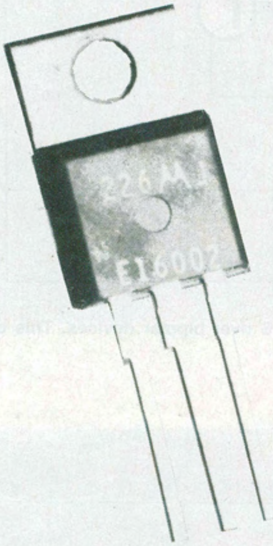
How to Design Analog Circuits

Audio Power Amplifiers



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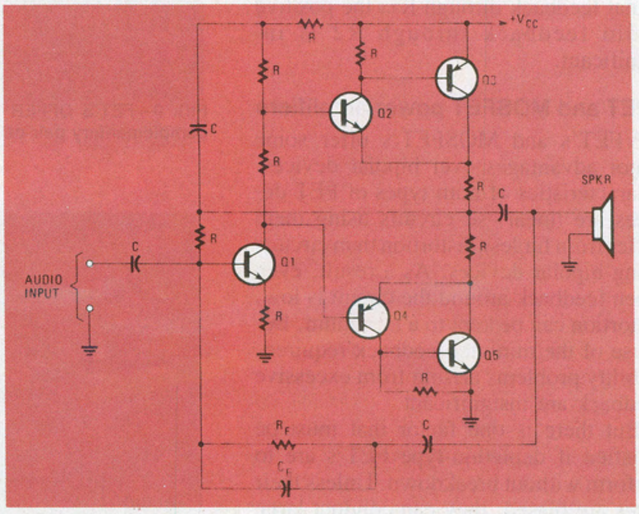
Here's a look at some practical audio power-amplifier circuits.



Part 2 AS WE FINISHED UP last month, we were designing the ouput stage of an audio power amplifier. We were aiming for a design that did not use output capacitors, but still had a stable DC output level.

We can take the arrangement in Fig. 6 (see the March 1983 issue of **Radio-Electronics**), one step farther. We can eliminate the discrete output devices and use two power op-amps instead. That type of arrangement is known as a bridge amplifier and is shown in Fig. 7.

Signals are applied to the two op-amps. While the input is fed to the non-inverting (+) input of IC1, it is fed to the inverting input of IC2. Thus, the signals are 180° out-of-phase at the outputs of the two op-amps. Because a loudspeaker is connected to those two outputs, the out-of-phase signals add across the loudspeaker to reproduce the original input signal.

Potentiometer R1, usually about 2 megohms, is used to set the level of the signal at the output. Potentiometer R2 is used to set the DC voltage levels at the outputs of the two op-amps. By adjusting that potentiometer, those voltages can be made identical and no DC current will flow through the speaker while the circuit is idling.

An interesting variation on the circuit shown in Fig. 6, is shown in Fig. 8. Because there is no differential amplifier at the input, a capacitor must be used between the output transistors and the loudspeaker. Only one driver or voltage-amplifier stage is used here and the individual transistors are in each leg of the push-pull circuit. Although that is a very simple circuit, amplifiers using that

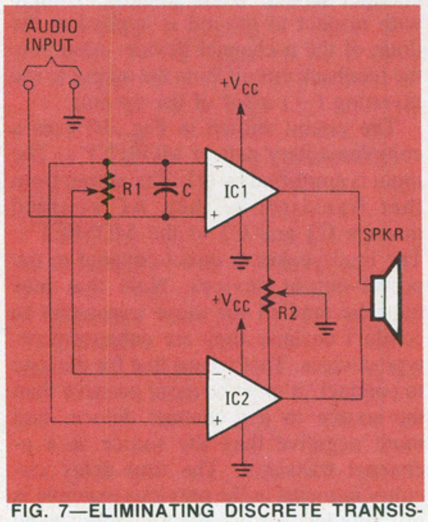


FIG. 7—ELIMINATING DISCRETE TRANSISTORS entirely, this op-amp circuit is known as a bridge amplifier.

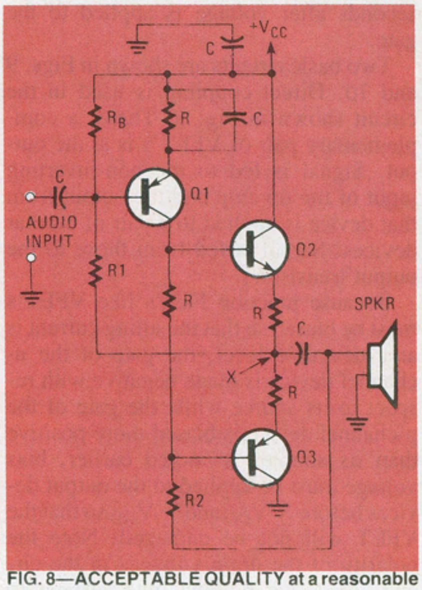


FIG. 8—ACCEPTABLE QUALITY at a reasonable price is the primary advantage of this low-cost circuit.

arrangement perform reasonably well. The big advantage here is acceptable quality at a relatively low price.

The two key components in the circuit are R1 and R2. Resistor R1 is in a DC feedback circuit. One end is connected to point the point labeled "X." Here, the voltage is ideally equal to one-half of $+V_{CC}$. Current is applied to the base of Q1 through R1. Resistor R_B, connected between the base of Q1 and $+V_{CC}$, works with R1 to help stabilize the circuit against current variations due to temperature changes.

Current is supplied from the collector of Q1 to bias output transistors Q2 and Q3. Resistor R2 helps keep that current at proper levels by providing an alternate path through itself and through the loudspeaker. While there is some negative signal feedback through R1, the positive audio feedback through R2 is insignificant.

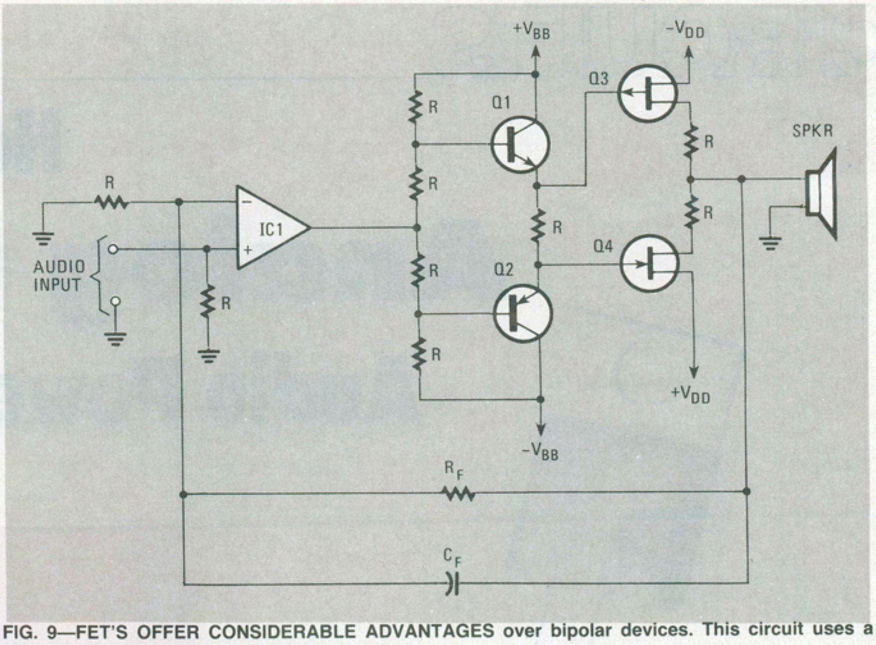


FIG. 9—FET'S OFFER CONSIDERABLE ADVANTAGES over bipolar devices. This circuit uses a complementary pair of VFET's.

VFET and MOSFET power amplifiers

VFET's and MOSFET's offer some major advantages over bipolar devices. Characteristics of both types of FET devices are linear, so circuits using them suffer from far less distortion than circuits using bipolar devices. As a result, even when feedback around the circuit is low, distortion can be kept to a minimum. Because of the minimal feedback required, stability problems arising from excessive feedback are insignificant.

But there is one factor that must be satisfied if depletion-type FET's are to perform without breakdown. Unless their gates are biased, they can conduct large amounts of current—enough to damage the device. As a result, bias must be applied to the gate before voltage is applied to the drain. One way to insure that this is done is to use a time-delay circuit. Another is to put a current-limiting device in series with the drain, along with a parallel circuit that will short that device a few seconds after voltage is applied to the gate.

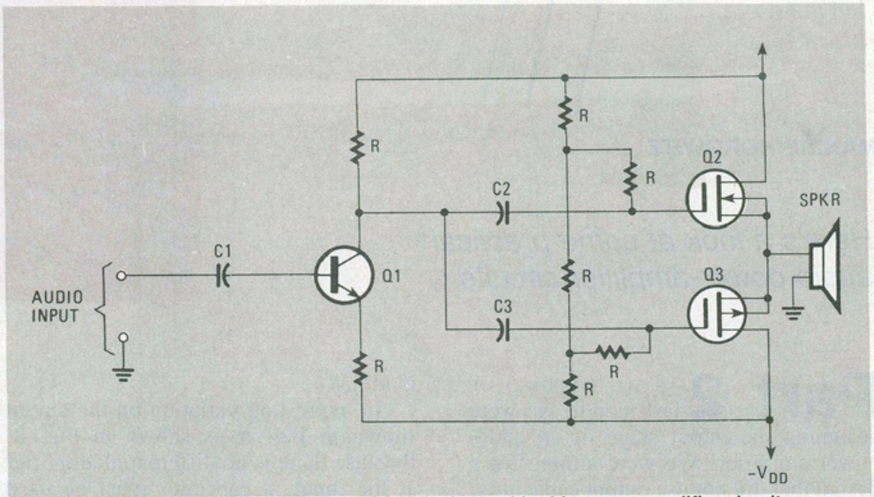


FIG. 10—A COMPLEMENTARY PAIR of MOSFET's is used in this power amplifier circuit.

Two basic circuits are shown in Figs. 9 and 10. Direct coupling is used in the circuit shown in Fig. 9. There, a complementary pair of VFET's is at the output. Signal is fed to the non-inverting input of the op-amp and the output from that device is applied to a pair of bipolar devices. Signal is fed from those to the output transistors.

Because junction FET's like VFET's must be biased so that the idling current is at a desirable level, the gate of the n-channel device is made negative with respect to its source while the gate of the p-channel device is biased more positive than its source. As noted earlier, bias voltage must be applied to the output devices before $+V_{DD}$ and $-V_{DD}$ so that the VFET will not be damaged. Note the polarity of the drain voltages in the circuit. Negative voltage with respect to ground is applied to the drain of the p-channel device while positive voltage with respect to ground is applied at the drain of the n-channel device. Also note the feedback circuit from the output to the inverting (−) input of the op-amp.

The circuit shown in Fig. 10 uses a complementary pair of MOSFET's. The input is amplified by Q1. The output from that transistor is then AC-coupled through C2 and C3 to the MOSFET's. The loudspeaker is direct-coupled to the power-output devices. Note that bias must be applied for those transistors to conduct because they are enhancement-type devices. That means that for the gate to conduct, it must be more positive than the source in a n-channel device, and more negative than the source in a p-channel transistor. The time-delay circuitry required in the previous example is not needed here—enhancement-type transistors will not conduct until the bias voltage is applied.

Quasi-complementary amplifiers

Up to now, in the complementary amplifiers we've described each half of the push-pull output stage used identical but complementary devices or amplifier circuits. Quasi-complementary amplifiers differ in that they use dissimilar arrangements in each leg of the push-pull power section.

Let's take another look at two true complementary amplifiers. Those were shown last month in Figs. 3 and 4; the one shown in Fig. 3 used a Darlington pair in both halves of the output circuit, and the amplifier in Fig. 4 used a complementary pair. The quasi-complementary arrangement, on the other hand, uses a pair of each type in each half of the push-pull output circuit. A typical amplifier of that type, is shown in Fig. 11. There, Q2 and

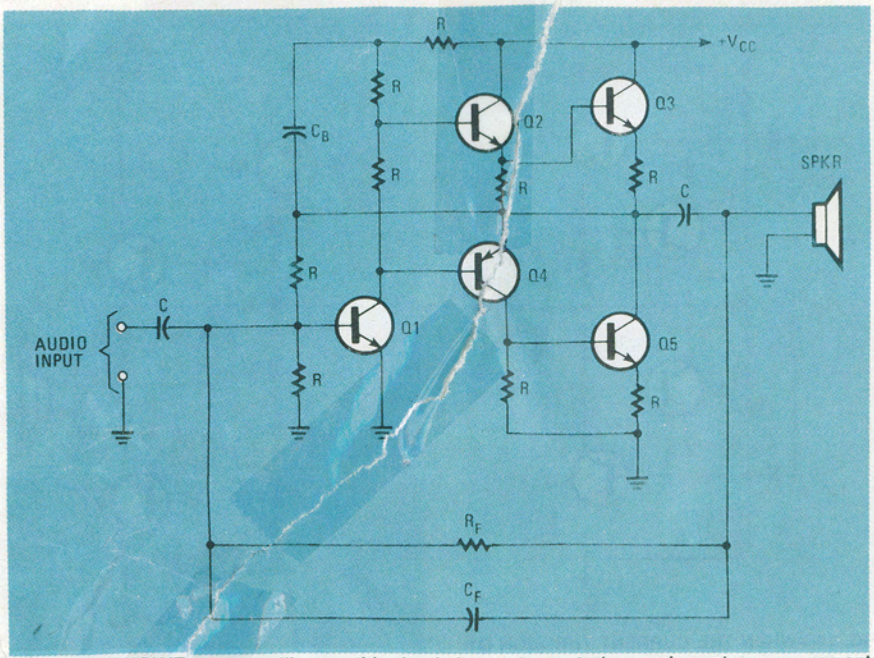


FIG. 11—THOUGH IT ACTS just like one, this circuit does not use a truly complementary arrangement. The chief advantages to this quasi-complementary amplifier are simplicity and cost.

Q3 form a Darlington pair while Q4 and Q5 form a complementary amplifier. Both circuits are driven by voltage amplifier Q1.

But why use such a circuit, especially considering that the true complementary circuit has inherently less distortion? The answer is economy and simplicity. The circuit in Fig. 11 will perform well using a minimum of critical components.

Modifications

A differential amplifier is used in the circuit shown last month in Fig. 5. The sum of the currents flowing through Q1 and Q2 must be constant. To do that, Q10 was used as a constant-current source. Current could also have been held relatively constant if Q10 were replaced with a large resistor and $-V_{CC}$ made very large. That arrangement will keep the current flowing through the transistors constant, provided that the voltage drop across the devices in series with it is much lower than the voltage drop across the resistor itself.

In Fig. 5, Q10, its emitter resistor, and the diodes from the base to $-V_{CC}$, determine how much current will flow through the circuit. Voltage is applied to both diodes through R. If they are silicon devices, a relatively fixed 0.7 volt is developed across each diode despite any minor variations in the amount of current flowing through each of those devices. Because the diodes are in parallel with the series circuit consisting of the base-emitter junction of Q10 and resistor R_E, there must be 1.4 volts across that series circuit. Of the 1.4 volts, 0.7 volt is across the base-emitter junction of Q10 (assuming, of course, that it too is a silicon device) so the remaining 0.7 volt must be across R_E. Thus, the current flowing through R_E is $0.7/R_E$. That same current also flows through the emitter and collector of Q10 and into Q1 and Q2. Thus, the sum of collector currents in Q1 and Q2 equals the the current from Q10 at all times.

Alternate constant-current sources using FET's, are shown in Fig. 12. In Fig. 12-a, the gate is connected to the source, making V_{GS} equal to 0. Now the current in the drain of the transistor is I_{DSS}. In Fig. 12-b, the fixed current can be adjusted by the potentiometer. It's setting determines the gate-source bias voltage, which, in turn, sets the drain current.

Another way to modify the various circuits we've described is to add some way to vary the bias; such a circuit would let you vary the idling current. A circuit of that type is included in the MOSFET amplifier shown in Fig. 13. Such an arrangement can also be used in circuits using bipolar devices. Because of the presence of Q1, the idling current is temperature-compensated, just as if diodes had been used instead.

Potentiometer R1 is used to adjust the amount of current flowing through Q1 and hence through R2, R3, and R4. The voltage across R1, and at the gates of Q2 and Q3, is equal to the sum of the voltages across Q1 and R2. Those voltages change with the setting of R1 and, in turn, change the bias voltage applied to the gates of the FET's.

Protecting output transistors

Output transistors are quite vulnerable when used in an amplifier. If a load or loudspeaker is shorted, the transistors may conduct excess current. If that current exceeds the rated maximum current permitted to flow in the device, the transistor may be forced to dissipate more power than it safely can and the device may suffer breakdown. Transistors may also break down if there is an instantaneous excess voltage applied across the device due to the presence of an inductive load. Another possible cause of breakdown is undesirable oscillation. That can be due to a capacitive load across the output, such as an electrostatic loudspeaker.

Several precautions can be taken to protect those devices. If a fuse is placed in series with the loudspeaker load, it should blow out before the output transistors are destroyed. (On the other hand, you may be unlucky enough that the transistors will be the first to go.) Another method is to keep the voltage applied to the driver transistor at the minimum level possible. In another arrangement, very poorly regulated voltage is applied to the output circuit, so that the voltage drops radically when there is a large demand for current from the power transistors. Fortunately, more effective protection circuits have been designed.

In the simplest arrangement, a resistor is placed between the loudspeaker and ground. Its resistance should be small—less than 20% of the resistance of the loudspeaker. Parallel-connected diodes,

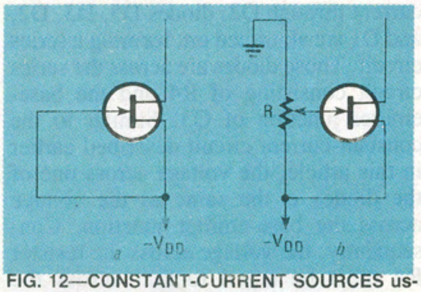


FIG. 12—CONSTANT-CURRENT SOURCES using FET's are shown here.

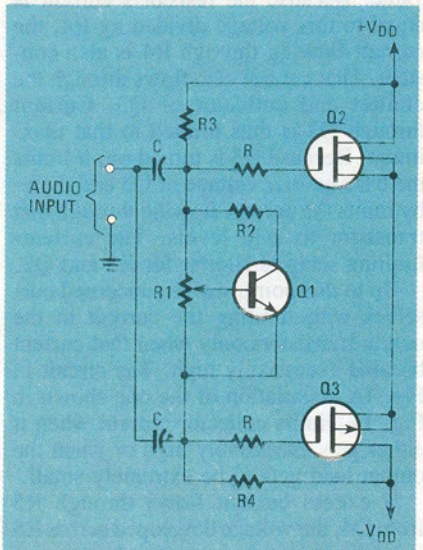


FIG 13—TRANSISTOR Q1 in this circuit is used to vary the bias voltage applied to the output transistors.

but with the cathode of one device connected to the anode of the second, are placed in a negative feedback loop from the junction of the resistor and loudspeaker to the driver transistor circuit. A voltage is developed across the resistor due to current flowing through it, through the loudspeaker, and through the output transistor. In direct-coupled circuits, that voltage may be due to an audio signal or DC, while in capacitor-coupled circuits, it is due solely to the audio. When that voltage exceeds the forward breakdown voltage of the diodes, they conduct and the resulting negative feedback reduces the circuit gain.

An alternate and more effective arrangement is shown in Fig. 14. Current from Q1 flows in R_{E1} and current from Q2 flows in R_{E2}. Those resistors are selected so that the voltage developed across them due to current from Q1 and Q2, turn on Q3 and Q4 when the output transistor current ratings are exceeded. After being turned on, transistors Q3 and Q4 divert current from the bases of the output devices. Limiting the base current reduces the collector currents of the output transistors to safe levels.

Yet another arrangement is shown in Fig. 15. Diodes D4 and D5 are normally turned off. Diodes D1, D2, and D3 conduct to bias Q2 and Q3 to the desirable collector-current levels. If the voltage across R3 becomes excessive due to the current through Q2, diodes D5, D3, D2, and D1 are all turned on, forming a series circuit. Those diodes are across the series circuit consisting of R4 and the base-emitter junction of Q3. Similar to the constant-current circuit described earlier in this article, the voltage across one of the diodes is the same as the voltage across the base-emitter junction. Consequently, the voltage across the resistor R4 must be equal to that across the remaining three diodes in the circuit. The voltage across the resistor is fixed at that value. Because the resistor's current is equal to this voltage divided by R4, the current flowing through R4 is also constant. That current also flows through the emitter and collector of Q3. Current through Q3 is thus limited to that maximum. Because D5 is turned on, it limits the base-emitter voltage of Q3 and thereby limits the current flowing through that transistor to safe levels. The current-limiting setup is similar for R3 and Q2.

Up to this point, we've concerned ourselves with limiting the current in the output transistors only when that current became excessively high. The circuit in Fig. 16, a variation of the one shown in Fig. 14, limits collector current when it either gets excessively high or when the output load gets to be extremely small.

If excess current flows through R5 from Q4, the voltage developed across R5 is applied to the base-emitter junction of Q2 through R3. Transistor Q2 is turned on to shunt current from the base of Q4. A

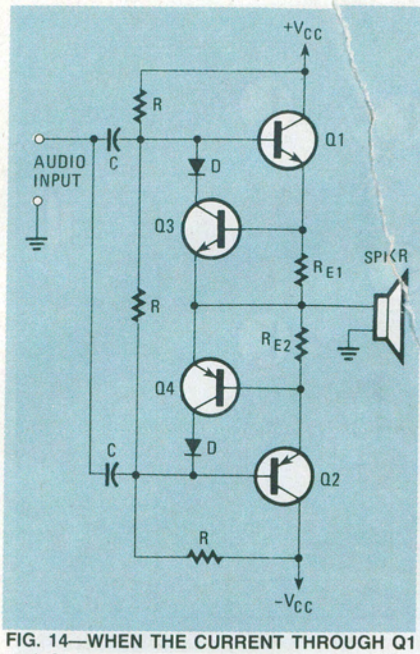


FIG. 14—WHEN THE CURRENT THROUGH Q1 and Q2 exceeds safe levels, Q3 and Q4 are turned on and current is diverted from the bases of the output devices.

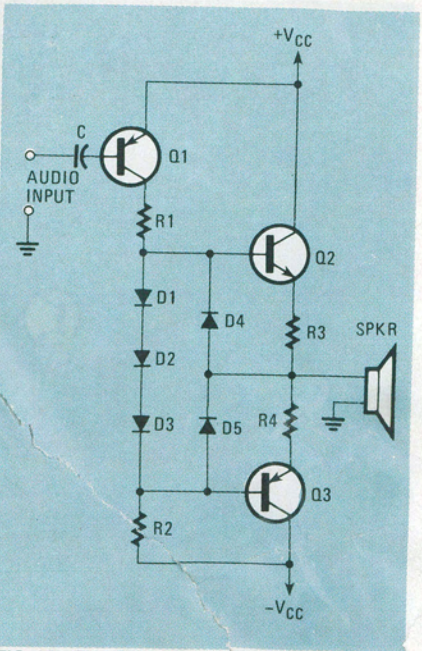


FIG. 15—THE DIODES in this circuit are included to protect the output transistors.

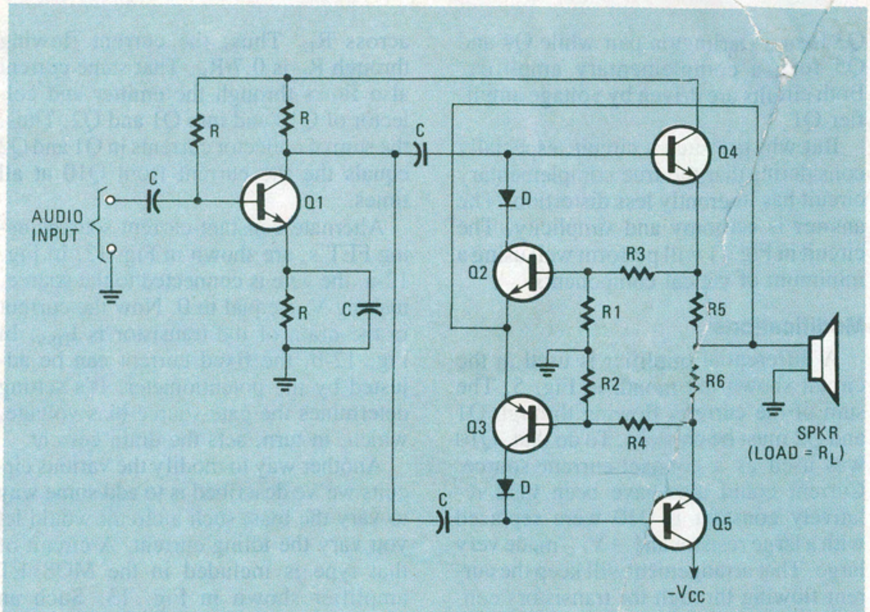


FIG. 16—RATHER THAN just protecting against excessive current, this circuit also protects the output devices against an insufficient load.

similar situation exists if excess current from Q5 flows through R6.

Should R_L be greater than a predetermined value, the voltage developed across the load, added to that across R5, is applied to Q2. The voltage across R5 is 180° out-of-phase with the voltage across R_L. The polarity of the sum of the voltages across R_L and R5 is such as to turn off the shunting transistor, Q2. If the resistance of R_L is below the predetermined acceptable minimum value, the voltage developed across R_L is low. Now the voltage across R5 is considerably above that developed across R_L. When the two out-of-phase voltages are added, the polarity is such as to turn on Q2. It can now shunt the base circuit of Q4. The magnitude of the load resistance as well as the emitter (and collector) current through Q4, are the two factors that determine if signal is to be shunted from the base of Q4. When the voltage across R_L is considered in together with that developed across R6 due to current in Q5, the magnitude of R_L is now an important factor in determining when shunting transistor Q3 is to be turned on.

Throughout this article and the previous one, feedback arrangements were mentioned as integral parts of various circuits. Feedback circuits are important in many different applications. In the next article, we will discuss different feedback circuits, their characteristics, and their importance in different applications. **R-E**