if an input level of 10mV results in 0.1 mil amplitude change for constant amplitude recording and a velocity of 5cm/s for constant velocity recording, then a change of input level to 20mV would result in 0.2 mil and 10cm/sec respectively – independent of frequency.

Each of these techniques when used to drive the vibrating mechanism suffers from dynamic range problems. Figures 2.11.2a and 2.11.2b diagram each case for two frequencies an octave apart. The discussion that follows assumes a fixed amplitude input signal and considers only the effect of frequency change on the cutting mechanism.

Constant velocity recording (Figure 2.11.2a) displays two readily observable characteristics. The amplitude varies inversely with frequency and the maximum slope is constant with frequency. The second characteristic is ideal since magnetic pickups (the most common type) are constant velocity devices. They consist of an active generator such as a magnetic element moving in a coil (or vice versa) with the output being proportional to the speed of movement through the magnetic field, i.e., proportional to groove velocity. However, the variable amplitude creates serious problems at both frequency extremes. For the ten octaves existing between 20Hz and 20kHz, the variation in amplitude is 1024 to 1! If 1kHz is taken as a reference point to establish nominal cutter amplitude modulation, then at low frequencies the amplitudes are so great that cutover occurs. At high frequencies the amplitude becomes so small that acceptable signal-to-noise ratios are not possible – indeed, if any displacement exists at all. So much for constant velocity.

Looking at Figure 2.11.2b, two new observations are seen with regard to constant amplitude. Amplitude is constant with frequency (which corrects most of the ills of constant velocity), but the maximum slope varies directly with frequency, i.e., groove velocity is directly proportional to frequency. So now velocity varies 1024 to 1 over the audio band – swell! Recall that magnetic cartridges are constant velocity devices, not constant amplitude, so the output will rise at the rate of +6dB/octave. (6dB increase equals twice the amplitude.) To equalize such a system would require 60dB of headroom in the preamp – not too practical. The solution is to try to get the best of both systems, which results in a modified constant amplitude curve where the midband region is allowed to operate constant velocity.

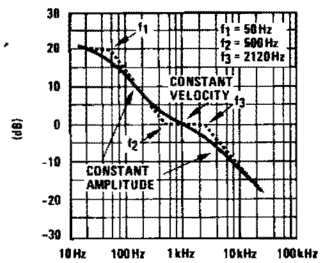


**FIGURE 2.11.3 RIAA Playback Equalization**

The required RIAA (Record Industry Association of America) playback equalization curve (Figure 2.11.3) shows the idealized case dotted and the actual realization drawn solid. Three frequencies are noted as standard design reference points and are sometimes referred to as time constants. This is a carryover from the practice of specifying corner frequencies by the equivalent RC circuit (t = RC) that realized the response. Conversion is done simply with the expression $t = 1/2\pi f$ and results in time constants of 3180μs for $f_1$, 318μs for $f_2$, and 75μs for $f_3$. Frequency $f_2$ is referred to as the *turnover* frequency since this is the point where the system changes from constant amplitude to constant velocity. (Likewise, $f_3$ is another turnover frequency.) Table 2.11.1 is included as a convenience in checking phono preamp RIAA response.

**TABLE 2.11.1 RIAA Standard Response**

| Hz | dB | Hz | dB |
|---|---|---|---|
| 20 | +19.3 | 800 | +0.7 |
| 30 | +18.6 | 1k | 0.0* |
| 40 | +17.8 | 1.5k | −1.4 |
| 50 | +17.0 | 2k | −2.6 |
| 60 | +16.1 | 3k | −4.8 |
| 80 | +14.5 | 4k | −6.6 |
| 100 | +13.1 | 5k | −8.2 |
| 150 | +10.3 | 6k | −9.6 |
| 200 | +8.2 | 8k | −11.9 |
| 300 | +5.5 | 10k | −13.7 |
| 400 | +3.8 | 15k | −17.2 |
| 500 | +2.6 | 20k | −19.6 |

* Reference frequency.

### 2.11.3 Ceramic and Crystal Cartridges

Before getting into the details of designing RIAA feedback networks for magnetic phono cartridges, a few words about crystal and ceramic cartridges are appropriate. In contradistinction to the constant velocity magnetic pickups, ceramic pickups are constant amplitude devices and therefore do not require equalization, since their output is inherently flat. Referring to Figure 2.11.3 indicates that the last sentence is not entirely true. Since the region between $f_2$ and $f_3$ is constant velocity, the output of a ceramic device will drop 12dB between 500Hz and 2000Hz. While this appears to be a serious problem, in reality it is not. This is true due to the inherently poor frequency response of ceramic and restriction of its use to lo-fi and mid-fi market places. Since the output levels are so large (100mV-2V), a preamp is not necessary for ceramic pickups; the output is fed directly to the power amplifier via passive tone (if used) and volume controls.

### 2.11.4 LM387 or LM381 Phono Preamp

Magnetic cartridges have very low output levels and require low noise devices to amplify their signals without appreciably degrading the system noise performance. Nevertheless, note that usually the noise of the cartridge and loading resistor is comparable to the active device and should be included in the calculations (see Appendix A5).

Typical cartridge output levels are given in Table 2.11.2.

Output voltage is specified for a given modulation velocity. The magnetic pickup is a velocity device, therefore output is proportional to velocity. For example, a cartridge producing 5mV at 5cm/s will produce 1mV at 1cm/s and is specified as having a sensitivity of 1mV/cm/s.

In order to transform cartridge sensitivity into useful preamp design information, we need to know typical and maximum modulation velocity limits of stereo records.

2

**TABLE 2.11.2**

| Manufacturer | Model | Output at 5cm/sec |
|---|---|---|
| Empire Scientific | 999 | 5mV |
| | 888 | 8mV |
| Shure | V-15 | 3.5mV |
| | M91 | 5mV |
| Pickering | V-15 AT3 | 5mV |

The RIAA recording characteristic establishes a maximum recording velocity of 25cm/s in the range of 800 to 2500Hz. Typically, good quality records are recorded at a velocity of 3 to 5cm/s.

Figure 2.11.3 shows the RIAA playback equalization. To obtain this, the desired transfer function of the preamplifier is given by:

$$\frac{V_{OUT}}{V_{IN}} = \frac{A(s+2\pi\cdot 500)}{(s+2\pi\cdot 50)(s+2\pi\cdot 2120)} \quad (2.11.1)$$

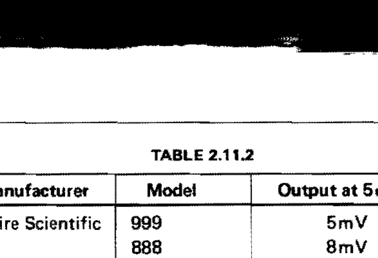


**FIGURE 2.11.4 RIAA Phono Preamp**

From Figure 2.11.4:

$$\frac{V_{OUT}}{V_{IN}} = \frac{K\left[s+\frac{R_1+R_2}{(C_1+C_2)R_1R_2}\right]}{R_6\left(s+\frac{1}{C_1R_1}\right)\left(s+\frac{1}{C_2R_2}\right)} + 1 \quad (2.11.2)$$

Equating coefficients of (2.11.1) and (2.11.2),

$$R_1C_1 = \frac{1}{2\pi\cdot 50} = 3180\mu s \quad (2.11.3)$$

$$R_2C_2 = \frac{1}{2\pi\cdot 2120} = 75\mu s \quad (2.11.4)$$

$$\frac{R_1R_2(C_1+C_2)}{R_1+R_2} = \frac{1}{2\pi\cdot 500} = 318\mu s \quad (2.11.5)$$

Substituting (2.11.3) and (2.11.4) in (2.11.5):

$$R_1 = 11.78R_2 \quad (2.11.6)$$

$$0\text{dB reference gain} = \frac{z+R_6}{R_6} \quad (2.11.7)$$

where: $z = \left(R_1 \parallel \frac{1}{2\pi fC_1}\right) + \left(R_2 \parallel \frac{1}{2\pi fC_2}\right)$

Resistor $R_5$ together with $R_1$ and $R_2$ sets the DC bias (Section 2.6) and $C_3$ stabilizes the amplifier by rolling off the feedback at higher frequencies since the LM387 is not compensated for unity gain.

**Example 2.11.1**

Design a phonograph preamp operating from a 24V supply, with a cartridge of 0.5mV/cm/s sensitivity, to drive a power amplifier with an input overload limit of $1.25V_{RMS}$.

**Solution**

1. The maximum cartridge output of 25cm/s is (0.5mV/cm/s) × (25cm/sec) = 12.5mV. The required mid-band gain is:

$$\frac{1.25V_{RMS}}{12.5mV_{RMS}} = 100$$

2. Before selecting $R_6$ to give a gain of 40dB at 1kHz, we must determine the complex impedance of the $R_1R_2$, $C_1C_2$ network at 1kHz. Ideally this should be such that $R_6$ is relatively low to minimize any noise contributions from the feedback network.
3. If we assume the amplifier output must be able to drive the feedback equalization network to the rated output at 20kHz, the slew rate required is:

$$S.R. = 2\pi Epf, \text{ where } Ep = 1.25X\sqrt{2}$$

$$= 2\pi \times 1.77 \times 20 \times 10^3$$
$$= 0.22V/\mu s$$

Using 1V/μs as a safety margin and noting that the output sink current of the LM387 is 2mA, the capacitance of the feedback network should be:

$$\leqslant \frac{2\times 10^{-3}}{1\times 10^{-6}}$$

$$\leqslant 0.002\mu F$$

Since $C_2$ will dominate the series arrangement of $C_1$ and $C_2$, put:

$$C_2 = 0.0027\mu F$$

4. From Equation (2.11.4):

$$R_2 = \frac{75\times 10^{-6}}{0.0027\times 10^{-6}} = 28k\Omega$$

Put $R_2 = 30k\Omega$

5. Equation (2.11.6):

$$R_1 = 11.78R_2$$
$$= 11.78 \times 30 \times 10^3 = 353k\Omega$$

Put $R_1 = 360k\Omega$