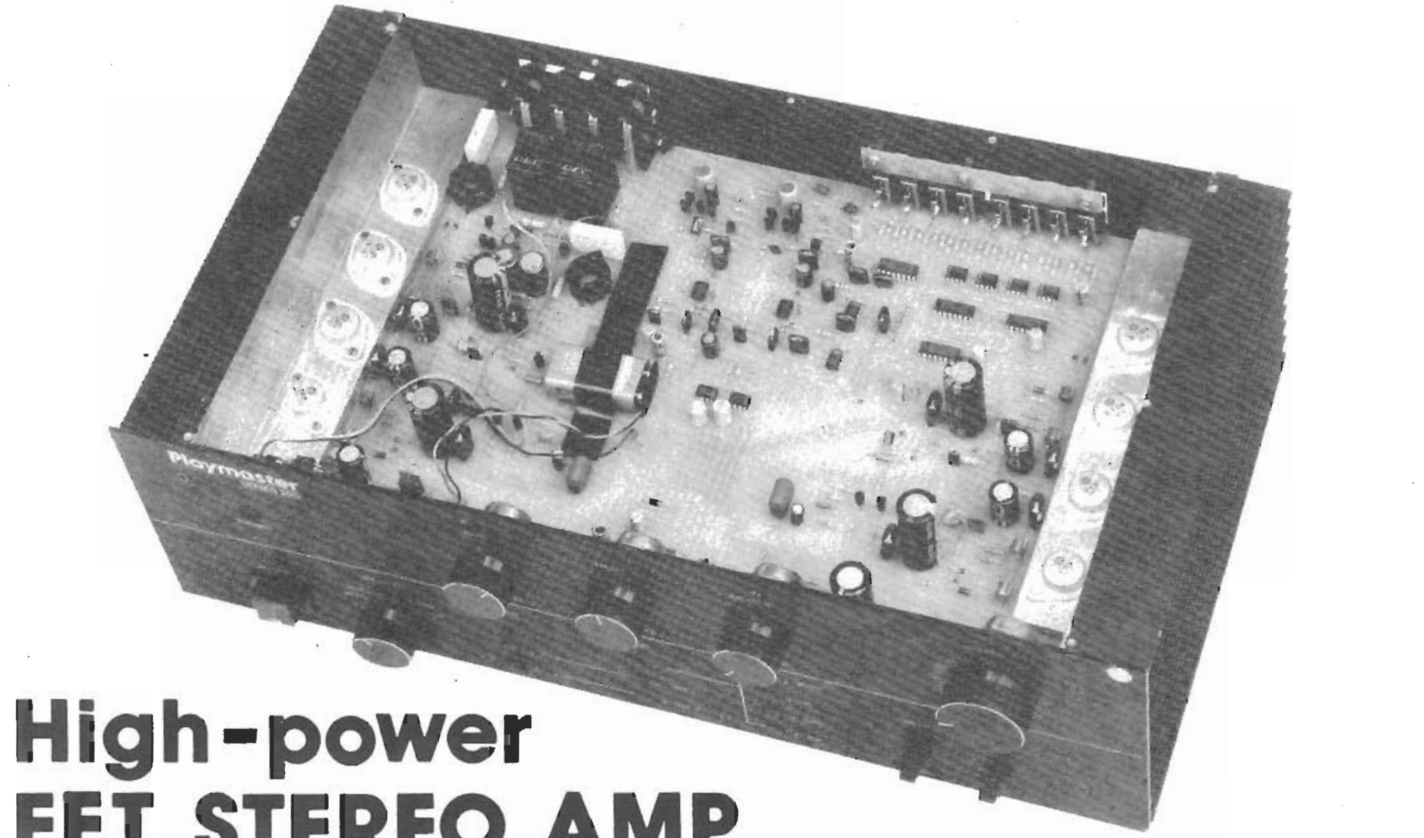


High-power FET STEREO AMP

Our amp's high-power output, low distortion, and easy construction make it a must for audiophiles who demand the very best!

LEO SIMPSON AND JOHN CLARKE*

IF YOU'VE BEEN WAITING FOR AN EXCUSE to junk your prehistoric stereo amplifier, your wait is over. Here's an amplifier that provides a conservatively-rated 95 watts (rms) per channel at eight ohms, with distortion that is less than 0.02%. Our amplifier can be built in a few evenings for under $300, and it will provide you with years of listening enjoyment as well as the satisfaction of knowing that the very latest in audio technology is providing that enjoyment.

The amplifier has all the latest convenience features, such as dual-recorder tape dubbing, speaker switching, muting, and a battery backup so that the amplifier will "remember" its configuration and return to that configuration the next time it is powered up.

The amplifier has four inputs: PHONO, CD, TUNER, and AUXILLIARY. The latter could be connected to a stereo TV tuner, a high-fidelity VCR, or another source. We also provide switching to monitor any one of the main inputs, or one of the two tape inputs. In addition, switching and the appropriate signal routing are provided so that you can dub from either tape recorder to the other. The amp also has provisions for connecting two pairs of loudspeakers; either, neither, or both pairs may be used at any time. In addition, a headphone jack is provided that is always "hot."

The amplifier is rather large. Overall it measures about 19 × 11.5 × 6 (inches). The size of the heatsinks determines the height and depth; those specially-tooled aluminium extrusions are necessary to cope with the large amount of heat dissipated when the amplifier is working near maximum output. Normally the heatsinks are just warm to the touch. The 19-inch width was chosen so that the amplifier could be rack-mounted, if the builder so desired.

Design philosophy

The amplifier represents the latest in a series of amplifiers that have been developed over the last ten years. We took the best features of the previous designs and combined them with the latest technical advancements to produce a truly superior amplifier. For the description that follows, see the block diagram of the amplifier that appears in Fig. 1. After discussing the overall operation of the circuit, we'll discuss each subsection in detail.

One paramount design goal was to eliminate the great amount of tedious hand-wiring of switches, controls, and jacks normally required by a project like this. We wanted to use a one-piece molded assembly for the input jacks so that it could be soldered to the PC board as a unit. That eliminates the need for shielded cabling, but creates a more severe problem: How could we provide appropriate switching for source selection, tape monitoring and dubbing from deck to deck?

We considered a mechanical switching solution, but there didn't seem to be any practical way of integrating mechanical switches neatly. So we considered using CMOS analog switches, since they are cheap and readily available in various configurations. However, analog switches are not without problems of their own. In an improper design, they can generate

*Adapted from material published by *Electronics Australia*

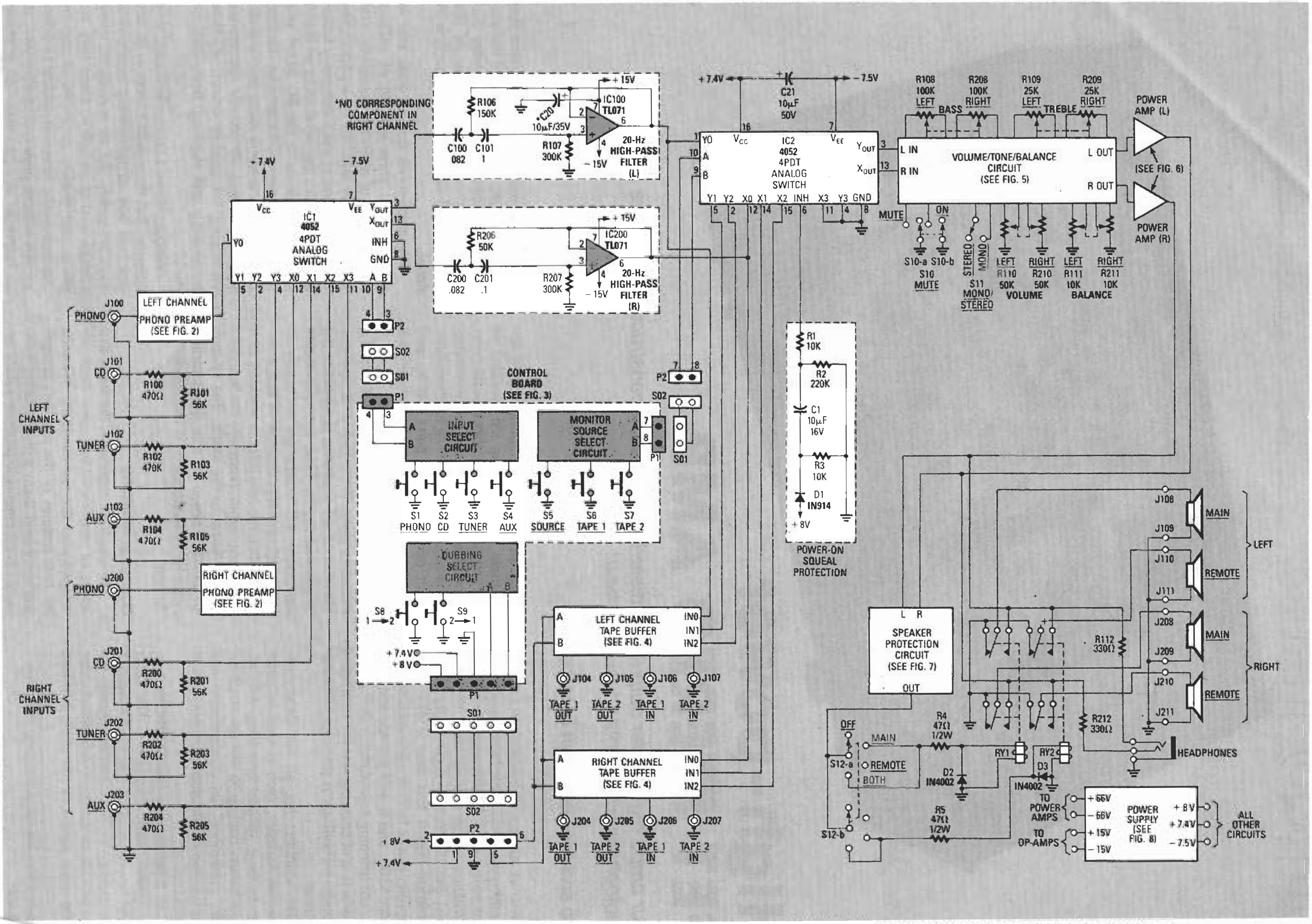


FIG. 1—OUR AMPLIFIER IS COMPOSED OF SEVERAL SUBSECTIONS, and the interconnections between them is shown here. The details of each subsection are shown in separate schematics.

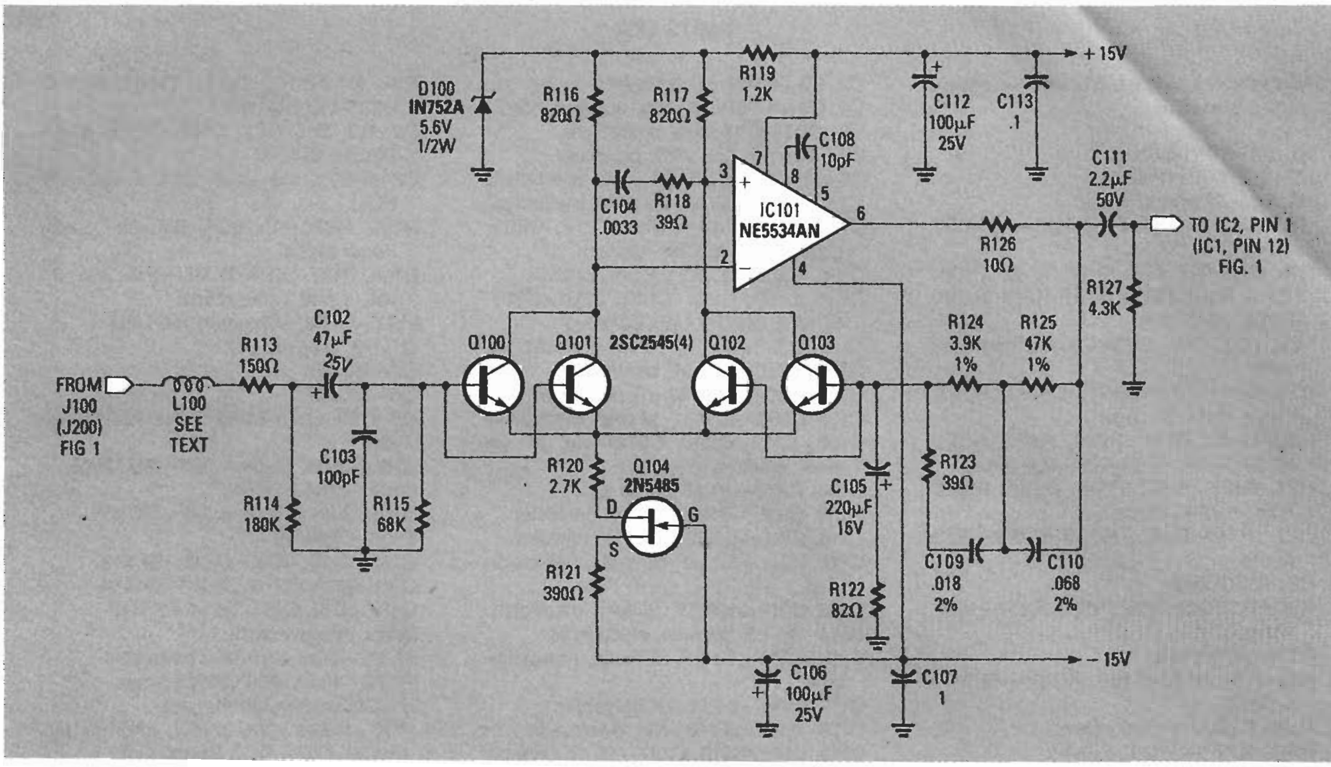


FIG. 2—THE RIAA PHONO PREAMPLIFIER is composed of a bipolar differential amplifier and an op-amp. The transistors are special low-noise types.

distortion. In addition, some sort of memory system would be required so that the amplifier's configuration would be "remembered" when the amplifier was turned off.

We overcame the distortion problem by buffering the outputs of the switches with low-noise FET-input op-amps (TL071's). Since distortion is caused by the non-linear resistance of the CMOS gate, it follows that, if the current through the gate were minimized, distortion would likewise be minimized. We achieve minimum distortion by buffering the output of each CMOS gate with a high-input-impedance, unity-gain op-amp. Buffering requires a few extra op-amps and discrete components, but we believe that the results more than justify the expense.

As for the memory problem, we could have built in some RAM (*R*andom *A*ccess *M*emory) and perhaps a microprocessor to control it, as some commercial Japanese designers have done, but that seemed like overkill. Instead, we chose to implement our memory with several CMOS gates and flipflops, which are powered by a pair of Ni-Cd cells when the amplifier is off. The flip-flops, switches, and indicator lights mount on a separate PC board, the control board.

Several other analog switches are mounted on the main PC board. For example, IC1 is the electronic equivalent of a 4PDT mechanical switch; it performs the input-source selection. Depending on the state of its A and B inputs, one pair of signals presented to the X and Y inputs is passed through to the appropriate outputs. For example, with both A and B low, the left- and right-channel outputs from the phono preamplifiers would appear at the YOUT and XOUT terminals, respectively.

Whichever signals are chosen, they pass through the 20-Hz high-pass (rumble) filters composed of IC100, IC200, and the associated discrete components. Those filters provide a 12-dB/octave rolloff below the corner frequency. (Due to filtering networks in the phono preamplifier, phonograph signals are rolled off a total of 18-dB/octave.) The op-amp rumble filters also provide high-impedance buffering that reduces loading on the analog switches. That loading could cause distortion.

By the way, for the sake of clarity, all left-channel components are numbered from 100–299; right-channel components are numbered from 200–299; and components common to both channels are numbered from 1–99.

Another analog switch, IC2, routes one of the main inputs or one of the tape recorder inputs through to the Volume/Tone/Balance circuit. The network attached to the INHIBIT input (pin 6) of IC2 forces that IC to turn on slowly, and that helps minimize power-on squeal through the headphones.

After passing through IC2, the stereo signals are processed by the Volume/Tone/Balance circuit, which also contains the MUTE switch and the STEREO/MONO switch. The signals are next presented to the power amplifiers and then to the speaker protection circuit and relays RY1 and RY2.

We had a problem with loudspeaker switching. We didn't want heavy wires running between the front-panel selector switch and the speaker output terminals. In addition, switches capable of handling the 10 amps or so of current the amplifier can develop at full power are expensive and not readily available. We solved the problem by letting a couple of relays do the switching. That solution allows us to use a small rotary switch to control just the coils of the relays. Further, that makes it easy to implement circuitry to provide power-on muting as well as to protect the speakers from an output-transistor failure.

The power supply is mounted beneath the main circuit board. Since the power supply is mounted so close to the main circuit board, we had to use a power transformer with a very low external hum field. Low hum is achieved by using a toroidal transformer that has the additional benefit of small size. Other special features of the power supply include 16,000 µF of capacitance on each of the 66-volt supplies, and a special, isolated +7.4-volt source for the CMOS switching components and their battery back-up.

With that background in mind, let's start over. Let's go back to the input of the circuit and examine each stage in detail.

The RIAA preamplifier

The complete schematic of the left-channel preamp is shown in Fig. 2. The right channel is identical, here and in other figures, unless a notice appears in a figure stating otherwise. We use special

PARTS LIST

All resistors ¼-watt, 5% unless otherwise stated.

R1, R3—10,000 ohms
R2—220,000 ohms
R4, R5—47 ohms, ½ watt
R6–R9, R11–R14, R16, R18—100,000 ohms
R10, R15, R17, R19, R100, R102, R104, R158, R163, R200, R202, R204, R258, R263—470 ohms
R20, R21, R22, R23—22,000 ohms, ½ watt
R24, R25, R101, R103, R105, R201, R203, R205—56,000 ohms
R26, R129, R121, R229, R231, R132, R232, R134, R234—270,000 ohms
R27, R128, R130, R144, R228, R230, R244—2200 ohms
R28, R159–R162, R259–R262—220 ohms
R29—130 ohms
R30, R31, R136, R151, R236, R251—1000 ohms
R32—1500 ohms
R33–R99, R165–R199, R2265–R299—unused
R106, R206—150,000 ohms
R107, R207—300,000 ohms
R108, R208—100,000 ohms, potentiometer
R109, R209—25,000 ohms, linear potentiometer
R110, R210—50,000 ohms, logarithmic potentiometer
R111, R211—10,000 ohms, linear potentiometer
R112, R212—330 ohms
R113, R213—150 ohms
R114, R214—180,000 ohms
R115, R215—68,000 ohms
R116, R117, R216, R217—820 ohms
R118, R123, R218, R223—39 ohms
R119, R219—1200 ohms
R120, R220—2700 ohms
R121, R221—390 ohms
R122, R222—82 ohms
R124, R224—3900 ohms, 1%, metal film
R125, R225—47,000 ohms, 1%, metal film
R126, R226—10 ohms
R127, R227—4300 ohms
R133, R135, R149, R150, R233, R235, R249, R250—4700 ohms
R137, R138, R143, R145, R146, R148, R155, R237, R238, R243, R245, R246, R248, R255—22,000 ohms
R139, R140, R239, R240—3900 ohms
R141, R147, R241, R247—680 ohms
R142, R232—68 ohms
R152, R252—12,000 ohms, 1 watt
R153, R154, R157, R253, R254, R257—100 ohms
R156, R256—500 ohms, trimmer
R164, R264—6.8 ohms, 1 watt

Capacitors

C1, C14–C22, C116, C120—10 µF, 50 volts, electrolytic
C2, C3—0.047 µF, polyester
C4, C5—47 µF, 50 volts, non-polarized
C6—100 µF, 16 volts, electrolytic
C7—0.01 µF, 250 volts, polyester
C8–C11—8000 µF, 75 volts, electrolytic
C12, C13—1000 µF, 25 volts, electrolytic
C23–C99, C144–C199, C214, C225, C226, C244–C299—unused
C100, C200—0.082 µF, polyester
C101, C107, C113, C142, C201, C207, C213, C242—0.1 µF, polyester
C102, C202—47 µF, 25 volts, electrolytic
C103, C203—100 pF, ceramic
C104, C204—0.0033 µF, polyester
C105, C205—220 µF, 16 volts, electrolytic
C106, C112, C206, C212—100 µF, 25 volts, electrolytic
C108, C208—10 pF, ceramic
C109, C209—0.018 µF, 2%, polyester
C110, C210—0.068 µF, 2%, polyester
C111, C211—2.2 µF, 50 volts, non-polarized
C112, C212—100 µF, 25 volts, electrolytic
C114—10 µF, 25 volts, electrolytic
C115, C215—10 µF, 50 volts, non-polarized
C117, C217—0.056 µF, polyester
C118—2200 µF, 16 volts, electrolytic
C119, C127, C219, C227—18 pF, ceramic
C121, C221—50 µF, 16 volts, non-polarized
C122, C222—0.01 µF, polyester
C123, C124, C223, C224—0.0047 µF, polyester
C128, C228—6.8 µF, 16 volts, non-polarized
C129, C229—1 µF, 100 volts, non-polarized
C130, C230—330 pF, ceramic
C131, C231—0.015 µF, 250 volts, polyester
C132, C232—47 µF, 25 volts
C133, C233—15 pF, ceramic
C134, C138, C234, C238—100 µF, 100 volts, electrolytic
C135, C136, C139, C140, C235, C236, C239, C240—0.22 µF, polyester
C137, C141, C237, C241—22 µF, 100 volts, electrolytic
C143, C243—0.15 µF, 250 volts, dual-dielectic (Philips type PKT-P)

Semiconductors

IC1, IC2—4052 4PDT analog switch
IC3–IC6—4011 CMOS NAND gate
IC7—74C14 CMOS hex Schmitt trigger
IC8—4013 CMOS dual D flip-flop
IC9—7815 15-volt positive regulator
IC10—7805 5-volt positive regulator
IC11—7915 15-volt negative regulator
IC12–IC99, IC105–IC199, IC205–IC299—unused
IC100, IC102, IC103, IC200, IC202, IC203—TL071 low-noise op-amp
IC101, IC201—NE5534AN bipolar op-amp
IC104, IC204—4053 CMOS triple SPDT analog switch
BR1—400-volt, 10-amp bridge rectifier
D1, D4–D17, D23, D101–D105, D201–D205—1N914
D2, D3, D18–D22, D108, D109, D208, D209—1N4002
D24–D99, D110–D199, D210–D299—unused
D100, D200—1N752A, 5.6-volt, ½-watt Zener diode
D106, D107, D206, D207—1N4739A, 9.1 volt, 1-watt Zener diode
LED1–LED9—Standard red LED
Q1, Q3, Q4—BC547
Q2—BC557
Q5—BC327
Q6–Q99, Q115–Q199, Q215–Q299—unused
Q100–Q103, Q200–Q203—2SC2545
Q104, Q204—2N5485
Q105–Q107, Q205–Q207—BC556
Q108, Q208–BF470
Q109, Q110, Q209, Q210—BF469
Q111, Q112, Q211, Q212—2SK134
Q113, Q114, Q213, Q214—2SJ49

Other components

B1, B2—Size AA Ni-Cd battery
F1, F2—Fuse, 250 volts, 5 amps
J1—Stereo headphone jack
J100–J103, J200–J203, J104–J107, J204–J207—RCA Phono jack
J108–J111, J208–J211—speaker connectors
L100, L200—see text
L101, L201—6.8 µH
P1, P2—9-pin SIP plug, 0.1-" centers
RY1, RY2—DPDT relay
S1–S9—SPST normally open, momentary contact
S10—DPST toggle
S11—SPST toggle
S12—2P4T rotary
S13—SPST toggle switch, 250 volts AC
T1—117 VAC primary, dual secondaries: 90 VCT and 30 VCT

Miscellaneous: Battery holder for B1 and B2, PC-mount fuse clips, Ferrite beads, 11-mm × 25-mm coil forms

Note: The following components are available from Dick Smith Electronics, Inc., P.O. Box 8021, Redwood City, CA 94063; 800-332-5373 (orders) 415-368-8844 (inquiries). Complete kit of all parts (No. K-3516) including PC boards, heatsinks, screened front and rear panels, and transformer T1, $299 plus $10 shipping. Separate components: set of two PC boards (No. KH-0106), $49.00; 2SC2545 transistor (No. KZ-1683), $0.39 each; 2SK134 transistor (No. Z-1815), $4.50; 2SJ49 transistor (No. Z-1816), $4.50; transformer T1 (No. KM-2000), $57.00; case including panels and heatsinks (No. KH-2700), $115. All component orders must add $1.50 for handling plus 5% of total price. California residents must add 6.5% sales tax. Orders outside U.S. must include U.S. funds and add 15% of total price for shipping.

ultra-low-noise transistors made by Hitachi (part number 2SC2545) to form a differential amplifier that drives an operational amplifier. Doing that allows the noise performance to be defined by the transistors rather than by the op amp and you can get better performance from discrete devices than from IC's.

The 2SC2545's are NPN types with very low intrinsic base resistance. We have found the 2SC2545 transistor superior in that respect to all others that we have

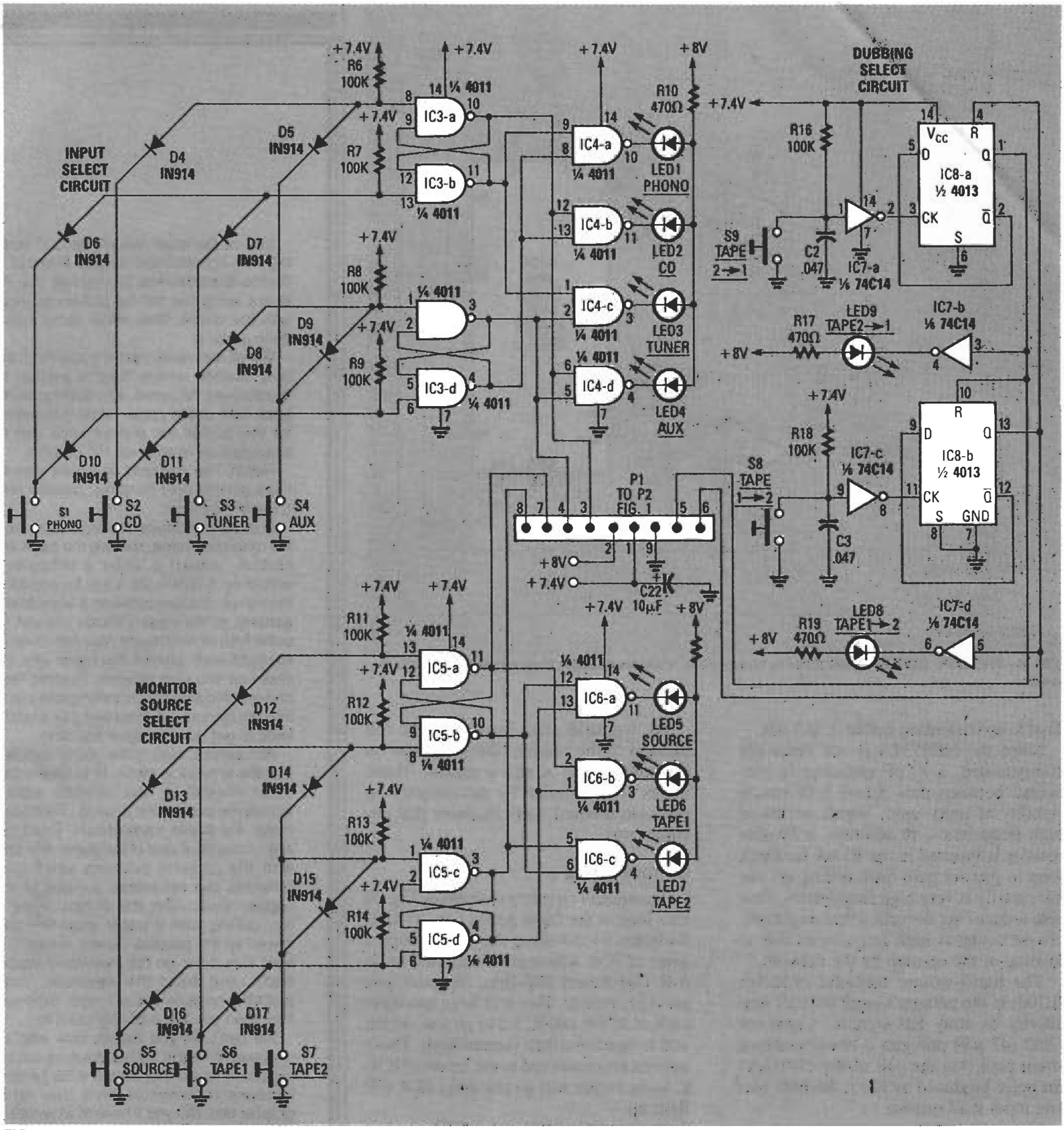


FIG. 3—THE CONTROL BOARD CIRCUITRY is shown here. Each section of the circuit is composed of several momentary switches that drive several flip-flops.

tested. To render residual noise in the phono preamp as low as possible, we use two transistors connected in parallel in each leg of the differential stage. That halves the intrinsic base resistance and improves noise performance a great deal.

Quiescent current through the differential pair is set at about 1.7 mA to optimize the signal-to-noise ratio for typical moving-magnet phono cartridges. That current is set by FET Q5, which functions as a constant-current source and ensures good common-mode performance, good PSRR (*P*ower *S*upply *R*ejection *R*atio), as well as optimum gain. In general, the better the PSRR, the less likely an amplifier will respond to variations in the power supply, including large ripple signals (hum), or to harmonics of the input signal, which increase harmonic distortion. Resistor R120 (2700 ohms) is connected in series with the drain of Q5 to protect transistors Q100–Q103 should Q5 fail. A failure of that sort is unlikely, but a resistor is cheap insurance.

We use a Signetics NE5534A op-amp for output drive; its high-performance capabilities include: low-noise, high slew-rate, and the ability to drive a 600-ohm load. That last capability is important for the circuit since it enables us to use a relatively-low-impedance negative-feedback network. The low-impedance network keeps circuit-generated noise to a minimum.

RIAA equalization is determined by the values of the components in the negative-feedback loop of the preamplifier (R124, R125, C109, C110). To ensure that there is minimum deviation from the ideal RIAA characteristic curve, those components should have tolerances of 1% or 2%.

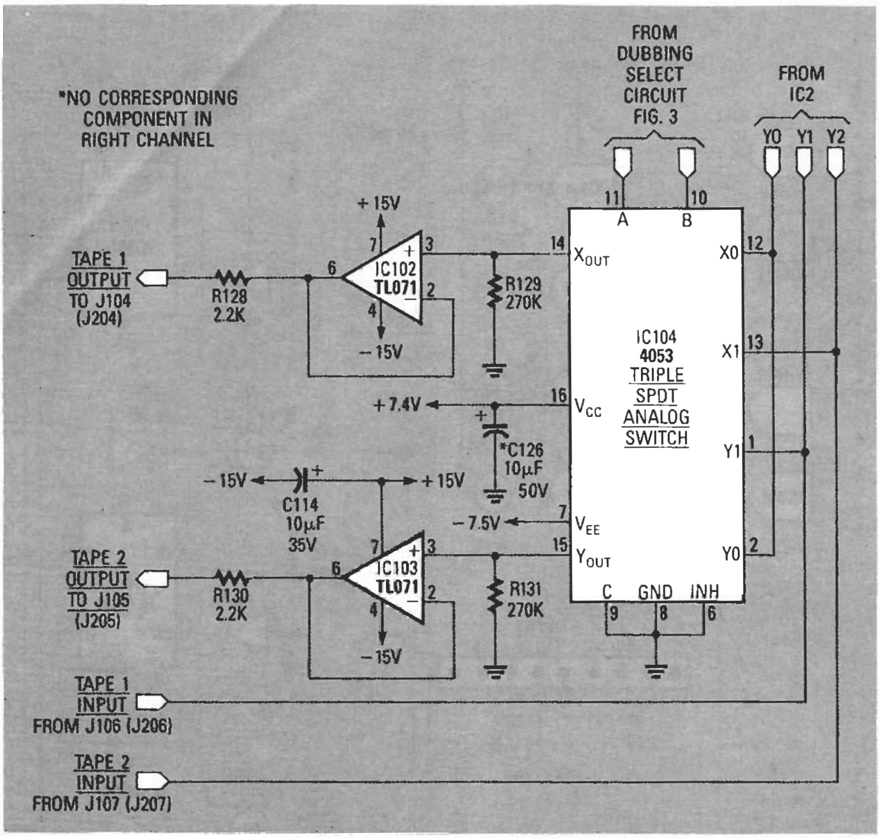


FIG. 4—THE TAPE BUFFER CIRCUITRY is shown here; it allows dubbing from either recorder to the other.

That keeps deviation within ±0.5 dB.

Since the NE5534A is not internally compensated, a 10 pF capacitor is connected between pins 5 and 8 to ensure stability at unity gain, which occurs at high frequencies. In addition, a 39-ohm resistor is inserted in the RIAA feedback loop to prevent gain from rolling off unnecessarily at very high frequencies. That also reduces the distortion that might otherwise occur at high frequencies due to loading of the op-amp by the network.

The hand-wound toroidal inductor (L100) in the preamp's input reduces sensitivity to stray RF signals. Capacitor C102 (47 µF) provides a low-impedance shunt path (via the coil of the cartridge) for noise produced by R115, the 68K bias and input load resistor.

The output of the preamplifier is coupled via a network consisting of a C111, a 2.2 µF non-polararized unit, and R127; those components form a low-pass filter that attenuates frequencies above 20 kHz. Next the signal is fed to IC1, the 4PDT analog switch that also handles the high-level inputs (CD, TUNER, and AUXILLIARY). That switch is powered by +7.4-volt and −7.5-volt supplies. The maximum peak-to-peak signal that can be handled by the switches without distortion is defined by the values of the plus and minus supplies. In our case, the maximum is about 15 volts, but the switch should never see more than about 2.5 volts rms, or 7 volts peak-to-peak.

As we said, the input source fed through to the rumble filters depends on the state of the A and B inputs. Those inputs are controlled by the circuitry on the control board. Let's examine that circuitry next.

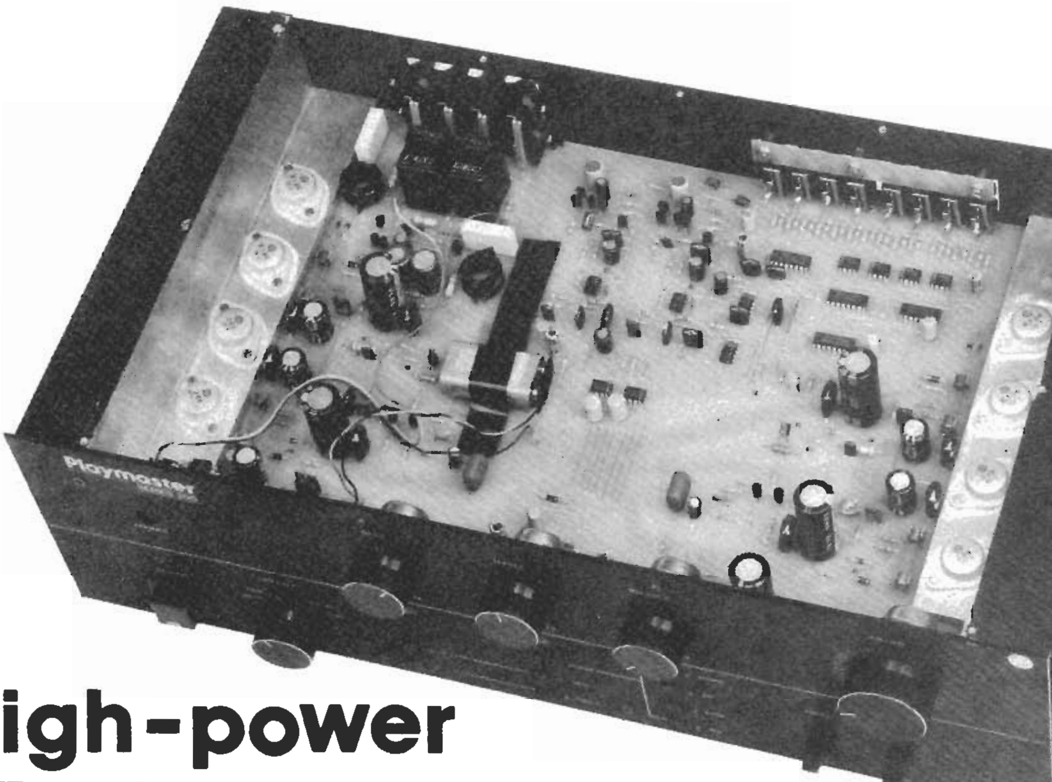
Control board

The control circuitry is shows in Fig. 3; let's look at the *Input Select Circuit* first. Switches S1–S4 drive the cross-coupled gates of IC4, which are configured as an S-R (*S*et-*R*eset) flip-flop. Suppose you press S1, PHONO. That will force one input each of IC3-b and IC3-d to go low, which will in turn force their outputs high. Those outputs are connected to the inputs of IC4-a, so its output will go low and LED1 will light up.

The outputs of IC3-a and IC3-c are low now; those outputs are connected to the A and B inputs of IC1. Since both inputs are low, the X0 and Y0 inputs—the outputs of the phono pre-amps—to the analog switch will be fed through to the outputs.

The other switches in that section of the Control Board (S2–S4) work in a similar manner, as do the switches in the *Monitor Source Select* section. The latched outputs of the latter section are cabled to the A and B inputs of IC2, another 4052 4PDT analog switch; it serves to route one of the source inputs (Phono, etc.) or one the tape recorder inputs through to the volume control circuitry.

continued on page 90



High-power FET STEREO AMP

Our amp's high-power output, low distortion, and easy construction make it a must for audiophiles who demand the very best!

LEO SIMPSON AND JOHN CLARKE*

Part 2

LAST MONTH WE DISCUSSED how the phono preamp and the analog switching sections of our amplifier work. Let's go on now and examine the volume/tone/balance circuit, the power amps, the speaker switching circuit, and the power supply.

Volume/tone control circuit

Whichever source is chosen to drive the amplifier, the signals from that source go through several stages of processing. Let's look at each in turn.

The output of analog switch IC2 is fed to IC105, shown in Fig. 5, which functions simply as a high-impedance, unity-gain buffer that drives the volume control, R110, and the STEREO/MONO switch, S11.

The wiper of the volume control is fed to IC106, another NE5534A, that is connected, in this case, as a non-inverting amplifier with a gain of 5.7. In addition to that gain, the op-amp provides a low-impedance source to drive the tone-control circuit.

We use yet another NE5534A in the tone-control stage; that op-amp is configured as a negative-feedback unity-gain amplifier when the BASS (R108) and TREBLE (R109) tone controls are set to their flat (mid-position) settings. Both BASS and TREBLE controls operate with a "constant-turnover, variable-slope" characteristic. Slope refers to the amount of boost or cut the circuit applies, and is a maximum of 6dB/octave for our circuit. Turnover refers to the frequency at which boost or cut occurs; our circuit uses a turnover frequency of 1 kHz for both bass and treble control circuits. When the wiper of the BASS control is rotated toward the input side of the ap-amp, gain below 1 kHz is increased; similarly, the TREBLE control causes the gain of frequencies above 1kHz to increase.

The tone-control amplifier drives the BALANCE and MUTE controls via a 6.8 µF non-polarized electrolytic capacitor. The mute circuit is a 20-dB attenuator composed of R141 (680 ohms) and R142 (68 ohms). The attenuator is switched into the circuit by S3, MUTE.

By the way, the NE5534's are bipolar op-amps that have higher input offset voltages than FET-input types like the TL071. Since we are using the NE5534's in gain stages, offset error is multiplied and therefore appears as a large DC offset at the output of the IC. The same problem occurs with the phono preamplifier. That's why we use non-polarized DC-blocking capacitors following each NE5534A.

Power amp

Moving on to the power amplifier, shown in Fig. 6, let's discuss a little of our design philosophy before getting into the actual circuit details. Our design, which is based on Hitachi application notes, did not come easily. Indeed, most of the development of the amplifier as a whole revolved around the power amplifier.

We tried many different circuits in many different configurations. Some were completely symmetrical designs with double-differential input stages and so on. We tried cascode driver stages and source degeneration in the MOSFET output stages. We also tried varying the driver stage currents to obtain the best overall distortion and slew rate.

---

*…pted from material published by *Electronics Australia*

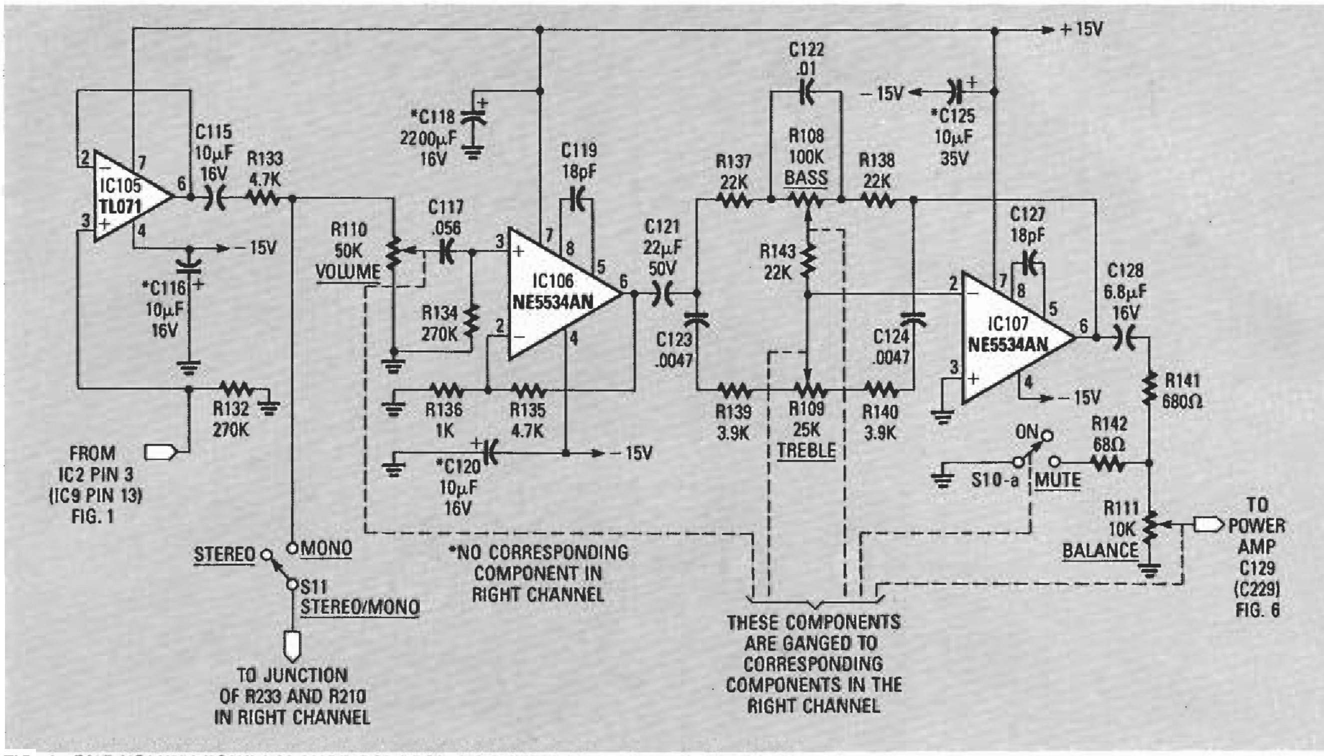


FIG. 5—THE VOLUME/TONE/BALANCE-CONTROL CIRCUITRY allows for ±6 dB of treble or bass boost or cut, volume and balance control, muting, and stereo/mono selection.

After all that we concluded that Hitachi's design was the best overall for both simplicity and performance. And we discovered one rather surprising fact: performance of the power amps is quite dependent on the layout of the printed circuit board. In fact, even subtle changes in layout made quite dramatic reductions in distortion. We'll present what we believe is the best layout next time. But for now, let's see how the power amplifier works.

The BALANCE control (shown in Fig. 5) is coupled to the power amplifier via a 1-μF non-polarized capacitor. Strictly speaking it should be possible to omit that capacitor because C128 (the 6.8-μF capacitor at the output of IC107) should block residual DC across the balance control. However, if C129 were eliminated, Q105's bias current could flow through the balance control as well as through R145, Q105's 22K base-bias resistor.

By itself that would be harmless, but the signal presented to the power amplifier would vary as the BALANCE control was rotated. In addition, whatever DC offset was present at the input would be amplified, and would lead to an increase in the residual DC voltage at the output of the power amplifier. Hence, the output of the push-pull amplifiers composed of Q111–Q112 and Q113–Q114 would become unbalanced, so output distortion could result.

Also, C129, R144 and C130 function as a low-pass filter that removes signals in the RF region. Resistor R144 functions as a "stopper" that reduces any tendency, on the part of the amplifier, to oscillate supersonically. For full power output the input to the power amplifier should be about 1.5 volts rms.

Transistors Q105 and Q106 form a differential pair, and Q107 acts as a constant-current "tail." By virtue of diodes D101 and D102, the base-bias applied to Q107 is about 1.3 volts. That sets the current through Q107 at about one milliamp; that current is shared equally by Q104 and Q106. And, as in the RIAA preamp circuit, the constant-current source improves the PSRR of the amplifier.

The balanced output signals from the collectors of transistors Q105 and Q106 are coupled to a second differential amplifier, consisting of Q109 and Q110, which forms a "current mirror," a circuit often used in IC op-amps. The current mirror helps us obtain higher gain from the stage, as well as better linearity over the full range of output voltage. In fact, the current mirror gives a greater voltage swing than could be obtained with a simple class-A driver stage with a boot-strapped collector load.

Transistors Q108, Q109, and Q110 each has a maximum collector voltage rating of 250 volts; they are intended for use as class-B video-driver stages in television reveivers. That voltage rating in conjunction with their 100-Mhz gain-bandwidth product and good beta linearity over a wide range of operating currents makes them ideal for use in a low-distortion audio driver stage.

Those two discrete differential amplifiers provide all the voltage gain of the power amplifier; the MOSFET output transistors are operated in source-follower mode, which gives slightly less than unity voltage gain. No source degeneration resistors are used in the output transistors. We found that we were able to dispense with those resistors and thus gain lower distortion.

Nor does there appear to be any need to take measures to ensure current sharing between the parallel-connected MOSFETs (by using small source resistors). In practice, if one MOSFET becomes warmer that its partner, its transconductance (gain) is reduced accordingly; thus it is temperature-compensated automatically.

The 500-ohm trimpot, R156, connected between the collectors of Q108 and Q110 sets the bias applied to the MOSFET gates; that bias determines the quiescent output current. The amount of current is a compromise between minimum distortion and output-stage power dissipation. Since the power amplifier employs a ±65-volt power supply, even a small current results in high power dissipation. So quiescent current must be set carefully.

Zener diodes D106 and D107, in combination with D104 and D105, determine the maximum voltage that can be deliv-

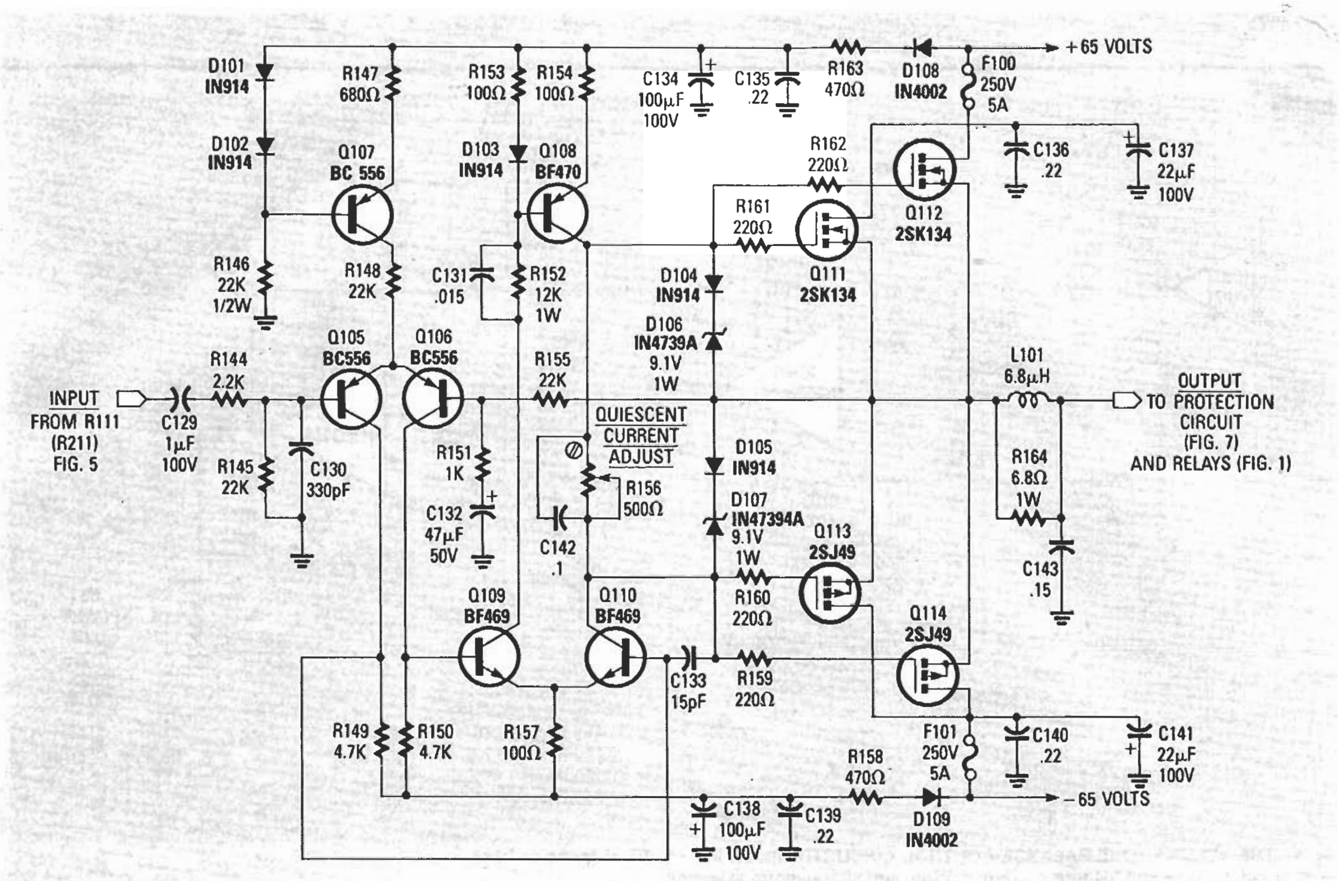


FIG. 6—THE POWER AMPLIFIER is built around two discrete bipolar differential amplifiers and power MOSFETS for output drive.

ered to the output transistors. Any signal in excess of ± 10 volts will be clipped. In that way the diodes form an effective overdrive circuit and prevent excessive power dissipation in the event of a short circuit. The gate of each output transistor has a series-connected 220-ohm resistor that functions as a "stopper" to prevent RF oscillation. Fuses are included in the output-transistor supply lines to protect the speakers should the output transistors fail. The fuse clips also provide a convenient way of measuring current (or voltage, when they are replaced by resistors) for trouble-shooting or setting the quiescent current.

Voltage gain of the power amplifier is determined by the ratio of the 22K and the 1K resistors (R155 and R156) at the base of Q106. The lower cutoff-frequency of the circuit is determined by 47 µF capacitor C132; that capacitor is in series with 1K resistor R151.

A final refinement involves the RLC network (L101, R164, and C143) in the output circuit. That network is used to render the amplifier unconditionally stable. We use a toroidal air-core inductor in that network, as a solid ferrite core can give rise to distortion, particularly when the amplifier is delivering a great deal of power.

It is necessary to use a special capacitor in the output network. We originally installed metallized polyester capacitors for C143 and C243, but found that high power operation of the amplifier caused them to fail quickly; they developed short-circuits. However, we found that dual dielectric (mixed paper and polyester) capacitors, normally specified for power-line interference suppression, work fine in that circuit. See the Parts List for more information.

Speaker switching

The main and remote loudspeakers are controlled with two relays rather than an expensive, high-current 4-pole switch. The relays also simplify wiring requirements, as we don't need to run heavy loudspeaker wiring to and from the front-panel SPEAKER SELECTER switch, S12. Instead, S12 controls the coils of the relays, so only low-current wiring is required for that connection.

The DC supply for the relay coils is supplied by the loudspeaker protection circuitry discussed below. When no fault is present, the output of that circuit goes high, and that energizes the coils of both relays, through resistors R4 and R5. Diodes D2 and D3 quench the EMF spike that is generated when the relay coil is de-energized.

The moving contacts of the relays connect to the loudspeakers while the unused stationary contacts are grounded. The reason for this is that, if a large DC voltage is generated in the amplifier by a fault condition, an arc is likely to result as the moving contact opens the circuit. So, as the contact moves to the "de-energized" position, that arc will be more likely to flow to ground than back into the circuit causing damage.

However, because of the high supply voltage used in our amplifier, an arc could be maintained even if the relay contacts were fully open. If that does occur, the power amplifier fuses will blow. There is a very slight chance that the amplifier itself could be damaged, but it is cheaper to repair an amplifier than to replace a loudspeaker.

Headphones

One small drawback to using the relays for loudspeaker control is that the headphones are permanently connected to the amplifier. They are not muted at power-on, but they are protected from DC faults by the 330-ohm feed resistors (R112, R212), which will limit any fault current to a safe amount.

The lack of muting is a problem since the phono preamplifier takes a little while to stabilize. During that time the amplifier is liable to emit some unpleasant sounds via the headphones if the volume control is advanced.

We solved that problem with the network attached to IC2 (shown in Fig. 1 last time), the analog switch that controls tape monitoring. That IC has an INHIBIT pin

PARTS LIST

All resistors ¼-watt, 5% unless otherwise stated.

R1, R3—10,000 ohms
R2—220,000 ohms
R4, R5—47 ohms, ½ watt
R6–R9, R11–R14, R16, R18—100,000 ohms
R10, R15, R17, R19, R100, R102, R104, R158, R163, R165, R167, R200, R202, R204, R258, R263, R265, R267—470 ohms
R20, R21, R22, R23, R146—22,000 ohms, ½ watt
R24, R25, R101, R103, R105, R166, R168, R201, R203, R205, R266, R268—56,000 ohms
R26, R121, R129, R132, R134, R229, R231, R232, R234—270,000 ohms
R27, R128, R130, R144, R228, R230, R244—2200 ohms
R28, R159–R162, R259–R262—220 ohms
R29—130 ohms
R30, R31, R136, R151, R236, R251—1000 ohms
R32—1500 ohms
R33–R99, R169–R199, R269–R299—unused
R106, R206—150,000 ohms
R107, R207—300,000 ohms
R108, R208—100,000 ohms, potentiometer
R109, R209—25,000 ohms, linear potentiometer
R110, R210—50,000 ohms, logarithmic potentiometer
R111, R211—10,000 ohms, linear potentiometer
R112, R212—330 ohms
R113, R213—150 ohms
R114, R214—180,000 ohms
R115, R215—68,000 ohms
R116, R117, R216, R217—820 ohms
R118, R123, R218, R223—39 ohms
R119, R219—1200 ohms
R120, R220—2700 ohms
R121, R221—390 ohms
R122, R222—82 ohms
R124, R224—3900 ohms, 1%, metal film
R125, R225—47,000 ohms, 1%, metal film
R126, R226—10 ohms
R127, R227—4300 ohms
R133, R135, R149, R150, R233, R235, R249, R250—4700 ohms
R137, R138, R143, R145, R148, R155, R237, R238, R243, R245, R246, R248, R255—22,000 ohms
R139, R140, R239, R240—3900 ohms
R141, R147, R241, R247—680 ohms
R142, R232—68 ohms
R152, R252—12,000 ohms, 1 watt
R153, R154, R157, R253, R254, R257—100 ohms
R156, R256—500 ohms, trimmer
R164, R264—6.8 ohms, 1 watt

Capacitors

C1, C14–C22, C116, C120—10 µF, 50 volts, electrolytic
C2, C3—0.047 µF, polyester
C4, C5—47 µF, 50 volts, non-polarized
C6—100 µF, 16 volts, electrolytic
C7—0.01 µF, 250 volts, polyester
C8–C11—8000 µF, 75 volts, electrolytic
C12, C13—1000 µF, 25 volts, electrolytic
C23–C99, C144–C199, C214, C225, C226, C244–C299—unused
C100, C200—0.082 µF, polyester
C101, C107, C113, C142, C201, C207, C213, C242—0.1 µF, polyester
C102, C202—47 µF, 25 volts, electrolytic
C103, C203—100 pF, ceramic
C104, C204—0.0033 µF, polyester
C105, C205—220 µF, 16 volts, electrolytic
C106, C112, C206, C212—100 µF, 25 volts, electrolytic
C108, C208—10 pF, ceramic
C109, C209—0.018 µF, 2%, polyester
C110, C210—0.068 µF, 2%, polyester
C111, C211—2.2 µF, 50 volts, non-polarized
C112, C212—100 µF, 25 volts, electrolytic
C114—10 µF, 25 volts, electrolytic
C115, C215—10 µF, 50 volts, non-polarized
C117, C217—0.056 µF, polyester
C118—2200 µF, 16 volts, electrolytic
C119, C127, C219, C227—18 pF, ceramic
C121, C221—50 µF, 50 volts, non-polarized
C122, C222—0.01 µF, polyester
C123, C124, C223, C224—0.0047 µF, polyester
C128, C228—6.8 µF, 16 volts, non-polarized
C129, C229—1 µF, 100 volts, non-polarized
C130, C230—330 pF, ceramic
C131, C231—0.015 µF, 250 volts, polyester
C132, C232—47 µF, 25 volts
C133, C233—15 pF, ceramic
C134, C138, C234, C238—100 µF, 100 volts, electrolytic
C135, C136, C139, C140, C235, C236, C239, C240—0.22 µF, polyester
C137, C141, C237, C241—22 µF, 100 volts, electrolytic
C143, C243—0.15 µF, 250 volts, dual-dielectic (Philips type PKT-P)

Semiconductors

IC1, IC2—4052 4PDT analog switch
IC3–IC6—4011 CMOS NAND gate
IC7—74C14 CMOS hex Schmitt trigger
IC8—4013 CMOS dual D flip-flop
IC9—7815 15-volt positive regulator
IC10—7805 5-volt positive regulator
IC11—7915 15-volt negative regulator
IC12–IC99, IC105–IC199, IC205–IC299—unused
IC100, IC102, IC103, IC105, IC200, IC202, IC203, IC205—TL071 low-noise op-amp
IC101, IC106, IC107, IC201, IC206, IC207—NE5534AN bipolar op-amp
IC104, IC204—4053 CMOS triple SPDT analog switch
BR1—400-volt, 10-amp bridge rectifier
D1, D4–D17, D23, D101–D105, D201–D205—1N914
D2, D3, D18–D22, D108, D109, D208, D209—1N4002
D24–D99, D110–D199, D210–D299—unused
D100, D200—1N752A, 5.6-volt, ½-watt Zener diode
D106, D107, D206, D207—1N4739A, 9.1 volt, 1-watt Zener diode
LED1–LED9—Standard red LED
Q1, Q3, Q4—BC547
Q2—BC557
Q5—BC327
Q6–Q99, Q115–Q199, Q215–Q299—unused
Q100–Q103, Q200–Q203—2SC2545
Q104, Q204—2N5485
Q105–Q107, Q205–Q207—BC556
Q108, Q208–BF470
Q109, Q110, Q209, Q210—BF469
Q111, Q112, Q211, Q212—2SK134
Q113, Q114, Q213, Q214—2SJ49

Other components

B1, B2—Size AA Ni-Cd battery
F1, F2—Fuse, 250 volts, 5 amps
J1—Stereo headphone jack
J100–J103, J200–J203, J104–J107, J204–J207—RCA Phono jack
J108–J111, J208–J211—speaker connectors
L100, L200—see text
L101, L201—6.8 µH
P1, P2—9-pin SIP plug, 0.1-" centers
RY1, RY2—DPDT relay
S1–S9—SPST normally open, momentary contact
S10—DPST toggle
S11—SPST toggle
S12—2P4T rotary
S13—SPST toggle switch, 250 volts AC
T1—117 VAC primary, dual secondaries: 90 VCT and 30 VCT

Miscellaneous: Battery holder for B1 and B2, PC-mount fuse clips, Ferrite beads, 11-mm × 25-mm coil forms

Note: The following components are available from Dick Smith Electronics, Inc., P.O. Box 8021, Redwood City, CA 94063; 800-332-5373 (orders) 415-368-8844 (inquiries). Complete kit of all parts (No. K-3516) including PC boards, heatsinks, screened front and rear panels, and transformer T1, $299 plus $10 shipping. Separate components: set of two PC boards (No. KH-0106), $49.00; 2SC2545 transistor (No. KZ-1683), $0.39 each; 2SK134 transistor (No. Z-1815), $4.50; 2SJ49 transistor (No. Z-1816), $4.50; transformer T1 (No. KM-2000), $57.00; case including panels and heatsinks (No. KH-2700), $115. All component orders must add $1.50 for handling plus 5% of total price. California residents must add 6.5% sales tax. Orders outside U.S. must include U.S. funds and add 15% of total price for shipping.

that opens all switches. The network connects to that pin and simply prevents signals from the preceding stages from passing on for a second or two at power-on.

The muting network works as follows. At power-on C1 is a virtual short-circuit. This means that pin 6 is pulled high, so all the switches in the IC are open. Then, as the capacitor charges, pin 6 is pulled low, and signals can pass on to succeeding stages. The delay that results makes for more pleasant headphone listening.

Loudspeaker protection circuit

A portion of the signal from each channel's power amplifier is fed to the speaker protection circuit shown in Fig. 7. The

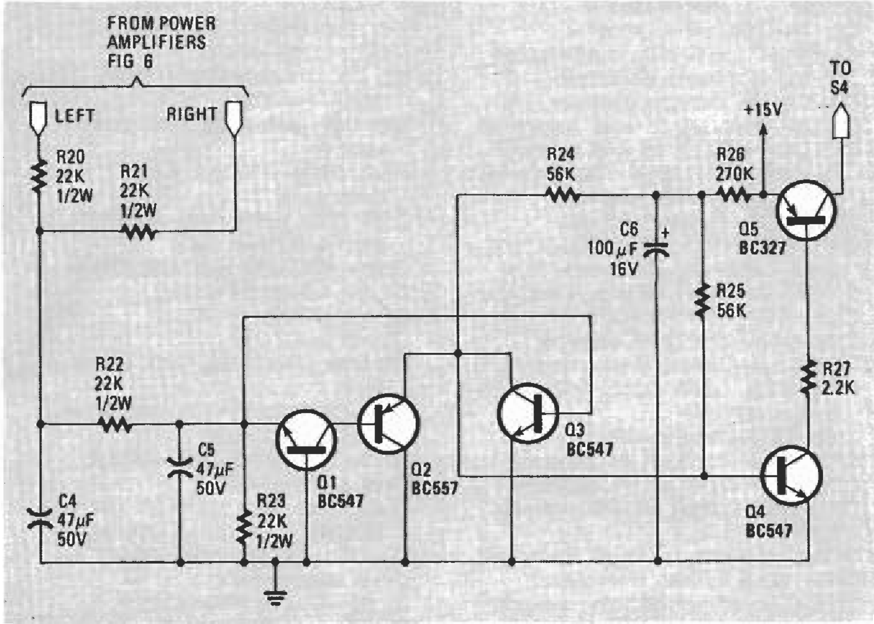


FIG. 7—THE SPEAKER PROTECTION CIRCUIT will disable the the output control relays (RY1 and RY2—shown in Fig. 1 last time) whenever the voltage produced by the output transistors becomes excessive.

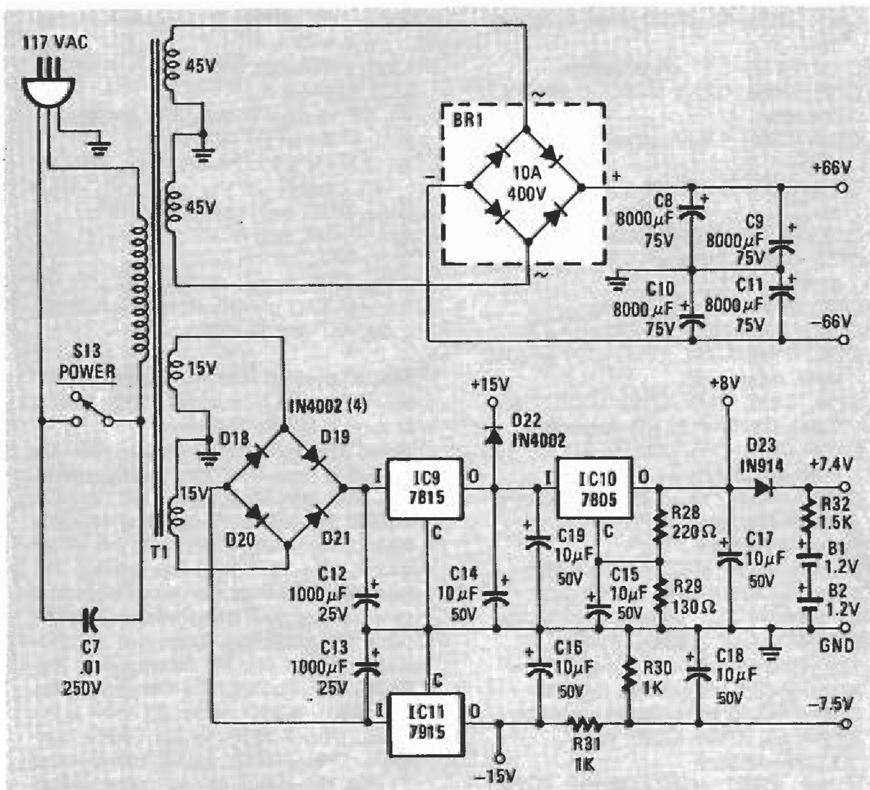


FIG. 8—THE AMPLIFIER'S POWER SUPPLY is built around a toroidal power transformer and it includes a trickle-charger for the CMOS-memory batteries, B1 and B2.

protection circuit does not protect the amplifier—it protects the loudspeakers. If a fault occurs in the amplifier that results in a large DC voltage at an output, a loudspeaker could be severly damaged. The loudspeaker protection circuitry prevents that from happening by de-energizing the relays that control the loudspeakers whenever an excessive DC voltage is sensed at the output of a power amplifier. The protection circuit also de-energizes the relay if a large low-frequency signal is presented to the circuit for an extended period of time. That could happen for a variety of reasons; for example, if the amplifier became unstable and began to motorboat.

Both power amplifier outputs are monitored via a low-pass network consisting of the four 22K-ohm resistors (R20–R23) and the two 47-μF non-polarized capacitors (C4 and C5). The two capacitors render the protection circuit immune to normal output voltages. But if one of the amplifiers develops an excessively negative DC voltage, Q1 will turn on. That turns on Q2 and removes the bias voltage from Q4; that in turn switches off Q5 so that no power can be fed through S4 (shown in Fig. 1), the speaker-selector switch that controls the coils of the relays. By the same token, if one of the power amplifiers develops an excessively positive DC voltage, Q3 will be forward biased. That again removes the bias from Q4 and Q5, preventing power from reaching the switch that controls the operation of the relays.

Note that the protection circuit is effectively fail-safe. If a malfunction prevents the relays from operating, the loudspeakers will be disconnected from the amplifier, so they will be safe from any potential damage.

Muting

The loudspeakers are muted (i. e., the relays are disconnected) for three seconds after power-on. That works as follows. When power is first applied, the 15-volt supply to Q5 is available almost instantly, but Q5 is unable to turn on because the base of Q4 is at ground potential, so it, too, is off.

The reason Q4 can't turn on is that its base is supplied via 56K resistor R25. That resistor is supplied by 100 μF capacitor C6, which is a short circuit at power-on. After power-on, C6 charges slowly via 270K resistor R26. Eventually Q4 turns on, so Q5 can turn on and energize the relays.

Switch-off thump

Another problem we faced was a loud thump from the loudspeakers whenever the amplifier was turned off. After investigation, we discovered that the problem was caused by the rapid collapse of the ±15V supply, which supplied the op-amps in the preamplifier stages enough juice to give a thump before the output relays released. If uncorrected, such thumps could eventually damage the speakers.

The solution was to isolate the op-amp supply. We did that by installing a 1N4002 diode (D22, shown in Fig. 8) in series with the +15-volt supply line, and by increasing the value of decoupling capacitor C118 by IC106 (the tone-control driver in Fig. 5) from 10 to 2200 μF. That large capacitor keeps the op-amp energized until the relays open. Hence, no switching transient can get through to the speakers, preventing the switch-off thump.

Power supply

The schematic of our power supply is shown in Fig. 8. In order to reduce induced hum, AC is provided by a dual-secondary toroidal transformer, shown in Fig. 9.

continued on page 74

FET STEREO AMP

continued from page 60

winding feeds a 10A 400V bridge rectifier, which in turn feeds four 8000-μF capacitors. That well-filtered supply powers the output amplifiers.

The other winding of the torrodial transformer provides a 30 VCT output that is rectified and filtered with 1000 μF capacitors C12 and C13. Separate positive and negative three-terminal regulators, IC9 and IC11, provide fully regulated

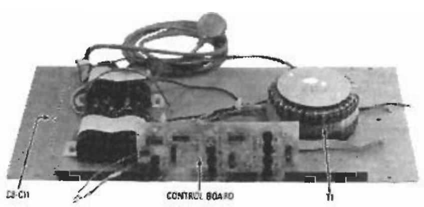


FIG. 9—THE LARGE TOROIDAL TRANSFORMER and filter capacitors provide low-ripple +/−65-volt outputs.

+15V and −15V supplies for the op-amps. As we just stated, D22 provides an isolated positive supply for the op-amps.

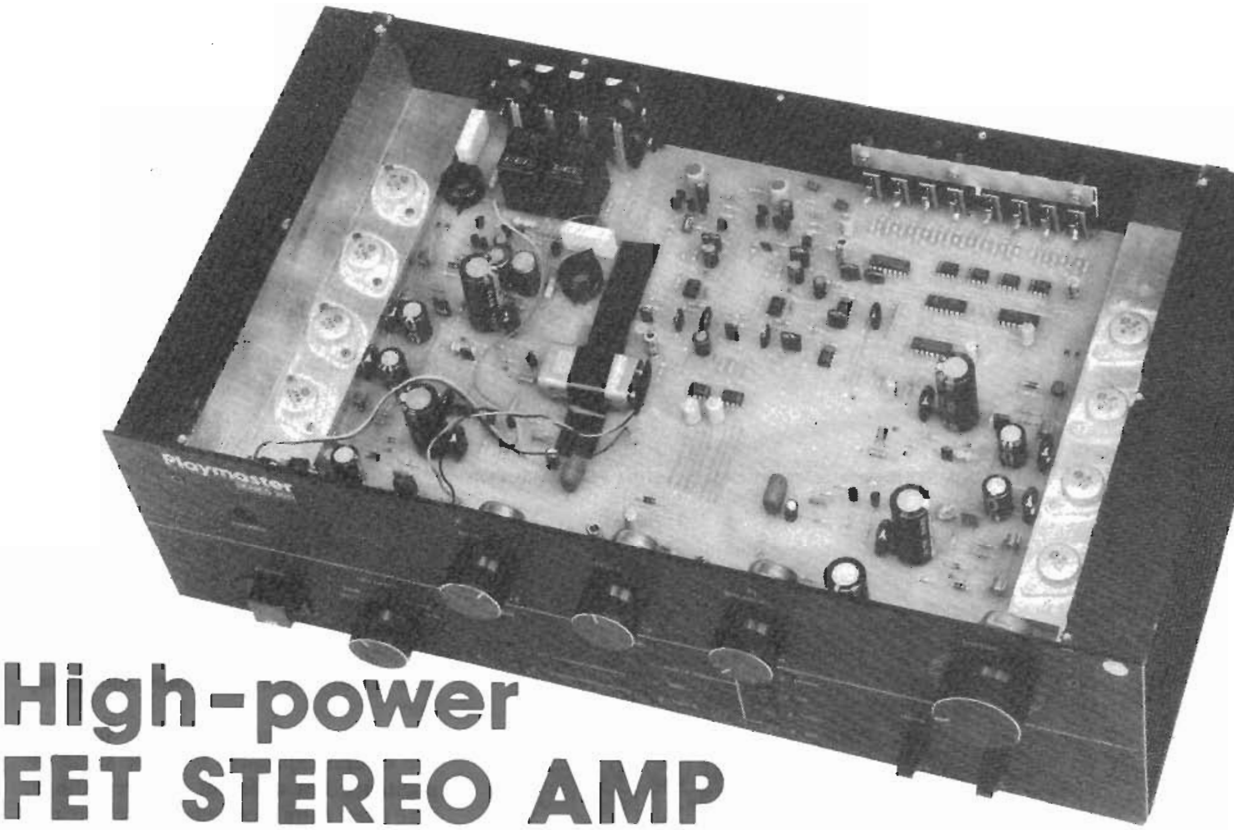
The negative supply that feeds the analog switches is derived from the −15-volt supply via a simple resistive divider composed of R30 and R31. We can get away with using that simple scheme since the CMOS IC's draw only about 100 μA of ...nt, and that loads the resistive divider negligibly.

The positive supply must provide more current than the negative supply because the LED's are fed from the positive supply. Hence a 7805 regulator is used. The 220-ohm resistor (R28) between the output and the ground terminals of the regulator has about 23 mA of current flowing through it, and that current in conjunction with the 15 mA flowing out of the ground terminal impresses about three volts across 130-ohm resistor R29. That raises the output of the regulator from five to eight volts. The latter voltage feeds the LED's, and diode D23 isolates that voltage for the CMOS memory circuit.

Standby power

Two nickel-cadmium batteries are used to supply standby power to the CMOS IC's. The batteries provide just enough voltage so that the flip-flops retain their contents when the main power is switched off. Diode D23 ensures that the the LED's don't drain the battery. Note that the minus rail is not powered by the batteries. That is because we are only interested in maintaining power in the logic circuits. Also, when the main power is on, the battery is trickle-charged via R32.

That (finally!) completes the circuit description. Start warming up your soldering iron; next time we'll go on and build an amplifier! **R-E**



High-power FET STEREO AMP

After several months of theoretical discussion, it's time to get our hands dirty and build this audiophile's dream amplifier!

LEO SIMPSON AND JOHN CLARKE

Part 3 WE'VE SPENT SEVERAL months talking about how the amplifier works and the philosophy behind its design. We've all had enough theory—so let's start building an amplifier!

Mechanical overview

First of all let's talk about PC boards. Two are required: the control board, which contains most of the digital input-switching circuitry, and the main board, which contains the vast majority of all other components. If you want to etch your own, we show the foil patterns for both boards in this issue's PC Service; alternatively, you may purchase boards from the source mentioned in last month's Parts List. In any event, we don't recommend that you try to build the amplifier without PC boards; success using any other construction technique is highly doubtful.

As you can see in Fig. 10, the mechanical arrangement of our amplifier is rather unusual in that two large heatsinks serve both as endpanels and as supports for the main PC board. That arrangement allows the output transistors to be bolted to the heatsinks and their leads soldered directly to the appropriate pads of the PC board. In addition, the front and rear panels bolt directly to the heatsinks, and so do the top and bottom panels. Both the top and the bottom panel also have flanges that help secure the front and rear panels making for a mechanically stable cabinet.

The terminals of the tape input/output jacks, the main input jacks, and the speaker connectors are soldered directly to the rear of the PC board; the jacks themselves protrude through cutouts in the rear panel, to which they are bolted. Similarly, on the front panel, the shafts of the PC-board mounted BASS, TREBLE, BALANCE, and VOLUME control potentiometers protrude through holes in the front panel, to which the potentiometers are secured using nuts.

Unlike the other switches and the potentiometers, the POWER, SPEAKER SELECT, MONO/STEREO, and MUTE switches are not soldered directly to the PC board. They are connected to it using short lengths of hookup wire and they are secured to the front panel with the appropriate mounting hardware.

The control board attaches to the front panel by means of three short threaded bushings. The bushings are attached to the component side of the PC board; the board is then screwed to the front panel. The lower screws pass through flanges on the base plate.

As shown in Fig. 9 last time, the high-voltage power supply components (T1, BR1, C8–C11) are mounted on the base plate of the amplifier, below the main PC board. Several screw-terminal strips are also attached to the base plate to facilitate interconnections between C7, S1, the line cord, and T1.

Electronic assembly

Construction is straightforward and mostly involves installing parts on the two PC boards. Before mounting any components, inspect both boards for shorted or open traces. Repair any faults before proceeding. A few minutes spent correcting faults on the PC board now could save considerable frustration—and cash—

*Adapted from material published by *Electronics Australia*

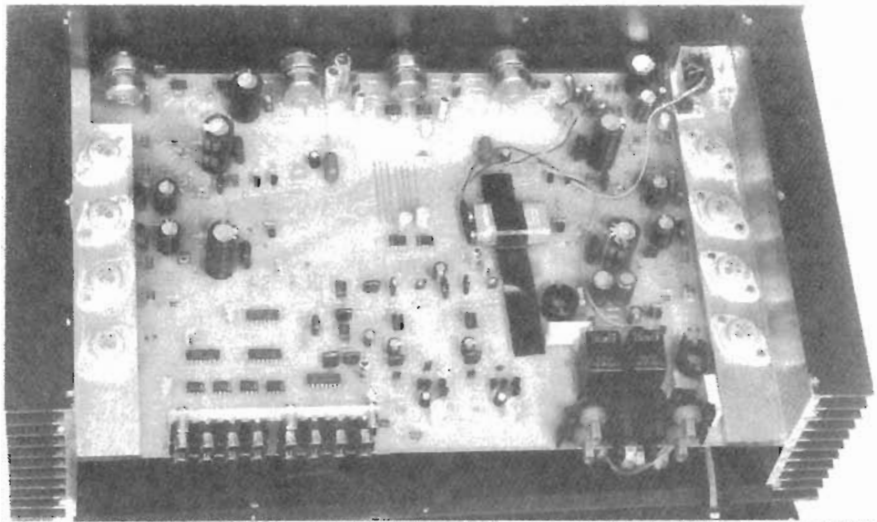


FIG. 10—MOST SWITCHES AND POTENTIOMETERS are soldered directly to the PC board; that eliminates much tedious wiring by hand.

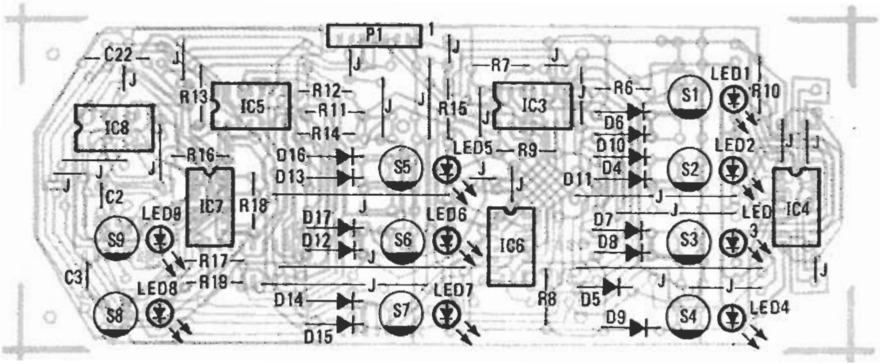


FIG. 11—MOUNT THE CONTROL-BOARD COMPONENTS as shown here. The switches and LED's mount with their flat sides down, and P1, if used, mounts to the back side of the board.

later on.

First let's build the control board. Follow the component overlay shown in Fig. 11 when installing the parts. Start with the jumpers and the diodes, then insert the resistors and the capacitors, the IC's, and the switches (S1–S9). Make sure that all semiconductors and the electrolytic capacitor (C22) are oriented correctly. The proper orientations are shown in Fig. 11. The two 0.047-µF capacitors (C2 and C3) must be pressed flat against the board; otherwise it will not mate with the front panel correctly. The switches should be oriented so that the flat side of each switch faces the edge of the PC board that mounts closest to the main board.

Last, install the LED's. The tops of the LED's should be the same height above the board as the tops of the switches. Before moving on, make sure that the LED's are oriented correctly—the flat side of each LED goes toward the bottom of the board.

After all parts are mounted, check everything carefully. After you're sure everything has been installed correctly, remove flux from the back of the board and solder a nine-pin SIP header plug in the space allotted for P1—but on the solder side of the board. Since the PC board is not double-sided, it has no pads on the component side, so you'll have to leave a enough space between the body of the connector and the PC board for the tip of your soldering iron to fit in. To solder the connector in place, tin pin 1 of P1 and the pad to which it will be soldered. Then melt the solder on the pad, insert the plug, and adjust it so that the body of the plug is parallel to the board. Remove your soldering iron. If the plug moves, re-heat the joint, and re-adjust the position of P1. When it is in place properly, solder pin 9 to the board. Then solder the remaining pins.

Wire up a nine-conductor cable with nine-conductor SIP sockets on both ends. Rather than use plugs and sockets, you could just hard-wire a nine-conductor cable from the control board to the main board. In either case, make sure the cable is long enough to reach both boards when they are installed in the chassis! Your completed board should appear as in Fig. 12. As you can see, for our prototype we hard-wired the cable and didn't use a plug-and-socket; use whichever arrangement suits you best.

The main board

Obviously it will take considerably longer to build the main board than it took to build the control board. The chances for error are also considerably greater. So take your time, be careful, and check your work often!

Refer to Fig. 13 and start installing the jumpers, resistors and diodes. Take particular care with the diodes. Don't confuse the 5.6- and 9-volt Zener diodes, and make sure that you install the 1N4002 and the 1N914 diodes in their designated positions.

The IC's and the transistors can be installed now, but don't mount the power transistors yet. Many different types of transistor are used in this circuit, so make sure that the correct one is inserted at each location. When mounting the IC's, make sure that they are oriented correctly and solder the power-supply pins first. Power is applied to pins 4 and 7 of the op-amps (TL071, NE5534), and to pins 7, 8, and 16 of the CMOS analog switches (4052, 4053). Then go on and solder the signal-carrying pins. After soldering, check for solder bridges between every pin and its neighbor. A little time spent doing that now could save a lot of time and money later.

Now install the capacitors. Since we use several capacitors with the same capacitance but different voltage ratings, take a few extra moments and be sure that you install the correct unit at each location. And be sure that the polarized capacitors are oriented correctly; the proper orientations are shown in Fig. 13.

The fuse clips, relays, trimmer potentiometers, and all the other small board-mounted components except the power transistors can be installed next. For best results, observe the recommendations that follow.

Now cut the shafts of the potentiometers to a length of about ½ inch. Then solder the potentiometers to the board. The lugs of the potentiometers should be inserted into the PC board all the way so that the shafts will line up with the holes in the front panel.

The strip of RCA jacks (J100–J107, J200–J207) supplied with the kit includes a ground lug that must be removed. Then cut the strip to an overall length of about 4¾ inches with a hacksaw. Last, drill a hole directly above the last RCA jack at the same height as the other mounting holes in the strip. Once all of that has been done, mount the strip on the PC board and solder the lugs.

The loudspeaker terminals can be installed now. Make sure that the two plastic locating lugs that are on those loudspeaker terminals mate with the appropriate holes in the PC board.

We used PC stakes to terminate wiring from the switches, the jumpers, and the power supply. Since most of those connections terminate on the underside of the

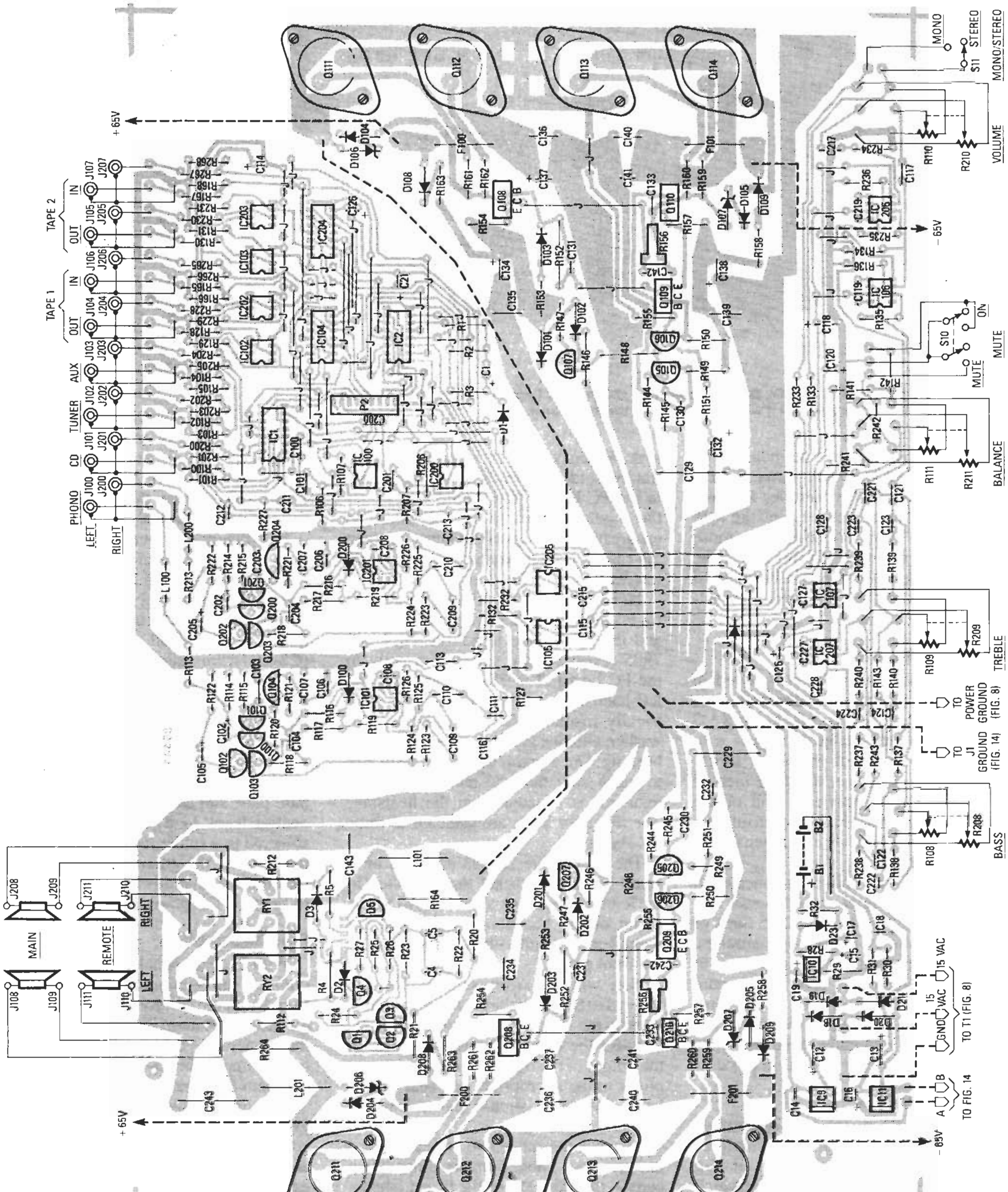
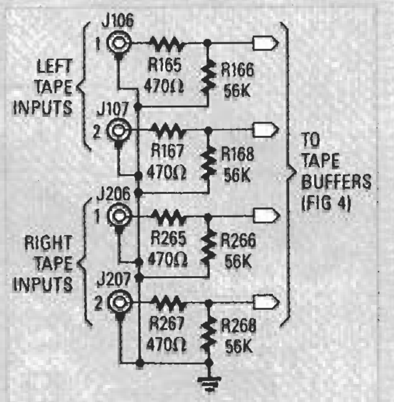


FIG. 13—MOUNT THE MAIN-BOARD COMPONENTS as shown here. A heavy jumper wire must connect the pad near Q111 to the pad to which R164 and L101 are soldered. Also, several additional wires (shown at the front left side of the board) are routed beneath the board.

Inadvertently the resistors in the figure shown here were not shown in Fig. 1 (in the June 1986 issue). In addition, the Parts List in that issue contained several errors. The correct Parts List was published in the July issue.



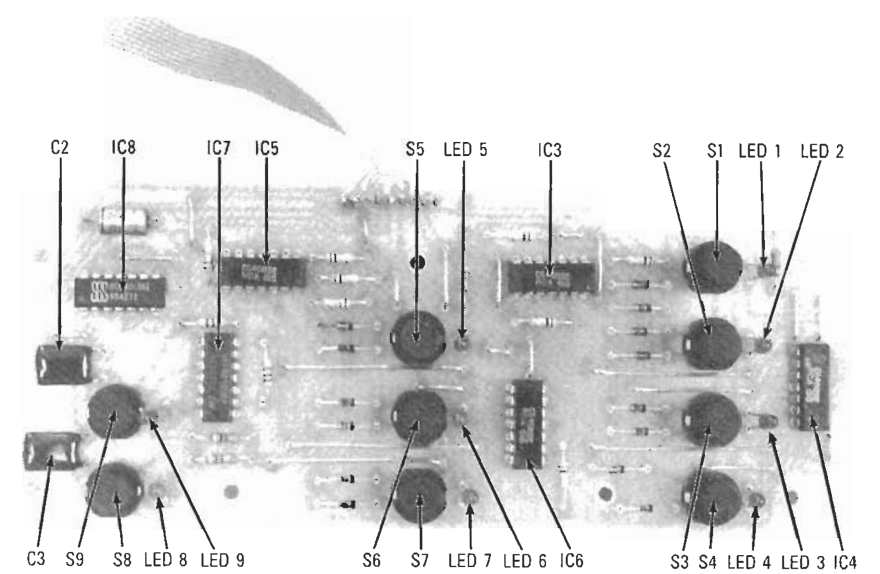


FIG. 12—THE COMPLETE CONTROL BOARD appears as shown here. Capacitors C2 and C3 must be bent flat against the board so that it won't interfere with the front panel.

board, the stakes should be mounted on the underside. The exceptions are the stakes that the Ni-Cd batteries (B1 and B2), the headphone jack (J1), and the 7815 regulator (IC9) are connected to—those components are wired to the top of the board, so the stakes should be inserted from the top of the board and then soldered from the bottom.

Winding the coils

A small hand-wound coil is wired in series with the input of each phono preamplifier. Wind each coil by feeding 5.5 turns of 28-gauge enameled copper wire through the center of the small ferrite bead. When complete, about ½ inch of wire should exit from each end of the bead. Remove about ¼ inch of insulation from each end of the wire and then solder the coil in place.

A larger 6.8 µH choke is connected in series with the output of each power amplifier. Wind each coil with 24.5 turns of 18-gauge enameled copper wire around a 7/16-inch plastic coil form. You'll have to wind three layers; the ends of the wire should exit from either side of the form 180° apart. Remove about ¼ inch of insulation from both ends, bend the leads down 90°, and solder the coil in place.

Power transistors

The MOSFET power transistors must be isolated from the heatsink using mica washers, silicone grease, and insulating bushings. Note that the heatsink which supports the right side of the PC board must be notched slightly in order to provide clearance for the VOLUME control. The power transistors are secured to the heatsinks with no. 6 screws and nuts. After each transistor is mounted, use your multimeter to make sure that there is no continuity between its case and the heatsink. When you're sure there's no continuity, solder the leads of the transistors to the PC board. You should also solder the mounting nuts to the PC board to ensure reliable long-term contact between the case of each transistor and the copper traces.

Finish building the main PC board now by installing the three voltage regulators and the headphone jack. The 7915 and 7805 regulators are soldered directly to the PC board. The 7815 is bolted to the left-hand heatsink and it must be electrically insulated from it using a mica washer, silicone grease, and an insulating bushing. Once again, use your multimeter to make sure that the metal tab of the regulator is isolated from the heatsink. The regulator leads are soldered to three PC stakes.

The headphone jack is mounted on a small L-shaped bracket that is bolted to the left-hand heatsink above the 7815. The barrel of the headphone jack must not make contact with either the heatsink or the front panel.

Now wire the MONO/STEREO (S9) and the MUTE (S11) switches to the appropriate pads on the PC board as shown in Fig. 13. Connect the beneath-board jumper from the output of the right-channel power amplifier to the appropriate pad near the relays. That wire should be at least 16 gauge.

Connect the other two beneath-board jumpers now. Those jumpers connect two pads at the front left of the board (shown in Fig. 13) to two pads in the row of five pads in front of the relays (shown in Fig. 14). Then connect wires to headphone jack (J1) and SPEAKERS switch S12.

Power supply assembly

Work can now proceed on the power supply components. Follow the wiring diagram in Fig. 8 (shown in the July issue) carefully since any errors here could be disastrous. Use insulating sleeves on the 0.01 µF capacitor (C7), and insulate the pins on the power switch with several turns of plastic tape or heatshrink tubing.

Bolt the transformer to the case with a bolt, a metal disc, and two large rubber washer. One washer is sandwiched between the transformer and the base, and another between the transformer and the disc. The four 8000 µF filter capacitors (C8–C11) are secured using aluminum brackets. The bridge rectifier is smeared on both surfaces with heatsink compound; then it is bolted to the base plate. Complete the power-supply wiring with 16-gauge wire.

Secure a 3-screw terminal block to the base plate and attach the 117-volt hot and neutral leads to it. The ground lead is soldered to a solder lug bolted to the base plate. Make the ground wire longer than the others so that this lead will be the last to break if the power-cord is pulled out.

Final assembly

With the base panel wiring completed, connect the 9-conductor ribbon cable from P1 on the control board to P2 on the foil side of the main PC board. Then make the connections between the high-voltage power supply, the 15–0–15 tap on T1, and the main PC board.

Use heavy duty cable—16 gauge or greater—for the ±65-volt power-supply connections. Run separate leads from the terminals of the 8000-µF capacitors to each power amplifier.

The chassis can now be assembled. The first step is to secure the base panel to the heatsinks using six machine screws. Four adhesive rubber feet can then be fitted in the corners.

Secure the power cord in place using a grommet, then fasten the rear panel to the heatsinks and to the base panel.

Next secure all loose switches to the front panel, and then attach it to the main assembly.

Then mount the front panel and make sure that the switches, the LED's, the potentiometers, and the headphone socket line up with the panel holes correctly. It may be necessary to shift the control board to one side or the other slightly to ensure that the switches align with the holes in the front panel. The front panel is secured to the heatsinks using countersunk, painted, self-tapping sheet-metal screws. Finally, nuts can be threaded onto the shafts of the potentiometers, and the knobs can be press-fitted.

Testing

STOP! Before going further, carefully check your work against the wiring and parts-placement diagrams.

Assuming everything checks out, remove the four five-amp fuses and apply power, but do not connect any signal sources or loudspeakers yet. One or more LED's on the front panel should light up immediately after power is applied.

Using your multimeter, check the outputs of the power supply. You should be able to measure ±65 volts at the fuse clips. Pins 7 and 4 of each op-amp should have +15 and −15 volts, respectively, and pins sixteen and seven of the CMOS switches should have +7.4 and −7.5 volts, respectively. The +8-volt supply can be checked by measuring the voltage at the output of the 7805 (IC10). That voltage can be reduced if necessary by reducing R29 from 130 to 120 ohms. If any supply voltage differs by more than 10% from its nominal value, remove power immediately and locate the fault.

When all power-supply voltages are correct, measure the voltages at several critical points in the circuit. There should be about 4.8 volts across R120, the 2.7K current-limiting resistor connected to the drain of Q104, which is the FET constant-current source in the phono preamplifier. Also, there should be about 4.9 volts across the collector of each transistor (Q100–Q103) in the input stage of the phono preamplifier. Those voltages should also be present in the corresponding right-channel components (R220 and R200–Q203).

In the power amplifier stages, there should be 0.6 volt across R147, the 680Ω emitter resistor of Q107. You should also measure about −55.5 volts at the collectors of Q105 and Q106. In addition, you should measure about 0.6 volts across R154, the 100Ω emitter resistor of Q108. Those voltages should also be present in the corresponding right-channel components (R247, Q205, Q206, and R254). If any of the voltages you measure differ by more than 10% from the values given, track down the source of the problem before continuing.

Setting quiescent current

When all voltages are correct, remove power and monitor the +65-volt supply at F100. After the supply falls below +5 volts, install a fuse there. Then connect a 1-amp ammeter F101's fuse clips. Rotate R156 fully counter-clockwise, and then apply power. Adjust R156 so that the meter indicates a current of 100 mA.

Remove power, and then wait two minutes for the voltage to drop. Remove the meter and install a fuse there. Repeat the procedure for the right-channel.

Now check the operation of the control switches. The LED associated with each switch should illuminate as that switch is pressed; no other LED in that section of the front panel should be lit. Also test the MONITOR and DUBBING switches and LED's.

Next, the Ni-Cd battery pack can be connected. Use a small rectangle of double-sided adhesive tape to secure the battery pack to the PC board. With the batteries in place, make sure that the switch settings are stored when power is removed. Note that the stored settings will change if the switches are pressed while power is off.

If the switches do not operate correctly, check the power supply connections to the IC's on the control board. If the correct voltages appear, then the problem possibly lies with the digital control lines from the control board to the main board.

Finally, connect a pair of loudspeakers, apply power, and listen for hum or other unpleasant sounds. If everything is working correctly, you should hear only a very slight amount of hum when the PHONO input is selected and the VOLUME control is fully advanced. Connect a tuner or a turntable and verify that the VOLUME, BASS, TREBLE, and TONE controls work correctly. Similarly, verify that the SPEAKER, STEREO/MONO, and MUTE switches all work correctly. Make sure signals from each of the four main inputs (PHONO, CD, TUNER, and AUX) can be heard through the speakers. Last, connect a pair of tape recorders to the appropriate jacks and verify that the MONITOR and DUBBING switches work correctly. **R-E**

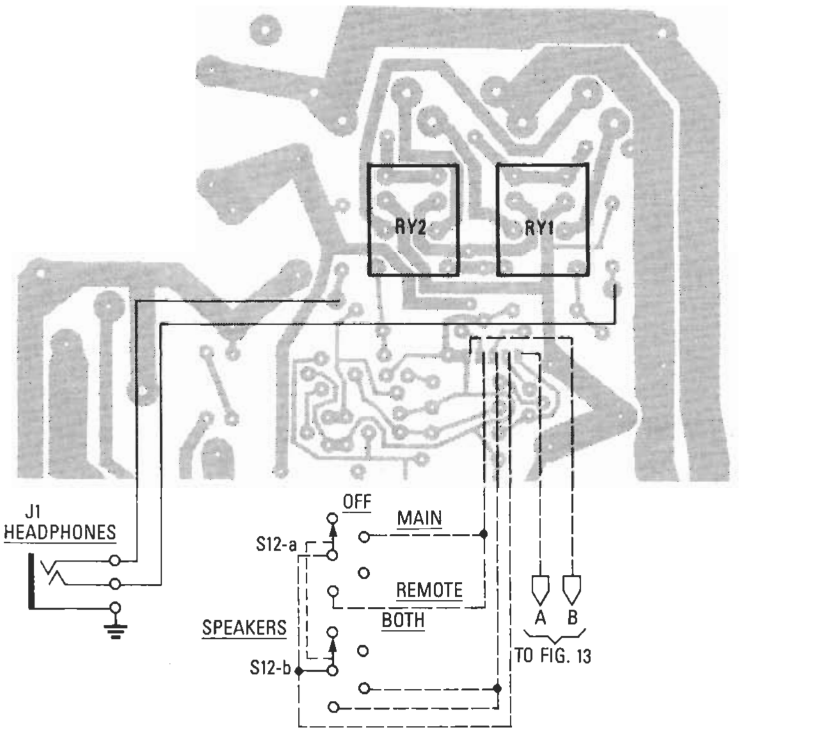
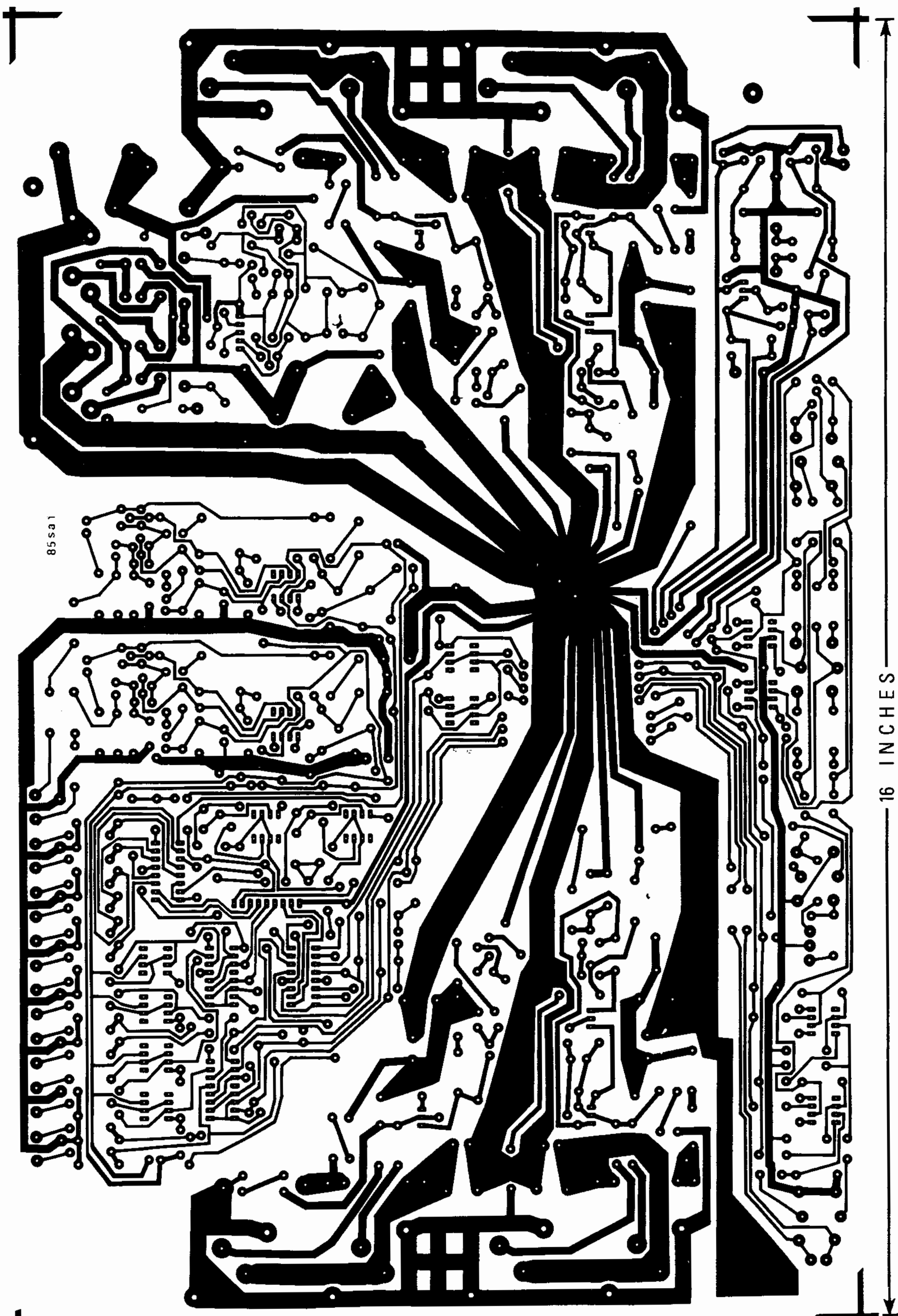


FIG. 14—THE LEFT REAR CORNER OF THE MAIN BOARD is shown here. The headphone jack (J1), the speaker switch (S12), and two jumpers are wired to the row of pads in front of the relays. The wires to J1 are routed above the PC board; the remainder are routed below the board.

ORDERING INFORMATION
Note: The following components are available from Dick Smith Electronics, Inc., P.O. Box 8021, Redwood City, CA 94063; 800-332-5373 (orders) 415-368-8844 (inquiries). Complete kit of all parts (No. K-3516) including PC boards, heatsinks, screened front and rear panels, and transformer T1, $299 plus $10 shipping. Separate components: set of two PC boards (No. KH-0106), $49.00; 2SC2545 transistor (No. KZ-1683), $0.39 each; 2SK134 transistor (No. Z-1815), $4.50; 2SJ49 transistor (No. Z-1816), $4.50; transformer T1 (No. KM-2000), $57.00; case including panels and heatsinks (No. KH-2700), $115. All component orders must add $1.50 for handling plus 5% of total price. California residents must add 6.5% sales tax. Orders outside U.S. must include U.S. funds and add 15% of total price for shipping.

PC SERVICE



BECAUSE OF ITS LARGE SIZE, the PC pattern for the main board of the FET power amp is shown here half sized. Also, the board is shown as a direct (*not* X-ray) view. Thus, the pattern *can not be used directly to etch a board.*

One of the most difficult tasks in building any construction project featured in **Radio-Electronics** is making the PC board using just the foil pattern provided with the article. Well, we're doing something about it.

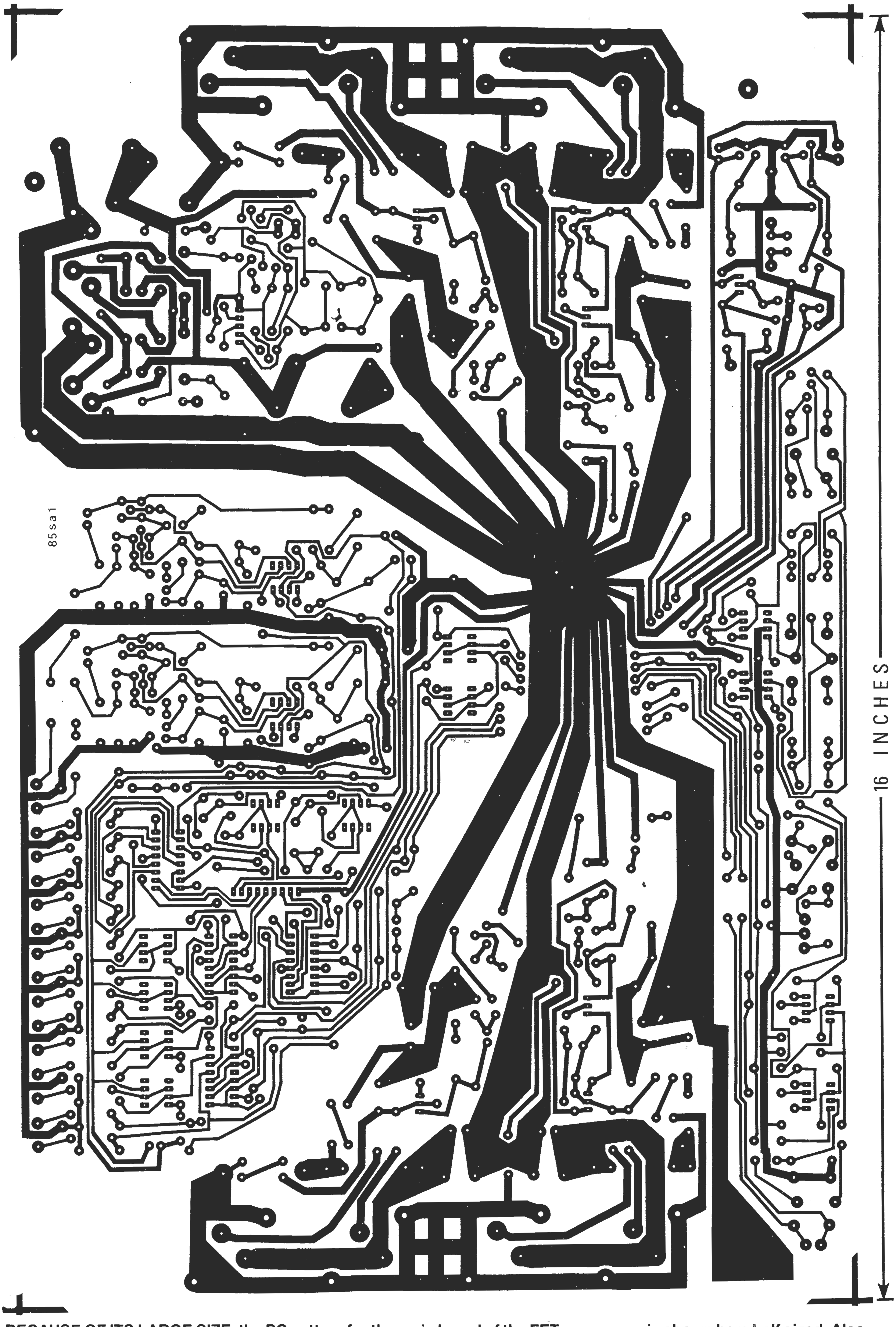
We've moved all the foil patterns to this new section where they're printed by themselves, full sized, with nothing on the back side of the page. What that means for you is that the printed page can be used directly to produce PC boards!

Note: The patterns provided can be used directly only for *direct positive photoresist methods.*

In order to produce a board directly from the magazine page, remove the page and carefully inspect it under a strong light and/or on a light table. Look for breaks in the traces, bridges between traces, and in general, all the kinds of things you look for in the final etched board. You can clean up the published artwork the same way you clean up you own artwork. Drafting tape and graphic aids can fix incomplete traces and doughnuts, and you can use a hobby knife to get rid of bridges and dirt.

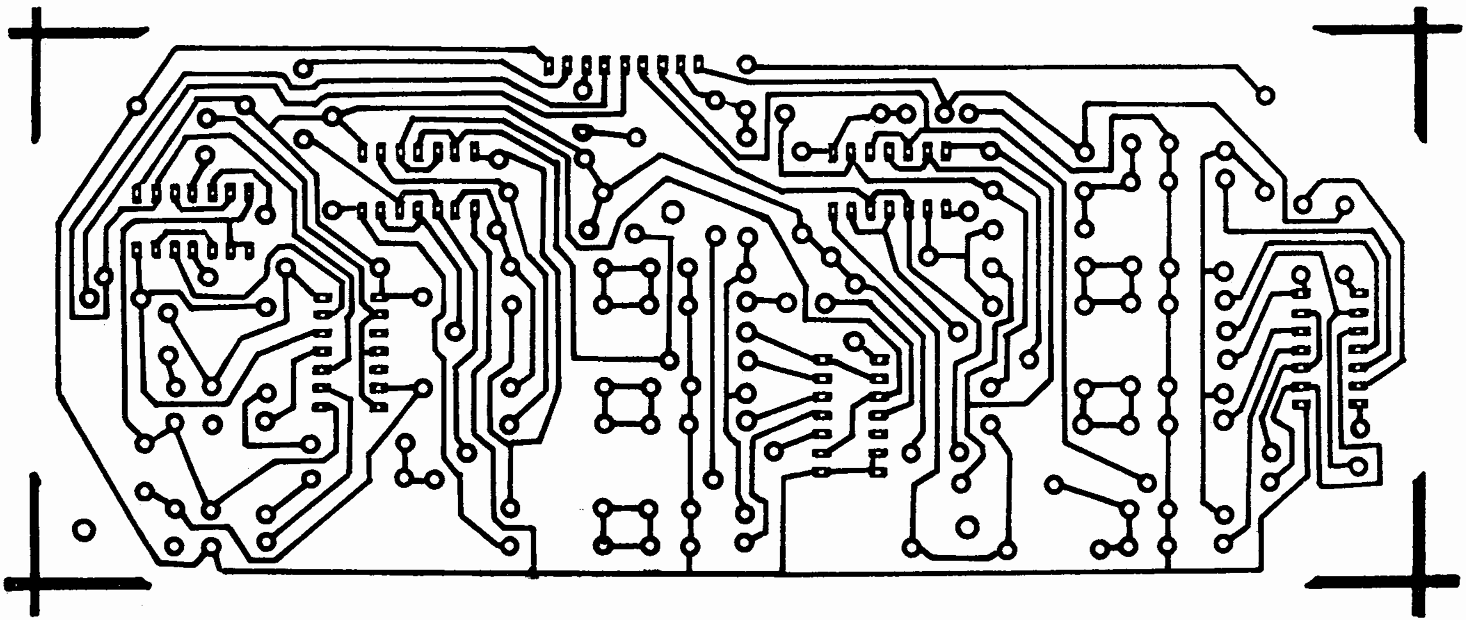
An optional step, once you're satisfied that the artwork is clean, is to take a little bit of mineral oil and carefully wipe it across the back of the artwork. That helps make the paper translucent. Don't get any on the front side of the paper (the side with the pattern) because you'll contaminate the sensitized surface of the copper blank. After the oil has "dried" a bit—patting with a paper towel will help speed up the process—place the pattern front side down on the sensitized copper blank, and make the exposure. You'll probably have to use a longer exposure time than you are probably used to.

We can't tell you exactly how long an exposure time you will need but, as a starting point, figure that there's a 50 percent increase in exposure time over lithographic film. But you'll have to experiment to find the best method for you. And once you find it, stick with it. Don't forget the "three C's" of making PC boards—care, cleanliness, and consistency.



BECAUSE OF ITS LARGE SIZE, the PC pattern for the main board of the FET power amp is shown here half sized. Also, the board is shown as a direct (*not* X-ray) view. Thus, the pattern *can not be used directly to etch a board.*

PC SERVICE



7-1/4 INCHES

THE CONTROLLER BOARD for the FET power amplifier can be built using this single-sided PC board. The pattern for the main board is shown on page 64.

COMPONENTS NOT SHOWN

I have been looking over your articles on the FET Stereo Amp presented in the June, July, and August issues, and I plan on building it, little by little. I am no expert in electronics, but it seems to me that you forgot to show where C238, C239, and R220 were supposed to be placed in Fig. 13 of the August installment. I would also like to know whether I should use 25- or 50-volt capacitors for C132 and C232.

TODD AUSMAN
LaCrosse, WI

In the right-channel preamp,

R220 mounts in the unused pads beneath Q200 and Q201. In the right-channel power amp, power-supply bypass capacitors C238 and C239 mount in the unused pads beneath Q209. Viewing the board from the component side, mount C238 to the right of D207, horizontally, with the + side to the right. Mount C239 to the right of C238, vertically, more or less in line with R255. Use 50-volt devices for C132 and C232.—Editor.