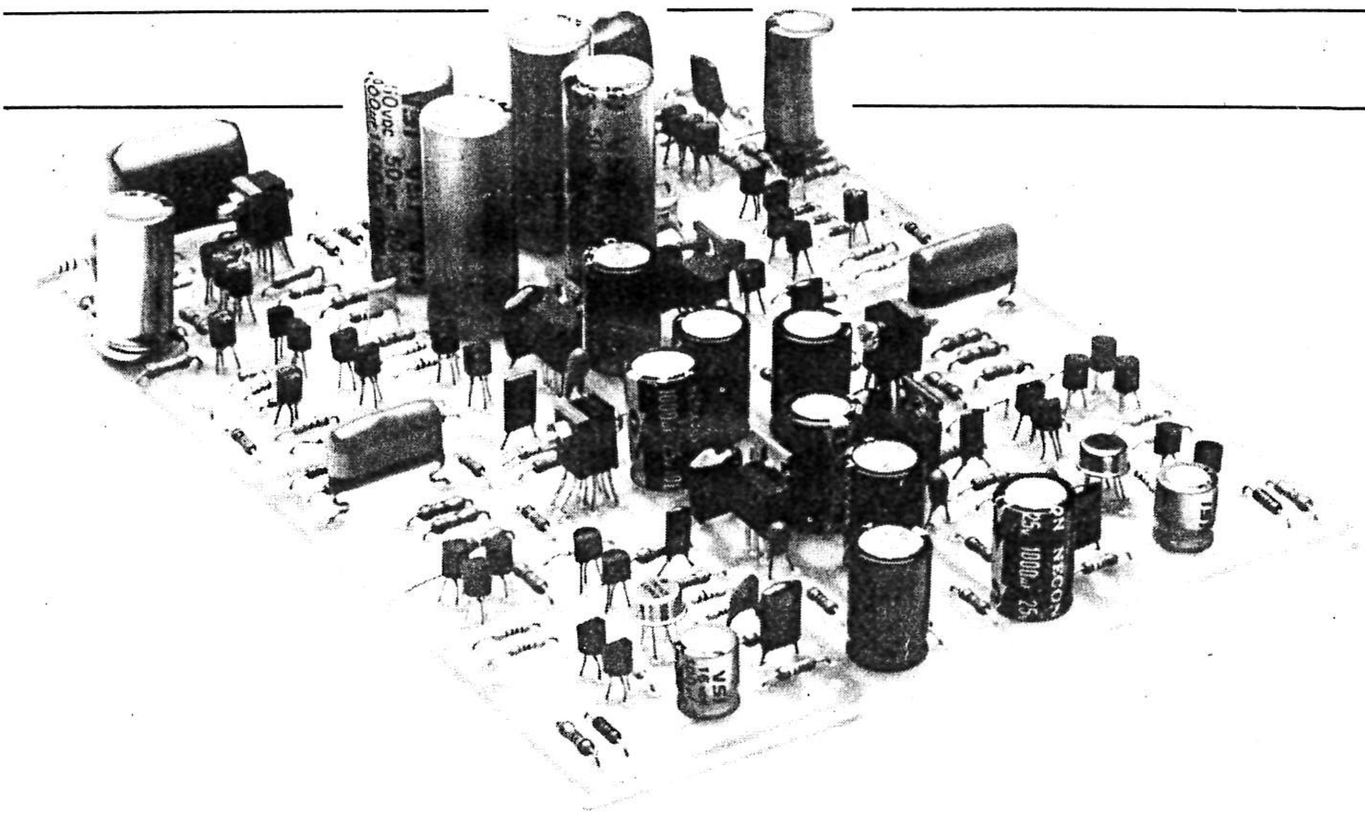


An 'ultra-fidelity' preamplifier

Part 1

David Tilbrook

This project is an ultra-fidelity linear preamplifier designed to meet the demands of the serious audiophile. The aim of the project was to design a unit that would challenge the finest commercial designs. The increasing use of compact disc players has placed new demands on the entire audio chain and this applies just as surely to the electronics as it does to the loudspeakers.

IT IS BECOMING a widely recognised fact that systems combining CD players with inferior integrated amplifiers or preamp/power amp combinations tend to sound considerably inferior to the same units used with cassette deck or cartridge sources.

The reasons for this would appear to be the increased demands placed on the electronics through the higher signal slopes and dynamic range generated by a CD player. Combine this with an otherwise clean signal source, excellent frequency response and distortion characteristics, and any inability of the subsequent electronics becomes particularly noticeable and objectionable.

The 6010 has been designed with the accent on acoustic performance. Its dynamic range, noise, distortion and frequency response characteristics are all extremely good. But just as important to the acoustic performance are such parameters as channel seperation, power supply regulation, to ensure freedom from certain types of dynamic distortion mechanisms, and maintainence of the integrity of the signal earth line.

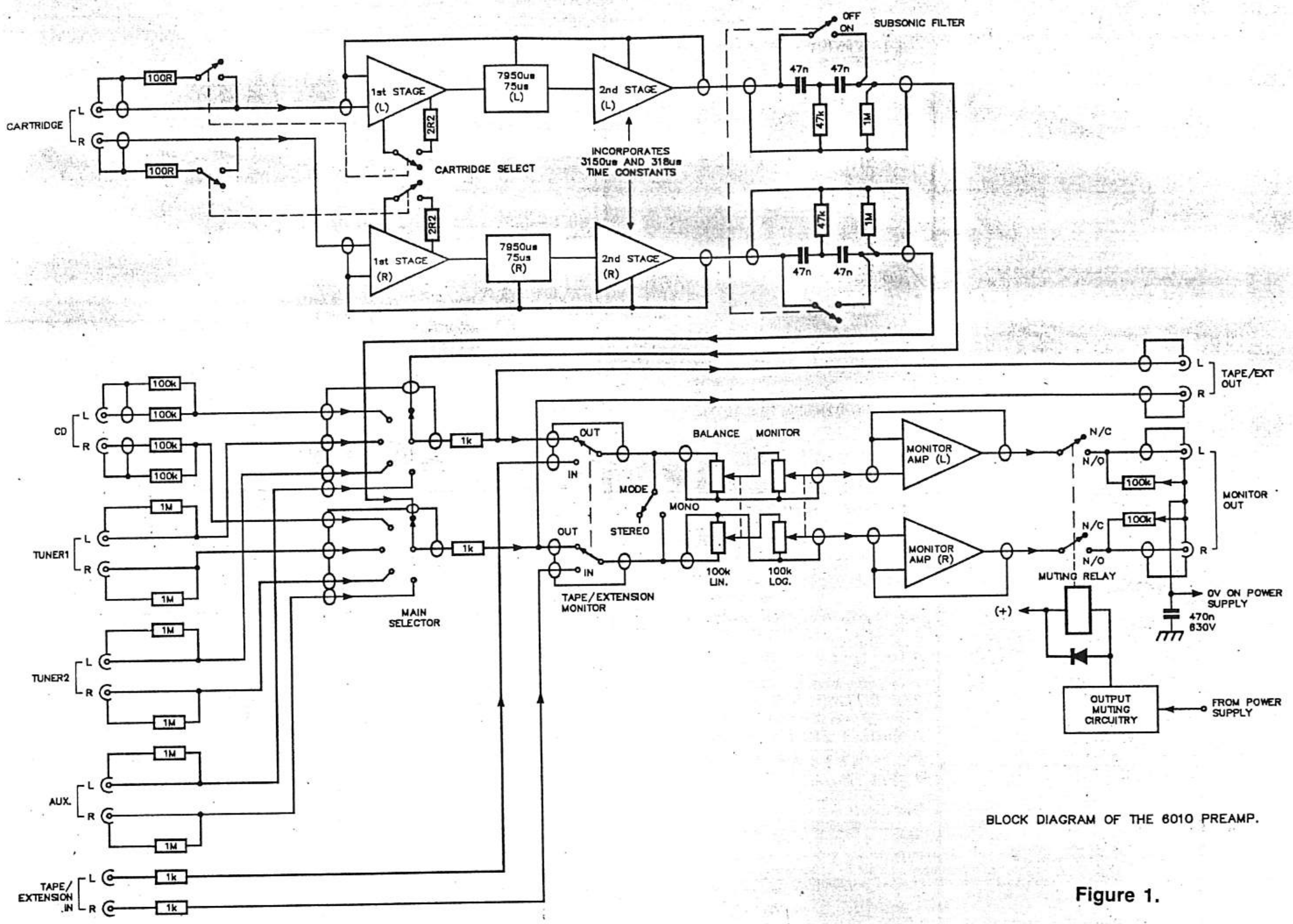
In order to ensure good performance in these respects the pc board layout must be done correctly. Many an otherwise good design has been ruined at the pc board design stage. All of these characteristics are important to the acoustic performance of audio electronics as undoubtedly are many others.

The design of a really good preamplifier (or power amplifier) at the present time is as much an art as it is a science because we simply do not understand all of the parameters that determine the acoustic performance of this equipment. The AEM6010, and the AEM6000 series of power amplifiers soon to be published, are the culmintion of a great deal of experiment and trial and error to develop a comprehensive range of audio equipment with impeccible acoustic as well as measured performance.

A block diagram of the 6010 is shown here.

The cartridge input can be configured for either a moving coil or a moving magnet cartridge by the appropriate setting of the input cartridge select switches. These two switches are mounted on the rear of the preamp chassis.

The low level (LL) cartridge input stage consists of two separate active gain stages and a passive filter stage which provides one half of the RIAA frequency correction. The rest of the RIAA is generated by feedback around the second stage. A detailed description of the topology of the LL stage is given later in the circuit operation section.



BLOCK DIAGRAM OF THE 6010 PREAMP.

Figure 1.

An important characteristic that should be mentioned at this stage, however, is its overlaod margin. The gain of the total LL stage is around 100, so that a 2 mV input signal at 1 kHz will produce an output around 200 mV RMS which is comparable to the level expected at the other high level inputs. As will be discussed later, it is possible for signal levels in the final LL stage to reach around 20 V RMS. To ensure that these very large output signal voltages do not cause clipping of the final LL stage it is powered from a regulated 70 V supply.

The high level inputs provided are compact disc (CD), two tuner inputs (TUNER 1 and TUNER 2) and an auxiliary input (AUX). The two tuner inputs are provided to enable separate FM and AM stereo tuners to be connected to the system. Alternatively, a video cassette recorder can be connected to some of these inputs.

The high level inputs provided are connected to the main selector switch together with the output of a passive subsonic filter that follows the output of the LL stage. This filter is used rather than a more sophisticated active filter to ensure minimum colouration of the low-frequency audio content. The filter provides a 12 dB/octave attenuation below 10 Hz and can be bypassed with a filter on/off switch located on the preamp front panel.

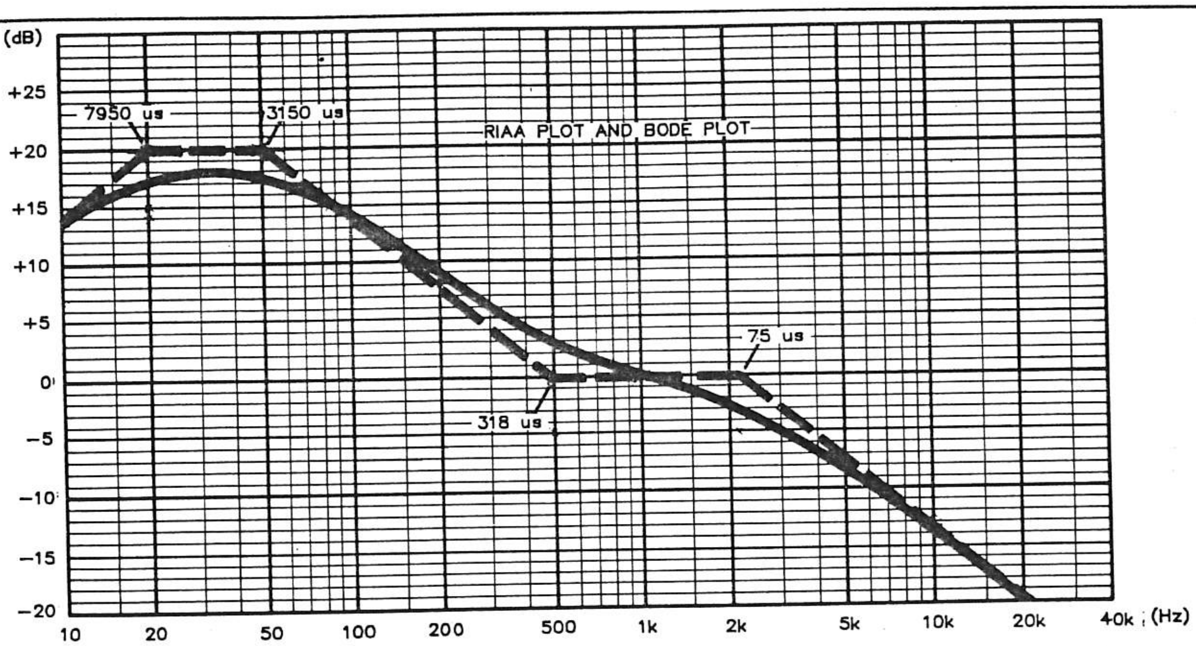
The output of the main selector switch is fed via the monitor switch and mode switch to the balance and monitor volume controls. There are no active gain stages provided between the selector switch and the monitor potentiometer to ensure complete freedom from any possibility of overload in this part of the preamp.

The final gain stage follows the monitor pot. This stage is powered from a regulated 30 V supply which provides more than ample overload margin since this stage will have a typical maximum output signal of around 1 V RMS. Remember that the output of the preamp is connected to the input of a power amp that will be driven to full power, and hence into clipping, by a typical 1 V output signal.

The output of the preamplifier is provided with relay muting that is driven from a control circuit and provides freedom from turn-on and turn-off thump.

Since the aim of the design was to produce a very high quality linear preamplifier at a reasonable price, additional features such as tone controls and level meters have been omitted. Nevertheless the demand for these facilities is such that they cannot be completely ignored.

In order to solve this problem a preamplifier extension unit is planned which provides additonal control facilities such as tape/tape dubbing for several tape decks, tone controls and headphone amplifiers. This unit expands the capabilities of the main linear preamplifier and is connected via the monitor switch on the 6010. When used without the extension unit this switch serves as the tape monitor and is therefore labelled EXTENSION/TAPE MONITOR. The use of the monitor ▶



The 20 Hz square wave consists of 25 ms of constant dc voltage followed by 25 ms of a zero voltage. In order to produce a constant voltage for a period of 25 ms, the stylus assembly must move at a constant velocity for that period. If we now consider the case of a typical MM cartridge producing around 1 mV/cm/sec then, in order to produce a 10 mV square wave, the recorded velocity must be 10 cm/sec. The total distance the cartridge will travel in the 25 ms is:

25 ms x 10 cm/sec = 2.5 mm

A different problem occurs at the opposite end of the frequency spectrum. If we wish to reproduce a 20 kHz square wave with the same amplitude as the one above, the stylus traces a triangle wave in the groove, but this time for only 25 us. The stylus moves a total distance of only 2.5 um. Such extremely small displacements at high frequencies mean that the surface irregularities of the vinyl are increasingly significant and an unacceptable signal/noise ratio results.

These problems are overcome when the record is cut by boosting the high frequencies to improve the signal/noise ratio and cutting the low frequencies to reduce the necessary stylus displacement. In order to do this, the frequency response of the recording amplifier is modified to conform to a special curve called the RIAA equalization (RIAA stands for Recording Institute Association of America).

It is the responsibility of the MM input amplifier to correct for this equalization so as to restore the overall flat response. The RIAA correction that must be incorporated in the playback electronics consists of four single-pole filters (a single-pole filter is one that can be formed by a single resistor/capacitor pair). These filters are:

high-pass, time constant RC = 7950 us
low-pass, time constant RC = 3150 us
high-pass, time constant RC = 318 us
low-pass, time constant RC = 75 us

The overall effect of the time constants is shown in Figure 3 which compares the Bode plot showing the individual time constants and the actual frequency response that results if the RIAA is implemented correctly. The MM preamp must have the frequency response shown here by solid line.

Notice that there is a 40 dB variation in the gain required of the MM stage. The low frequencies are amplified over 100 times more than the extreme high frequency.

As mentioned earlier, some designers (in fact most, until recent times) incorporated the RIAA equalization into the overall feedback loop around the first stage. Since the gain must vary over a 40 dB range, so must the amount of feedback. With almost all conventional designs this represents a major proportion of the overall negative feedback and the input impedance tends to become highly frequency dependent. Combine this with an already frequency dependent source impedance of the cartridge and it is not surprising that problems like cartridge impedence interaction arise.

The LL staged developed for the AEM6010 completely overcomes these problems by having a two-stage circuit and a combined passive/active RIAA equalization filter. The first stage is a completely linear preamplifier with an extremely low noise input differential pair formed from an LM 394 super-matched pair. There is no RIAA equalization in this stage and the frequency response extends from less than 1 Hz to well over 100 kHz. Since the stage has a flat gain of 11 when switched to the MM position and around 225 when switched to the MC position it will almost completely determine the overall noise figures of the input stage.

Since the overall gain of this first stage is flat, and the applied negative feedback very large, the input impedance of the stage is a constant over the entire audio range.

During the development of this input amp several experiments were conducted in which the stage was inserted between various moving magnet cartridges and the phono input of several commercial amplifiers. The improvement in overall acoustic performance over some of the commercial stages was stunning and this added considerable weight to the cartridge impedance interaction argument. Experiments were also carried out to ensure that the stage was free of cartridge impedance interaction by incorporating a FET buffer amplifier between the cartridge and the input of the 6010MM input stage. The only difference in the acoustic performance seemed to be a significant increase in the input noise when the FET was used. Another advantage of the two-stage approach is that the gain of the input amplifier can be divided between two stages and hence the distortion is reduced.

The output of the stage is connected to the passive filter forming the 7950 us and 75 us time constants of the RIAA. The 7950 us time constant is formed by capacitor C8 and resistors R21, R20 and R19. The 75 us time constant is formed by R22, R23 and capacitor C11. ▶

As mentioned earlier the other two time constants are formed by an RC filter placed in the feedback loop around the second stage. The filter consists of resistors R46, R45, R47, R48, R43, R44 and capacitor C16. In Figure 4, the distribution of the various filters among these two stages is shown together with the resulting Bode plot.

The second of the two stages is similar to the first but has a cascade amplifier included to form the main voltage gain stage. This is necessary since this stage incorporates two time constants for the RIAA equalisation in its negative feedback loop and it is essential that adequate feedback exists to ensure a reasonably constant input impedance. As mentioned earlier, this stage is supplied by a 70 V dc supply to help reduce the possibility of overloading by excessive drive from a high output cartridge.

Since the output of this amplifier can drive to within several volts of the supply, the maximum signal voltage that can be delivered from this stage without clipping is around 23 V RMS. Since the overall gain of the LL stage when switched for MM cartridges is 120.56 at 1 kHz, the maximum input signal that will not cause clipping of the second stage is 190 mV. Most MM cartridges have sensitivities around 1 mV/cm/sec and hence have typical maximum output voltages around 30 mV RMS.

Experiments carried out during the development of this preamplifier using digitally recorded discs showed typical maximum outputs from a variety of cartridges around 80-120 mV. The 190 mV input figure, which represents an overload margin of 40 dB with respect to a 2 mV input signal should therefore be ample for the vast majority of MM cartridges.

If your cartridge has a particularly large output, the gain of the first stage can be decreased by increasing the value of the 47 ohm resistor, R9. If this value is increased to 100 ohms for examle, the gain of the first stage is halved with consequent improvement in the overload margin.

Noise

One of the outstanding problems associated with all low level input stages is that of noise. Because the output signal levels from cartridges are so small the noise generated by the input stage must be kept to an absolute minimum or an unacceptable signal/noise ratio results. Unfortunately, there is a fundamental limit to the minimum noise voltage that can be present at the input since the resistance of the cartridge generates a type of noise called 'thermal noise'. This comes about due to thermal agitation of electrons and is not the result of any fault in the manufacture of the resistance. It is simply a fundamental law of nature. The equation that predicts the amount of thermal noise is:

$$e_n = \sqrt{(4kTR\Delta f)}$$

where k = Boltzmann's constant
T = absolute temperature
Δf = noise bandwidth
R = resistance
e_n = average noise voltage.

The equation predicts that the thermal noise is increased if either the temperature, resistance or bandwidth is increased. We can use this equation to calculate the minimum possible noise and hence the best possible signal/noise ratio using common MM cartridges. Assuming a noise bandwidth of 20 kHz, an absolute temperature of 290K and a source resistnace of 500 ohms which is correct for most cartridges, the thermal noise is:

$$e_n = \sqrt{(4 \times 1.37 \times 10^{-23} \times 290 \times 500 \times 20 \times 10^3)} = 399\text{nV}$$

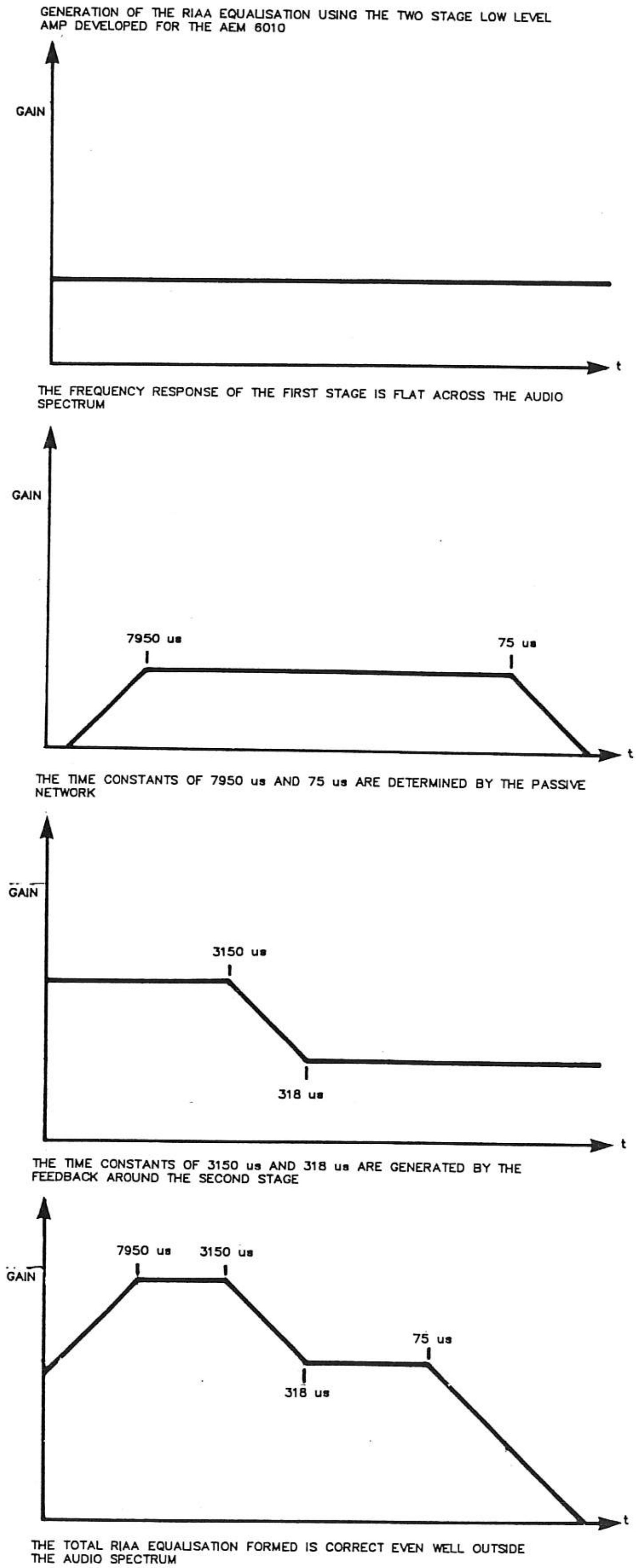


Figure 4.

This is equivalent to a signal/noise ratio of 88 dB with respect to a 10 mV input signal. The RIAA equalization has the effect of decreasing the noise bandwidth and therefore results in a considerably increased S/N ratio figure of around 100 dB. These noise figures are all based on a flat, or unweighted, noise frequency response.

The human ear, however, does not detect all frequencies with equal sensitivity, so that two amplifiers with identical noise figures can be subjectively very different. An amplifier with a high average noise figures can be subjectively very different. An amplifier with a high average noise voltage in the 1 kHz to 5 kHz region will sound considerably noiser than another amp with identical flat noise figures but with the noise concentrated around a lower frequency.

To attempt to correct for this most noise measurements done for audio purposes are carried out with some type of weighting applied. The most common is called "A"weighting. The frequency response of an A-weighting filter is shown in Figure 5. Notice that the curve accents the midrange, for which the human ear is most sensitive.

When A-weighting is applied to the thermal noise figures discussed above, the theoretical best signal-to-noise ratio, based on the 500 ohm source resistance, lies around 105-110 dB. Few commercial MM amplifier stages approach this figure, with the finest preamps usually quoting figures around 85-95 dB A-weighted with respect to a 10 mV input signal.

The AEM6010LL low level cartridge amplifier stage achieves a signal-to-noise ratio of 105 dB A-weighted, with respect to a 10 mV input signal and with the input shorted. With the input connected to a 500 ohm source resistance, the signal-to-noise ratio is still greater than 100 dB which is substantially better than the published specifications of any commercial designs seen to date.

The specifications for the stage in both moving magnet and moving coil modes have been included with this article. The total harmonic distortion of this stage cannot be measured using conventional noise and distortion analysers because the distortion generated is below the resolution of these instruments. The figures quoted here were measured using a Hewlett Packard 3561A Dynamic Signal Analyser.

In order to ensure good acoustic performance the output impedance of all of the stages is extremely low and is dominated by series output resistors that ensure a stable feedback loop within the stage by providing isolation of the loop from complex impedances that may occur in the output load.

All the stages are isolated from each other by substantial filtering capacitors as interaction via the supply line was found to be one of the major contributing factors to the poor acoustic performance of many of the experimental circuits developed in the design of this project. Another parameter found to be significant to ensure good audible performance was channel separation and this was particularly true with CD sources.

Most CD players quote channel separation figures of at least 90 dB over the entire audio range. The usual amplifier figure of 40-60 dB therefore represents a considerable degradation of the performance of the signal source which is of course unacceptable. The 6010 ensures excellent channel separation characteristics by isolating the power supplies of both channels through the entire preamp.

Similarly, the signal earth lines are isolated from each other at all points, except for a single connection at the output terminals of the preamplifier. This is also the only point at which a connection is made between the power supply 0 V lines and the signal earth lines. This earthing system will ensure that the performance of the amplifiers is not degraded by loss of integrity of the signal earth lines.

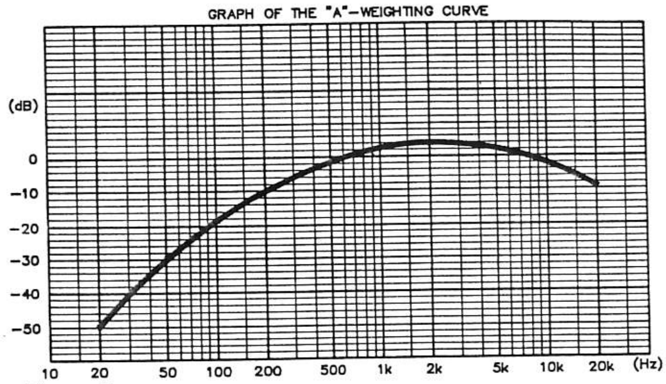


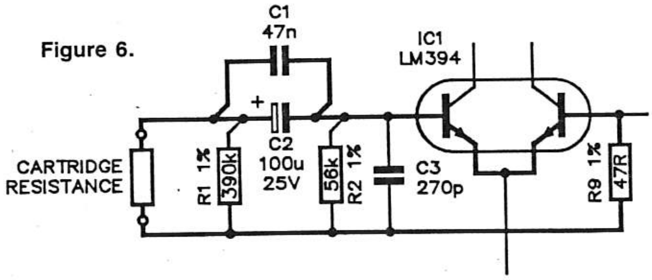
Figure 5.

Moving Coil cartridges

One of the big problems with moving coil amplifer stages is noise. MC cartridges produce only a fraction of the output signal voltage of a typical moving magnet cartridge having average outputs around 40-50 uV. If a conventional MM amp stage was used for the MC cartridges, with an appropriate gain increase, the signal-to-noise ratio would be only around 60 dB A-weighted, which is an unacceptably low figure. Fortunately their very low output impedance and the requirement to be loaded by a relatively low amplifier input impedance helps to reduce the noise problem.

A major proportion of the noise is due once again to thermal noise. To decrease this, the source resistance must be made as low as possible. In the case of the MC cartridge, however, with a typical resistance of only a few ohms, any resistance in series with the input circuit will contribute to the total source resistance and hence to the thermal noise.

Figure 6.



Differential input circuit employed in the AEM 6010LL
The main input circuit is shown in bold

Figure 6 shows the input circuit of the 6010LL differential input stage. In the case of differential input stages such as used in the 6010LL amp, two base emitter junctions are included in the circuit, both of which contribute to the noise figure and consequently degrade the signal-to-noise ratio. The overall degradation is only minor, however, if the full potential gain of the input stage is employed. Furthermore the differential input stage is intrinsically more linear than the single ended input stage and obviates the need for large emitter capacitors. The resistor R3 must be included in Series with the input source resistance and must therefore be at least the same order of magnitude as the cartridge source resistance or it will seriously degrade the noise performance.

The input stage of the AEM6010LL input amp is based around the LM394 which is manufactured by National Semiconductor. As mentioned earlier, this is a 'super-matched' pair of bipolar transistors in a single encapsulation. This device has a relatively low input resistance, reasonable h_{fe} (around 500) but most importantly for this application, it has an extremely low noise figure. ▶

The use of this device in the input stage together with a careful selection of emitter current used to bias the stage and a fully differential voltage gain stage results in a cartridge amplifier with excellent noise performance. With the input shorted and the stage set up for the MC cartridges the total equivalent input noise is around 34.6 nV A-weighted. This is equivalent to a signal/noise ratio of 83 dB with respect to a 500μV input, which compares well against the more usual figures of 70-80dB for most MC amplifiers.

The standard reference input level used for S/N figures in relation to MC input stages is 500 uV and, although this seems a little optimistic, the figures quoted in this article use this as a reference for the sake of uniformity.

Construction

The construction of the AEM6010LL stage is not particularly difficult, since all of the construction is limited to the soldering of the pc board. The board is reasonably complicated however, so care should be taken to ensure that all of the components are soldered into their correct positions. The two halves of the board are approximately mirror images, not direct copies of each other, so some of the components are oriented slightly differently. Since the pc board holds a number of large electrolytic capacitors, these tend to get in the way if soldered in place too soon. Leave these until last and start by soldering the small non-polarised components in place, such as the resistors and non-polarised capacitors. When this is done move on to the active components — the diodes and transistors.

Note that certain transistors must be bolted together so that they are in close thermal contact with each other. Each set of these transistors consists of two BD139s and a BD140, which should be bolted together using an appropriate length 6BA bolt and nut before soldering the assembly to the pc board. The correct positions for these are shown on the component overlay. Be careful however, to check that the transistors have the correct orientation on the pc board, otherwise the emitter and base of each of the transistors will be reversed. The metal faces of each of these devices are connected internally to their collectors and must remain insulated from each other after the devices are bolted together. This is not difficult, however, since the metal face of each transistor is in contact with the plastic face of its neighbour. Also, the mounting holes of the devices are insulated from the metal faces. It is probably a wise precaution to check that the collectors are all insulated from each other, using a multimeter on a resistance range, before soldering the transistor sets into position.

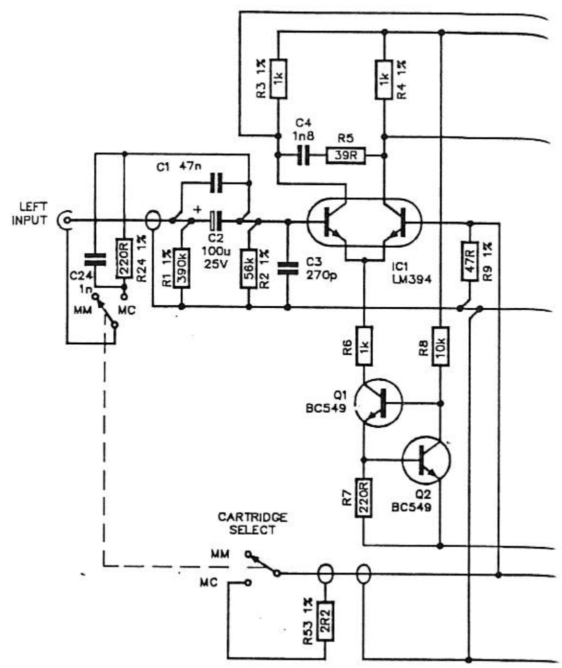
Capacitors C5, C6, C7, C13 and C14 provide freedom from RF instability. These devices are soldered on the copper side of the pc board. Their leads should be cut as short as possible and capacitors C5, C6, C13 and C14 should be soldered directly between the collector and base of the output transistors Q9, Q10, Q23 and Q24, as shown in the rear pc board overlay diagram. Capacitor C7 is soldered directly across resistor R17. The area in the centre of the pc board remains unpopulated at this stage. This provides possible power supply expansion for future additions to the preamp.

Powering up

As discussed above, the signal earth line and the power supply 0 V line are not connected to each other on either of the pc boards. In the completed preamp, to be described next month, this connection is made at the output terminals which ensures freedom from hum and maintains the purity of the signal earth line. In order to test the board at this stage therefore, it is necessary to make this connection externally before powering up. To do this, join all signal earth lines and 0 V connections to each other at the output end of the board and then join these to the 0 V line on the dc power supply used.

In order to power the boards correctly a split 70 V supply (i.e: +35 V/0/-35V) must be used.

(Next month we conclude the construction details of the preamplifier and discuss the monitor amp stages and the regulated power supplies.)



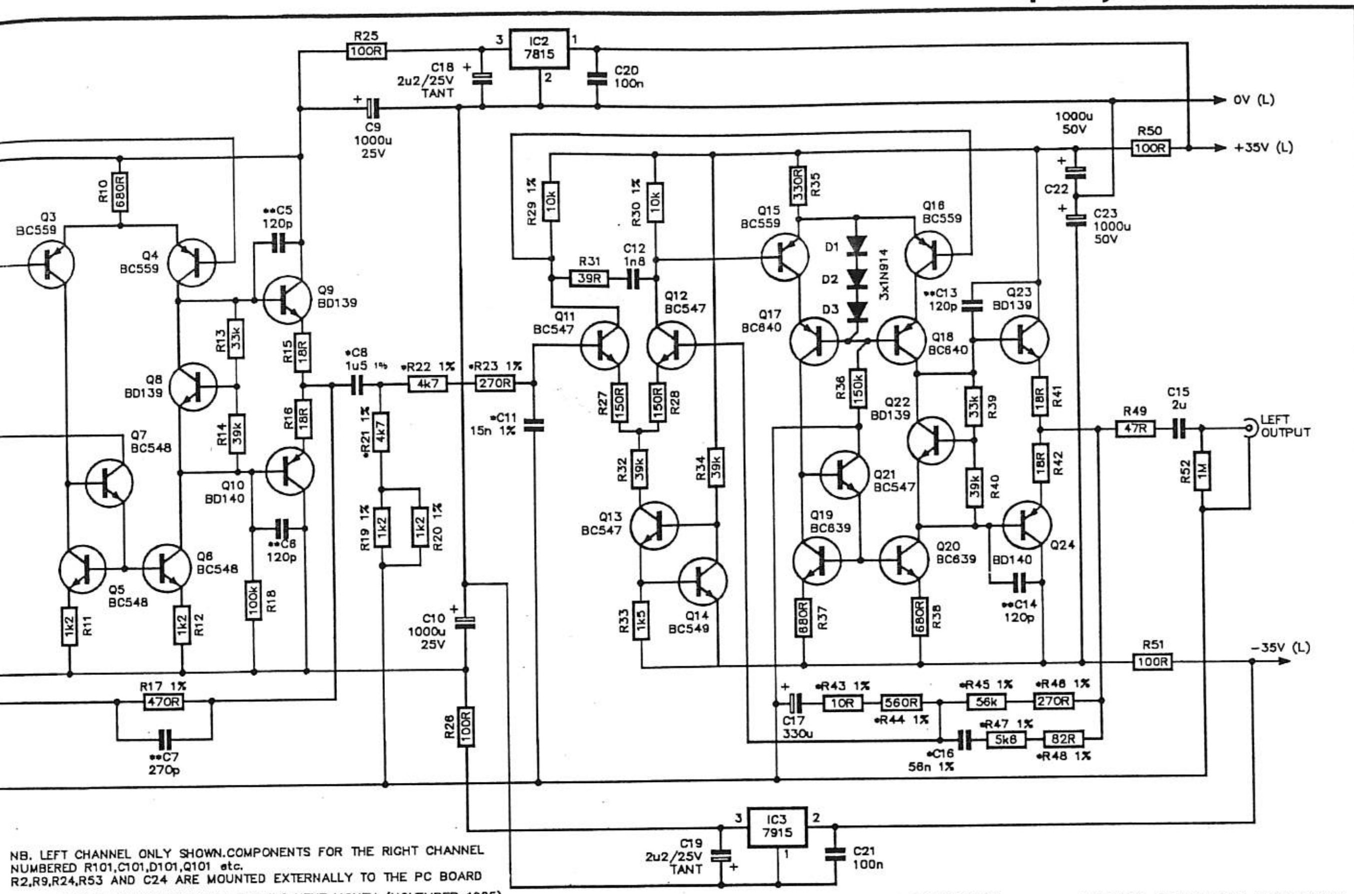
CIRCUIT OPERATION AEM6010LL

The circuit is divided into two active stages plus a passive filter stage that generates two of the time constants, 7950 us and 75 us, required for the RIAA equalization. The remaining time constants are generated by an RC network incorporated into the feedback loop around the second stage.

The first of the two active gain stages is a linear stage with an extended frequency response. Both of the amplifier stages are entirely dc-coupled with the exception of the input and output coupling.

The input to the preamp is ac-coupled via capacitors C1 and C2. C1 is included to offset any capacitor increase in the impedance of C2 at higher frequencies. Resistor R1 maintains the dc voltage at the input side of these capacitors at 0 V. Resistor R2 reduces the overall impedance to around 48k (i.e: the parallel combination of R1 and R2) to load a moving magnet cartridge correctly. This assumes that the input impedance switch is open. If this switch is closed the 100R resistor, R24, and 1n capacitor, C24 are shunted across the input, reducing the input impedance to 100R to suit moving coil cartridges. Similarly the parallel input capacitance is increased from around 270p to around 1n3 due to the parallel combination of C24 and C3.

The input differential pair is formed by the LM394, IC1. This is an extremely low noise 'super-matched' transistor pair. The emitter current is determined by a constant current sink formed by Q1, Q2, R8 and R7 while R6 serves to decrease the power dissipation in transistor Q1.



NB. LEFT CHANNEL ONLY SHOWN. COMPONENTS FOR THE RIGHT CHANNEL NUMBERED R101,C101,D101,Q101 etc.
R2,R9,R24,R53 AND C24 ARE MOUNTED EXTERNALLY TO THE PC BOARD

SEE MAIN PREAMP CONSTRUCTION DETAILS NEXT MONTH (NOVEMBER 1985)

• DENOTES COMPONENTS USED TO GENERATE THE RIAA EQUALIZATION.
1% TOLERANCE COMPONENTS SHOULD BE USED.

•• SOLDERED ON REAR SIDE OF PC.BOARD.

The collector load to the input pair consists of the two main collector resistors R3 and R4, a high frequency compensation network R5 and C4, and the second stage differential pair Q3 and Q4.

The bulk of the voltage gain of the input amp is generated by the second stage. The differential pair Q3, Q4 have a current mirror load formed by Q5, Q6, Q7 and resistors R11 and R12.

The output stage is an emitter follower to provide a very low output impedance. This consists of transistors Q9 and Q10, resistors R15, R16 and R18. The transistor Q8 and its associated resistors form a "variable diode" which serve to ensure that the output stage quiescent current remains constant for all output voltages. These three output transistors are bolted together enabling Q8 to provide thermal correction so that the quiescent current will remain constant for a broad range of operating temperatures. Capacitors C5 and C6 ensure stable operation of the output stage by decreasing the impedance of the bases of the output transistors at high frequencies.

Overall negative feedback is applied by resistor R17 and the parallel capacitance C7. The gain of the stage is determined by this resistor plus resistors R9 and R5. With the gain switch in the MM position only the 47R resistor is in circuit and the gain of the input amp is 11. When the gain switch is closed, the 2R2 resistor R5 is connected in parallel with R9 and the gain is increased to around 225.

Supply isolation is provided by the resistor/capacitor combinations R25, C9 and R26, C10.

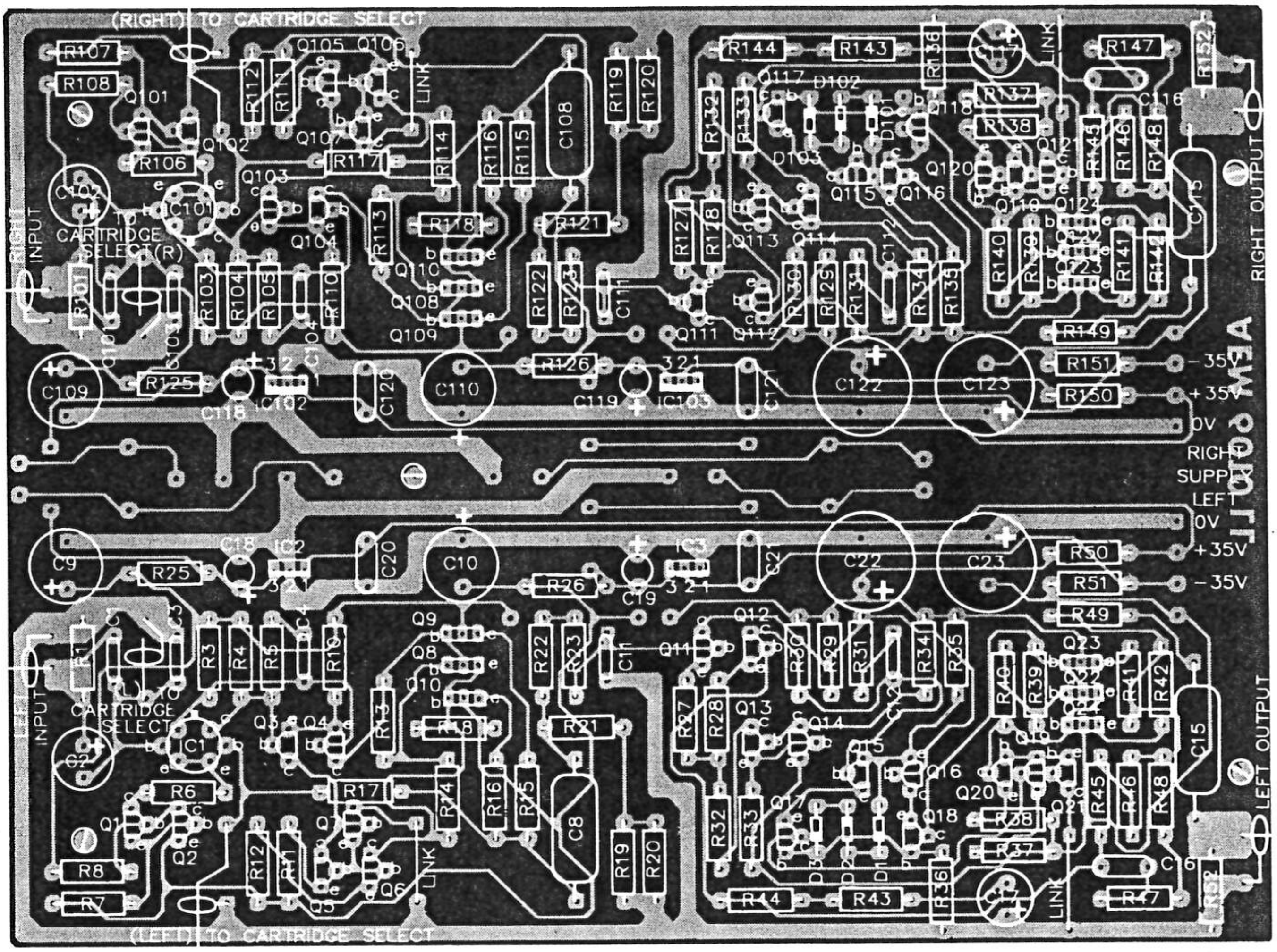
The output of the first stage is connected to the input of a two-stage passive filter that, as mentioned earlier, generates two of the time constants associated with the RIAA equalisation. Capacitor C8 serves the dual funtion of output coupling capacitor for the first stage and, together with resistors R21, R20 and R19, forms a high pass filter with a -3 dB point at 20 Hz (i.e: a time constant of 7950 us). Resistors R22, R23 and capacitor C11 form a low pass filter with a -3 dB point at 2122 Hz (i.e: a time constant of 75 us).

The output of the passive filter network is connected to the input of the second amplifier stage. This amplifier is similar to the first amplifier stage but has higher open loop gain due to the inclusion of the cascade stage in the voltage amp formed by Q17, Q18 plus diodes D1, D2, D3 and resistor R36. The higher open loop gain is necessary to ensure that sufficient negative feedback exists so that the input impedance will be constant with respect to frequency. If this is not the case the non-linear load on the passive filter degrades the accuracy of the RIAA equalisation.

The remaining two time constants necessary for the RIAA are generated by the RC network consisting of R43, R44, R45, R46, R47, R48 and C16. This network introduces a high pass filter with a -3 dB point at 500 Hz (i.e: a time constant of 318 us) and a low pass filter with a -3 dB point around 50 Hz (i.e: a time constant of 3150 us). Capacitor C17 serves to reduce the gain of the stage to unity for dc operation, decreasing the dc offset to a minimum. This increases the maximum signal level that the stage can reproduce without clipping by ensuring that the stage clips symmetrically.

The output from the preamp is coupled through resistor R49, which serves to isolate the feedback loop from the load, and capacitor C15 for dc isolation. R31 maintains a 0 Vdc level at the output of C15.

Supply isolation of the second stage is provided by resistors R50 and R51 and capacitors C22 and C23. The second stage assumes a supply voltage of around 70 Vdc centre-tapped, which is regulated down to the 30 V dc centre-tapped, required by the first stage. This is done by the IC regulators IC2 and IC3 and their associated filtering and stability capacitors C20, C21, C18 and C19.



AEM6010LL PARTS LIST

Resistors

All ¼W, 5% unless noted otherwise.

R1, R101 .... 390k, 1%
R2, R102 .... 56k, 1%
R3, R103, R4, R104 ... 1k, 1%
R5, R105 .... 39R
R6, R106 .... 1k
R7, R107 .... 220R
R8, R108 .... 10k
R9, R109 .... 47R, 1%
R10, R110 .... 680R
R11, R111 .... 1k2
R12, R112 .... 1k2
R13, R113 .... 33k
R14, R114 .... 39k
R15, R115, R16, R116 .... 18R
R17, R117 .... 470R, 1%
R18, R118 .... 100k
R19, R119, R20, R120 1k2, 1%
R21, R121, R22, R122 4k7, 1%
R23, R123 .... 270R, 1%
R24, R124 .... 220R 1%
R25, R125, R26, R126, ... 100R
R27, R127, R28, R128 ... 150R
R29, R129, R30, R130 10k, 1%
R31, R131 .... 39R
R32, R132 .... 39k
R33, R133 .... 1k5
R34, R134 .... 39k
R35, R135 .... 330R
R36, R136 .... 150k
R37, R137, R38, R138 ... 680R
R39, R139 .... 33k
R40, R140 .... 39k
R41, R141, R42, R142 .... 18R
R43, R143 .... 10R, 1%
R44, R144 .... 560R, 1%
R45, R145 .... 56k, 1%
R46, R146 .... 270R, 1%
R47, R147 .... 5k6, 1%
R48, R148 .... 82R, 1%
R49, R149 .... 47R
R50, R150, R51, R151 .... 100R
R52, R152 .... 1M
R53, R153 .... 2R2, 1%

Semiconductors

Q1, Q101, Q2, Q102 ... BC549
Q3, Q103, Q4, Q104 ... BC559
Q5, Q105, Q6,
Q106, Q7, Q107 .... BC548
Q8, Q108, Q9, Q109 ... BD139
Q10, Q110 .... BD140
Q11, Q111, Q12, Q112 . BC547
Q13, Q113 .... BC547
Q14, Q114 .... BC549
Q15, Q115, Q16, Q116 . BC559
Q17, Q117, Q18, Q118 . BC640
Q19, Q119, Q20, Q120 . BC639
Q21, Q121 .... BC547
Q22, Q122, Q23, Q123 . BD139
Q24, Q124 .... BD140
IC1, IC101 .... LM394
IC2, IC102 7815
IC3, IC103 7915
D1, D101, D2, D102,
D3, D103 .... 1N914

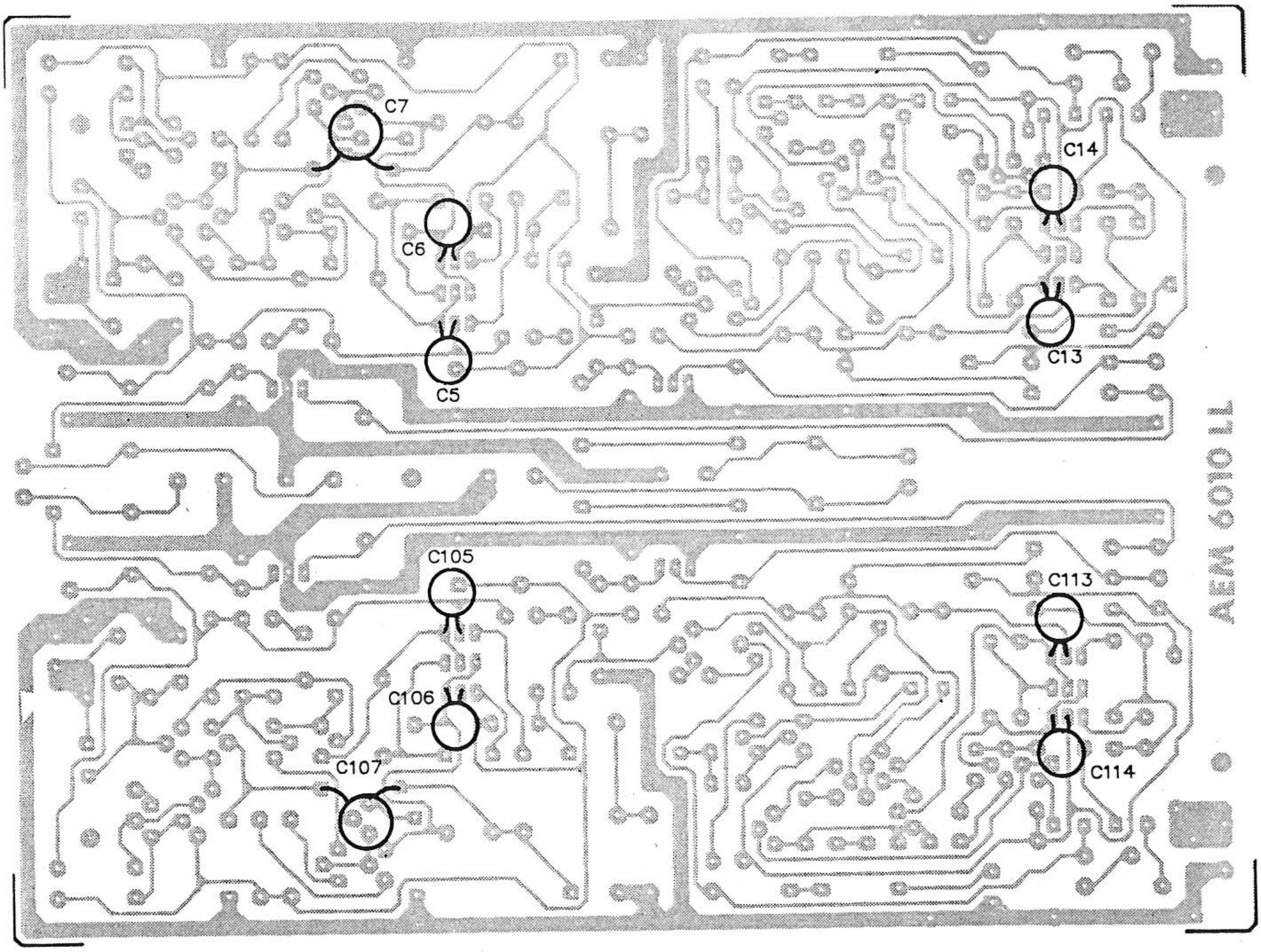
Capacitors

C1, C101 .... 47n greencap
C2, C102 100u/25 V RB electro
C3, C103 .... 270p ceramic
C4, C104 .... 1n8 greencap
C5, C105,
C6, C106 .... 120p ceramic
C7, C107 .... 270p ceramic
C8, C108 .... 1u5, 1%
C9, C109, C10,
C110 ... 1000u/25 V RB electro
C11, C111 .... 15n 1%
C12, C112 ...... 1n8 greencap
C13, C113
C14, C114 ...... 120p ceramic
C15, C115 .... 2u greencap
C16, C116 ...... 56n 1% poly.
C17, C117 330u/63 V RB electro
C18, C118
C19, C119 ..... 2u2/25 V tant.
C20, C120,
C21, C121 ..... 100n greencap
C22, C122,
C23, C123 1000u/50 V RB electro
C24, C124 .... 1n greencap

Miscellaneous

AEM6010LL pc board; 2 x DPDT miniature toggle switches; nuts, bolts etc.

Expected cost: $80-$88



MEASURED SPECIFICATIONS AEM6010LL

Input Sensitivity/impedance for 250 mV output
MM cartridge . . . . nom. 2 mV/48k shunted with 290 pF
MC cartridge . . . . nom. 100 uV/100R shunted with 1 nF

Maximum output . . . . >20 V RMS

Maximum input before output overload
MM cartridge . . . . nom. 190 mV @ rated sensitivity
i.e: overload margin is 40 dB w.r.t. 2 mV input
MC cartridge . . . . nom. 10 mV @ rated sensitivity
i.e: overload margin is 40 dB w.r.t. 100 uV input

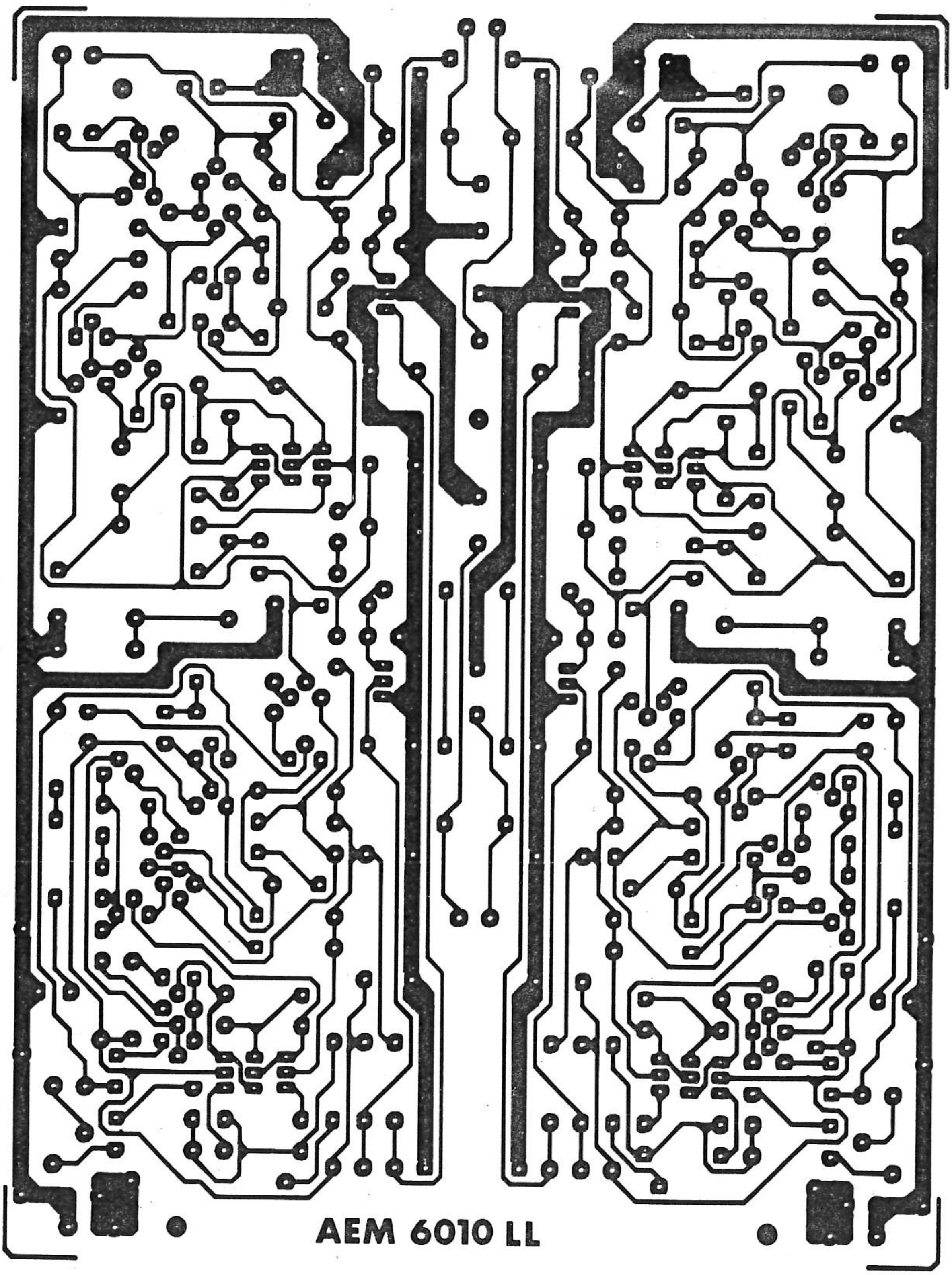
Frequency response . . . . conforms to RIAA within +/– 0.2 dB typical with 1% components. RIAA accuracy can be improved further by choosing component values exactly.

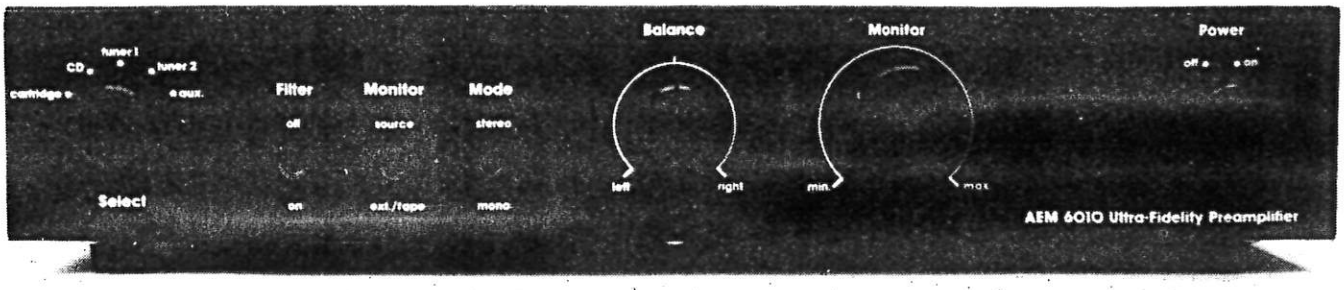
Total harmonic distortion
MM cartridge . . . . <0.001% @ 100 mV output, 100 Hz-10 kHz.*
MC cartridge . . . . <0.004% @ 100 mV output, 100 Hz-10 kHz

Total equivalent input noise
MM cartridge . . . . <56 nV A-weighted, input shorted
<88 nV A-weighted, 500R source
MM cartridge . . . . <35 nV A-weighted, input shorted
<43 nV A-weighted, 3R3 source

Signal-to-noise ratio (with respect to 10 mV input)
MM cartridge . . . . >105 dB A-weighted, input shorted
>102 dB A-weighted, 500R source
MC cartridge . . . . >83 dB A-weighted, input shorted
>81 dB A-weighted, 3R3 source

*Measured by increasing gain 10 times to overcome instrument resolution of 0.003%.


AEM 6010 LL



An 'ultra-fidelity' preamplifier

Part 2
David Tilbrook

This article concludes the description of the AEM6010 preamplifer design. In Part 1, published last month (October, 1985) the low level amplifier stages were described in detail. This month we describe the construction of the remaining electronics.

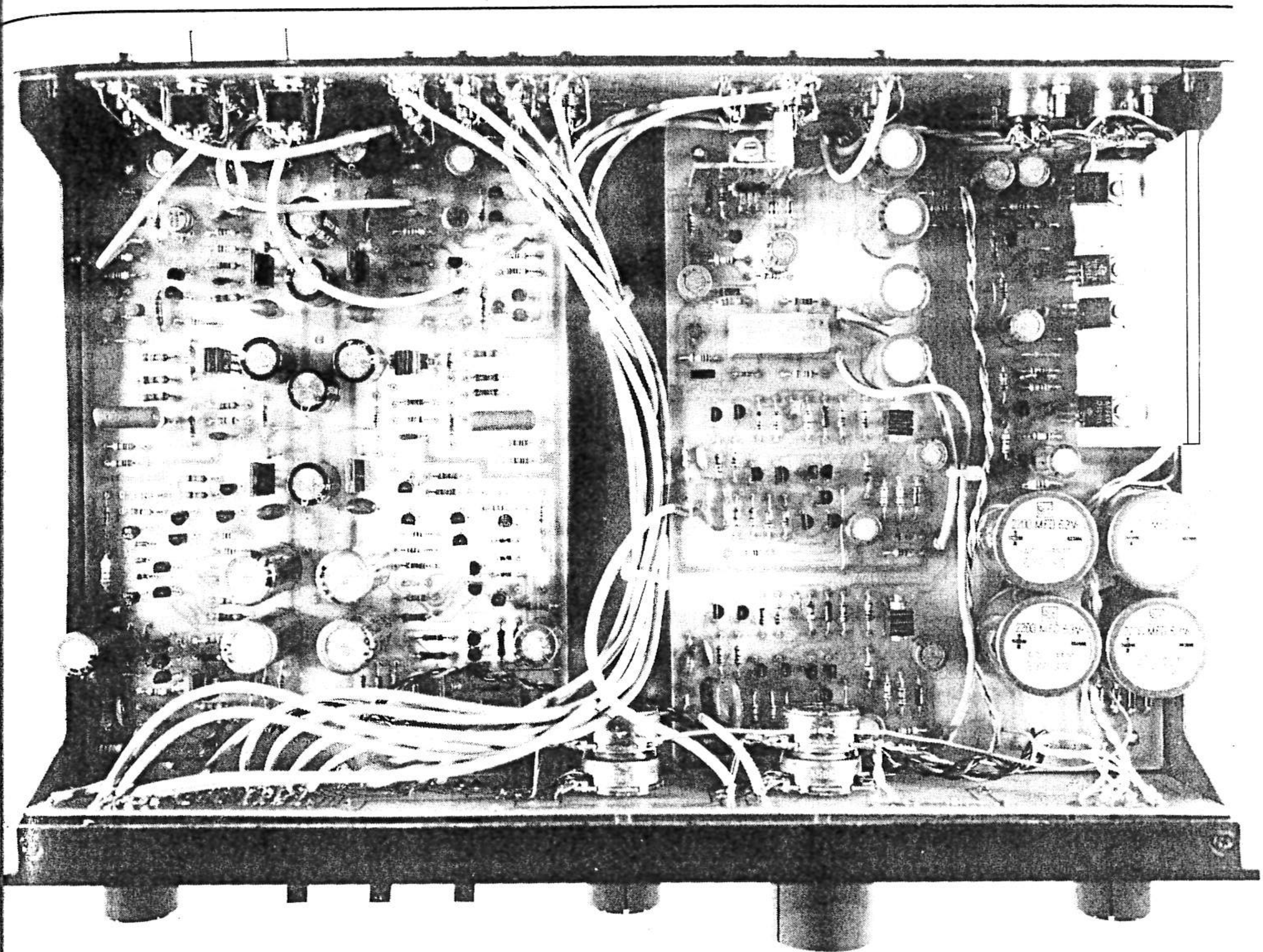
THE COMPLETE PREAMP CIRCUIT diagram is shown here in Figure 7 (Figures 1-6 are included with last month's article) while Figure 8 shows the circuit diagram for the power supply and relay muting circuitry.

The overall gain of the preamplifier is incorporated into two broad stages. The first of these is the low level amplifier stage which was described in detail in last month's article. The second gain stage is the line amplifier which has a flat gain of around 9.3. The line amplifier circuitry is based around the discrete amplifying stage that was developed for use in the AEM6010, which was described in last month's article. This stage provides the gain necessary to ensure the correct nominal output signal voltage (1 V RMS) when the preamp is driven from standard high level sources. The input impedance of this stage is around 470k, which is high enough to prevent excessive loading of the monitor volume control. The input bias current of this stage has been optimised for best possible noise performance when driven from the source impedance formed by the balance and volume potentiometers. The source impedance, of course, will vary depending on the position of the potentiometer wipers so the bias current must be a compromise.

The preamplifier assembly comprises four printed circuit boards. The first of these is the low-level amplifier stage described previously. The bulk of the remaining electronics is mounted on the line preamplifier pc board. The board contains the line amplifier stages, the electronics for the regulated power supplies and the relay muting circuitry. The two remaining circuit boards hold the components for the front and rear panels of the preamp. Some of the interconnections between these pc boards must be made using shielded cable to obviate susceptibility to hum pick-up. No power transformer is included in the preamplifier chassis to minimise any possibility of hum pick-up. The low voltage ac supply required by the preamp must be supplied either by the accompanying power amplifier or by a power transformer mounted in a separate chassis and this technique is a major contributor to the excellent hum and noise figures.

The source selector switch, SW3, is a six-position two-pole Lorlin rotary switch with make-before-break contacts and is in common usage, so availability should present no problems. A more expensive switch, possibly incorporating separate wafers for separate channels, could be used if desired. The switch used, however, was found to give impeccable performance. These switches, manufactured by C&K, are available in two types. The most common seems to be that supplied with solder lugs rather then the pc mount pin types. If you can only obtain the solder-lug type of switch these can be used simply by cutting off the ends of the pins with a pair of sidecutters. There is, however, only just enough pin left to pass through the pc board and leave a sufficient length of pin to solder to, so ensure that the cut is made as closely as possible to the solder eye.

This rotary switch, the power switch and the toggle switches are soldered directly to the front panel pc board. The remaining two front panel controls, the balance and volume control potentiometers are bolted to the pc board. Being dual-gang pots, the set of lugs closest to the board are soldered directly to the pads, the other lugs being wired to their pads using short lengths of hookup wire.



The extensive use of pc boards throughout this design helps to ensure maximum ease of construction and certainly reduces the possibility of incorrect earth wiring, one of the major constructional causes of poor performance in audio circuitry.

All of the inputs are tied to ground with resistors which maintain the dc voltage on these inputs at 0 V. Without these the different inputs can establish themselves at a non-zero dc voltage level. In this case, the preamp will generate a large transient voltage spike when the selector switch is operated which manifest itself as a loug thump in the loudspeakers.

The output of the selector switch is fed to the source/tape monitor switch via 1k resistors R63 and R163. The 1k resistors are also included in series with the tape/extension monitor input. These resistors serve to prevent excessive loading of the inputs when the mode switch is in the "mono" position. The output of the tape/extension monitor is fed to the balance and volume control potentiometers. The balance control consists of 100k linear dual potentiometer wired so that opposite ends of each half of the pot are grounded. This type of balance control was chosen because it enables the signal earths of each channels to remain isolated at this point.

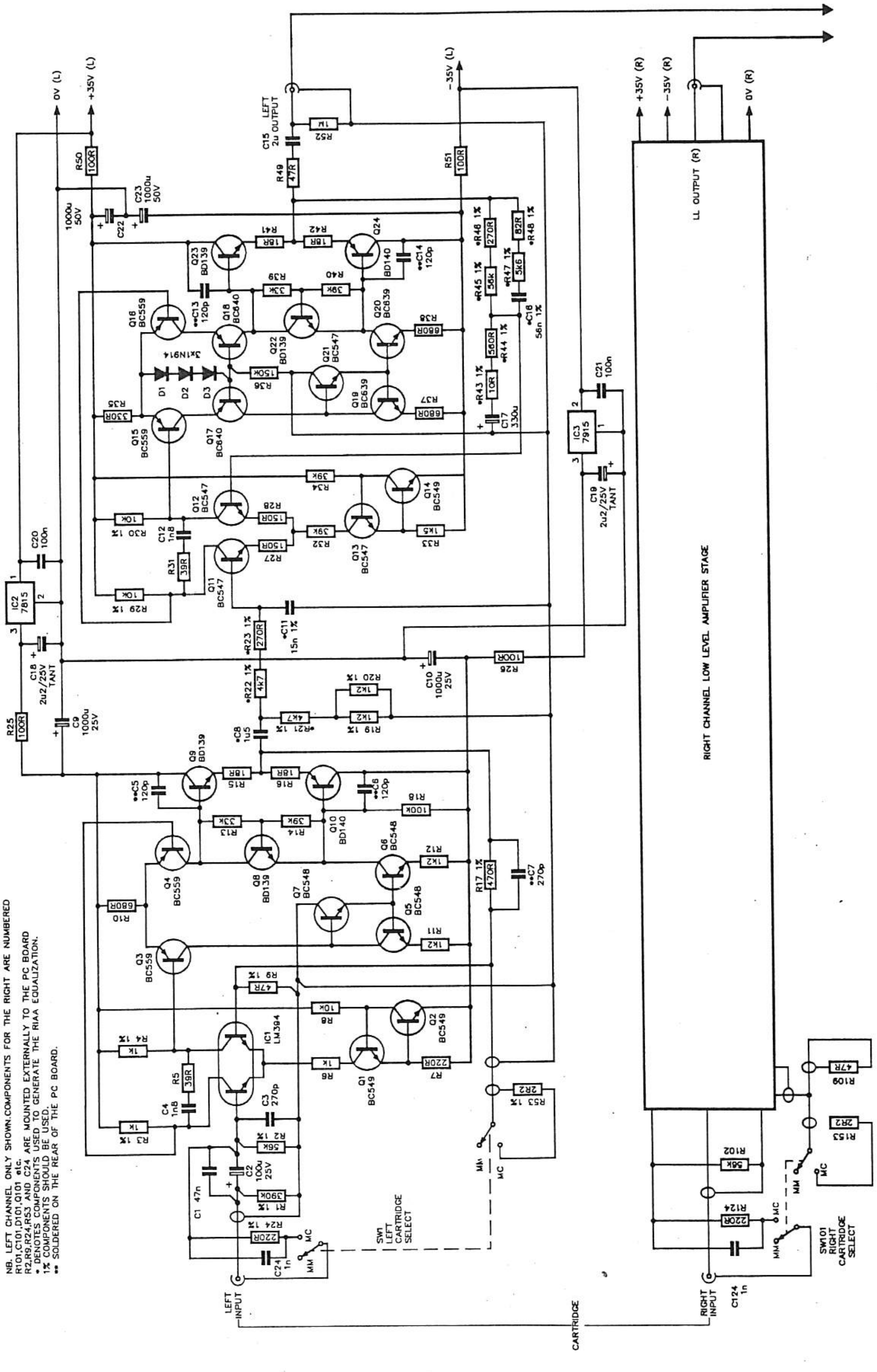
Earthing essentials

This technique of isolating the signal earth points of the channels is essential if good channel separation is to be maintained. Remember that when we speak of a signal voltage we are referring to a potential difference, i.e: a difference in potential between *two* points. The second reference point is usually what is referred to as the "earth". The problem is that in the real world there is no such thing as "earth". Every piece of hookupwire or length of copper pc board track has a finite, measurable resistance. Currents flowing in these conductors will generate potential drops across the ends of the conductors. An "earth" track, for example, that returns current to the centre tap of a power transformer from a pair of filter capacitors and bridge rectifier will have 100 Hz current pulses flowing in it when a 50 Hz supply is used. This current causes a 100 Hz voltage to be developed across the ends of the conductor. If any point along this conductor is "defined" to be the point we will call the *earth* then no other point on that wire will be at the same potential and hence no other point should be called the earth.

It is a recognition of this fact that gives rise to the so called "single-point" earthing schemes so often mentioned. The employment of a single-point earthing scheme, however, is not sufficient on its own to ensure effective earthing to minimise distortion or even to remove hum problems. The essential point to realise is that voltage is a measure of *potential difference*. It is as important to signal quality to ensure the integrity of signal earth line as it is to ensure the integrity of the "active" signal line.

In the AEM6010 this is done by maintaining the signal active and earth lines as a pair throughout the entire gain chain within the preamp. The signal earth lines of the two channels are isolated from each other and from all power supply 0 V lines until the output sockets. At this point the two channels are joined and connected to the power supply ▶

aem project 6010



NB. LEFT CHANNEL ONLY SHOWN. COMPONENTS FOR THE RIGHT ARE NUMBERED R101,C101,D101,Q101 etc.
R2,R9,R24,R53 AND C24 ARE MOUNTED EXTERNALLY TO THE PC BOARD
• DENOTES COMPONENTS USED TO GENERATE THE RIAA EQUALIZATION.
1% COMPONENTS SHOULD BE USED.
•• SOLDERED ON THE REAR OF THE PC BOARD.

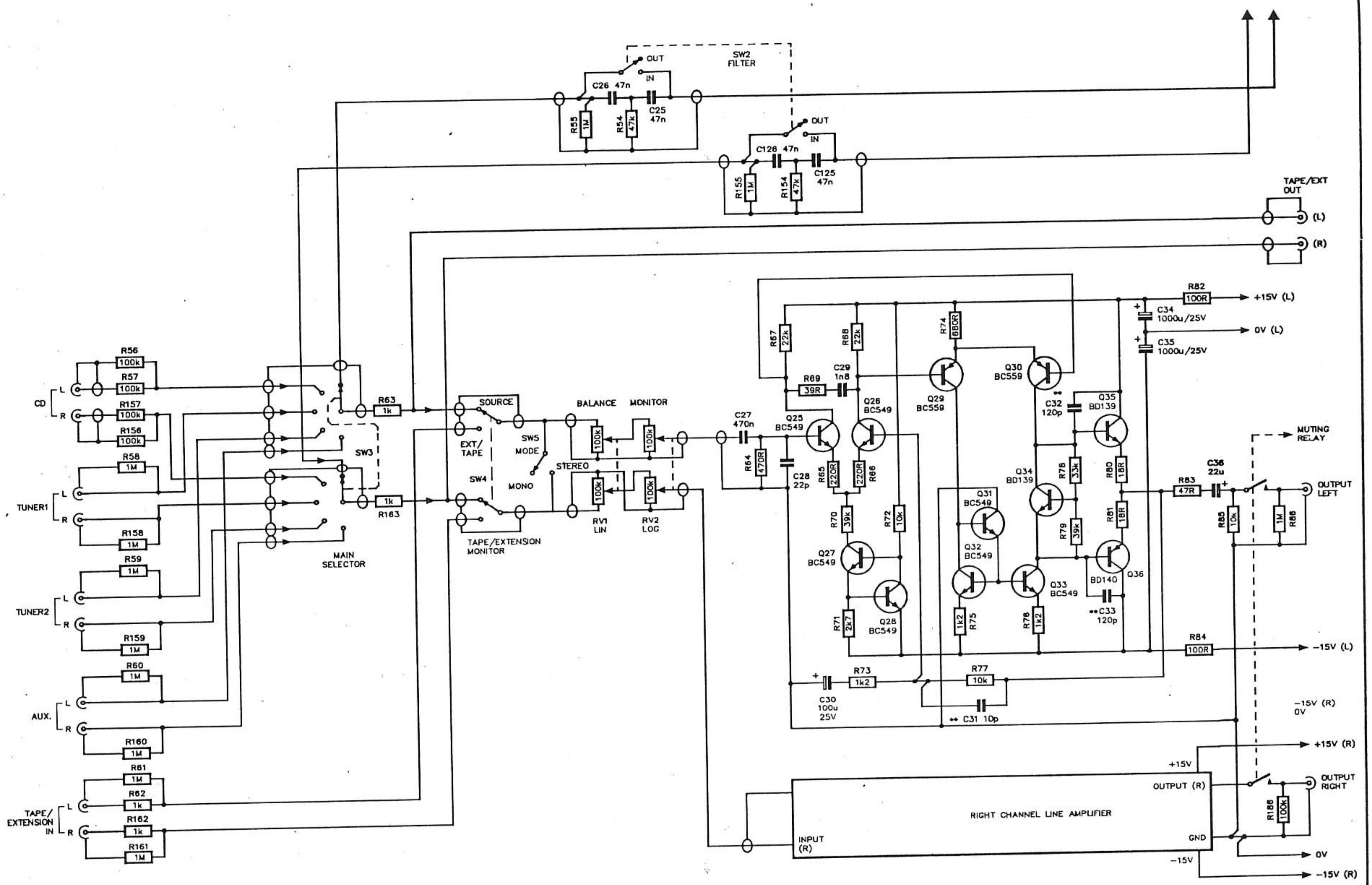
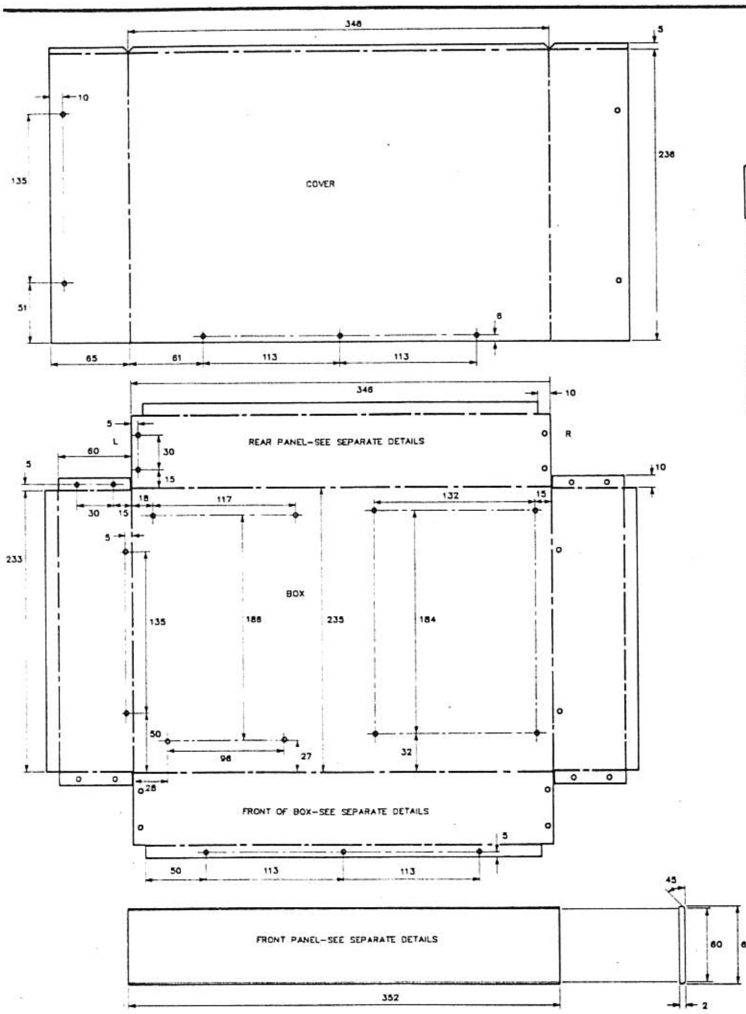
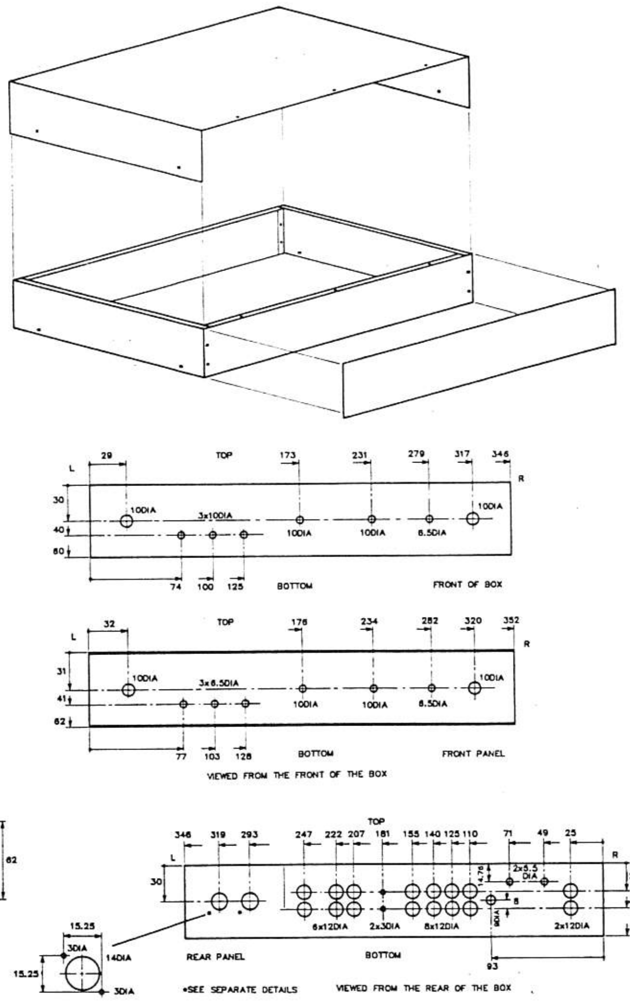

SW2
FILTER
OUT
IN
C26 47n
C25 47n
R55 1M
R54 47k
C128 47n
C125 47n
R155 1M
R154 47k
TAPE/EXT OUT
(L)
(R)
R82 100R
+15V (L)
C34 1000u/25V
0V (L)
C35 1000u/25V
CD
L
R
R56 100k
R57 100k
R157 100k
R156 100k
R58 1M
TUNER1
R158 1M
R59 1M
TUNER2
R159 1M
R60 1M
AUX.
R160 1M
R61 1M
R62 1k
TAPE/EXTENSION IN
R162 1k
R161 1M
R63 1k
R163 1k
SW3
MAIN SELECTOR
SOURCE
EXT/TAPE
SW5 MODE
SW4
MONO
STEREO
TAPE/EXTENSION MONITOR
BALANCE
MONITOR
100k
RV1 LIN
RV2 LOG
C27 470n
R64 470R
C28 22p
Q25 BC549
R67 22k
R69 39R
C29 1n8
R68 22k
Q26 BC549
R65 220R
R66 220R
R70 39k
R72 10k
Q27 BC549
Q28 BC549
R71 2k7
R74 680R
Q29 BC559
Q30 BC559
C32 120p
Q35 BD139
Q34 BD139
R78 33k
R80 18R
Q31 BC549
Q32 BC549
R79 39k
R81 18R
Q33 BC549
BD140
Q36
C33 120p
R75 1k2
R76 1k2
R84 100R
-15V (L)
R73 1k2
R77 10k
C30 100u 25V
C31 10p
MUTING RELAY
R83 47R
C36 22u
OUTPUT LEFT
R85 10k
R88 1M
-15V (R)
0V
+15V (R)
+15V
OUTPUT (R)
OUTPUT RIGHT
RIGHT CHANNEL LINE AMPLIFIER
INPUT (R)
GND
R188 100k
0V
-15V
-15V (R)

Figure 7.



CASE DRAWINGS, SHOWING ALL DIMENSIONS AND DRILLING DETAILS. THE PROTOTYPE WAS KINDLY SUPPLIED BY DICK SMITH ELECTRONICS.



earth point. This combination of single-point earthing and active/earth pair maintenance ensure that the AEM6010 is free of hum and enables the excellent noise and distortion performance of the active gain stages to be utilised freely.

Muting

As mentioned in Part 1, one of the important parameters in terms of the accoustic performance during the development of this preamp was found to be output impedance. Correspondingly, the active stages were designed with very low output impedance and this provided some problems in relation to the output muting system employed.

Output muting is needed in almost all audio systems to overcome the problem of turn-on and turn-off thump. Some integrated designs tend to provide relay switching for the output of the power amplifier. This is only necessary in descrete preamp-power amp combinations however, if the power amplifier generates a turn-on or turn-off thump. The AEM6500 general purpose power amp modules, for example, are not provided with output relay muting because their topology ensures that they do no generate a turn-on or turn-off thump when connected to any reasonably sized filter capacitors. Usually, it is the preamp which will generate most of the thump due to the large amounts of voltage gain following it in the power amp.

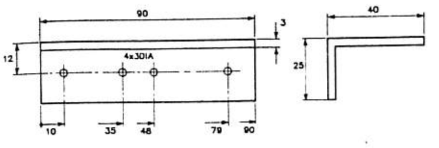
To overcome these problems the 6010 is provided with output muting which disconnects the power amps from the preamplifier output at turn-on until the preamp power supply has had time to settle, and immediately the power switch is turned-off, before the preamp power supply begins to drop.

In past designs I have tended to use active muting transistors which shorted the output of the preamp to prevent it being driven into overload during turn-on or turn-off. The "problem" mentioned before arises due to the very low output impedance of the line amplifier stage. Since any output-shorting transistor has a finite on-resistance the source resistance must be high enough to allow the on-resistance of the transistor to appear as an effective short when the output muting is activated. This is not the case with the 6010 output stage. The very low output impedance prevents this scheme from working effectively. As mentioned above, the output muting in the AEM6010 is achieved by the use of a relay in series with the output. Rather than shorting the output to ground when the muting is activated the relay open-circuits, disconnecting the line amplifier stage from the preamp output terminals.

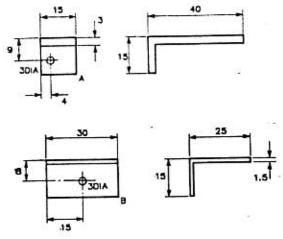
Construction

Commence the construction by assembling the 6010LL pc board described in last month's issue (October 1985) following the instructions detailed in that article.

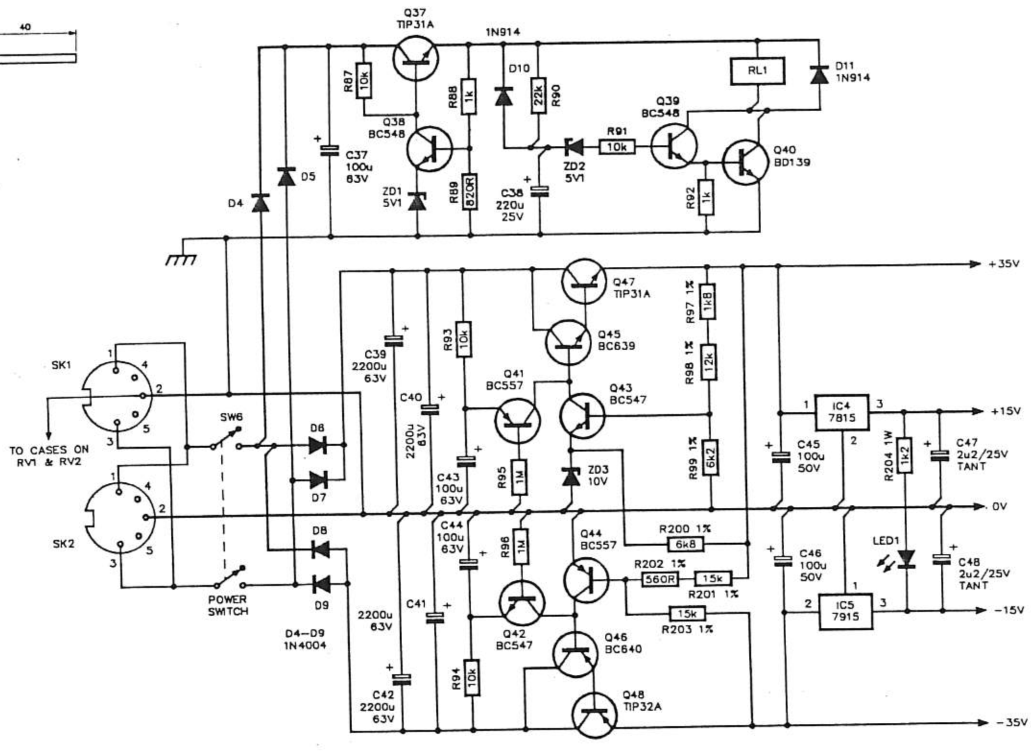
Next assemble the line amplifier pc board which contains the two line amplifiers, power supply and relay muting circuitry. This pc board contains two triple-sets of transistors as used on the low-level pc board. Apply the same procedure



HEATSINK FOR SUPPLY REGULATORS.



HEATSINK FOR Q37



when mounting these sets of transistors as that described in Part 1. This pc board also contains the heatsink for the power supply pass transistors and the positive and negative voltage regulators. The heatsink can be fabricated from a length of aluminium extrusion. A drawing showing the cutting and drilling details has been included with the article.

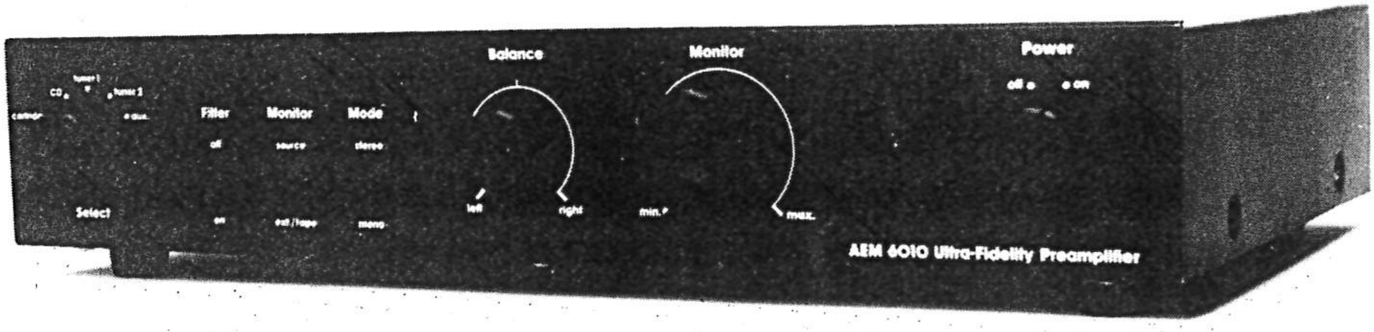
The centre lead of the two power supply pass transistors and the two voltage regulators is connected internally to the metal base of each transistor. Accordingly, the metal base of each of these devices must be electrically insulated from both the metal heatsink and the mounting screw to prevent shorting of the devices to each other. This is achieved through the use of special insulating washers and mounting bushes. To improve heat conduction across the metal/insulator interface a small amount of heat-sinking compound is applied to all surfaces before bolting the devices in place. The best order in which to mount these devices is to start by measuring the length of lead and bending the leads at the appropriate place. Insert the leads through the pc board but do not solder in place until later. Bolt the devices into place using insulated washers as discussed above. Using a multimeter, check that no short exists between the centre lead of each device and the heatsink. If all is well, solder the leads in place and trim off the excess with a pair of side cutters.

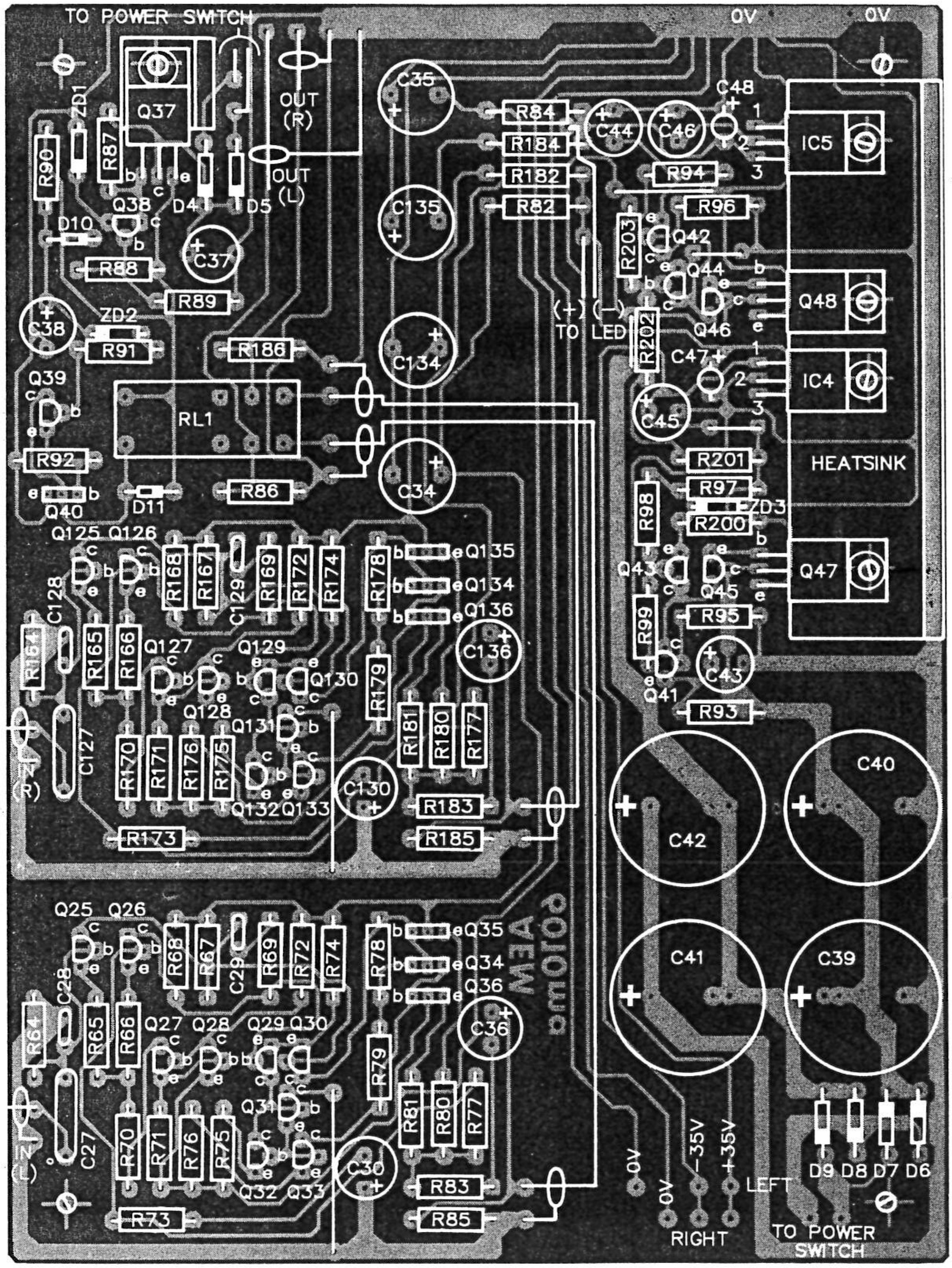
The usual precautions should be employed when constructing the rest of this board. It is wise to solder the smaller and more robust devices first, such as the resistors and non-polarised capacitors. These devices are less likely to be damaged while subsequently soldering the remaining components in place and are small enough so that they tend not to get in the way during the later stages. As always, be careful with the orientation of the polarised components such as electrolytic capacitors and diodes. These two-legged devices are particularly easy to insert the wrong way around and will often be destroyed if powered up in this condition.

Note that capacitors C31, C32, C33, C131, C132 and C133 are soldered on the track side of the pc board.

The front panel pc board contains the main selection switch as discussed above. The three toggle switches are soldered directly to the pc board as is the 4-pole Lorlin rotary switch used as the power switch. As discussed above, the pots are bolted to the pc board and wired in circuit with short links.

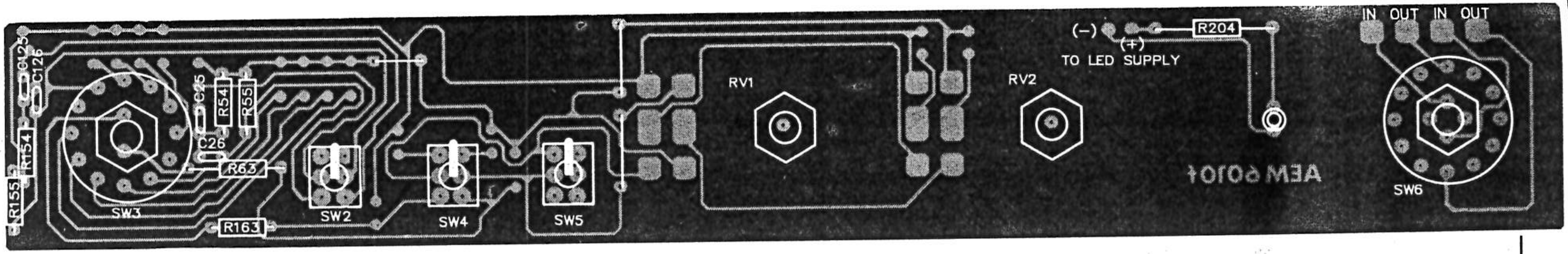
. . .continued next month.



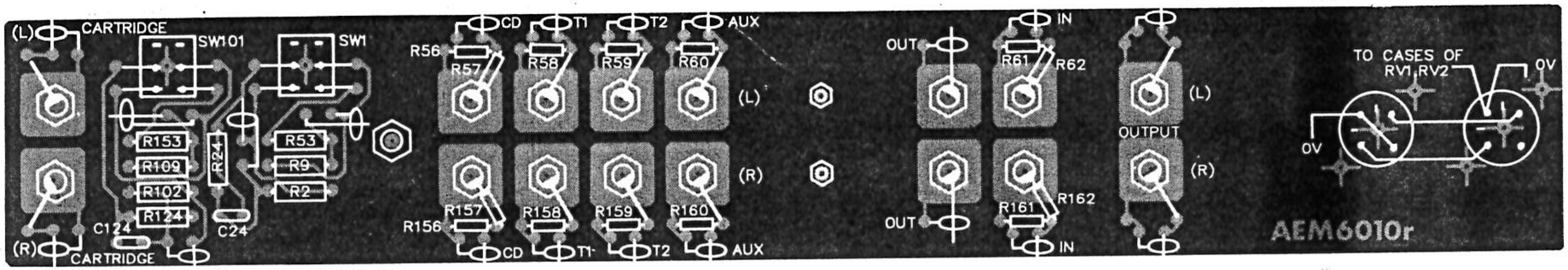


LEVEL

We expect that constructors of an **INTERMEDIATE** level, between beginners and experienced persons, should be able to successfully complete this project.



ABOVE: FRONT PANEL BOARD, LOOKING AT THE COMPONENT SIDE



ABOVE: REAR PANEL BOARD, LOOKING AT THE COPPER SIDE.

AEM6010MA F, R PARTS LIST

Semiconductors

Q25, Q125,
Q26, Q126 . . . . BC549C
Q27, Q127,
Q28, Q128 . . . . BC549
Q29, Q129,
Q30, Q130 . . . . BC559C
Q31, Q131, Q32, Q132
Q33, Q133 . . . . BC549
Q34, Q134,
Q35, Q135 . . . . BD139
Q36, Q136 . . . . BD140
Q37 . . . . TIP31A
Q38, Q39 . . . . BC548
Q40 . . . . BD139
Q41 . . . . BC557
Q42, Q43 . . . . BC547
Q44 . . . . BC557
Q45 . . . . BC639
Q46 . . . . BC640
Q47 . . . . TIP31A
Q48 . . . . TIP32A
IC4 7815
IC5 7915
D4, 5, 6, 7, 8, 9 . . . . 1N4004
D10, D11 . . . . 1N914
ZD1, ZD2 . . . . . . 5V1, 1 W Zener
ZD3 . . . . 10 V, 1 W Zener
LED1 . . . . TIL220R red LED

Resistors

All ¼W, 5% unless noted.

R54, R154 . . . . 47k
R55, R155 . . . . 1M
R56, R156,
R57, R157 . . . . 100k
R58, R158, R59, R159
R60, R160,
R61, R161 . . . . 1M
R62, R162,
R63, R163 . . . . 1k
R64, R164 . . . . 470k
R65, R165,
R66, R166, ... 220R
R67, R167,
R68, R168 . . . . 22k
R69, R169 . . . . 39R
R70, R170 . . . . 39k
R71, R171 . . . . 2k7
R72, R172 . . . . 10k
R73, R173 . . . . 1k2
R74, R174 . . . . 680R
R75, R175,
R76, R176 . . . . 1k2
R77, R177 . . . . 10k
R78, R178 . . . . 33k
R79, R179 . . . . 39k
R80, R180,
R81, R181 . . . . 18R
R82, R182 . . . . 100R
R83, R183 . . . . 47R
R84, R184 . . . . 100R
R85, R185 . . . . 10k
R86, R186 . . . . 1M
R87 . . . . 10k
R88 . . . . 1k
R89 . . . . 820R
R90 . . . . 22k
R91 . . . . 10k
R92 . . . . 1k
R93, R94 . . . . 10k
R95, R96 . . . . 1M
R97 . . . . 1k8, 1%
R98 . . . . 12k, 1%
R99 . . . . 6k2, 1%
R200 . . . . 6k8, 1%
R201 . . . . 15k, 1%
R202 . . . . 560R, 1%
R203 . . . . 15k, 1%
R204 . . . . 1k2, 1 W
RV1 . . . . 100k/A dual
RV2 . . . . 100k/C dual

Capacitors

C25, C125,
C26, C126 . . . . . . 47n greencap.
C27, C127 . . . . . 470n greencap.
C28, C128 . . . . 22p ceramic.
C29, C129 . . . . . . 1n8 greencap.
C30,
C130 . . . . 100u/25 V RB electro.
C31, C131 . . . . 10p ceramic.
C32, C132,
C33, C133 . . . . 120p ceramic.
C34, C134, C35,
C135 . . . 1000u/25 V RB electro.
C36,
C136 . . . . . 22u/25 V RB electro.
C37 . . . . . 100u/63 V RB electro.
C38 . . . . . 220u/25 V RB electro.
C39, C40, C41,
C42 . . . 2200u/63 V RB electro.*
C43, C44 . 100u/63 V RB electro.
C45, C46 . . . 100u/50 RB electro.
C47, C48 . . . . 2u2/25 V tant.
*"ROE" type EYF or similar.

Miscellaneous

SW2, SW4, SW5 . . . . DPDT min. toggle, C&K type 7201 L40 with black lever handles part no. 48102 and black dress ring type 7099 blk.

SW3 . 2-pole, 6-pos. Lorlin rotary switch (make before break).
SW6 . 4-pole, 3-pos. Lorlin rotary switch.

RL1 . . . . . DPDT 'standard relay' (e.g: DSE cat. no. S7130).

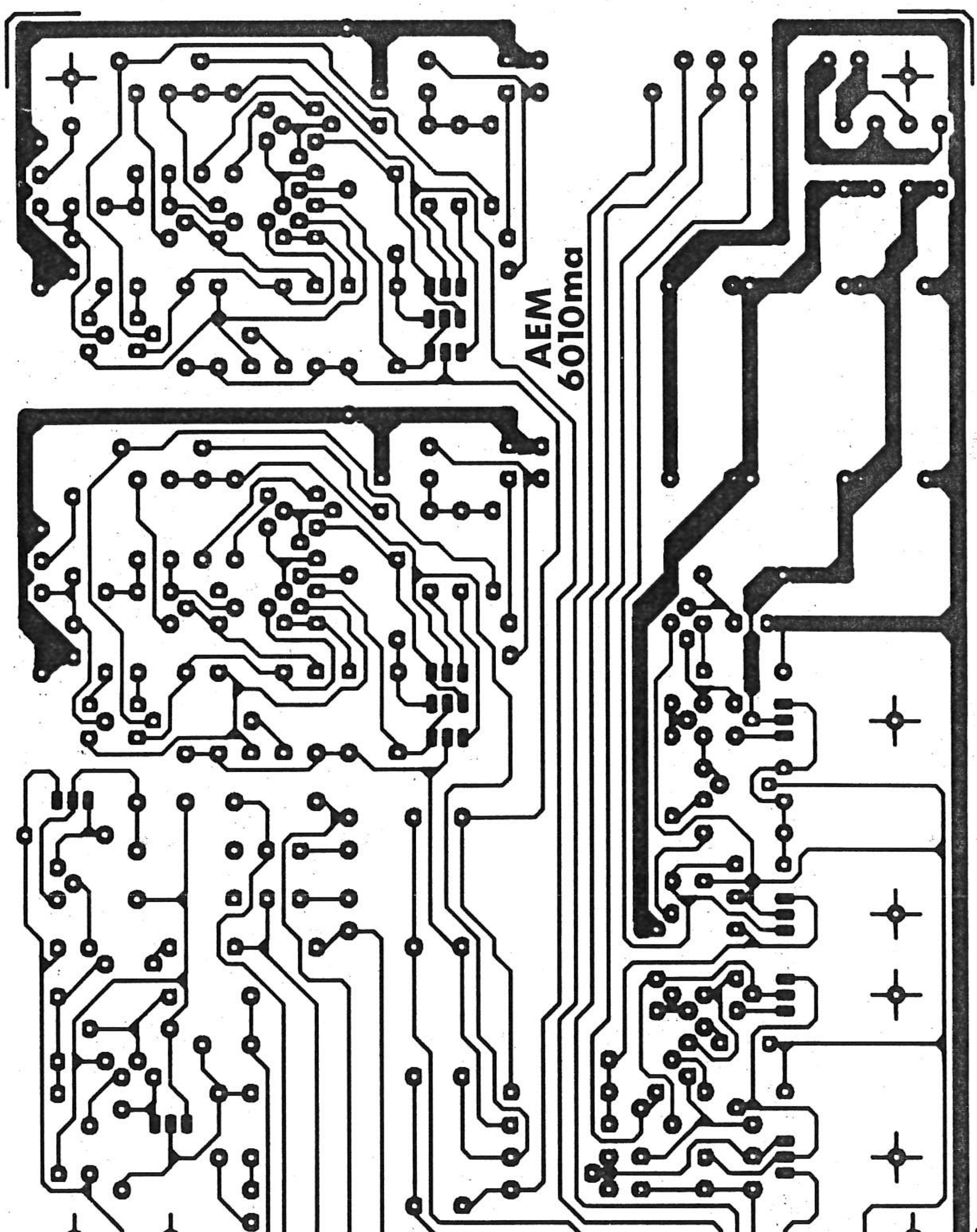
SK1, SK2 5-pin DIN sockets.

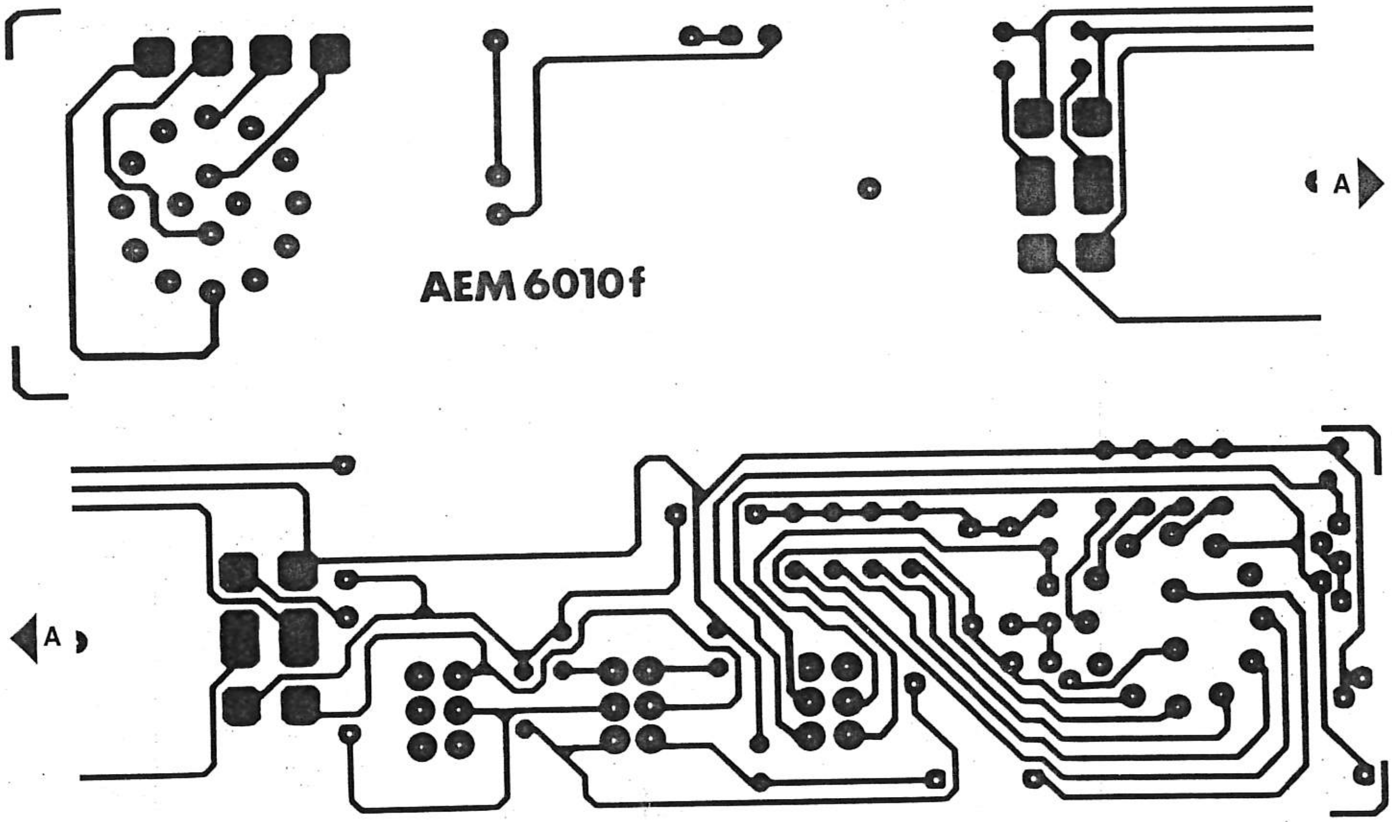
SK3, SK103, SK9,
SK109 chrome RCA sockets.

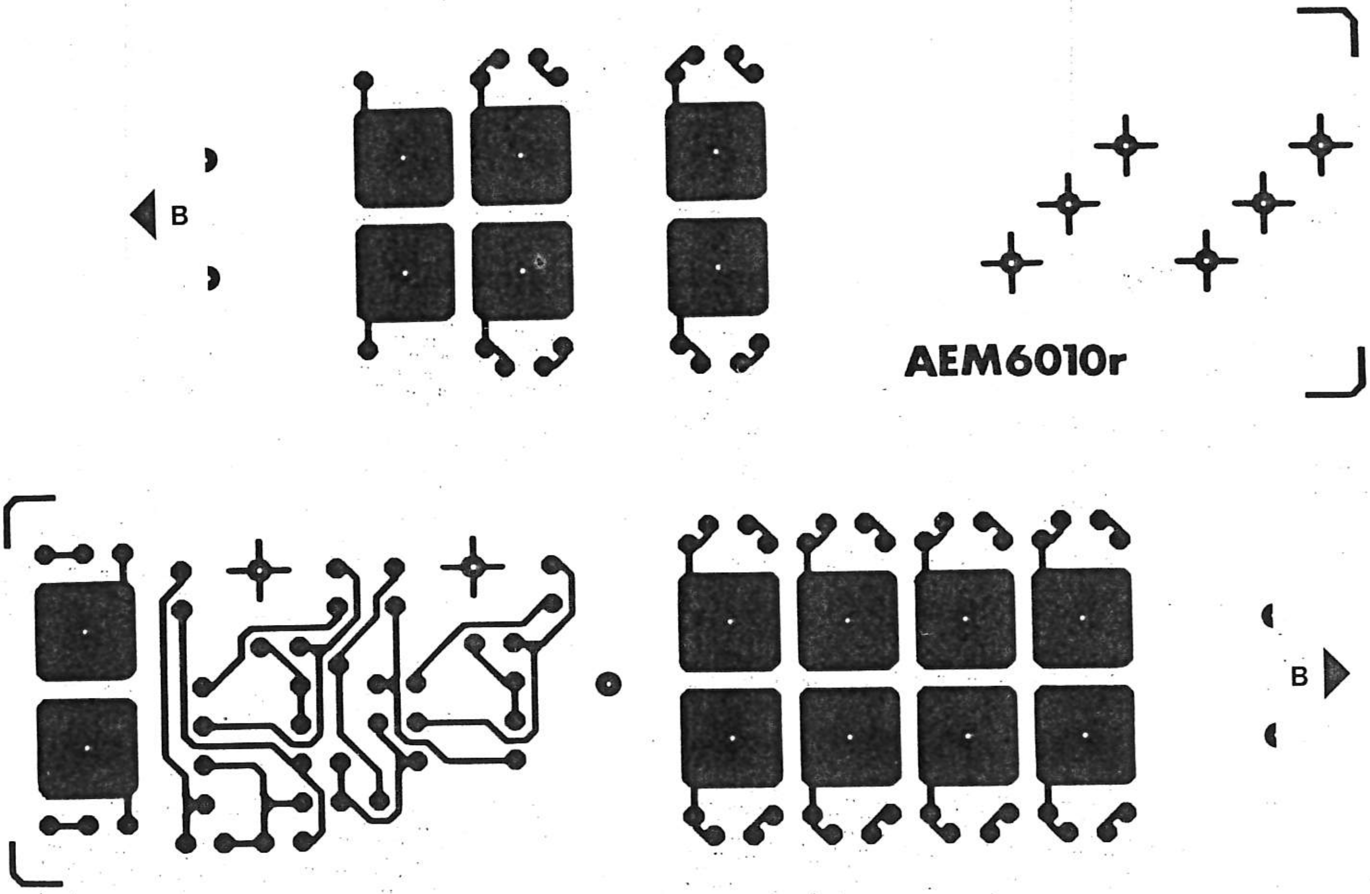
SK10, SK110 gold RCA sockets.

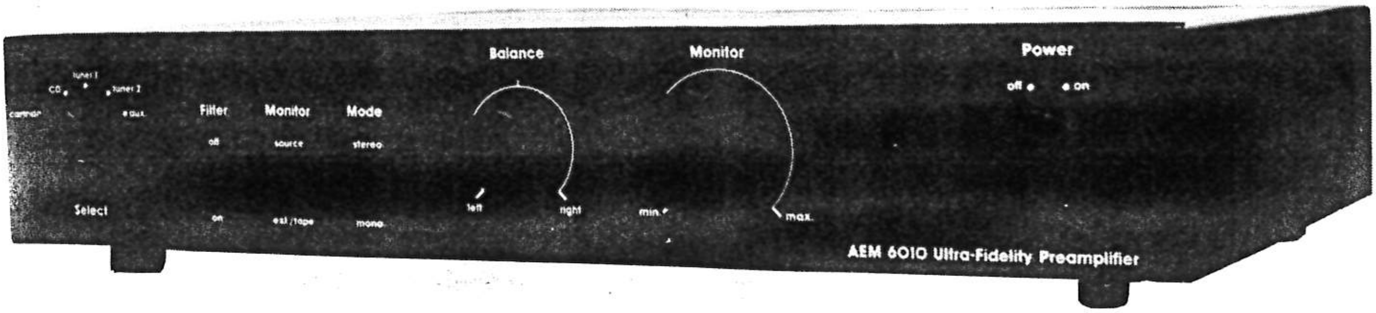
AEM6010MA, AEM6010F, AEM6010R pc boards; two aluminium angle heatsinks (as per drawings); 3 x 22 mm dia. black aluminium knobs; 1 x 30 mm black aluminum knob; length of shielded cable unbraided shield type 4 mm dia.; hookup wire; chassis as per drawings; 26 sets 12 mm x 6 BA bolts and nuts; 8 x 6 mm spacers; 5 x T0126 transistor insulating sets; 1 x 5-pin DIN plug.

Expected cost: $175-$195.


AEM
6010ma


AEM6010f
A
A


B
AEM6010r
B



An 'ultra-fidelity' preamplifier

Part 3
David Tilbrook

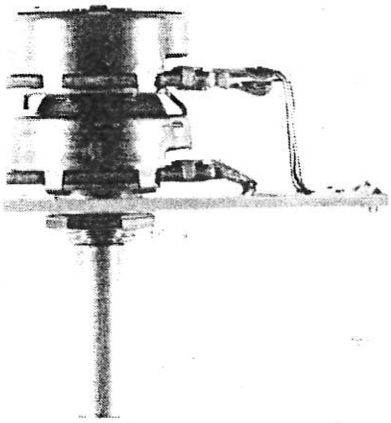
This stage completes the construction, interwiring and assembly of the preamp into the chassis.

BY THIS STAGE, you will have completed the assembly of the four printed circuit boards. Give them all a careful visual inspection. A little time spent doing this now can save lots of frustration later. Check that you have the six capacitors indicated in the penultimate paragraph of Part 2, soldered to the rear of the 6010ma board. All clear? Now we can get down to the 'final leg' — assembling them in the chassis and completing the necessary interwiring.

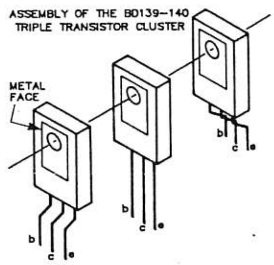
It is probably wise to use shielded cable for all the interconnections that carry audio signals within the preamp such as those to and from the rear panel sockets. Shielded cable is not difficult to use once a few basic techniques have been mastered. The area that causes most of the problems is usually that of removing the outside insulation without cutting the shield wires. The easiest way to overcome such problems is to invest in an inexpensive pair of insulation strippers. This is a very useful tool for an electronic experimenter and saves considerable time when preparing shielded cables. The easiest type of shielded cable to use is the lightest gauge, single conductor type although there are some excellent multiconductor cables available.

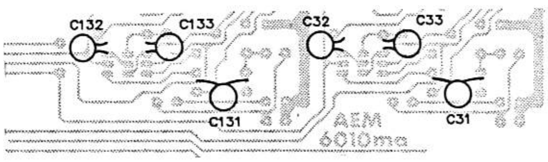
Once the pc boards have been constructed to this stage they should be positioned in the chassis to be made for the remaining lengths of hookup cable required. Each connecting cable should be cut to length, trimmed and soldered onto the low level amp and line amp pc boards. Once all of the cables are soldered into place the remaining pc boards can be bolted into place and the other ends of the shielded cables terminated to the front and rear boards. This is not difficult since the connections are made to the copper side of the pc boards.

The front panel pc board is held in place by the mounting nuts on the two Lorlin switches and then the three toggle switches. The toggle switches selected for this project are supplied separate from the black linear paddles which should only be fitted to the switches at the last stage. These switches are supplied with both a standard mounting nut and a black dress ring. The standard nut should be adjusted so that the dress ring tightens down correctly on the front panel of the preamp.

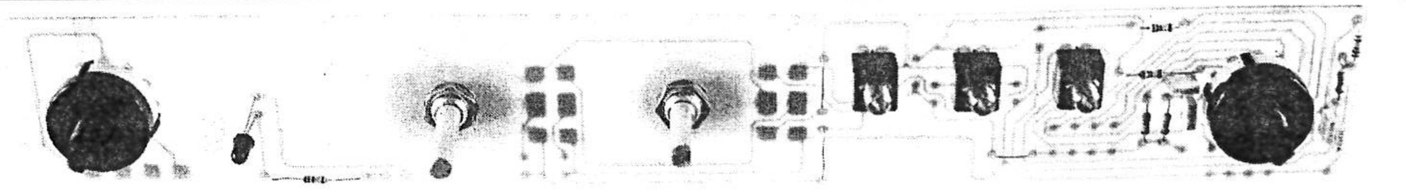


Showing how the dual-gang volume pot is wired to the front panel pc board.





Placement of the capacitors on the rear side of the board.



Overall view of the front panel pc board, showing how the switches mount on the front (non-copper) side.

The toggle switches and DIN sockets fitted to the rear panel mount through both the rear panel and the rear panel pc board and are wired using the shielded cables and hookup wires already soldered to the main pc boards.

The final stage in construction is to fit the toggle switch linear paddles and the knobs. The toggle switches have flats on the selector so the linear handles will only go on one way.

In the prototype unit we used 22 mm black knobs for the selector switch, balance control and power switch. A larger, 28 mm, black knob was used for the monitor volume control.

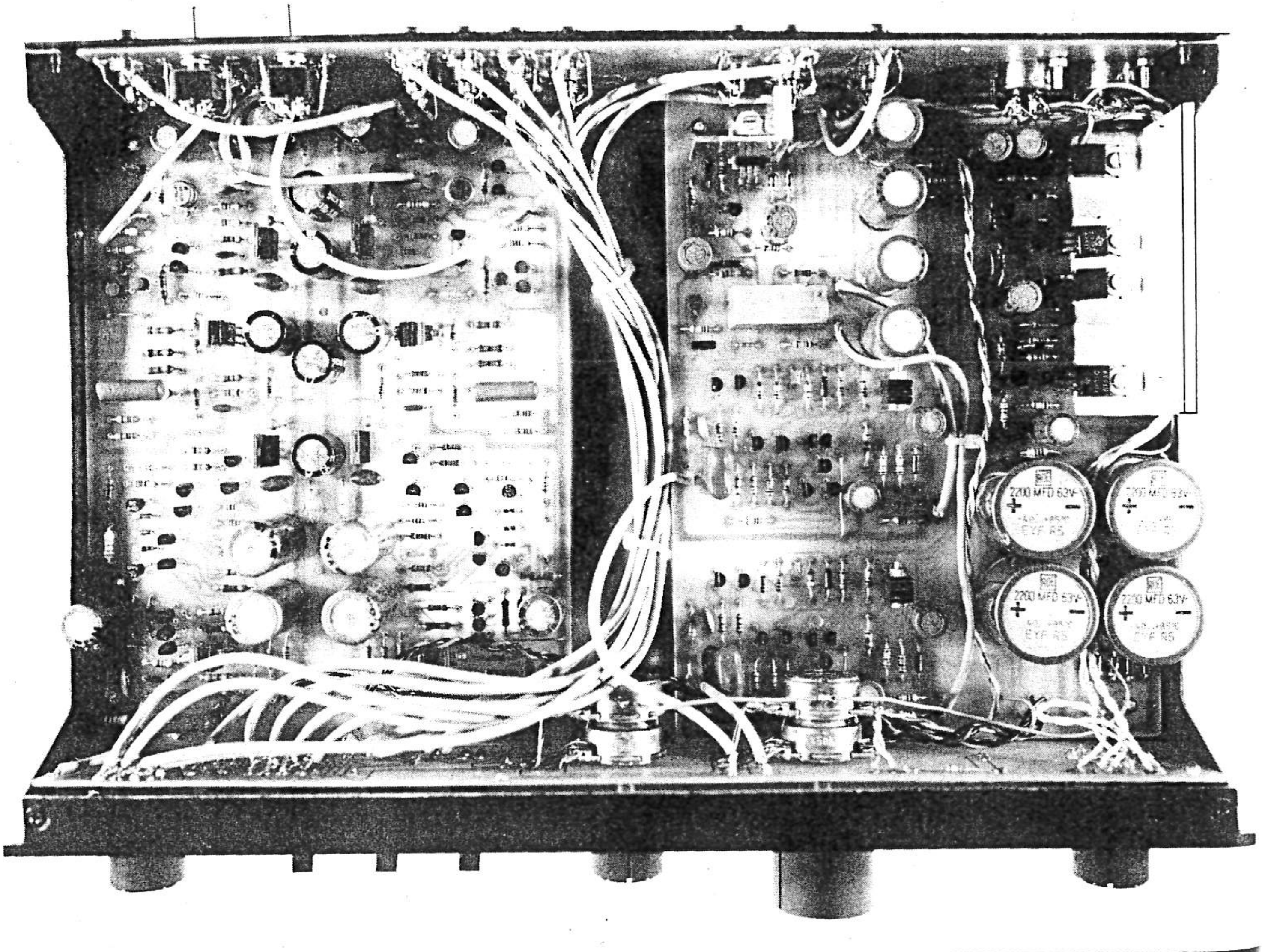
Powering up

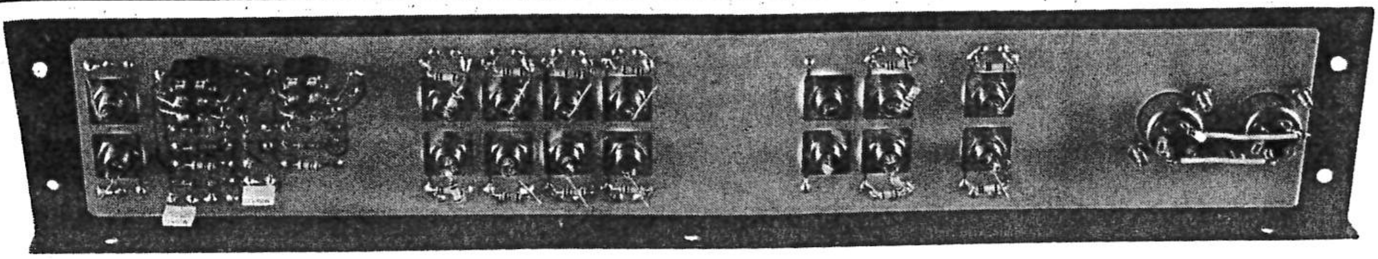
Before applying power to the unit recheck as much as possible. Check the orientation of diodes and polarised capacitors, check that the correct types of transistors have been inserted and check the power supply connection between the line and low level pc board. If these are incorrect it will almost certainly damage the low-level pc board assembly.

If all is well, connect a 35-0-35 V RMS transformer to a DIN plug according to the wiring diagram and apply power to the preamp. When the unit is switched on the amplifier muting relay should be heard to click approximately one second after switching on. The relay should switch immediately the preamp is switched off. Check that the power LED on the front panel is operating when the preamp is switched on.

If all is well turn the preamp off and connect it to a power amplifier, signal source and loudspeakers. Ensure that the balance is centred and the monitor volume is turned fully down. Switch the preamp on and slowly wind up the volume to a comfortable listening level and check the project behaves as you would expect.

If you intend to build the AEM6000 power amplifier (. . . coming!) you will only need to use the external transformer temporarily. The power amp will be provided with a suitable ac outlet to run the preamp and other accessories that are planned for this range of AEM audio electronics.





Overall view of the rear panel pc board. In this case, the components mount on the copper side of the board.

Overall wiring diagram. Reference to this and the internal photograph makes it all clear.