Experiments with proportional counter

1 Aim

1. Basic characterization of any gaseous detector.
2. Plateauing with radioactive source.
3. Measurement of gain

2 Required materials

1. Proportional counter
2. Argon + CO_2 gas mixture
3. HV power supply
4. Preamplifier
5. Spectroscopy Amplifier
6. SCA
7. Discriminator
8. Counter
9. Oscilloscope
10. LEMO, SHV and BNC cables
11. Gas pipes
12. Radioactive sources (^{55}Fe, ^{137}Cs, ^{60}Co, ^{90}Sr)

3 General Principle of Gas Detectors

The basic configuration of a gas detector consists of a container; let us consider a cylinder, with conducting walls and a thin end window. The cylinder is filled with a suitable gas and a conducting wire is suspended along its axis with positive voltage, $+V_0$ relative to the walls (Figure 1).

If a radiation now penetrates the cylinder, a certain number of electron-ion pairs will be created, either directly, if the radiation is a charged particle, or indirectly through secondary reactions if the radiation is neutral. The mean number of electron-ion pairs created is proportional to the energy deposited in the counter. Due to the applied electric field, these electrons will be

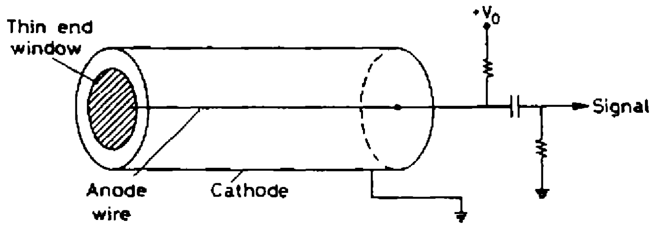

Figure 1: Basic configuration of a gas detector

accelerated towards the anode and the ions towards the cathode where they will be collected. The radial electric field is given by$E = V_0/[r \ln(b/a)]$, where, r is the radial distance from the anode, b is the inside radius of the cylinder and a is the radius of central wire.

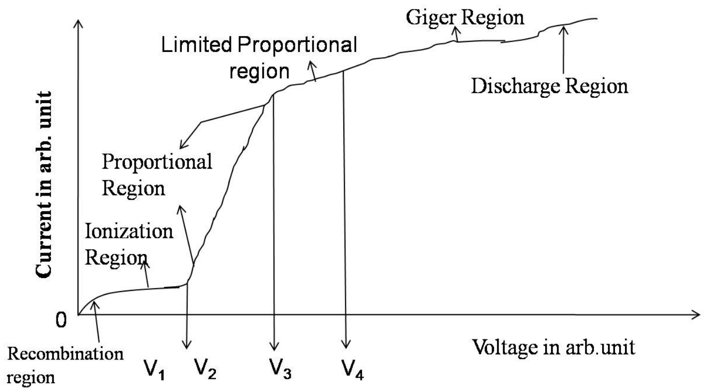

Figure 2: Current vs. voltage plot

The current signal generated will be a function of applied voltage as plotted in Figure 2. At very low voltages, no charge is collected as the ion-electron pairs recombine due to Coulomb interactions. This region is known as Recombination Region. As the voltage is raised, the recombination forces are overcome and the current begins to increase as more and more of the electron-ion pairs are collected before they can recombine. At some point, all created pairs will be collected and further increase in voltage show no effect. So we get a flat region, known as Ionization Region. A further increase in voltage beyond this region shows again an increase in current. At this point, the electric field is strong enough to accelerate freed electrons to energy where they are also capable of ionizing gas molecules in the cylinder. These electrons are known as secondary electrons and they can also be accelerated to produce still more ionizations and so on. As the number of electron-ion pairs in the avalanche is directly proportional to the number of primary electrons, this region is known as Proportional Region. If the voltage is now increased beyond this region, the total amount of ionization created through multiplication becomes sufficiently large that the space charge created distorts the electric field about the anode. This region is known as Limited Proportionality Region. Increasing the voltage still higher, the energy becomes so large that a discharge occurs in the gas. Physically, a chain reaction of many avalanches spread out along the entire length of the anode is triggered by photons emitted by de-excited molecules. The output current thus becomes completely saturated and this region is known as Geiger Muller Region. Further increase in high voltage beyond this region the discharge occurs in the gas. This region is known as Discharge Region.

4 Choice of gas

Gas multiplication is critically dependent on the migration of free electrons rather than on the much slower positive ions, the fill gas in proportional counter must be chosen such that they do not exhibit an appreciable electron attachment coefficient. Gas multiplication in the proportional counter is based on the secondary ionization created in collisions between electrons and neutral gas molecules. In addition to ionization, these collisions may also produce simple excitation of the gas molecule without creation of a secondary electron. These excited molecules do not directly contribute to the avalanche, but decay to their ground state through the emission of a visible or ultraviolet photon. Under the proper circumstances, these de-excitation photons could create additional ionization elsewhere in the fill gas through photoelectric interactions with less tightly bound electron shells or could produce electrons through interactions at the wall of the counter. Although such photon-induced events are important in the Geiger-Mueller region of operation, they are generally undesirable in proportional counters because they can lead to a loss of proportionality and/or spurious pulses. Furthermore, they cause the avalanches to spread along the anode wire to some extent, increasing possible dead time effects and reducing the spatial resolution in position-sensing detectors. It has been found that the addition of a small amount of polyatomic gas, such as methane, to many of the common fill gases will suppress the photon-induced effects by preferentially absorbing the photons in a mode that does not lead to further ionization. Most mono atomic counter gases operated at high values of gas multiplication require the use of such a polyatomic stabilizing additive. This component is often called the quench gas. The noble gases, either pure or in binary mixtures, can be useful proportional gases provided the gas multiplication factor is kept below about 100. Beyond this point, adding a quench gas is helpful in reducing instabilities and proportionality loss caused by propagation of ultraviolet photons. Because of cost factors, argon is the most widely used of the inert gases, and a mixture of 90% argon and 10% methane, known as P-10 gas, is probably the most common general-purpose proportional gas. When applications require high efficiency for the detection of gamma-ray photons by absorption within the gas, the heavier inert gases (krypton or xenon) are sometimes substituted. Many hydrocarbon gases such as methane, ethylene, and so on are also suitable proportional gases and are widely applied where stopping power is not a major consideration. In applications where the signal is used for coincidence or fast timing purposes, gases with high electron drift velocities are preferred.

Some considerations in choosing the gas include their atomic number and density if gamma rays or X-rays are to be detected in the gas, high drift velocities if fast-rising output pulses are needed, and small values of the electron diffusion coefficient to minimize charge spreading for gas-filled devices in which the position of the primary ionization is to be registered.

5 The experimental setup

The gas Argon:CO_2 in 80:20 or 70:30 volume ratio (premixed) needs to be flown for 2 hours through the counter (after some time one can operate the chamber in fixed gas mode).

Figure 3: Gas flow started through the chamber for flushing out any gaseous impurities

Figure 4: Experimental setup

The experimental set-up is shown in Figure 4 and the electronic circuit diagram is shown schematically in Figure 5. A voltage is to be applied to the chamber by using a high voltage (HV) module (CAEN N1470). ORTEC 142 IH Pre-Amplifier will be used to amplify and invert the signal (if needed) from the detector for further analysis. The high voltage is to be applied through the Pre-Amplifier.

The signal from the detector will be taken from the same Pre-Amplifier when the anode wire collects the electrons and a negative signal is generated. The negative signal from the detector will be inverted and signal to noise ratio increased by the Pre-Amplifier and an amplified positive signal with moderately large shaping time (~450 μs) will be obtained as shown in Figure 6.

The positive signal from the Pre-Amplifier will be fed to the CAEN N968 spectroscopic amplifier where the gain and shaping time can be adjusted and a unipolar signal will be put into the input of an ORTEC 550A Single Channel Analyser (SCA). The output of the SCA will be +3.2 V TTL signal that could be counted by a TTL scalar. The oscilloscope dumb of the unipolar signal from the spectroscopic amplifier is shown in Figure 7 and the TTL output signal

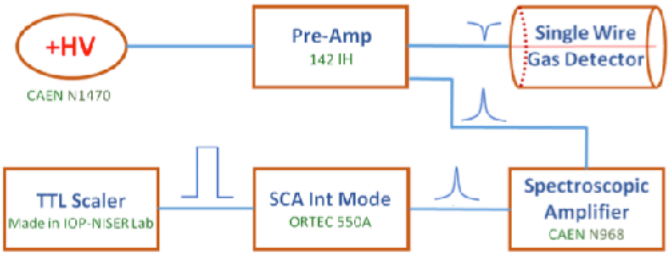

Figure 5: Electronics circuit diagram

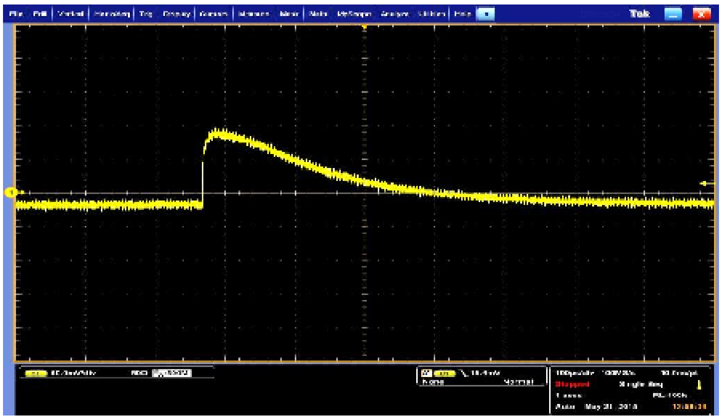

Figure 6: Signal after preamplifier (60 mV/div, 100 μs/div, 50 Ω termination)

from the SCA is shown in Figure 8. The SCA will be operated in INTEGRAL mode. In the INTEGRAL mode, all input pulse amplitudes above the lower level (called threshold) produce an SCA output logic pulse. This mode is useful for counting all pulses above the noise level, or above a well-defined lower amplitude limit.

5.1 Threshold Scan

1. Fix the bias voltage to +2600 V (say).
2. Change the threshold on the SCA and count the number of signals for a particular time with and without a radioactive source.
3. Plot the count rate in Hz versus the threshold voltage both for cosmic and source.
4. Fixed a threshold to cut all the noise for the subsequent studies.

5.2 Voltage Scan

1. Keep the threshold fixed using SCA (Single Channel Analyser)
2. Change the voltage applied to the detector. Measure the count rate for different radioactive sources and plot as a function of applied voltage.
3. Get a plateau of the count rate.

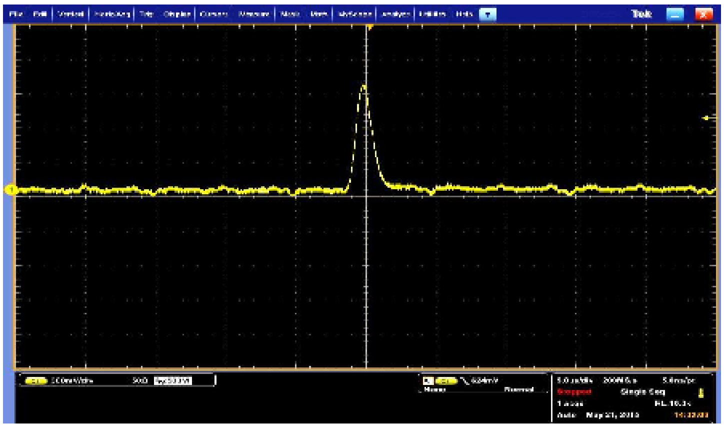

Figure 7: Signal after Spectroscopic Amplifier (Unipolar signal, 300 mV/div, 5.0 µs/div, 50 Ω termination)

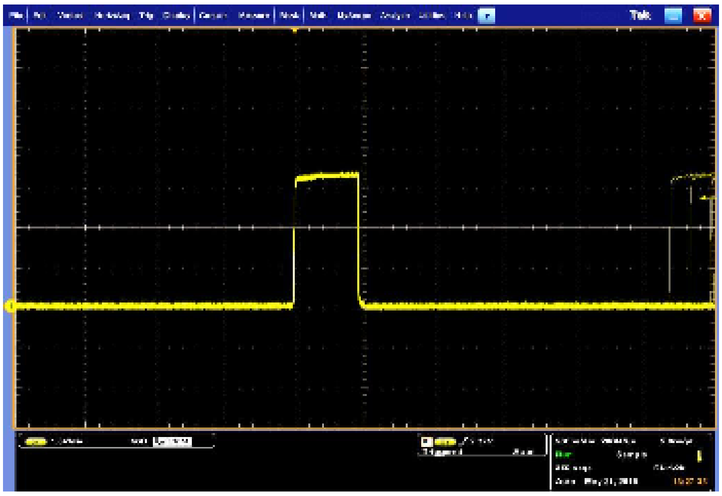

Figure 8: TTL Signal after SCA (Single Channel Analyser) (Digital signal, 1.0 V/div, 500 ns/div, 50 Ω termination)

5.3 Gain measurement

Measure the current from the power supply and using the count rate of the plateau region calculate the gain of the detector. Change the applied HV to the detector and repeat the current measurement. Plot the gain versus voltage curve.

One can also measure the gain from the ^{55}Fe spectrum taken using an MCA.