Systems Eng of Small Satellites and AI

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Former Director (Small satellite Projects), ISRO
Secretary, SSSS
Points covered in talk

- System of Small Satellites
- Systems Eng of IMS-1
- Mission Aspects and demands
- Systems Engineering for constellations
- Capacity Building
Small Satellites:

- Large: > 2000 kg
- Medium: 1000 kg --- < 2000 kg
- Small: 500 kg --- < 1000 kg
- Mini: 100 kg --- < 500 kg
- Micro: 10 kg --- < 100 kg
- Nano: 1 kg --- < 10 kg
- Pico: 100 g --- < 1 kg
- Femto: 10 g --- < 100 g

Following definition of small satellites, <1000 kg classes are considered, which include operational, experimental, scientific, exploratory and educational satellites.

- Failures are positive feedback – learn and correct (all big space organisations followed this path)
- Good documentation is essential – it shows where to correct

Some Indian SS examples:
- SARAL 450 kg class Small sat
- IMS-1, Youthsat...
- ANUSAT (~50 kg) ANNA U
- STUDSAT (<1 kg) 7 ENGG COLLAGES*
- SRMSAT (<10 kg) SRM U
- JUGNU (3 kg) IIT KANPUR
- SWAYAM (1 kg)
- SATHYABAMASAT (1.5 kg)
- PISAT (5.25 kg) PES U
- PRATHAM (<10 kg) IIT BOMBAY
- NIUSAT (~15 kg) NURUL ISLAM U
- INS-1A/B/C (<5 kg) ISRO

* Rohini series ISRO
* HAMSAT (50 kg) ISRO

Educational satellites:
- ANUSAT (~50 kg) ANNA U
- STUDSAT (<1 kg) 7 ENGG COLLAGES*
- SRMSAT (<10 kg) SRM U
- JUGNU (3 kg) IIT KANPUR
- SWAYAM (1 kg)
- SATHYABAMASAT (1.5 kg)
- PISAT (5.25 kg) PES U
- PRATHAM (<10 kg) IIT BOMBAY
- NIUSAT (~15 kg) NURUL ISLAM U
- INS-1A/B/C (<5 kg) ISRO

Courtesy: ISRO
- Mission goal defines system
- Goal can be societal application, technology development or knowledge expansion
- Systems ENGG is the process to make the system
- Never lose sight of the goal

IMS-1 AXES DEFINITION

COURTESY: ISRO
## SPACECRAFT
- 70 kg platform / 30 kg payload
- Orbit - SSO
- 500 – 1000 km orbit altitude
- Single System Configuration
- Life – 2 years

## PAYLOAD CAPABILITY
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Mass</td>
<td>30Kg max</td>
</tr>
<tr>
<td>Volume</td>
<td>450 x 600 x 500</td>
</tr>
<tr>
<td>Interface</td>
<td>LVDS</td>
</tr>
<tr>
<td>Data Rate</td>
<td>10 Mbps max</td>
</tr>
<tr>
<td>Power</td>
<td>30W Continuous</td>
</tr>
<tr>
<td></td>
<td>70W Duty Cycle</td>
</tr>
<tr>
<td>Power Bus</td>
<td>28 – 33V</td>
</tr>
</tbody>
</table>

## MAJOR PLATFORM SPECIFICATIONS
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>552 x 600 x 600 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>70 kg</td>
</tr>
<tr>
<td>Attitude Control</td>
<td>3-axis stabilized</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Pointing Acc</td>
<td>0.1 deg</td>
</tr>
<tr>
<td>Drift rate</td>
<td>5.0 e^{-04} deg/sec</td>
</tr>
<tr>
<td>Science Data</td>
<td>S-Band @ 8 Mbps</td>
</tr>
<tr>
<td>TM Data</td>
<td>S-Band @ 4Kbps</td>
</tr>
<tr>
<td>TC Data</td>
<td>S-Band @ 100bps</td>
</tr>
<tr>
<td>Power Generated</td>
<td>230W</td>
</tr>
<tr>
<td>Platform Power</td>
<td>70W</td>
</tr>
</tbody>
</table>

### PAYLOAD AREA

Ocean and Atmospheric missions
- Earth Imaging Payloads
- Microwave remote sensing payloads
- Scientific Payloads
IMS-1 STOWED VIEW

IMS-1 DEPLOYED VIEW

+COURTESY : ISRO
PAYLOAD - MINIATURIZED MULTI SPECTRAL CAMERA

HIGHLIGHTS:
• Indigenous 4K Linear Array CCD, 7μ x 7μ pixel
• Modular Configuration
• Miniaturized Electronics using AFE, FPGA Micro D, MLB
• Miniaturized LENS assembly (0.27kg) compared to LISS2 (6.5kg)
• Usage of COTS AFE.
• Multi Linear Gain Implemented in FPGA
• Application – Natural resource monitoring

Mx : 300 x 148 x 227 mm / 5.5 Kg

LISS 2A/B – 162 Kg

MINIATURISATION WITH A MEANING
PAYLOAD – ADVANCED HYPER SPECTRAL IMAGER

HIGHLIGHTS:
• Detector: Area array (512 row x256 columns) Active Pixel technology; 12 bit digitizer
• Wedge Filter for spectral separation; sampling at 1nm interval and 8nm bandwidth
• Optics: Multi lens assembly
• 512 bands processed to 64 bands by binning
• Application – Ocean and atmosphere study with fine spectral resolution

MINIATURISATION WITH A MEANING

Hyper Spectral camera Image - Part of Madhya Pradesh
**STRUCTURE**

**DESIGN**

- Structure is built in a classical manner
- Aluminum honeycomb sandwich based cuboid structure with a bottom deck, top deck and four cross ribs in a staggered fashion
- Four thin aluminum panels for covering deck
- Generates a central core to house tank and thruster elements

**SALIENT FEATURES**

- Direct Assembled Mode IST. (Systems mounted on Cross Ribs)
- No patch harness requirement
- Structure assembly time is less
- Provides easy unit access, flexible integration and checkout
- Reusable to maximum extent for other technology demonstration missions

- DESIGN STURDY TO MEET SURVIVAL REQ
- DESIGN AS A BUS WITH MODULARITY, ACCESSIBILITY AND ADOPTABILITY
NEW PACKAGING CONCEPT

SYSTEM ON CARD REALIZATION
- Individual subsystem electronics are reduced to single PCB.
- Six Systems Realized on 12” x 12” PCB

STACK1: BMU, PSDC, WDE
STACK2: IRU, BDH, SSR

ADVANTAGES
- Optimal utilization of available area and volume at S/C level.
- Reduction of mechanical hardware mass/subsystem.
- Reduction of intra and inter package harness.
- Standard packaging concept for small satellites.
- Better thermal management at S/C level.
- Reduction of integration and testing time.
- Reduced no of components – Less failure / More reliability

EXAMPLE: BMU MINIATURIZATION

<table>
<thead>
<tr>
<th>SYSTEMS</th>
<th>CONVENTIONAL BMU</th>
<th>IMS BMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of PCBs</td>
<td>8 cards</td>
<td>1 card</td>
</tr>
<tr>
<td>MASS</td>
<td>12.5 kg</td>
<td>1.3 kg</td>
</tr>
<tr>
<td>PCB</td>
<td>8” X 9”</td>
<td>12” X 12”</td>
</tr>
<tr>
<td>POWER</td>
<td>20W</td>
<td>7W</td>
</tr>
<tr>
<td>H/W REALIZATION</td>
<td>3 MONTHS</td>
<td></td>
</tr>
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</table>

PCB STACKS

CONVENTIONAL S/C BMU

IMS-1 BMU
CENTRALIZED POWER DISTRIBUTION SCHEME

REALIZATION HIGHLIGHTS

• Shared DC DC Converters used to meet Platform voltage requirements
  → Mass and Volume Saving at Spacecraft level

• Switched Secondary voltages provided to Sub Systems
  → Better real estate offered for Subsystems

• Spacecraft Structure used as secondary return path
  → Harness Reduction

ACHIEVEMENTS

• Only Five DC DC converters for platform
  IRS - 50 approx. (M&R)
• PSDC realized in single PCB (12” x 12”)
• Resistance from any point to point on spacecraft
  < 5 milliohms
  (IRS ~ 20 milliohms)
• Harness reduction

❖ DESIGN FOR LOW NOISE
**MICRO D CONNECTORS & FLEXI PCB**

**FLEXI PCB FOR HARNESS**

*Implemented for the first time*

- Reduces the no of connectors
- Reliability, Simplified Assembly
- Results in fewer wiring errors
- Repeatability and High Density.

**MICRO D CONNECTORS FOR HARNESS**

*Implemented for the first time*

- Less volume and weight
- 70% Micro D Connectors used

- Single harness for total spacecraft without any patch connectors
- Total harness has been formed on the harness jig itself

- Use miniature components with quality
- Reliability is respected and it protects goal

*Courtesy: ISRO*
DATA HANDLING SYSTEM – NEW TECHNOLOGIES

BDH

JPEG 2000 Compression
- Wavelet based Algorithm
- Improved low bit-rate compression performance (50% better than JPEG)
- Programmable compression ratio
- Improved lossless and lossy compression

RS Coding / Formatting

Use of BGA for the first time
Realized in a single 12” x 12” PCB (1kg)
Standardized electrical interface for payloads

SSR

Low Power, Volume and Mass (0.8kg)
Realized in a single 12” x 12” PCB
Use of SDRAMs for the first time
- HIGH THROUGHPUT WITH EXPANSION
- STANDARDISATION WITH SCALING
RF SYSTEMS – NEW TECHNOLOGIES

DIGITAL S-BAND RECEIVER

- Digital Non Coherent Receiver
- DSP based FM/FSK demodulator
- Less volume, mass and power (1.5 kg)
- Programmable / Reconfigurable
- Highly suitable for micro satellites where space and power is premium

RF SYSTEMS – NEW TECHNOLOGIES

SINGLE S-BAND TRANSMITTER FOR DATA / TM

- Single S-Band transmitter for Payload data/ TM
- Operates in high power / low power mode
- Direct modulation – PCM/BPSK

MINIATURE SPS

- Miniature SPS from SSTL; In-house developed SPS Interface module
- Less volume, mass and power (1 kg, 1 W)
- Highly suitable for micro satellites where space and power is premium

SS TECHNOLOGIES : GREAT CHALLENGES AND RESEARCH OPPORTUNITIES
AOCS – NEW TECHNOLOGIES

IRS 1kG
HAMSAT 650g
IMS-1 230g

MINIATURE MAGNETOMETER (MEMS)

Micro Reaction Wheels

Mass: 660g

Mass: 1.76 kg

APS STAR SENSOR
(Under development)

Experience gives books – books don’t give experience
Experience is the real knowledge

MINIATURE GYRO

COURTESY: ISRO
HINGE MECHANISM with tape springs

*Implemented for the first time*

Provides the energy for solar panel deployment and acts as the latch on deployment of panels.

Advantages ....
- Self drive & Self latch
- Less number of moving parts
- Less friction
- Low Mass (Tape spring -90g)

HOLD DOWN AND RELEASE MECHANISM

*(Paraffin Actuator Based)*

*Implemented for the first time*

Retains the stowed panel integrity on ground, during launch and ensures a reliable release of the panels on command.

Advantages...
- Non - explosive & Low source shock
- Reusable
- High reliability
- Low mass (Paraffin actuator – 75 g)

NECESSITY IS MOTHER OF INVENTION
COMPONENTS / QA PHILOSOPHY

COMPONENT PHILOSOPHY FOR EEE PARTS
• MIL grade parts preferred
• Industrial / COTS components usage allowed after Review
  Nearly 40 components used in IMS-1
• Usage of radiation-hardened components not mandatory AT ALL PLACES
• Shielding to be provided for parts if TID hardness is less than 10 k rad.

MATERIALS AND PROCESS CONTROL
• Usage of Commercial materials encouraged after Review
• Some of the new processes in IMS-1
  Wiring of Micro-D connectors
  Flexi PCB usage
  Mounting of the compression chip BGA in BDH

TEST AND EVALUATION
• Simple Non conformance control methods
• Responsibility of unit-level testing transferred to the subsystem manager

REALIZATION PHILOSOPHY
• Single Model Philosophy except for new development systems

NANO SATS ENTERING OPERATIONAL AREA REQUIRES STRONG QUALITY ASSURANCE
**IRS 1A/1B**  
*Mass* – 975 Kg  
*Power* – 600W  
*Payloads* – LISS –1, LISS –2A, LISS–2B

**Mass** – 83 Kg  
*Power* – 80W  
*Payloads* – Multi Spectral Camera  
Hyper Spectral Camera

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<table>
<thead>
<tr>
<th>SUB-SYSTEMS</th>
<th>IRS WEIGHT(Kg)</th>
<th>IMS-1 WEIGHT(Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAYLOAD</td>
<td>160</td>
<td>5.5</td>
</tr>
<tr>
<td>POWER EL</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>BMU</td>
<td>12.7</td>
<td>1.5</td>
</tr>
<tr>
<td>SSR</td>
<td>9.5 (60GB)</td>
<td>0.9 (16GB)</td>
</tr>
<tr>
<td>BDH</td>
<td>21</td>
<td>0.9</td>
</tr>
<tr>
<td>STAR SENSOR</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>WHEELS (4 NO.)</td>
<td>20(5NMS)</td>
<td>3.2(0.36NMS)</td>
</tr>
<tr>
<td>WDE</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>GYRO UNIT</td>
<td>14.5</td>
<td>1.8</td>
</tr>
<tr>
<td>GYRO ELE</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>RF RECEIVER</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>MECHANISMS</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>

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**EXTENT OF MINIATURIZATION**

- **GO AHEAD AGAINST ODDS – THESE ARE NATURAL FOR INVENTIONS**

**IMS-1**

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COURTESY: ISRO
- AVOIDING TESTS ENSURES RISK

IMS-1 - GLIMPSES

- IMS-1 - IN CLEAN ROOM
- IMS-1 - UNDER VIBRATION
- SOLAR PANEL DEPLOYMENT TEST
- SHIPPING TO SHAR
- MATED WITH LAUNCH VEHICLE
- PSLV C9 LIFT OFF
- FIX LAUNCHER(S) BEFORE STARTING DESIGN

- SATELLITES NEED TO BE IN ORBIT -- OTHERWISE IT IS A LAB MODEL

COURTESY: ISRO
YOUTHSAT -- SECOND MISSION ON IMS-1 BUS WITH ATMOSPHERIC AND IONOSPHERIC OBSERVATION PAYLOADS. FIRST INDIAN SATELLITE WITH PROFILE PROGRAMMING ONBOARD

- A SATELLITE BUS MEETS DIFFERENT MISSIONS WITH LEAST ADJUSTMENTS
- SATELLITE BUSSES ARE USEFUL FOR CONSTELLATIONS
# Increasing Application Demands

<table>
<thead>
<tr>
<th>Application</th>
<th>Resolution</th>
<th>Bands</th>
<th>Repetevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure building / Town &amp; Urban Planning and governance</td>
<td>0.5 to 1m</td>
<td>PAN</td>
<td>Daily to 1week</td>
</tr>
<tr>
<td>Agriculture</td>
<td>5 (1m) To 50 mtrs</td>
<td>VIS – NIR – SWIR (Hper spec, Microwave/SAR)</td>
<td>2 to 30 days</td>
</tr>
<tr>
<td>• Crop monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Crop yield estimation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forestry</td>
<td>50 (1 m) – 150 mtrs</td>
<td>VIS-NIR-SWIR (Hper spec, Microwave) TIR (forest fire monitoring)</td>
<td>Few months 1 – 5 days (Hourly)</td>
</tr>
<tr>
<td>Water resources</td>
<td>20 – 100 mtrs</td>
<td>NIR</td>
<td>Few months</td>
</tr>
<tr>
<td>Oceanography</td>
<td>100 – 1000 mtrs</td>
<td>VIS-NIR-TIR MW</td>
<td>Daily - weekly</td>
</tr>
<tr>
<td>Disaster management</td>
<td>&lt; 10 mtrs</td>
<td>VIS-NIR SAR</td>
<td>Few hours</td>
</tr>
</tbody>
</table>

- **EVERYWHERE ALL THE TIME MONITORING --- GREATEST DEMAND**
A satellite CONSTELLATION MISSION is number of satellites in orbit(s) to deliver an identified task or service with supporting ground infrastructure.
SINGLE SATELLITE SYSTEM

MISSION ELEMENTS

SATELLITE SEGMENT

- PAYLOAD1
- PAYLOAD2
- PAYLOAD3

GROUND SEGMENT

- DATA PROCESSING AND PRODUCT DELIVERY – M1
- DATA PROCESSING AND PRODUCT DELIVERY – M2
- DATA PROCESSING AND PRODUCT DELIVERY – M3
- DATA PROCESSING AND PRODUCT DELIVERY – M4

USER SEGMENT

- USERS – M1
- USERS – M1
- USERS – M1
- USERS – M1

SATELLITE BUILDING, TESTING AND QUALIFICATION : ~ 50 people

SATELLITE TRACKING AND CONTROL : 8
- Constellations are with all and for all.

**Satellite Segment**

- Const with Payload1:
  - Satellite BTQ: Pple C1 x N1

- Const with Payload2:
  - Satellite BTQ: Pple C2 x N3

- Const with Payload3:
  - Satellite BTQ: Pple C3 x N5

- Const with Payload4:
  - Satellite BTQ: Pple C4 x N6

**Ground Segment**

- Data Processing and Product Delivery – M1
  - Const control: C1 x N2

- Data Processing and Product Delivery – M2
  - Const control: C2 x N4

- Data Processing and Product Delivery – M3
  - Const control: C3 x N6

- Data Processing and Product Delivery – M4
  - Const control: C4 x N8

**User Segment**

- Users – M1
## Redundancy aspects

<table>
<thead>
<tr>
<th></th>
<th>Medium / Small /Mini</th>
<th>Micro</th>
<th>Nano/Pico</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload(s)</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Structure</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Power</td>
<td>R</td>
<td>RL</td>
<td>S</td>
</tr>
<tr>
<td>TTC</td>
<td>RL</td>
<td>R</td>
<td>S</td>
</tr>
<tr>
<td>Data Handling</td>
<td>R</td>
<td>R</td>
<td>S</td>
</tr>
<tr>
<td>AOCS</td>
<td>R</td>
<td>R</td>
<td>S (RH components)</td>
</tr>
<tr>
<td>Sensors</td>
<td>R</td>
<td>RL</td>
<td>S</td>
</tr>
<tr>
<td>Torquers</td>
<td>RL</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Prop</td>
<td>RL</td>
<td>S</td>
<td>S/NA</td>
</tr>
<tr>
<td>Thermal</td>
<td>RL</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Mechanisms</td>
<td>RL</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>

S: Single sys, R: Redundant, RL: Limited Redundancy,
Artificial Intelligence Requirements and Opportunities in Small Satellites in constellation

• For Satellite maintenance
• Payload Operations
• Onboard data processing product delivery
• Resource sharing
• Intersatellite communications
• Contingency and survival.
Constellations

Good points and advantages of small satellite constellations

- Constellation serves high temporal freq applications
- Participative collaborative missions
- Wide spectrum of applications
- Easier access to space for individual countries
- Capacity building in the countries
- Opening up for many research areas
- More job opportunities in all participating countries

Some of important Points to be taken care

- Quality and reliability
- More spacecraft autonomy designs
- Ready Product delivery (80%)
- Direct to mobile
- Data sharing
- Freedom within regulations
- Equal opportunities to all countries (with hand holding)
- Deorbiting rules
- Openness of purpose
SS PROVIDES CHALLENGES AND OPPORTUNITIES TO STUDENTS
Organisations / State, Central Govt Depts

- Workshops
- Conferences
- Expert panels
- Academic advisory
- E-Journals
- Research advisory
- International study
- Business advisory
- Startup advisory
- Policy advisory
- Student competitions

Universities / Educational Institutes

Industries / Start-ups

Organisations / State, Central Govt Depts

PARTICIPATION

ADVISORY

ICSS2019.IN

CAPACITY BUILDING IN INDIA

Manpower supply
SMALL SATELLITES
CONCLUSION

- SMALL SATELLITES: MINIATURISATION WITH A MEANING
- FAILURES ARE POSITIVE FEEDBACK – LEARN AND CORRECT (ALL BIG SPACE ORGANISATIONS FOLLOWED THIS PATH)
- GOOD DOCUMENTATION IS ESSENTIAL – IT SHOWS WHERE TO CORRECT
- MISSION GOAL DEFINES SYSTEM
- GOAL CAN BE SOCIETAL APPLICATION, TECHNOLOGY DEVELOPMENT OR KNOWLEDGE EXPANSION
- SYSTEMS ENGG IS THE PROCESS TO MAKE THE SYSTEM
- NEVER LOSE SIGHT OF THE GOAL
- DESIGN STURDY TO MEET SURVIVAL REQ
- DESIGN AS A BUS WITH MODULARITY, ACCESSIBILITY AND ADOPTABILITY
- SIMPLICITY IS BEST ENG
- RELIABILITY IS RESPECTED AND IT PROTECTS GOAL
STELLITE CONSTELLATIONS: WITH ALL AND FOR ALL

WORLD IS NO MORE GLOBAL VILLAGE

IT IS A GLOBAL ROOM
THANKS TO UNOOSA FOR THE OPPORTUNITY
THANKS TO ALL OF YOU FOR GREAT PRESENCE
THANKS TO ORGANISERS

THANKS FOR ATTENTION

I ACKNOWLEDGE ISRO AND THE YOUNG TEAMS FOR THEIR SUPPORT IN CREATING SMALL SATELLITE BUSSES AND MISSIONS
I ACKNOWLEDGE THE VELTECH UNIVERSITY FOR ENCOURAGING AND SUPPORTING THE CAUSE OF SMALL SATELLITES
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