since the maximum β is about 50, the actual total harmonic distortion, therefore, is only approximately 1.5%.

In other words, by accepting the penalties inherent in the emitter-follower, it was possible to start with a bandwidth greater than 200 kHz and a total harmonic distortion of only about 1.5%. Proceeding from this point, the cascaded three-stage T-circuit was developed to take maximum advantage of these performance capabilities.

Perhaps the most immediately apparent feature of the T-circuit is its excellent thermal stability. The output transistors (*Q5* and *Q6* in Fig. 1) are connected directly to a high current power supply of about ±40 v potential. Each base of the output circuit has a path allowing the collector-to-base leakage current to flow through its opposite driver-stage emitter. It can be seen that suitable collector-to-base leakage current paths are provided for all of the transistors.

The load impedance is amplified by a factor of about 100,000 as it is reflected back to the input of the T-circuit, and with an input driver collector load resistance of about 5,000 ohm, the DC stability factor is of the order of 20. There are no DC thermal runaway problems.

The ratio between reflected load impedance and input collector load is advantageous in another way as well. A typical 8 ohm load is reflected back to the input as about 800,000 ohm. Since *R9* is only 5,000 ohm, the resulting 160:1 ratio swamps out any effects propagated back by the beta nonlinearities of *Q5* and *Q6*.

A single bias supply consisting of diodes *D1* through *D5* provides the necessary forward bias for the three cascaded emitter-followers. The bias supply operates at a low current level and dissipates very little signal power. The operating point of each emitter-follower pair can be adjusted independently by adjusting the values of resistors *R5* through *R8*.

In practice, the transistors are biased so that with no signal they all draw a small amount of idling current. A positive signal from the input stage causes the output transistor *Q5* to conduct as necessary to deliver power to the load, and *Q6* is driven to cutoff. Since half of the T-circuit is essentially cut off when the other half is conducting, it is, in a sense, a Class B amplifier. But because we can adjust the no-signal "on" currents for each of the pair-stages independently, any crossover problems can be avoided.

Each of the driver stages has a lower beta cutoff frequency than the preceding one, so that the overall frequency limitation of the basic T-circuit is determined almost entirely by *Q5* and *Q6*. In practice, the bandwidth of the overall T-circuit is greater than 100 kHz. This gives more than two octaves above and below the audible frequency range of 20 to 20,000 Hz; thus, the classic textbook rules regarding reduction of distortion and noise with negative feedback apply. A feedback factor of 50 reduces the distortion of the output circuit alone by that factor. This is true for frequencies up to 20 kHz and essentially down to DC.

In commercial versions of this design, the output transistors *Q5* and *Q6* have a very high DC power dissipation capability as compared to that normally found in transistorized audio amplifiers. The transistors used are rated for DC dissipation of 150 watts each, so that there is no need for exotic high-speed electronic current limiting devices. All that is required is a simple thermal breaker that will open in one to sixty seconds. This is fast enough to protect the amplifier in the event of a shortcircuit at the output terminals.

It should be noted that it is necessary (one disadvantage of the T-circuit) to provide successively higher collector supply voltages going backward from the output transistors to take care of the saturation voltage drops of the preceding drivers. Supply for *Q5* and *Q6* is roughly ± 40 v, for *Q3* and *Q4* ± 45 v, for *Q1* and *Q2* ± 50 v.

Figure 2 shows the complete amplifier (one stereo channel) and the low-level driving stage. The latter is a two-stage differential DC amplifier having a voltage gain of 1200. The frequency response of the driving stage is far greater than 100 kHz, so that the single factor limiting the frequency response of the complete amplifier is still *Q5* and *Q6*. The closed loop gain of the complete amplifier is essentially *R11/R1*, or approximately 25. The feedback factor, therefore, is about 50.

MEASURED PERFORMANCE

The performance of the basic T-circuit only, without feedback, is represented in Fig. 3. This indicates total

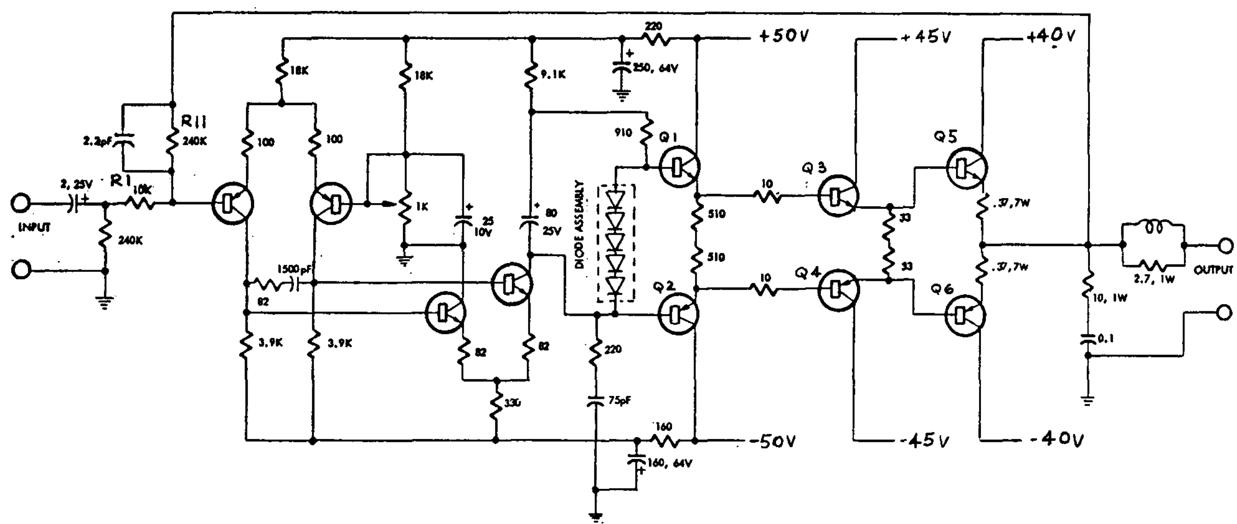

Fig. 2. Circuit of one channel of the complete amplifier.