Opening Up The Art of Low Noise

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Engineers need to consider op-amp noise in designs for an increasing variety of applications.

Today's world is challenging engineers to do more with less; to create new products that will help users improve aspects such as productivity or quality of life while consuming fewer resources such as fuel, finance or time. Pursuing these goals is driving a number of changes in design approaches, including the use of low-noise components and techniques in an increasing variety of equipment to improve performance. These include audio, imaging products, as well as sensing and monitoring subsystems used to create progressively more intelligent and economical machinery.

Traditionally, devices such as low-noise amplifiers have been aimed at designers of RF and microwave systems. Today, however, more and more engineers need to understand how to select components on the basis of their noise performance within the system. At the same time, new generations of components are emerging to provide a better trade off between noise and other important performance parameters. This trend can be seen among the latest generations of op-amps, as engineers are increasingly looking for low voltage or current noise without sacrificing performance in areas such as speed, offset and bias characteristics, bandwidth, or power consumption.

Noise in Op-Amp Circuits

$$V_n = \sqrt{4kTBR}$$

$$I_n = \sqrt{\frac{4kTB}{R}}$$

All resistive devices produce thermal noise that increases with resistance, temperature above absolute zero, and bandwidth. This may be expressed either as a voltage noise or as a current noise, as shown in equation 1a and 1b. Other, smaller noise generators such as contact noise and parasitic effects may also be present.

The op-amp itself includes both voltage-noise and current-noise sources. The device can be modeled as a noise-voltage source in series with one input terminal of an ideal noiseless op-amp, and two noise-current sources between each input terminal and common. These noise generators can usually be considered to be independent of each other. When current noise and voltage noise are described in the datasheet for an op-amp, the figures quoted are usually referenced to the input of the device, to eliminate any dependence on gain. The voltage noise and current noise also tend

to vary over the op-amp's bandwidth. Datasheet tables may quote figures at fixed frequencies, such as 1kHz and 10kHz. Depending on the application, the op-amp's performance should be analyzed in the intended operating frequency range; by inspecting the performance graphs in the datasheet, studying models of the device online, using simulation tools, or by experimentation.

The resulting noise at the op-amp's output is a function of these internal voltage and current noise sources, but is also influenced by the external circuitry connected to the device. In the amplifier schematic of figure 1, which includes the op-amp noise sources, the values of R1 and R2 are calculated with reference to the impedance of the signal source. This may be a sensor or a transducer such as a precision accelerometer, or a microphone in the case of an audio pre-amplifier.

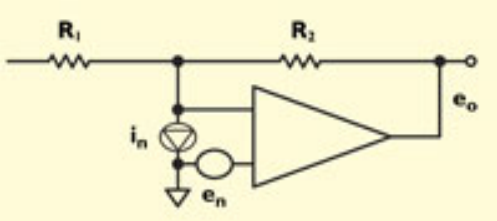
The instantaneous combined noise at the amplifier output can be calculated as follows:

eo = (1+ R2/R1) * en + (R2 * in) Where: eo = combined instantaneous output noise en = voltage noise in = current noise

From this equation, the relative contribution of each type of noise can be assessed as: en/in = R2 / (1+ R2/R1)

This shows that the op-amp voltage noise is the largest internal noise generator when the source has low impedance. Conversely, current noise is the dominant internal generator when the source impedance is high. The ratio of en to in (using RMS values) is referred to as the Characteristic Noise Resistance (CNR), which can be a valuable figure of merit to assess an amplifier's performance in relation to the impedance of any intended source.

Device Selection

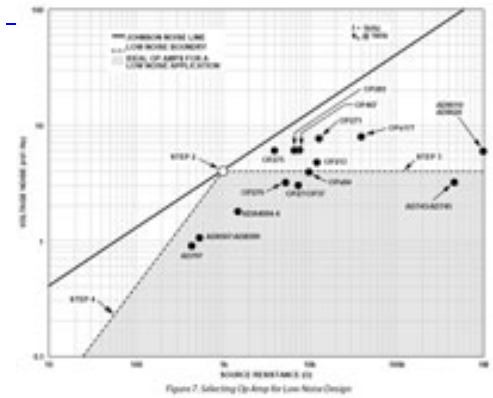


A short-list of op-amps providing adequate low-noise performance for a given application can be identified by plotting op-amp data against the thermal noise of the source resistance in the frequency range of interest (ignoring other noise generators such as contact noise and parasitic effects). This is illustrated in the diagram of figure 2, taken from Analog Devices Application Note 940 (Low Noise Amplifier Selection Guide for Optimal Noise Performance).

The Johnson noise line shown in the diagram describes resistive thermal noise. Assuming a source resistance of 1kΩ in this example, the 1kΩ point is located on the line. A horizontal line drawn to the right, from this point, defines the upper limit of acceptable op-amp voltage noise. Subsequently a line of decreasing voltage

noise is traced, reducing at one decade of voltage noise for each decade of resistance. Working from op-amp datasheets, the voltage noise at the frequency of interest is plotted against the CNR figure of merit for each op-amp. Those devices within the shaded area bounded by the two lines drawn from the source resistance thermal noise can be considered as low-noise op-amps in relation to the source resistance.

The Best of All Worlds



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Historically, bipolar op-amps have tended to offer the lowest values of voltage noise, because in bipolar technology the voltage noise is inversely proportional to the square root of the input-stage collector current. This allows the op-amp designer to control the voltage noise by increasing the collector current. Typical voltage noise for a low-noise bipolar op-amp may be in the region of 1-2nv/√Hz. However, current noise is directly proportional to the square root of the collector current and, as a result, is relatively high when voltage noise is low. Hence, the external feedback and source resistance must be kept low to ensure good noise performance. The most suitable applications for bipolar amplifiers, therefore, are those which have low input impedance.

Bipolar op-amp architectures are evolving toward trench-isolation technology, which enables greater transistor density per die compared to the traditional diffusion-layer structure. This delivers better speed, matching, linearity and stability, as well as improving voltage and current noise. Benefits include lower power consumption, allowing operation over an extended temperature range without requiring heatsinks, as well as smaller package sizes allowing higher density in multi-channel designs.

Bipolar op-amps featuring JFET input circuitry are known for their extremely low current noise, which makes them ideally suited to applications where the source impedance is very high. However, voltage-noise density tends to be around an order of magnitude higher than for a bipolar device. Advances in JFET fabrication technology include polygate transistor construction for optimal performance per transistor area, and have enabled voltage noise to be reduced while retaining ultra-low current-noise performance. The latest generations of devices achieve low total noise over a wide range of transducer impedance. These present a particularly

strong solution when amplifying low-level signals from high-impedance sources such as precision accelerometers or photodiodes.

A JFET-input op-amp such as the Texas Instruments TL081 (Newark 76C9114) has an equivalent input noise current of 0.01pA/√Hz, which is much lower than an ordinary bipolar device. Voltage noise, however, is higher at 18nV/Hz. The National LF353 (Newark 41K2542) is another example of a JFET-input op-amp achieving low input noise current of 0.01pA/√Hz, and input voltage noise of 25nV/√Hz. Both devices combine their low noise characteristics with high slew rate, low input bias current and offset voltage, wide bandwidth and low offset-voltage temperature drift. JFET amplifiers are also able to operate from a single-supply, which can ease power supply design.

Devices built in CMOS technology from National Semiconductor, Analog Devices, Linear Technologies and Texas Instruments tend to deliver good all-round noise performance. Voltage noise compares well with that of bipolar devices, and current noise can be comparable to the performance of JFET-input devices.

Op-amps, such as the Analog Devices AD8597/AD8599, demonstrate voltage noise as low as 1.15nV/√Hz, at the same time as achieving current noise as low as 2.0pA/√Hz. This low noise combines with other benefits such as low harmonic distortion of -120dB in the audio frequency range, allowing these devices to be used in pre-amplifiers for professional audio equipment. Other advantages include a high slew rate of 14V/µs and a wide gain bandwidth of 10MHz. These properties are often valuable in medical signal-processing applications. In addition, low distortion and fast settling time also make these devices suitable for instrumentation purposes such as buffering of high-resolution data converters.

These new generations of op-amps combining low noise with good performance across the board illustrate how low-noise device technology is responding to the needs of a more general audience. Improvements are being achieved throughout all low-noise technologies.

Conclusion

Engineers working in diverse application spaces, well beyond established low-noise fields such as microwave communication, are now demanding low-noise performance when using op-amps in new designs.

With this spreading of focus, a more nuanced understanding of the term "low-noise op-amp" is required. Techniques for assessing op-amp noise data in the context of the surrounding circuitry can help engineers to identify suitable devices capable of meeting diverse performance requirements, at the best price.

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