# Electronics/Particle Physics Assignment 574

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1. An ionization detector. A 5 MeV alpha particle travels through the center of a gas proportional counter, that consists of two parallel plates, 10 cm x 10 cm and separated by 1 cm, filled with argon gas at atmospheric pressure, and *biased* with enough voltage to create drift but not enough to multiply. Calculate the size of the pulse generated by the ionization in the gas. You will need to look up a variety of parameters to complete the calculation.

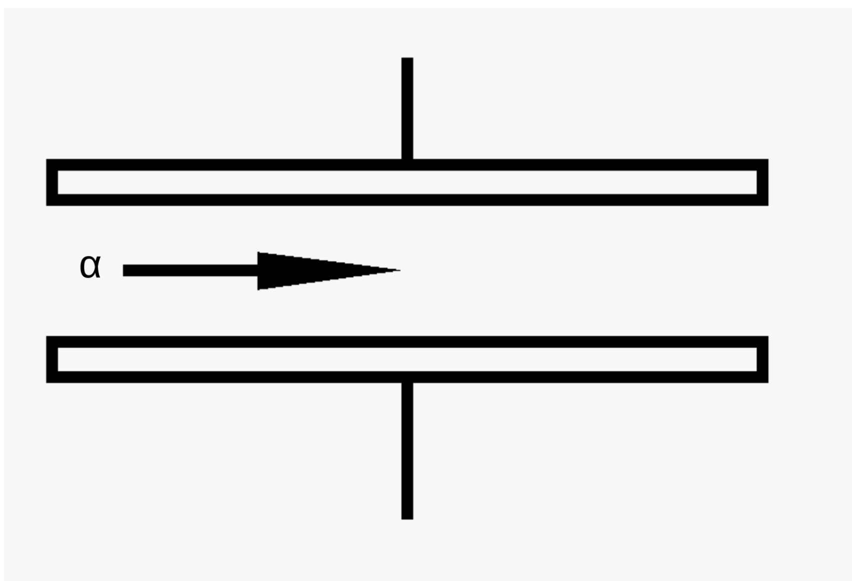


Figure 1: A cross section of the ion counter, showing the direction of the alpha with respect to the plates.

2. Assume that an experiment has 10000 PMTs, each with a dark noise rate of 500 Hz. Calculate (either analytically or numerically) the rate of n-fold random coincidences with a 100 ns time window. In other workds,

calculate the probability that $n$ of the tubes fire within 100 ns. Make a log plot of the rates for N=0 to N=30.

3. The effect of digitization rate. A sensor emits a pulse that is $\sigma = 1.3$ ns wide, with a variable pulse height. Assume that the pulse is a gaussian:

$$V(t \mid t_0, \sigma^2) = Ae^{-\frac{(t-t_0)^2}{2\sigma^2}}.$$

Here A is the amplitude of the pulse.

To analyze the problem, we are going to assume that $t_0$ are random and uniformly distributed between 0 and 20 nanoseconds, and that the pulse heights($A$ are uniformly distributed between 0-10 V.

a. The output pulse is fed into a digitizer, that reads the amplitude with a 250 MHz sample rate. The digitizer has 12 bit resolution- so the voltage is measured (instantaneously) at t=0,4, 8, 12, 16, ... ns in bins of 10/4096 V. Using the digitized output, find an algorithm to reconstruct the input $A$ and $t_0$ and histogram the difference between the measurement and the input parameters.

b. Now consider the case when the pulses are fed into the *shaping amplifier* shown below.

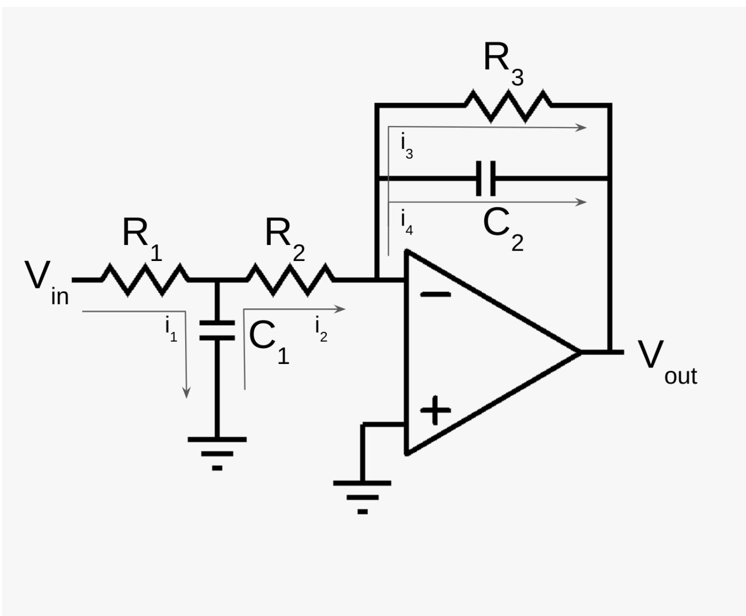


Figure 2: A simple op-amp circuit that allows one to tune the integration time and rise time of a pulse

We can analyze the circuit simply, using Kirchoff's laws for the passive components and the op-amp rules:

(a) The negative terminal is always at the potential of the positive terminal (in our case, ground). Feedback forces this, since the gain of the amplifier is huge.

(b) No current flows into the op amp

Then, the equations for each of the loops is:

$$V_{\rm in}(t) = i_1 R_1 + \frac{q_1 - q_2}{C_1} \tag{1}$$

$$0 = \frac{q_2 - q_1}{C_1} + i_2 R_2 \tag{2}$$

$$i_3 R_3 = \frac{q_2 - q_3}{C_2} \tag{3}$$

Here we use the convention that $q_i$ refers to the charge on a capacitor, and $i_i = \frac{dq_i}{dt}$. We have also used the fact that $i_4 + i_3 = i_2$, and the corresponding equation for charges.

Set up this equation so that one can numerically integrate. If you use either scipy.integrate solve_ivp or odeint, you need to provide a function that takes as input $t, q_1, q_2, q_3$ and provides as output $i_1, i_2, i_3$, (i.e. the derivatives of the charges).

To begin with, pick values $R_1 = R_2 = 37\ \Omega, R_3 = 100\ \Omega, C_1 = 2\ \mathrm{nf}, \mathrm{C}_2 = 100\ \mathrm{pf}$. Scale $A$ (in the circuit we would simply add an amplifier) so that the peak output voltage remains around 10 V.

Vary the values of $C_1$ and $C_2$. Which ones give you the most precise measurements of amplitude and time? (In this example we haven't included the effects of noise in the signals. It is straightforward to do, and ultimately is often the limiting factor in such measurements.)