RECENT DEVELOPMENTS IN HIGH VACUUM RECEIVING TUBES—RADIOTRONS, MODEL UV-199 AND MODEL UV-201-A*

By

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The present trend in vacuum tube development is largely toward the reduction of power required for excitation of the filament and at the same time, when possible, an improvement in the operating characteristics of the tube. This development is taking place as a result of several factors, the principal of which are the discovery and application of new physical phenomena, more complete knowledge of the relation between the mechanical and electrical design of the tube, better processes for carrying out of the designs required, and a better understanding of the requirements of the circuits in which the tube is to be used.

The purpose of this paper is to illustrate these points by a brief description of two receiving tubes which recently appeared on the market—the UV-199 and UV-201-A Radiotrons.

The UV-199 is a tube intended for use as a detector or as an amplifier and is designed for dry cell operation. The UV-201-A also may be used as a detector or as an amplifier and is designed to be interchangeable with the older UV-201, but requires only one-fourth as great filament current and has noticeably better operating characteristics than the UV-201. Internal and external views of the UV-199 and UV-201-A are shown in Figures 1 and 2.

Both of these tubes contain a new type of filament known as the X-L tungsten filament. Compared with the older tungsten filaments, the X-L filament operates at a much lower temperature, has a higher electron emission efficiency and a longer life. Another important but less apparent advantage is that for a given voltage and current, and at the normal operating temperature, the X-L filament is longer than the old type tungsten fila-

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ment. This has considerable influence on the design of the tube, as will be seen later.

Coincident with the introduction of the X-L filament, new exhaust processes have been developed which serve to assure

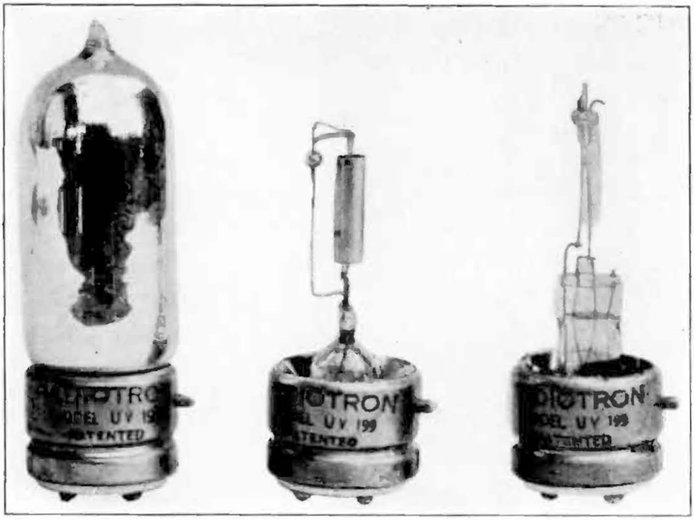

FIGURE 1—Radiotron Model UV-199

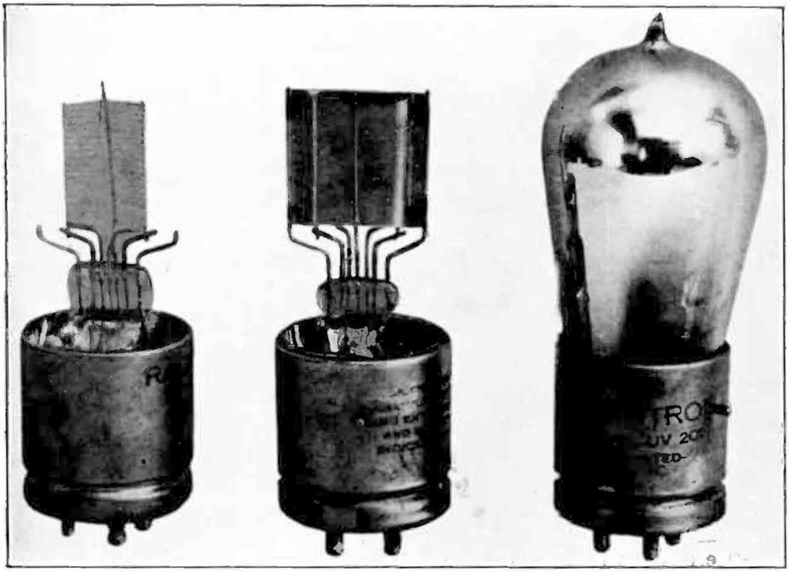

FIGURE 2—Radiotron Model UV-201-A

an extremely good vacuum in tubes containing the new filament. The typical silvered or colored appearance of the UV-199 and UV-201-A is incidental to these exhaust processes.

The filament of the UV-199 is conveniently operated from three dry cells in series as the filament rating is 3.0 volts and 60 milliamperes or 0.18 watt. The advantages of this rating are readily seen after a brief consideration of dry battery characteristics. Dry batteries are most efficient at small current loads; hence, for a given power it is most economical to draw this from the battery at a low current rate. Thus, the small current required by the UV-199 gives it an important advantage over other tubes in battery economy. The second requirement for best battery efficiency is that the battery be used until the closed-circuit voltage has fallen to one volt or less per cell, that is, the end-point of the cell should not be greater than one volt. The use of three cells in series on the UV-199 filament meets this requirement perfectly.

Figure 3 shows characteristics of an average "general purpose" dry cell which plainly indicate the advantage both of a low current rate and a low end-point.

Where it is desired to construct a receiving set of minimum size and weight, for instance for portable use, flashlight cells may be used for filament excitation. An ordinary three-cell

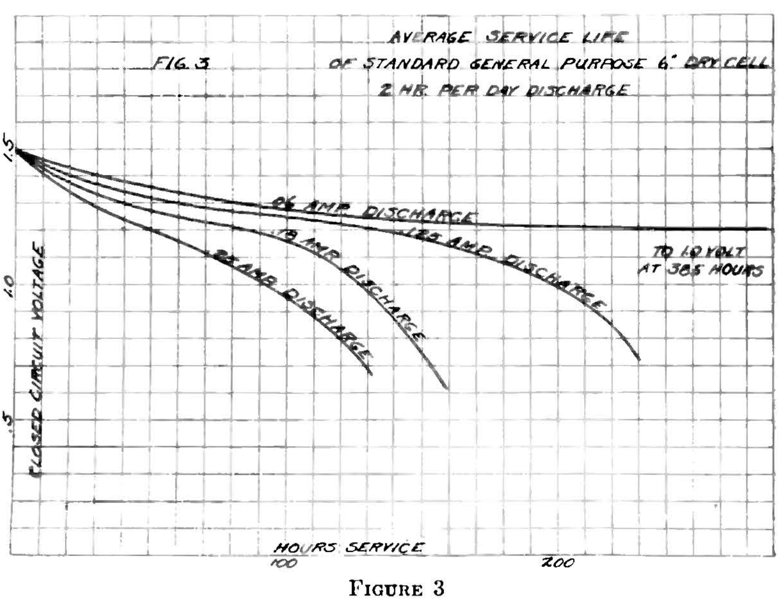

FIGURE 3

tubular battery will operate a one-tube set one hour per day for approximately one month. The economy of such operation is naturally less than when standard six-inch cells are used, but this is relatively unimportant in a portable equipment.

The small dimensions of the UV-199, 1 inch by 3½ inch (2.54 by 8.9 cm.), are a considerable advantage in designing portable sets as well as in the six to eight-tube combinations which are coming more and more into use.

It is, of course, important that when a tube is designed for low filament power consumption, the operating characteristics should not be sacrificed; and the UV-199, in fact, shows a substantial improvement over the UV-201 altho consuming only one twenty-seventh the amount of power in the filament. This has been made possible by careful design of the electrodes, and by the perfection of factory processes for making and assembling the various component parts, so that in spite of a relatively short filament the space charge characteristics are better than in many larger tubes.

Figures 4 to 7 show some of the usual characteristics of the UV-199 and UV-201-A, and for comparison, the corresponding curves on the UV-201 are given.

In general, the UV-199 may be used in any of the usual receiving tube circuits, and requires no special adjustments other than suitable filament voltage control. On account of the low filament current, the rheostat resistance must be considerably higher than is required by the older one-ampere filaments. For example, a single tube operated from dry cells requires a thirty-ohm rheostat.

As a detector, the UV-199 operates most satisfactorily with approximately 40 volts on the plate altho critical adjustment of plate voltage is never required. Slightly better detector action may be obtained at 60 volts, but since the grid return is normally connected to the positive side of the filament, causing the mean grid potential to be slightly positive, the plate current becomes excessive at the higher plate voltage.

As an audio frequency amplifier, the tube may be used with plate voltages up to 100 if suitable negative grid bias is provided. This bias is approximately the same as is required by any amplifying tube which is expected to operate with comparatively high input voltages, and varies from 3.0 volts at 60 volts plate to 6.0 volts at 100 volts plate. The most common conditions for operation are 80 volts plate and 4.5 volts grid. This combination allows reasonably distortionless amplification up to the amount

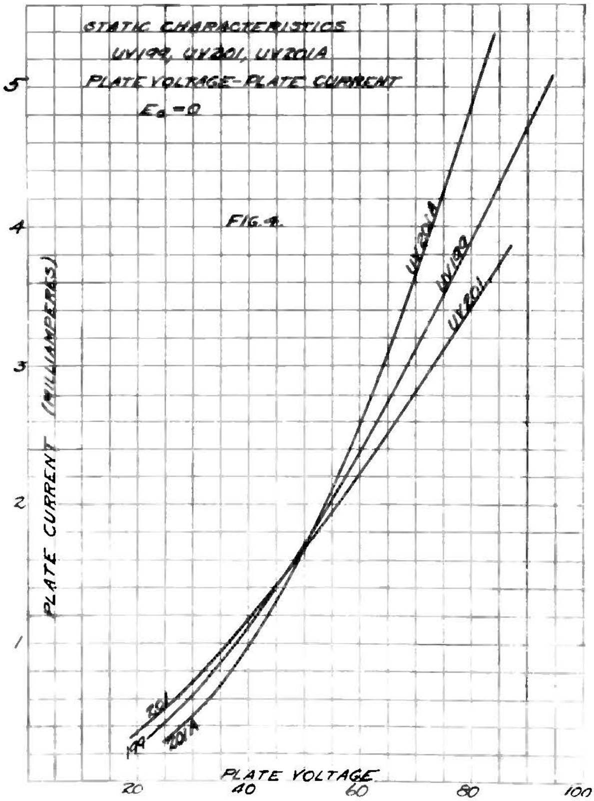

FIGURE 4

of power required to operate a loud speaker, and at the same time does not cause excessive drain from the plate battery. For head telephone reception, the higher plate voltages are unnecessary and very satisfactory results may be obtained at 40 volts. In this case a separate grid battery is unnecessary since the small bias obtained in the usual way by utilizing the voltage drop in the filament rheostat is sufficient. The purpose of this bias is to raise the input impedance of the tube to the point where it ceases to affect the terminal grid voltage, in other words to allow the total voltage induced in the secondary of the interstage transformer to be applied to the grid without loss in the windings of the transformer. A fraction of a volt is usually sufficient for this purpose.

The small elements and base of the UV-199 result in relatively low internal capacities, approximately 40 percent less than corresponding values for the UV-201. This feature is of particular importance when the tube is used in certain radio frequency amplifying circuits, and the utilization of the advantage of the low tube capacity is aided by the location of the grid and plate pins diagonally opposite from each other instead of adjacent, as in previous tubes. This arrangement allows short and direct connections from the tube socket to the interstage transformers or reactors. Since a grid bias other than the rheostat drop is seldom used on radio frequency amplifier tubes, and since the input voltages on the tubes are small, the most satisfactory plate voltage is usually about 40 volts.

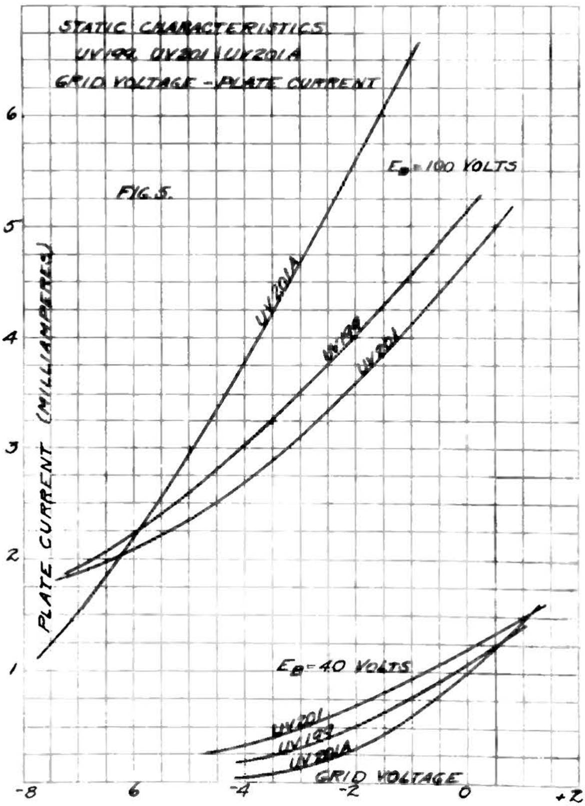

FIGURE 5

As has been mentioned before, the UV-199 is an example of a tube design in which the cathode is necessarily short, being about half the length of the UV-201 filament. In spite of this, excellent operating conditions have been obtained by careful arrangement of the other elements. In a tube of cylindrical construction, the space charge relation is such that the plate current at a given plate voltage is directly proportional to the effective length of the electrode structure and is inversely proportional to a function of the grid and plate diameters. Therefore, the mutual conductance of the tube, which is perhaps the best single measure of the effectiveness of the tube as an amplifier, is proportional to these same functions.

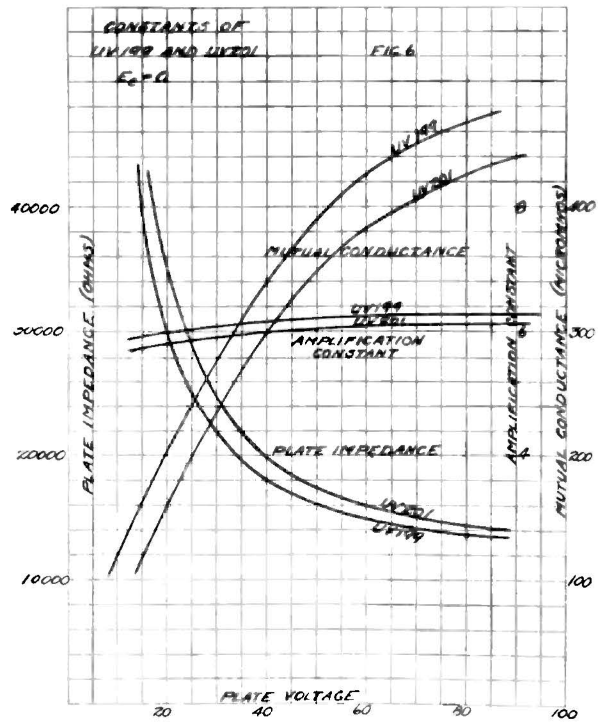

FIGURE 6

Similarly in a tube having planar structure, the mutual conductance is proportional to the effective area of the structure and inversely proportional to a function of the grid-filament and plate-filament distances.

The UV-201-A, while not having, strictly speaking, a planar structure, does owe its high mutual conductance to the large areas made effective by a long filament. The spacings, while comparatively small, are not as small as in the UV-199. This tube was designed to replace the UV-201 and besides requiring only 0.25 ampere as compared with 1 ampere for the UV-201, it has other marked advantages which are principally due to the desirable characteristics of the X-L filament.

The rated filament voltage of the UV-201-A is 5.0 volts, so that the tube can be used in sets designed for the UV-201 and the filament can be operated in parallel with the UV-201 filament. However, the average electron emission at this voltage is about 45 milliamperes, which is in excess of what is ordinarily needed in a receiving tube, and for this reason, it is often possible to secure excellent results with 4.0 volts or even less on the filament, particularly when 40 volts or less are used on the plate.

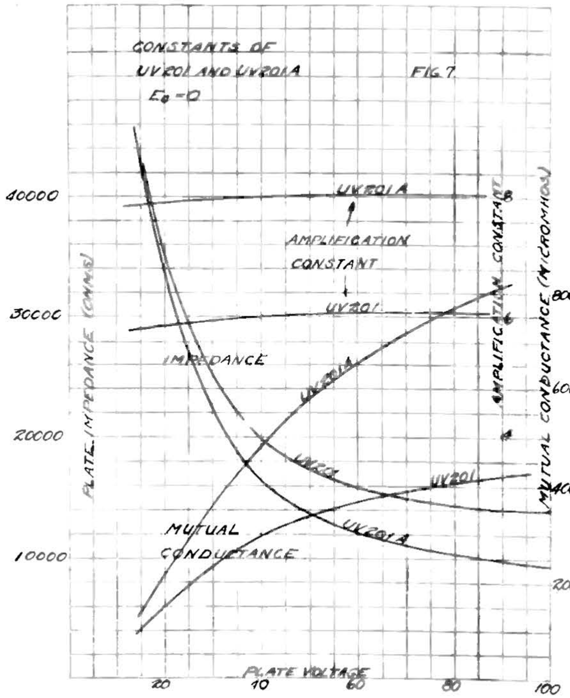

FIGURE 7

Figure 8 gives an interesting comparison of the total electron emission and the electron emission efficiency of the UV-201 and UV-201-A filaments. The great advantage of the X-L filament is shown by the fact that at normal voltage its efficiency is over twenty times as great as that of the older tungsten filament. Extensive life tests have shown that this high emission does not gradually decrease as the tube is run, but remains essentially constant until just before the end of life.

In determining the amplification constant and the plate impedance of the UV-201-A, there were evidently two ways of making use of the large electrode areas. First, the plate impedance could have been lowered, keeping the amplification constant the same as in the UV-201, or second, the amplification constant might have been raised, and the plate impedance left unchanged.

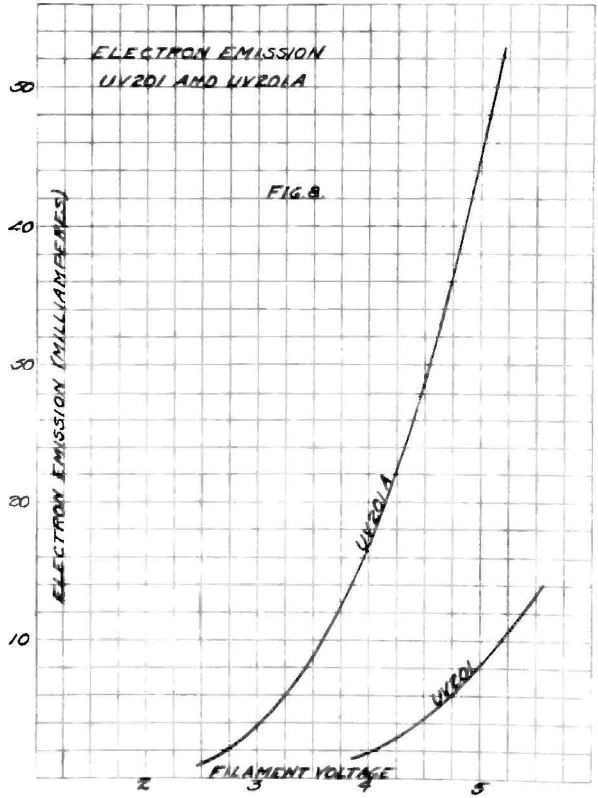

FIGURE 8

The design chosen represents a combination of these two possibilities as the amplification constant has been raised from 6 to approximately 8, and the plate impedance at 40 volts has been lowered from 20,000 ohms to approximately 16,500 ohms. The higher amplification constant serves to increase the ratio between output and input voltages, while the lower impedance aids in producing uniform amplification for all frequencies, and so reduces distortion.

The plate and grid voltages required by the UV-201-A are the same as for the UV-199 except that when the UV-201-A is used as an amplifier, the plate voltage may be increased to 120 volts without danger of overload. In this case a negative grid bias of 7.5 to 9.0 volts should be used.

On account of the high electron emission and high mutual conductance of the tube, it is especially suited to operation of loud speakers and the power output which may be obtained at a given input voltage is over twice as great as from the UV-201.

The detector action is noticeably good for a tube of the high vacuum type, due in part to the high mutual conductance. The usual conditions for detection are 40 volts on the plate, grid leak resistance of 2 to 10 megohms, and a grid condenser of 0.00025 microfarad capacity with the grid return connected to the positive side of the filament.

One other improvement which is due to the use of the X-L filament appears in both the UV-199 and UV-201-A tubes—the almost complete elimination of tube noises. These noises in tungsten filament tubes may ordinarily be divided into two classes, a crackling noise which is characteristic of high temperature filaments, and a hissing or frying noise which is due to small traces of gas in the tube. The low operating temperature of X-L filaments of course eliminates the first class entirely and the high vacuum renders the second class almost negligible.

While the various characteristics which have been illustrated are sufficient to enable prediction of the performance of these tubes in any amplifying circuit, it is of interest to compare some of the characteristics of the tubes under typical operating conditions. Figures 9 and 10 illustrate the alternating output current and output power of the UV-199 and UV-201-A with a 20,000 ohm resistance load in the plate circuit. These curves have been plotted from actual measurements, altho they check closely the curves calculated from the familiar amplification equation.

$$I_p = \frac{\mu E_g}{R_i + R_o}$$

where I_p = alternating plate current (root-mean-square)
μ = voltage amplification constant
E_g = voltage applied to grid (root-mean-square)
R_i = internal plate impedance of tube
R_o = load resistance.

No attempt is made here to determine the relation between the amplitude of the fundamental component of the output current and the amplitude of any harmonics which may be present, but practice has shown that any distortion due to introduction of harmonics in the output is slight within the range of input voltages shown.

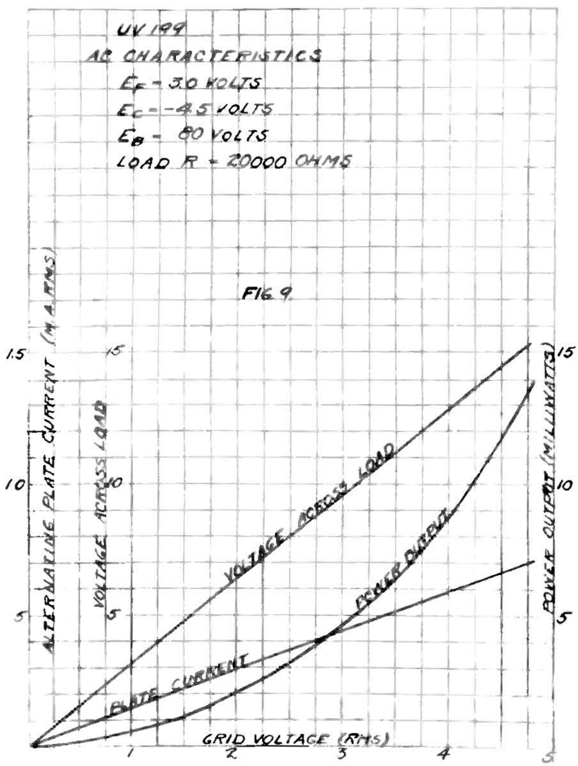

FIGURE 9

A brief consideration of the usual way of rating amplifier tubes calls attention to the need of a uniform method of rating, which will give the user of the tube or the designer of auxiliary apparatus a quantitative idea of the capabilities of the tube in the circuit for which the tube is best suited. The erroneous impression once existed, and still does to some extent, that the amplification constant of the tube was a measure of the actual amplification given by the tube in any circuit. The term itself is perhaps a misnomer, and the English term "voltage factor" would appear more suitable.

Recently the use of mutual conductance as a tube rating has come into use. This, of course, gives a much better idea of the capabilities of a tube than does the amplification constant, but still does not furnish nearly all of the quantitative information which is desirable. For example, a loud speaker may have a certain impedance and require a certain amount of power to give satisfactory intensity. The mutual conductance alone does not show whether the tube in question can furnish this power, because it is defined on the basis of differential quantities, while under actual operating conditions, the current and voltage amplitudes may be considerable.

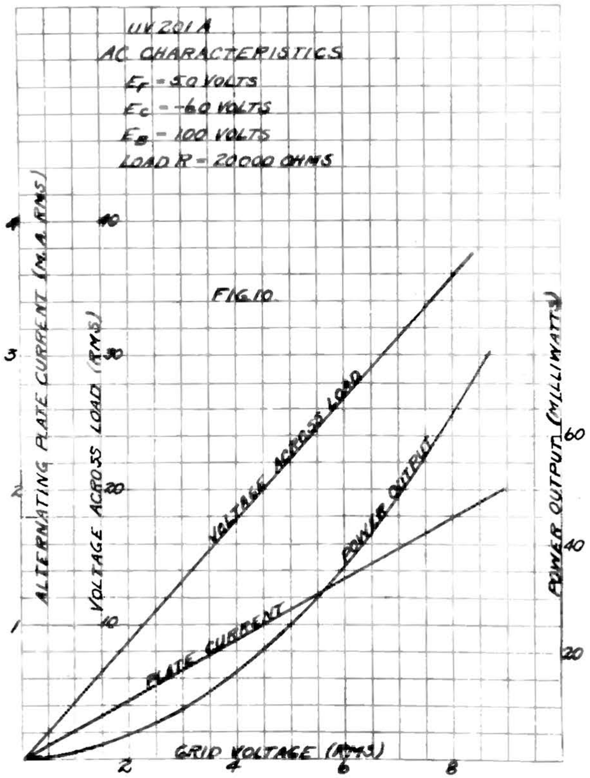

FIGURE 10

Hence, it would seem that the rating of the tube should include some such quantity as the power output in milliwatts or millivolt-amperes per volt squared input at rated plate and grid voltages, and also the maximum input voltage which can be handled without noticeable distortion, assuming the load conditions most suitable for the tube. Then knowing the amount of power actually required, it would become a simple matter to predict the size of tubes and number of stages of amplification required.

Such a method of rating would go far in placing the receiving tube and its associated apparatus on the same substantial basis as other older and better standardized sorts of electrical equipment.

SUMMARY: The operating characteristics of radiotrons UV-199 and UV-201-A are given, together with the general considerations which determined the design of these tubes. A method of rating receiving tubes (in place of mutual conductance) when appreciable undistorted output is required, as for loud speaker operation, is discussed.