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Electronic Instrumentation

Chapter 3

Noise and Interference in Instrumentation Systems

Chapter 3. Noise and Interference in Instrumentation Systems

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- Origin of Noise in Circuits
- Noise Models for Amplifiers.
- Examples of Calculation of the Noise Limited Resolution in Signal Conditioning Circuits
- Interference. Sources of Coherent interference.
- Minimization of Interference Effects.
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Introduction

- Both noise and interference, though of different origin, provide a major limitation to the precision of measurements and the detectability/resolution
- The different origins for electronic noise and coherent interference leads to different approximations when trying to reduce their effects.
- IMPORTANT: Although systematization of the noise and coherent interference influence is available (and a brief discussion follows), in real systems experience of the designer's is critical, as sometimes it is impossible to take into account all sources of error/interference in the design.

Origins of Noise in Circuits (I)

- Noise is considered to arise in a circuit or measurement system from completely random phenomena: usually from thermal or quantum origins.
- We will consider noise sources to be stationary and with zero means. The latter means that the unwanted DC components are best considered to be drifts or offsets and their influence are to be treated separately.
- The characterization of noise sources is usually done in terms of their power density spectrum ($S_n(f)$ in W/Hz) defined as the Fourier transform of the autocorrelation fuction of the noise. In this sense we can classified noise sources as "White" ($S_n(f)$ constant over f) or "coloured".

Origins of Noise in Circuits (II)

- Thermal (Johnson) Noise: Any pure resistance at temperature T (K) has a noise associated with power density spectrum:

$$S_n(f) = 4\,K\,T\,\left(\frac{W}{Hz}\right)$$

- The voltage noise being:

$$v_n(f) = \sqrt[2]{4\,K\,T R}\,\left(\frac{V_{RMS}}{\sqrt[2]{Hz}}\right)$$

- Thermal Noise is white (above the crossover frequency) and is the main source of noise in electronic circuits:

Origins of Noise in Circuits (III)

- Shot (quantum) Noise: Associated to DC currents through potential barriers. Appears mainly in light detection (shot noise limit) and in active devices as transistors. Expressed in current:

$$i_{sn}(f) = \sqrt[2]{2qI_{DC}}\ \left(\frac{A_{RMS}}{\sqrt[2]{Hz}}\right)$$

- Shot noise is also white for all frequencies of interest in instrumentation.

Origins of Noise in Circuits (IV)

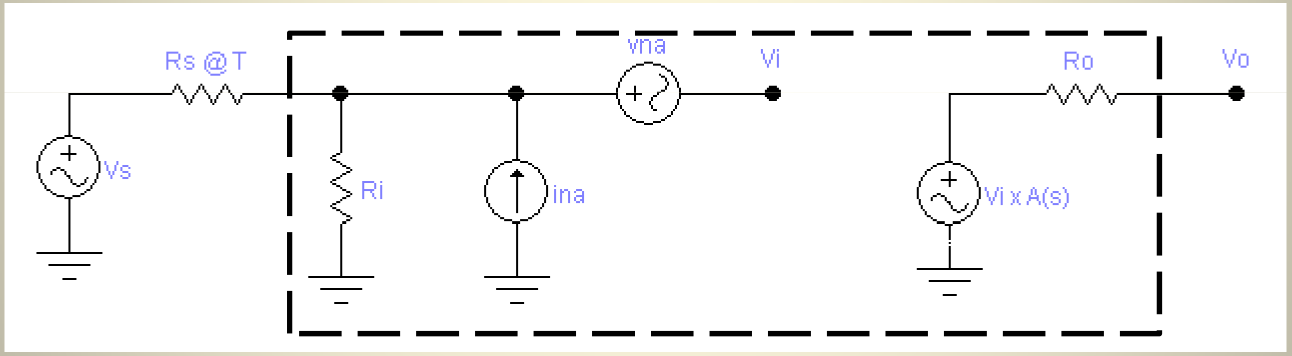
- Flicker (1/f) Noise: Associated to DC currents through Resistances. Is a colored noise of relevance only at low frequencies.

$$v_n(f) = \sqrt[2]{4\,KTR + A\frac{I^2}{f}}\ \left(\frac{V_{RMS}}{\sqrt[2]{Hz}}\right)$$

- Note that addition of noise sources is always done in variance (random errors)
- Crossover Frequency: frequency at which the flicker noise spectral density is equal to the white noise spectral density
- It is usually given in total peak-to-peak volt over a given bandwidth (example: AD620).

Noise Models in Amplifiers

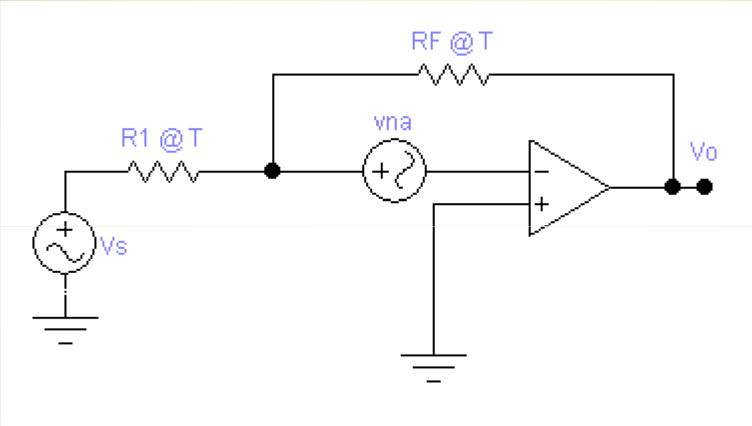
- Noise sources inside an amplifiers are multiple and it is impossible to address them separately. A model including only equivalent voltage and current noise sources are the input is used.



- Only white contributions (Thermal and Shot) are usually taken into account.

Examples of Noise Calculations: Noise limited Resolution (I)

- Minimum resolution at the output of an Inverter amplifier.



- Signal power: $$V_O^2 = \frac{V_S^2}{2}\left(\frac{R_F}{R_1}\right)^2 \ (V_{RMS}^2)$$
- Noise power: $$N_O = \left[4KT\left(\frac{R_F}{R_1}\right)^2 R_1 + 4KTR_F + v_{na}^2\left(1+\frac{R_F}{R_1}\right)^2\right] BW \ (V_{RMS}^2)$$

Examples of Noise Calculations: Noise limited Resolution (II)

- Signal to Noise Ratio:

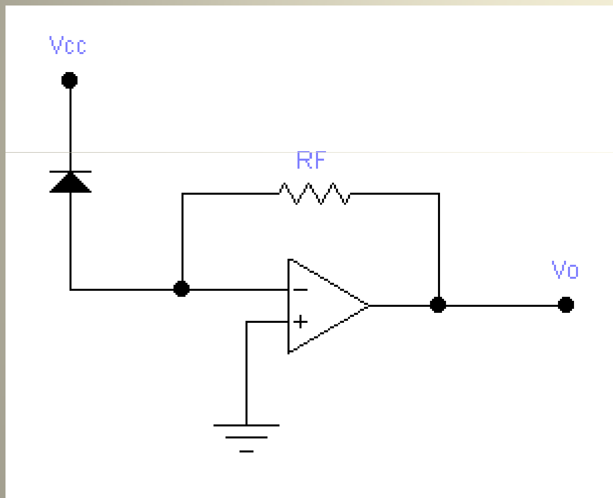
$$SNR = \frac{\frac{V_S^2}{2}\left(\frac{R_F}{R_1}\right)^2}{\left[4KT\left(\frac{R_F}{R_1}\right)^2 R_1 + 4KTR_F + v_{na}^2\left(1+\frac{R_F}{R_1}\right)^2\right] BW}$$

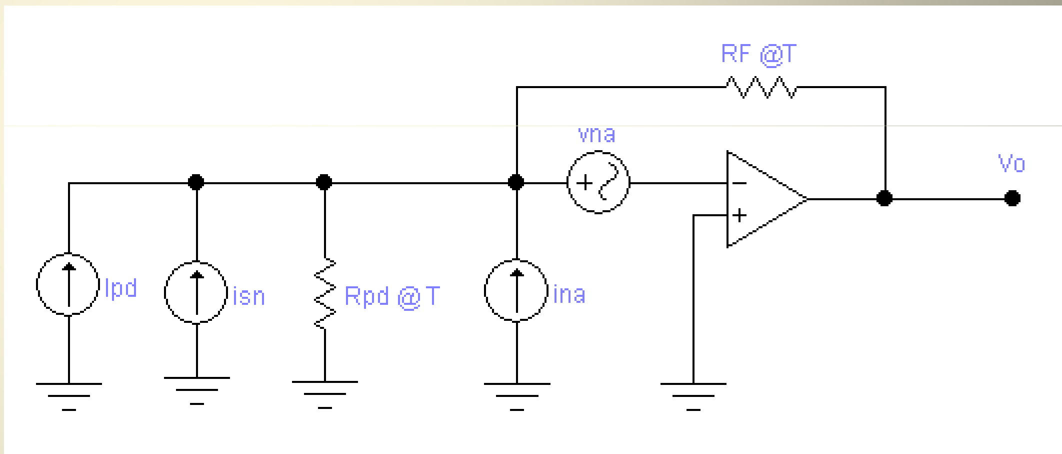
- Example:
  - Rf= 100 kΩ
  - R1= 1 kΩ
  - 4KT= 1.66 10^{-20} W/Hz
  - V_{na} =10 nV/√Hz
  - BW=200 kHz

SNR= 1 $\Rightarrow$ Vs (min) = 6.7 μV

Examples of Noise Calculations: Noise limited Resolution (III)

- Resolution in Photocurrent Measurement.





Input voltage noise of the amplifier has a flicker component of 0.18 µVpp (0.1 to 10 Hz BW) ⇒ b parameter calculation

$$v_{na}^2(f) = \left[v_{na}^2 + \frac{b}{f}\right]\left(\frac{V_{RMS}^2}{Hz}\right)$$

Examples of Noise Calculations: Noise limited Resolution (IV)

- Signal power: $V_O^2 = I_{pd}^2 {R_F}^2 \ (V_{RMS}^2)$
- Noise power: $N_O = \left[4KTR_F + \left[v_{na}^2 + \frac{b}{f}\right] + i_{na}^2 R_F^2 + 2qI_{pd}R_F^2\right] BW \ (V_{RMS}^2)$
- Note: $R_{pd} \to \propto$; b= 8.8 10^{-16} V^2

- Example:
  - $R_F = 10^{10}\ \Omega$
  - i_{na} =0.2 fA/√Hz
  - 4KT= 1.66 10^{-20} W/Hz
  - q= 1.6 10^{-19} C
  - v_{na} =35 nV/√Hz
  - BW=2 Hz

SNR= 1 $\Rightarrow$ I_{pd} (min) = 1.8 pA

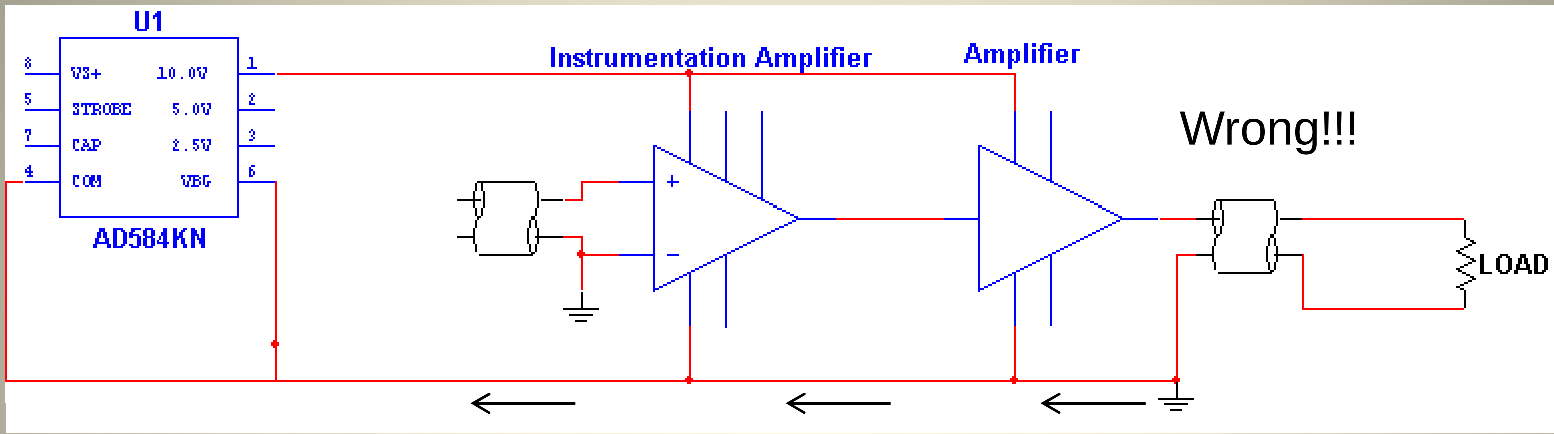
Interference. Sources

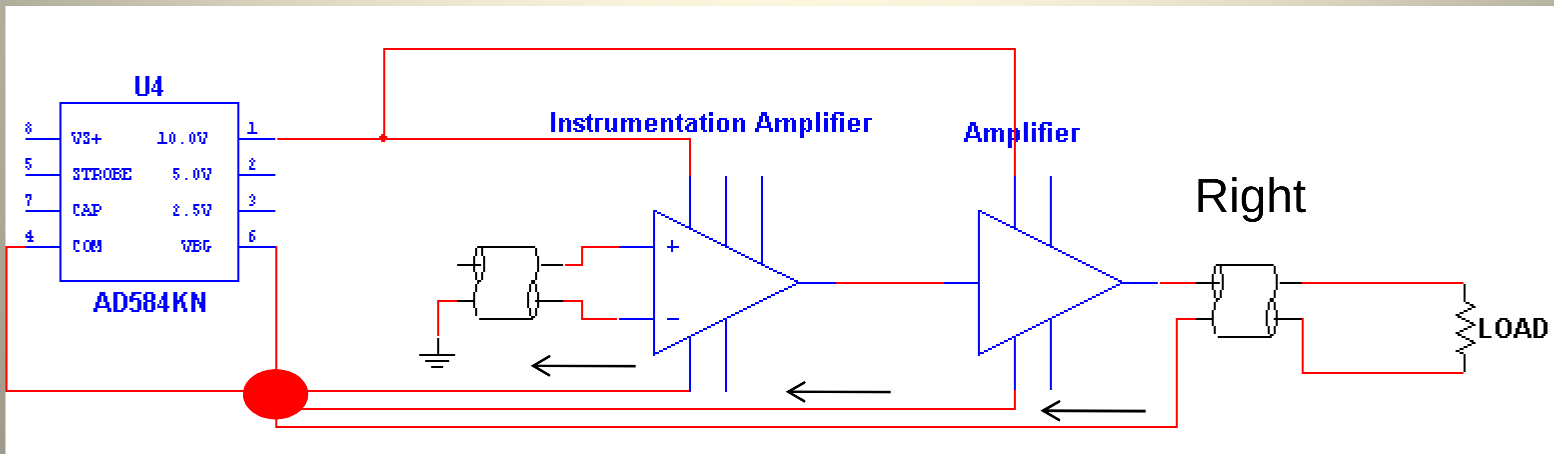
- Interference: Coherent signals from other systems (and sometimes the circuit itself) that enters our system. Although from coherent origin, and thus narrowband, they are better treated as random signals/errors.
- In opposition to noise, interference are *external signals*. For this reason, the best way to minimize its effects is to identified the interference paths to our circuit/systems.
- We can identify four major paths for interference:
  1. Signals coupled in inputs and outputs
  2. Capacitive Coupling
  3. Magnetic Coupling
  4. RF coupling

Minimization of Interference Effects

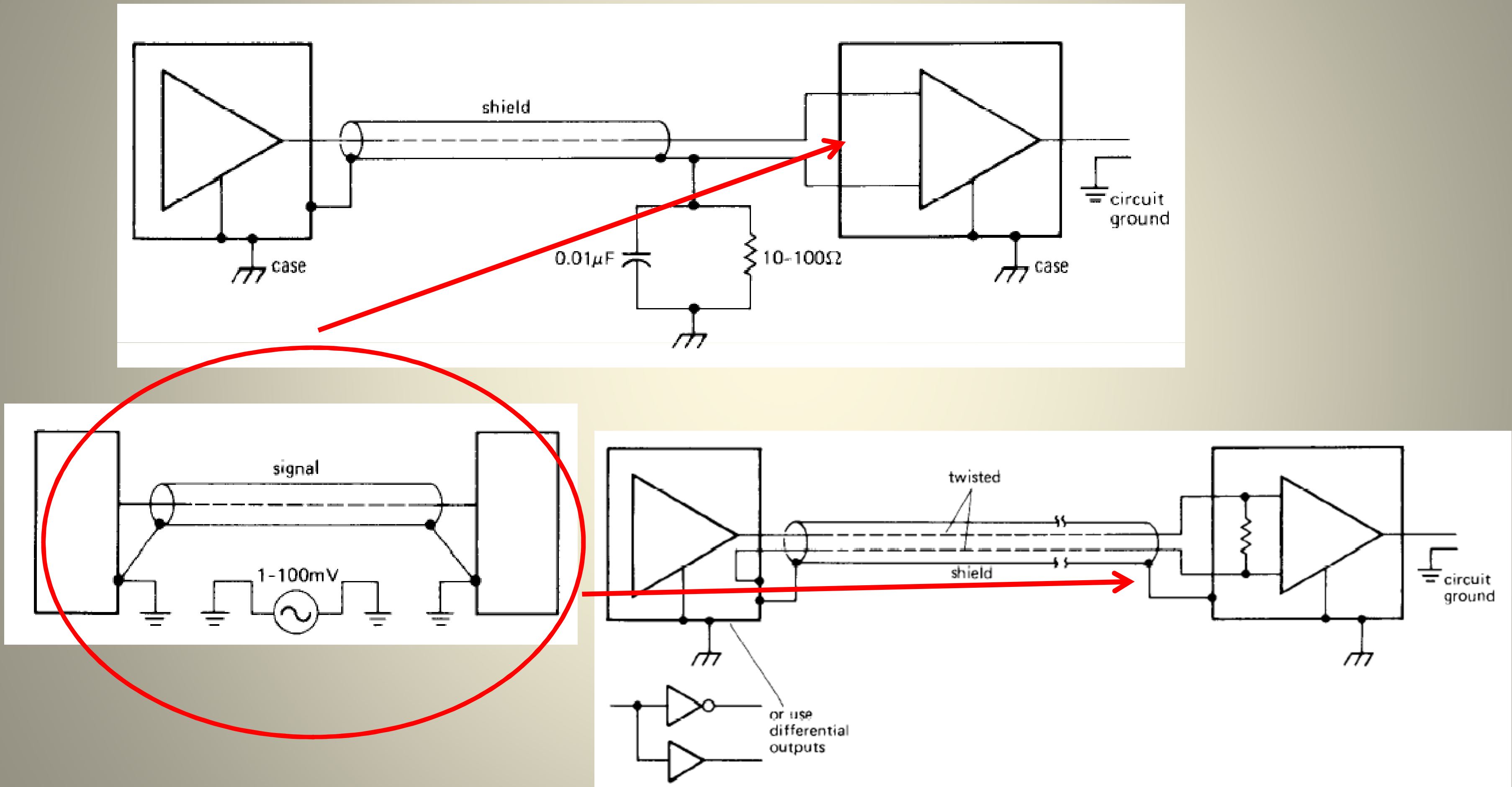
- The techniques of minimizing coherent interference often appear arcane to the inexperienced, but ultimately, all such techniques follow the laws of physics and circuit theory:
  - Avoid direct capacitive coupling between signals tracks using ground planes and guard rings.
  - Avoid magnetic coupling avoiding loops (use of twisted pair)
  - Protecting Power supply inputs with feedthroughs to avoid interference signal paths through Supply voltages.
  - Use shielding to avoid RF coupling when necessary.
  - Others…..

Ground Loops (I)

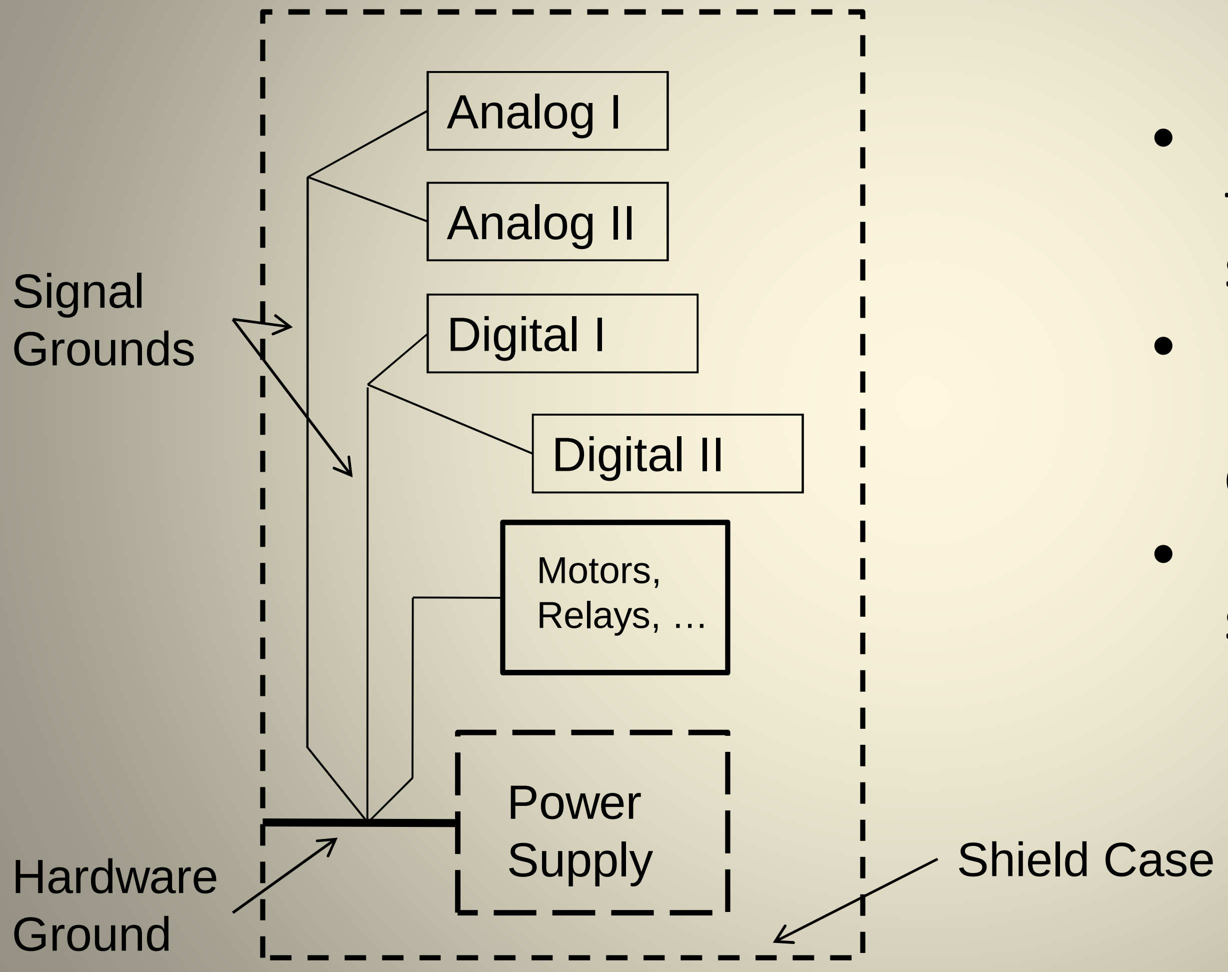




Ground Loops (II)



Ground Loops (III)



- Use separate grounds for digital/analog signals.
- Use only one point to "ground" the circuit/system.
- Use separate power supply when possible.

Summary

- Both noise and interference, though of different origin, provide a major limitation to the precision of measurements and the detectability/resolution.
- We have presented the main sources of noise in signal conditioning circuits and examples of its treatment in order to obtain the noise-limited resolution of the measurement circuits.
- Main paths for interference signals have also been identified and some guidance to minimize interference effects presented. Due to their importance, ground loops have been treated separately.