Electro Optical Components, Inc.
5464 Skylane Boulevard, Suite D, Santa Rosa, CA 95403
Toll Free: 855-EOC-6300
www.eoc-inc.com | info@eoc-inc.com

Click to go to Product Selector

Application note — Lock-In Amplifier

Basics

A lock-in amplifier is essentially a frequency-selective AC-voltmeter. It is used to measure weak signals (nV-range), which may be hidden by background noise of much higher magnitude than the signal. The measurement procedure is also called the carrier-frequency methode or phase-sensitive detection. The lock-in amplifier selects the signal with a specific frequency and phase from a mixture of mostly unwanted frequencies.

The measurement principle: A sinusoidal reference frequency (carrier frequncy) is generated and delivered to a measurement object, which modulates it. The resulting amplitude-modulated measurement-signal is amplified in the lock-in amplifier, passed through a bandpass filter and finally reaches a synchronous rectifier (or demodulator, phase sensitive demodulator (PSD), multiplier or mixer). Rectification of the signal is accomplished by multiplication by the reference frequency. The rectified voltage is equalized and reamplified.

The DC-voltage value at the lock-in´s output is proportional to the r.m.s. value of the sinusoidal input signal. Sensitivity is defined as the level of input signal required to produce full-scale (usually 10 V) output voltage.

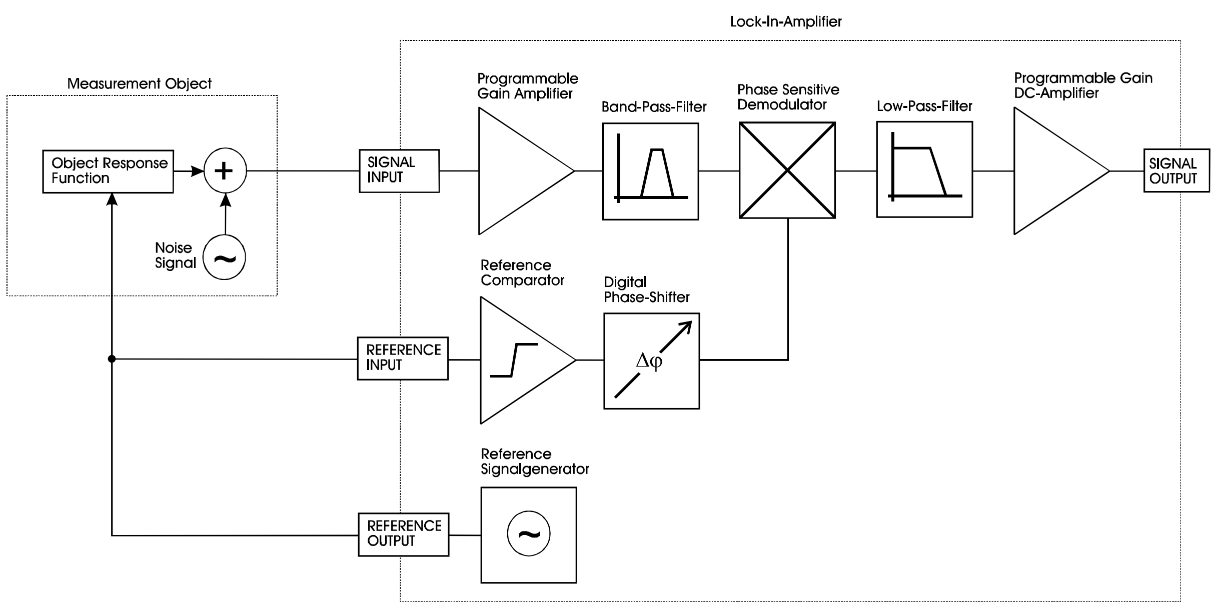
Important advantages of the lock-in technique:

- Elimination of DC-drift measurement errors
- Achievable filter quality up to 10^7 instead of max.100 as with conventional bandpass filters

Components of a Lock-In Amplifier

A lock-in amplifier consists of the following sub-units:

- **Programmable Gain AC-Amplifier**
  for matching the signal amplitude to the following sub-units
- **Signal Bandpass Filter**
  Pre-filtering of measurement signal for reducing sensitivity to spurious signals
- **Demodulator** / Phase Sensitive Demodulator
  Rectification of measurement signal by mixing with a reference signal
- **Low-Pass-Filter**
  Smoothing of rectified signal at demodulator output
- **Programmable Gain DC-Amplifier**
  Reamplification of smoothed signal after low-pass filter
- **Reference Comparator**
  Conversion of reference input signal to a square wave
- **Phase Shifter**
  Matching of signal phase to the reference signal
- **Reference Signalgenerator**
  Generation of a sinusoidal carrier frequency



Lock-in amplifier schematic diagram

Signal Processing in a Lock-In Amplifier

The first sub-unit after the signal input is a **programmable AC amplifier**, which multiplies the input signal V_{IN} by a fixed value without influencing the signal shape. This matches the amplitude of the signal to the input dynamic range of the demodulator.

The following **bandpass filter** has the same centre frequency as the reference frequency f_r and thereby reduces spurious contributions from frequencies other than the reference frequency. This is done without significantly changing the input signal amplitude or phase characteristics in the reference frequency range. The sensitivity to spurious signals is reduced, and the dynamic reserve increased, in this way.

The **demodulator** is the "heart" of the lock-in amplifier. Here the prefiltered signal is multiplied by the reference signal.

The demodulator transmission function, for signal frequency = reference frequency, is:

$$\overline{V_{OUT}} = \frac{2}{\pi} \cdot \hat{V}_{IN} \cdot \cos\varphi$$

where φ = phase shift between signal and reference frequency

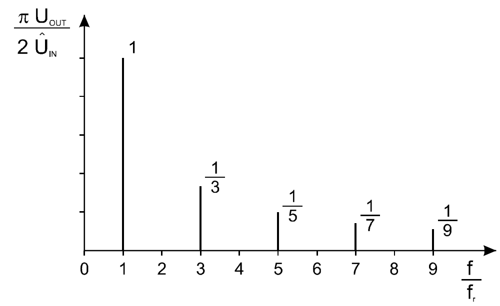
In the figure shown below the phase shift is zero. In this case, the value of the rectified signal at the lock-in amplifier output is a maximum. A non-zero phase difference between signal and reference frequency reduces the value by factor cos (φ). The phase difference may be adjusted manually by means of a phase shifter.

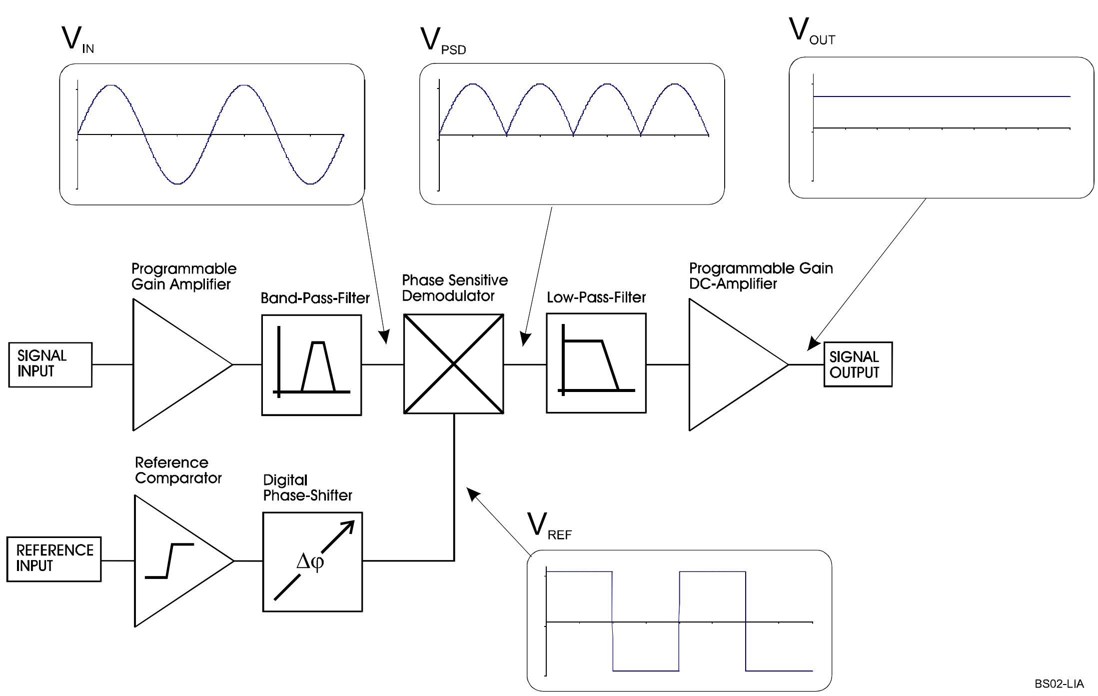
Note that the demodulator also rectifies odd harmonics of the reference frequency contained in the signal frequency. These harmonics create a false output signal, and should be attenuated by the bandpass filter prior to demodulation.
The transmission function for these harmonics describes their contribution to the rectified signal:

$$\overline{V_{OUT}} = \frac{2}{(2n+1)\pi} \cdot \hat{V}_{IN} \cdot \cos\varphi_{(2n+1)}$$

for $f = (2n+1) \cdot f_r$ where n integer

The figure below illustrates the demodulator transmission frequency distribution:





demodulator function illustration

A **low-pass filter** behind the demodulator removes any AC components from the signal. The time constant of the filter also defines the measurement time the rectified signal needs to reach the final value. The time constant may be increased up to 10 s if required by the measurement application, which corresponds to a limiting frequency of f_{TP} = 0,016 Hz. (1/2 π τ). The lock-in amplifier acts as a bandpass filter with a performance factor (Q-value) of e. g.:

f_r = 5 kHz, f_{TP} = 0,016 Hz
$\Rightarrow$ Q-factor Q = 5 kHz / 0,016 Hz = 312500 !

A **programmable DC amplifier** behind the low-pass filter provides a reamplification of the equalized signal. Adjustment of the gain gives various settings for the dynamic reserve. At the same time the DC-stability of the output signal is affected.

Single phase / Dual phase – Lock-In technique

In single phase lock-in amplifiers, as described above, the output signal depends on the phase shift φ between the measurement and the reference signal (factor cos (φ)).

This restriction can be eliminated by use of a second demodulation channel within the lock-in amplifier. In the first channel the measurement signal is demodulated directly with the reference frequency whereas in the second channel it is demodulated with a 90°-shifted reference signal. This gives two rectified values (=mean values) that correspond to a real part (0° = X, in-phase output) and a imaginary part (90° = Y, quadrature output) of the detected measurement signal:

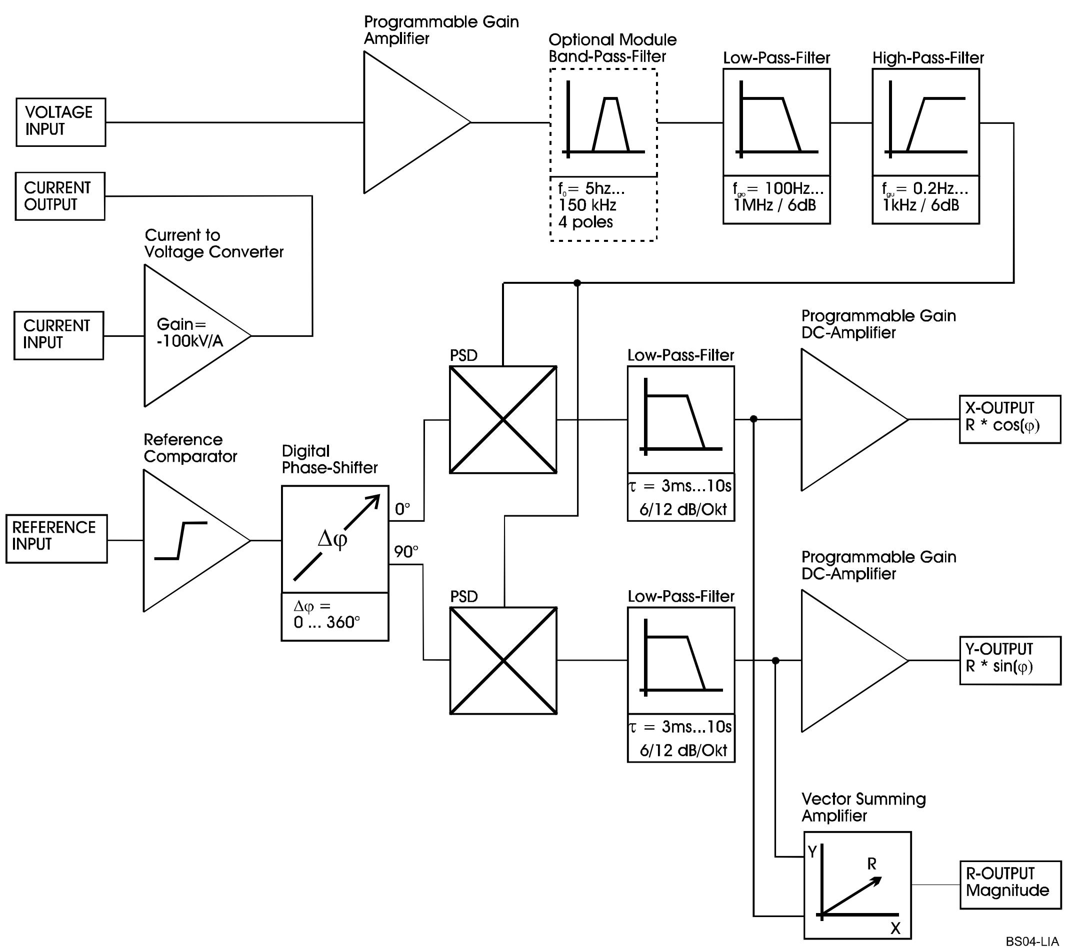
$$\overline{V_{X-OUT}} = \frac{2}{\pi} \cdot \hat{V}_{IN} \cdot \cos\varphi$$

$$\overline{V_{Y-OUT}} = \frac{2}{\pi} \cdot \hat{V}_{IN} \cdot \sin\varphi$$

What follows is the formation of a phase-independent vectot-sum of $V_{X\text{-}OUT}$ and $V_{Y\text{-}OUT}$ within the dual phase lock-in amplifier. The amount is designated magnitude:

$$\overline{V_{R-OUT}} = \sqrt{\overline{V_{X-OUT}}^2 + \overline{V_{Y-OUT}}^2}$$

See for instance the schematic diagram of a dual phase lock-in (FEMTO LIA-BVD-150) below:



Lock-In Amplifier Glossar

2f (3f)-mode	The lock-in amplifier detects double (three times) the reference frequency
DC-stability	Drift parameter, indicates level of voltage drift at the lock-in amplifier output, measured in ppm/K, relative to the output full scale signal
Differential input	A return line applies the measurement signal to the lock-in amplifier differential stage inverting input, thus eliminating problems with earth loops and potential differences
DSP lock-In amplifier	Lock-in technique, where the measurement signal is digitized. Multiplication by the reference signal is performed by means of a **D**igital **S**ignal **P**rocessor. Advantages are high dynamics and stability.
Dynamic reserve	A very complex parameter which requires a more detailed explanation. A basic definition is: Factor in dB, by which a spurious signal may be larger than the set full-scale sensitivity without overdriving the lock-in. The spurious signal definition strongly depends on the frequency range. The higher the dynamic reserve, the lower the output DC-stability.
Sensitivity	The rms value of the measurement signal which corresponds to the maximum level (usually 10 V) at the lock-in amplifier output
Filter performance (Q-value)	Defined as quotient of centre frequency and filter bandwith. In a lock-in amplifier Q is set by adjusting the time constant
In-phase (component)	Real Part at the lock-in amplifier x-output
Magnitude R	Phase-independent vector-sum output of a dual phase lock-in amplifier
Phase φ	The phase shift between measurement signal to be detected and reference signal
Phase shifter	Lock-in sub-unit, which produces a defined phase difference between measurement signal and reference signal
PLL	**P**hase-**L**ocked-**L**oop, installed in a lock-in amplifier to generate the reference signal for the demodulator
PSD	**P**hase **S**ensitive **D**etection = demodulation in the lock-in amplifier
Quadrature (-component)	Imaginary component at the lock-in amplifier Y-output
Reference-threshold	Comparator threshold at the lock-in amplifier reference input
Single Ended input	The measurement signal return line is connected to ground at the input. Easy to handle circuitry, but earth loops may occur under certain circumstances
Carrier frequency technique	lock-in technique mainly used in industrial applications, e. g. in connection with wire strain ganges
Unlocked	Condition, where the reference-PLL is not engaged and thus no output signal is available