A HIGH-POWER OUTPUT TUBE—THE 250

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THE 250-type power tube was developed to fill a definite place in the field of radio reception, that of a tube which would deliver a large output to a loud speaker without appreciable distortion and with a grid swing or input signal strength readily obtainable with available apparatus.

The tube as finally developed has been found to meet this requirement well. A filament of the coated type is used which insures an ample electron emission with a moderate filament power consumption. The plate resistance is inherently low, a plate voltage of only 450 being required for full power output.

The general characteristics of the tube were determined according to its intended use as a power amplifier. Consequently it is not well adapted for use as an oscillator or voltage amplifier. The use of a coated filament together with the low amplification factor, which were found to be very desirable features, are not ideal from the standpoint of oscillator tube design, although the tube can be used as an oscillator in certain cases.

Before going into the details of the development of the 250 it may be of interest to consider some of the factors which have made the production of tubes of high power output desirable.

A very few years ago about the only kind of loud speaker in general use was of the horn type operated by a vibrating metallic diaphragm. The characteristics of this type of loud speaker were such as to accentuate greatly the higher frequencies and to suppress the lower frequencies. Recent developments, however have made it possible to reproduce frequencies well below 100 cycles with practically normal relative intensity.

A general idea of the relatively large amount of power that the output tube must handle in order to reproduce the lower frequencies adequately may be secured by examination of a curve in the paper "An Analysis of the Voice-Frequency Range" by I. B. Crandall and B. MacKenzie, *Bell System Technical Journal*, July, 1922. This curve shows in a striking way that in normal speech the power associated with the low frequencies is enormously greater than that associated with the high frequencies.

The same general relation may be observed readily by the use of an oscillograph or a milliammeter inserted in the output circuit of a receiving set. Low notes at intensities which are not particularly striking to the ear are seen to have amplitudes many times greater than those of the higher notes. This effect is evident whether speech, vocal music, or instrumental music is being studied.

A little thought will show that the use of tubes designed for low power output in sets equipped with transformers which pass the low notes will, unless the output of the set be very much reduced, result not only in bad distortion of the low notes, but also in many cases the complete obliteration of the high notes.

Table I shows the power output, grid swing and other characteristics of the tubes which have been developed from time to time in order to meet the growing demand for a larger power output.

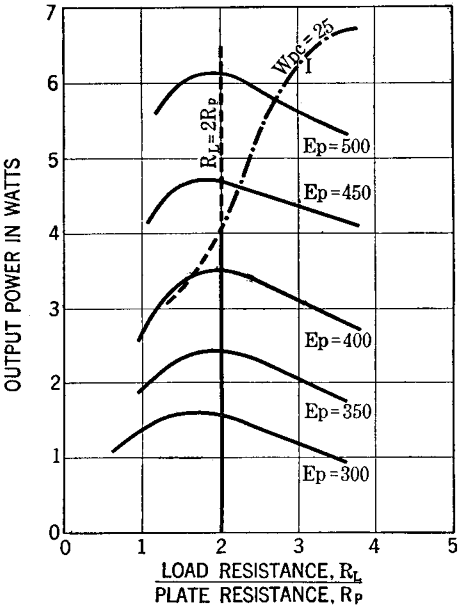


Fig. 1

Analysis of Various Types

OF THE tubes listed the 199- and 201A-types are general purpose tubes, the others were designed primarily as output tubes. The 112A, however, while distinctly an output tube, has a high amplification constant which makes it useful as a voltage amplifier and detector as well. The 210 also has a fairly high amplification constant which facilitates its operation as an oscillator; but as a power output tube, although the plate voltage is high, the grid swing is only 35 volts and the power output is low compared with that of the 250.

The power output of the 250 is about ninety times as great as the output of the 201A which originally was used as the output tube of most storage-battery-operated sets at the time when the horn-type loud speaker was common.

Most people readily appreciate the advantages of increased volume when it has been demonstrated that this can be obtained without distortion.

With the relatively poor fidelity of reception that was formerly obtained, people having a well-developed sense of musical harmony, generally preferred to use low volume due to their unconscious objection to the distortion at full volume. In many cases it was contended that the music was too loud although it was the distortion accompanying high volume which was the real source of the objection. With the best equipment now available most people, after becoming accustomed to the fact that good volume may be obtained without distortion, prefer to have their sets adjusted for a more normal volume.

Development of the 250

AT THE time work was started on the development of this tube it was decided to limit the plate potential to 450 volts; and in order to keep the physical dimensions within limits that would permit the use of the standard UX base the plate was limited to a size which was estimated to be able to dissipate 25 watts without an unduly high temperature rise; the blackening of the plate makes a larger heat dissipation possible, due to the resulting increase in thermal emissivity. It was further estimated that with one stage of audio-frequency voltage amplification, using equipment now available, a grid swing of 80 volts peak could be obtained.

With these factors fixed as a starting point, several tubes were made up having amplification constants ranging from 2.5 to 8.3.

A set of static characteristic curves was then taken for each tube and from these was calculated the maximum undistorted power output that could be obtained, using in each case the optimum value of load impedance and grid bias. The plate current in all cases was limited to 55 milliamperes, the value corresponding to a heat dissipation of 25 watts. The maximum second-harmonic distortion permitted in these calculations was five per cent., a value which has been assumed generally to be inappreciable in effect on reproduction.

The methods of calculating the maximum power output from a set of static characteristic curves have been described in detail by others ("Design of Non-Distorting Power Amplifiers" by E. W. Kellogg, *Proceedings* A.I.E.E., Feb., 1925, and "Output Characteristics of Amplifier Tubes" by J. C. Warner and A. V. Loughren, *Proceedings* I.R.E., Dec., 1926); a brief outline of the procedure will be sufficient here.

For a moderate plate voltage at which the heat loss at the plate is below the maximum allowable, the best load impedance is equal to twice the tube impedance. That this is true has been shown theoretically by W. J. Brown ("Symposium on Loud Speakers," *Proceedings of London Physical Society, 36*, Part III, April, 1924) and was verified experimentally by Hanna, Sutherlin, and Upp preceding their development of the 250.

An actual determination of the proper load impedance and grid bias for maximum power

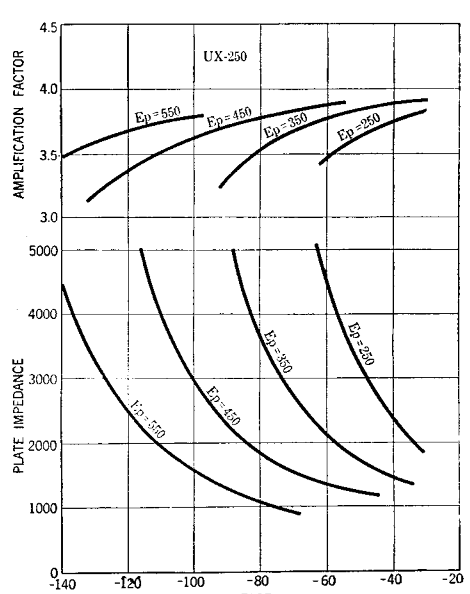


Fig. 2

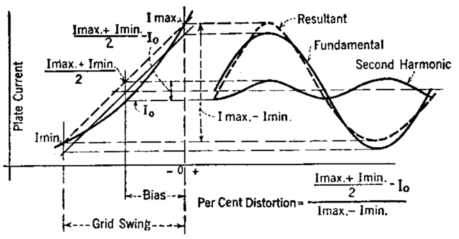


Fig. 3

output at a given plate voltage involves a considerable amount of cutting and trying, due in part to the fact that the tube resistance varies with plate current. The most straightforward procedure is probably that of taking points on the plate-current curves, at the desired plate voltage, corresponding to several values of plate current and determining for each the load impedance that will give the maximum power output without excessive distortion, Fig. 6.

The power output in watts for any dynamic curve is given by:

$$W = \frac{(I\ max - I\ min)\ (E_b\ max - E_b\ min)}{8}$$

The minimum plate current is that where the negative grid swing is equal to the fixed grid bias.

When this nas been done it will be found that the ratio of the load resistance to the plate resistance, R_l/R_p becomes less as the plate current is increased or the grid bias is decreased; and that the maximum power output is obtained at a point where the ratio is equal to approximately two.

If, however, the plate current at this point is greater than the maximum allowable, the output corresponding to the maximum plate current must be used, the load impedance being in this case greater than twice the tube impedance.

Fig. 3 illustrates one step in the procedure, that of determining the second-harmonic distortion due to the curvature of the dynamic characteristic. The formula used is—Distortion equals $\frac{\frac{1}{2}\ (I\ max + I\ min) - I_o}{I\ max - I\ min}$ and gives the amplitude of the second harmonic component as a decimal of the amplitude of the fundamental.

Fig. 1 shows the relation between the power output obtainable at various plate voltages and the load impedance. The curve marked $W_{DC} = 25$ shows the limiting values as determined by a plate dissipation of 25 watts. This curve also shows that when the plate current becomes the limiting factor, a load resistance greater than twice the tube impedance should be used. For example, at $E_p = 500$ the load resistance should be 2.8.

In Fig. 4 are summarized the results of the work done on the tubes of different amplification constants. Curve 1 shows how the maximum undistorted power output varies with amplification constant, the dotted portion indicating how the output would increase if the plate dissipation were not a limiting condition. Curve 2 shows the corresponding grid swing required in peak volts.

It will be seen that the grid swing required to operate the tube at full output becomes rapidly greater as the amplification constant decreases. Also it will be noted that the power output reaches a maximum and then decreases. Both of these conditions are due to the fact that at low values of amplification constant the grid becomes less effective in controlling the electron flow to the plate. This results is an excessive curvature of the plate-current characteristic which gives a correspondingly limited working range when the maximum distortion permitted is fixed at a low value.

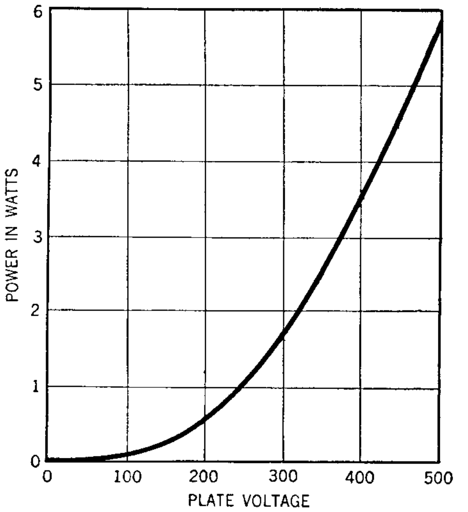


Fig. 5

Table I—Power Output of Various Tubes

TYPE TUBE	Ep	Eg*	MU	Rp	FILAMENT	OUTPUT MILLIWATTS
199	90	−4.5	6.6	15,500	(Thoriated)	7.6
	90	−7.15		18,000	(Tungsten)	17.5
120	135	−22.5	3.3	6600	(Tungsten)	105.
201A	90	−4.5	8.0	11,000	(Tungsten)	14.
	135	−9.0		10,000		55.
112A	180	−13.5	8.0	4700	Coated	275.
171A	135	−27.	3.0	2200	Coated	330.
	180	−40.5		2000		720
210	425	−35.0	7.5	5400	(Thoriated) (Tungsten)	1550
250	350	−58.5	3.8	1900	Coated	2450
250	300	−67.5		1800		3500
250	450	−80.0		1800		4600

**To negative end of filament.*

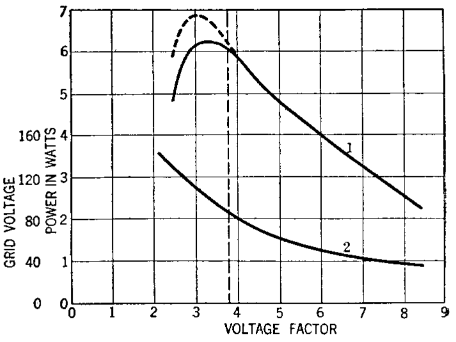


Fig. 4

Fig. 5 shows the relation between maximum undistorted power output and plate voltage. Over a limited range the power output may be taken as proportional to the square of the plate voltage.

Figs. 2 and 7 show the static characteristic curves.

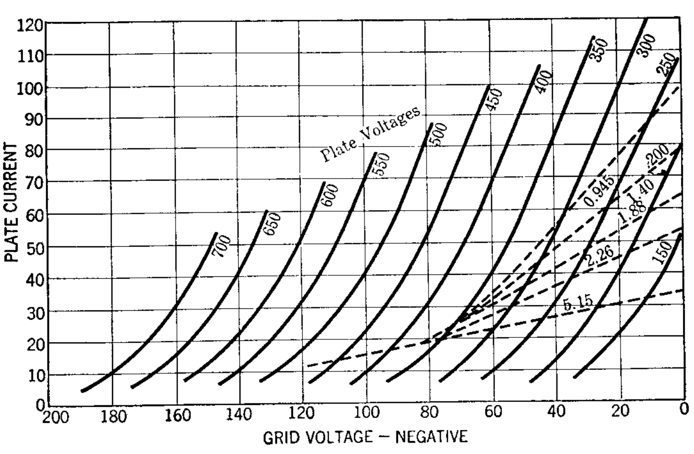
The dotted curves of Fig. 7 correspond to a filament voltage of 7. The maximum undistorted power output is in this case 4.27 watts, a grid swing of 78 volts being required. It will be seen that there is little loss in maximum power output or in sensitivity when the tube is so operated, and it is, in fact, frequently preferable to operate the tube slightly below normal filament voltage in order to protect it from over voltage due to line fluctuations when, as is usually the case, it is operated on alternating current. Careful control of filament voltage will help materially in securing satisfactory operation and long life.

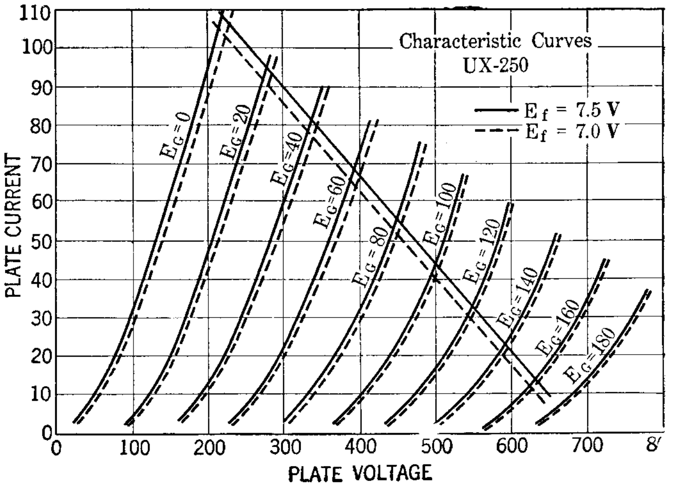
The inter-electrode capacities are: from grid-to-plate 9 mmfd., from grid-to-filament 7 mmfd., and from filament-to-plate 5 mmfd.

Operation of the 250

THE 250, requiring for full power output a grid swing of 80 volts, has been designed to be operated from a detector followed by one stage of audio-frequency amplification.

By the use of a high plate voltage on the detector, and the plate-current method of detection the intermediate stage of audio-frequency amplification may be omitted. This will tend to improve the quality, due to the elimination of one audio transformer, as well as to the improved detector action when plate-current detection is used. This, of course, will require rather high radio-frequency amplification preceding the detector. The power supply for use with an amplifier employing a 250-type output tube should use two 281-type half-wave rectifier tubes in a full-wave circuit.





Above: Fig. 6 Right: Fig. 7