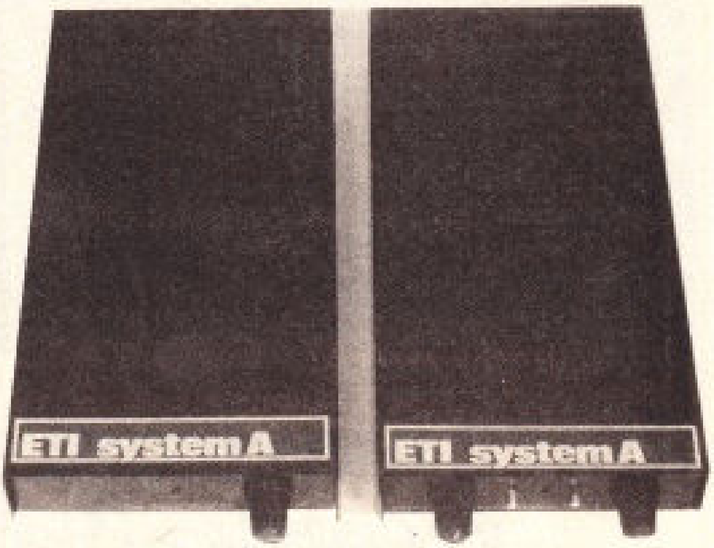
SYSTEM A AUDIO AMPLIFIER

Look no further. This superb amplifier is quite simply the best. Designed to out-perform even commercial equipment, the System A combines ease of construction with Class A quality. Design and development by Stan Curtis.



The initial design brief for this amplifier — 'no compromise' signal reproduction but at the lowest possible cost — proved to be deceptively difficult! The first preamp design eliminated all switches and controls to leave a pick-up input socket, an output socket and a volume control, but such a layout would be far too spartan for even the most serious audio enthusiast. The minimum input requirements were thought to be pick-up, tuner and tape, with tape recorder/monitor output. A stereo-mono switch is unnecessary for serious listening, as are all the other controls that came to mind (except volume and balance!).

The next choice was between discrete or integrated circuits. Despite the obvious benefits and inherent simplicity of IC-based circuitry, I decided upon good old-fashioned transistor stages. Why? Several reasons:

1. If labour costs are disregarded (which they are in this case) the discrete transistor version costs less.
2. Discrete stages can be more easily optimised for a particular design requirement, and give a lower component cost and higher sound quality.
3. There is a purely emotional feeling that when using audio ICs, the designer hasn't really contributed very much to the final design!

(In fact the final circuits are, in effect, discrete component operational amplifiers, so something of the IC design philosophy has obviously rubbed off.)

Pick-up An Input

Provision has been made for the preamp to be used with virtually any available pick-up cartridge, through the use of plug-in input circuit boards. Two input circuit boards have been designed although both use the same printed circuit layout. One is for moving-magnet cartridges and the other for moving-coil cartridges. The gain of both these modules can be varied to suit different cartridges by the change in value of a single resistor. Input loading (both resistive and capacitive) can be changed by the substitution of alternative components and, as a source of guidance, a comprehensive table has been produced showing the requirements for the majority of pick-ups currently on sale.

The whole of the preamp design is extremely flexible, permitting alterations to ensure compatibility with other equipment. The basic version has a nominal 775 mV output level and a 75 R output impedance.

PSUing Quality

The power supply is built into a separate case to achieve better screening as well as increasing the versatility of the system. This new 'Audiophile' system is conceived as a modular 'building block' concept offering a variety of facilities. The power supply is capable of powering several preamplifiers but will also be used to power a matching parametric equaliser unit and two other blocks still under development. Their basic designs will follow the existing format and will be published in the months to come.

As for the preamplifier, work goes on to take advantage of its ability to accept alternative input modules, and the design of new modules will be published periodically to enable constructors to update their models.

Outward Bound

Provision has been made on the main PCB for the fitting of an output coupling capacitor (C15). Normally this shouldn't be necessary and the two pads should be joined by a wire link to couple the output directly to the power amplifier. A very small number of power amplifiers are totally DC-coupled, so any DC voltage on their input terminals would result in an unacceptable DC offset across the loudspeaker. In such a situation the capacitor should be fitted. Its value can be selected to suit the input impedance of the power amplifier; a value of 3u3, 35 V (tantalum) is acceptable with a 10k input impedance and 470n with a 50k input impedance. The capacitor polarity should be aligned to correspond to the residual DC offset at the output of the preamplifier.

Construction

Although no metalwork plans have been provided it will be seen that the prototypes have been housed in a simple, compact, and functional case consisting of an aluminium chassis and a substantial steel cover. (Arrangements have been made for supplies of these cases to be made available to ETI readers — see Buylines.)

TABLE 1. SPECIFICATION

PREAMP

Rated output level:	775 mV (0 dBm)	
Maximum output level: (20 Hz to 20 kHz)	7V8	
Total harmonic distortion (including noise)		
Auxiliary input, 775 mV output	20 Hz	0.01%
	1 kHz	0.01%
	20 kHz	0.01%
Pick-up input, 1V5 output	20 Hz	0.02%
	1 kHz	0.02%
	20 kHz	0.02%

Pick-up input overload (ref rated input at 1 kHz)

	Moving Magnet	Moving Coil
20 Hz	43 dB	44 dB
1 kHz	43 dB	40 dB
20 Hz	43 dB	32 dB

Input sensitivity (ref 775 mV output at 1 kHz)	
Auxiliary	65 mV
Pick-up (moving magnet)	2.3 mV
Pick-up (moving coil)	550 mV
Noise level, 'A' weighted (ref 775 mV output at 1 kHz)	
Auxiliary	−90 dBA
Pick-up (moving magnet)	−80 dBA
Pick-up (moving coil)	−76 dBA

Channel separation, pick-up input (unused channel loaded)

1 kHz	62 dB
20 kHz	69 dB

RIAA equalisation accuracy: ±0.2 dB (20 Hz to 20 kHz)

Frequency response: (auxiliary input) ±0.5 dB, 5 Hz to 35 kHz

The above figures are for the standard version. The performance of the alternatives will vary in terms of sensitivity etc.

POWER AMP

Biasing mode:	Class A
Rated power:	60 W RMS into 8R, 20 Hz to 20 kHz
Transient delivery:	150 W into 8R

Harmonic and intermodulation distortion: less than 0.06% at rated power output (20 Hz to 20 kHz), decreasing monotonically with decrease in power. Distortion is virtually unmeasurable at small signal levels.

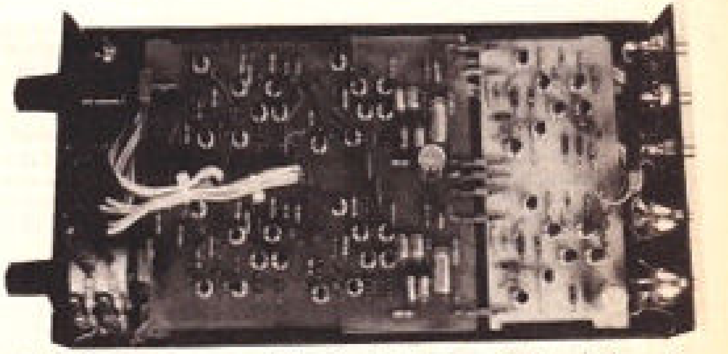
Frequency response: (ref 0 dB at 1 kHz)	10 Hz −1 dB 120 kHz −6 db
Power bandwidth:	5 Hz to 60 kHz
Hum and Noise:	100 dB below 24 V RMS output (CCIR)
Sensitivity:	700 mV RMS for 60 W into 8R

Negative feedback: the open loop gain is reduced by 22 dB by the application of overall negative feedback.
Transient intermodulation distortion: zero

The preamplifier circuitry has been constructed on two printed circuit boards which plug together using high quality gold-plated connectors. The construction of these boards should present no difficulties if the layout is followed correctly. There is a certain amount of wiring using screened cable and it is essential that this be done neatly and correctly. A wiring diagram has been given which shows the loom in detail and this arrangement should be followed fairly closely. The ends of all screened cables should be sleeved to avoid the danger of stray strands shorting out the signal. Particular attention is drawn to the earth connections which are always a problem with stereo amplifiers. The arrangement as drawn works. Others might not! You may wonder why this wiring has not been incorporated on the PCB. This could have been done for ease of assembly but only at the cost of the loss of isolation between the various signal and supply paths. In this context it is interesting that one of the world's best regarded preamps, the ultra-expensive Levinson, using several hundred dollars' worth of military grade, PTFE-insulated screened cable in the pursuit of signal isolation. However, our budget model uses common-or-garden screened cable to do the same thing! The use of this cable plus some care in layout results in a quite respectable figure for stereo separation at high frequencies.

It is recommended that the phono sockets for the pick-up inputs be gold-plated. These are expensive and difficult to obtain but, for optimum results to be obtained, they must be used. I have undertaken a lot of research into the effects of signal connections and have found that, while in theory both the gold-plated and nickel-plated contacts give equally good connections, in practice and over a period of time the gold-plating will prove its worth. I will say no more because a full summary of the problems associated with connectors would fill an article of its own.

Most of the transistors used are uncritical and the recommended types can often be substituted for, provided that due regard is paid to voltage ratings and so on. However, the 2N4401 first stage transistors are notably quieter than many alternative 'low noise' types (BC109 etc) and these should be fitted. The input transistors (Q1 and Q2) used for the moving-coil stage (module A-MC) are medium-power devices selected from the BC160 family. They are tested for low noise under the specified operating conditions. Transistors of this type could be fitted on a 'pot-luck' basis but this may lead to disappointment, frustration, and a need for a new nozzle on your solder sucker! Alternatively the correct pre-tested transistors can be used and a supply of these has been made available (see Buylines).



Inside the prototype preamplifier. Construction is on two boards, the main preamp module A-PR and the smaller input module. The latter is connected to the main board and the phono input by gold-plated connectors (see Buylines). This enables different input modules to be easily exchanged to match different cartridges. If you're certain you'll only ever be using one cartridge, you could dispense with the connectors and solder wire links instead.

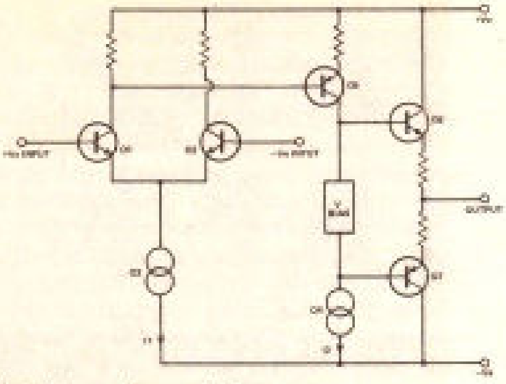
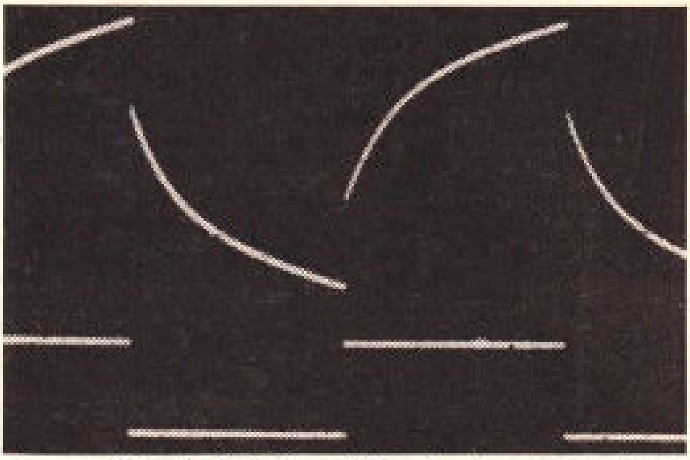


Fig. 1 Simplified diagram of one gain stage.



Response of the series feedback equalisation stage to a square wave input signal.

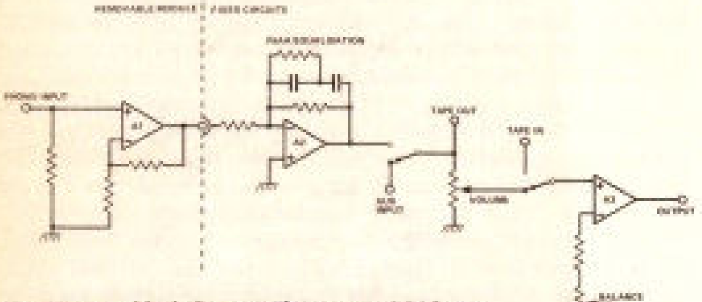


Fig. 2 Preamp block diagram. The 'op-amps' A1-3 are, in fact, built using discrete components.

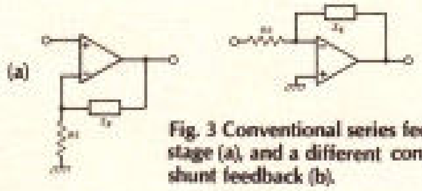


Fig. 3 Conventional series feedback equalisation stage (a), and a different configuration using shunt feedback (b).

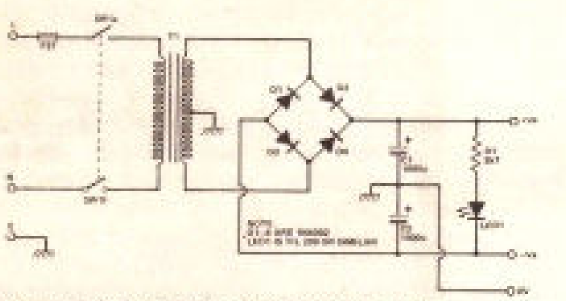


Fig. 4 Circuit diagram of the A-PSU preamplifier power supply.

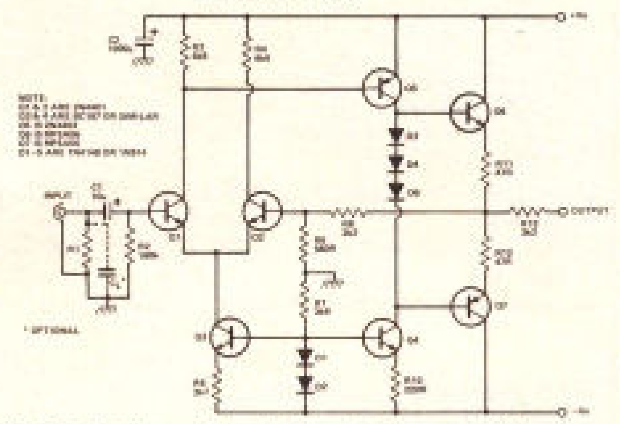


Fig. 5 Circuit diagram of the A-MM moving magnet module.

Each stage of the preamplifier uses a virtually identical discrete component operational amplifier. This op-amp is shown in simplified form in Fig. 1. The input stage is a long-tailed pair composed of transistors Q1 and Q2 whose collector current is determined by a constant-current source (Q3) and works out at about 100 uA for each transistor. This current has been chosen to give a low noise figure for this stage. The second stage is a voltage amplifier (Q5) which drives a constant current load (Q4) to set the standing current of this stage at about 2 mA. The four series diodes bias on the complementary output stage (Q6, Q7) to give a quiescent current of 8 mA. This value of standing current ensures that all the amplifier stages continue to operate in the linear Class A region even when driving low impedance loads.

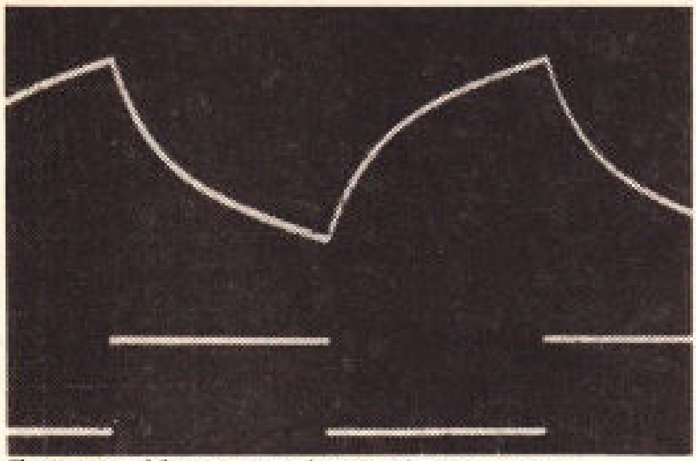
The moving-coil stage is virtually identical to the other op-amps except for the use of some different component values. Whereas the other stages are optimised for low noise when driven from medium impedance signal sources, the moving-coil cartridge can represent an almost pure resistance of between 2 and 10 R. To achieve a better noise figure medium-power transistors are used in the input stage, and each is operated at a collector current of slightly over 1 mA.

The three stages are arranged as shown in the system block diagram (Fig. 2). The first stage can be either a moving-magnet or a moving-coil stage. Whichever is chosen, the gain and input loading are optimised to suit the pick-up cartridge in use. This stage has a flat frequency response and no feedback equalisation. It does, therefore, buffer the cartridge from the equalisation stage and so ensures that the cartridge loading is not frequency-dependent.

The second stage is the equalisation stage with the RIAA network wired in a shunt feedback arrangement. This stage has a voltage gain of 20 dB (x10) at 1 kHz and brings the signal level up to a nominal 50 mV before the switching circuits. After the volume control comes the third stage (A3) which is wired as a simple 20 dB (x10) line amplifier. However, the feedback resistor is wired to ground through a potentiometer which acts as a balance control, giving a gain variation of 11 dB on this stage.

Shunt Feedback

The purpose of the equalisation stage is to provide a fixed degree of frequency de-emphasis exactly complementing the RIAA specified pre-emphasis applied when a record is cut. Although the equalisation is normally specified over the band 20 Hz to 20 kHz it was assumed that the response curve would be continued outside of the audio band. Most important, the replay response above 20 kHz should continue to reduce with frequency until at some infinitely high frequency the output is zero. This requirement is disregarded by most audio engineers who concentrate primarily on the audio band performance, but the music signal reproduced from a disc contains transients whose frequency content can lie outside the arbitary audio band. (Question: why 20 Hz to 20 kHz? Answer: because it has always been so!) The conventional series feedback stage of Fig. 3a is unable to provide an accurate transfer of these high frequencies. This is because the gain does not drop towards zero with increasing frequency but towards unity. The voltage gain of this stage is equal to $1 + (Z_F \div R1)$; so even if Z_F is made infinitesimally small the minimum gain cannot be less than unity. The same is not true of a shunt feedback equalisation stage such as the one shown in Fig. 3b. Here the voltage gain is equal to $Z_F/R1$, so that as Z_F continues to reduce so the gain continues to drop until finally the minimum gain is determined by the signal leakage through the stage. The accompanying photos show the reproduction of a square wave through the two types of equalisation stage and it will be clearly



The response of the same stage when wired for shunt feedback.

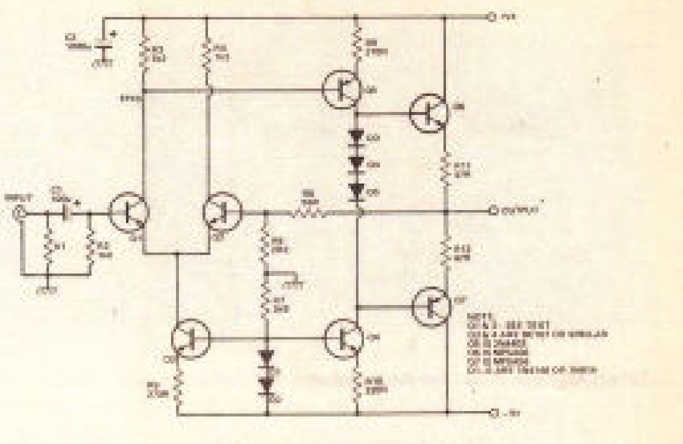


Fig. 6 Circuit diagram of the A-MC moving coil module.

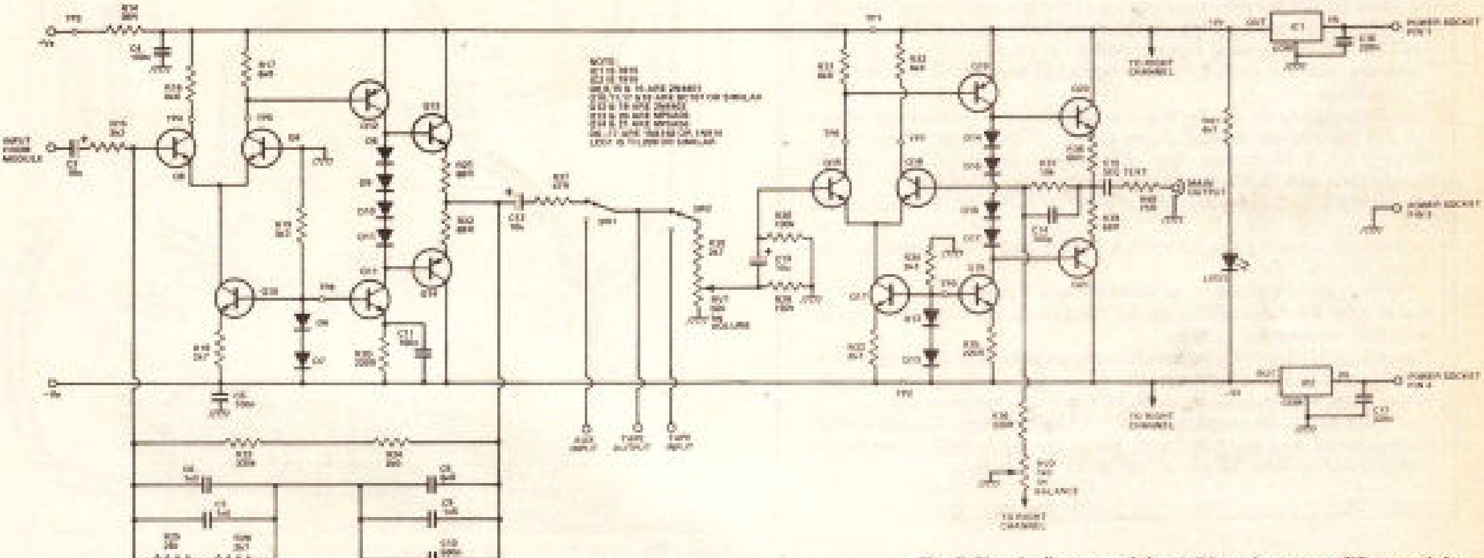


Fig. 7 Circuit diagram of the A-PR main preamplifier module.

HOW IT WORKS

seen that the series feedback arrangement imparts a degree of treble boost to the signal.

So why isn't the shunt feedback system commonly used in commercial preamplifiers? The answer is noise; to be exact, the noise generated by the series input resistor R1. Both input configurations use a nominally 47k resistor to load the cartridge, but in the series arrangement it is 'shorted-out' by the (approximately) 200R resistance of the cartridge. However, with the shunt arrangement this 47k resistor remains in series with the signal path and hence contributes a lot of Johnson (thermal) noise. It has been calculated that the maximum theoretical signal-to-noise ratios of the two stages (measured over the band 20 Hz to 20 kHz and RIAA equalised) are:

Shunt feedback 58.5 dB

Series feedback 72

Both ref. 2 mV at 1 kHZ

This difference is enough, in our world of specmanship, to have consigned the shunt feedback stage to the dustbin for many years.

However, to get the best of both worlds I have gone back to the system I used many years ago at Cambridge Audio. This is the use of a linear series feedback input stage followed by a shunt feedback equalisation stage. The equalisation stage can now work under far easier conditions as the signal has some initial preamplification. Furthermore the input resistor (R1) now no longer needs to be 47k but can be a lower value chosen to set the stage gain. In this case it has been set at 3k3 and so its noise contribution is quite low.

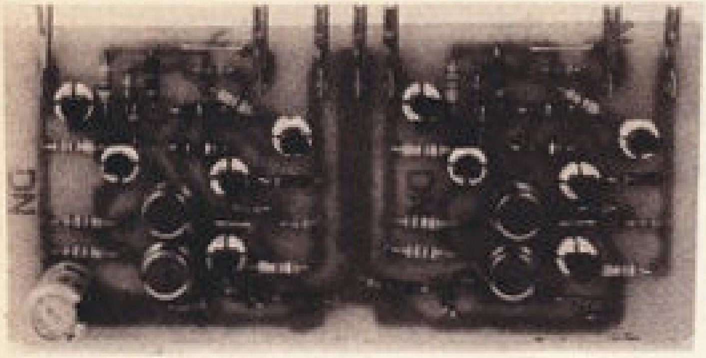
Now we have an input arrangement which buffers the cartridge from the equalisation stage (and so makes the input loading indepenent of the equalisation), continues the RIAA equalisation curve at high frequencies, and achieves the low noise figures typical of the conventional series feedback arrangements. Just as important, the shunt feedback sounds different (and in my opinion better), and that is the deciding factor. A revealing experiment is to wire one preamplifier in shunt and one in series feedback and (having equalised their gains) to listen to each in turn reproducing the 'off-record' noise. It will then be apparent that some preamplifiers emphasise such noises more than others.

Power Supply

The power supply circuitry is kept simple and consists of two integrated circuit regulators (IC1, IC2) which give a low ripple ± 15 V supply to the circuits. The positive rail is further decoupled at the pickup stage by resistor-capacitor filters (R14, C2). The negative rail is adequately decoupled for this stage as the long-tailed pair (Q1, Q2) is fed through a current source, but the positive rail is connected directly to the collectors of this stage and so some additional decoupling is required. The decoupling capacitor needs to be of quite a high value to maintain a low impedance supply. If this value is reduced the low frequency distortion can become excessive.

The supply indicator LED is wired across both supply rails so that the absence of either one will cause the LED to go off.

The power supply module is also simple. The incoming mains supply is fused and switched and fed to a toroidal transformer. The centre-tapped secondary feeds a bridge-rectifier to produce a split rail supply across the two reservoir capacitors (C1, C2). The off-load voltage at this point should be a nominal ± 21 V. Again the supply indicator LED is wired across both rails as a monitor.



This photograph shows the A-MC moving coil input module.

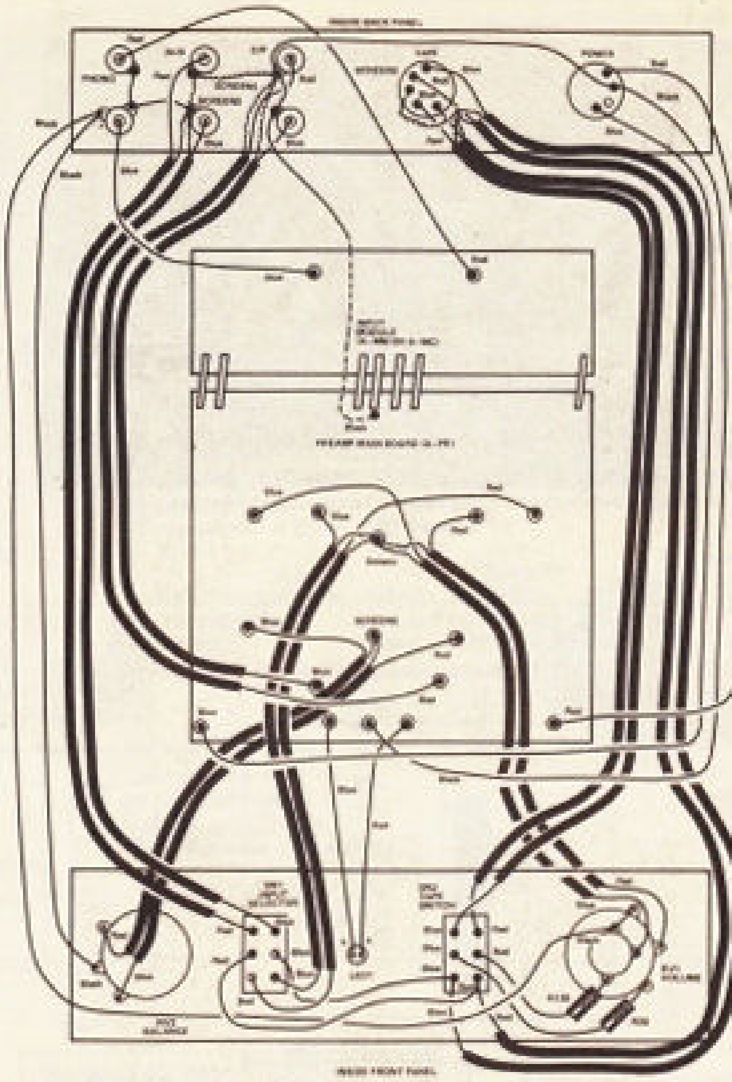


Fig. 8 Wiring diagram of the preamp. No wiring from the preamp main board crosses the input module; all cables are taken towards the front panel and back down either side of the case to the rear panel. See photos.

BUYLINES

Most of the components specified are readily available from the usual suppliers except for the connectors and the low noise transistors. The board-to-board gold-plated connectors (horizontal, 45°) are type 434-172, and the vertical input-to-board connectors are type 434-188. These are available from RS Components Ltd, and can be ordered via a local stockist.

Kits of parts for the System A amplifier are available from Jelgate Ltd, 215 High Street, Offord Cluny, Cambs. Prices are as follows:
Preamp Kit 1 containing two chassis (preamp and PSU), toroidal transformer, and all the chassis-mounting components; £28.
Preamp Kit 2 containing the A-PR and A-PSU PCBs and all components; £26.
Preamp Kit 3 containing A-MM/A-MC PCB and components; £12 for either version.
Set of four input transistors, selected for low noise; £2.
Power Amp Kit 1 containing all the metalwork, heatsinks and chassis-mounting components; £105.
Power Amp Kit 2 containing transformer, capacitors, power supply components and power transistors; £65.
Power Amp Kit 3 containing A-PA PCB and components; £23.

All these prices are exclusive of VAT and carriage. The cases are all ready-painted and screen-printed. Items can be bought separately; a comprehensive price list can be obtained from Jelgate.

PARTS LIST

INPUT MODULE A-MM

Components are listed for one channel only — add 100 for other channel.

Resistors (all ¼ W, 5%)

R1	100k (see text)
R2	100k
R3,4	6k8
R5	2k7
R6	560R
R7	3k9
R8	2k2
R10	220R
R11, 12	47R
R13	3k3
R9 is not used	

Capacitors

C1	10u 35 V tantalum
C2	1000u 16 V electrolytic (PCB type)

Semiconductors

Q1,2	2N4401
Q3,4	BC107 or similar
Q5	2N4403
Q6	MPSA06
Q7	MPSA56
D1-5	1N4148 or 1N914

Miscellaneous
Connectors, PCB.

INPUT MODULE A-MC

Components are listed for one channel only — add 100 for other channel.

Resistors (all ¼ W, 5% except where stated)

R1	100k (see text)
R2	1k0
R3,4	1k2
R5,9	270R
R6	2R2 2% metal film
R7	3k9
R8	56R
R10	220R
R11, 12	47R

Capacitors

C1	100u 6V3 tantalum
C2	1000u 16 V electrolytic (PCB type)

Semiconductors

Q1,2	BSS15 (specially tested — see text)
Q3,4	BC107 or similar
Q5	2N4403
Q6	MPSA06
Q7	MPSA56
D1-5	1N4148 or 1N914

Miscellaneous
Connectors, PCB.

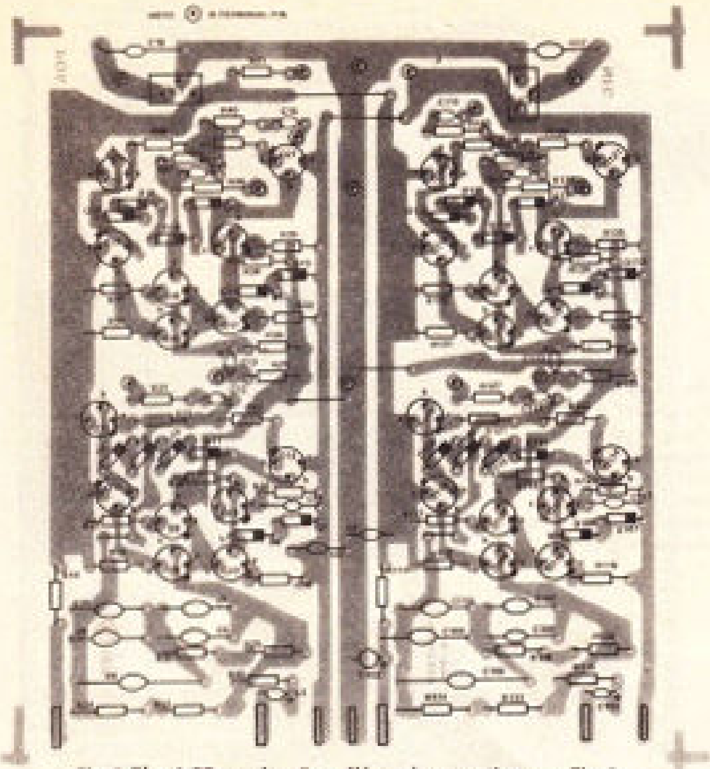


Fig. 9 The A-PR overlay. For off-board connections see Fig. 8.

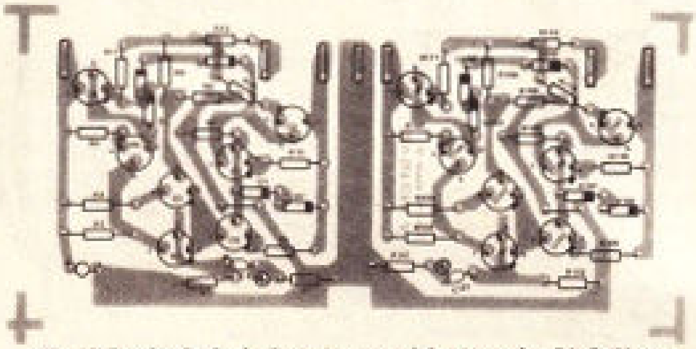


Fig. 10 Overlay for both phono input modules. Note that R9, R109 are replaced by wire links in the A-MM module.

Testing

The power supply should, because of its simplicity, present few difficulties. Before any connection to the mains supply, a visual inspection should be made to check the wiring, the polarities of the capacitors and rectifier, and not least the wiring of the mains switch. It never ceases to amaze me just how often mains switches are wired to short across the supply at switch-on. So take a little care and save a few bob!

With all checks completed, the fuse is fitted and a meter wired between the positive and negative output lines. The mains supply can be connected and for a 240 V nominal supply the meter should read 21 V (± 2 V). Then measure the supplies to 0 V to check that they are equal and that the LED is illuminated.

The preamplifier is fairly straightforward to test, albeit rather repetitive. The two power supply regulators are protected against excessive currents (eg shorts) and over-temperature, so they are unlikely to come to any grief providing they are correctly inserted into the PCB. Each of the amplifier stages on the main board can be isolated from the power supplies by the removal of wire links and, of course, the input module can be unplugged, so in the event of a fault the offending stage can be isolated.

Before connecting up the power supply it is a good idea to give the PCBs one final visual check, paying particular attention to transistor types, diode and capacitor polarities, and solder bridges on the PCB tracks. Now connect the power supply and monitor the supply lines. They should measure ±15 V (±0V6) and the LED should light up. The controls should now be set as follows:

Input:	PU
Tape:	OFF
Balance:	Central
Volume:	Minimum

Now measure the DC voltage between earth and the junction of the two emitter resistors in the output stage of each amplifier. This voltage should be zero, but can be ±2 V without any significant effect on the workings of the

PREAMP MODULE A-PR
Components are listed for one channel only — add 100 for other channel.

Resistors (all ¼ W, 5% except where stated)

R14	39R
R15,19,34	3k3
R16,17,31,32	6k8
R18,33,28	2k7
R20,35	220R
R21,22,38,39	68R
R23	330k 2% metal oxide
R24	2k0 2% metal oxide
R25	24k 2% metal oxide
R26	2k7 2% metal oxide
R27	47R
R29	150k
R30	100k
R36	330R
R37	10k
R40	75R
R41	4k7

Potentiometers

RV1	50k logarithmic
RV2	1k0 linear (preferably wirewound)

Capacitors

C3,12,13	10u 35 V tantalum
C4,5,11	100n 63 V ceramic disc
C6,7,9	1n5 2% polystyrene
C8	6n8 2% polystyrene
C10	560p 2% polystyrene
C14	100p ceramic
C15	see text

Semiconductors

IC1	7815
IC2	7915
Q8,9,15,16	2N4401
Q10,11,17,18	BC107 or similar
Q12,19	2N4403
Q13,20	MPSA06
Q14,21	MPSA56
D6-17	1N4148 or 1N914
LED1	TIL209 or similar

Miscellaneous

SW1,2	DPDT slide switch

Connectors, PCB, phono sockets, DIN sockets, Veropins, screened cable, case, knobs to suit.

preamplifier (although the blocking capacitor will be necessary). That completes the DC tests. The preamplifier will now almost certainly work but if you have test equipment available it would be a good idea to test each channel with an audio signal and to centralise the balance control.

The total current drawn from the negative supply is about 120 mA for the moving-coil version and 115 mA for the moving-magnet version; and about 15 mA less from the positive supply.

As an aid to fault-finding a list of test-voltages has been provided which can be used in conjunction with the main circuit diagram.

The cases supplied for the System A project ensure a professional appearance, and can be obtained from Jelgate Ltd (see Buylines). The modules shown here are the prototypes.

Table 2. Voltages measured between test points and ground with Avometer Model 8. These voltages should be taken only as a guide.

TP1	+15V	TP6	+14V3
TP2	−15V	TP7	+13V6
TP3	+14V5	TP8	−13V8
TP4	+13V6	TP9	−13V8
TP5	+14V3	TP10	+13V

Cartridge	Module
ADC	
ZLM	E
XLM-II	G
XLM-III	E
VLM-II	E
AKG	
P7E	G
P8E & P8E-S	E
AUDIO-TECHNICA	
AT-10	F
AT-11E	F
AT-12E	F
AT-13EA	E
AT-25	B
AT-30	C
Signet MkIIIE	C
Signet TK5E	F
Signet TK7E	E
AZAK	
DC2100K	C
CORAL	
MC81	C
777E	C
777Ex	C
DECCA	
Blue	E
London	F
DENNON	
DL103C	A
DL103S	A
DL103D	A
ELITE	
MC555	B
EE1500	G
EMPIRE	
500 D	E
2000 1E	G
2000 E4	G
600 LAC	E
2000 X	E
EMT	
XSD15	A
GOLDRING	
G 900 IGC	E
MAYWARE	
MC3L	E
MC2C	C
MICRO ACOUSTICS	
2002-e	E
NAGAOKA	
JT-R11	B
ORTOFON	
MC 30	C
SHURE	
75-ED	H
M75EJ	H
M97HE	H
V15-IV	G
SONUS	
BLUE	E
GOLD BLUE	E
SONY	
XL35	E
XL 55	A
STANTON	
680	E
881	E
681 EEE	E
SUPEX	
SD 9015	E
900E	C
TECHNICS	
EPC-300MC	D
ULTIMO	
10X II	E
20A	G
DV 20C	A
DV KARAT	A

Table 3. Cartridge matching table.

Variations On A Theme

Alterations can be made to the input modules to suit a wide range of cartridges. The recommended changes are given below; Table 3 lists most cartridges and the matching module. If your cartridge doesn't appear, write to us with an SAE and we will tell you which variant is suitable.

Moving-coil Cartridges

The gain of the A-MC input module can be varied by changing resistor R6. This resistor has a value of 2R2 to give a sensitivity of 550 uV on the standard version. Changing R6 to 0R6 (eg two 1R2 resistors in parallel) will increase the sensitivity to about 150 uV. The input loading can be varied by changing resistor R1 fom the standard value of 100R to any other value. The four recommended alternatives are:

A	550 uV sensitivity,	R1 = 1k0
B	150 uV sensitivity,	R1 = 100R
C	550 uV sensitivity,	R1 = 100R
D	150 uV sensitivity,	R1 = 1k0

Moving-magnet Cartridges

Again, the input loading of module A-MM can be changed by using an alternative value for resistor R1. An input capacitor C_i can also be wired across R1 to lower the input impedance at high frequencies and so 'equalise' the output from some cartridges. The gain of the standard version is set by R13 and gives a sensitivity of 2.3 mV. Reducing R13 increases the sensitivity and vice-versa. The four recommended alternatives are:

E	Standard version
F	R13 = 8k2
G	C_i = 180pF
H	R13 = 8k2 and C_i = 180pF

Table 3 assumes that the cartridges are mounted in tone-arms which have a total cable capacitance of about 100pF and below.

Next month we present the System A Class A power amplifier. This article will also include the overlay for the A-PSU module which had not been finalised when this issue went to press.

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