Solid-State Audio Circuits

Part 1

By Joseph J. Carr

Audio circuits are among the most interesting of linear circuits with which to experiment. They are excellent as weekend and one-evening projects for electronics hobbyists and experimenters. Part of the reason for their popularity is that they are so useful to so many people; another is that they are generally well-behaved and, thus, can easily be built with low-cost components.

In this first installment of our two-part article, we discuss the basic circuits used in modern audio-amplifying equipment and explore both discrete transistor and integrated-circuit (IC) audio amplifier circuits. The information contained here will lay the groundwork for the more detailed discussions of circuits, built around actual components, that will appear in next month's conclusion.

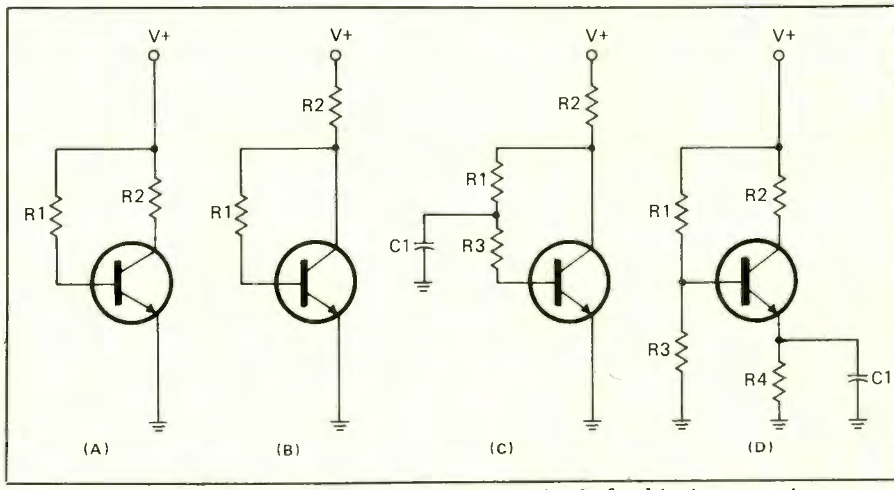

Fig. 1. Several of the most common methods for biasing transistors.

Transistor Biasing

One of the most important factors in understanding solid-state audio circuits is the methods used to achieve proper biasing of transistors. Figure 1 shows several of the most common methods. These circuits, or variations of them, are used in most discrete and IC audio circuits.

Figure 1A shows the simplest—and most practical—biasing scheme. Fixed base-current bias is established by current flow from the emitter-base junction of the transistor through *R1* to the supply voltage. The amount of bias is dependent on the value of *R1* and the supply voltage. The primary disadvantage of this bias arrangement is that it provides no means of automatically limiting collector current. Hence, fixed base-current biasing yields circuits that can be unstable.

Another simple form of self-bias, shown in Fig. 1B, is called collector feedback. Because *R1* is connected to the transistor side of load resistor *R2*, any change in collector current will cause a proportional but opposite change in transistor bias. For example, if collector current increases because of a temperature increase, the voltage at the collector decreases (becomes less positive). In turn, this reduces the current through the emitter-base junction and *R1* circuit. Although this bias system does provide a degree of stabilization, it also introduces deneration caused by feedback of any ac signal voltage developed across the load resistor.

Collector-feedback with ac bypassing is the same as in Fig. 1B, except that an electrolytic capacitor has been added to filter out (bypass) variations.

Combination fixed and self-bias (Fig. 1D) provides both good stabilization and minimum degeneration. Fixed emitter-base bias is developed by the *R1/R3* voltage divider. Usually, the value of *R3* is substantially less than that of *R1*. Resistor *R4* stabilizes the transistor. For example, if emitter-to-collector current increases because of an increase of temperature, the voltage drop across *R3* also increases. This places a more-positive voltage on the emitter,

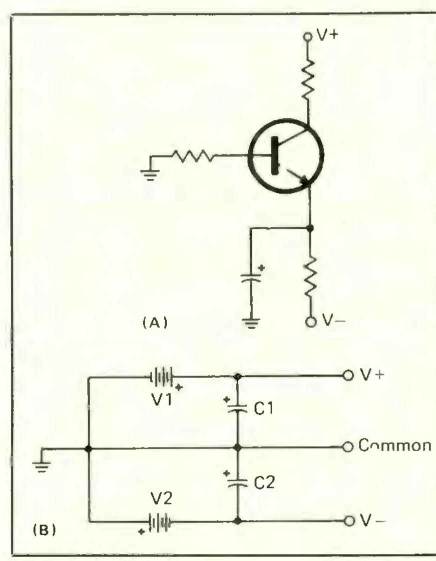

Fig. 2. An amplifier biased for dual-polarity power supply operation (A) and a typical dual-polarity power supply (B).

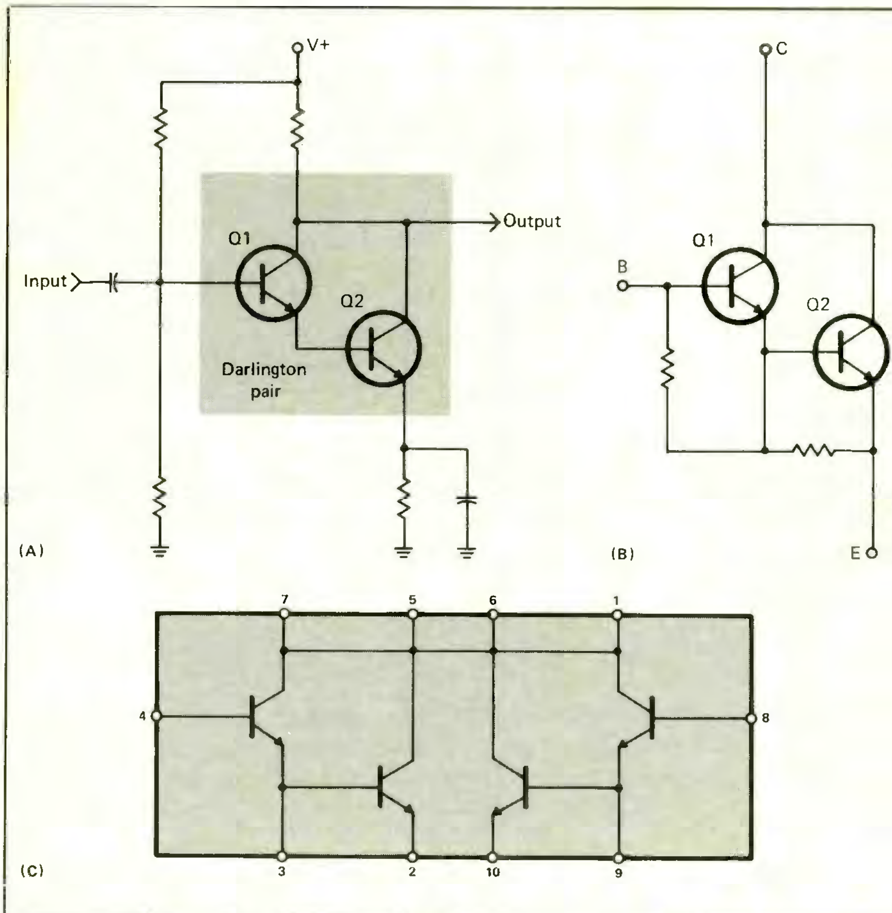

Fig. 3. A Darlington amplifier configuration built around two discrete transistors (A). Though the Darlington arrangement contains two separate transistors, when wired together as shown, the two can be treated as one transistor with single base, emitter and collector leads (B). Matched dual-Darlington transistor pairs are also available in convenient IC package form (C).

which reduces the forward bias on this transistor. The capacitor bypasses ac variations around the emitter resistor to prevent degeneration. The value of *R4* usually is five to ten times less than that of *R3*.

The dual-supply method (Fig. 2A) is a not so universally recognized biasing circuit as some of the others, but is being used more and more in modern circuits. It can be identified by the fact that the ground (or common) is not returned to the positive or negative side of the dc power supply. (The Fig. 2B circuit represents the kind of dc power supply used: two voltages, one positive to ground and the other negative to ground). Instead, in most applications, the ground, usually the chassis or a printed wiring board ground bus, "floats" at the electrical mid-point of the two supplies. In most cases, the two voltages are equal; in others, V− and V+ are different.

Increased output voltage swing is one of the advantages of the dual supply circuit, regardless of whether discrete transistors or integrated circuits are used. Another advantage is improved thermal stability. This can mean a lot in an amplifier that has marginal heat sinking or that is used inside a closed cabinet. A third advantage is that these circuits tend to be less sensitive to hum pick-up caused by power supply ripple.

Another type of circuit that is being used more often in solid-state audio applications is the Darlington amplifier—also called the Darlington pair, or the "super-beta" transistor (when both transistors are inside the same package). An example of this configuration is shown in Fig. 3A. Notice that the collectors of the two transistors are tied together. Also note that the emitter of the input transistor is tied directly to the base of the output transistor. This arrangement produces higher current gain and a much higher range of input impedance than is possible with single bipolar transistors. Beta gain is $H_{fe} = H_{fe(Q1)} \times H_{fe(Q2)}$.

If the transistors are identical, overall beta gain is the square of the beta gain of any one transistor. You can see why this configuration is called "super-beta" by a simple example. Suppose two transistors with a beta of, say, 100 are connected in a Darlington configuration as in Fig. 3A. Overall beta of this combination is 100 × 100, = 10,000.

Although discrete transistors can be connected in the Darlington circuit, several manufacturers offer Darlington-configured transistors in one package, or integrated-circuit Darlington amplifiers. Figure 3A shows the internal circuit of a Darlington transistor. Most often, the device is a power amplifier in which *Q1* is a driver transistor and *Q2* is an output power transistor. One common Darlington pair in hi-fi amplifiers uses a 2N3053 for *Q1* and a 2N3055 for *Q2*.

Figure 3C shows an IC dual-Darlington amplifier. This particular device is the RCA CA3036. There are also operational amplifiers and special-purpose ICs on the market that use a Darlington amplifier as the input circuit.

Audio Power Amplifiers

There are several basic designs for audio power amplifiers. For purposes of discussion let us turn to the Fig. 4 circuit. This basic audio amplifier chain has been used in a lot of equipment over the years. There are three stages shown: preamplifier, driver and power amplifier. The preamplifier builds up the voltage level of the input signal. The driver raises the power level of the amplified signal sufficiently to drive the output power amplifier stage. The output power amplifier, of course, develops the power to drive the loudspeaker.

In Fig. 4B is shown a simple circuit used in many car and home radios, though rarely in high fidelity applications. This single-ended class-A amplifier uses a choke or autotransformer for output impedance matching. It has several disadvantages. For one thing, as a class-A amplifier, the output collector current flows 100 percent of the time, even when there is no input signal. As a result, a lot of heat is generated. In some cases, a 3- to 5-watt fuse resistor ("fusistor") is placed in series with the transistor to protect the circuit if excess heat causes *Q1* to blow. Another disadvantage is that fidelity is not too good unless feedback is provided. Though the fusistor provides a small amount of beneficial degenerative feedback, additional feedback must be provided in most cases.

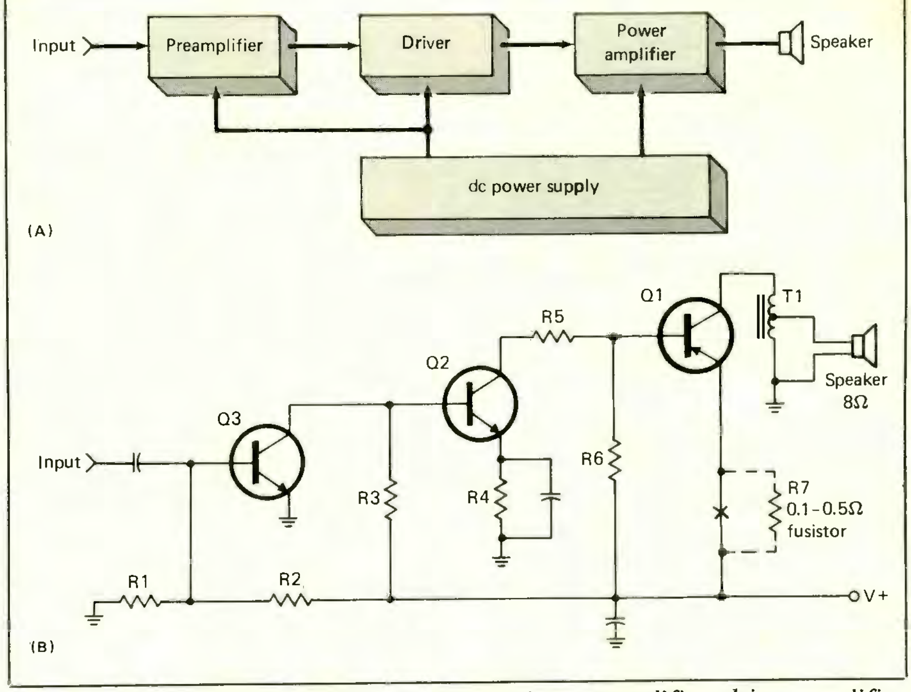

Fig. 4. A typical audio-amplifier chain contains preamplifier, driver amplifier and power amplifier stages, all powered by a common power supply. This arrangement is shown in block diagram form in (A), while (B) shows the schematic equivalent sans power supply.

Two basic kinds of feedback circuits are normally used in audio circuits. One is called the "second collector-to-first emitter" system (Fig. 5A). With correct values of components, this circuit can make a relatively mediocre amplifier sound like a more expensive one. Figure 5B shows the second widely used feedback system, dubbed the "second emitter- to first base" system. This circuit often employs only one resistor to supply feedback signals.

The push-pull circuit is widely preferred over other types for both power handling ability and overall fidelity. Figure 6 shows the standard transistor push-pull circuit that has

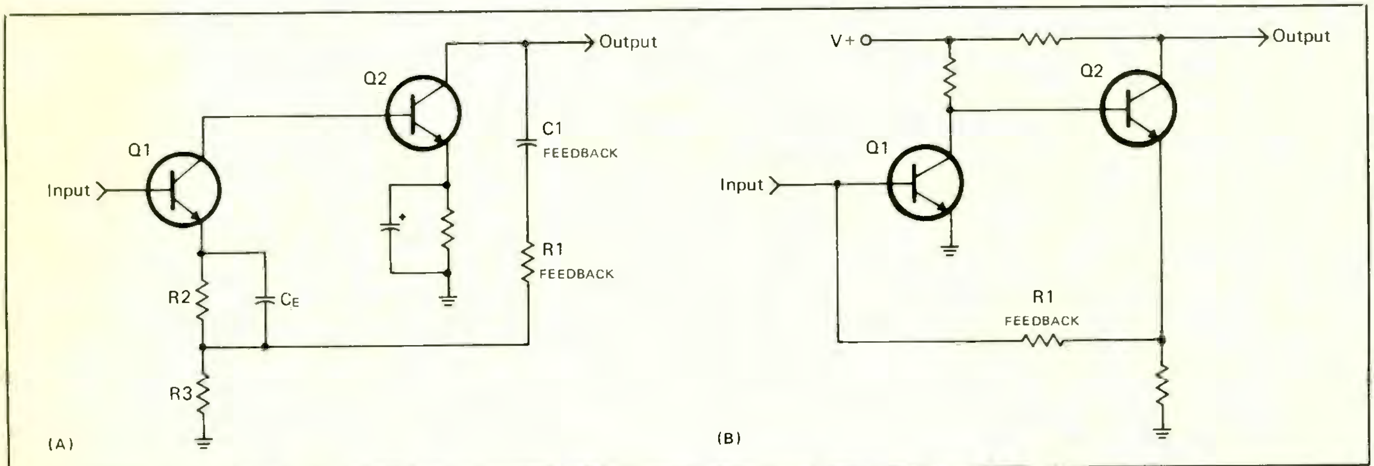

Fig. 5. The two basic kinds of feedback circuits normally used in audio circuits: second collector to first emitter (A) and second emitter to first base (B).

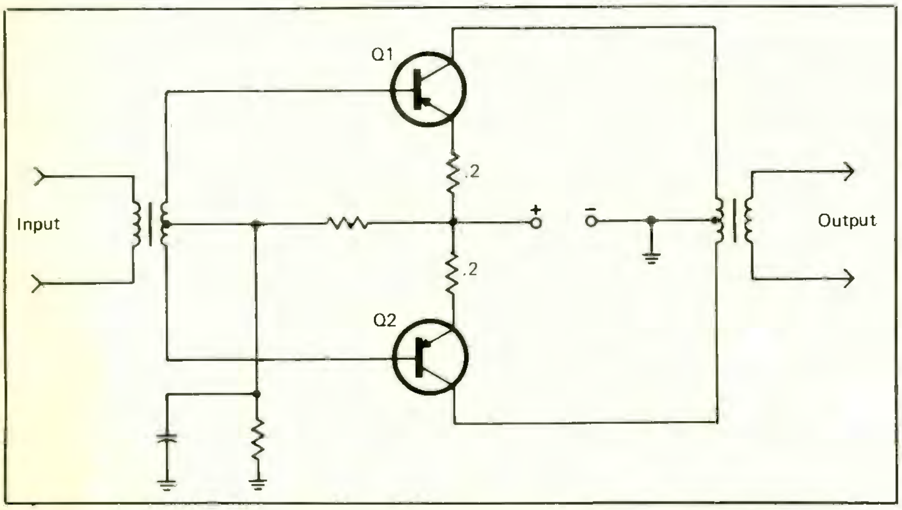

Fig. 6. A typical push-pull amplifier stage with transformer input and output. Note that this arrangement requires a dual-polarity power supply.

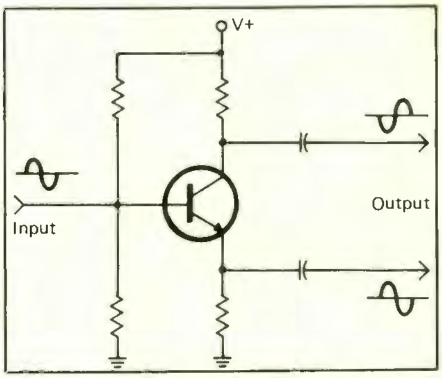

Fig. 8. A transistor phase inverter is one possible replacement for the in terstage (input) transformer needed for the opposite-polarity driving signals for the two halves of the push-pull amplifier circuit.

been used in almost every audio application, from $5 portable radios to relatively high-priced, medium-grade radios and stereos. It is, however, a lot less cost-efficient when compared with other circuits of more recent design.

Another breed of push-pull amplifier is shown in Fig. 7. Often called the "split-secondary, totem-pole" circuit, this one is used in many domestic and (especially) imported radios. The series connection of the output transistors and split-secondary interstage transformer *T1* are the two identifying features of this type of circuit.

One thing that all push-pull amplifiers have in common is the necessity of phase-splitting the input signal to provide two new signals 180 degrees out-of-phase to drive the two halves of the push-pull circuit. In older designs, this was accomplished with either a center-tapped transformer (Fig. 6) or a split-secondary interstage transformer (Fig. 7). In many modern circuits, however, the interstage transformer is replaced by another means to split the input signal.

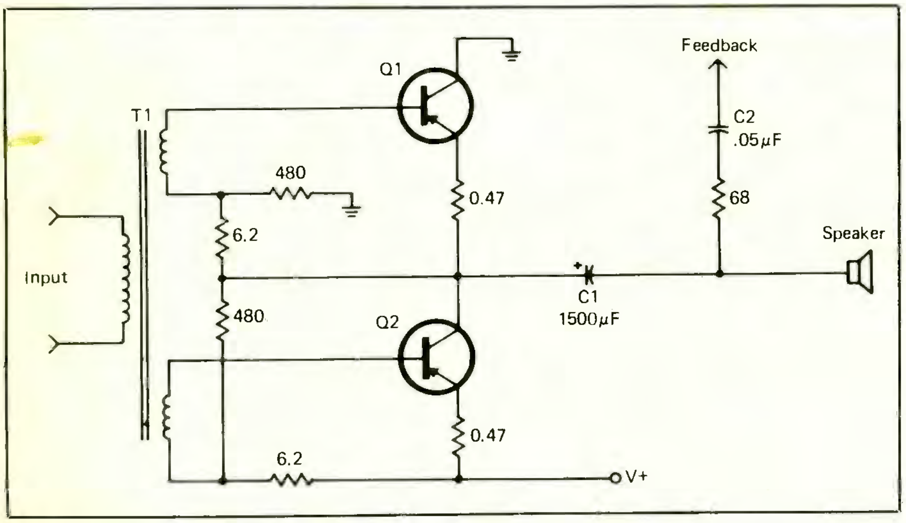

Fig. 7. The split-secondary totem-pole amplifier is similar to the conventional push-pull amplifier, except that it has no output transformer and can operate with a single-polarity power supply.

The transistor phase inverter is one possible replacement for the interstage transformer. These circuits (Fig. 8) have one driving signal taken from the collector, the other from the emitter of the transistor. Another method of providing drive signals of opposite polarity is to use an IC preamplifier that has both inverted and noninverted output terminals. Such ICs provide wideband, push-pull outputs from a common input signal. An example is shown in Fig. 9. This particular circuit is based on the RCA CA3020 IC preamp.

Designers have other methods of accomplishing phase inversion that is often more economical than either of the other methods. These methods are also used in IC and hybrid audio power amplifiers, and are called "complementary-symmetry" and "quasicomplementary" amplifiers. Complementary-symmetry methods, shown in simplified form in Fig. 10, take advantage of the fact that pnp and npn bipolar transistors require signals of opposite polarity to perform the same basic function. Notice that the speaker, minus output transformer, is connected to the midpoint of the two series-connected

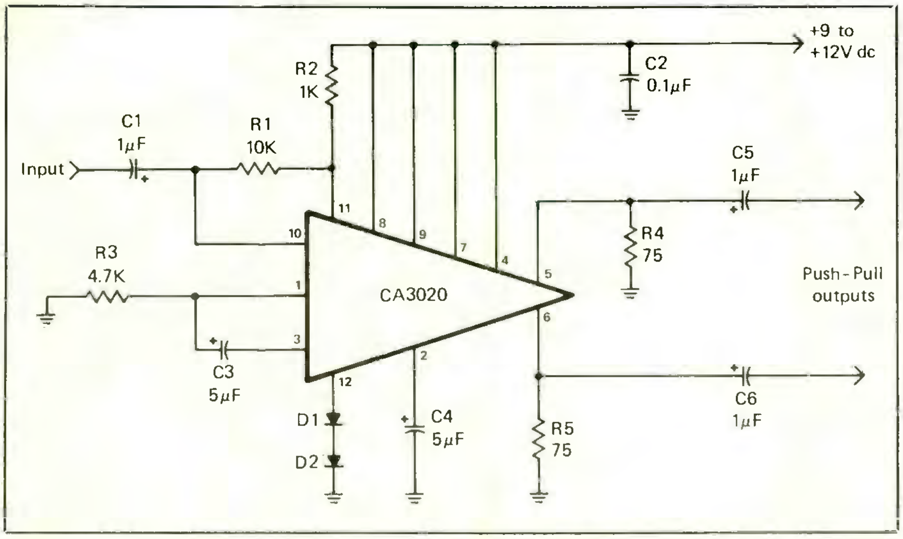

Fig. 9. An IC amplifier that has inverted and noninverted output terminals offers another way of obtaining phase-inverted signals for push-pull operation.

power transistors. Versions of this circuit that use a single asymmetrical dc power supply usually employ a capacitor to block dc from the speaker circuit. (The voltage at point "A" is usually V+/2). Dual-polarity circuits do not require the capacitor.

Complementary-symmetry amplifier circuits have at least one major disadvantage: It is difficult to locate matching pnp and npn transistors. Manufacturer "spec" sheets reveal that there are only a few types that can be paired for complementary service at any given output power level. As the amplifier's power level increases, the number of available types decreases dramatically. The problem becomes even more acute when selecting service replacements for these transistors.

It is relatively easy to find matched pairs of transistors for low- and medium-power complementary circuits. It is even relatively easy to find matched pairs for medium-power (a few watts) applications. But at higher power, the problem is greater. This has led to an interesting modification of the complementary-symmetry circuit, called the quasicomplementary circuit shown in Fig. 11. This circuit uses a "totem-pole" output in which the same type of npn or pnp transistors are in series with each other, and complementary driver stage *Q1/Q2*. It is fairly easy to find the medium-power complementary drivers and matched (identical) output transistors required for this type of circuit.

Coming Next Month

This concludes our primer on the general theory of transistor and IC audio amplifiers. In next month's concluding part of this article, we will discuss the details of audio preamplifier and tone-control circuits built around actual commonly available components. **ME**

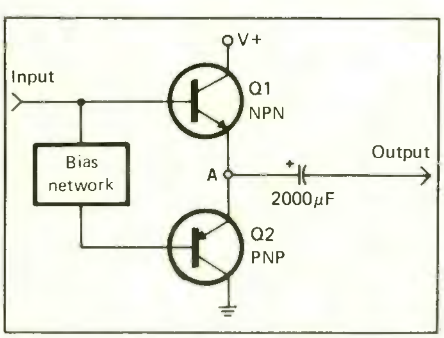

Fig. 10. An economical way of obtaining phase inversion is with the so-called "complementary-symmetry" circuit that uses npn and pnp transistors. Versions of this circuit that use a single asymmetrical power supply usually have a capacitor that prevents dc from getting to the speaker.

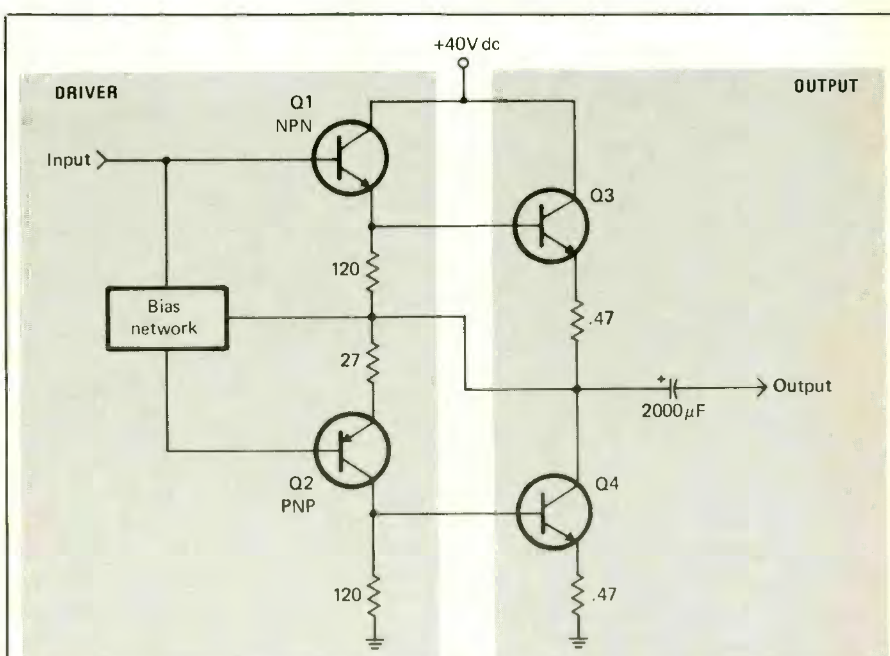

Fig. 11. The "quasicomplementary" circuit uses the same type of npn and pnp transistors in a totem-pole arrangement and a complementary driver stage consisting of Q1 and Q2.