

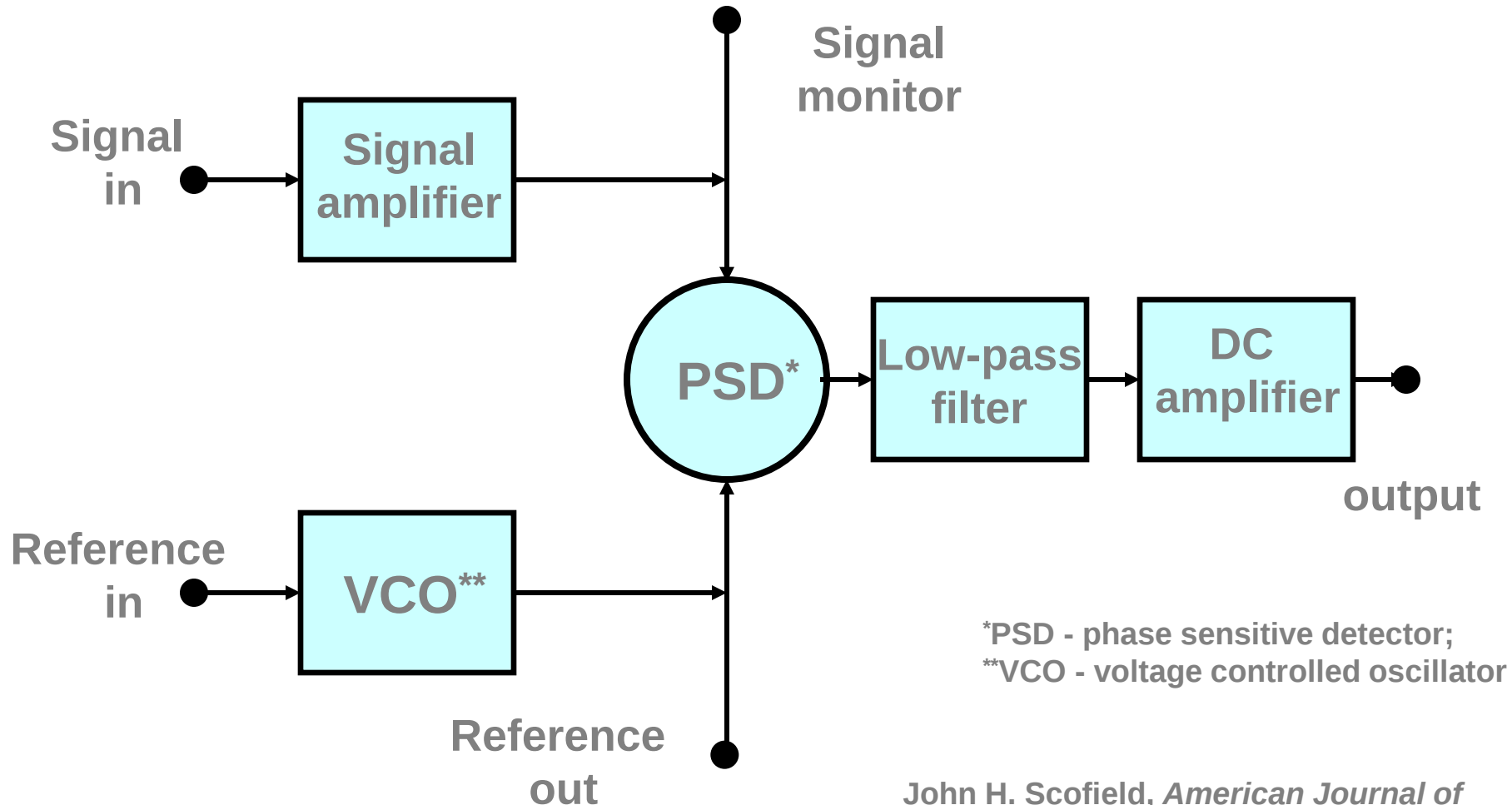
Measuring of small AC signals using lock-in amplifiers.



- ✓ Narrow band selective amplifiers + amplitude detector.
- ✓ Lock-in amplifiers

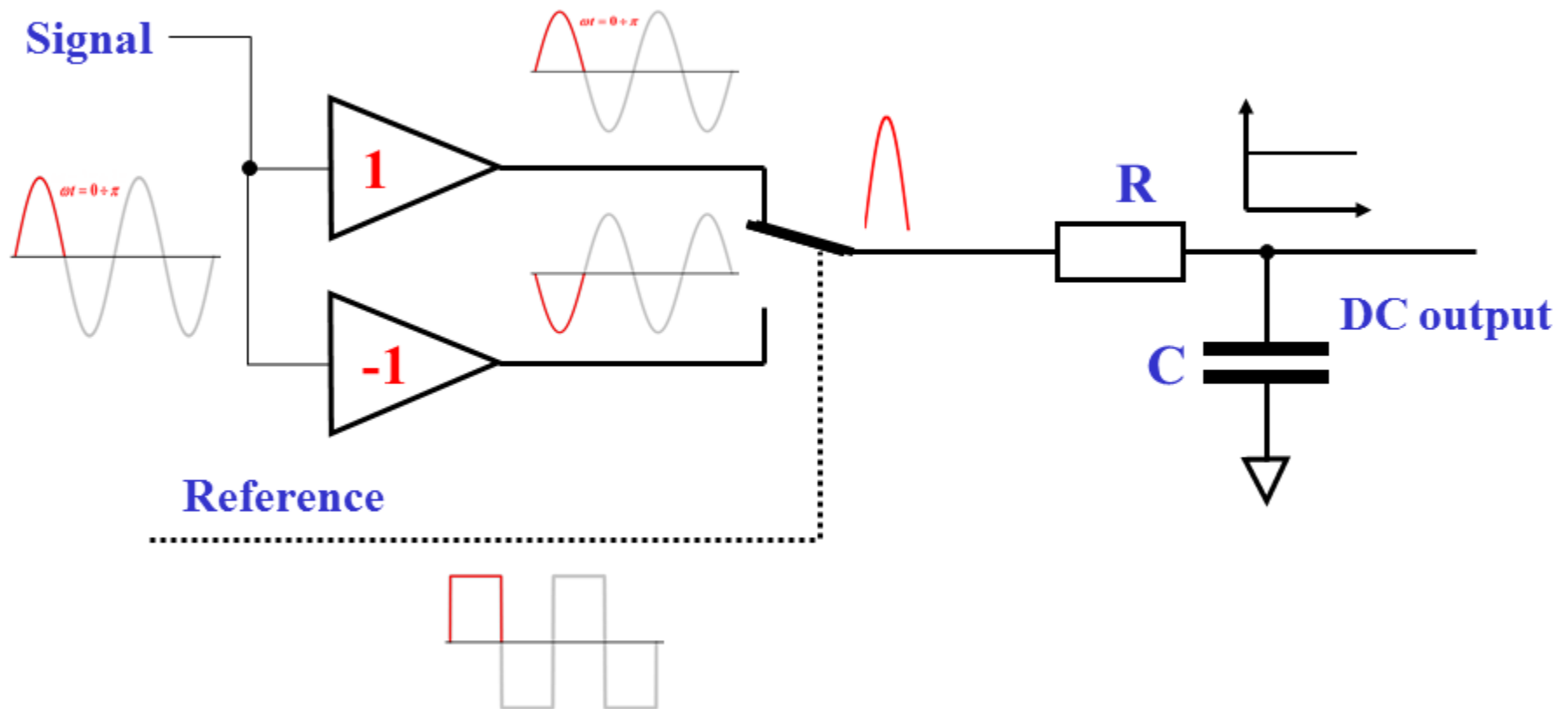
Lock-in amplifier technique

Simplified block diagram of a lock-in amplifier



John H. Scofield, *American Journal of Physics* 62 (2) 129-133 (Feb. 1994).

Lock-in amplifier. How it works.

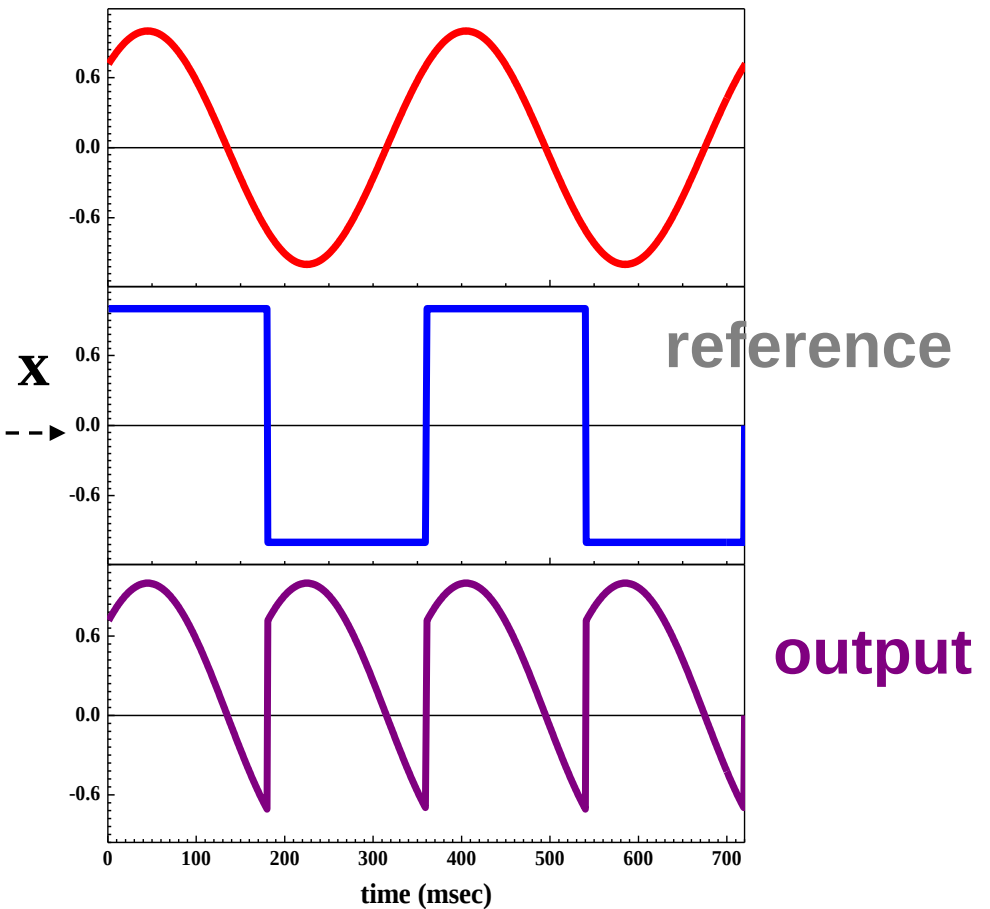
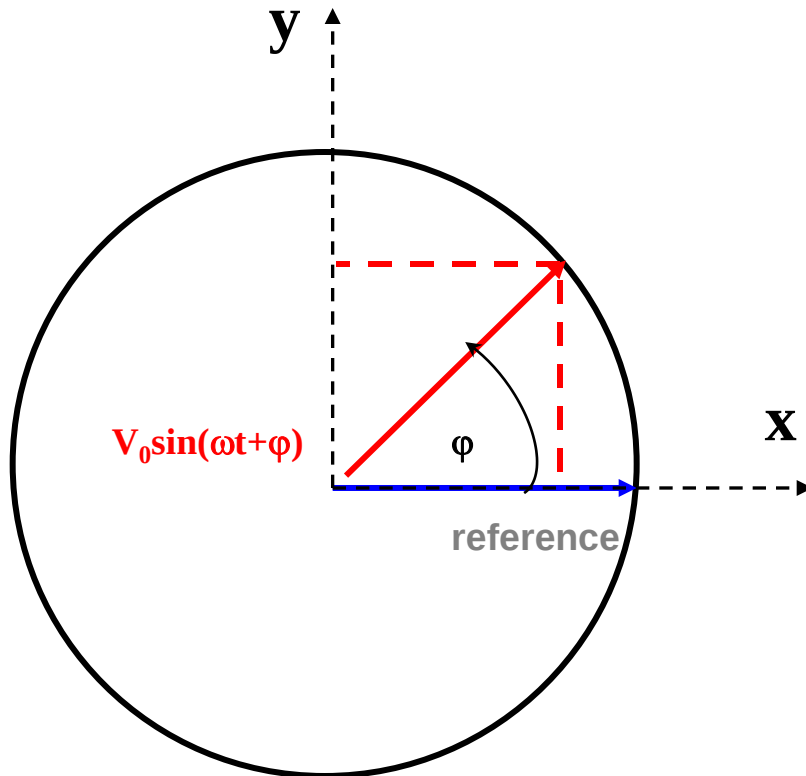


Lock-in amplifier technique

Phase shift

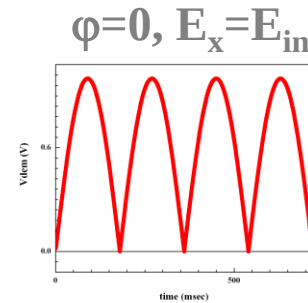
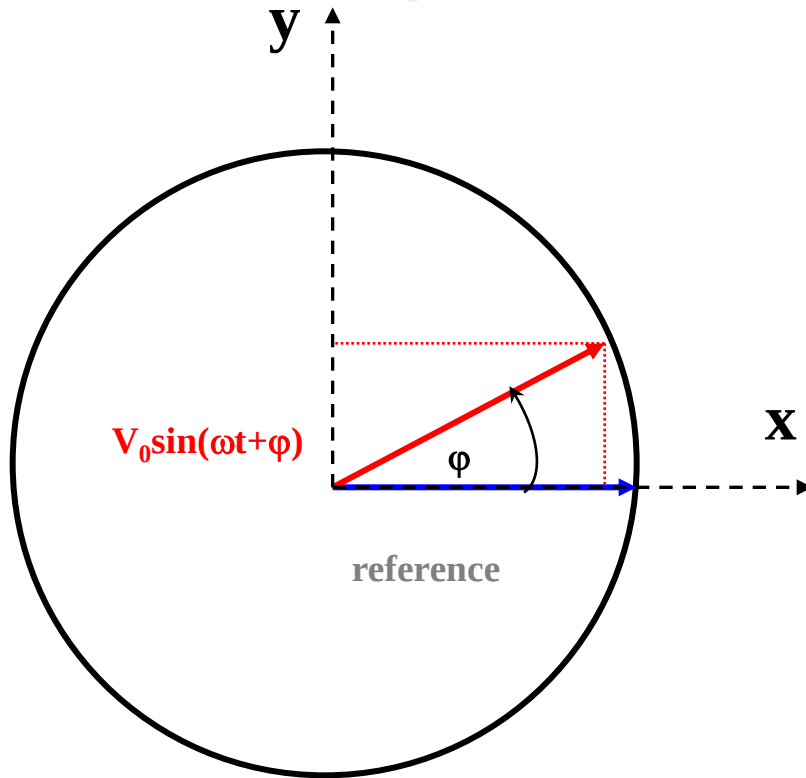
$$\phi = \pi/4, V_{\text{out}} = 0.72V_{\text{in}}$$

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

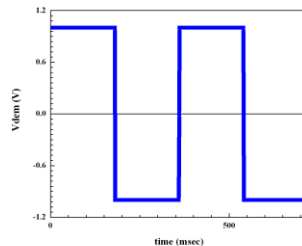
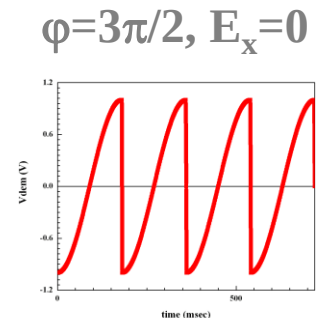
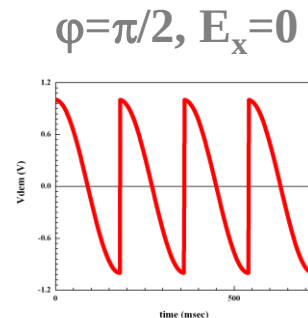
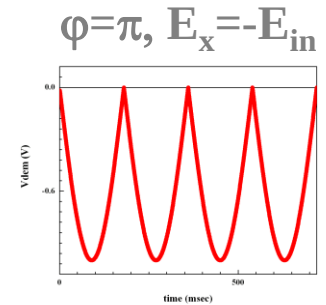
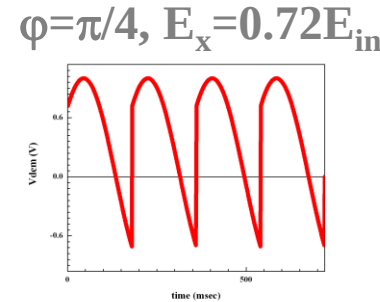


Lock-in amplifier technique

Phase shift



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



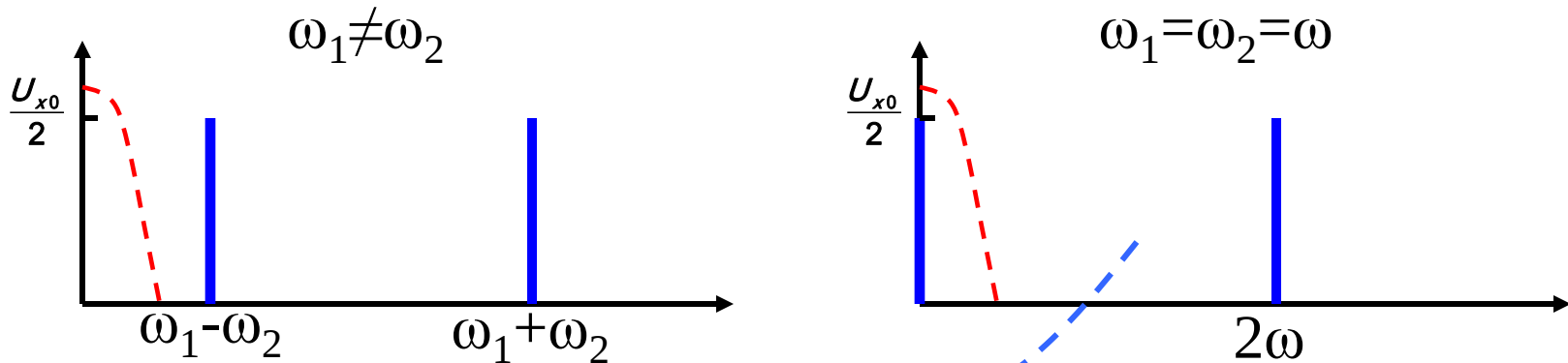
Lock-in amplifier technique. Simple math.

$$U_x = U_{x0} \sin(\omega_1 t + \theta_1) \quad \text{- input signal}$$

$$U_r = \sin(\omega_2 t + \theta_2) \quad \text{- reference signal}$$

$$U_{demod} = U_x \cdot U_r = U_{x0} \sin(\omega_1 t + \theta_1) \sin(\omega_2 t + \theta_2) =$$

$$\frac{U_{x0}}{2} [\cos((\omega_1 + \omega_2)t + \theta_1 + \theta_2) + \cos((\omega_1 - \omega_2)t + \theta_1 - \theta_2)]$$



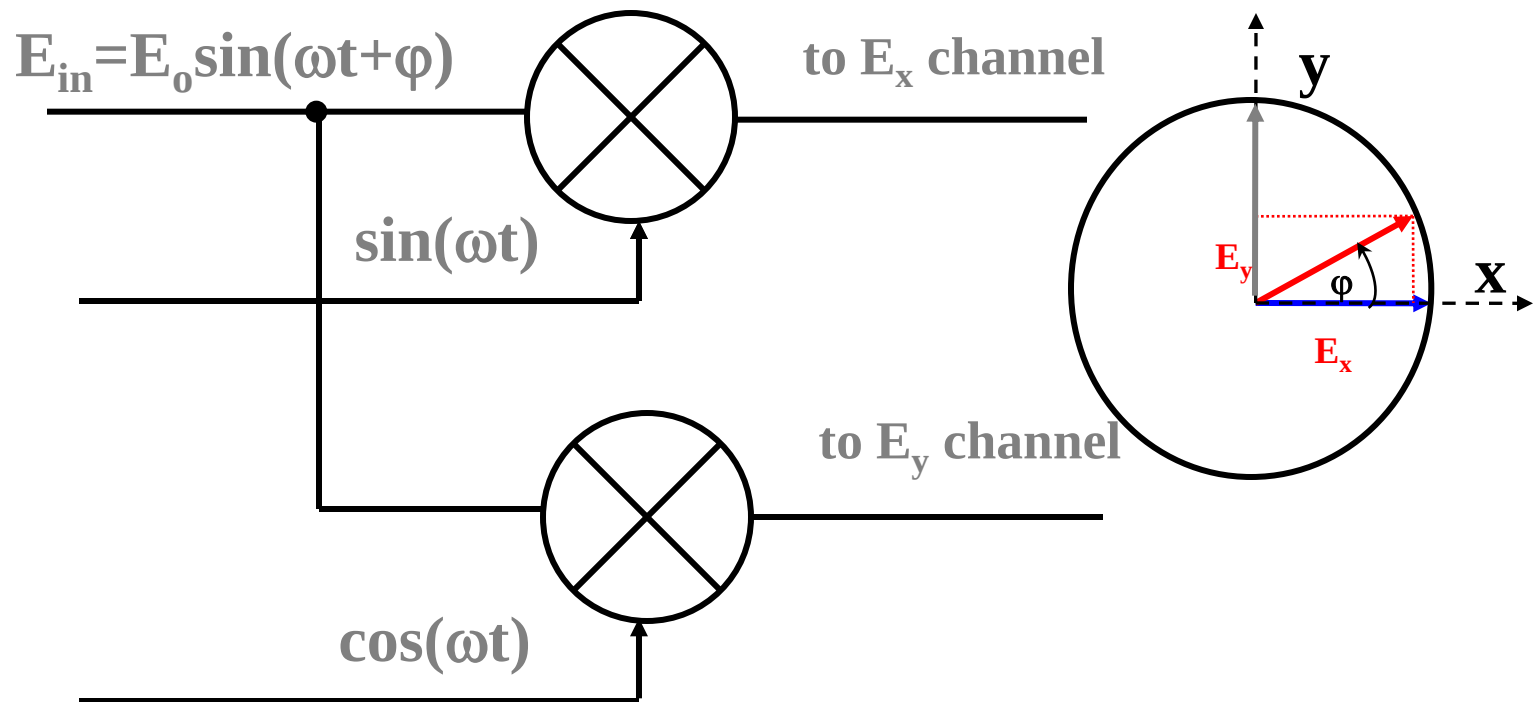
$$U_{demod} = \frac{U_{x0}}{2} [\cos(\omega t + \theta_1 + \theta_2) + \cos(\theta_1 - \theta_2)]$$

and after low-pass filtering $\longrightarrow U_{demod} = \frac{U_{x0}}{2} \cos(\theta_1 - \theta_2)$

Lock-in amplifier technique

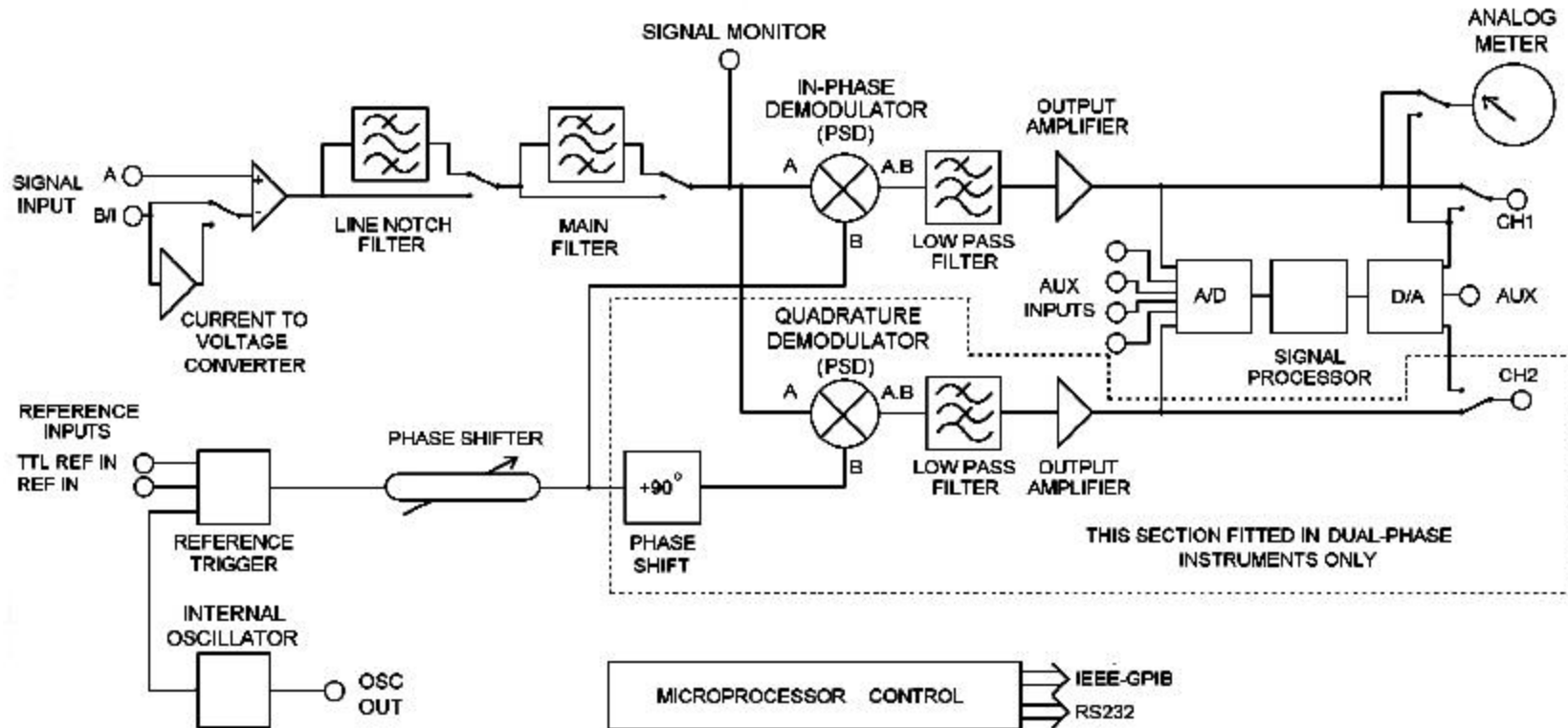
Two channels demodulation

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.



Lock-in amplifier technique

Analog and digital lock-ins



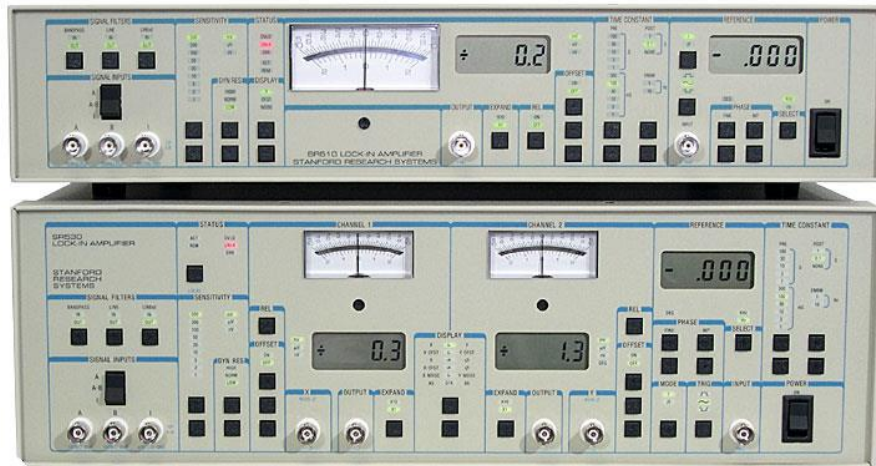
Block-diagram of analog lock-in

Lock-in amplifier technique

Analog and digital lock-ins



SR510 & SR530 Lock-In Amplifiers

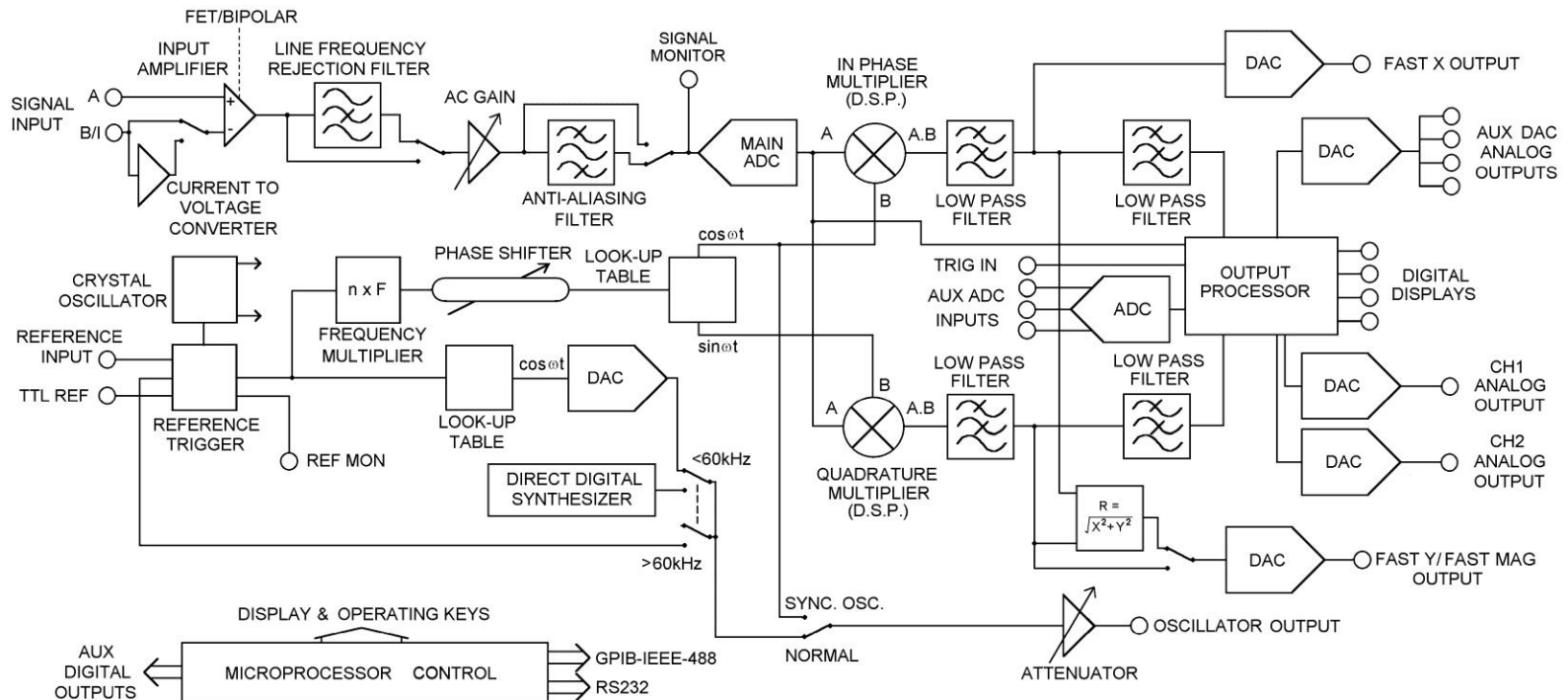


- 0.5 Hz to 100 kHz frequency range
- Current and voltage inputs
- Up to 80 dB dynamic reserve
- Tracking band-pass and line filters
- Internal reference oscillator
- Four ADC inputs, two DAC outputs
- GPIB and RS-232 interfaces

Analog lock-ins from Stanford Research Systems

Lock-in amplifier technique

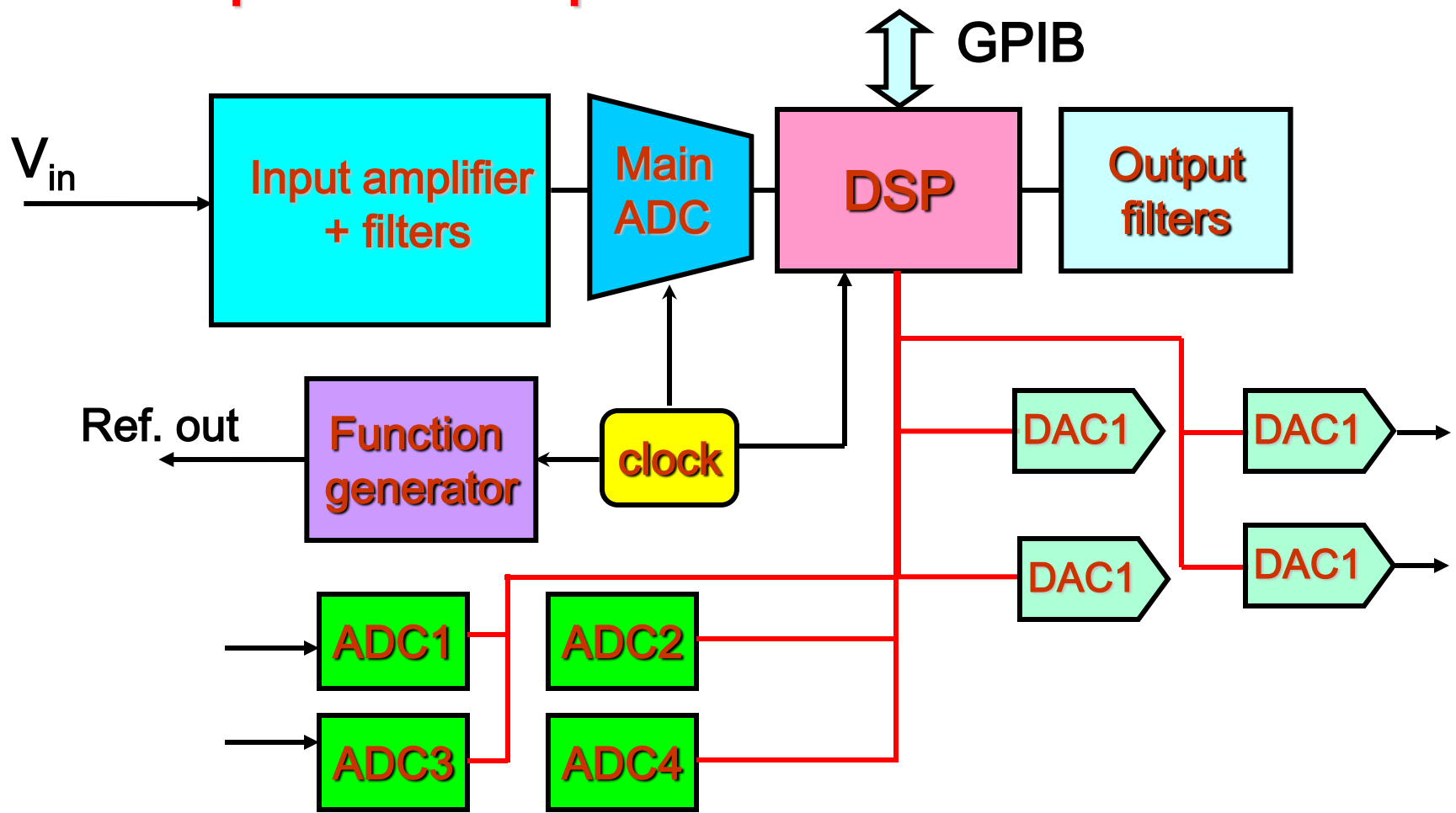
Analog and digital lock-ins



Block-diagram of digital lock-in

Lock-in amplifier technique

SR830 digital lock-ins



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.

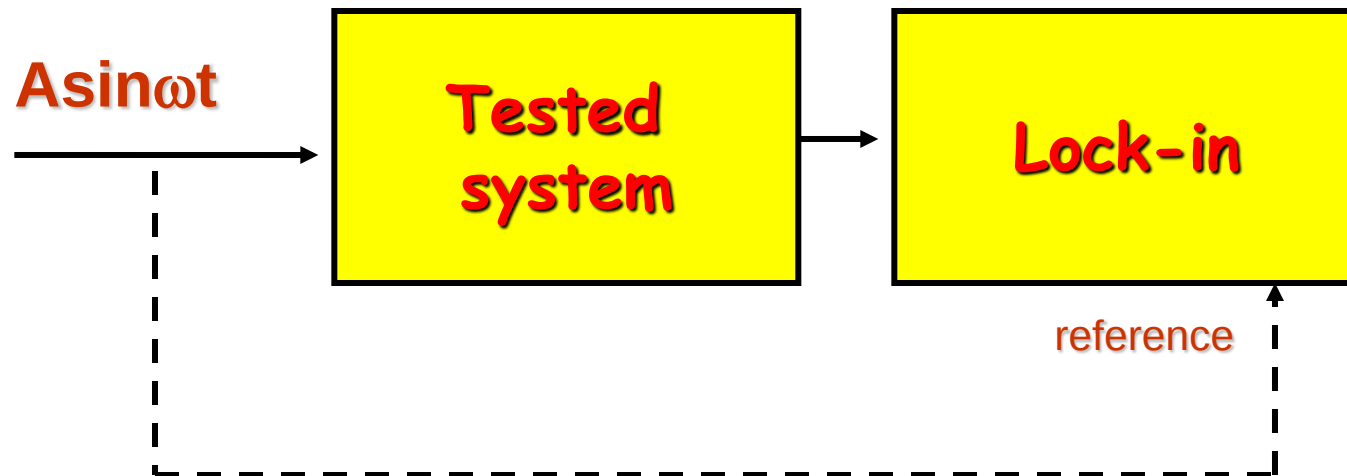


The main advantages of digital lock-ins:

- * 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

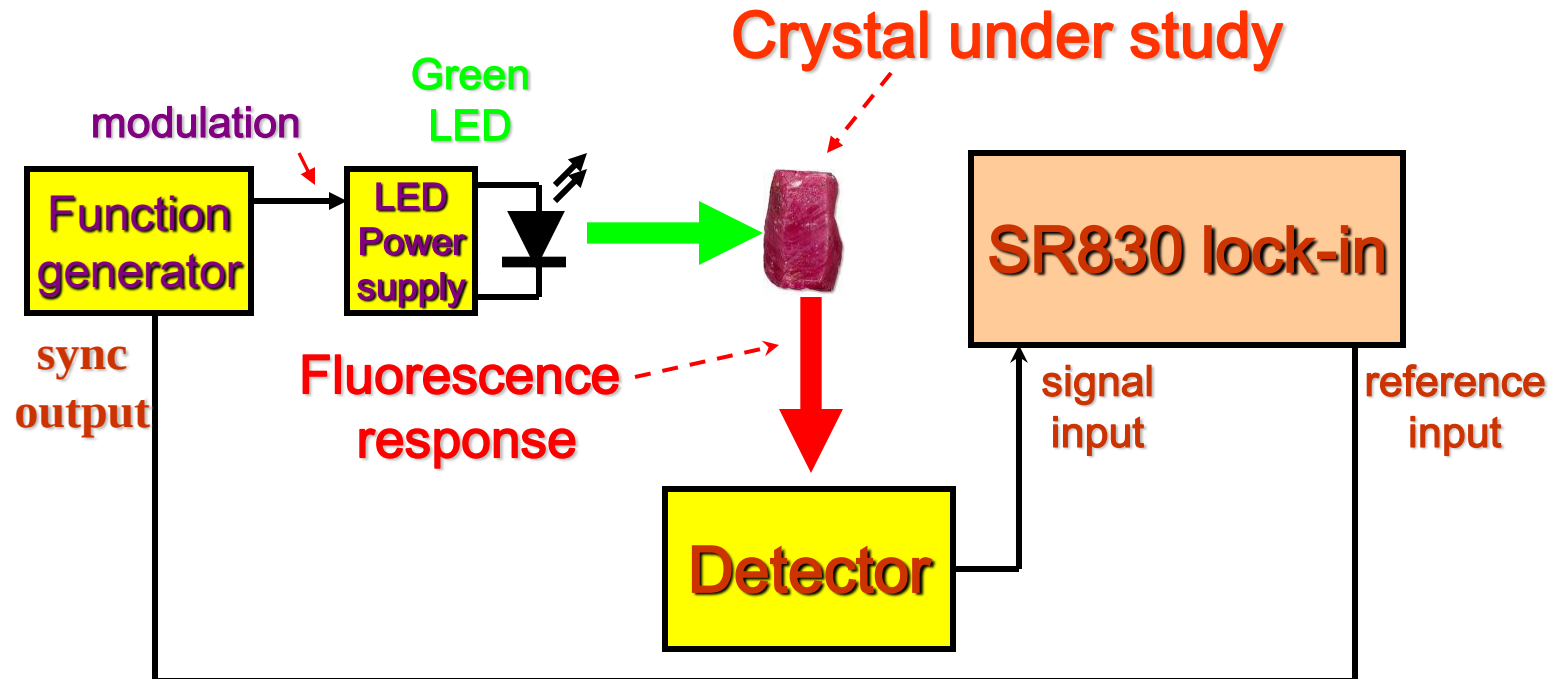
- (i) Applying a small test signal (locked to the reference signal) to the studied object



Examples: frequency domain spectroscopy (second sound), tunneling spectroscopy (analysis of the I-V curves), dielectric spectroscopy etc.

Lock-in amplifier technique: some applications

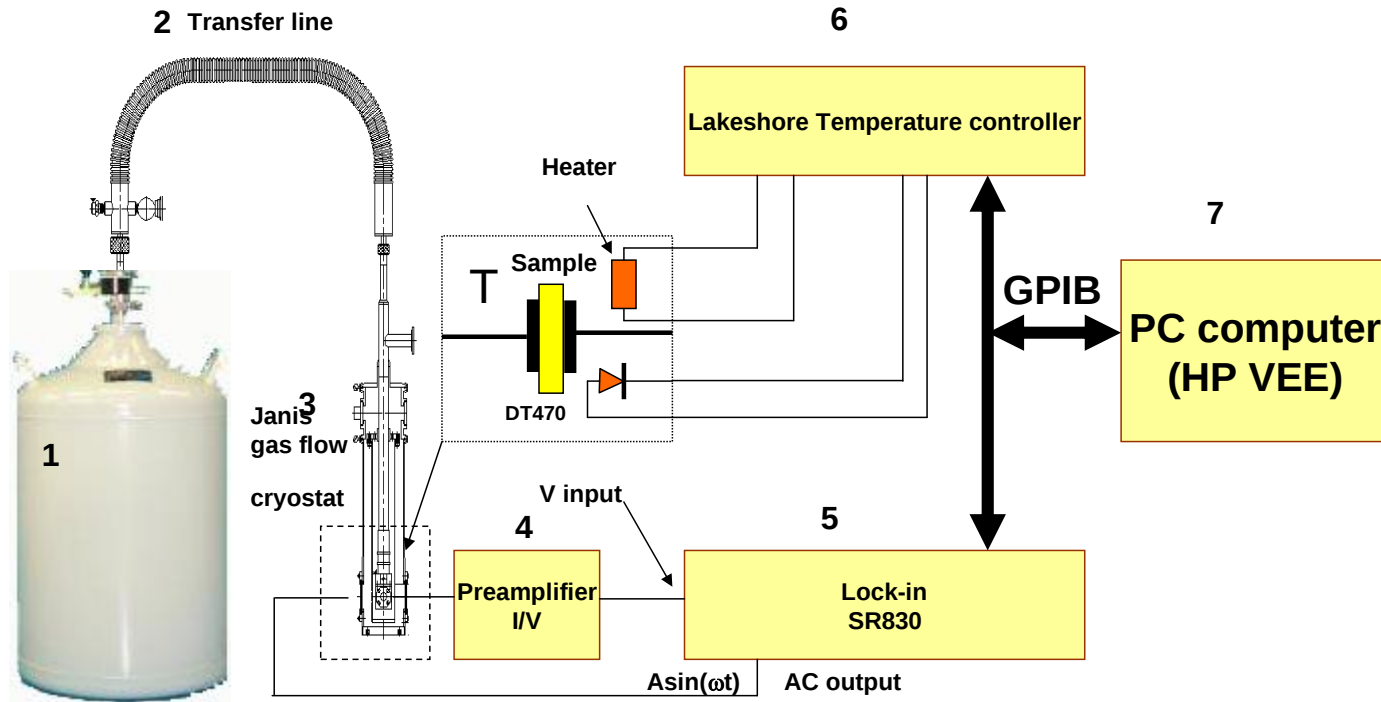
(ii) Modulating of the studied signal by the signal locked to the reference signal



Examples: fluorescence experiment

Lock-in amplifier technique

Examples of application



Experimental setup for measurement of the dielectric susceptibility (electrical conductivity) in the temperature range 15-450K

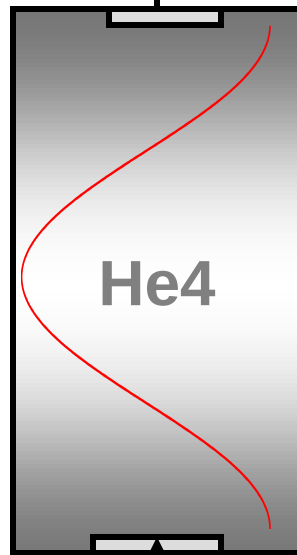
Lock-in amplifier technique

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

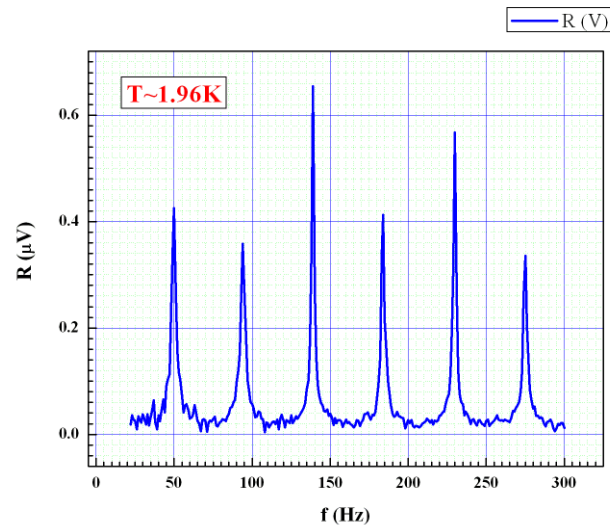
Examples of application.
Second sound experiment



Receiver



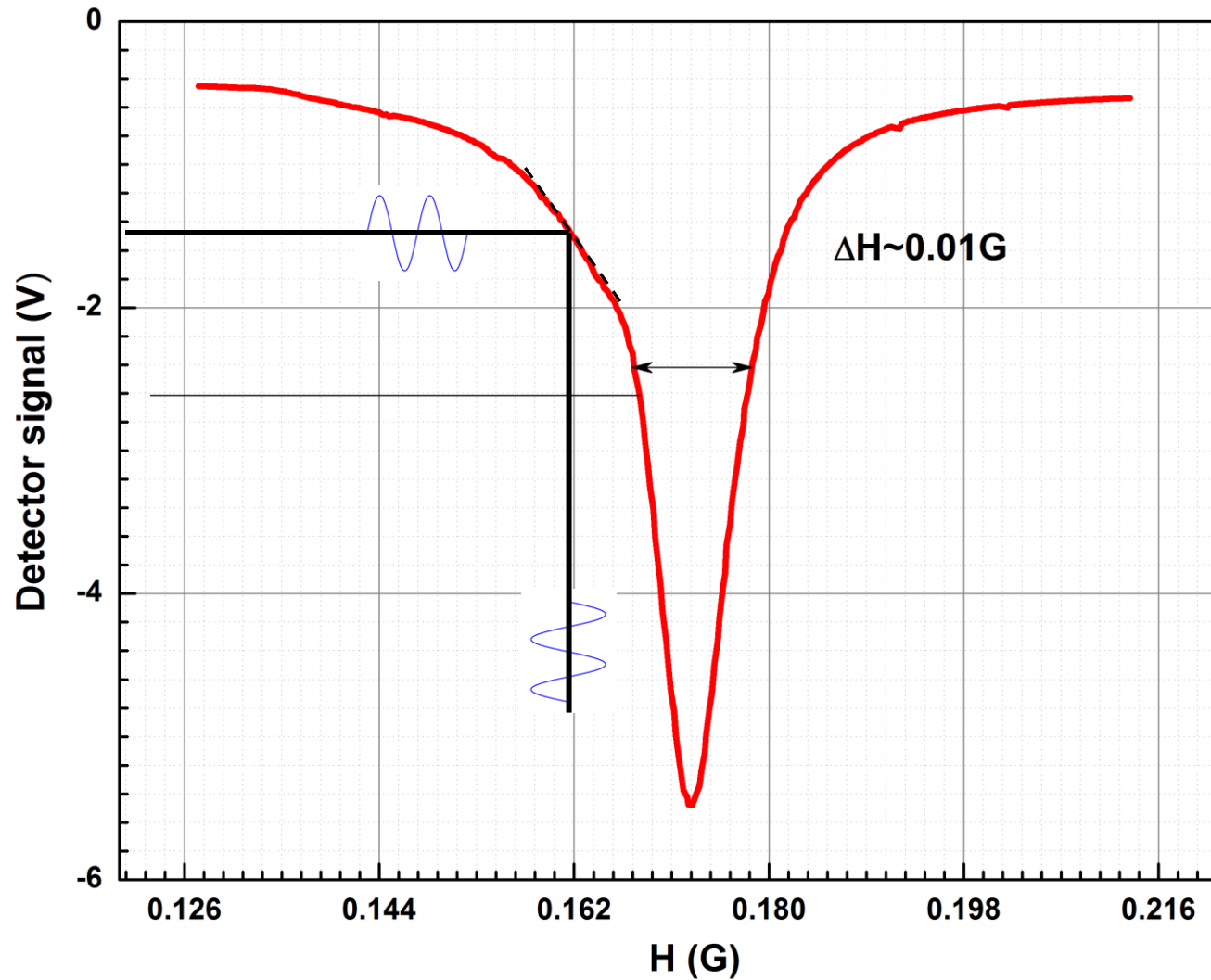
Transmitter (heater)



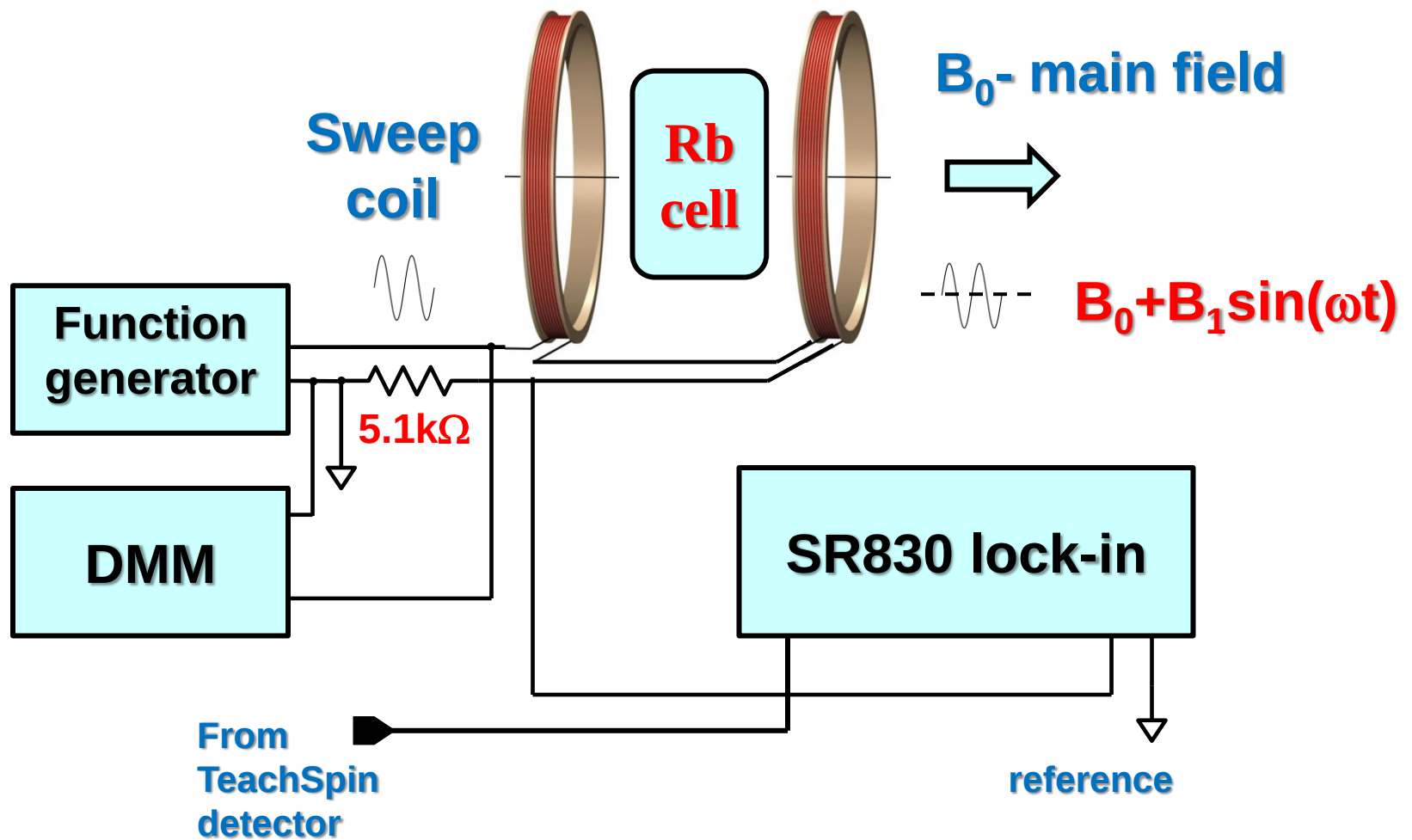
AC drive signal

Lock-in amplifier technique

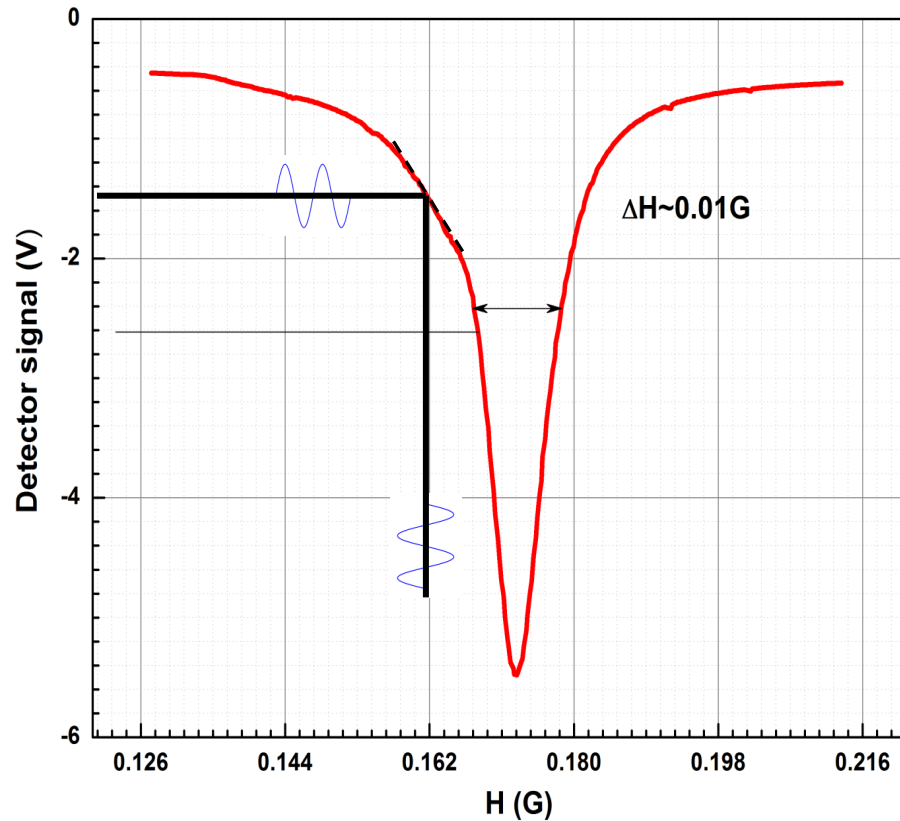
Examples of application. Optical pumping



Examples of application. Optical pumping



Examples of application. Optical pumping



The choice of amplitude modulation

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

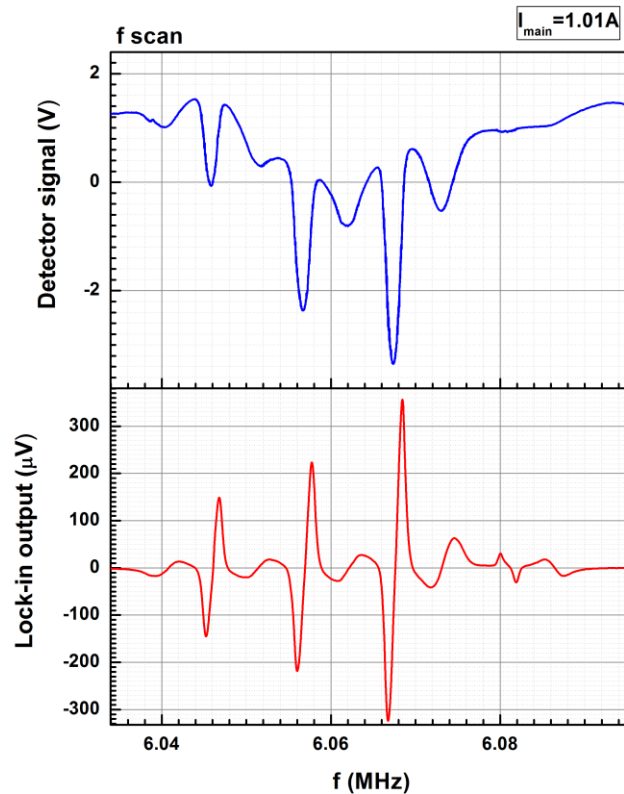
$$B_1 = k_{\text{sweep}} \bullet I_{\text{sweep}}$$

$$K_{\text{sweep}} \cong 0.6 \text{ G/A}$$

$$\text{If } V_{FG} = 1 \text{ V} \\ B_1 \sim 0.12 \text{ mG}$$

Lock-in amplifier technique

Examples of application.
Optical pumping

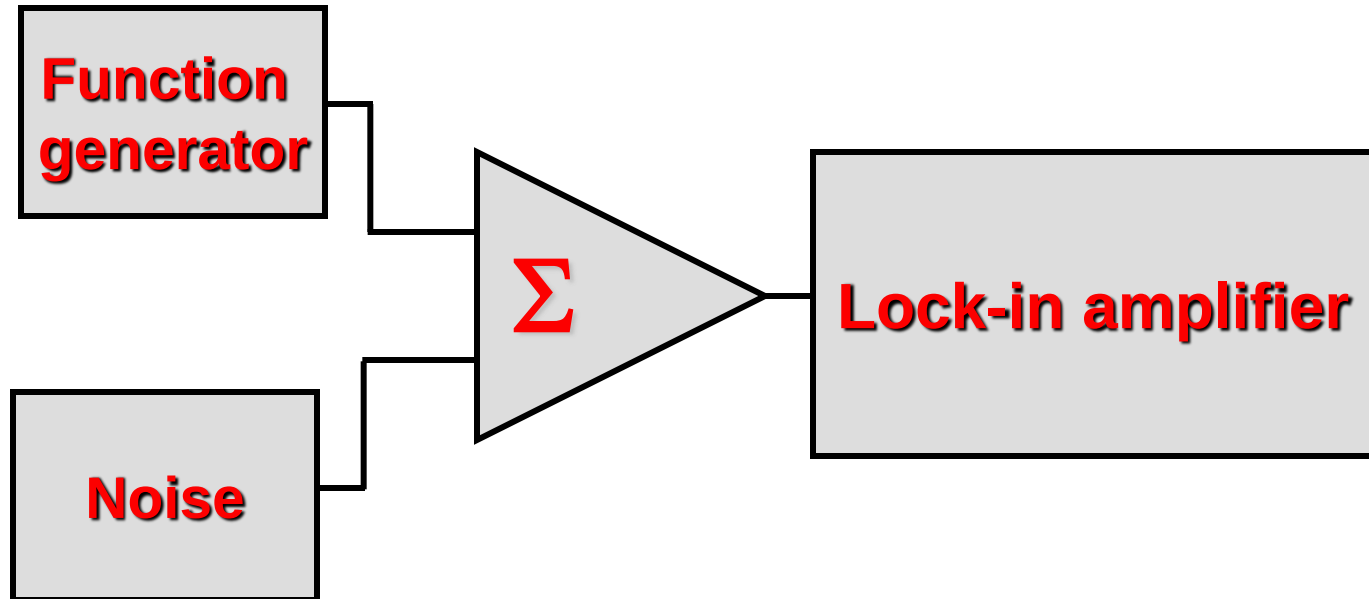


Mapping 0.5-2.5A from March 1st 2012: Graph6

Analog detector record $I(f)$

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

Lock-in amplifier technique: demo



demo lock-in