REMOTE SENSING SATELLITE, FORMOSAT-5

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ABSTRACT: FORMOSAT-5 is the first space program that National Space Organization (NSPO) takes full responsibility for the complete satellite systems engineering designs including payload(s). FORMOSAT-5 will operate in a sun synchronous orbit at 720-km altitude with 98.28-degree inclination angle. An optical Remote Sensing Instrument (RSI), which provides 2-m resolution panchromatic (PAN) and 4-m resolution multi-spectral (MS) images, will be the primary payload. Selecting a scientific instrument as secondary payload is on going. The paper will cover the FORMOSAT-5's mission, system architecture, key components developments and up-to-date status of the program.

1. INTRODUCTION

FORMOSAT-5 program will demonstrate the self-reliant space technology in Taiwan. Mission of the program is shown as follows:

- To build up Taiwan's self-reliant space technology on the remote sensing payload and spacecraft bus,
- To develop the key components of the EO-type remote sensing instrument and spacecraft bus by integrating the domestic resources,
- To continue to serve the global imagery users' community of FORMOSAT-2, and
- To promote the space science experiment & research.

FORMOSAT-5 will operate in a sun synchronous orbit at 720-km altitude with 98.28-degree inclination angle. An optical Remote Sensing Instrument (RSI), which provides 2-m resolution panchromatic (PAN) and 4-m resolution multi-spectral (MS) images, will be the primary payload which consists of one PAN band with 12,000 pixels and four MS bands with 6000 pixels each. The System Architecture is described in Figure 1.

The basic characteristics of FORMOSAT-5 are similar to FORMOSAT-2 which is still healthily operational beyond its designed mission life of five years. Due to the strict export license limitation on key technologies and the accumulated experience & knowledge from FORMOSAT-1, 2, & 3, NSPO is taking a bold step further to be responsible for the complete system development of FORMOSAT-5 while FORMOSAT-2 was developed by a well-experienced foreign contractor. NSPO is confident in its in-house capability to accomplish the FORMOSAT-5 program timely.

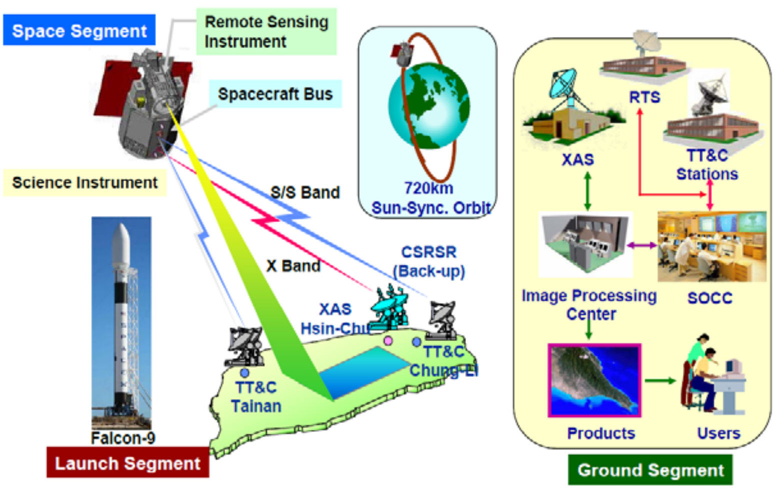

Figure 1 FORMOSAT-5 System Architecture

2. FORMOSAT-5 SPACECRAFT

FOMOSAT-5 Spacecraft is a three-axis stabilized satellite will carry Cassegrain-type Earth Observation (EO) Payload (RSI) and one Scientific Instrument. The block diagram of Spacecraft is described in Figure 2.

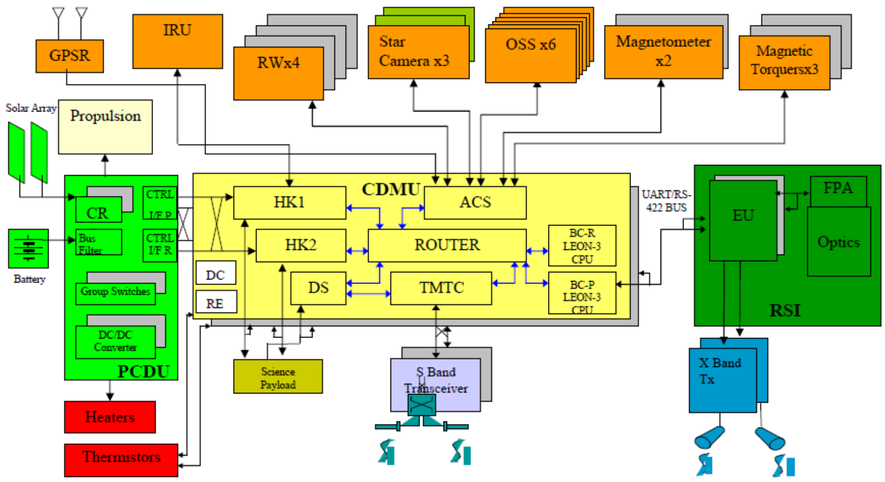

Figure 2 FORMOSAT-5 Spacecraft Block Diagram

FORMOSAT-5 will meet its major mission goal, to build up Taiwan's self-reliant space technology on the remote sensing payload and spacecraft bus, by integrating domestic resources to develop key components for both optical payload and bus. Key components for FORMOSAT-5 spacecraft bus include Power Control and Distribution Unit (PCDU), Command and Data Management Unit (CDMU). RSI payload (including Telescope/Focal Plane Assembly (FPA), Electronic unit (EU)) and Flight Software (FSW)are 100% developed by NSPO and domestic partners which include Taiwan CMOS Sensor Inc. (CSI), Instrument Technology Research Center (ITRC), National Chip Implementation Center (CIC), Aerospace Industrial Development Corporation (AIDC), and ChungShan Institute of Science and Technology (CSIST). Complementary Metal-Oxide-Semiconductor (CMOS) sensor technology has been adopted for the FPA development.

2.1 Key Components

2.1.1 PCDU

Power Control and Distribution Unit (PCDU) is one of the indigenous key components for FORMOSAT-5, used to control and regulate spacecraft electrical power during mission. PCDU consists of the following main modules to support the mission, 1) solar power input regulation for battery charging power, 2) power bus EMC reduction, 3) power distribution control and over-current protection, 4) secondary power conversion and distribution, 5) solar array deployment devices actuation, 6) redundancy management and bus low voltage protection, and 7) command, health data packaging and communication with on-board data processing system.

The PCDU as shown in Figure 3 is developed in a joint effort between CSIST and NSPO since 2006. During its design phase, several design changes take place to accommodate spacecraft configuration changes, component electrical interface changes etc. The most critical one occurred at the spacecraft changes, which affects component electrical interfaces. PCDU is considered as a solution to accommodate the system compatibility issues. It is also the rationale that NSPO determined to develop this key component domestically. The PCDU is a modular design and can be easily adjusted for various missions.

PCDU Engineering Qualification Model (EQM) was completed in April 2011 and is the first key component fully design and manufactured in Taiwan. After functional tests, NSPO will verify the quality of the PCDU EQM with a series of space environmental tests.

EMC and Random Vibration tests performed in June, 2011, respectively. The Thermal Vacuum (TV) Test was also accomplished. Eight temperature cycles with maximum high temperature of +85°C and minimum low temperature of -45°C were conducted. During the TV test both functional and performance tests were successfully finished.

One minor issue was failures are unfolded during the test, fix will be implemented into the flight model. The PCDU flight model manufacturing is underway and Manufacturing Readiness Review (MRR) expected in 2011. Therefore, the PCDU will become the first indigenous component of FORMOSAT-5 satellite.

Figure 3 FORMOSAT-5 PCDU

2.1.2 CDMU

The main features of Command and Data Management Unit (CDMU) are using System on Chip (SOC) of 32- bits fault-tolerant LEON3 processor which is based on SPARC RISC architecture, SpaceWire high speed inter-module data link protocol, and cross-strap architecture between primary and redundant CDMUs to allow operation by partial boards in both CDMUs simultaneously. The architecture is shown in Figure 4.

<u>Detailed characteristics:</u>
The summary of FORMOSAT-5 CDMU detailed characteristics are as follows:

- Radiation-tolerant FPGA implemented LEON3 processor,
- Integrated single CCSDS telecomand/telemetry ASIC,
- High speed inter-module data link by SpaceWire at >=16.7 Mbps,
- 4G bits Science Data,
- Cross-strap between processor and I/O modules,
- Up to 10 Mbps downlink and 100 Kbps uplink data rate, and
- Reliability>0.94 at end of 5-years mission.

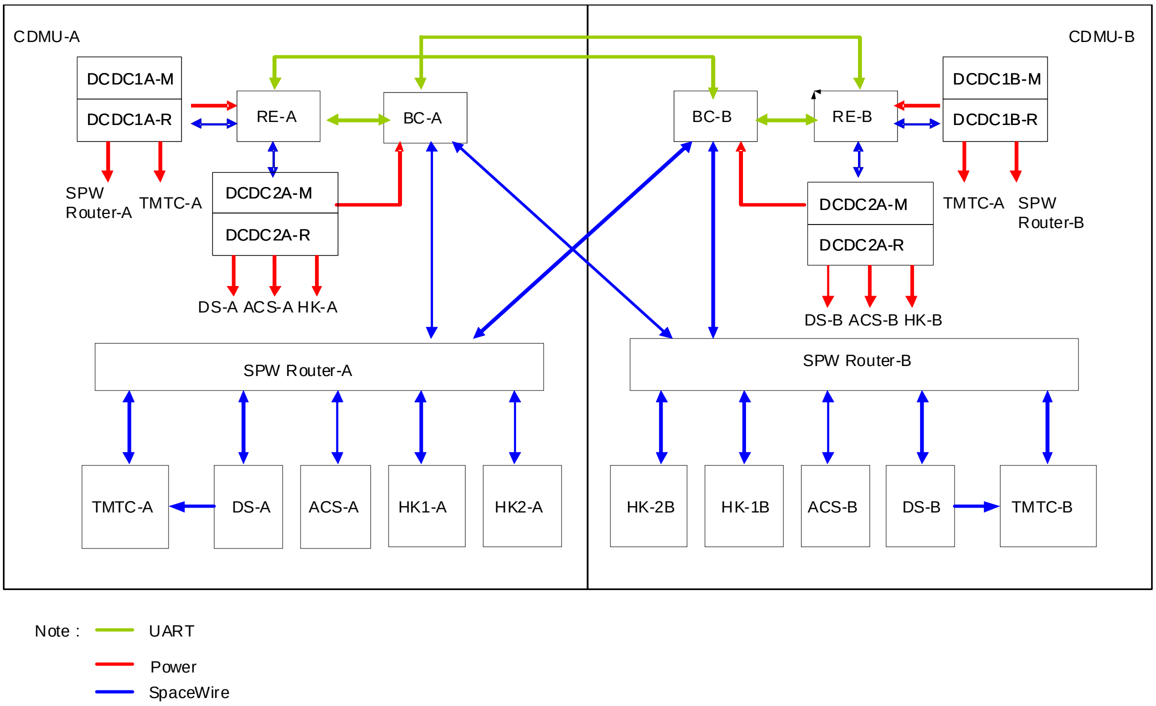

Figure 4 FORMOSAT-5 CDMU Architecture

<u>Functional Description:</u>

The baseline functions of FORMOSAT-5 CDMU are as follows:

- Telecommand reception, decoding, validation,
- Hoousekeeping telemetry data acquisition, storage, generation, formatting and transmission to S-band Transponder,
- Storage of boot loader in PROM,
- Storage of Flight Software (FSW) in EEPROM,
- Storage of satellite status-of health data, FSW data, and uplink telecommands in RAM,
- Storage of critical status and configuration by latching relays,
- Commanding power subsystem, thermal control subsystem, attitude control subsystem,
- Payload instrument management, and
- Re-configuration functions.

<u>Model Approach:</u>

The model approach adopted is based on minimizing both the technical and schedule risk. Therefore, the development plan includes two EMs (Engineering Models), one PQM (Proto-Qualification Model), and two (primary and redundant) FMs (Flight Models). EM's purpose is for electrical function verification. The conducted EMC test will be performed on EM. The EM will be utilized for System Validation and Verification (V&V) on EDM (Engineering Development Model) as shown in Figure 5.

PQM is for qualification purpose. Adequate design margin has be considered and will serve as a spare of FM to reduce the schedule risk during Spacecraft Integration and Testing.

2.1.3 FSW

The CDMU hosts the sophisticated FORMOSAT-5 flight software which is in charge of autonomous in-orbit mission operations such as spacecraft/payload monitoring & controls, satellite operation modes management, satellite hardware configuration management and space-ground TC/TM and data links managements.

The FORMOSAT-5 flight software adopts layered, hierarchical and modular software architecture. From the system hardware perspective, for each of the main spacecraft bus/payload hardware equipment there is a dedicated software module designed to provide its on-board processing and interfacing software functions. On top of this software hierarchy are so called "software managers" which implement high-level management/operation/control logics for specific system/subsystems/operation modes and oversees the operation status of corresponding set of hardware equipments.

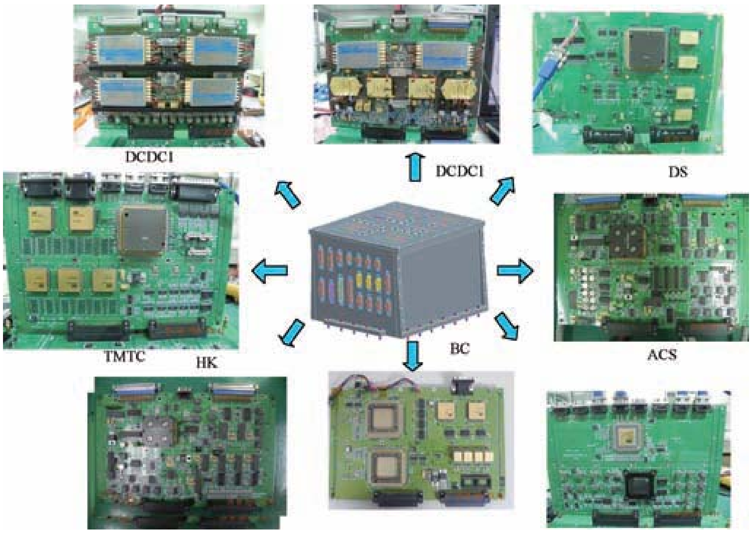

Figure 5 FORMOSAT-5 CDMU

2.1.4 EU

The Electronic Unit (EU) controls Remote Sensing Instrument (RSI) operation The operation includes instrument power on/off, thermal monitoring and control, and on-board image data processing (i.e., data compression, storage, formatting, encryption, channel coding and output to X-band transmitter). The EUs are developed by NSPO and local vendors, including CSIST, Camels Vision Technologies Inc. and CMOS Sensor Inc.

The EU unit is composed by the following modules as shown in Figure 6:

- DCDC Converter (DC1 and DC2) module: Converts PCDU +28V to secondary voltages, including +5Vdc to the FPA, and other DC power for internal usage. There are over current and under voltage protection to avoid fault propagation. The DC1 provides the power to CC, HC and FPA. The DC2 provides the power to MC, MM1, MM2, IDC and IDP.
- Heaters Controller (HC) module: Controls 32 heater switch circuits whose on or off status is managed by the Camera Controller.
- Camera Controller (CC) module: Handles RSI housekeeping, command and telemetry handling, camera operation control, thermal control, and time management etc. There is one 8051 micro-processor in the Actel FPGA AX2000 to handle these functions.
- Image Data Pre-processing (IDP) module: Performs FPA image data re-ordering.
- Image Data Compression (IDC) module: Performs Panchromatic (PAN) and Multi-Spectrum (MS) image data compression
- Memory Controller (MC) module: Performs image data formatting, mass memory control, data encryption and channel coding. There is one embedded PowerPC micro-processor in the Xilinx V4 FPGA to handle these functions.
- Mass Memory (MM) module: Provides the mass memory for image data storage. There are 128 Gbits mass memory with file management function in the EU to store image data.
- Back Plane (BP): Provides the power and data connection among the electrical boards

The EU development plan includes one Elegant Bread Board (EBB) model in 2011, one Engineering Qualification Model (EQM) in 2012 and two Flight Models (FM) in 2013. For future remote sensing missions, the modular EU can be upgraded by adding more data input channels and compression modules in parallel, or more memory modules to accommodate more image pixels or higher image resolution.

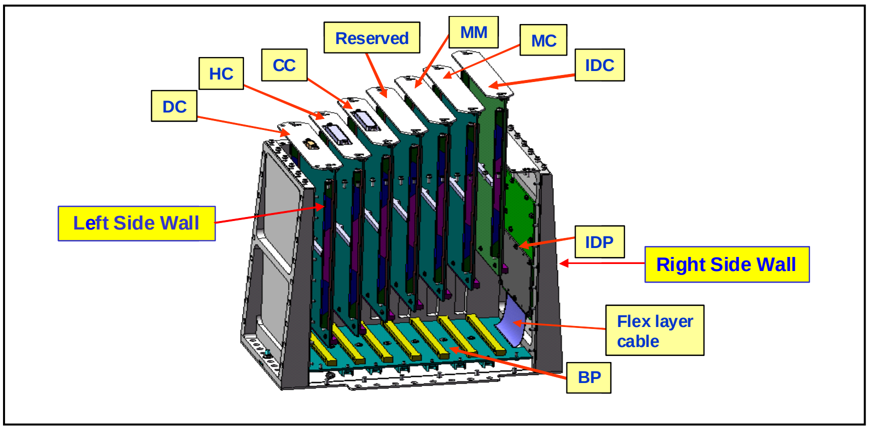

Figure 6 RSI EU Box and Modules

2.1.5 FPA

The Focal Plane Assembly (FPA) contains CMOS-type sensor, filters, driving circuitry, gain control circuitry, analog to digital converter (ADC), house keeping function, and structure etc. FPA/CMOS carries a heritage from India Moon mission (Chandrayean-1). CMOS Image Sensor electronic circuit designs, functions and test results were examined through a Critical Technology Validation Review. The advanced test CMOS IC has been fabricated with an 8″ wafer under 0.18 μm process by United Microelectronics Corporation (UMC). Each image sensor has 12000 pixels for PAN and 6000 pixels for MS bands as shown in Figure 7.

The Fomosat-5 CMOS Image sensor will be the first domestically made space-qualified optical component. The development includes numbers of innovative technologies: long chip sensor design, high data output rate by using multiple readout design, multiple chip technology combining 5 bands into one silicon chip, and low noise CMOS technology to achieve high SNR requirement.

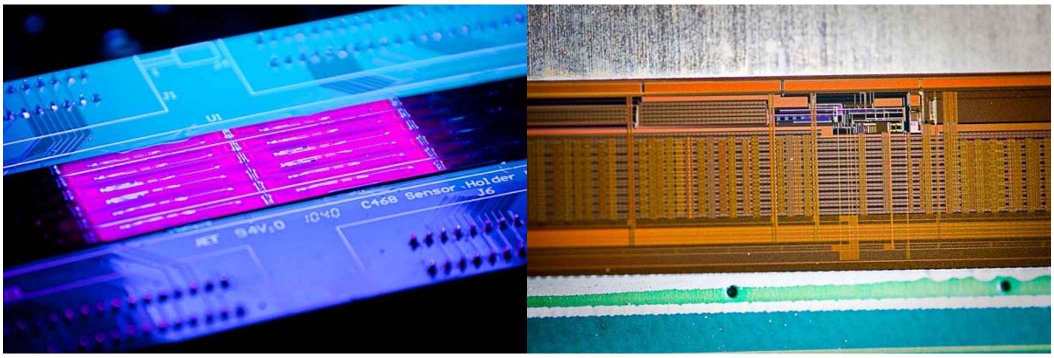

Figure 7 RSI C468 sensor

The main reasons of using CMOS-type FPA are the availability of CMOS manufacturing process, power consumption reduction, additional circuit functionality on-chip, robustness to ionizing radiation, and system design simplification etc.

One difficulty of the CMOS image sensor development for space is to meet SNR requirement. During the past year, C468 chip has gone through four versions of the design updates, fine tuning the pixel conversion rate, and the change of RESET and TR switches from NMOS to CMOS.

3. CURRENT STATUS

FORMOSAT-5 has been at full speed of its development since December 2009,since all domestic partners for the RSI payload were chosen. Satellite Engineering Development Model (EDM) has started testing out spacecraft electrical interfaces with, in-house-developed satellite databases, available key component Elegant Bread Boards (EBBs), and progressive FSW builds. Ahead of the RSI payload, Spacecraft bus development has completed its critical design phase; FORMOSAT-5 System Critical Design Review (CDR) will be accomplished in May of 2012. FORMOSAT-5 is currently scheduled to be launched in 2014.