HIGH-POWER HI-FI AUDIO AMPLIFIER

This powerful stereo amplifier offers outstanding performance.

REINHARD METZ AND MYZIL BOYCE

THIS IS THE SECOND PART OF THE article on the construction of a high-performance, lightweight, stereo amplifier for the demanding audiophile that can be built for less than $500 in parts. It outperforms factory-built units costing up to ten times that amount and is comparable to top-of-the-line commercial products. It can be packaged for home installation or as a more rugged portable version for sound reinforcement in halls and theaters.

The first part of this article published last month covered the building of two amplifier channel circuit boards and one switching power supply board that include most of the circuitry for this amplifier. It also explained the winding of two custom transformers.

This second and final part covers the construction or purchase of a suitable metal case as determined by the reader's packaging preference—home or portable stereo amplifier. It also covers the mounting and wiring of all off-board components, the matching of output MOSFETs, and the test procedures that apply to both versions.

Case options and packaging

There are two options for packaging this amplifier: The version for home use will be enclosed in a case that is cooled by convection, conduction and radiation. However, the portable version will be enclosed in a case cooled by two muffin-type DC fans. The dimensions of the two cases differ as does the placement of the three circuit boards within them.

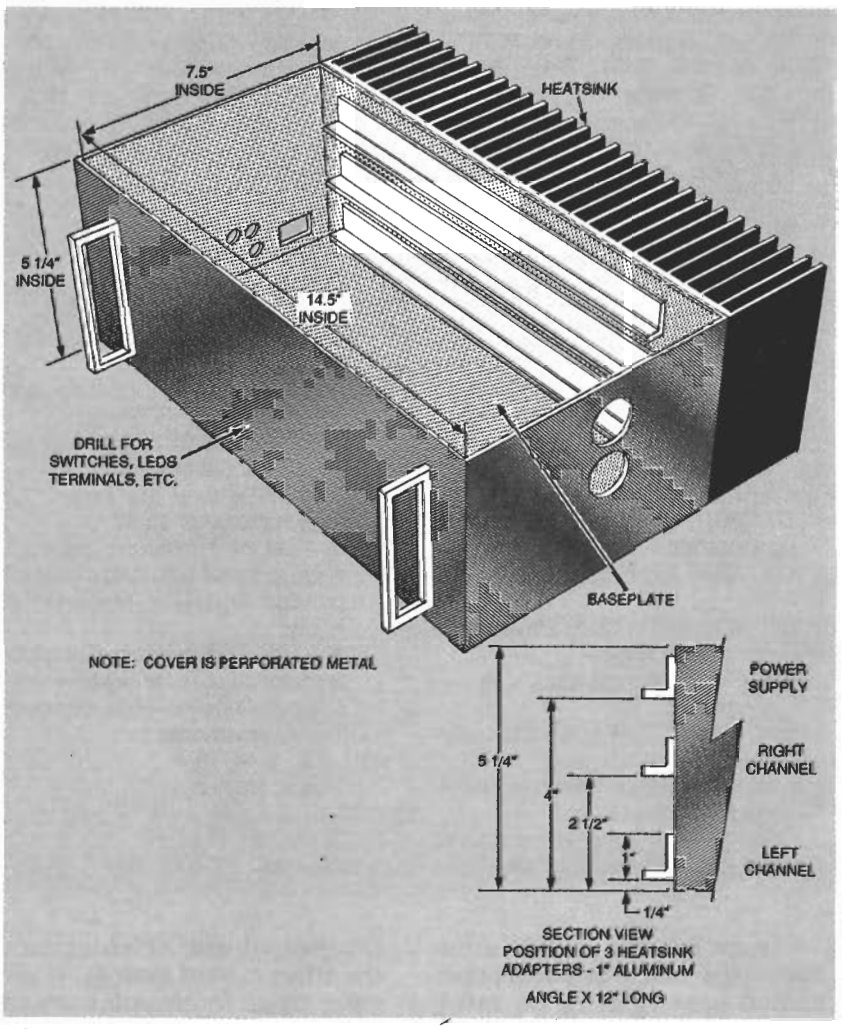

FIG. 7—INSIDE CASE DIMENSIONS FOR THE HOME AMPLIFIER. These minimum inside dimensions are given for a case to be made by you or purchased. The locations for mounting the three aluminum heatsink adapters are also given.

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 silicon 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

Miscellaneous (packaging) case with perforated metal cover (selection optional); heatsinks (for the convection-cooled version—one aluminum-finned 14×3×¼-inches, EG&G Wakefield No. 510 (for fan-cooled version, two finned aluminum finned 12×3×3¼-inches, EG&G Wakefield 510 (cut in half lengthwise); three 1×1×12-inch aluminum angle sections; power cable, two tubeaxial muffin-type DC fans, 3.5-inch diameter (60 to 80 CFM),(Optional); 120 VAC, 3-pin power jack; power switch, 20 ampere, panel mount, No.18 AWG insulated hookup wire, flat ribbon cable, No. 28 AWG; mica thermal-conducting washers; assorted nuts, bolts, lockwashers; silicon grease, mica thermal-conducting insulators for TO-220 cases, solder.

Note: The following options for 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 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.

Figure 7 is the outline drawing of the home or convection-cooled case, giving its minimum inside dimensions, and Fig. 8 is the assembly drawing of this version showing the arrangement and orientation of the three circuit boards. It provides basic information on the mechanical work required to mount the circuit boards, panel-mounted power switch, socket, LEDs, jacks and other components.

Figure 9 is an outline drawing similar to Fig. 7 for the forced-air cooled, portable case giving

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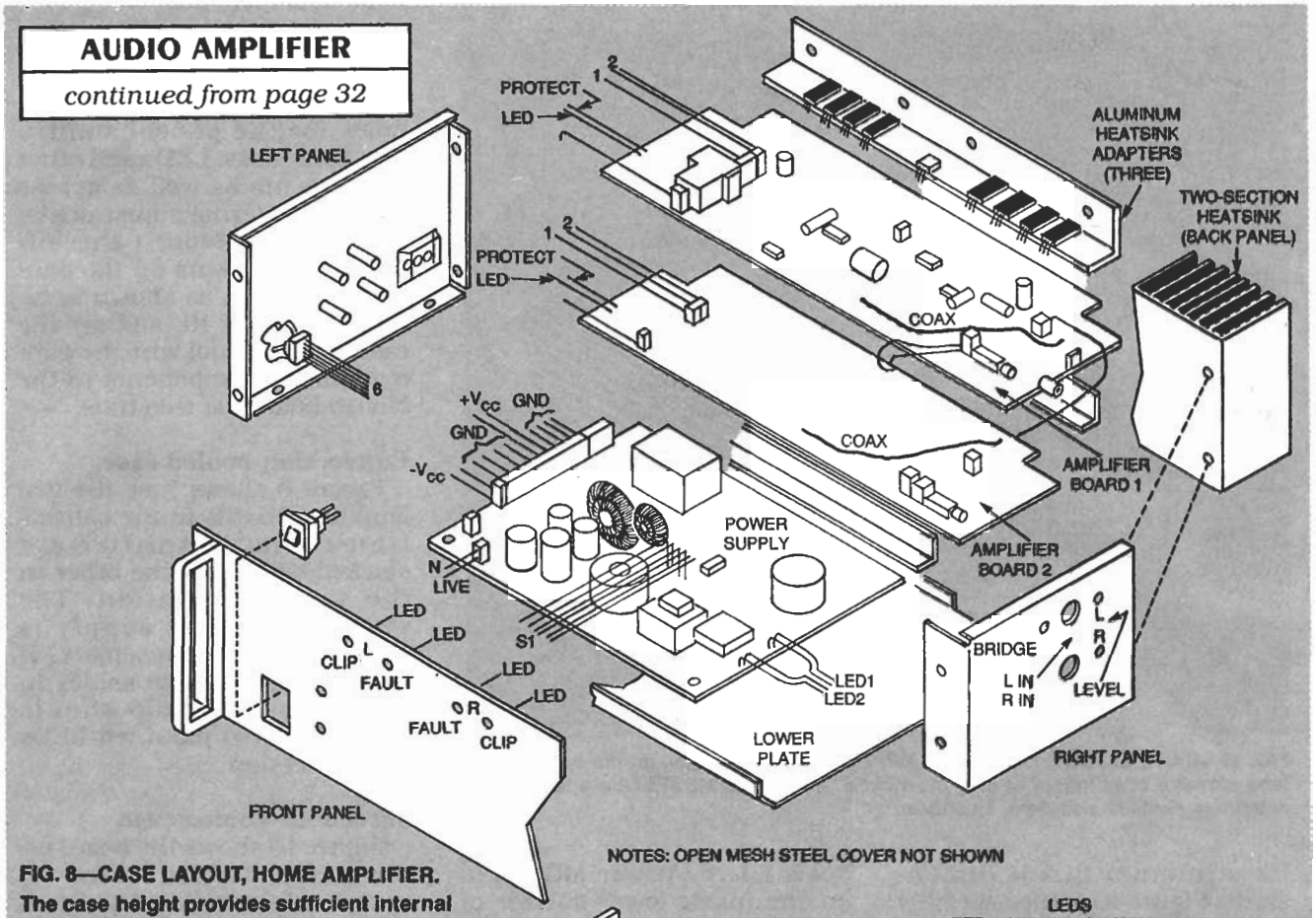

FIG. 8—CASE LAYOUT, HOME AMPLIFIER.
The case height provides sufficient internal space for natural thermal convection, conduction and radiation. The output MOSFETs are fastened to the aluminum heatsink adapters, as shown.

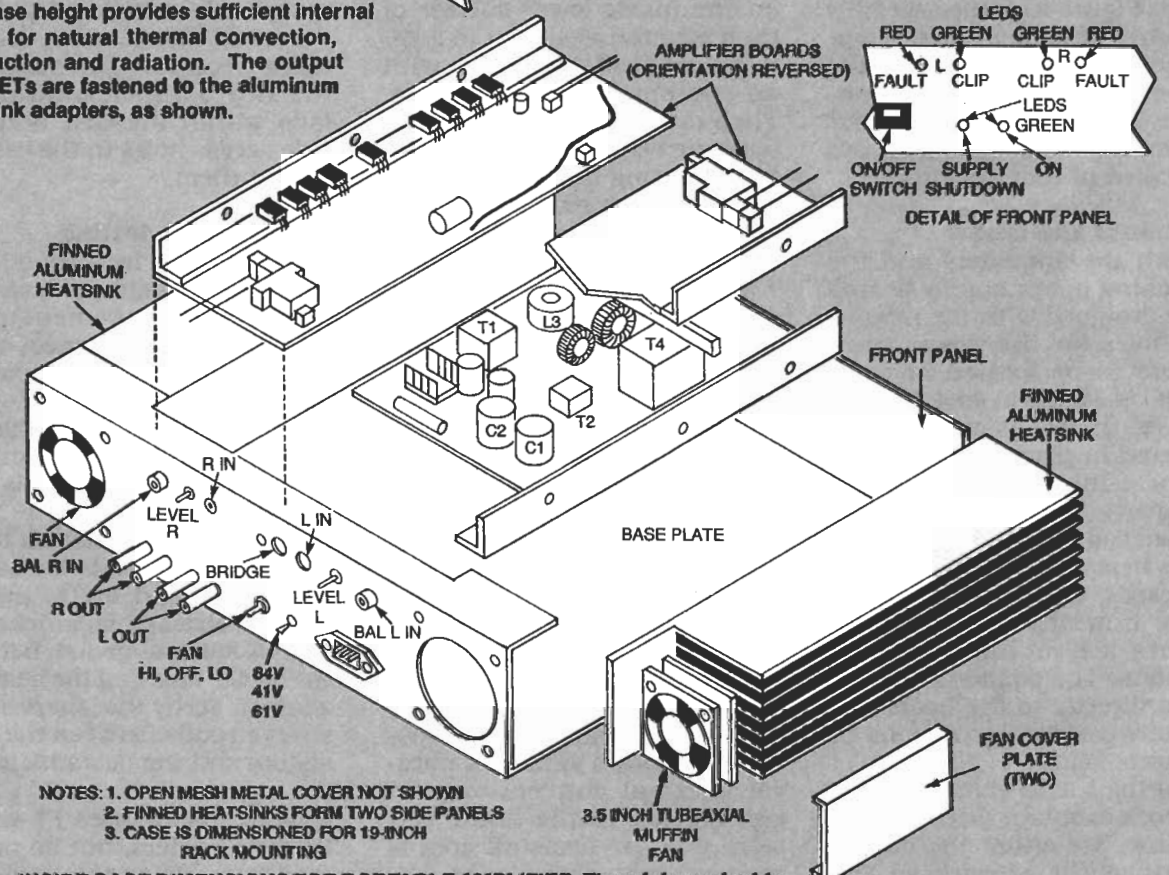

FIG. 9—INSIDE CASE DIMENSIONS FOR PORTABLE AMPLIFIER. The minimum inside dimensions are given for a case to be made by you or purchased. The locations for mounting the three heatsink adapters in this case are also given.

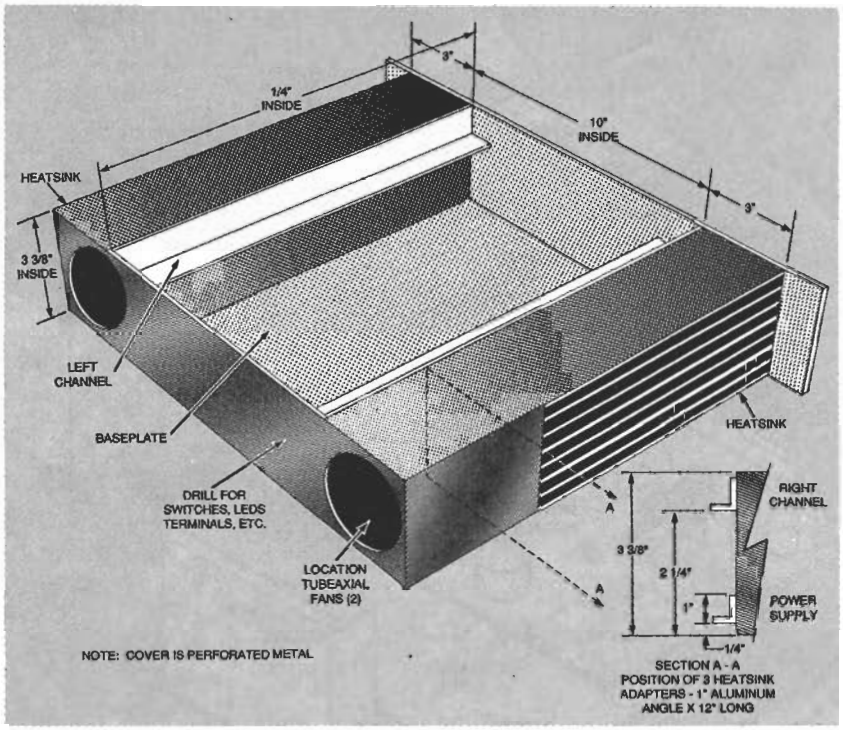

FIG. 10—CASE LAYOUT, PORTABLE AMPLIFIER. Two 3½-inch, muffin-type cooling fans permit a case height of only 3½-inches. The output MOSFETs are fastened to aluminum heatsink adapters, as shown.

its minimum inside dimensions. Figure 10 is the assembly drawing of this version, comparable to Fig. 8, presenting the same kinds of information. Note that the locations for mounting the cooling fans are indicated in that drawing.

Heatsinks and fans

Both the amplifiers and the switching power supply boards were designed with the mounting holes for the power transistors to be located at their edges. As stated in part 1 of this article, the transistors, when soldered in place, are bolted to the heatsink adapters.

Figures 7 and 9 show the mounting locations for the three heatsink adapters within the cases, and Figs. 8 and 10 show how the output transistors are mounted on the adapters. The adapters are fastened directly to the heatsinks in both packaging versions of the amplifier.

Cut the 1-inch aluminum angle stock to obtain three 12-inch lengths. Use either the circuit boards or the artwork for the circuit boards as drilling templates to locate the mounting holes for the power MOSFETs on the inside lower surface of each adapter, as shown in Figs. 8 and 10. Drill those holes with an appropriate sized drill bit. Then drill the four holes in the opposite surfaces of the angles for mounting them to the heatsink or heatsinks, depending on the case selected. Carefully deburr all holes.

If you do not have access to the facilities or equipment necessary to build the metal case of your choice, a standard 19-inch rack-mount case can be purchased and modified. It might be necessary to do some mechanical design work to adapt the circuit boards to the purchased case.

The inside dimensions of the case can be larger than the minimum values shown in Figs. 8 and 10, but it is not recommended that they be smaller because of possible mechanical interference and thermal problems. To obtain sufficient natural thermal convection and conduction in the home version, a larger heatsink area is required than that for the fan-cooled portable version, and the overall case height is higher.

After building or purchasing the metal case for the version you intend to build, drill the holes for the panel-mounted switches, jacks, LEDs and other components as well as access holes for external adjustments, as required. Mount the off-board components on the panels of the case, as shown in either Figs. 8 or 10, and set the case aside. Do not wire the panel mounted components to the circuit boards at this time.

Convection-cooled case

Figure 8 shows how the two amplifier boards in the convection-cooled amplifier are stacked one above the other in the same orientation. The switching power supply is mounted on the baseplate. It will be necessary to solder in point-to-point hookup wires to light the-panel mounted LEDs in this version.

Forced-air-cooled case

Figure 10 shows the board arrangement for the forced-air cooled version of the amplifier. If you build this version, drill the holes necessary for mounting the two 3.5-inch muffin-type fans within the case and provide access holes in the case for wiring them.

Power supply testing

Examine the completed power supply circuit board for the correct placement of all components, the correct orientation of all polarized components, and the absence of any inadvertent solder bridges or cold solder joints. Make any corrections necessary at this time before proceeding.

Fasten the transistors to the aluminum heatsink adapter with nuts and bolts, placing mica electrical insulators and a film of silicone grease between the device tabs and the heatsink adapter. Verify that there are no short circuits between the transistors and the heatsink adapter.

Next, install fuses F1 and F2 in their holders, but do not install fuse F3 at this time. Be sure that jumper J1 is installed for 120-volt AC-line operation.

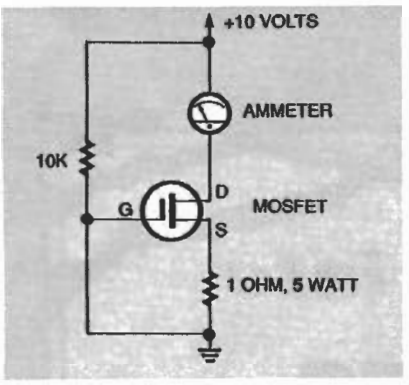

FIG. 11—MOSFET MATCHING CIRCUIT. After the 10-kilohm potentiometer is set to 0.5 to 1.0 amperes, the MOSFETs are measured for gate voltage or drain current so they are matched within 10% of their measured values.

Apply the AC input power by turning on the switch. *Caution*: Exercise extreme caution while handling the power supply board or any components on the board when making electrical measurements. The input circuitry of the power supply is connected directly to the power line, so contact will expose you to life-threatening electrical shock.

With a voltmeter, measure at the input to fuse F3 with respect to the ground side of capacitor C2, and verify that +320 volts is present. Also, measure the output of voltage regulator IC3 with respect to the board's ground, and verify that +15 volts is present. Double check to verify that transformer T2 is oriented as shown on Fig. 3. Turn off the input power and install fuse F3.

Install one 5-kilohm, 10-watt resistor per bus to provide a light load for the switching power supply. Set switch S2 to the 41-volt position, and apply AC line power. Verify that ± 41 volts is present at the power supply output. Switch S2 to ±58 volts and ± 82 volts, and verify that each of those voltage appears at their output terminals. Temporarily connect the shutdown input pin to +15 volts, and verify that the output is turned off.

Amplifier testing

The amplifier test procedure calls for each amplifier board to be tested first before the output transistors are installed. Begin the test procedure by verifying that all of the components have been correctly installed in their specified locations and that all polarized components have been oriented correctly. Then carefully examine all solder joints to verify that there are no inadvertent solder bridges or cold solder joints that will later cause problems. Make any corrections necessary at this time before proceeding.

Exercise patience and inspect all of your work carefully at this time. This attention to detail early on in the game will avoid the destruction of expensive components and save you disappointment with your project and perhaps hours of troubleshooting later.

Install ½-ampere amplifier fuses F1 and F2. Temporarily connect the power supply to an amplifier board and verify that the polarities are correct. For these tests you might want to use the current limiting capabilities of the power supply for extra protection. This can be done by placing a jumper on the power supply board between the junction of R17 and R18 and the junction of D5 and D9.

Apply power to the circuit and measure the ±15-volt supplies on the board and the ±30 volts at the input stages. Do all probing carefully, because if the probe slips, you could cause a destructive short circuit between two pins.

Carefully measure the voltages across diodes D7 and D8. The voltage values should be between 3 and 5 volts. Adjust trimmer potentiometer R18 until the voltages are each less than or equal to 3.5 volts. If you have a signal generator and an oscilloscope available, perform an additional valuable test by applying a small-signal voltage of 5 to 10 millivolts at a frequency of 1 kHz at the input and check for drive signals at the emitters of transistors Q14 and Q15.

Because the amplifier is open-loop at this time, the drive signals can easily be overloaded. The drive signal should appear as a train of squarewaves with an amplitude of about 12 volts peak-to-peak, as limited by diodes D7 and D8.

If all the tests have been passed satisfactorily, it is time to mount the matched output MOSFETs Q16 to Q23. Matched MOSFETs can be obtained from the source given in the Parts List, or you can match them by first building the simple matching circuit shown in Fig. 11. After the 10-kilohm potentiometer is set to 0.5 to 1.0 amperes, measure the MOSFETs for gate voltage or drain current. They must be matched within 10% of their measured values.

Install the matched MOSFETs on the aluminum heatsink adapters as shown in either Fig. 8 or Fig. 10 with nuts, lockwashers, and screws, after first placing mica thermal conducting washers and a film of silicone grease between the transistor tabs and the heatsink adapter. With an ohmmeter, measure the resistance to verify that there are no short circuits between the power transistors and the adapter.

For the home convection-cooled configuration or operations limited to 8-ohms, four output transistors per bus should be sufficient. However, if you plan to operate the amplifier in a bridging mode, or at high power with low impedance loads, include the additional MOSFETs Q26 and Q27 as well as resistors R79 and R80 in each channel.

Install a 1-ampere fuse in the F1 holder, and position a milliammeter across the terminals of the holder for fuse F2. Apply 120-volt line power at the holder terminals for fuse F2. Adjust trimmer potentiometer R18 for an "idle" current of about 200 milliamperes.

Remove the milliammeter, and install 1-ampere fuse F2. Verify that the output is within a few millivolts of ground. Apply an input signal at a low level, and verify that an amplified output appears.

If the amplifier responds as expected, replace fuses F1 and F2 with 8 ampere fuses, and repeat the tests on the second

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channel. If you elect to include thermal protection, mount the thermal cutouts on the heatsink adapters now.

Final assembly

After all three circuit boards have been tested, install them already attached to their aluminum heatsink adapters in the case.

Connect the power supply and perform all point-to-point wiring for the LEDs and power output connections to their related board terminals.

Connect input power to the power supply, and connect the amplifier inputs to the jacks. Connect the amplifier protection leads to the power supply shutdown input. Carefully recheck all of your workmanship for errors and if none are found, perform the final test procedure.

Operating instructions

These special operating instruction are limited to the proper use of the switching power supply voltage select switch S2. In general, the available lower voltages have two purposes: (1) To limit the power available to sensitive loads, and (2) for driving speakers with low impedance values that might otherwise be damaged.

Some listeners prefer to limit the available power to about 100 watts into an 8-ohm load. To operate under those conditions, select the 58-volt setting. If you have speakers with impedances of 1 to 4 ohms, the power dissipation in the amplifier can be limited by setting the voltage to 41 volts.

With either alternative, the current-detection circuitry in the power supply will protect the amplifier sections whether the output is 58 or 41 volts. A momentary shutdown will occur, and a LED indicator will light if an overload condition occurs. The power supply will reset itself when the overload is removed. Ω