Measuring of small AC signals using lock-in amplifiers.

- Narrow band selective amplifiers + amplitude detector.
- Lock-in amplifiers
**Lock-in amplifier technique**

Simplified block diagram of a lock-in amplifier

- Signal in
- Signal amplifier
- Signal monitor
- PSD*
- Low-pass filter
- DC amplifier
- Output

- Reference in
- VCO**
- Reference out

*PSD - phase sensitive detector; **VCO - voltage controlled oscillator

Lock-in amplifier. How it works.
Lock-in amplifier technique

\[ \varphi = \pi/4, \ V_{\text{out}} = 0.72V_{\text{in}} \]

\[ V_{\text{in}} = \sin(\omega t + \pi/4) \]

\[ V_{0}\sin(\omega t + \varphi) \]

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The dependence of pattern of the output signal after demodulator on phase shift between input and reference signals

\[ V_0 \sin(\omega t + \phi) \]

- \( \phi = 0, \ E_x = E_{in} \)
- \( \phi = \pi/4, \ E_x = 0.72E_{in} \)
- \( \phi = \pi, \ E_x = -E_{in} \)
- \( \phi = \pi/2, \ E_x = 0 \)
- \( \phi = 3\pi/2, \ E_x = 0 \)
Lock-in amplifier technique. Simple math.

\[ U_x = U_{x0} \sin(\omega_1 t + \theta_1) \quad \text{- input signal} \]
\[ U_r = \sin(\omega_2 t + \theta_2) \quad \text{- reference signal} \]

\[ U_{\text{demod}} = U_x \cdot U_r = U_{x0} \sin(\omega_1 t + \theta_1) \sin(\omega_2 t + \theta_2) = \]
\[ \frac{U_{x0}}{2} \left[ \cos((\omega_1 + \omega_2) t + \theta_1) \cos(\frac{1}{2} \omega_1 - \omega_2) t + \theta_1 - \theta_2 \right] \]

\[ U_{\text{demod}} = \frac{U_{x0}}{2} \left[ \cos(\omega t + \theta_1 + \theta_2 \cos(\frac{1}{2} \theta_1 - \theta_2) \right] \]

and after low-pass filtering

\[ U_{\text{demod}} = \frac{U_{x0}}{2} \cos(\theta_1 - \theta_2) \]
In many technical applications we need to measure both components \((E_x, E_y)\) of the input signal. To do this most of the modern lock-in amplifiers are equipped by two demodulators.

\[
E_{in} = E_0 \sin(\omega t + \varphi) \to E_x \text{ channel} \]

\[
sin(\omega t) \to E_y \text{ channel} \]

\[
cos(\omega t) \]

\[
E_y \quad \varphi \quad E_x
\]
Block-diagram of analog lock-in
**Lock-in amplifier technique**

**Analog and digital lock-ins**

SR510 & SR530 Lock-In Amplifiers

- 0.5 Hz to 100 kHz frequency range
- Current and voltage inputs
- Up to 80 dB dynamic reserve
- Tracking band-pass and line filters
- Internal reference oscillator
- Four ADC inputs, two DAC outputs
- GPIB and RS-232 interfaces

Analog lock-ins from Stanford Research Systems

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Lock-in amplifier technique

Analog and digital lock-ins

Block-diagram of digital lock-in
Block-diagram of digital lock-in
Lock-in amplifier technique

Analog and digital lock-ins

Two DSP lock-in amplifiers: SR830 from Stanford Research Systems and 7265 from Signal Recovery.

The main advantages of digital lock-ins:
* high phase stability;
* broad frequency range;
* ideal for low and ultra low frequencies (up to 0.001Hz)
* harmonics up to 65,536 (7265), 19,999 (SR830).
Lock-in amplifier technique: some applications

(i) Applying a small test signal (locked to the reference signal) to the studied object

Examples: frequency domain spectroscopy (second sound), tunneling spectroscopy (analysis of the I-V curves), dielectric spectroscopy etc.
(ii) Modulating of the studied signal by the signal locked to the reference signal

Crystal under study

Examples: fluorescence experiment
Lock-in amplifier technique: some applications

Experimental setup for measurement of the dielectric susceptibility (electrical conductivity) in the temperature range 15-450K
Lock-in amplifier technique: some applications

Scanning of the frequency of the AC signal applied to transmitter we can find the frequencies of the acoustical resonance.

Second sound experiment

Receiver

He4

Transmitter (heater)

AC drive signal

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Lock-in amplifier technique: some applications

Optical pumping

$\Delta H \approx 0.01 \text{G}$
Lock-in amplifier technique: some applications

Optical pumping

Rb cell

Function generator

DMM

5.1kΩ

Sweep coil

B₀ - main field

B₀ + B₁sin(ωt)

SR830 lock-in

From TeachSpin detector

reference
The choice of amplitude modulation

Optical pumping

\[ I_{\text{sweep}} = \frac{V_{FG}}{5.1k\Omega} \]

\[ B_1 = k_{\text{sweep}} \cdot I_{\text{sweep}} \]

\[ K_{\text{sweep}} \approx 0.6G/A \]

If \( V_{FG} = 1V \)

\( B_1 \sim 0.12mG \)
Lock-in amplifier technique: some applications

Optical pumping

Analog detector record $(I(f))$

Lock-in detector record $\frac{\partial I}{\partial H}(f)$

Mapping 0.5-2.5A from March 1st 2012: Graph6
Lock-in amplifier technique: some applications

Tunneling spectroscopy

\[ eV_{DC} + eV_{AC} \]
Lock-in amplifier technique: some applications

Tunneling spectroscopy

$eV_{\text{DC}}$ only

Sample #((n3-n9) Al-Al$_2$O$_3$-Pb

$T = 1.5475 \pm 7 \times 10^{-4}$ K

$\frac{dI}{dU_{\text{DC}}}$

Courtesy of Anna Miller and Everett Vacek
Lock-in amplifier technique: some applications

Tunneling spectroscopy

\[ eV_{DC} + eV_{AC} \]

**Sample #(n3-n9) Al-Al\textsubscript{2}O\textsubscript{3}-Pb**

- **Graph 1**: 
  \[ T = 1.5475 \pm 7 \times 10^{-4} K \]
  
  - **Graph 2**: 
  \[ T = 1.5475 \pm 7 \times 10^{-4} K \]

Phonon assisted tunneling results: Graph

*Courtesy of Anna Miller and Everett Vacek*

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Lock-in amplifier technique: demo

Function generator

Noise

∑

Lock-in amplifier

demo lock-in