WHY FIGHT GRID CURRENT IN CLASS B MODULATORS?*

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ABSTRACT

Grid voltage waveform distortion ranks with output transformer inadequacies among Class B audio amplifiers deficiencies. This article deals with the problem of grid voltage waveform distortion and suggests the use of low plate resistance low mu triode tubes as a solution. By avoiding operating conditions which result in grid current, the major source of distortion is eliminated. Direct coupled driving circuits which encourage large amounts of inverse feedback are readily employed under such conditions. A typical amplifier and its measured characteristics is used for illustration.

1. Why Is This Subject Important?

Class B operation of push-pull amplifiers is one of the best ways known today of obtaining high power with reasonable efficiency in the audio frequency spectrum. In order to keep the harmonic distortion to a tolerably low value, careful attention must be paid to the design of the output transformer and the grid circuit details. Proper transformer design has been expounded by several authors. Grid circuit design, on the other hand, has been more or less by rule of thumb.

2. Why Is Grid Current an Important Cause of Distortion?

Figure 1 illustrates the grid voltage plate voltage relationship in Class B operated vacuum tubes. It will be noted that the two lefthand curves are for a medium mu triode. The extreme left curve shows typical operation with intermediate values of grid voltage. The maximum value of grid voltage is less than the zero bias voltage so that the grid is always in the negative grid region. Plate voltage swing is nominal, being considerably less than the maximum capability of the tube. This operation naturally will be very inefficient because the minimum value of plate voltage is always rather large. The middle curve, on the other hand, shows a quite acceptable plate voltage swing which brings the efficiency to reasonable values but requires that the grid be driven into the positive region to do so. Please note that a small curve is shown which is designated grid current. Grid current

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starts flowing at the instant the grid voltage passes the zero line and moves into the positive grid region. It is during this interval when grid current flows that the driver is called upon to deliver power. If the driver voltage regulation is anything but perfect, the voltage will drop below what it should be during this grid current interval. The dotted curve shows a possible modification of the voltage waveform as a result of this grid current. It should be noted that this also affects the plate voltage swing. These points are the distortion which is common to this form of operation. The only way to operate under these circumstances without excessive distortion is to make the driver's impedance so low that its voltage regulation is essentially perfect. This, of course, is very wasteful of driver power and tends to offset the improved amplifier efficiency.

The curve on the right, which is designated as a low mu triode, illustrates a different approach. Here a tube is selected that is capable of efficient operation without the necessity of operating in the positive grid region. Grid voltage is shown always in the negative region. Even so, the plate voltage swing reaches a very satisfactory minimum value, which thus insures reasonably good efficiency, during the negative half of the cycle. Since it is never necessary for the grid to be driven positive, no grid current flows and therefore no power is required from the driver. The driver in this case is simply a voltage amplifier. It is true that the driver voltage required may be considerably higher than that required by a medium mu triode. This voltage swing is relatively easy to obtain since no power is required. It is only when a combination of voltage swing and power output are required that driver design becomes a serious problem.

3. What Are the Characteristics of an Ideal Audio Power Amplifier?

A power amplifier which approaches the ideal is one in which the grid to cathode impedance remains constant throughout an entire cycle of driving voltage. This might be some finite value in which case there would be a constant proportionality between the driving voltage and grid current, or it might be infinite. Unfortunately, there are no suitable vacuum tubes which present a constant finite input impedance. Therefore, we must choose a tube with infinite input impedance. This means that the grid must never be driven positive with respect to the cathode so that grid current never flows. Such a tube obviously never dissipates any power from the driving source and thus has a second advantage. This we shall set aside as characteristic --

a. No driving power required

In order that reasonable efficiency may be realized, it is important that the minimum plate voltage be reasonably low at the peak of the cycle. Since this peak occurs when the grid is at its maximum swing in the positive direction which is identically the zero grid voltage line, it is important that the tube have low plate resistance at this instant. Therefore, a second characteristic of a good audio power amplifier is --

b. Low plate resistance

A low plate resistance tends to make a constant voltage generator out of the amplifier which, for modulator service where the load is determined by the Class C amplifier loading, is a distinct advantage.

4. What Are the Particular Requirements of Tubes for This Service?

In a triode tube the relationship between the important tube parameters is expressed as $mu = G_M R_p$. It is apparent from this that to have low plate resistance the tube must have a high transconductance and a low mu factor. Generally speaking, then tubes which best meet this requirement will be low mu.

A few examples will illustrate the points just made.

Figure 2 is a typical plate current plate voltage characteristic of a triode of medium or high mu. It will be noted that the zero bias line has a rather flat slope. A typical load line has been superimposed to show that driving the grid only to the zero bias is a very inefficient use of the tube. The load line must be extended (dotted portion) into the positive grid region to realize any efficiency.

Figure 3 is a typical plate voltage plate current characteristic of a low mu triode. It will be noted here that the superimposed load line represents relatively low minimum plate voltage values when it intersects the zero bias line. The extra dotted lines illustrate a range of suitable load impedance values. It is to be noted that the plate voltage swing changes very little as the load impedance is changed.

Figure 4 is a typical tetrode characteristic curve. Here it is apparent that by careful choice of the load impedance very high plate circuit efficiency is obtained. It will be noted, however, that small changes in plate load impedance cause serious changes in plate swing. In many cases this is a serious disadvantage. What is not shown in these curves are the screen current variations. Screen current flows in pulses quite like grid current in positively driven grid circuits. Its peak value depends considerably on the minimum plate voltage during a cycle. Extremely good regulation of the screen voltage supply is therefore a must for proper operation of tetrodes in Class B amplifiers.

5. What Circuit Advantages Does Class B_1 Operation Provide?

(Class B_1 operation is defined as an operating condition where the plate current flows for one-half cycle, while grid current never flows for even a fraction of a cycle. The subscript 1 indicates this grid current limitation. A subscript 2 refers to operation wherein grid current flows during at least part of a cycle.)

Since there is no grid current to contend with, the coupling circuits between the driving amplifier and a Class B_1 modulator can be simple and of the type common to ordinary voltage amplifiers. Resistance capacitance circuits can replace the usual Class B driving transformer. Figure 5 is a circuit which illustrates this fact.

Figure 6 is a modification of the schematic shown in Figure 5 wherein a direct coupled circuit is substituted between the driver and the power amplifier. An input stage and a feedback circuit are also shown. This arrangement has very marked advantages where inverse feedback is to be employed. It will be noted that there is only one capacitor in the entire feedback loop which is almost a certain guarantee of proper low frequency phase versus feedback loop response characteristics. There can be no low frequency motor boating with this circuit, no matter how much inverse feedback is used. It will be noted also that the high frequency feedback loop response can be readily controlled by the strategic choice of plate load resistance values and rather simple response shaping circuits.

It will be noted that the driver is operated with its cathode negative to ground. This allows the voltage drop in the driver load resistor to be used directly as the bias and signal voltage for the modulator. Although a triode driver is shown, a tetrode may be used to considerable advantage to obtain higher voltage gain. The screen connection is shown dotted.

Typical characteristics of a modulator using the basic circuit shown in Figure 6, but with three 8C25 tubes in parallel on each side of the push-pull circuit (a total of six in all) are as follows:

<u>Tubes</u>

First Stage -- 12AX7	Plate Voltage -- 5 KV
Second Stage -- Push-pull 4-250A	Input Level -- +10 DBM
Third Stage -- (6) - 8C25	Inverse Feedback -- 20 DB
Power Output -- 25 KW	

Figure 7 shows the inverse feedback loop response for a 50 to 15,000 cycle passband. Both ideal and actual response curves are shown for stable operation with 26 DB of feedback and actual operation with 20 DB.

Figure 8 shows a typical response curve taken from the rectified RF of a 35 KW transmitter which was plate modulated by the modulator described. The high frequency cut-off shown is produced by a low pass filter following the modulator unit.

Typical values of distortion measured from the same rectified RF source are shown in this same figure. It will be noted that from 100 to 3,000 cycles the distortion is less than 1%, while between 60 and 15,000 cycles it is well below 2%.

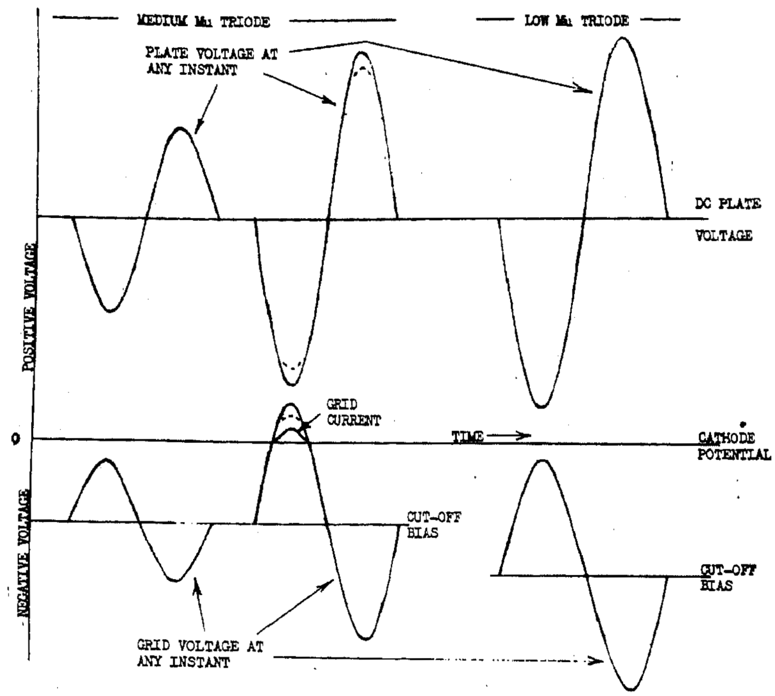

Fig. 1

Typical instantaneous plate and grid voltage relationships for Class B operated tubes. Left and middle curves are for medium mu, while right curve is for low mu triodes.

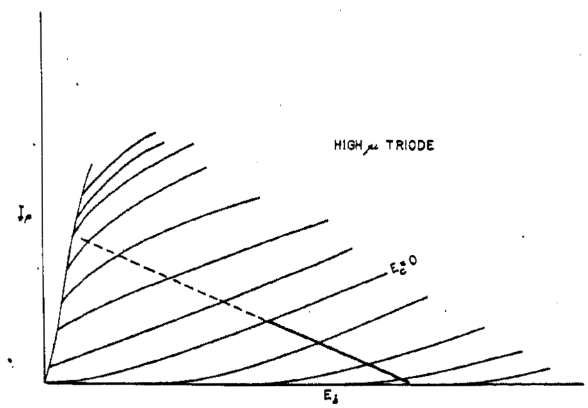

Fig. 2 Typical plate characteristic curves for a high mu triode with a possible load line superimposed.

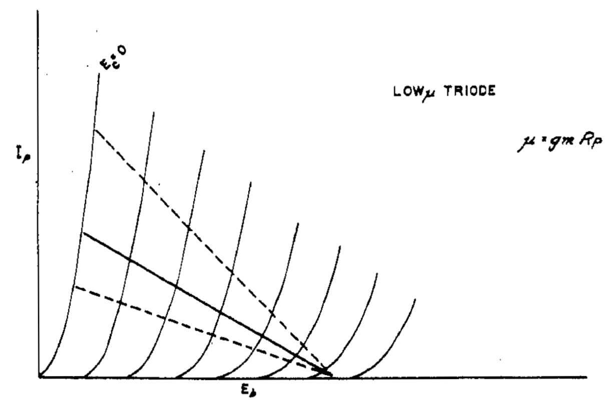

Fig. 3 Typical plate characteristic curves for a low mu triode with several possible load lines superimposed.

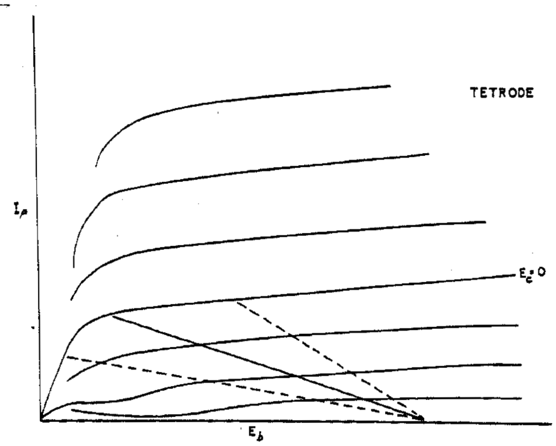

Fig. 4

Typical plate characteristic curve for a tetrode tube with several possible load lines superimposed.

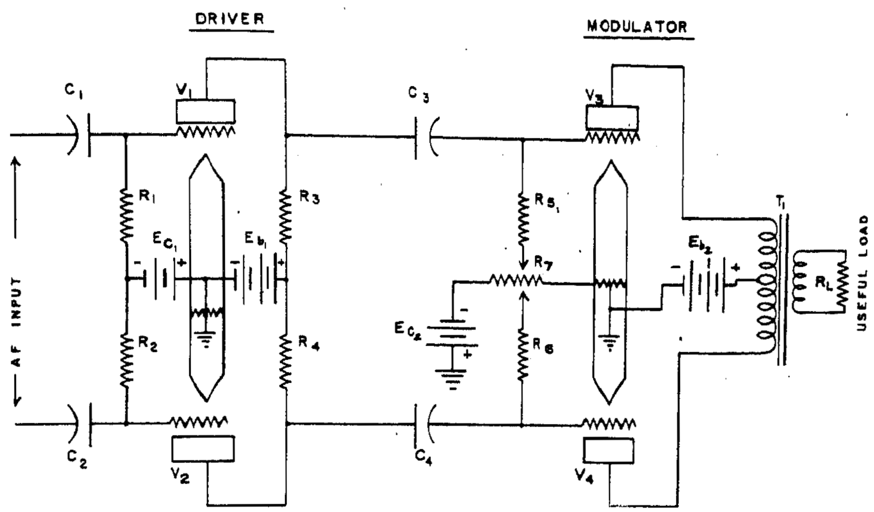

Fig. 5

Convential driver modulator arrangement for Class B_1 operation.

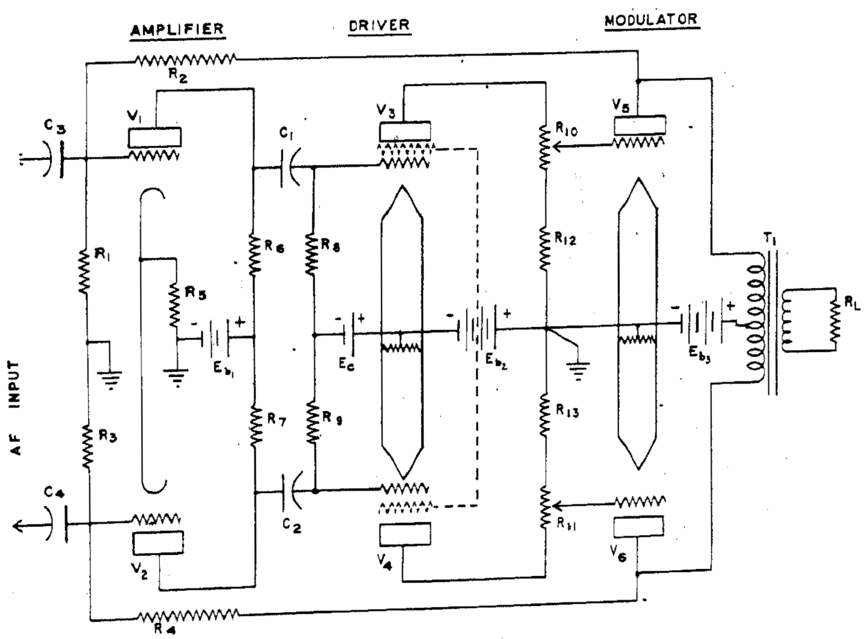

Fig. 6

Direct coupled driver modulator circuit arrangement with improved performance.

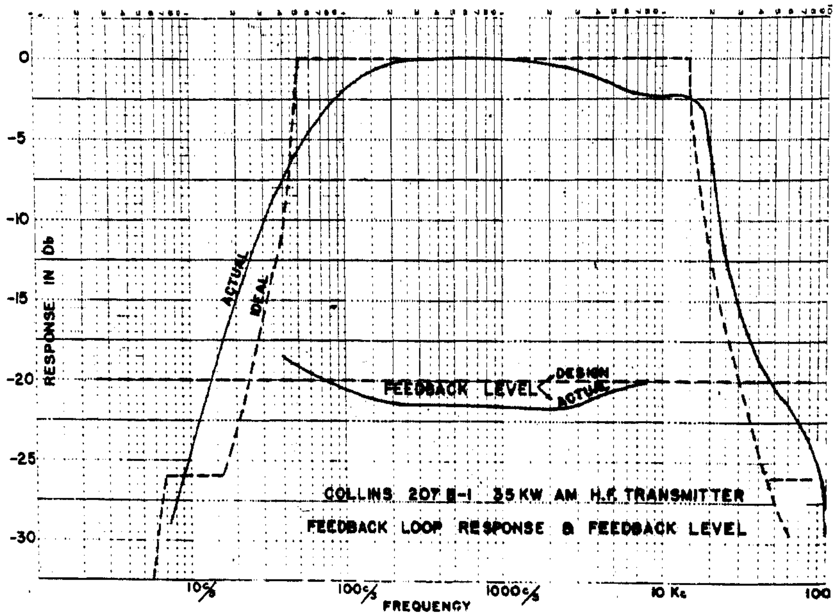

Fig. 7

Typical inverse feedback loop response showing the ideal curve for a 50 to 15,000 cycle passband and a solid curve depicting the curve actually attained.

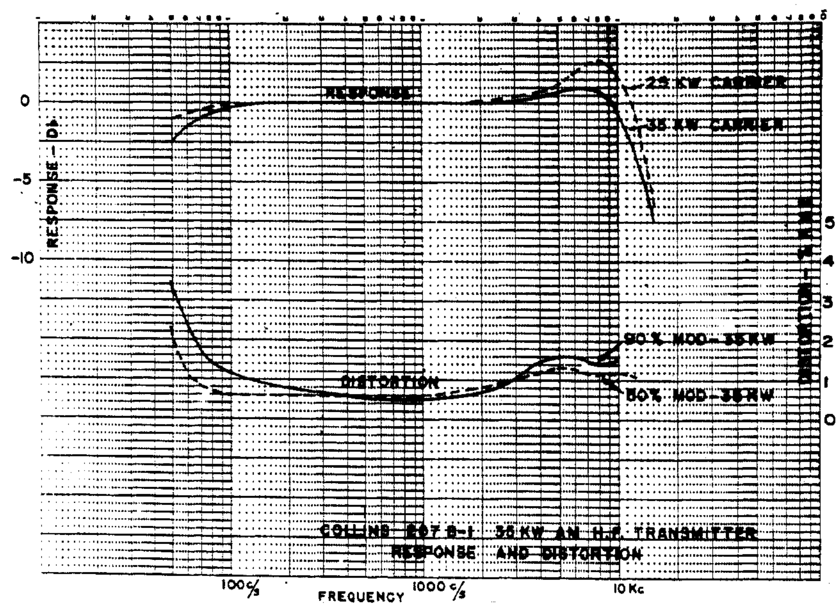

Fig. 8

Typical response and distortion data measured at the output of a 35 KW AM transmitter employing Class B_1 modulators in the direct coupled circuit described in this paper.