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X-ray imaging with proportional counters

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Abstract. Proportional counters are extensively used in X-ray astronomy. Position sensitive proportional counters have been used as imaging detector in the focal plane of the X-ray telescopes in the Einstein Observatory and ROSAT satellite. Here various methods of position sensing by proportional counters are briefly discussed. Design and construction of a Position Sensitive Proportional Counter (PSPC) being developed at TIFR is described. The PSPC has sensitive energy range from 2 keV to 20 keV. With the sensitive circular area of 30 mm diameter, it can be used as an imaging detector at the focal plane of a soft X-ray optics. For two dimensional position determination of an X-ray event, two multi wire cathode grids of 50 μm wire spaced at 0.5 mm are used The final position of the event is obtained by calculating the center of gravity of the charge spread. Position resolution of less than 100 μm can be achieved by this method. The main anode grid made up of 25 μm wire spaced at 1 mm gives the standard energy resolution of the proportional counter. Another anode grid is used as an anti-coincidence counter to achieve high degree of background rejection.

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1. Introduction

Proportional Counter was conceived during late 1940s as a special type of gas filled detector. Since then it is one of the most important tool for detection and measurement of X-rays. A proportional counter can be used for the detection as well as energy measurement of X-rays in a wide range from 0.1 keV to 100 keV. It has become an indispensable tool in the field of X-ray astronomy right from its birth in early 1960s. Apart from astronomy, proportional counters are also very useful in X-ray spectroscopy and high-energy particle physics experiments.

The usefulness of the proportional counter got an additional dimension with the invention of Multi-wire Proportional Counter (MWPC) in late 1970s.

With MWPC it became possible to measure not only the energy but also the position of an X-ray photon interaction. Today Position Sensitive Proportional Counters (PSPC) based on the multi-wire configuration are widely used in X-ray spectroscopy, digital radiography, etc. In X-ray astronomy, PSPC along with focusing X-ray optics, are widely used for X-ray imaging. Though other alternative X-ray imaging detectors are available, PSPCs stand out among all because of their ruggedness, wide dynamic range and low price.

We are developing a small area PSPC for use in the proposed Indian Multi-wavelength Astronomy Satellite (IMAS). It is proposed that this PSPC will be used for testing the gold-coated aluminum sheets used for the conical X-ray mirrors of X-ray telescope proposed for IMAS. In this paper we describe the design and construction of the PSPC.

2. Principle

Proportional counter is based on the principle of the gas filled detector. The basic gas filled detector is made up of two electrodes, an anode and a cathode and the gas between them. The incident radiation interacts with the gas and creates electron-ion pairs. When electric field is applied between two electrodes, the electrons and the ions are attracted towards the opposite polarity electrode. Collection of the electron-ion pairs at the two electrodes generates an electric signal which can be processed further. The amplitude of the the electric signal, i.e. the number of the electron-ion pairs depends on the energy of the incident radiation as well as the applied voltage. However, the electric signal due to only primary electron-ions is generally very small and hence processing of individual signals becomes difficult.

In proportional counters, very high electric field of the order of 10^5 to 10^6 V/cm are achieved by using a specific geometry. Due to the acceleration in the large electric field, primary electrons gain sufficient energy to cause further ionization of the gas and thus to create secondary electron-ion pairs. Because of this charge multiplication, the total number of electron-ion pairs is increased by a large factor. Typical charge multiplication factor of the order of 10^3 to 10^5 can be achieved, resulting in a sufficiently large signal. Since each primary electron is multiplied in the same way, the total number of the electron-ion pairs is still proportional to the energy of the incident radiation. Thus, the signal from the proportional counter can give information about the presence of the radiation, as well as its energy.

3. Position sensing with a proportional counter

Inherently proportional counters do not have position sensing ability. However, with some modification it is possible to get the position of the interaction in either one or two dimension. Various methods of position sensing with proportional counters are described briefly below.

One dimensional position sensing: generally used with single wire proportional counters (SWPC).

1. *Charge division method*

   This is the most preliminary method for position sensing. In this method a resistive wire is used as anode and the electric signal is taken from both ends of the resistive anode. Charge collected at each end is proportional to its distance from the interaction point. Hence ratio of the charges received at two ends gives the fractional position on the interaction. Position sensitivity of $\sim 1\%$ of the anode length can be achieved in this method.

2. *Rise time discrimination*

   Anode of a SWPC constitute an RC transmission line because of its capacitance with cathode. Hence, the rise time of the voltage pulse developed at a given end of anode depends on the distance of charge collection from it. Difference in the rise time of voltage pulse from both ends gives the fractional position of the interaction. This method yields a very good sensitivity of $\sim 0.1\%$ of total length.

3. *Charge sharing*

   In this method the charge collecting cathode is diagonally split into two parts. Total charge induced on the cathode is shared between two parts. Fractional area of a complete cathode ring occupied by one part changes linearly with its position along the length of the anode. Hence from the charges collected at each cathode portion it is possible to find the position of the interaction.

Two dimensional position sensing: generally requires multi-wire proportional counter(MWPC).

1. *Multiple anode wires*

   In this method a number of resistive anode wires are used between two cathode planes. In one direction interaction position is located by the charge division method, whereas the position resolution in the other direction is limited by the spacing between the anode wires. Position sensitivity of few tenths of a millimeter can be achieved by this method. However, the electronics becomes very complex.

2. *Cathode based methods*

   These methods utilize charge induced on the two cathode planes of MWPC. For 2-dimensional position sensitivity, generally two orthogonal position encoders are used. Various position encoding methods used are -

   - *Single wire method* This uses a Z-wound wire as a cathode plane. Charge division method is used to obtain position within the wire. It requires only two electronic channels for each direction, however, position sensitivity is limited to few a mm.

- *Delay line method* This uses several closely spaced parallel wires as a cathode plane. Wires are connected by electronic delay line. Position of the interaction in a given direction is determined by the time delay introduced. In this method also electronics is relatively simple, but the sensitivity is limited to a few mm.
- *Center of gravity method* In this method each cathode plane is divided into a number of strips. Center of gravity of the signal from various strips gives the location of the interaction. This requires complicated electronics, however the complexity is compensated by the position accuracy of few tens of micron.

3. *Wedge and strip method*

   This method is based on the charge sharing technique. Here the cathode plane is divided into shapes of a wedge and a strip. There are a number of cycles of wedges and strips. Shape of wedge is kept the same but the width of the strip varies with distance from one end. Position sensitivity in the direction along the strips is achieved by the wedges whereas in the direction perpendicular to the strips the sensitivity is provided by the varying width of the strips. This method also has a very good position sensitivity of few tens of microns, but it requires very high charge gain.

4. Development of a PSPC

Since the PSPC is to be used for the testing of the IMAS X-ray telescope its design parameters are determined by the design of the X-ray telescope The focal length of the X-ray telescope is 1.6 m. This requires the active area of the detector to be about 3 cm diameter, to cover the complete field of view of the telescope. Position accuracy less than 100 μm is required in both the directions within the circular area of 3 cm diameter.

4.1. *Design*

The PSPC is a multi-wire proportional counter. It is made up of four electrodes (Figure 1): The anode A1 and the corresponding cathodes K1 and K2 forms the main detector. Anode A2 is used as an anti-coincidence detector to reject the unwanted background events such as high energy X-ray, gamma-ray and cosmic ray interaction. Each electrode is a grid of thin gold plated stainless steel with an open area of 56.5 mm by 56.5 mm, in which the wires are soldered on the supporting "plastic" frame. The anode grids are made up of 25 μm diameter wires spaced at 1 mm (in A1) and 2 mm (in A2) respectively. The cathode grids K1 and K2 are made up of 50 μm diameter wire spaced at 0.5

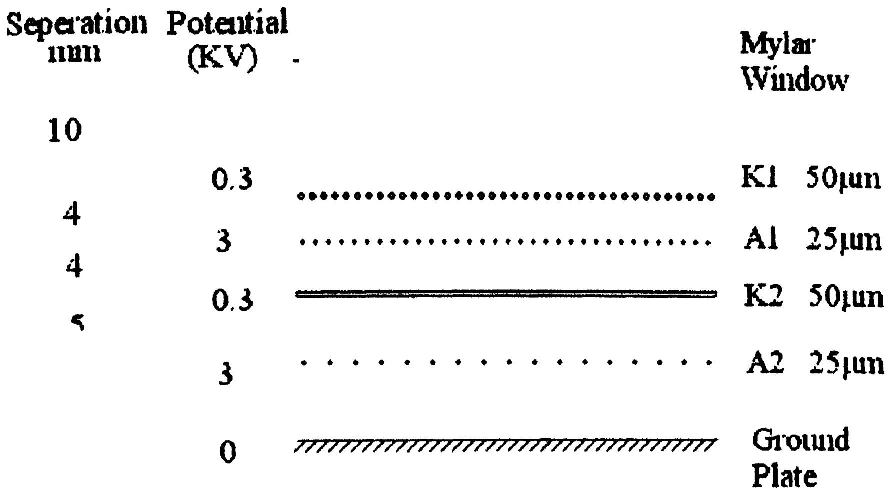

Figure 1. Four electrodes of the PSPC with their respective position, potentials and inter-electrode spacing.

mm. The detector has a window of 50 μm thick aluminised mylar. There is a drift region of 10 mm between the window and the first cathode K1. The spacing between the grids is as shown in Figure 1. During the operation the cathodes are kept at 300 V and anodes are kept at 3000 V.

4.2. *Position sensing*

An X-ray photon, after passing through the window, interacts with the counter gas in the drift region and produces a photo electron. The photo electron then looses its energy by collision ionization with the counter gas, and produces the primary electron cloud. This cloud drifts towards the positively biased cathode K1 and then towards the anode A1. Near the anode the charge multiplication occurs. The multiplied charge cloud, which is spread symmetrically with respect to the original position of the incident photon, leads to induced signals at the two cathodes K1 and K2.

The cathodes K1 and K2 are the main position sensing electrodes. Both are kept perpendicular to each other in order to achieve two dimensional position sensitivity. Each cathode is divided into 16 cathode strips of 7 wires connected to each other. In a typical X-ray event two to five adjacent strips are excited depending on the energy of the photon.The charge collected by any strip is proportional to the fractional area of the secondary charge cloud covered by the strip. Thus by measuring the charge collected by each strip and finding

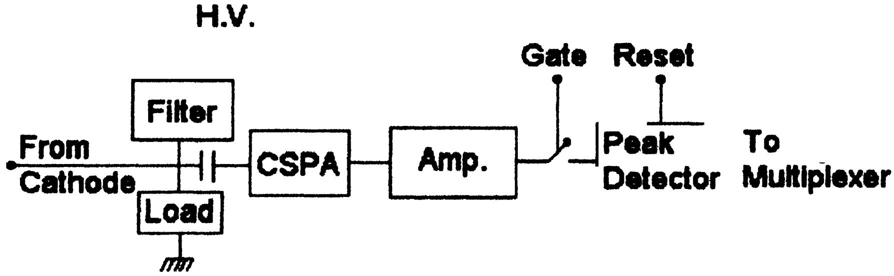

Figure 2. Block diagram of the analog channel.

the center of gravity of the charge spread we can find out the precise position of the incident X-ray photon.

4.3. *Electronics and software*

As described above, to determine position and energy of an incident X-ray photon we have to process 16 + 16 cathode signals + 1 anode signal, which requires 33 channels of analog processing i.e. amplifier, peak detector etc. To reduce this number two strips of each cathode grids are interconnected, limiting the final signals from each cathode to eight. These interconnections are made in such a way that a unique determination of the strips originally excited is possible. This procedure is based on the assumptions that (1) in any event minimum two and maximum five strips are excited, (2) all the excited strips are adjacent, and is carried out by the processing software.

Each cathode strip is connected to a separate charge sensitive pre-amplifier and a post amplifier (Fig. 2). The amplified signal is given to a peak detector via a gate operated by the control logic. The signals from the anodes A1 and A2 are given to the control logic, which decides whether the event is acceptable or not. The acceptable event is the one in which there is a signal above the minimum threshold from only anode A1. On receiving a genuine event the control logic sends a trigger to the PC (Figure 3). and closes the gates so that in the case of high event rate the information in each channel is not destroyed before being processed. It also opens the gates and resets all the peak detectors after a fixed time delay. This is the dead time of the detector, which in our case is about 200 μs.

The 17 signals from the 17 peak detectors, i.e. one anode signal and eight cathode signals from each cathode, (signal from A2 is used only by control logic) are then given to a multiplexer. The multiplexer output is given to a very fast ADC which in turn is connected with the PC (Figure 4). On receiving a trigger from the control logic PC selects the first multiplexer input and gives a signal to ADC. After a fixed time it reads the output of the ADC. It then

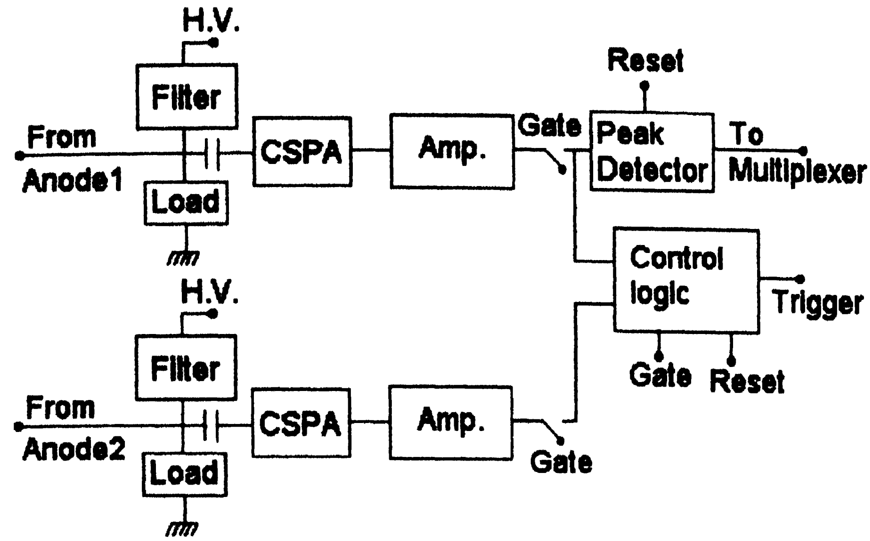

Figure 3. Block diagram of the control logic

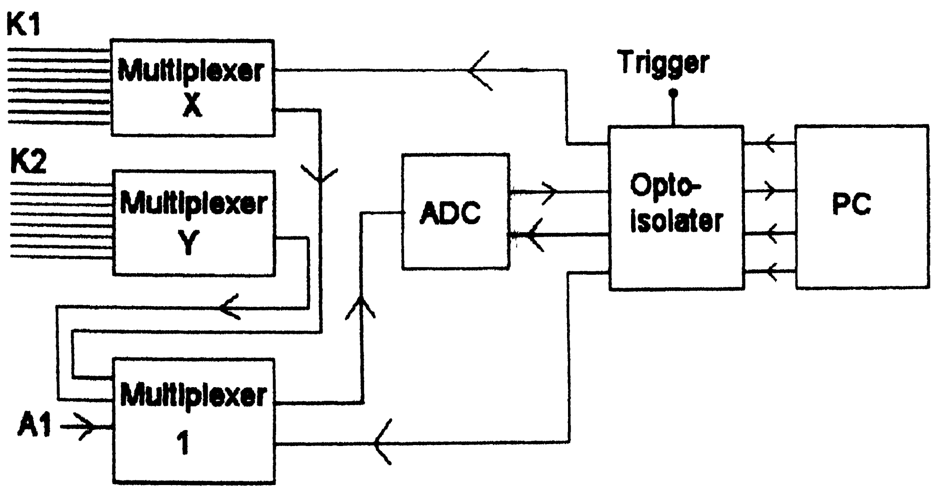

Figure 4. Block diagram of the interface circuit.

selects another input of the multiplexer and gives a signal to ADC. This is repeated 17 times to get the 17 digital signal. This entire process is to be finished within the fixed dead time after which the control logic resets the system.

Out of the 17 digitized signal, one from the anode gives the energy of the incident X-ray photon, and the eight signals from each cathode contains position information of the event in respective direction. From the order of the eight signal in each direction the processing software first derives the numbers of the originally excited adjacent strips. Now it has information about both the position of the excited strips as well as the charge induced in each strip. The software then calculates the center of gravity of the charge spread to give the final position of the event.

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