A 3-Way Drive System for Speakers

Active crossover divides the audio spectrum for individual drivers before power amplification

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IN TRADITIONAL multiway loudspeaker systems, the division of the driving signal into frequency ranges suitable for the several drivers is performed after power amplification. The crossover or dividing network is composed of a set of passive components—inductors, capacitors, and resistors—interposed between the power amplifier output terminals and the input terminals of the individual transducers.

From the point of view of economy, this approach is advantageous, but it is not without difficulties. One is that the dividing network must handle appreciable power. This means that the passive components (the inductors are most problematic) must behave in a linear manner at high current levels if distortion products are not to be generated. Optimal design often raises the cost of the passive components and causes some of the economic advantage to evaporate.

Another drawback of particular concern to the home constructor is that a high-level network capable of performing well with the drivers to which it is added can be very difficult to design. The reason is that most tables and formulas for the filter-section design are based on the assumption that the network will be terminated by a purely resistive load, while the driver impedances usually contain significant, frequency-dependent reactive components.

Clearly, it would be advantageous to eliminate this problem. We can do this with no loss of performance by multiamping the system and taking advantage of the fact that the power amplifiers act as buffers between the filters and the drivers. Another benefit is that, with several power amplifiers sharing the load, the demands made on each of them are less stringent than when a single unit must do the whole job. For example, since bass frequencies cannot intermodulate with treble frequencies in loud passages, a particulary audible form of distortion is minimized. Also, the bass power amp can have a relatively low slew rate and cause no problems, as it will not see rapidly changing signals. A treble amp, on the other hand, can have a low damping factor, with less feedback and fewer problems.

The Filters. A schematic diagram of the active crossover for one audio channel appears in Fig. 1. While other types of filters can give good results in this application, the 18-dB/octave active Butterworth filters used here offer a desirable combination of steep slopes and good phase response. Rolling off the drivers rapidly helps to suppress any anomalous behavior they may exhibit as the extremes of their useful ranges are approached. Using as sharp a network as this between a power amplifier and the drivers is often avoided because of expense. In a design of this type, however, the extra cost is minimal.

Quad operational amplifiers *IC1* and *IC2* are the central elements of the filters. Integrated circuits *IC1A, IC1B, IC1D,* and their associated components and *IC1C, IC2A, IC2B,* and their associated components comprise two active filters with ultimate slopes of 12 dB/octave. The first filter separates the high frequencies from the low and middle frequencies. The second

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PARTS LIST

C1—13,000-μF, 50-volt electrolytic
C2,C10,C12*,C15*,C17*,C18—1-μF, 50-volt radial-lead electrolytic
C3,C4,C9—1000-pF, 5% polystyrene
C5,C6,C7,C8,C16—10,000-pF, 5% polystyrene
C11,C14*,C20*—47-μF, 50-volt radial-lead electrolytic
C13*,C19,C21*—470-μF, 25-volt radial-lead electrolytic
C22 through C28—0.1-μF disc ceramic
D1,D2—6.8-volt, 1-watt zener diode
F1—1-ampere fast-blow fuse
IC1,IC2—LM324N, TL074CN, or similar quad operational amplifier
IC3*,IC4*—LM379S dual six-watt audio amplifier
J1—RCA phono jack
Q1*,Q3*—TIP31 npn power transistor
Q2*,Q4*—TIP30 pnp power transistor
The following, unless otherwise specified, are ¼-watt, 5%, carbon-film resistors.
R1,R32—1000 ohms
R2,R3,R4,R6,R8,R10,R12,R13,R24*, R25*,R31*—100,000 ohms
R5,R7,R11,R14,R15,R16,R17—68,000 ohms
R9—51,000 ohms
R18,R23*,R30*,R33—10,000 ohms
R19*,R22*,R28*,R29*—150,000 ohms
R20*,R21*—5.1 ohms, ½-watt, carbon-composition
R26—22,000 ohms
R27*—4700 ohms
R34,R35—10,000-ohm, pc-mount, linear-taper potentiometer
RECT1—6-ampere, 100-PIV modular bridge rectifier
S1—Spst toggle switch
T1—24-volt, 2-ampere transformer (Stancor No. P-8617 or equivalent)
Misc—Printed circuit board, heat sinks (four Thermalloy No. 6070 or equivalent, two Thermally No. 6072 or equivalent), line cord and strain relief, fuseholder, circuit board standoffs, hardware, hookup wire, shielded cable, etc.

Note—An etched and drilled glass-epoxy printed circuit board is available for $15.00 from Marchand Electronics, Inc., 1334 Robin Hood Lane, Webster, NY 14580. New York residents, please add 7% state sales tax.

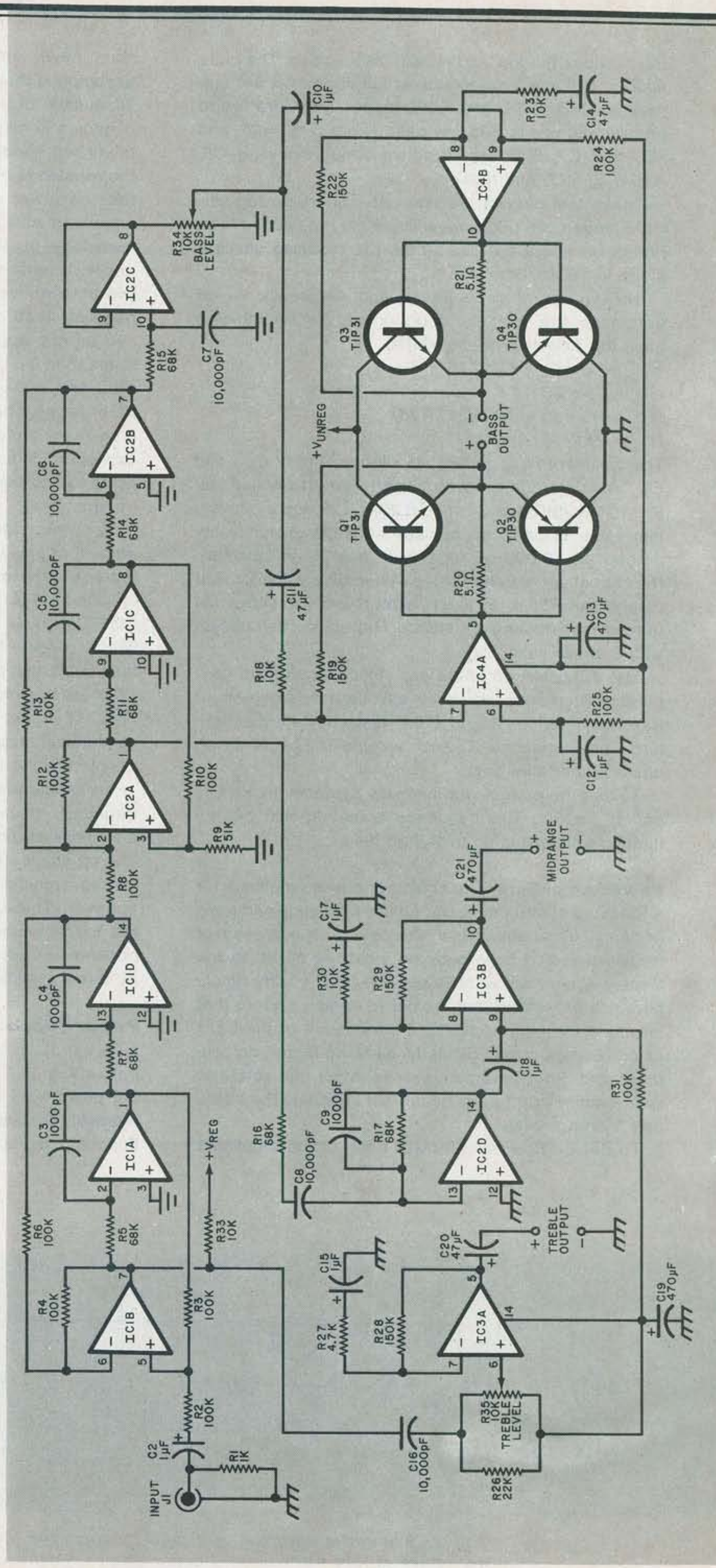

Fig. 1. Schematic diagram of the active crossover for one audio channel. Further power amplification may be added if desired.

then divides the low and middle frequencies. The high, middle, and low frequencies, which appear at the outputs of *IC1B, IC2A,* and *IC2B,* respectively, are fed to passive high-pass and low-pass filters *C16, R26,* and *R35* and *C7, R15* and to active band-pass filter *C8, R16, C9, R17,* and *IC2D.*

These last circuits are first-order filters having ultimate slopes of 6 dB/octave. Because the second- and first-order filters are cascaded, the resulting ultimate slope is 18 dB/octave.

The values of capacitance and resistance which determine the low and high crossover frequencies have the following relationships:

$C_{high}=C3=C4=C16/10$

$C_{low}=C5=C6=C7$

$R_{high}=R5=R7=10\ (R26 \| R35)$

$R_{low}=R11=R14=R15$

The values of R_{high} and R_{low} in kilohms and of C_{high} and C_{low} in picofarads are determined from the equations: $R=10^9/6.28fC$ and $C=10^9/6.28fR$. Choose a convenient value of capacitance, say 100,000 pF for a low crossover, 10,000 pF for a high one. Then calculate the necessary resistor values. A negative value for *R26* means that *R35* is too low to allow it and *R26* in parallel to reach the desired resistance. Repeat the calculation with a larger value for *C.*

The specified op amps are sufficiently fast to give good performance. However, anyone concerned about transient intermodulation (TIM) distortion may substitute a pin-compatible IC, such as type TL074CN, which has a higher slew limit.

To use the project with two-way systems, make f_{high} and f_{low} equal. The bandbass output should be left floating as there is no midrange driver.

Power Amplifiers. The choice of power amplifiers for a triamped system depends on the efficiency and power-handling capabilities of the drivers, the crossover frequencies and how loud you want the music to be. Generally, you will want to use the best quality amplifiers you can afford; but, as noted earlier, factors that influence the high-frequency performance of the bass amp are unimportant. Similarly, damping factor, dc coupling, and other parameters or features that relate to low-frequency performance are not critical in the treble and midrange amps.

To decide how much power each of the amplifiers must have, start with the reasonably conservative assumption that music has equal power in each of the 10 audible octaves. With your chosen crossover frequencies in mind, determine how many octaves each driver will handle. The number of octaves is given by the relation $N = \log_{10}(f_2/f_1) / \log_{10} 2$, where f_1 and f_2 are the lower and upper limits, respectively, of the passband allocated to a particular driver. (This is a formidable looking calculation, but it can be performed easily on most scientific calculators.) A driver handling five octaves would get 50% of the system power; one handling three octaves would get 30%, etc.

If an appropriate calculator is not available, draw a chart, marking octave boundaries at 20, 40, 80, 160 Hz etc., and note which bands contain your crossover frequencies. Then you can get an approximate idea of how many octaves are reproduced by each driver. Obviously, this method is not exact, but you are not likely to find power amplifiers in exactly the sizes you need anyway.

A constructor who can be satisfied with a modest amount of power at distortion levels that are adequate but not state-of-the-art can build the power amplifiers included in Fig. 1. These are built around two National LM379s, dual 6-watt integrated power amplifiers, which require few additional components and have built-in thermal protection. Integrated circuits *IC3A* and *IC3B* are the amplifiers for the high and middle frequencies. They are connected as standard noninverting operational amplifiers and the outputs are capacitively coupled to the loudspeakers via *C20* and *C21.*

To satisfy the higher power requirement of the low-frequency channel, *IC4* is arranged as a balanced amplifier with booster transistors *Q1, Q2, Q3* and *Q4.* The op amps are arranged as an inverting and a noninverting amplifier, differentially driving the bass loudspeaker. This doubles the maximum voltage across the loudspeaker, yielding four times the power. The booster transistors handle the doubled output current. All three amplifiers are designed for 8-ohm drivers.

Power Supply. Power for the filters and power amplifiers can be provided by the supply shown schematically in Fig. 2. A simple bridge rectifier and filter capacitor provide 35 volts dc at no load. As the LM 379 is relatively insensitive to power-supply ripple, no additional filtering is required.

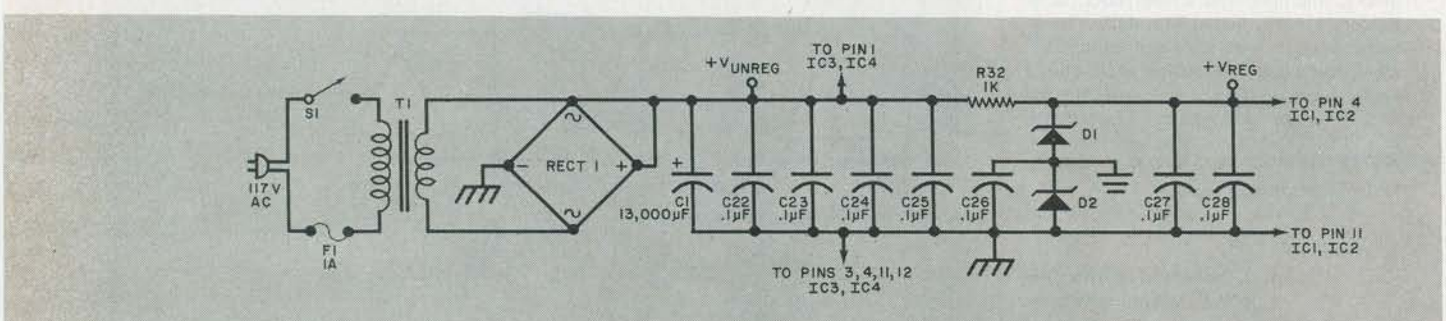

Fig. 2. Schematic diagram of a power supply for the filters and amplifiers. Capacitors supply filtering and zener diodes regulation for various voltages.

Supply voltages for *IC1* and *IC2* are provided by the 6.8-volt zener diodes, *D1* and *D2*. Capacitors *C22* through *C28* provide power-supply decoupling. Power amplifiers *IC3* and *IC4* require high-frequency power-supply decoupling to prevent ultrasonic oscillation. This decoupling is provided by *C22* through *C25*. These disc ceramic capacitors are mounted in pairs close to the LM379 integrated circuits.

Note that two distinct ground symbols are employed in the two schematic diagrams. This is so because the power supply is single-ended. The "earth ground" symbol is employed as the input and output signal ground and the negative supply line for the ICs. The "chassis ground" symbol signifies an artificial ground for operational amplifiers *IC1* and *IC2* that is at a dc level equal to one half the regulated supply voltage. It is derived by means of the voltage-dropping action of zener diodes *D1* and *D2*.

The gains of the low and high channels can be adjusted with potentiometers *R34* and *R35*. With the wipers of these controls at the center of their travel, the gains of all amplifiers are approximately 15. An input sine wave of 460 mV rms will then result in full power output.

Construction. The assembly of the project is relatively straightforward. All parts except the 24-volt power transformer are mounted on a single 5½-×-6½-inch printed circuit board. The full-size etching and drilling guide for this board appears in Fig. 3. A complementary parts placement guide is reproduced in Fig. 4. When inserting electrolytic capacitors, diodes, transistors and integrated circuits, be sure to observe proper polarity.

Resistors *R2* through *R17* and *R26* and capacitors *C3* through *C9* and *C16* determine the crossover frequencies. For best performance, these components should have a tolerance of no more than ±5%. Polystyrene capacitors are specified but other low-loss precision types, can be substituted.

Transistors *Q1* through *Q4* are mounted on Thermalloy No. 6070 or similar heatsinks with suitable mounting hardware. Cooling for the LM379 ICs is accomplished by mounting them directly on Thermalloy No. 6072 or similar heatsinks with two No. 4-40 machine screws. The holes in these heatsinks do not line up with the threads in the ICs, so two holes spaced 1 inch (2.54 cm) apart must be drilled in the heatsinks. Pin 1 of the power ICs is marked with a small white dot on the

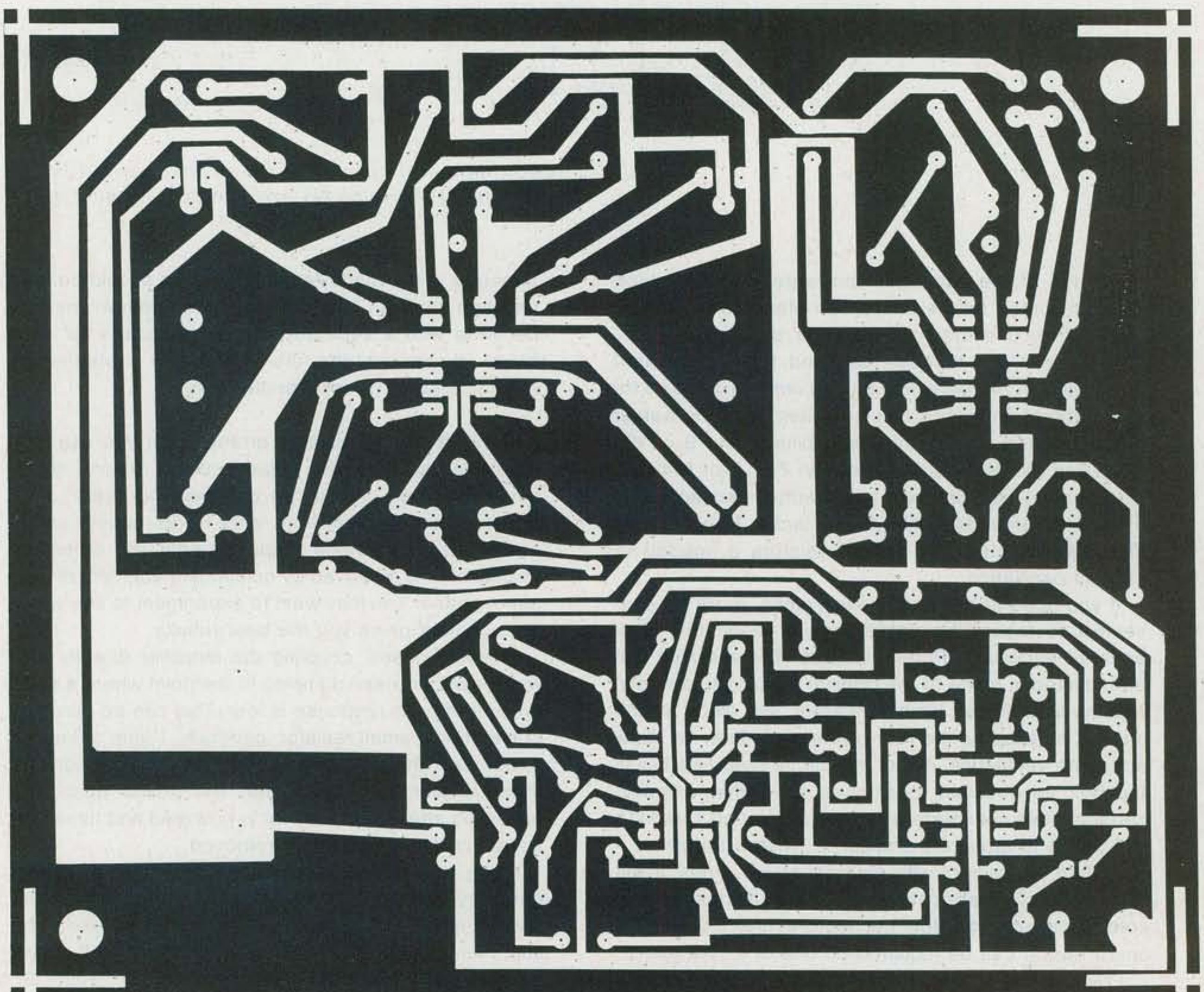

Fig. 3. Actual-size etching and drilling guide for printed circuit board.

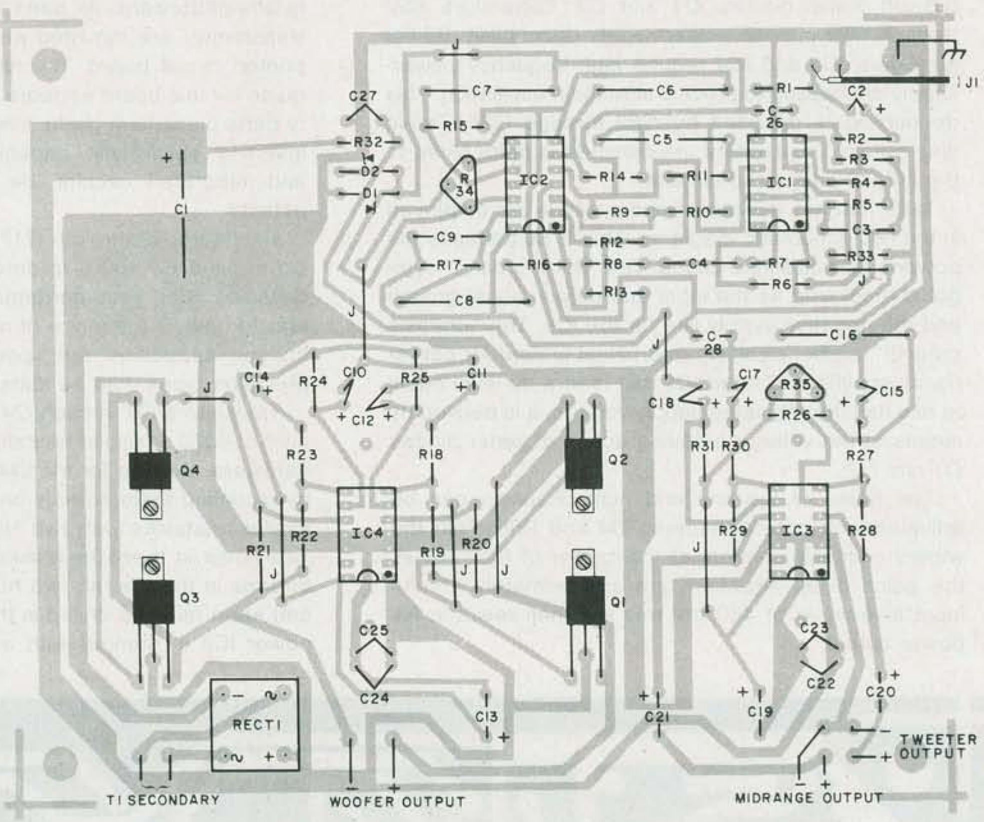

Fig. 4. Component layout diagram for the printed circuit board. Transistors Q1 through Q4 are mounted on heat sinks.

underside of the package. The large filter capacitor, *C1*, is mounted on the board with standard hardware.

Should you decide to use other power amplifiers, *IC3* and *IC4*, *Q1* through *Q4*, and their associated components (see parts list) can be omitted. Outputs for the external amplifiers can be taken from the solder pads intended to accommodate pins 6 and 9 of *IC3* (high and mid frequencies) and pin 7 or 9 of *IC4* (low frequencies). Use shielded cable with phono jacks and the shield grounded only at the jacks. Keep cables short, adding 100-ohm buffer resistors if needed to prevent oscillation.

If you use the on-board power amps, it will be convenient to mount the entire project inside the loudspeaker enclosure. Potentiometers *R34* and *R35* can be mounted in place of the original crossover controls, and the fuse holder, input connector, and on-off switch can be installed on the rear of the enclosure. To allow adequate ventilation, mount the circuit board as low in the box as possible, positioning it so that damping material does not interfere with air circulation. Leads to the pots and speakers should be twisted together.

To use the project with external power amps, it will be necessary to fabricate some form of enclosure. The controls, input and output connectors, fuse holder, and on-off switch can be mounted on one of its panels.

Power-supply components *T1*, *B1*, *C1* are more than adequate for two stereo channels of filtration. Decoupling capacitors *C22* through *C25* can be omitted, but a separate zener-diode regulator section should be used for each channel. The loudspeaker system will have to be fitted with a separate set of connectors for each driver. If desired, the drivers can be protected by individual fuses of appropriate ratings.

Setting it Up. Whichever arrangement you use, pay careful attention to the polarity of the drivers, sometimes indicated with a red dot meaning "plus" (+). Some authorities feel that, with 18-dB/octave crossovers, the best phase response near the crossover frequencies is achieved by connecting adjacent drivers out of phase. You may want to experiment to see which arrangement gives you the best results.

In some cases, coupling the amplifier directly to a woofer will increase damping to the point where a small amount of bass response is lost. This can be cured by connecting a small resistor, generally 1 ohm or less, in series with the driver. To protect the speaker drivers from transients, be sure that the power amps are turned on *after* the crossover is powered and turned off *before* crossover power is removed.

Once you are certain that the project is operating correctly, make all necessary corrections and set the level controls for flattest frequency response. The improvement in the sound of your speakers will not be earth-shaking but should be clearly audible. Many listeners who use tri-amping report clearer, tighter sound with reduced distortion. ◇