recip-riaa

The performance of bought or self-built preamplifiers for magnetic pickup cartridges is invariably not sufficiently well known. This is mainly due to the work involved in accurately measuring the amplitude response (RIAA or IEC curve), overdrive margin, distortion, signal-to-noise ratio and hum level. When the reproduction quality is not quite what it should be, the blame is by established tradition laid at the door of the disc manufacturer – or if his product is demonstrably above suspicion, at those of the cartridge or loudspeaker makers. The simple (and above all, electronic) preamplifier 'will surely not be misbehaving?' The weighting network described in this article greatly simplifies the above-mentioned measurements. Despite its simplicity, using only five components, it will deliver a measurement signal that is within 0.2dB of the standard RIAA cutting-curve. This should make it just about the smallest professional test instrument ever described . . .

During the cutting of gramophone records, optimum use of the possibilities of groove modulation requires that the lower audio frequencies be attenuated (relative to mid-range) and that the higher frequencies be emphasized. To enable a flat playback response to be readily obtained, this weighting is done according to an international (IEC) standard – the former RIAA-curve (figure 2). When the preamplifier amplitude-frequency response is the inverse of the cutting-curve, the overall response will be correct. Figure 1 shows this playback equalisation curve.

Carrying out measurements on the preamplifier now involves two specific, normally time-consuming complications. First of all, one cannot straightforwardly check the frequency response. The response of, for instance, a power amplifier should be 'flat'. This can be quickly checked by applying a constant voltage from a low distortion sine-wave oscillator, then observing the more or less stationary pointer of the output voltage meter as the oscillator is tuned through the audio range. By contrast, carrying out such a check on the dynamic preamplifier requires a point-by-point comparison of the meter reading with a voltage-frequency table to see if the figure 1 curve is accurately produced. (See table 1.)

This brings us to the second complication. A correct test of the nominal or maximum available output voltage as a function of frequency is only obtained when the input voltage follows the weighting curve used during cutting (figure 2). Allowing for typical levels of disc modulation and cartridge sensitivity, this measurement can be carried out using table 2 – which should cause the circuit to deliver a constant output voltage. The '0dB reference' level used in this table is 5mV at 1 KHz. The input voltages specified to achieve reference output level at other frequencies follow curve 2. The simple and direct solution to both problems should now be obvious: insert a weighting network having the amplitude-frequency response of figure 2 between the constant-voltage oscillator and the preamplifier under test. The input voltage will now vary with frequency according to table 2, whereby the 1 KHz reference level can of course be chosen according to individual requirements. If the preamplifier is doing its job properly, it will now deliver a constant output voltage – which can easily be checked.

The weighting network

The RIAA (IEC) characteristic is defined by the time-constants $\tau_1 = 75\mu S$, $\tau_2 = 318\mu S$, $\tau_3 = 3180\mu S$. τ_2 is opposite in slope to the others. The response of the equaliser-preamplifier (curve 1) must be:

$$H_e(p) = \frac{(1 + p\tau_2)}{(1 + p\tau_1) \cdot (1 + p\tau_3)}.$$

The cutting system, and therefore also the network described here, has the reciprocal transfer function:

$$H_c(p) = \frac{(1 + p\tau_1) \cdot (1 + p\tau_3)}{(1 + p\tau_2)}.$$

It is not difficult to design a single network which will show response breakpoints corresponding to the three time constants. With the network shown in figure 3, compensation for mutual interactions requires the use of three rather different RC-time constants:

$$\tau_1 = R_1 \cdot C_1 = 82\mu S;$$
$$\tau_2 = R_1 \cdot C_2 = 240\mu S;$$
$$\tau_3 = R_2 \cdot C_2 = 3000\mu S.$$

The network actually also has a fourth break-point, which causes the characteristic to flatten off at a frequency well above the audio range. This frequency is near 50 KHz, corresponding roughly to the time-product of R_3 and C_1 (about $3\mu S$).

The time-constants specified above are chosen to give the best fit of the IEC-curve using standard component values from the E24 (5%) range. The actual component values given in figure 3 fit particularly well. Use of 1% tolerance components will provide an inaccuracy of less than 0.2dB, theoretically, while

Table 1. Numerical values for the IEC (RIAA) playback curve. A preamplifier supplied with a constant input level should deliver these output levels.

Table 2. Numerical values for the IEC (RIAA) cutting curve. A preamplifier supplied with these input levels should deliver a constant output level.

Table 3. Comparison of the theoretical IEC/RIAA cutting curve and the response of a prototype weighting network. The error is less than 0.1dB from 40 Hz to 16 KHz – although this particular unit was assembled from 5% components!

Figure 1. The IEC/RIAA playback equalisation curve. For CD4 and UD4 carrier-channel discs the curve flattens off at 20 KHz, due to an extra time-constant of approx. 8µS.

Figure 2. The IEC/RIAA weighting curve used during disc-cutting. The 'recip-RIAA' network also produces this curve.

Figure 3. Circuit diagram of the network. C_2 can be made up by parallel connection of twice 1.5nF (or 2.2nF plus 820pF).

Figure 4. The measurement set-up. The weighting network (WN) is inserted between the LF generator (GEN) and the disc-preamplifier under test (DP). An AC millivoltmeter (mV) can now be used to check if the output voltage is the same for all audio frequencies.

Figure 5. Determination of drive-limits for disc cutting is a complex matter. The contours given here apply to the stylus tip velocity for the innermost grooves (diam. approx. 140mm) without use of a tracing-distortion compensator. Such devices allow far higher treble levels to be cut and are mandatory for carrier-discs.

Figure 6. The inner-groove maxima (figure 5) as they appear after equalisation (at the preamp output). The outer grooves will take +14dB from 50 Hz to 4 KHz. The preamp must have a further overload margin, particularly at higher frequencies, to allow for tracing distortion compensator cuttings.

Table 1

Frequency (Hz/KHz)	Output level (dB)	(mV)*	
20 (Hz)	19.3	923	
30	18.6	851	
40	17.8	776	
50	17.0	708	
60	16.1	638	
80	14.5	531	
100	13.1	452	
200	8.2	257	
300	5.5	188	
400	3.8	155	
500	2.7	136	
600	1.8	123	
800	0.8	110	
1 (KHz)	0.0	100	(ref)
2	− 2.6	74	
3	− 4.7	58	
4	− 6.6	47	
5	− 8.2	39	
6	− 9.6	33	
8	−11.9	25	
10	−13.7	21	
16	−17.7	13	
20	−19.6	10.4	

* millivolt table based on 0dB = 100mV; change of reference level means that all values have to be changed by the same factor.

Table 2

Frequency (Hz/KHz)	Input level (dB)	(mV)*	
20 (Hz)	−19.3	0.54	
30	−18.6	0.59	
40	−17.8	0.64	
50	−17.0	0.71	
60	−16.1	0.78	
80	−14.5	0.94	
100	−13.1	1.11	
200	− 8.2	1.95	
300	− 5.5	2.65	
400	− 3.8	3.23	
500	− 2.7	3.66	
600	− 1.8	4.06	
800	− 0.8	4.56	
1 (KHz)	0.0	5.00	(ref)
2	2.6	6.7	
3	4.7	8.6	
4	6.6	10.7	
5	8.2	12.9	
6	9.6	15.1	
8	11.9	19.7	
10	13.7	24.2	
16	17.7	38.4	
20	19.6	47.7	

* millivolt table based on 0dB = 5mV.

Table 3

Frequency (Hz/KHz)	IEC/RIAA curve (dB)	proto-type (dB)	error (dB)
20 (Hz)	−19.3	−19.1	+0.2
30	−18.6	−18.4	+0.2
40	−17.8	−17.7	+0.1
50	−17.0	−17.0	0.0
60	−16.1	−16.0	+0.1
80	−14.5	−14.4	+0.1
100	−13.1	−13.0	+0.1
200	− 8.2	− 8.2	0.0
300	− 5.5	− 5.5	0.0
400	− 3.8	− 3.8	0.0
500	− 2.7	− 2.6	+0.1
600	− 1.8	− 1.8	0.0
800	− 0.8	− 0.8	0.0
1 (KHz)	0.0	0.0	0.0
2	2.6	2.6	0.0
3	4.7	4.8	+0.1
4	6.6	6.7	+0.1
5	8.2	8.2	0.0
6	9.6	9.6	0.0
8	11.9	11.8	−0.1
10	13.7	13.7	0.0
16	17.7	17.6	−0.1
20	19.6	19.4	−0.2

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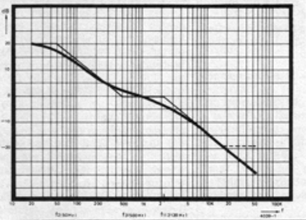

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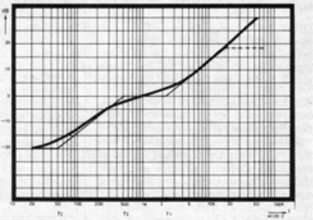

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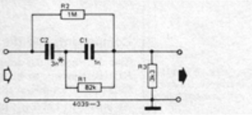

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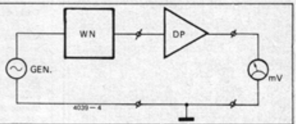

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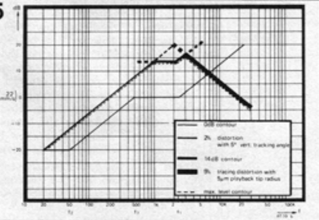

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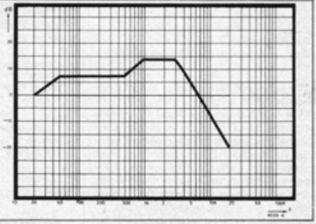

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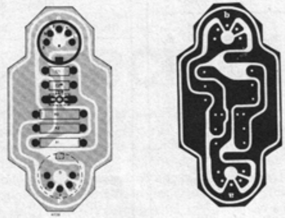

Figure 7. PC board and component layout for the network.

Table 4. Performance characteristics of the weighting network. Noise and distortion levels will in practice be those of the LF oscillator in use.

worst-case 5% components will cause maximum errors of about 1dB. High-quality components (particularly film resistors) are invariably well within their nominal tolerance – as shown in table 3 for a prototype network using 5% components. This stays within 0.1dB of the IEC curve throughout the entire audio range!

Other performance aspects of the network – such as noise and distortion – are of course orders of magnitude better than those of the best LF oscillator, which is therefore the actual limitation.

A signal-to-noise ratio of 80dB (for the network!) will be no problem at all – thermal noise is theoretically about 120dB down. From the point of view of long term accuracy, however, the use of metal-film resistors is to be preferred. Table 4 gives a summary of the overall measured performance.

Measurement procedure

Figure 4 shows the measurement set-up. The weighting network is inserted between the LF oscillator output and the preamplifier input. It is good practice – to avoid HF breakthrough, if for no other reason – to arrange that the signal-return is inside the cable screening sheath. This means the use of multiple-core screened cable, with the screen earthed at only one (either!) end. Far too much audio wiring uses the screen as a happy-dumping-ground for returning signal currents, simply asking for (and frequently getting) HF breakthrough and hum.

The reference level of disc modulation – the '0dB level' – corresponds (for CD4 and UD4 carrier discs) to a stylus tip velocity of 22.4mm/sec (peak value) at 1 KHz. Normal lp's (and some American CD4 discs) have a reference level about 5dB higher. This level generally corresponds to the average level in the loudest passages although the instantaneous peak programme level can be considerably higher, perhaps +10dB for carrier discs and at least +20dB for normal stereo discs. With typical cartridge sensitivities of 0.5 to 2mV (RMS value per peak cm/sec!) the preamplifier will operate at a 0dB level of 1 ... 5mV.

The suggested test level is 100mV from the oscillator – giving 3.5mV from the recip-RIAA network at 1 KHz input level. A preamplifier with sufficient overdrive margin should be able to handle 3.5mV + 26dB, i.e. 2 volts from the oscillator.

After all this the actual measurement procedure is quite simple: set the oscillator to 100mV output, then sweep it over the audio range and check for 'flat' output response. Some preamplifiers are designed to roll off in response at very low frequencies – 3dB at 20 Hz is typical, with a steep fall below that point. This attenuates 'rumble' and the high-amplitude subsonic frequencies occurring with a warped disc. This practice is legitimate, even desirable; it should certainly not be interpreted as a fault.

Table 4

Maximum amplitude error with 1% components	± 0.2dB
Maximum amplitude error with 5% components	± 0.9dB
Signal-to-noise ratio	80 ... 120dB
Distortion (with film resistors)	below noise
Oscillator output voltage for routine testing (0dB = ± 3.5mV at 1 KHz)	100mV
Oscillator output voltage for overdrive test (+26dB)	2V

Having checked the frequency response at '0dB level' one should also determine the amount of overdrive 'headroom' available. Set the oscillator to 1 KHz and 2 volts output. The preamplifier should handle this cleanly (unless it is a super-high-gain circuit used only with a low-output cartridge). Now check that this headroom is available at least from 500 to 2000 Hz, preferably also from 100 to 5 KHz. Figure 5 shows a few overload-risk contours due to various aspects of disc-cutting reality, as applied to the innermost grooves of a long-playing record. Bear in mind that the limits are higher at larger groove radii and/or 45rpm. Figure 6 shows the overall contour of figure 5 after IEC (RIAA) playback equalisation. It indicates that reduced headroom at very high and very low frequencies (the former is frequently met) need not be an objection.

Components and the PC board

The PC board is designed to enable DIN connectors to be soldered onto it directly.

As mentioned above, optimum accuracy will be guaranteed only when components of 1% tolerance are used – typically metal film resistors and polystyrene capacitors. With almost any available LF oscillator, however, use of carbon film resistors and normal ceramic capacitors will not degrade any other aspect of total performance. The simplest approach is therefore to use readily available 5% components, either selecting values with a bridge or else accepting the risk of ± 0.5dB inaccuracies. Few preamplifiers are better than this anyway.

The PC board has positions which enable C_2 to be made up with two components (e.g. 2 × 1.5nF or 2.2nF + 820pF), since the 'in-between' E24 values are not always easy to obtain.