The Proportional Counter Array (PCA) Instrument for the X-ray Timing Explorer Satellite (XTE)

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Abstract

A large area array of Xenon gas filled proportional counters has been developed as the main instrument of the X-ray Timing Explorer (XTE) satellite. The array is composed of 5 independent detectors, each operating in the energy range of 2-60 keV. Each detector provides event information timed to 1-microsecond, and spectral resolution of ~18% FWHM at 6 keV. This paper will describe the overall design of the detector and associated electronic system, their performance, and calibration results.

I. INTRODUCTION

The NASA X-ray Timing Explorer (XTE) mission is devoted to the temporal study of x-rays in the 2-200 keV energy range. The XTE satellite is scheduled to be launched by a Delta rocket, in late 1995, into a 600 km, 23 degree inclination, circular orbit. The planned mission lifetime is two years, however, there are no consumables on-board which would preclude a longer mission (5 years is the goal). The mission will study stellar and galactic systems containing compact objects. The spacecraft, shown in Figure 1, has articulated solar arrays which enable it to point anywhere in the sky at any time, except for a 30 degree half-angle solar exclusion zone. The spacecraft provides a pointing accuracy for the Proportional Counter Array (PCA) instrument of <6 arc minutes. Two star trackers (1 coaligned to the PCA look axis (X), and the other offset 9.9 degrees) provide a pointing knowledge to <130 arc seconds. On-board memory provide up to 4 orbits of data storage for periods without TDRSS coverage. Rapid response to transient phenomena is enabled by an All-Sky Monitor (ASM) provided by the Massachusetts Institute of Technology. The ASM monitors > 70% of the sky every orbit and provides ground controllers with near real-time information on variations in source intensities. When scientists are alerted to an interesting change occurring in any part of the sky by ASM data, the ground controllers can interrupt the preprogrammed observations and reorient the XTE satellite within about 5-hours to point its main bank of detectors at the transient phenomena. The slew rate for maneuvers is 180 degrees in ≤ 30 minutes, and up to 20 scheduled observations per day are anticipated.

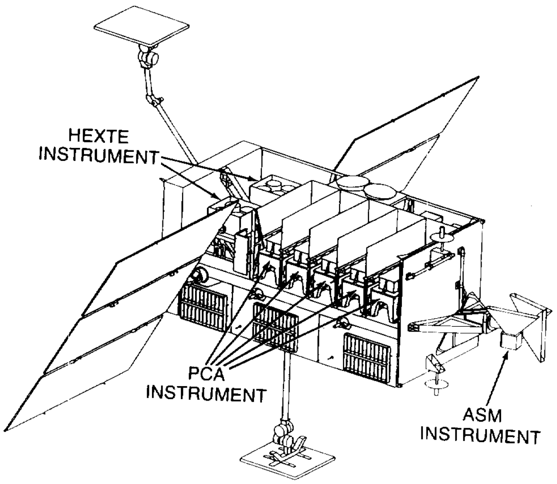

Figure 1: Cut-away view of XTE Satellite

The ASM instrument covers the energy range of 2-10 keV utilizing 3 shadow cameras, each with 60cm^2 collecting area (30 cm^2 net). The 3 shadow cameras rotate at a rate of ~1.5 degrees per second, and each covers a 6° x 90° FWHM field of view. Each detector is capable of <0.14mm RMS position resolution corresponding to an angular resolution of <0.2 arc minutes, in one dimension. The continuous monitoring of the sky by the ASM not only provides a transient event flag for the pointed instruments, but also provides a data base for long term studies (days to years) for bright sources.

The satellite's 2-200 keV energy range is covered by two primary detector systems. The 30-200 keV range is covered by an array of NaI/CsI phoswich detectors supplied by the University of California at San Diego. The High Energy X-ray Timing Experiment (HEXTE) consists of two independent modules each containing 4 detectors. Each module has a net collecting area of 800 cm^2 and provides ~18% resolution at 60 keV. The two detector modules are motor driven ±1.5° or

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±3.0° in two orthogonal directions from the on-axis position in order to allow background subtraction. The rocking period for HEXTE is 1-minute, with a 15 second dwell in each of the 3 positions. Data is telemetered to the ground at a 5 kbps rate.

The 2-60 keV energy range is spanned by a large array of proportional counters supplied by the Goddard Space Flight Center. The Proportional Counter Array (PCA) is comprised of 5 independent detector systems, each with a net viewing area of ~1475 cm^2. Each proportional counter, with its set of electronics, weighs 105 kg, and the complete array consumes 54 watts of power.

II. DETECTOR DESCRIPTION

The five identical gas filled proportional counters consist of two sealed volumes, the main detecting volume is filled with a 90%/10% mixture of Xenon/Methane gas at 845mm pressure. Figures 2 and 3 show a side and end sectioned view of a detector.

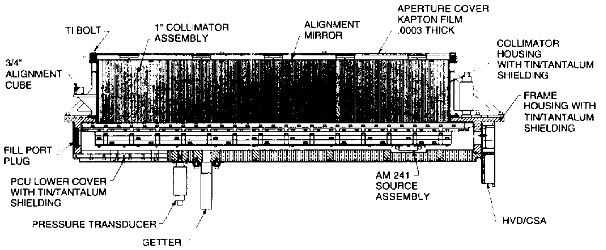

Figure 2: PCU Detector - Side View

The Xenon gas volume contains three multi-wire main detector layers plus a 3-sided anticoincidence layer. (The bottom anti layer is labeled "Frame 5" in Figure 3.)

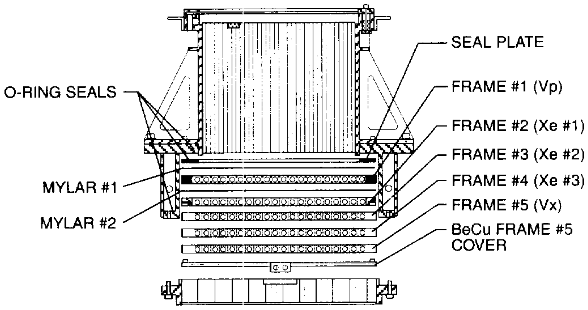

Figure 3: PCU Detector - End View

Each of the 3 main detecting layers contains 18 anodes connected in an alternating sequence to provide 2 outputs of 9 cells each. This alternating pattern, shown in Figure 4, allows the electronic system to distinguish when adjacent cells have detected simultaneous events. This, in addition to layer-to-layer anticoincidence events, greatly reduces the internal background of the detector.

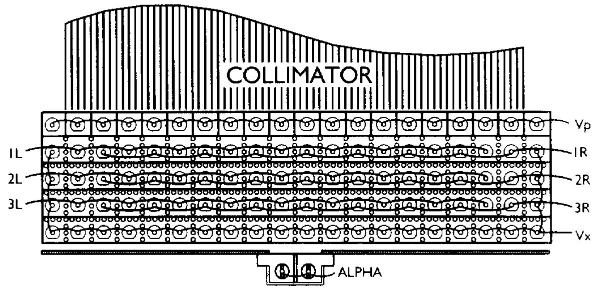

Figure 4: Grid Anode Wiring Sequence

Each of the 80 detecting cells in the Xenon gas volume (anticoincidence included) is 1.25cm square by 100cm long and its geometry is determined by 14, 50μ diameter, gold coated stainless steel wires. Each wire is constrained and positioned via a BeCu tube at each end of the wire frame assembly. All wires are soldered to the tubes at each end while under 100 ±8 grams of tension. The central anodes, which operate at a nominal +2050 volts, are insulated from the grid frame with Vespel insulators. The 2 edge cells of each layer, plus the last layer (4th Xenon layer), are all strapped together to form a 3-sided anticoincidence shield (Vx).

A BeCu back-plane provides several functions. It serves as the cathode plane for the deepest cells (4th Xenon layer), it provides passive shielding to events from the rear, and it houses a 5 nCi Am-241 alpha source which provides continuous long term calibration information (Figure 5).

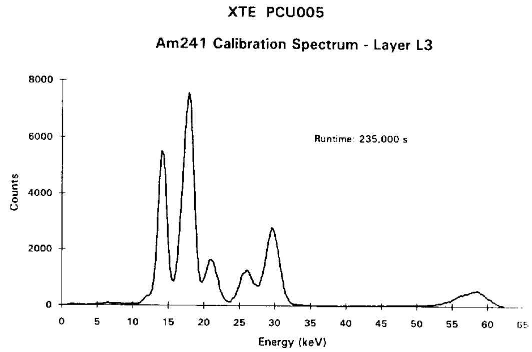

Figure 5: Internal Am-241 Source Calibration Spectrum

The entrance window to the Xenon filled main detecting volume is formed by a 25μ thick Mylar film coated on both sides with 700 angstroms of aluminum. A similar film provides the front entrance window to the detector. The volume between these two windows is filled with Propane gas and serves as a front entrance anticoincidence layer (Vp) to reject non-x-ray events entering the detector. This anticoincidence layer is filled to 798mm pressure and operates at a nominal +2800 volts. The Propane volume is 1.2cm thick with the same anode geometry as the main Xenon detector. The vertical side wires forming a typical cell in the main detector, however, have been replaced in the Propane layer with solid aluminum ribs (0.8mm thick). In addition to providing the cathode plane to form each cell, the vertical ribs provide support against the higher pressure being exerted on the inner window by the 845mm pressure Xenon gas. The pressure against the outer Mylar window is constrained by the detector mechanical collimator. All gas seals, both internal and external, are accomplished by using rubber compound gaskets.

The mechanical collimator for each proportional counter is constructed from solder plated BeCu corrugated sheets fused together to form hexagonal cells 0.32cm (1 degree FWHM) across the flats. Five collimator modules (each approximately 8,660cm^3) are coaligned and epoxied into a housing to provide approximately 1,475 cm^2 net viewing area per detector.

The aluminum detector housing is passively shielded over the external surfaces by a 0.38mm thick layer of tantalum covering a 1.27mm thick layer of tin. This graded shield provides over 10 optical depths of absorption for particles of 50 keV. The combination of shielding, plus the 4-sided anticoincidence for each cell, reduces the internal background by a factor of 20, to 5.9x10^{-5}cts/sec/cm^2/keV in the laboratory. Figure 6 shows a typical laboratory background spectrum. The peaks in the spectrum are due to lines from the internal Am-241 calibration source for which the alpha particle escaped detection.

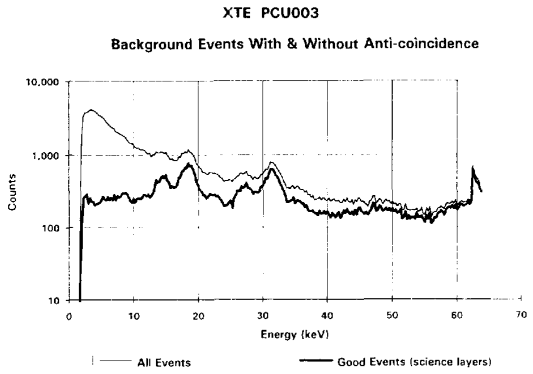

Figure 6: Background Reduction From Electronic Rejection

Other features of the detector are pressure transducers on both the Propane and Xenon gas volumes, and an activated (84%Zr-16%Al) getter (SAES type ST101) attached to the Xenon volume. Thermal loss via the front aperture is controlled by a single sheet of Kapton film, 8 μ thick, coated with 300 Å of SiO on the outside, and 500 Å of Al on the inside.

III. ELECTRONIC SYSTEM

Each Proportional Counter Unit (PCU) has its own set of support and readout electronics consisting of High and Low Voltage Converters, Test Pulse Generator, Remote Interface Unit, and Analog-to-Digital conversion system with associated logic. A block diagram of the electronic system is shown in Figure 7. The analog system processes 9 outputs from the detector (6-main Xenon channels, 1-Xenon anticoincidence channel, 1-Propane anticoincidence channel, and 1-calibration (Alpha) channel). A single ADC provides 250 channels of Pulse Height Analysis (PHA) information for each of the 6 main Xenon channels, plus the Propane layer.

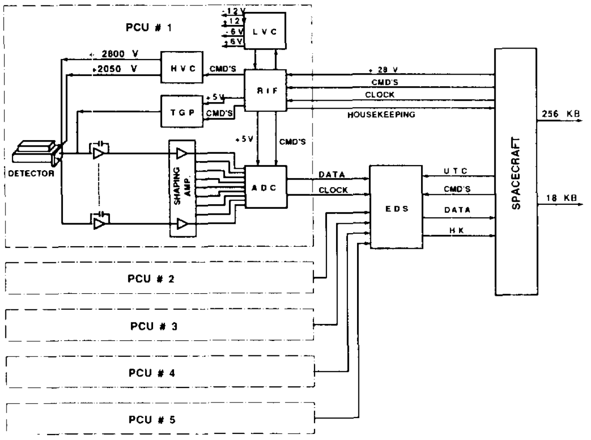

Figure 7: System Block Diagram

Event logic flags and event rates are also produced by the Analog System. PHA Data from each event, along with logic flags, are asynchronously sent serially to the Experiment Data System (EDS) utilizing 21-bit event words. The EDS, built by the Massachusetts Institute of Technology, time-tags each event to 1-microsecond and processes the event simultaneously with 6 Event Analyzers. Each Event Analyzer can be set up to bin data in separate commandable modes. PCA data are compressed by the EDS and formatted into data packets which are sent to the spacecraft telemetry stream for transmission at an average rate of 18 kbps.

A. *High Voltage Description*

The high voltage power supply box actually consists of two separate high voltage converters powered from the spacecraft +28V supply, one for the main detector, and one for the propane layer. Each supply operates independently and is capable of 16 discrete steps separated by about 20 volts.

The main detector volume operates at a nominal voltage of 2050 volts using step 8, and the propane volume operates at a nominal 2800 volts using step 12. A higher step was chosen for the Propane layer because it was thought that gas leakage may be more of a problem with that volume. In addition to normal ground control, there are two other controls over the high voltage which protect the detector from possible damage. First, the spacecraft on-board Stored Command Processor (SCP) is loaded with the prediction for entry and exit from the South Atlantic Anomaly (SAA) region of the orbit. Upon entering the SAA, the SCP will issue a command to lower the high voltage on all detectors by 1000 volts. Upon exit, the SCP will return the HV to its original potential. In addition, each detector has an independent high rate monitor (HRM) which is located in the Remote Interface Module. The purpose of the HRM is to turn off the high voltage to an individual detector if any of its 8 outputs exceed a preset count rate. The high voltage is distributed to the various detector elements through isolation resistors which are solid potted with Conathane EN-11.

B. Preamplifiers

The nine output signals from the detector (2-from each detecting layer, 1-anti, 1-propane anti, and 1-alpha) are capacitively coupled to a hybrid charge sensitive preamplifier (Amptek 250) using a 2N4858 JFET input stage. A 3pf capacitor and a 6.8M ohm resistor provide the feedback loop for this circuit which operates at a gain of approximately 0.25 V/pC. The charge sensitive amplifiers are mounted in the same box with the high voltage distribution and output coupling capacitors, on the end of the detector, in order to minimize the signal path prior to amplification.

C. Shaping Amplifiers

The output of each charge sensitive preamplifier is coupled to a shaping amplifier (SA) with an approximate gain of 18. The SA consists of a unipolar 4th order amplifier with a 3 µs peaking time. This signal will ultimately be pulse height analyzed. The shaping amplifier circuit also generates a differentiated 3µs zero crossing signal used for peak detection timing. A final amplification stage following the shaping amplifier stage allows gain trimming to match all detector outputs before pulse height conversion. Baseline restoration and pole-zero cancellation networks are also incorporated within the SA module.

D. Analog To Digital Converter

The unipolar main event and the differentiated zero-crossing signal output from the shaping amplifier are fed to the analog to digital converter (ADC) module. This module detects events, looks for coincidences, flags events, does A/D conversion, and shifts the digital data to the Experiment Data System (EDS). No events are rejected by the analog system. Suspect events are flagged prior to being sent to the EDS and the ground observer determines for each observation which selection criteria he or she wishes to apply to the data. The process starts when a 4-level commandable discriminator (4th level is off) detects an event. Another discriminator monitors all outputs for very large (VLE) events (>60keV). Upon detection of such a VLE, the signal being processed will be flagged and further transmission of additional events to the EDS will be inhibited for either 20, 50, 150, or 550 µsec, as established by ground command. Once any of the seven zero-crossing discriminators latch the analog pulse into its sample and hold circuit, it enables one channel of the analog multiplexer, and generates a System Busy signal to inhibit other event processing. The analog multiplexer receives 7 analog inputs and passes the selected output along to the ADC circuit. The ADC is a 12-bit successive approximation converter (AD7672) which accomplishes the conversion in 6.25µsec using a 2MHz clock. At the end of conversion a pulse latches all flags generated into the output register, re-enables the sample-and-hold circuits, and latches the ADC digital output into the dither processing circuit. The dither circuit provides a smoothing effect to mitigate the differential non-linearity effects of variable channel widths inherent in successive approximation ADCs. A 12-bit digital-to-analog converter (DAC) adds a small analog voltage to the event to be analyzed at the input of the linear gate, then digitally subtracts the equivalent digital voltage from the ADC output. The DAC is incremented after each ADC cycle thus spreading the differential non linearity error over several channels for each energy. The dither can be disabled by ground command. After processing, only the 8 MSB of the 12-bit ADC are sent to the EDS. If the System Busy signal is not reset within 64µsec, the system is assumed to be hung-up, and an unconditional reset is generated to clear the electronics.

The 3-sided Xenon counter anticoincidence cells (Vx) use three level discriminators (1, 10, 60 keV) to provide an integral analyzer with 2-bit resolution. The Vx signal is processed independently of the main detecting layers. If an event is being processed in the main detector, the Vx event will delay its transfer and be included in the same data word as the main event. After all buffers are loaded, the 21-bit data word is serially shifted to the EDS with the 4MHz clock. A logical 1 start bit, and logical 0 stop bit are appended to the 19 data bits. Although the EDS normally processes all PCA data, there is a mode whereby the EDS processing can be bypassed, and the data directly transferred to the spacecraft telemetry system for real-time transmission at a 256 kbit rate. This high rate mode is available for up to 30 minutes per day.

E. Test Pulse Generator

In-flight diagnostics are made possible by an on-board test pulse generator (TPG). The TPG is controlled by ground command and provides either a linear ramp mode, or 16 discrete monoenergetic lines. The TPG output is injected at the input of all nine preamplifiers via ~0.14pf charge terminators.

F. Remote Interface Unit

While all science data goes through the EDS for processing, none of the housekeeping data or PCA commands interface with the EDS. Each PCA detector system has its own Remote Interface module (RIF) which processes all commands and housekeeping data. The RIF unit provides switched 28 volt power to the LVPS and HVPSs plus generates +5 volts for the analog electronics and TPG. The RIF also monitors the state of the three 28 volt power relays. The RIF module receives serial command telemetry from the spacecraft, decodes, and distributes 42 discrete commands for the PCU, and monitors the state of these same commands. Eighteen analog parameters are sampled which include 7 temperatures, 7 low voltage busses, 2 high voltage busses, and 2 pressure transducers. The RIF module also accumulates 14 different event rates and monitors the 8 main detector outputs for excessive rates. If any of the 8 detector output rates exceeds the commandable level (8192 cps default) for three consecutive, 8-second, readout periods, the RIF turns off the HV to the detector. Once disabled by the RIF high rate monitor, the detector can only be reactivated by ground command. The spacecraft interface to the RIF unit is via a 1773 optical link. The housekeeping telemetry rate is 512 bps.

G. Experiment Data System

The 5 PCU detectors can output data at a combined rate greater than 5,000 kbit per second, whereas the PCA telemetry allocation is only 18 kb/sec. Therefore, on-board data compression is required. The EDS architecture is realized by 8 separate Event Analyzers. Two EAs are devoted to processing ASM data and the other 6 EAs are devoted to the parallel processing of PCA data. This compression is accomplished by the EDS system, shown in Figure 8.

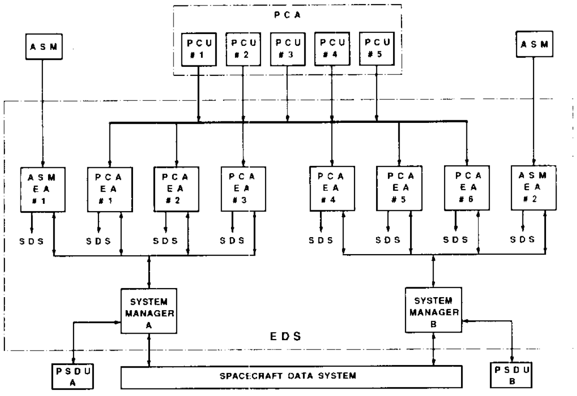

Figure 8: EDS System Architecture

Because microprocessors lack the speed needed to process the input data, look-up tables are utilized to quickly sort data. The ability to reprogram the look-up tables and microprocessors by ground command provides an unprecedented degree of flexibility for the scientific observer. In order to provide a common data set for all observations, two EAs are always maintained in standard modes (Binned and Event Encoded Modes). The 19 data bits associated with each event word are captured by the EDS and presented simultaneously to the input of the six EAs. The EDS time-tags each event received to a 1 μsec precision. There is an additional 18.2 μsec processing time through the analog electronic system, and data transfer buffers, which must be subtracted during ground analysis. However, the absolute time of the spacecraft clock is only accurate to ~1 msec. If the event meets the programmed criteria established for the scientific observation, the event is binned by the digital signal processor and stored in the EA memory. After completion of the preset observation time, the memory contents can be further analyzed by the EA's microprocessor to obtain the information required, and to further compress the data before transmission. Currently established EDS modes are listed below in Table 1, however, other modes may be uplinked if required for some special observation.

Table 1: EDS Data Analysis Modes

Event Encoded
Binned
Pulsar Fold
Single Bit Code
Burst Search
Fast Fourier Transform

IV. PERFORMANCE

In order to maintain the long term stability for both gain and resolution, the detector is evacuated for two weeks while being heated to 60 °C. At the end of this outgassing period, the pressure, at room temperature, is typically 2×10^{-6} Torr. At this time, the getter is activated and the detector filled with gas. After gain and threshold adjustments, extensive calibrations are carried out using radioactive sources and accelerator beams. A typical detector response at 22 keV, from a Cd-109 source, is shown in Figure 9. Resolution stability is shown in Figure 10.

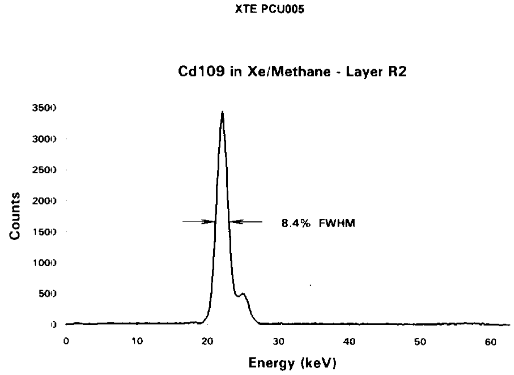

Figure 9: Typical Detector Response To Cd-109

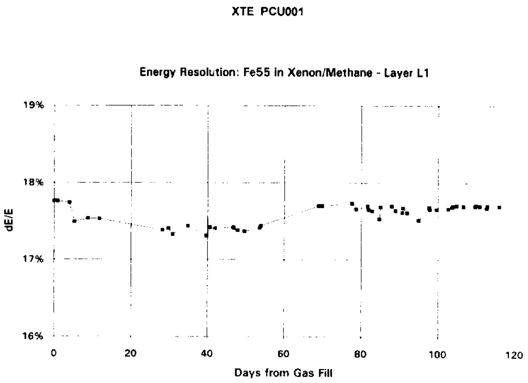

Figure 10: Typical Detector Resolution vs. Time

V. CONCLUSION

The PCA system described above, represents the latest in a series of highly successful proportional counter instruments flown to study x-ray phenomena. The unique features of the PCA instrument are its large collecting area and its accurate timing of events. This, coupled with the powerful on-board processing capability of the EDS electronics, and flexible operation of the satellite, will give x-ray astronomers an unprecedented opportunity to study time variability of faint x-ray sources, while at the same time maintaining moderate spectral resolution.

VI. ACKNOWLEDGMENTS

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