INTRINSIC (RANDOM) NOISE SOURCES

Random noise finds its way into experiments in a variety of ways. Good experimental design can reduce these noise sources and improve the measurement stability and accuracy.

There are a variety of intrinsic noise sources which are present in all electronic signals. These sources are physical in origin.

Johnson noise

Every resistor generates a noise voltage across its terminals due to thermal fluctuations in the electron density within the resistor itself. These fluctuations give rise to an open-circuit noise voltage,

$$V_{noise}\,(rms) = (4k\,TR\Delta f)^{1/2}$$

where k=Boltzmann's constant (1.38×10^{-23} J/°K), T is the temperature in °Kelvin (typically 300°K), R is the resistance in Ohms, and Δf is the bandwidth in Hz. Δf is the bandwidth of the measurement.

Since the input signal amplifier in the SR830 has a bandwidth of approximately 300 kHz, the effective noise at the amplifier input is $V_{noise} = 70\sqrt{R}$ nVrms or $350\sqrt{R}$ nV pk-pk. This noise is broadband and if the source impedance of the signal is large, can determine the amount of dynamic reserve required.

The amount of noise measured by the lock-in is determined by the measurement bandwidth. Remember, the lock-in does not narrow its detection bandwidth until after the phase sensitive detectors. In a lock-in, the equivalent noise bandwidth (ENBW) of the low pass filter (time constant) sets the detection bandwidth. In this case, the measured noise of a resistor at the lock-in input, typically the source impedance of the signal, is simply

$$V_{noise}\,(rms) = 0.13\sqrt{R}\sqrt{ENBW}\ \text{nV}$$

The ENBW is determined by the time constant and slope as shown in the following table. Wait time is the time required to reach 99% of its final value.

T= Time Constant

Slope	ENBW	Wait Time
6 dB/oct	1/(4T)	5T
12 dB/oct	1/(8T)	7T
18 dB/oct	3/(32T)	9T
24 dB/oct	5/(64T)	10T

The signal amplifier bandwidth determines the amount of broadband noise that will be amplified. This affects the dynamic reserve. The time constant sets the amount of noise which will be measured at the reference frequency. See the SIGNAL INPUT AMPLIFIER discussion for more information about Johnson noise.

Shot noise

Electric current has noise due to the finite nature of the charge carriers. There is always some nonuniformity in the electron flow which generates noise in the current. This noise is called shot noise. This can appear as voltage noise when current is passed through a resistor, or as noise in a current measurement. The shot noise or current noise is given by

$$I_{noise}\,(rms) = (2q\,I\Delta f)^{1/2}$$

where q is the electron charge (1.6×10^{-19} Coulomb), I is the RMS AC current or DC current depending upon the circuit, and Δf is the bandwidth.

When the current input of a lock-in is used to measure an AC signal current, the bandwidth is typically so small that shot noise is not important.

1/f noise

Every 10 Ω resistor, no matter what it is made of, has the same Johnson noise. However, there is excess noise in addition to Johnson noise which arises from fluctuations in resistance due to the current flowing through the resistor. For carbon composition resistors, this is typically 0.1 µV-3 µV of rms noise per Volt of applied across the resistor. Metal film and wire-wound resistors have about 10 times less noise. This noise has a 1/f spectrum and makes measurements at low frequencies more difficult.

Other sources of 1/f noise include noise found in