

Op Amp Total Output Noise Calculations for Single-Pole System

We have already pointed out that any noise source which produces less than one third to one fifth of the noise of some greater source can be ignored, with little error. When so doing, both noise voltages must be measured at the same point in the circuit. To analyze the noise performance of an op amp circuit, we must assess the noise contributions of each part of the circuit, and determine which are significant. To simplify the following calculations, we shall work with noise spectral densities, rather than actual voltages, to leave bandwidth out of the expressions (the noise spectral density, which is generally expressed in nV/ $\sqrt{\text{Hz}}$, is equivalent to the noise in a 1 Hz bandwidth).

If we consider the circuit in Figure 1 below, which is an amplifier consisting of an op amp and three resistors (R3 represents the source resistance at node A), we can find six separate noise sources: the Johnson noise of the three resistors, the op amp voltage noise, and the current noise in each input of the op amp. Each source has its own contribution to the noise at the amplifier output. Noise is generally specified RTI, or *referred to the input*, but it is often simpler to calculate the noise referred to the output (RTO) and then divide it by the *noise gain* (not the *signal gain*) of the amplifier to obtain the RTI noise.

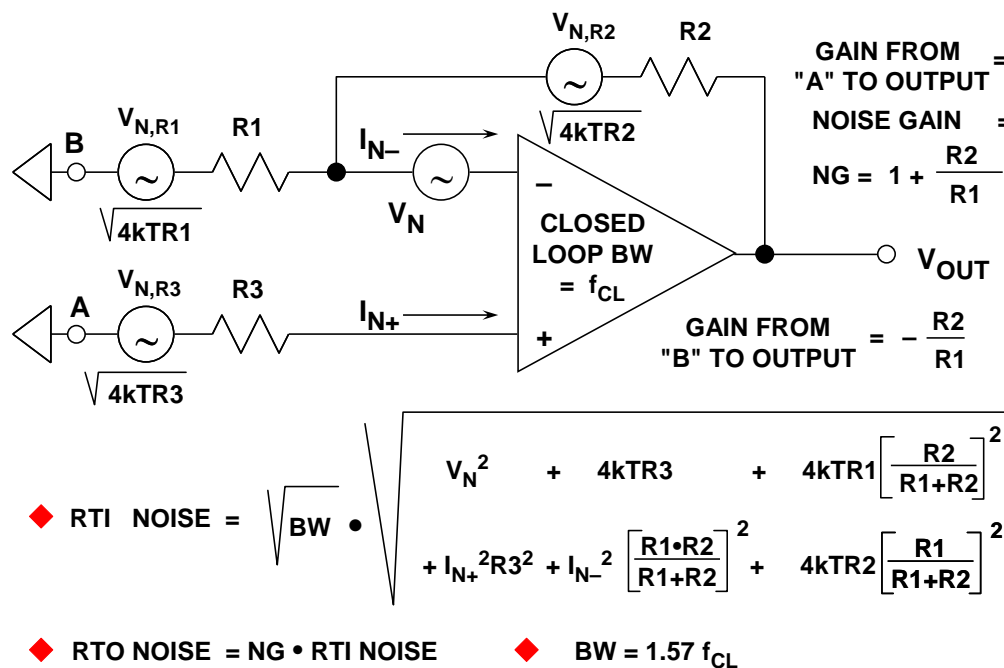


Figure 1: Op Amp Noise Model for Single Pole System

Figure 2 (below) is a detailed analysis of how each of the noise sources in Fig. 1 is reflected to the output of the op amp. Some further discussion regarding the effect of the current noise at the inverting input is warranted. This current, I_{N-} , does not flow in R1, as might be expected—the negative feedback around the amplifier works to keep the potential at the inverting input unchanged, so that a current flowing from that pin is forced, by negative feedback, to flow in R2 only, resulting in a voltage at the output of $I_{N-} R2$. We could equally well consider the voltage caused by I_{N-} flowing in the parallel combination of R1 and R2 and then amplified by the noise gain of the amplifier, but the results are identical—only the calculations are more involved.

NOISE SOURCE EXPRESSED AS A VOLTAGE	MULTIPLY BY THIS FACTOR TO REFER TO THE OP AMP OUTPUT
Johnson noise in R3: $\sqrt{4kTR3}$	Noise Gain = $1 + R2/R1$
Non-inverting input current noise flowing in R3: $I_{N+}R3$	Noise Gain = $1 + R2/R1$
Input voltage noise: V_N	Noise Gain = $1 + R2/R1$
Johnson noise in R1: $\sqrt{4kTR1}$	$-R2/R1$ (Gain from input of R1 to output)
Johnson noise in R2: $\sqrt{4kTR2}$	1
Inverting input current noise flowing in R2: $I_{N-}R2$	1

Figure 2: Noise Sources Referred to the Output (RTO)

Notice that the Johnson noise voltage associated with the three resistors has been included in the expressions of Fig. 2. All resistors have a Johnson noise of $\sqrt{4kTBR}$, where k is Boltzmann's Constant (1.38×10^{-23} J/K), T is the absolute temperature, B is the bandwidth in Hz, and R is the resistance in Ω . A simple relationship which is easy to remember is that a 1000 Ω resistor generates a Johnson noise of 4 nV/ $\sqrt{\text{Hz}}$ at 25°C.

The analysis so far assumes a single-pole system where the feedback network is purely resistive and that the noise gain versus frequency is flat. This applies to most applications, but if the feedback network contains reactive elements (usually capacitors) the noise gain is not constant over the bandwidth of interest, and more complex techniques must be used to calculate the total noise. Second-order system noise considerations can be found in [Tutorial MT-050](#).

REFERENCES

1. Hank Zumbahlen, *Basic Linear Design*, Analog Devices, 2006, ISBN: 0-915550-28-1. Also available as [*Linear Circuit Design Handbook*](#), Elsevier-Newnes, 2008, ISBN-10: 0750687037, ISBN-13: 978-0750687034. Chapter 1.
2. Walter G. Jung, [*Op Amp Applications*](#), Analog Devices, 2002, ISBN 0-916550-26-5, Also available as [*Op Amp Applications Handbook*](#), Elsevier/Newnes, 2005, ISBN 0-7506-7844-5. Chapter 1.

Copyright 2009, Analog Devices, Inc. All rights reserved. Analog Devices assumes no responsibility for customer product design or the use or application of customers' products or for any infringements of patents or rights of others which may result from Analog Devices assistance. All trademarks and logos are property of their respective holders. Information furnished by Analog Devices applications and development tools engineers is believed to be accurate and reliable, however no responsibility is assumed by Analog Devices regarding technical accuracy and topicality of the content provided in Analog Devices Tutorials.