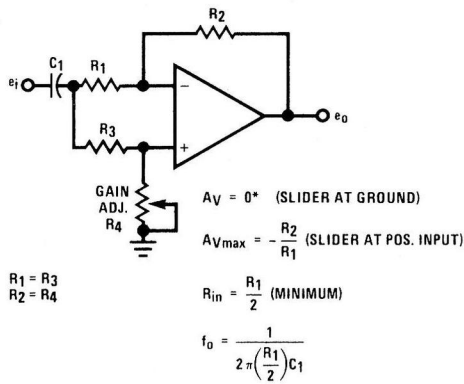
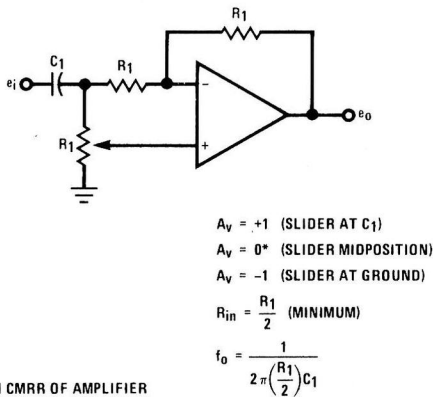


A4.7 Variable Gain AC Amplifier



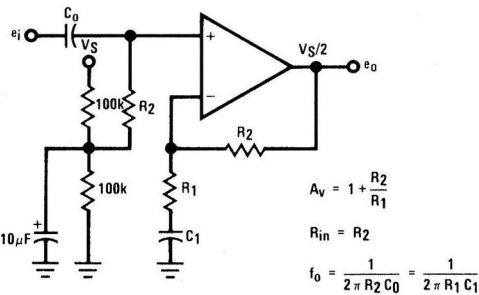
\* LIMITED BY CMRR OF AMPLIFIER AND MATCH OF  $R_1 = R_3$ ,  $R_2 = R_4$ , e.g., LF356 AND 0.1% MATCH EQUALS >80dB FOR  $A_{vmax} = 20$ dB.

A4.8 Switch Hitter (Polarity Switcher, or 4-Quadrant Gain Control)

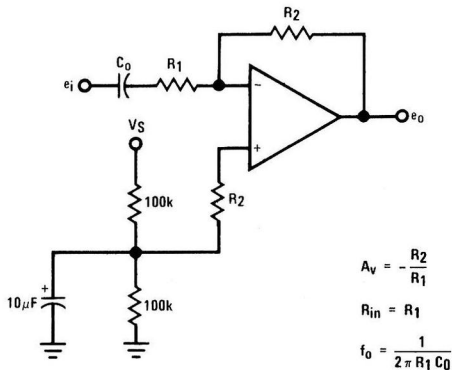


\* WITHIN CMRR OF AMPLIFIER

A4.9 Single Supply Biasing of Non-Inverting AC Amplifier



A4.10 Single Supply Biasing of Inverting AC Amplifier



A5.0 MAGNETIC PHONO CARTRIDGE NOISE ANALYSIS

A5.1 Introduction

Present methods of measuring signal-to-noise (S/N) ratios do not represent the true noise performance of phono preamps under real operating conditions. Noise measurements with the input shorted are only a measure of the preamp noise voltage, ignoring the two other noise sources: the preamp current noise and the noise of the phono cartridge.

Modern phono preamps have typical S/N ratios in the 70dB range (below 2mV @ 1kHz), which corresponds to an input noise voltage of 0.64μV, which looks impressive but is quite meaningless. The noise of the cartridge<sup>1</sup> and input network is typically *greater* than the preamp noise voltage, ultimately limiting S/N ratios. This must be considered when specifying preamplifier noise performance. A method of analyzing the noise of complex networks will be presented and then used in an example problem.

A5.2 Review of Noise Basics

The noise of a passive network is thermal, generated by the real part of the complex impedance, as given by Nyquist's Relation:

$$\overline{V_n^2} = 4 k T \operatorname{Re}(Z) \Delta f \tag{A5.2.1}$$

where:  $\overline{V_n^2}$  = mean square noise voltage  
k = Boltzmann's constant ( $1.38 \times 10^{-23} \text{W-sec/}^\circ\text{K}$ )  
T = absolute temperature ( $^\circ\text{K}$ )  
 $\operatorname{Re}(Z)$  = real part of complex impedance ( $\Omega$ )  
 $\Delta f$  = noise bandwidth (Hz)

The total noise voltage over a frequency band can be readily calculated if it is white noise (i.e.,  $\operatorname{Re}(Z)$  is frequency independent). This is not the case with phono cartridges or most real world noise problems. Rapidly changing cartridge network impedance and the RIAA equalization of the pre-amplifier combine to complicate the issue. The total input noise in a non-ideal case can be calculated by breaking the noise spectrum into several small bands where the noise is nearly white and calculating the noise of each band. The total input noise is the RMS sum of the noise in each of the bands  $N_1, N_2, \dots, N_n$ .

$$V_{\text{noise}} = (\overline{V_{N1}^2} + \overline{V_{N2}^2} + \dots + \overline{V_{Nn}^2})^{1/2} \tag{A5.2.2}$$

This expression does not take into account gain variations of the preamp, which will also change the character of the noise at the preamp output. By reflecting the RIAA equalization to the preamp input and normalizing the gain to 0dB at 1kHz, the equalized cartridge noise may then be calculated.

$$V_{EQ} = (|A_1|^2 \overline{V_{N1}^2} + |A_2|^2 + \dots + |A_n|^2 \overline{V_{Nn}^2})^{1/2} \tag{A5.2.3}$$

where:  $V_{EQ}$  = equalized preamp input noise  
 $|A_n|$  = magnitude of the equalized gain at the center of each noise band (V/V)

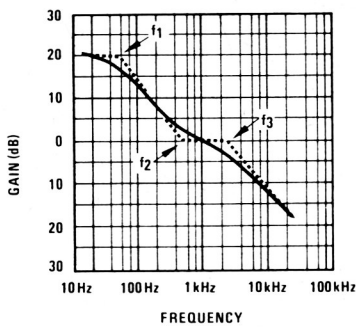
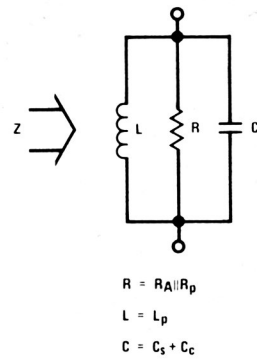


FIGURE A5.1 Normalized RIAA Gain



### A5.3 Cartridge Impedance

The simplified lumped model of a phono cartridge consists of a series inductance and resistance shunted by a small capacitor. Each cartridge has a recommended load consisting of a specified shunt resistance and capacitor. A model for the cartridge and preamp input network is shown in Figure A5.2.

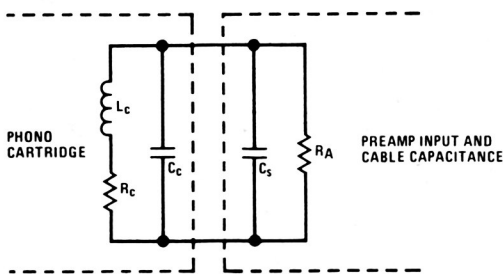
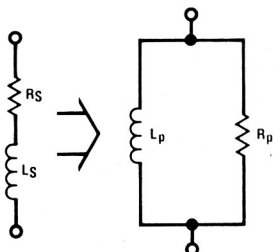


FIGURE A5.2 Phono Cartridge and Preamp Input Network

This seemingly simple circuit is quite formidable to analyze and needs further simplification. Through the use of Q equations,<sup>2</sup> a series L-R is transformed to a parallel L-R.



$$\begin{aligned}
 Q &= \frac{\omega L_S}{R_S} \\
 R_p &= R_S (1 + Q^2) \\
 L_p &= L_S \left( \frac{1 + Q^2}{Q^2} \right)
 \end{aligned}
 \tag{A5.3.1}$$

Simplifying the input network,

The impedance relations for this network are:

$$\begin{aligned}
 \text{Re}(Z) &= \frac{R X_L^2 X_C^2}{(R X_L - R X_C)^2 + X_L^2 X_C^2} \\
 |Z| &= \frac{R X_L X_C}{[(R X_L - R X_C)^2 + X_L^2 X_C^2]^{1/2}}
 \end{aligned}
 \tag{A5.3.2}$$

### A5.4 Example

Calculations of the RIAA equalized phono input noise are done using Equations (A5.2.1)-(A5.3.2). Center frequencies and frequency bands must be chosen: values of  $R_p$ ,  $L_p$ ,  $\text{Re}(Z)$ ,  $|Z|$  and noise calculated for each band, then summed for the total noise. Octave bandwidths starting at 25 Hz will be adequate for approximating the noise.

An ADC27 phono cartridge is used in this example, loaded with  $C = 250 \text{ pF}$  and  $R_A = 47 \text{ k}\Omega$ , as specified by the manufacturer, with cartridge constants of  $R_s = 1.13 \text{ k}\Omega$  and  $L_s = 0.75 \text{ H}$ . ( $C_c$  may be neglected.) Table A5.1 shows a summary of the calculations required for this example.

### A5.5 Conclusions

The RIAA equalized noise of the ADC27 phono cartridge and preamp input network was  $0.75 \mu\text{V}$  for the audio band. This is the limit for S/N ratios if the preamp was noiseless, but zero noise amplifiers do not exist. If the preamp noise voltage was  $0.64 \mu\text{V}$  then the actual noise of the system is  $0.99 \mu\text{V}$  ( $[0.64^2 + 0.75^2]^{1/2} \mu\text{V}$ ) or  $-66 \text{ dB S/N ratio}$  (re  $2 \text{ mV}$  @  $1 \text{ kHz}$  input). This is a 4 dB loss and the preamp current noise will degrade this even more.

TABLE A5.1 Summary of Calculations

f Range (Hz)	25 - 50	50 - 100	100 - 200	200 - 400	400 - 800	800 - 1.6k	1.6k - 3.2k	3.2k - 6.4k	6.4k - 12.8k	12.8k - 20k
f Center (Hz)	37.5	75	150	300	600	1200	2400	4800	9600	16.4k
fBW (Hz)	25	50	100	200	400	800	1600	3200	6400	7.2k
$Q = \frac{\omega L_s}{R_s}$	0.156	0.313	0.625	1.25	2.5	5	10	20	40	68.4
Q <sup>2</sup>	0.0244	0.098	0.391	1.56	6.25	25	100	400	1600	4678.6
1 + Q <sup>2</sup>	1.0244	1.098	1.391	2.56	7.25	26	101	401	1601	4679.6
$\frac{1 + Q^2}{Q^2}$	42	11.24	3.56	1.64	1.16	1.04	1.01	1.0	1.0	1.0
R <sub>p</sub> (Ω)	1.16k	1.24k	1.57k	2.9k	8.2k	29.4k	114k	454k	1.8M	5.29M
L <sub>p</sub> (H)	31.5	8.43	2.67	1.23	0.87	0.78	0.76	0.75	0.75	0.75
R <sub>p</sub>   R <sub>A</sub> (Ω)	1.13k	1.21k	1.52k	2.74k	7k	18.1k	32.9k	42.6k	45.8k	46.6k
X <sub>L</sub> (Ω)	7.42k	3.97k	2.52k	2.32k	3.28k	5.88k	11.45k	22.6k	45.2k	77.2k
X <sub>C</sub> (Ω)	17M	8.48M	4.24M	2.12M	1.06M	0.53M	0.265M	0.133M	66.3k	38.8k
R <sub>e</sub> (Z) (Ω)	1.11k	1.11k	1.11k	1.15k	1.26k	1.73k	3.86k	12.4k	41.5k	34k
I <sub>Z</sub> (Ω)	1.12k	1.15k	1.3k	1.77k	2.97k	5.59k	11.7k	24.4k	43.6k	40.1k
e <sub>nZ</sub> (nV/√Hz)	4.1	4.1	4.1	4.1	4.3	5.1	7.3	14	26	23
V <sub>N</sub> (nV)	20.5	29	41	58	86	144.2	292	792	2080	1952
V <sub>n</sub> <sup>2</sup> (nV <sup>2</sup> )	420.3	840.5	1681	3362	7396	20.8k	85.3k	627.7k	4.33M	3.81M
A <sup>2</sup>	63.04	31.6	10	3.17	1.59	0.89	0.45	0.159	0.05	0.025
A <sup>2</sup> V <sub>n</sub> <sup>2</sup> (nV <sup>2</sup> )	26.5k	26.6k	16.8k	10.7k	11.8k	18.5k	38.1k	99.7k	216.3k	95.2k

(ΣV<sub>n</sub><sup>2</sup>)<sup>1/2</sup> = 2.98μV unequalized noise.  
(Σ|A<sub>n</sub><sup>2</sup>|<sup>2</sup> V<sub>n</sub><sup>2</sup>)<sup>1/2</sup> = 0.75μV RIAA equalized noise.

Thus it is apparent that present phono preamp S/N ratio measurement methods are inadequate for defining actual system performance, and that a new method should be used — one that more accurately reflects true performance.

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3. Korn, G. A. and Korn, T. M., *Basic Tables in Electrical Engineering*, McGraw-Hill, New York, 1965.

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A6.0 GENERAL PURPOSE OP AMPS USEFUL FOR AUDIO

National Semiconductor's line of integrated circuits designed specifically for audio applications consists of 4 dual preamplifiers, 3 dual power amplifiers, and 6 mono power amplifiers. All devices are discussed in detail through most of this handbook; there are, however, other devices also useful for general purpose audio design, a few of which appear in Table A6.1. Functionally, most of these parts find their usefulness between the preamplifier and power amplifier, where line level signal processing may be required. The actual selection of any one part will be dictated by its actual function.

TABLE A6.1 General Purpose Op Amps Useful for Audio

Device <sup>1</sup>	Single	Dual	Quad	Compensated	Decompensated	Uncompensated	Slew Rate <sup>3</sup> (V/ $\mu$ s)	Supply Voltage Typical	Supply Current (Min. $\rightarrow$ Max.)	General Features of Audio Application Interest
LM301A	X				X	5 <sup>4</sup>	$\pm 3 \rightarrow \pm 18$	3		Low THD.
LM310	X		X			30	$\pm 5 \rightarrow \pm 18$	5.5		Fast unity-gain buffer.
LM318	X		X			50	$\pm 5 \rightarrow \pm 18$	10		High slew rate.
LM324		X	X			0.3	$3 \rightarrow 30$ ( $\pm 1.5 \rightarrow \pm 15$ )	2		Low supply current quad.
LM343	X		X			2.5	$\pm 4 \rightarrow \pm 34$	5		High supply voltage.
LM344	X				X	30	$\pm 4 \rightarrow \pm 34$	5		Fast LM343.
LM348		X	X			0.5	$\pm 5 \rightarrow \pm 18$	4.5		Quad LM741.
LM349		X		X		2	$\pm 5 \rightarrow \pm 18$	4.5		Fast LM348.
LF355	X		X			5	$\pm 5 \rightarrow \pm 18$	4		Low supply current LF356.
LF356 <sup>5</sup>	X		X			12	$\pm 5 \rightarrow \pm 18$	10		Fast, JFET input, low noise.
LF357	X			X		50	$\pm 5 \rightarrow \pm 18$	10		Higher slew rate LF356.
LM358		X	X			0.3	$3 \rightarrow 30$ ( $\pm 1.5 \rightarrow \pm 15$ )	1.2		Dual LM324.
LM394	—	—	—	—	—	—	—	—		Supermatch low noise transistor pair.
LM741	X		X			0.5	$\pm 3 \rightarrow \pm 18$	2.8		Workhorse of the industry.
LM747		X	X			0.5	$\pm 3 \rightarrow \pm 18$	5.6		Dual LM741 (14 pin).
LM1458		X	X			0.2	$\pm 3 \rightarrow \pm 18$	5.6		Dual LM741 (8 pin).
LM3900			X	X		0.5	$4 \rightarrow 30$ ( $\pm 2 \rightarrow \pm 15$ )	10		Quad current differencing amp.
LM4250	X		X			0.03	$\pm 1 \rightarrow \pm 18$	0.1		Micropower.

1. Commercial devices shown (0°C-70°C); extended temperature ranges available.

2. Decompensated devices stable above a minimum gain of 5V/V.

3.  $A_v = 1\text{ V/V}$  unless otherwise specified.

4. Compensation capacitor = 3pF;  $A_v = 10\text{ V/V}$  minimum.

5. Highly recommended as general purpose audio building block.