



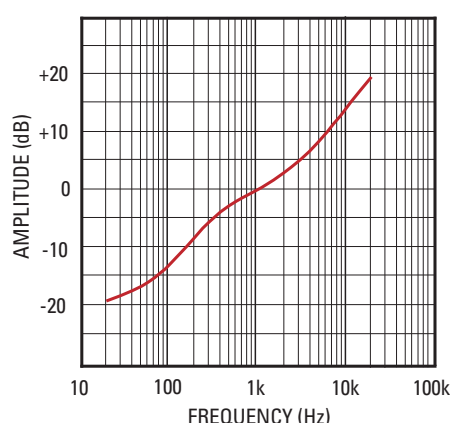
## Passively Equalized RIAA Phono Preamp using Sonic Imagery Labs Discrete Operational Amplifiers

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MARCH 2013

A current area of high audiophile interest is the passively equalized preamplifier circuits used for phonograph signal sources. The 990Enh-Ticha, 995FET, 992Enh-Ticha and 994Enh DUAL are high performance discrete operational amplifiers designed for professional audio applications and areas where ultra-low noise, low distortion and high output drive current is required. These discrete gain blocks are perfectly suited for phonograph preamp applications.

### Introduction

Phonograph preamplifiers differ from other preamplifiers only in their frequency response, which is tailored in a special manner to compensate, or equalize, for the recorded characteristic of a phonograph record. If a fixed amplitude input signal is used to record a phonograph disc, while the frequency of the signal is varied from 20Hz to 20kHz, the playback response curve of **Figure 1** will result. **Figure 1** shows a plot of a phonograph cartridge output amplitude versus frequency, indicating a severe alteration to the applied fixed amplitude signal. Playback equalization corrects for this alteration and re-creates the applied flat amplitude frequency response. To understand why **Figure 1** appears as it does, a detailed explanation of the phonograph recording and cutting process is necessary.



**Figure 1. Typical Phonograph Record Playback Characteristic for a Fixed Amplitude Recorded Signal**

### Recording Process and RIAA Curves

The grooves in a stereo phonograph disc are cut by a chisel shaped cutting stylus driven by two vibrating systems arranged at right angles to each other. The cutting stylus vibrates mechanically from side to side in accordance with the signal impressed on the cutter. This is termed a "lateral cut." The resultant movement of the groove back and forth about its center is known as groove modulation. The amplitude of this modulation cannot exceed a fixed amount or "cutover" occurs. (Cutover, or overmodulation, describes the breaking through the wall of one groove into the wall of the previous groove.) The ratio of the maximum groove signal amplitude possible before cutover, to the effective groove noise amplitude caused by the surface of the disc material, determines the dynamic range of a record (typically 58-60 dB). The latter requirement results from the grainy characteristic of the disc surface acting as a noise generator. (The cutting stylus is heated during master cutting to impart a smooth side wall to minimize the noise.) Of interest in phono preamp design is that the phonograph record noise performance tends to be ten times worse than that of the preamp, with typical wideband levels equal to 10uV of noise or more.

Amplitude and frequency characterize an audio signal. Both must be recorded and recovered accurately for high quality music reproduction. Audio amplitude information translates to groove modulation amplitude, while the frequency of the audio signal appears as the rate of change of the groove modulations. Sounds simple enough, but **Figure 1** should, therefore, be a horizontal straight line centered on 0dB, since it represents a fixed amplitude input signal. The trouble results from the characteristics of the phonograph cutting head due to its construction. The cutting head has a resonant peak at 700 Hz and to correct for this resonance, negative feedback coils are added to linearize or flatten the mechanical resonance. Adding the feedback coils produces a velocity output independent of frequency; therefore, the cutting head is known as a constant velocity device.

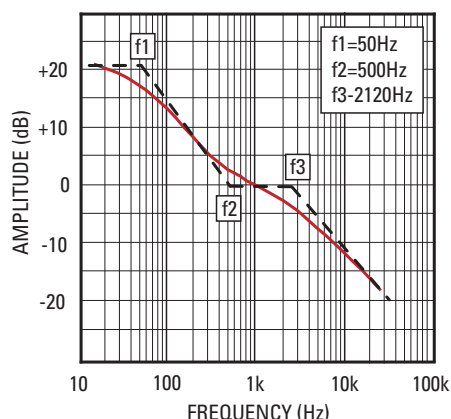
**Figure 1** appears as it does because the cutting amplifier is pre-equalized to provide the recording characteristic shown. Two reasons account for the shape: first, low frequency attenuation prevents cutover and overmodulation of the cutting stylus; second, high frequency boost improves the signal to noise ratio.



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The required RIAA (Record Industry Association of America) playback equalization curve (**Figure 2**) shows the idealized case dashed line 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 3180us for  $f_1$ , 318us for  $f_2$ , and 75us 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 1** is included as a convenience in checking phono preamp RIAA response.



**Figure 2. RIAA Playback Equalization**

### Low-Fi Ceramic and Crystal Cartridges

Before getting into the details of building a preamp for magnetic phono cartridges, a few words about crystal and ceramic cartridges are appropriate. In contra-distinction 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 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 500 Hz and 2000 Hz. 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 of these types of cartridges

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.

**TABLE 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.

### Passively Equalized RIAA Phonograph Preamp Circuit

A circuit topology which can be used for such RIAA phonograph applications is shown in **Figure 4**. There are many topologies for this application but we have chosen this configuration because it can be easily modified for experimentation. This circuit consists of two high-quality wide-bandwidth-gain blocks, U1 and U2, which are separated by a three-terminal network. The 990Enh-Ticha, 995FET, 992Enh-Ticha and 994Enh DUAL are high performance discrete operational amplifiers designed for professional audio applications and areas where ultra-low noise, low distortion and low offset is required. These discrete gain blocks are perfectly suited for phonograph preamp applications. Each of the gain stages is set up for the required gain, via R3-R4 and R5-R6. Input termination, as appropriate to the particular cartridge used, is provided by  $R_{term}$  and  $C_{term}$ , which are optimized for flattest response into this passive network. Since there is no real industry standard for interface, it is important to examine the phono cartridge manufacturers datasheet and understand its output specifications.

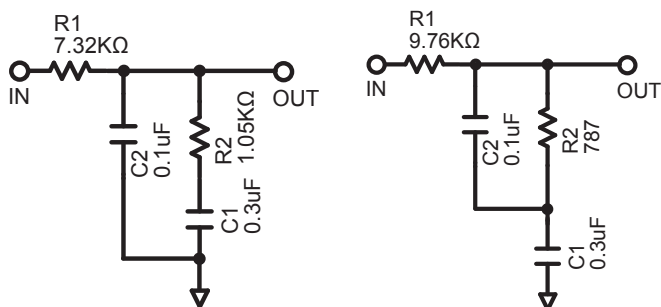


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## RIAA Equalizer Network

A three-terminal, four-component RC network can be designed to accomplish RIAA equalization, and two examples of such a network are shown in **Figure 3**. These networks can be used with either the conventional feedback-type of RIAA phono stages (also known as active equalization), or, with the passive equalized preamps between two gain stages.



**Figure 3. RIAA Playback Equalization Networks**  
( $f_1=3180\mu s$   $f_2=318\mu s$   $f_3=75\mu s$ )

Regardless of the circuit(s) within which they are used, the two RC networks shown are equivalent in terms of achieving the three time constants. Both have an input terminal, a common terminal, and an output terminal. Precision film RC components are recommended for best results. While practical standard values are shown, alternate sets can be attained, simply by multiplying the resistors by a desired factor, while dividing the capacitors by the same factor.

The actual network components should be precision high-quality types, both for initial equalization accuracy and also for minimal errors from nonideal properties. High-quality metal-film resistors and film capacitors of polystyrene or polypropylene are recommended, as they have low-voltage coefficients, low-dissipation factors, and low-dielectric absorption. (A capacitor type which generally should be avoided is the "high K" ceramic families.)

Obviously, the quality of the equalization/amplification can be no better than the components which are used to determine the transfer function (even if the amplifier itself is perfect).

## Gain Stages

Referring to schematic of **Figure 4**. The input RC components,  $R_{term}$  and  $C_{term}$ , terminate the moving magnet cartridge, as recommended by the manufacturer. The values shown are typical, with  $C_{term}$  typically being varied for flattest response. In terms of desired amplifier parameters, for optimum performance in this circuit, they are considerably demanding.

For lowest noise from the cartridge's inductive source, the amplifier should preferably have a voltage noise density of 5 nV/ $\sqrt{Hz}$  or less, and a current noise density of 1 pA/ $\sqrt{Hz}$  or less. The former requirement is best met by using low-noise bipolar-input amplifiers, such as the Sonic Imagery Labs 990Enh-Ticha, 992Enh-Ticha or the 994Enh-DUAL. Though the bipolar devices mentioned can meet this requirement for current noise density, it is best met by the use of FET-input amplifiers, such as the Sonic Imagery Labs 995FET-Ticha.

For the desirable low-noise bipolar-input amplifiers, DC input-bias current can be a potential problem when direct coupling to the cartridge; thus, in this circuit, the low-bias-current 995FET-Ticha amplifier is suggested. The amplifier used for U1 should have an input current of less than 100 nA, for minimum problems with the related DC offset (assuming a typical phono cartridge of about 1k resistance). FET-input amplifiers generally have negligible bias currents but they also tend to typically have a higher voltage noise. As mentioned before, the 995FET-Ticha is suitable as it has a reasonably well-controlled noise for this type of application (although not as low as the bipolar devices mentioned).

For high-gain accuracy, particularly at high stage gains, the amplifier should have a high gain-bandwidth product; preferably 5 MHz or more at audio frequencies.

The op-amp gain blocks, U1 and U2 could be identical for the purposes of simplicity, but are necessarily not so for reasons which are described next.



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The gain values shown yield a 1-kHz gain that is the product of the U1-U2 gains (24.7 times 40.2) times that of the interstage network. For a RIAA-equalized phono case, the 1-kHz gain is 0.101 times the DC gain, which yields an overall gain of 40 dB for this instance. Other gains can be realized most simply by minor increment changes to R4. In general, the 1-kHz gain of this circuit is:

$$G = 0.101 [1 + (R3/R4)] [1 + (R5/R6)]$$

The equalization network which follows U1 should use the lowest impedance values practical from the standpoint of low noise, as the noise output at the network is equivalent to the input-referred noise of U2. As noted previously, scaling can be applied to either network of **Figure 3** for component selection, as long as the same ratios are maintained.

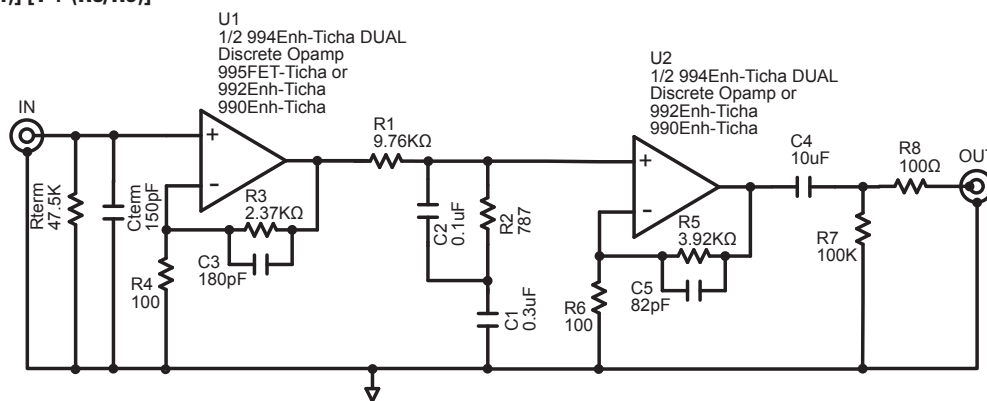


Figure 4. Passively Equalized RIAA Phono Preamplifier

A passively equalized preamplifier such as this must be carefully optimized for signal-handling capability, both from an overload standpoint and from a low-noise viewpoint. Stage U1 is desirably chosen for a gain sufficiently high that the input-referred noise will be predominantly due to this stage (and the cartridge, when connected), but yet not so high that it will readily clip at high-level high-frequency inputs. Several amplifiers with a 10-V rms output capability will allow U1 to accept 400-mV rms at high frequencies, as shown (with  $\pm 18V$  supplies). All Sonic Imagery Labs 99X series opamps can operate easily up to  $\pm 24V$  supplies.

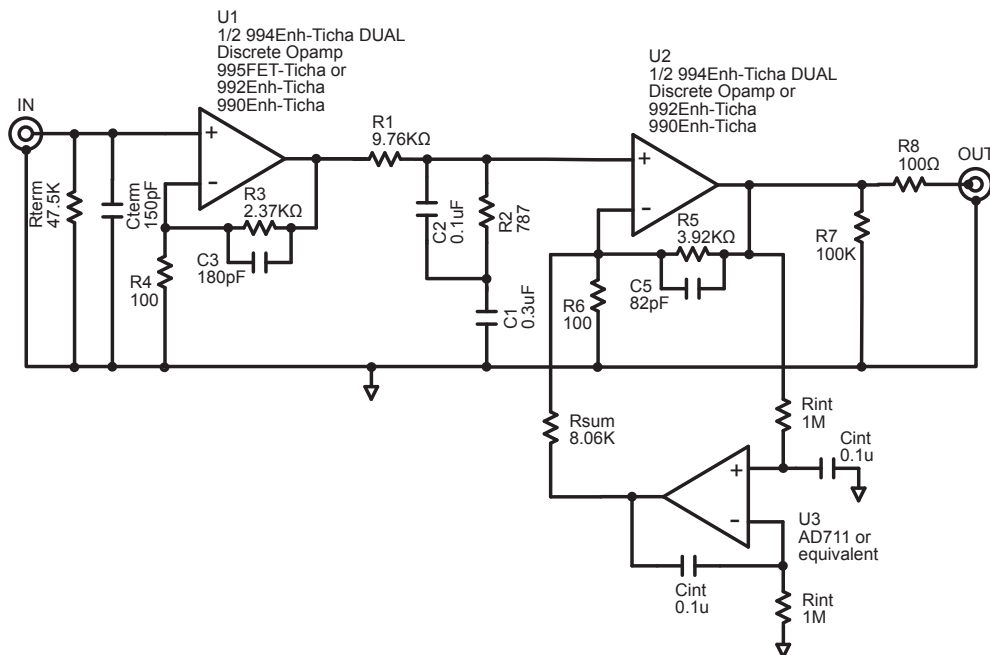
In general, the preceding factors dictate that the gain distribution between U1 and U2 be LOW/HIGH from an overload standpoint, but HIGH/LOW from a noise standpoint. Practically, these conflicting requirements can be mitigated by choosing the highest allowable supply voltage for U1 and U2, and the lowest noise device. Because of the near 40dB loss in the passive RIAA network, at 20 kHz, the output overload of the circuit will be noted at high frequencies first. With the gain distribution chosen, the circuit will allow a 3Vrms undistorted output to 20 kHz, with  $\pm 15V$  supplies, and proportionally more with higher supply voltages.

Amplifier U2 is less critical than U1 at low frequencies, but, still, is not negligible. A low-noise voltage-density device is very valuable to the U1, and U2 positions, as is a relatively low-input-current noise. As mentioned before, a low bias current is appropriate to U1, with the use of bipolar amplifiers. With a 100nA, or less, bias-current device, direct coupling to a moving magnet phono cartridge is practical. Similarly, the bias-current induced offset voltage of U2, from the 10k DC resistance of the passive RIAA network, will be low, relative to the amplified offset of U1. As a result, the worst-case overall-output DC offset at U2 can be held to under 500mV, allowing a single coupling capacitor to suffice for DC blocking purposes for the entire circuit if needed.



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**Figure 5. Passively Equalized RIAA Phono Preamplifier with Servo**

The low-end rolloff frequency is at the option of the designer. It can be extended towards DC by removing C4, or, alternately, rolled off at a low frequency below 50 Hz. This roll off, when applied, is popularly called a “rumble” filter, and it reduces the turntable/record-induced low-frequency disturbances and lessens the possibility of system and low-frequency driver overloading.

The circuit in **Figure 4** can also be easily adapted to servo control any of the output offset by the connection of a noninverting-type servo integrator around stage U2, as shown in **Figure 5**. The general-purpose noninverting servo described in the Sonic Imagery Labs 990Enh-Ticha opamp datasheet, along with a low-offset FET op amp, such as the AD711 is suitable. Remove C4 if one is to add the servo circuit.

#### References:

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