SSC03-VI-8

MACSAT - A Mini-Satellite Approach to High Resolution Space Imaging

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Abstract. To be launched in 2004, MACSAT is a 200kg satellite, designed to provide 2.5m ground sampling distance (GSD) resolution imagery on a near equatorial orbit (NEqO). The mission objective is to demonstrate the capability of a high-resolution remote sensing satellite system on a NEqO. Initiated by ATSB, the proprietary NEqO mission has advantages for monitoring the environment of equatorial regions of Malaysia with unique revisit characteristics from the baseline circular orbit of 7 degrees of inclination. For the designed duration of 3-year mission life, MACSAT is optimized to accommodate a Medium-sized Aperture Camera (MAC), a push-broom type camera with swath width of 20km. The spacecraft has +/-30 degrees of tilting and 30 Mbps class X-band downlink capability. This paper describes the overview of the MACSAT program, focusing on the key technical and operational aspects of the mission, and provides an update to the status of the mission as of June 2003.

1. Introduction

As an international collaborative program, SaTReC*i* and ATSB are developing the Medium-sized Aperture Camera Satellite (MACSAT) for Earth observation. MACSAT mission was initiated by Malaysia to launch a high-resolution remote sensing satellite into NEqO. Due to its geographical location, Malaysia can have large benefits from NEqO satellite operation. From the baseline circular orbit of 685 km altitude with 7 degrees of inclination, the neighboring regions around Malaysian territory can be frequently monitored. The equatorial environment around the globe can also be regularly observed with unique revisit characteristics.

The primary payload, MAC, is a pushbroom type camera with 2.5m of Ground Sampling Distance (GSD) in a panchromatic band and 5m of GSD in four multi-spectral bands. 32 Gbits of solid-state recorder is implemented as the mass image storage. A mini-class spacecraft bus is designed optimally to support the payload operations.

The integrated ground stations for mission control and payload operation are equipped with S-band up/down link for commanding and telemetry reception as well as 30 Mbps X-band down link for image transmission. The MACSAT system is capable of generating 1:25,000-scale (class III) image maps. It is also anticipated to have capability for cross-track stereo imaging for Digital Elevation Model (DEM) generation.

The primary mission objective of MACSAT program is to develop and validate technologies for a NEqO remote sensing satellite system. Malaysian and Korean joint engineering team was formed for the effective implementation of the satellite system. An integrated team approach is adopted for the joint development since November, 2001.

2. System Overview

Table 1. Mission Requirements and Specifications

Item	***Mission Requirements / System specifications***
Multi-spectral high resolution camera cartography	
Orbit	NEqO: 685km circular Inclination: 7 ~ 9 °
Ground Sampling Distance (GSD)	Four multi-spectral: 5m Panchromatic: 2.5m
Swath	Field of view: 1.6° Swath width: 20×400km^2
1:25,000 scale (Class III) mapping capability	5m localization mapping accuracy (90 %) using Ground Control Points
Short revisits	6 times a day over Malaysian region (Good Sun angle)
Image Production	Level I product within 5 hours from reception
Duty cycle and lifetime	
Duty cycle	> 10%
Lifetime	3 Years

MACSAT is a three-axis stabilized mini-satellite in a hexagonal shape. It weighs less than 200kg including MAC and provides more than 330W at the end of life from three deployed solar panels. Its attitude control and determination accuracy and off-nadir imaging capability allow generation of stereo images and image maps. When the satellite is tilted at 30°, the resolution still maintains within 3.5m. The high-speed image transmission system enables downloading 32 Gbits of stored image data within 3~4 daytime passes. The mission requirements and system specifications are summarized in Table 1. Key features of MAC and MACSAT are summarized in Table 2 and Table 3, respectively.

Accurate attitude knowledge is obtained using gyros and star sensors. The attitude control system provides sufficient stability during imaging, and satisfies the mapping accuracy requirements with minimum ground control points. Pointing of the satellite is performed using four reaction wheels that allow fast attitude slewing and stabilizing.

3. Bus System

System Overview

The satellite architecture is suitable for small satellites in which the number of subsystems is small and a high communication rate is required. MACSAT bus is designed to satisfy all mission requirements by incorporating three-axis stabilized, accurate, and agile attitude control for precise imaging operations. Full redundancies are adapted in the system architecture design to increase the reliability of the satellite system.

Table 2. Key Features of MACSAT

Mass	≤ 200kg
Envelope	ϕ1200mm × 1200mm
Power generation	≥ 330W @ EOL
Battery	NiCd ≥ 6Ah × 3
Attitude control accuracy	0.2 °
Off-axis imaging	Up to ± 30 °
Communication	1.2, 9.6 & 38.4 kbps (S-band)
Image Data D/L	30 Mbps (X-band)

Mechanical Structure and Thermal Control Subsystem

MACSAT features deck-and-longeron type structure allowing easy assembly and disassembly with about 1.2 m in diameter and 1.2 m in height as shown in Figure 1. Most of the electrical component units are positioned on the bottom deck, while reaction wheels and gyros are positioned on the middle deck. Three deployable solar panels are stowed during launch, where the sun sensors and the GPS antenna are position on these panels to guarantee the field of view clearance.

The interface with the launch vehicle is made through an adapter bolted to the bottom of the structure. The mechanical interface with the Electro-Optical Subsystem (EOS) of the payload is provided through three points at the middle deck.

Passive thermal control schemes will be applied to maintain the temperature of components and subsystems within the specified temperature ranges. In order to meet the thermal requirements, various thermal coating materials and thermal conductors are used, and component locations and mounting configurations are carefully taken into considerations.

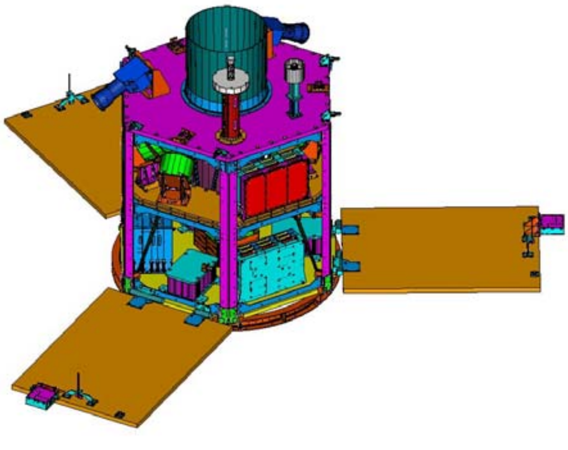


Figure 1. Mechanical Configuration of MACSAT

Command and Data Handling Subsystem

The Command and Data Handling (C&DH) subsystem handles serial communications for the satellite and the payload. It also manages the communications for bi-level commands, digital and analog telemetry data. C&DH provides command links for real-time control of the spacecraft as well as storing time-tagged commands that will be executed during out of contact period with the Mission Control Station (MCS).

C&DH subsystem is comprised of one primary OBC, one secondary OBC, four Telemetry and Command Modules (TCMs) – TCM1 (primary & secondary) and TCM2 (primary & secondary), and a GPS receiver. OBC has 12 serial lines; 6 are connected to the ACS actuators (reaction wheels and magnetorquer) and sensors (star sensors and Gyros) for commanding and receiving data via multiplexers. It is also connected to TCM1 and TCM2 (both primary and secondary). OBC has serial connection to both primary and secondary telecommunications subsystem. OBCs are connected to MAC via TCM1. Only one OBC shall be operational during housekeeping, imaging and data download mode, while the other OBC is in cold standby mode.

Electrical Power Subsystem

Electrical Power Subsystem (EPS) provides robust and sufficient power to ensure reliable operations of the satellite throughout the mission. EPS generates, stores, regulates and distributes electrical power to all subsystems including payloads. EPS consists of solar panels, batteries, Battery Charge Regulator (BCR), Battery Discharge Regulator (BDR), Power Conditioning Module (PCM), Power Distribution Module (PDM), Battery Monitor (BM), and pyro & heater controller.

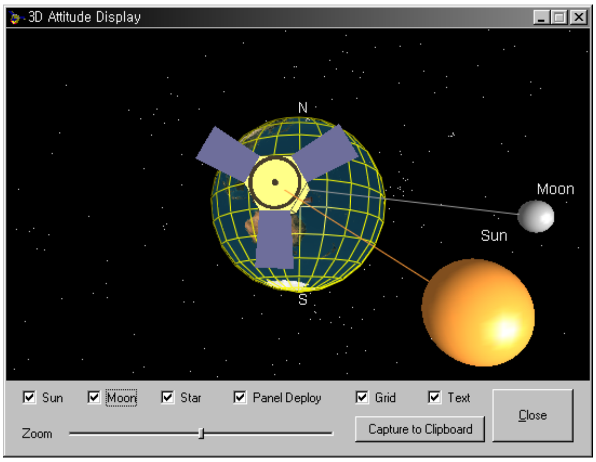
Flight-qualified GaAs solar cells are chosen to generate power for the satellite, 330W at EOL. The batteries consist of three packs of Ni-Cd cells, which delivers 6Ah each. A battery pack consists of 24 serially connected NiCd cells. The depth of discharge is kept below 20% for 3 years.

Charge and discharge are controlled by BCR and BDR.

BCR regulates the power generated from solar cells and provides the regulated power to the satellite during daytime. BDR controls battery discharge current and also performs load sharing between three BDRs. PCM regulates +28V bus power and generates +5V / ±12V regulated power from BCR and batteries. BM monitors the status of batteries and solar cells. It also monitors the charge-discharge current, voltage and temperature of the battery packs and of each solar panel.

Attitude Control Subsystem

The Attitude Control Subsystem (ACS) stabilizes the attitude of the satellite using reliable space proven sensors and actuators. ACS achieves autonomous three-axis stabilization in a closed-loop manner using an on-board computer. ACS consists of two magnetorquers, two fine sun sensors, three coarse sun sensors, two star sensor (STS), two magnetometers, and four sets of reaction wheels and fiber optic gyros. The reaction wheel system is oriented in pyramidal configuration for redundancy and optimal angular momentum management.



☑ Sun ☑ Moon ☑ Star ☑ Panel Deploy ☑ Grid ☑ Text

Figure 2. Attitude Control Visualization

ACS allows the attitude pointing accuracy of better than 0.2° (2σ) for all three axes. 0.016°/sec biased drift and 0.00135°/0.25sec of low frequency drift are allowed for quality imaging and ground processing using satellite ancillary data. STSs provide the attitude knowledge better than 10 arcsec (2σ). ACS is fully tested on ground by means of software simulation in connection with the hardware test bed as shown in Figure 2.

Telecommunications Subsystem

Telecommunications Subsystem (TS) provides uplink and downlink communications between the spacecraft and the ground station. TS consists of S-band TT&C transmitter and receiver, and Image Transmission Unit (ITU). Two S-band transmitters, two S-band receivers and two X-band transmitters provide redundancies for TS. It supports 9600 bps / 38.4 kbps S-band uplink and downlink for satellite control and monitoring and 30 Mbps image downlink in X-band.

4. Electro-Optical Payload: MAC

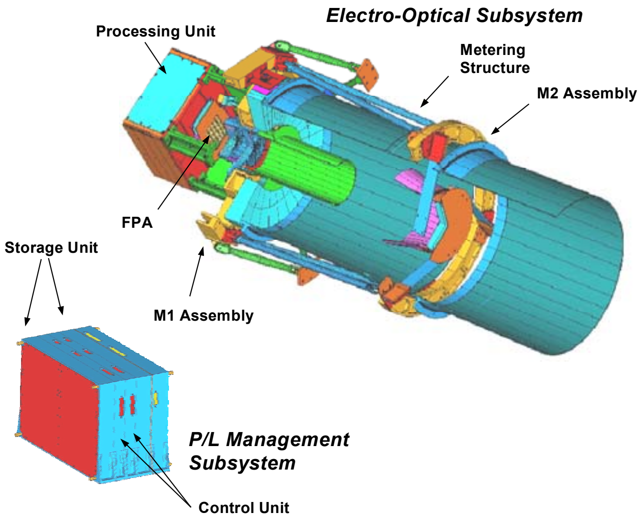


Figure 3. Configuration of MAC payload

MAC is a typical pushbroom system with five linear detectors aligned in parallel on its focal plane. MAC consists of two subsystems: Electro-Optical Subsystem (EOS) and Payload Management Subsystem (PMS).

Figure 3 depicts the configuration of the primary payload, MAC. EOS includes telescope, focal plane assembly (FPA) and signal processing unit (SPU). The telescope is made of two aspheric mirrors and two corrections lenses. Mirrors are made of the low-expansion glass, AstroSitall, and lenses are made of BK7. Its structural elements are made of different materials such as Super Invar, Invar, Aluminum, Stainless Steel and Titanium to protect optical elements during launch and to maintain the optical performance during operation.

Five identical linear detector dies with 8,192 active pixels, with the pixel size of 7 μm, are used for five spectral bands. The FPA is integrated on an Alumina board to guarantee thermal stability.

Two adjacent pixels are aggregated for multispectral bands. These detector dies were aligned and bonded on a ceramic substrate that has proximity electronics. Five spectral filters were bonded to the ceramic substrate in front of detector dies.

SPU is responsible for power provision to FPA, operation of detectors, processing and formatting of video signals and transmission of digital image data. It consists of four small modules that are assembled together and integrated to the telescope directly.

PMS includes Thermal and Power Unit (TPU) and Management and Memory Unit (MMU). TPU provides power to different electrical units generated from MACSAT primary power. It also includes switches for heater on/off control by MMU and it supports MMU in telemetry collection.

MMU has two control modules (MCM1, 2) in cold redundancy and two memory modules (MSM1, 2). MCM1 and 2 are responsible for overall management of MAC, image data storage, maintenance and transmission and communication with the MACSAT bus system, including the synchronization with the GPS.

Table 3. Key Features of MAC

Imaging channels	1 PAN 4 MS: R/G/B/NIR	
GSD (m)	PAN MS	2.5 5.0
Swath width	≥ 20km	
MTF (%)	PAN MS	≥ 8 ≥ 15
SNR	≥ 70	
Signal quantization	8 bits	
Signal gain	Programmable	
Mass storage	32 Gbits	
Mass	≤ 50kg	
Peak power consumption	≤ 60W (all heaters on)	

Each MSM was designed to provide the total storage capacity of 16 Gbits. It contains four memory packs made of 64 Mbits SDRAM devices. It was designed with a multiple level of tolerance to bypass damaged memory blocks or memory packs. Transmission of stored image and real-time quick-look data is supported at a speed of 30 Mbps.

5. EM/QM DEVELOPMENT, INTEGRATION & TESTING

Development of three models was planned for the MACSAT program for system verification. MAC Engineering Model (EM) was integrated with MACSAT Electrical Test Bed (ETB) and Structural Model (SM) and various tests were carried out successfully. Following the successful development of EM, Qualification Model (QM) was developed both in Malaysia and in Korea. Assembly, Integration & Test (AIT) of the QM model has been performed.

Figure 4. ETB Setup

The open structure style ETB setup was developed for easy access and probing as shown in Figure 4. This approach enabled to carry on the mechanical structure development and its environment testing with independent program plan, which allowed efficient schedule control. All the subsystem hardware was assembled in this setup. Flight software code was also verified using the ETB.

Figure 5 shows EOS being integrated with MACSAT bus structure. PMS was also integrated with MACSAT bus and its electrical interface and functionality was verified. The electrical interface between PMS and SPU and functionality of SPU was verified using a PCI-based interface card.

A Thermal/Vacuum (T/V) test of the telescope and a thermal cycling test of FPA were performed. No degradation of its optical performance or damage of detector dies was observed from these tests. Figure 6 shows EM telescope in bake-out preparation. And Figure 7 depicts the vibration test of MACSAT SM with EM EOS. EOS was integrated with SM and a random/sine vibration test was performed. The vibration test results showed that the structure has very high stiffness, where the fundamental frequency is over 72 Hz.

After vibration test, EM EOS was disintegrated from MACSAT SM for MTF measurement of telescope. Some degradation of MTF was observed from this measurement. From an analysis of the measured data, it was concluded that the secondary mirror slipped during the vibration test. The design modification of the secondary mirror assembly was made and re-tested. Flexures are used for the secondary mirror as for the primary mirror. This modification is reflected in the MAC QM development.

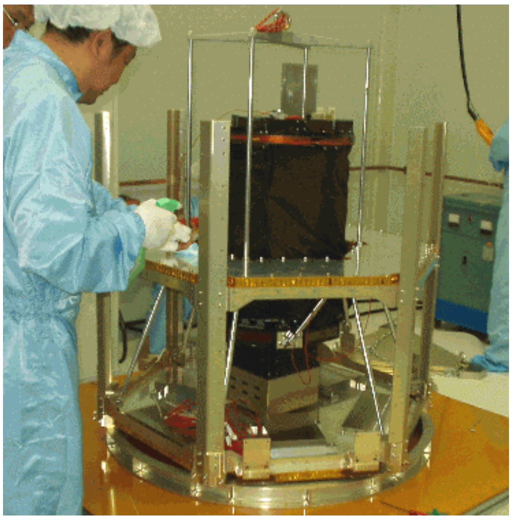


Figure 5. Integration of MAC on Bus

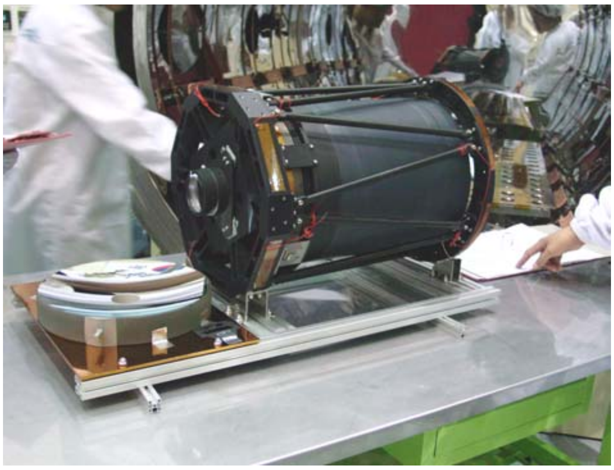


Figure 6. EOS T/V Test Preparation

Figure 7. Vibration Test of SM/EOS

6. Summary

We have described the design of 200kg mini-satellite, MACSAT, whose EM developments have been completed. While the environment tests for QM is being taken place, all the basic functions of QM subsystems have been tested and verified with fully integrated configuration.

The enhanced mini-satellite will be launched into a 685 km near equatorial orbit during mid of 2004, and will produce high quality multi-spectral Earth images with 2.5 m resolution.

We believe that the joint efforts of developing space technology between ATSB of Malaysia and SaTReC*i* of Korea will allow us to take part of developing more sophisticated satellite systems, and also wish to contribute in space research in developing countries.

7. References

1. H.J. Chun, B.J. Kim, and S.D. Park, "Design of a High Performance Earth Imaging Microsatellite" Proceedings of 15th Annual/USU Conference on Small Satellites, Utah, August 2001.

2. E.E. Kim and *et al*, "Development of Engineering Model of Medium-sized Aperture Camera System" Proceedings of 3rd IAA Symposium on Small Satellites for Earth Observation, Berlin, April 2003.

3. B.J. Kim and *et al*, "MACSAT - Mini-satellite for Earth Observation Mission" Proceedings of 1st International CubeSat Symposium, Tokyo, march 2003.