Latin-American alliance for capacity building in advanced physics

LA-CoNGA physics

Módulo de Instrumentación

Introducción a los Sistemas de Medida

Dennis Cazar Ramírez

Universidad San Francisco de Quito USFQ

27 - enero - 2021

Latin American alliance for
Capacity buildiNG in Advanced physics
LA-CoNGA physics

Cofinanciado por el
programa Erasmus+
de la Unión Europea

UAN UNIVERSIDAD ANTONIO NARIÑO
Universidad Industrial de Santander UIS
YACHAY TECH
UNIVERSIDAD NACIONAL DE INGENIERIA
UNMSM
UNIVERSIDAD SIMÓN BOLÍVAR
Université de Paris
TECHNISCHE UNIVERSITÄT DRESDEN
UNIVERSITÉ TOULOUSE III PAUL SABATIER
cnrs
CERN
DESY.
ICTP
Red CLARA
www.dbaccess.com DBACCESS
frontier x analytics

Contents

Introduction to Measuring systems

- Fundamentals of Data Aquisition Systems
- Sensors and Transducers
- Temperature Sensors
- Light Sensors

Fundamentals of Data Acquisition Systems

- Data acquisition (DAQ) systems are the main instruments used in laboratory research from scientists and engineers
- DAQ systems are mainly used for Test and Measurements
- DAQ systems are general-purpose DAQ instruments that are well suited for measuring voltage or current signals.

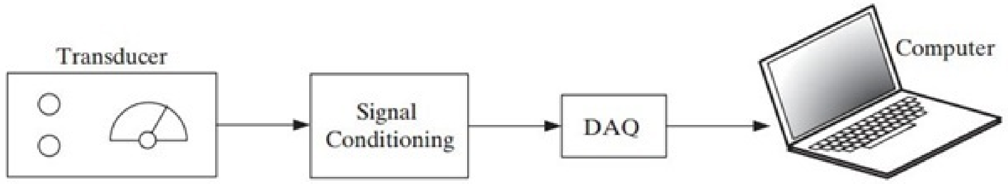
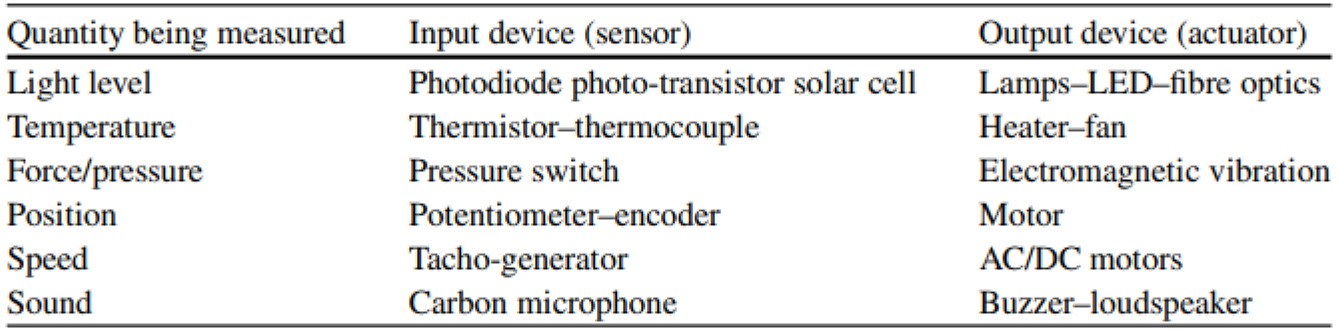


Figure 1: Block diagram of a general-purpose DAQ system

- The basic elements of DAQ are shown in Fig 1.
- Field wiring (for signals, power and communication) and DAQ software are also elements of a DAQ system

Sensors and Transducers

- **Sensors** are used to detect a wide range of different physical phenomena such as movement, electrical signals, radiant energy, and thermal, magnetic, or mechanical energy.
- **Transducers** translate the signal of a sensor into a current or voltage signal
- Devices with output function are called **actuators** and are used in control systems to change the state of the system.
- Figure 2 shows a list of the most common transducers and actuators for measuring or control several physical variables



Quantity being measured	Input device (sensor)	Output device (actuator)
Light level	Photodiode photo-transistor solar cell	Lamps–LED–fibre optics
Temperature	Thermistor–thermocouple	Heater–fan
Force/pressure	Pressure switch	Electromagnetic vibration
Position	Potentiometer–encoder	Motor
Speed	Tacho-generator	AC/DC motors
Sound	Carbon microphone	Buzzer–loudspeaker

Figure 2: Common transducers and actuators

- There are many different types of transducers; each transducer has input and output characteristics and the choice depends on the goal of your system

Sensors characteristics

- Sensors produce in output a voltage or current signal according to the variation of physical phenomena that are measuring
- There are two types of sensors:
    - **Active** sensors require external power supply to work
    - **Passive** passive sensors generate a signal in output without external power supply

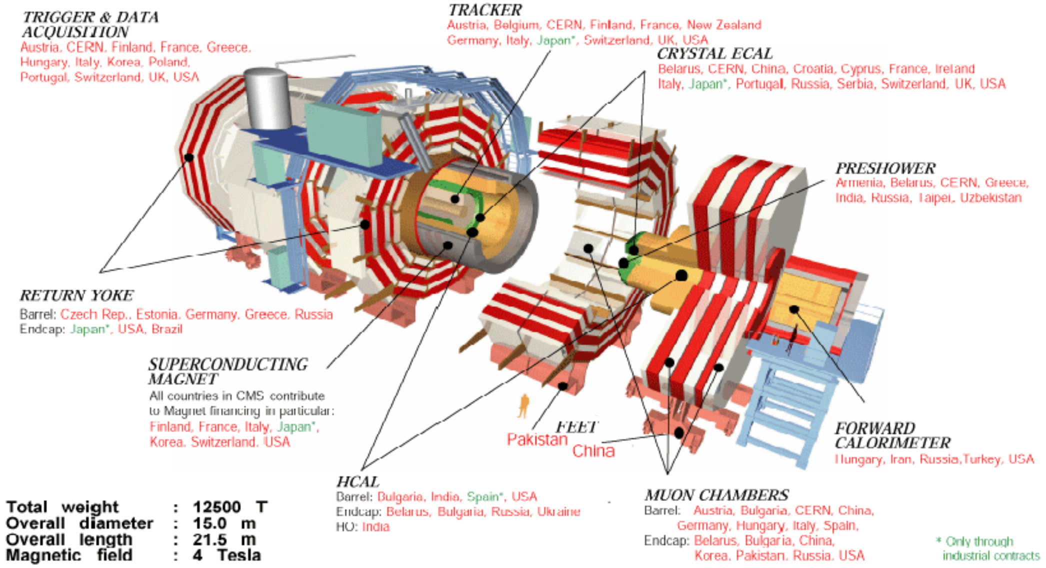


Figure 3: DAQ systems of CMS experiment at CERN

Temperature Sensors

- Several techniques for detection of temperature are currently used.
- The most common of these are resistance temperature detectors (RTDs), thermocouples, thermistors, and sensor ICs.
- RTDs and thermistors take advantage of the change of the temperature coefficient α pf a metal (platinum, copper, nickel, etc) with temperature
- The temperature coefficient is defined from the following equation

$$\alpha(t) = \frac{1}{R(T)}\frac{dR}{dT} \tag{1}$$

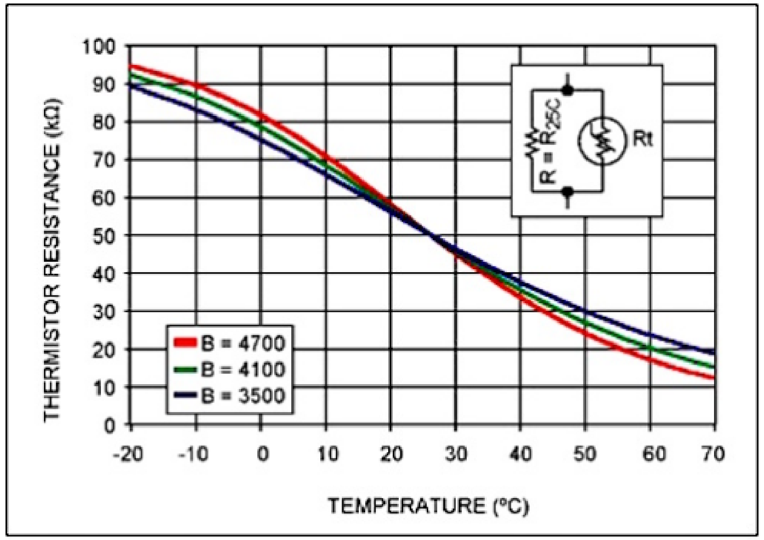
- For accurate temperature measurements, it is necessary to use the *Steinhart–Hart* equation

$$\frac{1}{T} = a + b \cdot ln(R) + c \cdot ln^3(R)$$

- Where a, b and c are parameters
- It's important to realize that the relationship between a RTD or thermistor resistance and its temperature is very non-linear.

Thermistors

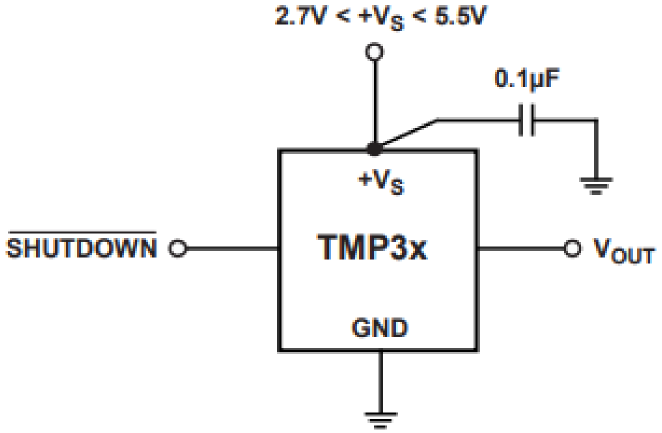
- **Resistive mode linearization** places a normal resistor in parallel with the thermistor.
- If the value of the resistor is the same as that of the thermistor at room temperature, the region of linearization will be symmetrical around room temperature.



- Voltage mode linearization places the thermistor in series with a normal resistor forming a voltage divider circuit
- The voltage divider circuit must be connected to a known, fixed, and stable voltage reference.

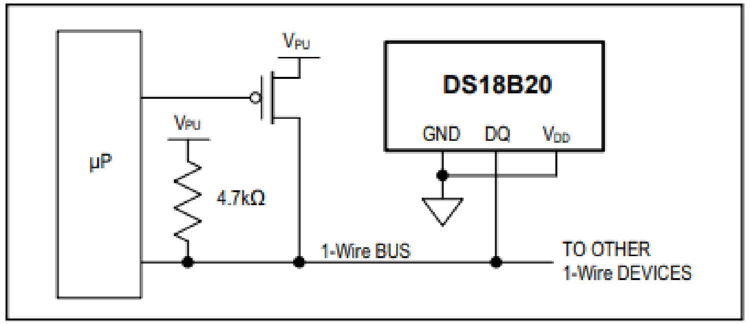
Analog Thermometer ICs

- In contrast to a thermistor, an analog IC provides an output voltage that is almost linear
- An analog low-voltage sensor as TMP36 has:
  - a slope of $10mV/^oC$
  - a temperature range of -40 to $+125^oC$
  - and it's accurate to $\pm 2^oC$.



Digital Thermometer ICs

- Digital temperature devices are more complex, but they can be highly accurate.
- Also, they can simplify your overall design, because analog-to-digital conversion takes place inside the thermometer IC instead of a separate device such as a microcontroller.
- For example as DS18B20 has:
    - accuracy of $\pm 0.5^o C$
    - a temperature range of -55 to $+125^o C$



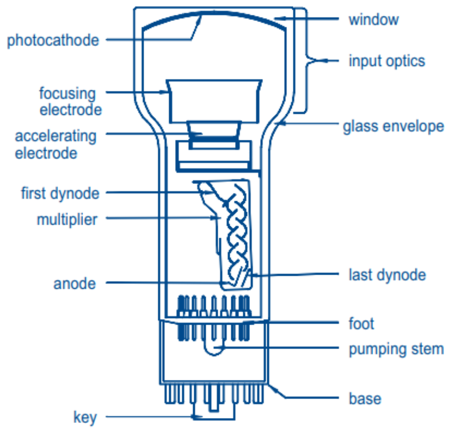
- Also, some digital ICs can be configured to harvest energy from their data line, allowing them to be connected using just two wires

Light sensors : PMTs

- For more than sixty years, photomultipliers (PMTs) have been used to detect low-energy photons in the UV to visible range, high-energy photons (X-rays and gamma rays) and ionizing particles using scintillators.
- The PMT's continuing superiority stems from three main features:
  - large sensing area,
  - ultra-fast response and excellent timing performance,
  - high gain and low noise.
- The last two give the photomultiplier an exceptionally high gain-bandwidth product.

Construction

- A photomultiplier tube is a non-thermionic vacuum tube, usually made of glass, that converts very small light signals into a measurable electric current.
- A PMT is formed by:
  - **a window** to admit light,
  - **a semitransparent photocathode** made of a thin layer of photoemissive material deposited on the inner surface of the window which emits electrons in response to absorbing photons
  - **an electron-optical input** system of one or more electrodes that accelerate and focus the emitted photoelectrons onto the first dynode of the tube,
  - **an electron multiplier** consisting of several electrodes (dynodes) covered with a layer of secondary emissive material.
  - an anode grid which collects the electron avalanche, providing an output signal.



Characteristics

- The response of a PMT to light is specified by its **photocathode sensitivity** which can be specified by its quantum efficiency
    - Quantum efficiency (QE, or ρ) is defined as the ratio of the number of photoelectrons emitted by the cathode to the number of photons incident on the window, and is usually expressed as a percentage
    - Quantum efficiency depends on the wavelength of the photons and is generally less than 35%.
    - Quantum efficiency is a particularly useful parameter when the number of incident photons is small and when the photons arrive in pulses.
- Because it is easier to measure the photocathode current produced in response to an incident light power than to count photons and electrons, photoemission is frequently described by the term **cathode radiant sensitivity** expressed in mA/W.

$$QE(\%) = \frac{124}{\lambda(nm)} \times RS(mA/W)$$

where λ is the wavelength of the incident light

- The most commonly used window materials are:
    - lime glasses (soft glasses)
    - borosilicate glasses (hard glasses)
    - UV-transparent borosilicate glasses
    - sapphire (ultraviolet grade)

Spectral response

- The spectral sensitivity characteristic is the curve showing how cathode radiant sensitivity varies with wavelength.
- The spectral response is determined at the longer wavelengths (photoemission threshold) by the photocathode type and thickness, and at the shorter wavelengths by the input window transmission.

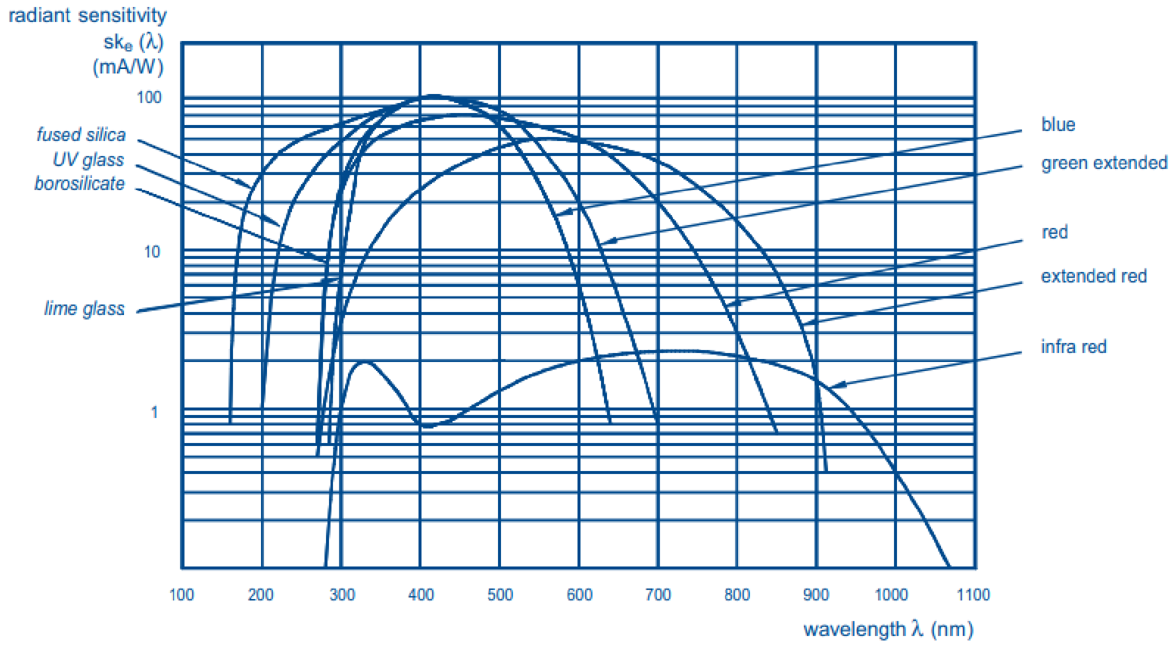


Figure 4: Typical spectral sensitivity characteristics of standard photocathodes with associated window materials.

The electron multiplier

- The electron multiplier of a PMT is a virtually noiseless, highgain, wideband amplifier for the electrons extracted from the photocathode.
- The electrons are multiplied by a cascade of secondary emission at several dynodes.

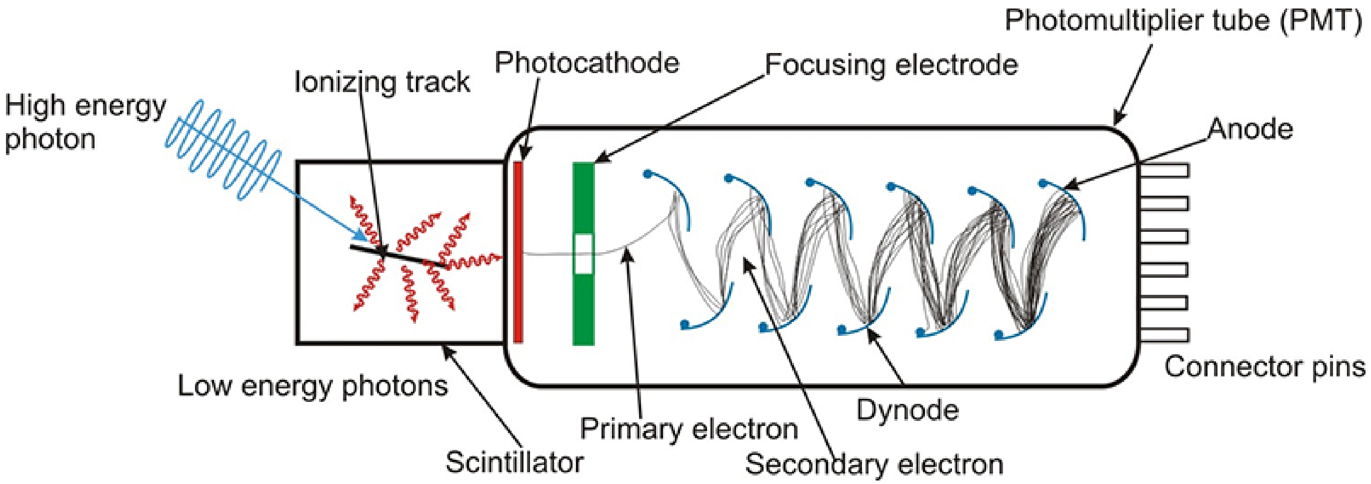


Figure 5: Simplified scheme of a light detecting system, scintillators translate HE photons into LE photons that can be detected by PMT

The Voltage divider

- The voltages required to create the electrostatic fields between dynodes to accelerate and focus the electrons in a PMT are most conveniently derived from a single high-voltage supply and a voltage divider network
- The electrons are multiplied by a cascade of secondary emission at several dynodes.
- Examples of voltage dividers schemes are:
  - **iterative voltage distribution**; the same voltage for all multiplier stages (except the first few). This distribution provides the highest gain for a given supply voltage and is particularly suitable for photometry and nuclear spectrometry applications.
  - **progressive voltage distribution** (increasing from the cathode to the anode). This distribution provides the highest linear peak current but with a much lower gain than iterative one
  - **intermediate progressive voltage distribution**. This distribution optimizes time characteristics while providing acceptable gain and linearity. Type C dividers are particularly suitable in physics experiments requiring accurate timing combined with ability to analyze pulse heights over a wide dynamic range.

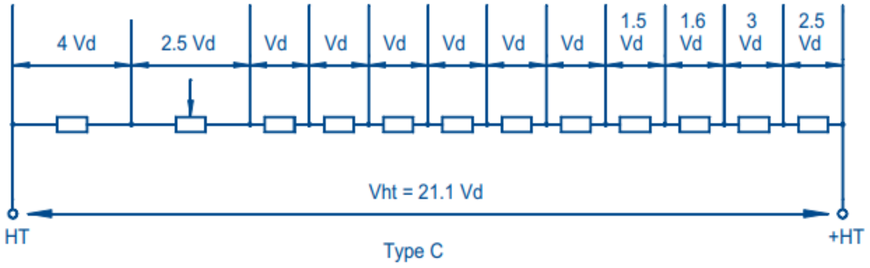
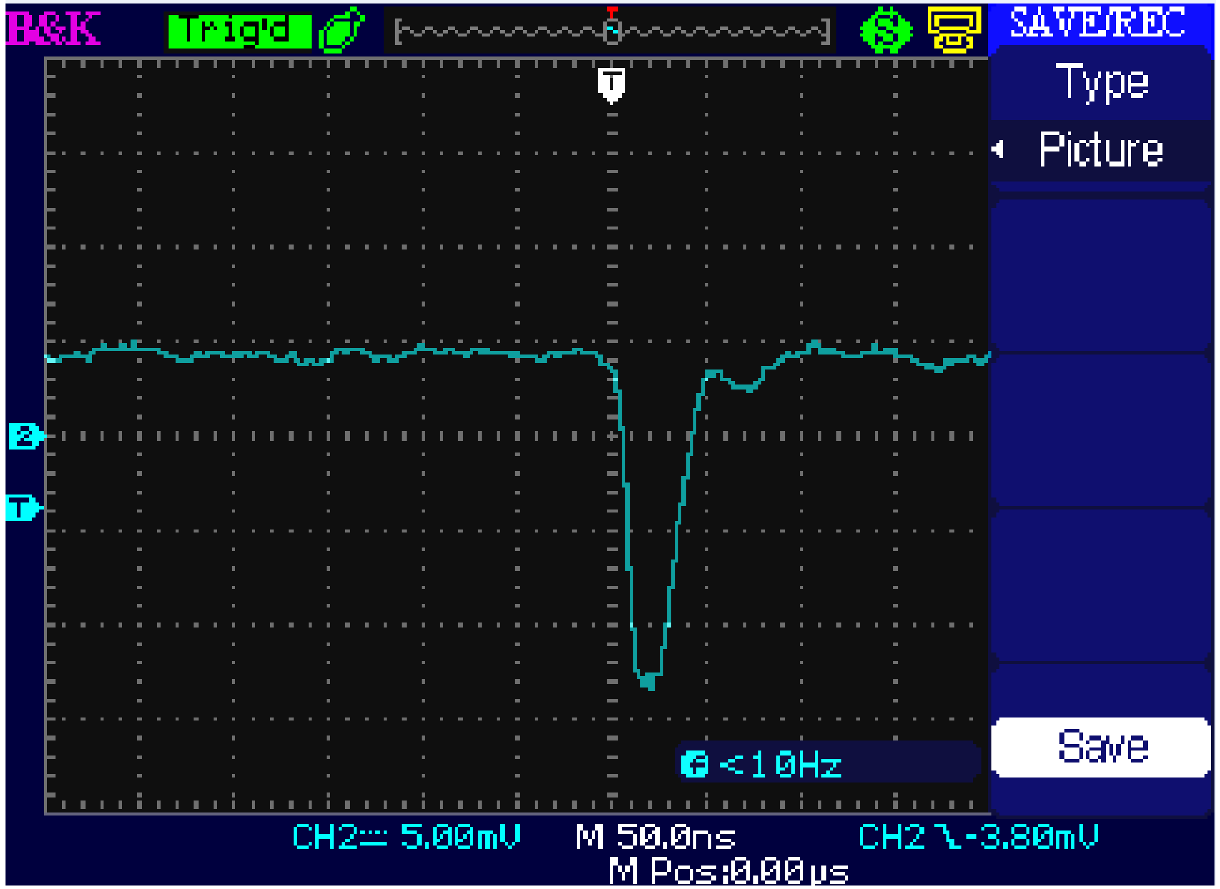


Figure 6: Simplified scheme of an intermediate progressive voltage distribution, V_d is the smallest inter-dynode potential

PMT pulse



CH2 5.00mV M 50.0ns CH2 -3.80mV
M Pos:0.00µs

Figure 7: Typical pulse from a PMT with 1200V HV

Silicon PMTs

- The Silicon Photomultiplier (SiPM) is a sensor that addresses the challenge of sensing, timing and quantifying low-light signals down to the single-photon level.
- A photodiode is formed by a silicon p-n junction that creates a depletion region that is free of mobile charge carriers. When a photon is absorbed in silicon it will create an *electron-hole* pair
- Applying a reverse bias to a photodiode sets up an electric field across the depletion region that will cause these charge carriers to be accelerated towards the anode (holes), or cathode (electrons).
- Therefore an absorbed photon will result in a net flow of current in a reverse-biased photodiode.

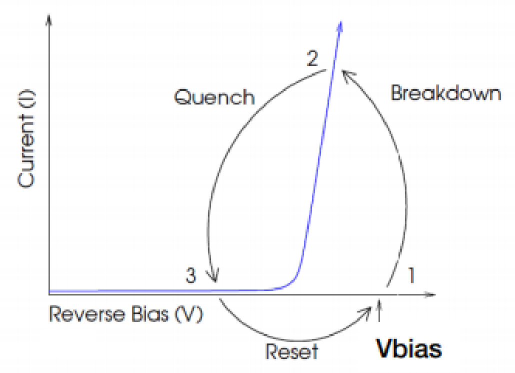


Figure 8: Breakdown, quench and reset cycle of a SPAD working in Geiger mode

SiPM pulse

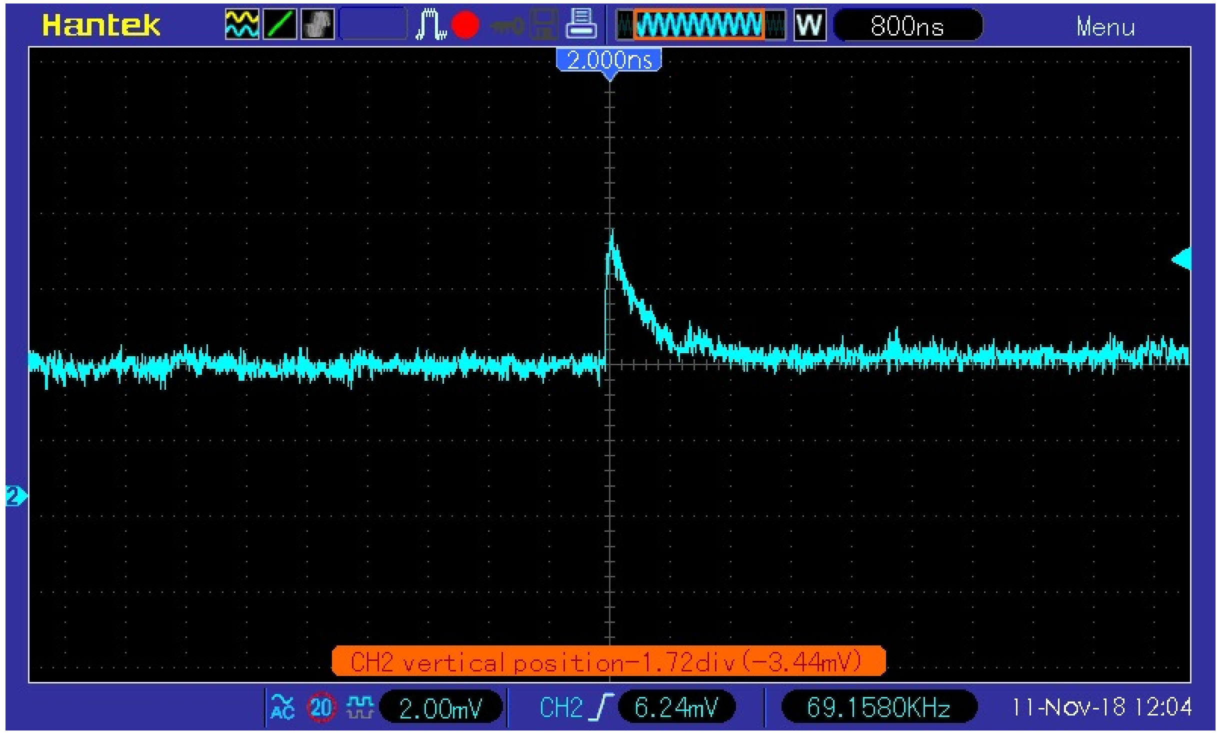


Figure 9: Typical pulse from a SiPM with 29V bias