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HIGH AUDIO POWER FROM RELATIVELY SMALL TUBES*

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Introduction

SINCE the early use of a headphone at the base of a horn for a loud speaker, the demand for higher output power from an audio system has steadily increased. This demand for higher power has been met mainly by the development of tubes for higher plate dissipation and lower plate resistance. As a result of such development, the 245-type tube is the most commonly used vacuum tube for output systems. Other output tubes are very closely related to the 245 tube in so far as amplification constant and plate resistance are concerned and differ principally in rated plate dissipation and plate voltage for various output levels.

These low plate resistance tubes developed primarily for audio output systems are intended to operate as class "A" amplifiers. To increase the output of such systems, it is necessary to resort to higher plate dissipation and usually to higher plate voltages, both of which are expensive to incorporate in the construction of a vacuum tube.

The purpose of this paper is to present a method by which audio outputs five to ten times the usual output of a tube of a given size may be obtained with the same plate voltage, lower average plate dissipation, and no serious effects on the tube. The above results are obtained by using the tubes in such a manner that advantage is taken of the essential features of the class "B" amplifier.

An amplifier of this type[1] was developed for use as a source of high audio power for plate modulation of a broadcast station and may be applied to any system requiring a relatively high audio output from a minimum of equipment.

A discussion of the class "A" and class "B" amplifiers with diagrams illustrating the operation of each class will be given to set forth some of the essential operating features of these amplifiers.

Class "A" Amplifiers

The class "A" amplifier as indicated above, is used almost exclusively for audio output systems in which the output is aperiodic. This

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[1] Loy E. Barton, "A plate modulation transformer for broadcasting stations", *University of Arkansas Engineering Experiment Station Bulletin* No. 8.

type of amplifier is also used in radio-frequency amplifiers in which the output of plate circuit is tuned for selecting the desired frequency.

The diagram in Fig. 1 represents the instantaneous plate and grid voltages and plate current for a condition of essentially maximum

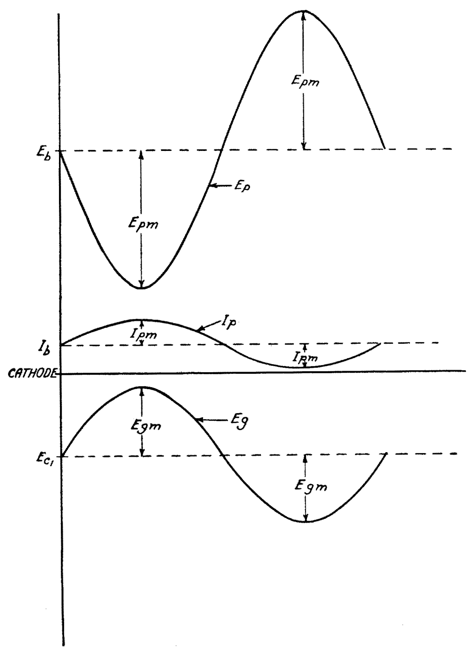

Fig. 1—Diagram of instantaneous voltages and currents for a class "A" amplifier.

output power of a class "A" amplifier into a tuned or untuned circuit, with a resistance load expressed in terms of the values indicated on the diagram as:

$$\frac{E_{pm}}{I_{pm}} = R_p \text{ or load resistance.}$$

In which

$$E_{pm} = \text{maximum a-c plate voltage} \tag{1}$$

$$I_{pm} = \text{maximum a-c plate current.}$$

The plate voltage is represented by the broken line E_b, the plate current, by the broken line, I_b, and the grid voltage (normally negative) by the broken line E_{c1}.

The power in the above case for sinusoidal waves is limited by the minimum plate current and may be calculated as follows when I_{pm} is somewhat less than I_b.

$$0.707E_{pm} \times 0.707I_{pm} = \text{power output} \tag{2}$$

$$E_b \times I_b = \text{power input.} \tag{3}$$

The plate circuit efficiency from (2) and (3) is given by the following relation:

$$\frac{0.5\,E_{pm}I_{pm}}{E_bI_b} = \text{efficiency.} \tag{4}$$

If E_{pm} approaches E_b as a limit and I_{pm} approaches I_b as a limit, the efficiency is 50 per cent for sine wave outputs.

The above expression for power output is independent of the required grid swings and internal plate resistance of the tube as long as a particular grid swing will cause the same maximum pulsating plate current through a resistance equal to the calculated value of R_p. In order that I_b equal a constant for tubes differing only in plate resistance and amplification factor, E_{c1} must be nearer zero for high plate resistance tubes and the grid potential may need to swing considerably positive to obtain a constant a-c plate current maximum I_{pm}. It is obvious that power will be necessary to maintain an undistorted voltage wave on the grid when it swings positive.

Load resistance curves for two tubes as class "A" amplifiers, differing only in plate resistance and amplification constant, are given in Figs. 2 and 3. These load curves are used in preference to the usual plate voltage plate current family of curves for output calculations because certain features of the class "A" amplifiers are revealed that are not commonly recognized and this type of curve is particularly adapted to output calculations for the class "B" audio amplifier. These curves are drawn for the same load resistance in a circuit as shown in the figures and the plate current is adjusted to 20 ma in the two cases by the proper grid voltage with 400 volts on the plate. The voltage drop in the load resistance R_p due to the plate current is compensated for by increasing the plate voltage supply. Referring to Fig. 1, the plate voltage represented by E_b is 400 volts and the plate current represented by I_b is 20 ma. Therefore, the plate dissipation for each of the two tubes is the same.

The grid potential is varied about the voltage line required to obtain 20 ma with 400 volts on the plate and the corresponding plate current is plotted. The load resistance R_p is adjusted to such a value that the maximum increase in plate current over the straight portion of the curve is equal to approximately the maximum plate current decrease for equal grid swings about the starting grid potential. It will be noted that in each case the grid must be driven positive if the above plate current condition is obtained. If the grid cannot be driven positive, the grid voltage for the 20 ma plate current for the given plate dissipation would have to be more negative so that a grid swing to zero will give the above plate current change. Such a bias will require a tube of the same type as the two tubes chosen but with a lower plate resistance and lower amplification constant.

It will be noted in the above cases, that the maximum plate current change above and below the 20-ma line is approximately 18 ma before the curve bends appreciably at either end. Therefore, the a-c power dissipated in R_p, which is 15,000 ohms for all cases, is obtained from (1) and (2).

$$0.5\ I_{pm}^2 R_p = 2.43 \text{ watts.} \tag{5}$$

In which $I_{pm} = 18$ ma

$$R_p = 15{,}000 \text{ ohms.}$$

The plate dissipation at no signal and input power with signal is:

$$E_b\ I_b = 8 \text{ watts.}$$

Therefore, the plate circuit efficiency for the above case is:

$$\frac{2.43}{8} = 30.3 \text{ per cent.}$$

In Fig. 2, the grid swings to a peak of 10 volts positive with a peak grid current of 3 ma,which represents a minimum instantaneous input resistance of approximately 15,000 ohms. This input resistance is based upon the peak grid current for the required voltage swing from the starting grid potential. Therefore, the peak instantaneous input power required of the driver is the product of grid voltage swing and the maximum grid current. Since the resistance of the input circuit over most of the cycle is very high and the resistance represented by the grid current curve is approximately 3000 ohms, the driver resistance must be sufficiently low to deliver the above peak power over a part of the input cycle without seriously affecting the wave shape of the input voltage. It will be noted that at 18-ma increase in plate current for this tube, the curve is still straight so that a power slightly above the 2.43 watts may be obtained if a slightly higher resistance is used.

In Fig. 3, the grid swings to a peak of 20 volts positive with a peak grid current of approximately 7.5 ma, which represents a minimum instantaneous input resistance of about 3000 ohms as calculated above, and the resistance from the grid current curve is approximately 2900 ohms. The peak input power is about the same as required by the tube

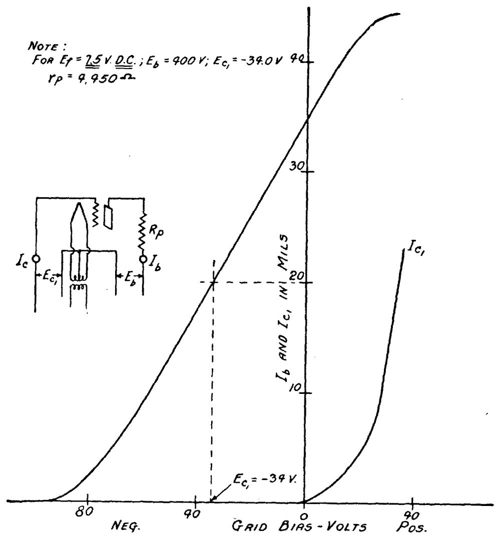

Fig. 2—Load characteristic of the UX-210 as a class "A" amplifier.

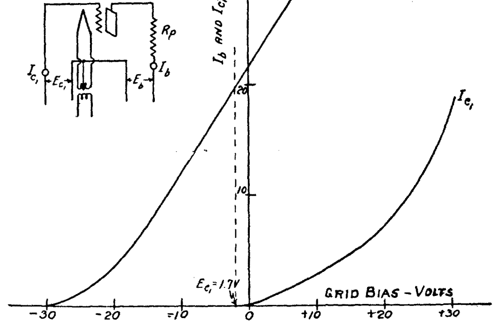

Fig. 3—Load characteristics of the UX-841 as a class "A" amplifier.

in Fig. 2, but because of the fact that the power is required over a larger part of the input cycle, it is somewhat easier to supply an undistorted wave to the grid.

If the tubes represented by Figs. 2 and 3 are operated in a push-pull amplifier connected as indicated in Fig. 4, the output transformer primary impedance from plate to plate is 30,000 ohms, the power output will be doubled and the problem of driving the grids becomes less difficult because the input resistance is more nearly constant over the entire cycle. This statement applies particularly to two output tubes operating at low bias so that one grid or the other requires grid current at all times. This flow of grid current through one side or the other of the input transformer secondary reflects to the primary of this transformer an essentially constant impedance into which the driver tube works.

It will be noted from Figs. 2 and 3 that the slope of the grid-current curve is nearly the same for the two types of tubes. This

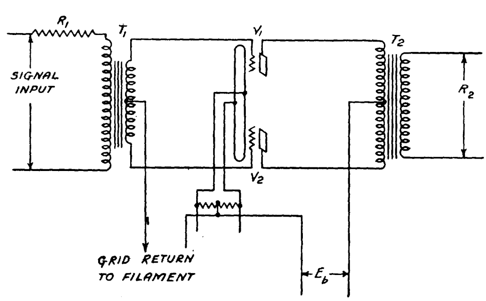

Fig. 4—Circuit for push-pull class "A" amplifier or for class "B" audio amplifier.

means that the effective series resistance of the source driving the amplifier must be considerably below the minimum value of input resistance if it varies considerably over the cycle as indicated in Fig. 2. Since the grid voltage swing for the tube in Fig. 2 is great, a driver capable of supplying considerable power must be used. Therefore, the higher amplification constant tubes are much more desirable if the grids are to be driven positive.

Since the input systems for the above tubes operating in a push-pull manner must be low impedance, a lower load resistance may be used which in turn, permits higher plate-current swings at the expense of added distortion, but with no greater plate dissipation. This increased plate current permits a much greater power output with a permissable increase in distortion.

From the above discussion, it is evident that for an undistorted input wave, the output load resistance for maximum power output is a function of the plate current and plate voltage and is essentially independent of plate resistance and amplification constant provided the grid swing is not limited. For example, in the above cases, the maximum plate current increase was 18 ma through a resistance of 15,000 ohms. The increased drop in the resistor is the product of these values which is 270 volts and the voltage at the plate for the increased current is only 130 volts. Consequently, a class "A" amplifier power output is limited essentially by plate dissipation and plate current change so that the value of load resistance is determined by the minimum plate voltage required at the maximum positive swing of the grid to permit a plate current of approximately 190 per cent of normal plate current.

The plate resistance was measured for each of the tubes under the conditions of bias and plate voltage as indicated above and is noted in each figure. Although the maximum output power into a definite load resistance is about the same for both the tubes, the regulation of the amplifier output under varying load resistances is a function of the load resistance and the internal plate resistance of the tube. Therefore, if a load resistance for optimum power output is used and the excitation is constant, the output voltage will be nearly constant for very low resistance tubes for small changes in load resistance. If, however, the plate resistance in the above case is very high with respect to the same load resistance, the output current will be nearly constant for small changes in load resistance.

Class "B" Amplifiers

A diagram similar to Fig. 1 is shown in Fig. 5 for the class "B" amplifier. The grid potential E_{c1} for this type of amplifier is such that the plate current without signal is essentially zero as represented by the broken line I_b. No plate current flows during the negative swing of the signal but the plate current is essentially proportional to the instantaneous value of the grid voltage on the positive swings. Therefore, the output voltage is essentially proportional to the input voltage during the positive half of the input cycle and the peak plate current is limited only by the emission, the load resistance, and plate voltage.

The load resistance for this amplifier is calculated as with the class "A" amplifier which is:

$$\frac{E_{pm}}{I_{pm}} = R_p \text{ load resistance.}$$

The power output for a condition as represented is:

$$\frac{0.707\, E_{pm} \times 0.707\, I_{pm}}{2} = \text{power output.} \tag{6}$$

The efficiency of this amplifier is given by:

$$\frac{\dfrac{0.707\,E_{pm}\times 0.707\,I_{pm}}{2}}{\dfrac{0.637\,I_{pm}\,E_b}{2}}=\text{efficiency}. \qquad (7)$$

If E_{pm} approaches E_b as a limit, then the efficiency becomes 78.5 per cent for half-sine-wave outputs.

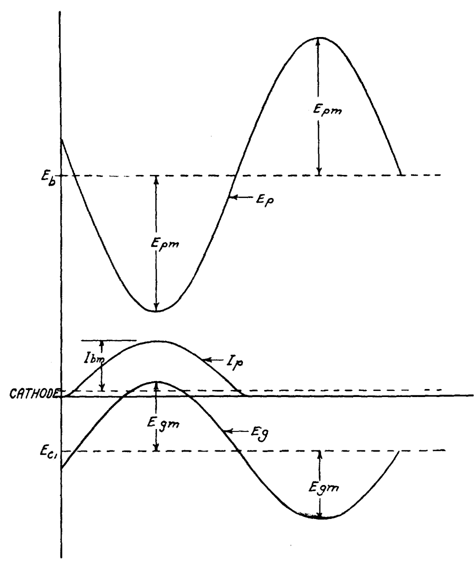

Fig. 5—Diagram of instantaneous voltages and currents for a class "B" amplifier.

If the output is tuned to the frequency of the input, the output voltage or E_b will be nearly sinusoidal but if the output is not tuned, only the half wave during plate current flow will be sinusoidal. As stated above, the maximum plate current I_{pm} is only limited by emission, load resistance, and plate voltage. Therefore, the value of the above expression for power may be several times the output power of a tube limited in plate current swing when operating as a class "A" amplifier. This type of amplifier with tuned radio-frequency output is commonly used as the output amplifier for radiophone transmitters and has a plate circuit efficiency on peak outputs of 50 to 70 per cent.

Class "B" Audio Amplifiers

The class "B" amplifier as explained above, is a tuned radio-frequency system and is not useful as represented for an audio output amplifier. However, if advantage is taken of the fact that the output during one-half of a cycle into an untuned load is essentially sinusoidal for a sinusoidal input, another similar tube may be used in such a manner that an undistorted output may be obtained. The circuit for such an amplifier is shown in Fig. 4.

A typical push-pull output circuit is used for the class "B" audio amplifier with certain deviations from the commonly used class "A" push-pull amplifier. The grid return to the filament in Fig. 4 is connected through the correct potential to limit the plate current of the tubes V_1 and V_2 to essentially zero. The impedance ratio of the input transformer T_1 is such that the reflected resistance on the primary, when the grids of V_1 and V_2 are driven positive, is high compared to the internal resistance of the driving source represented by R_1 as explained for class "A" amplifiers when the grids are driven positive. This relation of the internal resistance of the driver compared with the minimum reflected resistance of the grids of V_1 and V_2 reduces the distortion of the voltage applied to the grids of these tubes.

When the grid of one tube swings in a positive direction from its d-c value, the plate current for that tube increases with the swing and flows through one-half of the output transformer primary. The output voltage for this half cycle bears a linear relation to the input voltage. At the beginning of the next half cycle, the above tube becomes idle because its grid becomes more negative and the other tube functions in a manner similar to the first tube, except the plate current flows in the other half of the output transformer primary and the output voltage is 180 degrees out of phase with the first half wave. These two output waves then will form a wave similar to the input wave with no distortion if the plate current and grid voltage have a linear relation. This relation of plate current and grid voltage is not quite linear as will be seen from the grid voltage plate current curves, but by proper precautions, the distortion can be reduced to a point that is not objectionable.

It should be noted that the input transformer delivers current to the grids of the output tubes from only one side of the secondary at any particular instant which must be considered in the design of this transformer. It should also be noted that the entire output power must be transferred from only one side of the output transformer primary during each half cycle. Therefore, the load impedance the tube is working into is calculated as if only one tube is supplying the total power from one side of transformer primary but in calculating plate dissipation, each tube functions for one-half the time so that the total plate loss is divided between the two tubes.

The plate current input to the output tubes resembles a true full-wave rectified current, the frequency of which is double the frequency of the signal. Therefore, the power input to the plates of the output tubes is:

$$0.637\, I_{pm} E_b = \text{power input}$$

in which

$$I_{pm} = \text{peak plate current} \qquad (8)$$

$$0.637\, I_{pm} = I_b \text{ or average plate current.}$$

The output power from (6) is:

$$\frac{I_{pm}^2 R_p}{2} = \text{power output for two tubes} \qquad (9)$$

and,

$$\frac{I_{pm}^2 R_p}{1.274\, I_{pm} E_b} = \text{efficiency.} \qquad (10)$$

Load resistance curves similar to the load curves for class "A" amplifiers were taken for several tubes adapted to class "B" audio amplification. As was noted above, the plate current is not limited as in the class "A" amplifier so that a load resistance for maximum power output is such a value that the limit of emission is approached. The minimum instantaneous plate voltage and the allowable plate dissipation are also factors which determine the load resistance. No allowance for plate voltage drop due to the load resistance was made in taking data for the load curves because the plate current for zero signal is nearly zero.

The peak plate current at a point on the desired load curve which is within the permissible distortion limit is used to calculate the output power of two tubes operating as a class "B" audio amplifier. This value of peak plate current and the corresponding load resistance are used in (9) to obtain the power output of two tubes operating as a class "B" audio amplifier. The input plate power is calculated by using (8) and the plate circuit efficiency by (10).

The input resistance of the amplifier is more or less indefinite as with the class "A" amplifier with the grids driven positive, but a minimum value can be obtained from the grid current curves to indicate the input series resistance that may be permitted for a given distortion. The minimum input resistance is calculated from the maximum grid current and the voltage swing required for this current, however, the slope of the grid current curve must also be considered because if this resistance represented by the slope of the curve is low compared with the effective grid series resistance, considerable distortion will result This is especially true if the operating bias is considerably negative as it would be for the medium and low amplification factor tubes. If the grid current curve has a negative resistance, a condition for oscillation will occur over a small portion of the input cycle if the effective series input resistance is large compared with the negative resistance. A low negative input resistance produces an effect similar to a rattle and is not a harmonic of the input signal.

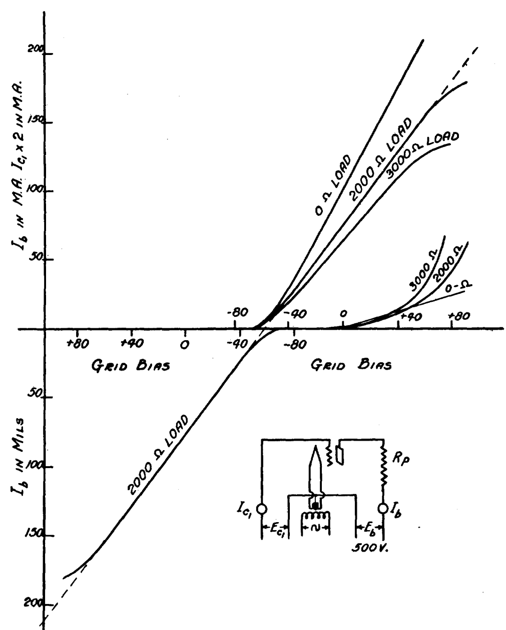

Fig. 6—Load characteristics of the UX-210 as class "B" audio amplifier.

The tubes used for the curves in Figs. 6 and 7 are the same tubes used respectively for the curves of Figs. 2 and 3. These identical tubes were used for the class "A" amplifier load curves and the class "B" audio-amplifier curves so that a direct comparison could be made in the operation of these amplifiers.

The standard UX-210 tube as represented in Fig. 6 has a peak plate current of approximately 170 ma without serious deviation from a line through the straight portion of the curve for the 2000-ohm load curve. Another load curve similar to the upper curve is drawn below the zero plate current line and with a reversed grid voltage scale. This curve represents another tube connected in a push-pull manner with the tube above the zero plate current line and is placed in such a position that a line drawn through the straight portion of the upper curve also passes through the straight portion of the lower curve. The point through which this line passes on the zero plate current axis is the proper bias to use for minimum distortion if the two tubes are similar. The above load is the load per tube during the time it operates so that the plate to plate impedance of the output transformer is 8000 ohms.

The above values of plate current and load resistance are used in (9) to calculate power output.

$$0.5\ I_{pm}^2\ R_p = 28.9 \text{ watts output}$$

Plate power input as calculated from (8) is:

$$0.637\ I_{pm}\ E_b = 54.15 \text{ watts input.}$$

The plate circuit efficiency is:

$$28.9/54.15 = 53.4 \text{ per cent.}$$

The plate loss for full power output is 25.25 watts for the two tubes and is essentially constant to an output power of about 30 per cent of the maximum below which it begins to decrease rapidly. This variation in plate loss with respect to the power output is obvious from (10) which indicates that the plate circuit efficiency is a direct function of the peak plate current.

The above calculations are based upon no distortion of the input sine-wave signal when the grid swings positive. Since the input resistance is a variable it is only possible to reduce the distortion to a practical minimum by the proper design of the driver. The peak grid swing for 170 ma in a 2000-ohm load is 75 volts positive from a bias of 58 volts or a total swing of 133 volts. The peak grid current is 15 ma so that the minimum input resistance is approximately 8800 ohms, and the peak instantaneous power is 2 watts which must be supplied without affecting the input wave seriously. The resistance as calculated from the slope of the grid current curve is approximately 5000 ohms.

The above information indicates that if only a small amount of distortion is permitted, the series input resistance to each grid should be approximately 20 per cent of the minimum input resistance or about 1000 ohms because the difference in the above resistances is great. If the effective input series resistance is the above value and two tubes having a plate resistance of 2000 ohms operating in push-pull are used to drive the UX-210 tubes, the resistance in series with the primary is 4000 ohms. Therefore, the impedance ratio from total primary of the input transformer T_1, Fig. 4, to each grid is 4 to 1 or a turn ratio of 2 to 1. The required grid voltage swing is 133 so that a primary voltage peak of 266 is required. A study of the UX-245 characteristics at normal voltages indicates that two of these tubes in push-pull will successfully drive the UX-210 tubes as class "B" audio amplifiers without serious distortion.

The same calculations as above may be made from the curves in Fig. 7 for the UX-841 tube which is a tube similar to the UX-210 except for amplification constant and plate resistance. So far as the power output is concerned, it can be seen that the output of two of these tubes is approximately the same as for the UX-210 tubes and the efficiency is essentially the same. However, the bias required for

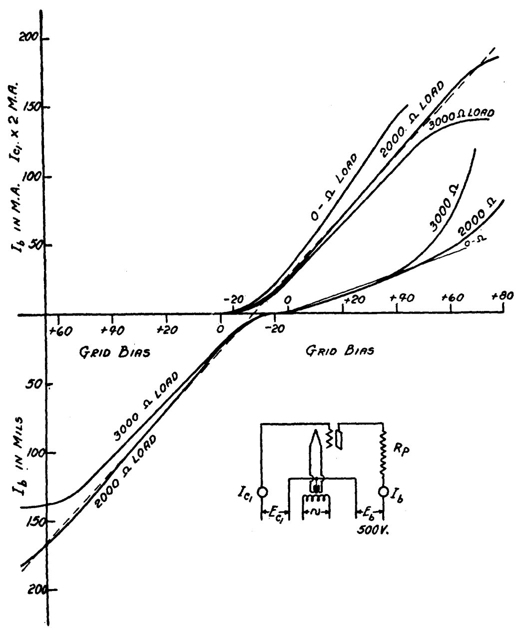

Fig. 7—Load characteristics of the UX-841 as a class "B" audio amplifier.

these tubes is approximately 13.5 volts and the peak positive grid swing is 65 volts with a peak grid current of 25 ma. The peak swing from normal bias in this case is 78.5 volts so that the minimum input resistance per grid is 3140 ohms and the slope of the grid current curve represents 2600 ohms. Since the above resistances are near the same value, the input series resistance may be as high as in the case of the UX-210 without increased distortion. If full advantage is taken of the above 255 volts peak swing on the primary of the driver transformer, an impedance ratio to each grid may be approximately 12 to 1 or an equivalent series input resistance of 330 ohms. This resistance is about

12 per cent of the minimum input resistance as compared to 20 per cent for the UX-210 tubes. Therefore, the UX-841 tubes are much easier to drive as class "B" audio amplifiers than the UX-210 tubes although the power output is essentially the same in the two cases.

The load curves in Fig. 8 for the UX-112A indicate what may be expected of two of these tubes as class "B" audio amplifiers. The curves indicate that the output power for the 2000-ohm load is about

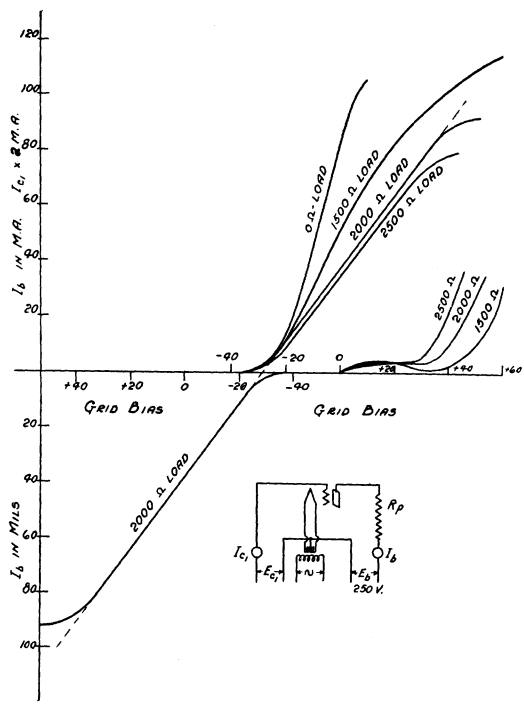

Fig. 8—Load characteristics of the UX-112A as a class "B" audio amplifier.

6 watts. If the plate voltage is raised to 300 volts, the optimum load resistance is about 2500 ohms and an output of 10 watts may be expected. The bias for 250 volts on the plates is about 28 volts and the positive grid swing is approximately 35 volts. The same precautions must be taken in driving these tubes as are taken with the UX-210 because of the flow of grid current on only a part of the input cycle. The grid current curves indicate a slight negative resistance at some points, but the resistance is so high that no difficulty is encountered.

One UY-227 operated at maximum rated voltages will drive the UX-112A tubes as class "B" audio amplifier without serious distortion although it is preferable to use two UY-227 tubes either in push-pull or parallel.

From a standpoint of high audio power from small tubes as a class "B" audio amplifier, the RCA-230 is perhaps the most interesting, especially as adapted to battery operated radio receivers. A study of the curves of Fig. 9 indicates that an output of approximately one watt can be obtained from these tubes with a maximum average plate

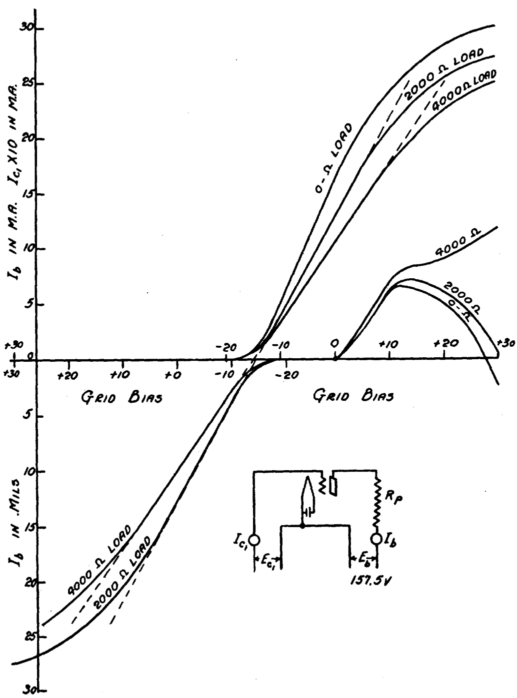

Fig. 9—Load characteristics of the RCA 230 as a class "B" audio amplifier.

battery drain of 14 ma at 157.5 volts, the other 22-volt block of a 180-volt battery being used for bias. The above plate current is the value for maximum output of a sine-wave signal. However, because of pauses, distorted musical waves, and extreme variation in amplitudes of radio signals, the average battery drain to the output tubes is probably 6 to 8 ma for a radio signal at full volume. A well designed battery operated set using two RCA-230 tubes as the output amplifier would have an average plate battery drain of 12 to 15 ma on full volume and a filament drain of approximately 0.5 ampere at two volts.

The grid current curves in Fig. 9 indicate negative resistance at certain load resistances and instantaneous grid voltages but the minimum resistance represented by the curves, positive or negative, is approximately 20,000 ohms. Consequently, an RCA-230 tube operating at 157.5 volts on the plate and 2-ma plate current, will successfully drive the output amplifier. The coupling transformer should have an impedance ratio of approximately 3 to 1 from the primary to each grid of the output tubes. The load resistance on each tube should be

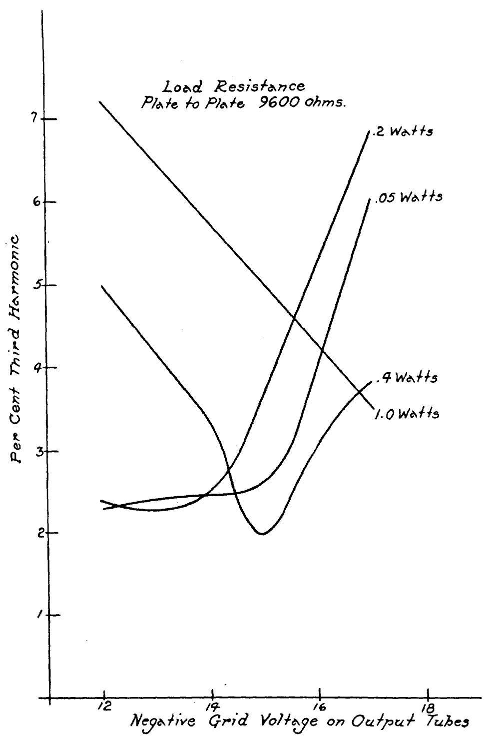

Fig. 10—Third harmonic distortion of two RCA 230 tubes as a class "B" audio amplifier for various power levels and bias voltages.

4000 ohms minimum or 16,000 ohms from plate to plate of the output tubes. Slightly more power can be obtained from the output stage by using a load resistance of 2500 ohms but at the expense of increased plate battery drain and excessive plate current peaks in the output tubes. The output tubes may be damaged by abnormally high volume if distortion is disregarded when a load resistance for maximum power output is used. If the higher load resistance of about 4000 ohms per plate is used, it is improbable that the output tubes can be driven with another RCA-230 tube to destructive plate current peaks.

Several curves of per cent harmonic distortion for various conditions of operation are given in Figs. 10 and 11 for two RCA-230 tubes as class "B" audio amplifiers and driven with an RCA-230 as indicated above. The input signal had less than 0.2 per cent second or third harmonics and the harmonics were measured by means of an RCA Victor voltage analyzer. Harmonics above the third are not plotted because they were below one per cent except in cases where the third was greater than 5 per cent. The curves in Fig. 10 indicate that the optimum bias is very nearly the bias obtained from the curves of Fig. 9. These curves also indicate that the bias may vary plus or minus one

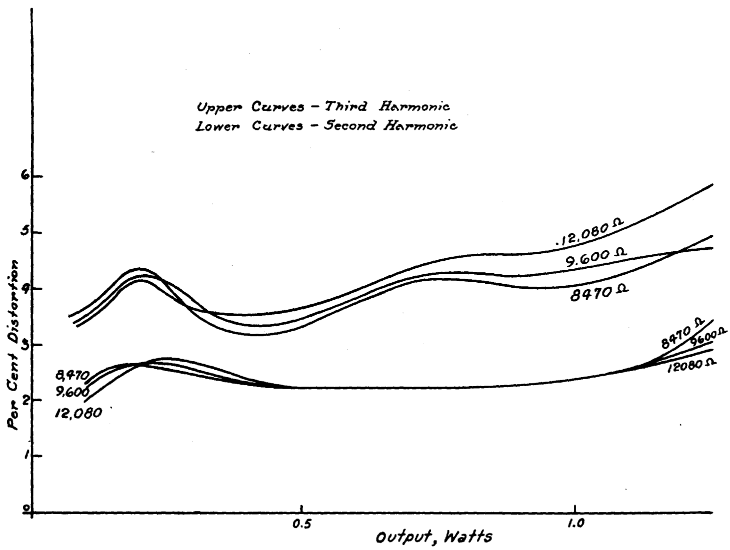

Fig. 11—Distortion of two RCA 230 tubes as a class "B" audio amplifier as a function of power output for various load resistances.

volt about the optimum value without serious distortion. The second harmonic curve corresponding to the curves in Fig. 10 are not shown but were below 3 per cent at 12 volts bias and about 2 per cent at 17 volts bias.

The above representative curves on a few of the common tubes may be used as guides in making estimates of the power output possibilities of other tubes. None of the present low plate resistance output tubes are desirable as class "B" audio amplifiers because of the required grid swing and the relatively high power required to swing the grids positive. It is of interest to know that 150 to 200 watts audio power may be obtained by using two UV-203A tubes or two UV-211 tubes with 1000 volts on the plate. It is also interesting to know that the RCA Victor Company has successfully constructed an audio amplifier of the class "B" type which delivers approximately 2500 watts. This amplifier uses four UV-849 tubes with 2800 volts on the plates and the output stage is driven by two UV-845 tubes in push-pull. The entire amplifier has not more than 4 per cent harmonic distortion and has a good frequency characteristic.The amplifier is entirely a-c operated and the plate voltage is supplied from a 4.5 kva high voltage transformer.

Conclusions

The class "A" amplifier is particularly adapted to use in cases where a single source of voltage is available for grid and plate supplies as in the case of a radio receiver or where poor regulation of the plate supply will cause difficulty. If provision is made to drive the grids of such an amplifier considerably positive greater peak plate current may be obtained for considerable increase in power output at the expense of relatively small increase in distortion. If the grids are driven positive for the peak plate current, the load resistance for maximum power output is a function of plate dissipation and in some cases, emission, but is independent of internal plate resistance of the tube.

Tests to date indicate the output voltage of a class "A" audio amplifier for a given signal input is a function of the relation of load resistance and the internal resistance of the output tubes. Consequently, if high plate resistance tubes are used compared to the load resistance, the output current is essentially constant for a wide range of load resistances for a given signal input. The output power is also nearly constant over a wide range of load resistances if the grid is driven to maximum output for the various loads.

The class "B" audio amplifier is very similar to the class "A" amplifier in regard to regulation of output and fairly constant output power for wide variation of load resistances except that this effect is more pronounced because the load resistance of the class "B" audio amplifier is much less than the optimum load resistance for the class "A" amplifier. However, the power output of the class "B" audio amplifier is usually limited only by emission or plate dissipation on peak signals. The plate current is nearly proportional to signal voltage so that the power taken from the plate supply source varies from a small value to full plate power required for maximum output. The problem of obtaining a plate supply with the necessary regulation is one which must be considered in connection with class "B" audio amplifiers unless batteries are used. As is obvious, this problem involves a rectifier supply which will carry the pulsating load with good regulation.

Another problem which has been met in developing this type of amplifier is to provide for a well regulated bias supply unless the supply source is a battery. This is difficult because of the relatively high grid current taken by the grids of the output tubes. This problem probably will be met commercially by using tubes that operate at very low bias, as indicated in Fig. 7. The bias is, at the present time, obtained preferably from a source separate from the plate supply to the amplifier and is not made automatic in the usual sense of the word. The above problems do not exist when a battery is used to supply the voltages which makes the class "B" audio output amplifier very practical for battery operated sets.

The problem of driving the amplifier can be successfully solved if some distortion is permitted. At the present stage of development, it seems that class "B" audio amplifiers inherently have a negligible amount of distortion because the power output must come from one tube at a time and the transfer of the load from one tube to the other cannot be made without a limited amount of disturbance or suitable compensation. However, as indicated above, the distortion is not serious if proper precautions are taken.

The low cost of the class "B" audio amplifier, the conservation of plate supply power for relatively high outputs and the ability of a tube to deliver 5 to 10 times its usual audio output, are factors worth considering where relatively high power is desired at a minimum cost.