impressed on the grid of a power tube without producing distortion, will be equal in peak value to the d. c. bias on the tube. For example if a particular tube requires a d. c. grid bias of 50 volts then the maximum a. c. voltage that the tube can handle without overloading will be one whose peak value is 50 volts. The peak value of an a. c. voltage is equal to 1.4 times the effective voltage. If two such tubes were connected in parallel the maximum a. c. voltage would be the same. If two such tubes were connected in push-pull they could handle, without overloading, twice as much voltage. In other words the total voltage from grid to grid could be 100 volts peak. If we wish to consider that the push-pull arrangement permits us to somewhat overload the tubes without producing serious distortion, then the maximum permissable a. c. voltage on the grids will be somewhat greater. If for example we consider that two tubes in push-pull can safely supply say 2.5 times the output of a single tube then the maximum permissable a. c. voltage becomes

NOTE*: The first article of this series on "The Essential Factors in the Design of Receiver and Amplifier System," appeared in the May-June 1930 issue of the Research Worker.

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about 25 per cent greater or, in this case, 125 volts peak. From this discussion we can obtain the following working rules. The maximum a. c. peak voltage which a power tube circuit can handle, is

(a) Equal to the d. c. bias on the grid, for a single tube, or for two or more tubes in parallel.

(b) Equal to twice the d. c. bias on the grid, for two tubes in push-pull.

(c) Equal to 2.5 times the d. c. bias on the grid, if two tubes are connected in push-pull and some over-loading is considered permissable.

These maximum permissable voltages represent the a. c. voltages which must be impressed on the power tubes. In a transformer coupled amplifier they are the voltages across the secondary of the last audio transformer. In the case of a resistance-coupled amplifier they are the voltages across the grid leak connected in the power tube circuit. With these rules and a knowledge of the d. c. bias required by various tubes together with data on the circuit arrangement of the power tubes it is possible to quickly and accurately determine the peak a. c. voltages required in the various stages of the amplifier to obtain a desired output from the amplifier (input to the power stage).

The overall voltage amplification or "gain" required in an implifier is determined by the maximum a. c. output voltage required and the a. c. voltage available at the input of the amplifier. If we need 100 volts peak at the output and the available input voltage has a value of 2 volts peak then the gain required is equal to 100 (the output voltage required) divided by 2 (the input voltage available). This gives 50 as the required gain which must be obtained from the amplifier.

Now let us see how we can calculate the gain of an amplifier. First let us consider the transformer coupled circuit. The gain of a transformer coupled amplifier is due to two things — the voltage step-up that occurs in the tube and the voltage step-up that takes place in the transformers. The total gain will be a product of all these individual gains. For example if an amplifier consisted of a tube giving an effective amplification of 7 connected between two transformers each with a turns ratio of 4 then the total gain would be 4 (voltage step-up of first transformer) times 7 (effective amplification of tube) times 4 (voltage step-up of second transformer). The product of these is 112, the total gain of the system.

Now let us assume a definite problem and work through the solution. Suppose two type 245 tubes are to be used in push-pull with 250 volts on the plates and a bias of 50 volts. Sufficient voltage is to be available to operate them at a slight overload (condition C above). The input voltage is one (1) volt peak. The amplifier is to be transformer coupled. Determine the required gain, the transformer turns ratio required, and the voltages at which the tubes should be operated. Heater type 327 a. c. tubes are to be used.

The maximum voltage output required from the amplifier will be equal to the d. c. grid bias of a single power tube (50 volts) times 2.5 (due to the increased power handling capacity of the two tubes connected in push-pull).

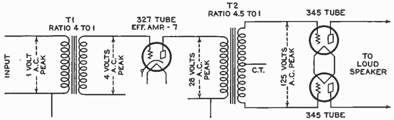


Fig. 1

The product is 125 volts, the peak voltage which can be impressed across the grids of the two power tubes connected in push-pull without causing undesirable distortion.

The gain required in the amplifier is then equal to 125 (the peak voltage required at its output) divided by 1 (the peak voltage available at the input). The gain required is therefore 125.

From a table of tube characteristics we can determine that a 327 tube has an amplification constant of 8. The actual amplification of the tube in a circuit can be assumed to be about 90 per cent of its amplification constant. So we figure that from a 327 we can obtain a gain of about 8 times .9 or approximately 7. Suppose we use an input push-pull transformer to couple the 327 to the two 345 tubes and that the turns ratio of this transformer is 4.5. Then from the tube and this transformer, the gain will be 7 (the effective amplification factor of the 327 tube) times 4.5 (the step-up ratio of the push-pull transformer). The overall gain of the 327 tube and the push-pull transformer will thus be 31.5.

Since the overall gain required is 125, the step-up or turns ratio required in transformer "T1" which feeds the grid circuit of the 327 tube must be 125 (the overall amplification required) divided by 31.5 (the amplification obtained by means of the 327 tube and the input transformer "T2"), or 3.97 and in practice we would use a transformer having a 4 to 1 ratio.

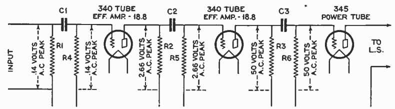
If we preferred to use a ratio of 3 for the first transformer then the first transformer and the tube combined would have a gain of 3 (ratio of transformer) times 7 (amplification of the 327 tube) or 21. To get an overall amplification of 125 for the amplifier system, the ratio required in the input transformer would have to be 125 (overall gain required) divided by 21 (combined gain of tube and first transformer) or 5.95.

Suppose we use the first arrangement i.e. input push-pull transformer to power stage having a ratio of 4.5 and the first transformer with a ratio of 4. The circuit that results is given in Fig. 1. Now what d. c. voltage and bias should be used on the 327 tube?

The peak a. c. voltage across the secondary of T2 is 125 volts. Since this transformer has a ratio of 4.5 the voltage across the primary of the transformer is 125 divided by 4.5 equals approximately 28 volts peak.

Since the effective amplification of the tube is 7 the voltage across the grid circuit of the tube is 28 divided by 7 equals 4 volts peak.

Now the peak value of the signal voltage on the grid of an amplifier should never exceed the d. c. bias on the tube. If it does the tube draws grid current and distortion is produced. Therefore in this case the bias on the 327 tube should be at least 4 volts and preferably somewhat more to prevent any possibility of the grid of the tube swinging positive and drawgrid current. Referring to a chart of tube characteristics we find that this type of tube with 6 volts on the grid takes 90 volts on the plate and these two voltages are very satisfactory for use in this case.



R1, R2, R3 — Aerovox Type 1094 Carbon Resistors
R4, R5, R6 — Aerovox Type 1092 Metalohm Grid Leaks
C1, C2, C3 — Aerovox Type 1450 Mica Condensers
Fig. 2

Now let us consider the case of the resistance coupled amplifier. Suppose a single 345 type tube is used in the power stage and the preceding tubes are to be type 340. The input voltage available is one-half (.5) volt peak. Work out the design of the amplifier.

The equation for voltage amplification obtained from a tube in a resistance coupled amplifier is approximately

$$AV = \frac{RL}{RL + RP} \times A$$

where AV is the voltage amplification or effective amplification of the tube in the circuit, RL is the load resistance, RP is the plate resistance of the tube and A is the amplification factor or mu of the tube.

The recommended plate resistor for use with the 340 tube is 250,000 ohms (0.25 megohms) and from a table of tube characteristics we can determine that the a. c. plate resistance of this type of tube is 150,000 ohms and the amplification constant is 30.

Therefore the approximate amplification obtained from the tube is

$$30 \times \frac{250{,}000}{250{,}000 + 150{,}000} = 18.8$$

Since the bias required on the 345 type tube is 50 volts, the peak a. c. voltage across the grid circuit must be no more than 50 volts. Therefore the voltage on the grid of the preceding hi-mu tube must be 50 divided by 18.8 (the effective amplification of the tube under existing load conditions), which equals 2.66 volts peak.

This means that a signal with a peak value of 2.66 volts, impressed on the grid of this tube would supply the required 50 volts at the power tube. But the voltage available to operate the amplifier is only 0.5 volts. We will therefore add another stage. Adding a stage will give a total gain of 18.8 times 18.8 or 354. The gain required in the amplifier is 100, obtained by dividing the peak voltage (50) required across the grid circuit of the power tube by the input voltage (.5) available.

Two stages therefore will give us more gain than we need. This is not any great disadvantage however, for it simply eliminates any possibility of overloading in the detector circuit of a radio receiver by making it possible to operate with somewhat reduced input voltage. Now what voltages are required on the tubes?

From a table of tube characteristics we find that two conditions of operation for these tubes are suggested when used in a resistance coupled amplifier with a 250,000 ohms (.25 megohm) plate resistor. They are:

"B" Battery Voltage	"C" Bias Voltage
135	—1.5
180	—3.0

With the aid of the amplifier circuit which is given in Fig. 2 we can work out which of the above two conditions of operation should be used. The peak voltage across the power tube is 50 volts and in working out the problem we calculated that this required 2.66 volts across the grid of the preceding tube. Since the bias must always be equal to or greater than the peak signal voltage it will be necessary to operate this tube with 180 volts on the plate and a 3 volt bias. The peak voltage across the grid of the first tube will be 2.66 divided by 18.8 or .14 volts, and this tube can therefore be operated with a grid bias of —1.5 volts and a plate voltage of 135 volts.

Suppose in the above problem that there was no way to reduce the input voltage below 0.5 volts. If we impressed this voltage on the amplifier, the peak voltage across the grid of the power tube would be .5 (input voltage) times 354 (overall gain of the amplifier) which would equal 177 volts peak, and the power tube would be sadly overloaded. If the input voltage must be .5 volt, and the maximum output 50 volts, then the amplifier gain should be 50 divided by .5 which equals 100.

If we use two type 340 tubes this means that the gain per tube must be 10 since two tubes each with a gain of 10 will give a total gain of 100. What value of plate resistor will give a gain of 10? We can determine this from the formula previously given. Substituting the desired gain of 10 in this formula we have

$$10 = \frac{RL}{RL + 150{,}000} \times 30$$

and solving for the load resistance we obtain a value of 75,000 ohms to obtain a gain per tube of 10.

The preceeding discussion has, we hope, helped to indicate how to calculate the gain of amplifiers and determine the correct operating voltages. The discussion will be continued next month with special references to the factors that influence the frequency response of amplifiers.