

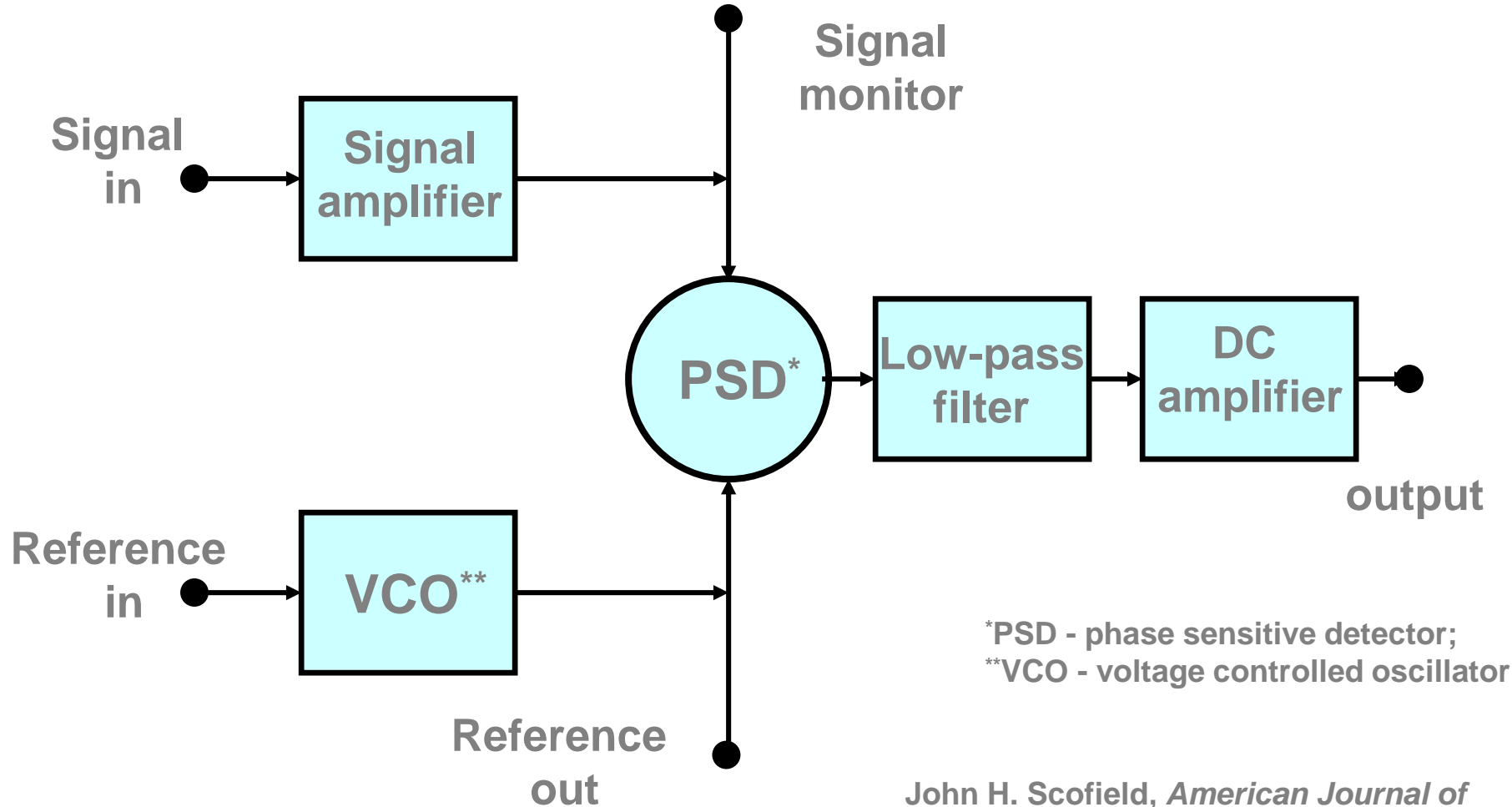
# Measuring of small AC signals using lock-in amplifiers.



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

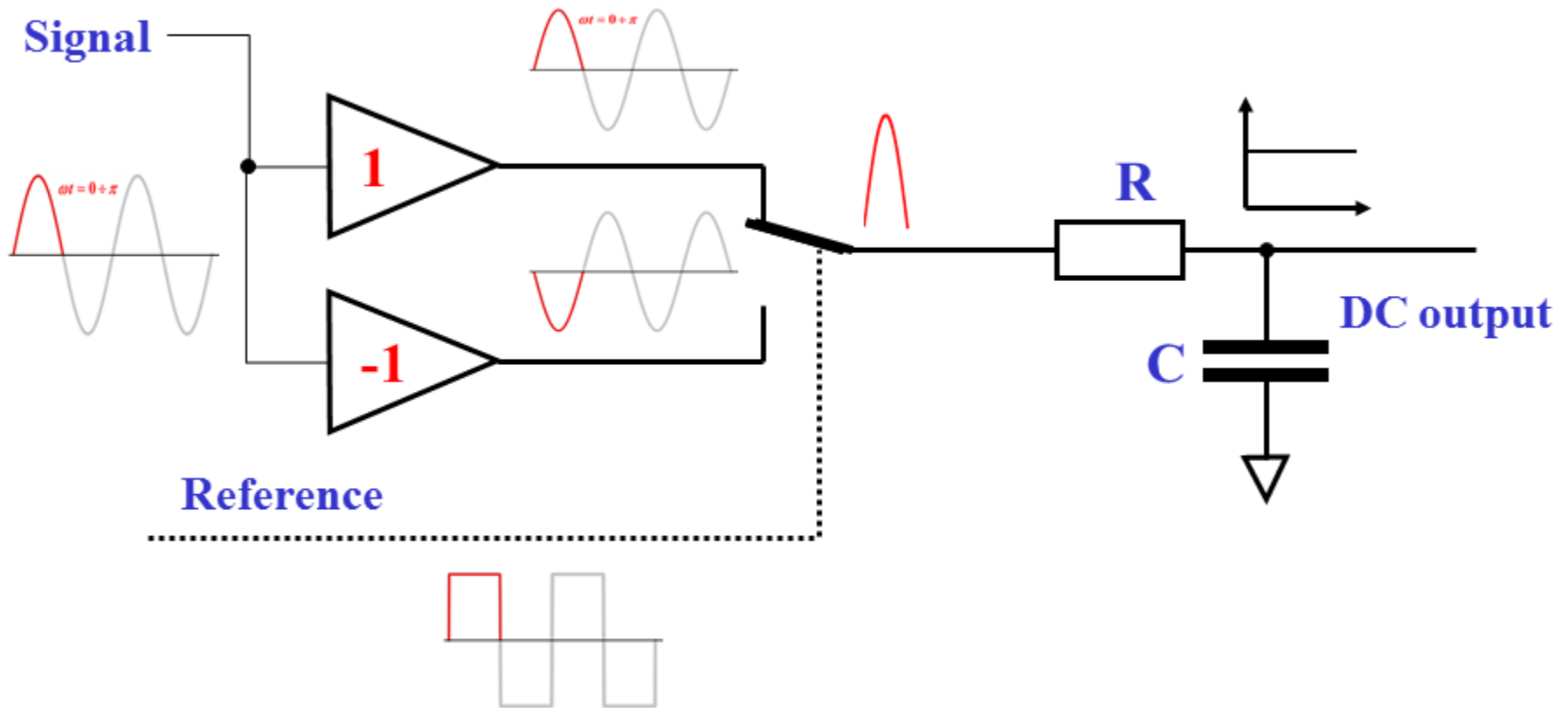
# Lock-in amplifier technique

## 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.

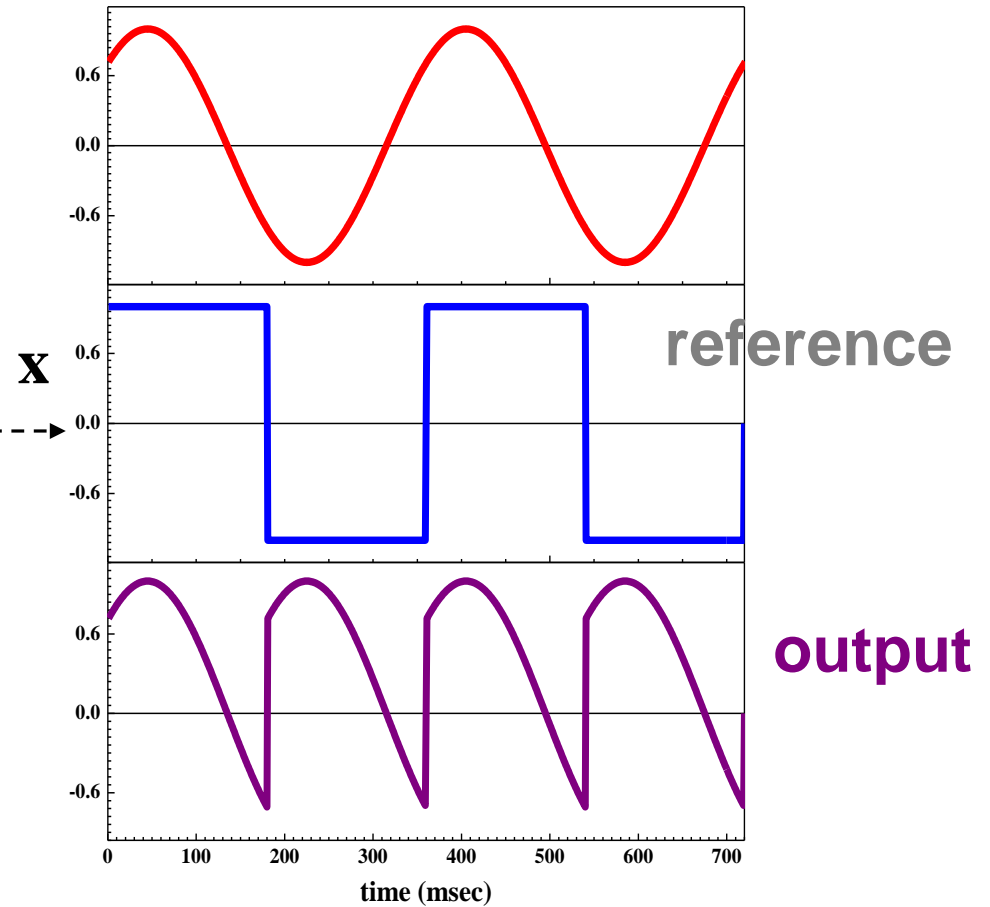
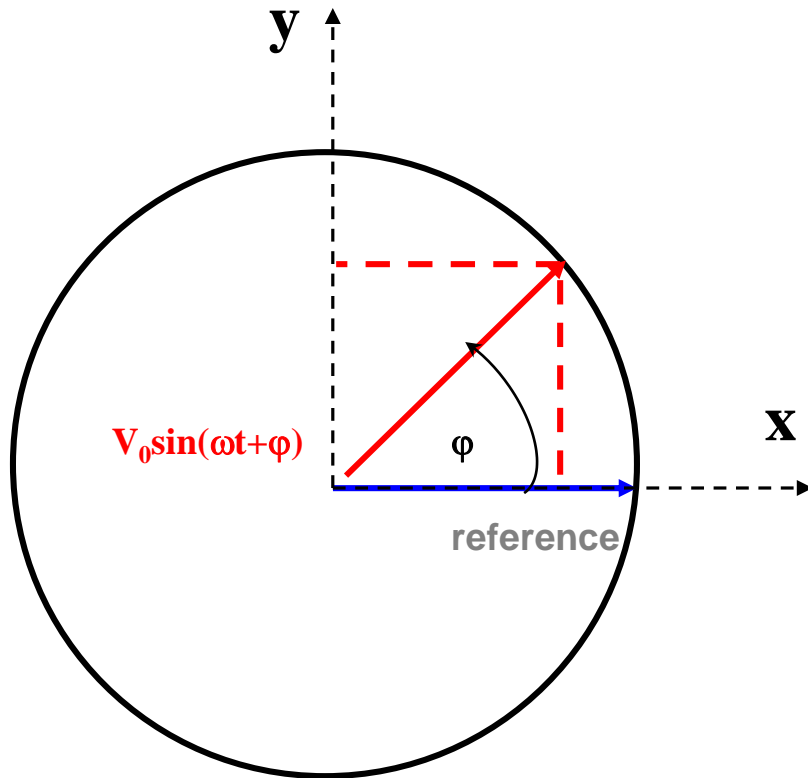


# Lock-in amplifier technique

## Phase shift

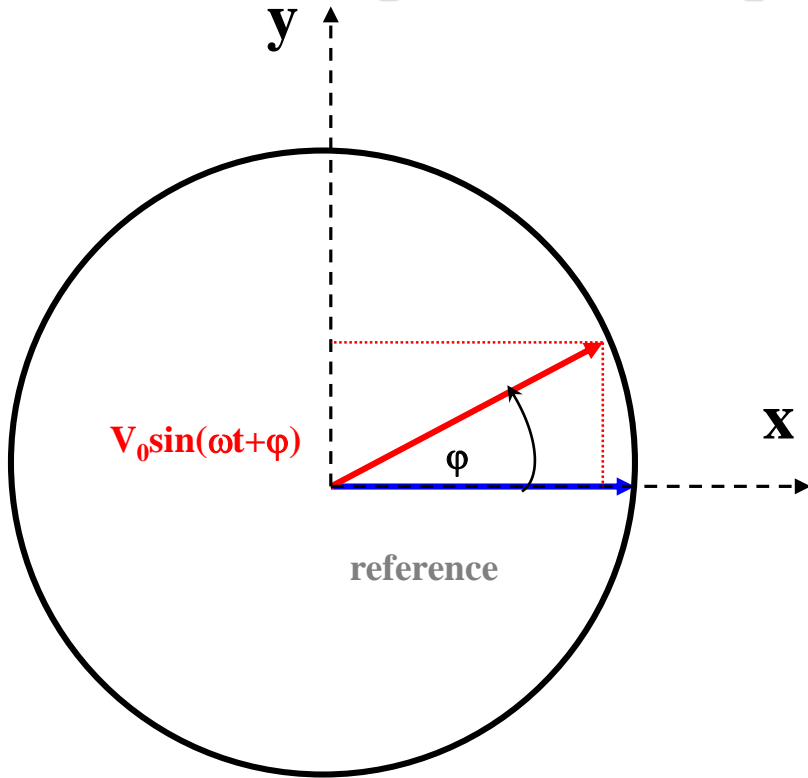
$$\varphi = \pi/4, V_{\text{out}} = 0.72V_{\text{in}}$$

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

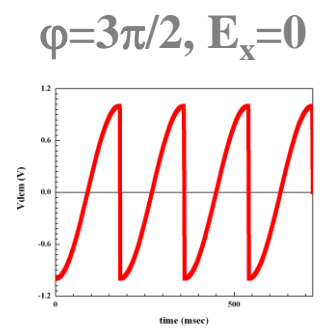
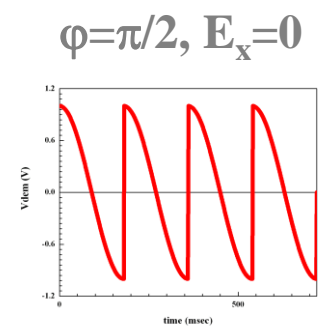
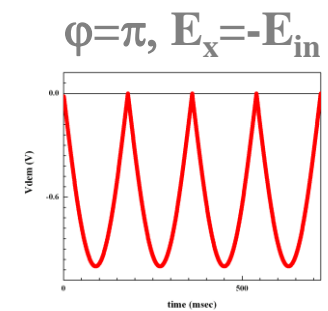
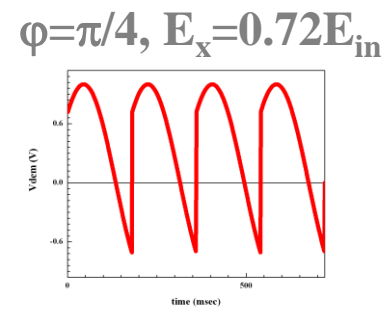
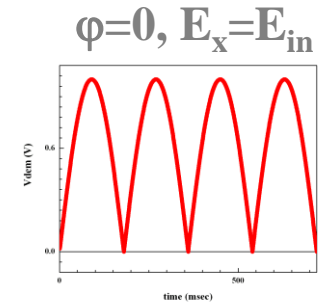
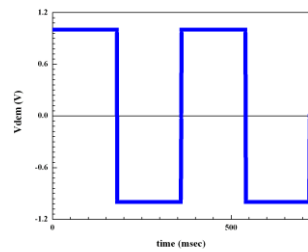


# Lock-in amplifier technique

## Phase shift



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



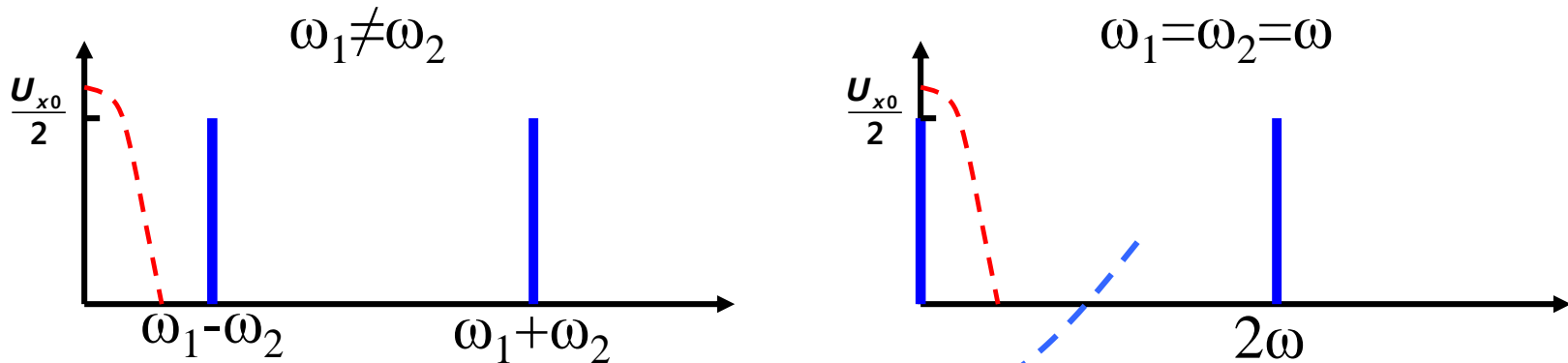
## Lock-in amplifier technique. Simple math.

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

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

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

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



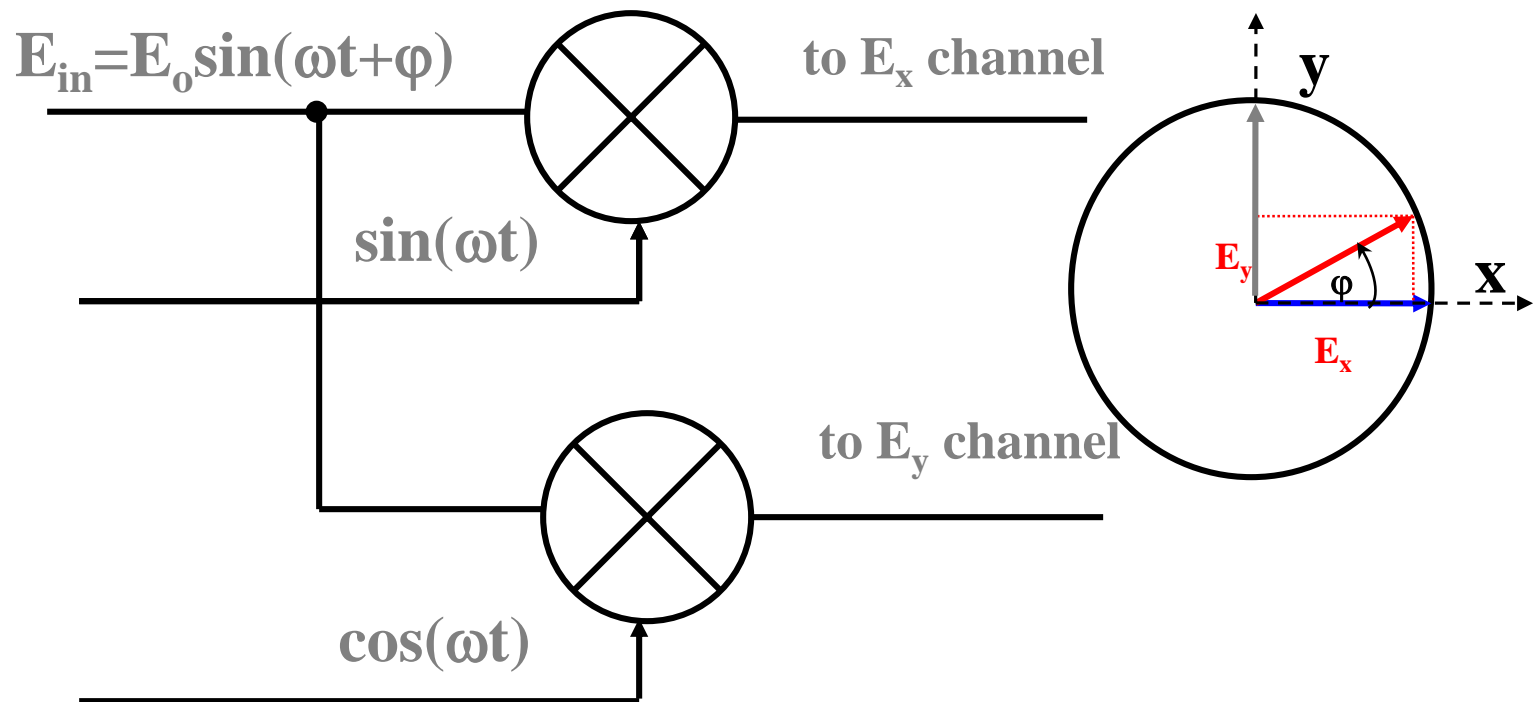
$$U_{de\ mod} = \frac{U_{x0}}{2} [\cos(2\omega t + \theta_1 + \theta_2) + \cos(\theta_1 - \theta_2)]$$

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

# 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.



# Invention of the Lock-in amplifier

In 1961, Princeton Applied Research was founded by a group of scientists from Princeton University and the Plasma Physics Laboratory. With a desire to establish significant improvements to research instrumentation the team developed the first commercial lock-in amplifier in 1962.



**Robert Henry Dicke**  
1916-1997



**Model HR-8**

**f range: = 5Hz÷150kHz**

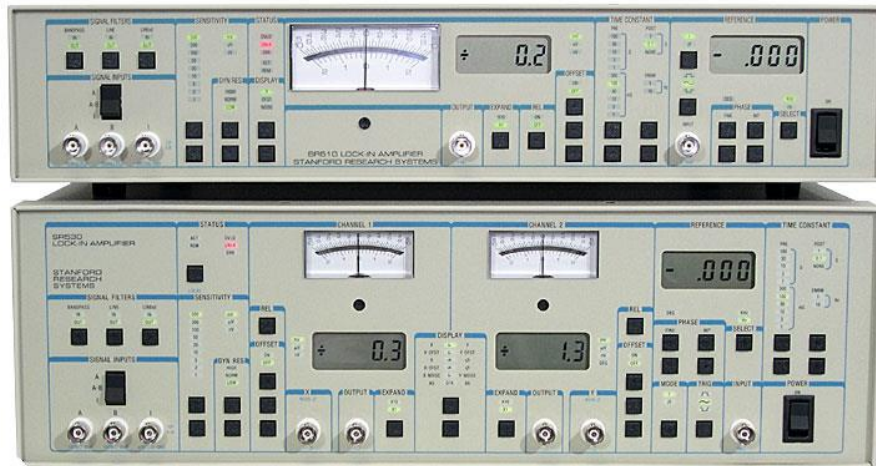


# Lock-in amplifier technique

# Analog and digital lock-ins



## SR510 & SR530 Lock-In Amplifiers

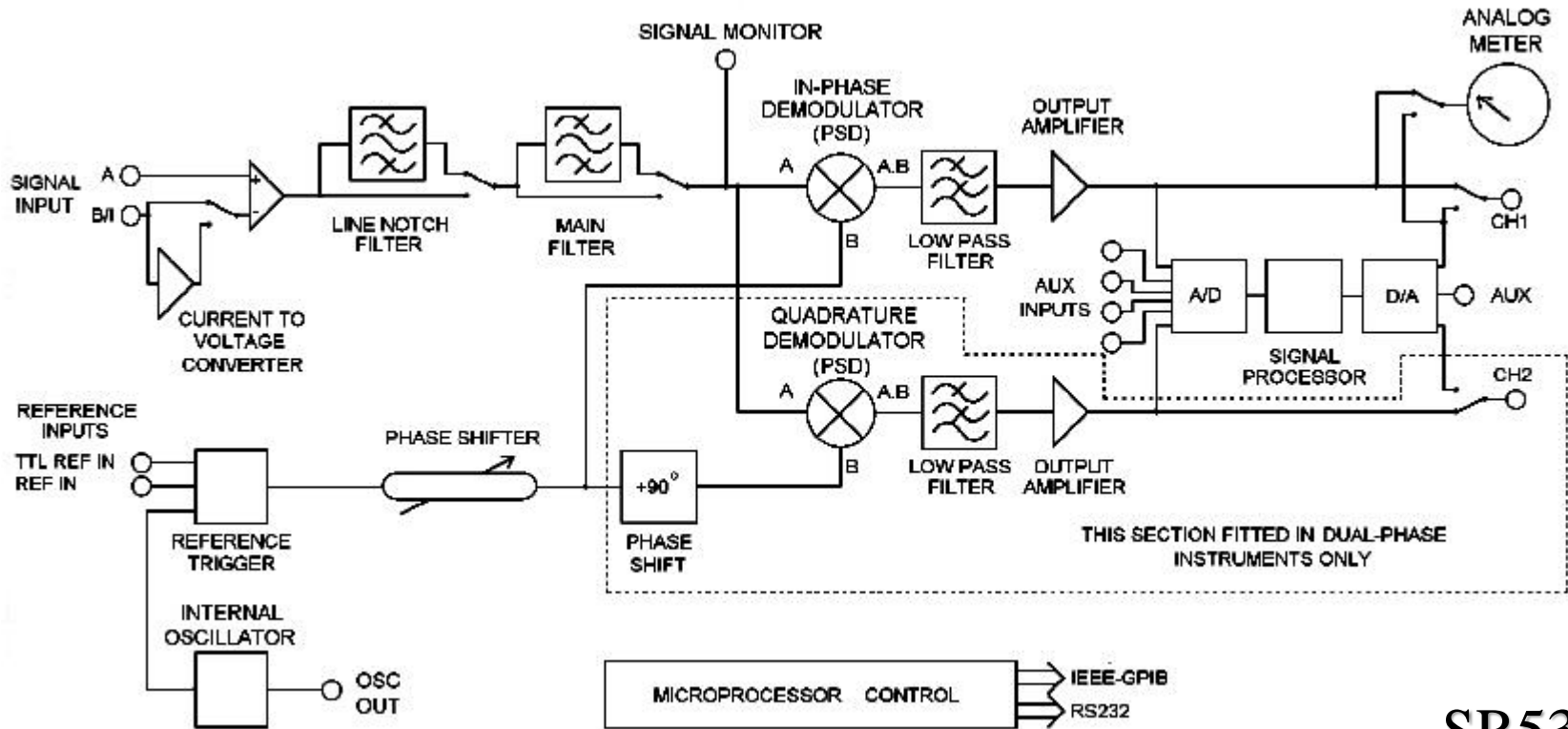


- 0.5 Hz to 100 kHz frequency range
- Current and voltage inputs
- Up to 80 dB dynamic reserve
- Tracking band-pass and line filters
- Internal reference oscillator
- Four ADC inputs, two DAC outputs
- GPIB and RS-232 interfaces

## Analog lock-ins from Stanford Research Systems

# Lock-in amplifier technique

# Analog lock-ins



SR530

Block-diagram of analog lock-in

## Lock-in amplifier technique

## Analog lock-ins



**SR124**

- Low noise, all analog design**
- No digital interference**
- 0.2 Hz to 200 kHz measurement range**
- Low noise current and voltage inputs**
- Harmonic detection (f, 2f, or 3f)**
- Selectable input filtering**

# Lock-in amplifier technique

# Digital lock-ins



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

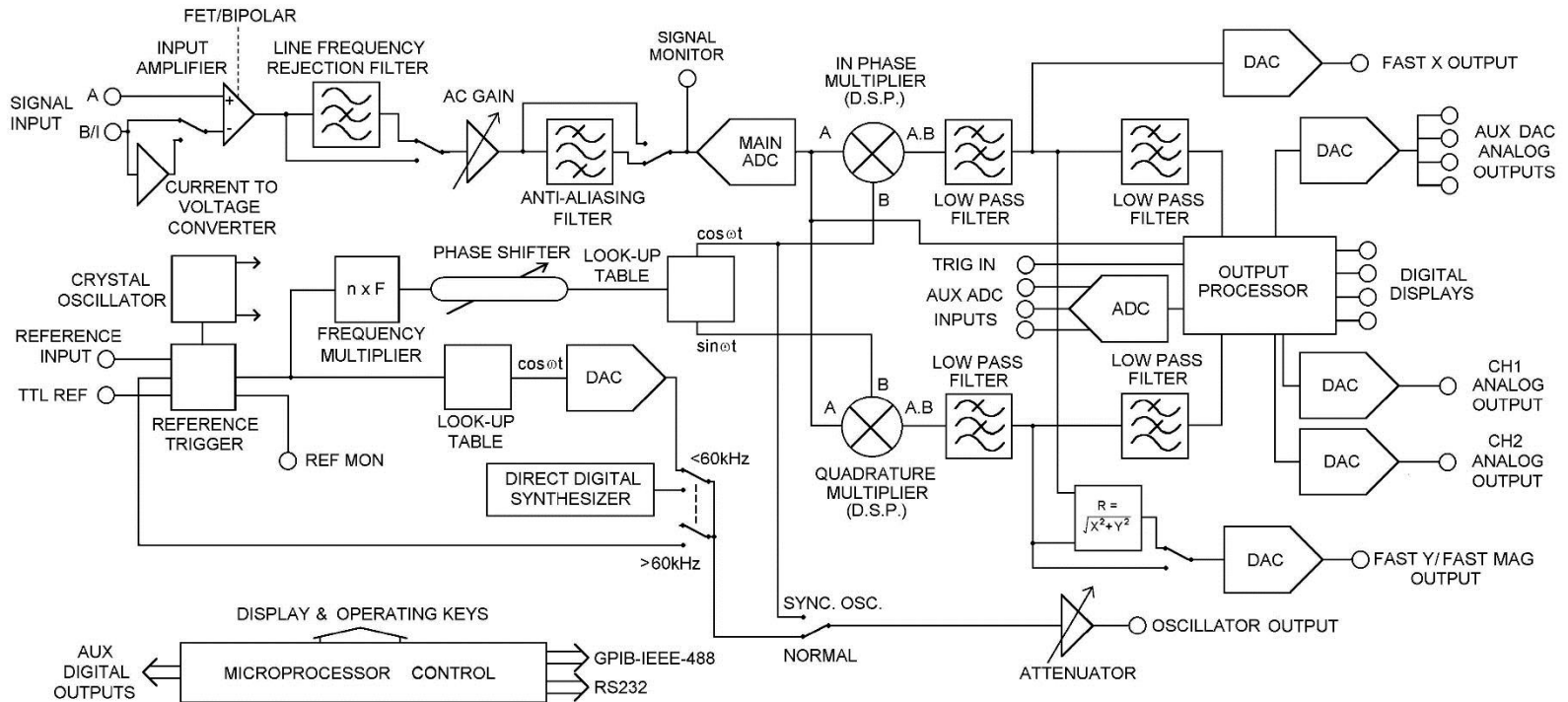


**The main advantages of digital lock-ins:**

- \* 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

# Analog and digital lock-ins

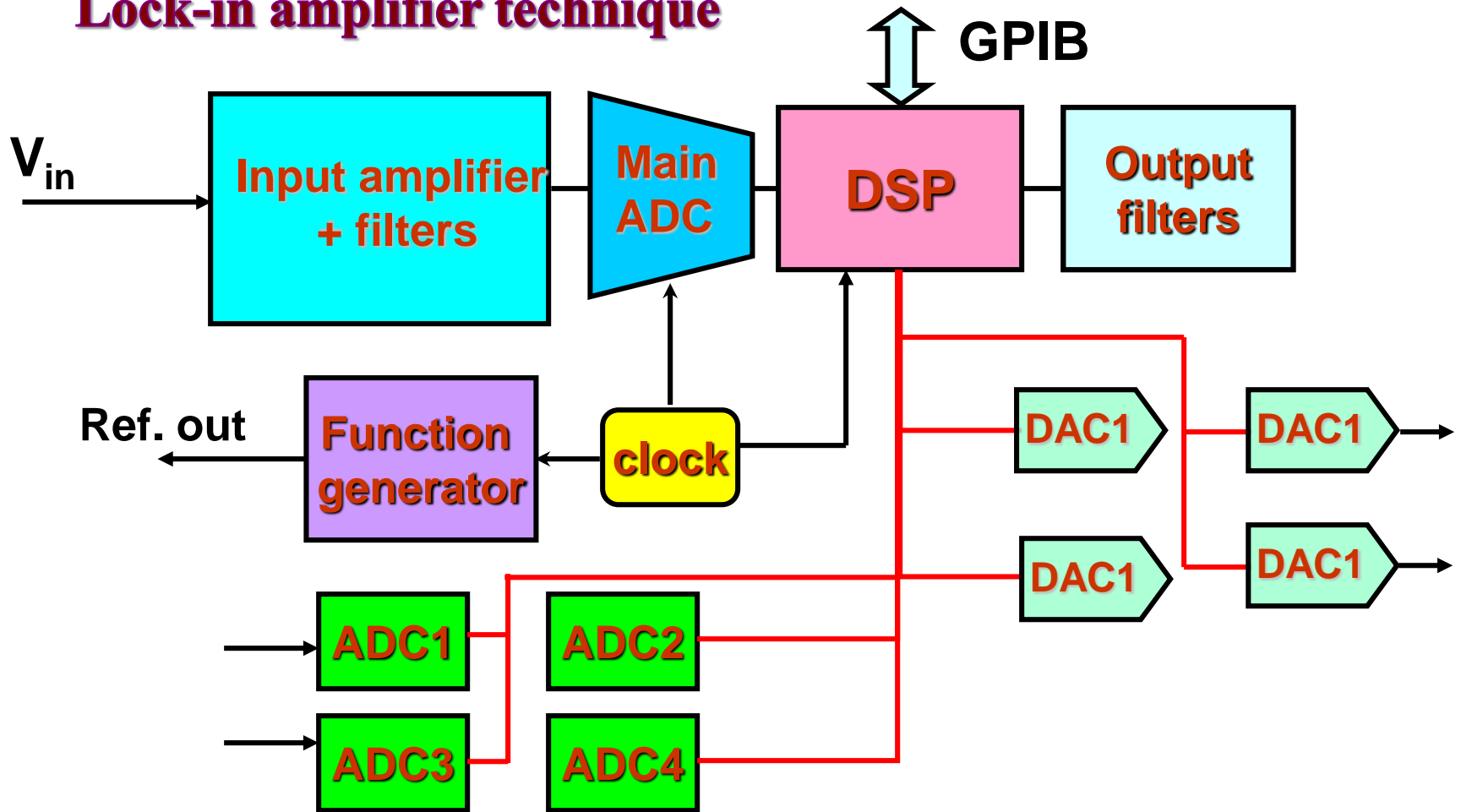


**SR830**

## Block-diagram of digital lock-in

# Lock-in amplifier technique

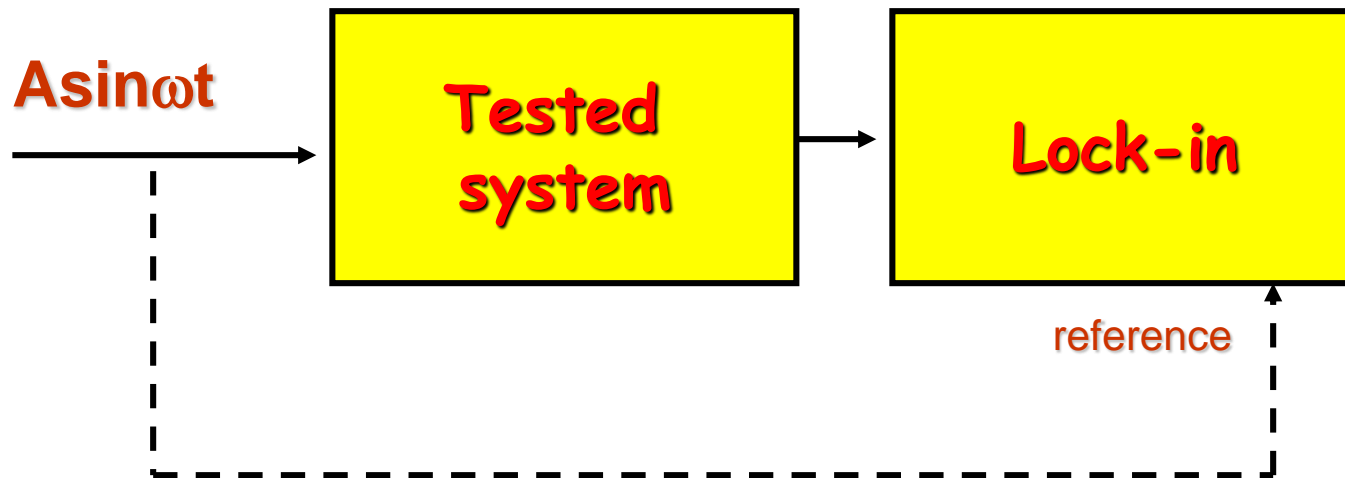
SR830 digital lock-ins



Block-diagram of digital lock-in

## Lock-in amplifier technique: some applications

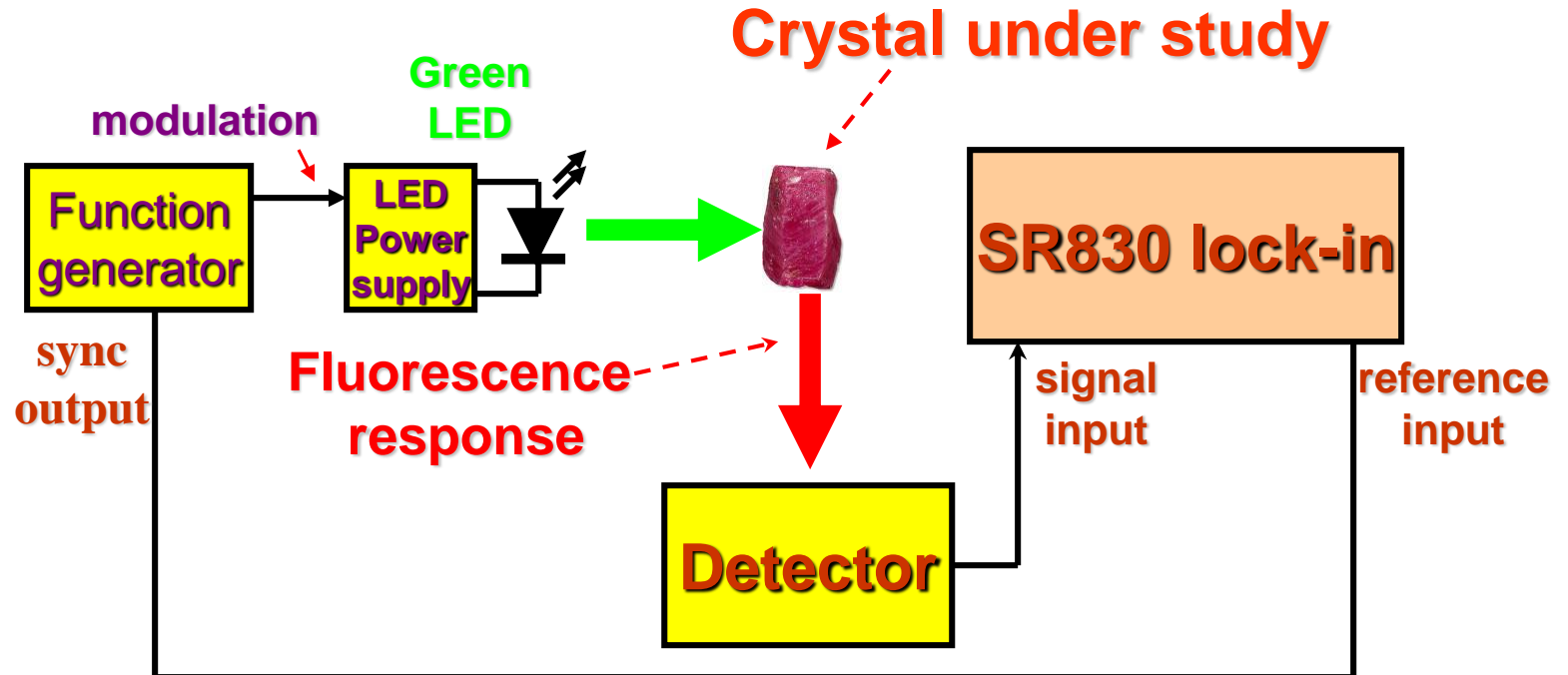
(i) Applying a small test signal (locked to the reference signal) to the studied object



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

# Lock-in amplifier technique: some applications

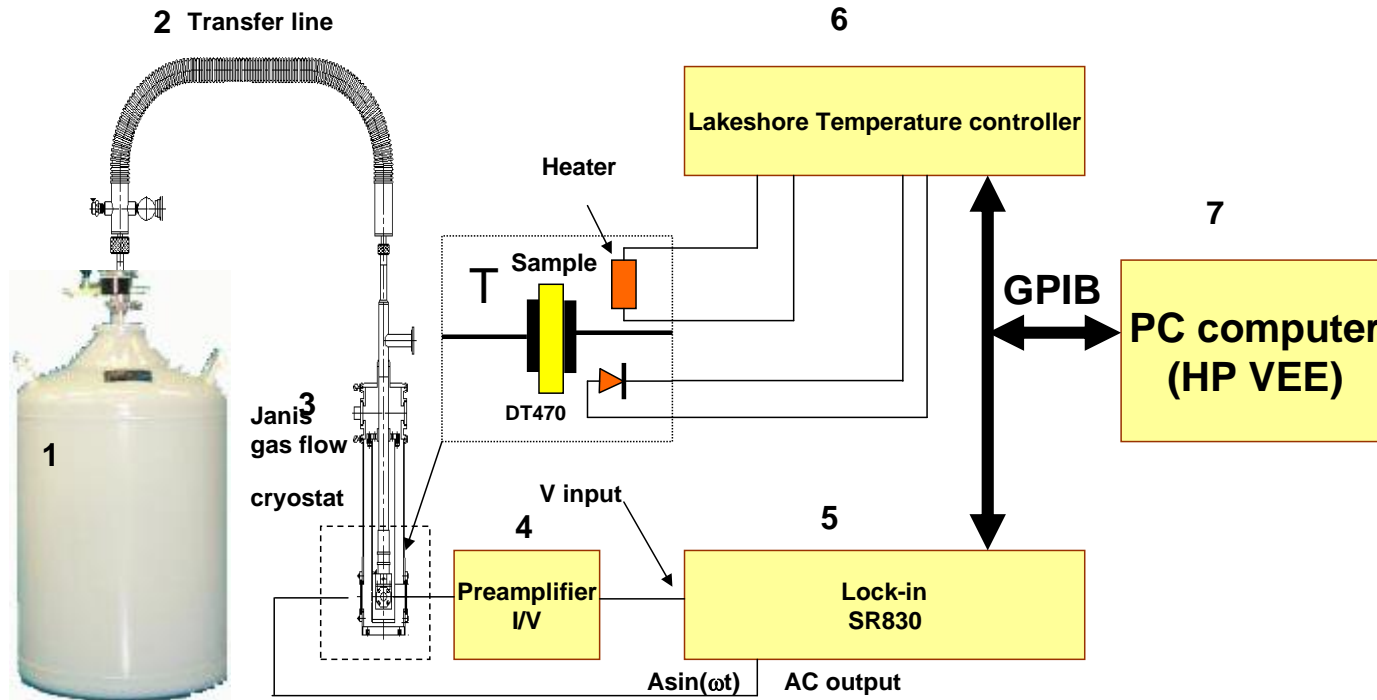
(ii) Modulating of the studied signal by the signal locked to the reference signal



Examples: fluorescence experiment



# Lock-in amplifier technique: some applications



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

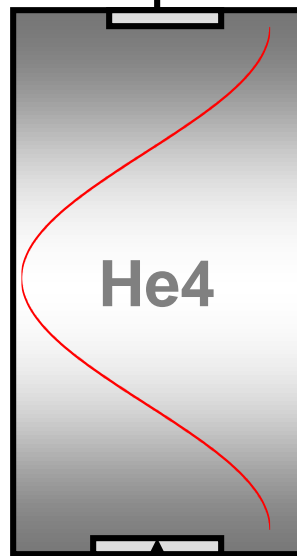
# Lock-in amplifier technique: some applications

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

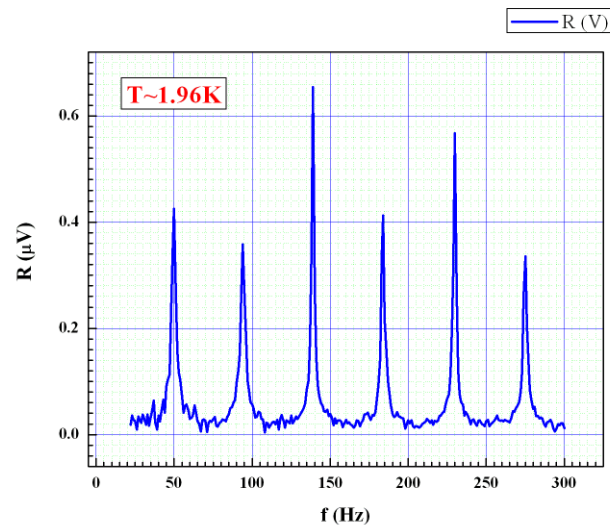
## Second sound experiment



Receiver



He4

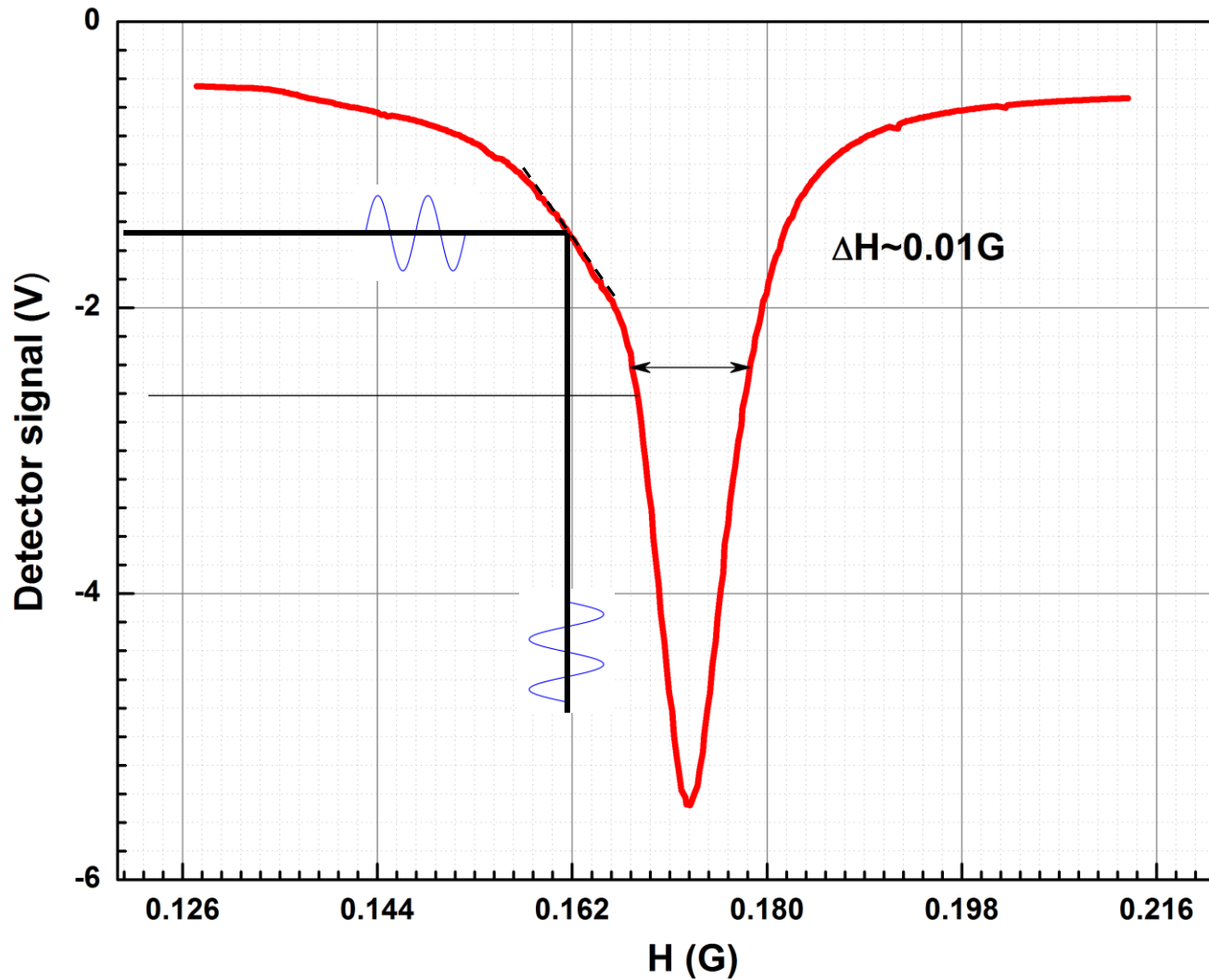


AC drive signal

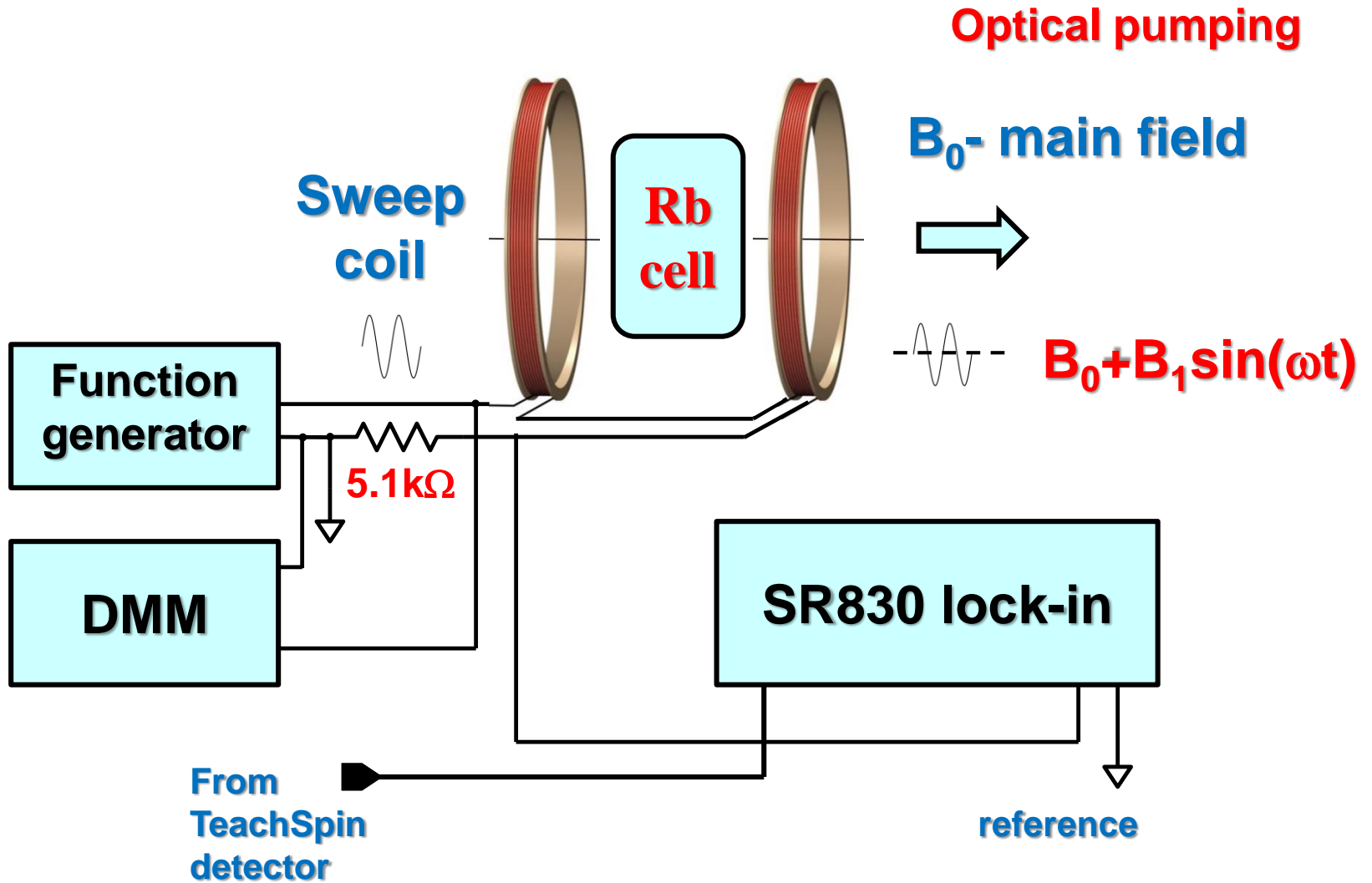
Transmitter (heater)

# Lock-in amplifier technique: some applications

## Optical pumping



# Lock-in amplifier technique: some applications



# Lock-in amplifier technique: some applications

Optical pumping

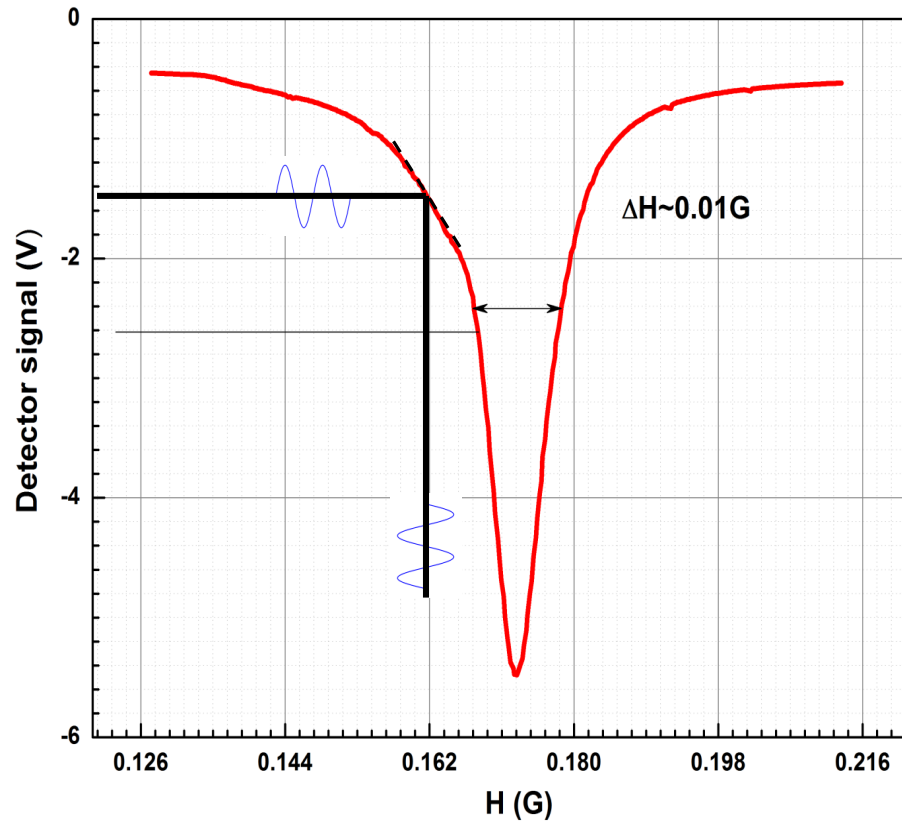
The choice of  
amplitude modulation

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

$$B_1 = k_{sweep} \cdot I_{sweep}$$

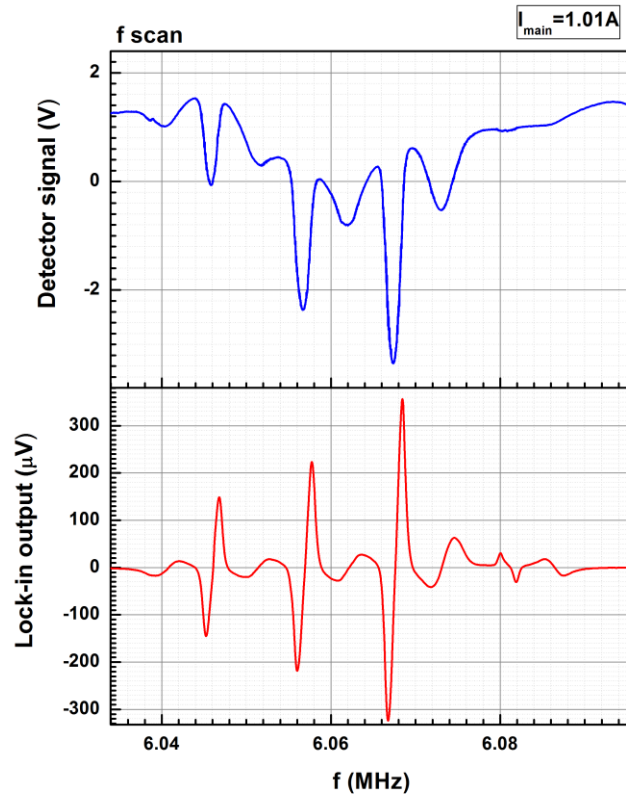
$$K_{sweep} \cong 0.6G/A$$

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



# Lock-in amplifier technique: some applications

## Optical pumping

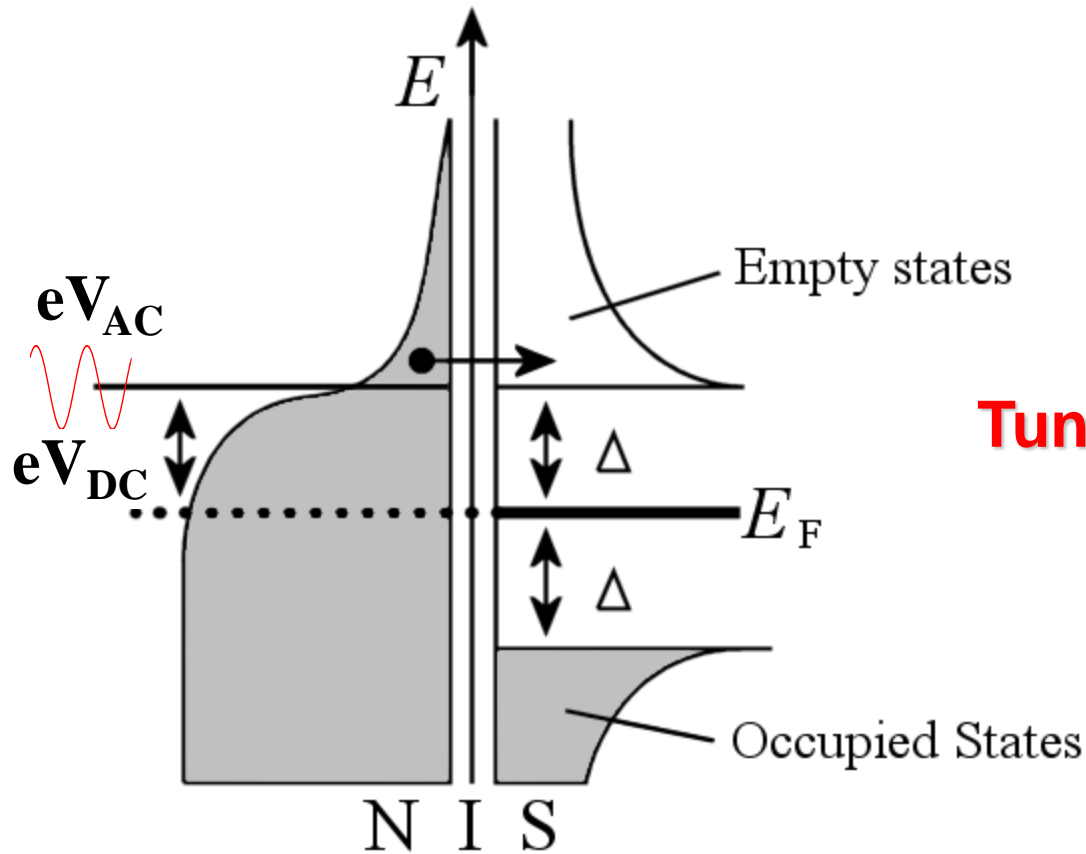


Mapping 0.5-2.5A from March 1st 2012: Graph6

**Analog detector record  $I(f)$**

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

# Lock-in amplifier technique: some applications



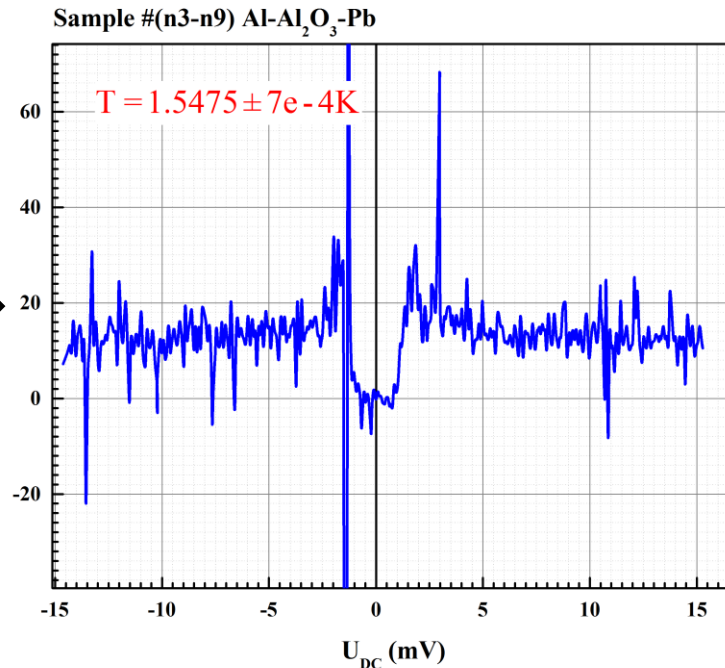
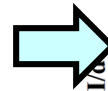
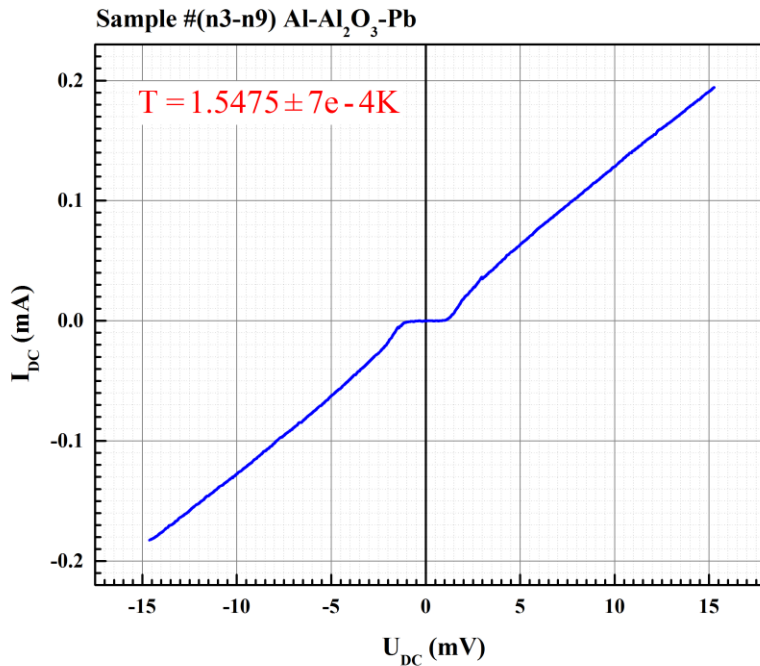
$$eV_{DC} + eV_{AC}$$

**Tunneling spectroscopy**

# Lock-in amplifier technique: some applications

## Tunneling spectroscopy

$eV_{DC}$  only



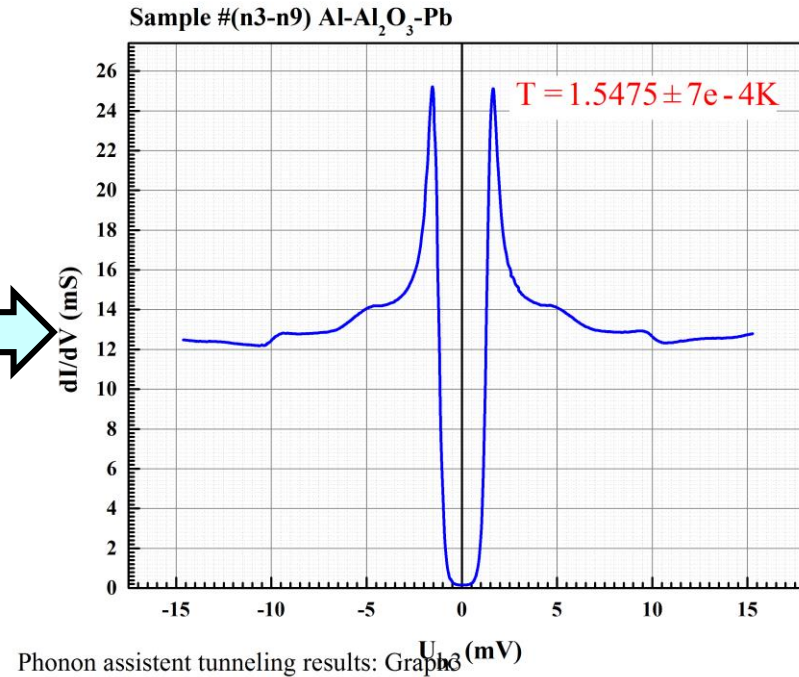
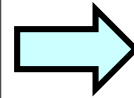
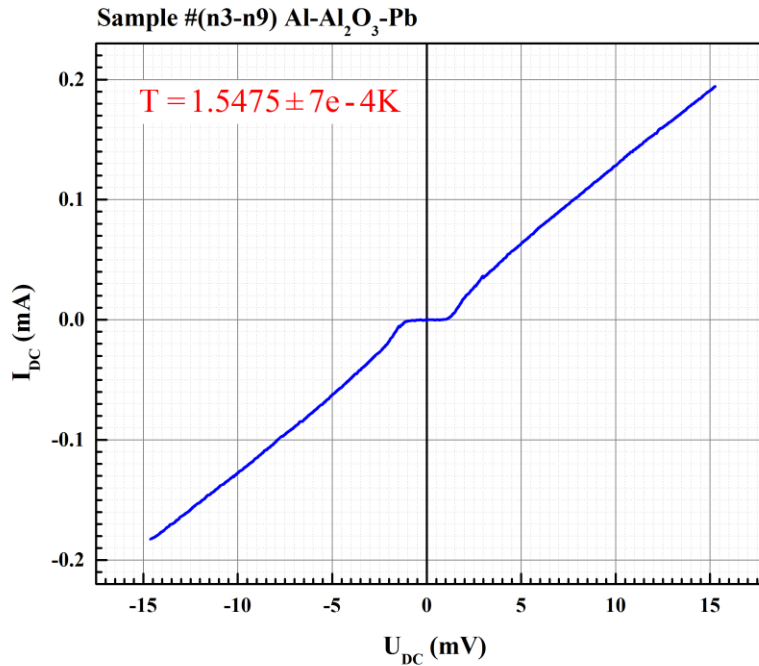
*Courtesy of Anna Miller and Everett Vacek*



# Lock-in amplifier technique: some applications

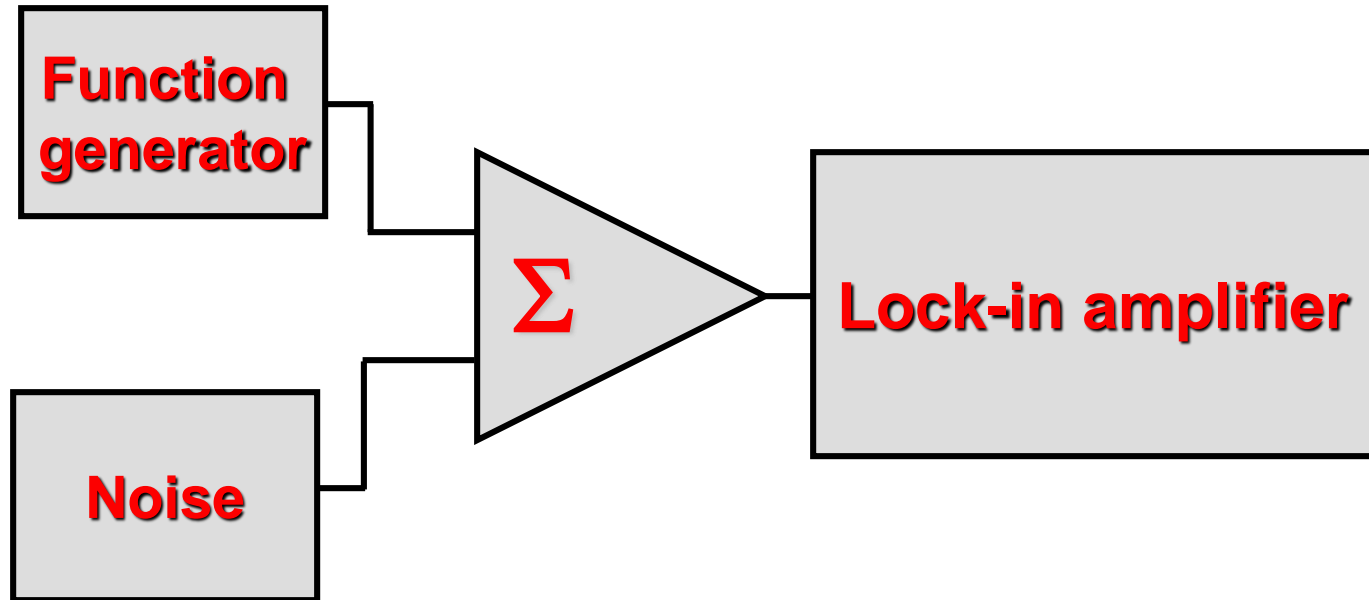
## Tunneling spectroscopy

$$eV_{DC} + eV_{AC}$$



*Courtesy of Anna Miller and Everett Vacek*

# Lock-in amplifier technique: demo



demo lock-in