RIAA Equalization

Designing RIAA networks that will accurately replay your analog discs.

By Wilfred Harms

RIAA equalization is an important feature of any amplifier designed to reproduce music from analog disc. Suitable circuit designs can be found in any number of published sources.

Unfortunately, the circuits contained in many handbooks, electronics journals and even inside some expensive pieces of audio equipment are often inaccurate. Incorrect designs are often repeated without question and the original requirements are simply forgotten.

This is a pity because it doesn't cost any more to use a resistor and capacitor of the correct value and the results are well worth the extra time and trouble. The purpose of this article is to show why RIAA equalization is important and how to go about choosing the right filter components when designing disc equalization networks.

In The Groove

From the earliest days of electrical recording it has been standard practice to modulate record grooves using a constant- velocity recording characteristic and to replay the signal with a velocity-dependent pickup. The maximum velocity is set at a certain value and the amplitude of the signal voltage is varied with frequency so this maximum is always achieved.

The system is illustrated in Fig.1. The maximum velocity is represented by the greatest rate of change of signal voltage, the steepest part of the waveform slope. On a sinewave this will always occur at the zero-crossing points.

On lower frequency signals, the maximum velocity will be less as the rising edge of the waveform is less steep. If, however, the amplitude of lower-frequency signals is increased, a point will be reached at which the rising edge is as steep as that of a higher frequency signal with lower amplitude. This is the principle on which constant velocity recording works, the maximum velocity remaining constant across the audio band while the amplitude varies according to the signal frequency.

The main drawback with this system is that bass frequencies require a very large amplitude. The result would be wide groove spacing and correspondingly little recording time on each disc. In addition, the comparatively small amplitude at high signal frequencies would yield a poor signal-to-noise ratio.

To overcome these problems, the basic constant-velocity characteristic is modified to a constant-amplitude characteristic over certain parts of the frequency range by means of a corrective network.

In the early days this was done very much at the whim of individual record manufacturers and a number of different replay characteristics grew up side by side. In order to handle the different recording characteristics correctly, amplifiers were fitted with a number of switch-selectable equalization networks.

The situation was eventually rationalized by agreement. British Standard 1928 (issued in 1955 and re-issued without changes in 1965) recommends a recording characteristic similar to that put forward by the Comite Consultatif International des Radiocommunications (CCIR) in Europe and the Recording Industries Association of America (RIAA). The latter term is the one most commonly used today.

Changing Shape

The RIAA characteristic modifies the basic constant-velocity characteristic to a constant amplitude characteristic at two points in the audio frequency band.

At very low frequencies the constant-velocity characteristic is retained so that the gain does not go on increasing right down to the lowest recorded frequencies. Using a constant-amplitude characteristic here would emphasize turntable rumble and vibration.

At bass frequencies the characteristic changes to constant-amplitude to limit groove pitch before switching back to a constant-velocity characteristic for the middle frequencies. At high frequencies the characteristic again becomes constant amplitude and remains so to the limits of the audio band.

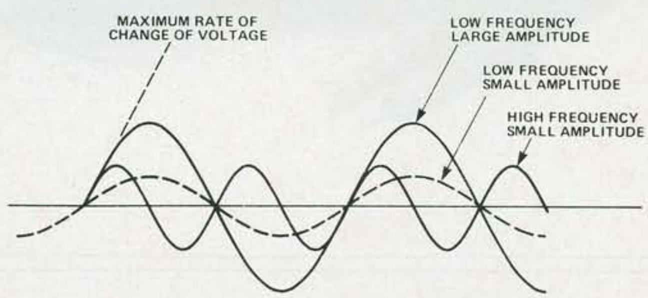

Fig. 1 For optimum modulation of the record groove when a velocity-dependent pick-up is used, all signal frequencies should have the same max. rate of change of voltage. To achieve this, lower frequencies are recorded with a correspondingly greater amplitude so as to give a steeper rising edge.

These four distinct regions give the RIAA characteristic its familiar flat-steep-flat-steep shape. The shape is sometimes shown instead as a series of angular lines but these are merely asymptotes to the curves. Provided the recording and replay networks are as near identical as possible, the exact shape of the response does not make a lot of difference. It therefore makes sense to use a series of curves which can easily be replicated to a high level of accuracy rather than an idealized, sharp-cornered response which could only be approximated with difficulty.

Calculated Curves

The response shape is described in terms of three curves (flat becoming steep, steep becoming flat and flat becoming steep again) which 'turn over' at frequencies of 50.05Hz, 500.5Hz and 2.115kHz. The slope of the curves is that given by a first order (6dB/octave) filter network comprising one resistor and one capacitor.

The RIAA replay characteristic is the exact opposite of the recording characteristic and is shown in Fig.2. The complete characteristic can, in theory, be reproduced using three capacitors, and three resistors in series and parallel pairs, although this is not necessarily the best way of doing it as we shall see later.

The actual values of the resistors and capacitors used will vary according to the individual circuit configuration, but the CR time constant for each filter curve is determined solely by the turn-over frequency and is therefore fixed. For this reason, it is usual to define the three curves in terms of CR time constants.

The values required must, at the frequency concerned, give CR values which result in C and R having equal impedances. This can be determined from the formula:

$$CR = \frac{1}{2\pi f}$$

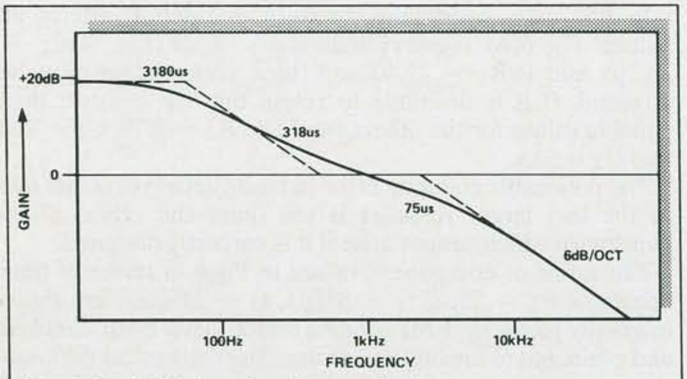

Fig. 2 The RIAA replay characteristic.

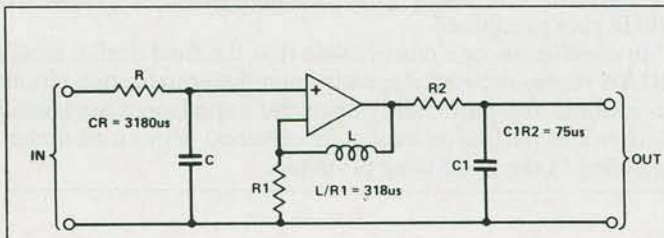

Fig. 3 A simple replay equalization circuit using separate filter networks for each of the three time constants.

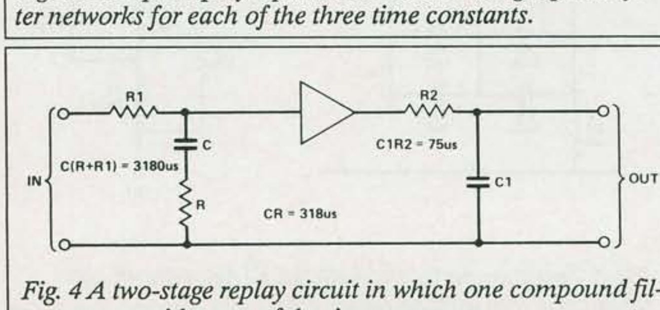

Fig. 4 A two-stage replay circuit in which one compound filter stage provides two of the time constants.

and for the RIAA characteristic gives time constants of 3180, 318 and 75 microseconds. These time constants are, incidentally, the period of one radian of one cycle at thee frequency concerned.

Fig. 3 shows a simple equation network which uses three separate stages to realize the RIAA characteristic. This will work but a much better approach is to merge two of the networks in the way shown in Fig.4.

In practice, all three stages are usually combined into a single network and some examples are shown in Fig.5. All of these circuits give similar results but in each case there will be a degree of interaction between the three time constants and this will affect all four circuit components.

The response curves for an RIAA network are defined in terms of a single reference frequency, 1kHz. Taking the circuit of Fig.4 as an example, the output level from the 318/3180μs section (the network comprising R, R1 and C) will be 11.17% of the input signal level. Similarly, the output from the 75μs section (the network comprising R2 and C1) will be 90.46% of the its input level.

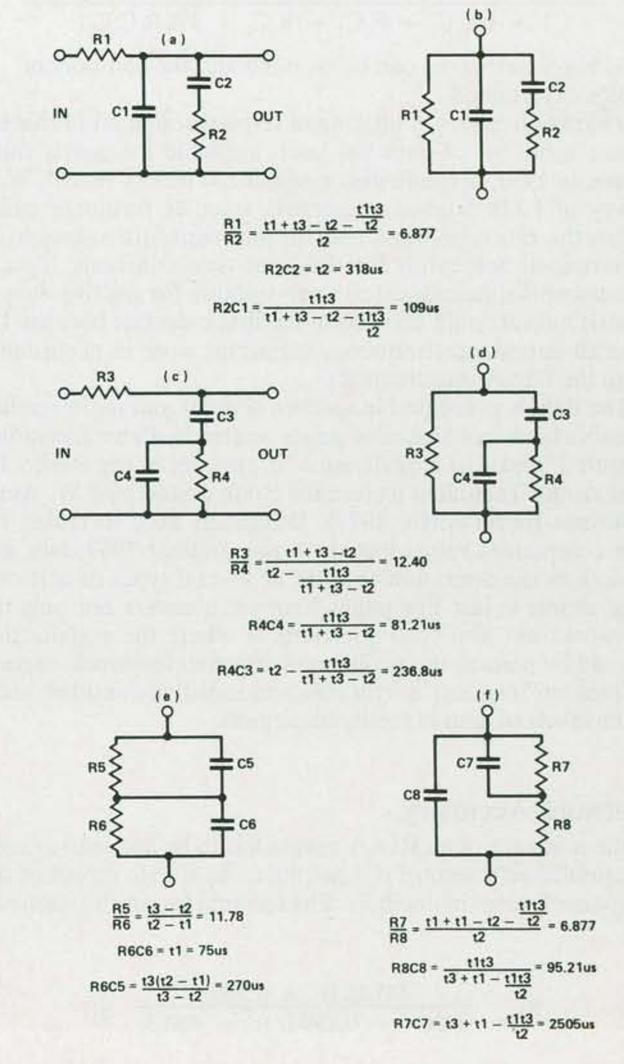

Fig. 5 Some examples of RIAA replay networks in which all three time constants are set using a single network.

Taking these two together, the final output level from the circuit at 1kHz will be (0.1117 x 0.9046) = 0.10103 times the input level or 10.103%. Therefore the input or zero frequency response for the network should be set at (1/0.10103 =) 9.898 times the reference response at 1kHz.

Network Design

Designing a network of the type shown in Figs.2 and 3 is quite straightforward but the single network of Fig.4 require a different approach.

For those who want to go into the mathematics of it all, the figure for output level/input level of an RIAA network is given by

$$\frac{(1 + st_2)}{(1 + st_1)(1 + st_3)}$$

Where t is the period of the CR time constant and $s = j\omega$ (ω, of course, is shorthand for $2\pi f$). Taking the circuit of Fig. 5a as an example, the output level/input level at a given frequency will be equal to

$$\frac{(1 + sR_2C_2)}{1 + s(R_1C_1 + R_2C_2 + R_1C_2 + s^2R_1R_2C_1C_2)}$$

The two expressions can be equated and the component ratios determined.

Thankfully, there is little need to go through all of this because a full set of data has been available for nearly thirty years. In 1957, in the British magazine Wireless World, W.H. Livvy of EMI Studios presented a set of formulae which allow the ratios between resistor and capacitor values to be determined accurately for different time constants. Two of the networks, he suggested were suitable for passive de-emphasis but all could be used in feedback circuits because the overall impedance/frequency variations were in accordance with the RIAA requirements.

The data is presented in an even simpler and more readily-useable form in a technical paper written by Peter Baxandall. Entitled 'Pick-Up Equalization' it appears in the Radio TV and Audio Technical Reference Book edited by S.W. Amos (Newnes-Butterworth, 1977). Baxandall uses formulae for the component ratios based on the original 1957 data and describes the operation and use of several types of network. The article is just five pages long yet it covers not only the networks but also such questions as where the equalization should be placed, the problem of inverted feedback, aspects of pick-up response correction and sensitivity and the minimum levels of gain in feedback circuits.

Network Accuracy

If the accuracy of an RIAA network is to be assessed against the published standard it is helpful to be able to calculate the response figures in decibels. The formula for any frequency, f is

$$10_{\log} \frac{441.18\,(r^2 + 0.2505)}{(100r^2 + 0.2502)(r^2 + 4.503)} \text{ dB}$$

where r = f/1000. if it is desired to check the characteristic of one network against another, the impedance must first be determined at any frequency and compared with the impedance at 1kHz to give

$$20_{\log} \frac{Z}{Z_{1k0}}$$

Design Misconceptions

Fig. 6a shows a type of network which is frequently used, and component values in similar proportions will be found in many RIAA circuits.

The zero-frequency impedance is 1M1 while the impedance at 1kHz is 122k which is too high. The result is a loss in response below 1kHz of up to 1dB.

Here $R_5C_3 = 75\mu s$ and $R_6C_4 = 3300ms$ which is acceptable. The error is in the false assumption that R_5C_4 should equal $318\mu s$. A check with the basic formulae in Fig. 5(e) shows that $R_6R_5 = 11.78$, and to meet this R_6 must be increased to 1M2 and C_4 reduced to 2n7.

Figure 6b shows another commonly used RIAA network, and again it is possible to find component values in similar proportions in many other networks. As with the previous circuit, the impedance at 1kHz is high resulting in a loss in response at both lower and higher frequencies. Since $R_5R_3 = 3300$, $R_4C_3 = 330$ and $R_4C_2 = 72.6$, what is wrong?

In this case, everything, because interaction affects all values. Fig 6(b) requires that $R_5C_3 = 2937\mu s$, $R_4C_2 = 81.2\mu s$ and $R/R_4 = 12.40$ and three components must be changed. If it is desirable to retain the 33k resistor, then suitable values for the others would be R_2 = 2.7k, C_2 = 30n and C_3 = 91n.

The noticeable common error in faulty networks is that one of the two larger resistors is ten times the other, a circumstance which cannot arise if it is correctly designed.

The ratios of component values in Fig.4 in terms of time constants ($t_1 = 75\mu s$, $t_2 = 318\mu s$, $t_3 = 3180\mu s$) are those originally given by EMI Studios which have been checked and evaluated to facilitate their use. The theoretical differences appropriate to a feedback circuit are within the normal component tolerances (1% recommended) provided the 1kHz gain exceeds 65.

In conclusion, one must realize that the final design of any RIAA replay network depends upon the equalization circuit as a whole and particularly upon the impedances associated with it. But perfection cannot be obtained without an understanding of the underlying principles.

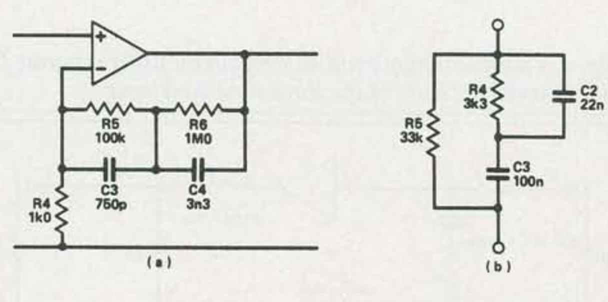

Fig. 6 Two commonly encountered RIAA network configurations with interaction problems.