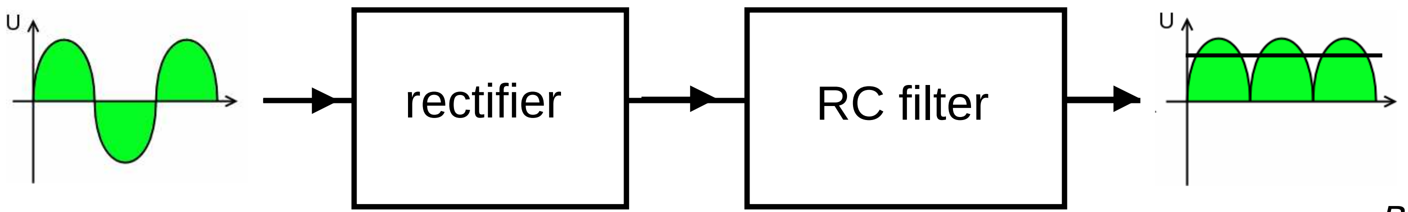
Synchronous detection

Laurea Specialistica in Fisica
A.A. 2007/08

Dr. Francesco Quochi

Detection of an AC signal

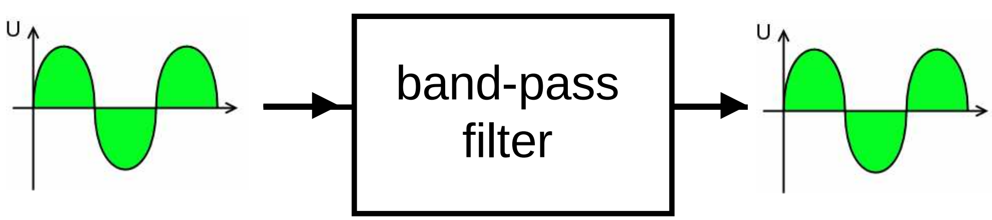
- rectifier + low-pass (e.g., RC) filter



Filtered noise: $\sigma^2_{\text{noise}} = \int_0^B S(f')df'$

$B = 1/2\pi RC$

- band-pass filter



Filtered noise:

$$\sigma^2_{\text{noise}} = \int_{f-B/2}^{f+B/2} S(f')df'$$

$$B = f/Q \gg 1/2\pi RC$$

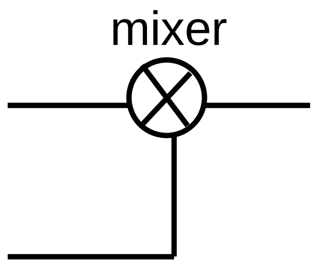
Phase-sensitive detection PSD

PSD to single out the signal at given frequency

Advantages:
- ✓ inherently AC measurement (no rectification)
- ✓ time integration with small bandwitdth

signal

$V_S \sin(2\pi ft + \varphi_S)$



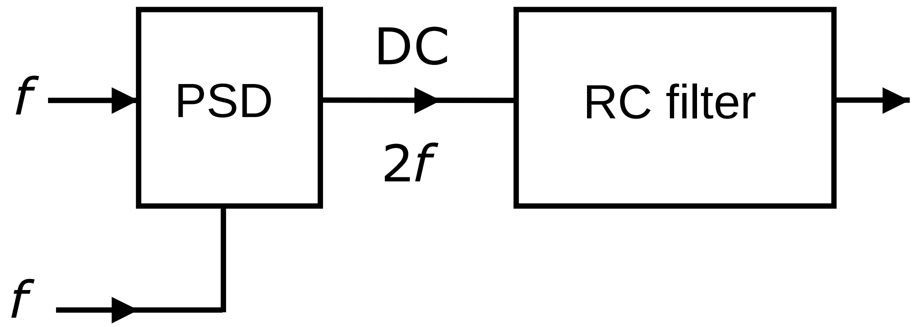
$V_R \sin(2\pi ft + \varphi_R)$

reference
at same frequency

$$V_{PSD} = V_S V_R \sin(2\pi ft + \varphi_S)\sin(2\pi ft + \varphi_D) =$$
$$\frac{1}{2}V_S V_R \cos(\varphi_S - \varphi_D) - \frac{1}{2}V_S V_R \cos\left[2\pi(2f) + \varphi_S + \varphi_D\right]$$
$$\propto V_S \cos(\Delta\varphi) + \text{sum-frequency term}$$

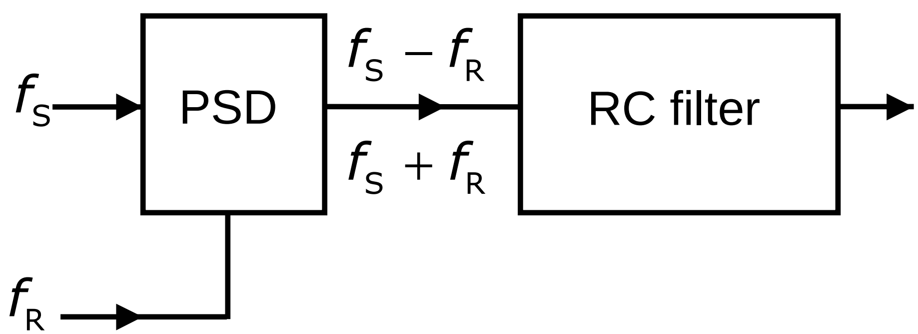
PSD with low-pass filter

1) $f_S = f_R = f$



$$S_{out} = \frac{A_s}{\sqrt{2}}\cos(\Delta\varphi)$$

2) $f_S \neq f_R$

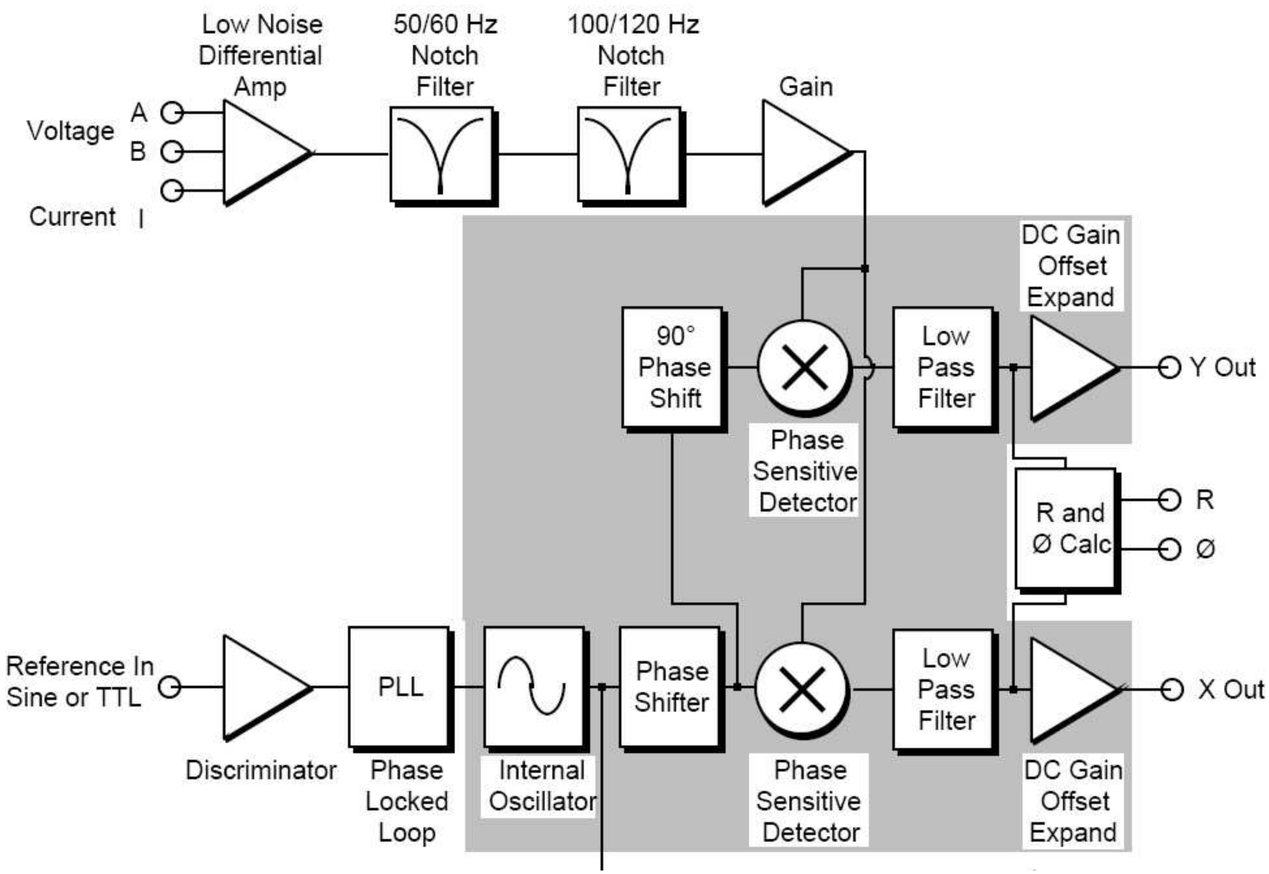


$$S_{out} = \frac{A_s}{\sqrt{2}}\cos(f_S - f_R + \Delta\varphi)$$

$$0 \text{ if } \left|f_S - f_R\right| > B$$

Lock-in amplifier

- AC amplification
- dual phase detection + integration → amplitude and phase retrieval
- DC amplification



$$X = \frac{V_S}{\sqrt{2}}\cos(\Delta\varphi)$$

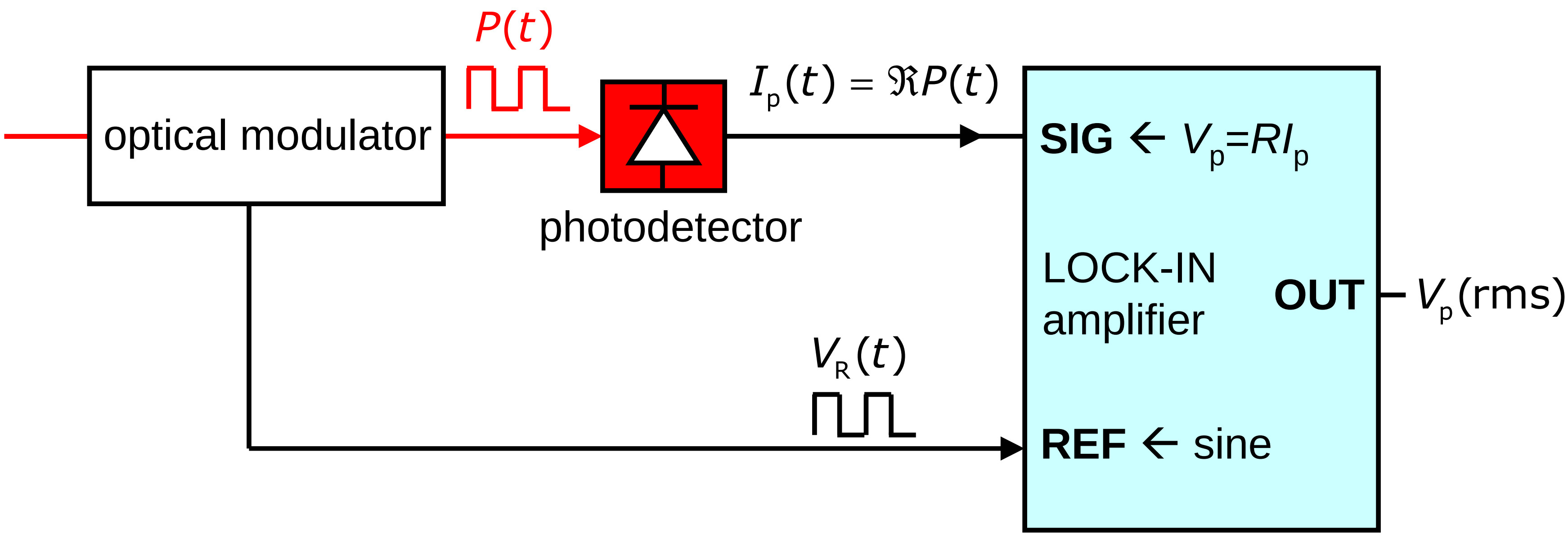
$$Y = \frac{V_S}{\sqrt{2}}\sin(\Delta\varphi)$$

$$R = \sqrt{X^2 + Y^2} = \frac{V_S}{\sqrt{2}}$$

$$\Delta\varphi = \tan^{-1}\left(\frac{Y}{X}\right)$$

Lock-in detection

- amplitude modulation of the optical signal
- generation of a reference signal at same frequency
- measurement with lock-in amplifier



Noise measurement using lock-in detection

- generation of a reference signal at noise frequency
- measurement of device (photodetector) noise with lock-in amplifier