HIGH-POWER HI-FI AUDIO AMPLIFIER

This powerful stereo amplifier outperforms commercial units. One version is for the home and the other is portable for sound reinforcement in halls, auditoriums, and theaters.

REINHARD METZ AND MYZIL BOYCE

THE AMPLIFIER DESCRIBED IN THIS article is a lightweight, high-performance stereo amplifier for the demanding audiophile. It can be built for less than $500 in parts, but it performs better than high-end amplifiers that cost up to ten times that amount. Its performance is comparable to top-of-the line professional products, and also is suitable for sound reinforcement because of its portability and rugged construction.

System description

Figure 1 is a block diagram for the amplifier. It consists of a pair of linear discrete amplifiers, both powered by a full-bridge, off-line, switching power supply. It is capable of providing well over 1 kilowatt of continuous power and 2 kilowatts peak with the most demanding audio loads. Both amplifier channels have MOSFET output stages rather than the more common bipolar power transistors.

The authors have found that MOSFET amplifier output stages deliver the best audio quality, but they recognize that they might not be as robust as their bipolar counterparts. That drawback was overcome in this stereo amplifier by powering it with a switching power supply. That supply contributes significantly to the amplifier's overall high performance because of its high instantaneous current capability.

The switching power supply permits the amplifier to be made smaller and lighter than if a comparable linear power supply were used. This high-performance amplifier weighs less than 20 pounds! The power supply's operation at 75 kHz permits the use of smaller and lighter magnetic components. As is true of all switching power supplies, this power supply has smaller filter capacitors than would be required for a linear power supply. The power supply can be switched between three different output voltages. This permits operation at lower voltage or power levels for speaker protection, or to drive lower than standard impedance loads.

A comparable conventional linear power supply would require a large and expensive transformer and large and expensive filter capacitors because they charge at the relatively low frequency of the 60-Hz power line.

Moreover, this higher charge poses a constant threat of damage or destruction to the output transistors if the amplifier is subjected to excessive loads or experiences short circuits. The smaller filter capacitors store much less energy to be dissipated if a short circuit occurs, reducing that threat.

This articles discusses two different amplifier configurations: One is intended for fixed installation in the home, and the other for portable applications so that it can be carried for use in large hall or auditoriums for sound reinforcement. The package for home use depends on natural thermal convection and conduction for cooling, while the portable package includes two 3½-inch, muffin-style fans for forced air cooling. Both cases have approximately the same volume and weigh about 18 pounds. The case for the home version is 5 inches high and the case for the portable version is 3½-inches high and is designed to fit a standard 19-inch instrument rack.

Both versions include two identical amplifier circuit boards and identical switching power supplies. Both include clipping indicators, DC output protection, optional bridging and differential input adapter stages on the amplifier boards. The optional bridging feature allows the amplifier to be reconfigured into a single channel capable of driving loads up to 700 watts and differential input adapter stages permit a 600-ohm balanced input.

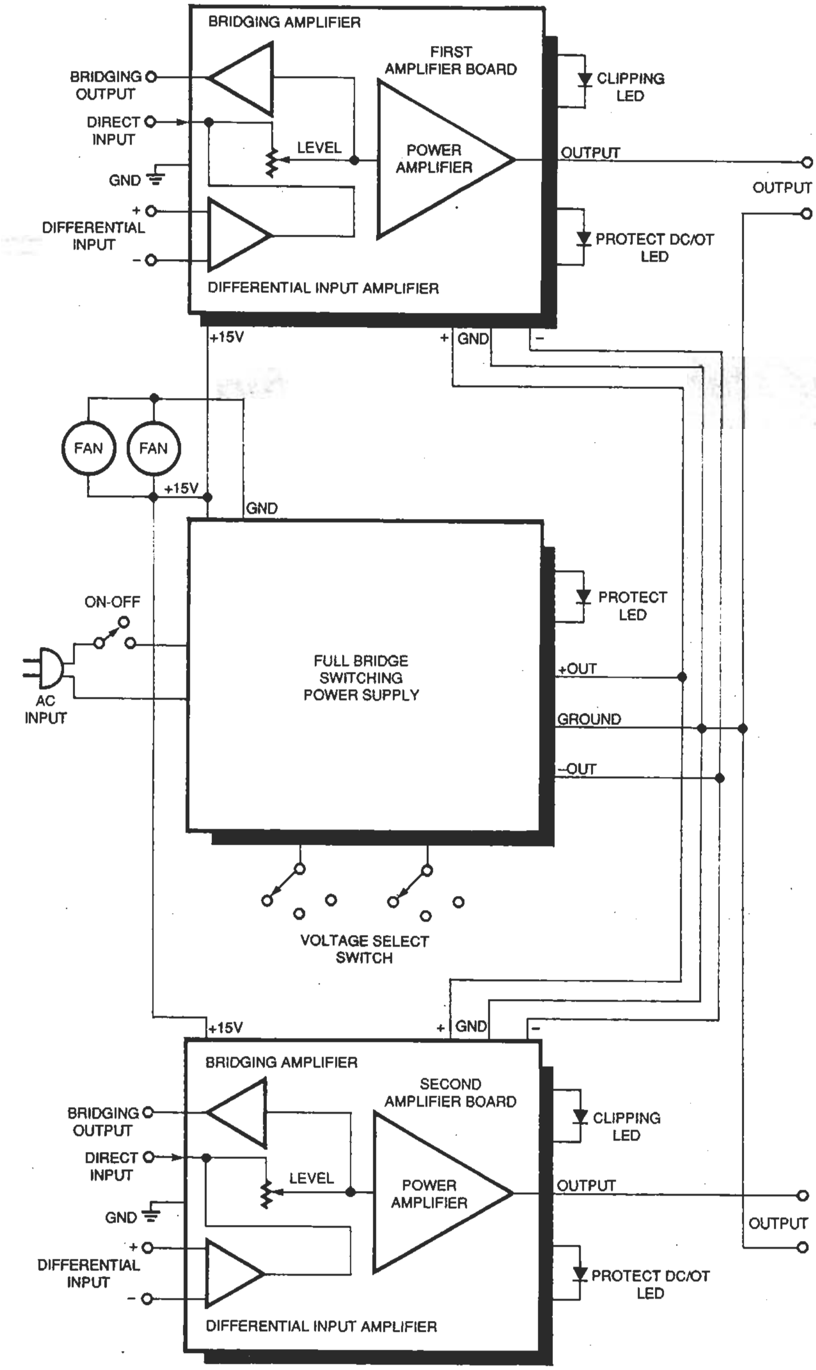


FIG. 1—BLOCK DIAGRAM OF STEREO AMPLIFIER. Designed for operation in homes or auditoriums, it contains two amplifier circuit boards and one switching power supply board.

The authors believe that there are discernible subjective differences between amplifiers even if the specifications do not identify them. In their view this just means that electrical measurements really don't test audio quality satisfactorily. Given otherwise favorable specifications, it has been the authors' experience that high output current capability is the most reliable predictor of subjective listening satisfaction, probably because it allows the amplifier to better handle the variations in a speaker's impedance. While the distortion and bandwidth specifications for this amplifier are commendable, the amplifier was specifically designed to optimize output current capability.

Performance specifications

The specifications for both versions of the amplifier are given in Table 1. When compared with the most expensive commercial amplifiers, it can be seen that these performance characteristics are outstanding. Often low distortion and wide bandwidth are proclaimed as predictors of audio performance, yet many amplifiers whose measured performance is rated excellent will sound different. The audio purists will continue to argue about characteristics and what the specifications will or will not reveal.

How the amplifier works

All of the components in both amplifier channels, with the exception of the bridging inverter and differential input adapter stage, are discrete, as shown in the schematic Fig. 2. Differential input capability is provided by IC2, an LM334 constant-current source and IC5, an LF357 JFET operational amplifier inverter that drives a second channel for bridging.

The normal single-ended input signal passes through the 10 μF input blocking capacitor C1 and the low-pass input filter network consisting of resistors R1, R2 and R3 and capacitor C2. Complementary differential input stage transistors Q1 to Q4 form the first gain stage and transistors Q5 and Q6 along with resistors R15 and R16 provide the second gain stage. Both stages drive the complementary cascode inversion stage.

Transistors Q10 to Q13 and Q24 develop the gate bias for the output power MOSFETs These MOSFETs, Q16 to Q23 (and optional Q26 and Q27) are mounted on aluminum angle stock that act as thermal adapters to the finned heat sink. In the home version the heatsinks form the back of the case; in the fan-cooled version they form two sides.

The inverter stage operates at

Continued on page 69

AUDIO AMPLIFIER

continued from page 34

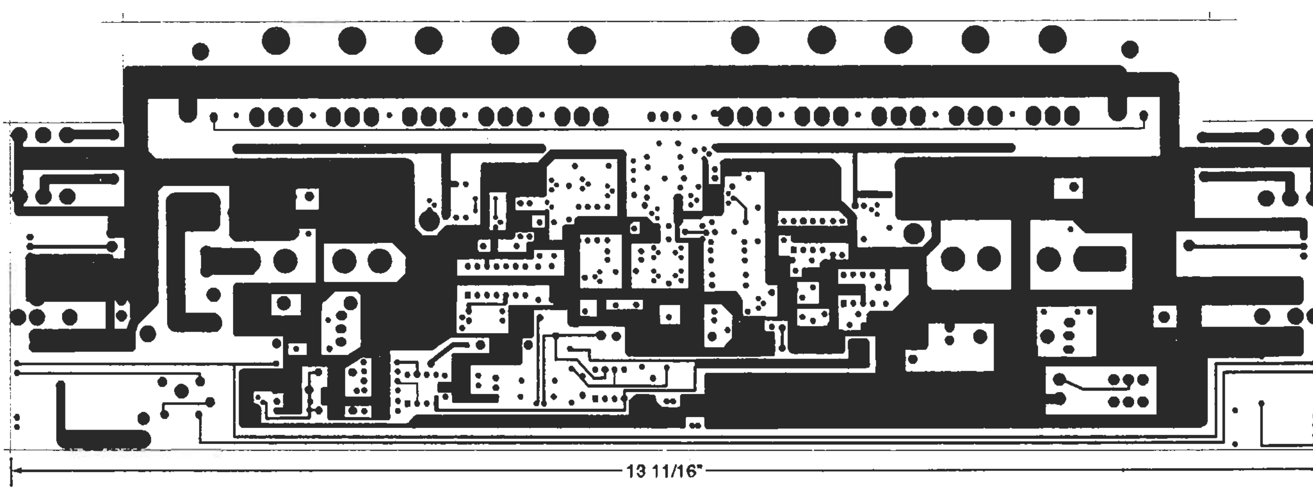
unity gain, splitting the approximately 8-volt bias generated by Q24 and applying it to the output transistor gates referenced to the power supply rails. Transistor Q24 is mounted on the heatsink to allow the bias to track the output stage temperature. Transistors Q14 and Q15 are emitter followers that drive the output transistors Q16-Q23. Finally, the output is obtained from the drains of the output transistors through relay RY1.

The output signal follows two feedback paths: the first is through resistor R36 to resistors R31, R32, and R35, setting the output stage voltage gain at about 30. The second feedback path, resistors R37 to R14 and the input differential amplifier, sets the overall amplifier gain at about 29, with a closed-loop bandwidth of about 350 kHz. This completes the primary signal path from the input terminals input to the speakers.

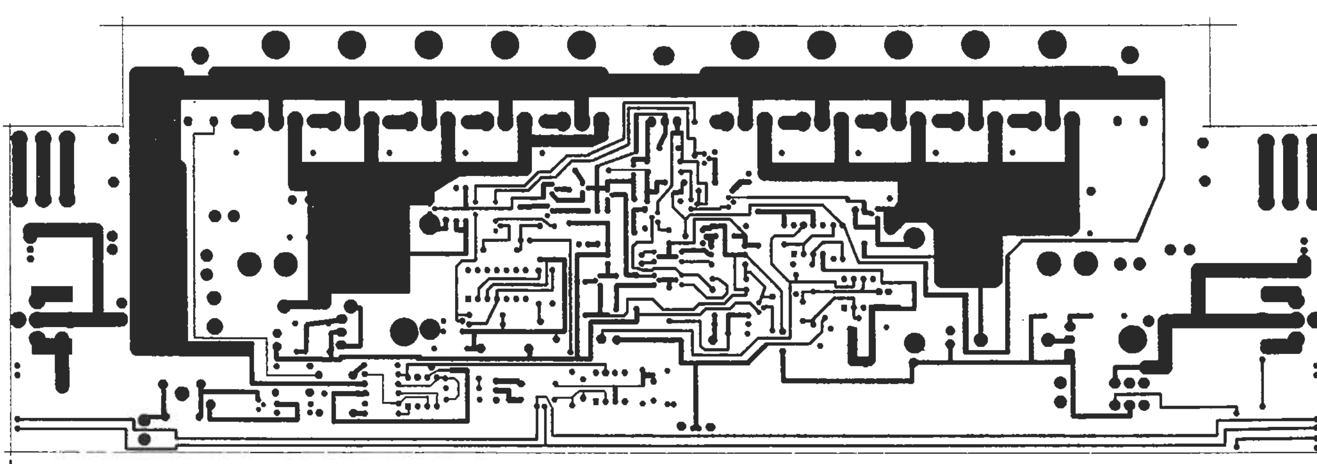
The amplifier circuit board also performs several other functions in addition to processing the audio signal. The first of these other functions is automatic servo-nulling of DC input offset voltages, performed by IC4, an LF411 JFET opera-

TABLE 1
AMPLIFIER SPECIFICATIONS

Power Output: (RMS/Channel) (Both channels driven)	>300 W into 8 ohms, >600 W into 4 ohms >700 W into 2 ohms
Frequency Response:	2 Hz - 300 kHz, +0, –1 dB
Total Harmonic Distortion	<0.05% 20 Hz - 20 kHz
Slew Rate:	200 V/µs (typical)
Rise Time:	500 ns (typical), 600 ns (rail-to-rail)
Pulse output current capability:	>50 A into 1 ohm
Damping Factor:	>200
Signal-to-noise ratio:	100 dB, 20Hz - 20 kHz
Dimensions (case with fans)	16.5 × 14 × 3.5 inches (19-inch rack mountable)
(case without fans)	16.5 × 14x × 5.5 inches
Weight:	18 pounds



AMPLIFIER CIRCUIT BOARD PATTERN, component side.



AMPLIFIER CIRCUIT BOARD PATTERN, wiring side.

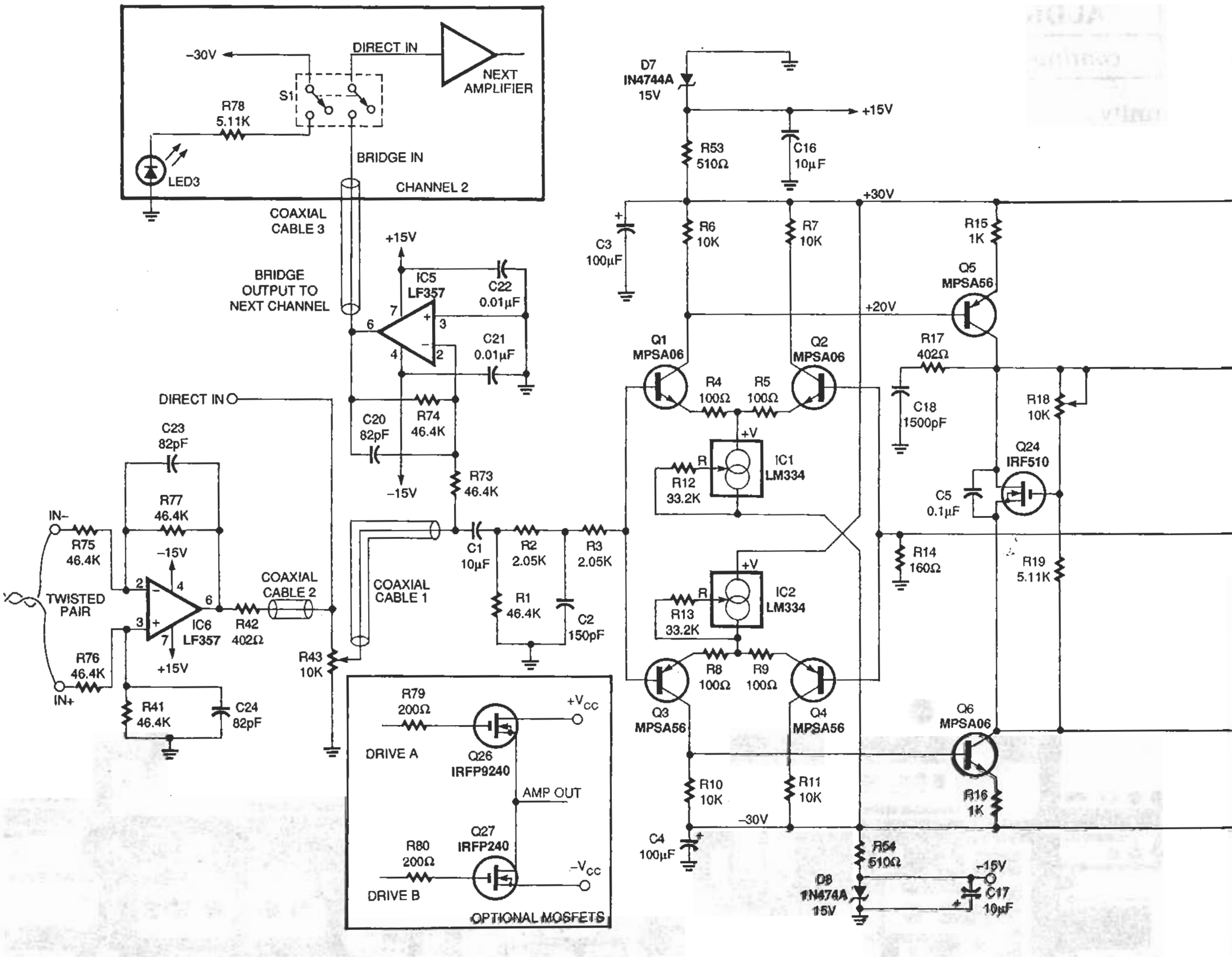


FIG. 2—SCHEMATIC FOR TWO AMPLIFIER CHANNELS. Bridge circuitry in box (upper left) shows bridging circuitry between channels.

PARTS LIST—AMPLIFIER BOARD

All resistors are ¼-watt, 1%, unless otherwise specified.

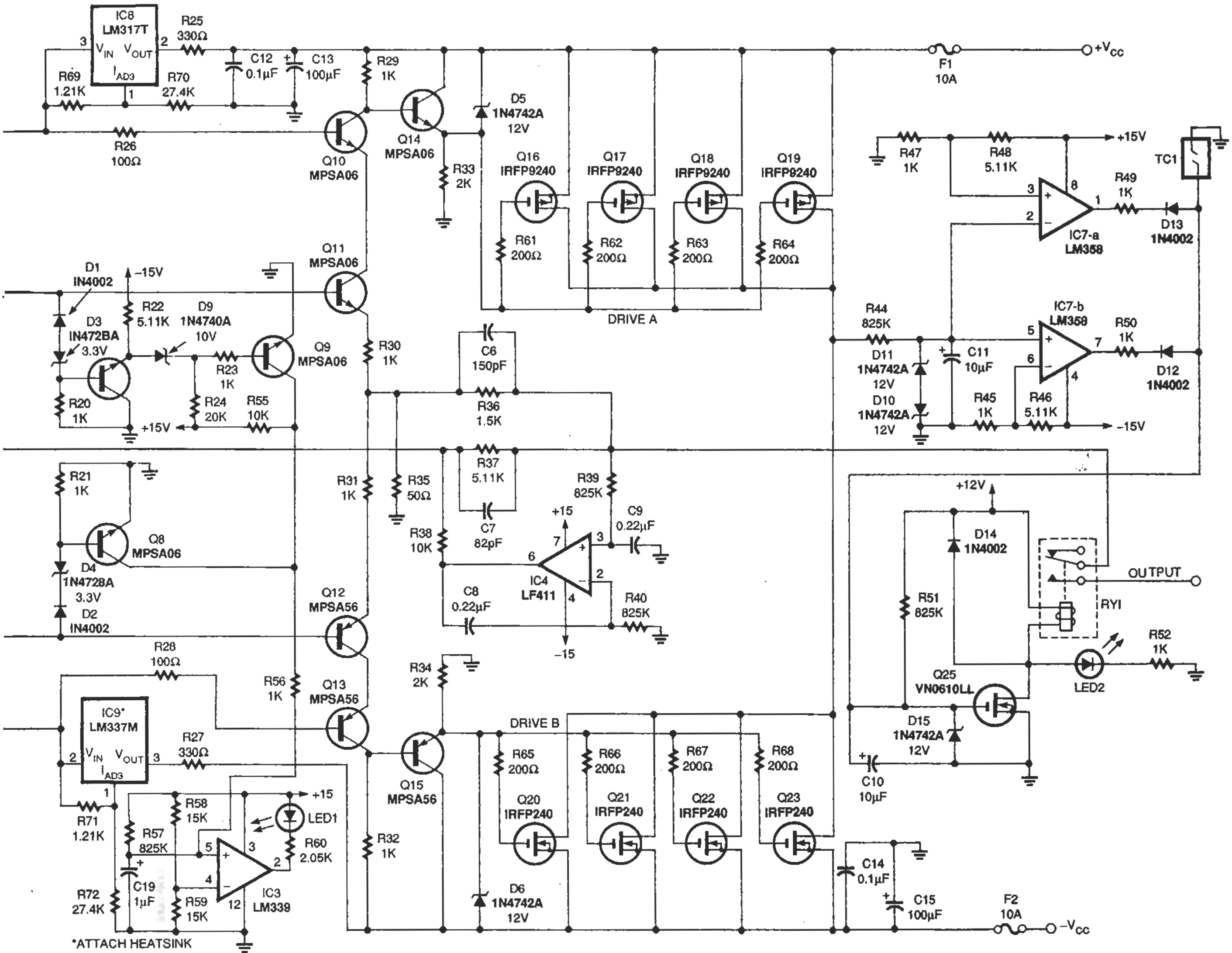
R1, R73, R74, R75, R76, R77—46,400 ohms
R2, R3, R60—2050 ohms
R4, R5, R8, R9,R26, R28—100 ohms
R6, R7, R10, R11, R38, R55—10,000 ohms
R12, R13—33.2 ohms
R14—162 ohms
R15, R16, R20, R21, R23, R29, R30, R31, R32, R45, R47,R49, R50, R52, R56— 1000 ohms
R17—402 ohms
R18, R43—10,000 ohms, trimmer potentiometer, PCB mount, top adjust Clarostat 408N103
R19, R22, R46, R48, R78—5110 ohms
R24—20,000 ohms
R25, R27—330 ohms, 3 watt, 10%
R33, R34—2000 ohms, 5 watts, 10%
R35—50 ohms
R36—1500 ohms, 2 watts, 10%
R37—5110 ohms, ½ watt, 10 %
R39, R40, R44, R51, R57—825,000 ohms
R41—46,400 ohms
R42—402 ohms
R53, R54—510 ohms, 1 watt, 10 %
R58, R59—15,000 ohms
R61, R62, R63, R64, R65, R66, R67, R68, R79, R80—200 ohms
R69, R71—1210 ohms
R70, R72—27,400 ohms
R79, R80—200 ohms (optional)

Capacitors

C1—10μF, polyester film
C2, C6—150 pF ceramic monolithic
C3, C4—100μF, 50 V, aluminum electrolytic
C5—0.1μF,50V, polyester film
C7,C20, C23, C24—82 pF ceramic monolithic
C8, C9—0.22μF, 50 volts polyester film
C10, C16, C17—10μF, 25 volts aluminum elecrtrolytic
C11—10μF, 35 volts aluminum electrolytic
C12, C14—0.1μF,100 volts polyester film
C13, C15—100μF 100 volts, aluminum electrolytic
C18—1500 pF ceramic monolithic
C19—1μF, 25 volts volts, aluminum electrolytic
C21, C22—0.01μF, 50 volts, polyester film

Semiconductors

D1, D2, D12, D13, D14—1N4002 sil-



icon diode

D3, D4— 1N4728A silicon diode, 3.3V

D5, D6, D10, D11, D15—1N4742A silicon diode;12 V

D7, D8—1N4744A, silicon diode, 15V

D9—1N4740A silicon diode, 10V

LED 1, LED 2, LED 3—light-emitting diode T-1-3/4, red or green

Q1, Q2, Q6, Q8, Q9, Q10, Q11, Q14—NPN transistor, Motorola MPSA06, or equiv.

Q3, Q4, Q5, Q7, Q12, Q13, Q15—PNP transistor Motorola MPSA56, or equiv.

Q16, Q17, Q18, Q19—P-channel, depletion mode MOSFET, International Rectifier IRFP9240 or equiv. (Q26 optional—see text)

Q20, Q21, Q22, Q23—N-channel, depletion-mode MOSFET, International Rectifier IRFP240 or equiv. (Q27 optional—see text)

Q24—N-channel MOSFET, depletion mode, International Rectifier IRF510 equiv.

Q25—VN0610LL N-channel MOSFET switch (TO-92) Motorola or equiv.

IC1, IC2—LM334Z constant-current source, National or equiv.

IC3—LM339AN quad comparator, National or equiv.

IC4—LF411CN JFET input op-amp Texas Instruments or equiv.

IC5, IC6—LF357N JFET input op-amp, National or equiv.

IC7—LM358 dual low power op-amp National or equiv.

IC8—LM317T medium-current, three terminal adjustable positive voltage regulator, Motorola or equiv.

IC9— LM337M medium current,3-terminal adjustable negative voltage regulator, Motorola or equiv.

Other components

F1, F2—fuse, 10 A

J1—jack, RCA-style

J2—jack, ¼ inch Rean No. 550-20301 or equiv.

RY1—relay, PCB, Potter & Brumfield T90N5D12-12 or equiv.

S1—switch, DPDT, E-Switch TA2EECAU or equiv.

TC1—thermostat, 80°, Airpax 67F080 or equiv.

Miscellaneous (amplifier board): amplifier circuit board, two heatsinks for TO-220 devices, five dual screw terminal blocks, OST, Inc. No. 16 and No. 18 insulated hookup wire, solder

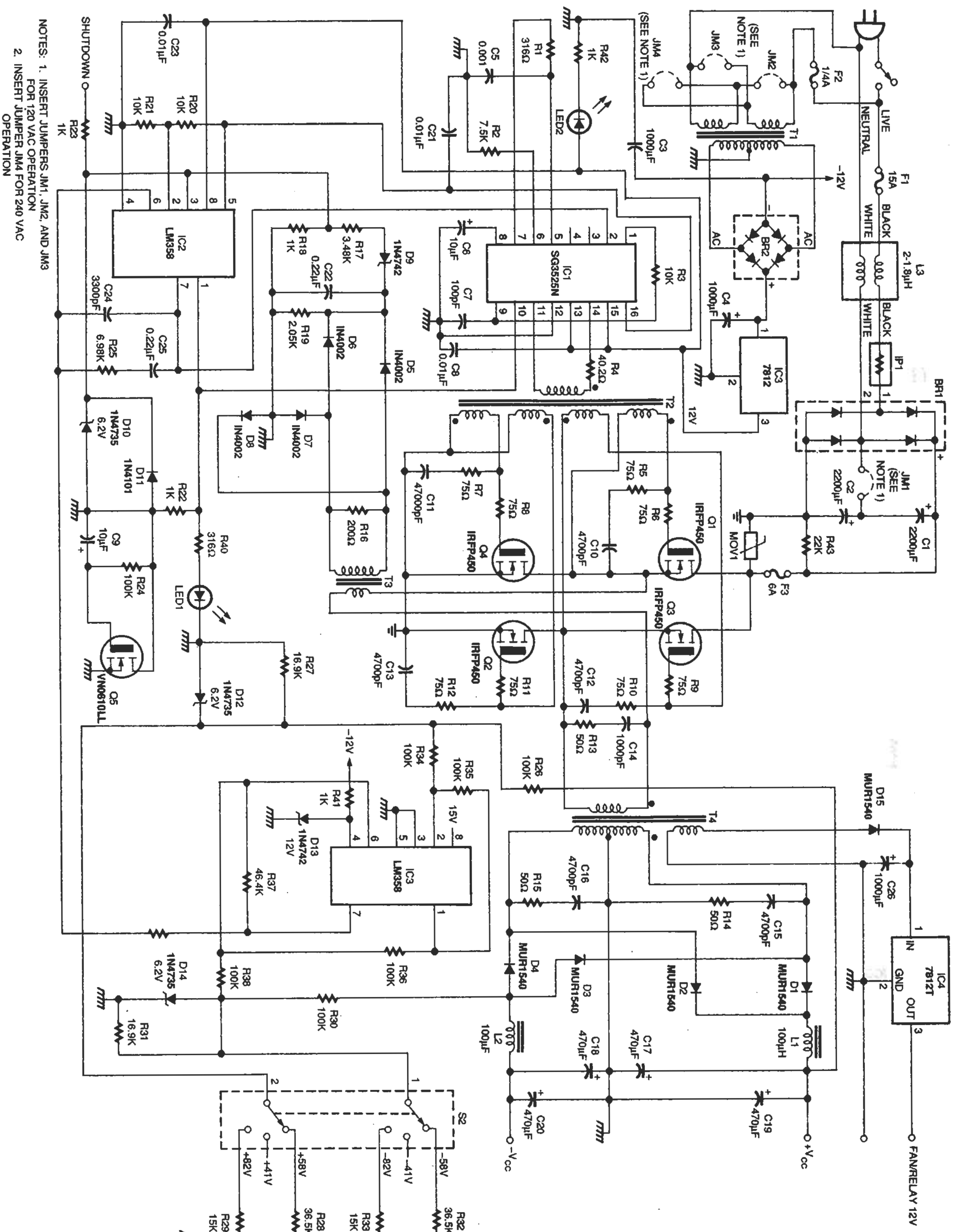


FIG. 3—SCHEMATIC FOR SWITCHING POWER SUPPLY. Circuit is a full bridge configuration that switches at 75 kHz based on four power MOSFETs.

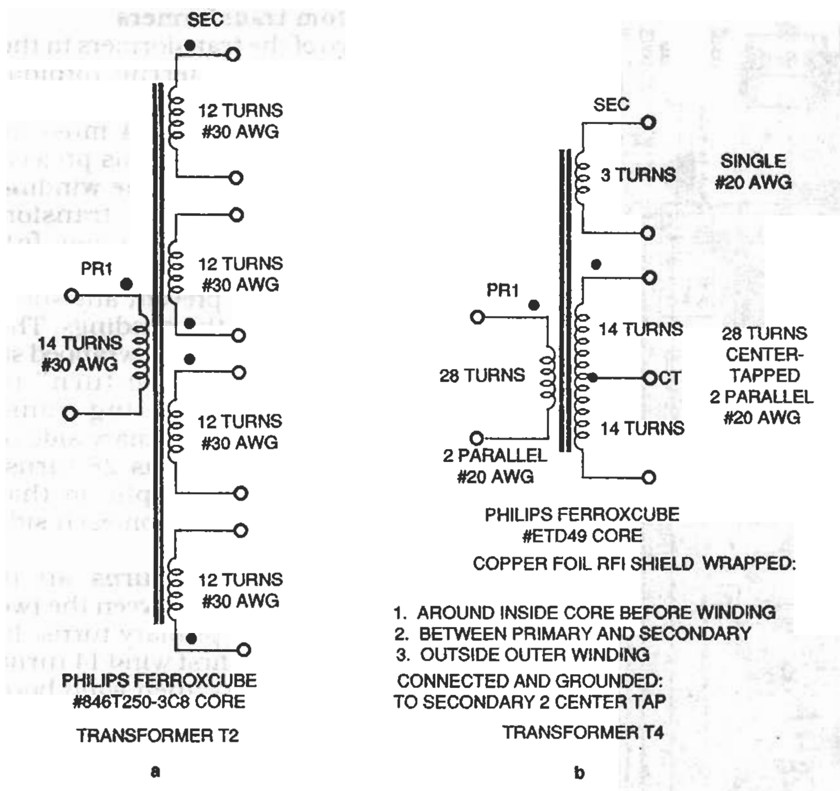


FIG. 4—TRANSFORMER WINDING INSTRUCTIONS for custom-made transformers T2 (a) and T4 (b).

tional amplifier that eliminates any DC at the output of the amplifier. This op-amp senses any DC at the output, and injects a compensating current through R38 into the feedback side of the input differential amplifier.

Next, transistors Q7 to Q9 detect amplifier clipping by sensing excessive internal drive signals that could occur when the feedback loop becomes nonlinear under overload conditions. Op-amp IC3, C19, and R57 capture any clipping that occurs and light LED1 for a minimum duration of 1 second.

Both sections of IC4(a and b) detect the presence of any DC offset at the output of the amplifier, and will de-energize relay RY1 to protect the speaker. TC1 is a thermal protector, which can also de-energize RY1 if the amplifier is overheating.

Voltage regulators IC8 and IC9 maintain the supply voltage for the input stages at ±30 volts. However, the output stage supply voltage can vary from ±41 volts to ±82 volts, as determined by the switching power supply setting. Diodes D11 and D12 regulate the ±15 volts for the operational amplifiers.

Switching power supply

Figure 3 is the schematic for the switching power supply. It is an off-line, full bridge circuit with both output current protection and shutdown capability and it offers three output voltage-setting options.

Line power input is filtered and rectified by inductor L3, full-wave bridge BR1, and capacitors C1 and C2. With jumper JM1 in place, bridge BR1 and C1 and C2 form a voltage doubler. MOSFETs Q1 to Q4 form a bridge with Q1 and Q2 and Q3 and Q4 conducting alternately in pairs. The bridge is driven by pulse transformer T2 from the SG3525N Silicon General monolithic pulse-width modulator/driver IC1. Transformer T4, the main power transformer, is driven by Q1 to Q4. Its output is rectified by fast-recovery rectifiers D1 to D4 and filtered by capacitors C17 to C20.

The positive output is divided by resistors R26 and R27. Resistor R27 is in parallel with either resistors R32 and R33, or no resistor. The feedback signal is fed to one section of the LM358 dual, low-power operational amplifier, IC3-a, acting as an inverting buffer amplifier. Its output is summed with a similar divider fed from the negative supply bus.

Operational amplifier IC3-b is an inverting summer whose gain of 0.42 is set by the ratio of the value of resistor R37 to that of R36. Zener diodes D12 and D14 ensure that neither power rail supplies more than approximately half of the 11.9 volt summed input necessary to generate the +5 volt sum output. The voltage at pin 7 of IC3-b is fed back to the pulse-width modulator comparator input pin 2 of IC1, where it is compared with the internal voltage reference applied to pin 1.

The feedback path includes a compensation network consisting of one section of an LM358 dual, low-power op-amp IC2-b, R25, C24, C25, and R39. Current in the bridge inverter is sensed by current transformer T3, whose output is rectified and filtered by silicon diodes D5 to D8 and capacitor C22. The transformer output is 2 volts for every ampere of current.

The result is compared with a fixed 2.5-volt reference by IC2-a, and if excessive current is detected, a shutdown signal is sent to pin 10 of IC1 and LED1 lights. The shutdown condition is latched through the diode D11 feedback path, until C26 charges. When C26 is charged, transistor Q5 resets the shutdown condition.

A small, low-voltage power supply consisting of transformer T1, full-wave bridge BR2 and monolithic regulator IC4 generates +15 volts to power the inverter's control circuits. Power for the 12-volt tubeaxial cooling fans is obtained from a separate winding on transformer T4 after being rectified by diode D15 and regulated by voltage regulator IC4.

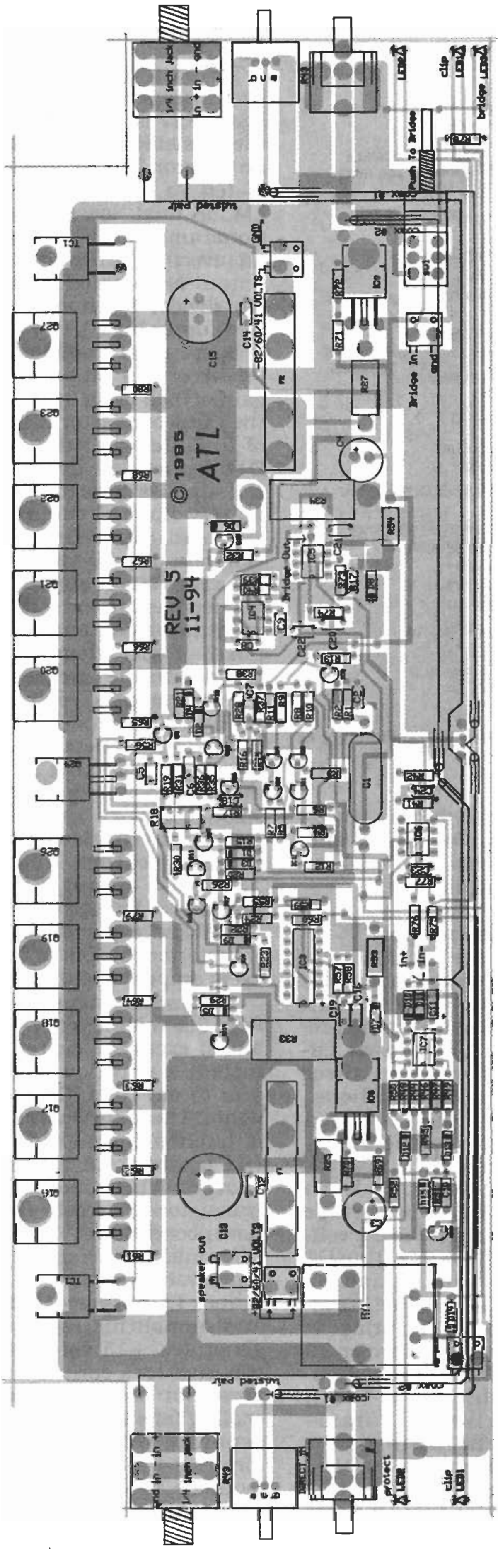


FIG. 5—AMPLIFIER PARTS PLACEMENT DIAGRAM, component side.

Custom transformers

Two of the transformers in the power supply, ferrite toroidal transformer T2 and ferrite E-core transformer T4 must be custom wound for this project. Refer to Fig. 4 for the winding details of these two transformers. Wind the copper foil shielding carefully on transformer T4 to prevent any short circuits with the windings. The copper foils must be wrapped so they remain "open-turn" to avoid short-circuiting transformer T4. The primary side of the transformer has 28 turns. These are to be split so that there are 14 turns on each side of the secondary.

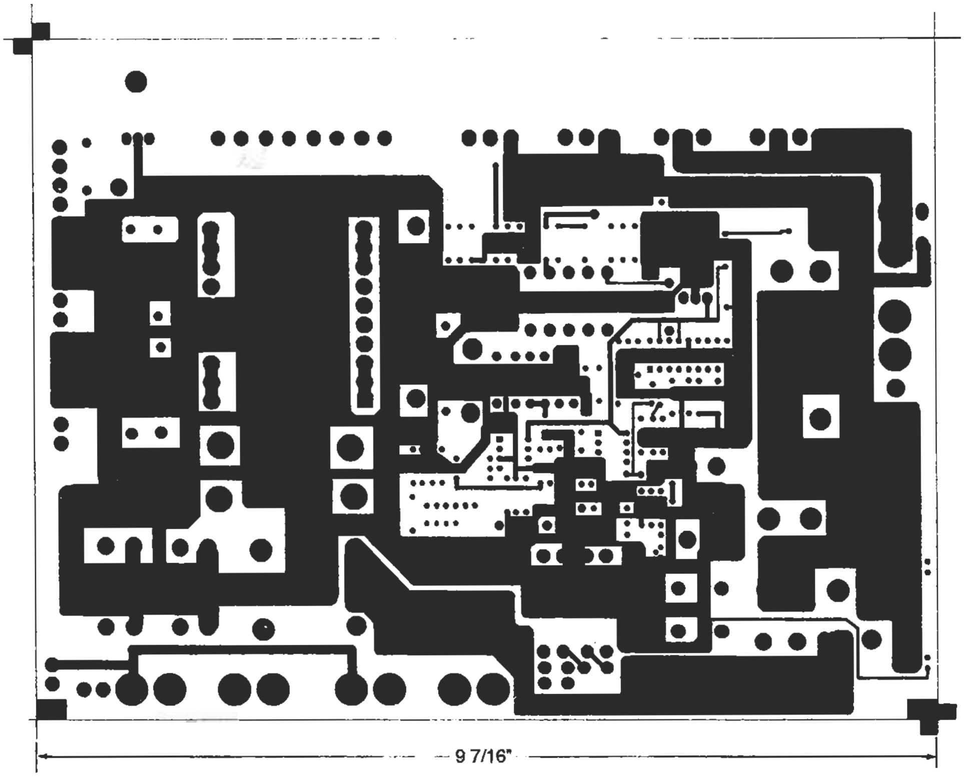
The secondary turns are to be sandwiched between the two halves of the primary turns. In other words, first wind 14 turns of the primary, then wind both

All resistors are ¼-watt, 1%, unless otherwise specified.

R1, R40—316 ohms
R2—7500 ohms
R3, R20, R21—10,000 ohms
R4—40.2 ohms
R5, R6, R7, R8, R9 R10, R11, R12—75 ohms
R13—50 ohms , 10 W
R14, R15—50 ohms, 5 W
R16—200 ohms, 0.5 W
R17—3480 ohms
R18, R22, R23, R42—1000 ohms
R19—2050 ohms
R24, R26, R30 R34, R35, R36, R38—100,000 ohms
R25—6980 ohms
R27, R31—16,900 ohms
R28, R32—36,500 ohms
R29, R33—15,000 ohms
R37—46,400 ohms
R39—4990 ohms
R41—1000 ohms, 0.5W
R43—22,000 ohms ,10 W

Capacitors

C1, C2—2200µF, aluminum electrolytic, 200 volts
C3—1000µF, 25 volts, electrolytic
C4—1000µF, 50 volts, electrolytic
C5—0.001µF, monolithic ceramic
C6—10µF, 25 volt, aluminum electrolytic
C7—100 pF, 50 volts ceramic
C8—0.01µF, polyester film
C9—10µF, 25 volts, aluminum electrolytic



POWER SUPPLY CIRCUIT BOARD PATTERN, component side

PARTS LIST—POWER SUPPLY

C10, C11, C12, C13,—4700pF, 50 volts, monolithic ceramic
C14—1000 pF, 500 volts,monolithic ceramic
C15, C16—4700pF, 500 volts
C17, C18, C19, C20—470µF, 100 volts, aluminum electrolytic
C21—0.01µF, 50 volts monolithic ceramic
C22, C25—0.22µF, 50 volts, monolithic ceramic
C23—0.01, 50 volts
C24—3300 pF . 50 volts, monolithic ceramic
C26—1000µF, 25 volts, aluminum electrolytic

Semiconductors

D1, D2, D3, D4, D15—MUR1540 Motorola
D5, D6, D7, D8, D11—1N4002
D9—Zener diode, 1N4742A,12 volt
D10, D12, D14—Zener diode, 1N4735A, 6.2 volt
MOV1—metal-oxide varistor Panasonic ERZ-V20D431 or equiv.
BR1—full-wave bridge rectifier, 600 volts, 6 amperes, General Instruments KBPC3506 or equiv.
BR2—full wave bridge rectifier, 200 volts, 6 amperes, General Instruments GBPC606CT or equiv.
LED1, LED2—light-emitting diode, T-1-3/4 package, one red, one green
Q1, Q2, Q3, Q4—N-channel MOSFET, depletion-mode International Rectifier IRFP450 or equiv.
Q5—N-channel MOSFET, depletion mode, TO-92, Motorola VN0610LLG or equiv.
IC1—SG3525N Pulse-width modulator, Silicon General or equiv.
IC2, IC3—LM358 dual low-power op-amp, National or equiv.
IC4, IC5—7812, 12-volt voltage regulator, Motorola or equiv.

Magnetics

L1, L2—coil 100µH, Pulse Engineering PE-92112 or equiv.
L3—dual coil, 1.8µH Pulse Engineering PE-96188 or equiv.
T1—low-voltage transformer, Microtran MT3137 or equiv.
T2—drive transformer, custom wound (see text)
T3—current transformer, Coilcraft D1871 or equiv.
T4—power transformer, custom wound (see text)

Other components

F1—fuse, 15 ampere, 250 volt, 3AG style
F2—fuse, ¼, 250 volt, 3AG style
F3—fuse, 6 ampere, 250 volt, 3AG style
S2—switch , DPDT PCboard, C&K 7201P3YZQE
IP1—inrush protector, Keystone KC001L-ND or equiv.

Miscellaneous (power supply): circuit board, 10 terminal blocks OST, Inc., No. 16 AWG insulated hookup wire, solder, 2 fuse clips.

Note: The following parts are available from A and T Labs, Box 4884, Wheaton , IL 60189

- **Amplifier printed circuit board for one channel, double-sided, plated-through holes, silk screened, solder masked (two required) (K6PCB1)—$39.00**
- **Switching power supply board,double-sided, plated-through holes, silk screened, solder masked (one required) (K6PCB2)—$42.00**
- **Switching power supply power transformer (K6T4)—$52.00**
- **Switching power supply driver transformer (K6T2)—$15.00**
- **Power supply inductors L1, L2 and L3 (K6L)—$32.00**
- **Heatsink set for convection-cooled case (K6HS1)—$110.00**
- **Heatsink set for forced-air cooled case (K6HS2)—$110.00**
- **Set of 8 matched MOSFETs for 1 amplifier channel (K6Q)—$90.00**

Add 5% U.S. or 12% Canada for shipping and handling.

Checks, money order, and VISA or Mastercard credit cards accepted.Illinois residents please add 6.75% local sales tax.

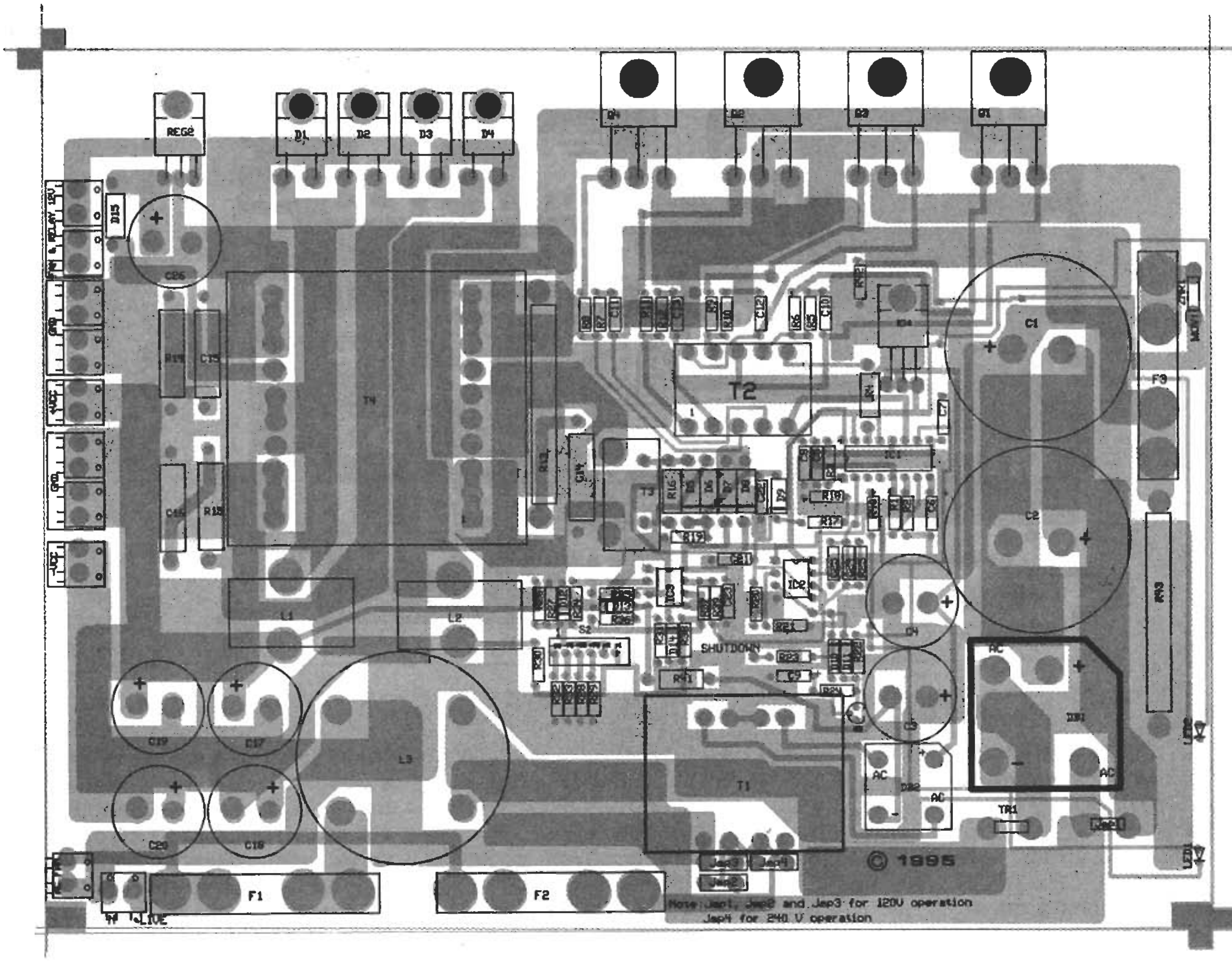
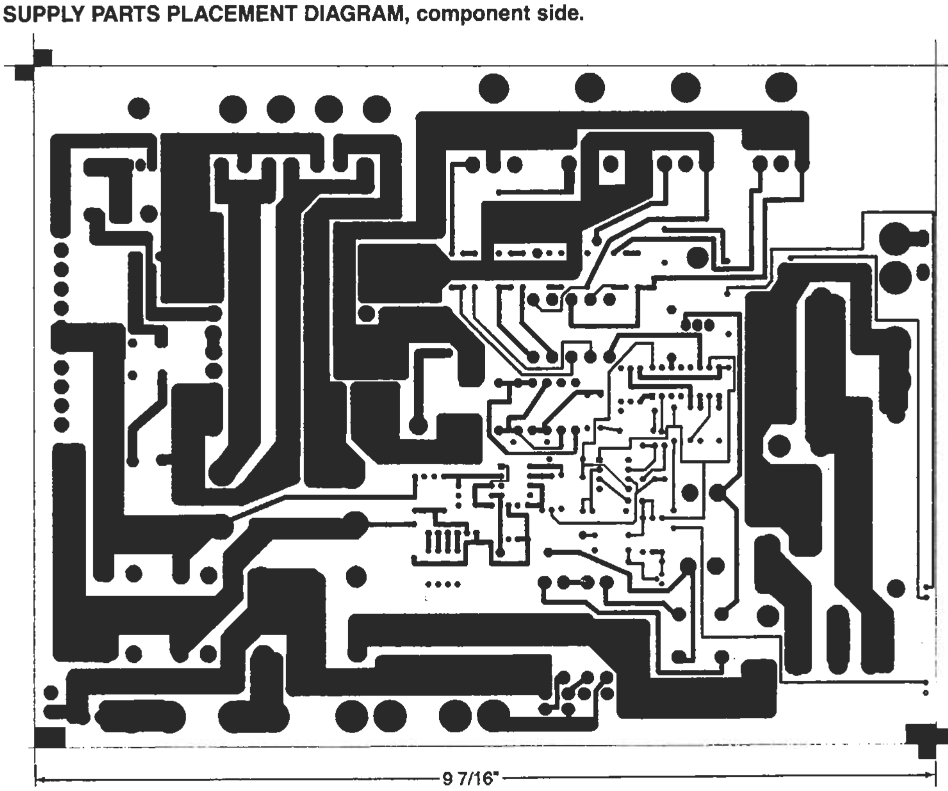


FIG. 6—POWER SUPPLY PARTS PLACEMENT DIAGRAM, component side.



POWER SUPPLY CIRCUIT BOARD PATTERN, wiring side

secondaries. After that, continue to wind the remaining 14 turns of the primary.

Be sure to apply a small amount of epoxy or silicone adhesive in a thin layer to bond the two halves of the ferrite core to each other. They must be bonded together to prevent the ferrite "E" core from producing an audible hum. Connect the three separate foil shields and ground them to the center tap of the secondary of transformer T4.

Building the amplifier boards

As stated earlier, both amplifier channels for this stereo amplifier are identical. Circuit boards are recommended for constructing to eliminate the tedious work of point-to-point wiring and for more reliable operation. Several features, such as bridging capability, are optional. The components related to these options will be identified in the description of the construction procedures.

The procedure that follows assumes that circuit boards are either purchased from the source given in the Parts List or the builder has either made them or obtained them from another source.

Begin amplifier board assembly by inserting and soldering all resistors, capacitors, and diodes in their specified locations, as shown on the parts placement diagram, Fig. 5. Verify the values of all components before inserting them, and be sure to identify the polarities of all diodes and electrolytic capacitors.

Next, insert and solder all small-signal transistors and ICs. Adjust trimmer potentiometer R18 to its approximate middle position. Note that transistor Q24 must be mounted later to the aluminum heatsink adapter. Install it at this time so that the transistor will be positioned at the correct distance above the board so that it can later be fastened to the angle stock with a screw and nut . A mica insulator and silicone grease will be between the MOSFET's tab and the aluminum surface.

Install the RCA input jack J1 and the level-set trimmer potentiometer R43 at the appropriate end of each channel circuit board. The clipping and protection indicating LEDs are mounted on the opposite ends of the board. If you plan to install bridging, include the bridging circuit on one of the channel boards, and switch S1 and LED 3 on the other.

For differential input capability, include the ¼-inch jacks on the appropriate ends of the boards, as well as the twisted wire pair from the jack to the center of the board. If you do not plan to install differential input, omit the length of coaxial cable No. 2, the LM357 IC6, and the components associated with it. As the last step, install the length of coaxial cable No. 1 and the relay RY1. Do not install the output transistors Q16 to Q19 and Q20 to Q23 until after preliminary testing is completed. (This will be covered in part 2 of this article.)

Power supply board

Refer to the power supply parts placement diagram Fig. 6 and follow the general procedure previously given for building the two amplifier channel circuit boards. Insert and soldering resistors, capacitors, and diodes first, carefully checking values and orientations. Install the small-signal transistors and integrated circuits next, followed by the transformers, the switch S1 and the fuse holders.

Bend the leads of the power transistors Q1 to Q4 and rectifiers D1 to D5 at right angles so the tabs are parallel with the circuit board but projecting outboard with a gap that will permit them to be fastened to the aluminum angle heatsink adapter. Solder them in position so that they can be aligned with the heatsink channels.

The second part of this article will cover: the selection of appropriate cases to house the configuration of your choice; the installation of the boards to the aluminum heatsink adapters; and the wiring to off-board, panel-mounted components. Ω