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Hyperspectral Remote sensing missions

- Hyperspectral sensors acquire more spectral information from objects with a high spectral resolution compared with Multispectral sensors.
- Hyperspectral sensor enables to distinguish a targeted object with a high accuracy, and give us lots of important information.
- Hyperspectral remote sensing has capabilities to innovate lots of practical applications.

Application area using hyperspectral technology

- Agriculture (Hyperion Validation Report)
- Geology (©EnMap homepage)
- Forest (©EnMap homepage)
- ©Examples of information products derived from hyperspectral data at CCRS
TAIKI: Hyperspectral Remote sensing Satellite

**Item Requirement**
- **Spacecraft mass**: 50 kg (including Mission payload)
- **Size**: 50 cm × 50 cm × 50 cm
- **EPS**: Body mounted solar cell panels, Power generation: = 50 to 100W
- **ACS (Attitude Control Subsystem)**: 3-axis stabilization, Attitude accuracy: ± 2.0 deg
- **C&DHS**: 32bit RISC microprocessor (SH-4)
- **COM**: Downlink: 10Mbps / Uplink: 9.6kbps, LCU (Laser Communication system)
- **Mission components**: HSC-III (Hyperspectral Camera-III)

**[Mission objectives]**
- To provide Hyperspectral image for **agricultural remote sensing in order to innovate the space industries**
- To acquire Visualization of the effect of climate change on plant distribution by measuring NDVI (Normalized Differential Vegetation Index)

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**Diagram**
- **HSC-III**: Hyperspectral Camera
- **Laser Communication Unit**
- **Mission components**
  - HSC-III (Hyperspectral Camera)
  - Sun acquisition sensor
  - Magnetic Torquer (3-axis)
  - Momentum Wheel
  - Magnetometer (3-axis)
  - Gyroscope (3-axis)
  - Solar Panels
  - Secondy Battery
  - DC/DC Converter
  - 32bit RISC MPU (SH-4)
  - Real Time Clock
  - FPGA
  - Mission Data
  - Laser Transmitter
  - Ku Band Transmitter
  - VHF Band Communication Unit
  - Telemetry & Command
  - Data Recorder
  - DHU
  - Router
Concepts of the Spacecraft bus-subsystem

• To develop the spacecraft as manufactured products

• To keep cost within 1 million $ (including mission payloads) in order to demonstrate the space business model

• To use lots of COTS (Commercial-Off-The-Shelf) components demonstrated by Pico-satellite HIT-SAT shown after this slide

• To employ attitude control subsystem providing an attitude accuracy within ±2 degrees

• To downlink by high-speed transmission ( > 100Mbps) for high-quality hyperspectral data
Pico-satellite “HIT-SAT”

Table: Specification of the HIT-SAT

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>2.7 kg</td>
</tr>
<tr>
<td>Size</td>
<td>12×13×12 cm³</td>
</tr>
<tr>
<td>Power</td>
<td>2.0 W</td>
</tr>
<tr>
<td>Orbit</td>
<td>Sun-synchronous, 277-633 km</td>
</tr>
<tr>
<td>Attitude control</td>
<td>Spin stabilization (3-axis MTQ)</td>
</tr>
<tr>
<td>Communication</td>
<td>Tx: 430MHz, Rx: 145MHz</td>
</tr>
<tr>
<td>Launching vehicle</td>
<td>M-V#7 by ISAS/JAXA</td>
</tr>
</tbody>
</table>

- HIT-SAT was developed as an experiment model of the TAIKI bus-subsystem and launched successfully on Sep. 23, 2006 as a sub-payload of M-V#7 launch vehicle (ISAS/JAXA).
- The very small bus subsystem including lots of COTS components have been demonstrated in orbit.
- We conducted the satellite by Armature radio frequency.

TAIKI spacecraft is equipped with these COTS components.
EPS: Electrical Power Subsystem

- Bus voltage must be kept $5[V] \pm 100[mV]$
- To realize a very compact electrical circuit
- PCU (Power Control Unit) performs the PPT (Peak Power Tracking) control by a 16 bit microprocessor and DC/DC converter

<table>
<thead>
<tr>
<th>Item</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar panel</td>
<td>Body mounted solar panels</td>
</tr>
<tr>
<td></td>
<td>GaInP$^2$/GaAs/Ge</td>
</tr>
<tr>
<td></td>
<td>Triple Junction Solar Cells</td>
</tr>
<tr>
<td></td>
<td>Efficiently: 26.8%</td>
</tr>
<tr>
<td>Power generation</td>
<td>Approx. 50-100W</td>
</tr>
<tr>
<td>Secondary Battery</td>
<td>Lithium Ion Polymer</td>
</tr>
<tr>
<td></td>
<td>Nominal voltage: =7.4V (@ 2series)</td>
</tr>
<tr>
<td></td>
<td>Nominal capacity: = 4.55Ah (@ 5 parallels)</td>
</tr>
<tr>
<td>PCU</td>
<td>16 bit Microprocessor (H8/3048F)</td>
</tr>
<tr>
<td></td>
<td>Flash memory (EEPROM)</td>
</tr>
<tr>
<td></td>
<td>DC/DC converter (bus voltage: +5V)</td>
</tr>
</tbody>
</table>

Fig. Breadboard model of DC/DC converter

Fig. Lithium Ion Polymer Secondary Battery on-orbit demonstrated by HIT-SAT
COM: Telecommunication Subsystem

**Downlink for Mission data**

- To downlink high-volume hyperspectral data the satellite is equipped with **Ku-band transmitter**
- It employs **BPSK modulation** at 10Mbps, and the output power is 200mW
- The transmitter has been developed in **Micro LAB, Co., Ltd at Kagoshima in Japan**.

**For Command and H/K telemetry**

- The data transmission rate is 9.6kbps by **GMSK modulation (VHF transmitter)**
- The RF output power of the satellite is 150mW, and the output power of the grand station is 50 W.
- The basic technologies of the components were proven by the HIT-SAT in orbit

<table>
<thead>
<tr>
<th>Item</th>
<th>Uplink</th>
<th>Downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>150MHz</td>
<td>20GHz</td>
</tr>
<tr>
<td>Band width</td>
<td>16kHz</td>
<td>12MHz</td>
</tr>
<tr>
<td>Transmitting Gain</td>
<td>16.15dB</td>
<td>19.6dBi</td>
</tr>
<tr>
<td>Receiving Gain</td>
<td>2.15dBi</td>
<td>38.74dB</td>
</tr>
<tr>
<td>Transmitting Power</td>
<td>50W</td>
<td>0.2W</td>
</tr>
<tr>
<td>Propagation Distance</td>
<td></td>
<td>1000km</td>
</tr>
<tr>
<td>Receiver noise</td>
<td></td>
<td>23dBK</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td>30dBK</td>
</tr>
<tr>
<td>G/T</td>
<td></td>
<td>4dB</td>
</tr>
<tr>
<td>Link Margin</td>
<td></td>
<td>4dB</td>
</tr>
<tr>
<td>C/N</td>
<td>60.515dB</td>
<td>96.862dB</td>
</tr>
</tbody>
</table>

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Copyright(c) NISHI MUSEN KENKYUSYO
ACS: Attitude Control Subsystem

System requirements

- Attitude accuracy: ±2.0 degrees
- Simple & Miniaturized configuration

### Sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-axis Magnetometer</td>
<td>Band width</td>
<td>1 [kHz]</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>40 [μgauss] to 2 [gauss]</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>Range</td>
<td>±500 [deg/s]</td>
</tr>
<tr>
<td>Earth Sensor (ES)</td>
<td>Accuracy</td>
<td>±0.06 [deg] (3σ)</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>±5.5 [deg]</td>
</tr>
<tr>
<td>Sun Acquisition sensor</td>
<td>Field of View</td>
<td>±45 [deg]</td>
</tr>
</tbody>
</table>

### Actuators

<table>
<thead>
<tr>
<th>Actuator</th>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic Torquer (MTQ)</td>
<td>Dipole moment</td>
<td>±6 [Am²]</td>
</tr>
<tr>
<td>Momentum Wheel (MW)</td>
<td>Max torque</td>
<td>0.012 [Nm]</td>
</tr>
<tr>
<td></td>
<td>Bias wheel momentum</td>
<td>0.84 [Nms]</td>
</tr>
</tbody>
</table>
(1) **Network Architecture**
- Bus type network
  - *Space Wire* or *Fire Wire* (IEEE1394)
  - Configuration using Router
- To have shared data recorder for each module
- To realize flexibility bus-subsystem by using network type architecture

(2) **Hardware configuration**
**CPU**
  - 32bit RISC microprocessor
    - SH4 (Renesas tech. Co.)
    - 300MIPS
  - This processor has been evaluated the radiology examination @ Takasaki Advanced Radiation Research Institute

*Fig: Radiology examination*

**Analyzed result by CREAM**
- SEL event probability: 2.87E-07 [SEL/bit/day]
- SEU event probability: 9.81E-05 [SEU/bit/day]

*This processor is expected to an experience SEU during 3 month in orbit*
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   1. Terrestrial laser communication experiment
   2. Pointing control device for laser beam

4. HSC-III: Hyperspectral sensor
   1. Outline
   2. Result of Breadboard model of each module

5. Conclusion
Laser communication

- Hyperspectral data requires high-volume mass memory of several Giga bytes
- To need technique of high speed transmission

Downlink by a Laser Communication

ADVANTAGE of LASER COMMUNICATION
- High bit rate data transmission
- Small size and low electrical power
- Large volume Remote sensing data
  - Hyperspectral data, High resolution observational data, etc…
- Space business and academic applications
LCS: Laser Communication System

**Parameter** | **Requirement**
--- | ---
**Laser diode** | Wavelength: 830nm  
Output power: 1.5 W  
By using Array of Single-mode LD  
Beam divergence: 1.0 mrad  
Transmitting diameter: 8mm

**Receiver in Ground station** | Device: APD (Avalanche photo diode)  
Amplifier type: Transimpedance amp.  
Quantum efficiency: 0.75  
Multiplication factor: 600  
Antenna diameter: 1.0m

**Signal format** | NRZ (Non-Return Zero)  
Time Division Multiplex

**Modulation** | IM/DD  
(Intensity Modulation/Direct Detection)

**Bit rate** | **100Mbps** (BER < 10^-6)

**Transmitter instrument** | Instrument mass: 3kg  
Electrical power consumption: 4W

**Tracking accuracy** | 250μrad(σ)
Terrestrial laser communication experiment

[Outline]
To verify the breadboard model of LCS
High-volume video is transmitted by terrestrial laser communication
JR tower @ Sapporo to Rakuno Gakuen University: Propagation distance = 15km

<table>
<thead>
<tr>
<th>Item</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser wavelength</td>
<td>655 nm</td>
</tr>
<tr>
<td>Output power</td>
<td>0.03 W</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>5 mm</td>
</tr>
<tr>
<td>Beam divergence</td>
<td>0.1 mrad</td>
</tr>
<tr>
<td>Receiving antenna diameter</td>
<td>130 mm</td>
</tr>
<tr>
<td>Bit rate</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Propagation distance</td>
<td>15 km</td>
</tr>
<tr>
<td>Visible distance</td>
<td>20 km (fine weather)</td>
</tr>
<tr>
<td>Back noise</td>
<td>10 nW</td>
</tr>
<tr>
<td>Detector</td>
<td>APD</td>
</tr>
<tr>
<td>Modulation</td>
<td>IM/DD</td>
</tr>
</tbody>
</table>
Terrestrial laser communication experiment

Table: Link budget result for “STAR on the Ground”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_t$: Transmitting antenna gain</td>
<td>81.5 dB</td>
</tr>
<tr>
<td>$P_t$: Laser output power</td>
<td>0.03 W</td>
</tr>
<tr>
<td>$L_t$: Optical lens loss</td>
<td>-1.0 dB</td>
</tr>
<tr>
<td>$L_f$: Free space loss (propagation distance: 15km)</td>
<td>-229.2 dB</td>
</tr>
<tr>
<td>$G_r$: Receiving antenna gain</td>
<td>112.9 dB</td>
</tr>
<tr>
<td>$L_{at}$: Atmospheric loss ($D = 15$km, $V = 20$km)</td>
<td>-10.0 dB</td>
</tr>
<tr>
<td>$P_r$: Receiving signal power</td>
<td>$-59.1$ dB ($= -29.1$dBm)</td>
</tr>
</tbody>
</table>

Link budget result
Received signal power:  $-29.1$dBm

Measurement result
Received signal power:  $-27.9$dBm
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4. HSC-III: Hyperspectral sensor
   1. Outline
   2. Current status

5. Conclusion
Hyperspectral sensor Development Road Map

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laboratory models</strong>&lt;br&gt;To verify the spectrometer</td>
<td><strong>Airborne models</strong>&lt;br&gt;To decided a standard concept</td>
<td><strong>Spaceborne models</strong>&lt;br&gt;To demonstrate on orbit</td>
</tr>
</tbody>
</table>

**Hyperspectral camera (HSC1.0)**<br>**Laboratory model in 2003**

The key technology to realize a very small hyperspectral sensor was demonstrated.

For compact spectrometer is equipped with the transmitting grating.

**Airborne Hyperspectral sensor**

The technology has been demonstrated by the airborne hyperspectral sensor.

It has successfully observed the ground surface to analyze the plant distribution by NDVI.

**Spin-off product model**

HSC1700 released by Hokkaido Satellite, Inc.

The HSC1700 is specified by the spectral range from 400 nm to 800 nm, 81 spectral bands, and image size of 640×480 pixels, radiometric resolution of 8 bits and data transfer rate of 30 frames/seconds. After the release of the spin-off product HSC1700 to the general market, many big companies have been keenly interested in and purchased the products.

**Spaceborne Hyperspectral sensor HSC-III**

At the beginning of 2008, development of the spaceborne hyperspectral sensor “HSC-III” based on the optical design of the HSC1700 has been started.

**Missions**

To provide hyperspectral image for agricultural remote sensing

To acquire visualization of the effect of climate change on plant distribution.
Overview of HSC-III Flight model

Table: Performance of HSC-III

<table>
<thead>
<tr>
<th>Item</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument mass</td>
<td>10 kg</td>
</tr>
<tr>
<td>Power consumption</td>
<td>10 W</td>
</tr>
<tr>
<td>Imaging type</td>
<td>Push-bloom method</td>
</tr>
<tr>
<td>GSD</td>
<td>30 m</td>
</tr>
<tr>
<td>Swath width</td>
<td>20.6km</td>
</tr>
<tr>
<td>Field of view</td>
<td>1.8 degrees</td>
</tr>
<tr>
<td>Telescope aperture</td>
<td>20cm</td>
</tr>
<tr>
<td>Telescope type</td>
<td>2 mirror configuration of Ritchey-Chretien type</td>
</tr>
<tr>
<td>Wavelength range</td>
<td>400-1000nm (<em>61 bands</em>)</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>10 nm</td>
</tr>
<tr>
<td>Spectral calibration stability</td>
<td>&lt; 0.25nm</td>
</tr>
<tr>
<td>Targeted SNR</td>
<td>&gt; 300@620nm</td>
</tr>
<tr>
<td></td>
<td>&gt; 200@400-1000nm</td>
</tr>
<tr>
<td>Digitization</td>
<td>10bit</td>
</tr>
<tr>
<td>Mass memory</td>
<td>30 GB</td>
</tr>
<tr>
<td>Mission target</td>
<td>Agriculture</td>
</tr>
</tbody>
</table>

Fig: Predicted Signal to Noise Ration

HSC-III: Hyperspectral Camera - III

Optics & Calibration unit

Electrical unit

Telescope

Soil (Alfisol) from ASTER Spectral Library

Vegetation (Grass) from ASTER Spectral Library

Albedo 0.3

HSC-III: Hyperspectral Camera - III

Optics & Calibration unit

Electrical unit

Telescope

Soil (Alfisol) from ASTER Spectral Library

Vegetation (Grass) from ASTER Spectral Library

Albedo 0.3
Breadboard model (BBM) of each module

Detector (BI-CMOS camera) (commercial component)

Telescope (Design phase now)

Spectrometer (based by spin-off product HSC1700)

Mission Data Handling Subsystem FPGAs-based

On-board Calibration Equipment
Spectrometer instrument

* telescope: mock-up

- The entrance slit is 15mm long by 15μm wide
- The transmitting grating is 25mm², 300 lines/mm grating frequency and approx. 75% maximum efficiency, and made by B270 glass.
- It requires 10nm ±1.5nm of spectral band with

**Principle of the spectrometer by using a transmitting grating**

**Fig: Normalized response of each band**

**Fig: Spectral band width as function of wavelength**
MDHS: Mission Data Handling Subsystem

**Characteristics**
- MDHS mainly consists of two FPGA
- Camera Link standard
  - 28bit to represent up to 24bits of pixel data and 3bits for video synchronous signals
  - Camera Link up to 2.38Gbps support the required transfer speeds of hyperspectral data.
- To reduce data volume by using ROI (Region of Interest) selection

**Diagram**
- Camera Link
- FPGA XC3S1500
- Power consumption < 4W
- FPGA: Spartan3 XC3S1500
- Detector I/F: Camera Link Standard
- DR bit rate: 1.848 Gbps
- SDRAM: 512Mbit × 14
- Flash ROM: 30Gbytes (SD card)
- Imaging area: Approx. 128.86km × 20km

Fig: MDHS breadboard model
OCE: On-board Calibration Equipment

- The On-board Calibration Equipment (OCE) which is the subsystem for on-board calibration is equipped with Visible-LEDs and Near-infrared-LEDs.
- The diffused panel provides 3 positions for Earth observation, the Sensor calibration and the LEDs calibration.
- Advantage of LEDs as on-board calibration source
  - High-energy efficiency, very long life, Small size and high-design flexibility
  - The calibration process can increase more calibration bands than the HYPERION (Hyperspectral sensor by NASA) equipped Atmospheric Limb Correction.

Fig: Schematic layout of the OCE
Fig: On-board Calibration Equipment Breadboard model
Spectral Lamp (Hg: Mercury, Xenon)

Calibration accuracy compared with Hg and Xe

It was excellent so that 0.02nm spectral calibration accuracy was achieved
Conclusion

• **TAIKI** spacecraft that is characterized by Hyperspectral remote sensing has been designed
  – The spacecraft is developed based on technologies of in orbit demonstrated bus-subsystems which consists of COTS components

• For the hyperspectral data downlink is equipped with the laser communication system **LCS**
  – LCS is being realized only for high-rate downlink
  – The possibility of laser communication has been confirmed in the terrestrial laser communication experiment

• The hyperspectral sensor **HSC-III** has been designed and the each module of BBM has been developed
  – TAIKI’s mission is targeted at Hyperspectral remote sensing
  – HSC-III is targeted at 30m GSD, VNIR and 300 SNR
  – BBM modules have been developed, which consists of the spectrometer, data handling subsystem and on-board calibration equipment
Thank you for your attention!!

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