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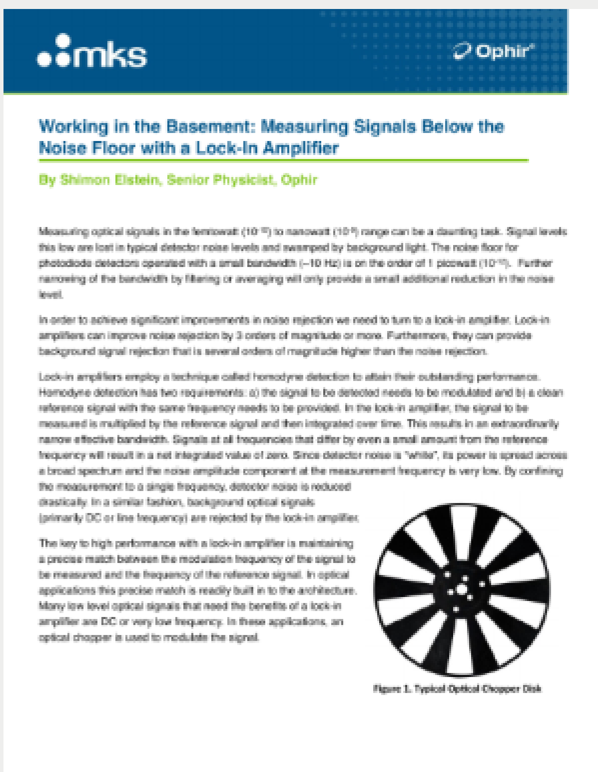
Working in the Basement: Measuring Signals Below the Noise Floor with a Lock-In Amplifier

By Shimon Elstein, Senior Physicist, Ophir

Measuring optical signals in the femtowatt (10^{-15}) to nanowatt (10^{-9}) range can be a daunting task. Signal levels this low are lost in typical detector noise levels and swamped by background light. The noise floor for photodiode detectors operated with a small bandwidth (~10 Hz) is on the order of 1 picowatt (10^{-12}). Further narrowing of the bandwidth by filtering or averaging will only provide a small additional reduction in the noise level.

In order to achieve significant improvements in noise rejection we need to turn to a lock-in amplifier. Lock-in amplifiers can improve noise rejection by 3 orders of magnitude or more. Furthermore, they can provide background signal rejection that is several orders of magnitude higher than the noise rejection.

Lock-in amplifiers employ a technique called homodyne detection to attain their outstanding performance. Homodyne detection has two requirements: a) the signal to be detected needs to be modulated and b) a clean reference signal with the same frequency needs to be provided. In the lock-in amplifier, the signal to be measured is multiplied by the reference signal and then integrated over time. This results in an extraordinarily narrow effective bandwidth. Signals at all frequencies that differ by even a small amount from the reference frequency will result in a net integrated value of zero. Since detector noise is "white", its power is spread across a broad spectrum and the noise amplitude component at the measurement frequency is very low. By confining the measurement to a single frequency, detector noise is reduced drastically. In a similar fashion, background optical signals (primarily DC or line frequency) are rejected by the lock-in amplifier.

The key to high performance with a lock-in amplifier is maintaining a precise match between the modulation frequency of the signal to be measured and the frequency of the reference signal. In optical applications this precise match is readily built in to the architecture. Many low level optical signals that need the benefits of a lock-in amplifier are DC or very low frequency. In these applications, an optical chopper is used to modulate the signal.

Figure 1. Typical Optical Chopper Disk

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