

# DESIGNING OTL

*A solid-state audio power amplifier can range from a multi-stage circuit using quite a few transistors and diodes determined by such factors as bandwidth, permissible distortion*

AN OUTPUT TRANSFORMER IMPOSES SEVERE limitations on the quality of a design. To overcome the bandwidth restriction, the transformer must be both expensive and bulky. Furthermore, phase shifts at high and low frequencies set boundaries on the amount of feedback that can be placed successfully around a circuit before it becomes unstable.

While practical amplifiers designed for public address systems use output transformers, the transformer is omitted in just about all modern solid-state high fidelity amplifiers. The loudspeaker is capacitive or direct coupled to the output devices. The industry uses variations on three basic circuits.

One circuit uses a driver transformer for phase inversion. Here the transformer is not as taxed as when it is used as an output device. Hence its size and cost are relatively small. A second arrangement, the quasi-complementary circuit, uses two identical output devices driven by two lower powered complementary transistors arranged to provide the equivalent of phase inversion. The third, the fully complementary amplifier, uses a complementary pair of devices in the output so that phase inversion occurs in the power output transistors themselves, or in the combination of the output transistors and their drivers. The basic characteristics of these three circuits are discussed here.

## Transformer phase inverters

A circuit using a transformer as the phase

inverter is shown in Fig. 1. Q1 and Q2 may be considered as a two-stage voltage amplifier driving the power transistors, Q3 and Q4, through the driver transformer. To be specific, each transistor stage can be thought of as a power amplifier. Thus Q1 delivers its minute amount of power to drive a somewhat larger device, Q2, which in turn, must deliver enough power to drive the high power output transistors, Q3 and Q4. Theoretically, Q3 and Q4 will be bigger devices than Q2, which is, in turn, bigger than Q1.

The input signal is capacitively coupled to Q1. Direct coupled to Q2, Q1 transistor receives its bias voltage from Q2's emitter circuit. As the dc feedback through  $R_{B1}$  from the junction of  $R_{E2}$  and  $R_{EB}$  is substantial, this circuit is extremely temperature stable.  $R_{EB}$  in the emitter circuit is bypassed to ground by  $C_{EB}$  to prevent any ac from being fed back from this point along with the dc.

The output from Q2 is fed to a transformer with two identical secondary windings — preferably bifilar wound. The phase relationship between the two windings are indicated by the dots. Dots at the ends of two windings indicate that these ends are in phase with respect to the unmarked ends.

Should the portion in a cycle be such that the unmarked ends are positive with respect to the ends with the dot, Q3 is forward biased and conducts while Q4 is reverse biased. In the next portion of the cycle, the opposite polarity exists at the bases and Q4 conducts while Q3 remains idle. The com-

posite signal is reconstituted across  $R_L$ .

The impedance ratio of the transformer is based upon the goal of presenting an ideal load to the driver transistor. Conventional designs use an impedance ratio of about 9:1. The ratio should be optimized in the laboratory, specifying this ratio for minimum overall distortion.

Assuming adequate transistors and heat sinking, the amount of power the circuit can deliver is based upon the size of the supply voltage,  $E_{CC}$ , the collector to emitter saturation voltage, and the voltage across emitter resistors  $R_{E3}$  or  $R_{E4}$ . Power is related to the load at the output by the equations  $V_{rms}^2/R_L$  and  $I_{rms}^2 R_L$ . Peak to peak voltage for a specific power output is  $V_{p-p} = 2.82 V_{rms}$  while peak to peak current is  $I_{p-p} = 2.82 I_{rms}$ . The supply voltage must be capable of swinging the peak to peak voltage  $V_{p-p}$  across the load in addition to the peak to peak current across one of the emitter resistors, or  $I_{p-p} R_{E3}$ .

Collector to emitter saturation voltage limits the swing of the voltage across the load. Because two transistors are involved, the sum of both saturation voltages at the peak of the collector current swing, must be added to  $V_{p-p} + I_{p-p} R_{E3}$  to estimate the minimum supply voltage required if the amplifier is to deliver a specified amount of power. Keeping the operation in the linear region requires that the specified saturation voltage is multiplied by a factor of at least three, before being added to the other quantities already in the relationship, to determine the minimum  $E_{CC}$  supply voltage required if the amplifier is to deliver a specific amount of power.

Diodes D3 and D4 in the output stage are forward biased and are in the circuit in the interest of stabilizing the quiescent current against variations of  $V_{BE}$  with temperature. The actual idling current is established by the voltage developed across the diodes as well as across the other resistors in the dc circuit.

In the emitter circuit, resistors  $R_{E3}$  and  $R_{E4}$  are used primarily to supply ac and dc feedback and provide some relief for the distortion and dc stability problems inherent in this circuit. As a "fringe" benefit, it somewhat limits the emitter current to offer some protection to the output devices against over-dissipation when load  $R_L$  is accidentally shorted. In class-A amplifiers, about 0.5 to 1.5 volts is developed across the resistor. Similar voltages are desirable in class-AB or class-B circuits during peak current intervals in the cycle.

Diodes  $D_{E3}$  and  $D_{E4}$  are not absolutely required in this circuit. Should they be used, the emitter resistor can be increased in size to improve the temperature stabilization characteristics. Should the resistors be large, diodes are required to by-pass the re-

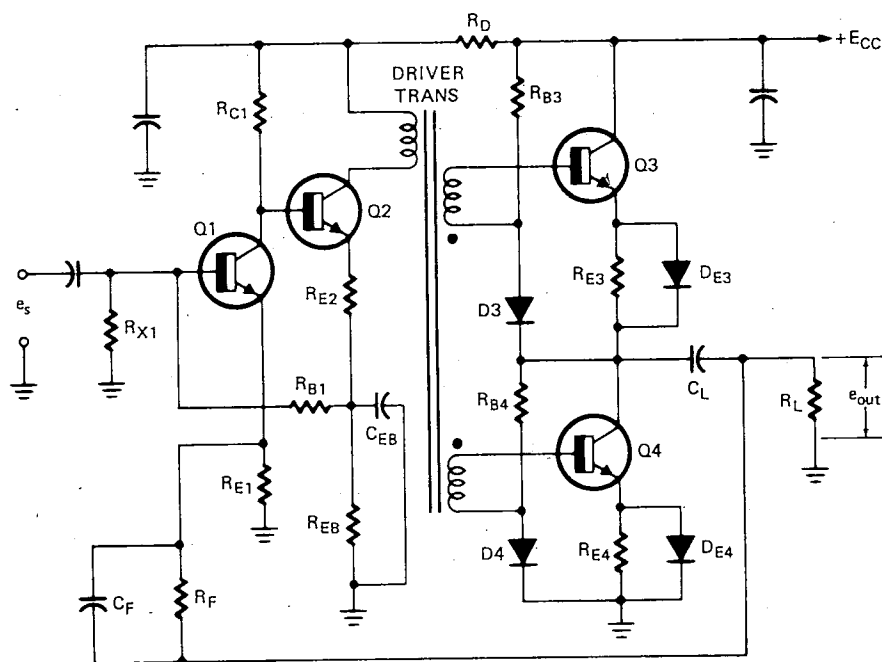


FIG. 1—A DRIVER TRANSFORMER is one method of providing phase inversion for the push-pull output stage. It simplifies circuit design and is sometimes used in inexpensive equipment.