CHAPTER 7

Autonomous Satellite Mission Building – System Features

The system features necessary in an autonomous satellite building have been enumerated in this chapter. The details of redundancy built-in all the spacecraft ground support and sub-system developments so that the failure of one system is taken care seamlessly without adhering to switching off of the systems. Other automated functions necessary for the systems are built through onboard stored programs such as payload sequencer program, control algorithms implemented with AOCS are presented.

7.1 Introduction

In the earlier chapter, it is shown that there is limited autonomy existing in the previous generation of satellites. There is a clear requirement for full autonomy is very well established. Because in present operation scenario, spacecraft operations are being done with human intervention, which requires 24×7 shift operations and lot of command uplink and telemetry monitoring by spacecraft controller, the amount of work stress in found to be enormous. At ground level, software for telemetry processing and display is present which gives parameter level limit (limited) checking based on the parameter values spacecraft controller identifies the sub-system health. So it is very much required to make sub-systems autonomous, or at ground level some software is required which takes present telemetry data and identifies the sub-system health status. In case of sudden requirement it should schedule required command (with authorization) automatically. In the following chapter the ground station system as well as spacecraft systems which have been configured and special functions built-in to tackle some of the failures and automatic functions to reconfigure them are addressed.

7.2 SCHEMACS

Currently, mission operations for a ground station are carried out using a software suite called SpaceCraft HEalth Monitoring And Control Software (SCHEMACS). It comprises of several component utilities for accomplishing various tasks. The telemetry from the spacecraft is presented in the form of engineering values in a Table format or as real-time plots. Examples of real-time telemetry data presentations are shown in figures 7.1 and 7.2. Figure 7.1 shows engineering values of telemetry data after processing in table form. Different parameters are grouped based on the subsystems or their relation to each other. Figure 7.2 shows the Real
Time telemetry data plot where several preselected parameters are plotted in real time. The short time trend of the parameters can be observed from the plots. Spacecraft controllers need to closely monitor the data and derive conclusions about the state of various subsystems of the spacecraft. There is a limited amount of software support in terms of limit checking of individual parameters. Figure 7.3 shows the alarm display software called Critical Alarm Display (CAD). CAD alerts the user with a pop-up window whenever some parameters cross their preset limits. However a system for looking at the spacecraft data with holistic view, combining the data and inputs from different related elements is not presently available.

Fig. 7.1: Telemetry Data Display

The SCHEMACS GUI for transmitting telecommands is shown in figure 7.4. Spacecraft controllers specify the command codes or the command sets from a file using this interface. The software will create the appropriate telecommand packet and send to the spacecraft via the specified ground station.
Fig. 7.2: Telemetry Plot Display
Fig. 7.3: Critical Alarm Display

Fig. 7.4: Telecommand GUI
7.3 DESIGN FEATURES OF POWER SYSTEMS

IRS power bus configuration is implemented as either single raw bus or dual raw bus. The block diagram of a typical Power Distribution function is shown in figure 7.5. Figures 7.6-7.8 provides different implementations at different satellites.

Fig. 7.5 Power Distribution Systems in IRS

Fig. 7.6 Typical IRS Power sub-system with Two Raw Bus Configuration

Power Subsystem Configuration of Megha-Tropiques
Power generation in IRS satellites is achieved in one of the following ways

1. Solar cells mounted on panels which are deployable and sun tracking using drive mechanisms (ex. IRS-1A/1B/1C/1D/P2/P3/P5, Resouresat, Oceansat etc.)
2. Solar cells mounted on panels which are deployable but fixed to the body
3. Solar cells mounted on the body for spinning satellites (ex. SROSS, IAMSAT etc.)

7.3.1 SOLAR ARRAY DRIVE ASSEMBLY (SADA)

Typical IRS satellite uses two solar arrays, one on the sun-side of the spacecraft and the other is on the anti-sun side driven by drive control mechanisms. Drive Control Electronics is common for both sun side and anti sun-side arrays in case of earlier satellites like IRS-1A/1B/1C/1D/P2/P3 etc. whereas independent drive electronics is employed for Resourcesat-1 onwards. Since the operation of the solar array drive mechanism is critical to the mission, complete redundancy in all electrical circuits including motor coils, potentiometer tracks, electronics and DC/DC converters are provided. Slip rings are used to transfer signals and power generated on the panels in to the spacecraft. In a typical IRS satellite, the solar array is divided into 2 wings - one on sun-side and the other on anti-sun-side. Each wing consists of 3 identical sun-tracking, un-canted solar panels, each of size 1.4m x 1.8m typically. These panels are hinged together and connected to the spacecraft via the yoke. The solar panel substrate is CFRP substrate with Kapton insulator between cells and substrate. The electrical harness is routed on non-cell side of the panels. The Solar Panel orientation error with respect to the Sun is obtained by Sun-sensors with redundancy located on the Solar panels. Power is distributed to various sub-systems through two raw bus lines, which vary from 28 to 42.5V. Typically, each bus consists of 10 strings. Two strings are permanently connected to the bus whereas the remaining eight strings are switchable. Out of the two permanently connected strings, one is pulse width modulated (PWM).

7.3.2 FEATURES OF SOLAR ARRAY DRIVE ASSEMBLY (SADA)

A functional block diagram of SADA system is provided in figure 7.9.

1. SADA can operate in basically two modes of operation namely Normal and Acquisition mode. Acquisition mode is required to "capture" the sun soon after launch and also when reacquisition is required. The drive mechanism is made to rotate fast in the open mode till the sun sensor "sees" the sun and the error reduces to near zero.
In **Normal mode** SADA is made to rotate in synchronism with the orbit so that the sun angle error is always near zero. These operations can be done in closed loop or open loop to actuate the motor to make the sun sensor error zero.

2. **Variable Motor Torque** operation: SADA can be operated in various motor driving schemes from 1Nm to 4 Nm full width or micro-stepping selectable through data command.

![Fig. 7.9 Functional Block Diagram of SADA system](image)

3. **Safe Mode** Operation: This mode is initiated by AOCE/BMU on detection of loss of lock. In this mode, the performance of SADA is same as that in Acquisition mode. This command automatically deselects Normal mode in both panels. SADA continues
to be in this mode until a Reset Safe command is issued by AOCF. Repeated SAFE operation is possible.

4. **Offset Mode** operation: Solar Panel Offset can be enabled independently for both SS and ASS panels. Similarly the offset direction also can be independently chosen. The Offset command magnitude range is ±64 degrees, with a resolution of 1 degree. Offset commands are sent as a data command. The offsetting of the panels is carried out at Acquisition mode rate.

5. **Rotation Inhibit**: During Payload operation, the panels can be inhibited. For optimizing the power generated, the panels are advanced before inhibiting such that, at the middle of the payload operation the panels will generate maximum power. After the payload operation is completed, the panels are enabled and the error is corrected at the acquisition rate.

6. **Fault Detection Logic (FDL)**: If the mechanism is driven by the main channel DCE, and if the sensor error exceeds ± 20 deg. in the normal mode of operation, the redundant channel switches ON automatically and then main is switched OFF. The redundant channel switched on through FDL remains in the acquisition mode till the issue of ground command.

7. **Auto capturing scheme**: In this scheme, if panel does not see sun within 38 minutes after entering to eclipse (detected by absence of Sun Presence Signal), SADA will go in to acquisition rate automatically to acquire the sun. After acquiring, it goes back to the normal mode. This feature is selectable through data command.

### 7.3.3 Energy Storage Devices

Typically, two 28 cells, 24 AH Nickel-cadmium batteries are used to support eclipse period, peak electrical load and during payload operations. Each battery is tied to a raw bus, from where it is charges. During Emergence, the battery under emergency is charged through fixed strings of its respective bus, while the rest of the strings corresponding to the 2nd raw bus are used to charge the other healthy battery. However, other types of batteries like lithium-ion are also being used for some satellites like IMS-1, Youthsat and RISAT-1.

**Battery management in IRS satellites**

**Taper Charge Regulator (TCR)**: The TCR controls the charging of the battery with the power generated by the solar array by including or excluding the solar array strings.
Typically, Solar Array-A (SA-A) and Solar Array-B (SA-B) each having 10 strings are used to charge Battery-A and Battery-B. Out of the 10 strings, string-1 is connected to main TCR and string-2 is connected to redundant TCR. Both string-1 and string-2 are operated in PWM mode while the rest of 8 strings are operated in ON/OFF mode. The average current delivered by the PWM string is achieved by controlling the duty cycle of the shunt switch at the PWM string when main TCR is selected string-2 is permanently connected to bus and when redundant TCR is selected string-1 is connected to bus. The output of PWM controller used to drive the PWM shunt switch with a duty cycle of 10% to 90%. In PWM mode the outputs of the voltage controller and current controller are diode-ORed and fed to a pulse width modulator. The output of the pulse width modulator is fed to the solar array string. This type of bus management is advantageous in avoiding the excess shunt current and hence avoiding the shunt element in the spacecraft.

In ON/OFF TCR, normally all the isolation relays are kept in respective buses. The power output control to cater for battery charging and raw bus loads is done by suitably switching the transistors. This is done as follows: the battery voltage and current measured are compared with voltage reference and current reference. The difference between the actual value and the reference voltage is amplified and the two outputs are diode-ORed. The diode ORed output is used to control (ON/OFF) the string. The current reference is set by the data command and nominally a charge current of around 6A is set. The voltage reference is also set by data command to control the terminal voltage of the battery.

The final terminal voltage controlled is dependent upon the temperature. The received data command is converted to analog and is used to shift up / down the voltage reference. With existing reference, if the charge current is tapering off even before the battery is charged around 90% of its capacity, and then the taper voltage reference needs to be suitably increased to allow for more charging.

Due to any unknown reasons, when spacecraft enters into the safe mode/emergency mode, all the spacecraft loads are switched off except essential loads are connected to the bus. During safe mode of the spacecraft is made to sun pointing, resulting in maximum power generation. The two permanently connected PWM strings will continue to supply power to the bus/battery charging. The battery will continue to over-charge since load is minimal till the spacecraft emergency mode is released.
**Battery Overcharge Protection**

**TCR auto change over logic:** This logic is implemented to protect the batteries against overcharging. Failure of the taper charge regulator can result in the overcharging of the battery. Overcharging of the battery, which can cause irreversible damage to the battery and is avoided by this logic which is provided for each battery separately. The logic takes care of the failure of one TCR and change over to redundant TCR automatically if one of the following conditions is observed.

- Battery absolute temperature exceeds beyond a set limit (typically 25 °C).
- Battery differential temperature exceeds beyond a set limit with respect to its mounting plate temperature (typically 8 °C).
- Total battery voltage exceeds beyond a set limit (typically 43 V).

The outputs of all three comparators are diode ORed and used to change TCR main to TCR redundant (Such logic for redundant to main is not there). This logic can be enable/disabled through a command. Normally, it will be in enable condition.

**Over Voltage Protection logic:** For charge control of Li-Ion batteries, Overvoltage protection circuit is incorporated since Li-Ion batteries are very sensitive to overcharging. Overcharge can result permanent degradation of capacity and can prove to be hazardous. This stringent requirement calls for the automatic charge control circuit, where charge current is reduced to 0 Amps once battery voltage reaches the specified limit. Charging current is set to 0 by Bus Management Unit after getting the signal from the OVP circuit.

**Battery Over-discharge Protection**

**Emergency Logic:** This protection logic is to guard against over discharge of the batteries. This logic is implemented to avoid continuous depletion of charge from the batteries which could lead to cell reversal and permanent damage to the batteries.

**Soft Emergency Logic:** In some of the IRS satellites, this logic is used via BMU so that it puts off the main loads from the BUS/Battery to reduce the load on the battery if the battery reaches the soft emergency voltage limit (settable through command)

**Hard Emergency Logic:** Two logics are present to sense battery hard emergency. These are Four Cell Logic (FCL) and Conventional Logic (CL) (c.f. Figure 7.10). Selection between FCL and CL is accomplished through a command.
The four cell logic consists of seven differential amplifiers and comparators for monitoring seven groups of four cells. When any group cell voltage falls below 4.0V, the emergency related actions are initiated. The conventional logic compares the entire battery voltage with a reference and if the voltage falls below 28V, then emergency related actions are initiated. There is a provision to select either FCL or conventional Logic and also to enable and disable the entire Emergency Logic.

**Bus Parallel Relays and Emergency Relays:** There are two emergency relays connected in parallel on each raw bus. These are EA 1 and EA 2 for raw bus 1 and EB 1 and EB 2 for raw bus-2. After the emergency relays, the raw buses are interconnected through two relays called Bus parallel relays; BPR 1 and BPR 2. These relays automatically close when any battery goes into emergency, thereby shifting the loads of both the buses on to the working battery. BPR 1 and BPR 2 are connected in series, with a fuse. EA 1 and 2 relays get opened automatically by emergency logic of Bat-A. EB 1 and 2 relays are automatically opened by the emergency logic of Bat-B. Also EA 1 & 2 can be opened and closed by separate manual commands.

**Fig. 7.10 Four cell Logic and Conventional Logic**
7.4 RCS Systems

Thruster Operation - Attitude control:

All the odd numbered thrusters are grouped as Block-1 and all the even numbered thrusters are grouped as Block-2 thrusters respectively. In IRS -1A/1B generation of satellites, Block-1 consist of R1, R3 (mounted on positive roll side) R5, R7 (mounted in negative roll side) and P3, P7 (mounted on positive pitch side) P1, P5 (mounted in negative pitch side) all odd number thrusters. Block-2 consists of R2, R4 (mounted on positive roll side) R6, R8 (mounted in negative roll side) and P6, P4 (mounted on positive pitch side) P2 and P8 (mounted in negative pitch side) all even number thrusters.

In order to generate torque about Yaw axis the diagonal Roll thrusters R6 and R2 or R5 and R3 can be fired. The same torque can be had by firing thrusters R1, R7 and R4, R8 combination. Similarly to generate torque about Roll axis diagonal pitch thrusters can be fired by suitably selecting the combination. For generating positive roll torque thrusters P2 and P4 or P5 and P7 can be fired. For generating a torque about negative roll thrusters P1 and P3 or P8 and P6 can be fired.

As far as the torque requirements about the pitch axis Roll thrusters on the same face can be used. For example in order to generate positive pitch axis torque thrusters R1 and R5 can be used or R6 and R4 together can be used. For generating negative pitch torque thrusters R8 and R2 or R7 and R3 can be used.

In current generation, Block-1 consist of R1, R2, R3, R4 (1N) & D1, D3 (11N) and Block-2 consist of R5, R6, R7, R8 (1N) & D2, D4 (11N) thrusters. All thrusters mounted only one side of the body and canted (only 1N) to provide torque on the entire axis but the force in only one direction. A typical RCS thruster arrangement for Block 1 and 2 are shown in Figure 7.11.
The toque and force tables are shown below in Table 7.1.

Table 7.1 Torque and Force Computation Algorithms

<table>
<thead>
<tr>
<th>Force</th>
<th>Roll</th>
<th>Pitch</th>
<th>( T=RXF )</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF1</td>
<td>0</td>
<td>( 1\sin \theta ) (-1\cos \theta )</td>
<td>( TR1 = (-1y \cdot -1r \cdot -1p)X(0y 0.5r -0.86p) = 0.86 y -0.86 r -0.5p )</td>
</tr>
<tr>
<td>RF2</td>
<td>0</td>
<td>( 1\sin \theta ) ( 1\cos \theta )</td>
<td>( TD1 = (0y -1r -1p)X(0y 11r 0p) = -11y )</td>
</tr>
<tr>
<td>RF3</td>
<td>0</td>
<td>( 1\sin \theta ) ( 1\cos \theta )</td>
<td>( TD2 = (-ay -ar -0p)X(0y 11r 0p) = -11p )</td>
</tr>
<tr>
<td>RF4</td>
<td>0</td>
<td>( 1\sin \theta ) (-1\cos \theta )</td>
<td>( TD3 = (0y -ar +0p)X(0y 11r 0p) = 11y )</td>
</tr>
<tr>
<td>DF1</td>
<td>0</td>
<td>11N</td>
<td>( TD4 = (ay -ar -0p)X(0y 11r 0p) = 11p )</td>
</tr>
<tr>
<td>DF2</td>
<td>0</td>
<td>11N</td>
<td></td>
</tr>
<tr>
<td>DF3</td>
<td>0</td>
<td>11N</td>
<td></td>
</tr>
<tr>
<td>DF4</td>
<td>0</td>
<td>11N</td>
<td></td>
</tr>
</tbody>
</table>

Force and torque derivation for present satellites as examples are shown in the following Table 7.2 and 7.3.
Table 7.2 Torque Direction Table for CARTOSAT-1

<table>
<thead>
<tr>
<th></th>
<th>Yaw</th>
<th>Roll</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1,R5</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>R2,R6</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>R3,R7</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>R4,R8</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>D1</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>D3</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>D4</td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

Table 7.3 Force and Torque Table for CARTOSAT-2

<table>
<thead>
<tr>
<th></th>
<th>Thrust</th>
<th>Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
<td>R</td>
</tr>
<tr>
<td>R1, R5</td>
<td>0.866</td>
<td>-0.5</td>
</tr>
<tr>
<td>R2, R6</td>
<td>0.866</td>
<td>0.5</td>
</tr>
<tr>
<td>R3, R7</td>
<td>0.866</td>
<td>0.5</td>
</tr>
<tr>
<td>R4, R8</td>
<td>0.866</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

In this configuration to generate positive yaw torque R2, R4 (Block-1) or R6, R8 (Block-2) combination can be used torque created in roll, pitch axis will cancel out. For negative yaw torque R1, R3 or R5, R7 combination can be used.

**Hardware Redundancy:**

**Tank:** In case of single tank there is no redundancy but satellites with multiple tank redundancy exists.

**Latch valve:** Two Latch valve is installed with each plumb line and both of them are ON to take care of any single point failure.

**FCV:** FCV is made with series redundant solenoid valve, so redundancy is present in FCV itself. But if both valves fail there will be no redundancy.
**Pressure Sensor:** There are two sensors in each plumb-line. There is no redundancy for the sensors. As the sensor output does not take part in any controlling action, failure can be tolerated.

**Fill & Drain/Vent Valve:** These valves are used in ground to fill or vent the fuel from tank. So any failure can be repaired on ground.

**Thruster:** Any of the thruster failure can be replaced by thruster of other block.

**Operational redundancy**
There exists complete (100%) redundancy for each pair of thrusters that are to be used for generating a particular kind of torque about an axis. Block-1 and Block-2 thrusters are completely functionally redundant. During any attitude or orbit control, any or both Blocks thruster can be used. No of Block to be used is decided through ground commanding. If only one block is used and any thruster from that block fails there is no hot redundancy for block change over to choose thruster from other block. If both blocks are used then AOCE can take care of failed thruster in hot redundant mode. Redundancy also exists in Latch Valve (LV) configuration. Because of this redundancy any block of thruster can use any of the propellant tanks in case of multiple tank configurations. Hence most of the RCS elements are having redundancy and they are actively participating in the operation mode in hot redundant once configured. So a hardware failure in RCS may not disturb the operation. However the general orbit /Attitude maneuver operation can be made full autonomous as describe in the next section.

**7.5 Results and Discussions**

This chapter provides details of hardware / software redundancy features built-in in (i) Ground Support (ii) Power Systems and Battery and (iii) RCS sub-system developments such that failure of systems is taken care seamlessly without adhering to switching off of the systems. Other automated functions necessary for the system coordination are built through onboard stored Payload Sequencer as described in Chapter 5 and other control algorithms implemented with AOCS.

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