Bias Compensation for TRANSISTOR OUTPUT STAGES

By PATRICK HALLIDAY

Circuits recommended by British manufacturers to minimize crossover distortion in class-B type transistor audio stages.

THE bias applied to the class-B push-pull output stages of transistor devices has to be reasonably accurately determined to avoid crossover distortion. However, it is difficult, using conventional resistor networks, to avoid some degree of crossover distortion as the battery voltage falls, particularly in low ambient temperatures. This problem has long been recognized and has resulted in the development of compensation techniques designed to automatically adjust the bias conditions to changes in battery voltages and/or ambient temperature. Two effective techniques involve the use of either temperature-sensitive thermistors or junction diodes.

Crossover Distortion

Crossover distortion in a transistor class-B stage arises when the bias conditions, or any substantial difference in the characteristics of the output pair, result in discontinuities at the changeover point so that the two half-cycles of the amplified waveform do not accurately fit together. Fig. 1 shows two common forms in which this type of non-linearity distortion takes place.

This distortion is highly objectionable to the listener as it produces high-order harmonics resulting in discordant speech or music. Provided that a well-matched pair of transistors is used, crossover distortion can be kept low by careful choice of bias current arranged so that there is appreciable idling current flowing under no-signal conditions; therefore, the stage is not operating in true class B. Negative feedback is also valuable in reducing this form of distortion.

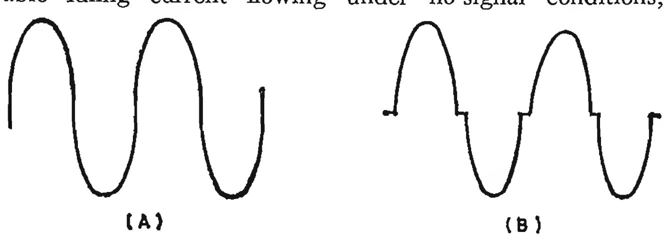


Fig. 1. Crossover distortion may take these forms in class-B transistor amplifiers. In (A), the sine waves have straight sides in the area on both sides of the zero crossover point.

When the bias network is made up of conventional resistors, these are often specified as 5% tolerance to ensure that the bias current is close to design optimum. Split-load output stages have also been used to reduce the effects of crossover distortion.

With most non-compensated output circuit arrangements, the designer has the difficult problem of choosing a bias condition that will suit the stage when it is operated from a new battery or at the much lower end-point voltage of dry zinc-carbon cells. The problem would be much less acute if mercury cells were universally employed, since these maintain almost constant voltage throughout the greater part of their useful life.

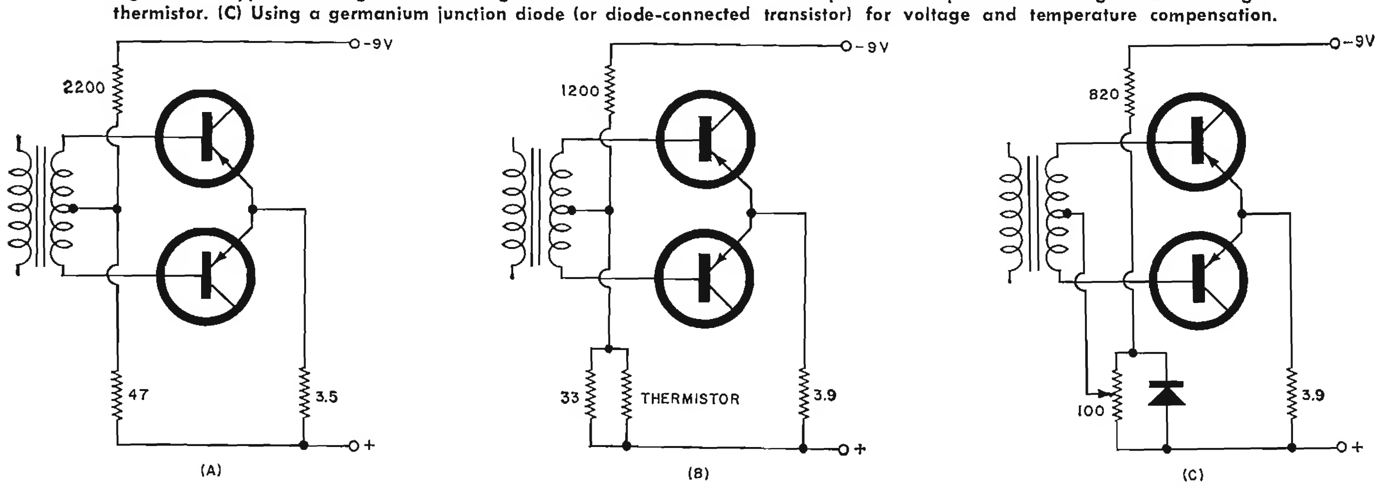
If the designer chooses the bias conditions to keep crossover distortion low throughout a wide variation of supply voltage, it is necessary to make the idling no-signal current high at full voltage. This is not only uneconomical for the user but also increases the possibility of thermal runaway.

On the other hand, a moderate idling current at initial battery voltage usually results in crossover distortion becoming objectionable while there is still a lot of potentially useful energy left in the battery. In many transistor receivers, it is the onset of considerable crossover distortion that indicates to the user that a new battery must be installed.

With portable receivers designed to provide some 400 mW of continuous output power, crossover distortion can usually be reduced to an acceptable figure for as long as there is an idling no-signal collector current of about 1 mA for each transistor.

A change in ambient temperature also affects the situation because of the thermal sensitivity of germanium transistors. Crossover distortion will tend to be accentuated at low temperatures since collector current for any one level

Fig. 2. (A) Typical biasing network using 5% tolerance resistors. (B) Temperature-compensated biasing network using a thermistor. (C) Using a germanium junction diode (or diode-connected transistor) for voltage and temperature compensation.



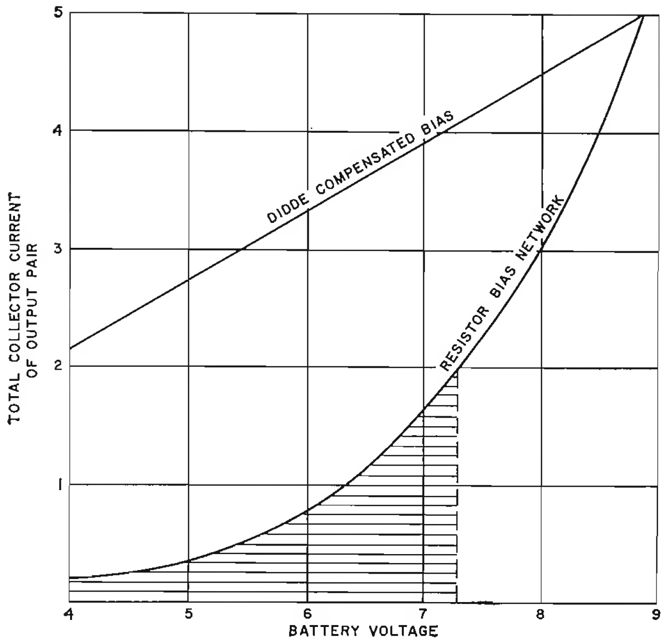


Fig. 3. How the no-signal collector current changes with supply voltage for both types of bias networks. These curves are based on a diode current of 9 mA. The shaded portion shows region in which crossover distortion is likely to occur. →

of base-emitter voltage decreases with falling ambient temperature in the area of the transistors.

Thermistors

The need to change bias conditions with temperature soon led to the use in the bias network of thermistors—semiconductor resistors having a high negative temperature coefficient. Any fall in ambient temperature causes the resistance of the thermistor to rise appreciably, and with good design this can be made to compensate the bias current to the transistor. Fig. 2A shows a simple form of resistor bias network, while Fig. 2B indicates how a thermistor may be incorporated. With compensation, there will usually be some increase in battery wastage due to additional current in the bias network, but the advantages generally outweigh this disadvantage.

Diodes

Selenium diodes having a non-linear voltage/current relationship have been used in some receivers to adjust the bias current automatically as battery voltage falls.

Although these two individual techniques can provide either temperature or voltage compensation, more recently an effective means of combining both functions within a single component has been developed. This technique uses a small semiconductor junction diode (or a transistor diode-connected by using only the base and collector leads, leaving the emitter lead disconnected). The junction diode is usually germanium, although somewhat more effective compensation can be obtained by using silicon diodes in this circuit.

When a junction diode is connected in the bias network, two useful effects come into play. First, its non-linear voltage/current relationship means that voltage across the diode falls more slowly than the current flowing through it, and in a bias network, the current will be roughly proportional to the supply voltage. Second, the voltage across the diode will decrease with rising temperature.

Of particular value, the non-linear voltage/current relationship of the junction diode corresponds to that of the output transistors, and this allows an almost linear relationship to be achieved between the no-signal collector current of the output transistors and the diode current. Fig. 2C shows how a junction diode can be connected into a bias network to provide voltage and temperature compensation.

From Fig. 3, it can be seen that with the help of a compensating germanium diode, a typical output stage using a nominal 9-volt battery could be expected to operate satisfactorily to below 4 volts without reducing the total no-signal collector to below 2 mA, whereas, with a conventional resistor bias network, the current falls to this figure when the supply voltage reaches 7.3 volts. Furthermore, these results can be achieved with the same initial no-signal current of 2.5 mA for each transistor.

In general terms, with germanium bias-compensating junction diodes, battery voltage can fall to below half its nominal value before performance is likely to drop below acceptable levels, even at low temperatures.

The compensating diode is, of course, affected by temperature in a parallel manner to the output transistors, and in a typical class-B output stage, the circuit can be arranged to at least halve the over-all effect of temperature changes.

In the typical compensated circuit of Fig. 2C, the diode is connected across a preset potentiometer to allow the stage to be set up to suit the particular component and semiconductor tolerances. The potentiometer must be of a value which will keep input losses low without shunting too

Fig. 4. Battery economy circuit that allows part of the compensating diode current to be derived from driver stage.

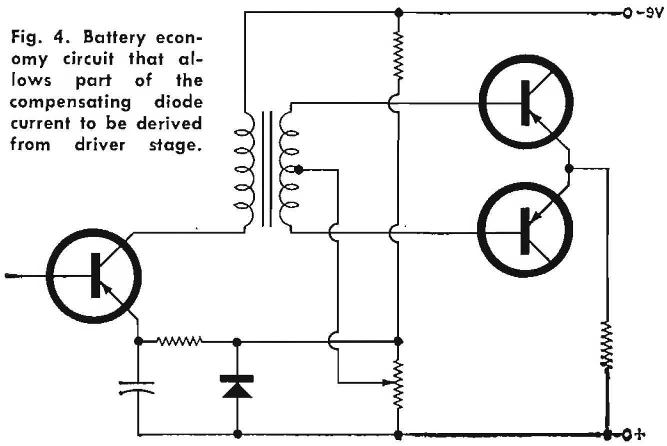
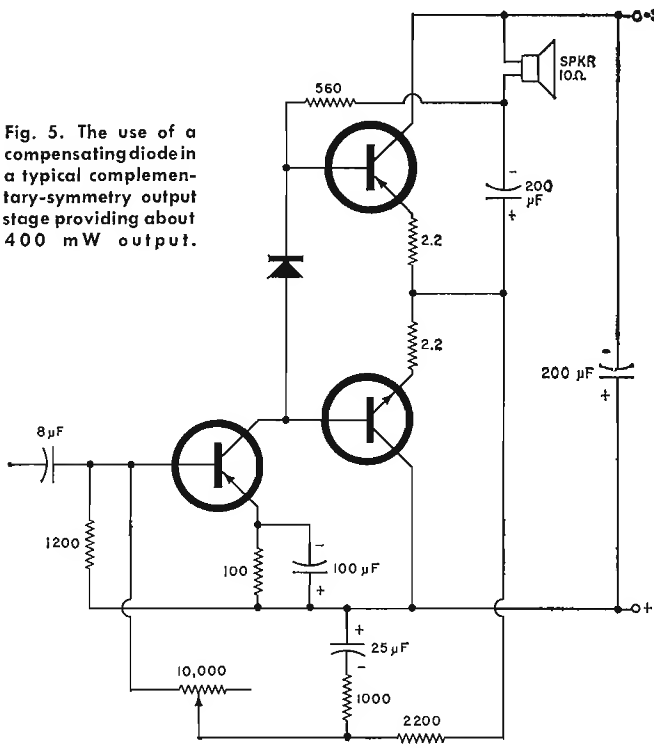


Fig. 5. The use of a compensating diode in a typical complementary-symmetry output stage providing about 400 mW output.



much of the forward bias current flowing through the diode. Diode current must be in the region of 8 mA for proper operation.

Current flowing through the bias network represents drain on the battery. This wastage can be reduced by obtaining some of the diode current from the emitter current of the driver stage, as shown in Fig. 4.

A further benefit is obtained from a compensating diode used in a transformerless complementary-symmetry output stage of the type shown in Fig. 5. Because of the low a.c. resistance of the diode, any changes in current in the driver stage produce less effect on the output stage than would conventional biasing resistors. In a typical circuit, the use of a diode rather than a circuit where the differential a.c. resistance and d.c. resistance are the same can reduce bias changes due to driver current variations to less than one-fifth.

Thus, in this case, the bias-compensating diode reduces the effects of variations in signal, temperature, and supply voltage upon the bias conditions of the output stage. Because of the varying load of a class-B stage, voltage stabilization is important with power-line-operated as well as battery-operated equipment.

Other Arrangements

A different form of bias stabilization, which has been used in some radio receivers, is shown in Fig. 6. Here the bias current applied to the push-pull output transistors (Q3 and Q4) is determined by the collector-emitter voltage of stabilizing transistor Q5. This in turn depends upon the base-emitter voltage derived across the 12-ohm resistor which, with the 470-ohm resistor, forms part of a voltage divider in the emitter circuit of driver stage Q2. Any voltage change in the emitter of Q2 will result in a corresponding change in the control voltage applied to the base of Q5. The effects of temperature variations are compensated by a change in the base-emitter voltage of Q5. Supply-voltage variations are similarly compensated by the change in the emitter current of Q2.

By using compensation techniques, the onset of the unpleasant-sounding crossover distortion can be postponed to well beyond the voltage and temperature limits possible in uncompensated output stages.

A number of the diagrams shown in this article are derived from reports of the British firms *Thorn-AEI Radio Valves and Tubes Ltd.* and *Mullard Ltd.*, both of whom have introduced small junction diodes (types AA120 and AA129) for this application. ▲

Fig. 6. Transistor bias stabilization circuit in which bias of the push-pull output stage is determined by the collector-emitter voltage presented across control transistor Q5.