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.

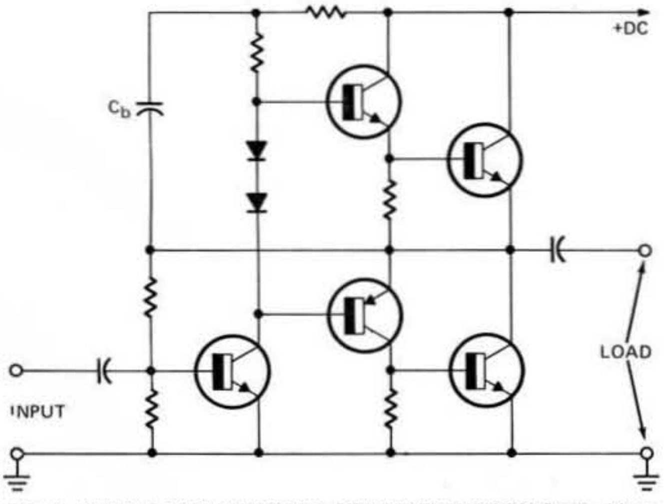

FIG. 1—QUASI-COMPLEMENTARY OUTPUT TRANSISTORS are driven by driver in complementary configuration.

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

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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

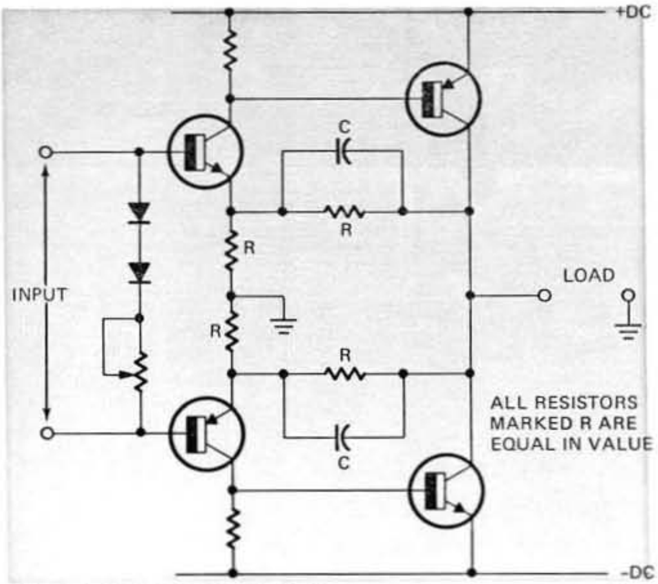


FIG. 2—OUTPUT STAGE WITH GAIN uses complementary transistors in circuit requiring relatively low drive voltage.

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-

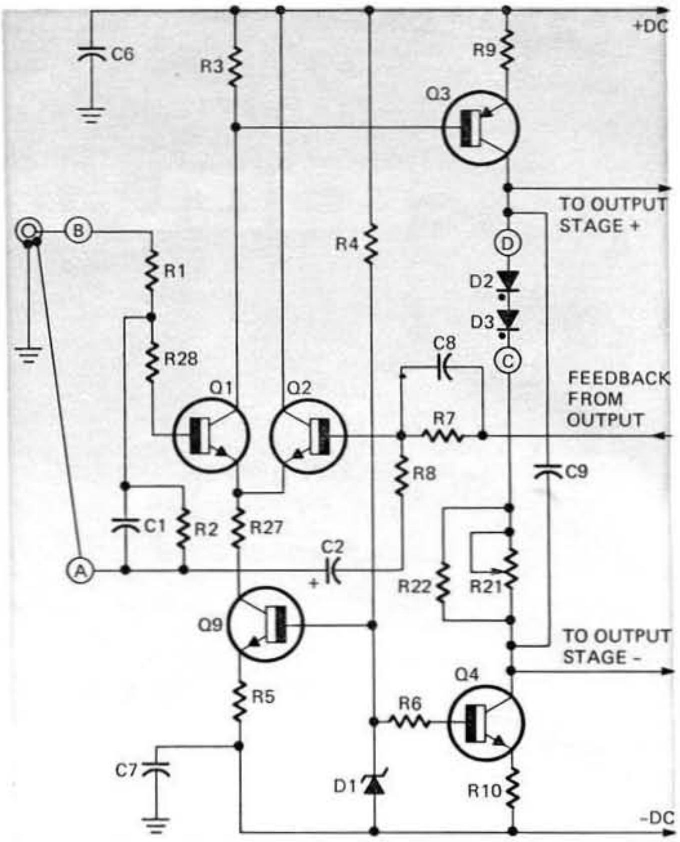


FIG. 3—CROSSOVER DISTORTION IS INHERENTLY LOW when current source replaces the driver bootstrap capacitor.

SPECIFICATIONS

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

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

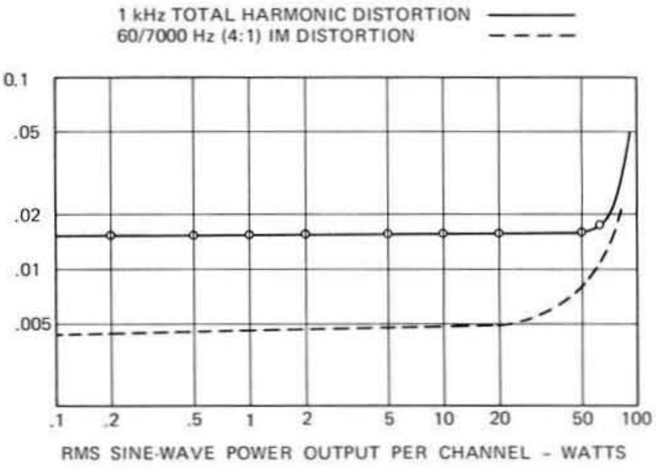
Distortion—Less than .01% IM distortion up to rated output. See graphs for complete distortion information.

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.



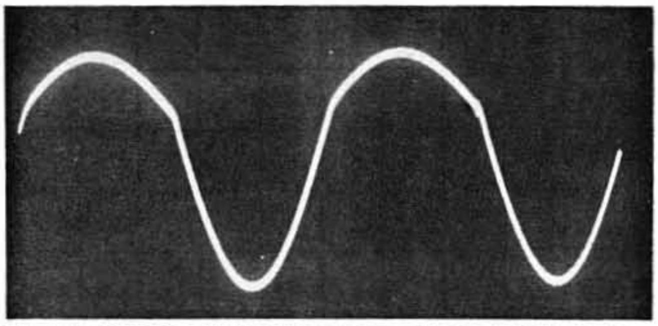
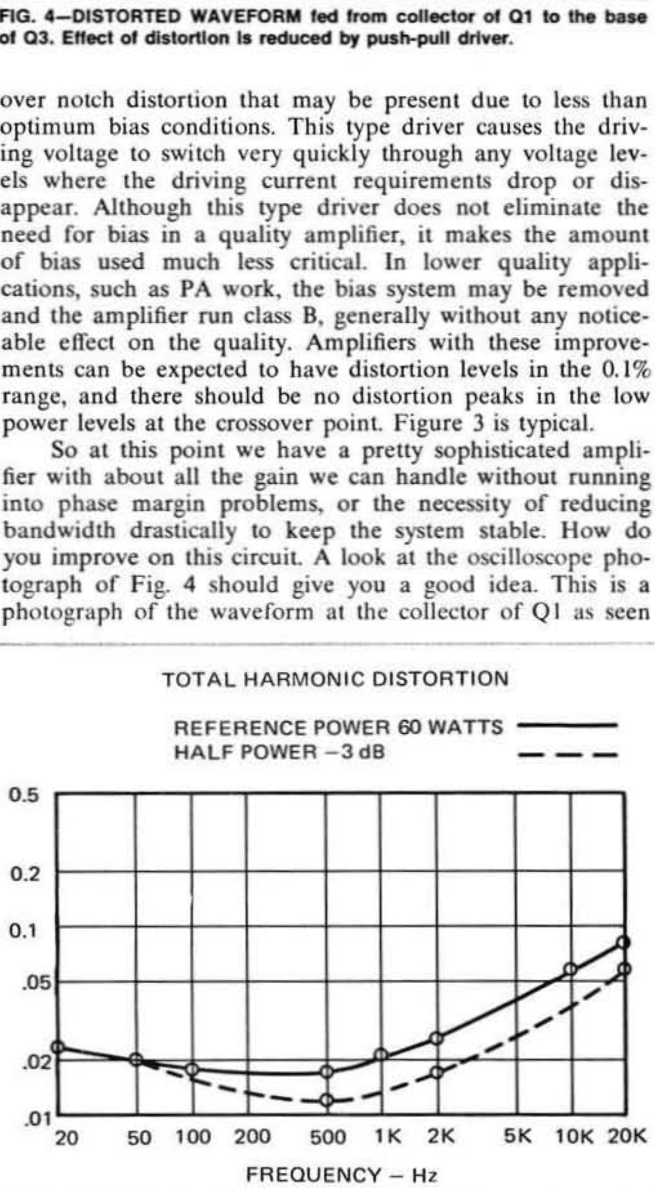


FIG. 4—DISTORTED WAVEFORM fed from collector of Q1 to the base of Q3. Effect of distortion is reduced by push-pull driver.

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.

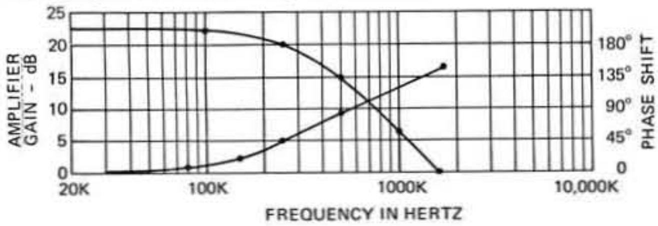
So at this point we have a pretty sophisticated amplifier with about all the gain we can handle without running into phase margin problems, or the necessity of reducing bandwidth drastically to keep the system stable. How do you improve on this circuit. A look at the oscilloscope photograph of Fig. 4 should give you a good idea. This is a photograph of the waveform at the collector of Q1 as seen at base of Q3 point in the circuit of Fig. 3.



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.



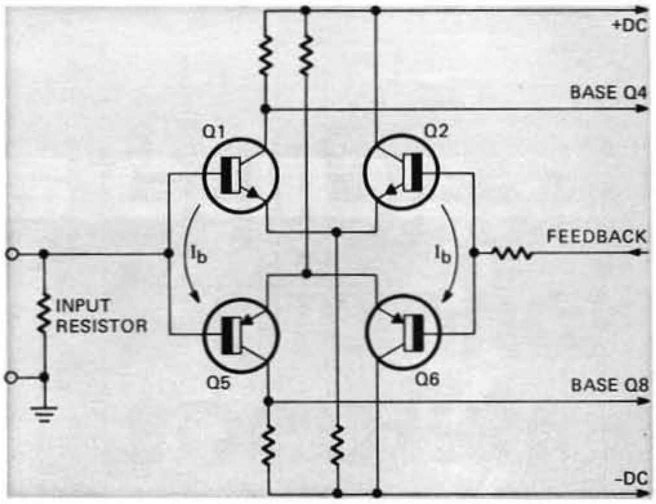


FIG. 5—COMPLEMENTARY DIFFERENTIAL INPUT STAGE. Several of its characteristics can be used to good advantage.

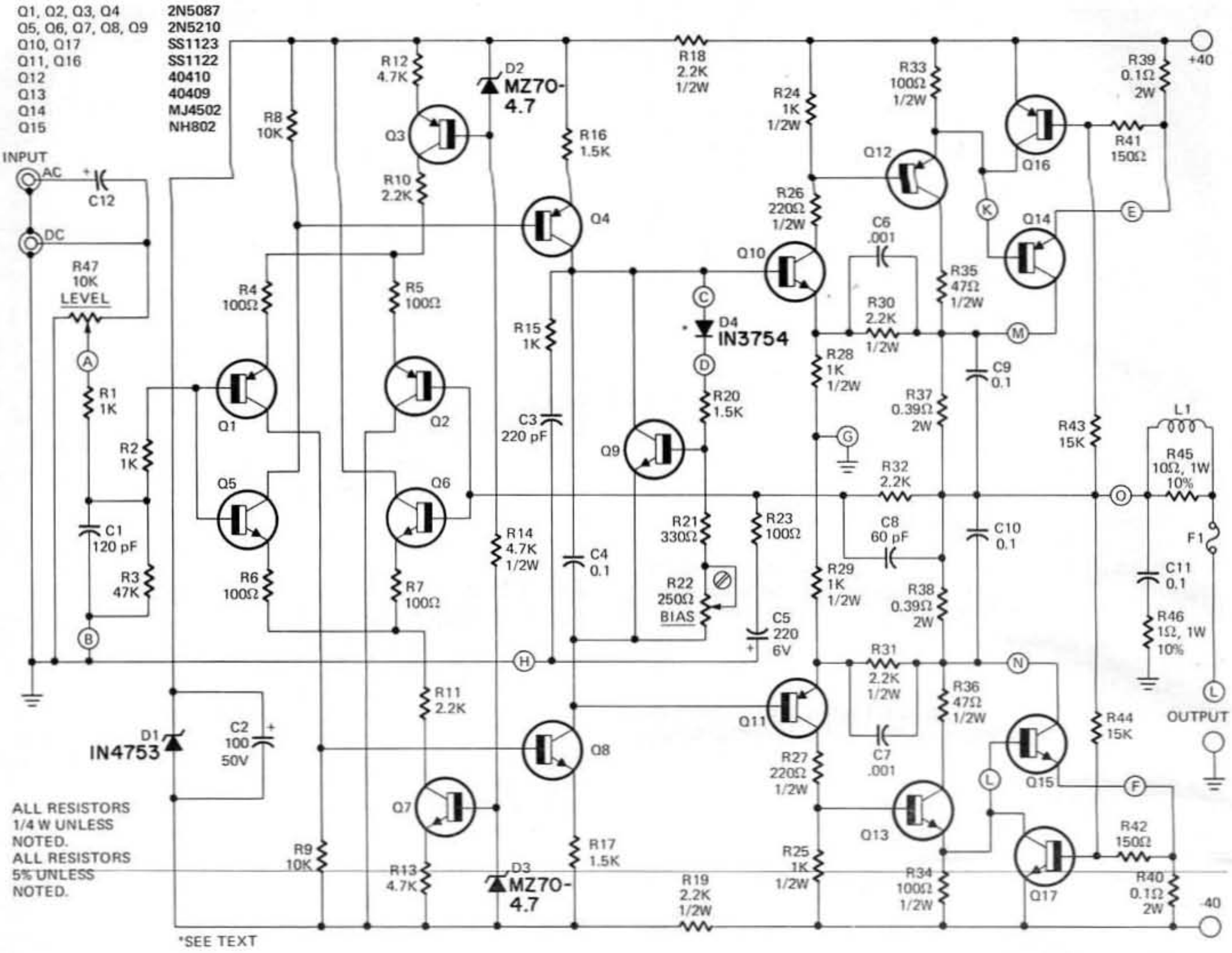
Why is this waveform so highly unsymmetrical you ask? Well the reason is quite simple. Q1 is supplying the current at this point to drive stage Q3. On positive half-cycles of the signal swing, Q3 must supply current to the driver in the upper half of the output section and also must supply the constant 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-



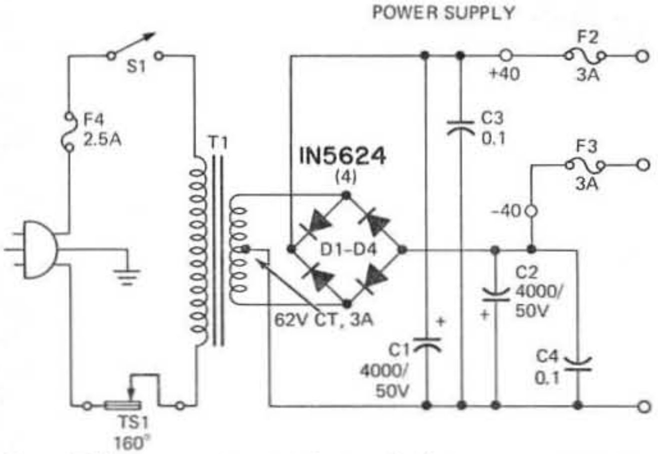


FIG. 6—COMPLETE CIRCUIT OF ONE OF THE FOUR CHANNELS. PC board patterns and complete construction details next month.

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.

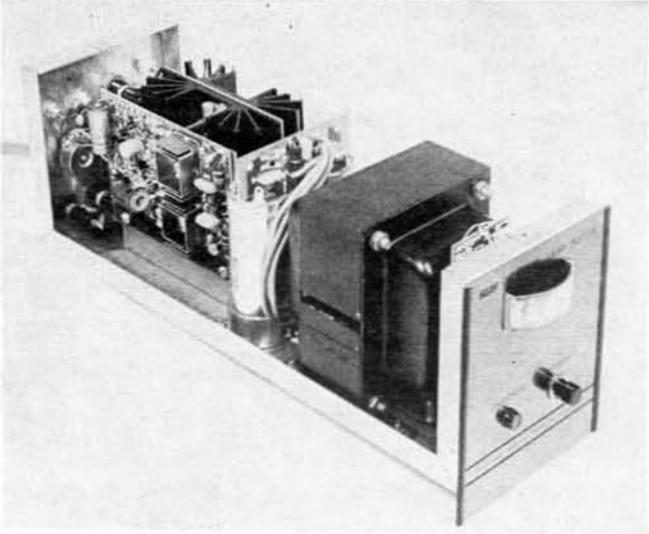
The power supply is a simple bridge rectifier system with capacitor-input filters. Due to the large amount of isolation from supply ripple and hum in the voltage amplifier stages, excellent noise figures are obtained without any complicated regulated supplies. It is doubtful that any measurable improvement 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.

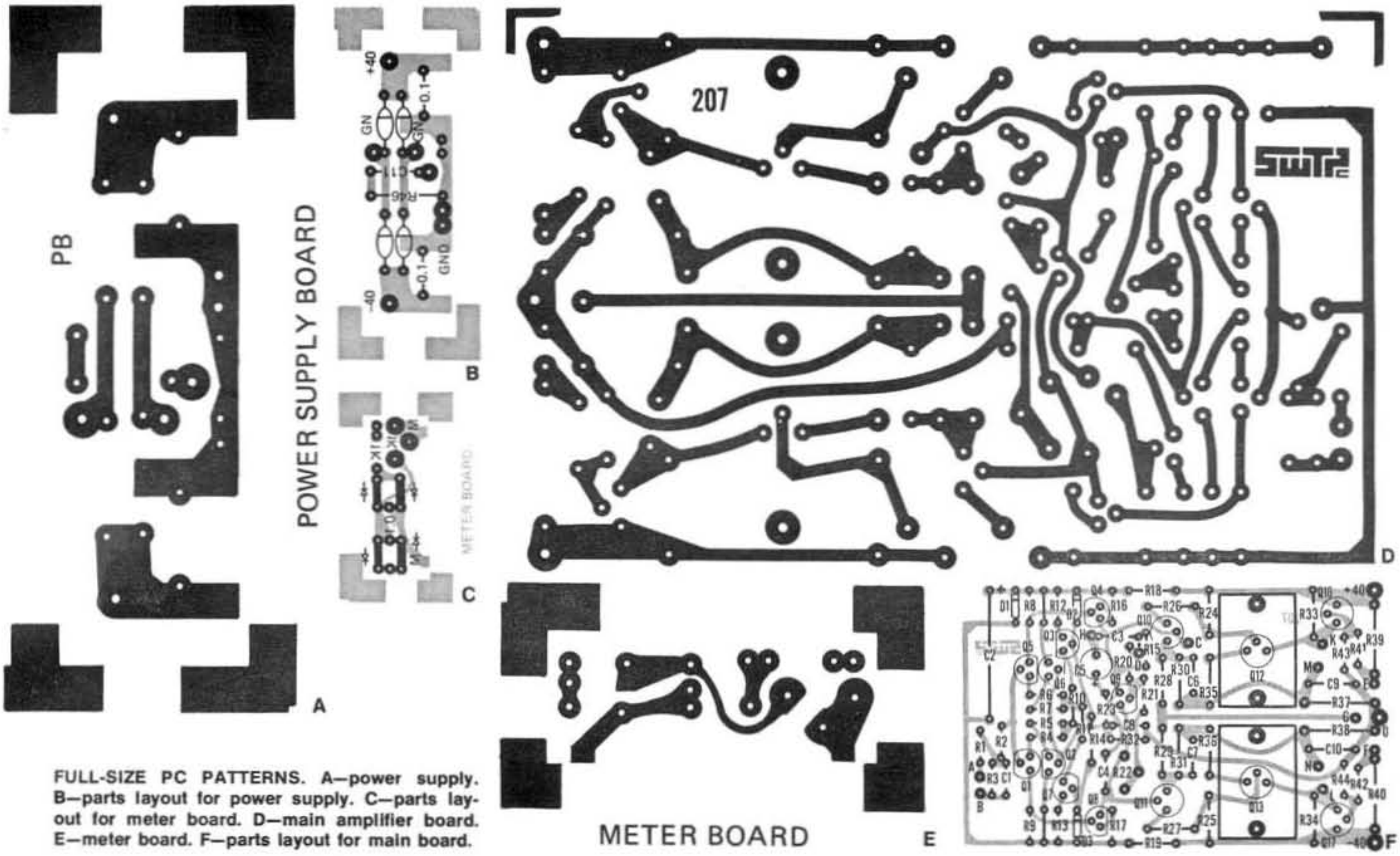
That's all we have room for this month. Next issue we'll present full construction information; along with parts lists, full-size circuit-board patterns, and parts layout diagrams. We'll also have additional photos of the unit. **R-E**

4-CHANNEL AMPLIFIER

distortion is a feature of this This month we conclude the construction details.

by DANIEL MEYER





FULL-SIZE PC PATTERNS. A—power supply. B—parts layout for power supply. C—parts layout for meter board. D—main amplifier board. E—meter board. F—parts layout for main board.

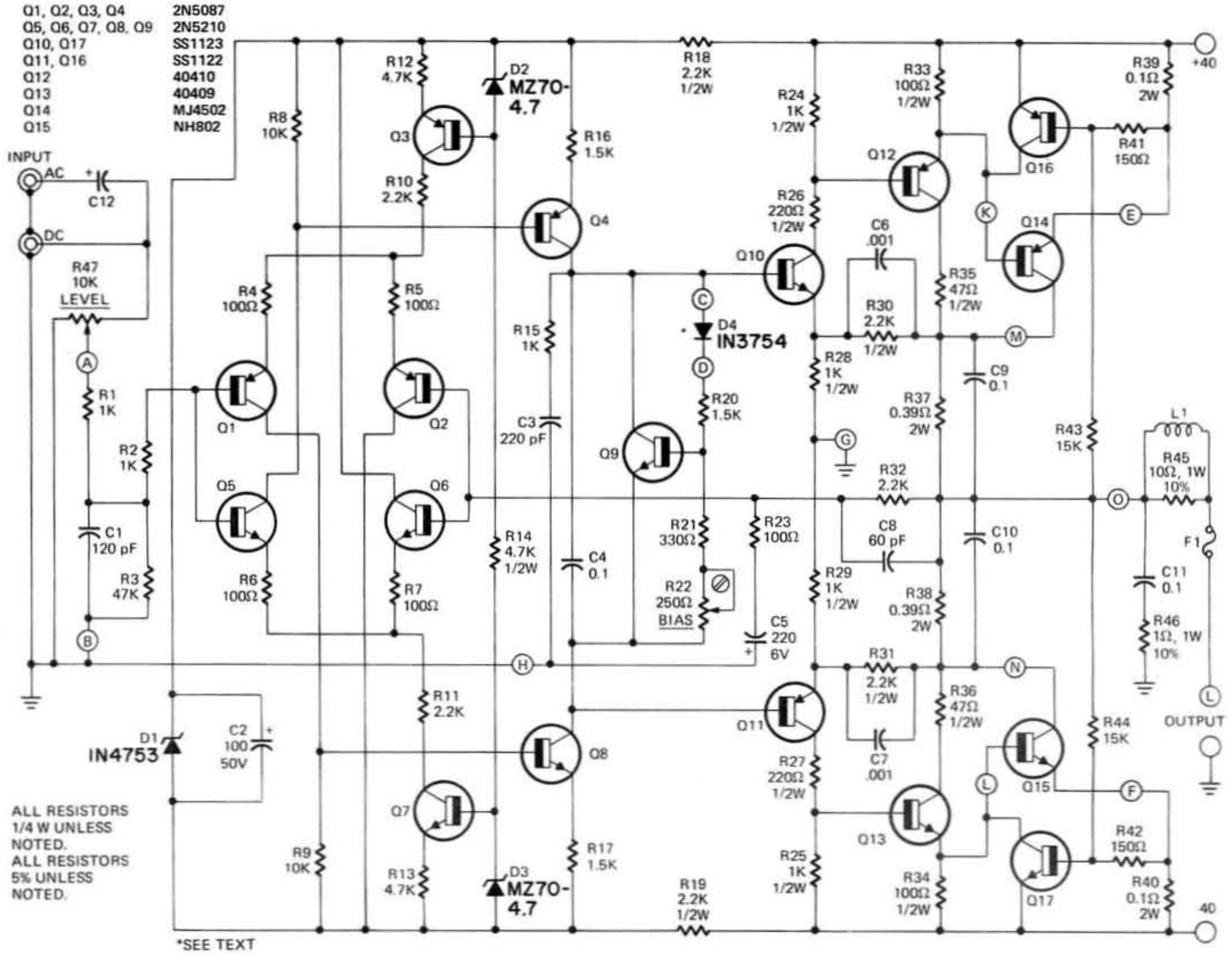
and on the heat sink surfaces where they contact the mounting bracket.

Base and emitter connections are made to the output transistors with pins removed from a miniature tube socket with insulating tubing over the pins. Mount the bracket with the sink and output transistors in the chassis. Install the parts on the main circuit board and solder them in place. Pull everything except the plastic transistors down firmly against the circuit board before soldering and trim the excess lead length on the etched side. Mount the board on the bracket after all input connections and connecting point **"O"**.

Do not connect the output transistors to the board yet. Connect the bias diode leads to points **"C"** and **"D"** after the board is mounted to the bracket. Attach your voltmeter to the output terminals and put it on the 10 to 15-volt scale dc, whatever is close. Install the positive and negative supply fuses and the output fuse. Plug in the line cord and turn on the switch. If there is any noticeable reading on the meter after the initial turn-on transients, or any obvious overheating of a part turn the amplifier off and start troubleshooting. If all looks normal so far you can apply an input signal and check for proper amplification.

Q12 and Q13 can provide a few hundred milliwatts of power without the output transistors which should be enough to tell if operation is correct. If it is going right so far, turn off power and connect the output transistors. Turn the bias trimmer to *maximum* resistance, connect an 8.0-ohm load and apply power again. Connect A dc voltmeter across either R37 or R38 and adjust the bias trimmer for a reading of slightly less than 20 mV. This will set the output stage for an idle current of around 50 mA. which is close to optimum.

If you have a sensitive IM analyzer with a .1% full scale range, you can adjust the bias for minimum distortion with a power output of 1 to 3 watts. Watch the meter on the front panel while testing and adjusting and if at any time the reading jumps up, or shows an output when you



*SEE TEXT

PARTS LIST—POWER AMPLIFIER

All resistors 5%, unless noted:
R1, R2, R15—1000 ohms ¼ watt
R3—47,000 ohms ¼ watt
R4, R5, R6, R7, R23—100 ohms ¼ watt
R8, R9—10,000 ohms ¼ watt
R10, R11, R32—2200 ohms ¼ watt
R12, R13—4700 ohms ¼ watt
R14—4700 ohms ½ watt
R16, R17, R20—1500 ohms ¼ watt
R18, R19, R30, R31—2200 ohms ½ watt
R21—330 ohms ¼ watt
R22—250 ohms, trimmer
R24, R25, R28, R29—1000 ohms ½ watt
R26, R27—220 ohms ½ watt
R33, R34—100 ohms ½ watt
R35, R36—47 ohms ½ watt
R37, R38—0.39 ohms 2 watt
R39, R40—0.1 ohms 2 watt
R41, R42—150 ohms ¼ watt
R43, R44—15,000 ohms ¼ watt
R45—10 ohms 1 watt 10% resistor
R46—1 ohm 1 watt 10% resistor
R47—10,000 ohms linear potentiometer

Miscellaneous parts

L1—Single layer of wire close wound on body of resistor R45
F1, F2, F3—3-amp standard fuse
F4—2.5-amp slow-blow fuse
T1—62 Vac C.T. 3A secondary 117 Vac primary
LM1—NE-2 neon lamp

The following are available from: Southwest Technical Products Corp. Box 32040, 219 W. Rhapsody San Antonio, Texas 78284

No. 207-b Circuit board for single channel of the "Tiger .01" Amplifier $2.65 postpaid
No. 207-C Complete Kit of parts for single channel of the "Tiger .01" Amplifier including chassis and cover. $75.00 plus postage for 15 lbs and insurance if desired

Meter Parts

0-20 mA meter
1N914 Rectifiers (4)
.1-μF capacitor
1000 ohms trimmer resistor
1000 ohms ¼-watt resistor

Capacitors

C1—120-pF polystyrene
C2—100-μF 50Vdc electrolytic
C3—220-pF polystrene
C4, C9, C10, C11—0.1-μF mylar
C5—220-μF 6Vdc electrolytic
C6, C7—0.001-μF 10% discap
C8—60-pF polystrene
C12—4.7-μF tantalum

Semiconductors

D1—36-volt 1-watt Zener 1N4753 or equal
D2, D3—4.7-volt 400-mW Zener MZ70—4.7 or equal
D4—1N3754 compensating diode
Q1, Q2, Q3, Q4—2N5087 silicon
Q5, Q6, Q7, Q8, Q9—2N5210 silicon
Q10, Q17—SS1123 silicon
Q11, Q16—SS1122 silicon
Q12—40410 silicon
Q13—40409 silicon
Q14—MJ4502 silicon
Q15—MJ802 silicon

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have no input; **STOP** quickly and check for circuit oscillation. With luck such a condition may blow the fuses, but it can also fry the outputs so don't allow such a condition to continue if it is found. The *Tiger .01* should be quite stable if built and wired as shown, but any amplifier with this kind of gain, feedback and bandwidth can cause you lots of ulcers and heartburn if wire routing and grounding are not properly done.

Using your amplifier

Listening test show that builders of this amplifier will need systems in which all other components are the best available to really appreciate the quality of this amplifier. If possible, listen to some recordings with extended high-frequency response on a wide-range electrostatic speaker system. The beautiful transient response and the smooth, effortless way in which highs are reproduced with no sign of strain, or roughness is unreal. The bass response is limited by the speaker system characteristics. The amplifier will handle material far lower than any known speaker will go. Only time will tell, but all indications are that the *Tiger .01* circuit will be another of those large steps forward in the development of quality audio amplifiers. Try it, you'll like it! **R-E**

BUILD POWER

Exceptionally low
quadraphonic amplifier.
story with additional

THE TIGER *.01* AMPLIFIER IS THE RESULT OF MY LATEST *efforts to produce a better power amplifier by reducing distortion to a new low. It is a 4-channel unit with four completely separate power amplifiers, each delivering up to 60 watts sinewave continuous power into an 8-ohm load. This story began in last month's issue.*

It would be well to mention at this point that although the circuit is well supplied with limiting resistors and volt-amp protection in the output stage, it is still quite possible to "zortch" the outputs if rf signals are allowed to get into the amplifier. To provide good square-wave response out to 20,000 Hz, the bandwidth of the amplifier must be made 300 to 500,000 Hz. This is all well and good, but the output transistor efficiency becomes very poor after about 30,000 to 50,000 Hz due to storage-time effects in these devices.

As long as the input is an audio-range frequency there is no problem, but if higher frequencies are fed into the amplifier the output transistors will *both* be on to some extent for a considerable portion of each cycle. This is just like shorting the positive supply to the negative supply by turning on both output transistors. The effect is called "mutual conductance" and as you can imagine it causes considerable heating of the output transistors. If you want the superior transient response that you get with this kind of bandwidth, you just have to be careful about this kind of thing.

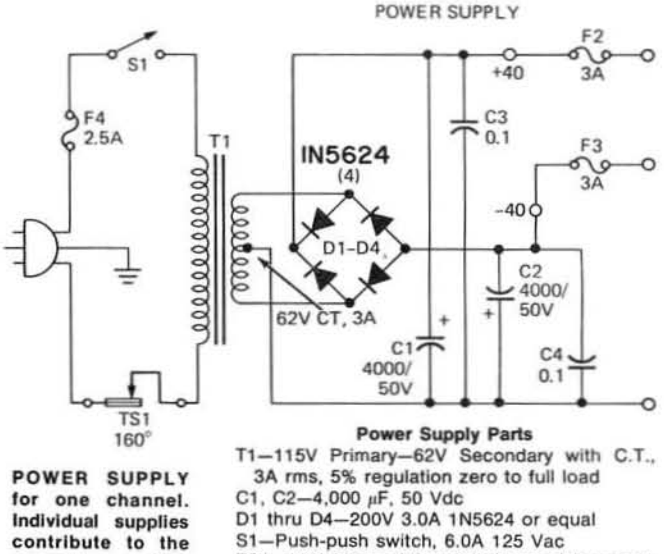
Packing and construction

Since stereo is now almost universal in home music system and the trend seems to be to four channels, the *Tiger .01* package is designed to be used in anything from a single unit to four or more channels by simply adding the new channels as needed and replacing the outer trim portion of the case. The front panel is quarter-rack size, so four of these can be mounted side by side in a standard 19-inch relay rack. Each amplifier is complete with it's own separate power supply, so there is no reduction in power when all channels are driven to full output and absolutely no interaction, or crosstalk. The meter to monitor output level makes it very simple to balance the complete system and gives you a good idea of what level you can operate at before you are likely to begin clipping peaks and running into excessive distortion, no matter what the speaker efficiency may be.

The majority of the parts are mounted on circuit boards to insure proper operation, and make construction simple. The rectifiers are mounted on a small circuit board that attaches directly to the lugs on the filter capacitors. The meter circuit parts are mounted on another small circuit board that attaches to the meter terminals. The amplifier parts are mounted on the main circuit board in the positions shown on the board layout. The output transistors are of course mounted to the heat sink along with sensing diode D/4.

The heat sink consists of two "Wakefield" type 641K sinks drilled so that they may be mounted back-to-back. In this way enough square inches of heat sink can be obtained to safely operate the circuit at full rated power continuously with no overheating problems. A 160° thermostat is mounted just below the heat sink just in case the amplifier is used in a cabinet, or location that does not have sufficient air circulation. This thermostat turns off the amplifier and turn on the overheat indicator lamp on the front panel if the amplifier gets too hot for further safe operation.

Construction should be no problem if the layout system shown in the photographs is used. The various parts that mount on the chassis should be installed first and the supply wired. The power supply can be tested for proper output voltage at this point. The no load dc output voltage should be in the order of ±45 volts with normal line voltage. The meter and its circuit board and the meter illumination lamps should be installed next. The heat sinks are attached to the mounting bracket with the same screws that hold the power transistors in place. Use an insulating mica, or similar washer under the transistor cases and insulating washers under the nuts on the mounting screws. Use a thin coat of heat sink compound on each side of the washer



POWER SUPPLY for one channel. Individual supplies contribute to the overall performance of the amplifier.

Power Supply Parts

T1—115V Primary—62V Secondary with C.T., 3A rms, 5% regulation zero to full load
C1, C2—4,000 μF, 50 Vdc
D1 thru D4—200V 3.0A 1N5624 or equal
S1—Push-push switch, 6.0A 125 Vac
TS1—160° Thermal Cutoff "Elmwood Sensors"
C3, C4—0.1-μF 250-V film