Measuring of small AC signals using lock-in amplifiers.

- Narrow band selective amplifiers + amplitude detector.
- Lock-in amplifiers
Lock-in amplifier. How it works.
Lock-in amplifier technique

Phase shift

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

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

Reference

Output

Time (msec)
The dependence of pattern of the output signal after demodulator on phase shift between input and reference signals.

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

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

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

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

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.

\[ E_{in} = E_0 \sin(\omega t + \phi) \]

\[ \sin(\omega t) \]

\[ \cos(\omega t) \]

\[ \text{to} \ E_x \text{ channel} \]

\[ \text{to} \ E_y \text{ channel} \]

\[ E_y \]

\[ E_x \]

\[ \phi \]

\[ \text{y} \]

\[ \text{x} \]
Lock-in amplifier technique

Analog and digital lock-ins

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
Lock-in amplifier technique

Analog and digital lock-ins

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

SR830 digital lock-ins

GPIB

V_{in}\rightarrow Input\ amplifier +\ filters

Main ADC

DSP

Output filters

Ref. out\rightarrow Function\ generator

clock

ADC1\rightarrow DAC1

ADC2\rightarrow DAC1

ADC3\rightarrow DAC1

ADC4\rightarrow DAC1

Block-diagram of digital lock-in

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Physics 403 Fall 2016
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.
Modulating of the studied signal by the signal locked to the reference signal

Examples: fluorescence experiment

Diagram:
- Function generator
- LED power supply
- Green LED
- Crystal under study
- SR830 lock-in
- Detector
- Sync output
- Modulation
- Fluorescence response
- Signal input
- Reference input
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

Second sound experiment

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

Transmitter (heater)

Receiver

He4

AC drive signal

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Optical pumping

Lock-in amplifier technique: some applications

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

Optical pumping

$B_0$ - main field

$B_0 + B_1 \sin(\omega t)$

Sweep coil

Rb cell

From TeachSpin detector

Function generator

DMM

5.1kΩ

SR830 lock-in

reference
Optical pumping

The choice of amplitude modulation

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

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

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

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

\( B_1 \approx 0.12mG \)
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

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

Tunneling spectroscopy
Lock-in amplifier technique: some applications

Tunneling spectroscopy

$eV_{\text{DC}}$ only

Sample #1 Al-Al$_2$O$_3$-Pb

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

Sample #2 Al-Al$_2$O$_3$-Pb

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

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

Tunneling spectroscopy

eV_{DC} + eV_{AC}

Sample # (n3-n9) Al-Al₂O₃-Pb

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

Phonon assisted tunneling results: Graph

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

Function generator

Noise

Lock-in amplifier

demo lock-in