Construct a Wide Bandwidth Preamplifier

W. Marshall Leach*

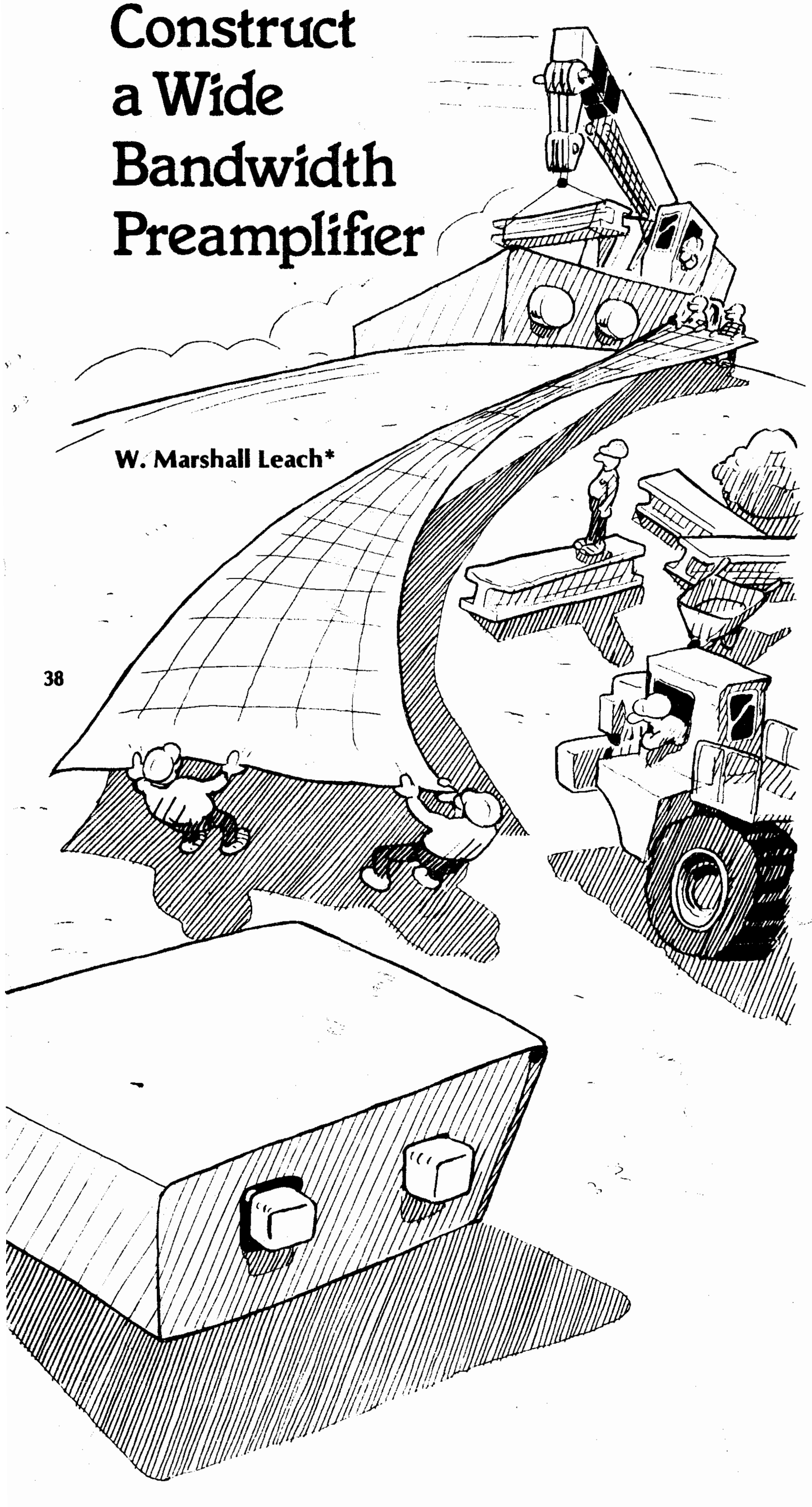


Illustration by Richard Weiss

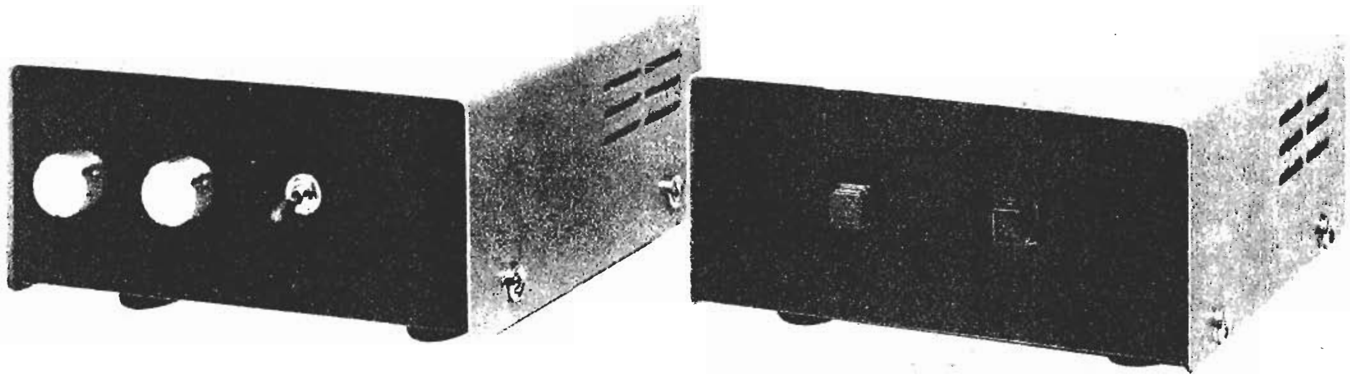
Some of the most important functions in the signal processing chain of a sound reproduction system are performed by the phono preamplifier. This circuit must amplify signals from millivolt level to peak levels of two to three volts or more in order to drive a power amplifier. In addition, the circuit must equalize the signal to correct for a nonuniform frequency response which can vary by as much as 40 dB over the 20 Hz to 20,000 Hz frequency band. It must do this while introducing a minimum amount of electronic noise, and it must contend with a phono cartridge whose output impedance can vary by as much as a factor of 60 to one over the audio band.

Of particular importance are the high-frequency and transient overload characteristics of the preamplifier. Before a signal enters the preamp input, it has been processed by the RIAA recording equalizer, the constant velocity disc recording process, and the time derivative response of the magnetic playback cartridge. The combination of these three can create input signal levels which are 100 times as great at 20,000 Hz than at 20 Hz. In addition, record ticks and pops, when processed by the time derivative response of the playback cartridge, can contain high-frequency components whose amplitudes far exceed those of normal signal levels. Thus, the high-frequency overload characteristics of the preamplifier become very important considerations if transient IM distortion and slew-rate distortion are to be minimized.

This article describes an RIAA phono preamplifier primarily designed with these considerations in mind, and the author's unit is shown. It uses a separate chassis for the power supply to eliminate hum induced by inductive coupling from the power transformer. At a one volt rms output level, the preamplifier's SMPTE IM distortion measures 0.004%. Its A-weighted signal-to-noise ratio is 84 dB referenced to a 10 mV input signal at 1000 Hz, which could be improved if low-noise, metal-film resistors were employed in the critical input stages.

The output circuit used to drive the power amplifier output has a 10-dB gain to insure that the power amplifier is driven to full output power. This stage has a Butterworth-aligned high-pass filter characteristic which has

*Assistant Professor,
School of Electrical Engineering,
Georgia Institute of Technology,
Atlanta, Georgia 30332



been designed to reject subsonic and inaudible frequency components below 15 Hz, which can result from record warp, offset center holes in records, turntable rumble, and acoustic feedback. In particular, vented-box loudspeaker systems using high compliance drivers are very susceptable to overdrive by subsonic signals. The rejection of these signals can produce a marked improvement in loudspeaker performance plus a decrease in power dissipation in the power amplifier. An added advantage provided by the subsonic filter circuit is the protection of the loudspeaker and power amplifier from low-frequency transients which can occur when a tonearm is accidentally dropped on a record or when an FM tuner is rapidly tuned across the band. In both cases, low-frequency loudspeaker cone motion is reduced to a minimum to prevent possible driver suspension damage or power amplifier failure.

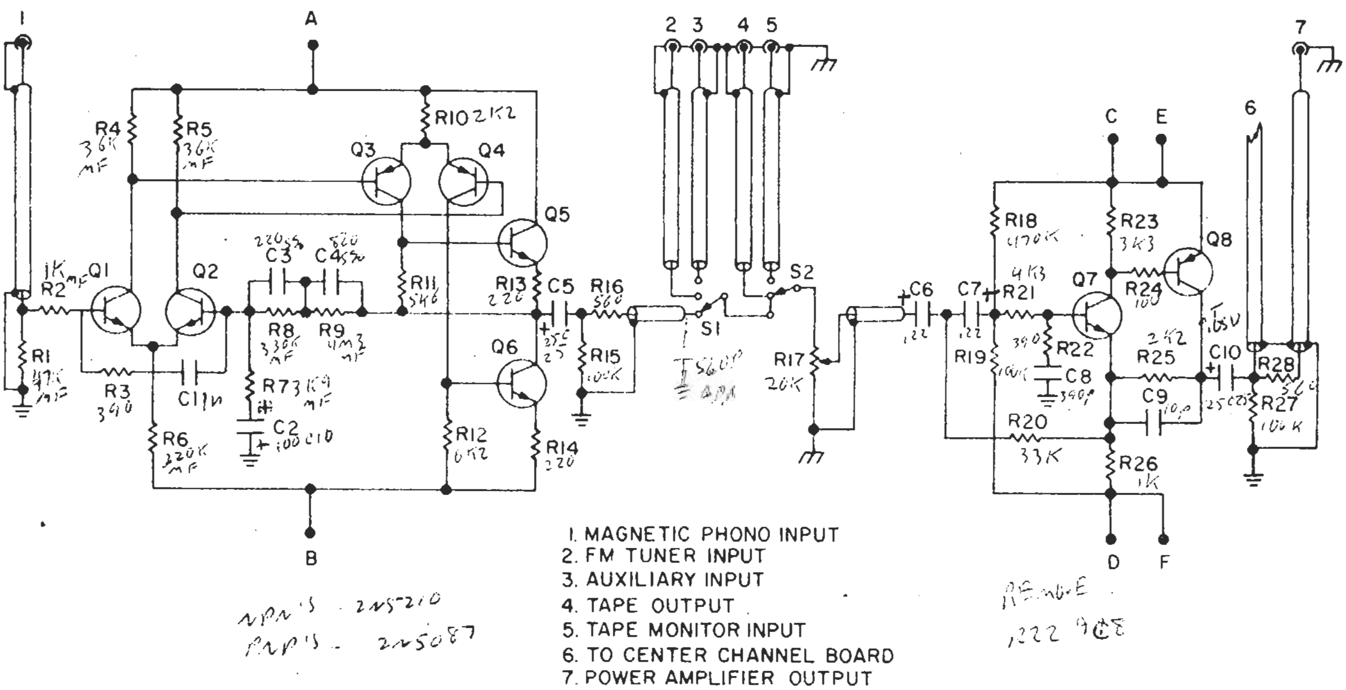
An optional center-channel circuit is described which can be used to drive a front center-channel amplifier and speaker system. A three-channel system has long been advocated by Paul W. Klipsch as representing the closest approach to true realization of sound reproduction. The circuit is simple and can be added to the preamplifier at any time.

Circuit Description

The circuit diagram of the preamplifier minus the power supply and optional center-channel circuit is shown in Fig. 1. It has input switching facilities for magnetic phono, FM tuner, and auxiliary inputs, and outputs for tape recorder and power amplifier. In addition, a separate tape monitor switch is provided for tape input. The volume is controlled by a potentiometer which effects only the signal level to the output stage which drives the power amplifier output jack. The circuit uses positive and negative balanced power supplies which are separately regulated by zener diodes for each stage.

The phono preamplifier circuit consists of transistors Q1 through Q6. An initial design used passive equalization between the cartridge and the input stage to equalize for the 75 microsecond pre-emphasis in the RIAA

Fig. 1—Circuit diagram of the preamplifier minus power supply and center-channel circuit.



recording characteristic. This would have greatly reduced the high-frequency overload characteristics required in the phono preamplifier circuit. However, the approach was abandoned because of the uncertainty in the interaction of the output impedance of the phono cartridge and the input impedance of the circuit and because of noise considerations. Transistors Q1 and Q2 form an input differential amplifier. The differential amplifier configuration was suggested by Meyer [1] in 1972 for use as a preamplifier input stage. It has been suggested more recently by Holman [2] in a circuit similar to the one published by Meyer. Q1 and Q2 are biased by R6 at 50 microamperes each. This low bias current is necessary to provide low noise performance since the input stage determines the signal-to-noise ratio of the preamplifier. A potential problem associated with differential amplifiers is that of maintaining a balanced quiescent current in the two transistors. With the aid of a microammeter, the components in Fig. 1 have been chosen to insure that Q1 and Q2 are conducting balanced or equal quiescent currents. This insures optimum distortion characteristics of the input stage since the predominant second-order nonlinearities in the base-to-emitter junction characteristics of Q1 and Q2 theoretically cancel when the bias currents in the two transistors are the same.

The output signal from the input differential amplifier is applied to a second differential amplifier which consists of transistors Q3 and Q4. In addition to supplying a second stage of voltage gain, the differential connection of Q3 and Q4 provides the very important cancellation of any common-mode noise from the input stage due to thermal noise generated by the emitter bias resistor R6. Without this feature, the signal-to-noise ratio that is established by the input stage would be inferior to that which could be achieved by employing a single-ended input stage rather that the differential configuration [3]. The signals from Q3 and Q4 drive the class-A, push-pull output stage consisting of transistors Q5 and Q6. These transistors provide the current gain necessary to drive the feedback network and the following stages of the preamplifier. Since Q5 and Q6 operate in a true class-A mode, there is nothing to be gained from the added complexity necessary to drive a complementary output stage.

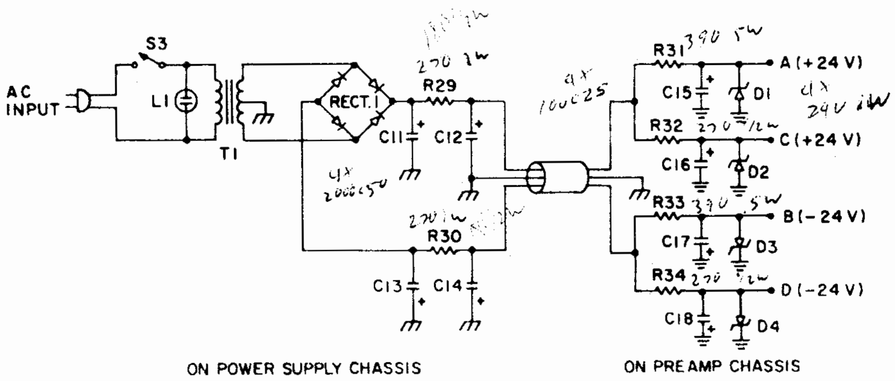


Fig. 2—Power supply circuit diagram. Note that not all components are mounted on the power supply chassis.

The feedback network consists of resistors R7 through R9 and capacitors C2 through C4. The resistors in this network have been chosen so that the closed-loop gain at 20 Hz is 60 dB, more than 20 dB lower than the open-loop gain of the preamplifier. Thus, a low-frequency feedback ratio of greater than 20 dB insures an extended low-frequency response with low distortion characteristics. C2 has been chosen so that the lower minus 3-dB frequency of the phono preamplifier circuit is less than 1 Hz. If the circuit is used to drive a power amplifier without the 10-dB gain output circuit, it is recommended that C2 be changed from 100 microfarads to 5 microfarads in order to provide some rejection of unwanted subsonic signals. With this change, the minus 3-dB lower frequency of the phono preamplifier will be moved up to 8 Hz.

The time constants for the RIAA equalization are set by R8, R9, C3, and C4. Since the open-loop gain and bandwidth of the phono preamplifier will also effect the RIAA equalization, these elements cannot be calculated precisely, rather they must be determined experimentally for optimum equalization. The approach taken in the present case was to first calculate these components from network theory under the assumptions of an infinite open-loop gain and bandwidth and zero output impedance. The elements were then tuned experimentally to optimize the equalization. This was done with the aid of the passive inverse-RIAA equalization circuit recommended by Audio Research for the testing of preamplifiers. The experimental tuning procedure was performed by exciting the preamplifier from a General Radio pink noise source through the inverse-RIAA equalizer. The output of the preamplifier was then monitored on a Hewlett-Packard real-time spectrum analyzer, and the feedback network elements were tuned for the flattest overall equalization. The transient response of the preamplifier was also monitored during this process with a square wave input signal through the inverse-RIAA equalizer to insure that the square wave response was also being optimized.

The overload characteristics of the magnetic phono input circuit are adequate to insure that it will not be driven into clipping or slewing during normal use. This circuit will put out a

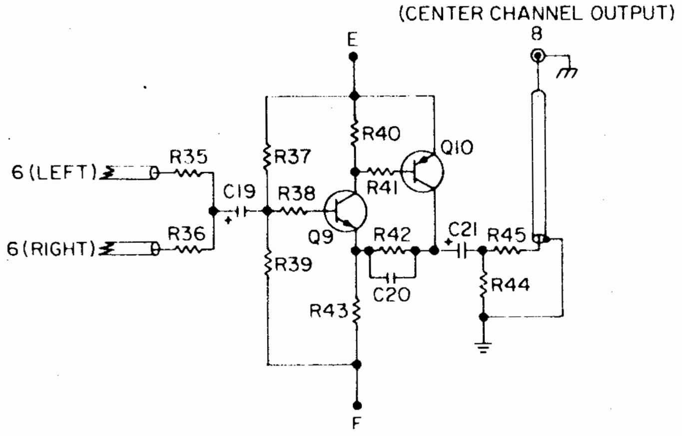


Fig. 3—Center-channel circuit diagram.

40-volt peak-to-peak sine wave signal up to a frequency of 120 kHz, and its clipping characteristics are symmetrical under these conditions. The overload margin of a preamplifier is an important consideration, especially at high frequencies. Although limitations in disc recording make it impossible to cut large amplitude high-frequency signals on records, the output of a magnetic cartridge increases with frequency at 6 dB per octave because of its time derivative response. Normal frequency response plots for cartridges do not show this since the plots are corrected for it. However, phono preamplifiers must handle the boosted high frequencies without overload or slewing. Record ticks and pops are impulsive in nature, and thus they contain very broadband frequency spectra. In combination with the rising frequency response characteristics of the cartridge, they can easily cause high-frequency overload, transient IM distortion, and slew-rate distortion if the high-frequency overload characteristics of the phono preamplifier are not adequate. In addition, four-channel discs recorded with the CD-4 process can cause surprisingly large high-frequency subcarrier signals at the cartridge output, even if it is not designed for CD-4 use. Although preamplifiers are not designed to put out appreciable signals at these frequencies, the high-frequency overload margin in any circuit which uses negative feedback for equalization can be seriously degraded. Thus, it is the author's opinion that CD-4 discs are best used with only CD-4 equipment.

The output of the phono preamplifier is fed through the input switching facilities in Fig. 1 to a 20-kilohm volume control. When the tape monitor switch is in the normal mode, the input impedance to any tape deck connected to the tape output jack appears in parallel with the volume control. It is recommended that only a high impedance tape deck be used with the tape output, otherwise, the total load impedance on the preamplifier circuit may drop too low.

The volume control drives the output stage which consists of transistors Q7 and Q8. The gain of this circuit is set at 10 dB by resistors R25 and R26. The circuit is designed to have an active-filter, Butterworth high-pass alignment which is flat above 20 Hz. It exhibits a 12-dB-per-octave rolloff below its 3-dB cutoff frequency of 14 Hz. The alignment of this filter is set by C6, C7, R18, R19, and R20. Substitute

PARTS LIST

Parts List for one channel. All resistors are ¼ watt, 5% unless otherwise specified. Resistors should be carbon film rather than carbon composition unless otherwise specified.

R1 47 kilohm, metal film
R2 1 kilohm, metal film
R3 390 ohm
R4, R5 36 kilohm, metal film
R6 220 kilohm, metal film
R7 3.9 kilohm, metal film
R8 330 kilohm, metal film
R9 4.3 megohm, metal film
R10 2.2 kilohm
R11 5.6 kilohm
R12 6.2 kilohm
R13, R14 220 ohm
R15 100 kilohm
R16 560 ohm
R17 20 kilohm, dual potentiometer
R18 470 kilohm
R19 100 kilohm
R20 33 kilohm
R21 4.3 kilohm
R22 390 ohm
R23 3.3 kilohm
R24 100 ohm
R25 2.2 kilohm
R26 1 kilohm
R27 100 kilohm
R28 560 ohm
R29, R30 270 ohm, 1 watt
R31, R33 390 ohm, ½ watt
R32, R34 270 ohm, ½ watt (200 ohm, ½ watt with center-channel circuit)
R35, R36 91 kilohm
R37 68 kilohm
R38 3.3 kilohm
R39 5.6 kilohm
R40 3.3 kilohm
R41 100 ohm
R42 3.6 kilohm
R43 430 ohm
R44 100 kilohm
R45 560 ohm

C1 0.001 μF, 100 volt, ceramic capacitor
C2 100μF, 10 volt, electrolytic capacitor
C3 220 pF, 100 volt, 5% silver mica capacitor
C4 820 pF, 100 volt, 5% silver mica capacitor
C5 25 μF, 25 volt, electrolytic capacitor
C6, C7 0.22 μF, 25 volt, 5% ceramic capacitor
C8 390 pF, 100 volt, ceramic capacitor
C9 10 pF, 100 volt, ceramic capacitor
C10 25 μF, 25 volt, electrolytic capacitor
C11, C12, C13, C14 2000 μF, 50 volt, electrolytic capacitor
C15, C16, C17, C18 100 μF, 25 volt, electrolytic capacitor
C19 25 μF, 25 volt, electrolytic capacitor
C20 10 pF, 100 volt, ceramic capacitor
C21 25 μF, 25 volt, electrolytic capacitor

Q1, Q2, Q5, Q6, Q7, Q9 2N5210 transistor
Q3, Q4, Q8, Q10 2N5087 transistor

S1 3-position, rotary selector switch (stereo)
S2 double-pole, single-throw toggle switch
S3 single-pole, single-throw toggle or pushbutton switch
L1 120 volt a.c. neon pilot lamp with dropping resistor
T1 Stancor P8605 transformer (Use Output Taps 2 and 3)
Rect. 1 bridge rectifier, 1 amp, 100 volt PIV
D1, D2, D3, D4 24 volt, 1 watt Zener diode

Miscellaneous Two chassis and covers, phono jacks, power cord, phone jacks and plugs, shielded cable, knobs, screws, nuts, lockwashers, circuit board standoffs (conducting), heat sinks for Q8 and Q10, terminal strips, etc.

Printed circuit boards and matched transistors for the preamplifier are available for a limited time. Prices are $10 for a set of stereo boards for the RIAA circuits and output circuits, $5 for the center-channel board, and $1.50 for a matched pair of 2N5210 or 2N5087 transistors, plus $1 shipping and handling. Address orders to Components, P.O. Box 33193, Decatur, Ga. 30033.

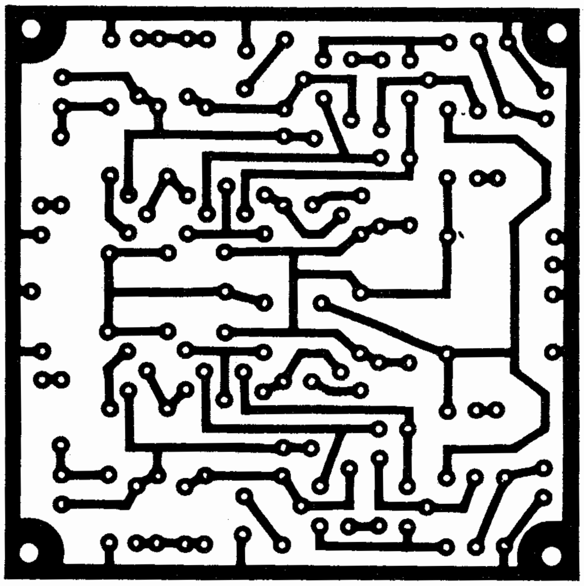


Fig. 4—(a) Circuit board foil pattern for the RIAA input board.

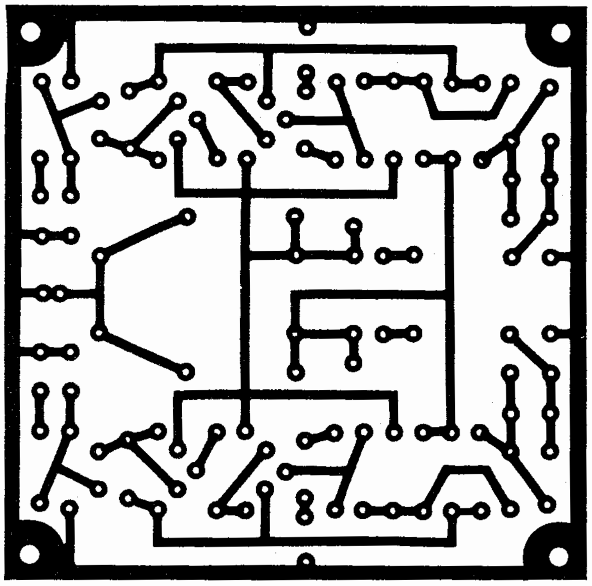


Fig. 4—(b) Circuit board foil pattern for the output board.

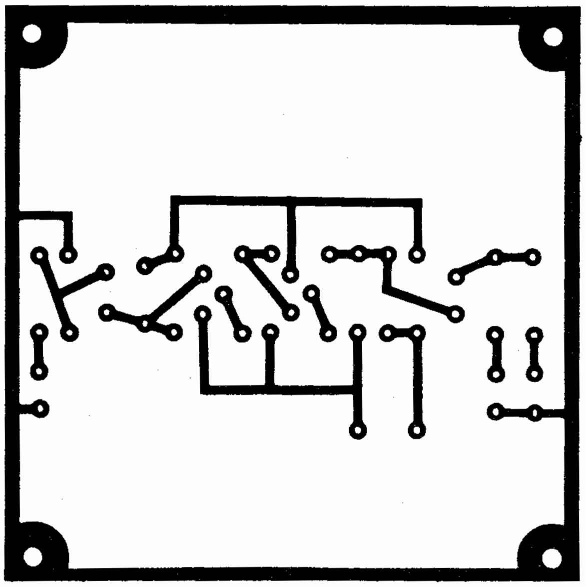


Fig. 4—(c) Circuit board foil pattern for the center channel board.

values should not be used for these elements. The lead compensation provided by C9 in combination with the low-pass filter formed by R21, R22, and C8 suppresses any transient IM distortion and slew-rate distortion in this stage [4]. Power supply terminals E and F and signal output 6 on the output stage diagram are used with the optional center-channel output circuit described in the following.

The power supply for the complete preamplifier is shown in Fig. 2. By isolating the power supply on a separate chassis, any inductive hum coupling from the power transformer is eliminated. With this arrangement, there is no measurable hum in the preamplifier unless it is picked up by a ground loop in the input or output cables. The resistor values for R31 through R34 must be chosen correctly for proper bias of the zener diode regulators D1 through D4. The value for R31 and R33 is 390 ohms. The value for R32 and R34 is 270 ohms if the center-channel circuit is not used and 200 ohms if it is.

The optional center-channel output circuit is shown in Fig. 3. This circuit is designed so that the center-channel output is 6 dB below either input with only one channel driven. The two inputs are linearly added so that for equal left and right inputs, i.e. center-front channel, the gain of the circuit is unity. If the two inputs are equal in amplitude but 180° out of phase, i.e. center-rear channel in matrix quadraphonic systems, the center-channel output is zero. If desired, a 20-kilohm volume control can be used at the center-channel output. However, this is not necessary if the center-channel power amplifier and loudspeaker system are the same as those used for the left and right channels or if the center-channel amplifier has a volume control. In the former case, the center-channel output will be at the correct level since it tracks the left and right volume controls.

Construction Details

The preamplifier has been designed with separate 3 inch by 3 inch circuit boards for the phono input stage, the output stage, and the center-channel circuit. The circuit board foil patterns for these circuits are given in Fig. 4. The views in this figure are from the foil side of the boards, i.e. the side opposite to that on which the components are mounted. The foil patterns in Fig. 4 are full scale so that printed circuit boards can be reproduced from the layouts without enlargement.

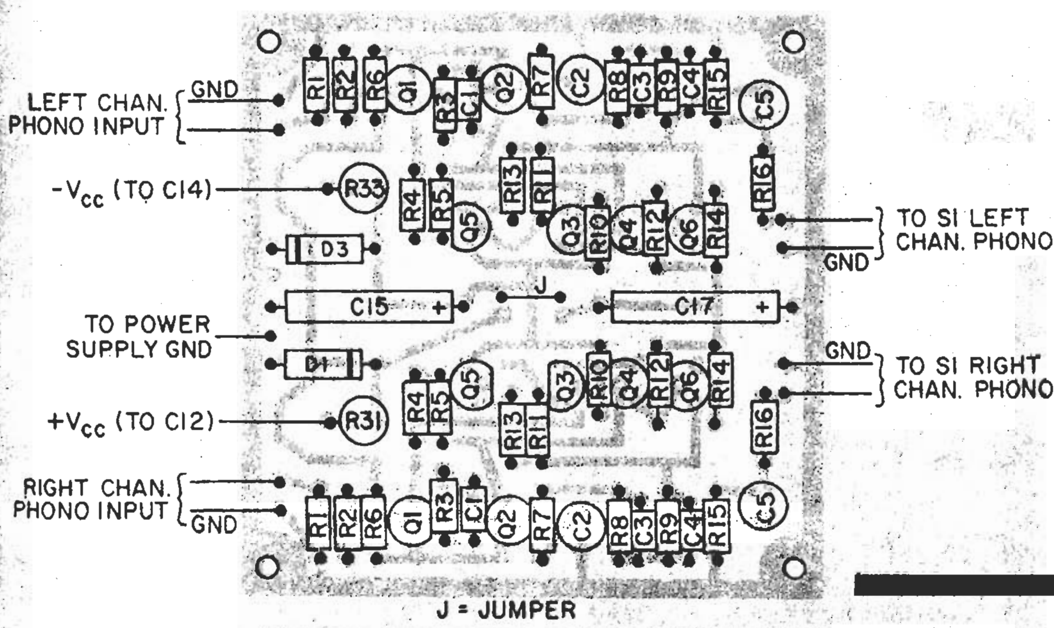


Fig. 5—(a) Component layout for the RIAA input stage.

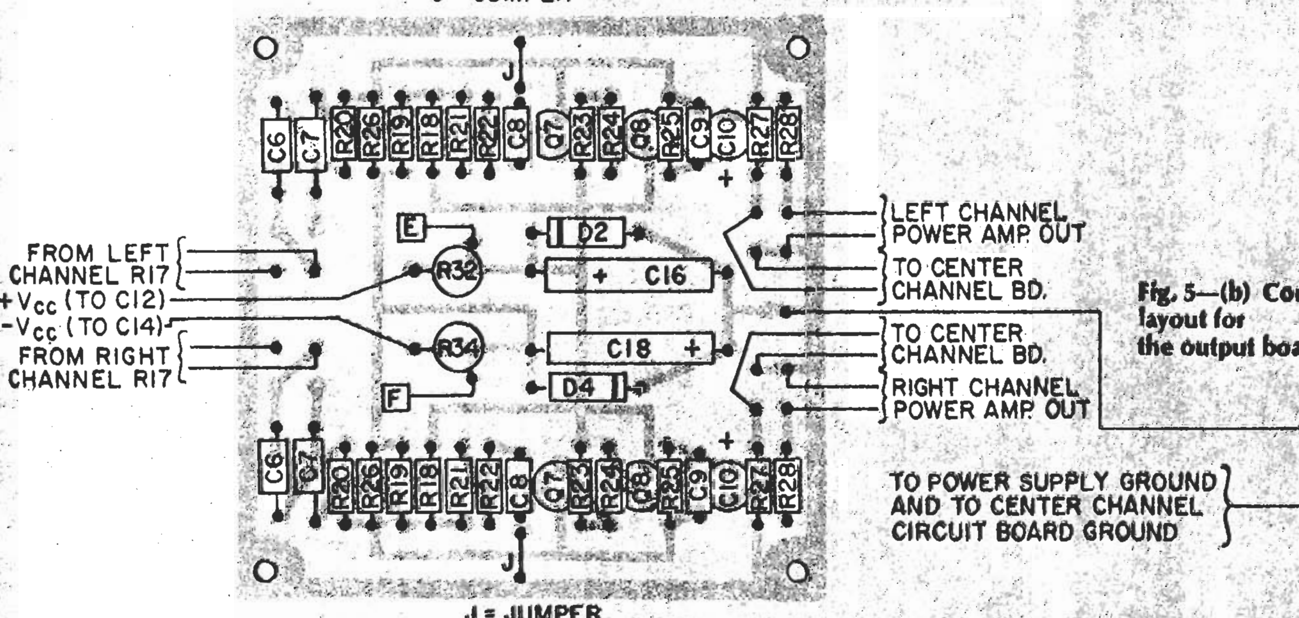


Fig. 5—(b) Component layout for the output board.

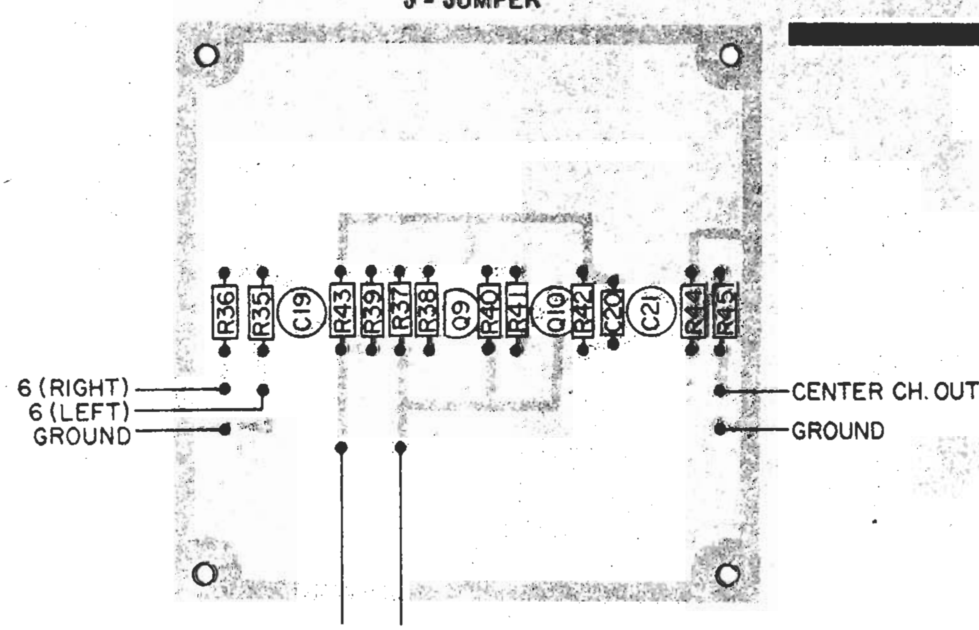


Fig. 5—(c) Component layout for the center channel board.

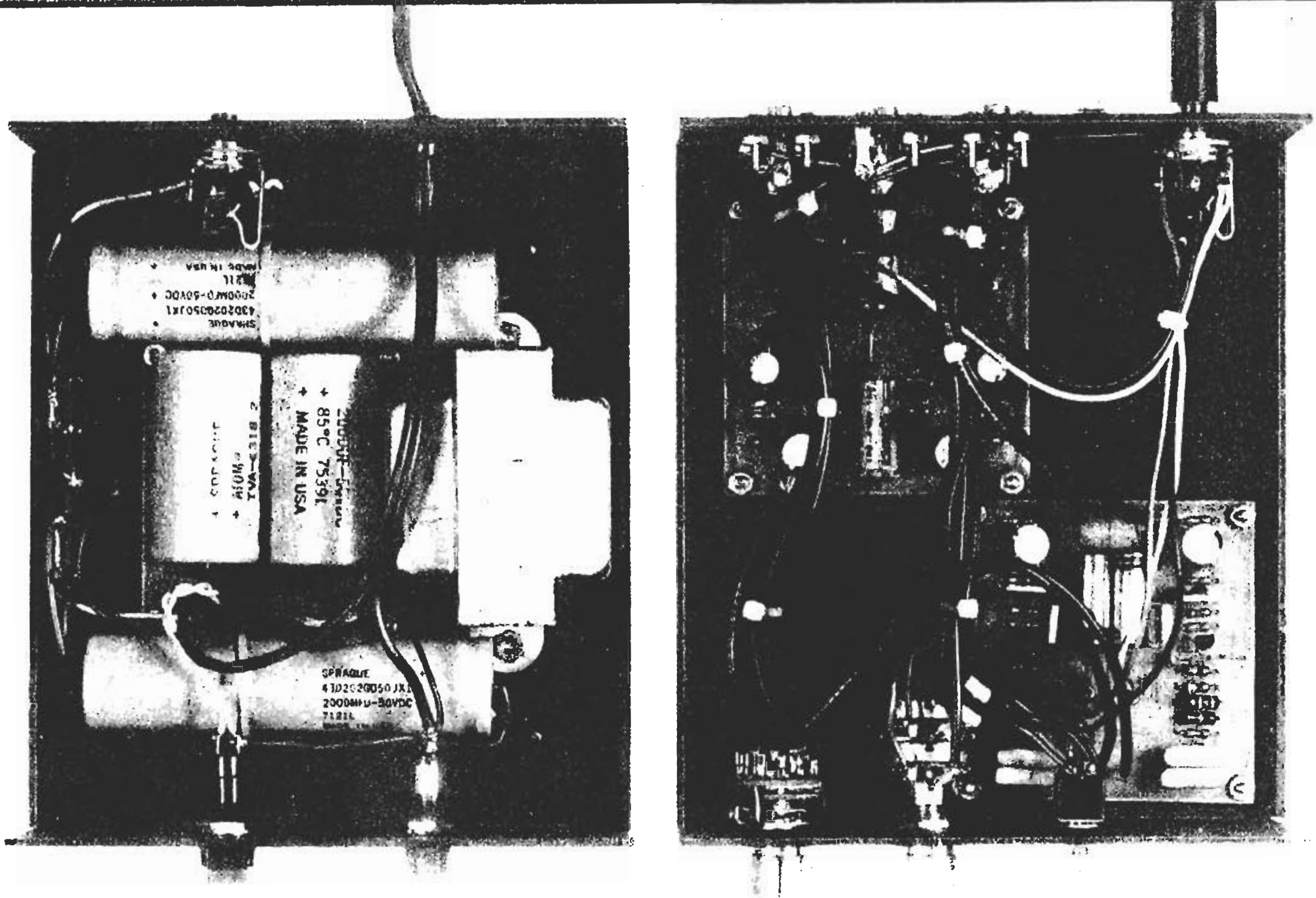
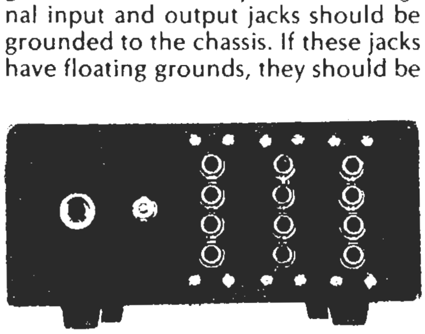


Fig. 6—Photograph of the chassis wiring in the author's preamplifier.

The component layouts for the three circuit boards are given in Fig. 5. The view in these figures is from the component side of the boards, i.e. the side opposite from the foil circuit. There are no special instructions for mounting the components on the circuit boards. It is recommended that the transistor leads be inserted no more than ¼ inch through the boards before soldering. This will prevent any heat damage from the soldering iron due to excessive heat conduction through transistor leads which are too short. Normal precautions should be taken to insure that all transistors, electrolytic capacitors, and diodes are inserted correctly. Otherwise, failure could result at turn on.

After all components are mounted and soldered to the boards, the next step is to solder all input and output cables and all power supply leads to each board. It is recommended that only shielded cable be used for signal input and output leads. No. 22 stranded wire should be used for the power supply leads. The connection of cable grounds illustrated in Figs. 1 and 3 should be adhered to if ground loops are to be avoided. The figures show that the shielded cable grounds are not connected at the signal inputs of either the output circuit board or the center channel board or at the tape output or power amplifier output jacks.

The main chassis should be drilled for the input selector switch, volume control, tape monitor switch, power input jack, signal input and output jacks, the circuit board mounting holes, and the external ground lug connection. The latter can be a 6-32 by ½ inch screw attached to the chassis with a No. 6 nut and an inside star lockwasher. The screw should be installed near the phono input jacks with its head inside the chassis and with a second nut loosely screwed down over the first nut outside the chassis. The jacks for the magnetic phono inputs should have floating ground terminals, i.e. they are not grounded to the chassis. All other signal input and output jacks should be grounded to the chassis. If these jacks have floating grounds, they should be connected to ground through a common ground bus which connects to chassis ground through a securely tightened lockwasher grounding lug. One end lug on the volume control for each channel is grounded to chassis through a lockwasher grounding lug mounted concentric with the volume control shaft. The end lug to be grounded is that one which measures zero resistance to the center lug when the volume control is set fully counter-clockwise.



After the chassis hardware is mounted, the shielded cables from all input and output jacks which connect to the selector switch and tape monitor switch should be installed and soldered. Care should be taken when soldering the shielded cable grounds, for the heat can melt the inner cable insulation and cause the center conductor to short to ground. To minimize this possibility, the cable grounds should be soldered before the center conductors. In this way, the center conductors will not be flexed when the grounds are soldered.

The circuit boards can now be installed in the chassis as shown in Fig. 6. These should be mounted with a 3/8 inch No. 4 metal standoff under each corner with 4-40 by ¼ inch screws and No. 4 nuts. A No. 4 inside star lockwasher should be used *on each end* of each standoff to insure good connection of the circuit board grounds to chassis ground through each standoff. The mounting screws should be securely tightened so that the lockwashers will be firmly engaged. Once the circuit boards are mounted, the remainder of the chassis wiring can be connected. Once this is done, the cables should be neatly tied so that they do not run near the circuit boards. It is preferable to route the cables down along the chassis. However, if there is insufficient room, they can be routed over the circuit boards, as has been done in Fig. 6. The final step is to attach a ¼ inch by ½ inch heat sink made from 1/16 inch sheet aluminum to transistors Q8 and Q10. The heat sinks can be glued to the flat sides of the transistors with a small dab of contact cement. None of these transistors dissipate over 180 mW quiescently, while they are rated at 310 mW. However, the heat sinks are a worthwhile and effective protection measure which will improve the reliability of the preamplifier, especially if it is operated near heat producing equipment.

The power supply is wired as shown in Fig. 2. It should be noted that not all the components in this figure are mounted on the power supply chassis. The output power leads from the power supply chassis and the input power leads to the preamplifier chassis should be wired to a three-conductor phone jack, one conductor of which is grounded to its respective chassis. A six-foot length of three-conductor power cable with phone plugs attached to each end can then be used to connect the power supply to the preamplifier. The a.c. power cord to the power supply should be insulated from the chassis feed-through hole with a proper size strain relief or grommet. In the latter case, an insulated cable clamp should be used to secure the power cord inside the chassis to prevent its being pulled loose.

Check Out and Turn On Procedures

Before any power is applied to the preamplifier, the entire circuit should be carefully checked. Trouble points include diodes and electrolytic capacitors installed with the incorrect polarity, transistor leads reversed, poor ground connections to chassis (especially if the chassis is painted), cold solder joints, shorted cables, etc. After all wiring has been checked, the power supply can be checked out. With the preamplifier power cable disconnected, apply a.c. power to the power supply and measure the d.c. voltages on C11 through C14. These capacitors should have approximately 42 volts across them with no load. At this point, the polarity of the voltage across these capacitors should be checked to verify that none is installed backward. After the power supply unit is checked out, remove the a.c. power and connect the power cable between the power supply and the preamplifier chassis. If phone jacks and plugs are used for these connections, a slight spark may be noticed when the plugs are inserted if there is a charge stored on C12 and C14. Care should be taken to insert the phone plugs *fully* into the jacks. Otherwise, a short circuit to ground will occur and R29 and R30 will smoke when the a.c. power is turned on.

Before connecting any equipment to the preamplifier, power should be applied and the circuits should be checked out with a d.c. voltmeter. First, measure the voltages across C15 through C18. These should be exactly 24 volts. Next measure the voltages across C12 and C14. These should be 31.5 volts plus or minus 0.5 volts. If these voltages are not in this range, R29 and R30 should be changed to the next higher or lower value to respectively decrease or increase the voltage across C12 and C14. Next measure the voltages from ground to the junctions of C5 and R13, C10 and R25, and C21 and R42. These should be less than one volt. If not, a wiring error has been made or there is a defective component in the circuit.

Before connecting any equipment to the preamplifier, all a.c. power to the complete system should be turned off. Connect all inputs and outputs including the turntable ground wire which attaches to the No. 6 external grounding screw on the rear of the preamplifier chassis. Since there is a slight turn-on thump caused by the charging of capacitors in the circuit, the preamplifier should be turned on before the power amplifier. It can be left on if desired with no harm to the circuits. Normal precautions should be observed when using the preamplifier. These include never connecting or disconnecting an input or output cable with the power amplifiers turned on. Otherwise, an open ground connection can cause a large 60-Hz signal to be fed to the power amplifier when the phono jack is removed or inserted. Happy listening!

References

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