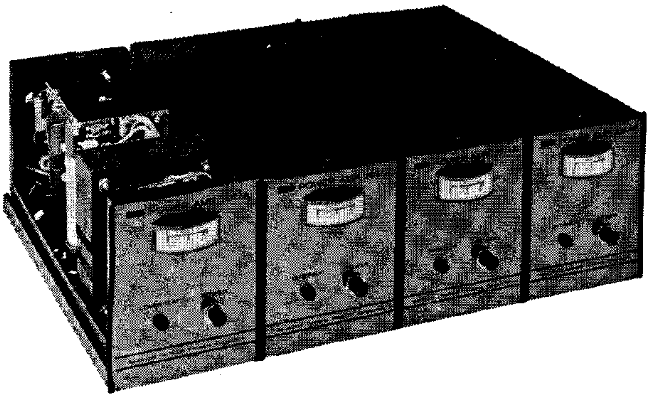


BUILD 4-CHANNEL POWER AMPLIFIER

Unbelievably low distortion is a feature of this four-channel amplifier for quadraphonic applications. Each channel drives an 8-ohm load at up to 60 watts rms.

by DANIEL MEYER

TIGER .01 IS MY LATEST EFFORT TO PRODUCE A BETTER audio power amplifier. With this design, distortion is reduced to a level of less than .01% at any power level up to rated output. With distortion products pushed down to a level more than 80 dB below the program material, it is very tempting to announce that this is the ultimate and that no further improvement in amplifiers will ever again be necessary.

Since the same thing was said when amplifier distortion was reduced to 5%, then 1% and finally to 0.1% and each time has been proven false, we will simply have to await improvements in other components to a comparable level of distortion before we can know for sure, but don't take any bets. The ear has proven to be considerably more sensitive to such things than anyone imagined ten or twenty years ago.

Like most things, the *Tiger .01* circuit has evolved slowly over a number of years with small, but steady improvements. It is usually possible to consider a power amplifier as consisting of two parts; the input, or voltage amplifier portion and the output, or matching portion. The point of division is obvious in most circuits, since the portion following the bias system is the output portion.

Except for car radios and a few other low/power special cases almost all development effort has been toward perfecting the class AB, or B type circuits. Class-A circuits are only practical for power outputs up to approximately 10 or 12 watts. Beyond this point the high quiescent power dissipation caused by low efficiency of class A-circuit discourages serious attempts at more powerful circuits.

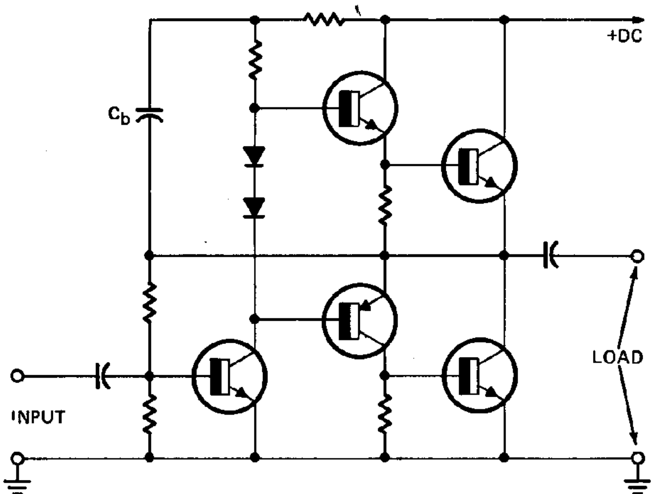


FIG. 1—QUASI-COMPLEMENTARY OUTPUT TRANSISTORS are driven by driver in complementary configuration.

The advantages of complementary class-AB and class-B amplifiers have been known for at least twenty years.[1] Most of the complementary circuits in use today are described in this paper. High-power complementary transistors were not available at this time though, and the few germanium npn types that could be obtained were terribly expensive. This led to wide use of quasi-complementary circuits in which only one polarity of output transistor is used with a complementary driver pair as in Fig. 1.

This type circuit presents a number of problems. First, the output stage must operate at unity gain, since (in the form shown here) the positive half cycle of the signal passes through a pair of emitter followers that cannot provide any gain. In addition, the circuit inherently has greater distortion than a complementary circuit due to the different number of junctions in the signal path on positive and negative half cycles and the difference in input impedance of the upper and lower pairs. Despite all of this, the quasi-complementary output circuit delivers reasonably good performance and is still widely used today.

Fully complementary output circuits became popular in the late '60's when reasonably priced complementary silicon transistors became available. Some of the best of these were the Marrantz 15 and the JBL "T" circuits. In 1967 the first of the present series, *Lil Tiger* was introduced. Although not designed to be the worlds lowest distortion amplifier, this circuit gave quite respectable performance at minimum cost, due to the use of complementary plastic output transistors. In October 1970 the *Universal Tiger*[2] introduced a new variation in output circuits, an output stage with gain; see Fig. 2. You will note that that type circuit is completely complementary and also cannot be built without complementary transistors in the output stage. Using this type of output circuit reduces the drive voltage needed for the output section of the amplifier and also makes it possible to control the response of the output section very neatly by proper choice of capacitor C in the schematic.

The *Tiger .01* uses a similar output circuit, but with a

1. G. C. Sziklai, "Symmetrical Properties of Transistors and Their Applications" Proceedings of the IRE, 41, 717-724 (1953)
2. "The Indestructible 125 Watt Power Amplifier." *Popular Electronics,* October, 1970

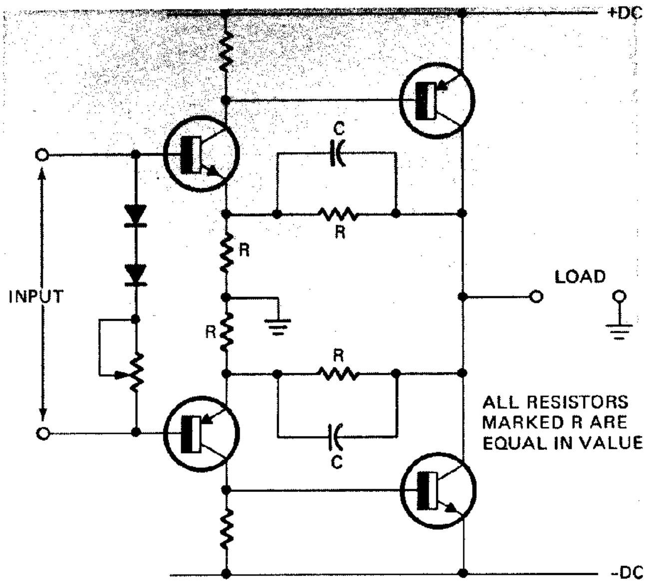


FIG. 2—OUTPUT STAGE WITH GAIN uses complementary transistors in circuit requiring relatively low drive voltage.

Darlington output; thereby making the output section of the circuit a triple. Doing this increases the current gain of the output section of the amplifier and further reduces the amount of drive current needed from the amplifier portion of the circuit. From this we get greatly reduced gain variation with signal output and can almost eliminate any need for matching of the complementary transistors.

The only problem with a triple is that temperature tracking of the bias and output stage is far more critical now. Feedback from current sensing resistors R37 and R38 to the first stage of the triple, Q10 and Q11, along with thermal compensation diode D4 takes care of this problem. Output feedback resistors R28 through R31 set the gain of the output triples at approximately three, so we have a very linear output section for our amplifier that only requires around 8 volts rms and a few milliamps to drive it to full output.

With the output section of the amplifier taken care of, the voltage amplifier portion can be considered. Most early power amplifiers and even a few current ones, used single-stage voltage amplifier and driver systems with a bootstrap collector load of the type shown in Fig. 1. Sometimes an additional impedance matching stage was added at the input to allow matching to tube preamps. Capacitor C_b allowed the amplifier to produce full positive supply output on signal peaks by adding the output voltage to the supply voltage at the junction of the two collector resistors. This type voltage amplifier does not lend itself to use with split power supplies and it is generally used with a single-ended power supply. Due to the half-supply voltage offset at the output the speaker must be coupled through a large capacitor.

This system normally has 20 some odd dB of negative feedback and will produce an amplifier with less than 1% distortion. The circuit can be improved and the amplifier can be used with a split supply, if the input stage is made a differential amplifier. This allows the input and feedback points at the two bases both to be referenced to ground and keeps the output point at dc ground. This is a considerable improvement since there are now two stages of gain, which allows more feedback to be used to lower distortion and the speaker now has no reactive components between it and the output of the amplifier. The entire amplifier may now be dc coupled if desired.

Another improvement is the use of a current source as the driver collector load instead of the bootstrap capacitor, split resistor system. This considerably reduces any cross-

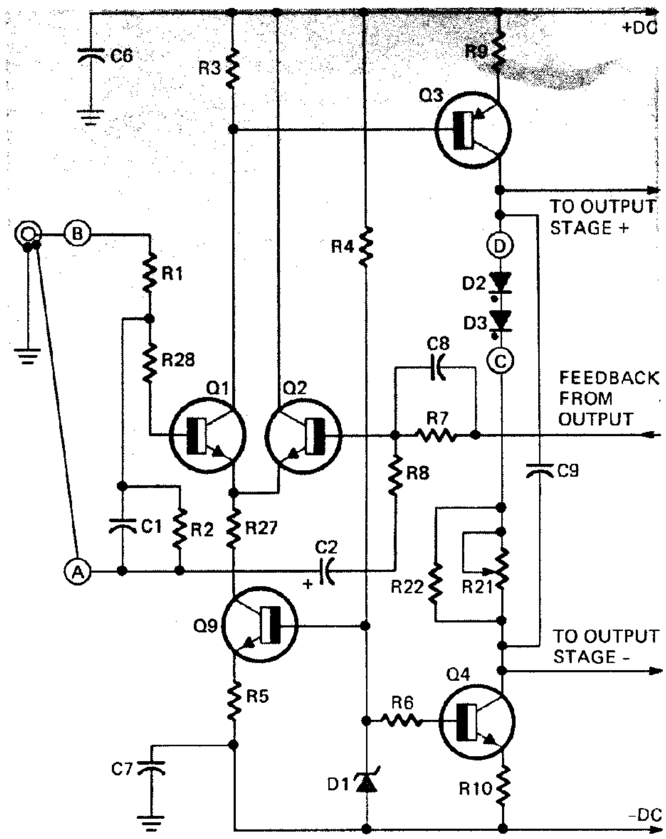


FIG. 3—CROSSOVER DISTORTION IS INHERENTLY LOW when current source replaces the driver bootstrap capacitor.

SPECIFICATIONS

Power Output—60 watts sine wave continuous; 8-ohm load.

Frequency Response—5.0 to 100,000 Hz at −1.0 dB points.

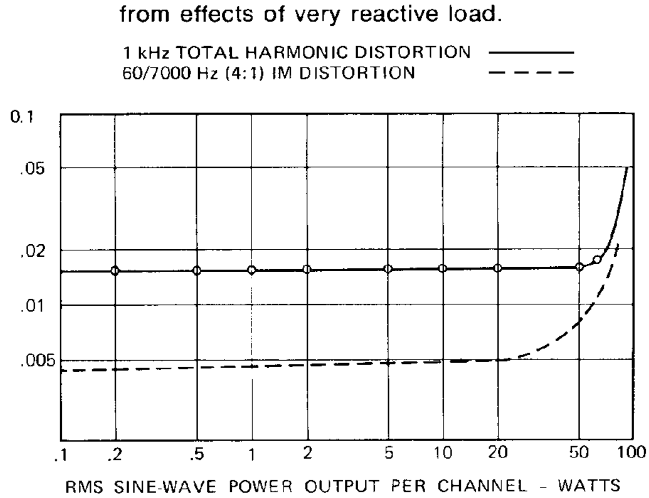
Distortion—Less than .01% IM distortion up to rated output. See graphs for complete distortion information.

Output Impedance—Less than 0.1-ohm 20 to 20,000 Hz.

Hum and Noise—More than 80 dB below full output.

Input Sensitivity—0.8 volts rms maximum for full rated output. Level control provided to reduce sensitivity if needed.

Stability—Completely stable with any type load. Volt-Amp limiting provided to protect output stage from effects of very reactive load.



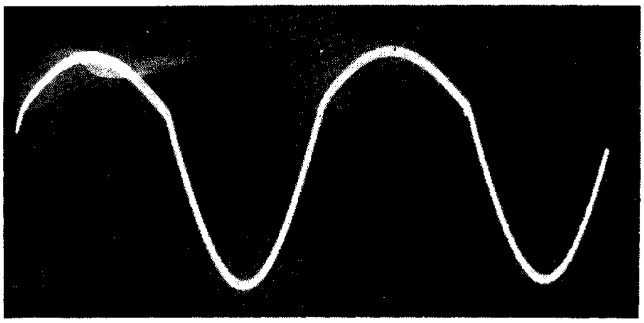
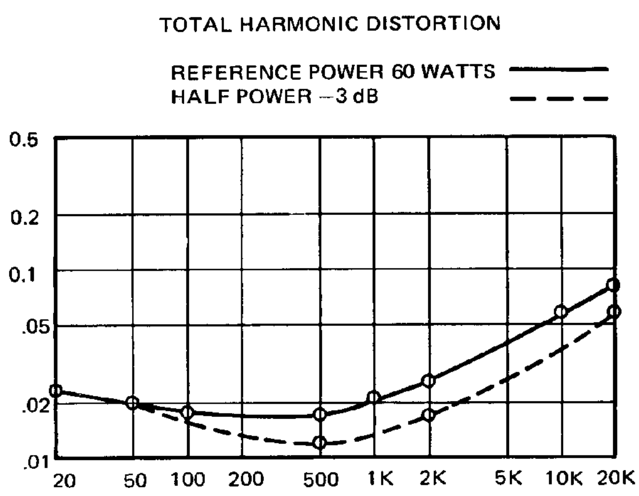


FIG. 4—DISTORTED WAVEFORM fed from collector of Q1 to the base of Q3. Effect of distortion is reduced by push-pull driver.

over notch distortion that may be present due to less than optimum bias conditions. This type driver causes the driving voltage to switch very quickly through any voltage levels where the driving current requirements drop or disappear. Although this type driver does not eliminate the need for bias in a quality amplifier, it makes the amount of bias used much less critical. In lower quality applications, such as PA work, the bias system may be removed and the amplifier run class B, generally without any noticeable effect on the quality. Amplifiers with these improvements can be expected to have distortion levels in the 0.1% range, and there should be no distortion peaks in the low power levels at the crossover point. Figure 3 is typical.

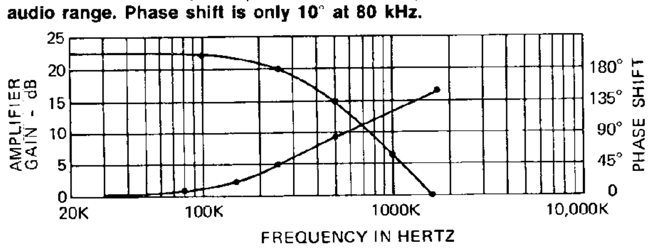
So at this point we have a pretty sophisticated amplifier with about all the gain we can handle without running into phase margin problems, or the necessity of reducing bandwidth drastically to keep the system stable. How do you improve on this circuit. A look at the oscilloscope photograph of Fig. 4 should give you a good idea. This is a photograph of the waveform at the collector of Q1 as seen



TOTAL HARMONIC DISTORTION is very low at all frequencies (curves above) and is less than 0.1% at full- and half-power levels.

DISTORTION VARIATIONS WITH POWER are illustrated by curves at left. Typically, IM distortion is below THD up to rated power output.

GAIN-PHASE PLOT (below) shows how little phase shift there is in the audio range. Phase shift is only 10° at 80 kHz.



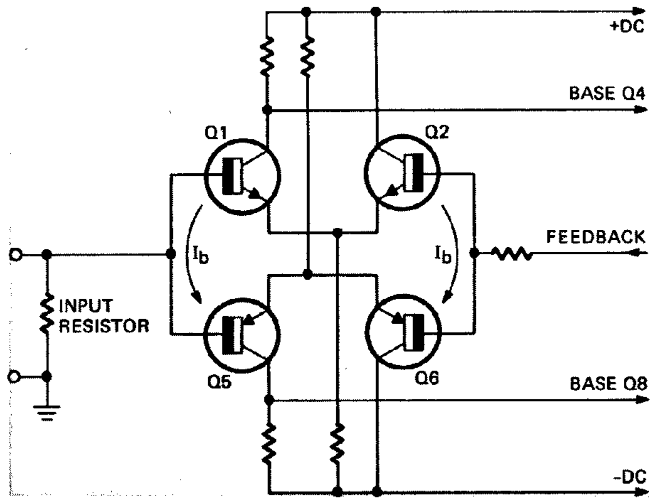


FIG. 5—COMPLEMENTARY DIFFERENTIAL INPUT STAGE. Several of its characteristics can be used to good advantage.

at base of Q3 point in the circuit of Fig. 3.

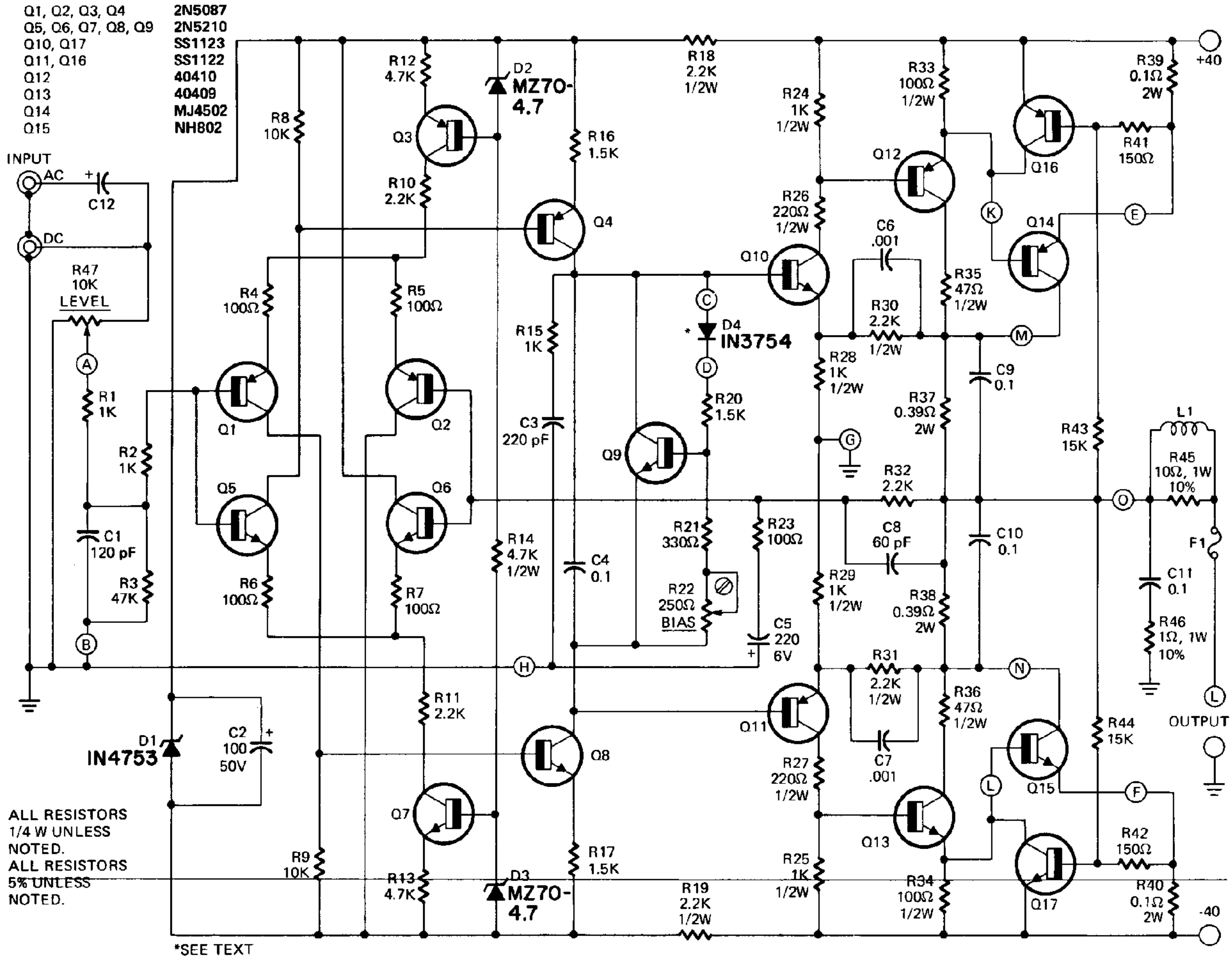
Why is this waveform so highly unsymmetrical you ask? Well the reason is quite simple. Q1 is supplying the current at this point to drive stage Q3. On positive half-cycles of the signal swing, Q3 must supply current to the driver in the upper half of the output section and also must supply the constant amount of current being soaked up by stage Q4. On negative half-cycles, however, the output requires no current from Q3 and most of the current from the current source Q4 is used to drive the lower portion of the output section. Thus on positive half-cycles, Q3 supplies output *plus* current source and on negative half cycles current source *less* output drive. Obviously the driving signal at the base is going to be very unsymmetrical under these conditions.

So what can be done to improve on this situation? Obviously a push-pull driver would be a good solution. Then we would have two signal swings on opposite ends of the circuit that would still be unsymmetrical, but which would be of opposite polarity. Thus the distortion would be reduced as in any push-pull arrangement. There are several possible ways to drive such a system, but the most elegant is to use a complementary, cross-coupled input system. This makes the whole amplifier symmetrical and push-pull from the very input.

The complementary differential input stage also provides us with some additional advantages. With this type circuit the base current for the input pair does not all have to flow through the input resistor from ground and through the feedback resistor from the output as in a normal single ended differential pair. Referring to Fig. 5, the base current path is from Q1 into the base of Q5 provided that the base currents of the two transistors are equal. This results in *no* offset voltage across the input resistor.

Exact matching is impossible, but even if the matching is not perfect, we still have only the difference between the two base currents flowing through the input resistor to produce an offset rather than the entire base current of one transistor as in a single-ended situation. Since the differential current is so small through this resistor we can either make the resistor quite large and have a very high input impedance on the amplifier, or we can use a smaller resistor and get away with a rather large difference in base resistors without getting the considerable offset at the output of the amplifier that this would normally cause. Since input impedances over 50,000 ohms are of little value the later course was followed on *Tiger .01*.

The only thing remaining is to choose a bias system for the output stage. The input amplifier pretty well dictates the use of a transistor for this purpose. The dual dif-



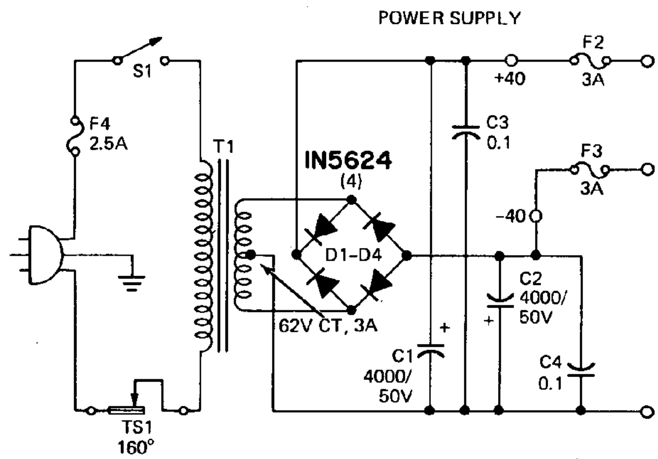


FIG. 6—COMPLETE CIRCUIT OF ONE OF THE FOUR CHANNELS. PC board patterns and complete construction details next month.

FIG. 7—POWER SUPPLY FOR ONE CHANNEL. The bridge rectifier supplies the dual-polarity voltages needed for the amplifier.

ferential input stage cannot be perfectly temperature compensated easily. As a result the idle current in the driver stage varies with temperature to some extent. If we attempted to use diodes for bias, this current variation would result in bias voltage changes. This is highly undesirable, and besides this it would take a bunch of diodes to get the 3 to 4 volts of bias that we need with this circuit (Fig. 6).

The bias voltage is set by the emitter-to-collector voltage drop across Q9. This voltage tracks quite well with the base-emitter voltage changes of Q10 and Q11 when ambient temperature changes occur. The temperature of the output transistors however is more dependent on the power output at any given time and Q9 needs some feedback information on this temperature rise if anything is to be done about stabilizing the output current with these temperature changes. This information is provided by D4. The diode's forward voltage drop changes with temperature and changes the bias on Q9 to reduce the bias voltage slightly as the output transistors warm up. All this keeps the amplifier's idle current under control under all power output and ambient temperature conditions it is likely to be subjected to.

The power supply is a simple bridge rectifier system with capacitor-input filters. Due to the large amount of isolation from supply ripple and hum in the voltage amplifier stages, excellent noise figures are obtained without any complicated regulated supplies. It is doubtful that any measurable improvement would be obtained if such a supply was used. The output transistors are protected from highly reactive loads by Q16 and Q17. These transistors monitor the output transistor current and voltage drop. If either of these, or a combination of the two occur that could cause operation of the output transistor outside it's rated safe operating area the protection transistors will turn on and bypass enough drive current to keep the output device from going into secondary breakdown.

That's all we have room for this month. Next issue we'll present full construction information; along with parts lists, full-size circuit-board patterns, and parts layout diagrams. We'll also have additional photos of the unit. **R-E**