PREAMPLIFIER FOR MOVING-MAGNET PICK-UP

by T. Giffard

The basic function of a pick-up element is to translate the motion of the stylus into an electrical signal. The most popular cartridges in use are the moving magnet (fixed coil and tiny magnet) and the moving coil (fixed magnet and tiny coil). In both designs the vibrations of the stylus cause fluctuations in a magnetic field. Last month we published a preamplifier for advocates of the moving coil design; this month we turn our attention to those who favour a moving magnet element.

MOVING magnet carrtridges have a relatively high output and require a load of some 47 kΩ in parallel with a specified capacitance, normally 200–500 pF, for optimum performance.

The output voltage of the cartridge increases with frequency as shown in Fig. 1 following the recording characteristic of LP records in accordance with the IEC recording standard. This is a 1976 adaptation of the well-known RIAA (Recording Industry Association of America) recording standard. The preamplifier is therefore required to have a playback characteristic as shown in Fig. 1 with de-emphasis time constants of 8 ms, 3180 µs, 318 µs and 75 µs, corresponding to roll-off points of 20 Hz, 50 Hz, 500 Hz and 2120 Hz respectively. The output level is 0.8–2.0 mV cm^{-1} s^{-1} of groove modulation velocity, resulting in a mean output of some 3–10 mV at 1 kHz.

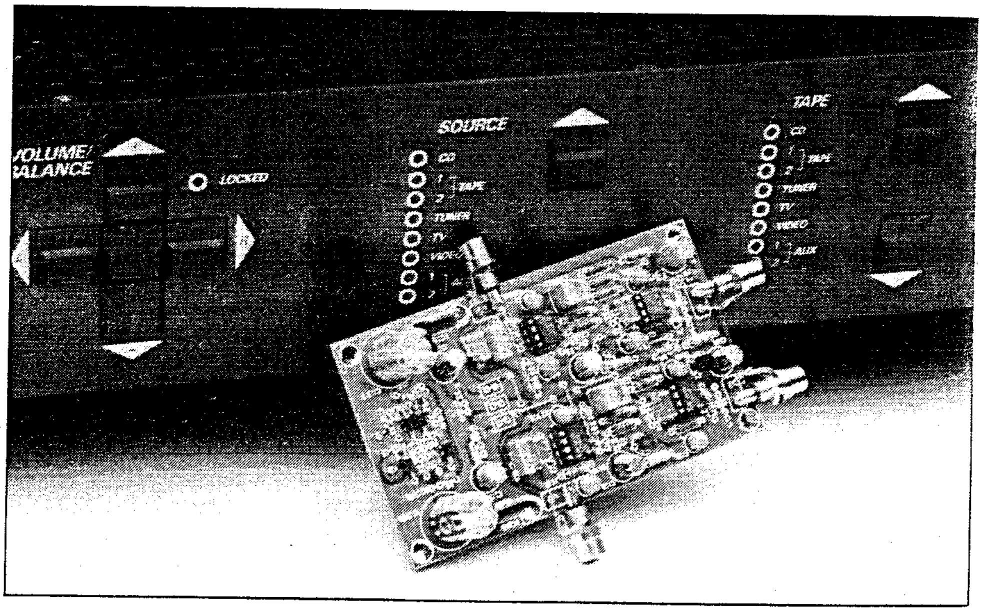
The RIAA recording characteristics did not specify the 8 ms time constant which, particularly in the present preamplifier, is of importance since it attenuates all kinds of subsonic sound (at 2 Hz by as much as 20 dB compared with the RIAA characteristic). The use of the IEC rather than the RIAA characteristic means that the amplifier reproduces records cut according to the RIAA standard with a greater attenuation of any rumble, while those cut in conformity with the IEC standard are reproduced correctly. This assumes, of course, that the components in the correction networks are close tolerance types.

Circuit description

This is the first quality preamplifier designed round opamps that we have ever published. The opamps used have the lowest noise figure currently commercially available—more bout this later.

The circuit diagram of the preamplifier is hown in Fig. 2; it will be discussed on the asis of the left-hand channel.

The signal from the pick-up element is pplied to the non-inverting input of IC_1. he input impedance is formed by the par- lel network R_1-C_1. The correct value of these omponents is normally given by the manu-



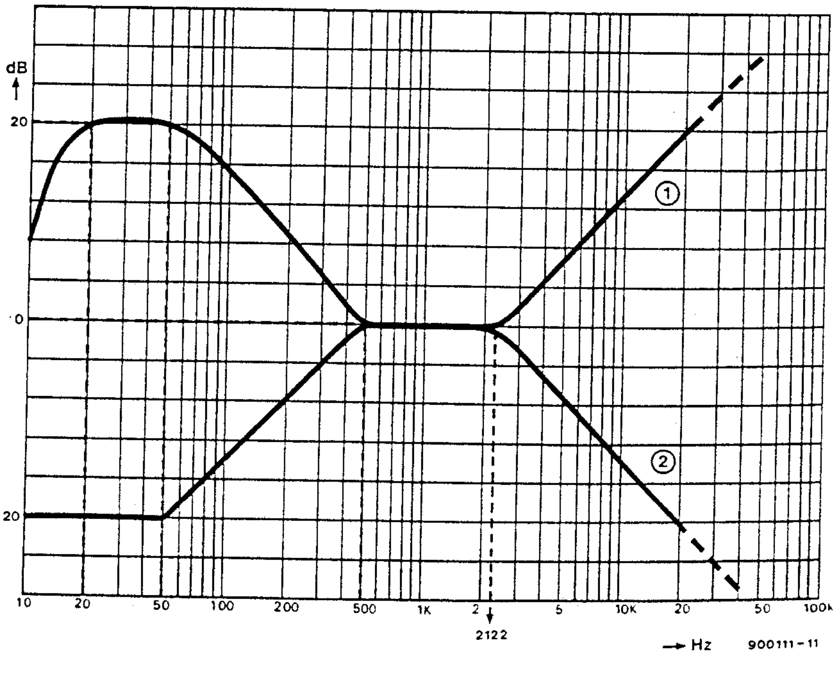


Fig. 1. Recording (1) and playback (2) characteristics according to the 1976 IEC standard.

facturer of the cartridge, although that of the resistor is usually taken as 47 kΩ. The value of the capacitor varies between 200 pF and 500 pF. Note that C_1 is shunted by the capacitance of the cable, which is normally 100–200 pF and this must, of course, be deducted from the capacitor value specified by the manufacturer. If no manufacturer specification is available, make R_1 = 47 kΩ and C_1 = 100 pF.

The feedback of low-noise opamp IC_1 has been arranged to ensure that the opamp does not only provide an amplification of ×10, but also the required correction of the low frequency part of the signal. The high-frequency part is corrected by R_7-R_8-C_9. Apart from the 20 Hz roll-off point, that completes the frequency response requirement according to the IEC standard.

The output of IC_1 is applied to IC_2, whose characteristics are virtually identical with those of the well-known OP27. The amplification of the stage is ×6.5.

Although R_{11} at first sight appears to have no function, it does, in fact, stabilize the opamp if the load is highly capacitive.

The 20 Hz filter is formed by the parallel combination of C_{10} and C_{11} and the input impedance of the power amplifier connected to K_2. The value of the capacitors may be calculated from $C_{10}+C_{11} = 1/40\pi R_i$, where R_i is the input resistance (47 kΩ). The old RIAA characteristics may be retained by giving both C_{10} and C_{11} a value of 470 nF.

The power supply for the stereo preamplifier contains no fewer than six regulator stages. The transformer rating is about 4.5 VA.

Any spurious noise signals produced by the rectifier diodes are suppressed by capacitors shunting the diodes.

The ±15 V output of regulators IC_5 and IC_6 is suitable for powering IC_2 and IC_4, but for the low-noise opamps it needs further smoothing in T_1–T_4. Strictly speaking, since these transistors are not saturated, they function not so much as regulators but more as filters. Their bases are driven via *RC* networks with a very low cut-off point (0.7 Hz). This arrangement ensures effective suppression of any residual hum and other noise extant on the output voltage.

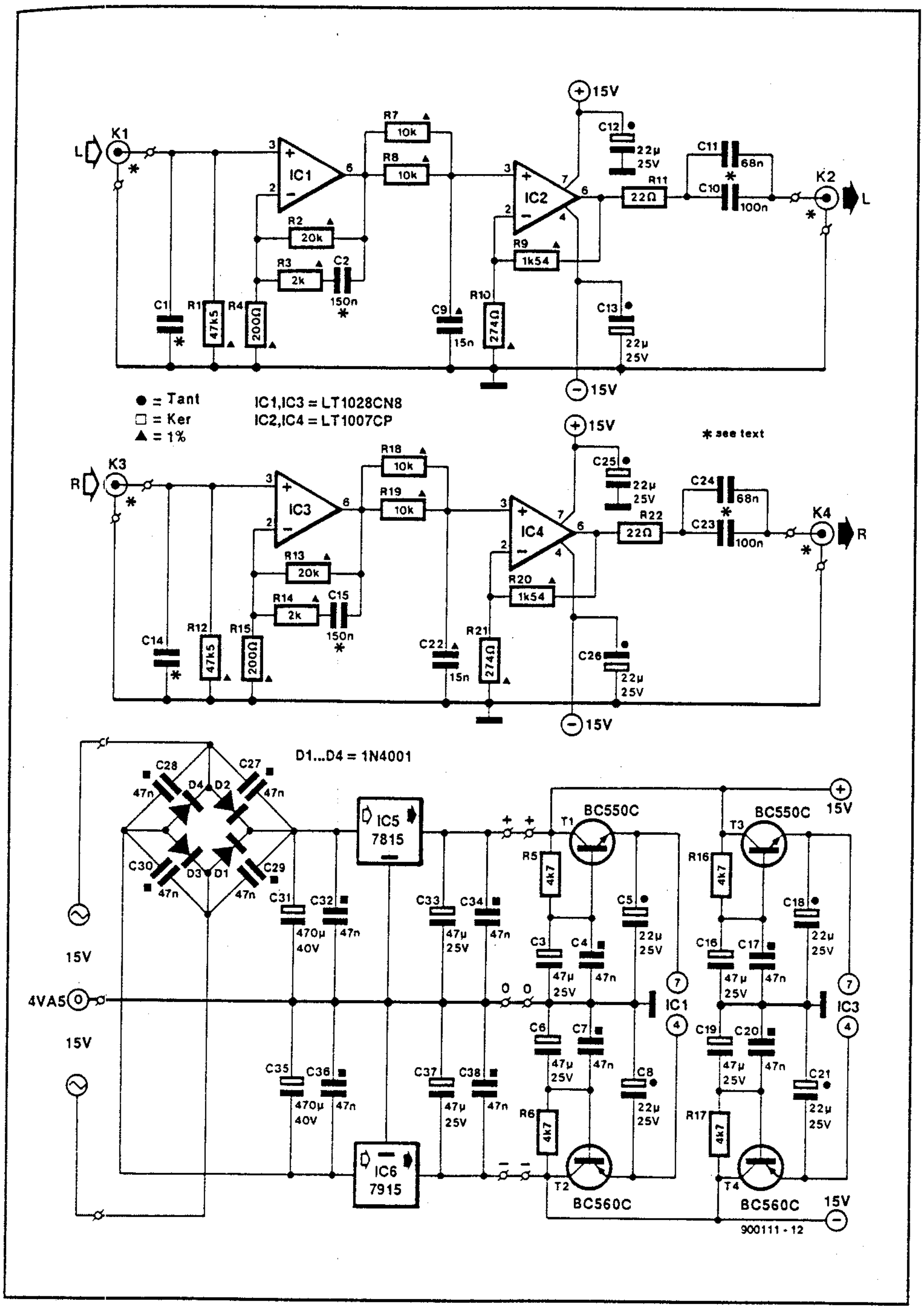


Fig. 2. Circuit diagram of the stereo preamplifier and associated power supply.

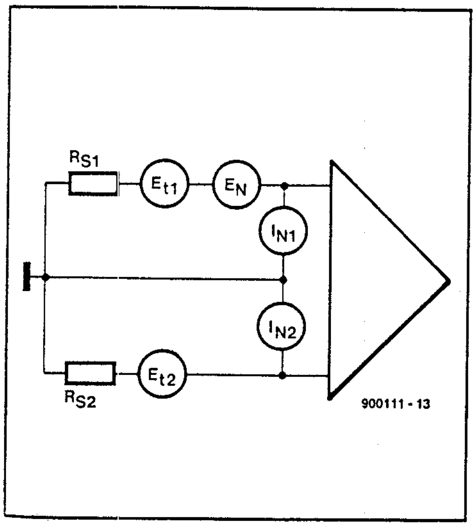


Fig. 3. Equivalent circuit of all noise sources associated with the preamplifier.

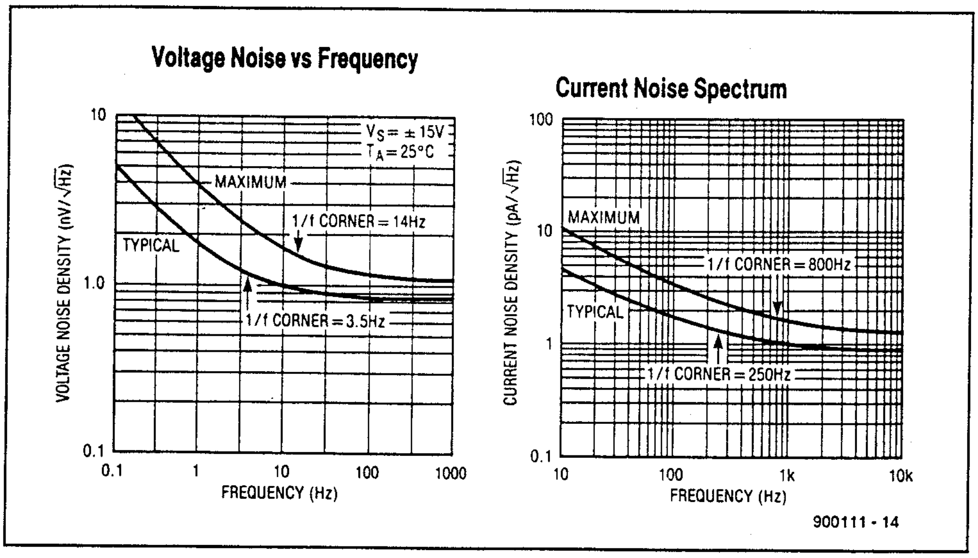


Fig. 4. Voltage noise and current noise as a function of frequency (Courtesy Linear Technology).

Noise

Noise figures do not tell the whole story of the noise that an amplifier will produce. The level of noise is determined primarily by the input circuit(s). The equivalent circuit in Fig. 3 shows where the sources of noise are to be found. Sources E_N, I_{N1} and I_{N2} represent all possible causes of noise in the opamp. Sources E_{t1} and E_{t2} represent the thermal noise level of the source impedances (R_{s1} and R_{s2}) that are connected to the opamp. The noise level at 25 °C is about $0.13\sqrt{R}$ (nV $\sqrt{Hz^{-1}}$) where R is expressed in Ω. Although this noise is not under the direct control of the designer, it does have an effect on the amplifier. The extent of its effect can only be assessed once we know more about the noise caused by the opamp.

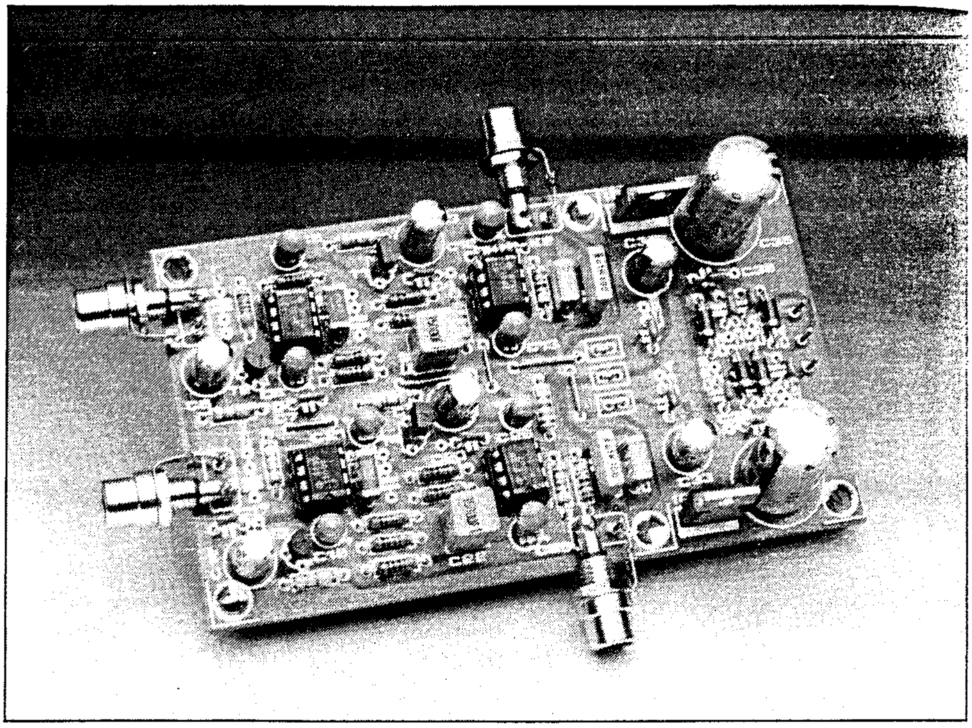
The noise voltage, E_N, and noise current, I_N, as function of frequency are shown in Fig. 4. In both, the characteristic may be divided into two: a flat part and a part where the amplitude rises with decreasing frequency. This comes about because, basically, both voltage noise and current noise consist of two types of noise: white noise and 1/*f* noise.

White noise is characterized by by its level being the same at all frequencies, whereas the level of1/*f* noise is inversely proportional to the frequency. The characteristic curve is therefore a descending line (1/*f* component greater) that slowly becomes horizontal (white noise greater). The frequency at which the levels of the two components are equal is usually called the rolloff frequency.

The effects of these noise sources may be limited by three golden rules:

- The source impedance must be kept as low as possible to keep thermal noise low. This in turn will keep down the level of the noise voltage caused by noise currents I_{N1} and I_{N2} across the source impedances. Note, however, that with the LT1028 the effects of the noise current are already exceeded by those of the thermal noise when the source impedance is smaller than 20 kΩ. Nevertheless, to ensure minimum noise in the LT1028, the source impedance must be less than 400 Ω to ensure that both the noise current and the thermal noise may be ignored: only the noise voltage then still plays a role. In their data book, Linear Technology therefore state that the use of the LT1028 is sensible only when the source impedance <400 Ω.
- The 1/*f* rolloff frequency must be chosen as low as necessary (and possible). This ensures that the amplifier has a good signal-to-noise ratio at even low frequencies. It does not make sense to use a 1/*f* rolloff frequency that lies beyond the bandwidth of the amplifier.
- Match the bandwidth of the amplifier to that of the signal. Noise that lies outside the bandwidth of the amplifier is amplified to a lesser degree than noise within it. In other words, the output of an amplifier with a correct bandwidth will contain less noise than that of an amplifier with too large a bandwidth.

With the LT1028 a big step has been taken



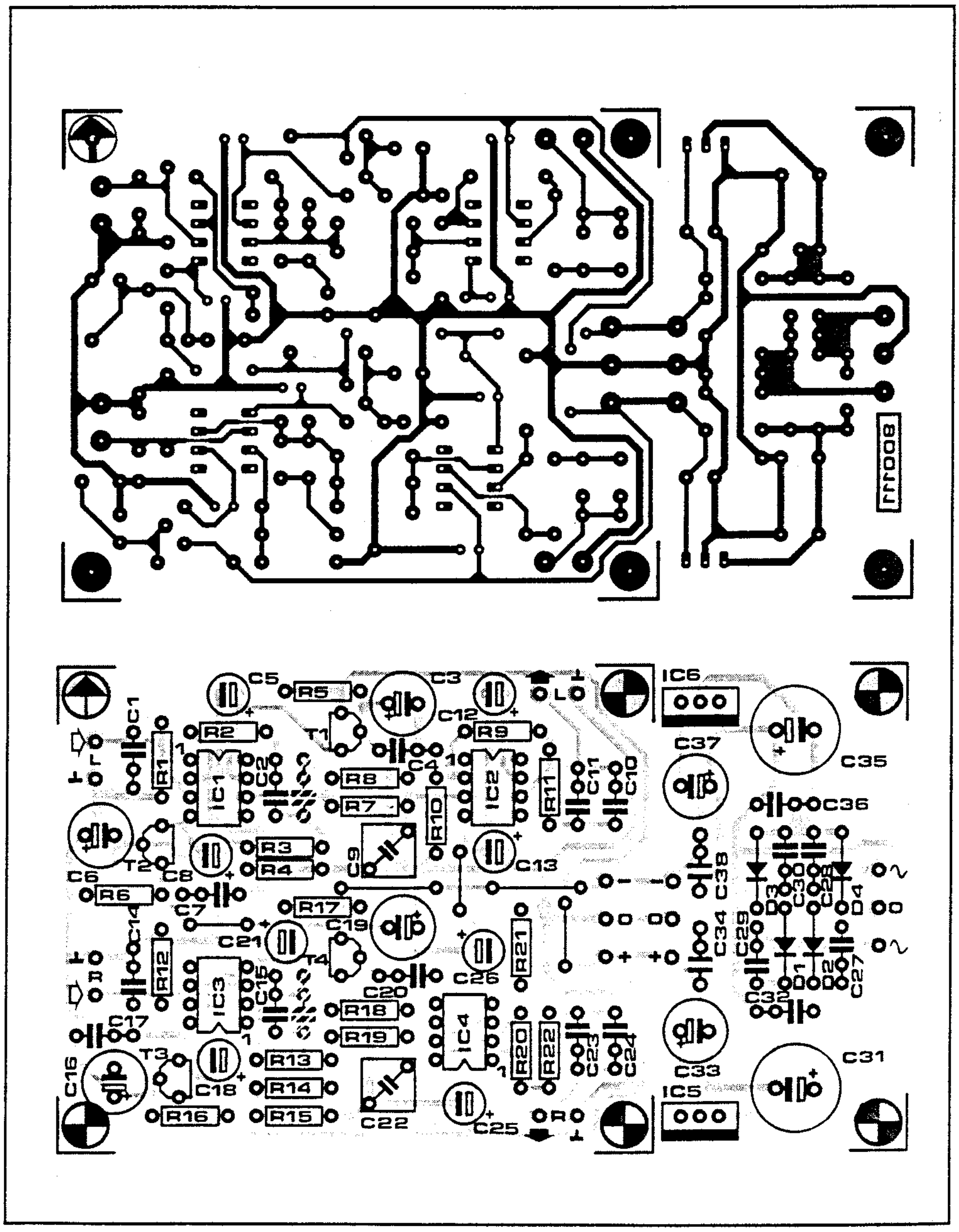


Fig. 5. The printed-circuit board for the preamplifier is available through our Readers' services.

towards a low-noise design, but the designer has little control over the source impedance. A moving-magnet cartridge usually has an impedance of 1–2 kΩ and that means that not the opamp but the pick-up element produces most noise. In other words, the amplifier is too good for a moving-magnet element.

There are, however, high-output moving-coil elements with an impedance of about 200 Ω; when these are used, it is the noise voltage of the opamp that will determine the signal-to-noise ratio.

In the latter case, the 1/*f* frequency also becomes important. For the LT1028 that lies at about 10 Hz. That is well below the 20 Hz rolloff frequency designed into the preamplifier: no problem here. In case of a moving-magnet element, the frequency at which the noise of the cartridge is exceeded by the 1/*f* noise is lower still, so no problem here either.

PARTS LIST

Resistors:

All resistors are 1% metal film types unless otherwise stated

R1, R12 = 47.5 kΩ[1]
R2, R13 = 20 kΩ
R3, R14 = 2 kΩ
R4, R15 = 200 Ω
R5, R6, R16, R17 = 4.7 kΩ[2]
R7, R8, R18, R19 = 10 kΩ
R9, R20 = 1.54 kΩ
R10, R21 = 274 Ω
R11, R22 = 22 Ω[2]

Capacitors:

C1, C14 = 100 pF[1]
C2, C15 = 150 nF MKT (match)
C3, C6, C16, C19, C33, C37 = = 47 µF; 25 V; radial
C4, C7, C17, C20, C27–C30, C32, C34, C36, C38 = 47 nF, ceramic
C5, C8, C12, C13, C18, C21, C25, C26 = 22 µF; 25 V; tantalum
C9, C22 = 15 nF; 1%; polystyrene
C10, C23 = 100 nF; MKT
C11, C24 = 68 nF; MKT[1]
C31, C35 = 470 µF; 40 V; radial

Semiconductors:

D1–D4 = 1N4001
T1, T3 = BC550C
T2, T4 = BC560C
IC1, IC3 = LT1028CN8[3]
IC2, IC4 = LT1007CP[3]

Miscellaneous:

K1–K4 = gold-plated phono sockets
Mains adapter or transformer, 4.5 VA, with 2×15 V secondary
PCB Type 900111

[1] See text
[2] carbon film type
[3] Linear Technology

The question is, however, what are we going to do with the bandwidth? After all, the correcing networks are affected by the bandwidth. To keep the bandwidth as narrow as consistent with the amplifier requirements, the entire IEC correction network should be incorporated in the feedback loop. Only then, no more noise than absolutely unavoidable will be amplified. There is, however, also the requirement of keeping the source impedances small. This means that the value of R_4 (R_{15}) must be kept low (200 Ω in the prototype).

Since the consequent 40 µF capacitor would be very large (it has to be a film type, because an electrolytic one would not do),the 20 Hz high-pass filter can not be accommodated in the feedback loop.

Similarly, the 2122 Hz low-pass filter can not be included in the feedback loop, because an opamp that is used as a non-inverting amplifier has an amplification of not less than ×1. The required attenuation of the highest frequencies can not, therefore, be achieved by the feedback loop.

Construction

As always, a high-quality amplifier as described here should preferably be constructed on the printed-circuit board shown in Fig. 5. The most conspicuous aspect of this is the earth track that divides the left- and right-hand channels.

It is also possible to separate the power supply from the the remainder of the board, at least as far as its part without transistors T_1–T_4 is concerned. Those transistors are located as close as possible to IC_1 and IC_3 for reasons explained earlier.

This arrangement makes it possible for a range of a.c. input voltages to be used: the amplifier works readily from ±7.5–20 V. In all cases, it is essential to keep the mains transformer or adapter well away from the board. If, for instance, the amplifier is built as a stand-alone unit (in a metal enclosure), it is advisable to house the transformer in its own (metal) enclosure away from the amplifier.

The connecting cables between the amplifier and the pick-up element must be as short as feasible. It is not a bad idea to build the amplifier within the record player.

Populating the board is fairly straightforward, although it requires absolute first-class soldering. It is necessary to tin the earth track again before any other work is begun. The only components that require extra care are:

R_1, C_1, R_{12}, C_{14}, which ensure correct termination of the pick-up element. Their value is as indicated in the documentation of the element. Note that the cable capacitance must be deducted from the specified capacitance to arrive at the correct values for C_1 and C_{14}. If no data on terminating the element are available, use the values given in the parts list.

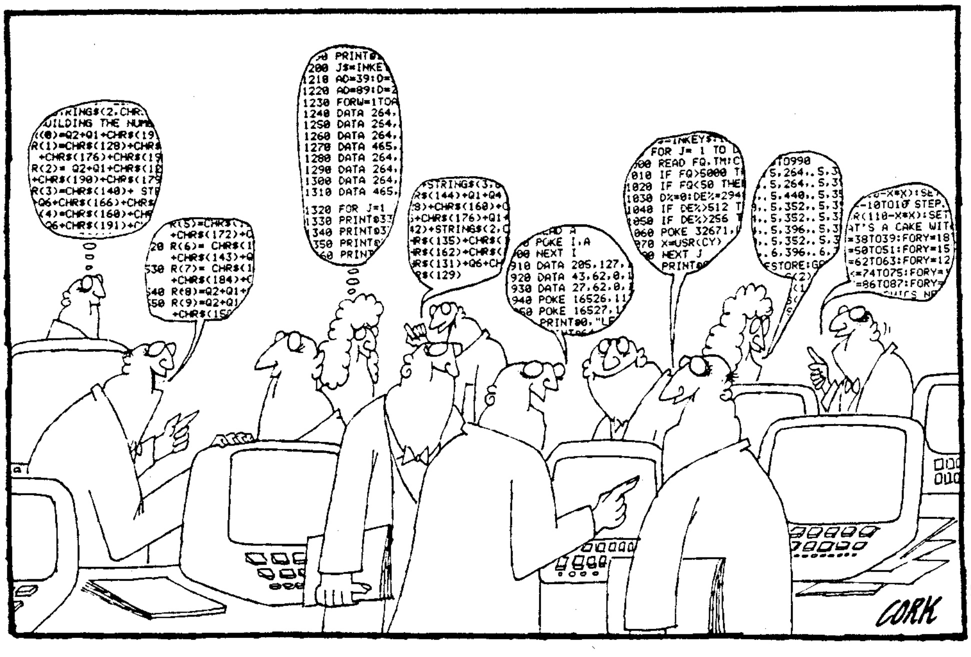
C_2, C_{15} should preferably have been 1% polystyrene types, but those are so large that the size of the PCB would have to be increased by almost 40%. It was therefore decided to use MKT—metallized polyester (PEPT)—types. These must, however, be carefully selected to ensure accuracy of the circuit. Apply soldering heat for a short time only, because the value of MKT capacitors changes when they are overheated.

C_{11}, C_{10}, C_{23}, C_{24} form, together with the input impedance of the amplifier connected to K2 and K4, the 20 Hz high-pass filter. The correct value is calculated from

$$C_{10} + C_{11} = C_{23} + C_{24} = 1/40\pi R_i.$$

Note that the board allows the use of two capacitors in parallel.

It is important that the capacitors just discussed are of exactly the same value in the lefty- and right-hand channels. This means that two capacitors for the C_2 and C_{15} positions that have the same value are preferred over two values that are not equal but are closer to 150 nF. ■



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