

## Noise Calculations in Op Amp Circuits

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Noise calculations in op amp circuits are one of the most confused calculations that an analog engineer must perform.

One cannot just look at noise specifications; the total op amp circuit including resistors and operating frequency range must be included in calculations for circuit noise. A "low" noise amplifier in one circuit will become a "high" noise amplifier in another circuit.

As a part of this Design Note, an IBM-PC or compatible computer program, NOISE, has been written to perform the noise calculations. This program allows the user to calculate circuit noise using LTC op amps, determine the best LTC op amp for a low noise application, display the noise data for LTC op amps, calculate resistor noise, and calculate circuit noise using noise specs for any op amp. At the end of this Design Note there are detailed operating instructions for the computer program NOISE.

To calculate noise for an op amp circuit, one must consider the op amp voltage and current noise density and 1/f corner frequency, the frequency range of interest, and the resistor noise.

The most comprehensive specification for voltage or current noise is the noise density frequency response curve as shown in Figure 1.

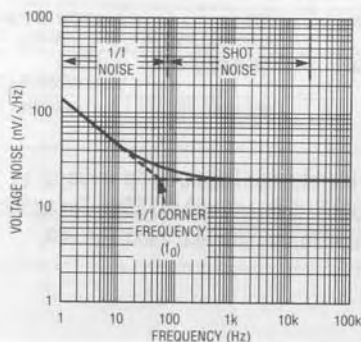


Figure 1.

There are two distinct regions to consider:

1. The high frequency part of the curve shows the shot noise and is independent of frequency.
2. The low frequency part of the curve is the 1/f noise as shown by a rapidly increasing noise density. In low frequency applications, the 1/f noise limits the minimum level of noise. The point on the curve where the asymptotes of the shot noise and 1/f noise intersect is the 1/f corner frequency.

To calculate the total RMS noise of an op amp over a bandwidth:

$$N = NO \times \sqrt{FC \times LN (FH/FL) + (FH - FL)} \quad (\text{Equation 1})$$

Where N is the RMS current or voltage noise measured from a lower frequency FL to an upper frequency FH and NO is the current or voltage shot noise density with a 1/f corner frequency FC.

Consider an audio preamplifier using an LT1037 as a simple inverting circuit (Figure 2) and the corresponding noise model (Figure 3).

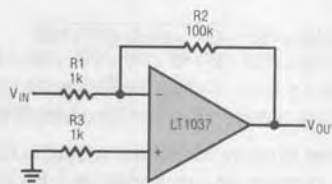


Figure 2.

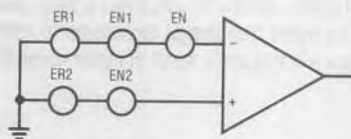


Figure 3. Noise Model

EN is the voltage noise of the op amp, EN1 is the voltage noise developed by the current noise in resistors R1 and R2, EN2 is the voltage noise developed by the current noise in resistor R3, ER1 is the voltage noise of R1 and R2, and ER2 is the voltage noise of R3.

Since we are using an LT1037 over the audio frequency range,  $NO = 2.5nV/\sqrt{Hz}$ ,  $FC = 2.0Hz$ ,  $FH = 20kHz$ ,  $FL = 20Hz$ . Plugging into Equation 1:

$$EN = 2.5 \times \sqrt{2 \times LN(20kHz/20Hz) + (20kHz - 20Hz)}$$

$$EN = 354nV, RMS$$

To calculate EN1, first the current noise must be calculated using Equation 1 and a current noise density of  $0.57pA/\sqrt{Hz}$  and  $1/f$  corner frequency of  $120Hz$ .

$$IN = 0.57 \times \sqrt{120 \times LN(20kHz/20Hz) + (20kHz - 20Hz)}$$

$$IN = 82pA, RMS$$

IN will flow into the parallel combination of R1 and R2.

$$EN1 = 82pA \times 1k \parallel 100k = 82nV, RMS$$

Similarly, EN2 results from IN flowing in R3.

$$EN2 = 82pA \times 1k = 82nV, RMS$$

The voltage noise of the resistors must be calculated next. In general, resistor noise is given by:

$$ER = \sqrt{4 \times K \times T \times R \times (FH - FL)}$$

Where K is Boltzman's Constant,  $1.39 \times 10^{-23}$ , T is temperature (K), R is the resistor value, FH is the upper frequency, and FL is the lower frequency of interest.

At  $25^\circ C$ , this equation reduces to:

$$ER = \sqrt{R \times (FH - FL)} \times 1.28 \times 10^{-10}$$

To calculate ER1 we must consider R1 in parallel with R2,

$$ER1 = \sqrt{1k \parallel 100k} \times (20kHz - 20Hz) \times 1.28 \times 10^{-10}$$

$$ER1 = 570nV, RMS$$

Similarly, to calculate ER2,

$$ER2 = \sqrt{1k} \times (20kHz - 20Hz) \times 1.28 \times 10^{-10}$$

$$ER2 = 570nV, RMS$$

To calculate the total noise of the audio preamplifier using an LT1037, the RMS sum of the individual terms must be calculated.

$$TOTAL\ NOISE = \sqrt{EN^2 + EN1^2 + EN2^2 + ER1^2 + ER2^2}$$

$$TOTAL\ NOISE = \sqrt{353^2 + 80^2 + 80^2 + 570^2 + 570^2} = 880nV, RMS$$

To calculate p-p noise, multiply the RMS noise times 6; the total peak-to-peak noise is  $5.3\mu V$  for this preamplifier.

It is important to realize this noise is referred to the input of the circuit; to obtain the output noise level, the input noise must be multiplied by the noise gain which can be different from the circuit gain:

$$OUTPUT\ NOISE = TOTAL\ NOISE \times NOISE\ GAIN$$

$$OUTPUT\ NOISE = 880nV \times 101 = 89\mu V, RMS \text{ or } 534\mu V, \text{ peak-to-peak}$$

It should be noted that design techniques to optimize DC performance will frequently result in higher noise. For exam-

ple, to minimize DC errors, a balance resistor is often placed in the + Input of an op amp to compensate for an error voltage created by bias current flowing in gain setting resistors connected to the - Input. This resistor will increase the output noise since op amp noise current must flow through the resistor, and thus create a voltage noise generator. For minimum noise levels, the resistor in the + Input should be  $0\Omega$ . As a side note, for precision op amps (LT1001, LT1007, OP07) that employ bias current cancellation techniques, this resistor should be  $0\Omega$  to minimize DC errors since the bias current equals the offset current.

### Instructions for Operating NOISE

NOISE is a general purpose computer program to calculate noise in op amp circuits. It will run on any IBM-PC compatible computer with a direct call from DOS.

Noise specifications and data for Linear Technology op amps (LT10XX) are contained in the program's data file. All noise specifications are based on typical specifications at  $25^\circ C$ .

To operate NOISE:

1. Boot the system with DOS and wait for DOS prompt "A >".
2. Insert the NOISE.EXE program disk into the A disk drive.
3. Type "NOISE" and <return>.

Operation in NOISE is menu driven throughout the program with default values on all parameters initially.

### Best Op Amp for Lowest Noise vs Source Resistance

SOURCE R ( $R_{eq}$ )	BEST OP AMP	
	@ LOW FREQ. (10Hz)	@ WIDEBAND (1kHz)
$0\Omega$ to $400\Omega$	LT1028	LT1028
$400\Omega$ to $1k$	LT1007/37	LT1028
$1k$ to $4k$	LT1007/37	LT1028, LT1007/37
$4k$ to $15k$	LT1001	LT1007/37
$15k$ to $30k$	LT1001	LT1001, LT1007/37
$30k$ to $70k$	LT1001, LT1012	LT1001
$70k$ to $150k$	LT1012	LT1001, LT1012 LT1055/56/22, LT1057/58
$150k$ to $600k$	LT1012, LT1006/13/14	LT1012, LT1006/13/14 LT1055/56/22, LT1057/58
$600k$ to $2M$	LT1012 LT1055/56/22, LT1057/58	LT1012, LT1006/13/14 LT1055/56/22, LT1057/58
$2M$ to $10M$	LT1055/56/22, LT1057/58	LT1012 LT1055/56/22, LT1057/58
$> 10M$	LT1055/56/22, LT1057/58	LT1055/56/22, LT1057/58

For literature on low noise op amps, or a 5 1/4" "NOISE" disk, call 800-637-5545. For applications help, call (408) 432-1900, Ext. 361.