New Biasing Circuit for Class B Operation*

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Switching distortion is generated in class B operation because an input signal above a certain level causes the two transistors performing the push-pull operation to switch off completely at the same time. It is discussed how complete switching off of the transistor can be avoided and how the off state can be transferred smoothly to the subsequent on state.

Ultimately it was found how these effects can be achieved simply by adding a pair of transistors to the bias circuit.

0 INTRODUCTION

Several papers have been written about improved bias circuits in class B amplifiers to reduce distortion [1]–[3]. Class B amplifiers are popular because they are more economical than class A amplifiers and because a reasonably good response is possible with advanced negative-feedback techniques. Yet there are still those who assert that class A amplification is the only means to achieve accurate and faithful reproduction.

Indeed, class B amplification is inferior to class A amplification in some respects. For instance, a class B amplifier produces switching distortion as its bipolar transistors switch on and off. We have seen several developments in which bipolar transistors are prevented from generating switching distortion, and some of these require highly complicated circuitry. The few that do use simple circuitry operate, but not perfectly.

The bias circuit we have developed and which we discuss in this paper eliminates switching distortion completely without sacrificing operating stability and without complicated circuitry; the simple addition of two transistors to the conventionally designed bias circuit accomplishes this improvement. And since switching is completely avoided, high-frequency distortion is largely reduced in the new amplifier.

1 MECHANISM OF SWITCHING-DISTORTION GENERATION

It is common knowledge that switching distortion occurs when bipolar power transistors are operated in the class B mode.

In Fig. 1 the bias voltage across A and B is adjusted so that a small current flows through TR_a and TR_b when there is no input to amplify. This small current is commonly called "quiescent current."

When there is an input, current flows through the final-stage power transistors. As it does so, the transistor's V_{BE} voltage and the voltage across the emitter resistor R_a increase. Thus when either of the transistors draws current, the other does not, since it is cut off.

Fig. 2(a) illustrates the operation of the two transistors at low level. As power output increases, waveforms of the two transistor currents become "hard" [Fig. 2(b)], leading to switching distortion. Fig. 2(c) shows the waveforms of the V_{BE} voltages at increased power. Not only is the current of one transistor cut off, but its V_{BE} voltage is also reversed (reverse biased).

Another cause of switching distortion are the discharge and the charge of the transistor base carriers under the influence of large voltages. One way to cope with switching distortion, therefore, has been to use power transistors with f_T as high as 100 MHz.

At present there are several techniques to reduce switching distortion, all developed rather recently.

1) A low-power class A amplifier is connected in series with a high-power class B amplifier, the amplifiers operating as one with little switching distortion [4].

2) In addition to a conventional bias circuit, a separate bias voltage supply is used. Its voltage is fed, as determined by diode switching, to the transistor, thereby preventing the "low" transistor from cutting off.

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3) The bias circuit is designed so that bias will increase to compensate for the deficiency in forward voltage as output current increases [5].

2 EXISTING CIRCUIT DESIGNS FOR IMPROVED SWITCHING DISTORTION

Let us examine the three existing circuits more closely.

The first technique (Fig. 3) connects two amplifiers in series. Here the high-power class B amplifier drives the floating power supply of the low-power class A amplifier. The advantage of this design is that even if the power-supply voltage of the class A amplifier is low, the clipping level is equal to that of the class B amplifier, because the former is supplied by the latter.

Therefore, seen as a whole, the amplifier operates as if in class A mode, generating no switching distortion. Yet because they are connected in series, both the class A and the class B amplifiers must be capable of large current. This capability leads to higher cost.

The second technique (Fig. 4) needs, in addition to a conventional bias circuit V_1, two more bias circuits V_2 and V_3, referenced to the output of the amplifier. By means of diode switching, current in the output transistors is prevented from cutting off.

When one power transistor is conducting, the other is fed bias current from V_2 (or V_3) through the switching diode. Since current in the power transistors is never cut off, minimal switching distortion occurs.

However, in this technique current is switched by abrupt action of the diodes, and it is almost impossible to eliminate switching distortion completely.

The third technique is represented by the following two circuit designs.

1) In one (Fig. 5) the bias current is made of eleven transistors. When current flows through the power transistor TR_a, its V_{BE} voltage increases, as does the voltage across R_a. The corresponding voltage increase occurs across A and C.

Current flowing through TR_6, R_3, TR_8, and TR_{10} also increases, with voltage across R_3 increasing as well. Since TR_6 and TR_4 form a current-mirror circuit, the same current flows through R_1 as through R_3. When R_1 and R_3 have the same resistance, the same voltage appears across R_1, which is equal to the increase appearing across A and C.

This voltage increases the emitter-collector voltage of TR_2. In other words, the voltage increase across A and C causes a voltage increase across A and B. The same action applies to TR_b as well.

In this manner, switching distortion may be reduced without running short of bias voltage. Despite its complicated configuration, using as many as eleven transistors, the bias circuit operation results only from positive feedback. Therefore thermal compensation for bias current is hard to achieve.

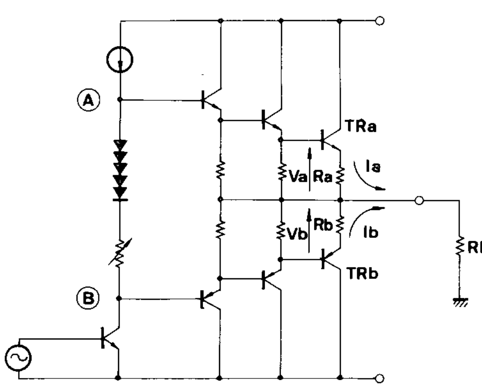
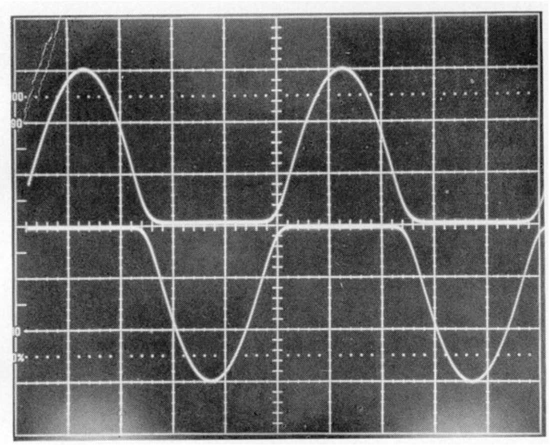
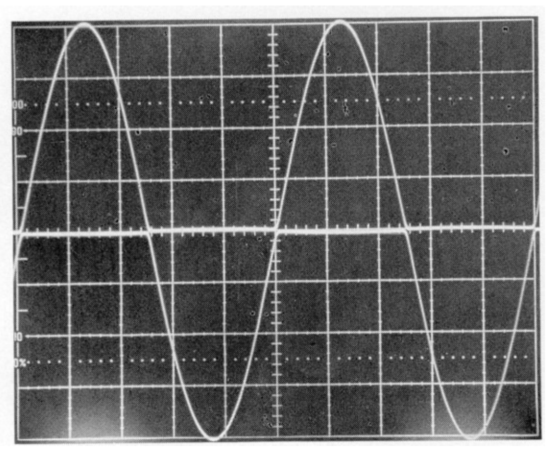


Fig. 1. Class B amplifier circuit diagram.



(a)



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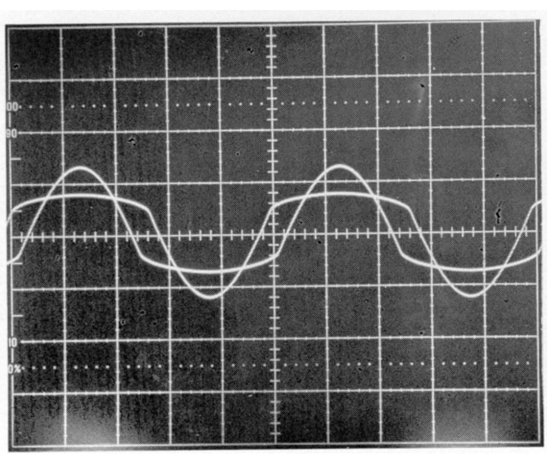

(c)

Fig. 2. Fixed bias circuit. Vertical scale: (a) 0.1 A/div. (b) 1 A/div. (c) 1 V/div.

2) The other design (Fig. 6) uses a six-transistor bias circuit. TR_5 and TR_6 form a constant-current circuit, furnishing constant voltages E_1 and E_2. This circuit operates in the same manner as the one just described. The increase in V_{BE} voltage of the power transistor and the voltage increase across R_a appear across A and C. As the voltage increases, so does the current flowing through R_1, TR_3, and E_1, causing a voltage increase across R_1 equal to the increase seen across A and C. This voltage increase causes a like increase in the voltage across the collector-emitter of TR_1, leading to a voltage increase across A and B.

Since this technique does not lack bias voltage at any time, it prevents switching distortion.

In both techniques 1) and 2), positive feedback is used, whereby the V_{BE} of the conducting output transistor and the increased voltage across its emitter resistor are sensed and used as a means of increasing the voltage of the bias circuit. But neither employs negative feedback in which the decreased bias in the nonconducting transistor is sensed and used as a means to increase its bias voltage.

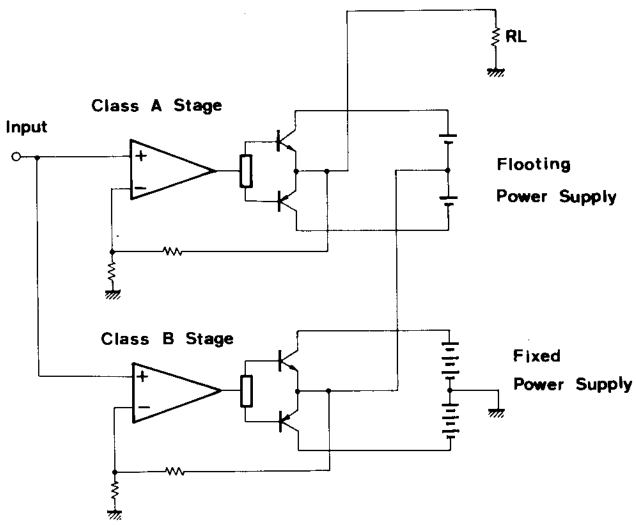

Fig. 3. Circuit diagram of class A and class B amplifiers connected in series.

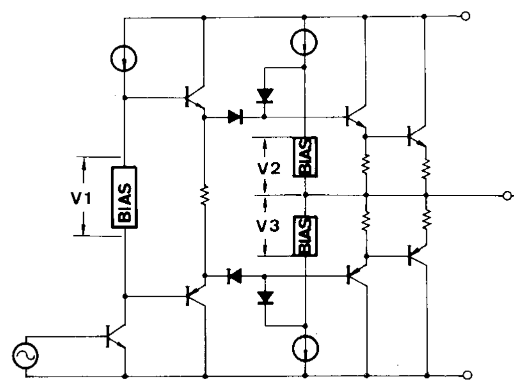

Fig. 4. Circuit diagram of amplifier using two additional bias circuits.

3 NEW BIASING CIRCUIT DESIGN

From the foregoing, two bias-circuit designs to reduce switching distortion are as follows:

1) Positive feedback applied by sensing the increase in the conducting transistor V_{BE} and its emitter-resistor voltage, and correspondingly increasing the voltage of the bias circuit. Positive feedback gain must never be greater than unity, because otherwise the power transistors may break down. Nevertheless, the design has the conflicting characteristic that the closer its gain is to unity, the easier it is to reduce switching distortion.

2) Negative feedback applied by sensing the decrease in the nonconducting transistor V_{BE} and its emitter-resistor voltage, and correspondingly increasing the voltage of the bias circuit. Operation is stable. Sensing is possible only during the half-cycle in which the transistor is nonconducting. In addition, a sudden change of state from conducting to nonconducting, or vice versa, should be prevented.

Our newly developed circuit is simple, with a bias circuit that uses both positive and negative feedback and is also stable (Fig. 7). Let us first examine the positive-feedback operation.

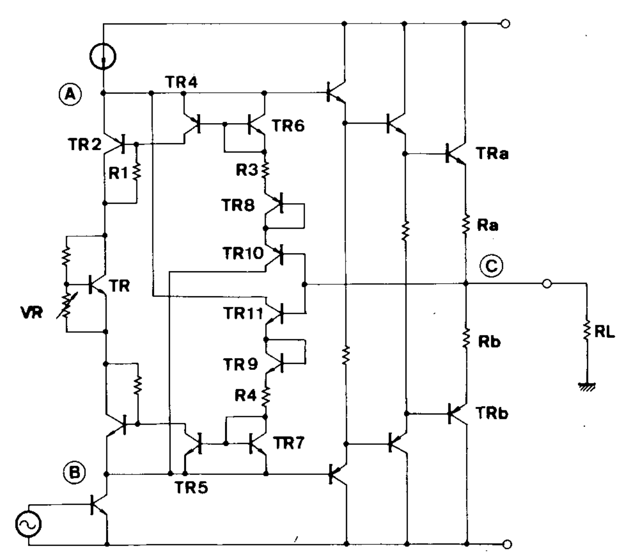

Fig. 5. Circuit diagram of amplifier using 11-transistor bias circuit.

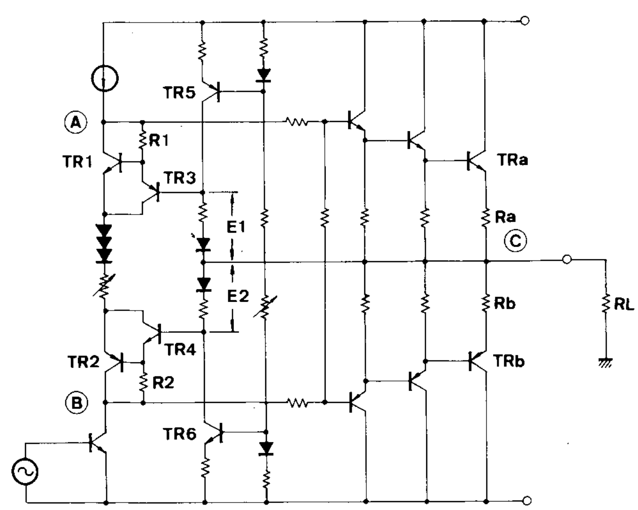

Fig. 6. Circuit diagram of amplifier using 6-transistor bias circuit.

In this circuit, the increase in the conducting output transistor V_{BE} and R_a voltage drop appears across A and B, because TR_1 forms a quasi-constant-current circuit. TR_1 is an emitter follower in the bias circuit; its operating gain will never exceed unity.

In the negative-feedback circuit, the voltage increase, divided by R_1 and D_1, is applied to the base of TR_1. However, when the transistor is conducting, the voltage across C and D is large, the current flow through D_1 is large, and the internal resistance of D_1 is small. Therefore there is little negative-feedback operating during the conducting half-cycle.

As for the nonconducting transistor, since voltage across C and E is small, D_2 has high internal resistance, assuring sufficient negative-feedback operation. This operation occurs only during the half-cycle in which the transistor is nonconducting. That is, when TR_b is switched off, voltage across C and E decreases, reducing the voltage of D_2. As a result, voltage from base to base of TR_1 and TR_2 decreases.

Since the emitter-to-emitter voltage of TR_1 and TR_2 is constant, an increase in voltage across the collectors of TR_1 and TR_2 is seen, while current through TR_1 and TR_2 is reduced. Thus the current in the nonconducting output transistor increases, preventing it from cutting off and generating switching distortion.

The circuit has a reduced impedance across A and B because of negative feedback; therefore it has the advantage of allowing efficient transmission of currents, or audio signals, from A to B. Another advantage is that switching between conducting and nonconducting states is not drastic but gradual, because it takes advantage of the gradual shoulder response of the diode.

The major difference between this and other circuit designs lies in having only the collectors of TR_1 and TR_2 connected to A and B. Since a low-impedance emitter is not connected to the signal path, the bias circuit does not load the voltage-amplifying stage and generate distortion at that point. Fig. 8(a) shows the current waveforms of output transistors biased by the circuit. Fig. 8(b) shows the current waveforms at higher power. Note that the push-pull waveforms are connected smoothly. In Photo 8(c), the V_{BE} voltage waveforms of the output transistors, note that the base-emitter voltages are not reverse biased.

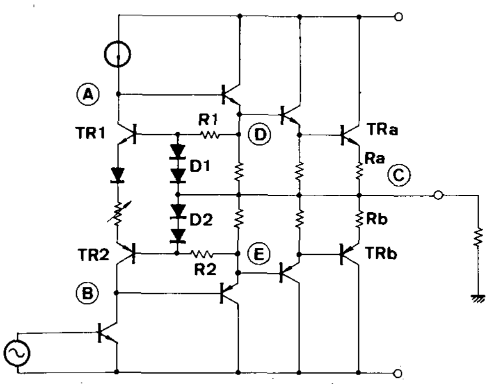

Fig. 7. Circuit diagram of amplifier with bias circuit using positive and negative feedback.

4 ADVANTAGES OF THE NEW BIASING CIRCUIT

We added the bias circuit to a conventional-design amplifier and measured the improvement in distortion. Fig. 9 shows the output versus total harmonic distortion of an amplifier with conventional fixed bias; Fig. 10

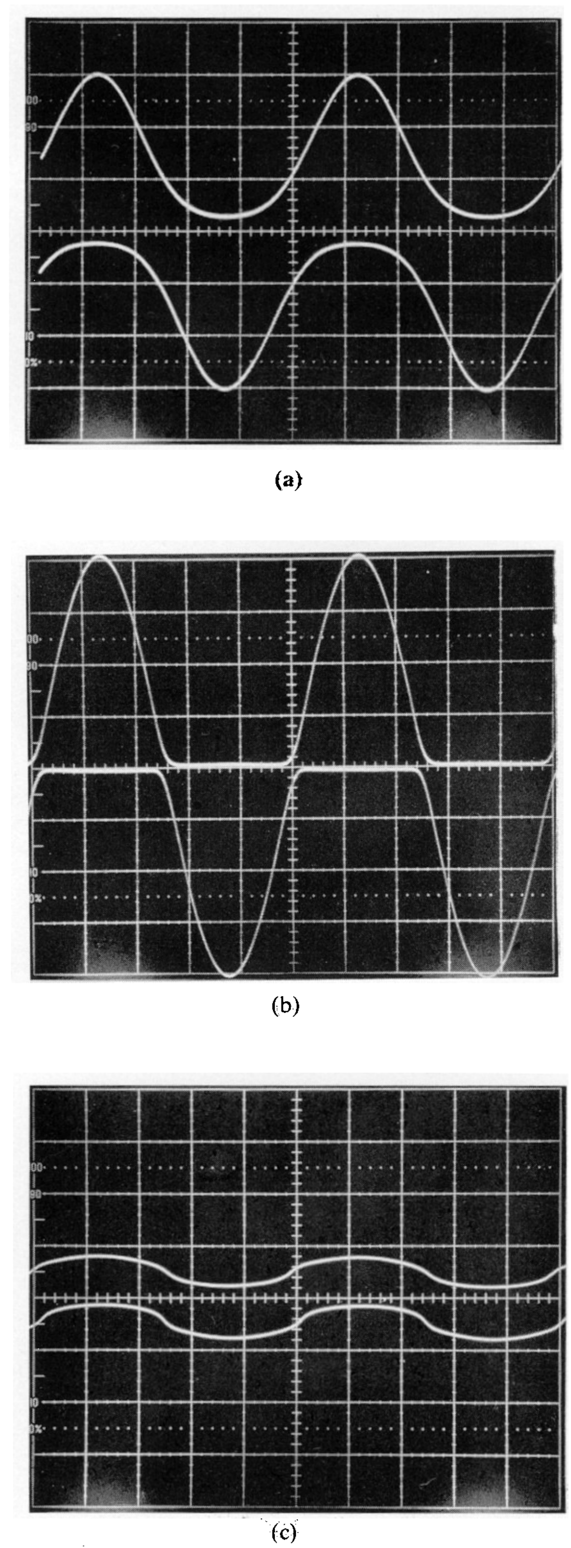

Fig. 8. New biasing circuit. Vertical scale: (a) 0.1 A/div. (b) 1 A/div. (c) 1 V/div.

shows that of an amplifier with the new bias circuit. Comparison shows greatly improved total harmonic distortion in the high-frequency range. The 20-kHz total-harmonic-distortion waveforms are likewise different (Fig. 11); they show the complete elimination of switching distortion.

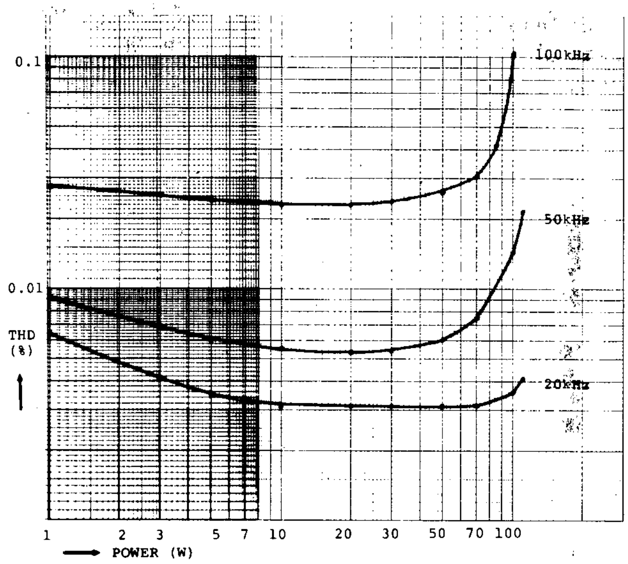

Fig. 9. Total harmonic distortion versus power output. Load 8 Ω. Fixed bias circuit.

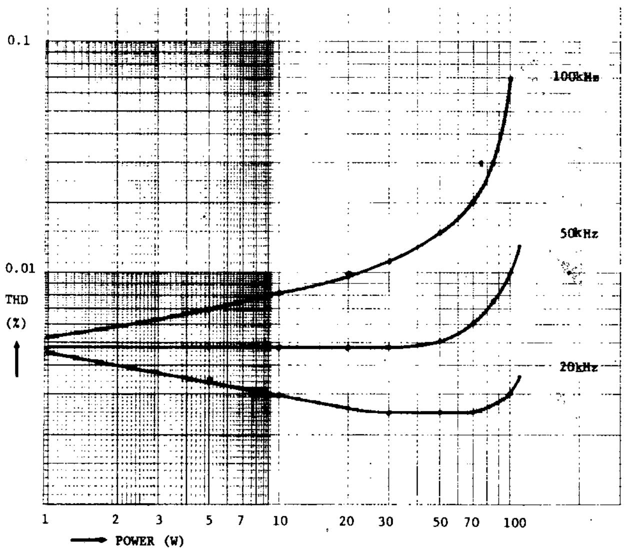

Fig. 10. Total harmonic distortion versus power output. Load 8 Ω. New biasing circuit.

5 CONCLUSION

In this paper we have presented several techniques to eliminate switching distortion generated when bipolar transistors are operated in the class B mode.

With a simple two-transistor design a new bias circuit controls the bias by positive and negative feedback to completely eliminate switching distortion.

Efficiency is a little lower than that of a conventional class B amplifier at low power, but at rated power output it is as high as that of a conventional amplifier.

Although the circuit reduces switching distortion to a level on a par with a class A amplifier, class A amplifiers have more to offer in terms of quality. This should be the subject of future discussions.

6 ACKNOWLEDGMENT

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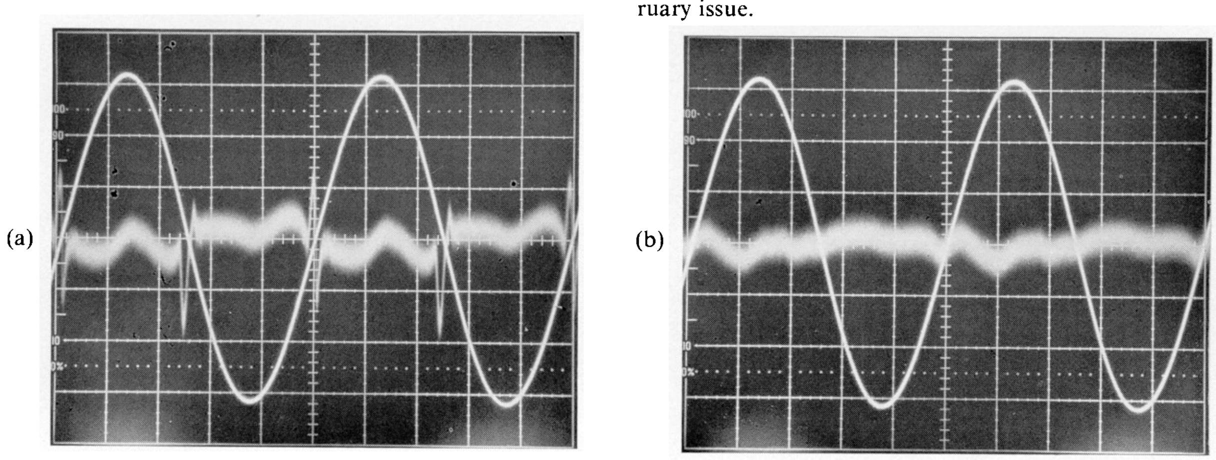

Fig. 11. Total-harmonic-distortion waveforms. Frequency 20 kHz; power 100 W/8Ω. (a) Fixed bias circuit. (b) New biasing circuit.