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# RECENT DEVELOPMENTS OF THE CLASS B AUDIO- AND RADIO-FREQUENCY AMPLIFIERS*

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***Summary***—*Class B audio-frequency and radio-frequency amplifiers have many applications and the distortion can be kept to a very low value if the necessary precautions are taken to prevent nonlinearity of such amplifiers. Undoubtedly, the most important factor in the design of a class B amplifier for low distortion is the characteristic of the driver system. Tube characteristics and the use of a proper load are also important but are more definite and more generally understood.*

*The purpose of this paper is to present the results of recent developments of the class B audio and radio amplifiers to reduce distortion. The results of the investigations indicate that a heavily loaded driver system in general is undesirable because of the power consumed and because such loading results in greater distortion than obtainable by other means.*

*The general procedure adopted to reduce distortion was to prevent distortion in each unit of the amplifier system. Distortion balancing schemes are not only critical to adjust but are likely to introduce higher order harmonics and sum and difference tones which may be more objectionable than a higher measured value of lower order harmonics. Actual performance data are presented for medium and relatively high powered audio and radio systems. The necessary input requirements to permit the performance obtained are discussed.*

*Sufficient theory is given to make the paper complete and to show that the actual performance of such amplifiers can be quite accurately predicted if the necessary tube characteristics are known.*

## Introduction

THE general tendency toward high fidelity performance for radiophone transmitters as well as high modulation capability has necessitated appreciable development of the class B audio- and radio-frequency amplifiers to reduce distortion. The class B radio-frequency amplifier has, for several years, been used almost exclusively for the output system of radio transmitters. However, the application of the class B audio amplifier for high level modulation is gaining much recognition in the past few years, although such an amplifier was successfully used for modulating a 1000-watt broadcast transmitter as early as 1928.[1] The application of the class B audio amplifier for

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[1] Loy E. Barton, "A plate modulation transformer for broadcast stations," Univ. of Arkansas, Eng. Exp. Station Bulletin No. 8.

high level modulation has also been applied to a 500-kilowatt station[2] and to a number of medium powered stations.

This general trend permits considerable saving in power costs, reduces the number of tubes operating in parallel for a given output, and is inherently a more simple system as regards design, adjustments, and general maintenance.

For power outputs such that no convenient or economical tube complement is available, the saving of power in high level class B modulated systems may be offset by the cost of tubes and the modulation transformer and reactor. In such cases, the class B radio-frequency amplifier may be used to an advantage. The advisability of using a low level modulated system in such cases may be questionable when an economical class B audio amplifier for modulation is developed for the particular power classes now using low level modulation. Because of the similarity of the class B radio- and audio-frequency amplifiers, it is convenient to discuss some of the recent developments of both amplifiers for low distortion output.

## Definitions

Since there is some question as to the true definition of the various types of amplifiers, it is desirable to define and discuss briefly the principle types of amplifiers as a basis for the discussions in this paper and to clarify some of the misconceptions regarding the various types of amplifiers.

*A class A amplifier* is an amplifier in which the plate current is essentially proportional to the grid voltage for the entire signal cycle or 360 electrical degrees.

*A class B amplifier* is an amplifier in which the plate current or resultant plate current is essentially proportional to the grid voltage for 180 electrical degrees of the signal and the power output for each tube is appreciably lower on one half cycle than the following half cycle.

*A class AB amplifier* is an amplifier that fulfills the conditions for a class A amplifier for low grid swings and fulfills the conditions for a class B amplifier during the upper part of a cycle for high grid swings.

*A class C amplifier* is an amplifier in which the grid excitation and bias are such that the direct-current value of the plate current and output current is proportional to, or tends to be proportional to, the direct plate voltage for intervals of time large as compared to the period of time for a radio-frequency cycle.

[2] J. A. Chambers, L. F. Jones, G. W. Fyler, R. H. Williams, E. A. Leach, and J. A. Hutcheson, "The WLW 500-kilowatt broadcast transmitter," Proc. I.R.E., vol. 22, pp. 1151–1180; October, (1934).

It should be noted that in the above definitions the value of bias is not given nor is the grid swing stated. These values for the amplifier tubes are not given because of the various types of tubes that may be used for any, or all, three types of amplifiers. For instance a zero-bias class B tube may be used as a class A amplifier if a positive bias is used such that a signal voltage applied to the grid will result in a plate-current change essentially propotional to the applied grid voltage for the entire 360 electrical degrees. Therefore, it is evident that a class A amplifier cannot be defined as a function of grid bias but it can be defined in terms of the relation of the grid voltage and plate current over certain ranges of grid voltage. The limit of grid swing and grid bias depends entirely upon the grid conditions that permit the plate current to meet the requirements of a class A amplifier.

The proper grid conditions for a class B amplifier are also the conditions that will permit the plate current to behave according to the definition for the class B amplifier given above. It is well known that no tubes are yet available and probably will not be available that have a linear plate current with respect to grid voltage from zero plate current to the limit of plate swing. Therefore, for low distortion in a class B amplifier the resultant plate current obtained from the slope of the plate-current vs. grid-voltage curve must be essentially linear from the operating bias point. This resultant plate current will be discussed in detail later.

From the definition of a class AB amplifier (sometimes called class A prime amplifier) the resultant slope of plate-current vs. grid-voltage is different at low and at high values of grid swing. If the plate resistance of the tube used is very high compared to the load resistance the resultant slope of plate current of two tubes in push-pull over the class A part of the cycle will approach two times the slope at points where only one tube is working. For very low plate resistance tubes, the two slopes may approach the same value if the load resistance is several times the value of plate resistance. It may be seen that in any case the class AB or A prime amplifier will inherently introduce distortion to a degree depending upon the plate resistance of the tubes used. A class B amplifier may have the proper bias for low amplification factor tubes and appreciable ouput may be obtained with no positive grid swing. This type of operation is a class B amplifier and not a class A prime amplifier as sometimes called.

The class C amplifier will not be discussed further except to state that for plate modulated service the grid bias and excitation necessary to cause the direct plate current to be proportional to plate voltage may vary with instantaneous value of plate voltage. In general, however, the class C amplifier conditions are usually met if the grid is operated at so-called saturated condition as regards bias and alternating-current excitation for all values of plate voltage to be applied to the amplifier.

## Class B Audio Amplifier

The essential circuit and tube requirements for successful operation of a class B audio amplifier are much more severe than the requirements for a good class B radio amplifier because the output of the audio amplifier is a function of the instantaneous value of the plate current, whereas, in the case of radio-frequency amplifiers a distorted plate current is smoothed out by the tuned plate circuit.

The two most important factors in a good class B audio amplifier are the driver system supplying the audio voltage to the grids of the class B stage and the relation of the plate current to grid voltage for the particular tube. These two factors are discussed at some length because of their importance in the design of a low distortion class B audio amplifier.

## Operation of the Driver Tubes

The grid current characteristic of a tube operating as a class B audio amplifier for a given plate load resistance must be known in order that a good driver system may be devised. The plate characteristics are also necessary for output calculations so that by using the circuit as shown in Fig. 1, the grid and plate characteristics may be obtained simultaneously. Such characteristics are shown in Fig. 1 for two 849 tubes and are used to illustrate more fully the driver requirements. It should be noted that the characteristics of the plate and grid currents plotted for various load resistances are for two individual tubes and that the grid current characteristics may vary widely for individual tubes. However, for a given load resistance and grid voltage, the plate current will be quite uniform for various tubes of the same type.

Referring to the grid current curves in Fig. 1, tube *A* is somewhat more erratic than tube *B*. The positive grid resistance represented by the slope of the grid current curve of each tube at a point soon after grid current starts is approximately 600 ohms. As the grid swings further positive, the resistance increases to infinity and then decreases to a negative resistance of approximately 600 ohms for tube *A* but the minimum negative resistance of tube *B* is not nearly as low. At peak grid swings of about +110 volts the instantaneous grid resistance of each tube is about 600 ohms positive resistance.

It will be noted that the plate current curves are essentially linear for grid voltages between −75 or −80 volts and +100 to +120 volts when the grid voltage swings in a positive direction. Therefore, if no voltage distortion is applied to the grids there should be no distortion in the plate circuit from approximately the −75-volt bias point to the plate current limit. However, the grid current wave to the grids of the 849 will be badly distorted as can be readily observed. If the grid current is applied from a source having appreciable impedance, the

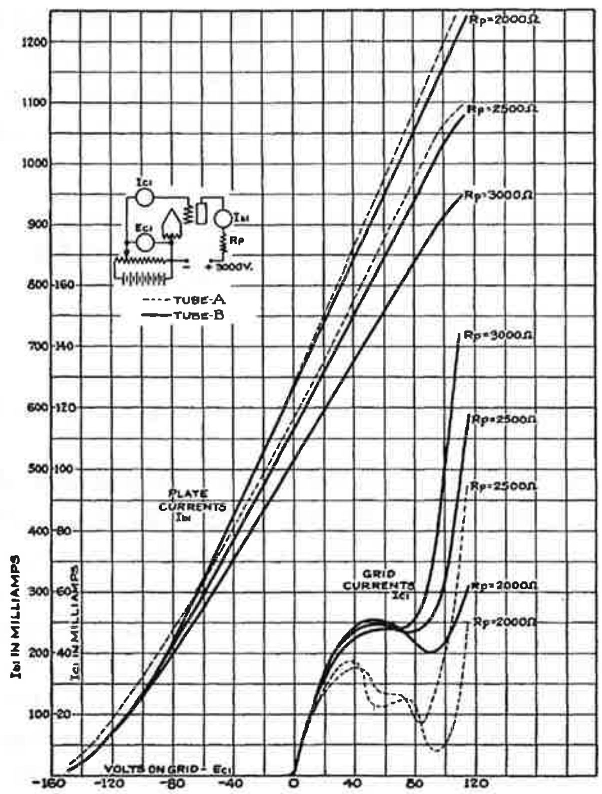


**Fig. 1—Dynamic transfer characteristics of RCA 849.**

voltage wave applied to the grid will be distorted, which will cause distortion in the plate circuit. Therefore, the internal resistance or impedance of the source supplying audio voltage to the grids of the class B tubes must be as low as practical in order to reduce voltage distortion to the grids.

Since the driver system is essentially aperiodic, it is obvious that any change in impedance in the grids of the class B tubes is reflected directly through the coupling means to the plate circuit of the driver tubes provided the coupling transformer approaches the performance of an ideal transformer. If an ideal coupling transformer is assumed the lowest equivalent resistance in series with the grids of the class B tubes is obtained when there is no loading resistance across the grids of the class B amplifier, thus permitting a maximum step-down ratio of the driver transformer, provided low impedance driver tubes are used. There has been considerable disagreement on the question of loading the secondary of the driver transformer to improve regulation to the grids of the class B audio amplifier tubes so that a short proof of the above statement is given. A proof of this statement is also given by McLean.[3] As will be shown later, this general statement also applies to class B radio amplifiers in so far as the audio cycle is concerned.

The equivalent circuit for a driver system in a class B audio amplifier is shown in Fig. 2 in which two tubes operating as a push-pull class

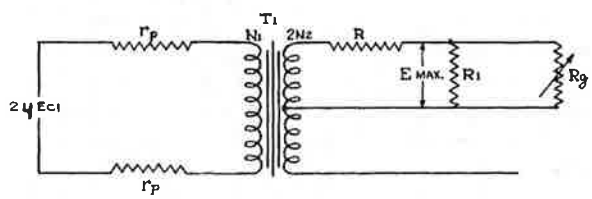


Fig. 2—Equivalent circuit of driver for class B audio amplifier.

A amplifier are assumed to be connected to the primary of the driver transformer, $T_1$. The generated peak voltage in the plate circuit of the two tubes in push-pull is $2\mu E_{c1}$ and the plate resistance in series with each lead to the transformer primary is $r_p$. The turn ratio of the driver transformer $T_1$ from total primary to total secondary is $N_1$ to $2N_2$ and the ratio to one side of the secondary is $N_1$ to $N_2$. The resistance, $R$, is the equivalent resistance transferred from the primary of $T_1$, in series with each grid; $R_1$ is the equivalent loading resistance across one side of the secondary, and $R_g$ is the resistance of the grid of the tube which in general varies from a very high value to some low value. The variation of $R_g$ depends on the particular class B tube and conditions under which it operates. From the characteristics of a tube such as shown in Fig. 1, the peak grid voltage $E_{max}$ for a given power output may be read. From the characteristics of the driver tubes the expression $2\mu E_{c1}$ can be found. The general quantities in Fig. 2 may be used in the following expression to determine the equivalent series resistance $R$ for a required peak grid voltage $E_{max}$ for an ideal transformer:

$$2r_pN^2 = R \qquad (1)$$

[3] True McLean, "An analysis of distortion in class B audio amplifiers," Proc. I.R.E., vol. 24, pp. 487–509; March, (1936).

in which $N = N_2/N_1$

$$2N\mu E_g \frac{(R_L)}{N^2 2r_p + R_L} = E_{max} \tag{2}$$

in which $R_L$ = parallel resistance of $R_1$ and $R_g$.

When $R_1$ is omitted the variation of $R_L$ is from a very high value to the minimum grid resistance of the class B tube. If a loading resistance $R_1$ is used, the maximum resistance of $R_L$ is then $R_1$. It is obvious

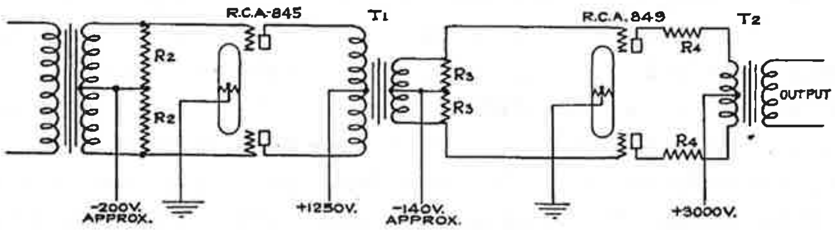


Fig. 3—Circuit for class B audio amplifier and driver.

from (1) that the regulation of the driver system improves as the plate resistance $r_p$ is decreased so that tubes with minimum plate resistance should be used. It is not so obvious from (2) that $R_1$ should be omitted

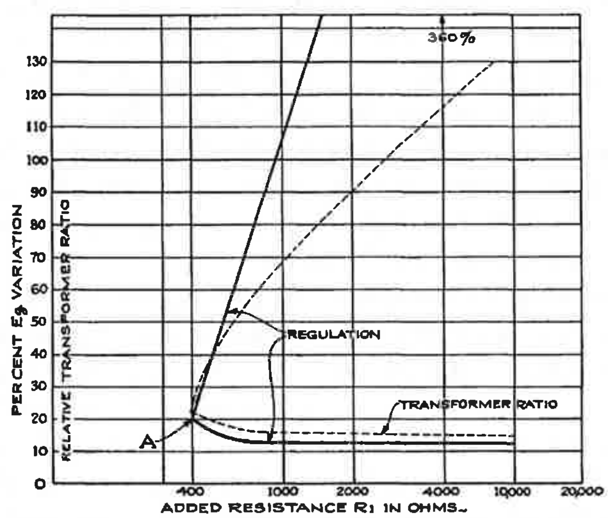


Fig. 4—Relative transformer ratio and voltage regulation to grids of RCA 49 class B audio amplifier.

for best regulation of the voltage $E_{max}$ when $R_g$ varies from a very high value to a comparatively low value for any practical driver system, therefore the essential circuit constants are assumed for a system such as shown in Fig. 3 in order that relative values may be substituted in (2) to obtain data for the curves in Fig. 4.

It will be noted that there are two solutions for $N$ in (2) that will satisfy the value assigned for $E_{max}$. At point $A$ on the regulation curves, the equation has only one solution and for lower shunting resistances the solution of the equation is imaginary for the output voltage assumed for $E_{max}$. Therefore, the output voltage assumed cannot be obtained for lower values of shunt resistance. It is obvious that if the higher transformer ratio solution is used the regulation is improved very much by making the shunt resistance as low as possible for a given voltage output. On the other hand, if the lower transformer ratio solution is used the regulation is improved by omitting the shunting resistance, provided the transformer ratio is reduced accordingly.

The above curves and solutions are obtained on the basis of ideal operation of the driver tubes as a class A push-pull amplifier and that the driver transformer is an ideal impedance coupling device. A study of the plate characteristics of the 845 tube indicates that the tubes operate more nearly as ideal class A amplifiers when the load resistance is very high. If the load resistance is comparatively low, the plate resistance of the tube increases at the extreme negative grid swing which in turn raises the resistance in series with the primary of transformer $T_1$. Therefore, in practice the regulation of the driver system becomes worse than is indicated by the curves in Fig. 4 when shunting resistance is added. The variations of plate resistance upward at extreme negative grid swings is perhaps the greatest disadvantage in using shunting resistors across the secondary of the driver transformer to improve regulation. This is the result of grid swings causing very low values of plate current for an appreciable part of a cycle. Other tubes, such as the 2A3 at maximum plate voltage may require loading to obtain class A operation of the tubes.

It is also possible to operate low plate resistance driver tubes as class B amplifiers without loading. In this case, for grid swings equal to the class A condition, it is obvious from Fig. 2 and (1) that the effective resistance $R$ in series with the secondary of the driver transformer is double the value for class A operation of the tubes. By driving the tubes as class B amplifiers into the positive region, some improvement is obtained but is not equal to class A operation of low plate resistance tubes unless a greater step-down driver transformer can be used because of greater plate voltage swing.

The effective impedance in series with the grids of the class B amplifier tubes is the combined resistance transferred to the secondary of the driver transformer from the plate circuit of the driver tubes plus any loss and effective leakage reactance. The transformer ratio is determined by methods discussed above but the losses in the transformer and effective leakage reactance in series with each half of the secondary winding is a function of the transformer design. The losses in the transformer can be kept relatively low but the leakage reactance of a driver transformer is not as easily kept to a low value.

A convenient way in which to obtain the approximate effective impedance in series with each side of the driver transformer secondary with the normal tube plate resistance connected to the primary terminals is indicated by the circuit in Fig. 5. The curves, also shown in Fig.

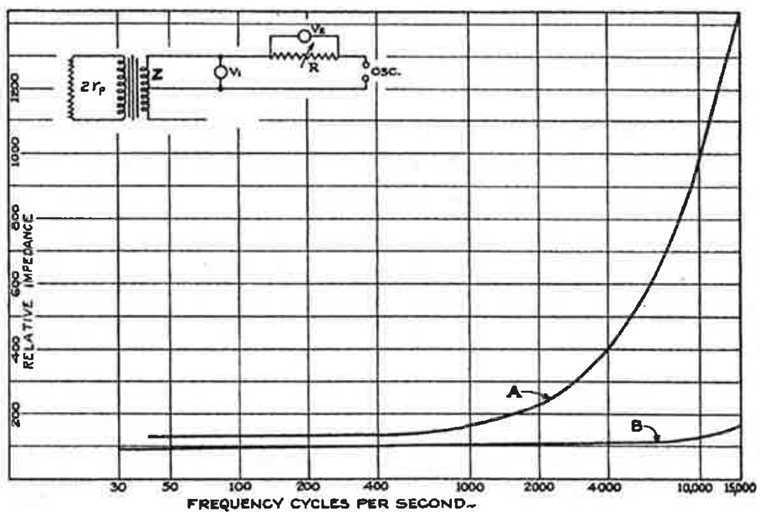


Fig. 5—Equivalent impedance in series with each grid of a class B audio amplifier showing effect of leakage reactance for two transformer designs.

5, are the results of tests on two driver transformers designed to drive 849 tubes as class B audio amplifiers. It will be seen that the effective impedance in series with each side of the secondary of the transformer represented by curve *A* increases quite rapidly as the frequency increases because of the leakage reactance to each secondary winding. The curve of impedance in series with the grids for the transformer represented by curve *B* is essentially flat over the audio-frequency band.

Referring to the curves for the grid current in Fig. 1, it will be noted that the grid current for the 849's will be composed of higher order harmonics so that these currents correspond to frequencies in the upper audio-frequency range for comparatively low fundamental frequencies. If such grid currents must be supplied through a relatively large effective impedance as the result of high transformer leakage, it is obvious that a grid voltage similar to the grid current wave will be superimposed on the signal, resulting in appreciable distortion. Another objection to the use of a transformer with high leakage reactance is that its impedance at high frequencies may be greater than the negative resistance of the grids of the class B tubes over certain portions of a cycle, in which case a condition for dynatron oscillation is present. The use of a transformer in which the leakage is very low, reduces the distortion to a negligible value and prevents the generation of high parasitic voltages across the output transformer.

## Output Circuit Requirements

It is obvious that for low distortion from class B audio amplifiers the bias must be approximately correct so that the resultant output from the two tubes in push-pull at points near the zero signal axis will have the same slope as the output at higher values of signal. The plate current curves in Fig. 1 indicate that the proper bias is about-135 volts for approximately twenty-five milliamperes no-signal plate current. However, due to the fact that the cutoff characteristic of the 849 is somewhat extended under operating conditions because of the increased instantaneous plate voltage, as a result of its push-pull relation with the other tube, the no-signal plate current for minimum distortion is about forty to sixty milliamperes with a corresponding reduction in bias. The extended plate-current cutoff effect is present because of the relatively low plate resistance of the 849 as compared to the plate load resistance. Therefore, it will be seen that the resultant plate current as stated in the definition of class B amplifiers must be linear from the bias point, and that the no signal plate current is not necessarily essentially zero but may be appreciably higher than usually given.

Another factor affecting the distortion in a class B audio amplifier is the leakage reactance in the output transformer shown as $T_2$ in Fig. 3. It will be noted that the total power output is supplied from one tube through one half of the output transformer primary during most of alternate half cycles. Since the power is transferred through one half of the primary winding, due consideration must be given to the leakage reactance of this transformer. Undue leakage in the output transformer not only reduces the response at high audio frequencies but also increases the percentage distortion of the output signal.

## Experimental Results

The above discussion on the class B audio amplifier indicated the procedure in recent developments of this class of amplifier. The characteristics of the 849 tube were used to illustrate the various items of importance to develop a low distortion class B audio system. Although an amplifier of this type may be used for any purpose for which approximately 1000 watts of audio power is desired, the most common use for the amplifier is for high level modulation of a 1000-watt radiophone transmitter. Distortion measurements were made on a complete high level class B modulated 1000-watt transmitter using 849 class

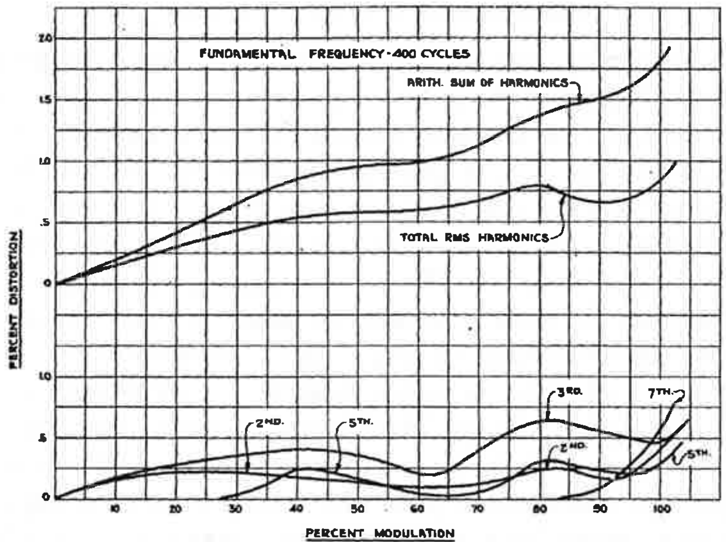


Fig. 6—Performance of a 1000-watt high level class B modulated transmitter.

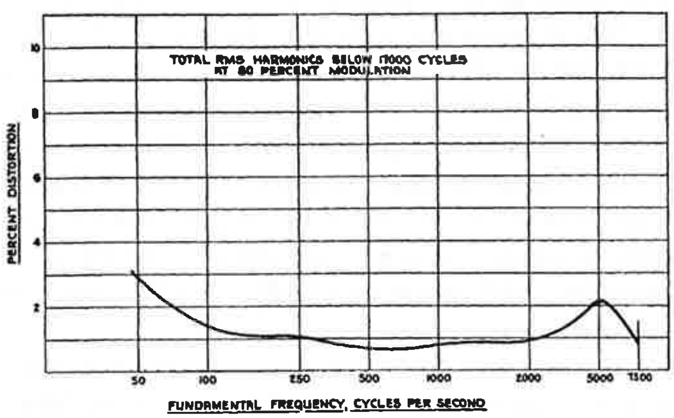


Fig. 7—Distortion at various frequencies for transmitter as adjusted for performance in Fig. 6.

B modulators. The input signal level was approximately 1.8 volts across 500 ohms and a rectified portion of the radio-frequency output was applied to the analyzer.

The data obtained from the above distortion measurements are plotted in Figs. 6 and 7. It is believed that a distortion approximating the values shown in Figs. 6 and 7 is sufficiently low to meet any present high fidelity requirements. This is especially true when no visible disturbance is indicated on the carrier envelope by a cathode-ray oscillograph.

## Zero-Bias Class B Amplifiers

The plate-current grid-voltage characteristic for a vacuum tube follows approximately a three-halves power curve. For tubes having a low plate resistance as compared to the load resistance in series with the plate, the resultant curve becomes nearly linear so that little distortion results from the use of such tubes as class A amplifiers, or as class B amplifiers if the proper bias is used. On the other hand if the tube is to be used at zero bias the plate resistance of the tube must be high compared to the load resistance resulting in little change in the normal three-halves power curve for the plate-current grid-voltage dynamic transfer curve or the curve in which the plate load resistance is included in the plate circuit. Therefore, it is improbable that a zero-bias tube can be made to have low distortion output with essentially zero no-signal plate current. A possible solution is to allow appreciable zero-signal plate current so that the resultant plate current as related to the grid voltage will be linear from the operating point for one-half cycle as indicated in the definition of a class B audio amplifier. The maximum zero-signal plate current is limited by the plate dissipation of the tube so that if maximum output is to be had, the average plate current will rise appreciably at peak outputs.

By using a relatively high zero-signal plate current for zero-bias tubes the normal three-halves power curve of plate current vs. grid voltage can be altered appreciably by the use of a special grid structure so that the resultant plate current slope of two tubes in push-pull at points near the zero-signal axis will be equal to the slope of one tube during peak positive grid swings at which point the plate current will be zero for the other tube.

The new 838 tube has approximately the characteristics desired for a zero-bias tube as outlined above. Because of the difficulty and complications in design and manufacture, the 838 was so designed that it could be used for zero-bias operation as a class B audio amplifier for applications in which some distortion could be tolerated, and for applications requiring very low distortion a small bias could be used.

The dynamic transfer curve for an individual 838 is shown in Fig. 8 and represents approximately the characteristic of this type of tube. Two resultant plate currents are drawn which indicate the slopes of the resultant plate current for zero-bias operation and for $-15$-volt bias operation. The circuit with which the curve data were taken is the same as in Fig. 1.

The resultant curve $A$, drawn for a bias of $-15$ volts, is much more linear than the resultant curve $B$. It should be noted that the grid current for this tube represents approximately a constant resistance as compared to the erratic grid resistance of the 849 tube shown in Fig. 1. As a result of the more or less constant value of grid resistance

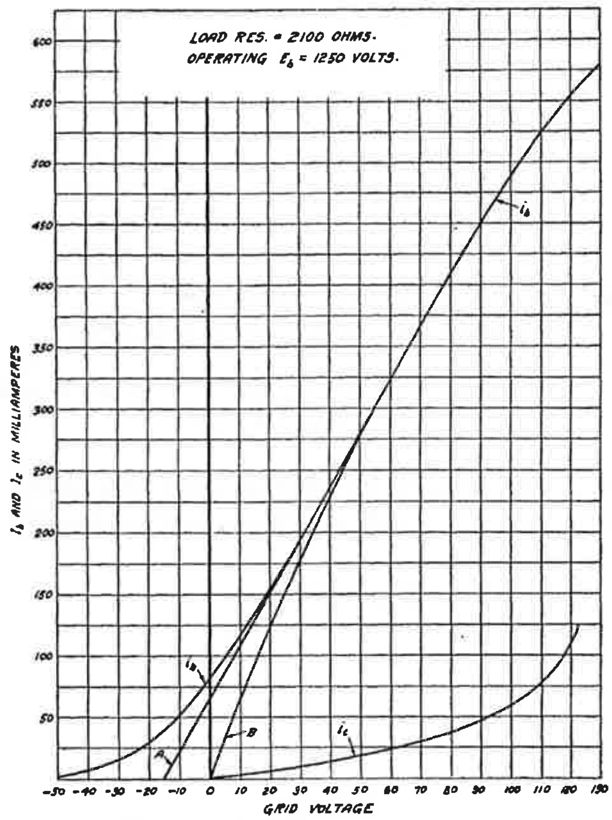


Fig. 8—Dynamic transfer characteristics of an 838 tube.

the 838 is much easier to drive than the 849; however, the output of a pair of 838's is approximately 250 watts as compared to 1000 watts output for two 849's.

Distortion measurements were made for operation of the 838 at zero bias and are shown in Fig. 9. Distortion curves are shown for the $-15$-volt bias operation in Fig. 10. These curves agree quite well with distortion that may be predicted from the dynamic transfer curves in Fig. 8. The driver systems for the above curves were practical class A driver systems. The impedance of the driver systems for Fig. 10 was somewhat higher than the system driving the grids for the curves in Fig. 9 which accounts to some extent for the somewhat higher output power per pair of 838's in Fig. 9.

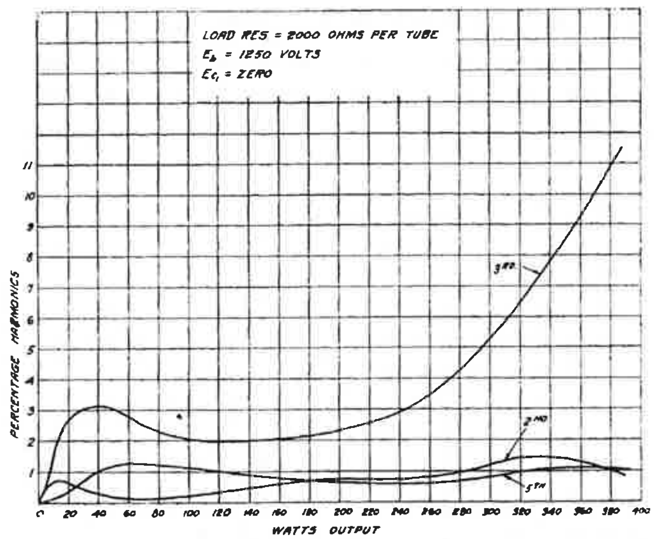


Fig. 9—Performance of two 838 tubes in a class B audio amplifier with zero bias.

The 838 tube may be used for class B radio and class C amplifiers. When the tube is used for class C radio service the bias can be obtained

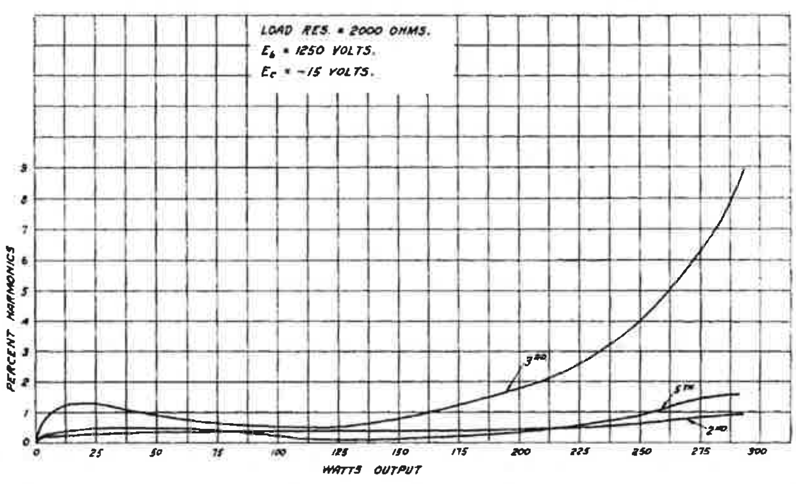


Fig. 10—Performance of two 838 tubes in a class B audio amplifier with fifteen volts bias.

from a grid leak, thus eliminating the bias problems in case excitation is lost, because the plate dissipation at zero bias is normal operation for the tube. Therefore, this tube should be welcomed in radio-frequency systems because the problem of bias source is simplified and the power required to drive the tube is about equal to the power required to drive other tubes of similar size.

## High Bias Class B Audio Amplifiers

The high bias type of class B audio amplifier is quite interesting and useful in applications where the power requirements permit the use of an available tube. For such amplifiers, the driver problem is not nearly as severe because the grids need not be driven into the positive region. In general, the plate resistance of the high bias, low amplification factor tubes increases appreciably during that part of the signal cycle at which one tube approaches plate current cutoff. As a result of the increasing instantaneous plate resistance with the usual decrease in grid control at high negative grid voltages, the tailing-off effect of the dynamic transfer curve of the low-mu, low plate resistance tubes is extended beyond the value normally expected. This is especially true for the small 2A3 and the water-cooled 848 types of tubes. The extended dynamic plate current for two of these tubes operating in push-pull results in a comparatively high value of no-signal plate current in order that the resultant plate currents will meet the condition for class B audio amplifier operation as defined above.

In the case of the small 2A3 tube, the no-signal plate current for 300 volts on the plate is very nearly as great for class B operation of the tubes as the normal plate current for approximately class A operation at 250 volts on the plate. At higher plate voltages, the tube is not very satisfactory for class B audio operation, because the plate dissipation limits the high no-signal plate current needed for low distortion. The maximum class B audio output of two 2A3's is about fifteen watts.

The 845 type of tube does not have such an extreme tailing-off characteristic as the other two tubes mentioned; but this characteristic is present to some extent. The maximum output of two 845's as class B amplifiers is approximately 100 watts.

The 848 type of tube has a plate current tailing-off effect similar to the 2A3 and in some respects these two tubes have plate current characteristics strived for in the zero-bias 838 type of tube except that the 838 tube operates at essentially zero bias. The maximum output of two 848 tubes as class B audio amplifiers at approximately 13,000 volts on the plates is about ten killowatts. However, the plate voltage is limited to a value appreciably below the above value because of the relatively high no-signal plate current unless a high velocity of water is used around the plate for cooling purposes. The high velocity of water is necessary because the tube has a comparatively coarse meshed grid for a low amplification factor, resulting in local hissing or boiling of the water at hot spots. The hot-spotting of the plate is the result of electrons focusing at points on the plates for high values of grid bias and plate voltage.

Distortion measurements were made on two 848's as class B audio amplifiers and the results are plotted in Fig. 11. It will be noted that the distortion is very low for the comparatively high no-signal current operation, which is also true for class B operation of the other two types of low amplification factor tubes mentioned above. However

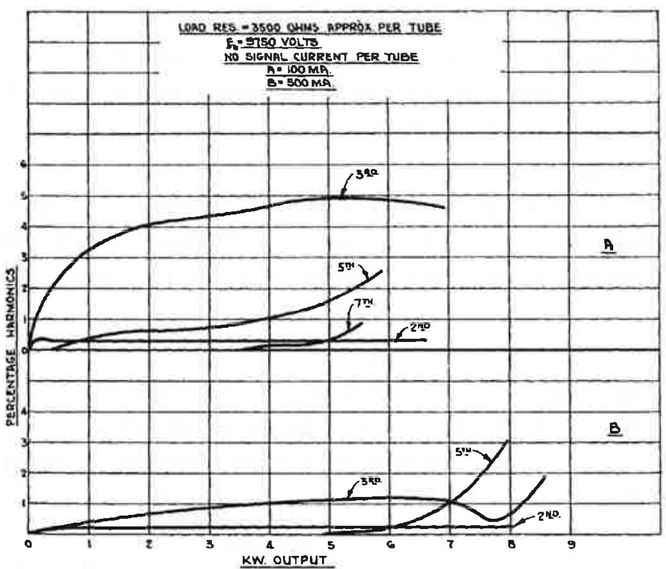


Fig. 11—Performance of two UV 848 tubes in a class B audio amplifier.

the curves shown in Fig. 11 for low no-signal current operation indicated appreciable distortion because of the long "tail-off" characteristic of the 848 tube. The low distortion from the high bias type of class B audio amplifier when operated at the proper no-signal plate current is made possible because of the remote cutoff of the plate current, the relatively low plate resistance as compared to load resistance, and the relatively simple problem of driving the tubes when the grids are not driven into the positive grid region. However, it must be remembered that if maximum output is needed from a particular size tube, the grid must be driven into the positive region necessitating good regulation of the driver system. Because of the high grid swings necessary for high bias class B amplifiers, it is not practicable to drive the high bias tubes into the positive grid region and still have low distortion. This point is evident from (1) and (2) given above. Approximately 250 watts can be obtained from the zero-bias 838 tube, which is physically about the same as the 845, and approximately twenty-five kilowatts can be obtained from the 863 tube, which has the same structure as the 848 except for grid mesh. The bias for the 863 is zero to about $-100$ volts, depending upon the plate voltage while the bias for the 848 is $-1200$ to $-1600$ volts, which also depends on the plate voltage.

## Class B Radio Amplifier

As indicated at the beginning of this paper, there are certain power ranges of transmitters in which there is no economical tube comple-

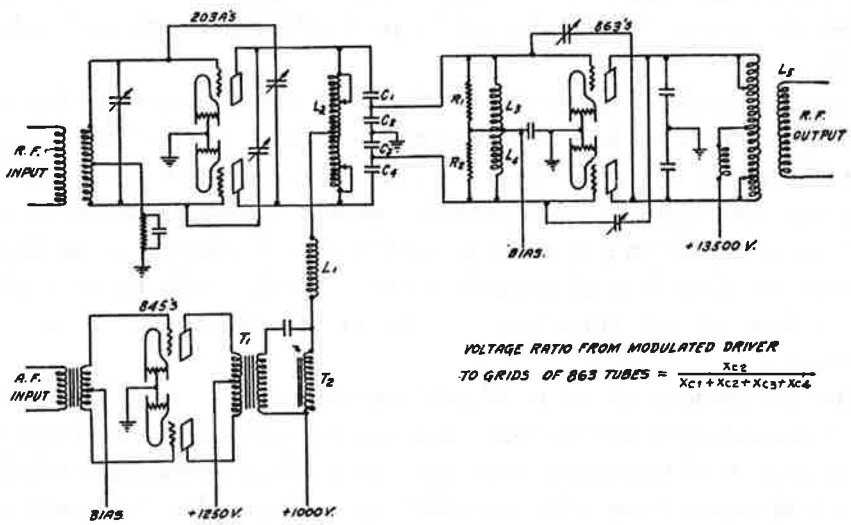


Fig. 12—Essential circuit for driver and output systems for a recently developed five-kilowatt transmitter.

ment available for high level modulated systems. In such cases, fewer tubes are needed for a class B radio output system and, of course, the high power modulation transformer and reactor are not needed. The possible saving in number of total tubes used, plus the saving of the cost of modulation transformer and reactor, may more than offset the disadvantages of the class B radio output system. The class B radio amplifier need not be unnecessarily critical if the circuit constants are correctly chosen for a typical circuit as shown in Fig. 12.

According to the definition of a class B amplifier, two tubes in push-pull will function in the same manner whether the frequency is audio or radio. At radio frequency, a single tube may be used because the plate circuit can be tuned to the desired frequency and the tube can store energy in the tank circuit during one half cycle to be dissipated over the complete cycle. Referring to Fig. 12, 863 tubes are shown in the output system for a transmitter developed for five killowatts output. It will be noted that the tubes are connected in a usual push-pull fashion except for the fact that the grids are coupled directly to the condenser part of the modulated class C amplifier tank circuit. The general discussion of the driver and output systems for the class B audio amplifier above applies equally well to the class B radio amplifier. Therefore, it is very desirable to reduce the leakage of the driver system as much as possible. A low impedance system is obtained by using as large a ratio of $C_2$ and $C_3$ to $C_1$ and $C_4$ as possible without appreciable loading by $R_1$ and $R_2$. The resistors $R_1$ and $R_2$ are used to suppress parasitic oscillations and have a relatively high value of resistance. The radio-frequency choke coils $L_2$ and $L_3$ are used for grid returns to a bias supply.

Since the grids of the class B radio tubes are excited from low impedance condensers and low power is supplied to the tank circuit, $L_2C_1C_2C_3C_4$, by the 203A class C amplifier, no regulation problem is present for any constant radio-frequency voltage applied to the 863's. However, during modulation of the class C amplifier, the power taken by the class B amplifier grids varies over the audio cycle, so that the problem of low impedance audio driver system becomes very important.

The direct-current value of grid current to the 863's at normal carrier conditions is usually quite low, because of negative grid current over a portion of the radio-frequency cycle. The approximate relative direct grid current curve for the 863's operating under the conditions as shown in Fig. 12 is shown in Fig. 13 for various instantaneous values of upward and downward modulation. The change of slope of this curve at various instances over an audio cycle indicates the variable resistance the driver system must work into. The curve shown is only approximate because the actual curve depends upon individual tubes and the load under which the tubes operate. The curve can be used for the purpose of discussion and in any case, it is obvious that a high impedance driver system will result in distortion depending upon the particular shape of the grid current curve such as is shown in Fig. 13.

The impedance of the driver system over an audio cycle is the resulting impedance of the modulator through the class C amplifier, which in turn is coupled to the class B radio amplifier. The impedance of the modulated class C amplifier is comparatively low corresponding to 1000 ohms or less for each of the class C tubes. That is, within reasonable limits, a change of load resistance on the class C amplifier causes the amplifier to draw more plate current with little change in output voltage. Therefore, since the regulation of the grid voltage applied to the 863's is a function of the regulation of the audio voltage applied to the plate, the regulation of the driver system is largely a function of the regulation of the output of the modulator. Because of this fact, low impedance 845 tubes were used for modulators and as explained above, according to (1) and (2), the lowest impedance driver system can be obtained when the loading resistance is a maximum, thus permitting a maximum step-down ratio of the modulation trans-

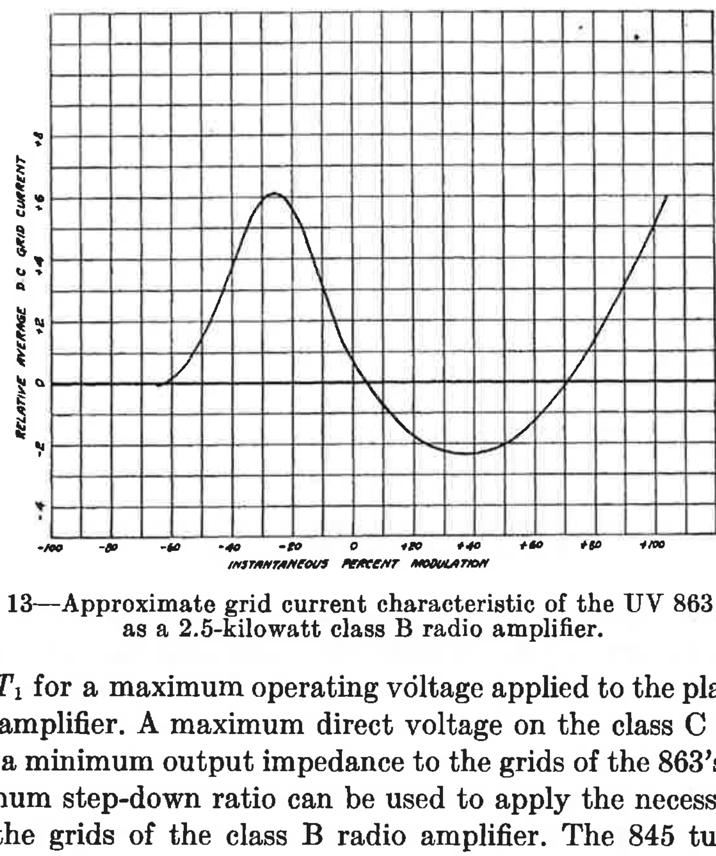


Fig. 13—Approximate grid current characteristic of the UV 863 tube as a 2.5-kilowatt class B radio amplifier.

former $T_1$ for a maximum operating voltage applied to the plate of the class C amplifier. A maximum direct voltage on the class C amplifier permits a minimum output impedance to the grids of the 863's because a maximum step-down ratio can be used to apply the necessary voltage to the grids of the class B radio amplifier. The 845 tubes were operated as class B audio amplifiers and, of course, according to (1) and (2) four modulator tubes will result in a driver system with lower impedance than two tubes. If sufficient driver tubes are used to permit class A operation, a still lower impedance driver system could be had. However, two modulator tubes operating as a class B audio amplifier quite successfully drove the class B radio amplifier through the class C amplifier with a power input of only 80 to 100 watts to the class C tubes. Distortion curves are given for such operation in Fig. 14 for five kilowatts output from the 863 output system.

As a matter of interest, four tubes were used in the modulated class C amplifier and the resistors $R_1$ and $R_2$ were decreased to such a value that two 203A's as modulators were driven to approximately full power output. The output of the class C amplifier was about 250 watts. The measured distortion in the output of the 863's under these conditions was appreciably higher than the distortion shown in Fig. 14. This result was due principally to the fact that the decreased value of the loading resistance $R_1$ and $R_2$ was not as effective in reducing driver impedance as the use of the low impedance modulator tubes.

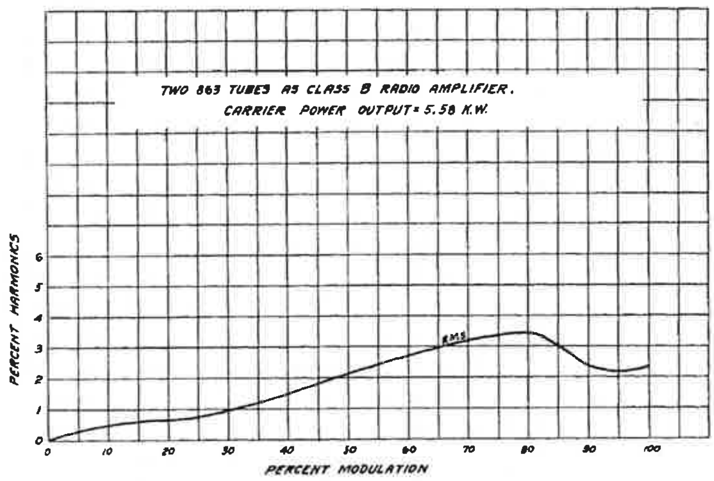


Fig. 14—Distortion introduced by a recently developed five-kilowatt broadcast transmitter.

The driver system for a fifty-kilowatt class B radio output system used the same low impedance radio-frequency coupling means as used for the five-kilowatt system shown in Fig. 12. Because of greater driver power requirements for the 898 water-cooled tubes for fifty kilowatts output, it was found most convenient to replace the high plate resistance 863 tubes in Fig. 12 with low impedance 848 tubes and so biased that the tubes operated as nearly as a class A radio amplifier as possible. The output impedance of the 848 driver stage as a class A radio amplifier can be determined approximately by (1) and (2) and it was found that the highest value of loading resistance across the grids of the 898, connected in the same manner as $R_1$ and $R_2$ in Fig. 12, resulted in the minimum distortion from the 898 class B radio output system. As shown in Fig. 4, if the loading resistance is increased, a decrease in driver impedance is obtained only if the step-down ratio of the coupling condensers to the grids of the 898's is increased. It is interesting to note that under normal operation with a fifty-kilowatt carrier, the direct grid current to the 898 tubes was negative, and that the power dissipated by the parasitic resistors across the grids of the 898's was approximately 750 watts. The general shape of the direct grid current at instantaneous values of upward and downward modulation for the 898 tubes was the same as shown in Fig. 13, except that the negative values over certain grid regions were much greater than shown in this figure.

The grids of the 848 tubes were not driven into the positive grid region so that the output impedance of the plate modulated system

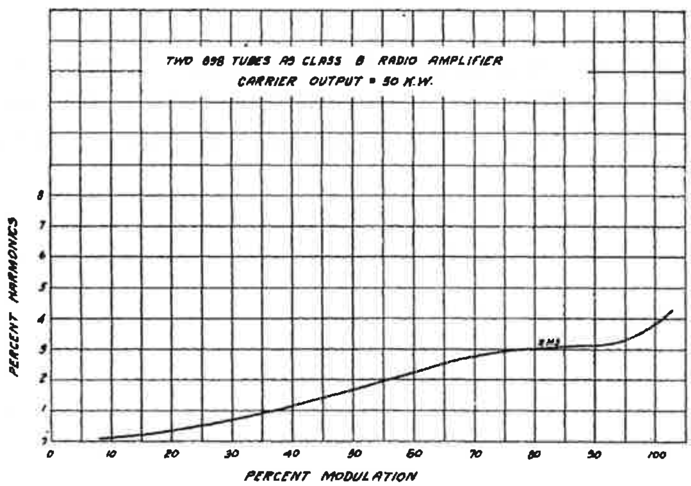


Fig. 15—Distortion introduced by a recently developed fifty-kilowatt broadcast transmitter.

as shown in Fig. 12 did not have to be as low as was necessary when 863's were being driven. The success with which the 898 tubes were driven with the low impedance 848 driver system is indicated by the curve shown in Fig. 15, data for which was taken at normal fifty-kilowatt carrier output and was the distortion introduced by the entire transmitter from an audio level of approximately 1.5 volts signal across 500 ohms.

## Conclusions

The theoretical considerations for the driver systems for class B audio- or radio-frequency amplifiers and the experimental results which substantiate the accuracy of the theory indicate that a low impedance driver system is very important for low distortion class B amplifier systems.

Another important consideration for class B amplifiers, especially for audio systems, is the plate current characteristic of the tube. This characteristic should be such that the disturbance in the output wave near the zero axis of plate current may be as low as possible. Practically this result can best be obtained by purposely causing the plate current to tail-off appreciably, which results in appreciable no-signal plate current. The remote plate current cutoff is particularly helpful in reducing distortion when high plate resistance tubes are used as class B audio amplifiers.

The class B amplifier plate load is somewhat critical for maximum power output and minimum distortion. However, this phase of the subject has been discussed in other papers and space does not permit a review of the proper plate load for the class B audio and radio amplifiers.

If the above factors affecting class B amplifier design are satisfactorily solved, class B audio- and radio-frequency amplifiers can be built for very low distortion output systems with existing tube designs.