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A Large Area, Modular Multianode Proportional Counter for X-ray Astronomical Observations

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A large area multianode proportional counter of modular design for studies of cosmic X-rays in the energy range 0·1-10 keV has been designed and developed. A four-micron polypropylene film coated with ~ 200 Å of carbon forms the entrance radiation window of the counters and is supported by two slat collimators that define a field of view of 13° × 25°. The detectors are filled with a gas mixture of argon and carbondioxide in the ratio 19 : 1 and maintained at a nominal pressure of 765 mm. Signals from the X-ray detector are processed through a 256-channel pulse height analyzer and transmitted by means of a PCM/FM telemetry system. Design considerations for the optimization of circuitry and systems for signal processing and transmission are discussed. The minimum detectable flux from X-ray sources at the 3σ level of sensitivity in the 1-10 keV energy range for experiments to be flown from Thumba using a Centaure rocket is estimated to be about $3{\cdot}4 \times 10^{-11}$ ergs cm^{-2} sec^{-1}.

1. Introduction

Gas proportional counters with thin plastic films as entrance radiation windows are frequently employed for observations of celestial X-ray sources in the energy range 0·1 to 20 keV (Ref. 1). They can be constructed in a variety of shapes and sizes to suit the limited volume and weight capability of a rocket or a satellite; they have relatively high efficiency for detecting soft X-rays and their energy resolution is good at energies greater than about 1 keV. In this paper we present details of a modularized multianode proportional counter system and its associated instrumentation that have been optimally designed for X-ray astronomical observations using Indian Centaure rockets. The modular construction would also enable us to adapt the design for very large detector systems for experiments using other vehicles such as Rohini 560 S rocket and the space shuttle.

2. The Detector System

The detector system consists of two identical counter banks mounted back-to-back, each side consisting of 36 proportional counter cells arranged in 3 layers of 12 cells per layer. Each cell has a cross-section of 15 mm × 15 mm and a length of 360 mm. The total area of each side is therefore 648 cm^2. The anodes are made of 50 μm gold-coated tungsten wires. The wire-walled cathodes, with a centre to centre spacing of 5 mm each, consist of 100μm gold-coated molybdenum wires. Each of the anode and the cathode wires is tensioned by means of a spring kept inside a housing at the edge of the wire-bridge. An exploded view of the counters is shown in Fig. 1, which also shows the method used for tensioning the wires. The individual modules are separately wired and after assembly, the end cells are interconnected and operated as a side veto counter. The remaining 10 anodes per layer form the signal cells and the 3 layers are operated in mutual anticoincidence. (Interconnecting alternate anodes of a given layer and operating them in mutual anticoincidence will reduce the background still further.[2] This scheme will be adopted in future flights with capabilities for larger payload weights.).

The counters are flushed with a gas mixture consisting of 95% argoa and 5% CO_2 till 5 min before the rocket launch and are closed and maintained at a nominal pressure of 765 mm of Hg during the flight with the help of solenoidal valves. The inflight pressure of the counters is monitored by means of a small calibration cell attached to each side and sharing the gas volume of the main counter. The calibration cell has an Fe^{55} radioactive source mounted inside it, and the spectrum of this source is continuously monitored in flight. This enables a determination of the change in pressure inside the counters due to leakage of gas and/or bulging of the counter body and possible

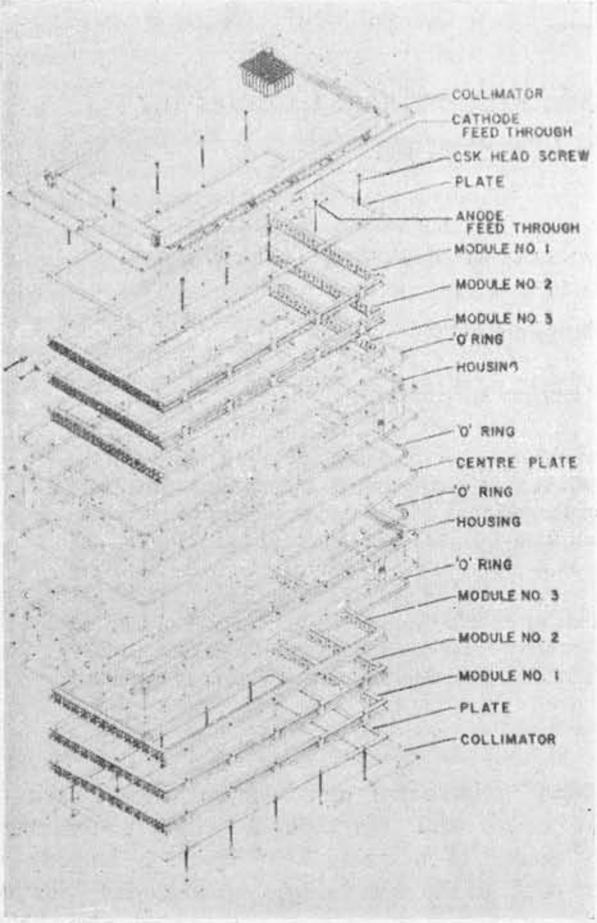

Fig. 1 — An exploded view of the counter system

deterioration in energy resolution due to contamination of the gas by degassing from internal parts.

The entrance radiation window of the counters consist of 4-μm thick polypropylene films coated with approximately 200Å of colloidal carbon in alcohol. The carbon coating provides a conducting cathode for the top layer.

Leakage of gas across this 4-μm window under a differential pressure of 1 atmos in space is negligible. If one uses one or two micron plastic film as the entrance window, the leakage of gas will be significant, and therefore, an on-board gas-replenishment system will have to be employed, thereby increasing the total payload weight and complexity. It must, however, be noted that the detection efficiency of our counter with a 4-μm thick polypropylene window at 0·28 keV is 50% whereas that with a 2-μm thick window increases to 70%. It was, therefore, decided to use the 4-μm window, sacrificing a little bit on the efficiency, while saving considerable weight to the payload, which, in turn, gives a larger apogee for the rocket and hence a longer observation time.

X-rays are collimated by means of slat collimators consisting of 0·4 mm thick aluminium vanes. The field of view depends upon the experimental objectives. For an observation of the Crab nebula, the vicinity of which is free from other strong X-ray sources, and a study of the absorption of X-rays by the interstellar medium along the line of sight to Crab, we use collimators with FWHM angles of 13° and 25° in the azimuthal and elevation directions, respectively. The collimator vanes are etched in sodium hydroxide to obtain correct thicknesses and to provide a smooth bottom surface which touches the thin plastic window. The slats thus provide both collimation of X-rays and support of the thin windows that have to withstand a differential pressure of 1 atmos across them. A stainless steel window frame which consists of 10 horizontal strips of 3 mm thickness and 20 mm height and mounted above the aluminium vanes, provides the collimator support against roughly the 1-ton force that operates across the counter window in vacuum. Fig. 2

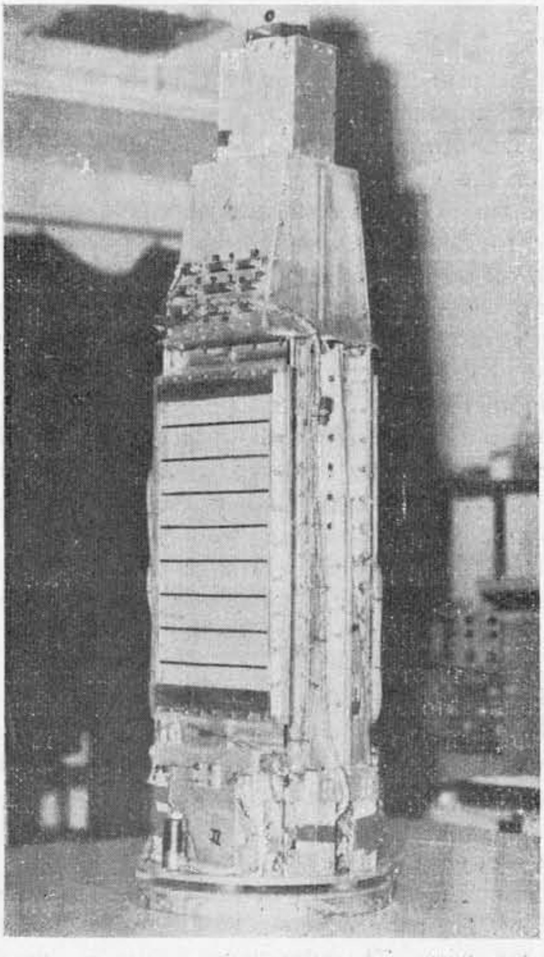

Fig. 2 — A photograph of the integrated payload

shows a photograph of the integrated rocket payload.

3. Electronic System

The high voltage required to operate the counters in the proportional region is obtained from a dc/dc converter. The voltage required by each one of the counters is drawn from a bleeder chain such that all signal cells have the same gain at a particular pressure. The output from each anode is charge integrated by means of a low noise charge sensitive preamplifier and further amplified in post amplifiers (Fig. 3). All the eight amplifier outputs corresponding to the six layers and those of two calibration cells are mixed in a mixer amplifier. The output of the mixer amplifier is stretched to about 25 μsec by a pulse stretcher circuit. If this event fulfills certain requirements the pulse height will be kept available by enabling a linear gate for further processing.

The requirements are the following.

(i) The pulse height lies within an energy window set by lower and upper level discriminators (LLD and ULD).

(ii) The pulse is not coincident with pulses from signal cells of other layers or from the two veto cells.

The anticoincidence logic consists of a discriminator which decides the coincidence of an event with a resolving time of 0·5 μsec.

The veto counter outputs are shaped and given to scalers. The scaler (divided by 8) outputs are added by a resistance adder and given to a VCO. The pulse heights from veto 1 and veto 2 scalers are adjusted to 3V and 2V, respectively, so that the identification is obtained from the pulse height and the input to VCO does not exceed 5V.

An A/D converter converts a qualified pulse height into an 8-bit binary number which is equivalent to 256 channels of pulse height information. The pulse height analyzer consists of a pulse height-to-time converter (PHTC), a standard crystal oscillator and an 8-bit counter. The pulse height spectrum is converted to a time spectrum by the PHTC. A 6V pulse height is converted into a 255 μsec pulse width. The standard 1 MHz clock is gated during this pulse width and the gated pulses are counted in an 8-bit binary counter. The counter output is loaded into a parallel-in parallel-out (PIPO) buffer register.

The event occurrence location is identified by a number which is the address of the counter. An address generator selects the counter and requests the transfer of the measured pulse height provided

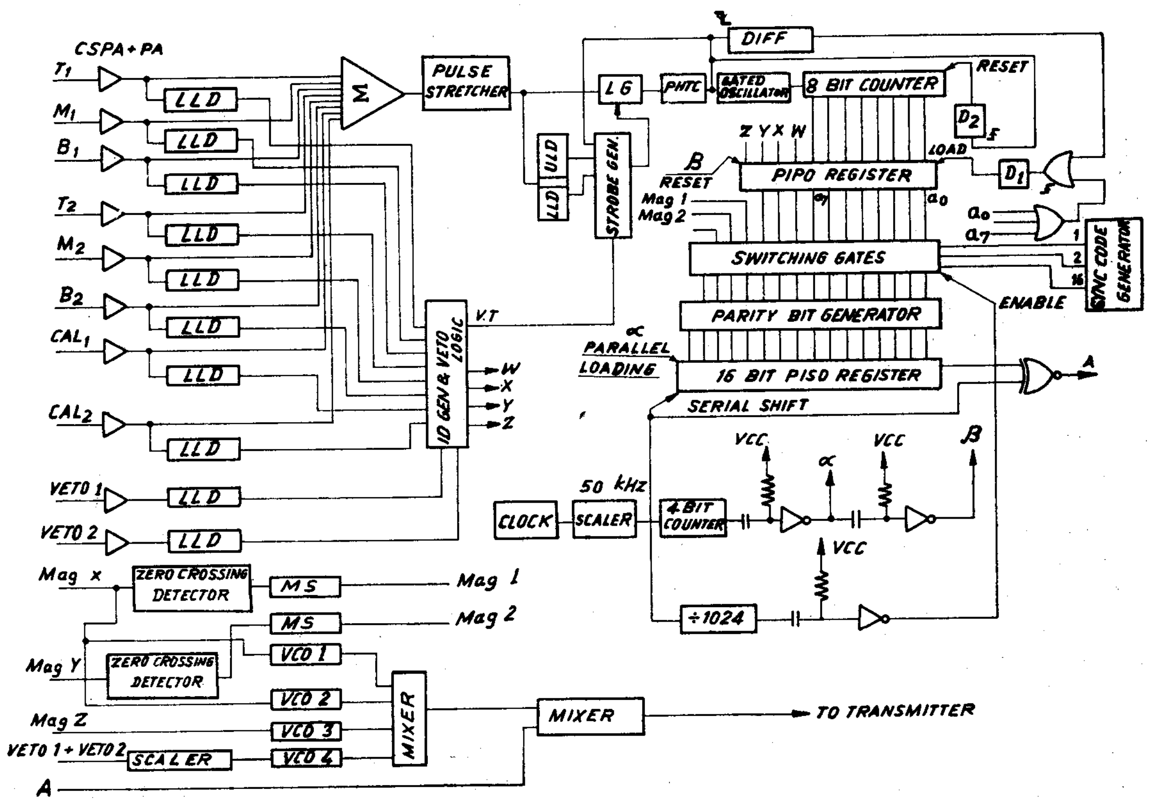

Fig. 3 — A schematic of the electronic system

the buffer PIPO register is empty; otherwise the new data are lost. The address of the counter is 4 bits in length.

A check on the pulse height word is made by introducing an odd parity bit. The 16-bit word is then loaded into a parallel-in serial-out (PISO) register once in 320 μsec. The data in this register are serially shifted at the rate of 50 kilo bits per sec. The data generated are NRZ-(L) code. An exclusive NOR gate is used to convert NRZ-(L) data into Bi-ϕ(L) with the help of 50 kHz frequency and are fed to the digital telemetry system. The Bi-ϕ(L) code is used for the following reasons.

(i) The Bi-ϕ family provides transitions for every bit period. This property deletes the need for dc-coupling required by the NRZ code.

(ii) Bi-ϕ provides clock information continuously so that the bit synchronizer does not fall out of synchronization when 1s or 0s are continuously transmitted. One of the disadvantages with the Bi-ϕ system is that the maximum power spectral density coefficient occurs at the frequency corresponding to the bit rate thereby requiring a larger transmission bandwidth.

Data needed for the aspect determination of the payload are provided by a triaxial magnetometer. Coarse aspect information is obtained in each word of the telemetered data (bits 13 and 14). These bits register the zero-crossing of the X and Y magnetometer outputs. Fine aspect information is obtained through three VCO discriminators, one each for the three units of the triaxial magnetometer.

The transmitter of the digital telemetry system is PCM/FM modulated with the digital words from the payload electronics. The magnetometer outputs and veto outputs are coupled to the mixer amplifier through four subcarriers, whose frequency responses are set according to IRIG standards.

PCM/FM telemetry system is used for this payload for the following reasons.

(i) The signals from the payload are basically digital in nature like, for example, the number of counts during a particular time interval.

(ii) The eight channels in the present payload require the same frequency (0·5 kHz) responses. According to IRIG standards this is not possible. PCM/FM is the only alternative as it is a time multiplexed sampled data system in which the values of the input channels sampled are expressed in series of n successive pulses for each sample. As the signals in the payload are not periodic, they are mixed in a mixer amplifier and an address of the event is generated and added in the word.

(iii) Noise immunity is quite high since the information is transmitted in the form of either the presence or absence of a pulse. Noise levels up to $\sim$ 40% of the total pulse amplitude can be tolerated.

(iv) It can handle both analog and digital channels.

(v) The information efficiency (channel capacity utilization) is generally high and maximum utilization is possible.

(vi) As the data are in coded form, parity check bits and other forms of redundant or error correcting codes may be used to make PCM system less susceptible to noise in RF link.

The specifications of the telemetry format are as follows.

Number of bits/word	16 bits
Word format	Bits 1-8 : X-ray pulse height data Bits 9-12 : addresses Bits 13-14 : M_x, M_y Bit 15 : always 1 Bit 16 : odd parity check
Frame format	64 words/frame
Frame rate	20·5m sec
Bit rate	50 KBS
Frame sync code	15 bit pseudo random code
Subframe sync	Nil
Output signal	Bi-ϕ (L)
Output impedance	50 ohms
Signal level	0-9 V
Modulation	PCM/FM
Clock stability	Better than 0·02%

The telemetered data are recorded on a multi-track analog tape together with a standard time signal which is supplied by the telemetry ground station. Before detailed analysis, the PCM data are separated from the composite signal, decoded and

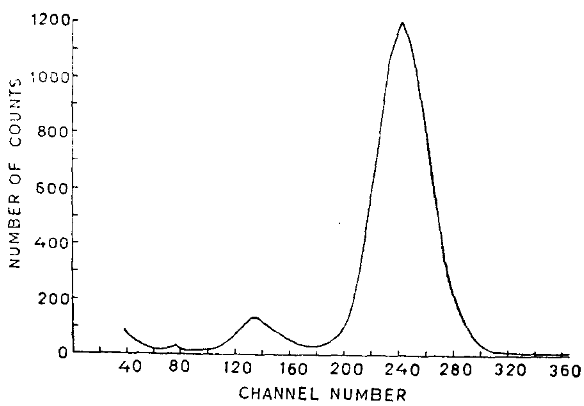

Fig. 4 — Spectrum of Fe^{55} showing the photo peak and escape peak (Pressure : 690 mm of Hg; temperature : 25° C; high voltage: 1900 V)

printed by a fast digital recorder for quick look analysis.

4. Calibration

Energy resolution and proportionality check of the counter are obtained with the help of radioactive sources of known energies. Fig. 4 shows the spectrum of Fe^{55} obtained from one of the signal cells. The overall energy resolution at 6 keV so far achieved is about 18%.

5. Sensitivity Estimates

For a 3-min rocket observation above 120 km, the time on a given source would be about 6 sec. The minimum detectable flux at 3σ level of sensitivity in the 1-10 keV range with the present detector system is about 2 Uhuru counts or $3{\cdot}4 \times 10^{-11}$ ergs cm^{-2} sec^{-1}. We can, therefore, determine the low energy turnover in the energy spectrum of Crab with better than 5σ statistical significance. The detector system is also suitable for the study of a number of other X-ray sources and mapping the distribution of the diffuse soft X-ray background.

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