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SENSITIVITY SPECMANSHIP IN LOCK–IN AMPLIFIERS

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Rev. 2 12/93

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Manufacturers of lock–in amplifiers (LIA) often provide very high sensitivity ranges (e.g., 10 nanovolts full scale) on their instruments and then make this a key sales feature. This is a misleading tactic, since the input–referred spectral noise (e_n) of the LIA will make this range practically useless.

Consider one such specification for a competitive instrument, which lists $e_n = 7\ nV/\sqrt{Hz}$ (typical) at 1 kHz and a maximum time constant (T) of 100 seconds with only a 6 dB/octave rolloff available. For this LIA the narrowest possible equivalent noise bandwidth (B), which will yield the least output fluctuation, will be 1/(4T) or 0.0025 Hz. The signal fluctuation will be the inverse of the output–referred signal–to–noise ratio. Therefore, per ITHACO Application Note IAN 49 *"Speed/Accuracy Tradeoff When Using A Lock–In Amplifier To Measure Signal In The Presence Of Random Noise"*, for a full scale input (e_s) of 10 nV on the 10 nV sensitivity range we have a reproducibility given by:

$$\frac{1}{SNR} = \frac{e_n \sqrt{B}}{e_s} = \frac{7\ nV}{10\ nV}\sqrt{.0025} = 0.035,\ rms$$

This figure (1/SNR) represents the rms output variation expressed as a fraction of the signal reading. It is mathematically identical to the standard deviation (σ) of the measurement. The output peak–to–peak fluctuation will be roughly six times the rms value (6σ). Therefore, for the example above, we would observe a 21% (2.1 nV) peak–to–peak variation in the measurement (.035 x 6 x100%) with a fluctuation rate on the order of several minutes. On an analog meter, we could read this sort of result just as well on the 100 nV scale (will observe 10% of full scale). For a digital readout the same accuracy can be obtained on the 1 µV sensitivity range due to the higher resolution available.

The point is this: the 10 nV range buys you ***nothing***. This is the reason ITHACO does not provide a 10 nV range on its instruments. For example, using a DYNATRAC® instrument with 5 $nV/\sqrt{Hz}$ max noise, T max = 125 seconds, 12 dB /octave rolloff (B = 1/(8T) = .001 Hz) and 100 nV sensitivity will yield a reproducibility relative to 100 nV of 0.0016, or a 6σ peak–to–peak output fluctuation of 1% of full scale (1.0 nV).

The key feature which places an ultimate limit on resolution is the self noise of the lock–in rather than its output scaling. Even this limit may not be attained in less carefully designed instruments. The noise is usually expressed in volts with the input shorted (e_n). Be cautioned that if you are working with high impedance sources, the effect of LIA input self *current* noise (not always specified) may far exceed that of the voltage noise. You can gauge current noise when comparing lock–ins by connecting a scope directly to the open–circuited signal input.