ELECTROOPTICAL PAYLOADS FOR EARTH AND PLANETARY OBSERVATION

First Day Image of Earth taken by MCC

Image acquired on 19th Nov, 2013 13:50 IST

Altitude: ~ 68,000 km
Resolution: ~ 3.5 km

Mode: 3 (0.4ms)

Saji A Kuriakose, SEDA Space Applications Centre, ISRO Ahmedabad
Electro-optical Imaging Systems Developed By ISRO - Synopsis

Sensors developed to observe earth (land, ocean, atmosphere) and moon from space in various wavelength bands

From a Kilometer to a Meter

1km

Bhaskara 1979

360m

188m

72m

56m

36m

23m

5.8m

<1m

2.5m

ALTM

MOON

Cartosat-2B 2010

Bhaskara 1979
Optics
Mechanical structures

AWiFS

LISS IV
Detectors

6K SWIR Detector

6K VNIR CCD (191A)

6K VNIR CCD (191A)
Payload Electronics

- Detector drive signals (Bias and clocks)
- Analog and digital processing of detector output
- On-board calibration electronics
- Timing and control signal generation
- Onboard data processing like Non Uniformity Correction (NUC)
- Power supply for all payload electronics systems
- Interface to data handling, Tele-command, Telemetry and Raw bus
Resource Monitoring
Bhaskara

- First Remote sensing camera on satellite
  - Spin stabilized satellite,
  - Super Vidicon TV cameras (area detector)
  - Mechanical & electronic shutters
  - High voltage circuitry (14KV)
  - Slow readout of Vidicon with precision current sources
  - Low noise video processing, 400Kbps data rate, contiguous pictures
  - Discrete components based CMOS logic, ADC etc.

IGOV-1Km, Swath-400Km
2 Bands

4/22/2014
IRS-1A/B: Quantum jump in resource observation

- First operational satellite designed for resource monitoring
- Circular sun synchronous polar orbit, 3-axis stabilized satellite
- Resolution improved from 1Km to 36.5m, Data rate -26Mbps
- Solid state technology (2048 element, 13μ pixel CCD)
  - Better SNR & radiometric accuracy, reduced complexity
- Band wise modular architecture to survive single point failures.

- CCD based imaging technology mastered & quantization (7 bit) limited noise systems achieved
- Phased readout of CCD to minimize hardware
- LS/STTL devices used meet speed
- Non-space grade ICS like Op-amps, clock driver, ADC, analog switch used after in house qualification.
- S & X band Tx systems developed.

Development helped in understanding the sensitivities of band to band registration.

Occasional radiometric jump & blooming at few places understood & corrected in subsequent payloads.

The overall data quality was very good.
IRS-1C/D

Three tier imaging capability

- WiFS: Coarse resolution (188m) & wide swath (700Km)
- LISS-3: Medium resolution (23.5m in VNIR, 70m in SWIR), swath: 140Km
- PAN: High resolution (5.8m) & swath 70Km

Challenges

- WiFS
  - Indigenous lens design & development
- Dark signal issues, large signal levels & data rate matching
  - Resolved by combination of optical along track alignment and line sampling
- PAN-First time development of 3mirror off-axis un-obscured reflective telescope
  - Swath achieved with three 7μm pixel, 4000 element CCDs
  - Steering mechanism (±26°) for faster revisit & stereo
  - Optical bias of CCDs to improve the charge transfer
  - FTTL for high speed logic, Data rate increased (85Mbps)
  - In house qualified high-speed Op-amps (GBW: 350MHz), ADC (20Mps) & precision switch, etc. to meet speed

4/22/2014
IRS-1C/D

LISS-3

- 6K element high capacity low noise CCD developed for (VNIR)
  - Challenges in electrical interfacing to realize proper PAM signal met
- First time, SWIR band realized with InGaAs detector (2100 element, 26 μ pixel, staggered)
  - Complex detector- development a challenge
  - Vidicon mode of operation-new CE to meet complex signal processing

- Blooming problems avoided with large dynamic range detectors
  - Caused overdrive of signal processors at high illumination resulting in phase reversal of Op-amp and high current conditions
  - Resolved by incorporating anti-blooming control at CCD and high-speed clipping circuits in video chain
- BBR and thermo-mechanical stability
  - Structures of PAN & LISS-3 realized by milling them from large Invar forgings with weight reduction techniques

The spacecraft was considered best in civilian remote sensing
RESOURCESAT-1

Follow on of IRS-IC/D PAN enhanced to Multi-spectral (LISS-4)
LISS-3 (SWIR) improved to 23.5m ground resolution
AWiFS realized with 70m ground resolution, 4 bands (B2,B3,B4, B5) and 10 bit radiometric data

RESOURCESAT-2

LISS-4
✓ Improved contrast, 100% albedo with single gain
✓ Full 70Km data (23Km in RS-1) Transmitted

Data compression (Tx-105Mbps)
✓ DPCM for LISS-4 and LISS-3 with 10 bit radiometric resolution
✓ MLG (AWiFS) to enhance radiometric accuracy (12 bit) at low illuminations

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<tr>
<th>RESOURCESAT</th>
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<th>2</th>
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<tr>
<td>Total Cards</td>
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<td>Packages</td>
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<td>Volume (in³)</td>
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<td>3082</td>
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<tr>
<td>Weight (Kg)</td>
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<td>32</td>
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<tr>
<td>Power (W)</td>
<td>223</td>
<td>180</td>
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</table>
OCEANOGRAPHY SENSORS
Detected radiance ($\mu$W/cm$^2$/sr/nm)

Sensor detected radiance =
- Raleigh path radiance (molecular scattering) +
- Aerosol path radiance (aerosol scattering) +
- Water leaving radiance $\times$ Atmospheric transmittance

- Sea & land imaging
- Large dynamic range & low signal from sea
- Large atmospheric path radiance (ocean -20%, atmosphere-80%), radiance contamination due to sun-glint
  - Narrow spectral bandwidth
  - 6K detector with large charge handling capacity + exposure control & anti-blooming control
  - Atmosphere correction - B7 & B8
- Sun glint (season & global)
  - Dealt by $\pm 20^\circ$ tilt mechanism
  - Light weight structure
  - NESR< 1.08$\mu$W.cm$^{-2}$sr$^{-1}$µm$^{-1}$ @1x1Km2 resolution

- Spatial footprint:360m-Best in its class
- Swath 1420 Kms, 2 day repeatability
- 8 spectral bands
- Large FOV ($\pm 43^\circ$) met with telecentric lens

4/22/2014
- True 12 bit digitization (first time)
  - Noise modeled, apportioned & controlled
  - Achieved photon noise limited performance
  - Band wise separate lens, filter, detector and electronics to maximize performance
  - Lens barrel material selected to compensate CTE of Lens back focal length

**SYSTEM NOISE**

\[ N_{NP} \times 1.1 = 2460 \text{uV} \]

**PHOTON NOISE**

\[ N_{DP} = 2116 \text{uV} \]

**DETECTOR NOISE**

\[ N_{D} = 2237 \text{uV} \]

**DARK NOISE**

\[ N_{DD} = 725 \text{uV} \]

**ELECTRONIC NOISE**

\[ N_{E} = 1025 \text{uV} \]

**COMPONENT NOISE**

\[ N_{C} = 418 \text{uV} \]

**ENGINEERING NOISE**

\[ N_{EG} = 418 \text{uV} \]

**POWER SUPPLY NOISE**

\[ N_{S} = 418 \text{uV} \]

**Kavaratti site (in-situ) data**

- On-board calibration
  - Low noise current controlled LED source
  - Exposure selection for 16 levels
  - NIST traceable uniform source for radiometric calibration on ground
  - In-situ ocean measurements for validating sensor calibration after launch.
Global OCM Chlorophyll

Cyclogenesis using OSCAT

Sea Ice decay in the Antarctic during summer

OCM & SeaWiFS

Sea Ice decay in the Antarctic during summer

Oil Spill Detection - Gulf of Mexico
CARTOGRAPHY SENSORS

TES

Cartosat 1

Cartosat 2
Challenges associated with HR sensors
(a) Signal strength
(b) Large focal length requirements
(c) Diffraction limit of optics
(d) Large data rate
(e) Platform stability

High resolution Camera
- 560mm on-axis RC telescope (F/7)
- Required speed 6x PAN met by velocity reduction + IRS- PAN camera electronics
- First time complex satellite slewing technology tried

Short development time - 1 year
CARTOSAT-1

- First Real time stereo imaging
- Two fore & aft. PAN cameras (500-850 nm)
- Better than 2.5 m resolution
- Swath 27.5 km for stereo and 55 km for monoscopic mode
- across track tilt to give better revisit

LAUNCHED: 5/05/2005

New technologies

- 500mm dia TMA optics for large FOV(±1.08°)
  - Mirrors polish:λ/80 accuracy
  - Iso-static mirror mounts
  - Matching of mechanical/ thermal/ opto-mechanical properties
- Light weighted Invar structure (EO module weight 250Kg)
- 12000 element CCD, Focal plane CCD drive Electronics near to detector
- Video processor - processing within 200ns, (100% albedo). Digital double sampler designed with 12Bit ADC(40Msps) & current feedback Op-amps
- Digital logic, 105MHz Tx -First time ECL logic for timing & interface
- Transmission limit of 105Mbit/s, onboard 3.2:1 data compression (338 Mbit/s)

The data products software development was a major milestone. Best quality Digital elevation data realized in the world.
CARTOSAT-2

- Indigenous large mirrors (50% light weighted 700mm dia)
- Light weight CFRP structure (39Kg) & kinematic mirror mount
- Compact f/8 system-Ritchey-Chretien on-axis Telescope
- Model for telescope performance developed. Assembled in 1g conditions to meet operations in zero gravity
- Stresses minimized, optics surface finish of $\lambda/50$ maintained
- Thermal control of large size P/L – difficult task (better thermo-mechanical performance)
- Agile spacecraft- designed around payload

- Carto-2-Jan 2007
- Carto-2A-April 2008
- Carto-2B July 2010

Growth of Aperture
Space Instrumentation for Weather monitoring
Weather monitoring - INSAT 2A/2B/2E/3A & Kalpana

Very High Resolution from GEO orbit

- Large spectral range, multi-band
  - Reflective telescope + dichroic beam splitters
  - Oversampling (electronics) - improve contrast at Nyquist
- Long dwell time
  - Multiple detectors used
- Large FOV – 24° x 18° (full globe +)
  - Whiskbroom configuration with 2 Axis electro-mechanical scanning
    - Programmable scanning - selected area
    - Complex, accurate, synchronous scan mechanism developed for long life
  - Select materials & torque for Thermo-mechanical stability
- IR detector - Cooling
  - Passive cooler realized - 90K

- Cloud picture
- Sea surface temperature
- Wind
- Vertical temperature profile
- Vertical humidity profile and its horizontal positional distribution
- Total Ozone and its vertical profile
- Aerosol density and its vertical profile
- Trace constituents and their vertical profiles

Development of coolers, temperature sensor integration for very low temperature operation was an uphill task

4/22/2014  
CANEUS SSTDM 2014  
23
Challenges in weather monitoring instruments

- **Large background**
  - Cold view beyond earth
  - Black body view

- **High resolution ADC**
  - 14 bit dynamic range & accuracy achieved by ingeniously using 10 bit ADC

- **Small signals (pA, nV)**
  - Very low noise bridge preamplifiers
  - High gain trans-impedance amplifiers

- Data processing & display of VHRR data achieved after accounting for
  - scan mirror position
  - Spacecraft attitude
  - Sensor non-uniformities
  - Earth's sphericity & oblateness

- **Spatial Resolution:**
  - 2 Km
  - 8 Km

- **Dynamic Range:**
  - 100% Albedo
  - WVP and TIR: 4K-340K

- **NEdT/SNR:**
  - 6 @2.5% Albedo
  - 0.5K (@300K)
  - 0.25K (@300K)

- **VHRR (INSAT-3A, KALPANA)**

- **INSAT-3A /2E upgraded with SWIR channel (1Km resolution) for monitoring cloud, snow delineation, forest fire detection etc.**

- **INSAT 2E, 3A & Kalpana additionally have water vapour channels**

4/22/2014
INSAT-3D Challenges

- Improvements in Imager resolution
- 18 narrow IR channels in sounder (measurement of vertical profile of CO2, water vapour, Ozone etc.)

Hardware was realized in same volume

New technologies

- Filter wheel at 200K & shaft at 0-40°C
- 14 bit ADC to meet large dynamic range
  - Realized chain noise, referred to detector-3 nV/√Hz
- Black-body temperature measured with 0.1°C accuracy
- Large electronics hardware miniaturized

<table>
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<tr>
<th>Channels</th>
<th>Resolution</th>
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<tbody>
<tr>
<td>Visible, SWIR</td>
<td>1 km</td>
</tr>
<tr>
<td>MIR, TIR-1, TIR-2</td>
<td>4 km</td>
</tr>
<tr>
<td>Water Vapor</td>
<td>8 km</td>
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MINIATURE SENSORS
DEVELOPMENT
MINIATURISED MULTISPECTRAL CAMERA (IMS-1)

IMPROVEMENTS OVER TIME

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<tbody>
<tr>
<td>Size (mm³)</td>
<td>2 x (505 x 504 x 450)</td>
<td>311 x 250 x 167</td>
<td>120 x 140 x 130</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>150</td>
<td>5.8</td>
<td>1</td>
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MISSION GOALS

- Space craft altitude: 632 Km
- Resolution: 37 m
- Swath: 151 Km
- Spectral bands: 4 (VNIR)

Design for small satellite

- Small volume, low weight & power
  - Size & weight limit
- Focal length – Resolution
- Aperture – SNR & Contrast
- Power limits
  - Camera speed
  - Transmission data rate,
  - Thermal control aspects, etc.

✓ Indigenously Developed compact Lens
✓ Indigenously Developed 4K, Four Port CCD
✓ FPGA & AFE (instead of video processor) based miniature camera electronics – First time

Power: 13.2 W
Terrain mapping camera for moon mission

Design Challenges

✓ Miniature stereo triplets, B/H = 1 & F0V : ±25° (5m)
  • Single lens + fold Mirrors (innovative optical field compressor)
✓ Low power (20W), small volume & low mass (8Kg)
  • Honeycomb with CFRP Face sheets
  • APS with On-Chip Digitizer, FPGA based logic

TMC

- YAW = 450 mm
- ROLL = 362 mm
- PITCH = 255 mm
- Weight < 6.3 kg
- Power < 1.8 W

Central peak of Tycho crater
TMC data

1, 2 : Evidences of Volcanism on Central peak
Of Tycho Crater using TMC data

Spectral range – 0.5 to 0.75 um
Gain / Exposure – 4 each
Quantization – 12 bit
MTF -- >15%
SNR - >80 (@ 1.2 mW/ cm2/str/um)
     >300 (@ 14 mW/ cm2/str/um)
Datarate – 16.286Mbps/chain
Hyper Spectral Imaging Payload - Mineral/chemical mapping of lunar surface & air glow measurement

First time

☑️ 64 bands, 15nm spectral band

► Optics - wedge filter based spectral dispersion & wide band lens for simplicity & compact size

► Spectral bandwidth by pixel binning

► Active Pixel Sensor-256x512 pixs with on-chip digitizer for low power & weight + FPGA based camera electronics & Tray packages

► Structure using CFRP-Honeycomb
NEW SENSORS UNDER DEVELOPMENT & TECHNOLOGY CHALLENGES
Challenges

PAN -0.67 m . MX 1.5m imagery,
Optics & structure same as in Carto-2/2A/2B
High Data Rate
Radiometric improvements

- Multi-line TDI detectors
- Optical butting -large swath with short detectors
- Improved FOV
- Strip filters for spectral selection
- Low power, high speed focal plane electronics
- Data rate – 3.2 Gbps
- Sync. of satellite movement with TDI detector
- On-board radiometric correction
- Thermal handling – 200W at focal plane
- Development of test bench & data archival
Cartosat-3 Mission

Challenges

- Agile & stable platform
- High data rates (~41Gbps & 1.6 Tb SSR)
- Variable Compression
- 8-PSK modulation, Ka / X band Tx
- Precise bus control system
- Programmable Integration time w.r.t altitude
- Speed increases by 10 fold
  - Focal plane electronics, 400 signal processors & high capacitance drive
- Higher power requirements (>950W)
  - Focal plane heat removal- heat Pipes/ SIL Pad etc. Power converter design
- On-board focusing
  - High speed ground checkout system

PAN : 0.25 m (400 – 950 nm)
Mx (VNIR) : 0.5m, 4 Bands
MIR : 5m (3- 5 μm)
Swath : 16 Km@ 450 Km Alt.

Payload Size: 1.3m Dia* 2.1m
Payload Weight : 550Kg
Payload Power : 1275 W

Mirror - light weighted to 70 Kg from 420 Kg

0.2 Kg, 1.9” X 3.5” X 2.4”

04/22/2014
GISAT challenges

- Surveillance, Monitoring of transient phenomena (cyclones, tsunami etc.)
- Continuous spectral discrimination & parameter extraction of vegetation, soil/vegetation, rock/soil, inland & coastal water

- Imaging & spectroscopy for land, ocean & atmosphere studies
- Very high resolution (50m VNIR, 1.5Km LWIR) imaging
- Very high resolution Imaging spectrometers in VNIR, and SWIR

- Versatile scanning modes
  - Optics FOV ~ 1°, S/C slewing to cover earth disc
  - Spectral range from 0.4 to 12.5 um
  - High density focal plane
  - Calibration using cold and planetary view
  - 24K VNIR, 512x 256 VNIR, 1000x 256 SWIR, 320x 256 LWIR detectors for higher scan speed
  - Convex grating based spectrometers
  - Long life active coolers
  - 7 scan modes including arbitrary scan for irregular area
  - Compact focal plane electronics.
  - Photon noise limited system SNR
  - Versatile Formatter design (CCSDS, Space packet protocol) & MIL-STD-1553 interface

Meteorology and night time imaging
Mars Orbiter Mission Payloads

- Methane Sensor for Mars (MSM)
- Thermal Infrared Imaging Spectrometer (TIS)
- Mars Colour Camera (MCC)
Thanks