Intro to Measurement Systems

LA-CoNGA physics

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FINAL PROJECT 1: PMT signal conditioning circuit

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Contents

1 Objective

In this activity you have to design and simulate a signal conditioning circuit which be used to convert the PMT signal to an impulse suitable for a digital system which will perform the counting task.

Some of the knowledge needed to this work you already know, others must be studied during this activity.

2 Background

The basic task in detecting sub-atomic particles is to calculate the rate, i.e. count the amount of particles arriving at the detector in a certain time. Rate is measured in Hertz and depends of several factors, for further details see ref. 2

A block diagram of the system circuit is shown in figure 1. PMT signal (or pulse) must be inverted and amplified before it enters the peak detection block which produces a DC voltage level proportional to the maximum amplitude of the pulse, this voltage can be easily processed by a digital circuit. An explanation of each block follows.

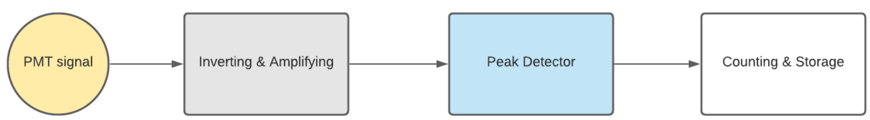

Figure 1: Basic signal acquisition chain

2.1 PMT signal

A photomultiplier (PMT) is the most popular transducer in High Energy Particle (HEP) detection. A PMT converts light (produced by the interaction of a sub-atomic particle with matter) into an electrical signal or pulse which is amplified to a useful level using a high voltage field (HV) of around thousands of volts, for details see ref. 1

PMT signal is a negative pulse of few tenths of milivolts height and microseconds wide, an example is shown in figure 2. The rate of the pulses depends of many factors, for this experience we can assume $100Hz$.

2.2 Signal amplifier

PMT signal must be inverted to produce a positive signal and amplified to a hundred of milivolts range to allow the peak detector to generate a DC voltage suited to an Analog to Digital Converter (ADC) or any digital circuit used to record and post process this signal. Take into account that a typical PMT signal voltage range is $20mV$ to $200mV$.

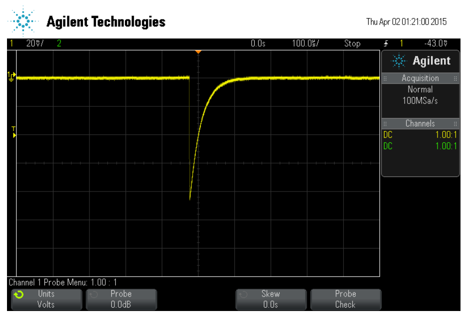

Figure 2: Typical signal from a 9" PMT working at 1200V HV nominal level

As you can see in figure 2 the signal has a very fast transition from $0V$ to V_{peak}, the amplifier must be capable to "follows" this variation so a fast op-amp must be used. Select an op-amp with adequate slew rate is mandatory, see ref. 4 for an explanation about this op-amp parameter.

2.3 Peak detector

A peak detector circuit is based on a rectifier, a simple rectifier circuit could act as a peak detector but it has limitations in both precision and frequency response. Circuit based on op-amps have better performance, an example is shown in figure 3.

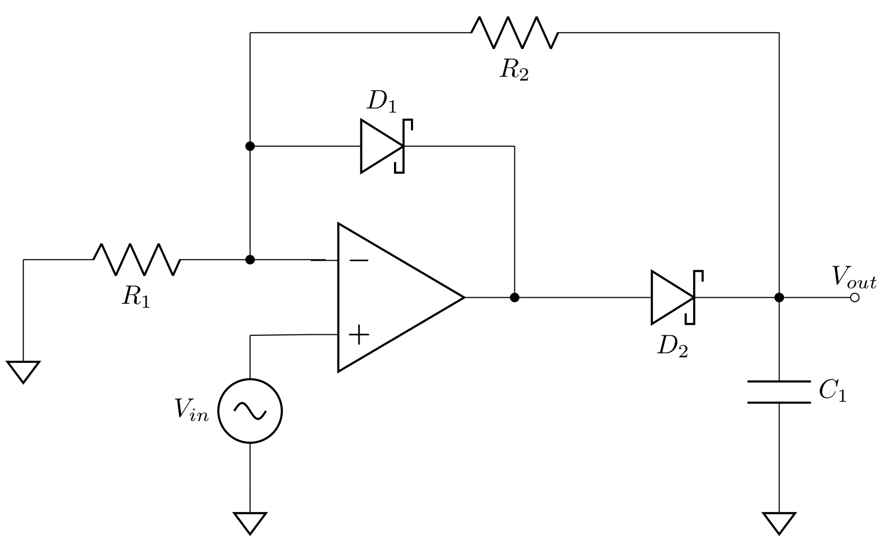

Figure 3: Precision peak detector circuit with op-amp

A signal diode is the key component of a peak detector, to improve precision a *Schottky* diode is often used due to its low voltage drop and fast response to change in polarity.

Other examples of peak detectors circuits and an explanation of how to choose components and resistor values can be found in ref. 5.

3 Procedure

3.1 Input signal

The design must be tested whit two input signals:

- A sinusoidal wave of $200mV$ amplitude $10KHz$ frequency negative biased
- A "replica" of the PMT signal, this can be created and stored in a file to be loaded in a voltage source (function generator) in LTSpice, see ref. 3

3.2 Design

The whole circuit can be divided into two main blocks:

- Inverting amplifier: Design a circuit that inverts and amplify the signal, choose the right op-amp model, factors as slew rate and bandwidth are important.
- Peak Detector: Design a peak detector capable to detect signals as low as $100mV$ and a rate of 1KHz.

3.3 Simulations

Simulate the whole circuit and test it with the two signals described above. Characterize the circuit determining

- What is the minimum and maximum signal level.
- What is the maximum frequency

3.4 Hints

The circuit used in simulation must have to blocks:

- An inverting amplifier with $G = 10$
- A peak detector circuit, the one showed in fig. 3 is an example (you can use any other configuration)
- Suggested components for circuit in fig. 3 are:
  - Op-amp LT6201 or equivalent
  - $D_1 = D_2$ MBR0540TR-ND or equivalent
  - $R_1 = R_2 = 100k\Omega$
  - $C_1 = 1nF$

4 Testing

- Test the circuit built in the lab following the same steps as in simulations.
- Use the signal generator to generate a sinusoidal signal as in simulation.
- Use the LTSpice pwl file as an starting point to program the arbitrary function generator of ELVIS to generate a "PMT like signal".

5 Report

- Compare the results of simulations and lab and draw conclusions
- Write a detailed report of this activities focusing in how you can use this circuits to build a cosmic ray particle detector, see ref 6.
- Can you determine the maximum frequency response of the circuit?
- Can you imagine other applications of this circuit?

6 References

1. Photomultiplier Tube Wikipedia
2. Cosmic Ray Detectors: Principles of Operation and a Brief Overview of (Mostly) U.S. Flight Instruments
3. LTspice: Piecewise Linear Functions for Voltage & Current Sources
4. Understanding Operational Amplifier Slew Rate
5. Op Amp Rectifiers, Peak Detectors and Clamps
6. The desktop Muon Detector: A simple, physics-motivated machine- and electronics-shop project for university students, S.N. Axani, J.M. Conrad and C. Kirby, 2017