The 8th Mission Idea Contest for Multiple Nano-satellites

Paridhi - 6U Nanosatellite constellation mission for observation and study of the Van Allen Belt

Raahil Rana[1], Ashish Shinde[2], Anil Kumar Sahoo[3], Karan Gupta[4], Divyam Gupta[5], Rahul Shukla[6], Bharath Prajwal B.R.[7]

Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala – 695547, India

The Team

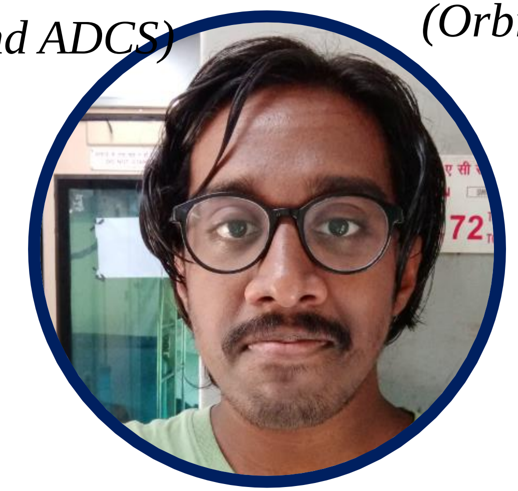
Raahil Rana
(Structures and Thermals)

Ashish Shinde
(Structures and ADCS)

Anil Kumar Sahoo
(Orbital Mechanics)

Rahul Shukla
(CDH)

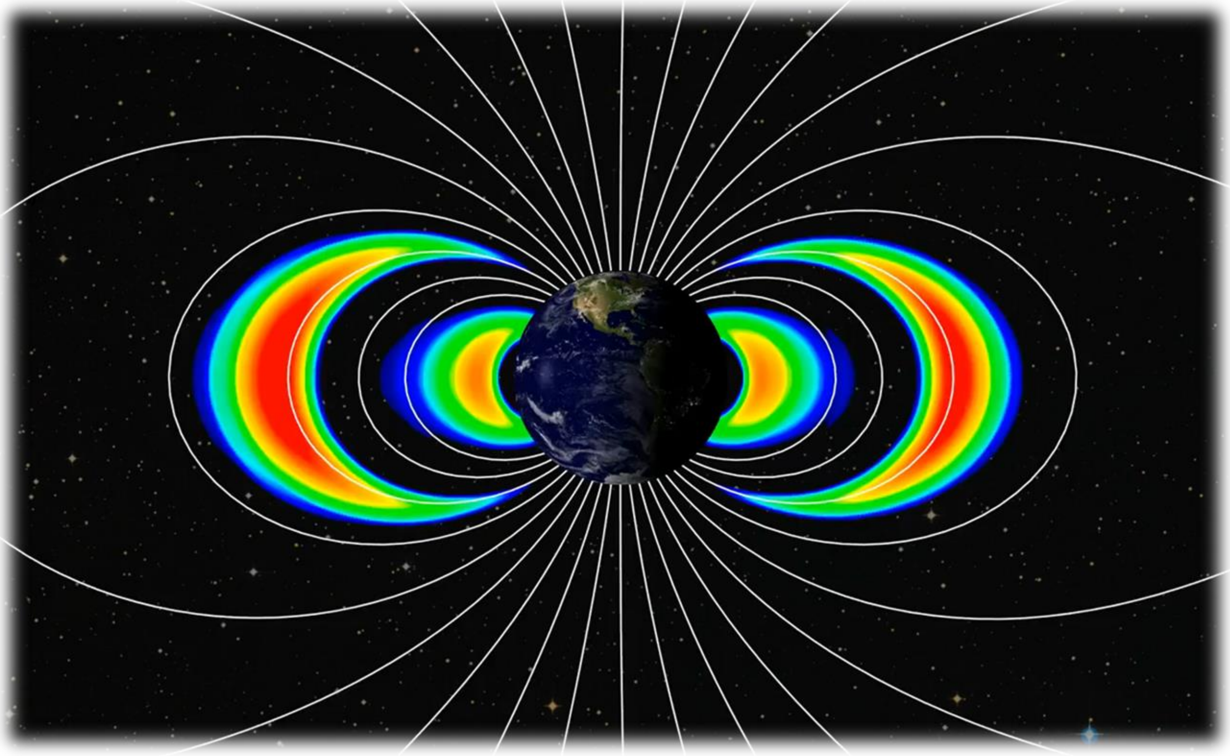
Karan Gupta
(EPS)



Bharath Prajwal B.R.
(Payload Science)

Divyam Gupta
(Communications)

The Need:



Region of Intense Radiation

Significant obstacles to space exploration

Mysteries of Anti-matter

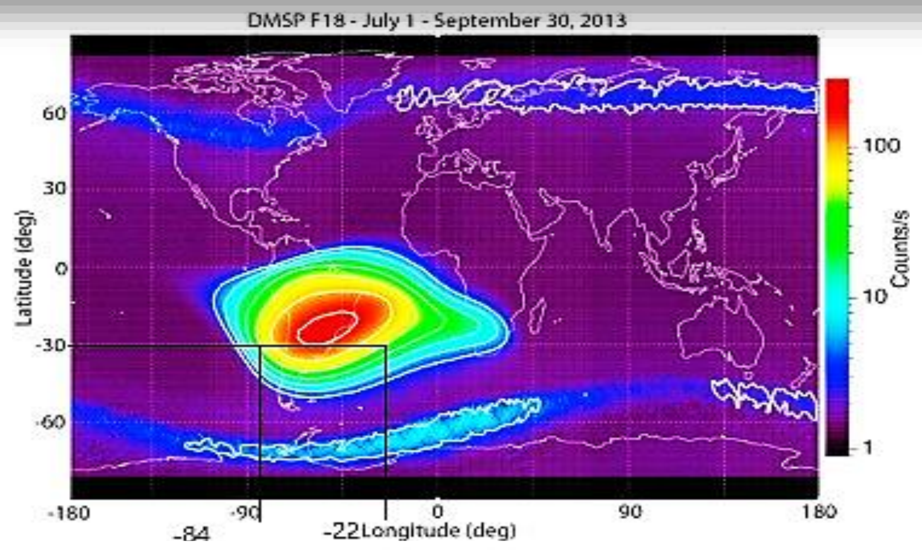
Mission Objectives:

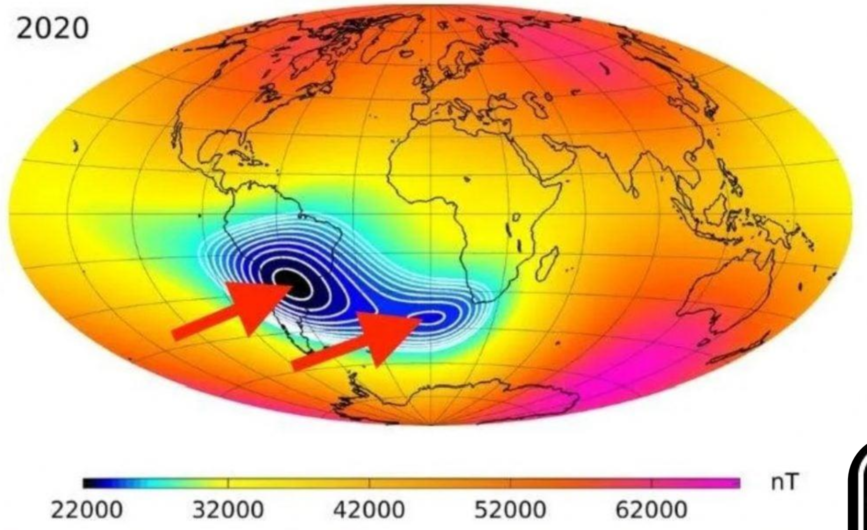
1. **Study of South Atlantic Anomaly**

2. **Radiation Environment Analysis**

3. **Correlation Between Radiation And Antimatter**

4. **Space Exploration and Technological Implications**





Mission Objectives:

1. **Study of South Atlantic Anomaly**

2. **Radiation Environment Analysis**

3. **Correlation Between Radiation And Antimatter**

4. **Space Exploration and Technological Implications**

Measure:

- Radiation levels
- Energy Spectra
- Particle Fluxes

Mission Objectives:

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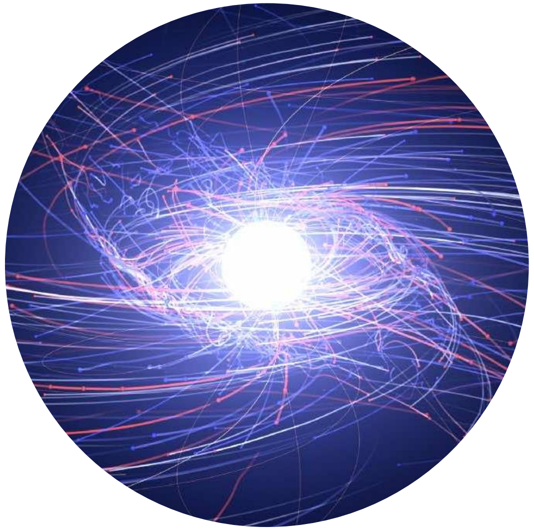


Understand interactions and dynamics in the belt

Mission Objectives:

1. Study of South Atlantic Anomaly

2. Radiation Environment Analysis

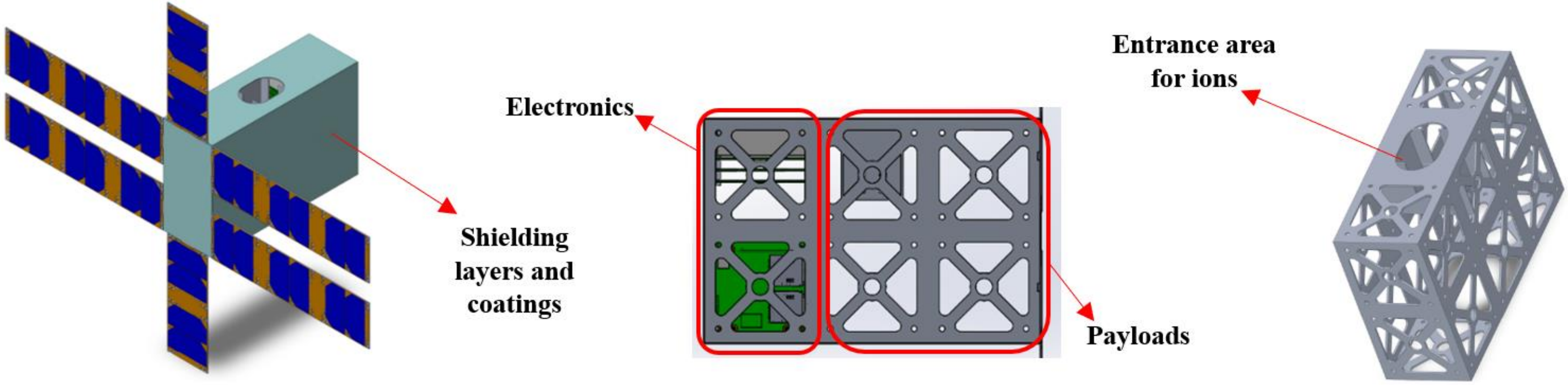
3. Correlation Between Radiation And Antimatter

4. Space Exploration and Technological Implications

- Improve spacecraft design
- Radiation shielding
- Advanced materials

CubeSAT Subsystems

Structures:


Shielding layers and coatings
Electronics
Payloads
Entrance area for ions

Structures: Mass & Volume Budget

Subsystem	Components	Parts	Dimensions (mm x mm x mm)	Mass (g)
Payload	MagIS	Medium energy Unit	2U (Upper limit)	3000 – 4000
	Dosimeter	piDOSE – DCD	30 cm^3	30 – 40
	Magnetometer	NMRM – Bn25o485	70 – 90 cm^3	<85
	RPA	Module	1.5 U (upper limit)	200
ADCS	Reaction Wheel Star Tracker Magneto-torquer	CubeADCS 3 - Axis	90 * 96 * 57	506
Communication	S – band antenna	SSA01 – Wide bandwidth S- band patch antenna	96.5 * 69.7 * 4.8	40
	High data rate S – band transmitter	ISIS TXS	98.8 * 93.3 * 14.5	132

Structures: Mass & Volume Budget

Subsystem	Components	Parts	Dimensions (mm x mm x mm)	Mass (g)
CDH	FPGA	Actel RTAX – S	40 * 40 * 2	10 (min)
	SD Card	Delkin Devices MB32FQQFZ – 42000 – 2	32 * 24 * 2.1	3
EPS	Battery Pack	ISIS iEPS	96 * 92 * 26.45	184 ± 5
	Solar Cells	45 cells		126
Structure	Al 6061	Body frame	100 * 200 * 300	3000
		Total	**4.51 U**	**8.2 kgs** *[Excluding thermals and other panels]*

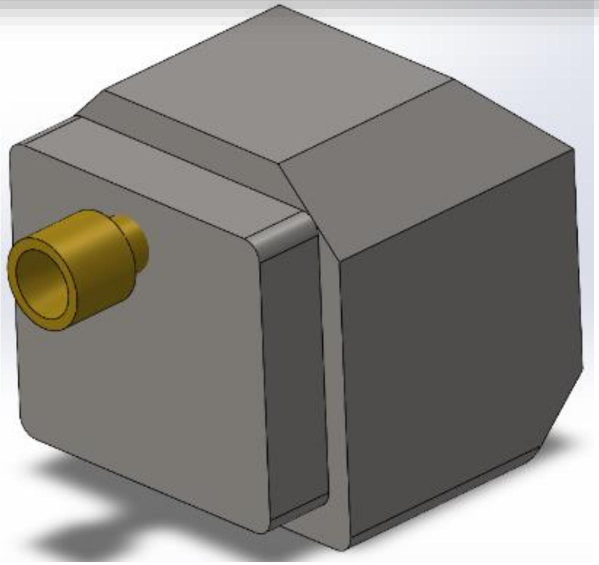
Thermals

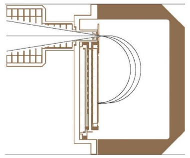
- Robust radiation shielding strategy.
- Radiation shielding uses specific materials and calculated thicknesses to protect sensitive components.
- Charge Dissipation Coatings like LUNA XP are applied to dissipate the energy of charged particles, safeguarding electronic components.
- Multilayer Insulations (MLIs) maintain a stable thermal environment, addressing temperature variations in the satellite's orbit.

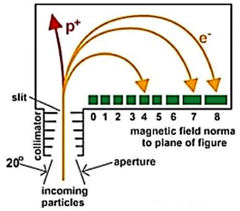
Payload

Magnetic Ion Spectrometer (MagIS)

- Understand characteristics of charged particles
- Utilizes chamber under influence of magnetic field and silicon detector array to assess charged particle's momentum, charge, and energy.
- Major inspiration: NASA's twin Van Allen Probes
- Detects antiparticles using specific charge identification.



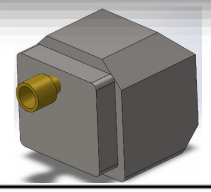


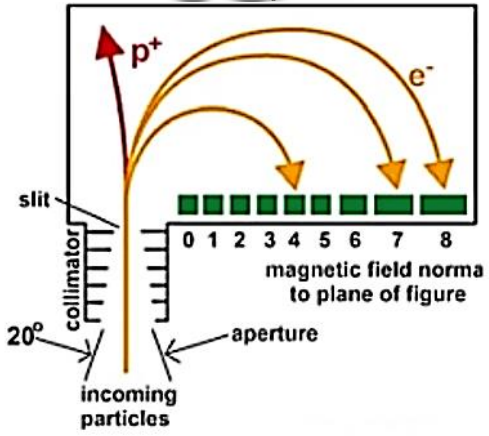


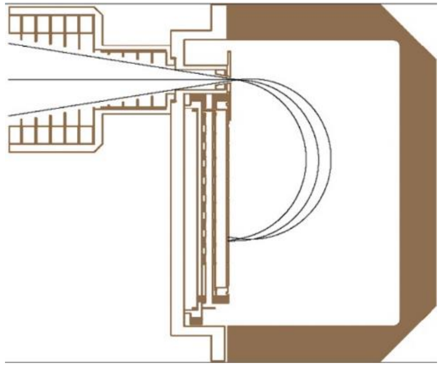
Payload

Magnetic Ion Spectrometer (MagIS)

- Uniform magnetic field deflects charged particles based on specific charge.
- Detector array matches energy, with lower-energy electrons striking lower-numbered pixels and higher-energy electrons reaching higher-numbered pixels.
- Detector thickness corresponds to the electron energy range it measures.
- Electron impact generates current pulses in the detector, digitized into pulse heights, proportional to energy.
- Magnetic spectrometer provides two measures: momentum selection and energy from pulse heights.
- Protons, with opposite charge, follow similar principles but require thicker silicon detectors.







Payload

1. Magnetic Ion Spectrometer (MagIS)

Magnetometer

- Tri-axial magnetometer with Anisotropic Magneto-Resistive (AMR) sensors for measuring magnetic fields in three directions.
- AMR: Relies on electrical resistivity changes with the angle between current and magnetization directions in ferromagnetic materials.
- Detects magnetic fields by observing resistivity changes as magnetization rotates under an external field.
- AMR response influenced by temperature
- Includes offset compensation circuitry to nullify AMR sensor offset voltage and enhance performance.

Common off the shelf NSS - magnetometer

NSS Magnetometer [COTS] - https://www.cubesatshop.com/product/nss-magnetometer/

Payload

1. Magnetic Ion Spectrometer (MagIS)

2. Magnetometer

Retarding Potential Analyser (RPA)

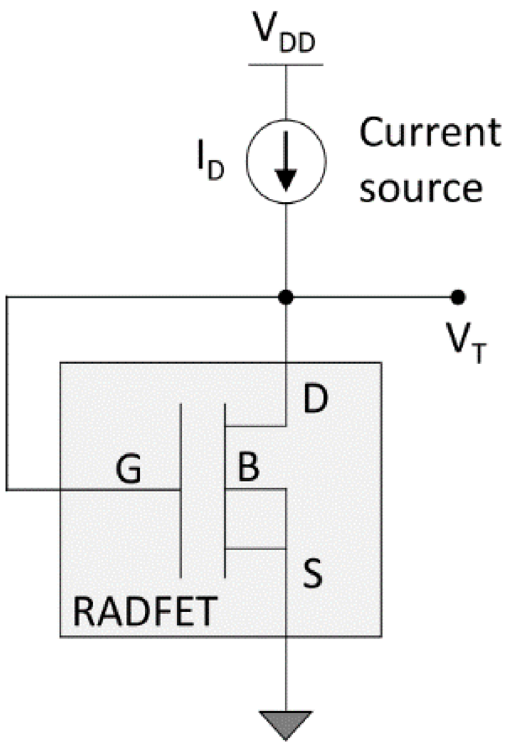
- Measures energy distribution of charged particles in a vacuum, like electrons or ions.
- It applies an electric potential to incoming particles and observes how it affects their kinetic energy.
- Particles with kinetic energy exceeding the retarding potential pass through, while those with lower energy are slowed or halted.
- RPA calculates current of particles passing through as a function of the retarding potential.
- Scanning retarding potential and measuring current allows construction of an energy distribution profile.

Payload

1. Magnetic Ion Spectrometer (MagIS)
2. Magnetometer
3. Retarding Potential Analyser (RPA)

RADFET

- Measures absorbed dose by converting the threshold voltage shift (ΔVT) caused by radiation-induced charge into absorbed dose (D).
- When exposed to ionizing radiation, RADFET generates electrons and holes through ionization.
- Measures both dose and dose rate by monitoring threshold voltage shift and current.
- The relationship between threshold voltage shift and absorbed dose $\Delta V_T = S \cdot D^n$, with n representing linearity and S as sensitivity.
- Radiation-induced current (I) expressed as a function of dose rate (Ḋ) $I = k \cdot \dot{D}$, with k as sensitivity coefficient and m - linearity coefficient.



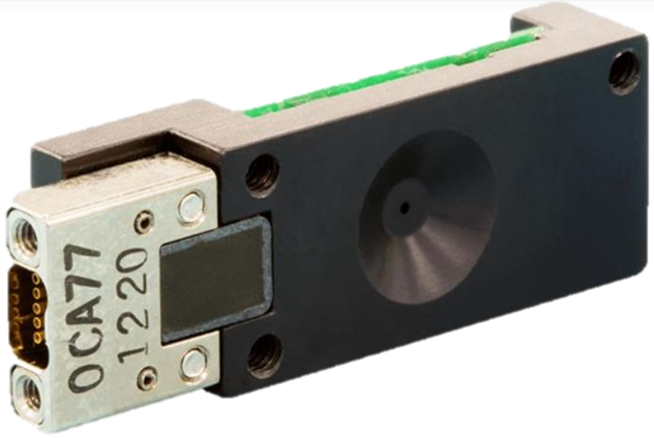
Attitude Determination and Control Subsystem

1. Sun Sensor

2. Nadir Sensor

3. Magnetometer

4. Dosimeter



- Monitors the Sun's position and intensity relative to the satellite.
- Establishes a reference frame and maintains satellite orientation for accurate measurements and data collection during the mission.

Attitude Determination and Control Subsystem

1. Sun Sensor
2. **Nadir Sensor**
3. Magnetometer
4. Dosimeter

- Nadir sensor observes the Earth's surface directly beneath the satellite.
- Aids in determining the satellite's attitude relative to the Earth.
- Provides feedback for precise attitude control, ensuring alignment with observation targets and orbits.

Attitude Determination and Control Subsystem

1. Sun Sensor
2. Nadir Sensor
3. **Magnetometer**
4. Dosimeter

NSS Magnetometer

- Integrated into the ADCS to measure the Earth's magnetic field.
- It is integrated into the ADCS to measure the Earth's magnetic field.

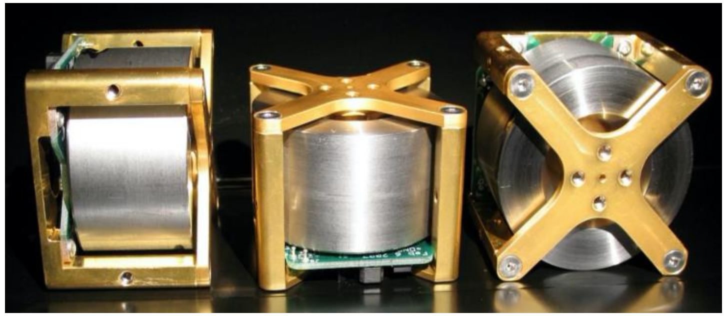
Attitude Determination and Control Subsystem

1. Sun Sensor
2. Nadir Sensor
3. Magnetometer
4. **Dosimeter**

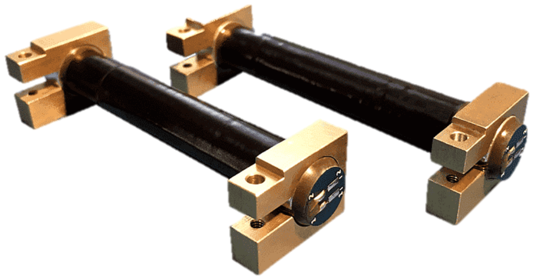
- Continuously measures radiation levels, detecting variations and fluctuations in radiation intensity.
- Aligns pointing direction to desired radiation patch.
- This feedback from the dosimeter allows the satellite's onboard systems to make necessary adjustments to its orientation and pointing angle

Attitude Determination and Control Subsystem

Considered actuators for control operation:



Reaction wheels
(Planned to be designed and built in the lab)



Magneto torquers
(Planned to be designed and built in the lab)

Communication subsystem

Data volume: 200 Mb/rev.

Data volume budget for MagIS:

per orbit = 6.2~7 Mb and in 1 day = 81 Mb

Communications

Downlink Telemetry Budget:

Parameter:	Value:	Units:	Comments:
Spacecraft:			
Spacecraft Transmitter Power Output:	0.8	watts	"Transmitter power"
In dBW:	-1.2	dBW	Transmitter power expressed in dB above one watt
In dBm:	28.8	dBm	Transmitter power expressed in dB above one milliwatt
Spacecraft Total Transmission Line Losses:	3.0	dB	This value is transferred from "Transmitters" -->**Ltl**
Spacecraft Antenna Gain:	6.5	dBi	"Antenna Gain" -->**Ga**
Spacecraft EIRP:	2.3	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Downlink Path:			
frequency	2050.0	MHz	
Spacecraft Antenna Pointing Loss:	0.6	dB	"Antenna Pointing Losses"
Path Loss:	160.0	dB	Lp = 22 + 20LOG(D/λ);
Atmospheric Loss:	2.1	dB	
Ionospheric Loss:	0.4	dB	
Rain Loss:	0.0	dB	This is the signal level received at the Earth in the vacinity of the ground static
Isotropic Signal Level at Ground Station:	-160.8	dBW	Pr= EIRP-pointng loss-pathlosses-all other loss
Ground Station (EbNo Method):			
------- Eb/No Method -------			
Ground Station Antenna Pointing Loss:	2.0	dB	
Ground Station Antenna Gain:	38.8	dBi	"Antenna Gain"
Ground Station Total Transmission Line Losses:	3.0	dB	
Ground Station Effective Noise Temperature:	500	K	
Ground Station Figure of Merrit (G/T):	8.8	dB/K	G/T = Ga-Ltl-10log(Ts).
G.S. Signal-to-Noise Power Density (S/No):	74.6	dBHz	Boltzman's Constant: -228.6 dBW/K/Hz
System Desired Data Rate:	500000	bps	This is the data rate.
In dBHz:	57.0	dBHz	This is simply = 10log(R); R= data rate
Telemetry System Eb/No for the Downlink:	17.6	dB	
Demodulation Method Seleted:	GMSK		Modulation-Demodulation
System Allowed or Specified Bit-Error-Rate:	1.0E-05		The selected value is transferred from the "Modulation-Demodulation
Eb/No Threshold:	9.6	dB	This is the result of the "Modulation-Demodulation"
System Link Margin:	8.0	dB	

Communications (contd.)

Uplink Command Budget:

Parameter:	Value:	Units:	Comments:
Ground Station:			
Ground Station Transmitter Power Output:	10.0	watts	"Transmitter power"
In dBW:	10.0	dBW	Transmitter power expressed in dB above one watt
In dBm:	40.0	dBm	Transmitter power expressed in dB above one milliwatt
Ground Stn. Total Transmission Line Losses:	3.6	dB	This value is transferred from "Transmitters" -->**Ltl**
Antenna Gain:	38.0	dBi	"Antenna Gain"--->**Ga**
Ground Station EIRP:	44.4	dBW	Ground Station Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Uplink Path:			
frequency	2250.0	MHz	
Ground Station Antenna Pointing Loss:	4.0	dB	"Antenna Pointing Losses"
Gnd-to-S/C Antenna Polarization Losses:	0.1	dB	
Path Loss:	161.8	dB	$L_p = 22 + 20\log(D/\lambda)$
Atmospheric Losses:	2.1	dB	
Ionospheric Losses:	0.7	dB	This is the signal level received in space in the vacinity of the spacecraft using an omnidirectional antenna.-->
Isotropic Signal Level at Spacecraft:	-124.3	dBW	**Pr= EIRP-pointng loss-pathlosses-all other loss**
Spacecraft (Eb/No Method):			
------- Eb/No Method -------			
Spacecraft Antenna Pointing Loss:	0.6	dB	"Antenna Pointing Losses"
Spacecraft Antenna Gain:	6.5	dBi	"Antenna Gain"
Spacecraft Total Transmission Line Losses:	2.0	dB	
Spacecraft Effective Noise Temperature:	300	K	
Spacecraft Figure of Merrit (G/T):	-20.3	dB/K	$G/T = G_a - L_{tl} - 10\log(T_s)$.
S/C Signal-to-Noise Power Density (S/No):	83.5	dBHz	Boltzman's Constant: -228.6 dBW/K/Hz
System Desired Data Rate:	100000	bps	This is the data rate.
In dBHz:	50.0	dBHz	This is simply = 10log(R); R= data rate
Command System Eb/No:	33.5	dB	
Demodulation Method Seleted:	Non-Coherent FSK		Values selected from "Modulation-Demodulation
System Allowed or Specified Bit-Error-Rate	1.0E-05		
Demodulator Implementation Loss:	1.0	dB	
Telemetry System Required Eb/No:	9.6	dB	The selected value is transferred from the "Modulation-Demodulation
Eb/No Threshold:	10.6	dB	This is the result of the "Modulation-Demodulation"-9.6+1(other losses)
System Link Margin:	22.9	dB	

Communication subsystem

S Band Antenna: SSA01 – Wide Bandwidth S-Band Patch Antenna

Features:

- Flight heritage since 2020
- Wide bandwidth: 2025 to 2120 MHz and 2200 to 2300 MHz

Band Range:

o First range:

2025 to 2120MHz

o Second range:

2200 to 2300MHz

- 6.5 dB Gain typical
- 195 MHz total bandwidth

o Vertical beam: 60 degrees ; Horizontal beam: 60 degrees

Mass: 40 g

- Dimensions: 96.5 x 69.7 x 4.8 mm
- Operating Temperature: -80 to +140°C
- Radiation Tolerance: 4 years minimum in LEO

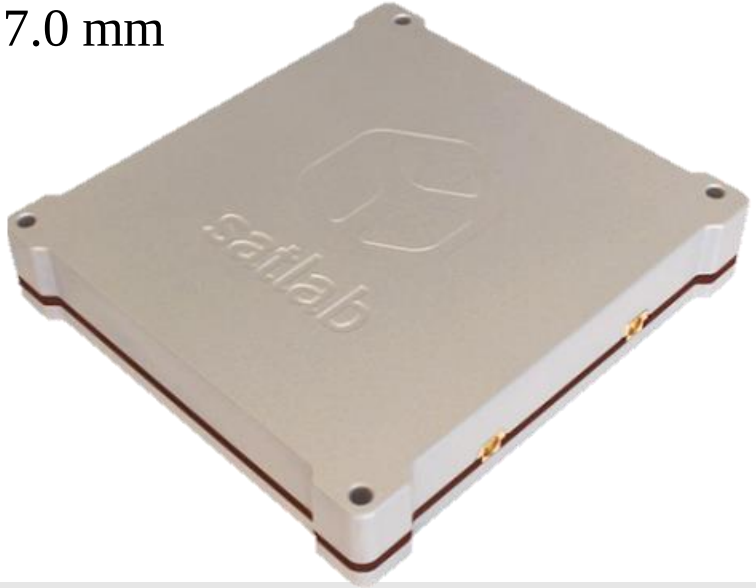
Cubesatshop EXA

Communication subsystem

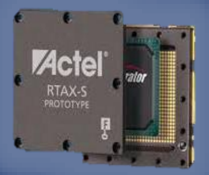
S Band Transceiver

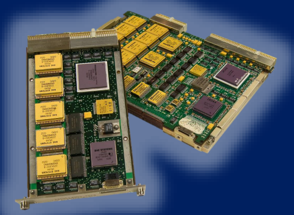
This full-duplex low-power S-band Transceiver is designed by NanoAvionics' partner Satlab for TM & TC on micro- and nano-satellites

- Transmit frequency: 2200 to 2290 MHz
- Transmit bit rate: 100 to 500 kbps
- Transmit power: Adjustable 20 to 30 dBm
- Receive frequency: 2025 to 2110 MHz
- Receive bit rate: 100 kbps
- Receive sensitivity: -110 dBm
- Input voltage: 5 – 40 V
- Typical power consumption (5 V input, 25°C):
  - Rx: 0.65 W
  - Rx+Tx: 6.5 W (30 dBm Pout)
- Operating temperature:
- Rx: -40°C to +85°C
- Tx: -40°C to +70°C
- Dimensions: 93.0 x 87.2 x 17.0 mm
- Mass: 191 g



CDH Components





Command and Data Handling

Delkin Devices MB32FQQFZ-42000-2 SD Card *(radiation tolerant)*

Technical Specifications:

Capacity: 16 GB
Form factor: SD
Operating Temperature: -55°C to +125°C
Storage Temperature: -55°C to +125°C
Vibration: 20G (20-2000Hz)
Shock: 50G, half-sine, 11ms
Altitude: 80,000 ft
EMI/RFI: MIL-STD-461F
Radiation: Total Dose >100Krad(Si)

Data retention: 10 years
Endurance: >100K program/erase cycles
Write speed: 16MB/s
Read speed: 32MB/s
Power consumption: 2.7V - 3.6V

Command and Data Handling

Actel RTAX-S FPGA

Radiation-tolerant field-programmable gate array (FPGA) designed and developed by Microsemi Corporation (now a part of Microchip Technology Inc) to withstand high levels of radiation exposure in space and other harsh environments.

Command and Data Handling

Technical Specifications:

Logic resources:
RTAX2000S - up to 1.2 million gates
RTAX1000S - up to 600K gates
Clock resources:
RTAX2000S - up to 120
RTAX1000S - up to 60
Memory resources:
RTAX2000S - up to 96Mb
RTAX1000S - up to 48Mb
JTAG boundary scan: Yes

Command and Data Handling

Radiation Performance:

Radiation Tolerance: >100 krad (Si) total dose

Single Event Upset (SEU) Immunity: <1 error per device per year

SEU cross-section: <1e-9 errors/device-day

Single Event Latchup (SEL) Immunity: >100 MeV/mg/cm2

Operating Temperature: -55°C to +125°C

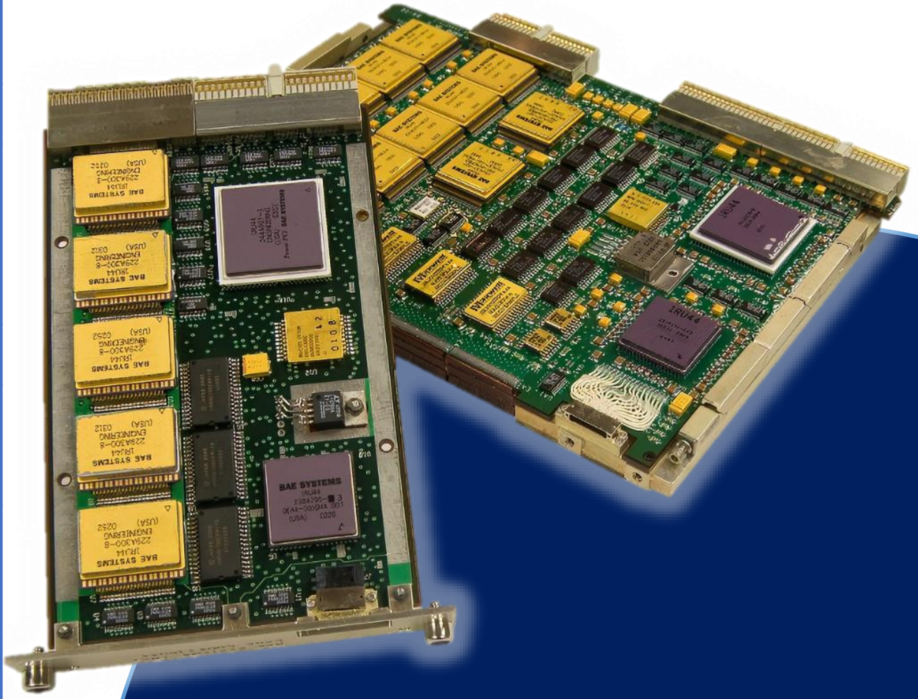
Packaging: Ceramic or plastic packaging

Power supply: 3.3V

Power Dissipation: 3.3V, 2.5W maximum

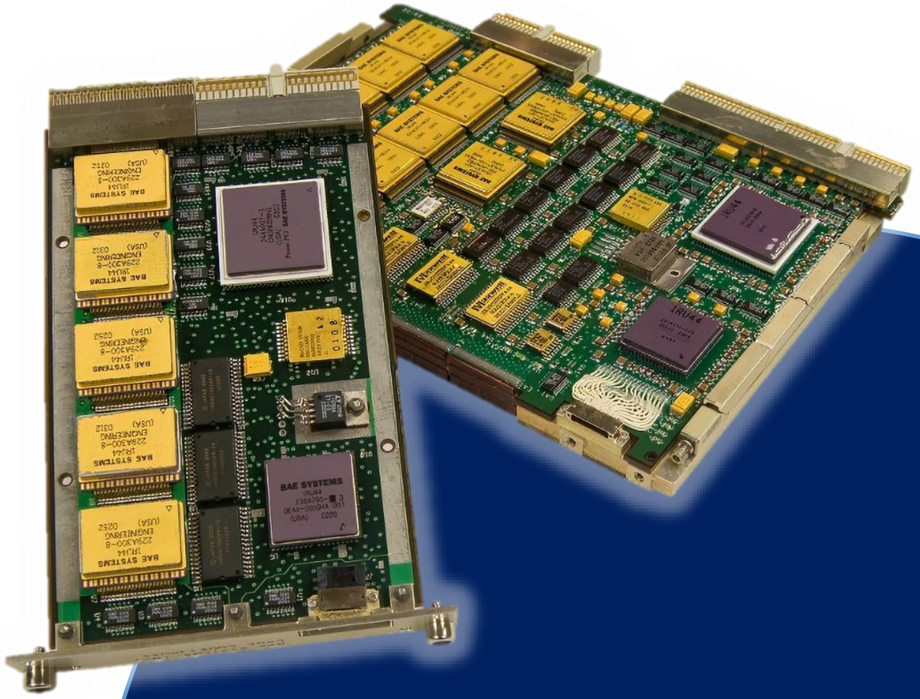
Command and Data Handling

Processor core	Single-board computer
Memory	512 kB of Flash memory 128MB SDRAM; 256KB SUROM
Speed	110 MHz to 133 MHz
Clock, reset and supply management	3.3 V I/O, 2.5 V core supply and I/Os – POR, PDR, PVD and BOR – 4-to-26 MHz crystal oscillator – Internal 16 MHz
Power	5 W at 133 MHz
Radiation-hardness	Total dose: 200 Krad (Si) SEU: <1.6e-10 errors/bit-day
Interfaces	Up to 20 communication interfaces – SPDIFRx – 4 × I2C interfaces (SMBus/PMBus) – 4 USARTs/2 UARTs (11.25 Mbit/s, ISO7816 interface, LIN, IrDA, modem control) – 4 SPIs (45 Mbits/s)– 2 × CAN (2.0B Active) – SDIO interface.



Command and Data Handling

Operating temperature	Between -55°C and 155°C
Programming interface	JTAG connector or USB2.0 port (in system programming)
Bus Size	64-bits
Transistors	10.4-million
Other peripherals	2 X TWI (I^2C) 1 X SPI 8 channel 12-bit ADC and 8 channel 10-bit ADC 1 x Temperature sensor (I^2C connected) 1 x Backup battery 1 x UART 1 x USB SpaceWire Port



Command and Data Handling

ADCS:
Interface: 1xRS-485

EPS:
Interface: 1xI2C, 1xUART

External Storage:
Interface: 1xSPI

Communication:
Interface: 1xRS-232 and 1xUART

Payload:

I. MagEIS
Interface: 100BASE-TX

II. Magnetometer
Interface: 100BASE-TX

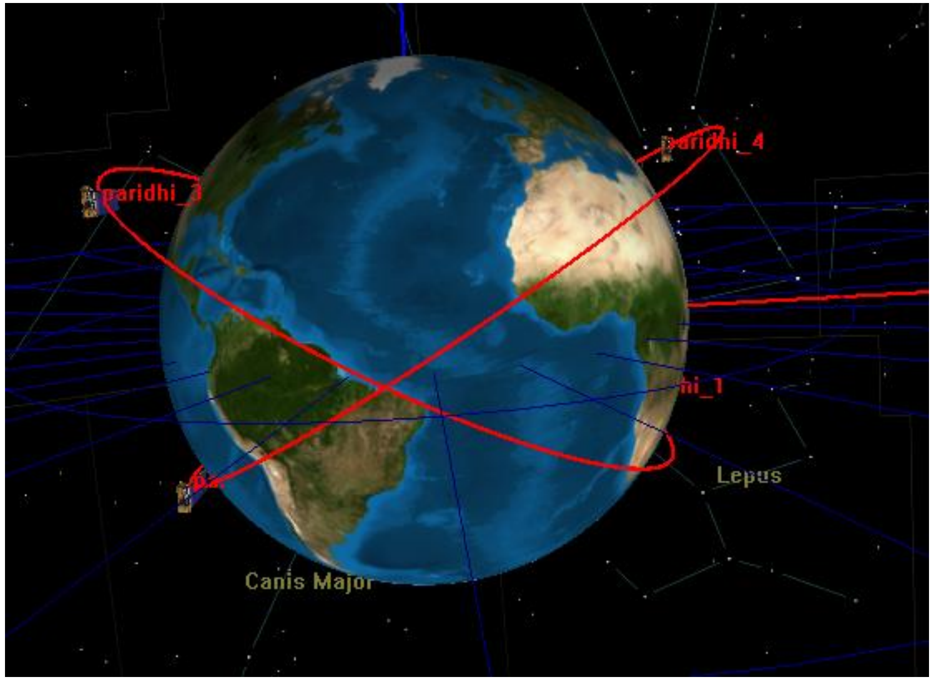
III. Geiger Counter
Interface: 1xUSB

Note:
These can work only if Shielding and error-correction techniques perfectly used either we have a another
Best option is SpaceWire that majorly Design for radiation environments.

Interfaces Requirement

Orbital Mechanics

Walker delta notation: [i: t/p/f] = [30: 4/2/1]
Here, inclination (i) = 30°
Total number of satellite (t) = 4
Number of planes (p) = 2
Phasing parameter (f) =1



Elements

SMA	7600.000000000003	km
ECC	0.1052630000000002	
INC	29.99999999999999	deg
RAAN	90	deg
AOP	270.0000000000001	deg
TA	0	deg

Paridhi - 1

Elements

SMA	7600.000000000004	km
ECC	0.1052630000000007	
INC	29.99999999999998	deg
RAAN	90	deg
AOP	270.0000000000002	deg
TA	180	deg

Paridhi - 3

Elements

SMA	7600.000000000009	km
ECC	0.1052630000000004	
INC	29.99999999999995	deg
RAAN	270	deg
AOP	269.9999999999998	deg
TA	0	deg

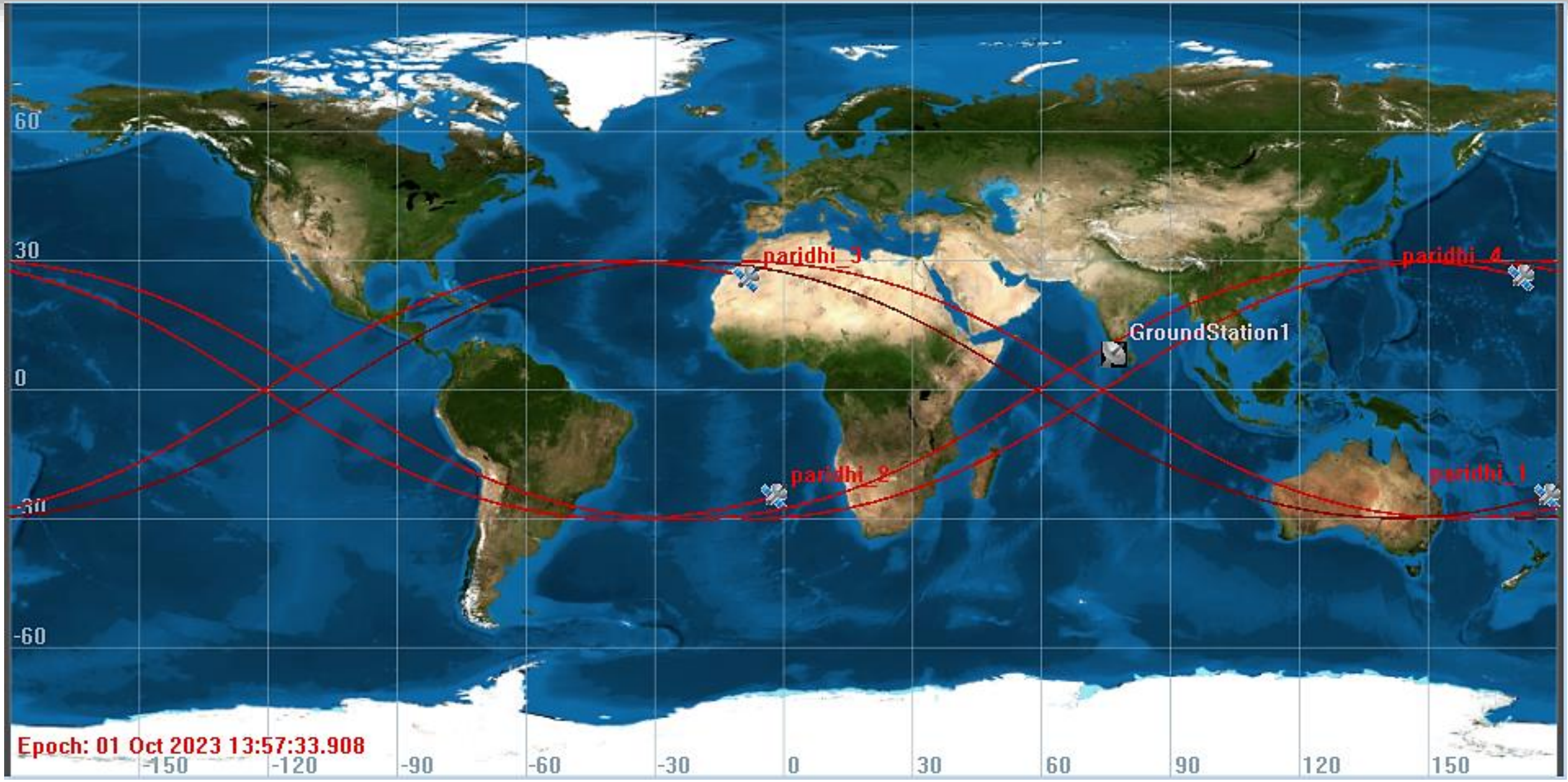
Paridhi - 2

Elements

SMA	7600.000000000004	km
ECC	0.1052630000000007	
INC	29.99999999999998	deg
RAAN	270	deg
AOP	270.0000000000002	deg
TA	180	deg

Paridhi - 4

Orbital Mechanics



Orbital Mechanics

1. **Perigee at 400 kms**: The perigee is set at 400 kms above Earth, always over the southern hemisphere, to increase the satellite's frequency of entry into the South Atlantic Anomaly (SAA) region.

2. **Apogee at 2000 kms**: The apogee is set at 2000 kms, taking the satellite into the inner Van Allen Belt, a high radiation region starting at about 1000 kms above Earth. This maximizes the satellite's interaction time with the belt, allowing for extensive data collection on the radiation environment.

3. **30 Degree Inclination**: The orbit's inclination is set at 30 degrees, aligning with both the SAA region and a designated ground station.

Interaction with the Van Allen Belt (for 1 satellite)

Time period $T = \frac{2\pi}{\sqrt{\mu}} a^{3/2} = 6593.73 \text{ s} = 1.83 \text{ hr}$

Number of orbits in a day = 13.1 ≈ 13 times

Interaction with the Van Allen belt (in SAA) for nearly 7 times with average interaction time 8.4 minutes.
Average interaction time with the SAA in a day = 58.74 minutes.

So the time spent by a satellite in the region having altitude more than 1000 km (inner Van Allen belt) is found to be 1.1225 hr in a single orbit.

So average interaction time in a day = 875.6 min = 14.6 hr.

Total interaction time with the belt = 875.6+58.74 = 934.34 min = 15.57 hr.

Orbital Mechanics

Interaction with the ground station:

Ground station (Latitude= 8.6262° and Longitude= 77.0339°) - nearly 8 times.

Average interaction in a day = 147.0884 minutes or 2.45 hr.

Lifetime:

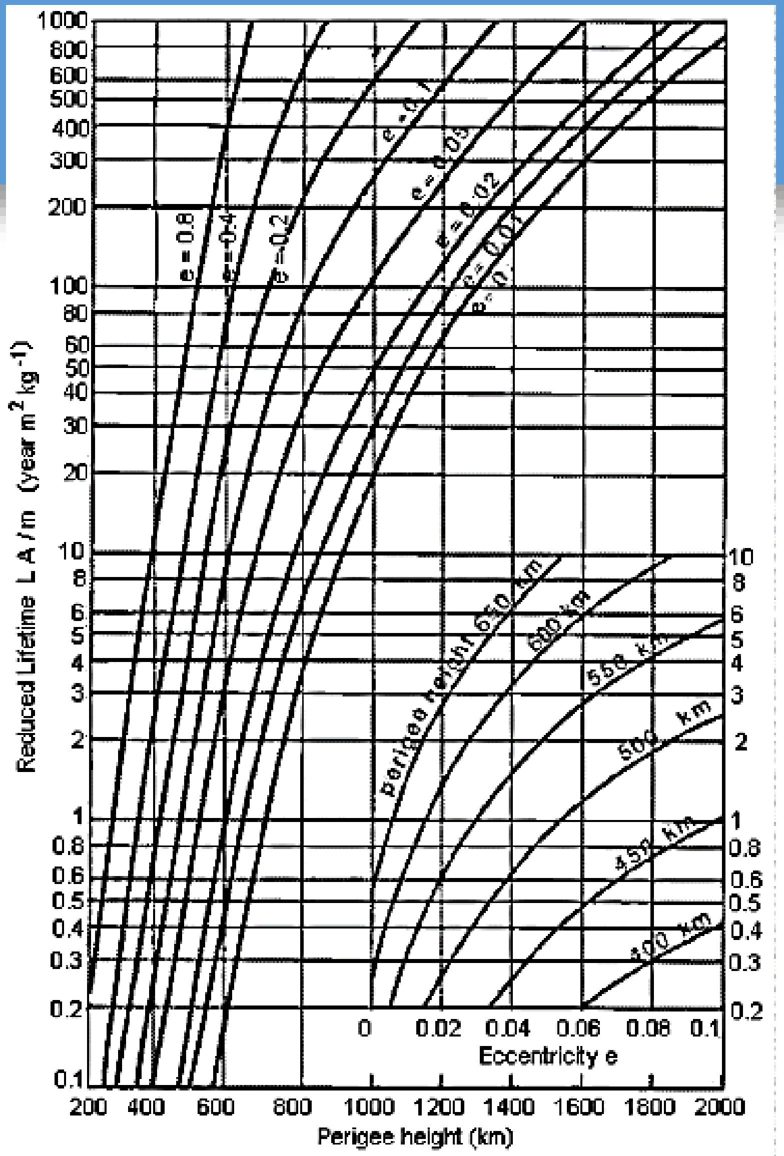
At perigee height 400 km and eccentricity 0.1052 ≈ 0.1 the reduced life time is nearly 0.4.

Satellite mass (m) = 8.2 kg

Area (m2) = 0.3 X 0.1 = 0.03

Lifetime = 0.4*m/A = 109.33 years

Much stable orbit - atmosphere drag is very less.



King Hele graph

Implementation plan

Pre – launch preparations

- Structures and payload design – in IIST (Collaboration with SSPACE)
- Manufacturing and assembly with help from collaborators
- Payload sensors and electronics (with shielding) testing @ ISRO or EPDL lab, IIST
- Vibration and thermal testing at VSSC, ISRO
- Establishing partnership between ground stations

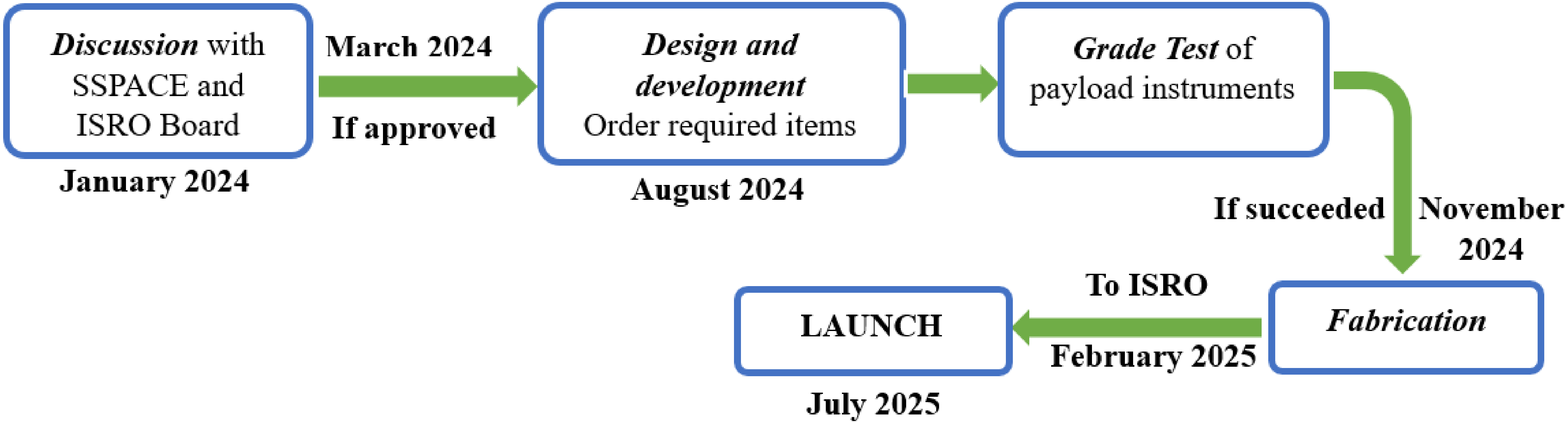
Launch Phase

- Integrate CubeSats onto PSLV
- Choose a launch window
- Testing and simulations (high acceleration phase of launch)

In – Orbit Operations

- Monitor solar panel performance and degradation
- Established ground stations - communication and tracking

Project Schedule



Cost Budget

NSS Magnetometer	15000$	**CDH board**	Approximately 5000$
CubeADCS	43500$	MagIS	To be designed indegeniously
Transceiver	Approximately 15000$	RPA	To be designed indegeniously
Antenna	Approximately 6000$	RADFET	$90 –160 (differs with company)