ANALOG MODULES, INC.

Specialists in Analog and Laser Electronics

AMPLIFIER MODULES
300-2 APPLICATION/OPERATING NOTES

HOW TO MEASURE NOISE

VERIFICATION

One question that is frequently asked is how to verify the noise performance of voltage and current amplifiers. This note suggests some methods.

For both current and voltage input amplifiers, the convention is to refer the noise to the input and specify it for a bandwidth of one cycle. This method gives a figure of merit which can be used to compare performance without the variables of gain or bandwidth which affect the output noise. The output noise is the input noise times the gain (V/V or dB for a voltage amplifier, V/A or ohms transimpedance for a current-to-voltage amplifier). Noise increases as the square root of bandwidth, so the input SPECTRAL NOISE DENSITY is specified in amps per root hertz, or volts per root hertz.

To convert from the input spectral noise density to the output noise, multiply by the mid-band gain, and also by the square root of the NOISE BANDWIDTH.

True noise has a random amplitude and frequency distribution. To measure noise, the heating effect or rms value is used. When viewed on an oscilloscope, the "bright band peak-to-peak" noise is about five times the rms value. A true rms voltmeter may be used to measure noise. An important consideration is the bandwidth of the meter. Unless it's greater than the overall amplifier bandwidth, the NOISE BANDWIDTH of the meter must be determined. For a single pole HF roll off (6dB/octave), the NOISE BANDWIDTH is 1.57 times the 3dB down bandwidth. A two pole roll off gives a NOISE BANDWIDTH of 1.22 times the 3dB down bandwidth. This figure is used as the measurement root hertz whenever the amplifier bandwidth is greater than the meter bandwidth. If the meter bandwidth is greater than the amplifier bandwidth, then the noise bandwidth of the amplifier is taken to determine the root hertz. Another method of measuring noise is to use a waveform analyzer or spectrum analyzer which has the capability to measure rms voltage in a known bandwidth. The output spectral noise density is obtained by dividing the measured output noise by the root of the measurement bandwidth. The AMI specified noise value is averaged in a measurement range from 8Hz to about 40MHz. An increase in spectral noise density at low frequencies is normal, due to l/f or flicker noise. Ensure that true rms noise is being measured, not peak or average.

CURRENT AMPLIFIER

With a current input amplifier, the noise is measured with no current in, i.e., the input is open-circuit, and is usually specified in pA/root hertz. When wires and devices are attached to the input, generally the noise will increase, but the open-circuit test measures the current noise of the amplifier which is specified.

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CURRENT AMPLIFIER – cont'd

Current input amplifiers do have a voltage noise also. With perfect current source inputs, this voltage noise has no effect, but with a shunt resistor or capacitor across the input, the voltage noise will cause a current to flow which will increase the overall noise. The noise increase due to the input capacitor rises with frequency at 6dB/octave. In this circumstance, it is desirable not to specify any more bandwidth than is necessary to pass the signal of interest. Uncorrected noise sources are added by converting them all to currents or voltages, squaring them, adding the squares, and taking the square root to obtain the sum noise. The theoretical thermal current noise at 25° from a feedback resistor R_f is:

$$i_n \,/\, root\; hertz = \sqrt{\frac{1.61\; x\; 10^{-20}}{R_f}}$$

The value of R_f may not be the amplifier gain, since AMI's amplifiers usually comprise several stages. Practical noise is 20-30% worse than theoretical due to component limitations. Other noise sources will add to the thermal noise. The tradeoff is that high bandwidths require lower values of feedback resistor for speed, resulting in more thermal noise. Increased input capacitance requires a lower impedance virtual ground and lower feedback resistor to drive the input, thus increasing the noise (in addition to the voltage noise related effect discussed earlier).

VOLTAGE AMPLIFIERS

To measure the noise of a voltage amplifier, the input is short-circuited. The output noise is measured as described above and is referred to the input. This value is the input short-circuit SPECTRAL NOISE DENSITY and usually is specified in nV/√Hz. The resistor will generate thermal noise at 25°C in accordance with the formula:

$$Vn/root\; hertz = \sqrt{1.61\; x\; 10^{-20}\; xR}$$

Where R is the input resistance. For example, if R = 50 ohms, noise is 0.9nV/√Hz.

When the amplifier is driven from a source impedance, then this may reduce the effective input impedance to lower the noise if the source is resistive. Noise factor (NF) is an alternative way of specifying the noise performance of an amplifier. AMI does not normally specify it since it depends on operating at a particular impedance level, for example, 50 ohms, or 600 ohms. This can be misleading since the NF for a 600Ω system will appear to be much lower (better) than the NF for a 50Ω system. The NF is defined as:

$$NF = 10 \log\left(\frac{noise\; of\; input\; resistor\; and\; amplifier\; noise}{noise\; of\; input\; resistor}\right)$$

One advantage the NF computation has is that it takes into account both voltage and current noise at the impedance level being used. To deal with this, take the voltage noise (as specified in the short circuit test) and add to it the (input current noise x the source impedance). Generally, AMI amplifiers such as the Model 322 series with low input impedances specified are designed for use with low impedance sources where the current noise contribution is negligible. Amplifiers with high input impedances, i.e., Model 324, have both low voltage noise and low current noise. There is always a trade-off between current noise and voltage noise, and the amplifier design can be optimized when the source impedance is known. With higher input impedances, any capacitance will result in a pole, which will roll off both noise and signal at 6dB/octave. As a rule of thumb, when the input impedance is below 1K, voltage noise is dominant. Above 1K, low current noise is important.