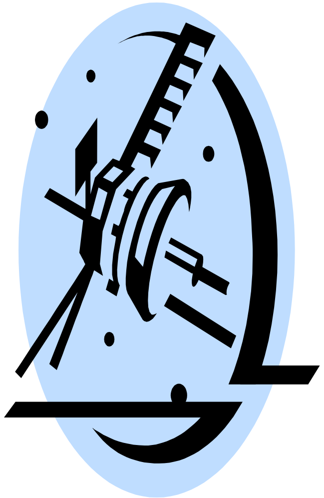
NMIMS MPSTME's Annual College Technical Festival Taqneeq



ASTROSAT mission: challenges in payload design and implementation

February 25-26, 2012

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Tata Institute of Fundamental Research

Outline of presentation

- Introduction of ASTROSAT.
- ASTROSAT Instruments.
- Payload functional requirements to meet all the Scientific Objectives of the mission.
- Electronics subsystem design goals.
- Design considerations & challenges.
- Functional overview of electronics.

ASTROSAT:A Broad Spectral Band Indian Astronomy Satellite

An Indian National Space Observatory

A Collaborative Project of

Tata Institute of Fundamental Research (TIFR), Mumbai

ISRO Satellite Centre (ISAC), Bangalore

Indian Institute of Astrophysics (IIA), Bangalore

Inter-University Centre for Astronomy & Astrophysics, Pune.

Raman Research Institute, Bangalore

Physical Research Laboratory, Ahmedabad

Canadian Space Agency, Canada

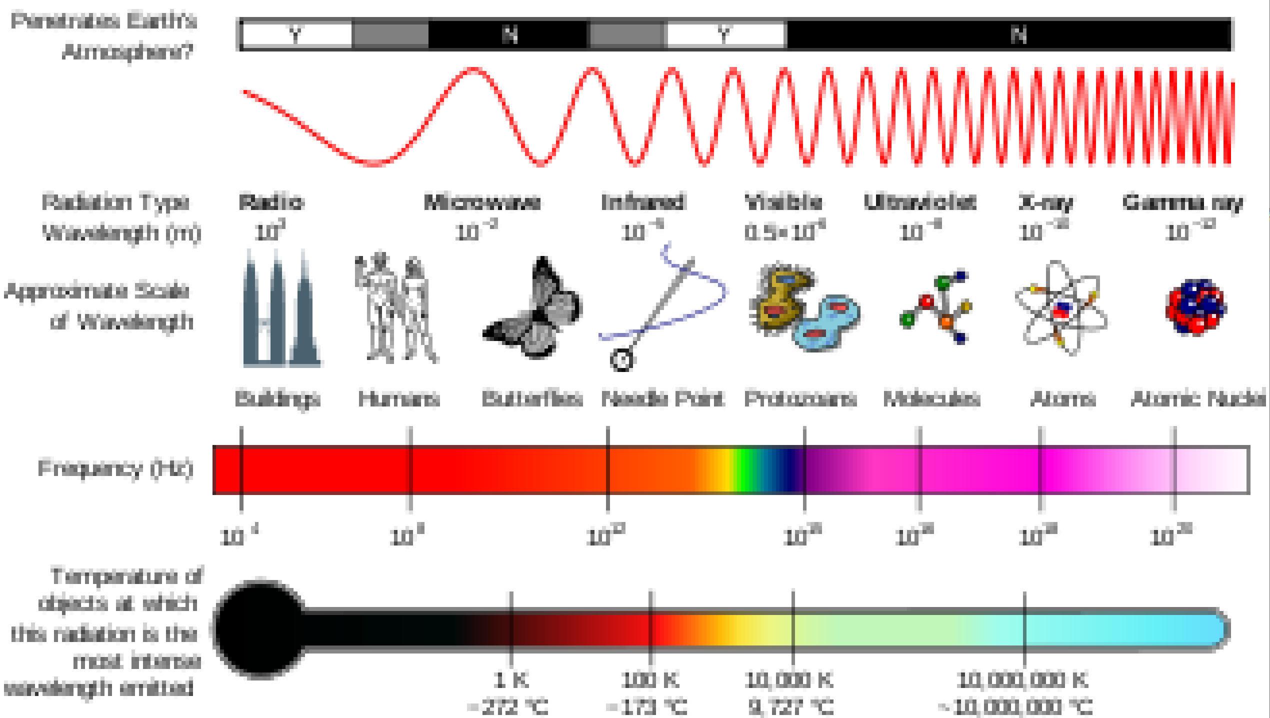
Leicester University, U.K.

With participation of Many Indian Universities and research centres

ASTROSAT

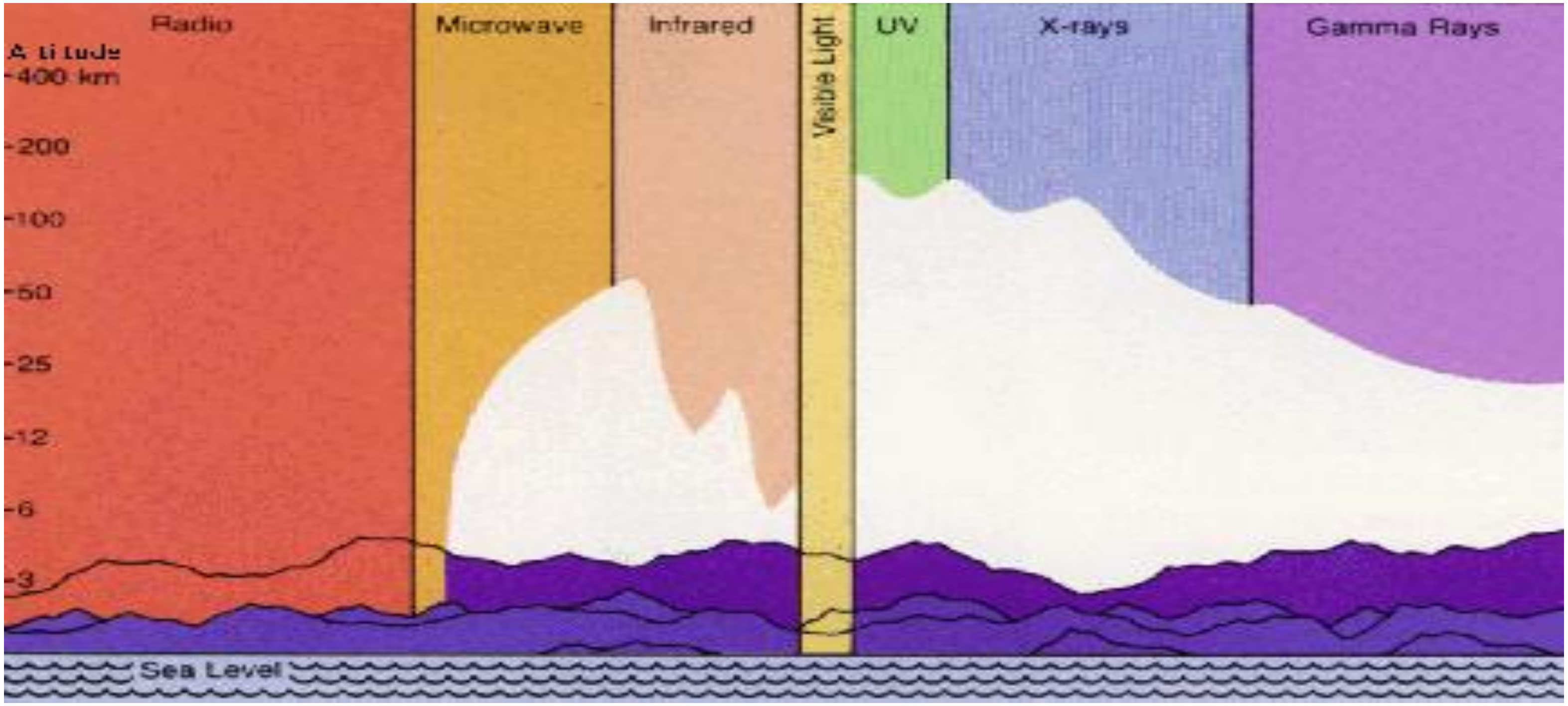
- India’s first dedicated national space borne observatory
- Multi-wavelength astronomy satellite mission
- Conceived with the principal objective of multi-wavelength studies of different classes of celestial sources and associated phenomena in wide range of X-ray and UV bands.

Electromagnetic Spectrum



CLASS: γ, HX, SX, EUV, NUV, NIR, MIR, FIR, EHF, SHF, UHF, VHF, HF, MF, LF, VLF, VF/ULF, SLF, ELF

FREQUENCY	WAVELENGTH	ENERGY
300 EHz	1 pm	1.24 MeV
30 EHz	10 pm	124 keV
3 EHz	100 pm	12.4 keV
300 PHz	1 nm	1.24 keV
30 PHz	10 nm	124 eV
3 PHz	100 nm	12.4 eV
300 THz	1 μm	1.24 eV
30 THz	10 μm	124 meV
3 THz	100 μm	12.4 meV
300 GHz	1 mm	1.24 meV
30 GHz	1 cm	124 μeV
3 GHz	1 dm	12.4 μeV
300 MHz	1 m	1.24 μeV
30 MHz	10 m	124 neV
3 MHz	100 m	12.4 neV
300 kHz	1 km	1.24 neV
30 kHz	10 km	124 peV
3 kHz	100 km	12.4 peV
300 Hz	1 Mm	1.24 peV
30 Hz	10 Mm	124 feV
3 Hz	100 Mm	12.4 feV

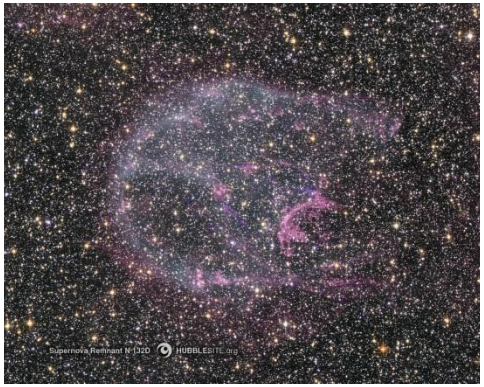


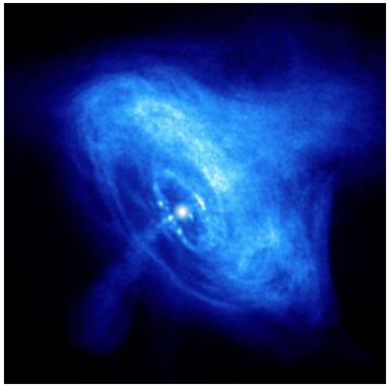
Electromagnetic radiation from space is unable to reach the earths surface, except at a very few wavelengths, such as the visible spectrum, radio frequencies, and some ultraviolet wavelengths. Astronomers can get above enough of the Earth's atmosphere to observe at some infrared wavelengths from mountain tops or by flying their telescopes in an aircraft. Experiments can also be taken up to altitudes as high as 40 km by balloons which can operate for days. Rocket flights can take instruments all the way above the Earth's atmosphere for just a few minutes before they fall back to Earth. **For long-term observations, however, it is best to have your detector on an orbiting satellite ... and get above it all!**

Brightest X-ray and UV Sources

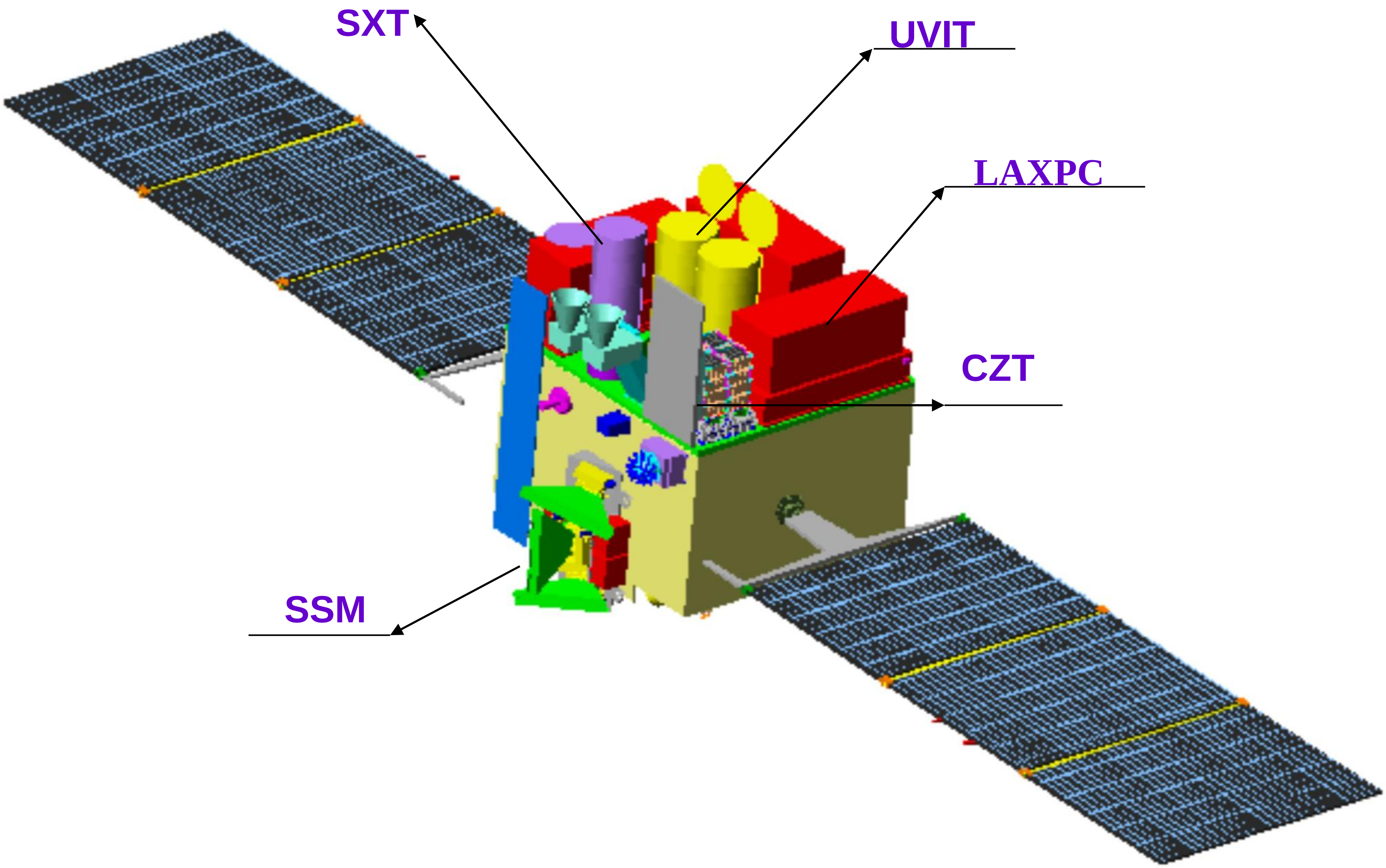
Supernova Remnants : About 200 SNRs in galaxy.

Shock heated gas (T ~10^5-10^7) emits UV and X-rays





ASTROSAT



Distinguishing Features of Astrosat

- Multi-wavelength observation capability with co-aligned instruments.
- Broad energy coverage in X-rays from soft X-rays to hard band (0.3-100 keV).
- Beppo-SAX had this feature but had limited area in hard X-rays.
- Hard X-ray capability to be better than earlier missions.

Astrosat Science Goals

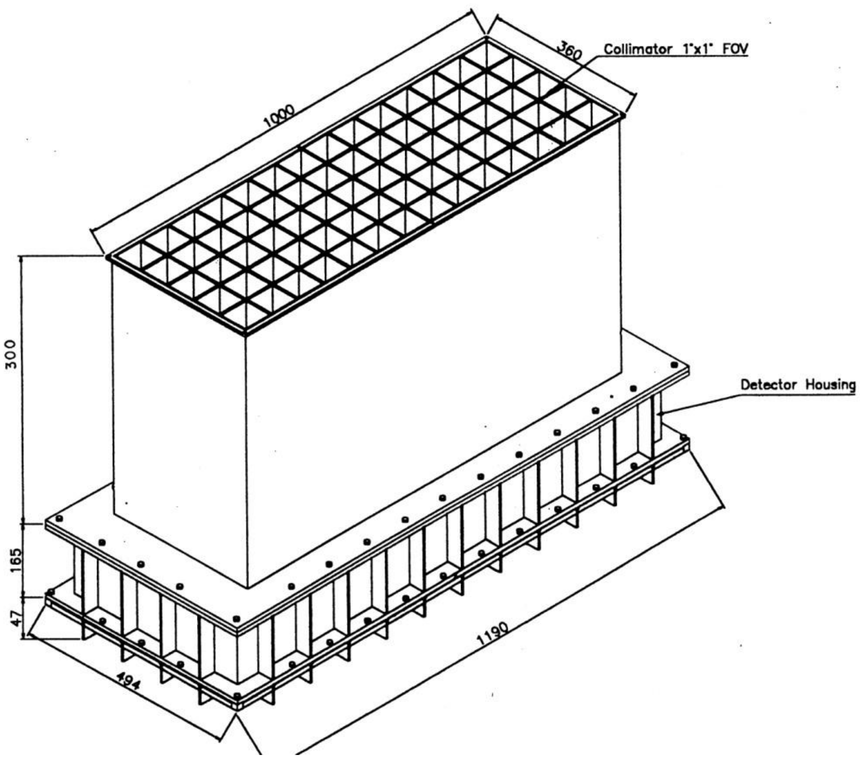
- Detection and profiles of Cyclotron Resonance Absorption features in the spectra of X-ray Pulsars
- High resolution (2 arc sec) UV imaging studies of Star Burst Galaxies, Normal Galaxies, AGNs, Hot stars, SNRs etc.
- Deep UV survey of selected regions of sky X-ray scans of Galactic Plane and Center for detection of new transients and other variable sources
- X-ray monitoring of sky for detection of Transients, Bursts and Flaring activity and studies of persistent sources

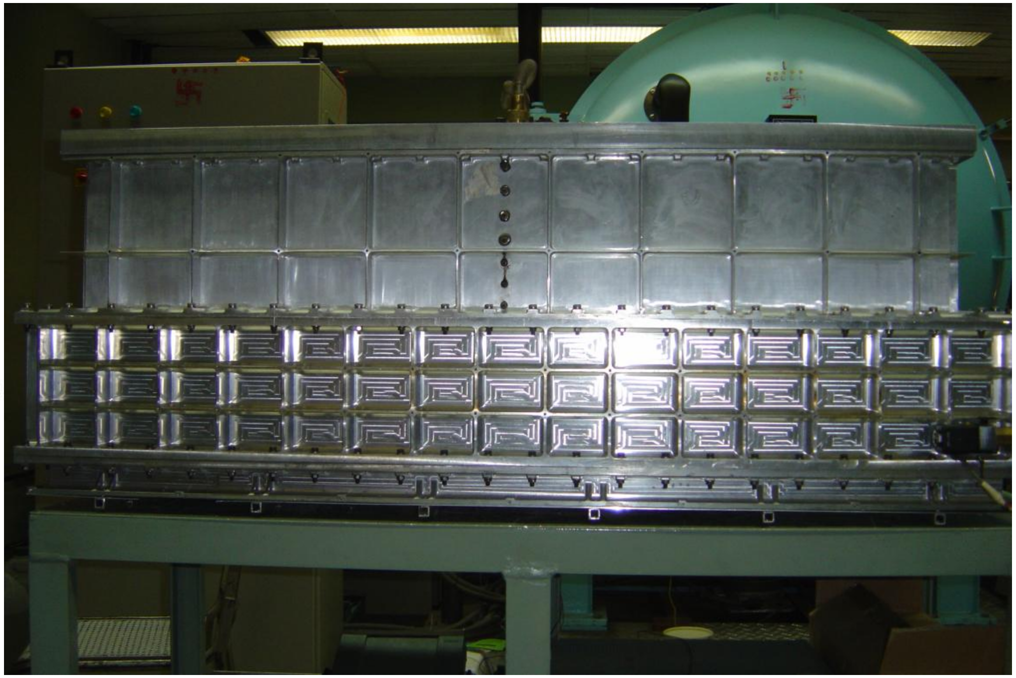
Astrosat Instruments:

Four X-ray Astronomy Instruments and one Ultraviolet Instrument With two Telescopes.

1. **LAXPC**: Large Area X-ray Proportional Counters with A_{eff}≈6000cm^2 at 20 keV, FOV =1° x 1°, sensitive in 3-80 keV band with low spectral resolution (E/ΔE ≈ 5-12).
2. **CZT Imager**: X-ray detector CdZnTe (Cadmium-Zinc-Telluride) array with a coded mask aperture having A_{eff} =500cm^2 and medium spectral resolution (E/ΔE ≈ 20 to 30).
3. **SXT**: Soft X-ray Imaging Telescope using conical-foil mirrors with medium angular (~3') and spectral (E/ΔE ≈20 to 50) resolution in 0.3-8 keVwith A_{eff}≈200 cm^2 at 1 keV.
4. **SSM**: Scanning Sky Monitor using 3 position sensitive proportional counters (PSPCs) with coded mask aperture , each with A_{eff}= 30 cm^2 and energy band of 2-20 keV.
5. **UVIT**: Ultraviolet Imaging Telescope (UVIT) has two similar telescopes each with 38 cm aperture primary mirror and photon counting imaging detectors covering simultaneously near-UV, far-UV and visible bands.

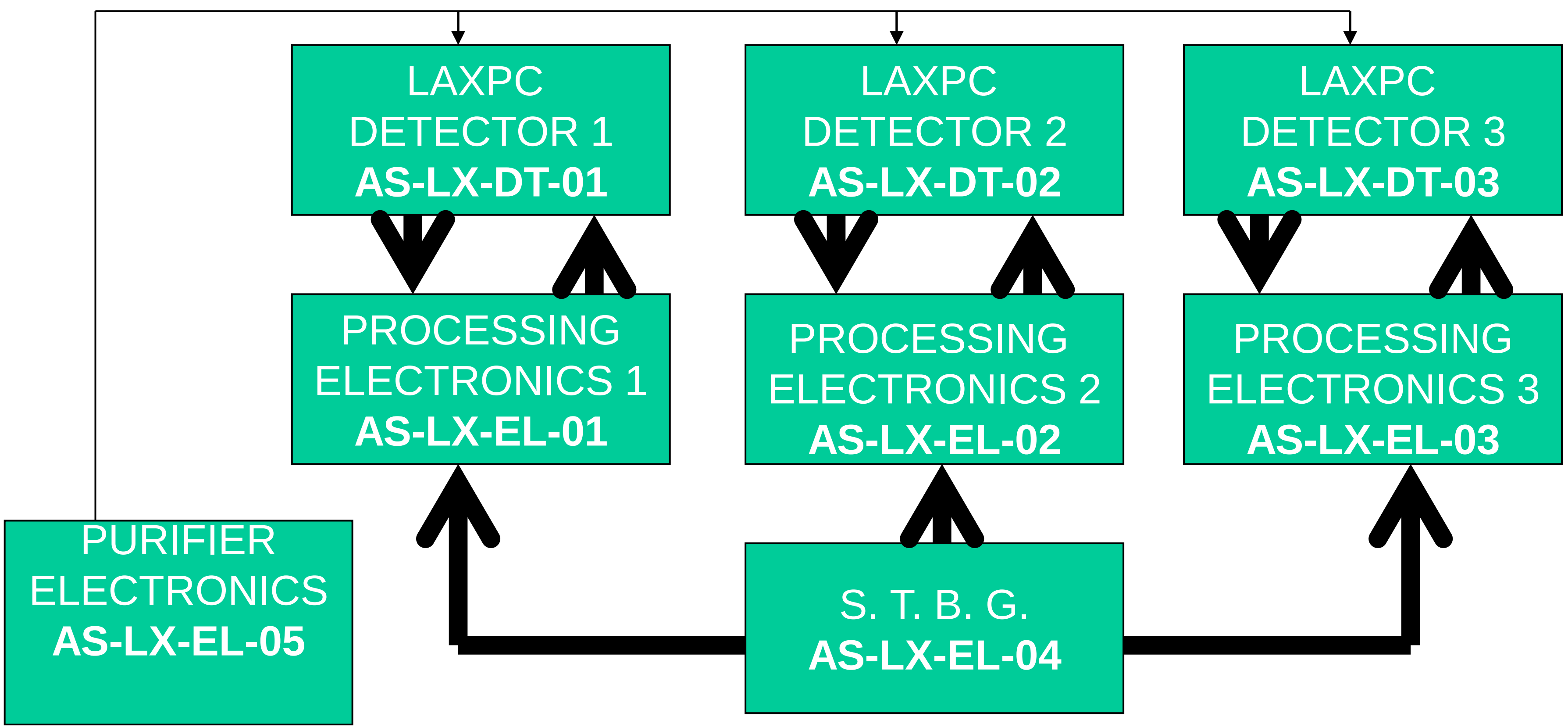
Large Area X-ray Proportional Counter (LAXPC)





LAXPC Packages

- LAXPC payload has 8 flight packages.
- Three detectors,
- Corresponding Processing Electronics,
- Common System Time Base Generation (STBG) package



Functional Requirements

- Generate Stable and command selectable High Voltage for detector operation.
- To collect and analyse charge generated due to X-ray photon interaction with gas molecules in the detector.
- Detector background reduction : Only accept events, which are qualified through (a) Level Discrimination (b) Mutual coincident and (c) Anti coincident.
- Ability to handle event rates varying from as low as detector background levels to as high as 20000 events per second.
- Capacity to time tag each qualified x-ray event accurately.

LAXPC Specifications

- Low level Energy Threshold : 3 KeV (~ 0.24V pulse from CSPA).
- High level Energy Threshold : 80 KeV (~ 6.4V pulse from CSPA).
- Detector Energy Resolution : ~ 10% @ 22 KeV (~ 160 millivolts).
- Resolution in measuring Pulse Height: 10 bit effective in 0-10V dynamic range ADC. (~10 millivolts).
- Time variability Analysis : Temporal data generation by Broad Band Counters (BBC) for different layers.
- Real time tagging of each qualified events to 10 μsec.
- System Time Base Generation (STBG) system resolution of 10 μsec.
- Absolute Time accuracy : within 3 μsec of UTC (SPS provided).

Design Challenges

- Tight power, weight and volume budgets - every gram of payload costs Rs. 10K!
- Harsh operating environment in space
- Severe shocks and vibrations generated during takeoff.
- Rapid temperature variations in orbit : -15°C to +50° C.
- Exposure to severe cosmic radiation.
- Limited availability of analog as well as digital devices with Space grade qualification that can withstand harsh cosmic radiation.
- Stringent EMI & EMC requirements to ensure minimal interference to other payloads as well as to satellite control and operation.
- Repair or replacement of components once space-borne is impossible

Design Goals

- Three Independent and modular electronics systems for 3 LAXPC Detectors.
- All three detectors to use a common and accurate time reference.
- To ensure high reliability and adequate safety measures against single-point failures.
- To have adequate redundancy built into the electronics to overcome any failure of critical processing components.
- Payload health monitoring and operational control.
- Independent electrical interfaces to satellite buses (Power, Tele-Command and Telemetry) for all the sub-systems.
- Optimum design in terms of power consumption , package size, weight and resources utilisation like on-board storage memory.

LAXPC Electronics Characteristics

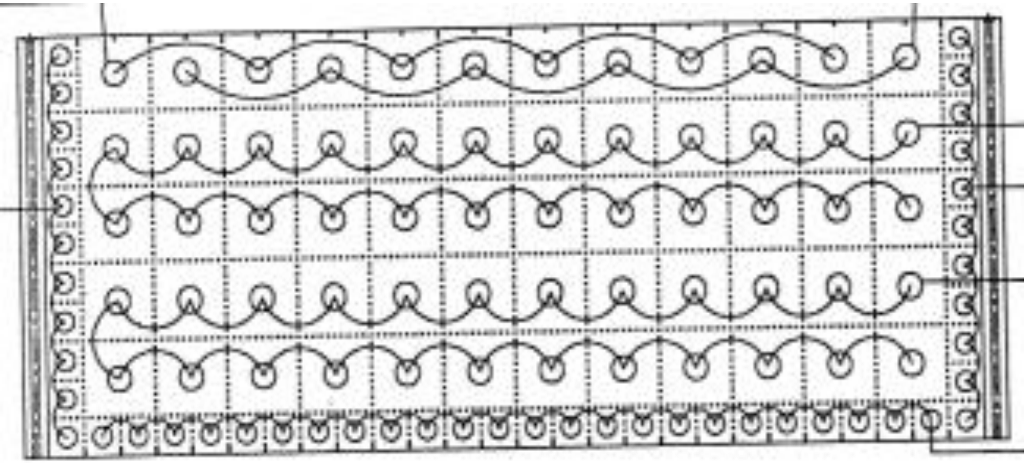
LAXPC electronics is designed to have

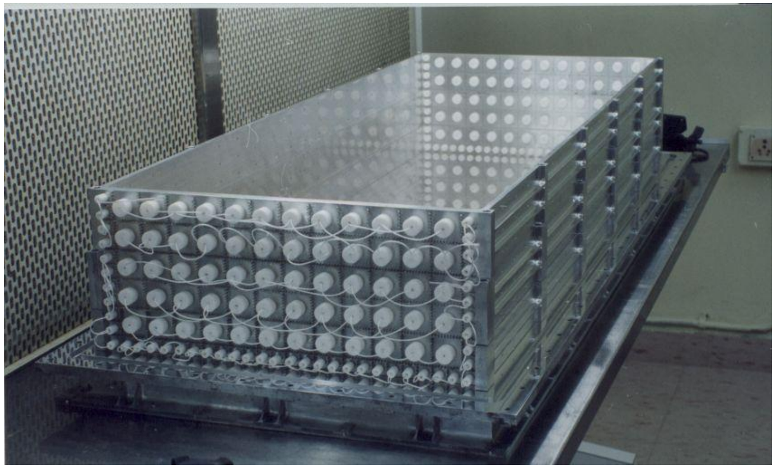
- High timing accuracy in tagging detected x-ray photons.
- Wide CSPA dynamic range of ~ 40 (0.2Volts to 8Volts).
- Multiple modes of operation to suit variety of different x-ray sources.
- Capacity to handle event rates from few hundreds per second up to 20,000 per second.
- Background reduction and optimum utilisation of on board storage capacity.
- Withstand severe launch vibration as well as harsh operating environment in orbit.

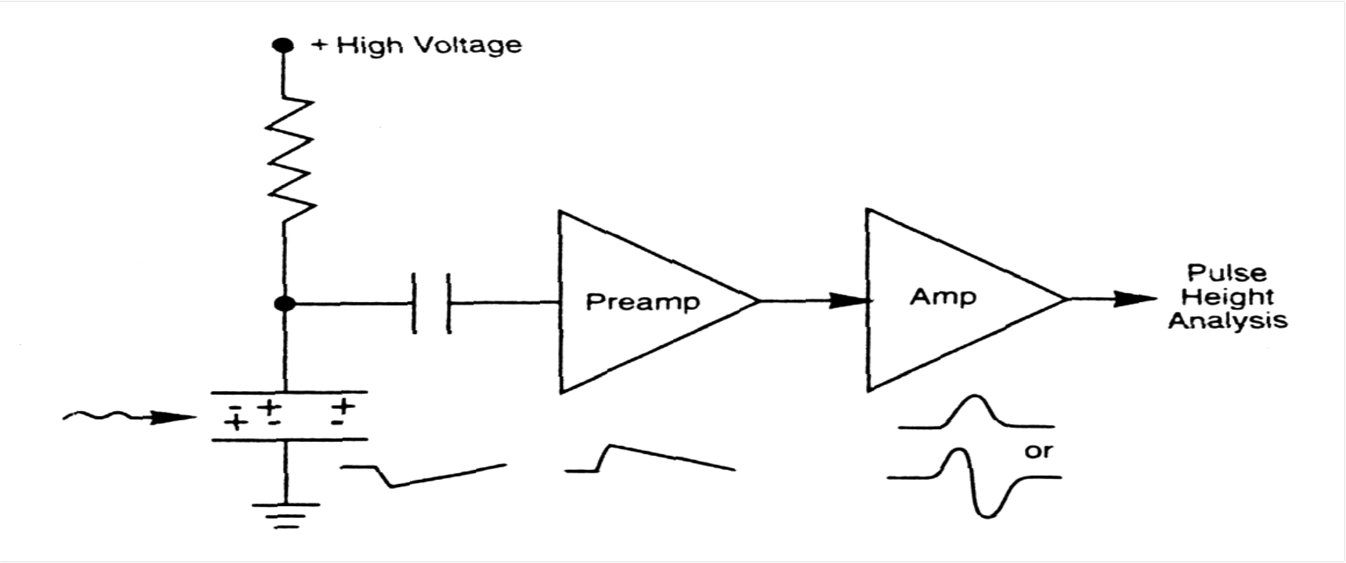
LAXPC Data Generation

- Worst case data generation for all modes combined i.e, 201K time tagged data + 8K BBC count rates data = 209KBytes/sec per LAXPC detector.
- Data transfer to SSR in packets of 2048 bytes every 8 msec. i.e, transfer bandwidth is 2K x 125 = 250KBytes per LAXPC detector channel.

Schematic end view layout of LAXPC wire frame

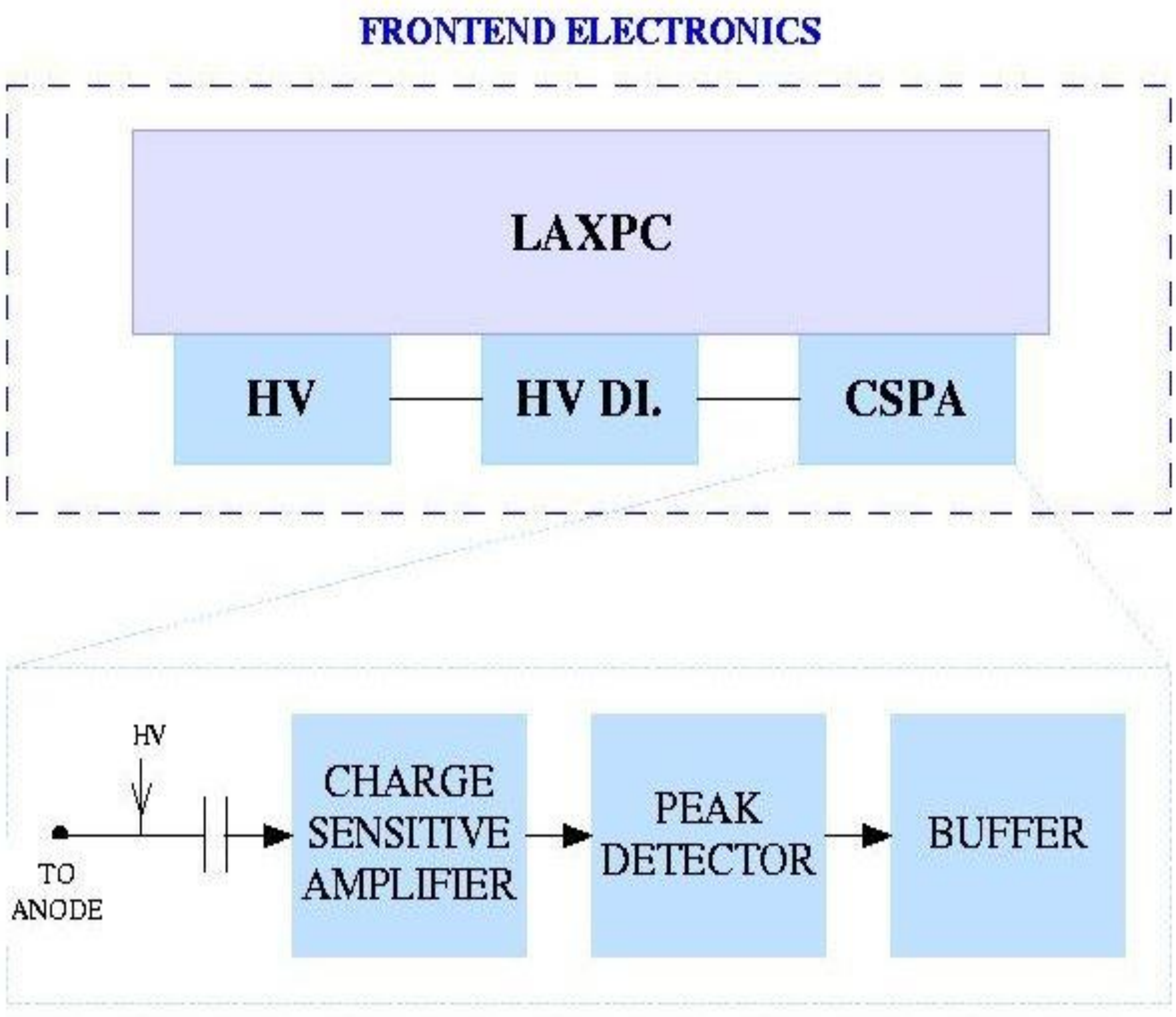






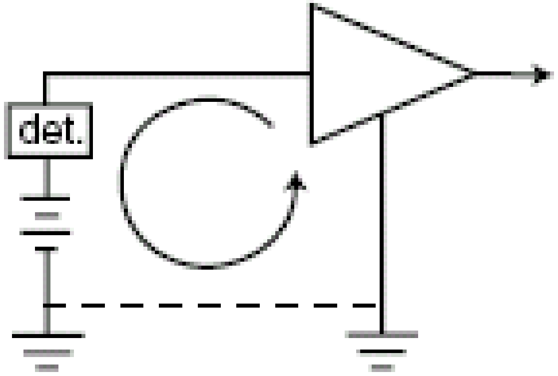
Schematic diagram of Basic Detector and Amplification Stages

Detector Front-End Electronics



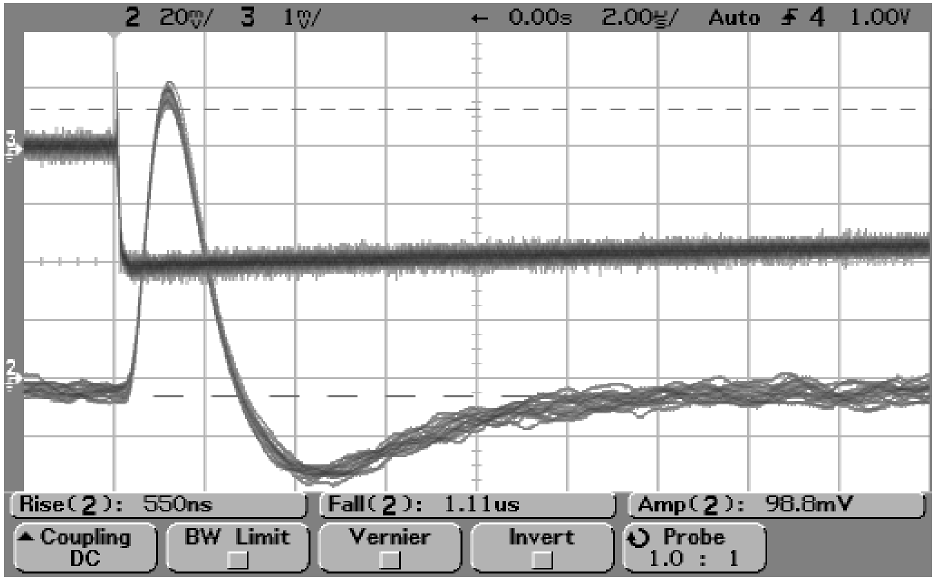
Preamplifier design considerations

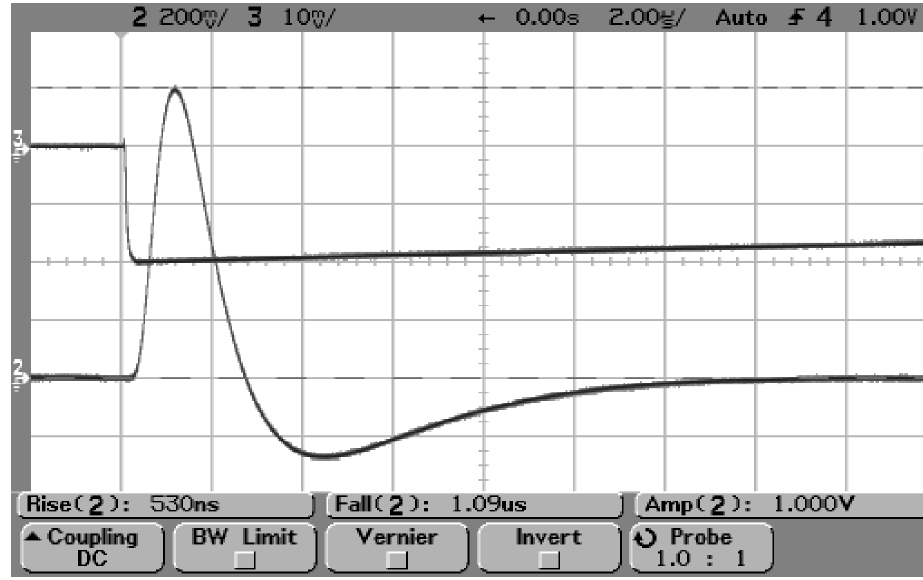
- Low noise Input FET with High Ciss.
- Careful design to avoid ground loops.
- Minimise RF pickup from other circuits mainly High Voltage DC-DC circuit.
- Appropriate decoupling and filters to minimise cross-talk.

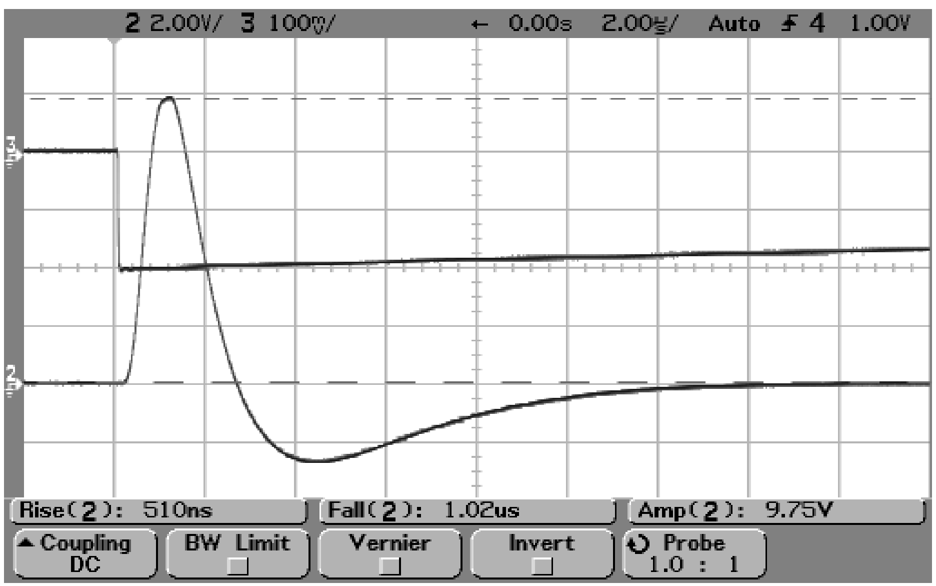


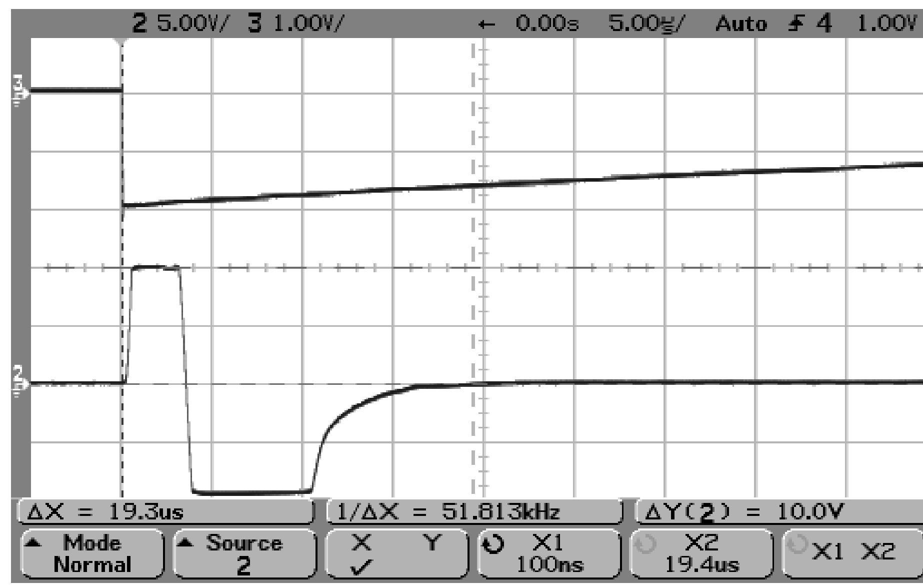
Ground loops, caused by multiple paths to ground, can make a detection system sensitive to external RF by acting as an antenna.

CSPA waveforms

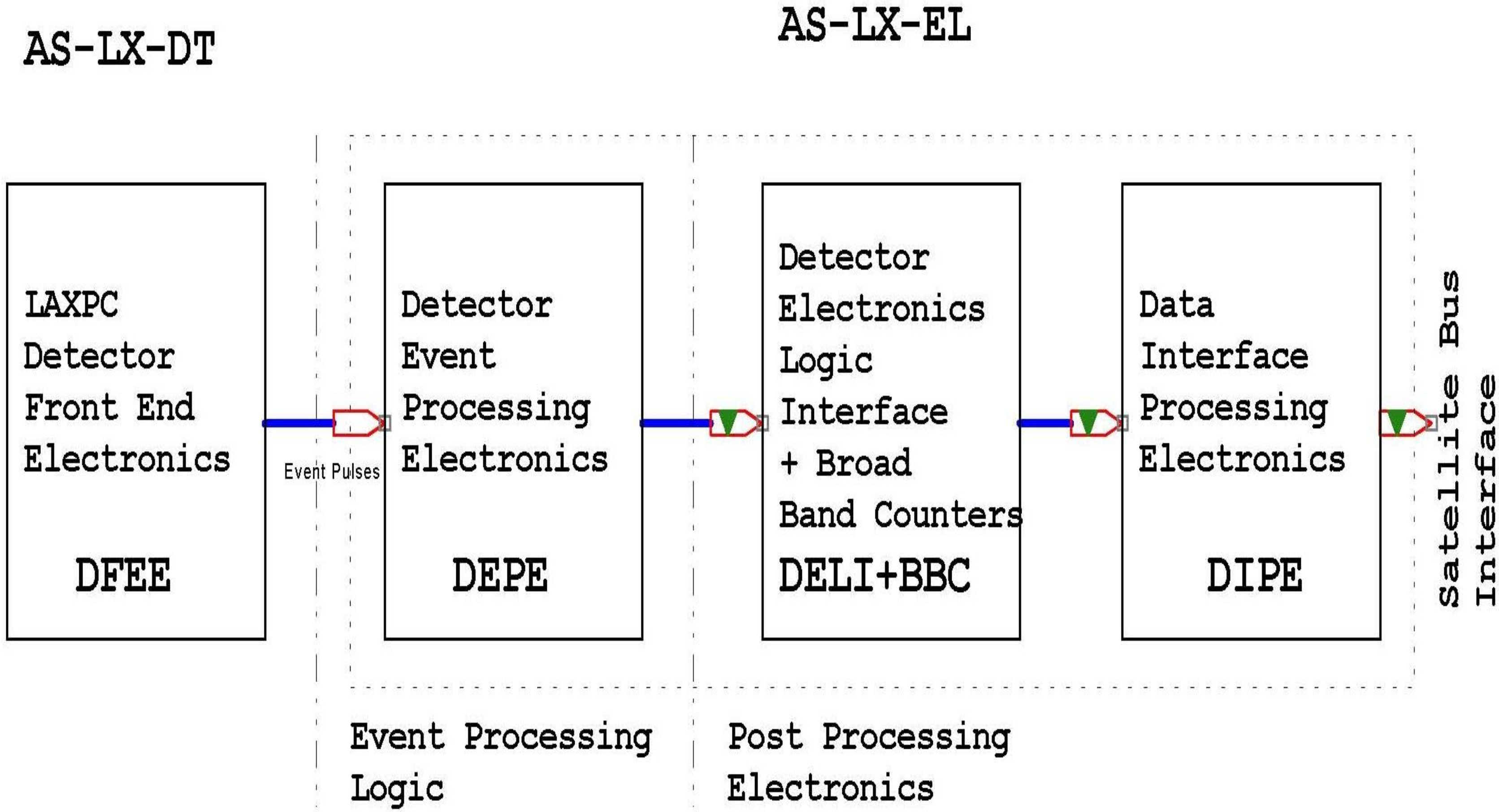








Schematic Block Diagram Representation of LAXPC Signal Processing Electronics.



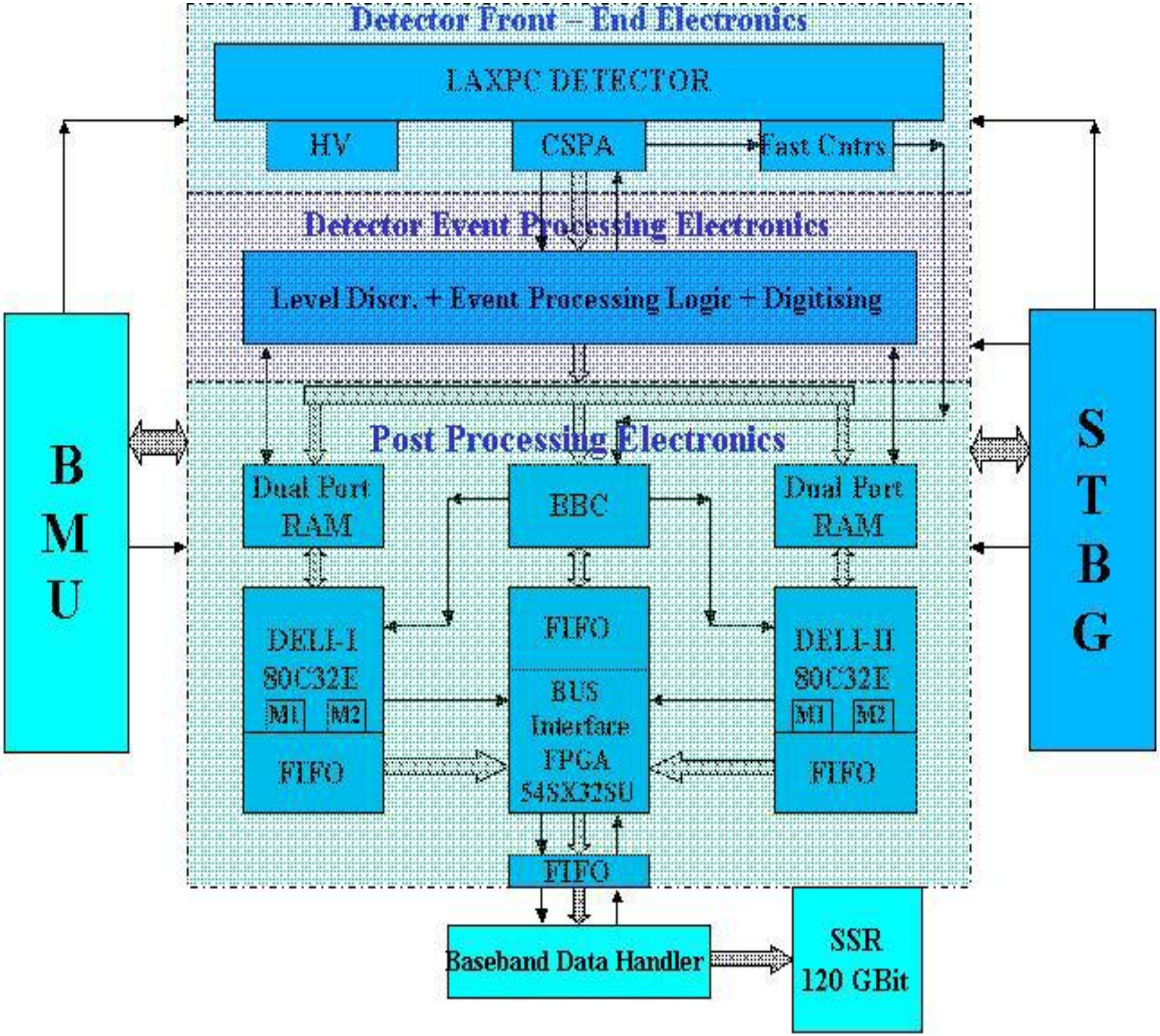
Post Processing Electronics

•BBC counters implemented in FPGA and funnels data independent of micro controllers to SSR channel.

• Broad-band count rates recorded with command selectable integration time from 8 msec to 1024 msec.

• With fastest integration time for BBC, System generates 125 x 64 = 8000 Bytes/second.

• System designed to be capable of simultaneously processing events in all three modes.


Detector Front – End Electronics
LAXPC DETECTOR
HV
CSPA
Fast Cntrs
Detector Event Processing Electronics
Level Discr. + Event Processing Logic + Digitising
Post Processing Electronics
Dual Port RAM
BBC
Dual Port RAM
DELI-I
80C32E
M1
M2
FIFO
FIFO
BUS Interface FPGA 54SX32SU
DELI-II
80C32E
M1
M2
FIFO
FIFO
Baseband Data Handler
SSR
120 GBit
B
M
U
S
T
B
G

Detector Electronics Logic Interface

- Designed using 80C32E Radiation Tolerant Microcontrollers.
- Two parallel data pipelines processed independently.
- Does the post processing of event data as received from DEPE.
- Creates fixed length (2048 Byte) Time Tagged event data frames.
- Both controllers are capable of stand alone operation thus avoiding a single point failure by providing a redundancy.
- This system Funnels the Fast counter mode data and provides FIFO based interface for data transfer to solid state data recorder.

Event Analysis Modes

- High resolution Time Tagging Mode: each qualified event's arrival to be time tagged with 10 microsecond accuracy.
- Broad Band Counting Mode: analyse the rate of occurrence of events in various energy bands with selectable BIN period (8 msec to 1024 msec).
- Fast Counter Mode: Generates event rate data for top layer of detector in 4 different energy bands with fixed BIN period of 160 μsec.

Satellite Bus Interfaces

- Power Interface
- Tele-command Interface
- Low Bit-rate Telemetry (LBT) Interface
- High Bit-rate Telemetry (HBT) Interface

Power Requirements

- Normal Operation mode : All three detectors & corresponding signal processing electronics powered on.
- Purification mode : One of the detector purifier system powered on. All other packages of LAXPC powered off.
- System Time Base Generator always remains on.
- LAXPC packages draw power from 2 different RAW buses to provide protection against single point failure.

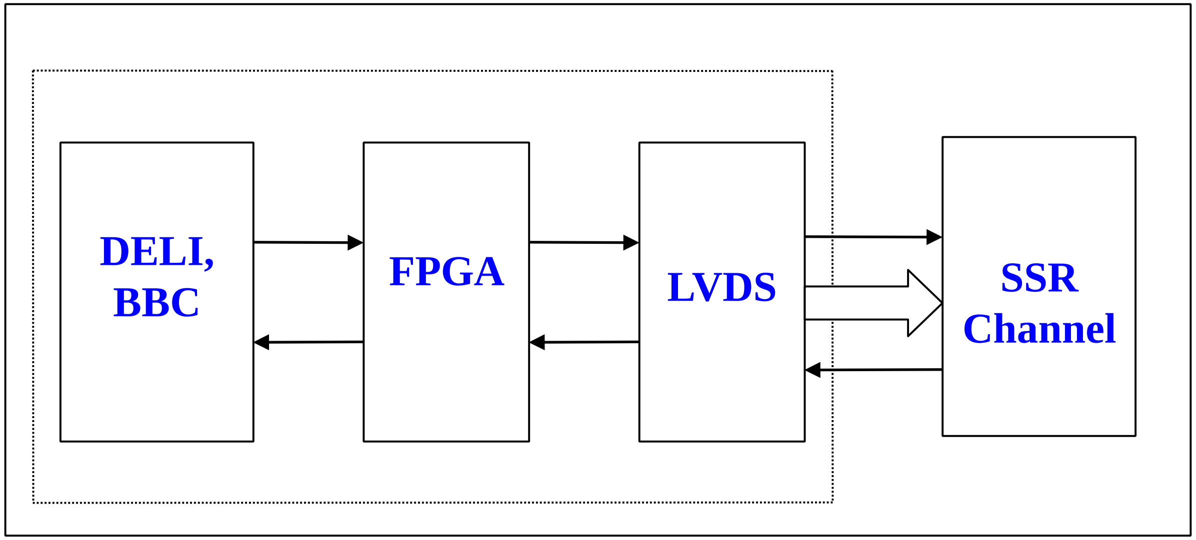
Tele-command Interface

- All LAXPC packages to have independent command interface with satellite Bus Management Unit (BMU).
- High Voltage power ON/OFF pulse command to have time-tagged functionality.
- STBG Sync pulse command is time-tagged.
- List mode to upload a large set of commands sequenced together.
- In total LAXPC payload needs 50 Pulse commands & 17 data commands for payload control & for various modes of operations.

Low Bit-rate Telemetry to BMU

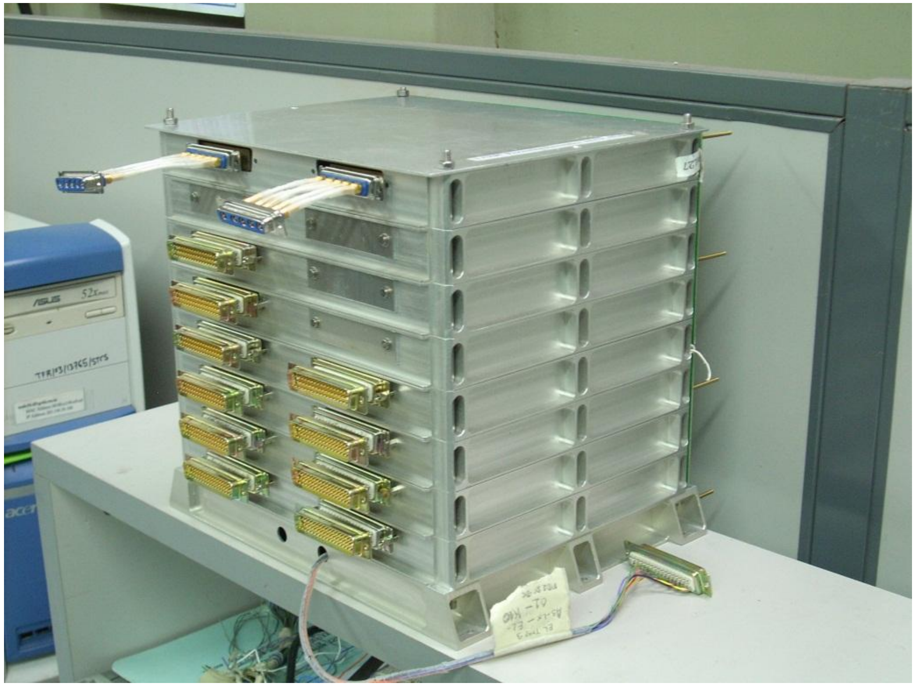
- Used for transmitting payload health monitoring and other housekeeping data.
- Serial transmission with 40KHz clock and P/S (Parallel / Serial), ALE (Address Latch Enable) & Channel Address data.
- Each of the LAXPC package has independent LBT interface with Bus Management Unit.

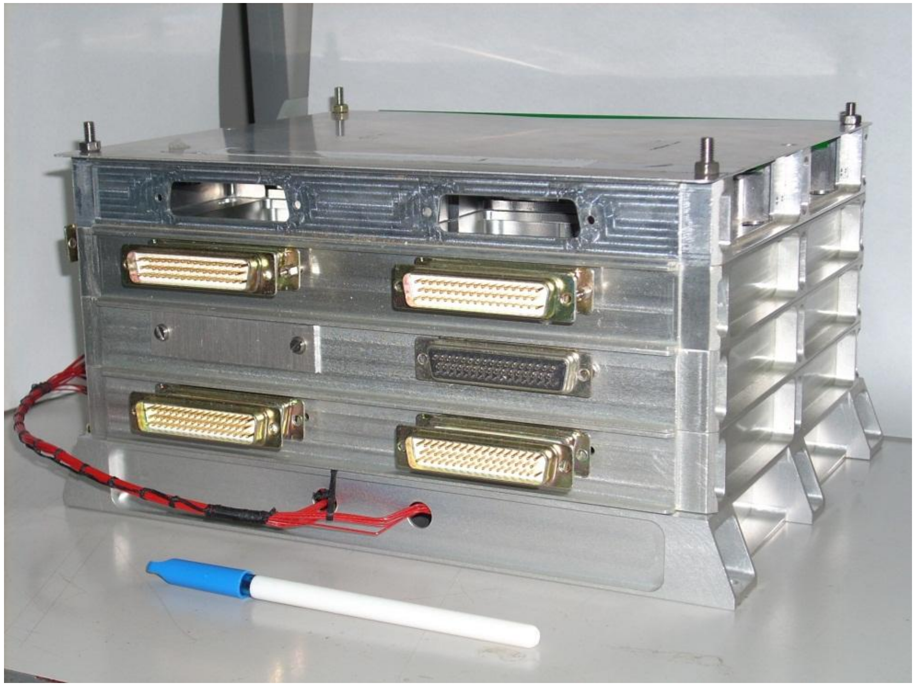
High Bit-rate Telemetry (SSR Interface)



Assuming 10 minutes of data dump time, buffer capacity for during dump storage required = 10 x 60 x 2K x 125 = 150 Mbytes / channel for fastest data generation mode. (Total 451 Mbytes for all three LAXPC channels combined).

LAXPC Electronics – *ready to go*





Concluding remarks

- Various detectors are going through their final integration tests; in parallel, launch vehicle is also getting ready; should be all in place by end of this year.
- ASTROSAT is slated for launch on PSLV-XL version flight c23 or c24 around this time next year.
- Payload cost (excluding the rocket) ~400 crore
- Let us all wish the ASTROSAT team good luck and a great mission.
- ASTROSAT will be an important milestone for Indian space science and technology

Thank you