# Latin-American alliance for capacity building in advanced physics
# LA-CoNGA physics

## Módulo de Instrumentación

Introducción a los Sistemas de Medida

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**Introduction to Measuring systems**

- Signal conditioning basics
- Operational Amplifiers
- Circuits with op amps

## Fundamentals of Data Acquisition Systems

- To properly design a DAQ system, we must know important **Parameters** of the system
- DAQ systems must be designed to comply specific **Requirements**
- DAQ systems must interconnect with other equipment so they must be designed to comply with **Standards**

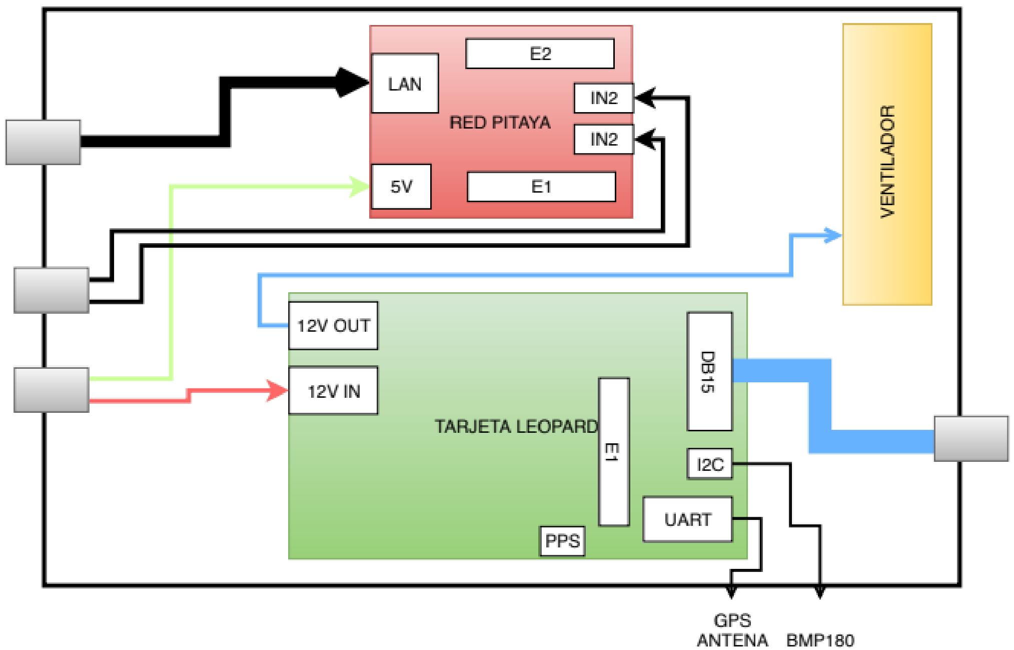



Figure 1: Block diagram of LAGO WCD DAQ system

## DAQ parameters

- Accuracy and Precision
  - In the fields of science, the **accuracy** of a measurement system is the degree of closeness of measurements of a quantity.
  - The **precision** of a measurement system, instead, is called reproducibility or repeatability of measurements.
  - **Absolute Accuracy at Full Scale** is a calculated theoretical accuracy assuming the value being measured is the maximum voltage supported in a given range.

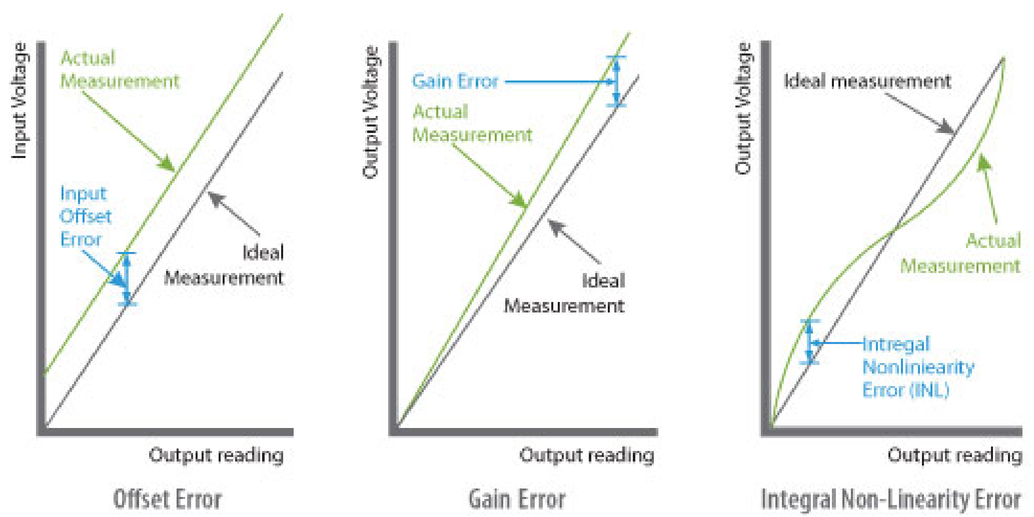



Figure 2: Common errors of DAQ system that degrade system accuracy

## Noise

- Noise is a random fluctuation in an electrical signal generated by electronic devices.
- Electromagnetic interference, power supply glitches, thermal agitation are the most common sources of noise
  - **Thermal Noise** may be described with a gaussian probability densisty funcion
  - **Flicker noise** p consists of unavoidable random statistical fluctuations of the electric current in an electrical conductor

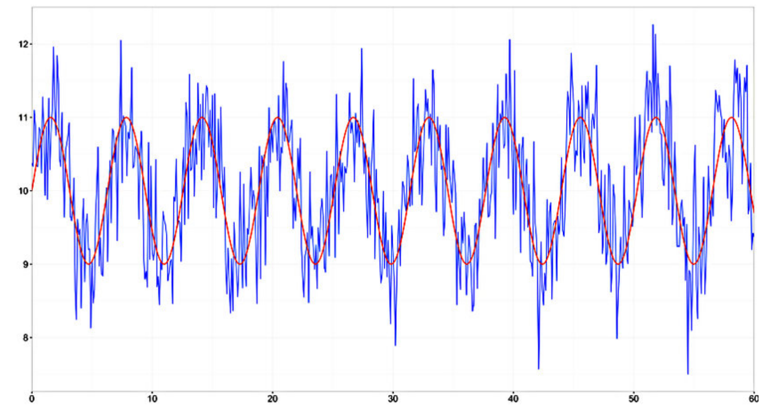



Figure 3: Typical noisy signal with high frequency and low frequency noise

- Signal to Noise ratio is a useful parameter

$$SNR(dB) = 10 \cdot log \left( \frac{P_{signal}}{P_{noise}} \right) \tag{1}$$

## Settling time

- The settling time of an electronic device is the time elapsed from the application of an ideal step input to the time at which the value output has entered and remained within a specified error range (2% or 5%).

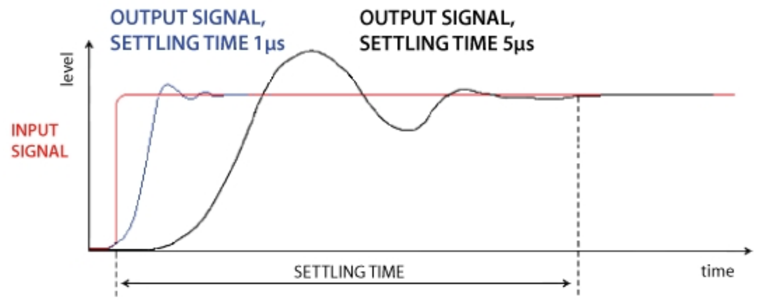



Figure 4: Two examples of settling time, propagation delay and slew are shown

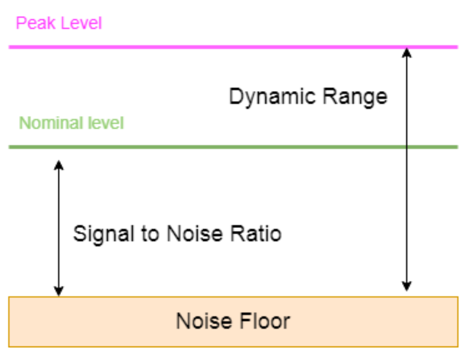
- Settling time includes a propagation delay, plus the time required for the output to slew to the vicinity of the final value
- Settling time depends on the system response and the frequency of the input signal.

## Dynamic Range

- **dynamic range** of a device is the ratio of the largest and smallest signals that can be measured by circuit, normally expressed in $dB$

$$DR(dB) = 20 \cdot log\left(\frac{V_{max}}{V_{min}}\right) \tag{2}$$

- In most cases, the full scale input of a device is the largest signal that can be measured
- Noise level determines the smallest signal that can be measured




- Dynamic Range refers to the maximum resolution of your data acquisition device

## Gain Factor or Amplification

- **Gain Factor** is simply the factor by which gain is increased.
- An increase in gain factor produces an increase in resolution.
- An increase in resolution allows for a more detailed representation of your waveform(s)

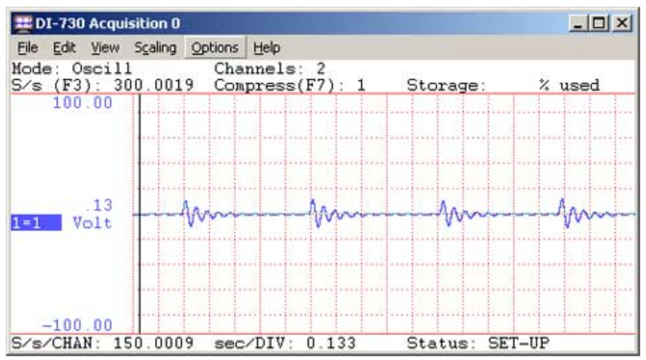



Figure 5: Waveform displayed with a gain factor of 10

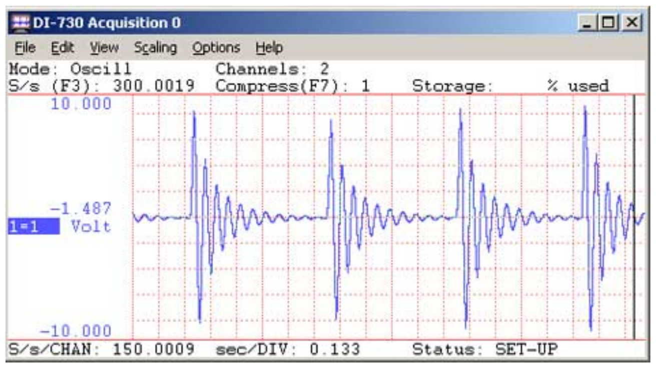
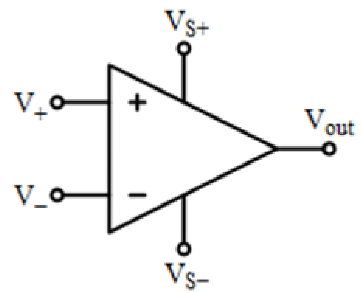



Figure 6: Waveform displayed with a gain factor of 10

- Gain factor and Dynamic Range are closely related:
  - Gain factor must be set in order to use all DAQ dynamic range
  - Distortion and Noise amplification mus be avoided

## Operational Amplifiers

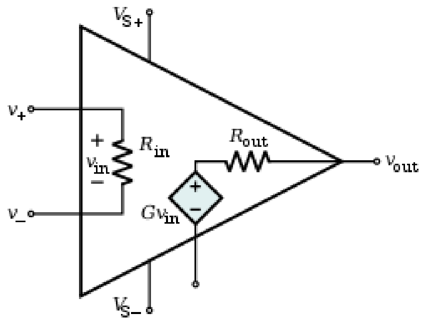
- An **operational amplifier or op amp** is a voltage amplifying device.
- With the help of some external components, an op amp can perform mathematical operations such as addition, subtraction, multiplication, division, differentiation and integration.
- An op amp is an active circuit element.
- For example the $\mu$A741




- Where:
  - $V_+$ : non-inverting input
  - $V_-$ : inverting input
  - $V_{out}$ : output
  - $V_{S+}$ : positive power supply
  - $V_{S-}$ : negative power supply

## The Ideal Op amp

- The op amp is designed to detect the difference in voltage applied at the input terminals ($V_+$ and $V_-$)
- The difference is also known as the **differential input voltage**.
- The output, then, is the difference sensed at the input multiplied by some value $A$ - the **open-loop gain**
- An op amp behaves as a voltage-controlled voltage source.



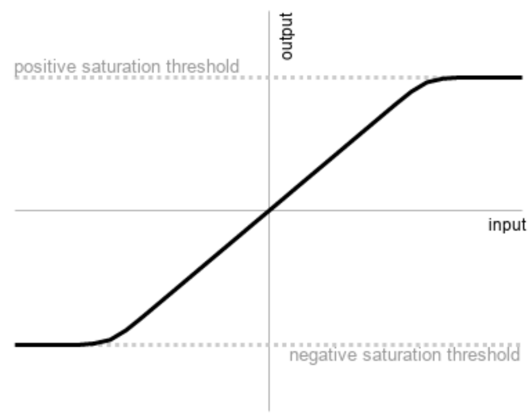

- Ideal op amp characteristics
  - Infinite open-loop gain
  - Infinite input resistance
  - Zero output resistance
  - Zero common-mode gain = infinite common mode-rejection
  - Infinite bandwidth
  - Zero noise
  - Zero input offset

## The Ideal Op amp

- Because the input resistance ($R_{in}$) is infinite, we can deduce that the current seen at the terminals ($V_+$ and $V_-$) are zero
- Since the output resistance ($R_{out}$) is zero, there is no voltage loss at the output
- The gain is normally referred to as $A$ in texts, so the equation for the output is given by:

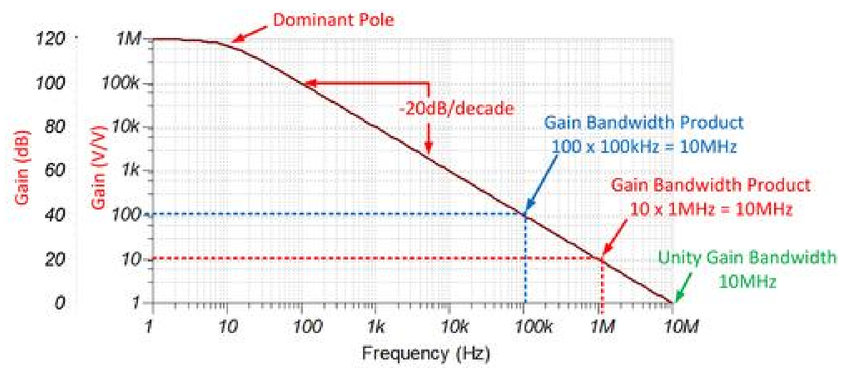
$$V_{out} = A(V_+ - V_-) \tag{3}$$

- A slightly voltage difference between the inputs causes the output to saturate



## Feedback with Amplifiers

- Op amps are not used in open-loop gain
- We are going to talk about **feedback** and **closed-loop gain**
- **What is feedback?** Feedback occurs when the output of a system is fed back into as input(s).
- Feedback is applied to the system to affect one or more of the following properties:
  - Desensitize the gain - the value of the gain becomes less sensitive to variations in the values of the circuit component, such as temperature effects on transistors.
  - Reduce non-linear distortion - the output is proportional to the input.
  - Reduce the effect of noise - reduces the amount of unwanted electrical interference on the output. This interference could be external or from the circuit components themselves.
  - Control the input and output resistances - with an appropriate feedback configuration the input and output resistances can be controlled.
  - Extend the bandwidth of the amplifier, i.e. the op amp gain behavior with respect to frequency.



## Circuits with op amps

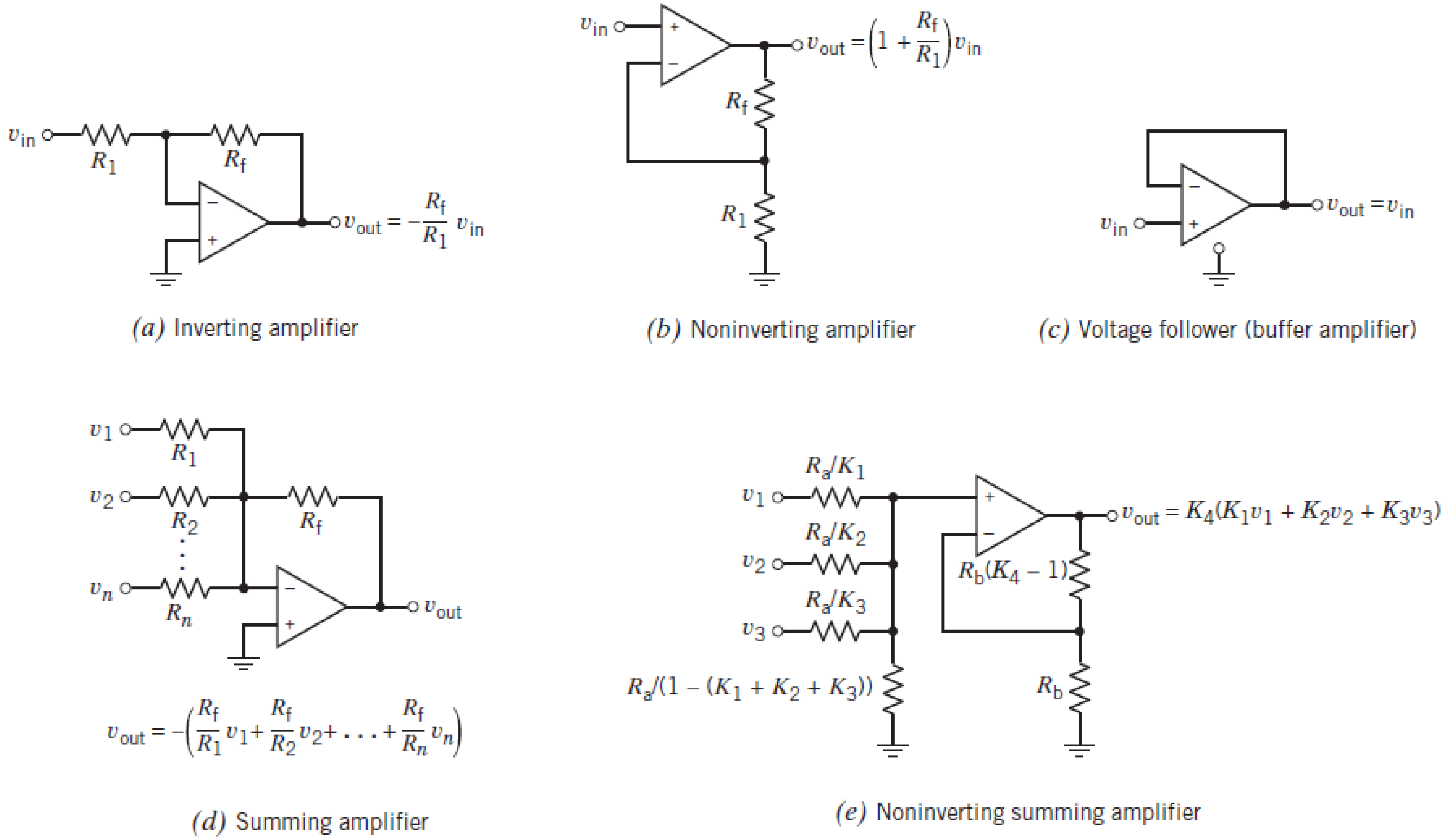



Figure 7: Most popular applications of op amps

## The golden rules

In order to analyze an op amp circuit we must apply the golden rules

1. **Infinite Open Loop Gain**: Open loop gain is the gain of the op-amp without positive or negative feedback. Ideally, the open loop gain of an op-amp will be infinite but typical real values range from about 20,000 to 200,000.
2. **No current flowing through both of the Inputs**: The input impedance of an op-amp, is the ratio of the input voltage to the input current and is assumed to be infinite. With this very high input impedance, any current flowing from the source supply is prevented from entering into the amplifier's input circuitry. Although ideally it is assumed that the input impedance of an op-amp is infinite and has zero current flow into the inside, real op-amps have input leakage currents from a few pico-amps to a few milli-amps.
3. **Potential Difference between input terminals is ZERO**: When negative feedback is added to an op-amp, the input pins become identical. Meaning, whatever is the voltage present in the non-inverting input is also present in the inverting input.

## Instrumentation amplifier

- Instrumentation amplifiers (in-amps) are precision gain blocks that have a differential input and an output that may be differential or single-ended with respect to a reference terminal.
- These devices amplify the difference between two input signal voltages while rejecting any signals that are common to both inputs.

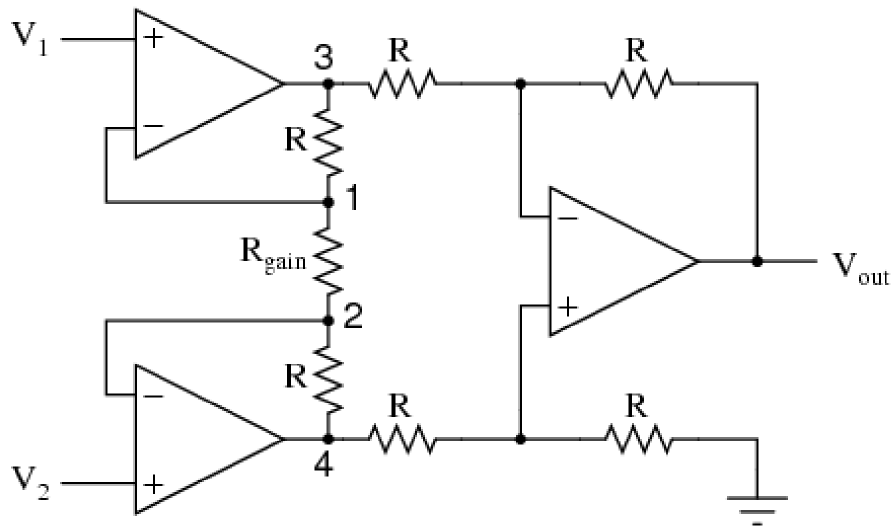



Figure 8: Simplified scheme of an instrumentation amplifier, commercial ICs are avalaibles

The in-amps are widely used in many industrial, measurement, data acquisition, and medical applications where *DC* precision and gain accuracy must be maintained within a noisy environment,