State-of-the-art design has ultra-low distortion

Universal preamplifier for MM/MC cartridges

Many current and older stereo amplifiers do not have input facilities for moving coil cartridges and, in many cases, their existing moving magnet phono preamplifier is not really comparable with later designs. This new Universal Phono Preamplifier has ultra-low noise and distortion and is switchable to suit moving magnet or moving coil phono cartridges.

by PAUL DE NOSKOWSKI and LEO SIMPSON

Whether one has great regard for moving coil cartridges or whether you regard their increasing popularity as a silly fad, there is no doubt that the renaissance of the moving coil cartridge has caused designers of stereo amplifiers to reassess their preamplifier circuits very carefully. The greatly increased gain required by moving coil cartridges, hereafter referred to as MC cartridges, means that preamplifier design has become far more stringent, particularly in regard to signal-to-noise ratio.

A number of state-of-the-art amplifiers we have seen and tested lately have brought home to us the fact that the last preamplifier design developed by EA was getting rather long in the tooth. The preamplifier in question was first published in the November 1973 issue and was subsequently featured in the Playmaster Twin 25, Forty-Forty and Mosfet stereo amplifier designs with slight changes in each case. This preamplifier has certainly stood the test of time very well indeed. Countless thousand stereo amplifiers are running reliably with this circuit and, in absolute terms, they are very quiet.

In fact, the most oft-commented feature of the recent Playmaster amplifier designs, particularly the Playmaster Mosfet Stereo Amplifier described in January and February 1981, has been their excellent quietness. People have left them running for days on end without realising they were on. And compared with the large majority of mass-produced stereo amplifiers and stereo receivers, the Playmasters have stood up very well.

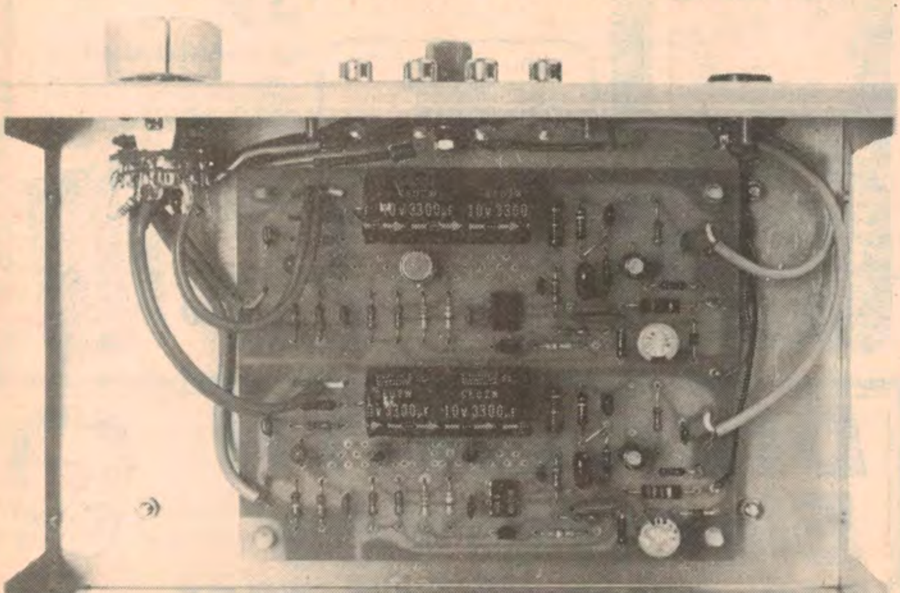
But now we are glad to report that our new preamplifier will put the old design completely "in the shade".

Without any doubt, the new preamplifier is quieter than the old, by at least 8dB! This refers to the moving magnet (MM) mode only, since the old preamplifier was not configured for MC cartridges.

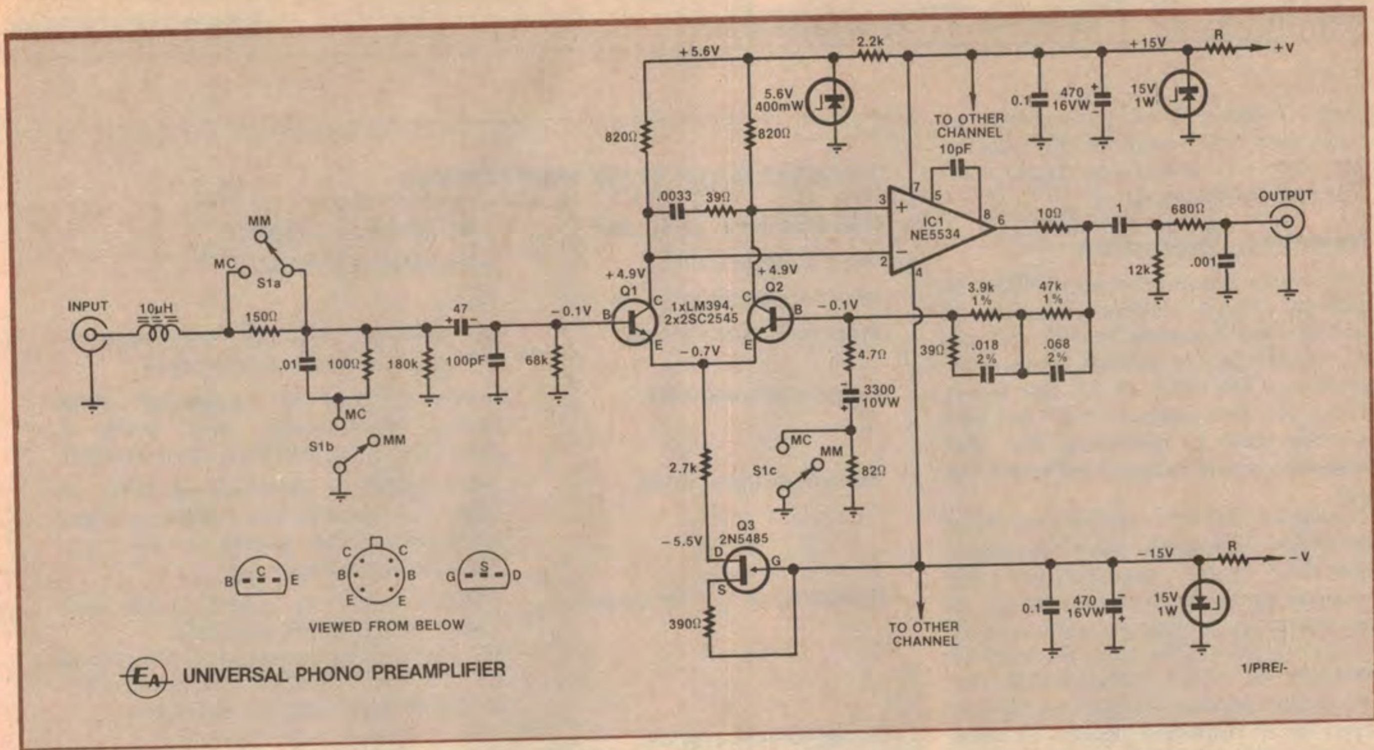
In fact, while (at the time of writing) we have yet to perform the considerable calculations necessary to prove it beyond all doubts, it would appear that in the moving magnet mode, the new preamplifier is within just a couple of dB of the theoretical maximum possible signal-to-noise ratio.

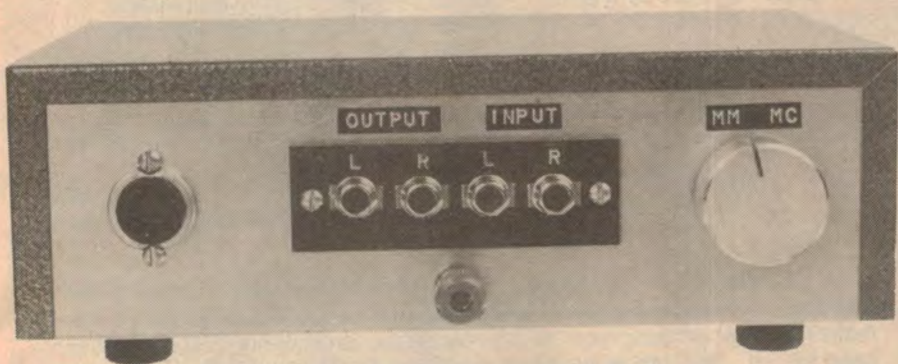
This is because for any preamplifier design, the ultimate signal-to-noise ratio possible is determined by the noise voltage actually generated by the cartridge. This is logical when you think about it because not only will the cartridge resistance itself generate a noise voltage but depending on how well it is shielded, the cartridge will also generate a hum voltage.

In the MC mode, the new preamplifier is also very quiet but it could possibly be bettered by some "head-amps" used in front of good standard RIAA preamps. These head-amps would presumably have their operating conditions optimised for MC cartridges. Principally, this means that their collector operating currents would be a good deal higher than would be optimum in typical MM



This version of the new Universal Phono Preamplifier uses an LM394 dual transistor in one channel and two Hitachi 2SC2545 transistors in the other.





We built our preamplifier into a K & W instrument case, although ideally the case should be of all-steel construction to provide maximum hum shielding.

preamps. But even though some of the latest head-amps may better our universal design, it is doubtful whether their input overload margin would be anywhere near as good. But more of that later.

Let us now discuss the principal performance paramaters of the new preamplifier in some detail. The specifications are summarised in a panel elsewhere in this article.

In the MM mode, there are three figures quoted for signal-to-noise ratio. The first two are for resistive termination while the third is measured with a typical MM cartridge which simulates an actual listening situation. We do not see the point of quoting signal-to-noise ratios with a short circuit input because it is not only unrealistic (nobody listens to records with the preamplifier inputs shorted!), but also gives results which are much better than can be expected in practice.

The cartridge actually used in these tests was a Stanton 500A picked mainly because its inductance and series resistance figures are close to those recommended for signal-to-noise tests by the IHF-A-202, 1978 specification. Many of the newer cartridges in use today will have a lower inductance than the Stanton and so can be expected to give an even better signal-noise figure. This is because the lower overall impedance of the cartridge tends to shunt off noise generated by the preamplifier input resistors.

Correspondingly, if your cartridge inductance is on the higher side, you can expect that the residual noise will be slightly worse than the figures quoted. This is a general rule with most preamplifiers these days, by the way. All the MM S/N figures are referred to an input signal level of 5mV RMS at 1kHz, as per the above IHF test specification. This means that 6dB must be added to figures noted here to make them directly comparable with the figures published for our preamplifiers in the past which were referred to an input signal of 10mV RMS.

All our S/N figures are unweighted by the way, rather than using the "A" weighting suggested in the IHF specification. We do not use "A" weighting because it can conceal noise problems at the low frequency end, particularly hum and ripple components which can be surprisingly audible against an otherwise quiet background.

If you are attempting to make comparisons between the figures noted here and weighted figures for other preamplifiers, you would be reasonably fair in adding about 5 or 6dB to our unweighted figures to gain a more favourable comparison. But make no mistake, this new preamplifier is really quiet. In fact, there is a fair chance that with many amplifiers, noise in the later tone control stages will swamp the noise produced by the preamplifier.

Overload margin referred to the 5mV RMS reference level is a generous 30dB or 160mV maximum at 1kHz. More importantly, the overload margin is inversely proportional to the RIAA characteristic so that at 10kHz, for example, the maximum input signal is 13.7dB higher or about 775mV RMS.

In this respect, our universal preamplifier is superior to those "head-amps" which have a flat frequency response and therefore a constant overload characteristic across the whole audio band. So while some head-amps may be able to accept a higher input signal at mid-frequencies, our design has a good overload margin over the entire audio range.

These remarks are also applicable to

some "esoteric" RIAA preamplifiers we have seen which perform the equalisation over two amplifying stages, some using passive networks.

Harmonic Distortion

Harmonic distortion is very difficult to quantify when it becomes as low as it is on our new preamplifier. Not only are the signal levels vanishingly low and approaching the limits of the test equipment but one cannot even be sure whether one is measuring the nonlinearities of the output load resistor or not.

However, for the record, we have published comprehensive harmonic distortion figures, together with the residual harmonic distortion figures of the Sound Technology equipment which was used. The results apply for both the MM and MC modes, although in theory, the greater applied feedback would give even lower distortion figures. In short, harmonic distortion is b---y low, but we don't know just how low it is.

Equalisation in the new preamplifier includes the IEC (International Electrotechnical Commission) proposal of a 7950us time-constant for rolloff of frequencies below 20Hz. This means that there is less response to record warps and arm/cartridge resonances at these low frequencies.

When this new time-constant is taken into account, the RIAA equalisation of the new preamplifier is within ±0.3dB over the range from 40Hz to 20kHz and within ±0.5dB from 40Hz down to 20Hz. However, the only way that kit builders can ensure that they obtain the same performance is to use the specified 1% resistors and 2% capacitors.

It may be thought that such close adherence to the RIAA curve is not really necessary. However, consider that a +1dB error in the equalisation characteristic at 10kHz really amounts to a small lift to an entire portion of the audio spectrum which can markedly change the sound of the cartridge.

PERFORMANCE OF PROTOTYPE

Nominal input impedance:	50kΩ(MM) or 100Ω(MC)
1kHz voltage gain:	35dB(MM) or 60dB(MC)
Internal output impedance:	700Ω
Maximum output level:	9V RMS at 1kHz into 50kΩ load for 0.002% total harmonic distortion
Frequency response:	within ±0.3dB of "proposed" RIAA replay characteristic from 40Hz to 20kHz, and ±0.5dB from 20Hz to 40Hz
Maximum input level:	160mV(MM) or 9mV(MC) at 1kHz. At other frequencies the maximum input level follows the inverse of the "old" RIAA replay characteristic
Distortion at 8 volts output:	0.003% 40Hz to 10kHz, 0.004% at 15kHz, and 0.005% at 20kHz NB: Residual test equipment distortion is 0.002% from 40Hz to 10kHz, 0.003% at 15kHz, and 0.0035% at 20kHz.
Signal-to-noise ratios:*	
MM mode (referred to a 5mV input level at 1kHz):	84dB with 1kΩ resistive termination 77dB with 10kΩ resistive termination 77dB with a typical MM cartridge (500mH inductance, 700Ω resistance)
MC mode (referred to 500μV) input level at 1kHz):	76dB with 100Ω resistive termination (IHF-A-202, 1978 recommended termination) 74dB with Ortofon MC20 MkII pickup cartridge (lower figure due to stray hum fields)

Note that the above input levels are in accordance with the IHF-A-202, 1978 standard measurement methods for audio amplifiers. However, a more realistic reference input level for MC cartridges is probably 150μV, in which case the MC signal-to-noise ratios would be 65dB and 63dB respectively.

* Taken with LM394 dual transistor in first stage.

Interchannel separation:	
MM mode:	90dB 20Hz to 400Hz, 85dB at 1kHz, 56dB at 10kHz, 51dB at 15kHz and 48dB at 20kHz.
MC Mode:	90dB 20Hz to 3kHz, 85dB at 10kHz and 78dB at 20kHz.
Minimum power requirement:	±18 VDC at 30mA.

Circuit Description

Broadly, the circuit concept of this new preamplifier is the same as that for our previously successful preamp in that it uses two low noise transistors (or a transistor array) to drive an operational amplifier IC. However, this apparent similarity belies the considerable differences in the devices used and the operating parameters.

Two ultra-low-noise transistors in a differential pair drive the inputs of op amp IC1. The collector currents of these transistors are set at the best compromise in noise performance between the two modes (MM and MC) of operation. The resulting compromise figure of 0.85mA is biased for a better result in the MC mode and has made it necessary to incorporate a FET current source in the "tail" of the differential amplifier to ensure good common mode and supply rejection as well as optimum gain.

The op amp used is the Signetics NE5534 which, in itself, can be regarded as a low noise type but more particularly, it has the ability to drive a 600Ω load. This is important because it has allowed us to reduce the series resistance of the feedback network by a factor of about 12. This means a very worthwhile reduction in residual noise generated by the feedback network.

There is no way in which a TL071 or 741 op amp used in our previous designs could drive this low value of load and still deliver full output. So it is this reduction in the feedback path resistance which is the single most important factor in the improvement in noise performance obtained in this design.

Since the NE5534 is not internally compensated (ie not stable in unity gain applications where the negative feedback is high), an external 10pF compensation capacitor is connected between pins 5 and 8 of the IC. This reduces the open-loop gain at high frequencies and confers the appropriate order of stability. In addition, a 39Ω resistor is inserted in the feedback loop to prevent the gain rolling off unnecessarily at supersonic frequencies. This reduces distortion at high frequencies which would otherwise occur due to excessive loading by the feedback network.

Other measures to ensure stability are the step network between the collectors of the input differential pair and a 150Ω "stopper" resistor in series with the input when in the MM mode. In the MC mode this stopper resistor is not necessary and it is switched out to prevent degradation of the signal-to-noise ratio which would otherwise be the result of inserting a relatively high value resistor in series with a low resistance source.

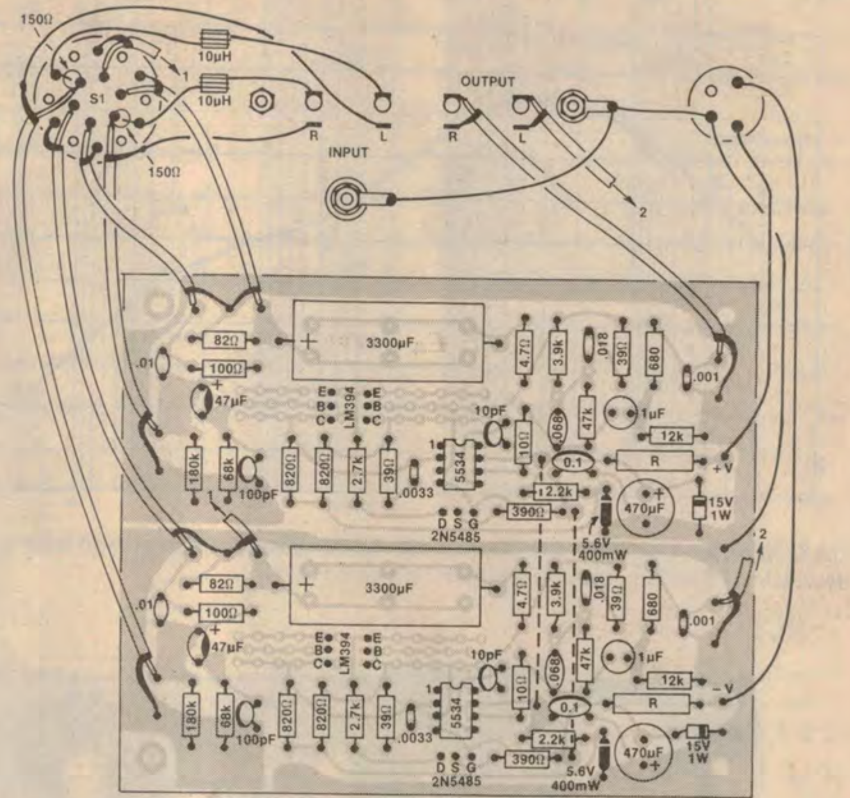
Also in the input network is a 47μF tantalum coupling capacitor which provides a low impedance path via the cartridge for noise produced by the 68kΩ bias and input load resistor. We should comment here that tantalum capacitors are often deprecated in high performance preamplifier designs because AC signals across them can modulate their capacitance and thus cause distortion. However, since the input signals are so small this effect is not at all evident and distortion is very low, as already discussed.

Readers may ask why we did not eliminate the capacitor altogether and just couple the cartridge in direct. After all the resultant DC current which would flow through the cartridge would be negligible and would not cause any problems. In fact, this is precisely what we did in the Playmaster Mosfet version of the previous preamplifier.

However, since this new preamplifier operates in two modes, the input offset voltage would be changed, as would the output offset voltage, whenever the mode was changed. This could lead to switching transients and, possibly, reduce output voltage swing.

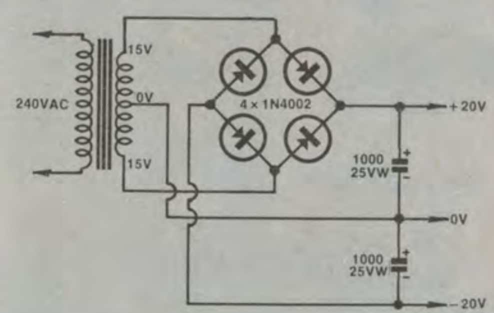
Sensitivity to stray RF signals into the input leads is eliminated by the small inductor and 100pF capacitor across the input signal path. This inductor can either be in the form of a 10μH choke or five and a half turns of 28 B&S enamelled copper wire threaded through an FX1115 ferrite bead. Two such inductors will be required, one for each channel.

A six-pole, two position switch is used to select the mode. One pole (in each channel) is used to switch out the 150Ω stopper resistors in each channel, as already discussed. The second pole is used to switch the 100Ω plus .01μF input



Component overlay diagram for the new high-performance preamplifier. See text regarding alternative transistors for the differential input pair.

This simple power supply can be used to power the new preamplifier and should be housed separately to avoid hum.

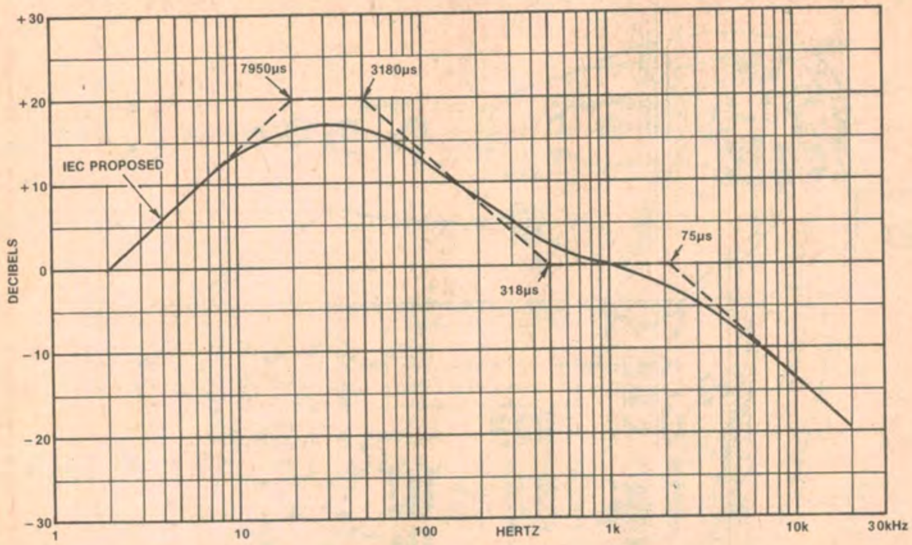


loading network for the MC cartridge in each channel while the remaining poles switch the shunt leg of the feedback network, to change the gain.

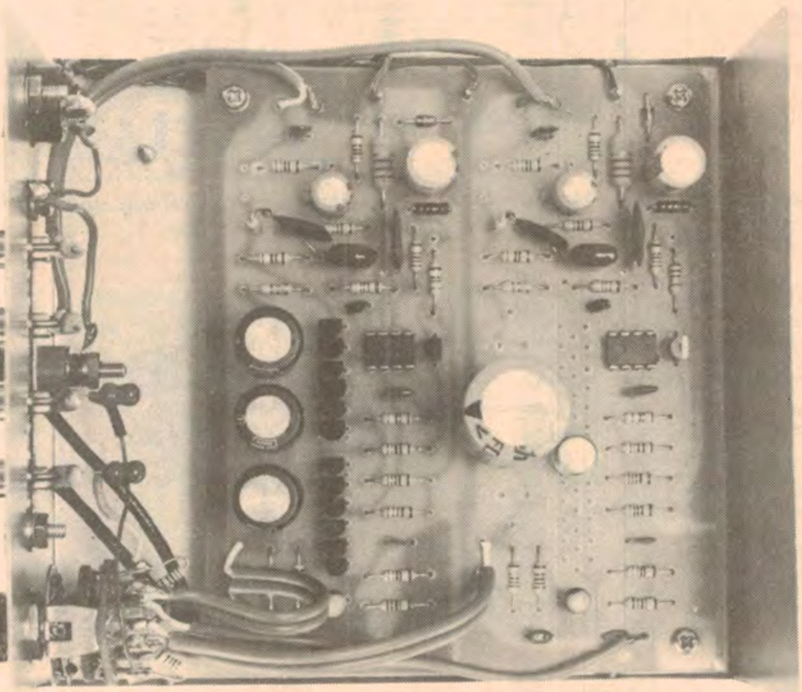
As it is, the preamplifer can be expected to have very small DC offset voltages at the outputs: of the order of a few tens of millivolts, depending on the closeness of match in the input differential pair. If the LM394 is used, this match is very close and the offset very small.

The two 1% resistors and two 2% capacitors in the feedback network determine the three RIAA time-constants of 75μs, 318μs and 3180μs, corresponding to breakpoints at 2122Hz, 500.5Hz and 50.05Hz respectively. The additional time-constant of 7950μs, corresponding to a breakpoint at 20Hz, is provided by the combination of the 1μF output capacitor and the 12kΩ resistor across the output.

Incidentally, anyone who takes the trouble to calculate the time-constants based on single RC combinations in the feedback network will find errors in the result. This is particularly the case for the output RC network which, by itself, has a time constant of 12000μs (ie 12ms). However, when bass rolloff in the shunt leg of the feedback network (ie in the 3300μF capacitor) is taken into account, the 7950μs time-constant is closely adhered to. Similarly, other interactions in the feedback network have been taken into consideration to produce very



RIAA characteristic of the new preamplifier. Equalisation is within ±0.3dB from 40Hz to 20kHz and within ±0.5dB from 40Hz down to 20Hz.



This second version of the preamplifier uses 12 BC550C transistors in one channel and an LM394 in the other. Note the use of PC mounting electrolytics instead of the 3300µF pigtail electrolytics.

close adherence to the RIAA curve.

Note also that the components specified for the 7950µs time-constant assume that the input impedance of the following amplifier will be 50kΩ. For other input impedances, the 12kΩ resistor will have to be adjusted so that the parallel combination of the shunt resistor (ie., 12kΩ) and amplifier input impedance is approximately 10kΩ. For example, if the input impedance of the following amplifier stage is 30kΩ, increase the 12kΩ resistor to 15kΩ.

It is most important that the 1µF output coupling capacitor is not a tantalum type because in this application a tantalum capacitor will cause a marked increase in distortion at low frequencies. You may use a metallised polyester (greencap) or, as we did, a bipolar electrolytic type.

Bipolar electroltyic capacitors are generally specified as being within ±20% of value but in our experience, they are normally well within ±10% which is adequate for this application. And they don't add to the distortion!

PARTS LIST

HARDWARE

- 1 PC board, code 82p5, 125 x 102mm
- 1 6-pole, 2-position switch
- 1 knob to suit
- 2 FX1115 ferrite beads and ½-metre 28-gauge B&S enamelled copper wire (or 2 10µH RF chokes)
- 1 metre hook-up wire
- 1 metre light-duty shielded audio cable

ADDITIONAL HARDWARE
(for free-standing unit)

- 1 mild steel case, 200 x 130 x 65mm
- 1 4-way RCA socket panel
- 1 4-pin DIN socket and plug
- 4 Richco CBS-6N plastic PC board supports solder lug
- 4 rubber feet
- 1 binding post terminal for chassis earth

SEMICONDUCTORS

- 2 1N752 zener diodes (5.6V, 400mW; do not use 1W types)
- 2 1N4744 zener diodes (15V, 1 watt)
- 2 2N5485 field effect transistors
- 2 LM394 dual transistors (or 4 Hitachi 2SC2545 transistors)
- 2 NE5534 operational amplifiers

RESISTORS

(¼W, 5% tolerance)
2 x 180kΩ, 2 x 68kΩ, 2 x 12kΩ, 2 x 2.7kΩ, 2 x 2.2kΩ, 4 x 820Ω, 2 x 680Ω, 2 x 390Ω, 2 x 150Ω, 2 x 100Ω, 4 x 39Ω and 2 x 10Ω.
(¼W, 1% tolerance, metal film)
2 x 47kΩ, 2 x 3.9kΩ, 2 x 82Ω, 2 x 4.7Ω.
(½W, 1W or 5W)
2 off, as per accompanying table

CAPACITORS

- 2 3300µF, 10V axial lead electrolytics (or 6 1000µF, 10V PC electrolytics)
- 2 470µF, 16V PC electrolytics
- 2 47µF, 6.3V tantalums
- 2 1.0µF, 25V bipolar PC electrolytics
- 2 0.1µF, 25V ceramic
- 2 0.068µF greencaps (metallised polyester), 2% tolerance
- 2 0.018µF greencaps, 2% tolerance
- 2 0.01µF greencaps (or miniature ceramic)
- 2 3300pF greencaps
- 2 1000pF greencaps
- 2 100pF ceramic NPO
- 2 10pF ceramic NPO

MISCELLANEOUS
Machine screws and nuts, solder, PC stakes etc.

Four zener diodes are used in the circuit. Two 15V 1W zeners provide regulated supplies for the entire preamplifier while an additional 5.6V 400mW zener in each channel reduces the voltage fed to the input differential pair. This also protects the Fet current source from possible breakdown in the event of a gross overload which could occur if someone hamfistedly drops the cartridge onto the record. The 5.6V zener must a be 400mW type, by the way. A 1W type is not suitable.

The resistor feeding each 15V zener is marked as "R" and suitable values together with recommended power ratings to suit various amplifier supply rails are tabulated below. If you wish to power the preamplifier separately, we do not recommend that the supply be housed in the same case, to avoid hum. A suggested power supply circuit with ±20V rails to feed the zeners is also provided with this article.

Transistor types

While we have specified an LM394 as the input differential pair for each channel of the preamplifier, there is a suitable substitute in the form of a pair of Hitachi 2SC2545 transistors. We tried these transistors in our prototypes and found them to be excellent. In fact, in the MC mode, they are actually 1 to 2dB better than the LM394 although in the MM mode, they are about 1dB worse.

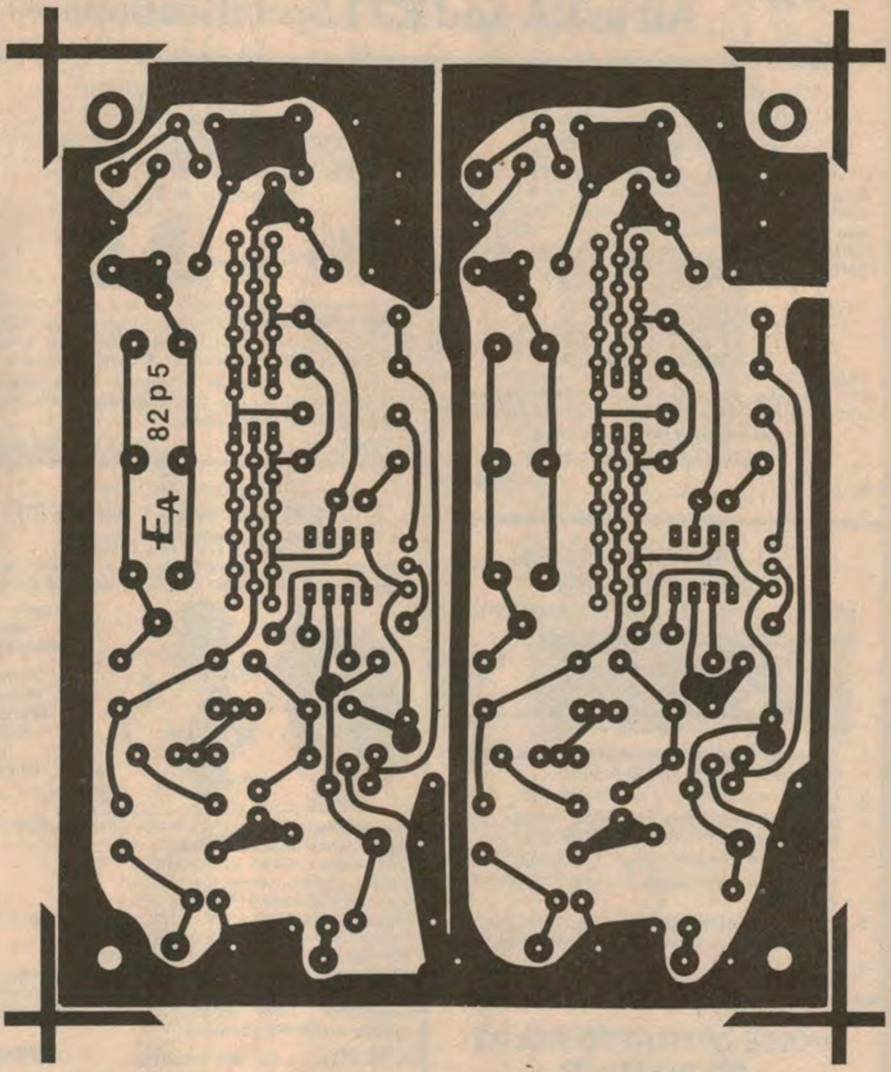
Unfortunately, at the time of writing, these 2SC2545 transistors are not generally available in Australia although Hitachi transistors are distributed in this country by Plessey Components. They are ideal for the job and are used in a number of high performance Japanese amplifiers. They are, in fact, available as a spare part for some of these amplifiers.

It is also possible to substitute 12 BC550Cs (2 x 6) in each channel but the resulting performance vis-a-vis noise is not up to the standard of the LM394 and is about 2dB worse in both MM and MC modes and is quite noticeable. A pity!

Construction

If you decide to install this new preamplifier inside an existing amplifier, a great deal of care will be required to ensure that hum pickup is not a problem. Similarly, if you decide to house the preamplifier in a separate case, it should ideally be all-steel construction to provide effective hum shielding.

Note that if a separate housing is used it must be provided with an earthing terminal to connect the arm or turntable earth, otherwise 50Hz "buzz" will be apparent.



Above: actual size reproduction of the PC board artwork (code 82p5).

We estimate that the current cost of components for this project is

$35

including sales tax. This does not include the cost of the additional hardware required for a free-standing unit or the cost of a separate power supply if required.

Below: use this table to determine the value of the two resistors marked "R".

± Supply Voltage	'R'	Wattage
18	100Ω	½W
20	150Ω	½W
22	220Ω	½W
25	330Ω	1W
30	470Ω	1W
35	680Ω	1W
40	820Ω	1W
45-50	1kΩ	5W
50-60	1.2kΩ	5W
60-75	1.5kΩ	5W
70-90	1.8kΩ	5W

All the components for the preamplifier, with the exception of the input inductors and switch, are accommodated on a PC board measuring 124 x 102mm and coded 82p5. If you wish to build the preamplifier to provide MM or MC mode alone, the switch may be omitted and the relevant components either omitted or wired in permanently. In the MM mode, this modification would have the benefit of improving the high frequency crosstalk figures which would appear to be mainly due to capacitance in the switch.

Care should be taken to observe the polarity of electrolytics, transistors and diodes. Provision has been made for a

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Phono preamplifier

cont'd from p59

3300μF pigtail electrolytic or three 1000μF PC electrolytics, so you can use whatever is available. The 2% capacitors are not available as over-the-counter items so you will have to purchase and select your own, using a capacitance meter. We hope that parts suppliers will make this service available. One per cent resistors are readily available from a number of suppliers.

The wiring diagram for the preamplifier should be closely followed, in conjunction with the main circuit diagram.

If 5W dropping resistors have to be used for the supplies to the preamplifier, they should be mounted on separate tagstrips to avoid heat damage to the PC board.

When all construction is complete, check your work very carefully for errors. Then connect a suitable power supply and check all voltages marked on the circuit diagram. They should all be within 0.5V of the values shown. Similarly, the DC voltage at the output of each op amp should be within about 10-30mV of 0V.