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DETECTOR DEVELOPMENT FOR X-Ray POLARIMETER

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ABSTRACT:

POLIX is an X-ray Polarimeter for astronomical observations in the energy band of 5-30 keV. The instrument is made of a collimator, a scatterer and four X-ray proportional counter detectors surrounding the scatterer. The scatterer is made of low atomic mass material which causes anisotropic Thomson scattering of incoming polarised X-rays. The collimator restricts the field of view to 3 degree x 3 degree so as to have only one bright source in the field of view for most observations and it is also designed to minimize the dead area between the cells and also to minimize the mass. These requirement are met with a collimator made of tapered hexagonal cells with a flat top angular response. This flat top response helps in mitigating any small pointing error of the satellite.

1.Introduction:

POLIX is an X-ray polarimeter being developed at the Raman Research Institute (RRI), Bangalore. This is an experiment approved for a small satellite mission of Indian Space Research Organisation (ISRO) named XPoSAT Qualification model and a flight model detectors of the instrument is being built at RRI based on the design.

2. Main objective:

The proposed experiment will be very useful for the measurement of degree and direction of the X-ray polarisation of a few bright cosmic X-ray sources including accretion powered binary X-ray pulsars, galactic black hole candidates, rotation powered pulsars and magnetars, supernova remnants and pulsar wind nebulae, and active galactic nuclei. For each of these sources many details are known but some very crucial information are missing that can be learnt only from X-ray polarisation measurements.

3.POLIX instrument configuration and design considerations:

There are four different ways in which polarisation can be measured in the X-ray band, Bragg reflection, Photo-electron emission, Thomson scattering, and Compton scattering. The Bragg reflection method works in a very narrow energy band and the Compton scattering method gives very few X-ray photons, both giving very low sensitivity for Xray polarisation measurements. Between photo-electron polarimeter and Thomson scattering X-ray polarimeter, the former requires extremely small pixel X-ray detectors and X-ray focusing optics, which is not suitable for a small satellite. We have therefore selected the method of Thomson scattering which is the exclusive method in the energy band of 10-30 keV and can be extended to 5-50 keV range. Some cosmic sources, like the accreting X-ray pulsars are brightest in this energy band as they are absorbed at lower energies and have steeply falling spectrum at higher energy, which also makes a Thomson X-ray polarimeter ideal to study these sources. The basic configuration of the instrument consists of a collimator, a scatterer and X-ray detectors surrounding the detector as shown in Figure 1. The collimator restricts the field of view to a small part of the sky, 3 degree x 3 degree so that there is only one bright X-ray source in the field of view for most of the observations. The scatterer is made of a low atomic mass material, Lithium and/or Beryllium which causes Thomson scattering of the incoming X-rays, a process that is sensitive to polarisation of the X-rays. The scattered X-rays are absorbed and detected in a set of X-ray proportional counters surrounding the scatterer. The whole instrument is rotated around the viewing axis, thus providing azimuthal distribution of the scattering of X-rays in each element of the detectors, which enables X-ray polarisation measurement.

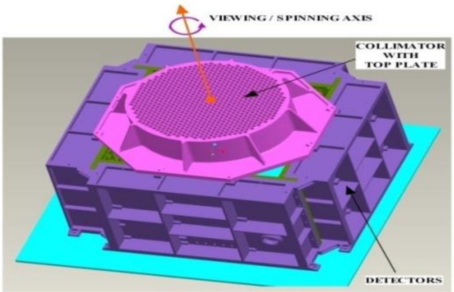


Figure 1 Instrument configuration.
(courtesy- POLIX PDR document)

POLIX – SPECIFICATIONS

Description	Value
Photon collection area	640 cm^2, Detector area=4*1080 cm^2
Energy range	5-30 keV
Field of view	3×3 degree with ± 0.2 degree flat topped response
Detectors	Position sensitive proportional counters
Total weight	~ 120 kgs.
Overall dimension	~ 650 x 650 x 600 mm^3 (excluding electronics)
Power	~ 80 Watt (Raw power)
Data generation rate	6 Gbits per day max
Scattering element	Beryllium/Lithium
Life time	3-5 years
Modulation	~ 40%

factor	
Sensitivity	**2-3% Minimum Detectable Polarisation (MDP) for 50 mCrab sources with 1 mega sec exposure**

Figure 2 Instrument specifications.

4. POLIX Detector Systems

For the energy range of 5-50 keV, that is accessible for X-ray polarisation measurement by the method of Thomson scattering, here we describe how the different components of POLIX have been configured

- Detector Components:

The POLIX detector systems consist of a collimator, a scatterer below the collimator, and four X-ray detectors surrounding the scatterer.

- Collimator:

The collimator is to restrict the field of view of POLIX so as to have only one bright Xray source in the Field of View (FoV) during most of the observations.

- Scatterer

Scatterer is a passive element directly mounted on satellite deck

To minimize the effect of photoelectric absorption of photons in the scattering element, a low atomic mass scatterer like lithium or beryllium is preferred.

4.1 Detectors

To meet the requirement of large area to surround all four sides of the scatterer and operation in the energy band of 5-50 keV, X-ray proportional counters have been chosen as the detectors elements for POLIX. Proportional counters have long heritage in space astronomy missions. The POLIX detectors are basically multi wire proportional counters and consists of four main parts (1) The wire frame (2) The detector housing (3) The top plate (also called window support plate) and (4) The mylar window. Figure 3 shows the exploded view of the detector showing the assembly. All the detector elements are milled out from single aluminum block.

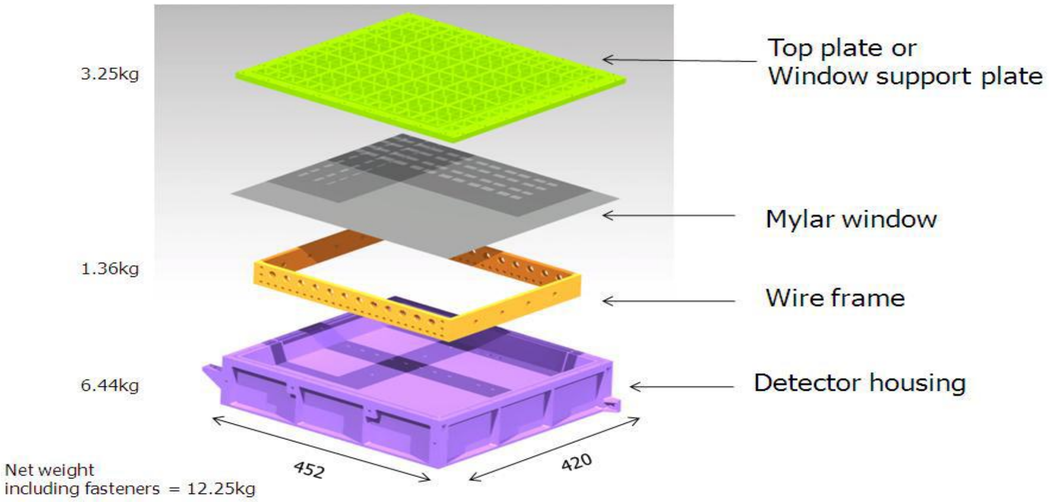


Figure: 3 Exploded view of the detector showing the different parts. The individual weights are also shown

4.1.2Wire frame

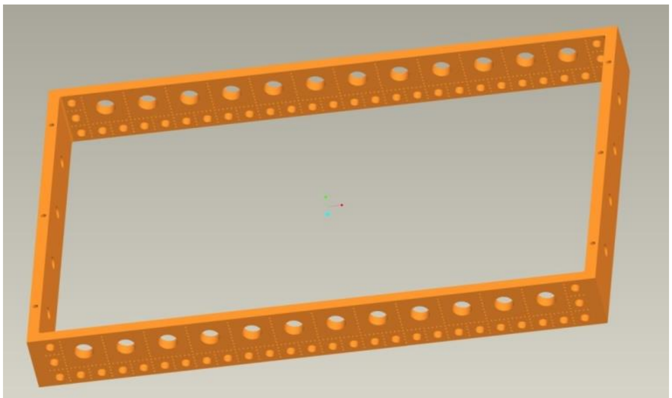


Figure : 4 The detector wire frame

Wire Type	Wire Material	Diameter (microns)
Main Anode	Nichrome	25
Anti anode	Gold coated SS	25
Cathode	Be Cu	50

Figure : 5 Wire details.

4.1.3 Mechanical dimensions of the wire frame

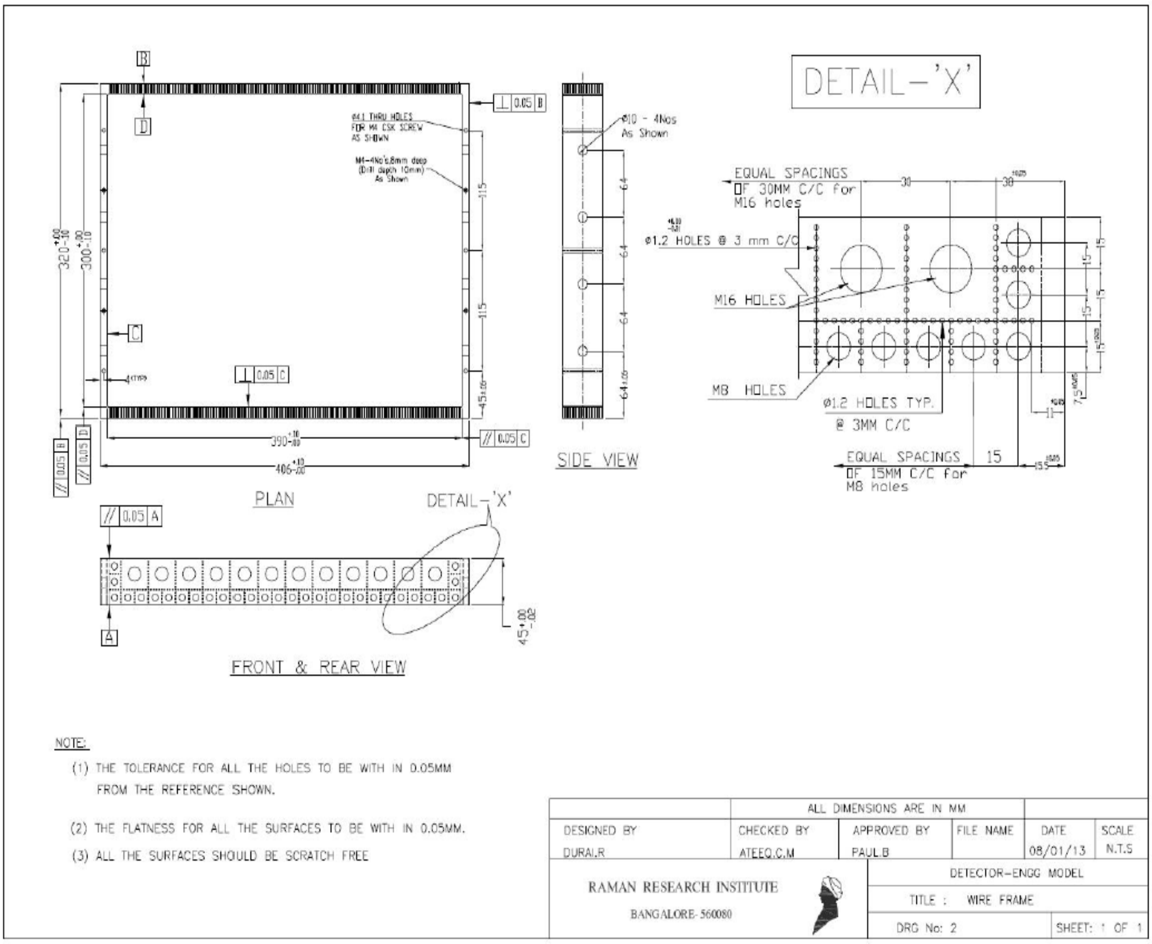


Figure: 6 Mechanical diagram of the Detector
(courtesy- POLIX PDR document)

The wire frame houses the proportional counter cells, wherein photons interact with the gas volume, and are detected.

For the POLIX detectors, the wireframe divides the detector volume into 12 proportional counter cells of size 3cm x 3cm x 30cm. Along the length of each cell, at the centre, 25 micron diameter resistive Nichrome wires are placed through Teflon insulators and these will be the anode wires of the proportional counters. A high DC voltage of the order of 1800-2400 V is applied on these anode wires. The 12 anode wires are grouped into two channels of 6 wires each. The anode cells are separated by 50 micron diameter Be-Cu alloy wires which form the cathode layer or the ground plane. For the purpose of background rejection,the main detector volume is surrounded on three sides by an anti-coincidence layer. All the anti-coincidence wires are connected together at the end to form a single output signal as shown in the figure below. Pulses from the anti-coincidence layer are used to veto simultaneous pulses from the main anode.Thus each detector there are five signals to be acquired and analysed. Pulses from two halves of the detector are analyzed separately and independently.

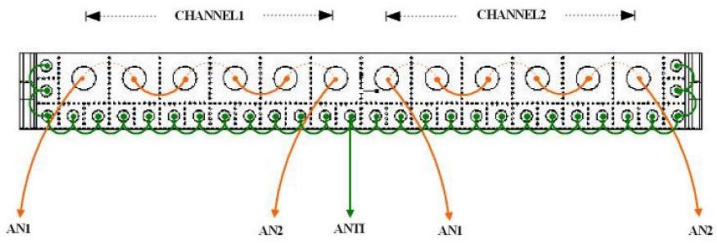


Figure :7 The detector internal wiring
(courtesy- POLIX PDR document)

There are 12 anode, 30 anti-anode and 354 cathodes ,Total of 396 wires in this frame

There are four anode signals from one detector, two each from the ends of each anode channel. One end of each anti-anode wire is shorted together and is taken out as the anti-coincidence signal. Simultaneous signals from the anti-coincidence layer and the main detector volume corresponds to a charge particle event and will be rejected.

4.1.4 Detector housing, window and the window support plate:

The wire frame is mounted inside a rectangular chamber, with one side open called the detector housing. The housing is closed with a plate which has rectangular sections milled out, so as to allow entry of X-rays, called the top plate. A 50 micron thick mylar window is placed between the detector housing and the top plate with one Viton o-ring on each side. The window allows the X-rays to enter into the detector and isolates the detector gas from the vacuum outside. The top plate also acts as a mechanical support for the window. This is required because the window will experience a positive differential pressure of 800 Torr, when the payload is in orbit. Hence it is also called window support plate. Figure 8 shows the top and bottom views of the detector housing. At the bottom side of the detector, there is a gas filling and evacuation port that will be sealed after the detectors are ready and calibrated. Figure 9 shows the detector top plate.

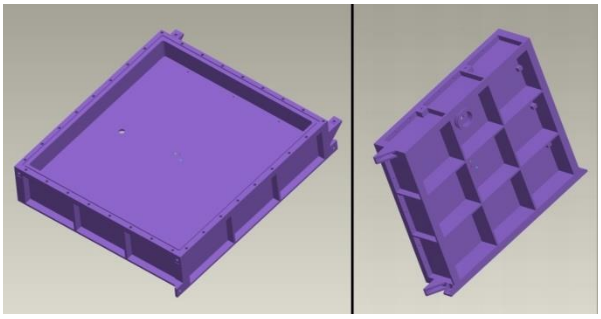


Figure : 8 Top view of the detector housing (left) and bottom view of housing (right)

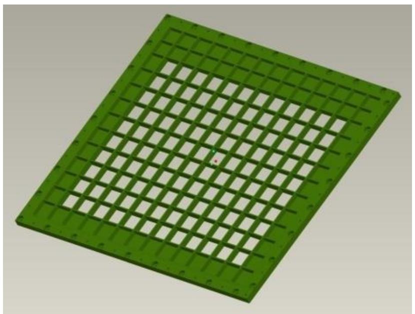


Figure : 9 The detector top plate

The detector gas is filled in the volume contained between the detector housing and the thin mylar window and is kept sealed by means of o-rings. Figure 10 shows the cut-away section of the assembled detector showing the o-ring positions. The o-rings used are 3 mm diameter Viton. It should be noted that there are two o-rings - one between the housing and the mylar window and the second between the mylar window and the top plate.

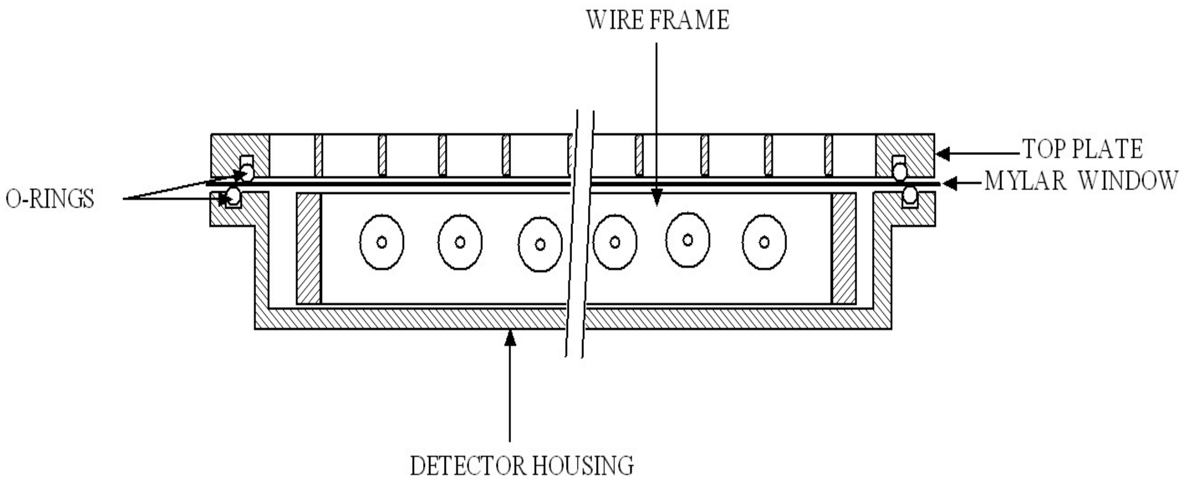


Figure : 10 O-ring positions in assembled view

(courtesy- POLIX PDR document)

4.1.5 Gas port

The detector gas port, located at the back of the detector housing serves the purpose of filling up of the chamber with detector gas to the required pressure level. It also helps in evacuating the detector chamber to the required level of vacuum before filling the chamber with gas. Figure 11 shows the exploded view of gas port along with the brass ring and closing button. The brass ring is epoxied to the housing and acts as a hard threading surface for fixing the closing button. The inner surface of the closing button has an o-ring which seals the port after gas filling.

Figure : 11 Exploded views of the Gas Port

4.1.6 Detector gas

Xenon is the most preferred detector gas for proportional counters in this energy band due to its large cross section for absorption of X-rays by photoelectric process. Along with xenon, 9% argon will be added for higher mobility of the electrons in the gas and 1% methane will be added as quench gas. Xenon gas at 800 torr in the detector volume will also give significant effective area in the band of 35-50 keV, thus extending the energy band upto 50 keV for a few very bright sources.

4.1.7 Charge division

Each of the four X-ray detectors of POLIX have 12 cells that are positioned azimuthally around the scatterer. To determine the azimuthal distribution of the scattered X-ray photons, identification of the cell is required for every X-ray photons detected in POLIX. Resistive anode wires used in the detectors cells are connected in series and a method of charge division of the signal amplitude at two ends is employed to identify the cell of Xray photon absorption.

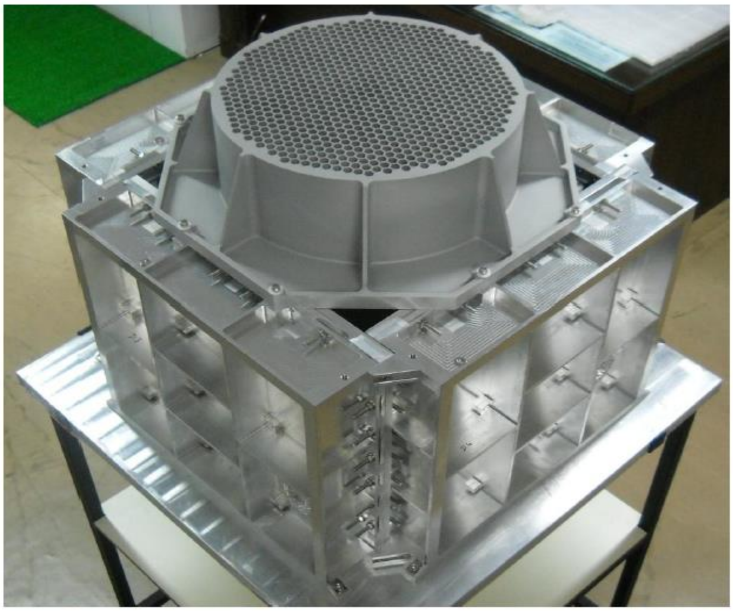


Figure : 12 POLIX four detector and collimator assembly.
(courtesy- POLIX PDR document)

4.2 Detector preparation

For prolonged operation of a few years in space, the proportional counter detectors need to be free of any gas leakage. Possible locations through which gas can leak out are the thin X-ray window, the O-rings, high voltage feed-throughs, and the gas filling and evacuation port. Other than checking any gas leakage through these parts, the stability of gas gain of the detectors are also monitored for extended period, which is very sensitive to any gas leakage. Throughout preparation of the detectors, any contamination of the detector surfaces with chemicals is avoided and any electronegative gas molecules like oxygen and water adsorbed in the inner walls of the detector chamber is removed by baking the detector body in vacuum for extended period. Residual impurity levels should be below a few tens of ppm for Xenon as the active gas, and this is ensured by measuring the energy resolution of the detectors at the end of the preparation activity.

4.2.1 Detector wiring procedure

The following is the procedure adopted for wiring of detector frames

(a) After fabrication, the wire frames are first soap water cleaned and then ultrasonic cleaned in Iso-propyl Alcohol (IPA) to remove any contaminations like coolants or oil deposited on the unit during machining. The anode pins, cathode pins as well as the anode and anti anode teflon bushes are also ultrasonic cleaned in IPA for 9 minutes.

(b) The next step is to insert cathode pins in the wireframe holes with the V-grooves of all pins aligned in the vertical direction. Extreme care is taken in the process of inserting the pins because there can be machining tolerances in both the pins as well as the holes. Reasonable push-fit tightness is ensured for each pin by trial and error. If required, any loose cathode pins are re-coated with Silver for attaining a tight push fit. The anode and anti anode Teflon bushes are then fixed on the frame, and the corresponding pins are inserted in the bush holes, maintaining similar push fit tightness and with all V-grooves aligned in vertical direction. The frame is once more ultrasonic cleaned and it is ready for wiring.

(c) The wiring work is done inside a class 1000 clean room with class 100 level below laminar flow benches. The cathode wiring is taken up first. The Be-Cu wires of diameter 50 microns are drawn through the cathode pins and weights of 40 gms is suspended on both sides so as to maintain tension. The wires are then soldered on both sides.

(d) After completing the cathode wiring, the anti-anode wiring is taken up next. Here the procedure is similar to cathode wiring except that the wires used are Gold coated SS of diameter 50 microns. All the anti-anode pins on one side of the frame are connected or looped together by multi-strand wires so as to form part of a single anti-anode layer. This layer is connected by means of a multi-strand wire to a feedthrough on the detector housing so as to take the signal out.

(e) The last layer to be wired is the main anode wires. Here the procedure is slightly different from the previous two layers. We use 25 microns diameter Nichrome wires for this layer. Since Nichrome wires are not solderable, they need to be epoxied. The looping for the main anode layer is first soldered to the bottom of the pins. The connection to the feedthroughs are also soldered and taken out initially itself. The nichrome wires are then drawn through the anode pins and weights of 14gms is suspended on both sides so as to maintain tension. The wires are then epoxied to the pins using conductive silver based epoxy and then cured under IR light for 48 hours. This completes the wiring procedure

(f) After completion of wiring, the wireframe is assembled inside the housing, and temperature cycled every day in vacuum between room temperature to 70 deg, for three cycles. This is to check for any breakages or sags developing in the wires due to thermal expansion or loose contact. After temperature cycling, problems if any, are rectified. This cycle is repeated till no more problems arise due to temperature cycling. This completes the detector wiring.

Figure : 13 Different steps involved in the wiring.(a)Soap water cleaning,(b)Ultrasonic cleaning,(c)Cathode pin fixing,(d) Teflon bushes fixing(e) Cathode wiring, (f) Antianode loop wiring(g) Anode wiring, (h) The completed frame.

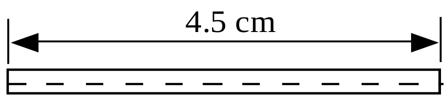
4.3 Wiring Details of the detector.

Wire Type	**Wire Material**	**Diameter (microns)**
Main Anode	Nichrome	25
Anti anode	Gold coated SS	25
Cathode	Be Cu	50

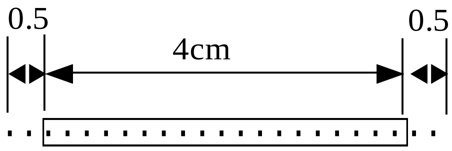
Figure: 14 Wiring Deteails of the detector.

- Looping wire length measurements:
- Anti- Anode loop wire length:

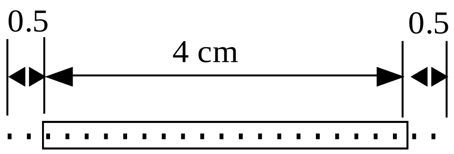
Cut the wire length to 4.5cm



Strip the wire edge to 0.5 cm on both the sides

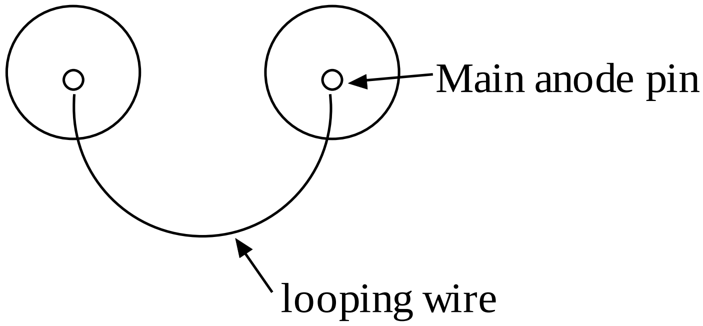


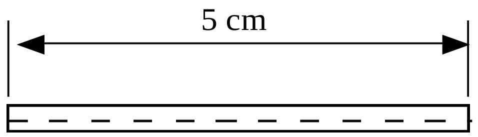
Tin and then cut off 0.5 – 1mm on both the sides



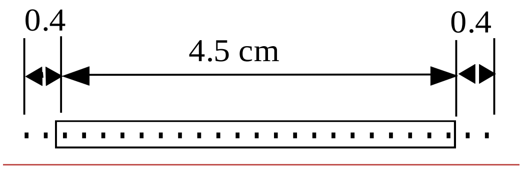
- <u>Main anode loop wire length:</u>

The length of loop wire is shown below:



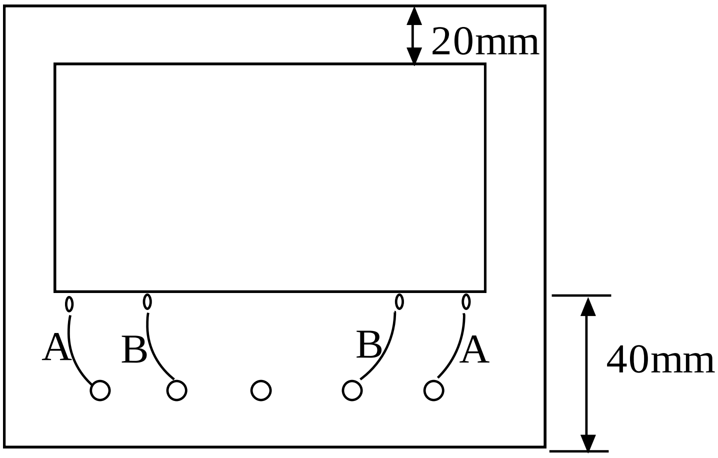


Cut the wire length to 5cm



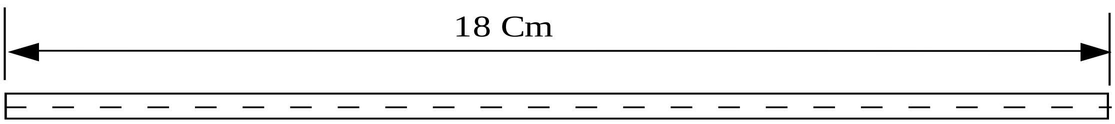
Strip the wire edge to 0.5 cm on both the sides and then tin it.

- Wire length from Main anode pins to feed thru.

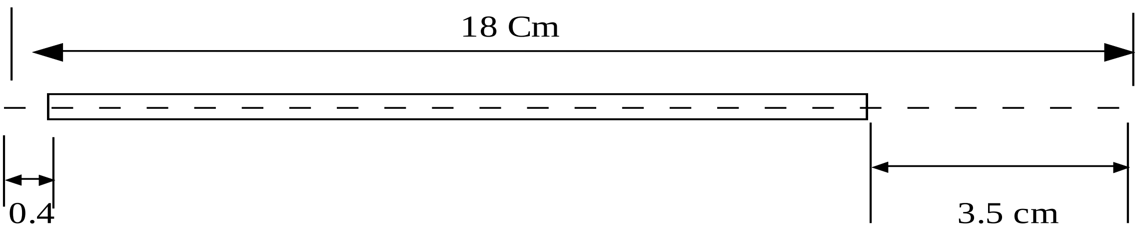


Length of the wire A and B

- Wire length to the feed thru's:

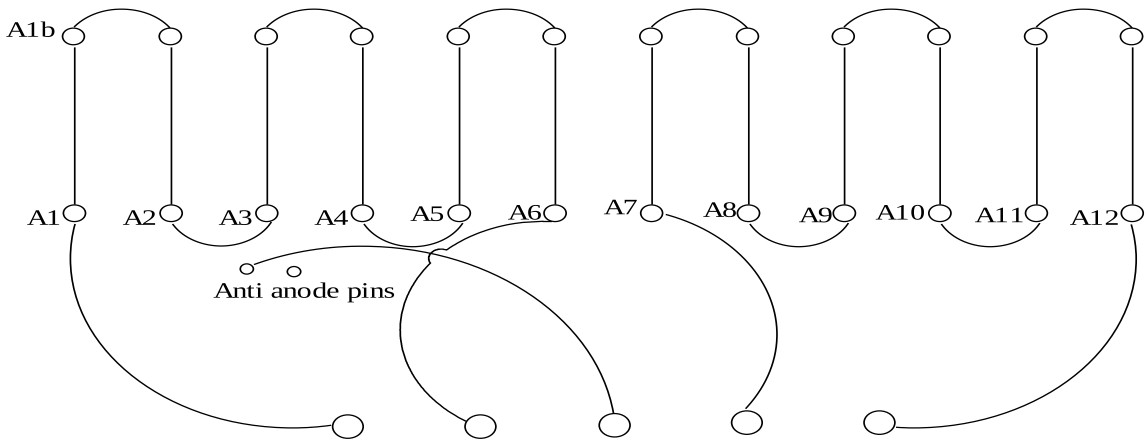


Cut the wire to 18cm lenght.



strip off 0.4 cm on anode side and 3.5cm on the feed thru side

➢ Wiring diagram of Detector :



4.4 Detector assembly

The high voltage feed-throughs and components of the gas filling and evacuation port are fixed on the detector housing using torr-seal epoxy with appropriate curing time. The Xray window, made of aluminised mylar is then installed on the detector housing. The system is closed with the window support structure (top plate). Two Viton o-rings are used on two sides of the X-ray window to make the detector housing leak-proof. Any possible gas leakage is checked with a Helium leak detector. On successful leak check, the window side of the detector is first evacuated using an evacuation plate that is temporarily fixed on the top along with an o-ring. The inside of the detector housing is then evacuated through the gas port with a turbo-molecular pump and the detector housing is purified by baking at a temperature of 70^{o}C or at 100^{o}C for one day. At the end of the baking cycle, the detector is brought to room temperature and it is filled with P-10 gas to a pressure of 80 torr and then xenon gas is filled upto a total pressure of 800 torr.

5. Overall Electronics requirements

The POLIX instrument works on the principle of Thomson scattering, wherein photons from the source are made to fall on a low atomic mass material; and the direction in which the photon scatters is used to extract information about the degree and direction of polarisation of the incoming photon stream. The scatterer is covered on all four sides with proportional counter detectors, which have wires perpendicular to the plane of the scatterer. Thus the direction in which photons have scattered can be determined by identifying the detector wire in which the photon has fallen after scattering. Thus the primary requirement of the electronics is to determine the detector and the wire in which the photon has finally fallen after scattering as shown in Figure 15.

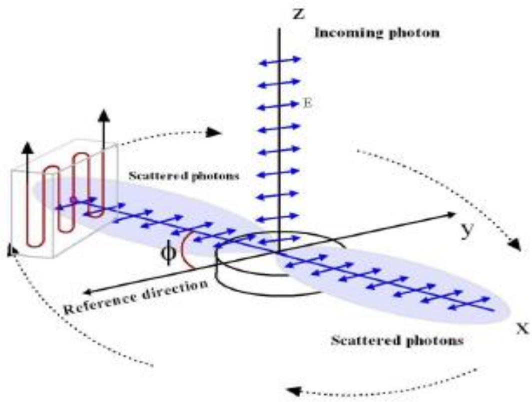


Figure : 15 Determing the directions of photon scattering.
(courtesy- POLIX PDR document)

5.1 Detector operation :

The detectors used in the instrument are multi-wire proportional counters. Proportional counters require high voltage biasing for their operation. This high voltage needs to be variable so that the gain of the proportional counters can be adjusted. Therefore one of the main electronics requirements is a variable high voltage generator, with provision for high voltage control. The high voltage electronics should have protection against any potential coronal discharge, by switching it off on detection of current above a pre decided threshold value. The high voltage also needs to be filtered to avoid noise and distributed to the anodes of the proportional counter. When an X-ray photon is absorbed in the detector gas, it produces a small ionisation track in the gas. The primary electrons are accelerated towards the anode wire and very near to the anode, they cause further ionisation in the gas, called avalanche, as a result of which a large charge is deposited on the anode wire. To measure this charge, we need to convert it to measurable voltage. Hence we require charge sensitive preamplifiers immediately following the detectors which convert the charge pulses produced by detectors to proportional voltage pulses, which can be measured by subsequent electronics.

5.2 Charge division, digitization :

The primary requirement of the electronics is to determine the detector and the wire on the detector in which the photon has finally fallen after scattering. To identify the wire on which the photon has fallen, we use the principle of Charge Division. In this method, we use resistive Nichrome wires, looped together at the ends as detector anodes. The photon absorbed in one cell of the detector causes deposition of charge on the corresponding anode wire. This charge will split and flow towards the two ends of the wires. This splitting of charge will occur in such a way that the end of the anode which is farther away (which provides higher resistance to the flow of charge) will receive less charge and vice versa. Thus the amplitude of the charge pulses collected at the anode ends is linearly related to the distance from the point at which the photon has impinged. Dividing the pulse amplitude at one end by the sum of the pulse amplitudes at both ends, we obtain the position of the point of interaction of the X-ray photon along the length of the wire. This technique of position determination by the concept of charge division is shown in Figure16

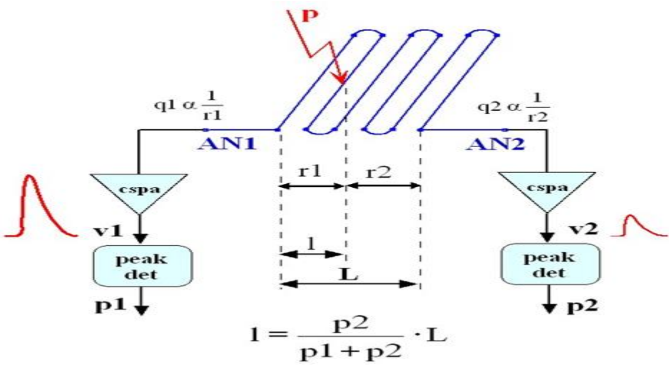


Figure : 16 Charge division

(courtesy- POLIX PDR document)

Therefore to obtain the position of the point of interaction of the X-rays, the electronics need to hold the peak of the voltage pulses appearing at the end of wires and digitize the pulse amplitude. In case of POLIX, the position calculation is done offline. For the purpose of background rejection, the main detector volume is surrounded on three sides by an anti-coincidence layer. All the anti-coincidence anode wires are connected together at the end to form a single output signal .Pulses from the anti-coincidence layer are used to veto simultaneous pulses from the main anodes and anti-coincidence layer. Thus, from each detector there are five signals to be acquired and analyzed. Pulses from two halves of the detector are analyzed separately and independently

5.3 Electronics block diagram

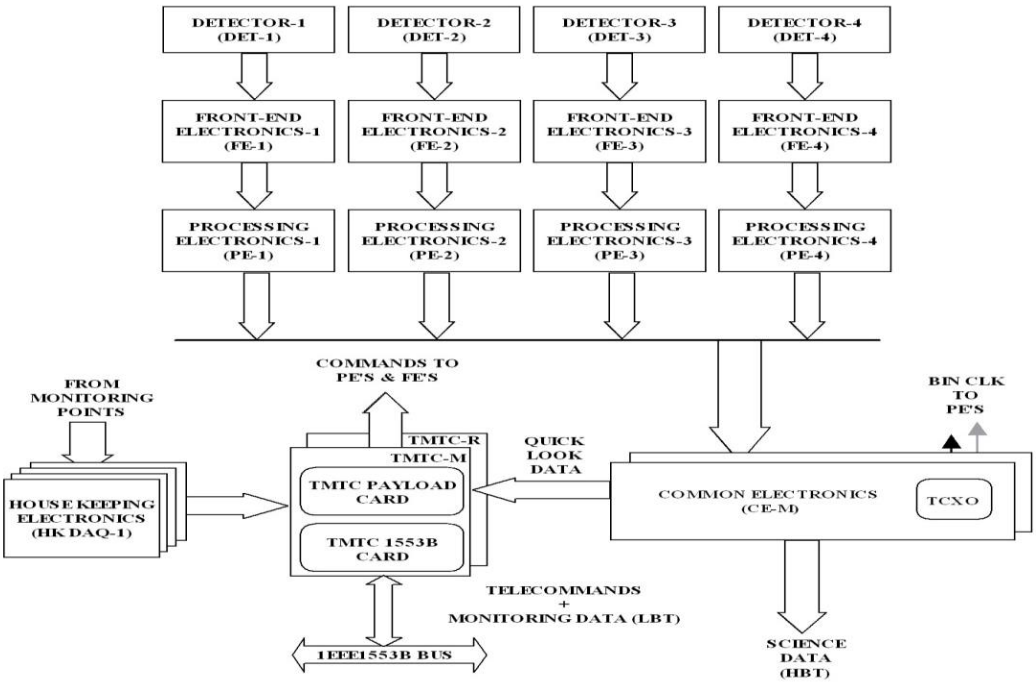


Figure : 17 The block diagram of Polarimeter electronics.
(courtesy- POLIX PDR document)

The Detectors (DET): There are 4 detectors. These are basically proportional counter detectors with the wires looped together. For each photon falling in the detector, a charge pulse is produced at the two ends of the wire.

The Front end electronics (FE): The Front end electronics converts this charge to proportional voltage pulse. It also provides controlled and stable high voltage bias to the detector

The Processing electronics (PE): The Processing electronics digitizes the peak values of these pulses and passes the data to CE. It also sends the total count of different types of pulses processed on every BIN clock

The Common electronics (CE): The Common electronics combines data from 4 PEs, time tags the data, packetizes and stores data and transfers the data to satellite bus.

The House keeping electronics (HK): The House keeping electronics acquires and monitors important payload parameters like high-voltage, thresholds, power supply voltages etc and passes the data to TMTC

The Telemetry and Tele-command electronics (TMTC): The telemetry and tele-command electronics acts as a command interface between the polarimeter electronics and the satellite bus. It also passes on monitoring data, quick look data to the satellite bus.

6 .Calibration results:

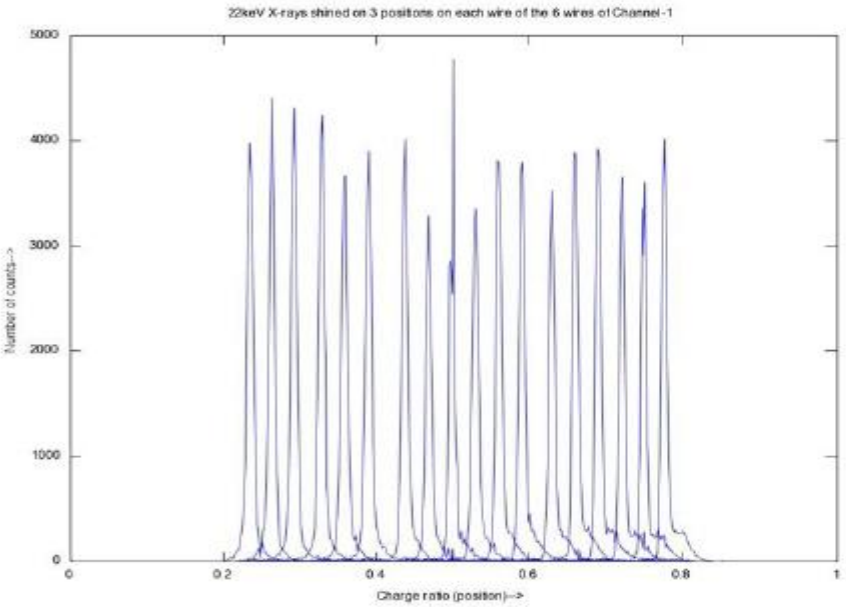


Figure : 18 Charge ratio vs position at 18 positions along the anode wire.
(courtesy- POLIX PDR document)

Figure 15 shows the position determination by charge division for this detector when shined with radioactive source. Peaks in the figure show the position of the radioactive source when shined on the detector.

Conclusion:

Wiring for 4 FM wire frames , 2 QM wire frames and the wire frames used for prototyping and vibration tests are completed. Testing of these wire frames assembled in proportional counters is under progress.

Acknowledgements:

We thank all members of EEG , POLIX and MES for providing us all the support in this work.

References:

1.Preliminary Design Review Document for Indian X-ray POLarimeter POLIX onboard XPoSat.