CHAPTER 4

Automation Features of Ground Station Systems and Spacecraft Systems

The need for Automation of the Ground Operations and Onboard the Spacecraft are the two major criteria to achieve automation of the Spacecraft operations. Therefore in this chapter attempts have been made to provide details of the various techniques adopted for automation in both Ground as well as in Spacecraft. Primarily, the systems required for Ground operations are; TTC network, computer network and Communication systems network and several spacecraft sub-system details which require constant monitoring and immediate action through some auto-features are presented in this chapter. Second, some of the automation functions and tools built and used for spacecraft operational centre and some important spacecraft sub-systems are elaborated. The automation efforts in ground operating systems and in case of failures how the planned redundant features are utilized for seamless operations are discussed. Spacecraft related operations such as scheduling and planning and flight dynamic activities are elaborated which are accomplished by means of software features. Several spacecraft sub-system fundamentals along with possible automation possibilities and Fault Detection and Identification (FDI) methods employed have been presented and it is shown how they are suitably incorporated in the autonomous space mission operations. Though spacecraft sub-systems are adequately built with redundancy and reconfigurable features that avoid failures, many autonomous functions are accomplished using payload sequencers the details of which are presented in a later chapter.

4.1 Introduction

Satellite Mission Operation Centre is responsible for providing Space Operation services namely, (i) Telemetry, Tracking and Command (TTC) activities through the ISRO TELEMETRY TRACKING AND COMMAND NETWORK (ISTRAC) TTC ground stations located at various places during all phases of the mission, (ii) Health monitoring and control of the spacecraft during pre-launch, LEOP and normal phase of the mission and (iii) Payload data (science data) reception, processing, archival and dissemination to users. ISTRAC ground segment consists of a comprehensive network of ground stations distributed all over the globe to provide Telemetry, Tracking and Command (TTC) support to Satellite and Launch vehicle missions. Multi-mission operations support at ISTRAC includes (1) TTC network operations, (2) Spacecraft operations, (3) Scheduling Operations, (4) Flight
Dynamics Operations, (5) Computer network support, (6) Communication network support and (7) Control Centre Facilities support. Out of these activities, Spacecraft Operations, Scheduling Operations and Flight Dynamics operations can be automated on ground using specially developed software tools. Other system failures have to be managed using built-in redundancy for TTC network operations, Communications network support and Facilities support. On the other hand, some automation tools can also be thought of and built onto the spacecraft systems such as (i) AOCS operations (ii) Reaction Control Systems (RCS) operations, (iii) Passive Actuators operations and (iv) Payload Systems and their operations which can drastically reduce the on-ground monitoring and planning but increases the complexity of the onboard systems.

4.2 Ground Support Systems of Mission Operations

4.2.1 TTC network operations

ISTRAC has a network of S-band TTC stations to provide Telemetry, Telecommand and Tracking support for low earth orbiting satellites. ISTRAC provides multi-mission support with a network of dozen or so TTC stations, suitably distributed around the world including our own independent stations. When necessary suitable international stations are hired and used for a brief period during the initial phase of the satellite mission. The functions to be performed by TTC network are: (1) Telemetry data reception, recording, conditioning and transmission to Mission computers, (2) Transmission of commands to the satellite in S-band, (3) Tracking the satellite and collection & transmission of tracking data to SCC and (4) Reception and transmission of various health keeping data like DW, HK-PB, SS-PB, TC-PB, SPS-PB etc. Figure 4.1 provides the elements of an Earth Station.

To efficiently use the TTC station network for operations in multi-mission scenario, following features are implemented.

- Remote monitoring and Control of all ground station equipment from ISTRAC Network Control Center (INCC), Bangalore
- Schedule based automated operation of the ground station.
- Remote operation of ISTRAC Network stations from a centralized INCC.
4.2.2 Computer Network support

Distributed computer architecture has been implemented at Control Center in client server architecture configuration. The computer system will support all the missions in the multi-mission environment. Computers will provide prelaunch phase, initial phase, on-orbit phase and terminal phase support services for all LEO missions. The computer configuration for a satellite comprises of:

- Work stations for health processing and display of spacecraft data
- File servers/Data base servers for data management
- Routers for interconnecting control center to ground stations
- Gateway systems for interconnecting control center with external agencies
- Virtual LANS for LAN connectivity of all the work stations, communication processors, file servers, Layer-3 switch / routers etc.,
- TCP/IP Data network is used to connect control center with other Ground stations

On these systems, a unified software system will run consisting of a set of layered software products catering to the functions of data communication, data management and data flow monitoring. Figure 4.2 provides the computer architecture followed in a ground station.
4.2.3 Communication Network Links

ISTRAC Communication Network provides real time voice/data/fax connectivity for TTC operation between Spacecraft Control Center (SCC), Bangalore / Vehicle Control Center (VCC), SHAR and other Network Stations both in India and abroad, supporting Launch Vehicle & Satellite during its launch phase, early orbit and normal phase of missions.

**Sky Links:** All the communications are provided with 128/256/384/512/768 kbps digital direct satellite links. Communication Links with Network stations within India are established by using INSAT-3E. Port Blair redundant link is established using INSAT-3A satellite. Biak station connectivity is through INSAT-2E Satellite.

**Terrestrial links:** The terrestrial links are hired from the communication providers (BSNL, VSNL, and MTNL). Terrestrial links are planned for redundancy wherever sky link exist. Two terrestrial links (main and redundant) are planned in an alternate route to avoid single point failures between VCC/SCC and TTC network stations not having connectivity through sky link. ISDN links are also established between BLR-MAU used as backup link. Figure 4.3 provides a communication link configuration for spacecraft support.
4.3 Spacecraft Sub-systems and Features

4.3.1 Telemetry, Tracking and Telecommand (TTC) System

TTC Subsystem has a basic function to make spacecraft in contact with the ground station, so that health status of the satellite can be known to the ground station. In earlier satellite designs, a separate TTC subsystem was used, but as technology advanced, a Bus Management Unit (BMU) has been employed. TTC subsystem has 3 main parts.

Telemetry: Housekeeping telemetry accepts the data from other sub-systems of the spacecraft multiplexes and formats into a form suitable for transmission to the ground station through transmitter. The telemetry system is a low bit rate telemetry adopting the respective modulation scheme for each satellite. Telemetry system uses some multiplexing devices e.g. Remote Multiplexing Unit (RMU) on the panel so that harness weight will be less and all the monitoring data will be through the RMUs. Additionally a semiconductor memory is included to store the data during non-visibility time and played back during the next visible pass.

Tracking: In S-band transponder, a receiver and a transmitter is placed, in which receiver is phase-locked with the transmitted carrier with a specified turn-around ratio so that system can
be facilitated with two-way Doppler Effect. With this effect, range of the spacecraft can be easily approximated.

**Tele-Command:** The TELECOMMAND system provides uplink capability for the effective in-orbit control of different functional modes of the various satellite systems like attitude and orbit control system, payload operation, changing over to various standby units in case of failure. This system generally operates on S-Band but some satellite also has VHF links also.

TELEMETRY, TRACKING and TELECOMMAND system generally uses the same antenna. For this purpose a diplexer unit is also provided in the system. At every point in the spacecraft to avoid single point failure redundancy is provided in the systems. A typical telecommand receiver chain and transmission chain are shown in figures 4.4a and 4.4b.

**Fig 4.4 Telecommand Receiver Chain**

![Diagram of Telecommand Receiver Chain]

**Fig 3.4b Telecommand Transmission Chain**

![Diagram of Telecommand Transmission Chain]

TTC systems are built with (i) different multiple uplink and downlink frequencies (ii) different modulation and coding schemes, (iii) multiple sub-carriers and data formats, (iv) a telecommand processor and (v) CCSDS formats. In present technology scenario, on-board complexity single point failure tolerant system, and keeping simple ground operations into mind some level on autonomy has been implemented in the spacecraft. Some of the autonomy features are given below:
\begin{itemize}
\item Hot standby receiver
\item Cold standby transmitter
\item Sub-carrier sharing for different data formats
\item Onboard timer based operations
\item Differential time-tagged commands
\item Command configurable block
\item Watch dog timer
\item OBT overflow monitor
\item Automatic temperature controller
\item Auto payload sequencer and abort
\end{itemize}

Much more automation features can also be thought of such as (i) auto changeover of transmitter (ii) auto SPS storage and Playback, (iii) auto SPS reset and (iv) OBT auto drift correction etc.

\subsection{4.3.2 Spacecraft Power Systems}

The electrical power system is one of the critical systems of any spacecraft. The reliability and performance of this system through the mission life dictates the successful completion of the mission objectives. The system configuration, bus topology, the energy storage devices and power distribution system could vary from mission to mission. The basic design of the power system should ensure that there is no single point failure and adequate redundancy should be implemented for all functional elements. Also, some level of automation is essential in order to reconfigure the systems in case of any system malfunction so that the mission goal is not affected. The power system for a spacecraft is selected through a selection process and this is illustrated by a block diagram in figure 4.5.

The power system consists of two components namely (i) Power Generation and (ii) Energy storage & distribution through battery. Power generation is achieved using Photovoltaic solar cells arranged in an solar array for satellites in low earth orbits to geosynchronous orbits, which convert incident solar radiation directly to electrical energy. Regulation of the solar array generated power is achieved either by shunt regulation in which excessive power is shunted from the spacecraft power bus into power dumps or series regulation where excessive power is blocked from the power bus by series regulators. Energy storage is through batteries and batteries provide the power and energy requirements of spacecraft during eclipse operations and support peak spacecraft power demands during sunlight. The battery management system on board the spacecraft should automatically protect the batteries
and cells against open circuit failures, under voltage, overvoltage, over temperature and or over pressure.

**Fig. 4.5 Spacecraft Power System Selection Process**

Protection against loss of battery due to a cell open circuit failure can be provided by relays or by diodes connected in parallel with each cell. Battery under voltage protection is necessary to retain an essential energy margin to allow recovery of the spacecraft power source from any failure which causes an excessive expenditure of its stored energy. This protection functions by switching off all non-essential loads should the battery voltage fall below a predefined level. The possibility to inhibit this protection by ground command in order to allow battery reconditioning is usually a design requirement. Care must be taken to ensure that the battery voltage level at which the protection operates is stable and low enough to ensure that the required battery capacity is available for nominal operations over the full operational temperature range. Cell under voltage protection is necessary to protect against a cell reversal failure as the battery load current flowing through a reversed cell could cause the cell to rupture. This protection should disconnect the battery from the power bus. The parameters used to indicate the state of charge of the battery are cell voltage, temperature and pressure. Two of these parameters are usually used to determine the end of charge criteria, however all three parameters are interdependent. The battery mounting platform temperature varies with mission phases, seasonal changes and operational modes and if cell failures and
degradation are taken into account it is very difficult to definitively set end of charge criteria prior to launch for these missions. Programmable end of charge levels are generally preferred. A second level of protection is also required to prevent overcharging of cells as this adversely affects their operational life and if the overcharge is excessive can result in rupture of the cells. Battery end of charge and overcharge protection levels must be high enough to ensure that the battery can be fully charged and low enough to prevent overcharging. The stability of the protection levels is critical and where feasible it should be possible to inhibit them in case of failure.

4.3.2.1 Current Level of automation implemented for Power Systems in IRS satellites

The basic design of power system is such that single point failure does not jeopardize the mission. To do this, effective redundancy is provided for all the functional elements.

System Redundancy and Re-configuration features implemented

1. **Dual raw bus configuration**: In this configuration, the total power is distributed into two buses to ensure that in case of one bus failure, the spacecraft remains still operational, though with limited capability. The two buses can be cross-strapped using a set of Bus Parallel Relays (BPR).

2. **Solar array strings switching**: The total number of solar array strings are distributed equally to the two raw buses and in case of problem with one bus, the strings on that bus (except the PWM strings-1 &2) can be switched to the other working bus through relays.

3. **Two Battery Configuration**: Typically, two batteries are configured to the two raw buses. In case of problem with one of the batteries, the load on this battery can be switched to the other battery through relays until the problematic battery recovers.

4. **Emergency and Bus Parallel Relays**: There are two emergency relays and two bus parallel relays provided.

5. **Taper Charge Regulator**: There are two TCRs namely Main and Redt. provided for each battery and normally only one of them will be selected for charge control of each battery. Provision for automatic changeover from Main to Redt. TCR is available with the redundant TCR configured as passive redundancy.

6. **DC-DC convertors**: Two DC-DC convertors namely Main and Redt. are provided for redundancy. Redt. DC-DC is configured as cold redundancy and is selected through command.
7. **Drive Control Electronics for SADA**: Two Drive Control Electronic systems are provided for each solar array wing configured as Main and Redt. and one of them will be powered ON and selected for control. Provision for automatic changeover from Main to Redt. SADA is available with the redundant SADA configured as cold redundancy.

8. **Solar Panel Sun Sensors (SPSS)**: Two SPSS namely Main SPSS and Redt. SPSS are provided for each SADA. In case of problem with selected SPSS, other SPSS which is configured as hot redundant can be selected through command for solar panel tracking.

9. **Pyro Drive Electronics Module (PDEM)**: The pyro electronics comprises of two independent channels- main and redundant which are cross-coupled to eliminate single point failure of the system.

### 4.3.2.2 Functional Automation implemented in power systems

1. **Taper Charge Regulator (TCR)**: Battery charging is controlled by TCR through sequential switching of the solar array strings and by adjusting the duty cycle of the PWM string. The charge current is automatically controlled based on the current and voltage references set.

2. **TCR auto change over**: TCR auto change over from Main to Redundant is carried out automatically based on the three conditions i.e. overvoltage, absolute temperature and the differential temperature to protect the battery from over charging due TCR failure which may lead permanent damage of the battery.

3. **Emergency Logic**: This logic is used to cut off the loads from the battery to protect it from over discharge. If one battery is in emergency, the loads of this battery are connected to the other bus while if both the batteries are in emergency, all loads except core power electronics, S-Band receiver and telecommand package.

4. **Fault Detection Logic (FDL)**: If Solar Panel Tracking errors cross a specified limits (typically 20 deg.) in the normal mode of operation, then the SADA electronics is switched from Main to Redundant to ensure solar panel tracking and power generation. Here the redundant system is in cold standby and this logic issues redundant system power ON and configures the panels for acquisition mode tracking.

5. **Auto Capture Logic**: If the solar panel is not seeing the Sun (Sun Present Signal Absent) continuously for 38 minutes, then this logic automatically put the SADA in acquisition mode to acquire Sun and track.
6. **Safe Mode Logic: If S/C enters safe mode**, the solar panel tracking mode is put in acquisition on receiving a Safe Mode detect signal from BMU or AOCE and continue to be in the same mode until a safe reset command is issued.

Spacecraft failures have been found to be about 27% due to power system components failure and the details are provided in Chapter 6 and how they can be managed has also been elaborated.

4.3.3. **Spacecraft Payloads, Baseband Data Handling (BDH) and Antenna System**

**Payload Systems**: The choice of remote sensing payloads depends on the user requirements. The payload system of IRS-1A/1B was Linear Imaging Self-scanning Sensor (LISS) (c. f. figure 4.6) working on the ‘pushbroom scanning’ concept. Basically the payload system consist of two solid state cameras (LISS-1 & LISS-2) operating in four spectral bands in the visible and near-IR range using charge coupled device linear array as a sensors. LISS-2 had two modules LISS-2A & LISS-2B. LISS-1 provides a geometric instantaneous field of view (IFOV) of 72.5 meters and covers a swath of 148 Kms on ground, while LISS-2 (LISS-2A & LISS-2B) provides an IFOV of 36.25 meters and individual swath of 74 Km each. The combined swath of both LISS-2 cameras is 145 Km, with in the LISS-1 swath, with a 3 Km side-lap between them.

Whereas the Cartosat-2/2A/2B optical system is a modified RC system consisting of two mirror RC type telescope, three lenses, a window and a band pass filter. The camera operates in the spectral band of 0.5 – 0.8 micrometer using 12000 elements CCD array. The payload configuration consists of a telescope having an obscured two mirror system with field correcting optics, two CCDs located in the focal plane along the band pass filters and calibration using LEDs. The payload is a single panchromatic camera with a spatial resolution of 1m. and swath of 9.6 km. The camera is mounted on a highly agile platform capable of being steered across and along the track to provide spot imageries of the desired locations. Detector is a 12K element linear CCD (THX31543A) with a pixel size of 7 x 7 μ staggered by 35μ. It provides video data on 8 ports. JPEG compression is used to compress the data.
The payload systems comprise of several components and are enumerated as below:

**Detector:** Payload detectors need (i.e. CCD) redundancy for safeguarding the mission. In all satellites, the detector is provided with 1:2 redundancy in the form of main detector and redundant detector. Though the redundancy is available, it is in the form of cold redundancy i.e. whenever one module fails, other module has to be selected through ground commanding in offline mode.

**P/L Electronics:** The entire signal processing of payload data is done in this package. Once the image is formed, it is read by the Payload electronics. Like payload detectors cold redundancy using 1:2 redundancies is planned for payload electronics in form of main
electronics and redundant payload electronics. Whenever one module fails, the other module has to be selected through ground commanding in offline mode.

**P/L Data Formatter:** In this package the payload data gets formatted. The satellite data is compressed followed by RS coding or by convolution coding in this module. Satellite auxiliary data (gyro parameters, SPS parameters, spacecraft body attitude quaternion etc.) is added here with the payload data and the frame-sync code is also added. Also, in this package cold redundancy is planned with main and redundant systems. Whenever one module fails, the other module has to be selected through ground commanding in offline mode.

**Data Recorder:** Payload data is stored in this system. The data storage facility gives the option to take the image for the whole world. In IRS-1A there is no facility to store the data on board so only real time payload was possible. Presently all the satellite has storage facility and all of them have the cold back-up in 1:2 redundancies.

**Modulators:** Payload data is formatted in the formatter and then it goes to the modulator block. This system has also got 1:2 redundancies. At a time one modulator only is selected for data transmission. By ground commanding one has to select the fault free decoder. Presently all the working satellites is using QPSK modulation.

**Amplifier:** Once modulation is over and the signal frequency is unconverted then the signal is passed through power amplifier. Two types (Travelling Wave Tube Power amplifier and solid state power amplifier) of power amplifier is used in satellites. Cold redundancy is maintained in amplifier as well. In case of selected amplifier is failed then the other amplifier is selected by telecommand.

**Data Handling (DH) System:** The data handling chain basically consists of Base Band Data Handling packages and a solid state recorder (SSR). Complete cold redundancy is provided on DH chain except for the SSR. The input to DH system is digital video data from the CCD video processing unit of the PLE though the odd and even ports and is first sent to Data Interface Package (DIP-10). DIP provides separate two channel inputs to data compression system at 17.5 Mega words/sec. After compression the data of I and Q channels are encrypted (if encryption is enabled), RS encoded for error correction and formatted. Auxiliary data containing information necessary for ground processing of video data is appended to video data at the formatter, this is followed by randomization, differential encoding. This data then undergoes Quadrature Phase Shift Keying (QPSK) modulation at either XBS (M) or XBS(R)
package. The modulated P/L data is amplified by Solid State Power Amplifier (either SSPA (M) or SSPA (R)) and transmitted to ground via P/L antenna in X-band to P/L data receiving station. The formatted data can be also recorded in a 64 GB SSR before QPSK modulation in case the P/L operation occurs in absence of receiving station visibility. The recorded data can be played back and transmitted via X band over suitable station visibility later on.

**P/L Antenna:** There are two different antennae, namely Phased Array Antenna (PAA) and Dual Gimbal Antenna (DGA) for P/L data transmission in X band (8150 MHz), either one of which can be selected for spacecrafts. Both type of antenna have been designed to transmit the high bandwidth rate (105 MBPS) in real-time to the desired station through a narrow beam to ensure minimum data spillage in spite of fast attitude maneuvers which the spacecraft may likely to undergo during imaging.

It should be noted that the payloads and BDH and antenna systems need to be suitably selected based on the scientific goals, expected data rates and capability requirement of the mission and is widely varied for an earth imaging mission, oceanographic mission and to a science mission. The redundancy and automation features need to be selected appropriately. It to be noted that the redundancy built are all are in cold redundancy only and anything one need to operate and changeover autonomously need to be planned from ground at this point. Special features need to be addressed for redundant hardware operations after identifying the failed main systems. However, the operations of payload have been automated using a payload sequencer and is capable of handling even other systems such as SSR, antenna and solar arrays.

### 4.3.4. Reaction Control Systems (RCS)

The spacecraft RCS positions the spacecraft precisely in the orbit viz. polar orbit or geosynchronous orbit for a mission suitably. It enables orientation of the spacecraft in the orbit, control and maintains the orbit altitude. It performs the following basic functions in a spacecraft.

- Remove the launch vehicle injection errors.
- Position of the spacecraft.
- Controls the attitude and orbit
- Spin control
- Controls the speed of momentum wheels/reaction wheels.
- Adjust attitude and orbital parameters.
- De-orbit the spacecraft at the end of life
Recently, the RCS thruster configuration has been changed to have a new optimal system. The multiple tanks have given way to a single tank and instead of 16 thrusters only 8 thrusters (2 blocks of 4 each) are mounted canted by 30 degrees to the negative roll axis parallel to the roll-pitch plane. The firing of each thruster can generate a component about all three axes thus enabling control about three axes while still having only four thrusters. A typical schematic of the thruster configuration is provided in Figure 4.7.

Thruster control has been achieved using a Proportional and Derivative (PD) controller with Pulse width pulse frequency modulator, Thruster Selection Logic (TSL). Spacecraft Dynamics model, Attitude got through sensor model and rates from Gyro models etc. The PWPFM parameters are designed to have minimum pulse width less than 32msec. The PD controller parameters are designed based on the requirements of each mode and the sensors used. More than one set of control parameters are designed so as to have the flexibility of selecting the required set of gains onboard, depending on various conditions like faster convergence, less fuel consumption, small steady state errors, less interaction with solar panel flexibility, thrust development etc. Though spacecraft orientation maneuvers are through onboard maneuver algorithms, RCS is initiated from ground commands only. Periodicity of in-plane operation is once in 20 days to 3 months dependents on satellites GTS specification. On the other hand, out of plane maneuvers for inclination correction frequency is found to be once in 2 years for most of the satellites. Therefore, automation of in-plane maneuvers specifically for satellites in very near altitudes say 500 Km need to be planned for. Ground based schemes are discussed in Chapter 4 and serious research effort is underway for onboard implementation.
4.4 Spacecraft Health Monitoring and Data Processing

Spacecraft Mission Operations broadly comprises of two activities. One is the processing of received telemetry from the spacecraft and verification of the state of various subsystems and elements. The other is to instruct the different elements of the spacecraft to perform various tasks, by sending telecommands to the spacecraft. Currently, mission operations are carried out using a software suite called **SpaceCraft HEalth Monitoring And Control Software (SCHEMACS)**. SCHEMACS 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. Different parameters are grouped based on the subsystems or their relations to each other. 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. Spacecraft
controllers specify the command codes or the command sets from a file using SCHEMACS GUI. The software will create the appropriate telecommand packet and send to the spacecraft via the specified ground station.

In present operation scenario where one spacecraft controller has to handle multiple spacecraft simultaneously, it is very much necessary to have some kind of software support for watching the health parameters. Catering to this requirement, some of the operation tasks are automated by SCHEMACS. They are:

CAM (Critical Alarm Monitor): This process checks the real-time telemetry data against expected limit or expected status. If there is any deviation between expected status and real-time telemetry, it indicates the same in the display pages by highlighting the corresponding parameter with a different color.

CAD (Critical Alarm Display): CAM highlights the parameter in the display pages. But it is not sufficient to attract the controller's attention since there are numerous display pages and the deviated parameter may not be present in the currently selected page. The Critical Alarm Display (CAD) alerts the controller with a pop-up window if the parameter is out of limits for a pre-specified duration.

Auto Archival: As and when the real-time pass gets over, all the data formats collected during the pass are getting archived for future use automatically.

Command Confirmation: This feature helps to confirm the reception and execution of the transmitted command by the onboard receiver system.

File Mode of Commanding: This feature assists in uplinking a set or a subset of commands from a pre-generated command file. There is provision for verifying the operation of each transmitted command before proceeding to the subsequent command.

List Mode of Commanding: Using this feature, one can load a list of commands to the ground station computer and transmit the entire list in a single shot.

AOCE List VERifier (ALIVE): There is a specific memory area in the onboard computer called remote memory. Several configuration settings for payload operations and AOCE operations are residing in this memory area. These settings are updated on daily basis depending on payload requirements. ALIVE verifies the correctness of the data residing in this area by comparing against the uplinked commands.

Checksum Verifier: This does the same job as ALIVE, but it uses checksum based verification for the transmitted commands.
Auto Commanding: There feature facilitates uplinking of commands from a pre-generated command schedule file according to a predefined time-line without any user-intervention.

In addition to SCHEMACS, two additional packages are also built in for operations. They are

1. Spacecraft Health Analysis and Reporting Package (SHARP) and
2. Auto Command Execute (ACE).

**Spacecraft Health Analysis and Reporting Package (SHARP):**

While SCHEMACS can be used for archival, retrieval and processing of telemetry data, another layer of software tools is required for extraction of higher level information from the data. SHARP is a prototype for such software. It acts as supplementary software to augment the manual health checking process. The main objective of SHARP is automated check of maximum possible number of spacecraft health parameters. This can lead to:

- Faster detection of anomaly due to exhaustive background health check
- Effective reporting mechanism

As the work load of exhaustive health monitoring is shared by SHARP, the controllers become better equipped to handle multiple spacecraft operation. Since commanding is the prime activity during real-time pass, monitoring is usually focused to only a few critical parameters. It is mainly aimed at ensuring that no major anomaly has occurred. However, the offline data is used to carry out exhaustive analysis. The variation of the parameters over a larger span of time is scrutinized for any anomalous signature. Manual process of health evaluation is usually confined to a limited number of parameters, as more than 100 to 200 parameters cannot be scanned manually with adequate reliability in a routine basis. Moreover, a single set of limit is chosen for a given parameter, which must encompass the entire range of parameter variation for all possible spacecraft conditions. This results in broadened limits which often lead to missing of anomalies. SHARP assists in overcoming these limitations.

**Auto Command Execute (ACE):** Auto command execution software is aimed at minimizing human intervention in planning and execution of command operations in IRS satellites. In broad sense it can replace two major functions of the present system.

- Plan pre-pass activities and generate command schedule in time line.
– Conduct command operation in Automatic mode if enabled for auto commanding.

Otherwise the command files can be used for manual/semiautomatic modes.

All the commands are classified into two types, viz., regular commands and varying or special commands. The examples of regular commands are:

– HK Playback ON, sample mode and ratio selection
– HK Storage/Rec ON
– SPS Playback on
– SPS Rec ON etc.,

The examples of Varying or Special commands are:

– POP, CCB exe commands, OBT for AOCE, SSR, part of POP and Orbit coefficients.
– DSS offset data commands
– Orbit maneuver commands
– Commands for subsystem maintenance etc.

In spite of all the developments over the years, still lots more need to be addressed for automation of ground operations. They form a very extensive subject which cannot be addressed in this thesis elaborately.

4.5 Results and Discussions

In this chapter the elements of Ground Operations & their planned redundancy in providing seamless operations for various types of spacecrafts and the samples of the Automation onboard are brought out. Several systems features required for Ground operations viz. TTC network, computer network and Communication systems network and different spacecraft sub-system details which require constant monitoring and immediate action have been presented. The need for autonomy functions to be incorporated in the ground systems and Satellite have been well understood and justified in earlier chapters. Therefore in this chapter elaboration of some of the methodologies, techniques and systems adopted for automation of the ground systems and the satellite are presented.

In the first part of this chapter, the efforts and the initiatives in bringing about the automation in ground operating systems have been explained. In case of failures in any of the systems, the planned and built-in redundant features have been utilized for seamless operations are
brought out clearly and presented. Spacecraft Ground Mission Operations comprising of receiving telemetry from the spacecraft and verifying of the state of various subsystems for a ground station through built-in features of SCHEMACS have been elucidated. This is one of the important features in any ground station. Further, several other features such as remote monitoring and Control of all ground station equipment from ISTRAC Network Control Center (INCC), Bangalore, Schedule based automated operation of the ground station and Remote operation of ISTRAC network stations from a Centralized Control Centre is presented.

In spacecraft, attempts are made in automating those specific functions of spacecraft onboard amenable to automation criteria with high degree of reliability in operation and lowest risks. As case study autonomy associated with TTC, Power, RCS and Payload is presented. On board autonomy, needs usage of state of the art technologies in spacecraft design and also usage Fault Detection and Identification (FDI) techniques along with fault corrections. Presently high level Fault Tolerant Systems (FTS) is being worked out in the space industry.