Noise and Drift

- Noise sources
- Noise Characterization
- Noise abatement
- Signal recovery

Noise Sources

Thermal noise: $I_{th} = \sqrt{\dfrac{4k_B T f_{3dB}}{R_{shunt}}}$

Shot noise: $I_{shot} = \sqrt{2q(I_p + I_d)\, f_{3dB}}$

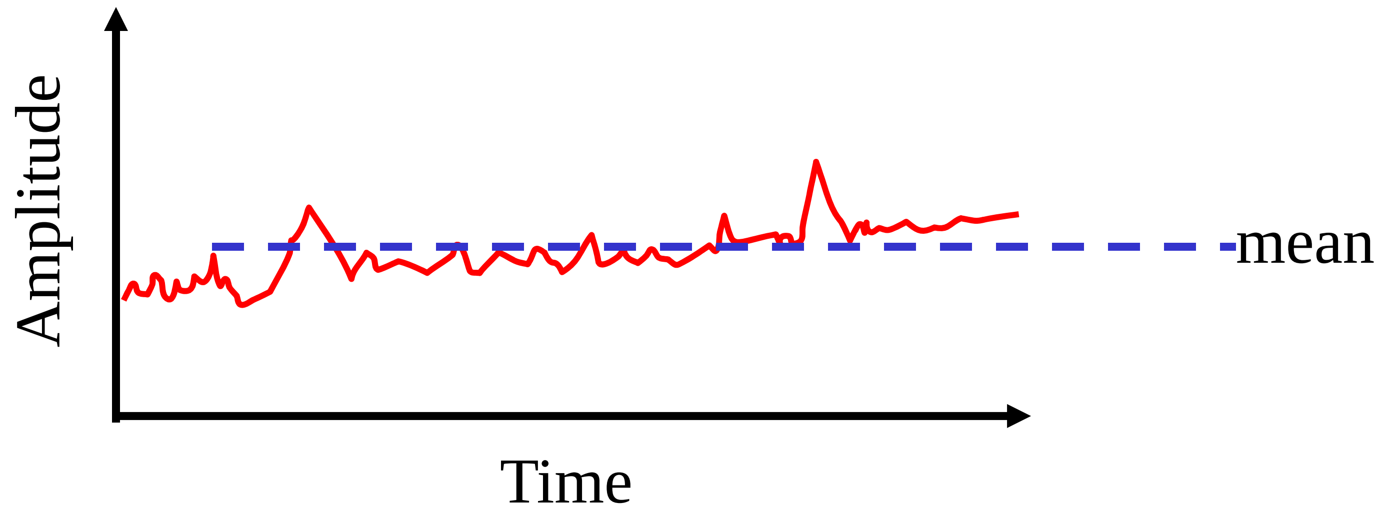
1/f noise: Thermally ionized traps, miscellaneous effects

Readout noise: Electronic circuitry associated with arrays

Interference: EMI: power line harmonics, radio and microwaves, digital and power switching noise

Thermal drift: Amplifier gain depends on temperature

Time Domain Characterization



- Peak-to-peak deviation: V_{max} - V_{min}
- Root-mean-square (rms) deviation: $\left[\frac{1}{T}\int\left(V(t)-V_{mean}\right)^2 dt\right]^{1/2}$
- Specify time period of measurement

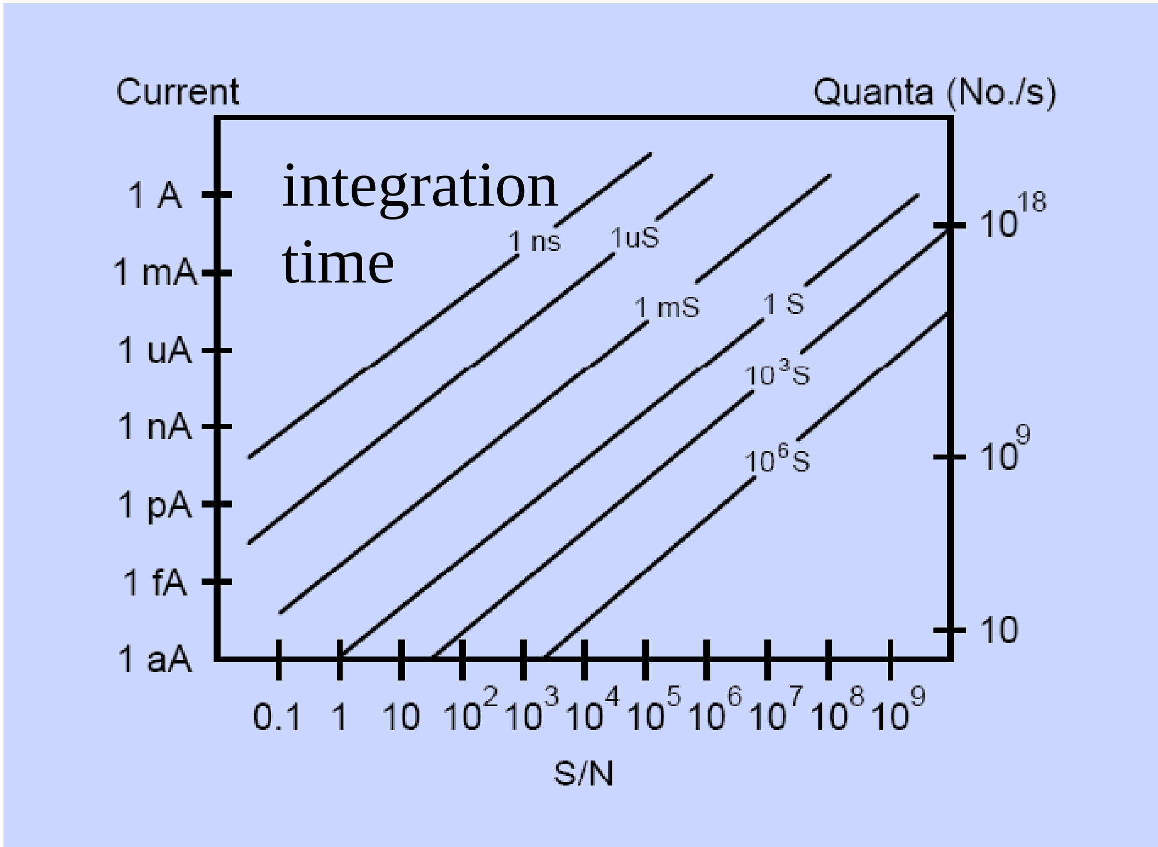
Signal Averaging

$$\frac{SNR_{out}}{SNR_{in}} = \sqrt{\text{Number of samples}}$$

- Time-integrated signal: what "DC" instruments measure
- Example: Optical power meters with adjustable integration time
- Drift in experiment limits amount of averaging possible

  (ambient temperature drift, sample degradation…)

Shot Noise Limited SNR

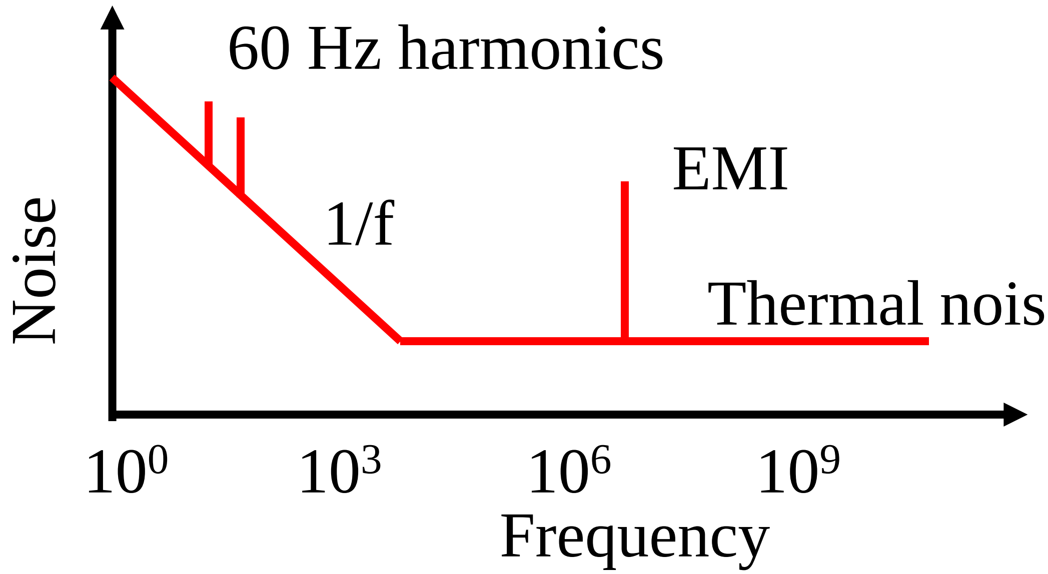


Example

1E-9 BER requires SNR ~ 10

1 ns integration time (1 Gbps) requires 1 microamp photocurrent

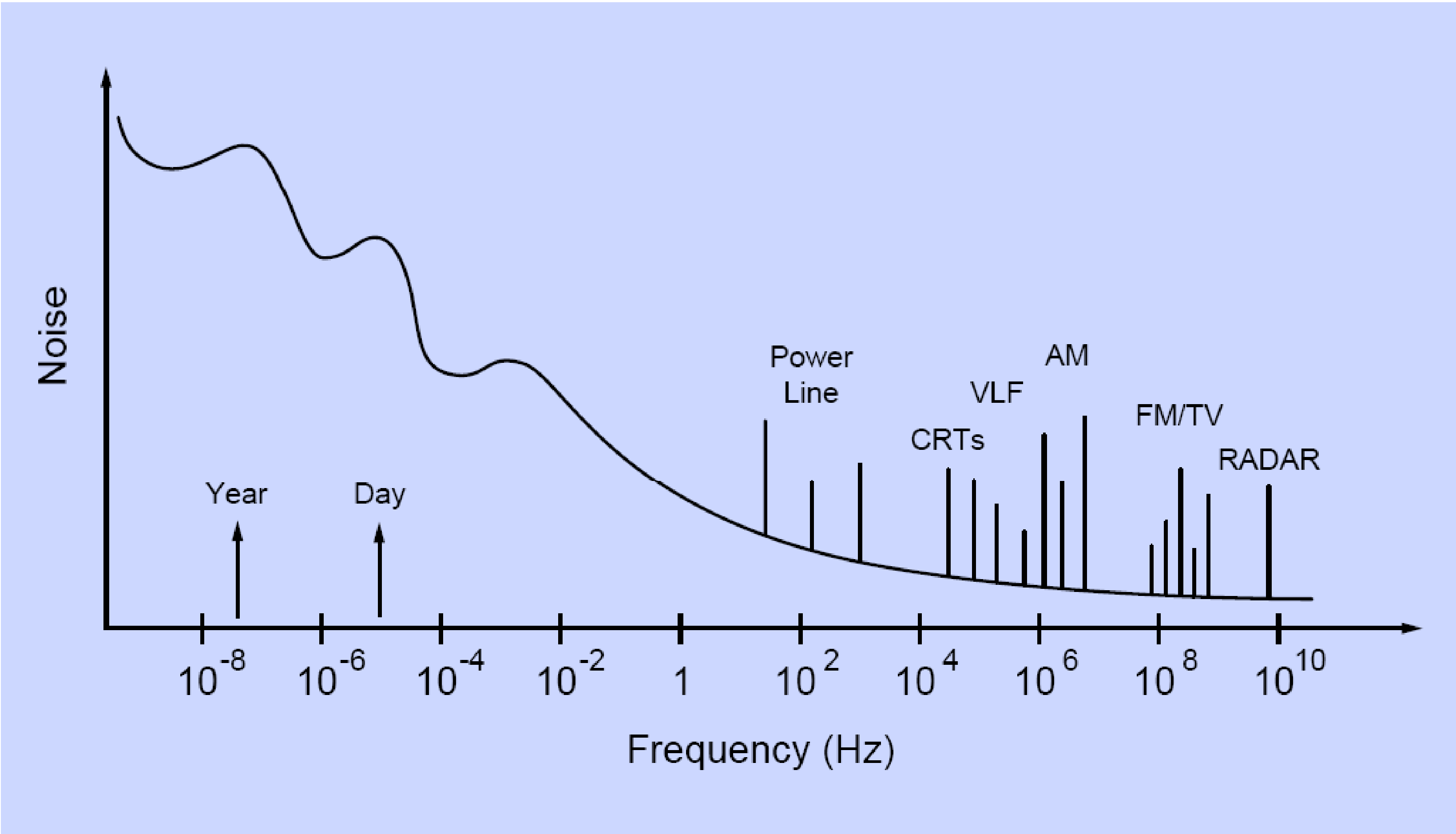
Frequency Domain Characterization



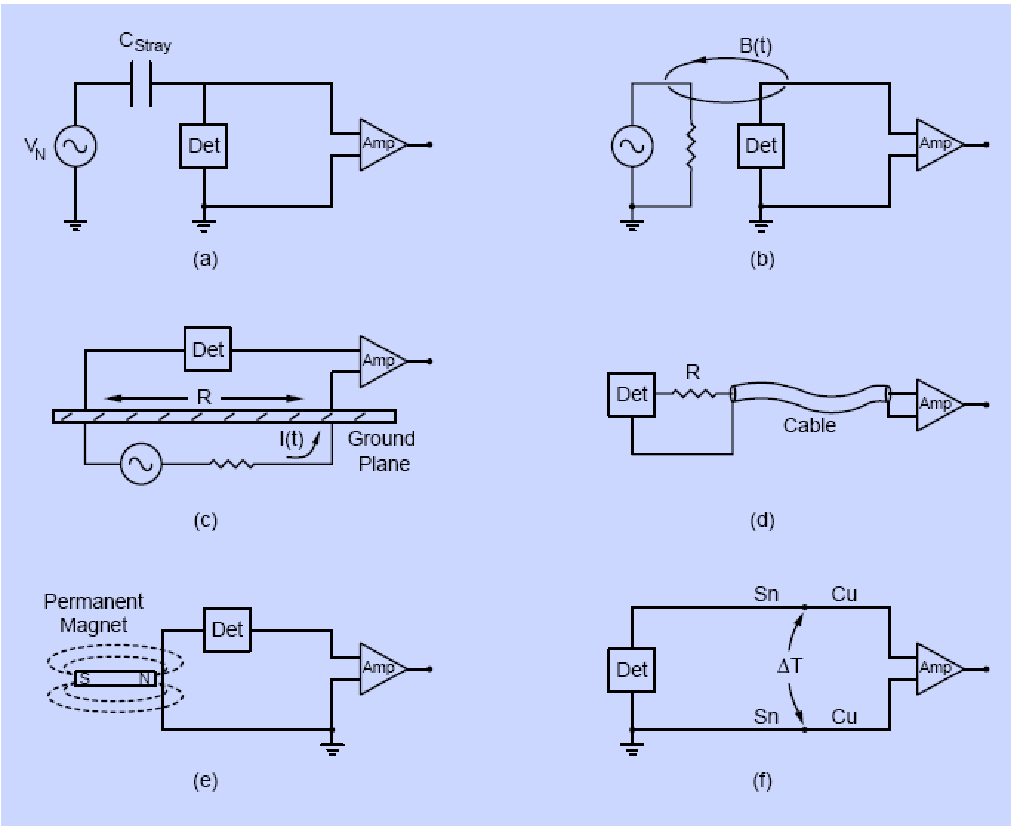
Noise power spectral density: W/Hz

Noise voltage spectral density: V/Hz ^{½}, I/Hz $^{1/2}$

Noise Spectrum



Coupling External Noise Sources

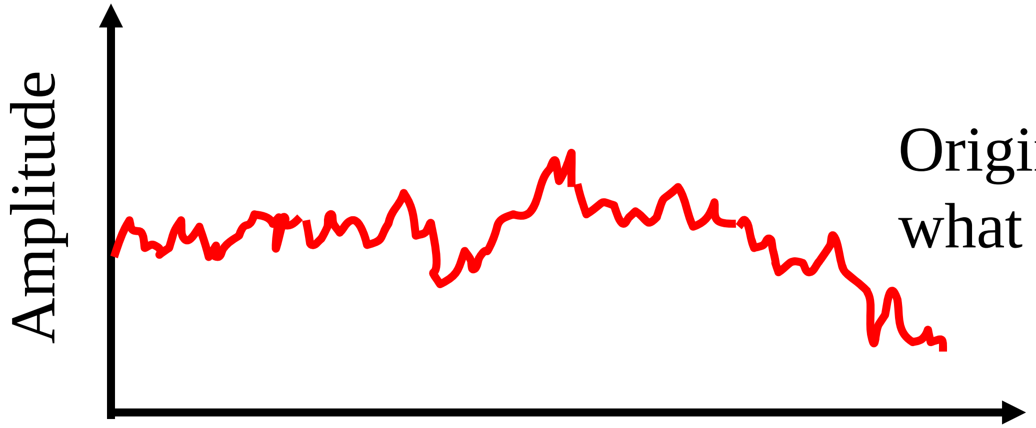


- Capacitive
- Inductive and magnetic
- Ground loops
- Microphonics
- Accidental thermocouples
- Injected via power cord

Noise Abatement

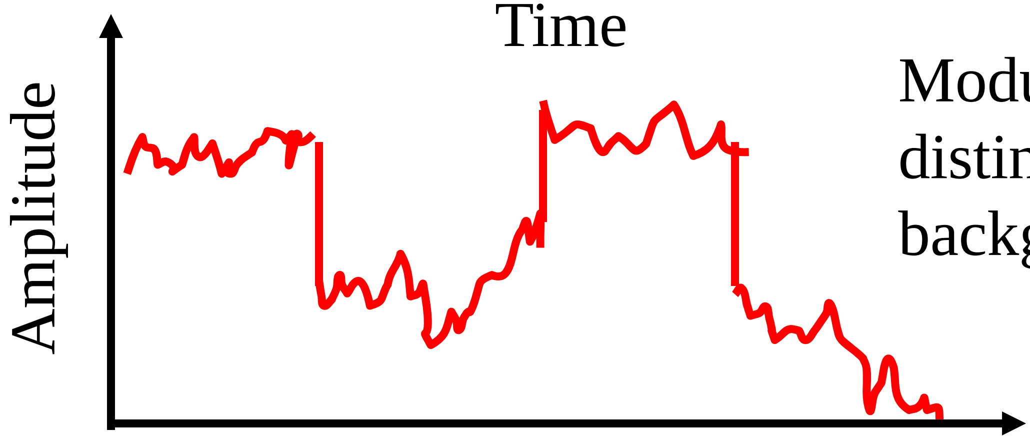
- Shielding: coax, twisted pair, Faraday screens
- Differential inputs
- Bandwidth limiting
- Modulation in quiet frequency range
- Synchronous detection

AC Techniques



Time

Original: What is signal, what is background?

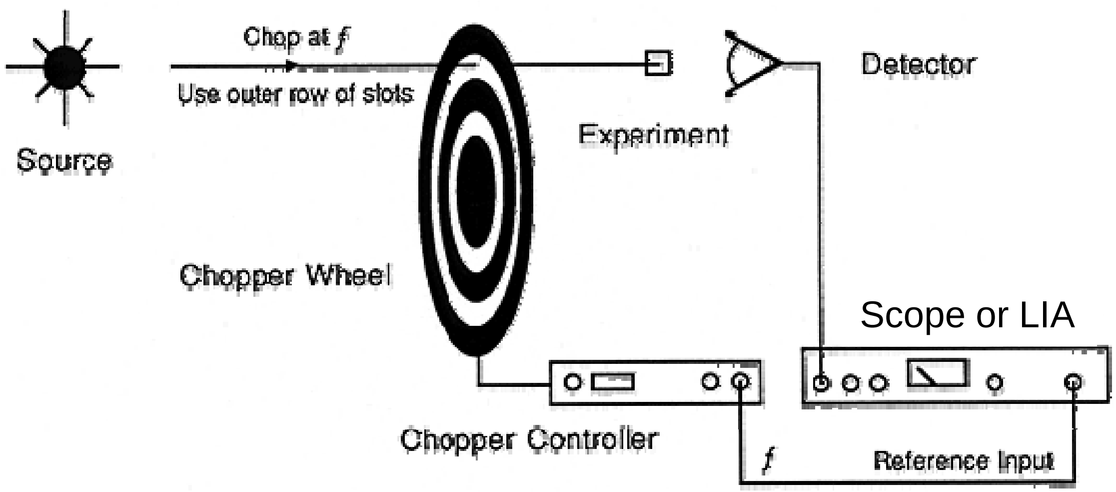


Time

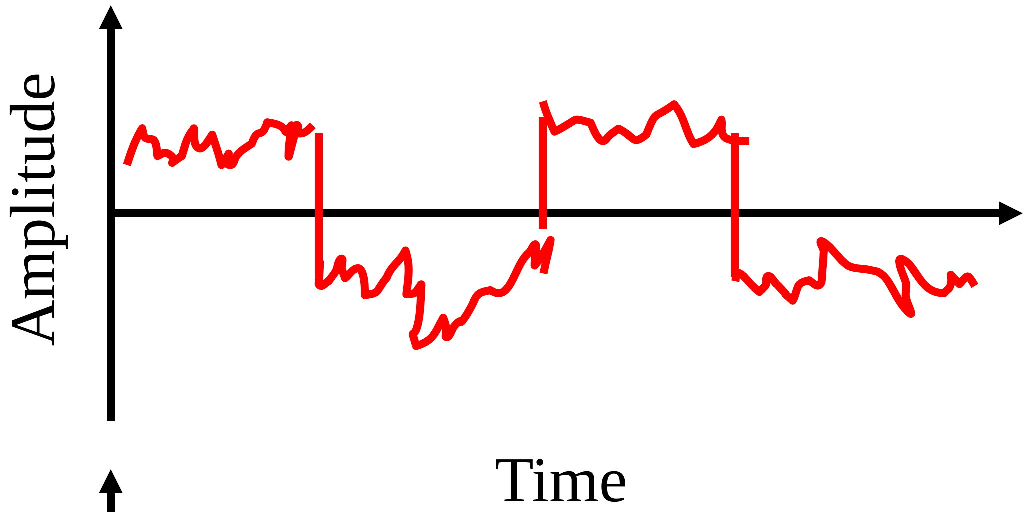
Modulate signal to distinguish from background

Modulation Methods

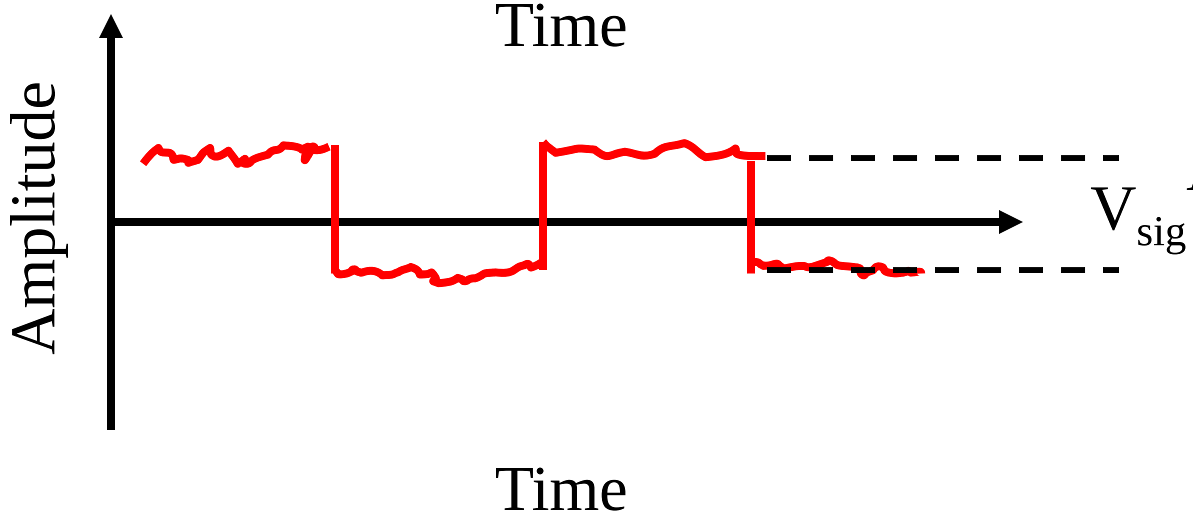
- Direct modulation of LEDs, diode lasers
- Mechanical shuttering of lamps, gas or solid state lasers



AC Techniques

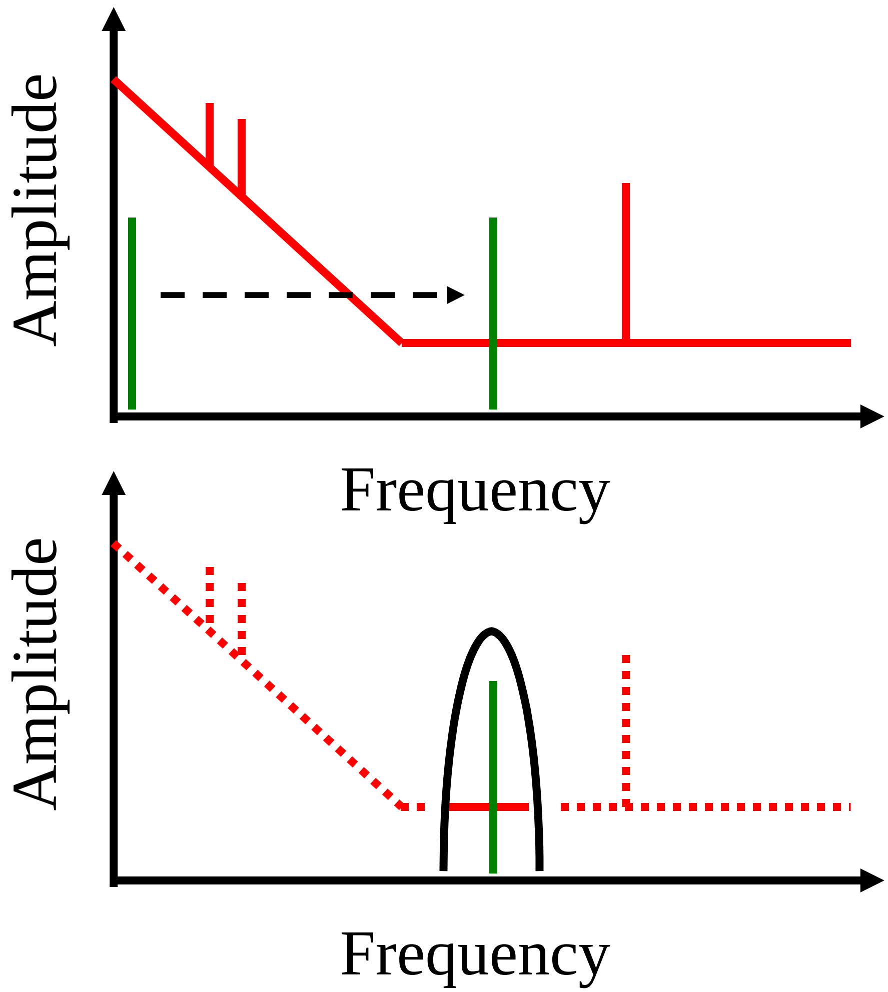


AC-Coupling
removes slow drift



Averaging

Frequency Domain Interpretation



Modulation moves signal away from 1/f noise and drift near DC

Averaging (filtering) limits noise bandwidth

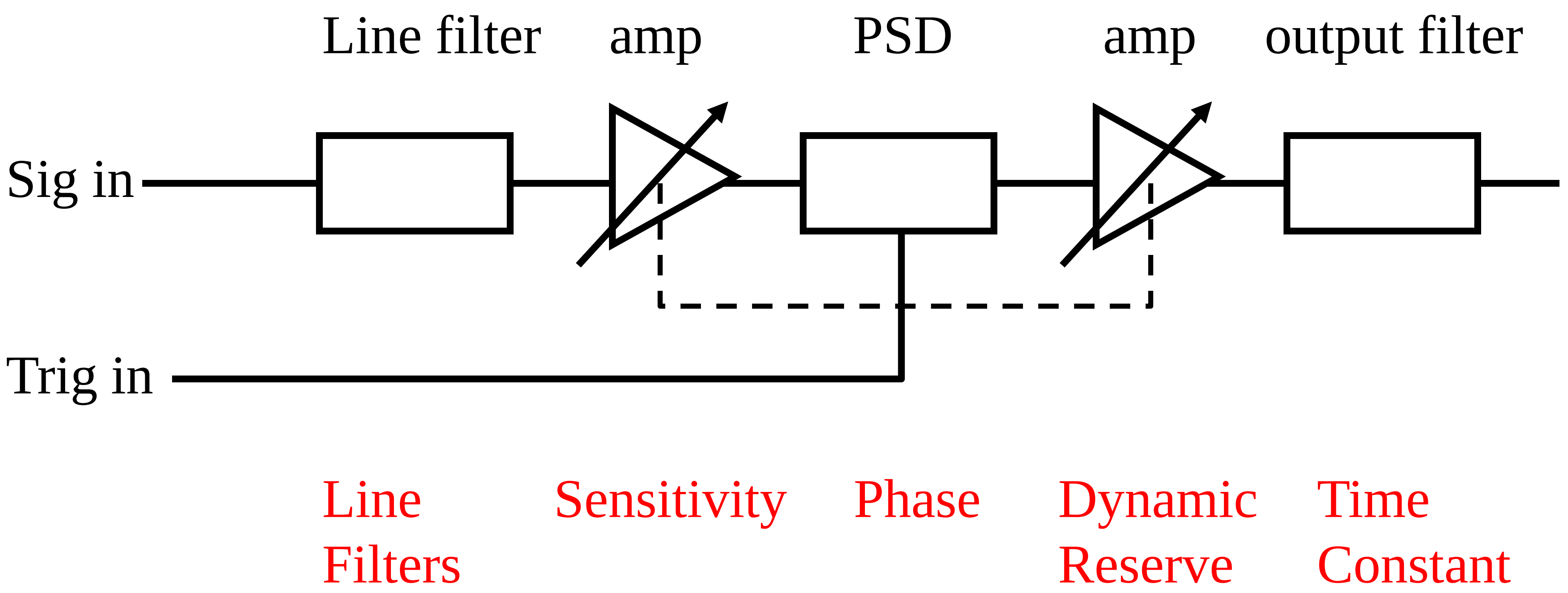
$$\frac{SNR_{out}}{SNR_{in}} = \frac{BW_{in}}{BW_{out}}$$

Problems with DSOs

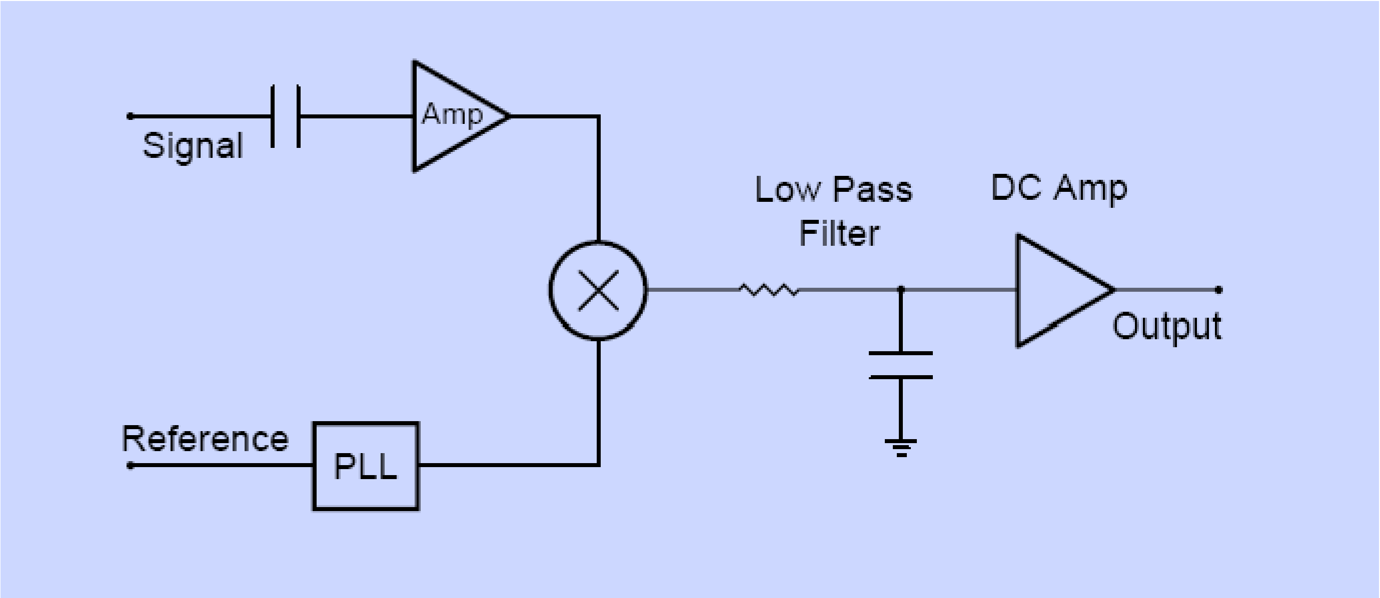
- Equivalent time sampling slows data collection
- Limited amplitude resolution: 8-bit DAC common
- Limited sensitivity: 1 mV common
- Relatively poor noise performance
- Limited dynamic range: poor rejection of interference

- DSOs can measure signals with fast modulation

Lock-in Amplifiers



Phase Sensitive Detection



Lock-in amplifier block diagram

$$A\cos(\omega_1 t+\phi)\times B\cos(\omega_2 t)=\frac{1}{2}AB[\cos((\omega_1+\omega_2)t+\phi)+\cos((\omega_1-\omega_2)t+\phi)]$$

Only signal components at the modulation frequency remain

LIA Advantages

- High sensitivity from high-gain low-noise amplifier
- Analog input filters suppress line noise
- Tracking filter with variable bandwidth
- High resolution A/D for high dynamic range
- Maintains phase information

LIA Terminology

- Sensitivity: signal (I or V) needed for full scale response
- Time constant and slope (dB/Octave) of the final filter
- Dynamic reserve: Max interference level / min signal level
- Line filters f, 2f: additional rejection of power line harmonics
- Single phase or dual phase:
    - single phase requires manual adjustment of ($\theta_{sig} - \theta_{ref}$)
    - dual phase calculates quadrature (xy) or Mag-phase (Rθ)

SRS 830 LIA

- Analog input filters, but the rest is done with DSP

Some Lock-in Amp Details

- Current or Voltage input accommodates various signal sources
    - gain or transimpedance (V/A) $10^6 – 10^8$
- Full scale sensitivity down to nV / fA range
- Input filters avoid saturating input amp with line noise
- Time constant ~ 1/BW
    - allow signal to settle for 3 TCs, for accuracy
- Trigger signal is renamed “reference”

More Lock-in Amp Details

- Dynamic Reserve setting transfers gain between input and output amplifiers. High reserve also has higher output drift
- Magnitude and phase information at output
- Phase sensitive detection also useful for feedback loops, and detection of transparency point in LD or SOA

Credits

- www.thinksrs.com/
- M. L. Meade, Lock-in Amplifiers, TK7871.58.L57 M43 1983