Analysis, Development of Reconfigurable Systems and Modelling towards the Automation of Remote Sensing Satellite Data Acquisition

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By

T.CHANDRASEKHARA SARMA

Under the Supervision of
Prof.B.L.DEEKSHATULU

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE
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C E R T I F I C A T E

This is to certify that the thesis entitled "Analysis, Development of Reconfigurable Systems and Modelling towards the Automation of Remote Sensing Satellite Data Acquisition" and submitted by Mr.T.Chandrasekhara Sarma, ID No.2003PHXF401 for award of Ph.D. Degree of the Institute, embodies original work done by him under my supervision.

Date:

Prof.B.L.Deekshatulu
Visiting Professor
University of Hyderabad
Hyderabad

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Abstract

Background of the Proposed Research

Satellite Remote Sensing is playing an important role in national planning, earth resources observation, exploration and utilization and disaster identification monitoring and management (like floods, drought) etc. Remote Sensing technology has spread its applications even to the micro level planning based on the availability of higher and higher resolution data from low earth orbiting, sun synchronous, polar satellites moving with the velocities around 6 - 8 km./sec. Based on the applications, the value added satellite data product services are also increasing rapidly in addition to the standard data products. Therefore utilization of data and in turn the satellite are also appreciating globally. This is resulting in the focused services to the user to make the precise data available. In order to cater to the multi user requirements in a given satellite orbit, multi segment data programming and transmission is also put to practice. These are realizable due to the technology advancements on-board the satellite and in the ground segment systems. The imaging (Targeting) accuracies of the order of few hundred meters both along track and across track along with the associated location accuracies of the products around 200 to 300 mtrs. is being achieved. The technology advancement is enabling the satellite controller to authorize the users to control and configure the satellites for imaging specific areas of his interest. All these technological inventions and advancements make the data more and more valuable. However few other conditions like cloud, fog etc., make the data unavailable from optical sensors. Therefore the need for precise, reliable and error-free data acquisition.

There are number of Indian Remote Sensing satellites in orbit with different data rates and resolutions per channel. Similar is the case with the other remote sensing satellites in the world. Finer and finer resolutions and the increased data rates have resulted in higher and higher volumes of data to be handled for each satellite visibility. Therefore with the increased data channels and data volumes per satellite, handling the data acquisition systems is a complex issue for providing reliable, error-free data particularly when the visibility / orbit is shared by the multiple users sequentially for their requirements of data sets programmed with appropriate encryptions for privacy.

This scenario call for acquisition of short data sets at different elevations. The current data reception systems have certain limitations to acquire the data at high elevation and particularly for overhead passes. There are limitations for the acquisition of data at lower elevation angles more so for low gain antennas.

(a) Tracking limitations for Satellites at higher antenna elevations beyond 87^0

(b) Data acquisition problems at low elevations due to ground reflections, obstructions, environmental conditions, slant range path loss, signal distortions etc., severe the received signal to noise ratio

(c) Therefore for a given antenna and system G/T, receiving error free data from horizon to horizon becomes impossible

(d) These limitations are concerning to the tracking of the satellite in auto acquisition and auto tracking mode. The Backup programming mode will also become ineffective at higher elevation angles due to forced errors through prediction inaccuracies driving the antenna away from the line of sight, thus causing reduction in the signal to noise ratio

Realization of automatic acquisition system for high data rates has certain limitations including the technology . The real time data archival is equally complex for higher data rates per channel. The advent of high speed processors, high speed computer buses, high speed interfaces like ultra SCSI, fiber channel catering to Gigabit bandwidths, high speed disks with improved transfer rate along with embedded system controllers with appropriate cache to match the Fiber Channel data rates made it possible to handle the data in Realtime by the Processors. The VLSI design techniques could facilitate the designers to realize the realtime frame synchronizers up to the data rates of 200 Mbps and the concept of parallelism for higher data rates. Development of Gigabit Ethernet systems, Storage Area Networks with Fiber Interfaces made the higher volumes of data to move across the platforms even in the heterogeneous environments.

However the data acquisition systems being the front-end in the high frequency range need to be developed to the matching technologies. It calls for the development of newer techniques to overcome the current limitations in receiving the data reliably from say 2deg to 2deg, including the total automation for Remote Configuration and control of systems to make them net centric to collect the data from the remote stations to cater to the requirements. Multi Satellite Acquisition systems require powerful centralized remote control of not only computer systems but also devices and instruments applying the virtual instrumentation approaches. Comprehensive user interfaces and connectivity for device access and control to the existing network for remote management also need to be addressed. Development of intelligent and programmable controllers with the necessary hardware and software is an emerging requirement for reliable and efficient systems. System complexities also call for lesser and lesser human interaction to reduce the human subjectivity and call for transferring the intelligence to the system controllers to make the decision making part of the system and not operator dependant. In order to acquire the data from almost horizon to horizon, the system is required to be modelled for a newer approach in program track mode so that the data acquisition is continuous even at higher elevation angles. This is an important concept and requirement for remote sensing satellite data acquisition so that acquisition of short data sets irrespective of Elevation angle is possible without any loss of data.

The automated systems operations are achieved by introducing the digital systems design concepts using the VLSI design process with proper hardware and software. Manually managed applications and systems represent biggest costs and subjectivity. Additionally the automation will be robust than the manually controlled counterparts. This is yet another essential requirement and a gap in the current day technology. Remote Sensing Data Acquisition Stations will be installed at any place including the inaccessible regions as the data transmission channel bandwidths are no more a limitation, remote control becomes a normal operational mode. The new generation resource solutions, enable the systems to recover from disruptions more rapidly and without human intervention at aggressively lower costs enabling the support team to operate more efficiently. Development of methodologies for the software to handle multi satellite/multi sensor functions through a scheduler environment for common control data acquisition systems is complex. It also need to address the elements including simulations, performance evaluation including pre-pass, real-time, post-pass and generation of system performance profiles etc., in an automated manner by the system. Therefore the proposed research address the new methodologies to fill the gap and also to suit the current requirements.

Objective of the Research

The basic objective of this research is to develop new approaches to remove the uncertainties given above in Data reception, to establish the certainty of error-free data availability taking all the conditions into consideration, to develop remote configurability and controllability of the system, to characterize the systems functionality for remote management leading to automated testing mechanisms, to develop of data acquisition information management system covering the process flow, status, error handling etc..

Major research goals are

- Development of intelligent program tracking system while overcoming the current limitations
- Remote Computer Control of RF Systems, Test Equipments etc., Automatic evaluation of systems, error handling, recovery, on line

parameter monitoring like signal strength, spectrum, BER etc. in realtime.

- Development of intelligent remote configurable high band width cross point switches for routing the data channels under multi sensor / satellite environment. These technological developments also need to address the complexities involved with such high frequency systems.
- Development of the methodologies in realizing the adequate software for the station automation under the defined scheduler environment to provide uninterrupted data services supporting multi satellites with Graphic User Interfaces, pull down menus etc., *.*
- Development of data acquisition information management system to provide system performance analysis reports, error analysis reports and daily operational reports in an automated manner.

Important conclusions of the research

This research has resulted in the development of new concepts and new systems with the focus on automation and remote management using current technologies.

- New concepts in the development of satellite data format simulators by incorporating programmability to suit the multi satellite/sensor missions. The method uses the reconfigurable FPGAs, injection of realistic/simulated ancillary data to the data stream to create the actual environment for simulation while considering all the parameters for the image handling and processing. Also introduced the approach of injecting the compressed/uncompressed image into the serial data stream of the simulator instead of simple data patterns using zeros, ones etc.. This has simplified the validation/end-to-end tests of the entire data handling chains of the ground segment.
- Modelling of bit errors and development of the associated systems for the validation of the data reception chains in a computer controlled environment.
- Characterization of the reception systems through simulation and fine tuning of the same for realtime performance. Automation of the simulation process based on time tagging as per the sequence in a given day.
- BER validation of the reception chain during image data download is another new challenge through statistical modelling while using the system functional models derived from simulations.
- Major issue of data reception from horizon to horizon has been resolved by developing an efficient program track system to track the satellite. This was augmented with a specific elevation dependant tracking model for tracking high elevation satellite passes. This new development enabled the remote sensing data acquisition systems to be totally remote configurable/controllable with no uncertainties in data acquisition.

- Development of high speed cross point switches, for 8X8, 16X16, 32X32 signal pairs, helped for the data connectivity and for the data path configuration changes remotely.
- Developed the computer controlled systems, processes for the automated operations with appropriate Hardwares and softwares along the provision for net centric operations.
- Developed automated report generation systems for the operational events and status and make the status and diagnostics information services available to all users through net.

Some Important End Results

- This research has resulted in the development of several systems using reconfigurable approaches viz.. Bit Error Test Systems, Data Path Controllers, Timing systems, Station Control Systems for automated tracking, Satellite Data Format Simulators, Realtime Data Archival systems, Automated Report Generation and Information Management Systems for data acquisition etc.. These systems are supplied to several National and International remote sensing satellite ground stations under the Indian Remote Satellite program from department of space through Antrix Corporation. The international users are Iran, Algeria, Euromap-Germany, China, Scanex-Russia, UAE, Taiwan, Myanmar, Thailand Svalbard(Norway) etc...The Indian users are ministry of defense and ministry of home affairs and earned appreciable revenues. Many more international requirements are in the pipeline for revenues to the nation. This is one of the revenue earning R&D s to the dept. of space.
- This research enables the user to locate the data acquisition systems even in remote inaccessible areas.
- This has resulted in publication of 28 papers. The distribution is 7- IEEE-International Publications, 4-other International publications and 17- national publications.
- The paper published and presented by the author in an international seminar ICSCN2007 on “Design and implementation of high bit rate satellite image data ingest and processing system” has got the best paper award.

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ABBREVIATIONS

ACU	:	Antenna Control Unit
ADIF	:	Ancillary Data Information File
AOS	:	Acquisition of Satellite
ASCII	:	American Standard Code for Information Interchange
AZ	:	Azimuth
BCD	:	Binary Coded Decimal
BER	:	Bit Error Rate/Ratio
BERTS	:	Bit Error Rate Test System
BERTS	:	Bit Error Test Systems
BSSC	:	Bit Synchroniser and Signal Conditioner
CG-ROM	:	Character Generator Read Only Memory
CL	:	Confidence Level
CPLD	:	Complementary Programmable Logic Devices
DAQLB	:	Data Archival Quick Look and Browse
DARSD	:	Data Archival and Realtime Systems Division
DEMOD	:	Demodulator
DFD	:	Data Flow Diagram
DLT	:	Digital Linear Tape
DOS	:	Department of Space
DPC	:	Data Path Controller
DQE	:	Data Quality Evaluation
DRS	:	Data Reception Systems
ECL	:	Emitter Coupled Logic
EL	:	Elevation
EMC	:	Electro Magnetic Conduction
EMI	:	Electro Magnetic Interference
EPLD	:	Electrically Programmable Logic Devices
ERS	:	European Remote Sensing Satellite
FEH	:	Front End Hardware
FIFO	:	First In First Out
FPGA	:	Field Programmable Gate Array
FRED	:	Framed Raw Extracted Data
GMT	:	Greenwich Mean Time
GPIB	:	General Purpose Interface Bus
GPS	:	Global Positioning System
GUI	:	Graphic User Interface
I/O	:	Input and Output
IF	:	Intermediate Frequency
IRIG	:	Inter Range Instrumentation Group
IRS	:	Indian Remote Sensing Satellite
LBT	:	Low Bit rate Telemetry

LC	:	Line Count
LCD	:	Liquid Crystal Display
LED	:	Light Emitting Diode
LNA		Low Noise Amplifier
LO	:	Local Oscillator
LOA	:	Linear Orbit Approximation
LOS	:	Loss of Satellite
MOD	:	Modulator
MPU	:	Micro Processor Unit
OCM	:	Ocean Color Monitor
PAN	:	Panchromatic
PCI	:	Peripheral Computer Inter Connect
PPP	:	Pre Pass Planner
PTM	:	Program Track Module
RAID	:	Redundant Array of Inexpensive Disks
RDAIS	:	Realtime Data Acquisition Information System
RF	:	Radio Frequency
SAC	:	Station Automation Computer
SAS	:	Station Automation System
SCC	:	Station Control Computer
SCS	:	Station Control System
SCSI	:	Small Computer Systems Interconnect
SDFS	:	Satellite Data Format Simulator
SNR	:	Signal to Noise Ratio
SSR	:	Solid State Recorder
SV	:	State Vector
TB	:	Terra Byte
TCT	:	Time Code Translator
TES	:	Technology Experimental Satellite
TPG	:	Test Pattern Generator
USB	:	Universal Serial Bus
UTC	:	Universal Time Coordinated
VLSI	:	Very Large Scale Systems Integration
VRAM	:	Video Random AGS Memory
ZPC	:	Zenith Pass Controller

Chapter – 1
Introduction

1.1 Background

Satellite Remote Sensing has become a part of national planning for the utilization of earth's resources, disaster identification, monitoring and management etc., There are number of Indian Remote Sensing Satellites in the orbit to cater to the requirements in-house as well as globally. Department of Space through Antrix Corporation extended the services of these satellites globally. The data requirements are also increasing enormously and overflowing the capacities of couple of stations in the country for the data collection. Therefore Antrix Corporation is also acquiring the data through Svalbard Ground Station where the satellite is visible for maximum number of orbits due to the orbit convergence at the higher latitude. Therefore it can be a reality to have ground stations at such places and the controlling can take place from any part of the globe.

1.2 Brief description of the remote sensing satellite ground station

The primary function of the ground station is to acquire the data transmitted from the satellite that would be useful for further product generation. The configuration of a remote sensing satellite receive ground station is briefly described with reference to the block diagram in Fig 1.1. The main subsystems of the earth station are: (i) Antenna, feed and front end subsystem (ii) RF/IF subsystem (iii) Servo subsystem and (iv) Tracking Pedestal .The references were drawn from the author's paper [8] which was presented in second Asian conference on remote sensing at Beijing, China.

Antenna, feed and front end subsystem receives the signals from the satellite in X-band (8.025 - 8.4 GHz) and S-band (2.2 - 2.3 GHz) simultaneously. The parabolic antenna is usually mounted over the elevation-over-azimuth pedestal system and is fully steerable between 0^0 to 365^0 in azimuth and 0^0 to 180^0 in elevation. The system has an S-band single-channel monopulse tracking-feed mounted in prime focal or Cassegrain configuration to derive the tracking error signals for driving the antenna in a direction to nullify this error. Similar feed is also incorporated at X-band.

The monopulse signals from the feed-horns are fed to the monopulse comparator unit which derives the difference channel offset signals corresponding to azimuth and elevation of the antenna along with the sum channel signals. The difference channel signals are given to a phase-commutation unit, which carries out binary phase shift keying and time division multiplexing to the AZ and EL error signals with reference to the scan pulses being transmitted from an Antenna Control Unit (ACU). The output of the phase commutation unit is power combined in a 6 dB-directional coupler with one portion of sum channel to form the single-channel monopulse-tracking signal. The other portion of the sum channel signal from the feed is processed without monopulse modulation.

Both sum and tracking RF signals are fed to the RF/IF subsystem, which consists of a synthesized signal up/down converter unit that converts different input RF frequencies to corresponding IF- frequencies, all centered at 375 MHz (70 MHz in S-band chain), through synthesizing the local oscillators. The down converted sum and tracking signals at IF center frequency on each carrier are brought down to the control room where difference channel signal is fed to a tracking receiver. The tracking receiver detects the tracking monopulse modulation synchronously and feeds the dc error signals corresponding to azimuth and elevation antenna offset angles to the servo subsystem consisting of the ACU. The tracking pedestal is an elevation over azimuth housing structure with dc motors, gear boxes, break assembly, synchros and limit switch packages mounted in it.

The ACU processes the dc error signals and feeds them to the pedestal drive dc motors through dc power amplifiers. The dc motors drive the gear system and antenna in such a way that the antenna tracks the satellite in line of sight with required accuracies .The corresponding IF data signals received in sum channel is fed to the data demodulators and bit-synchronizers, which are the part of the RF/IF subsystem. The data demodulators/bit-synchronizers are designed with multifunction capabilities to receive data from any satellite with only plug-in augmentation in the bit-synchronizer unit as per the data rate.

To test the end-to-end performance of the receive chain in local loop before a satellite-pass, a simulator with facility to simulate satellite-transmitted spectrum at variable data rates is used to inject the up-converted test-signal into the front-end LNA amplifier, through a 30-dB test-coupler.

The synchronized data and clock streams from the demodulator/bit-synchronizer unit are given to the data archival and realtime systems.

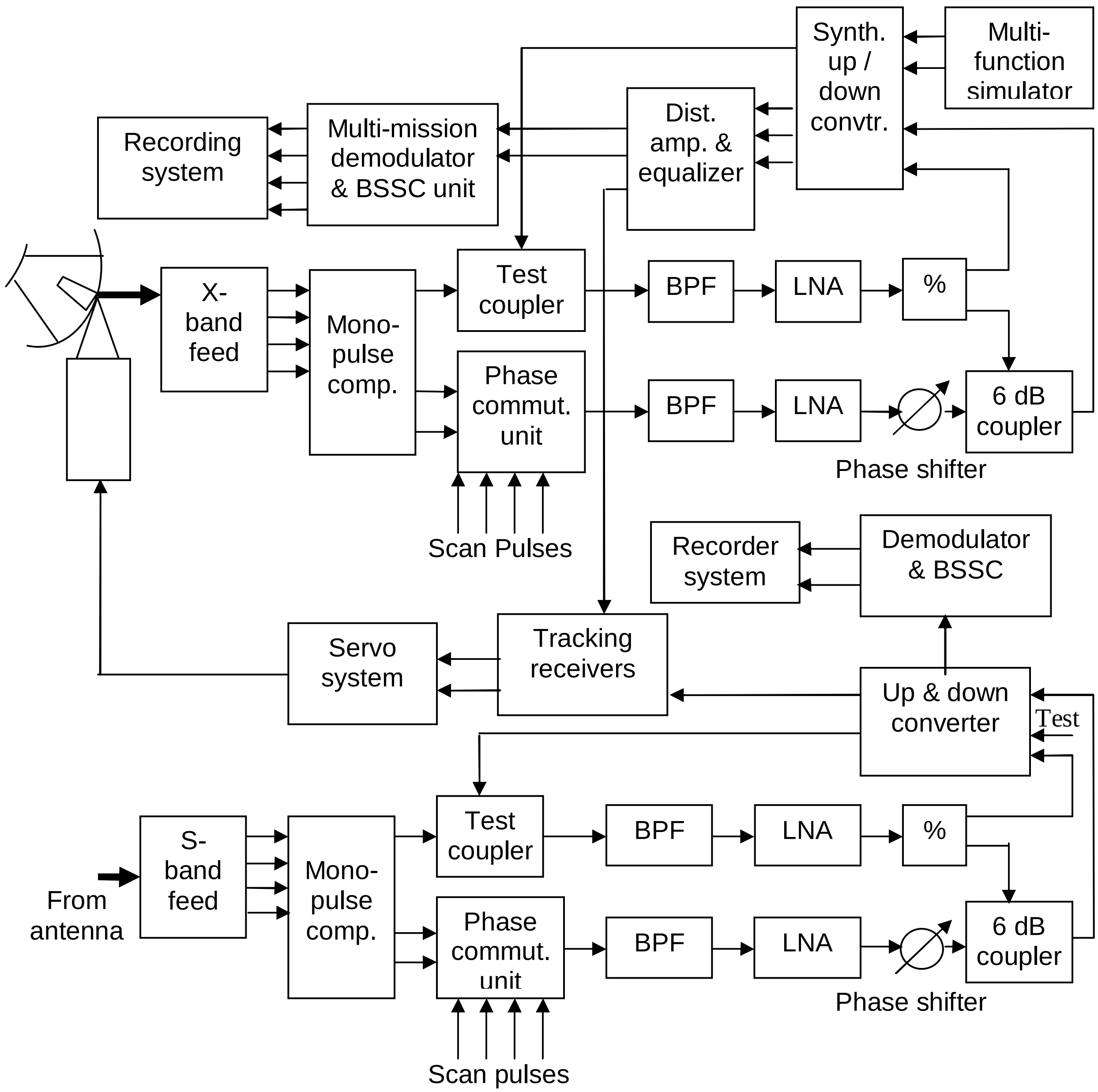


Fig 1.1 Block diagram of a remote sensing satellite ground station

1.3 Brief Description of the Data Archival and Realtime Systems

The integrated diagram of the data archival systems with the data reception systems is given in fig 1.2. Brief description of the data archival and realtime systems is as follows. The references were taken from authors publications [8,9,10,11].

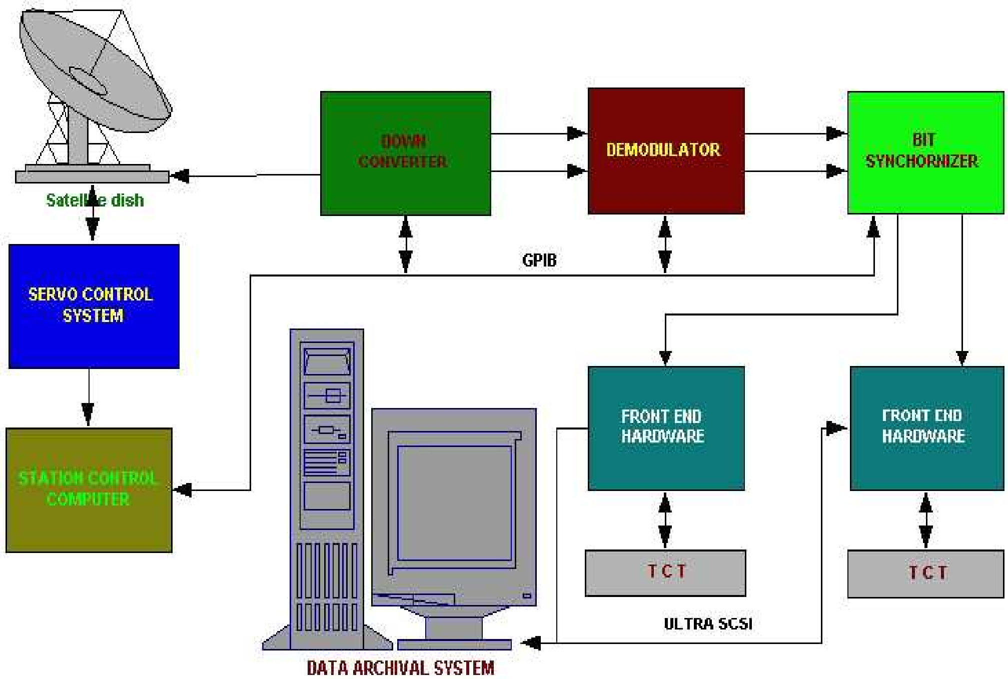


Fig 1.2 Data archival system

During real time, the Data and Clock from two Bit Synchroniser and Signal Conditioner(BSSC) units corresponding to 2 camera systems along with IRIG-A(Inter Range Instrumentation Group) time code is fed to two independent frame synchronizing units (Front End Hardware-FEH). The Time Code Translator(TCT) provides the GPS time in Binary Coded Decimal(BCD) format to FEH for stamping the Coordinated Universal Time(UTC) with video for every line and IRIG-A (serial) time to computer system for synchronization with UTC. FEH converts the incoming serial data into parallel after the frame synchronization. The Parallel data in turn fed to system through Ultra SCSI. The computer system in real time logs the incoming data from FEH and stores it into RAID also provides a sub sampled quick look display for each sensor. After the Payload passes, the raw data from the RAID system[4] is converted into FRED (Framed Raw Extracted Data) format for each sensor and gets archived onto DLT as a part of data archives. The simplified block diagram is as follows. The realtime systems on functional basis are also termed as Data Archival, Quick Look and Browse(DAQLB) systems.

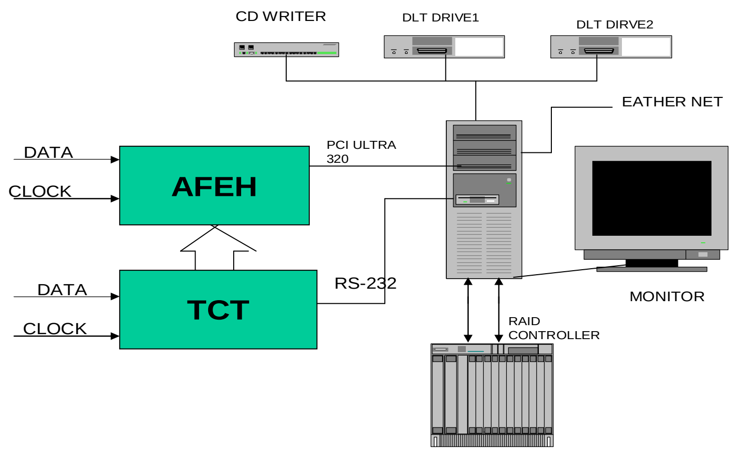


Fig 1.3 Block diagram of realtime systems

Immediately after the real-time pass, the stream / sensor-wise auxillary data is extracted and a file is created after processing in a given format for a given path / orbit. This is called Ancillary Data Information File (ADIF). Subsequently this information will be used to generate data products of any sensor. The outputs of DAQLB system are shown in Fig.1.4. Sensor/ Port-wise Histograms are provided in near real-time to demonstrate the status of detectors on-board.

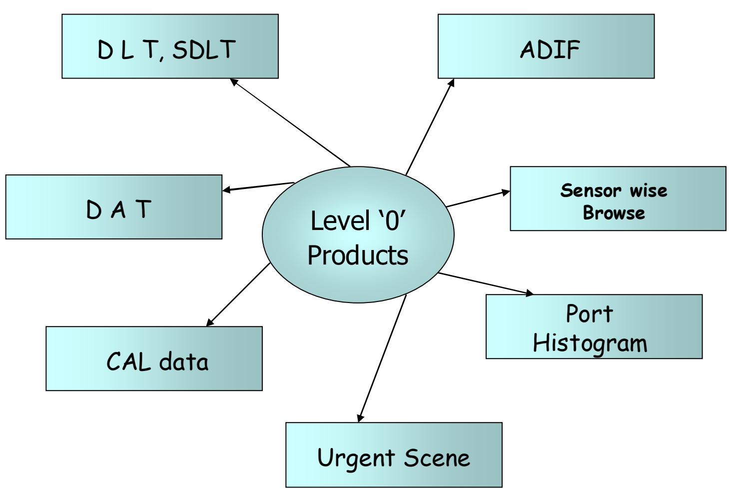


Fig 1.4 Outputs from realtime systems

Subsequently the sub-sampled video data file is created for each sensor and for each pass / segment for a given data while using the inputs with respect to the start and end details of each pass/segment. Browse image chips are generated from these data files for each stream/sensor and loaded on to the browse server after the compression so that they are available on the net for the users to select the data sets required.

The main functions are summarized below. The detailed flow is given in Fig. 1.5.

- Generation of orbital information for all visible passes, which includes path no., orbit no., AOS and LOS timings, antenna look angles etc., from satellite state vectors.
- Real-time data archival on RAID and quick look display for each sensor.
- Separation of the auxiliary information from the video stream and validation of the auxiliary data with reference to linecount, GRT etc...
- Scene framing information which includes scene start, scene center and end timings for each sensor and its corresponding line counts along with latlongs.
- Extraction of scene/pass wise data quality information, which includes no. of line losses, time jumps and LC-GRT correlation for each payload pass and OBT-GRT correlation for each SSR pass.
- Attitude determination using earth sensor, star senor, gyro information and satellite positioning system.
- Generation of attitude and orbit information.
- Attach the data quality, orbit and attitude information in a predefined format (ADIF).
- Extraction and generation of sub sampled browse data scene wise for each sensor for making it available on the net for the data users.

All these tasks are repeated for all the payload data including on board solid state recorded data. SSR dump is scheduled even in night during free orbits. Hence the Systems are operated continuously to meet the data requirement and product generation.

Similarly the calibration passes are scheduled during night for each sensor to collect the sensor calibration data. This data like any other payload pass is acquired and stored on RAID. Calibration data becomes input to data processing as it provides evaluations of sensor as a feedback etc. In order to cater to higher resolutions, the data rates from each camera are of the order of 100 to 150 Mbps. Such high speed ,high volume data could handled due to the technological advancements in processor, memory, i/o, and storage [5]. In order to automate the system functions, all the processes are implemented through a scheduler software [6].

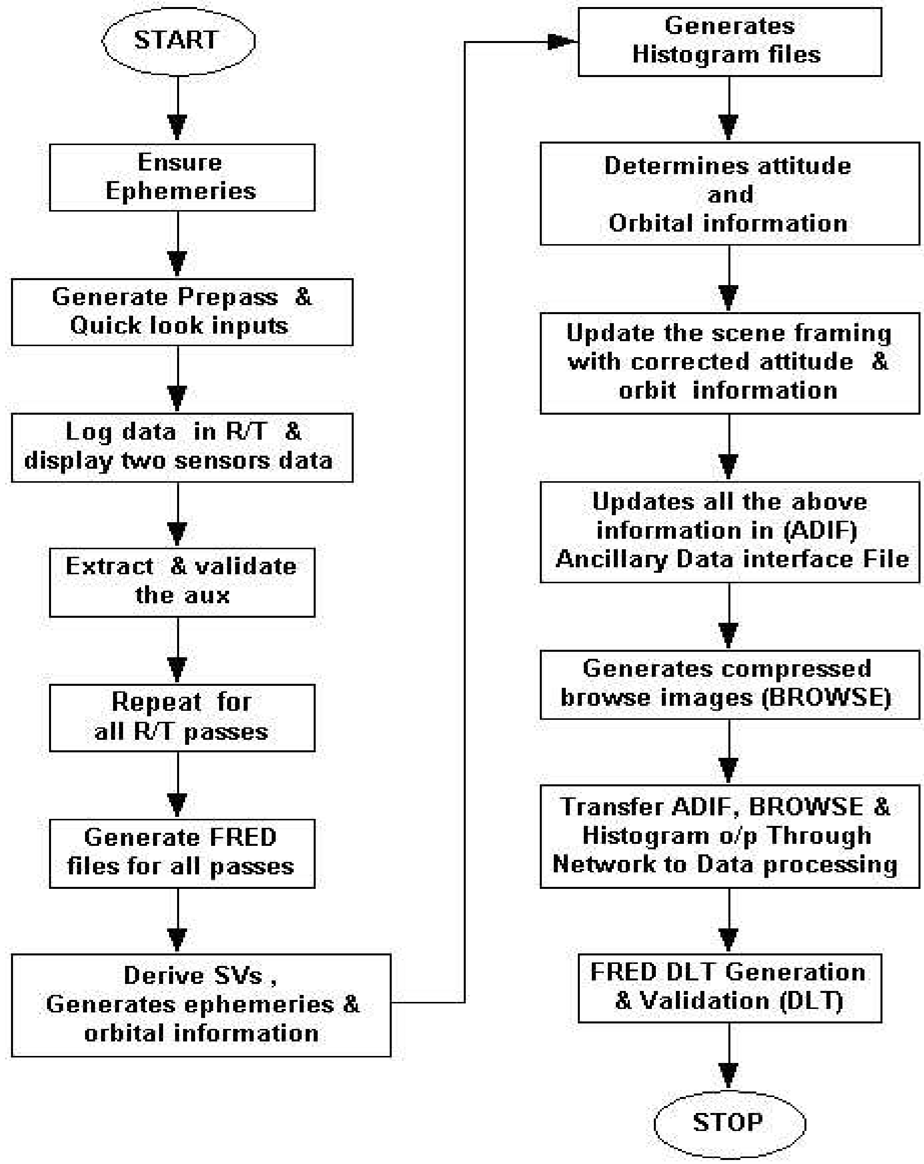


FIG. 1.5 Software flow for realtime systems

Data quality evaluation

Data Quality Evaluation(DQE) parameters are defined to qualify and quantify radiometric/geometric accuracy achieved on the product. These parameters are evaluated for every repetitive cycle from the sensor data acquired on DAQLB system. The various DQE parameters are classified with respect to payload, platform stability and type of product. Radiometric DQE is done in two ways i.e. calibration analysis and scene related analysis.

For calibration analysis, calibration data is obtained from the satellite during night passes. It is used to study the long-term performance of the detector and processor electronics. It is implemented using LEDs in the Onboard. These LEDs are driven with a constant current and integration time is varied to get 16 exposure levels covering the dynamic range in a sequential manner and it repeats in a cyclic form. The cycle time again varies from sensor to sensor. In this manner the calibration data is collected for each sensor and the parameters like spectral response, dark current, dynamic range, temperature and linearity are extracted and compared with ground reference data.

After the evaluation of calibration data, the deviations are noted and the radiometric lookup tables are updated accordingly. These lookup tables will be used during product generation. In scene related analysis, spectral response of the sensor is evaluated by comparing spectral signature of various known terrains viz., desert sand, river sand, vegetation, water, barren land, urban land are and snow at different sun elevation angles.

Similarly the geometric DQE is done to evaluate the location accuracy of data products, Band to band misregistration and Internal distortions in a scene. Once these parameters are evaluated and checked whether they are with in the limits or not, as defined by the project. If any deviations were noticed it will be fed back to DAQLB for analysis. After analyzing the above the required biases will be updated in DAQLB.

1.4 Growth of Remote Sensing applications in India

NRSA has started the remote sensing satellite data acquisition activities in 1979 and developed the remote sensing applications in the country and also initiated and helped State Governments to establish their own state remote sensing centers for various applications of remote sensing. The technology has further spread through the establishment of Regional Remote Sensing Service Centers(RRSSC) by Department of Space under National Natural Resources Management System(NNRMS). The remote sensing satellite data product requirements have increased enormously along with the applications. The following table gives an idea about the volume of the products that were generated in the last one decade.

REVENUES FROM REMOTE SENSING DATA PRODUCT SALES

YEAR	**1987-88**	**1988-89**	**1989-90**	**1990-91**
Rs. In lacks	233	296	349	316

1991-92	**1992-93**	**1993-94**	**1994-95**
314	414	451	582

YEAR	1995-96	1996-97	1997-98	1998-99	1999-2000
Rs. In lacks	671	860	1125	1543	1754

2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
1591	1926	2220	2441	3468	3533

Table 1.1 Trends in the revenue from Remote Sensing data products

1.5 Motivation for the Research Work

Satellite Remote Sensing has become a part of the societal and intelligence gathering requirements and it has spread its wings to various applications and hence there is a stress on having the remote sensing satellite data acquisition systems with 100% availability to provide error-free data. As the satellites are visible for short periods of time, the systems validation is done offline and fine tuned with online results. The offline assessment of the data reception systems is carried out based on BER performance of the complete RF chain by injecting the simulated data modulated spectrum into the front end. This is carried out manually before each satellite pass to ensure the quality for proper functioning of the receive chain. These BER measurements are carried out manually using internally generated pseudo random sequences of a standard sequence length. Similarly the boresight measurements for the evaluation of pointing accuracies and data reception are done manually. Based on these test results, the systems are diagnosed and corrected for proper acceptable performance in realtime. All these operations are traditionally done with the manual interaction and the decision support. During the satellite visibility periods, there is no mechanism to estimate the data quality to qualify the data reception chain quickly. As the data received is an image and the certification of the image is subjective matter when it is done online or near realtime. All these processes are designed for offline with all the human subjectivities at every stage for decision making. The most important function that is required by all remote sensing ground stations is to have the uninterrupted data acquisition from 0 deg. to 0 deg. covering the entire visibility circle of a given station. This has to address two important issues. (a) Handling of disturbances at lower elevation angles (b) Handling of high velocity requirements at higher elevation angles.

Therefore there is a definitive need to develop the system that can receive the data covering the entire visibility zone without any interruption as the data is extremely valuable. With the newer concepts of digital systems designs and the design tools that are available, development of controllers for the above performance is certainly within the reach of a designer. In addition to this when the data is getting transmitted from satellite one must be able to model the requirements for handling the high elevation passes while taking all the system parameters into account so that uninterrupted tracking takes place. The current processor technologies along with the associated high speed memories, interfaces and storage systems support these requirements.

Currently in the era of VLSI, the reconfigurable products have motivated designers to increase the adoption of programmable architecture. As such growing number of products now utilize the programmable logic devices such as FPGAs and CPLDs and programmable non-volatile memories such as EEPROMs and FLASH. Designing the systems with the ability to remotely upgrade the programmable logic and non-volatile memory of the system while in the field is applied in these developments.

The field programmable gate arrays are configurable VLSI devices for various logical functions. SRAM based FPGAs were introduced in 1984 with the concept of configuring them only at the beginning of the operation. Now almost two decades later, in 2004 , the current FPGA technology includes the concepts of reconfigurability. The reconfigurability has to be looked at from two levels. One approach is the actual dynamic reconfigurability of a device while the other is a support built into the CAD tools supplied for the device. At present devices with support limited or full version of the limited reconfigurability are available in the market. It is called limited because it has been incorporated fully into the design tools supplied and the platforms can enable the software Programmer to take the advantage of possible hardware implementation of a user function while not being directly involved in the hardware design process. This is made possible by providing the universal hardware software interfaces and library of pre-compiled configuration bit streams that are selected by the Programmer to the required hardware function.

Therefore the reconfiguration of the devices using the above concepts call for redesigning of the system in the newer platforms to make all the devices remotely configurable and controllable. The process of automation has been widely used in the software designs for the systems functionality. These concepts are extended to automate the functions of the system as a whole under the single controlled environment of Scheduler to handle the multi processes. The system is designed to acquire the knowledge of each process and also updates for every subsequent operation. This enables the system to provide the necessary diagnostics for the analysis.

These concepts are extendable for the remote management of the ground stations located at far away places like poles as the current technologies in the networks and the band widths that are available support these approaches. This is an important issue as the visible orbits at poles are high due to convergence.

1.6 Review of literature

Satellite Remote Sensing has become part of the national planning for the utilization of earth resources, disaster management, intelligence gathering and management etc.[1,2] Based on the applications, the value added satellite data product services are also increasing rapidly in addition to the standard data products. Therefore utilization of data and in turn the satellites in the space are also increasing globally. This is resulting in the focused services to the user to make the precise data available. In order to cater to the multi user requirements in a given satellite orbit, multi segment data programming and transmission is also put to practice. The imaging (Targeting) accuracies of the order of few hundred meters both along track and across track along with the associated location accuracies of the products around 200 mtrs. is being achieved [3]. The technology advancement is enabling the satellite controller to authorize the users to control and configure the satellites for imaging specific areas of their interest in a coordinated system. All these technological inventions and advancements make the data more and more valuable. This called for the acquisition of data from multiple satellites through multiple reception terminals. The data collection, realtime data archival and data handling functions are highly involved processes and hence it is preferable to make every process intelligent so that the entire process flow can be handled by the system. This called for the study of every system for modelling its behavior and functionality. Functional model based system design was carried out using the new concepts of reconfigurability and remote management. Therefore the literature review and study covers different subjects starting from the data reception systems, tracking systems, realtime data handling, storage systems, digital systems designs, Information management systems, process automation etc. The references were drawn from the author's publications [5,8,9,10,11,12], text books for programming [6], net [4] and other publications of N.R.S.A [16].

The research includes the systems modelling, simulation, development, verification of the results for reliable functionality and operationalisation. The literature study include the Journals, satellite specific documentation from Department of Space, Conference Papers, Text Books, Manuals etc. These are all referred appropriately including the author's publications.

Realization of automatic data acquisition system for high data rates has certain limitations including the technology. The real time data archival is equally complex. The advent of high speed processors, high speed computer buses, high speed interfaces like ultra SCSI, fiber channel catering to Gigabit bandwidths, high speed disks with improved transfer rate along with embedded system controllers with appropriate cache to match the Fiber Channel data rates made it possible to handle the data in Realtime by the Processors[4,5] Development of Gigabit Ethernet systems, Storage Area Networks with Fiber Interfaces made the higher volumes of data to move across the platforms even in the heterogeneous environments [5].

One of the best ways to certify the data acquisition system in the absence of the satellite is through simulation[14]. Simulation of the systems through the Pseudo Random Sequences is one of the standard approaches. Pseudo Random Sequences generation through Shift Register Sequences are well explained by Solomn W Golomb [30].The reception channel is validated in the form of bit errors through Bit Error Test Systems[23] developed by the author. The probability of bit errors in digital communication systems are explained by Golomb,Shanmugam and Balan [15,17]. S.B.Wicker[19] has brought out the error correction techniques. Agilent and National Instruments have brought out the newer concepts [13] in the areas of test systems development environment. The error detection and analysis are important and the author has published two papers on this subject [25,26]. Pointing accuracies and bore sight measurements play an important role in system management[22,24]. Simulation of the systems include boresight functions.

The data archival and realtime systems handle the satellite data in its specific format and therefore satellite specific data formatters are required for the simulation of these systems. With the increased number of satellite missions and with different data formats for each, the design complexity of a satellite data format simulator called for the configurability in the system so that the same can cater to all the satellites [32,33,34].Satellite data simulation in general is confined to known data patterns like ones and zeros or allied combinations due design complexities. Totally new concepts were introduced by the author for the satellite data simulation providing realistic auxiliary data, realistic attitude data and realistic image with compression and encryption. Provision of realistic attitude is a task by itself. In order to limit the channel band width as per the allocation for remote sensing satellite applications, image data compression concepts are used world wide .Data encryption/decryption and compression/decompression are handled as block box modules to follow the basic concepts of secrecy. The simulation with compressed data is a complex process and therefore devised a new approach. In this approach compressed data as a set was injected into the serial stream. Then the timing Synchronization, with the above independent data sets injected in the data stream, is a challenge to the designers [20]. The simulators were designed by the author for reconfigurability to cater to the multi satellite missions and to cater to the remote management.

The important aspect of the simulation is the characterization of the reception systems by making the profiles for Bit Error Rates against the signal to noise ratio, Eb/No etc..[31]. Using these new concepts SDFS systems were developed and introduced by the author into the operational systems at NRSA. The references are taken from the author's publications [28,29].

The ratio of the number of the bits received erroneously to the total number of bits transmitted is BER. The quality of BER increases as the total bits transmitted are increased. In the limit as the number of bits approaches infinity, the BER becomes perfect estimate of the true error probability[42].Most bits in the real systems are the result of random noise[21].The main issue is how many bits must be transmitted [38] through the system for a perfect BER testing. In order to estimate the quality of the data reception chain in realtime, concepts of finite test times were thought of and derived through statistical means [39,40,41,44] by introducing the concepts of confidence levels. These concepts were applied to Indian Remote Sensing Satellites to derive a model for the channel quality evaluation with reduced measurement times. This concept after development, validation and implementation was also published by the author [45]. The digital correlator is used for the online BER validation [36,39]. As the data rates are increased along with the satellite data resolution requirements, high speed digital correlators were developed by the author using the concepts of parallel correlators [35] to overcome the limitations of the correlators that are available in the world market[37]. This development was published as a paper in IEEE by the author[43] and the design has 4 times improved performence compared to the available products and publications. The VLSI design concepts provided the designs to work up to 200 Mhz. per channel.

Satellite auto tracking has certain limitations for tracking the satellite due singularity with reference to low elevation angles and high elevation angles. This called for the study of the tracking system [55,56,57,58]. It also called for full knowledge about the true position of the satellite at all times [46,47,48]. After the development of Alfa computer ,the processor technology has improved tremendously. Moore's law has become a reality for semiconductor developments. The I/O speeds, storage technology and the networking speeds have increased unimaginably so that the system can handle the orbit predictions and program tracking online. Online system behavior modeling, control loop analysis and performance reporting[54] could be done by the system online. This has resulted in computer controlled tracking system in a programmed mode of operation. Development of adaptive control system with appropriate interfaces was also a challenging task for the automated program track [52,53]. Author has developed the computer controlled tracking system and the same is in use for error free functionality [54] in India and abroad . This could eliminate the deficiencies in auto tracking except for high elevation angles where the system is expected to experience very high azimuth velocities beyond the system specifications. These system requirements were simulated extensively and modelled to handle such passes by augmenting the predictions for a specified window with the satellite trajectory values from this model[60]. Extensive program development was carried for the development of intelligent program control based on the above models for automated tracking [49,50,51].

The paper published by the author [60] had the best paper award in an international seminar.

The automation of the satellite data acquisition systems for remote sensing satellites is a complex issue and call for detailed study and development of number of new concepts and systems. One of the important developments is to develop high bandwidth cross point switches for controlling the data paths to switch between one source to one destination or one source to many. This development was a challenging task and called for review of several publications and text books as the design involved handling multi high frequency channels while providing identical electronic environment to all signals with no interference to other . Number of publications and the text books on digital systems designs were referred for the completion of this task [61,62,66,67,68].This development was published by the Author[70]. This is one of the standard products from the author. EMI/EMC considerations are most important for a reliable product and a paper was published by the author on this [71] in reference to the time code translator development.

The automation called for the development of various sub-systems associated interfaces to the computer. Development of reliable systems was another important task as the systems were supplied internationally [62,65,69]. Extensive software developments and user friendly GUIs called for referring number of text books[63,64,72,73,74,75]. Number of C language text books, the manuals and the documents related to the software packages from National Instruments and Agilent were also referred. For the development of reporting mechanisms and report generation by the system in an automatic manner programming was done in the environment of C and JAVA after referring to the associated text books.

As the data collected from the satellite is voluminous and of the order of 1TB per day, the parameters associated with each satellite/sensor are also voluminous, therefore the status reporting called for an extensive data bases development [76,77,78,79,80,81,82]. The automatic reporting mechanism through the concepts of process automation was developed using the concepts of information storage, management of data bases and dissemination. Number of text books were referred [73,77,85] for this development. The Author has published a paper based on these developments[84]. While the systems are used for such critical realtime satellite data handling applications with huge data storage, it is necessary to have a backup management system. The systems are developed to manage all the data resources, processes, system functions, users, reports etc., very effectively and without any human interaction. Backup has been achieved by developing the back up and retrieval softwares [83].

The field programmable gate arrays are configurable VLSI devices for logic functions. SRAM based FPGAs were introduced in 1984 with the concept of configuring them at the beginning of the design. This platform along with the associated CAD tools have changed the design cycle and the basic design concepts. The developments in the processor speeds, memory, I/O Interfaces, storage systems further provided the openings for handling the complex designs through improved EDA tools. Newer simulation and verification concepts have improved these design philosophies further. High speed links and developments in the Networks provided the technology for remote access to the systems. By 2004 partially reconfigurable devices were introduced providing the scope for remote Hardware design upgradability [88,89,91] . Therefore the reconfiguration of the devices using the above concepts call for redesigning the systems in the newer platforms [92,93,98] to make all the devices remotely configurable and controllable [85,86]. The process of automation has been widely used in the software designs for the systems functionality. The similar concepts are extended for deploying the hardware for in systems upgrades [88,89]. In a simple configuration PROMs are predominantly used to reconfigure FPGAs where the configuration data is loaded into PROMs. The current and improved approach is to have Test Bus Controller for reconfiguration[89]. A simple configuration and test processor at power-up can automatically run the built-in diagnostics and provide status[91]. Hardware remote upgrades need a robust methodology for managing and delivering the bit streams to the target location. The bit streams are made intelligent by adding the data such as network protocol data, target location information etc., The intelligent bit stream is called the Hardware object and the Hardware Object Technology[94,97] provides the transportation link between bit stream generation and runtime use of the bit stream within executable programs. The hardware object technology also provides the status feedback which is used for remote diagnostics approach. This platform help the designers to upload the designs, configure the devices, control the devices, run the diagnostics and take the status feedback etc., remotely [95,96,99]. This concept is a major milestone in the technological developments.

1.7 Research Work done in this thesis

In order to automate the remote sensing satellite data acquisition systems, functions/processes and to build the intelligence into the same, it is necessary to make the systems/functions configurable/controllable by a computer. In addition, all the individual units/functions/processes need to be coordinated in a programmed mode of operation called a Scheduler which is intelligent enough to look at each unit/process for its configuration, status etc., The same concept is used in this research to automate the total functions of remote sensing satellite data acquisition. In order to make the systems intelligent and user configurable/controllable, each unit is required to be characterized for its functionality. Based on these, it is required to develop the systems functional models and realize the same for their operationalisation. Therefore based on this methodology, three concepts were developed by the author for the automation of remote sensing satellite data acquisition systems. (i)The first one is modelling of the data acquisition system for its functionality using the simulated data and generate the system profiles signal strength vs. BER etc.. (ii) During the image data download from the remote sensing satellites, no mechanism is available for defining the satellite to ground communication channel efficiency/performance. Therefore a new model has been developed based on the statistical concepts to evaluate the satellite ground link during the image data down load. As the data rates are in the increasing order from remote sensing satellites to suit the current and future location accuracies, high speed digital correlators were developed working for 160Mhz and above. Enhanced their frequency of operation by using parallel pipe techniques. Synchronizing the data in the parallel pipes in a high speed Correlator is a challenging task. Using these two developments, the satellite down link channel performance is evaluated in realtime for a given bit error rate and for a given confidence level with reduced measurement timings while using the system performance profile that was deduced during off-line simulation. This is totally a new concept developed for the evaluation of the remote sensing satellite down link during the image data down load. These new conceptual developments by the author made the controlling system to know and record the behavior of the reception system during the satellite data down load which in turn helps to tag/qualify image data that is received and also to work for online diagnostics/correction mechanisms. (iii)Based on the environmental conditions and other influencing factors, the satellite image data acquisition from remote sensing satellites get affected resulting in loss of data on number of occasions even though sufficient signal margins are available from the satellite. This is resulting in loss of the satellite tracking. Therefore a programme track system has been designed to replace auto track system using the current digital systems design techniques and the computers are currently able to handle these loads. The programme track system has been fine tuned based on the tracking system model derived to track satellite for all the possible passes with a negligible error in elevation and azimuth. This development by the author has provided 100% efficiency irrespective of the environmental conditions. As the tracking is totally under the control of the computer, entire tracking status is available with the controlling computer system for local/remote operations and diagnosis. There are difficulties with respect to tracking the satellite in the cone of silence for higher elevation angle beyond 87 deg. In order to generate a system model for handling these satellite passes, the systems behavior was characterized for all high elevation angles and extensive computer simulations were carried out to generate effective trackable models under the programmed track . The model developed has provided a solution for all the elevation angles with acceptable picture quality and the deterioration in signal strength is expected when the antenna is moved away from the predicted path for a pre-determined time on either side of the vertical position in order not to lose the satellite. Though there is a deterioration in the signal strength for the highest elevation, the system never looses the track of satellite throughout its visibility to a given ground station. The tracking control with the incorporation of this model provided uninterrupted satellite tracking.

In order to implement the above models all the equipments are required to be configured and controlled through a system and therefore the necessary hardware interfaces and the user friendly software were developed for all the systems in the reception chain of the remote sensing satellite data acquisition. In addition, systems automation call for the development of high speed, high band width remote configurable cross point switches to switch the data channels from one acquisition chain to one or other recording systems/processing system. These switches are developed with built-in intelligence to configure for the default working configurations automatically in case of any problem. The systems automation also called for the development of the satellite data format simulators catering to each remote sensing satellite, the bit error rate systems as per the PN sequences of a given satellite and user friendly softwares to configure/ control of these devices in a scheduled environment. It also called for the development of the software under the scheduler environment for each function with user friendly GUI. These developments resulted in an automated reliable tracking system for remote sensing satellites and supplied to many international users.

In order to implement the hardware upgrades within a given system (local/remote), the new research approaches of evolvable hardwares using the reconfigurable logics were developed for automation/remote management. These are the current research trends in the digital systems designs for providing reconfigurable and lab on chip concepts with additional infrastructure in the FPGAs, reconfigurable memories etc., in a given system.

Building intelligence into the system is not enough unless the system communicates to the user locally or in remote in the form of a report containing status for each task/system/unit at regular intervals. These reports should contain all the configured parameters with respect to each unit and system and also the status like the satellite signal strength at regular intervals of time, the satellite positional information with respect to time, derived satellite data channel performance based on the above models, the errors in tracking with reference to the predicted and the status of the system including the backups along with the associated profiles for easy understandability by the user and for the diagnosis. The user friendly reporting software by name real time information management system was developed to enable the system to generate report on its own with least interaction to avoid the user subjectivities. These softwares also generate the statistical averages or the monthly statistics or the system performance profiles over period of time. These system generated reports developed by the author as above became one of the standard dependable outputs among the satellite designers and user community in dept. of space.

Effectively the research aimed at the development of automated data acquisition from remote sensing satellites with remote configurability and control. It also aimed to have a full automated status report generation and transmission along with the data to the user. This research enables the user to locate the data acquisition system even in remote inaccessible areas. All the above developments resulted in standard reliable products/systems from dept. of space. This research has resulted in publication of 27 papers both national and international after going through the review mechanisms. The paper published and presented by the author in an international seminar ICSCN2007 on Elevation independent tracking system for remote sensing satellites has got the best paper award. These systems were supplied to several national/international users under the IRS programme department of space. They are all working error free from the time of installation.

1.8 Organization of the thesis

The subsequent chapters of this thesis describe in detail the research work carried out.

CHAPTER – 2: **Characterization of data acquisition system through simulation**

This chapter deals with the design and development of Bit Error Systems, the satellite data format simulators and associated software developments for the simulation of the data acquisition systems in auto mode. All the necessary background and the mathematical models are also detailed in this chapter. The characterization of the reception systems for the derivation of the functional models for the automation through simulation is the key concept in this chapter.

CHAPTER-3: Modelling and Development of online BER Measurement System

This chapter deals with the development of a model for the qualification of the data acquisition channel during the video data download using the statistical approaches. Application of the same for remote sensing satellites and in particular the IRS series of satellites is detailed in this chapter. This new concept uses the system behavioral model derived in the previous chapter and deduce the BER of the satellite data acquisition channel in realtime. As a part of this system high bit rate digital correlators for the frame synchronization in realtime are also covered in this chapter.

CHAPTER-4: Computer Controlled Tracking System

This chapter deals with the development of a computer controlled tracking system with all the in-house developed softwares for automation etc…Automation of the tracking systems call for understanding and characterization of the station control systems. Along with the systems development the reliability of the system is also covered in this chapter.

CHAPTER-5: Modelling of Zenith Passes and implementation through program tracking

. This chapter deals with the analysis and development of a model to handle the tracking of high elevation passes as the tracking requirements for high elevation passes are beyond the specification of a given system. The azimuth rate requirements vary from one elevation to the other. Therefore a model is developed to derive the trajectory information for all high elevation angles with appropriate augmentation to the program track so that the satellite tracking becomes uninterrupted.

CHAPTER-6: Development of the Systems for the automated operations of ground station

The technology developments in the VLSI, design tools, computer processors, storage systems, I/O interfaces and the reconfigurable FPGAs provide the flexibility for the designs for the process automation and the remote configuration/ control of the systems. This chapter deals with the application of these concepts to the data acquisition systems for the automated operations and also with the development of all the associated systems.

CHAPTER-7: Realtime Data Acquisition Information System (RDAIS)

This chapter deal with development of the necessary softwares for handling the systems status information to generate status reports in auto mode by the system to make it accessible and available to all the authorized users. It also addresses the management of this information through data bases etc..

CHAPTER-8 Conclusions and Future work

This chapter deal with the conclusions and future work based on the reconfigurable systems. Developing the Hardwares for remote upgradeability are covered under reconfigurable systems as future work in this chapter.

Chapter-2

Characterization of Data Acquisition Systems Through Simulation

***Abstract* :**

The satellite visibility periods are too small, it is necessary to characterize the system in the absence of the satellite using the satellite data simulators so that the same model can be used to qualify/diagnose the system in real time quickly. The entire process is carried out through a simulation function enabling it to have the knowledge of the reception system to provide the online diagnostics for the subsequent functional tests/receptions. As the process is repeated on a day to day basis, the system functional model gets fine tuned and behavioral models can also be generated. The quality of the data reception depends upon the signal at the input of demodulator and qualified with the Bit Error Performance.

The simulation of the data archival and realtime systems is a complex process as it requires precise modelling of orbit and attitude for a given satellite. Therefore the new concepts were introduced (a) to inject realistic auxiliary data (either simulated or the real) to the satellite data stream in the simulator(b) to inject the compressed image data to the satellite data simulator for a given satellite pass (c) to develop the programmable multi satellite data simulator catering to the data formats of different satellites (d) to develop the Computer Controlled Simulation Models. Characterization of the reception system using Bit Error Test Systems and Satellite data format simulators and associated developments for the automation is detailed in this chapter. These new concepts and all the associated systems were developed by the author. These systems are used operationally at NRSA and supplied to several national and international users from dept. of space.

2.1 Characterization of Data Acquisition Systems and its importance

Remote sensing Satellites are in the orbit of 600Km to 800 Km height from the earth and the orbital period range from 90 to 100 minutes per orbit. For a given point on the surface of the earth the Satellite is visible for 2 or 3 orbits and each orbit for a period of 10 to 15 minutes from horizon to horizon. During this short periods of 12 to 15 minutes visibility time, Satellite imaging and simultaneous data transmission takes place to the ground station. During the visible orbits in the night the ground stations can take the dump of the data that was recorded onboard the satellite with the data pertaining to a different region. Therefore the short period of visibility where the data dumping takes place is very critical for ground station. During these instances ground segment systems have to demonstrate the 100% availability and reliability as unreliability results in loss of data which is irreversible and an expensive process. Therefore ground segment is required to be planned and developed for the above efficiency on a continuous basis uninterruptedly. The systems and processes are required to be designed to demonstrate the reliability on day to day basis. This led to the development of simulators to validate the processes/systems in the absence of satellites. Developments in VLSI and availability of software tools made the entire process feasible including the online diagnostics and remote management.

The characterization of Data Reception Systems (DRS) through the simulation process is an important task as the same can be used for the quick certification of the DRS in realtime. Day to day systems validation is done with reference to this model addressing simulation of data reception systems, without the antenna movement and including the antenna movement. One of the best sources for the characterization of DRS is through Bit Error Performance which also provides thresholds for systems operations for acceptable BER in providing error free data. Simulation of the data archival and realtime systems is a complex process as it requires the orbit and attitude models etc., for going through all the functional tests. This called for the development of Satellite Data Format Simulators (SDFS) catering to the formats of each remote sensing satellite with the new concepts of embedding either the simulated or the actual aux data to the data stream. In order to handle the data compression and encryption, new concept of embedding the encrypted and compressed data to the data stream in SDFS was also deployed. These are totally new concepts and developed by the author for the characterization and simulation of data acquisition systems for remote sensing satellites. The simulations are carried out under the programmed mode and hence the system will have the total knowledge of the process and status.

2.2 Simulation of Data Reception Through Bit Error Performances

The references [14-16] were taken for conceptual theory. The data reception channels are validated for the efficiency in terms of bit errors. The systems are expected to provide the specified bit error performance based on the minimum signal threshold levels of E_b/N_o at the demodulator input. As the system design caters to the required margins, the reception systems are expected to provide the acceptable BER from the specified threshold for the specific bit error rate of 1×10^{-6}. With the advent of technology and the VLSI approaches, the bit error performance of these channels have improved and the systems are able to provide much better bit error performance in the current day technologies. Therefore one of the best sources that is used for this simulation processes is the bit error test system consisting of PN sequence transmitter and receiver. The bit error rate is defined as a ratio of bits in error and total number of bits and mathematically it is represented as

$$\text{Bit Error Rate(BER)} = \frac{\text{No. of Bits in Error}}{\text{Total No. of Bits}}$$

In the bit error test system the transmitter or the generator routes, the PN sequence of selected code length, through the system under test. The receiver synchronizes its internal sequences to the received sequences from the system under test and checks for mismatches or errors.

The PN sequence data for a specific frequency for a given satellite from the data simulator after the necessary modulations and conversion passed through the reception chain and at the output of the BSSC the BER performance is measured. This method allows to detect with the minimum threshold that is required to produce the acceptable BER as per the system environment. It helps to ensure the evaluation for proper data quality, during the real-time. This also helps to validate the system for the Jitter as per Doppler specifications and realtime satellite data environment.

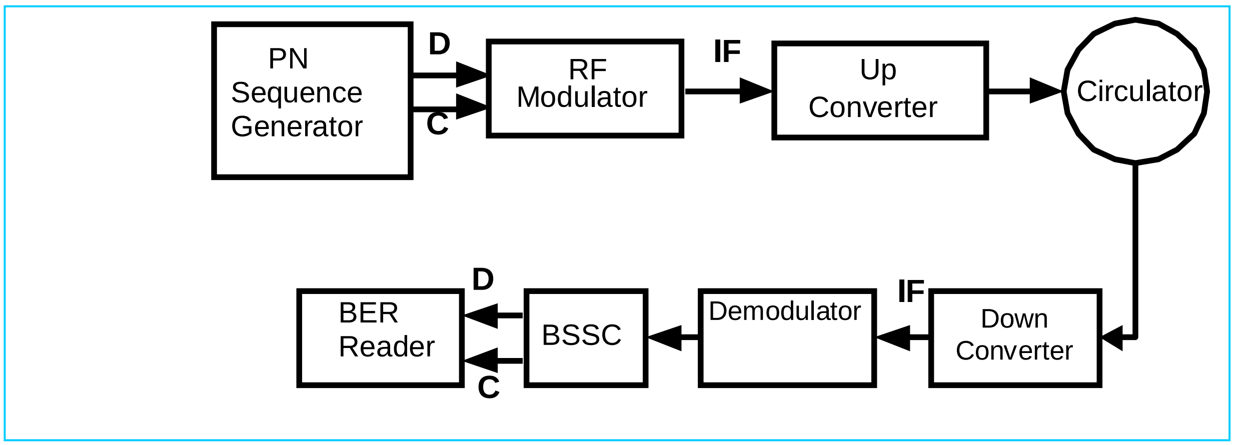


Fig. 2.1 Validation of Reception System by PN sequence

- **Boresight Simulations:**

Bore sight simulations [17,19,21,22,24] are used for the calibration and validation of reception systems including the tracking systems where the data from the bore sight is taken as data source for tracking. The antenna gets certified at the antenna test site before the installation and therefore the boresight simulations are handled to cater to the dynamic and daily operational requirements of the system with reference to the pointing accuracies etc., some of the important considerations with reference to the antenna range and the boresight measurements are as follows:

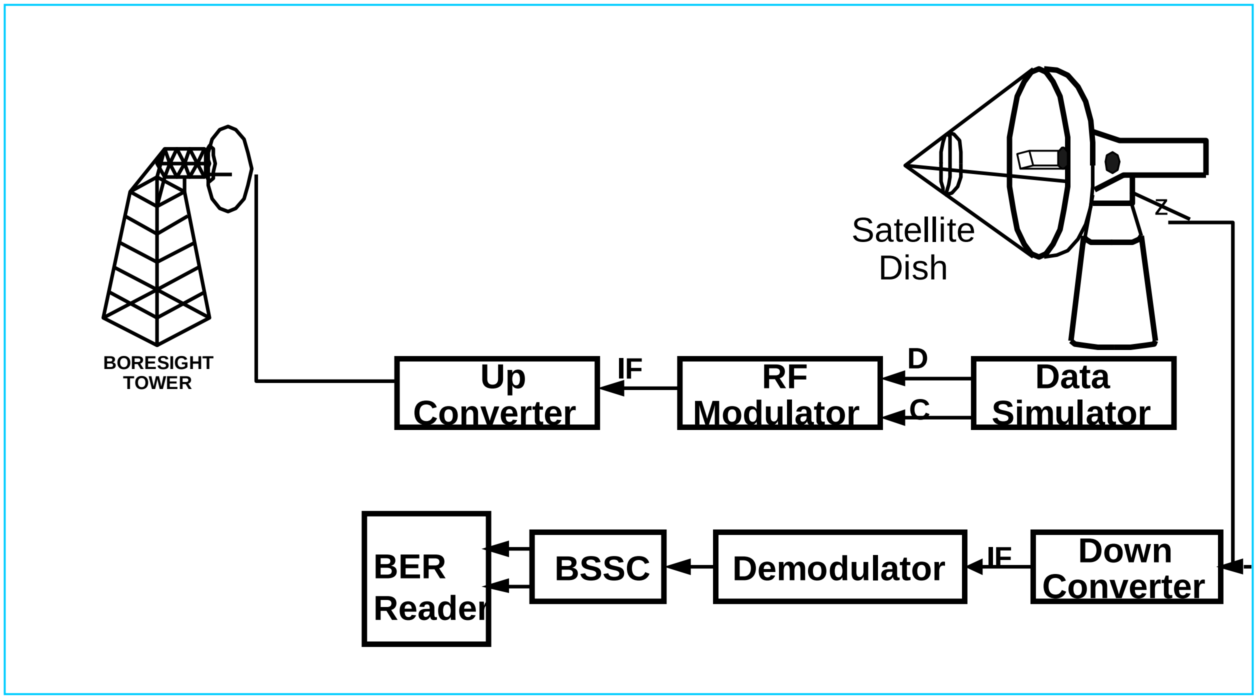


Fig. 2.2 Boresight tests for validation of DRS

The choice of the antenna test range depends on many factors such as the directivity of the antenna under test, the frequency range and the desired test parameters. Often the mechanical features of the antenna (size, weight and volume) can have deeper influence on the selection of the antenna test range as do the electrical performance factors. Regardless of the chosen test range, the given factors that are to be addressed and to be ensured for the successful measurement are: Phase variations of the incident field, the amplitude variations of the incident field and the stray signals created by reflection within the test range. The criteria used are that the phase should be constant to within 22.5 deg. of the incident field. Under the normal operating conditions, the criteria are easily achieved due to the large separation between transmitting and receiving the antenna systems. From the point of view of antenna test, it is desirable to make the antenna measurement at short ranges due to various practical considerations. Since the measurement must simulate the operating situation, it is necessary to determine the minimum operation between transmitting antenna and the receiving antenna for a reasonable approximation of far field gain and radiation patterns. At distances from the transmitting antenna which are large compared to the antenna dimensions, the phase front of the margin wave is nearly spherical in shape. For extreme separation, the radius curvature is so large that for all practical purposes, the phase front can be considered planar over the aperture of the antenna. The mathematical expression for this minimum range

$$R \geq \frac{2D^2}{\lambda}$$

Where

R = Range Length

D = Aperture Diameter of the Antenna under test

λ = Operating Wavelength

The major affect of small deviation ‘D’ is to produce minor distortions on the side load structure. For the X-Band Frequency operations, range ‘R’ will be approximately equal to 5 Kms.

2.3 Simulation of the Data Archival and Realtime System

As a readiness to acquire the data from the satellite, simulation process is used to validate the real-time data archival systems too. The concept is to pump the data from satellite data format simulator in the identical format as of the satellite and to go through the total process as if it is the satellite data. The data from the satellite data format simulator gets recorded on the Redundant Array of Inexpensive Disks(RAID) systems after going through the real-time frame synchronization, injection of UTC etc. If the data is a PN sequence data, the data on the RAID can be evaluated for bit errors through the specific software while separating the AUX and line count embedded in the data format. In case the data is of a specific pattern, either 0 or 1 or in combination which can also get evaluated from the RAID for the known data pattern sets for calculating the bit errors. In addition to the above, the data also can get evaluated in the display of the computer monitor while viewing it physically with the help of the software. In case the data is an image, the same can be evaluated through the real-time display on the system monitor. Therefore this process will provide the error information or the data loss information with respect to the frame synch and bit errors in the data in case the data is a PN sequence or a known pattern. The data can be fed directly from the data format simulator to the real-time data archival system for the quick evaluation of data archival and realtime systems. Certain references were taken from text books [13,18,20] and other references are from author’s publications.

In the other mode, the data simulator output is passed through the RF up-link and receive chain and the final output available from the BSSC (bit synchronizer and signal conditioner) of receive chain is connected to the computer via front-end hardware. This mode is used to evaluate the receive chain except the antenna and feed. In addition to the above, the following functions are carried out in the realtime systems.

- The separation of the auxiliary information and processing the same for the derivation of the orbit information, attitude information etc., so that the same can be used to derive all the necessary parameters for processing the data subsequently
- The system also generates sub-sampled browse chips for the data that is received using the scene framing information derived from the orbital elements and the actual data information from the auxiliary information as above.
- The system also generates the raw data products for the national archives.

The validation of these systems through the simulation process also exercises all the above functions of the system so that all the real-time and the near real-time functions are validated to provide 100% availability of the systems on 24 x 7 basis uninterruptedly.

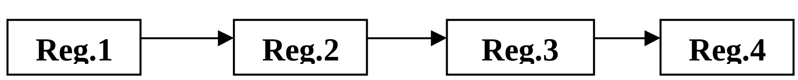
2.3 Development of Systems

The simulation process described above necessitated the development of two systems namely (a) BER Test Systems and (b) Satellite Data Format Simulators. It also called for the development of associated softwares for handling the process automatically and for remote management. Necessary softwares were designed to handle simulation as a process to validate each device, system and as a function. The automation of softwares along with necessary GUIs for logging the data, validation, report generation and also to provide necessary inputs for diagnostics. These systems were developed by the author at N.R.S.A and published [23,25,26,29]

2.4.1 Theory of Shift register sequences for the Development of BERTS:

[30,31]

A shift register is an arrangement of ‘m’ tubes in a row, where each tube



either on (1) or off(o), which shifts the contents of each tube to the next tube in time with a clock pulse. If no new signal is introduced into the first tube during this process, then at the end of ‘m’ shifts (or even sooner) all the tubes will be off and will remain that way.

One way to keep the shift registers active is to feed back the status of certain of the ‘m’ tubes into the first tube. That is, leads from certain of the ‘m’ tubes feed into the mod 2 adder, and when the next shift in the register occurs the mod 2 sum is transferred to the first tube.

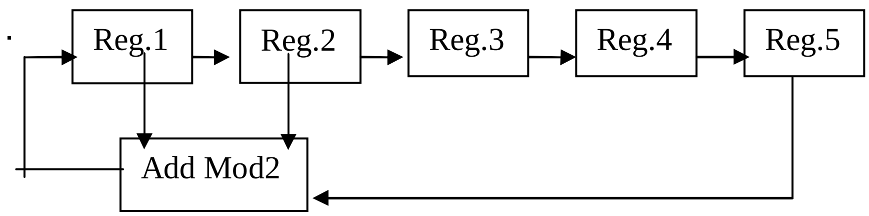


Fig. 2.3 Concept of shift register sequences

The succession of the status in a shift register is periodic, with a period of

$P \leq 2^m - 1$ where m is the number of tubes. A linear shift register sequence is defined by a linear generator polynomial g(x) of degree m>o where

$G(x) = g_m x^m + g_{m-1} x^{m-1} \ldots + g_1 x + g_o$

For binary sequences g_i equals to 0 or 1 and $g_m = g_0 = 1$ setting g(x) = 0 yields the recurrence $x^m = g_{m-1} x^{m-1} + g_{m-2} x^{m-2} + \ldots + g_1 x + 1 \pmod 2$

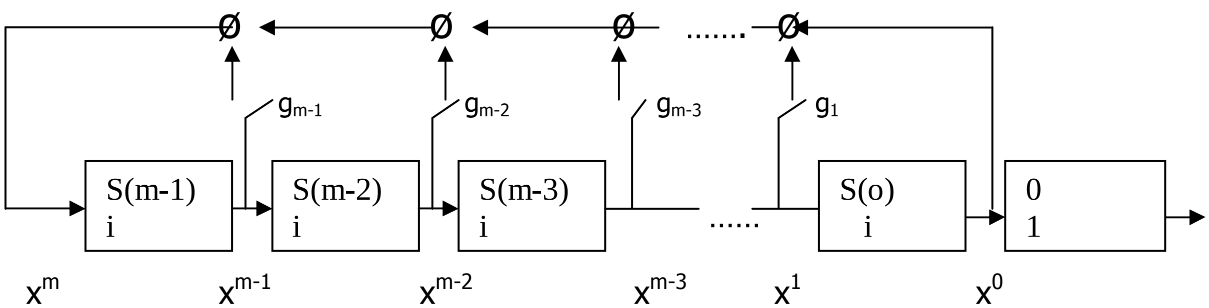


fig. 2.4 m stage mod2 binary sequence generator

With x^k representing k delay units, this recurrence equation specifies the feedback connections in the binary shift register circuit of the above circuit where the exclusive OR gates perform the mod2 operations, If $g_i = 1$, the corresponding circuit is closed otherwise if $g_i \# 1$, it is open. The shift register is a binary finite state circuit with ‘m’ memory units. Hence the maximum number of non-zero states in $2^m - 1$ which is equal to the maximum period of the output sequence C = $(C_o, C_1, C_2 \ldots)$.

Let $S_i(J)$ denote the value of the J^{th} shift register at clock pulse i. The state of the shift register at clock pulse ‘i’ is the finite length vector $S_i \{ S_i(m-1), S_i(m-2), \ldots S_i(0) \}$

The output at clock pulse i is $C_i = S_i(o)$
Replacing x^m by C_{i+m} in the above equation, the sequence recurrence condition is

$$C_{i+m} = g_{m-1} C_{i+m-1} + g_{m-2} C_{i+m-2} \ldots + g_1 C_{i+1} + C_i \pmod 2$$

For i$\geq$0, for example consider the generator Polynomial $g(x) = x^5+x^4+x^2+x^1+1$ and based on this equation: $C_{i+5} = C_{i+4} + C_{i+2} + C_{i+1} + C_i \pmod 2$

and construct the linear feedback circuit as below:

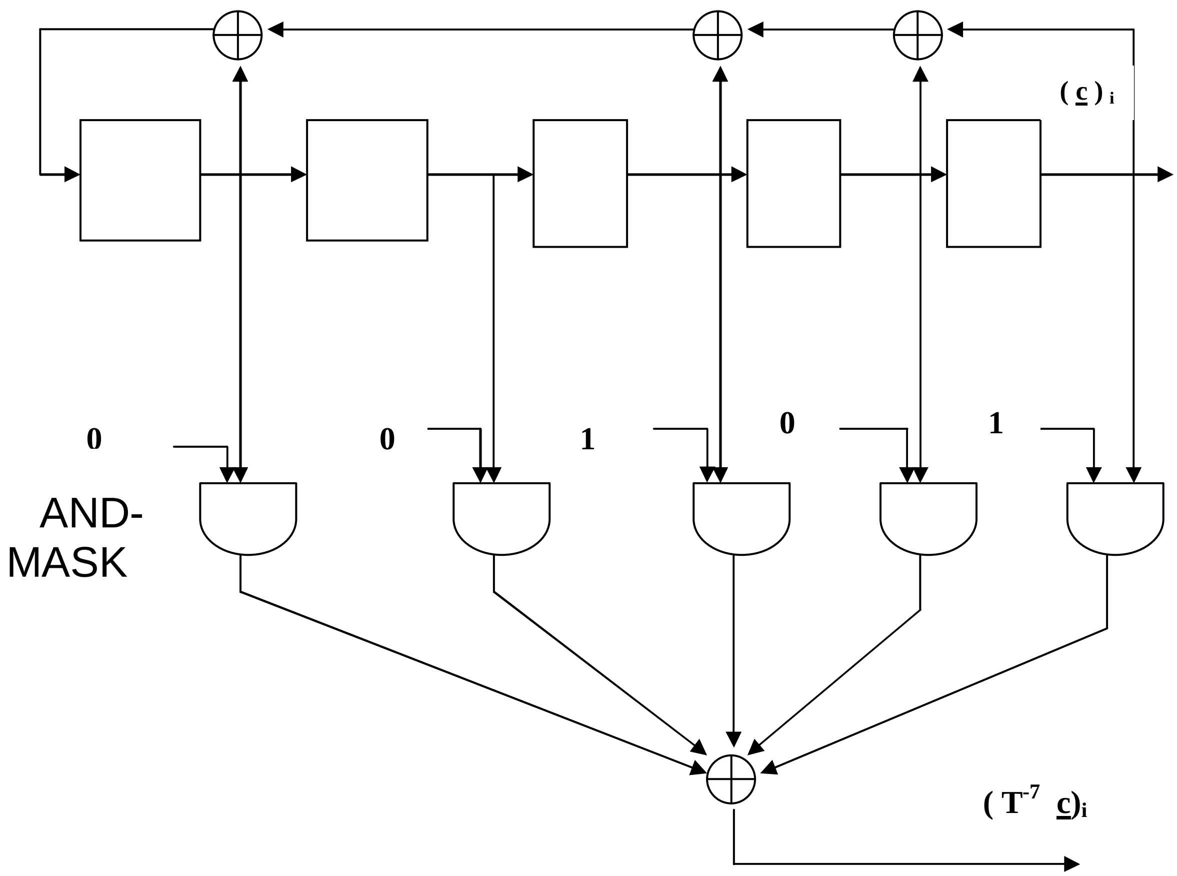


Fig. 2.5 **Concept of linear feedback shift register sequences**

Clock pulse i	State
0	11111
1	01111
2	10111
3	01011
4	00101
5	00010
6	10001
7	01000
8	00100
9	10010

10	01001
11	10100
12	01010
13	10101
14	11010
15	01101
16	00110
17	00011
18	00001
19	10000
20	11000
21	11100
22	01110
23	00111
24	10011
25	11001
26	01100
27	10110
28	11011
29	11101
30	11110
31	11111
32	01111
33	Repeats

Table2.1 State diagram for 5th order polynomial

Example of Shift-register sequence with $g(x) = x^5 + x^4 + x^2 + x^1 + 1$.

Since the degree of g(x) is equal to m=5, there are 5 memory (shift registers) units in the circuit. For any non-zero starting state {ie S_0…(0,0,0,0,0)} the state of the shift register varies according to the recurrence condition as specified by the generator polynomial g(x).In this, the output periodic sequence is the last column in the above figure is C = 111110100010010 10110 00011 100110…….. Which has a period of N=31 (2^5-1 = 31).

In this particular circuit configuration, the first m-bits of the output sequence is equal to the initial loading of the shift register which is set to S_0 = 11111. For a different initial loading of say So = 00001, the corresponding output sequence becomes 100001110011011 11101 00010 010101……. Which is a shift (to the right by N-I = 31-18=13 units) of the sequence C

A shift register sequence period N has N shifts or phases. Let T^{-J} C denote a shift of the sequence C- to the left by J units, Likewise T^{+J} C- represents a shift of the sequence C- to the right by J. The other shifts of C- can be obtained by a linear combination of these m=5 outputs. The shift operator $T^{\pm J}$ is now interpreted as cycle shift operator with

$T^{-J} C = (C_J, C_{J+1, \ldots\ldots} C_{N-1,} C_{o\ldots\ldots} C_{J-1})$ and $T^{+J} C = (C_{N-J,} C_{n-J+1\ldots} C_{N-1,} C_{o\ldots} C_{N-J-1}$

The clock speed of the above circuit is limited by the sum of the time delay in one shift register and the time delays in all the exclusive OR gates in the feedback path and expressed as $\{ \check{T}_{\text{Shift register}} + \check{T}_{\text{OR-gates}} \sum_{i=1}^{m-1} g_i \}$ where Ť denotes the time delay For high speed implementation with clock speed as fast as $\{\check{T}_{\text{shift register}} + \check{T}_{\text{OR gates}})^{-1}$ the circuit configuration will be different where the exclusive OR gates are introduced as given below

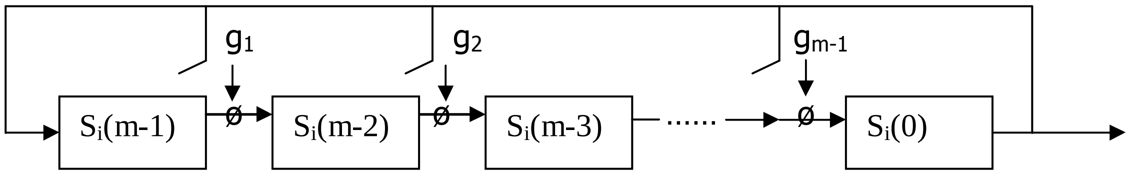


Fig. 2.6 Register sequences for high speed implementation

A binary linear shift-register sequence that has a period N equal to 2^m-1 , where m is the number of memory units in the circuit or the degree of the polynomial, is called a binary maximum-length sequence or m sequence. The generator polynomial of an m-sequence is called a primitive polynomial. A mathematical definition of a primitive polynomial is that g(x) is a primitive polynomial of degree m if the smallest integer n for which g(x) divides x^n +1 is n=2^m-1 . For example $g(x) = X^5 + X^{4+} X^2 X + 1$ is a primitive polynomial of degree m=5 since the smallest integer for which g(x) divides
$X^n + 1$ is n = $2^5 - 1 = 31$

Generator Polynomial Specifications

The generator polynomial parameters can be specified in either of the ways.

- A vector that lists the coefficients of the polynomial in descending order of powers. The first and last entries must be 1. The length of the vector is one more than the degree of the generator polynomial.
- A vector containing the exponents of x for the non zero terms of the polynomial in descending order of powers. The last entry must be zero.

For example [100000101] and [8 2 0] represent the same polynomial
$g(x) = x^8 + x^2 + 1$
Initial status is a vector specifying the initial values of the registers, must be binary numbers and the length of the initial status vector must be equal to the degree of the generator polynomial with at least one element of the initial status vector must be non zero.

Sequences of maximum length

To generate a sequence of the maximum possible length for a fixed degree 'm' of the generator polynomial, one can set generator polynomial to a value from the following table:

m	Generator Polynomial	m	Generator Polynomial
2	[2 1 0]	21	[21 19 0]
3	[3 2 0]	22	[22 21 0]
4	[4 3 0]	23	[23 18 0]
5	[5 3 0]	24	[24 23 22 17 0]
6	[6 5 0]	25	[25 22 0]
7	[7 6 0]	26	[26 25 24 20 0]
8	[8 6 5 4 0]	27	[27 26 25 22 0]
9	[9 5 0]	28	[28 25 0]
10	[10 7 0]	29	[29 27 0]
11	[11 9 0]	30	[30 29 28 7 0]
12	[12 11 8 6 0]	31	[31 28 0]
13	[13 12 10 9 0]	31	[32 31 30 10 0]
14	[14 13 8 4 0]	33	[33 20 0]
15	[15 14 0]	34	[34 15 14 1 0]
16	[16 15 13 4 0]	35	[35 2 0]
17	[17 14 0]	36	[36 11 0]
18	[18 11 0]	37	[37 12 10 2 0]
19	[19 18 17 14 0]	38	[20 6 5 1 0]
20	[20 17 0]	39	[40 8 0]
40	[40 5 4 3 0]	47	[47 14 0]
41	[41 3 0]	48	[48 28 27 1 0]
42	[42 23 22 1 0]	49	[49 9 0]
43	[43 6 4 3 0]	50	[50 4 3 2 0]
44	[44 6 5 2 0]	51	[51 6 3 1 0]
45	[45 4 3 1 0]	52	[52 3 0]
46	[46 21 10 1 0]	53	[54 6 2 1 0]

Table 2.2 Maximum length sequences

2.4.2 Design and Development of BERTS:

The functional block diagram of the Bit Error Rate Test (BERT) System is shown in fig 2.12. The major blocks of the system are PN sequence Generator/Transmitter, the output of which will be a selectable code length, becomes the input to the system under test. The output of the system will be connected to the receiver. The configuration and control of both transmitter and receiver are realized through an interface control using a Microcontroller. The interface control provides connectivity to front panel LCD and keypad. The remote control is implemented through GPIB. The references are design platforms[13,20] and author's publications[23,25,26].

Fig. 2.7 **LED indicator based BERTS**

Fig. 2. 8 **LCD front panel based BERTS**

2.4.2.1 Transmitter:

This module basically generates the PN sequence. The input to the sequence generator is a clock of selected frequency. The clock is generated from a synthesized clock generator as shown in the functional block diagram of BERTS Transmitter Fig.-2. 13

The Transmitter also has a provision to accept fixed frequency clocks from additional crystal clock sources. This provision is basically introduced to aid the user to the most frequently used frequencies. This is an important design feature so that user can have the typical frequencies of his choice in addition to the variable clock input. Transmitter has shift registers and the parallel outputs of the same are taken to a modulo -2 adder to provide a feedback to the shift registers in order to generate a PN binary sequence with feed forward technique. Feedback taps are selected as per the table such that the maximum length sequence will result at the output. The half sequence generation approach is used to double the frequency of operation.

Pattern Selected	$2^7 - 1$	$2^{15} - 1$	$2^{20} - 1$	$2^{23} - 1$
Full Sequence Taps	**6,7**	**14,15**	**17,20**	**18,23**
Hal Sequence Taps	**5,6**	**13,14**	**16,19**	**17,22**

Table 2.3 Feedback taps for commonly used PRBS

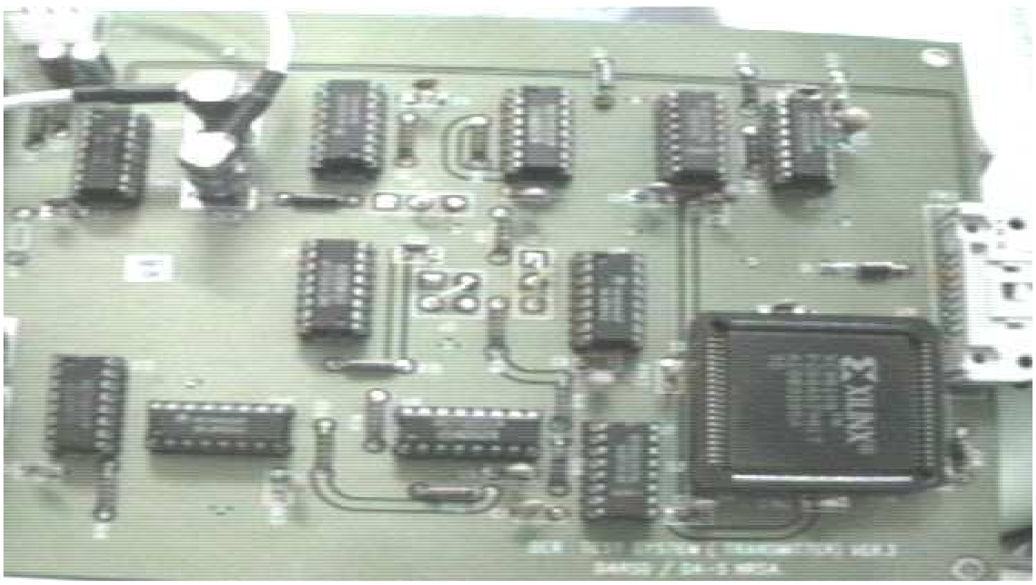


Fig. 2. 9 Transmitter logics of BERTS

The sequence length control logic selects the sequence. Selection is done using the keypad through the micro controller interface logic. The sequence generator is intelligent to avoid all Zero state. In this case “all zero detection logic” will inject a “ONE”, ensuring an uninterrupted output for sequence generator. There is provision for the injection of an error once in every thousand bits. The entire configuration and the control signals are generated through the Microcontroller 87C51. The transmitter logic is implemented in one EPLD.

General Specifications:

- Generates PN Sequence of Code Lengths 2^7 -1,2^{15} -1,2^{20} -1 & 2^{23} -1
- Supports user defined crystal frequencies up to 2 numbers.
- Provision for Known Error Injection (1 in 1000 Bits)

2.4.2.2 **Receiver**:

The functional block diagram of BERTS receiver is shown in Fig.2.14. The Receiver Logics in BERT were implemented in 3 EPLDs of Xilinx make. In the Receiver module, the sequence that is received is synchronized to the same Bit Clock in the synchronizer module. The Receiver is set to the expected known sequence length through the GPIB/Key Pad. In case the input sequence has an injection of errors, it will be transparent in BER. Subsequent to the synchronization of the input sequence with reference to the same Bit Clock, the sequence is fed to the shift registers. As the sequence length is already set, the system assumes the search loop to obtain the lock. Thus the Receiver checks for the PN sequence property in the open loop condition for the known self-generated PN binary sequence and correlates it with the received sequence. When the correlation takes place, the loop gets closed with the received PN sequence seed word to generate error free PN sequence in synchronization with the input sequence. Subsequent to the match of the input PN sequence, the agreement detector changes the state to lock state and during the lock state, the Receiver has to check the input PN sequence for the errors during a sample window. Therefore the error counter gets enabled by the sample window repeatedly and counts the errors. The errors in the form of Bit Error Rate are displayed in the front panel graphics LCD.

In the presence of many Bit Errors, the error counter is expected to count large numbers and the same is termed as state of bad BER wherein the error detector and loop control logic drops the lock status to unlock and opens the internal loop in order to keep the internal loop in search state. Subsequently as and when the match takes place, the agreement detector changes the lock status to lock and so on. Thus this process repeats from search mode to lock mode etc., depending on the number of errors in the input sequence. The micro controller interface with associate software provides all the necessary configuration and control signals to the Receiver module. All the user interfaces are handled through the keypad fixed in the front panel. The remote operations are carried out through GPIB Interfaces.

General Specifications:

- Supports PN Sequences of Code Lengths 2^7 -1,2^{15} -1, 2^{20} -1 & 2^{23} -1.
- Supports Data Rates up to 160 Mbps
- Displays Bit Error Rate as a function of Exponent
- Variable Exponent Window from 10^{-2} to 10^{-9}
- Displays input frequency on a Six-Digit Scale.
- Lock, Gating, Overflow Indications on Front Panel.

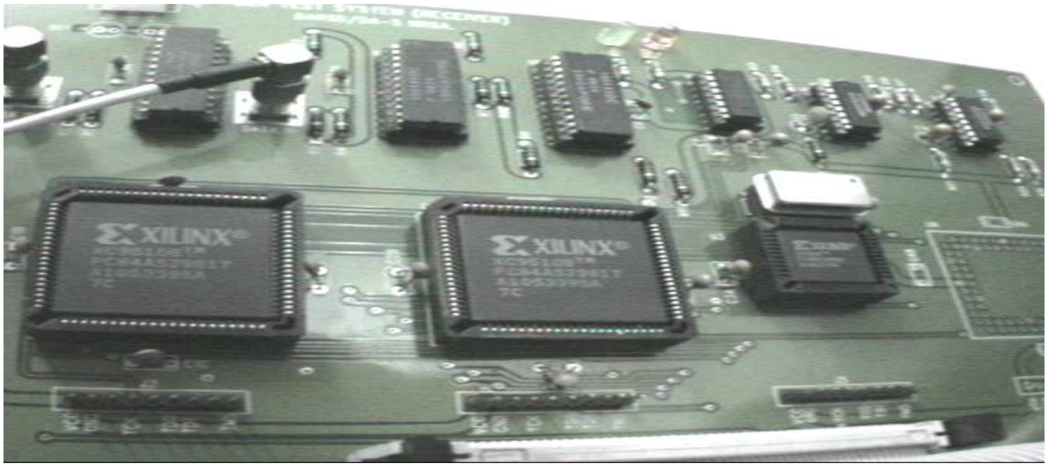


Fig.2.10 Receiver logics of BERTS

2.4.2.3 Front Panel and GPIB Interface

The Micro Controller 87C51 is used for the keypad interface, the graphic LCD interface and the GPIB. The functional block diagram of Front Panel & GPIB interface is shown in Fig.2.15. The remote operations for configuration and control are realized through GPIB. The System is interactive through front panel in the local mode of operations. In the local mode of operation, the system has two functions viz., the display and edit. During the display function, the system reads the data from the transmitter and receiver as the status viz., the BER, the clock frequency, lock status, gating window status and error overflow etc., In the edit function, the configuration controls can be edited through the front panel keypad. The editable controls are transmitter clock frequency, additional fixed crystal source, sequence lengths, enable and display of error injection, code selection, exponent selection etc. The entire software is user friendly and made easy for operations.

Fig.2.11 GPIB Interface for BERTS

General Specifications:

- Local/ remote selection
- Device initialization
- Clock source selection
- Frequency measurement
- Tx & Rx Code length selection
- BER Exponent window selection
- Reading of Bit Error Rate
- SYNC, Overflow flag status

2.4.2.4 Specifications

Power Supply

Power Input	: AC 230 Volts/50 Hz.
DC Power Outputs	: Regulated + 5V/3A and – 5.2V/2A

BER Receiver

Data & Clock	: ECL, 50 Ohm terminated, into front panel BNC connector.
Frequency range	: 1MHz to 160MHz.
PN Sequence Patterns	: **2^7 –1, 2^{15} –1, 2^{20} –1 & 2^{23} –1** supported
Displays	: High brightness TIL displays/LCD panel.
Resolution	: Error measured over a span of 1 in 10^{-2} to 1 in 10^{-9} selectable by two switches on front panel

BER Transmitter

Data & Clock	: ECL, 50 Ohm terminated, into front panel BNC connector.
Frequency range	: 42.452 MHz & 84.903 MHz&105 MHZ selectable from front panel &from an external clock upto 160 Mhz
PN Sequence Patterns Supported	: **2^7 –1, 2^{15} –1, 2^{20} –1 & 2^{23} –1** selectable from front panel
Error Injection	: I –2 errors in 1000 bits.

Environment

Temperature	: 10 deg C to 50 deg C
Humidity	: Up to 95% relative.

Physical

Panel height	5.25 inches

Chassis Width : 17 inches

Chassis Depth : 19 inches

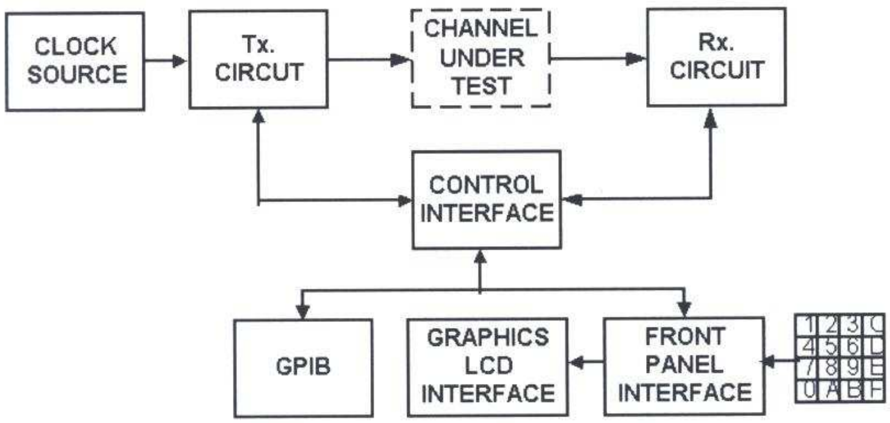
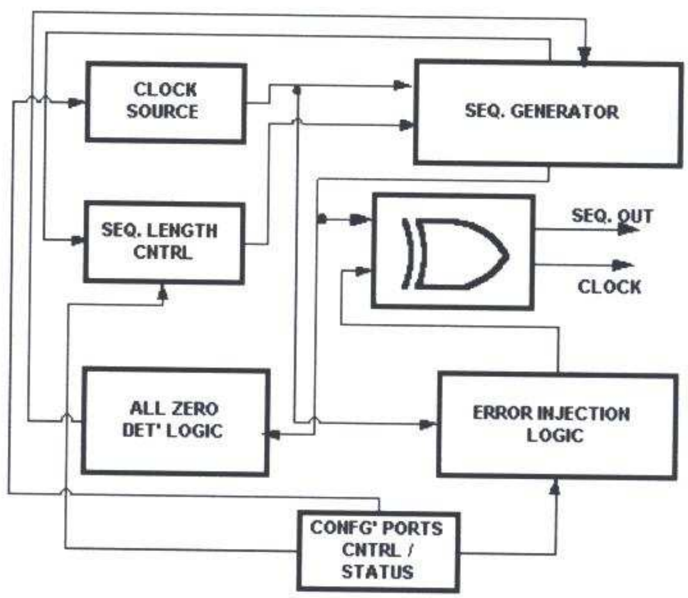
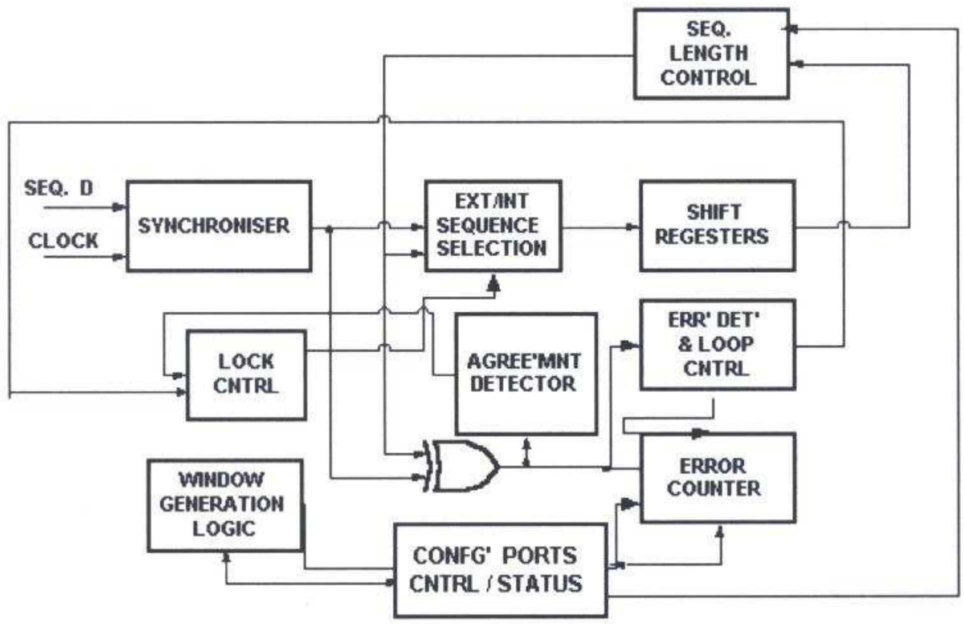


Fig .2.12 BERTS OVERALL BLOCK DIAGRAM



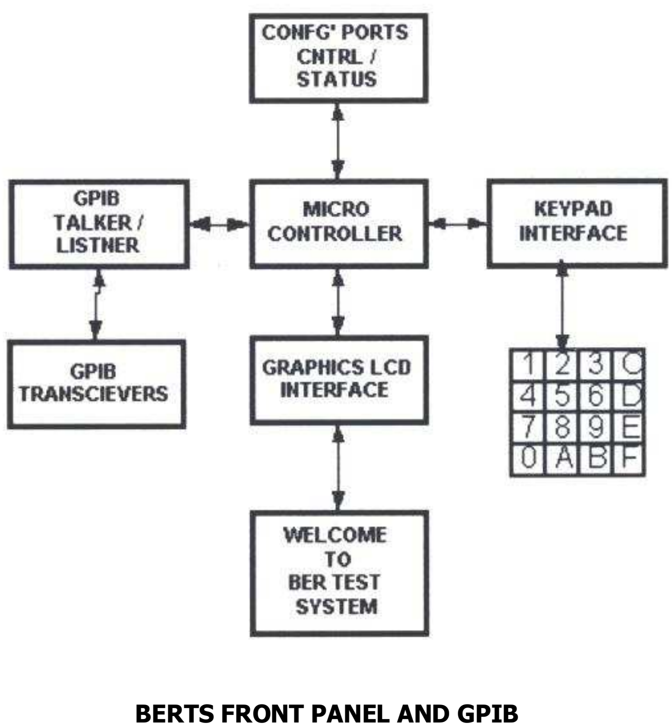
BERTS TRASMITTER

FIG.NO. 2.13 FUNCTIONAL BLOCK DIAGRAM



BERTS RECEIVER

FIG.2.14 FUNCTIONAL BLOCK DIAGRAM



BERTS FRONT PANEL AND GPIB

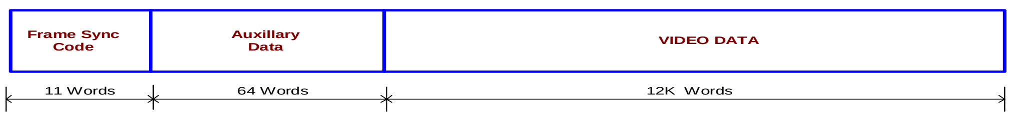
FIG.2.15 FUNCTIONAL BLOCK DIAGRAM

2.4.3 Development of Satellite Data Format Simulators

The Realtime systems are required to be tested with the data in the same format as the satellite covering all the Hardwares, Software and processes. The Realtime systems receive the data for a given sensor/satellite through the Data Reception Systems, in a serial format specific to each satellite, record the data in real-time in RAID system, and simultaneously display the data in the monitor. In order to test these systems in the absence of the satellite, Satellite Data Format Simulators (SDFS) were designed and developed by the author. As the satellite data formats vary from satellite to satellite, these SDFS are also required to be programmable/reconfigurable for each satellite[13,18,20]

- **Satellite Data Format**

The typical data format of a satellite contains the frame sync code, Auxiliary data and the image data as follows:
The external data sets AUX and Image can be injected into the data stream in the data format simulator from PC through standard Interfaces like GPIB/USB.



Word Size: 8 bit/10 bit ; Aux Data contains DH ON/OFF STATUS,LBT (HK) Data, Line Count, OBT Count. SPS Data, Video Data (mono/ multiband data), Multi Band Video Data.

The frame sync code is specified for each satellite. The auxiliary information is embedded in the video data stream contains the Telemetry, channel ID and value, satellite health parameters like temperatures, status of important elements, attitude information based on each sensors, star sensors, satellite positioning systems, gyro information, payload modes and associated cameras onboard times and related parameters etc. The video data in a specific format for each satellite contains single band data in case of Panchromatic Sensor and multiband data in case of multiband sensor. The auxiliary information is dynamic information from the satellite with sampling period of each type of data varying from 32m sec to 1 sec. Some of the parameters in Auxiliary data get repeated for some frames to provide redundancy at the ground to ensure error free reception. The video data is an image of the ground and hence totally dynamic. The stream also contain the line count to represent each line of data with unique and incrementing number in the satellite visibility. When the data handling system for a given station visibility is switched on, it presets the Line Count (LC) to one. Then onwards the LC increments at the rate of Line Integration Time (LIT) till the data handling system is switched off. During data acquisition at the ground in realtime the Universal Time (UTC) will be embedded to each line of data so that UTC or the line count can work as a reference for each line of data.

- **Design Challenges**

The main purpose of the Satellite Data Format Simulator is to provide the serial data in the identical format and data rate of a given satellite. As described above the data format contains Frame Sync Code, Auxiliary Data and Video data. The auxiliary data contains realistic data pertaining to orbit, attitude, rate values etc., of the satellite. For image data processing, auxiliary information plays an important role as the parameters derived from the auxiliary information are used for Geometric and radiometric corrections etc.. The simulation of auxiliary data by any external logic particularly the attitude etc. .will not match the satellite parameters for processing.

Therefore simulation of auxiliary data is an involved issue. One of the approaches is to use the real auxiliary data of the same satellite pertaining to the previous orbit in the same visibility etc., This concept complicates the logics as the satellite auxiliary data (external) to be injected. The line count numbers etc., can be generated and can be incremented logically like satellite through logics in the simulator. The other approach is to generate the auxiliary data as per the satellite model specific to the given orbit and inject into the stream.

The external data sets AUX and Image can be injected into the data stream in the data format simulator from PC through standard Interfaces like GPIB/USB. The image data generated internally through logics can be of different patterns like all zeros, all ones, zeros and ones arranged, grey patterns etc., It is also possible to introduce Image data externally of the same size or from the same satellite.

Data Encryption for security and data compression for Channel Bandwidth saving are used in the satellites. Simulations of such data sets add to the complexity of the simulator. However all these are essential to evaluate the ground processing.

- **Design implementation**

The design uses a micro controller for the control, USB/GPIB Interface for the management and Field Programmable gate arrays (FPGA) for data pattern generation including external aux data embedding, CPLDs are used for the interface logics, FIFOs are used to store the external data as given in the block diagram. Micro Controller 8751 is used to control all the functions of the simulator unit including user interaction, control parameter setting in FPGAs and Remote interface and all the controls for controlling the FIFOs for external data storage. GPIB interface is implemented using NAT 4882 Controller chip.

The external AUX is transferred to FIFOs through DMA mode. The AUX is then integrated to the main data stream. The data generation logics are implemented in FPGAs. External AUX is read from FIFOs. Similarly external data is also channelised in FPGA for embedding into the data stream.

All the configurations and controls are the functions of microcontroller. The line count that is generated is integrated to the data stream at the end of data. Different data patterns are generated by FPGAs in the internal data mode as explained in the design approach. These patterns change from sensor to sensor so that a sensor/satellite has different patterns for distinction. The data is multiplexed and serialized identical to the satellite data through shift registers at bit rate clock. The user interface to this unit is through a 4 x 3 matrix keypad and 128x64 Graphic LCD modules. The microcontroller accepts the user inputs through keypad along with encoder chip in interrupt driver mode. LCD will display the system configuration mode. The coherent clock at bit rate and the serialized data are available at the output as final data and clock. The unit photograph is given below:

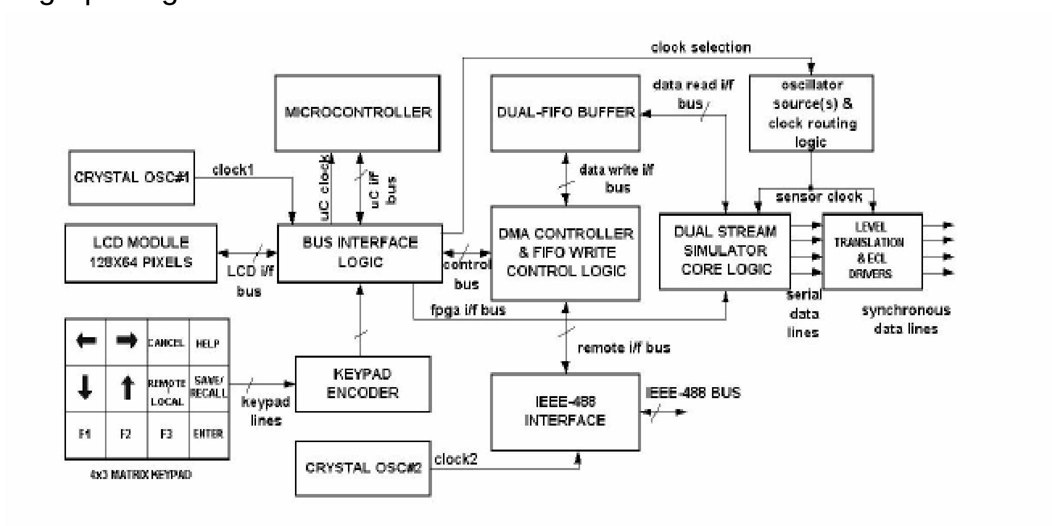
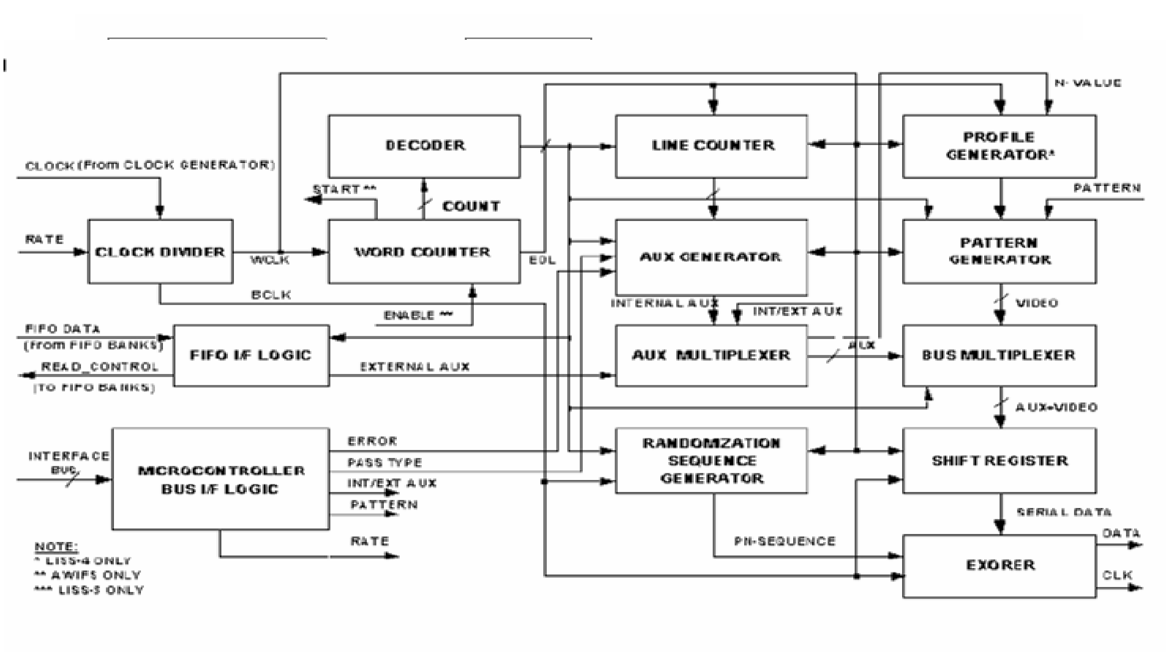


Fig 2.16 SDFS Block Diagram

Fig 2.17 Data Generation Logic of SDFS



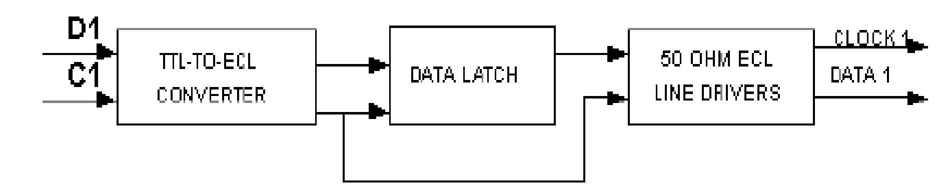


Fig *2.*18 Serial data output logic (Single Channel) of SDFS

To realize this concept a programmable hardware platform is required where the same hardware can be reconfigured for different satellites and the output data streams are available on the same ports of the data simulator. This was achieved through VLSI based design approach using Field Programmable Gate Array (FPGA). FPGA is a programmable logic device, which is in-system-reprogrammable, and multiple circuit configurations can be implemented by loading different configuration bit streams into it. The entire OCM data format of IRS-P4 was implemented in a single FPGA. This low chip count and highly integrated design approach has improved the reliability of the system and also provided a simple way for future modification and upgrades.

Later to streamline loop check through multi-satellite support, a multi-mission data simulator is designed and developed using the IRS-P4 data simulator circuit board. This system supports simulation of IRS-1A, 1B, P3, P4, 1C and 1D satellite sensor data. It can simultaneously simulate PAN and LISS sensors of IRS-1C/1D. This mode of simulation added more integrity to loop checks as both receive chains are checked in a condition that is similar to the real-time. A new feature, pseudo-random noise sequence (PN sequence) generation is added to this data simulator. This mode provided for quantitative evaluation of the chain by measuring bit error rate (BER).

TES data simulator is a full-fledged dual-stream data simulator designed for TES mission with a provision for downward compatibility for all the previous satellites. Though the logic is similar to that of IRS-P4 data simulator design, a new design had to be made as the line count data in both the PAN sensor streams differ by a fixed value. It has an IEEE-488 interface to enable system configuration and monitoring through a computer.

For IRS-P6 data simulator was implemented with an interface to download auxiliary data from computer and generate different video data patterns. For IRS-P5 due to onboard compression, compressed image data files are taken, converted to serial form and injected into the data stream. These systems were developed by the author and also published [28,29]. Other references are the internal satellite documents of dept. of space for satellite data formats [32,33,34].

2.4.4 Satellite Data Format Simulator for different satellites

Fig.2.19 IRS-P4 SDFS Front Panel

Modes:

1. OCM R/T
2. OCM R/T + OCM P/B
3. OCM R/T + MSMR P/B
4. MSMR P/B
5. OCM P/B
6. OCM CAL + OCM P/B (PN SEQ)

Patterns:

OCM R/T --- All Zeroes, All Ones, 0101…,
1010…, GREY Scale

MSMR P/B---RAMP

OCM P/B ---GRAY Scale, PN sequence

Speed: *Real-time and ½, 1/3, ¼, …,1/16 of Real-time*

Frame Sync Error Injection*:*

Maximum 11 bits (error in MSB of frame sync words)

Output:

Streams --- I, Q and I+Q
Logic --- ECL single-ended

Impedance --- 50 ohms

Format --- NRZ- L Clock phase--- 0 and 180^o

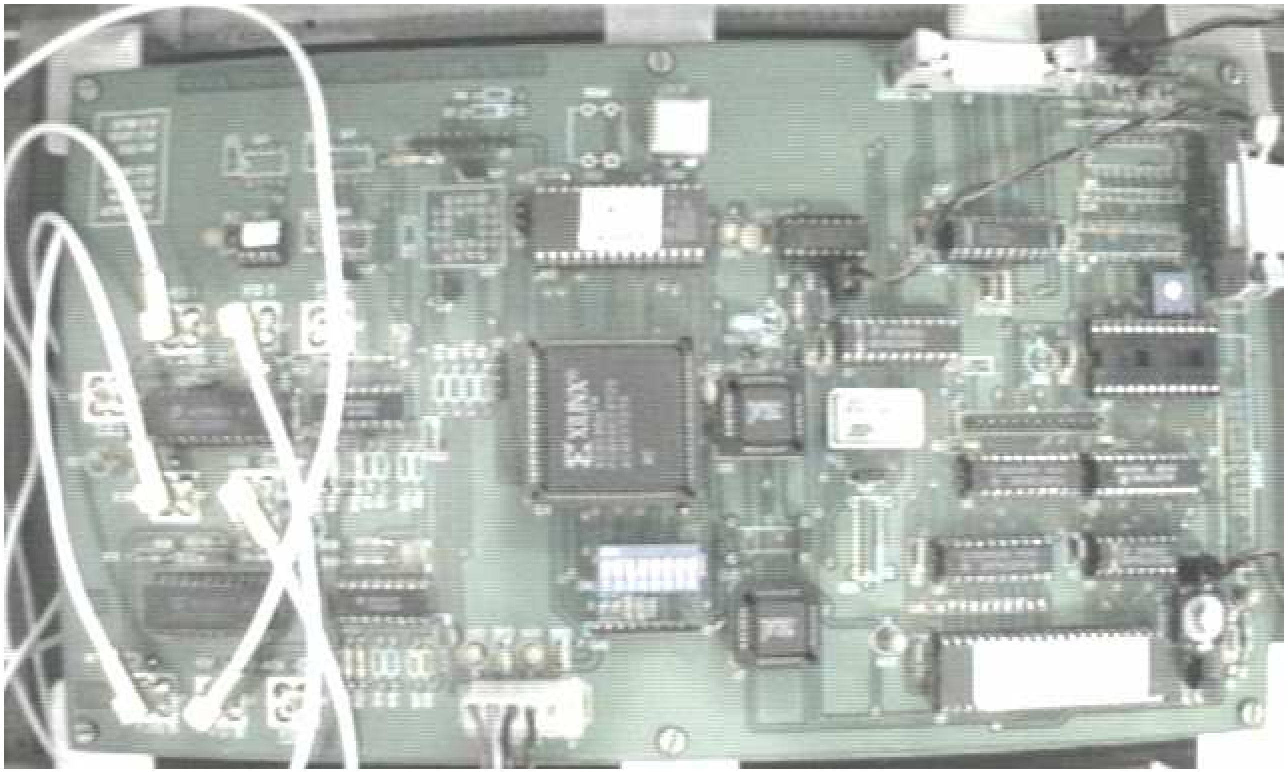


Fig.2.20 IRS-P4 SDFS PCB

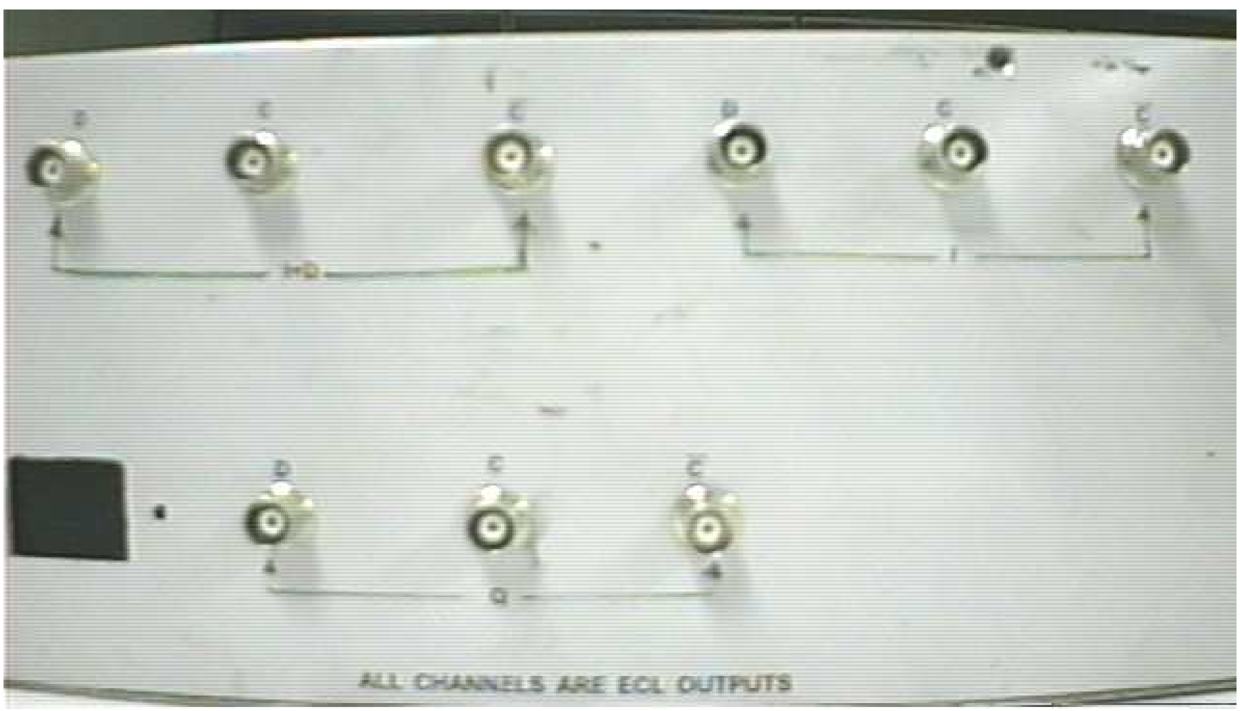


Fig.2.21 Back Panel SDFS

- **Multimission Data Simulator specifications**

Satellites:

IRS-1A/1B
IRS-P3
IRS-P4
IRS-1C/1D

Modes:

PAYLOAD
PNSEQ*

Pattern :*GRAY SCALE*

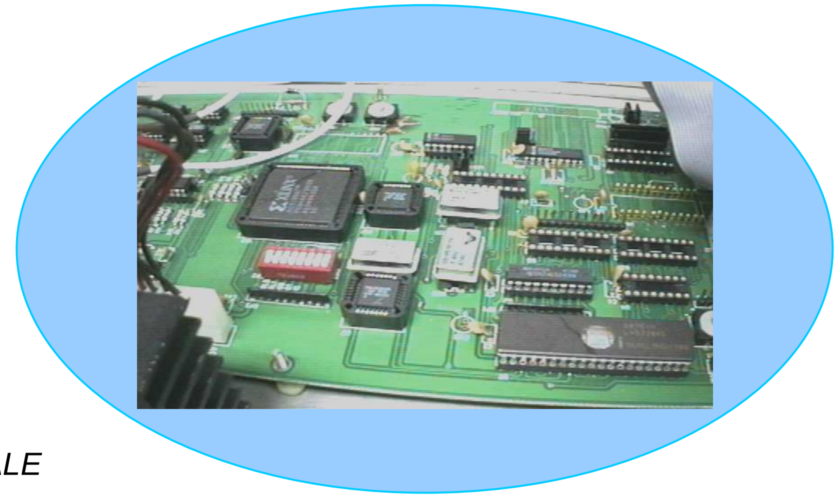


Fig.2.22 **multi-mission SDFS**

Speed: *REALTIME*

*PN-sequence mode is incorporated to generate either (2^7-1) or (2^{15}-1) code sequence at the selected satellite stream frequencies to enable quantitative checking of the receive chain

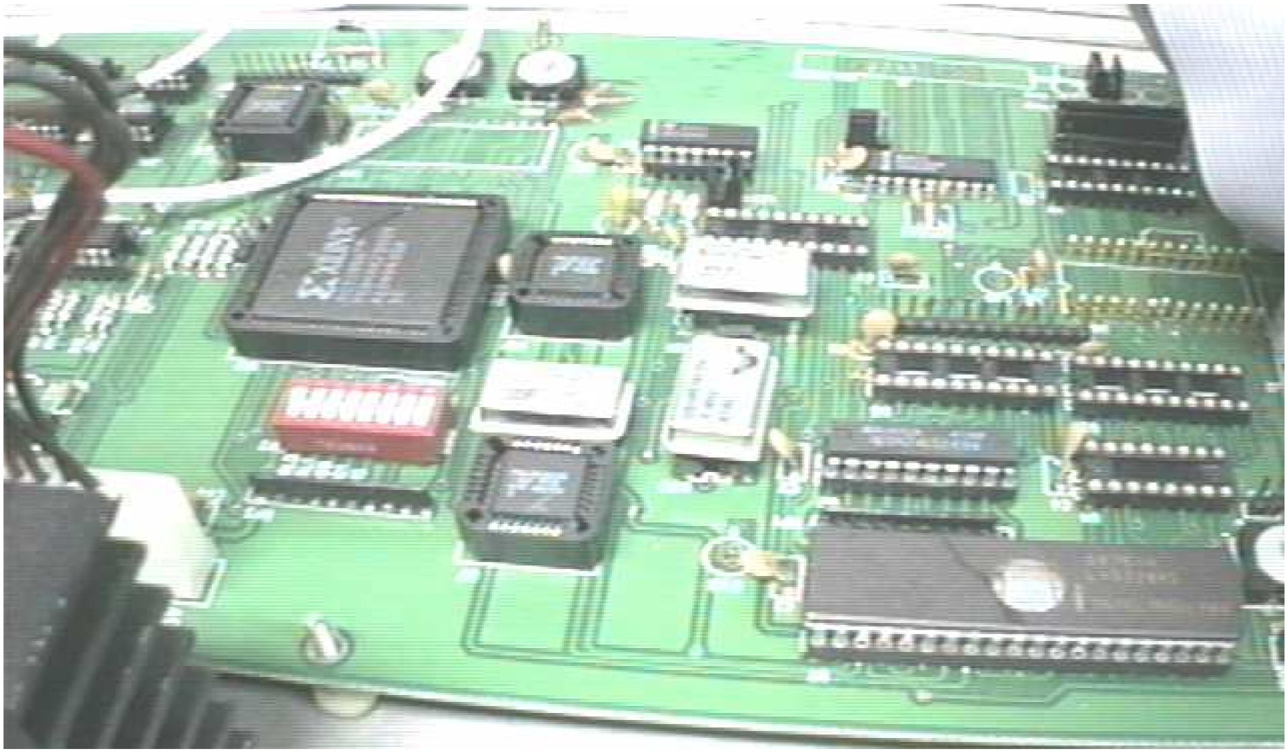


Fig.2.23 **SDFS Multi-mission Main PCB**

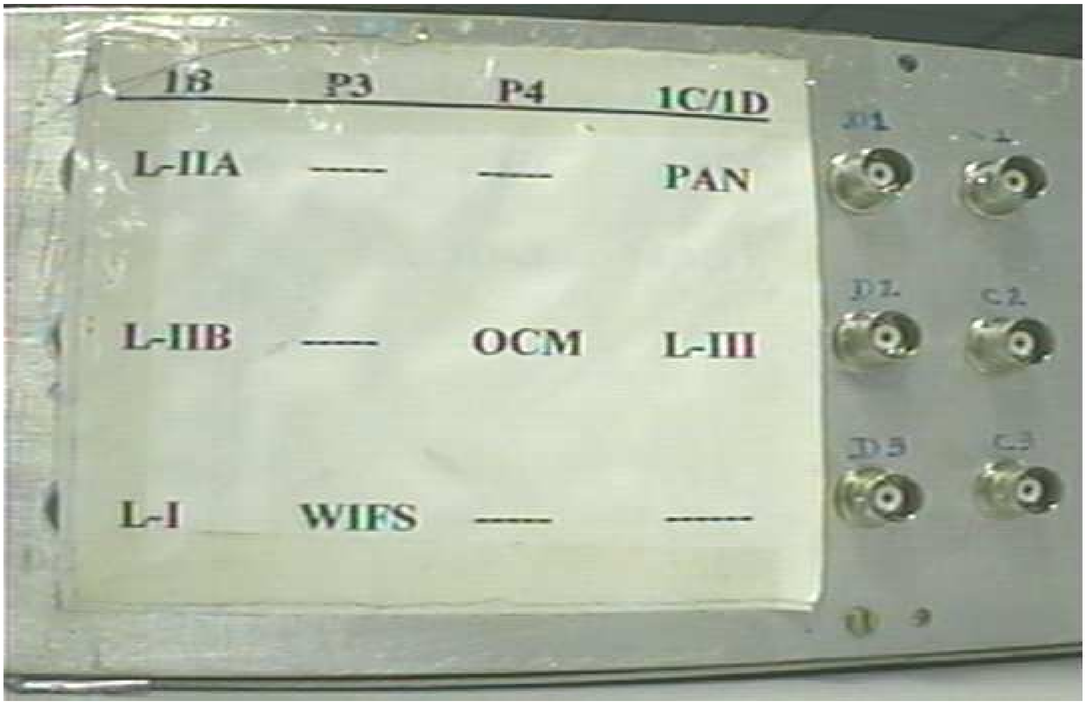


Fig.2.24 Back of multi-mission data simulator

Technology Experimental Satellite(TES) Data Simulator Specifications

Modes:

1.PAYLOAD
2.PNSEQ

Patterns:

All Zeroes, All Ones, 0101…,
1010…, GREY Scale

Speed:

Real-time and ½ of Real-time

Frame Sync Error Injection:

Upto 7 bits (error in MSB of frame sync words)

Output:

Streams --- I+Q streams of FORMATTER#1,#2
Logic --- ECL single-ended
Impedance --- 50 ohms
Format --- NRZ-L
Clock phase--- 0 and 180^{o}

Fig.2.25 TES Data Simulator Back Plane

Fig.2.26 TES data simulator PCB

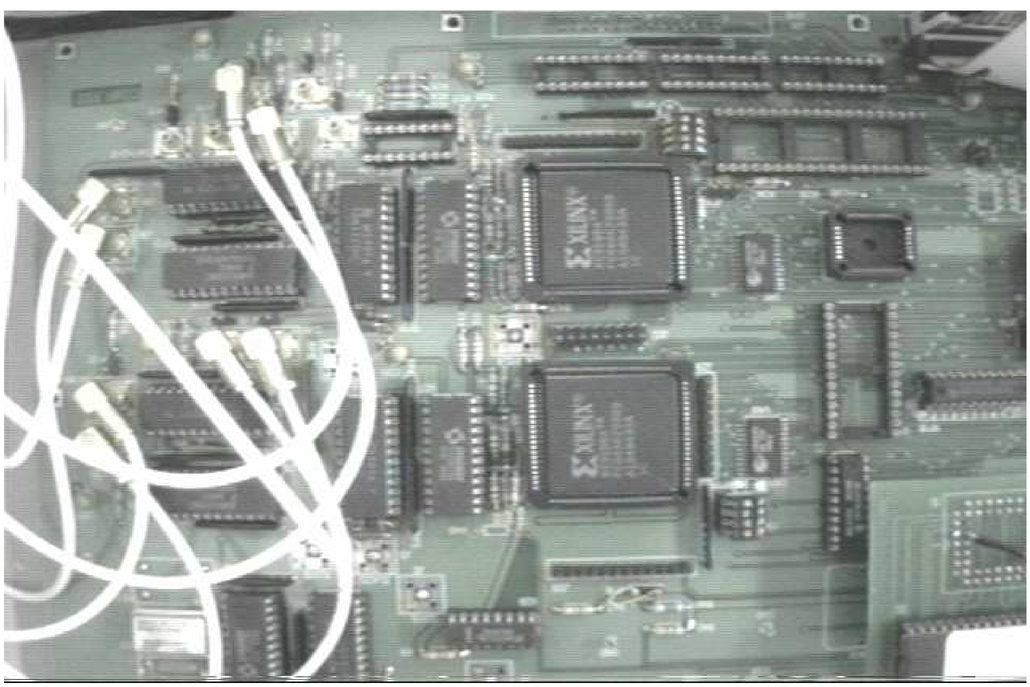


Fig.2.27 TES data simulator PCB

- **IRS P6 Data Simulator**

Fig.2.28 IRS-P6 data simulator PCB

Fig.2.29 IRS-P6 data simulator Front Panel

Fig.2.30 IRS-P6 data simulator back panel

2.5 Configuration of Systems for Simulation in the Operational Environment

The systems are validated using BER Test Units and the Satellite Data Format Simulators in the following configurations

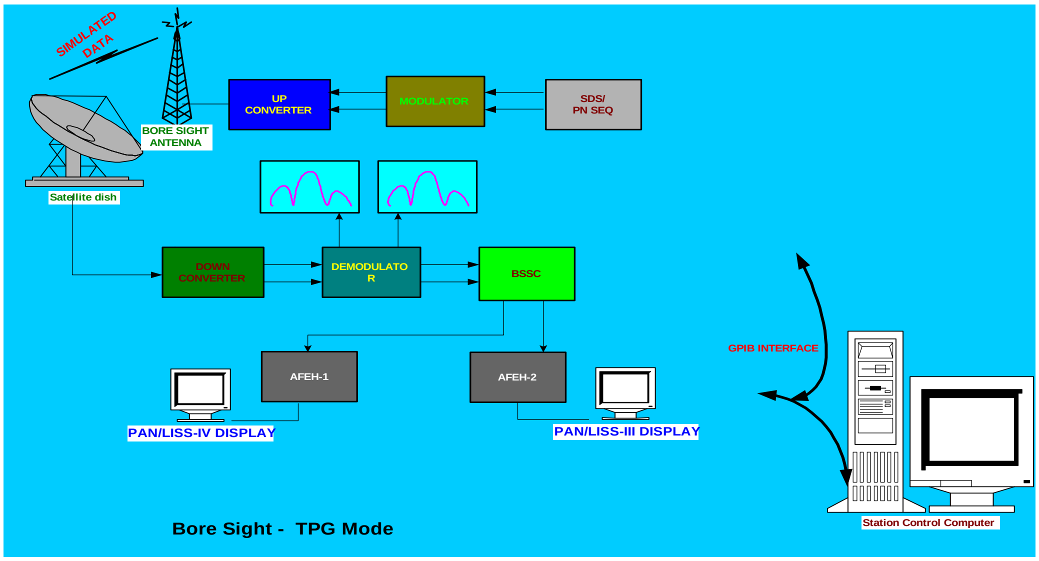


Fig.2.31 Boresight evaluation – TPG mode

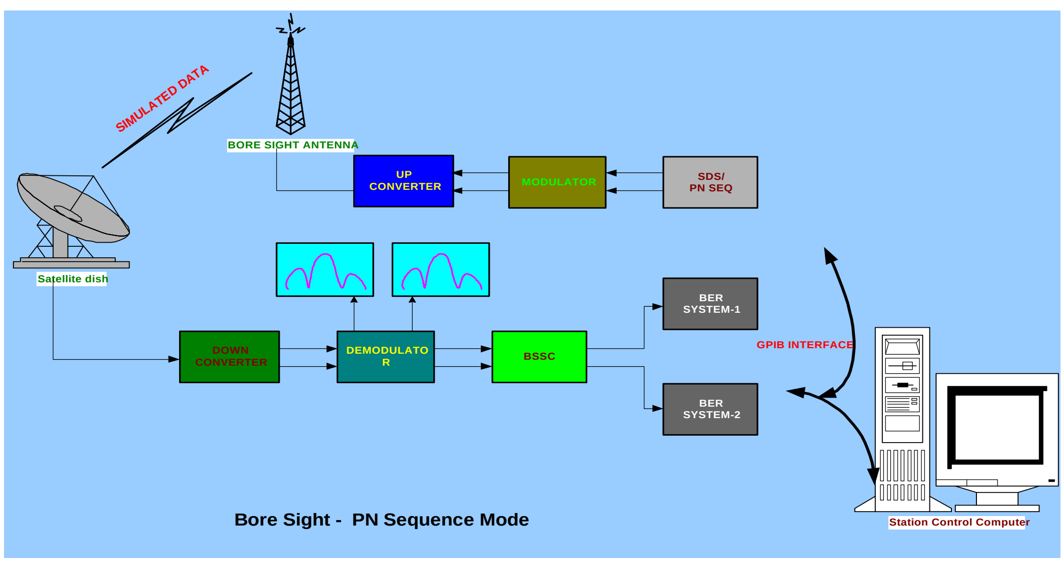


Fig.2.32 Boresight validation through PRBs

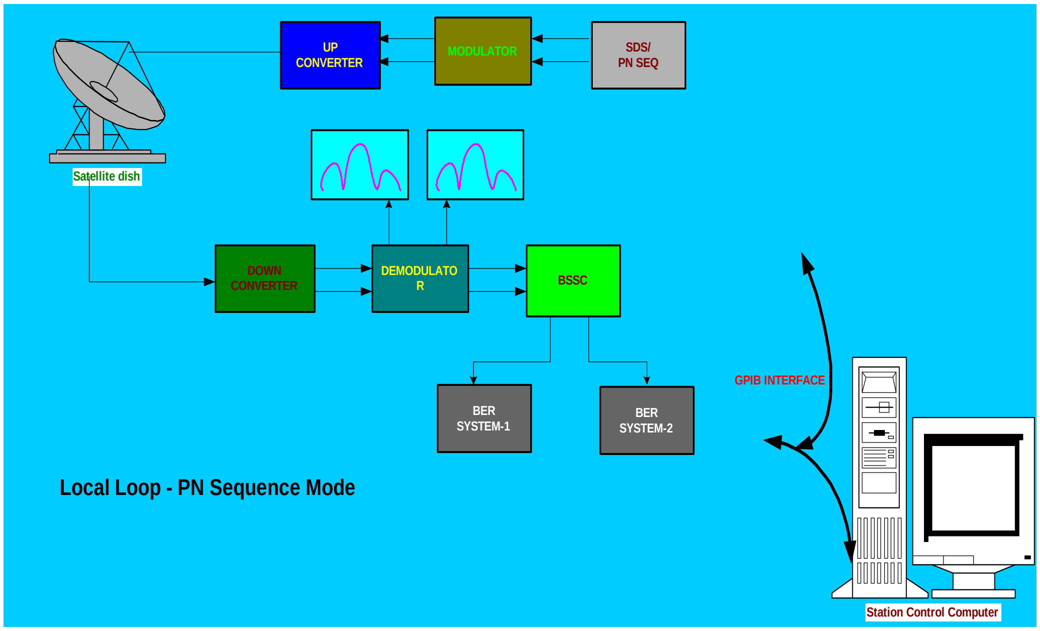


Fig.2.33 Realtime Systems Validation through PNS Generator

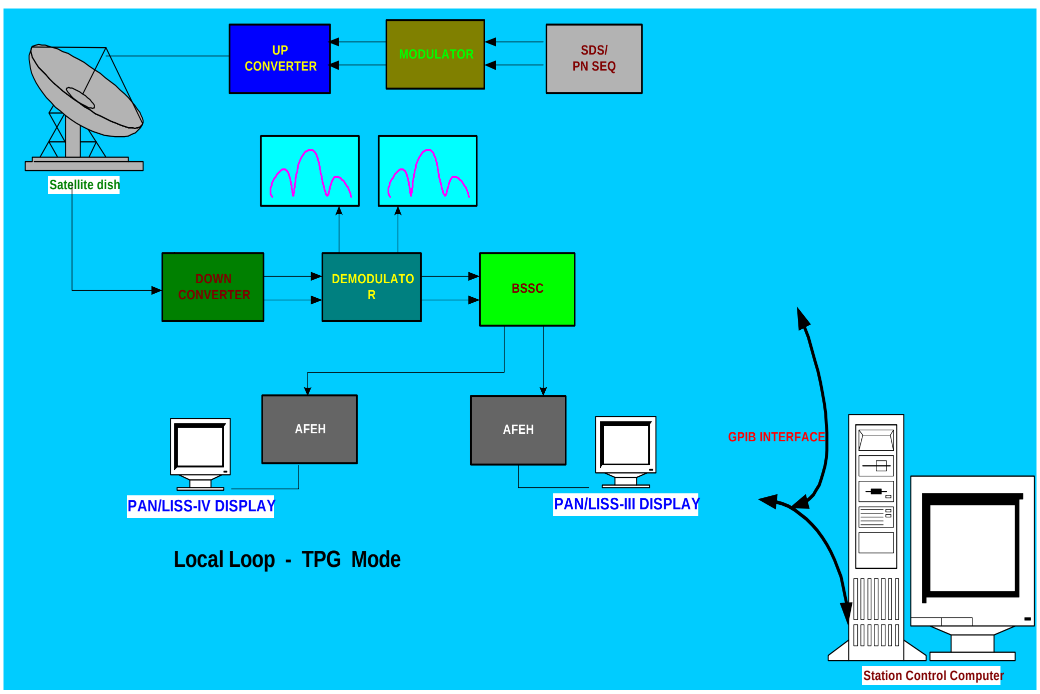


Fig.2.34 Realtime systems validation through SDFS

2.6 TEST RESULTS

2.6.1 Bit error performance test

TABLE NO.2.4 BER Performance Test (L-III) OF IRS-P6

C/No dB-Hz	Demod I/P dBm	I Channel BER
90	-19.6	$3 * 10^{-7}$
91	-18.6	$3 * 20^{-8}$
92	-17.3	$1 * 10^{-8}$
93	-16.3	0.0
94	-15.3	0.0
95	-14.3	0.0

TABLE NO.2.5 BER Performance Test (L-IV) OF IRS-P6

C/No dB Hz	Demod I/P dBm	I Channel BER
91	-11.5	4 * 10-6
92	-10.5	1 * 10-6
93	-9.6	2 * 10-7
94	-8.4	5 * 10-8
95	-7.5	1 * 10-7
96	-6.5	0.0
97	-5.5	0.0

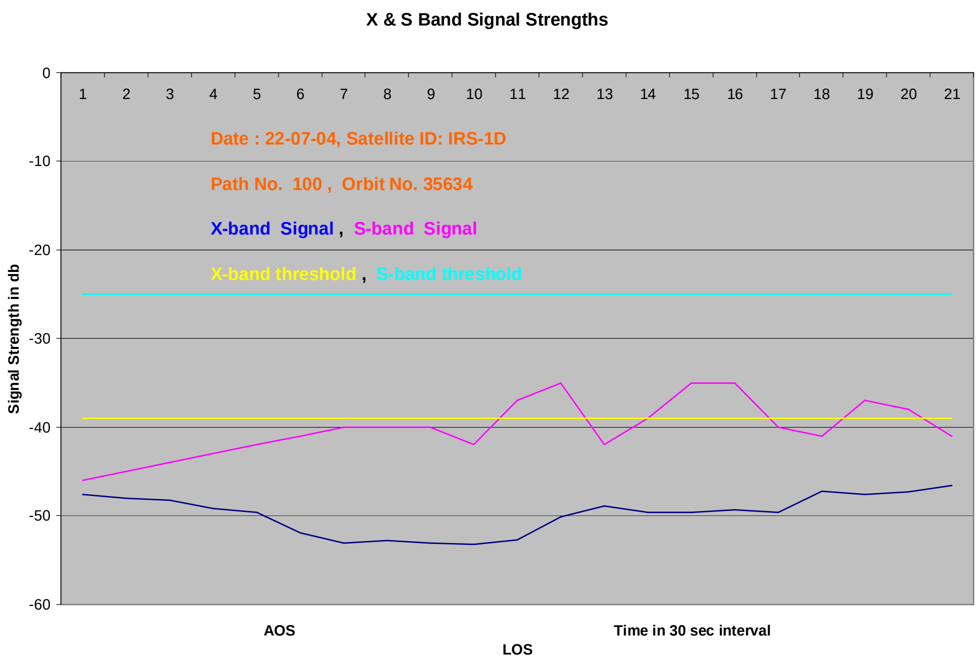
TABLE NO.2.6 BER PERFORMANCE TEST (L-IV) OF IRS-P6

C/No dB Hz	Demod I/P dBm	Q Channel BER
97	-11.5	0
96	-10.5	0
95	-9.6	0
94	-8.4	$1 * 10^{-7}$
93	-7.5	$1 * 10^{-7}$
91	-11.5	$3 * 10^{-6}$

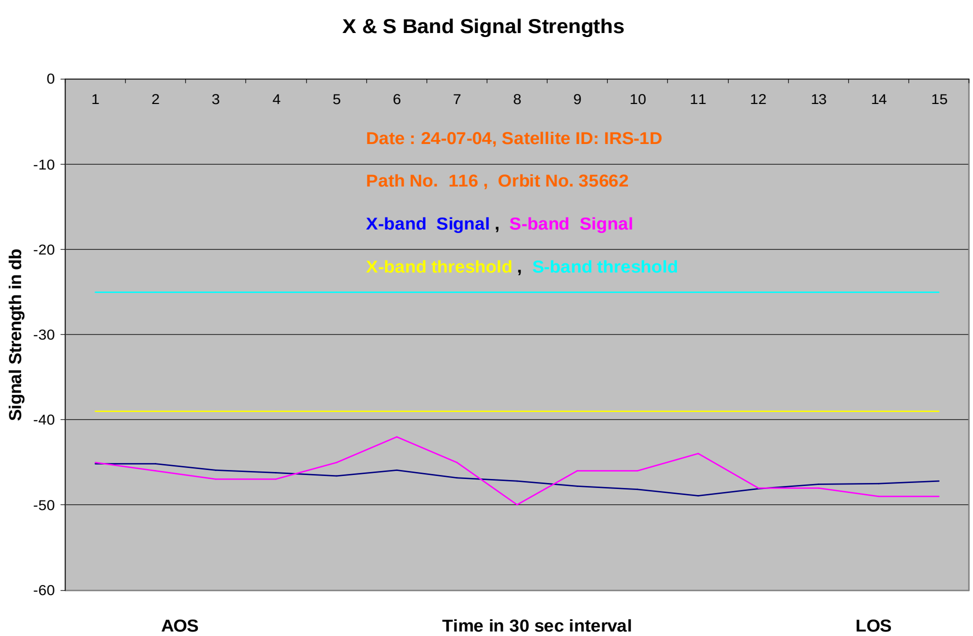
Table Signal Strength Table for X-Band and S-Band

SL.NO.	SAT. ID	DATE	PATH NO.	ORBIT NO.
1.	IRS-1D	22-07-04	100	35634
2.	IRS-1D	23-07-04	108	35648
3.	IRS-1C	23-07-04	83	44473
4.	IRS-1D	23-07-04	83	35649
5.	IRS-1D	24-07-04	116	35662
6.	IRS-1D	24-07-04	91	35663

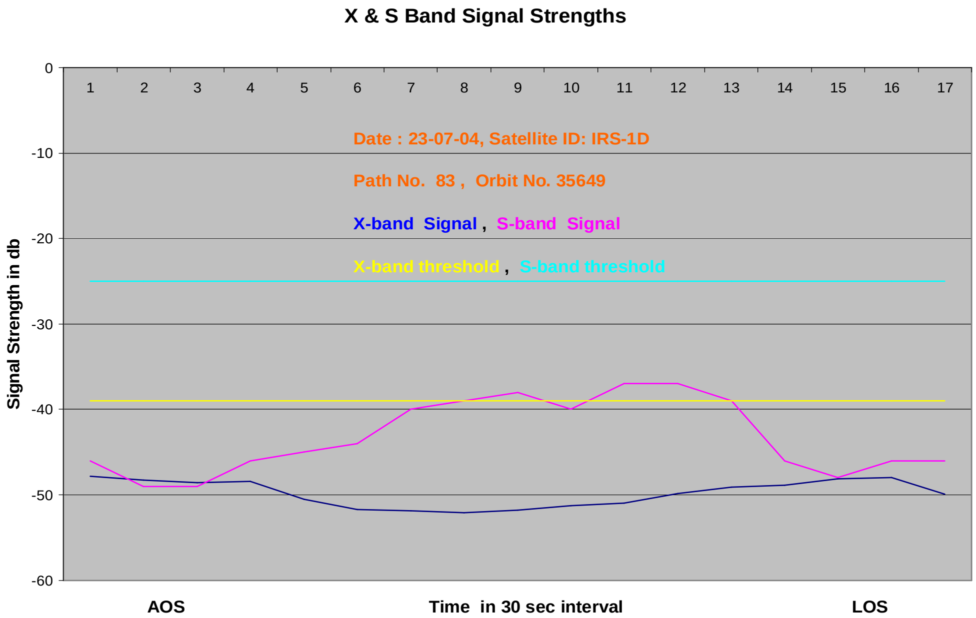
PLOT :2.7



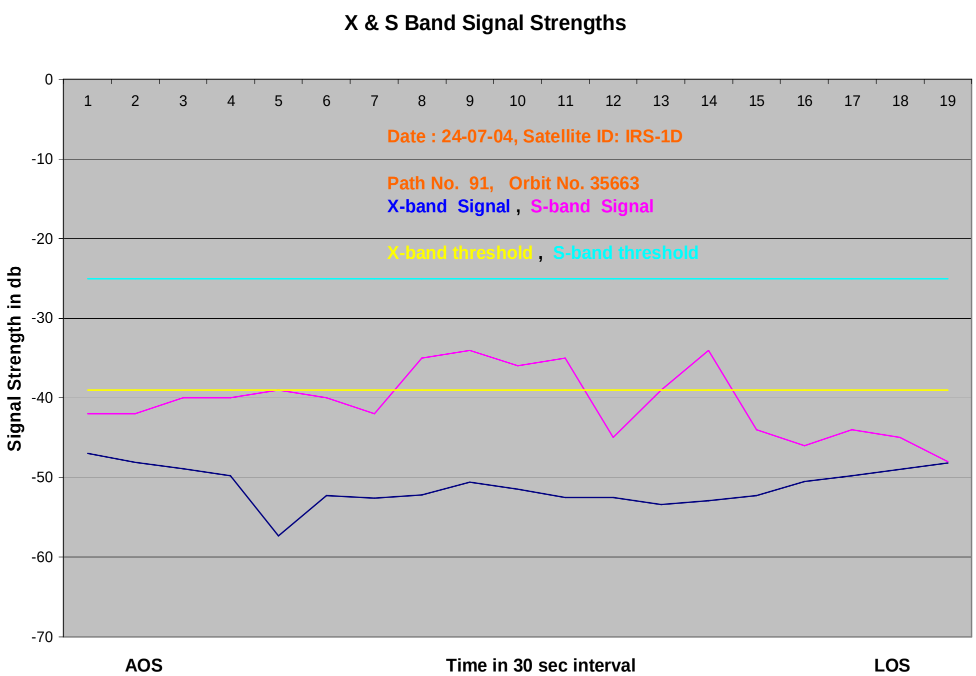
PLOT :2.8



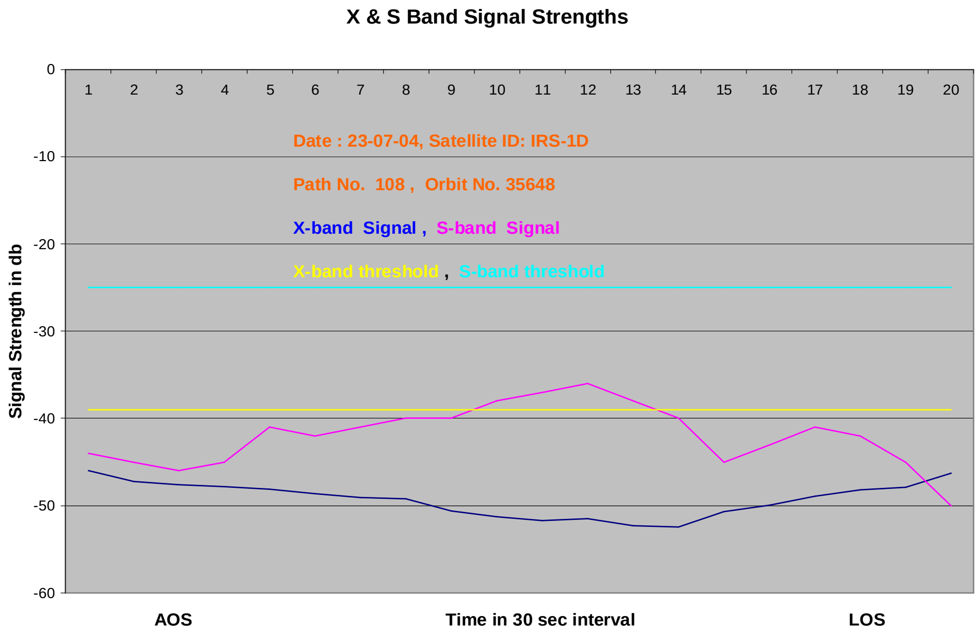
PLOT :2.9



PLOT :2.10



PLOT :**2.11**



2.6.2 **Outputs from Realtime Systems**

The simulated data take the satellite data either grey scale/patterns/actual image get recorded into the RAID Systems directly. Auxiliary data get separated and validated. The sample validated output is as follows:

IRS-CARTO2 MOVIES SUMMARY REPORT FOR orbit 24 Date 11-Jan-2007 at SAN

Taking Up Channel (O:PAN-I, 1:PAN-G) ….. 0
Size of Aux file : 11.3573888 Bytes i.e. 1774592 lines

Continuous Data Start : LN : 392578 LC : 22177
Continuous Data End : LN : 1546550 LC : 1176149

Observations in above Data Set

Total No. of Lines in this Sat : 1153973

Good Lines in this Sat : 1153973

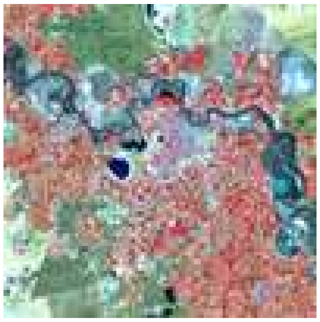
Good lines percentage is : 100 %

Sync Loss GRT Jump : O /Line Count Jumps : 0

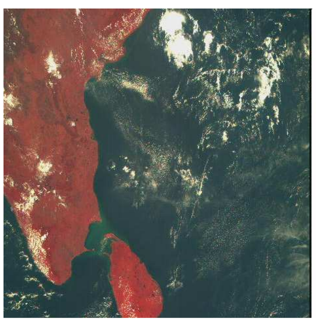
The other products from the realtime systems are ADIF, Browse and the data on DLT for national archives.

2.6.2 Browse images

IRS-P6 : LISS-IV Mx Fig.No.2.37



IRS-P6 : AWIFS Fig.No.2.38



IRS-P5 : Fig.No.2.39

2.6.4 Boresight Simulation Test Results

L-IV of IRS-P6	BER (I CHANNEL)
C/No dB Hz	$1 * 10^{-6}$
93.5	$5 * 10^{-7}$
L-III of IRS-P6	
C/No dB Hz	BER (I CHANNEL)
93	$1 * 10^{-6}$
TERMINAL – I/L-IV	
C/No dB Hz	BER (I CHANNEL)
94	$1 * 10^{-6}$
TERMINAL – I/L-III	
C/No dB Hz	BER (I CHANNEL)
94	$7* 10^{-6}$

TABLE :2.12 BORESIGHT SIMULATIONS TEST DATA

2.7 Characterization of Reception Chain

The quality of reception depends upon signal strength and E_b/N_0 available at the input of a demodulator and hence the analysis regarding the received data quality through quantitative measurements and spectrum analysis becomes essential to characterize the system.

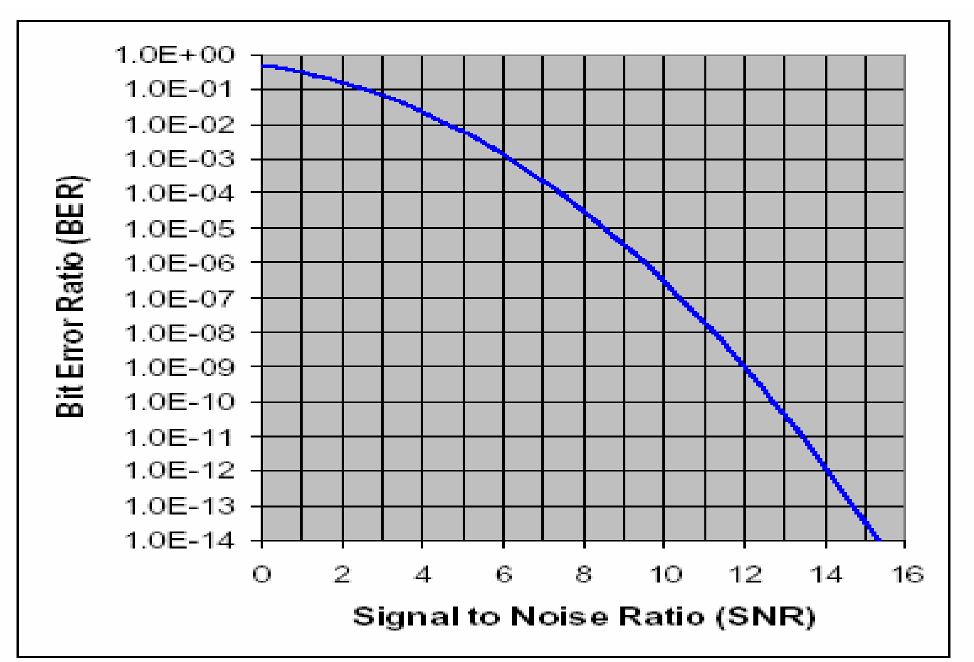
The measurement of E_b/N_0 is done by simulating the satellite transmitted spectrum by a RF simulator unit which has the facility to provide variable signal strengths to simulate different S/N values at different data rates and spectral characteristics at receive demodulator input.

These spectral characteristics can be read on the spectrum-analyzer by switching 'OFF' the modulation for measuring total signal above noise level within the resolution bandwidth of spectrum-analyzer. The carrier to noise density ratio (C/N_0) is calculated using this quantity and E_b/N_0 is finally obtained by dividing the C/N_0 with the bit rate. Spectrum-analyzer correction factor (noise power bandwidth correction and correction for the log display mode combined with the detector characteristics) is taken into account while calculating the C/N_o.

This measurement of E_b/N_0 on spectrum-analyzer is done only "off-line", i.e., in simulated mode, before the satellite-pass. However, the real time or "on-line" measurement of E_b/N_0 is not possible as there is no provision to switch-off the modulation during the satellite-pass to enable the measurement of C/N_0 on spectrum-analyzer. The distributed nature of the suppressed carrier modulated spectrum of higher bandwidth makes it impossible to calculate the C/N_0 at the centre IF frequency and the carrier is needed for the purpose, which is not possible in real time as the received signals are modulated signals.

The estimation of E_b/N_0 actually available at the input of demodulators during the real time satellite-pass, hence, is exclusively based on the assumption/approximation made by comparing/mopping the simulated spectrum power on the spectrum-analyzer with the actual spectrum received from the satellite. The respective E_b/N_0 values measured from simulation are taken equivalent to real time received E_b/N_0 values. The method obviously leaves the scope of inaccuracy as it is done by comparison of simulated and real time spectral characteristics. However these values are fine tuned with repetitive samples to reduce these inaccuracies and hence a functional model could be derived One such sample is as follows.

Fig no 2.38 Relation between signal strength verses BER



2.8 Conclusion

The simulation process is an essential element of the satellite data acquisition systems and is operationally used as a part of the system events on regular basis for both day and night. Considerable effort has gone in the development of necessary systems for this process viz., BER Test Systems for all the frequency range of operations and the satellite data format simulators etc..These are developed in-house specific to each satellite with reference to the formats and data rates. Extensive software developments have gone in for the automation of these processes and also to log the events and results in the form of data bases to enable the process to generate a status report on day to day basis which in turn works as a diagnostics tool. The VLSI design approaches and the newer software engineering techniques made the systems implemented with lowest possible design cycle times. These approaches are extended to every satellite that is being launched by the Department of Space for Remote Sensing Applications. The frequency limitations are driven by the frequency responses of the FPGAs and CPLDs in the market. Characterization of the systems is an essential requirement for the online diagnostics.

Chapter-3

Modelling and Development of Online BER Measurement System

***Abstract* :**

Remote sensing satellites are visible to any given ground station for short periods of time ranging from 3 to 12 minutes based on the altitude and position. During the image data download ,the reception chain quality can not be quantified quickly as image qualification is time consuming and subjective. As this helps for online corrections if any for good data reception, online diagnostics and remote management, the author has developed a new concept for quick online BER measurement for remote sensing satellites.

The bit error ratio of a digital communication system is the estimated probability of receiving the bits erroneously to the total bits transmitted. As the number of errors that occur is a random variable, the main issues will be the number of bits that are used for testing and the test times. For a perfect BER these two factors are unbounded. However during the real-time imaging, one must be able to test the reception channel in a short periods of time preferably in few seconds. In order to achieve this, the author has developed a model based on statistical approaches. BER was modeled using the probability. The errors due to uncertainties were also derived and identified with respect to image data. Through the concepts of confidence levels ,reduction in test times were deduced for a given BER of a system. This model has been applied to IRS series of satellites to derive the online BER in shorter periods of time. As the frame sync correlation was used for error detection high speed correlators were developed. This development has resulted in the correlators that are four times robust than the conventional correlators that are available. Both these concepts are published and the paper on correlators is a referred paper in IEEE. These developments were carried under the Technology Development Programmes of NRSA, Dept. of space. With the incorporation of this concept the system is aware of the online BER and therefore it is one of the important steps for the online diagnostics and remote management.

3.1 **Introduction** [21,39,42]

The Bit Error Ratio of a Digital Communication System can be defined as the estimated probability with any bit transmitted through the system will be received in error. The ratio of the number of bits received erroneously to the total number of bits transmitted is the BER. The quality of the BER estimation increases as the total number of bits increase. In the limit, as the number of bits approach infinity, the BER becomes a perfect estimate of the true error probability. Most bits in real systems are the result of random noise and therefore in a well designed system BER performance is limited by random noise and/or random jitter. The number of errors that occur over the life time of the system is a random variable. The main issue is how many bits must be transmitted through the system for a perfect BER test is therefore unbounded. Since practical BER testing requires finite test times, we must accept less than perfect estimation and can be done using the concept of statistical confidence levels. The calculations for the confidence level are based on the use of statistical methods involving the binomial distribution function and poisson theorem. For a given application based on the allowable errors the confidence levels can be derived. For the satellite systems where the data transmission formats are fixed, the number of bits transmitted are known. One common method of shortening the test time involves intentional reduction of the Signal to Noise (SNR) by a known quality during testing and the relationships between SNR and BER can be modeled for a given system.

The above concept of reducing the measurement timings for a given confidence level is applied to derive the online BER of the remote sensing satellite data channel during the video data download. This approach development has become useful in developing the system for the online BER during the video data download as the channel quality information in the form of BER help the environment to have a good knowledge about the quality of the reception and to carry out online system tunings for the improvement of the channel. This concept has been used to develop the system under the technology development projects at DARSD/NRSA, Department of Space, Govt. of India by the authors for use by all the remote sensing data acquisition community. The higher resolution imaging requirements driving the data rates to the higher end of the ladder which in turn call for the development of high speed digital correlators and are addressed in the second part of the chapter.

3.2 **Concept of Probability to Bit Error Rate (BER)** [38,39,42]

The concept of Bit Error Ratio/Rate (BER) is ubiquitous in the communications systems. It is the fundamental measure of performance for digital communications systems. The BER can be thought of the average number of errors that would occur in a sequence of ‘n’ Bits. Consequently where ‘n’ is equal to 1, the BER becomes the probability that any given bit will be received in error. Formally the BER is expressed in terms of the following ratio BER = (1 error / n bits transmitted)

If the device BER is 1/n, it means on the average. 1 bit error for every ‘n’ bits sent. In order to understand this clearly, the basic concepts of probability need to be explained.

If a coin is flipped, the probability of getting either heads or tails is 50/50. However it will not be shocking to get 3 heads or 3 tails in a row by flipping the coin 3 times. Even though the chance of getting heads or tails for a given number of consecutive flips is 50%, it is entirely possible to get any number of heads or tails for any given number of consecutive flips and it is difficult to say something about how often this happens. This is clearly understood by ‘Bernoulli Trial” which is based on 3 characteristics.

(a) Each trial has two possible outcomes, generally called success and failure.

(b) The trials are independent, this means one trial has no influence over the outcome of any other trial.

(c) For each trial, the probability of success is P where P is some value between 0 and 1 and probability of failure (the alternate outcome to success) is 1-P.

When a coin is flipped 3 times there can be 8 possible combinations.

H-H-H
H-H-T
H-T-H
H-T-T
T-H-H
T-H-T
T-T-H
T-T-T

There are 8 combinations and the chances of getting a head are the same as getting a tail. The chances of getting one specific combination is 1 in 8 or 0.125. The same is derived through probability. The probability of getting one head is 0.5, then the probability of getting 3 heads in a row is just 0.5 x 0.5 x 0.5 = .125(1/8). Similarly the chances of getting a tail is 0.5 x 0.5 x 0.5 = .125. The chances of getting only one head makes up three of the 8 total combinations as given in the table.

Sl.No.	**Condition**	**Possible outcomes**	**Total Probability**
1.	Probability of getting 0 heads	TTT	1/8
2.	Probability of getting 1 head	HTT, THT, TTH	3/8
3.	Probability of getting 2 heads	HHT, HTH, THH	3/8
	Total probability of getting up to 2 heads		7/8

In the above table, the sum of all the probabilities are added to get 7/8. In any experiment the sum of all the total possibilities must always add upto 1. Hence the above can be derived by subtracting the probability of not getting upto 2 heads in all the 3 tails which is 1-1/8 = 7/8.

3.3 BER Model

Expanding the above coin flipping example, suppose the coin flips tails only 10% of the time (instead of normal 50%), a model can be created as follows:

The probability of getting Zero tails (in getting 10 heads) in 10 consecutive flips.

$P(_{\text{no. of tails}})$ = (# of ways to get 10 heads) X $P(_{\text{10 heads}})$ = 1 X $[P(_{\text{1head}})]^{10}$

$P(_{\text{1 head}})$ refers to probability of getting one head

Now in general case, the formula for finding the probability of getting any 'K' number of tails out of 'n' total flips is

$P_{tot} = C(_{n_1,k})\ [P^k \text{ X } (1\text{-}P)^{(n\text{-}k)}]$

The probability of getting one tail in 10 flips is the probability of getting 1 tail and 9 heads and represented by $[P^k \text{ X } (n\text{-}p)^{(n\text{-}k)}]$ where 'k' represents the number of tails and (n-k) represents the heads.
If 2 tails are taken in 10 flips where $P(_{\text{tail}}) = 0.1$

$[P^k \text{ X } (1\text{-}P)^{(n\text{-}k)}] = [P(_{\text{tail}})]^2 \text{ X } [P(_{\text{head}})]^8$

$= (0.1)^2 \text{ X } (0.9)^8 = 0.0043$

This represents the probability for one way of getting 2 tails in 10 flips and $C(_{n,k})$ in equation in the Binomial Coefficient tells the total no. of possible combinations and in this case

$$C(_{n,k}) = C(_{10,2}) = \frac{10!}{2!8!}$$

Therefore, $P_{tot} = C(_{n,k}) \text{ X } [P^K \text{ X } (1\text{-}P)^{(n\text{-}k)}]$
= 45 X [0.0043]
= 0.1937

This means if $P(_{\text{tail}})$ is 1/10, then for ten flips there are 19.37% chance of getting exactly 2 tails. Then the probability of getting just one tail in 10 flips is

$P_{tot} = C(_{n,k}) \text{ X } [P^k \text{ X } (1\text{-}P)^{(n\text{-}k)}]$
$= C(10,1) \text{ X } [1' \text{ X } 0.9^9] = 0.3874$

Similarly the case for 0 tails (in 10 heads)

$P_{tot} = C(_{n,k}) \text{ X } [P^k \text{ X } (1\text{-}P)^{(n\text{-}k)}]$
$= C(10,0) \text{ X } [0.1^0 \text{ X} 0.9^{10}]$
$= 1 \text{ X } 0.3487 = 0.3487$

So if $P(_{\text{tail}})$ is 1/10 and in ten flips there is approx. 35% chance that zero heads are seen in those 10 flips.

Binomial Distribution for $P(_{\text{tails}}) = 0.1$ and n = 10 flips

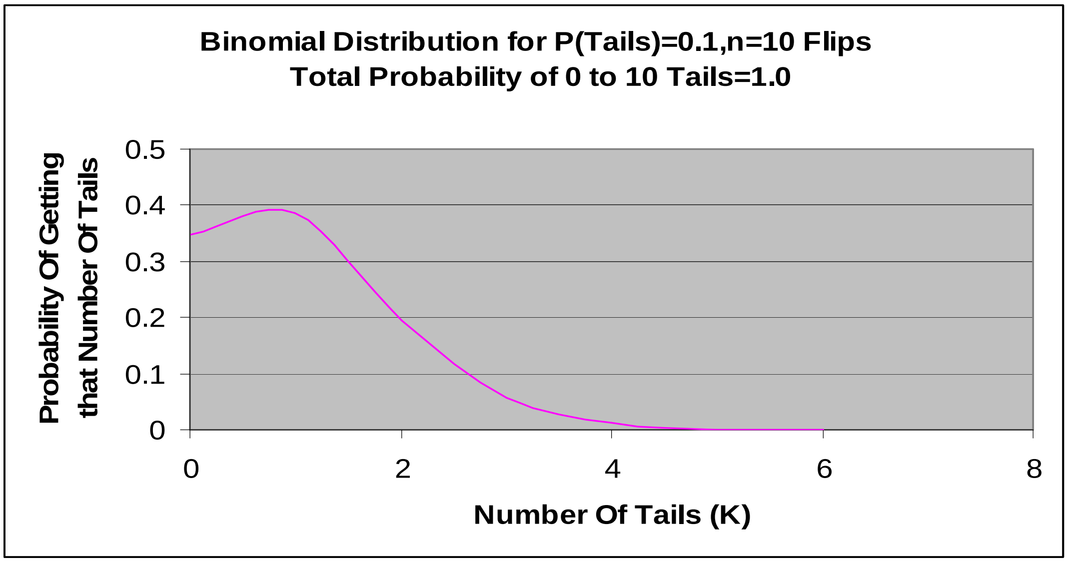
Table

n = 10 P = 0.1

	K=0	K=1	K=2	K=3
P_{tot}	0.3487	0.3874	0.1937	0.05739

K=4	K=5	K=6
0.01116	0.001488	0.00013778

Table: 3.1 Calculation of $P_{(tot)}$ for P=0.1 and n=10



Plot No.: 3.2 Binomial distribution for Table

The above plot represents the discrete values 0 through 10 for which the probabilities were calculated. The sum of all the probabilities from 0 to 10 tails adds upto 1.000.

In this 2^{nd} trial, it is assumed that $P_{(tails)}$ = 2/10. The distribution will be as follows:

Table

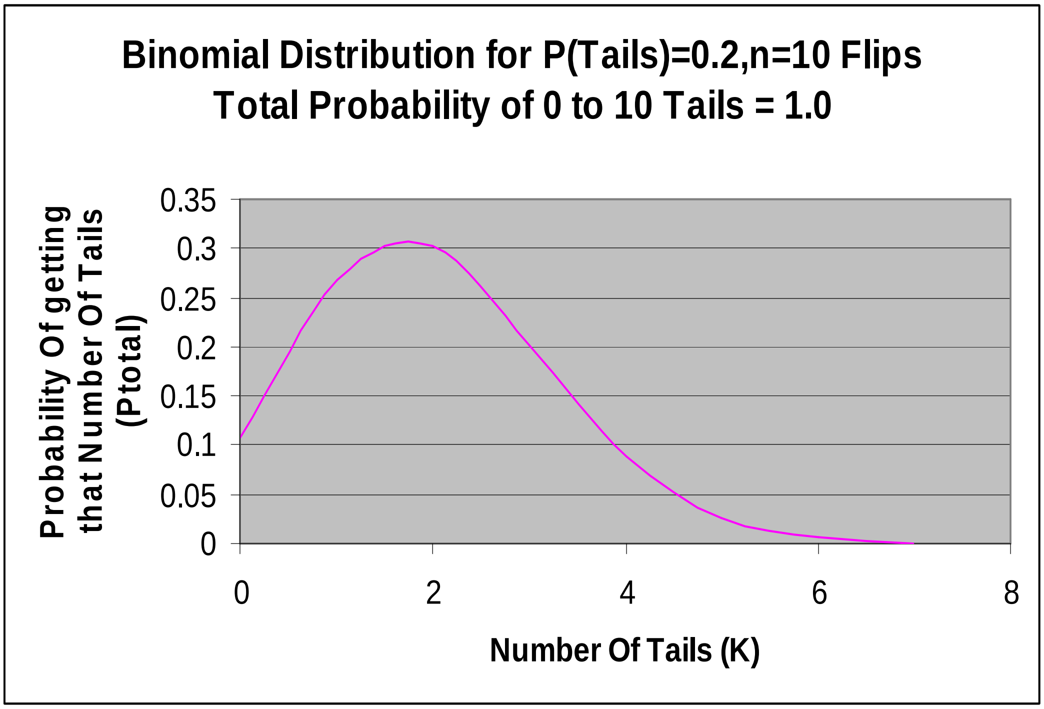
n=10 P=0.2

	K=0	K=1	K=2	K=3
P_{total}	0.107374	0.268435	0.301989	0.20132

K=4	K=5	K=6	K=7
0.0880	0.0264	0.0055	0.000786

Table: 3.3 Calculation of $P_{(tot)}$ P=0.2 and n=10

Even though P(tails) = 2/10 approximately 10% of the time during 10 flips zero tails are seen. Approximately 27% of the time just one tail is seen.



Plot No.: 3.4 Binomial Distribution for the table

Hence if we design a BER Test to verify a particular device BER is equal to or better than 1/10 by sending 10 bits and allowing upto 1 error to occur it may pass the test approximately upto 37% of the time (10+27) which is clearly substandard even compared to 2/10. If the threshold is 0 errors to be seen to pass, still have bad devices slipping by and passing 10% the time.

Important conclusion from the above is bad devices get certified by allowing the errors, this type of error is known as 'Type II Error' where the device is given a passing result even though it truly have a failing BER. A type I error describes the opposite case where the device actually have a valid BER but have multiple errors causing it to fail.

In plot 3.2, total probability show the sum of the first 2 values of k upto and including one error, the BER is really 1/10 approximately

{1-(0.3487+0.3874)} = (1-0.7361) = 0.264 = 26.4%. It means 2 or more errors can be seen and erroneously assign a failing result even though the device BER is conformant.

In case more bits are transmitted for BER, it increases the chance of more errors. Another example when the no. of bits are tripled like n=30 bits the binomial distribution for P(error) = 0.1 is as follows:

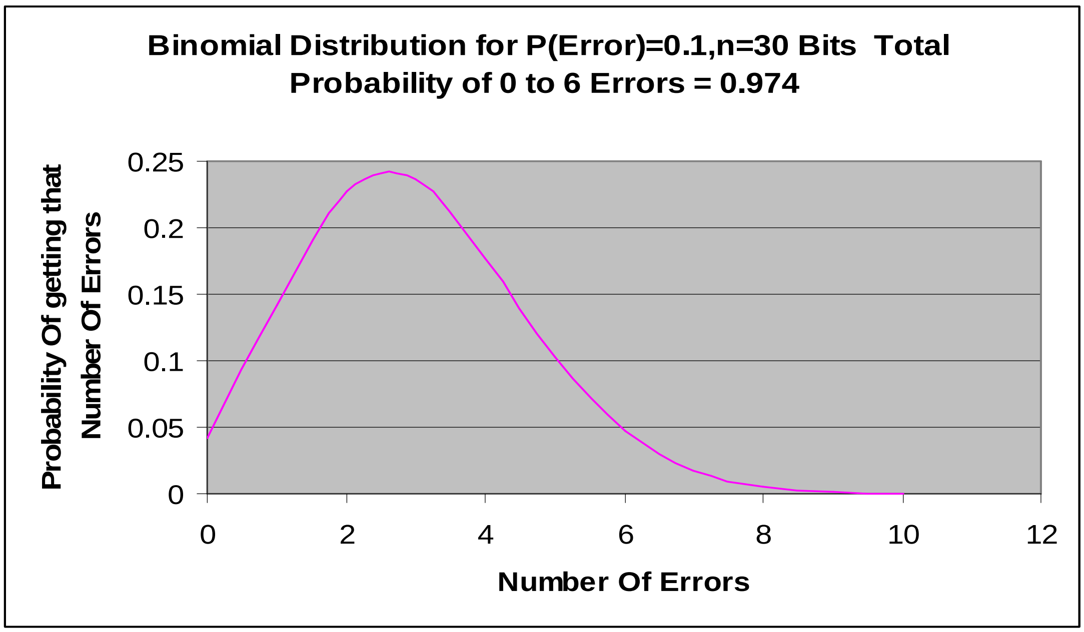
Table

n=30 bits   P = 0.1

	K=0	K=1	K=2	K=3	K=4
P_{total}	0.0423	0.1413	0.2276	0.236	0.1770

K=5	K=6	K=7	K=8	K=9	K=10
0.1023	0.0473	0.018	0.0057	0.0015	0.00036

Table:3.5   Calculation of $P_{(tot)}$ P=0.1 and n=30



Plot No: 3.6   Binomial Distribution for the table

When the BER is 1/10 for 30 bits transmitted, it is likely to see 3 bit errors. From the above graph, 97.4% of the time, 6 bit errors or less are expected. Important observations

(a) Zero errors are seen for less than 5% time
(b) The distribution is shifting to the right

When $P_{(error)}$ is increased to 0.4 for the same number of bits transmitted n=30 the distribution is as follows:

Table

P=0.4 n=30

	K=0	K=1	K=2
P_{total}	$0.22x10^{-6}$	$0.44X10^{-5}$	$0.427X10^{-4}$

K=3	K=4	K=5
$0.266X10^{-3}$	$0.119X10^{-2}$	$0.4148X10^{-2}$

	K=6	K=7	K=8
P_{total}	$1.15X10^{-2}$	$2.634X10^{-2}$	$5.05X10^{-2}$

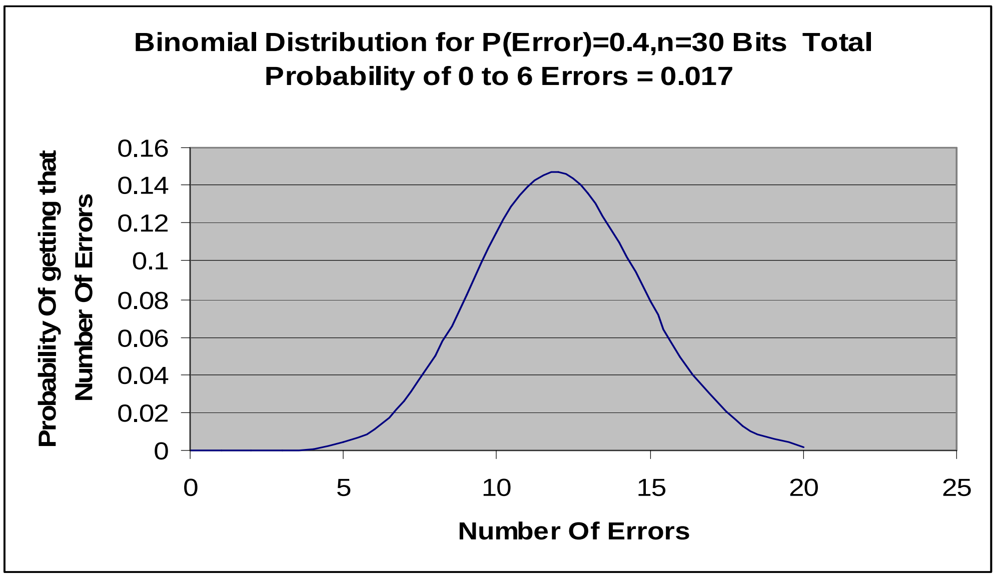
K=9	K=10	K=11
$8.22X10^{-2}$	$11.5X10^{-2}$	$13.96X10^{-2}$

	K=12	K=13	K=14
P_{total}	$14.73X10^{-2}$	13.6X10-^{2}	$11.0X10^{-2}$

K=15	K=16	K=18
$7.86X10^{-2}$	$4.89X10^{-2}$	$1.29X10^{-2}$

	K=20
P_{total}	$0.199X10^{-2}$

Table: 3.7 Calculation of $P_{(tot)}$ P=0.4 and n=30



Plot:3.8 Binomial distribution plot for Table

In this case, the chance of getting 6 errors or less falls to about 2%. As the actual BER increases, the peak of the distribution moves further and further to the right as a function of 3 times the BER. In other words depending on whatever the actual BER is, (in terms of errors per 'n' bits) the peak of the distribution will be shifted further and further to the right by a factor of 3, in 3n bits.

Thus in this graph, the question remains as to how to interpret the results when 1 to 6 errors are observed. This is exactly same as "Type-II Error as seen earlier while transmitting n bits instead of 3n bits and looking or the probability of zero errors. This is like a range where the results are effectively inconclusive. The only solution is to transmit more bits. The other option is to declare a device fit if the BER exceeds lower specified band with a higher degree of confidence.

From the above, it is seen that if you want to verify a BER of 1/n we send 3n bits and interpret as follows:

(a) 0 errors seen. 95% sure that the actual BER is equal to or better than 1/n
(b) 7 or more errors seen. 97% sure that the actual BER is worse than 1/n
(c) 1 to 6 errors. Can't say anything with high confidence, so the device passes by default

The quality of the BER estimation increases as the total number of transmitted bits increases. In limit, as the number of transmitted bits approaches infinity, the BER becomes a perfect estimate of the true error probability and follows a binomial function as above.

The bit errors occur randomly as a function of time, which means that the accuracy of the measured BER increases, the longer measurement is performed infinitely.

This can be demonstrated by means of a numerical example. If measurement is performed for one second at a transmission rate of 1000 bits/sec. and 2 bit errors occur, the BER will be 0.2%. If it is only one bit, it will be 0.1%. However 200 bits are measured over a period of 100 seconds, the BER is also 0.2% and one bit error less however would in this case result in a BER of 0.199%. Hence the influence of a single bit error on the overall result thus decreases with longer measurement times. It is important to note that BER is essentially a statistical average and therefore valid for large number of bits.

3.4 Type I and Type II errors

Type I error : is the case where the device actually does have a valid BER, however for that particular set of flips it just happened to get really unlucky and have multiple bit errors causing it to fail. As an example one image of IRS-P6 pertaining to April 01, 2006 is shown below centering the line losses.

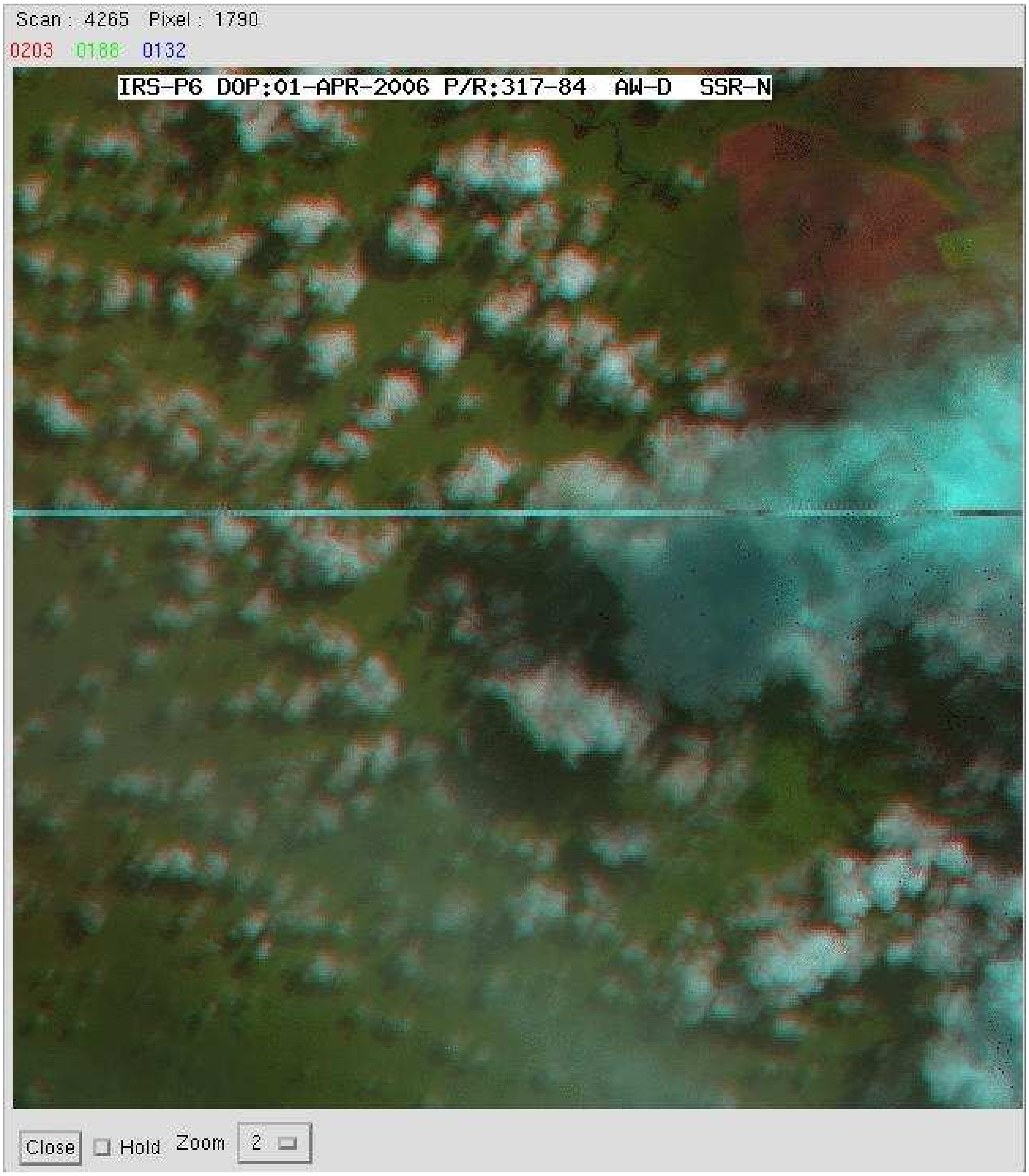


Figure 3.1 **Image showing the line losses**

Type-II error : The device is given a passing result even though it truly does have a failing BER. That means zero errors are seen in order to pass, we still have bad devices slipping by and passing. This may seem like a good thing to the person who built the device, it is certainly a bad thing from the perspective of the person trying to verify the actual BER. In other words the bad data is tracked as good and passed. Hence Type II error is most important from the user point of view. Images with pixel dropouts are shown below get classified as Type-II errors.

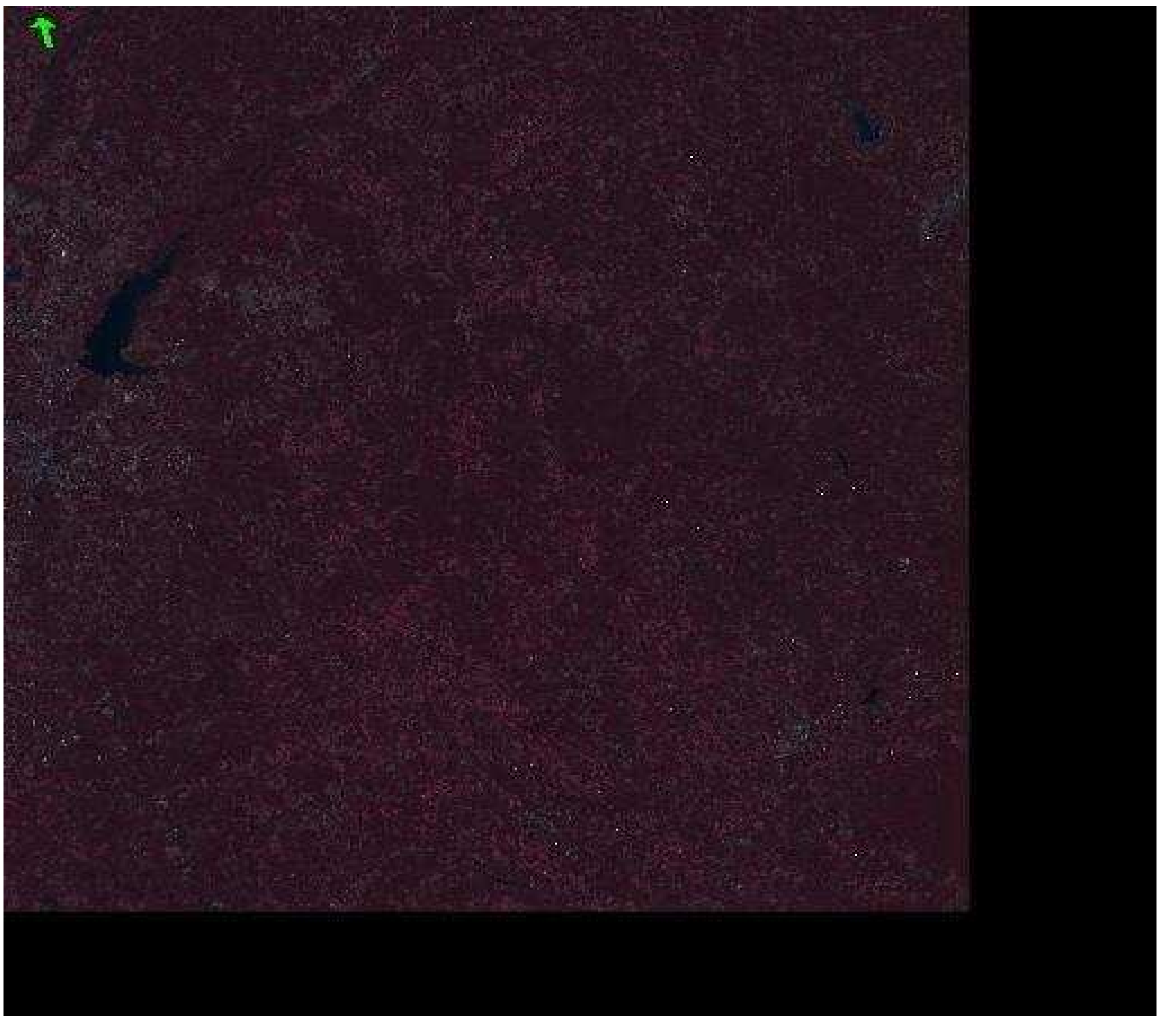


Figure3.2 Image showing the pixel dropouts

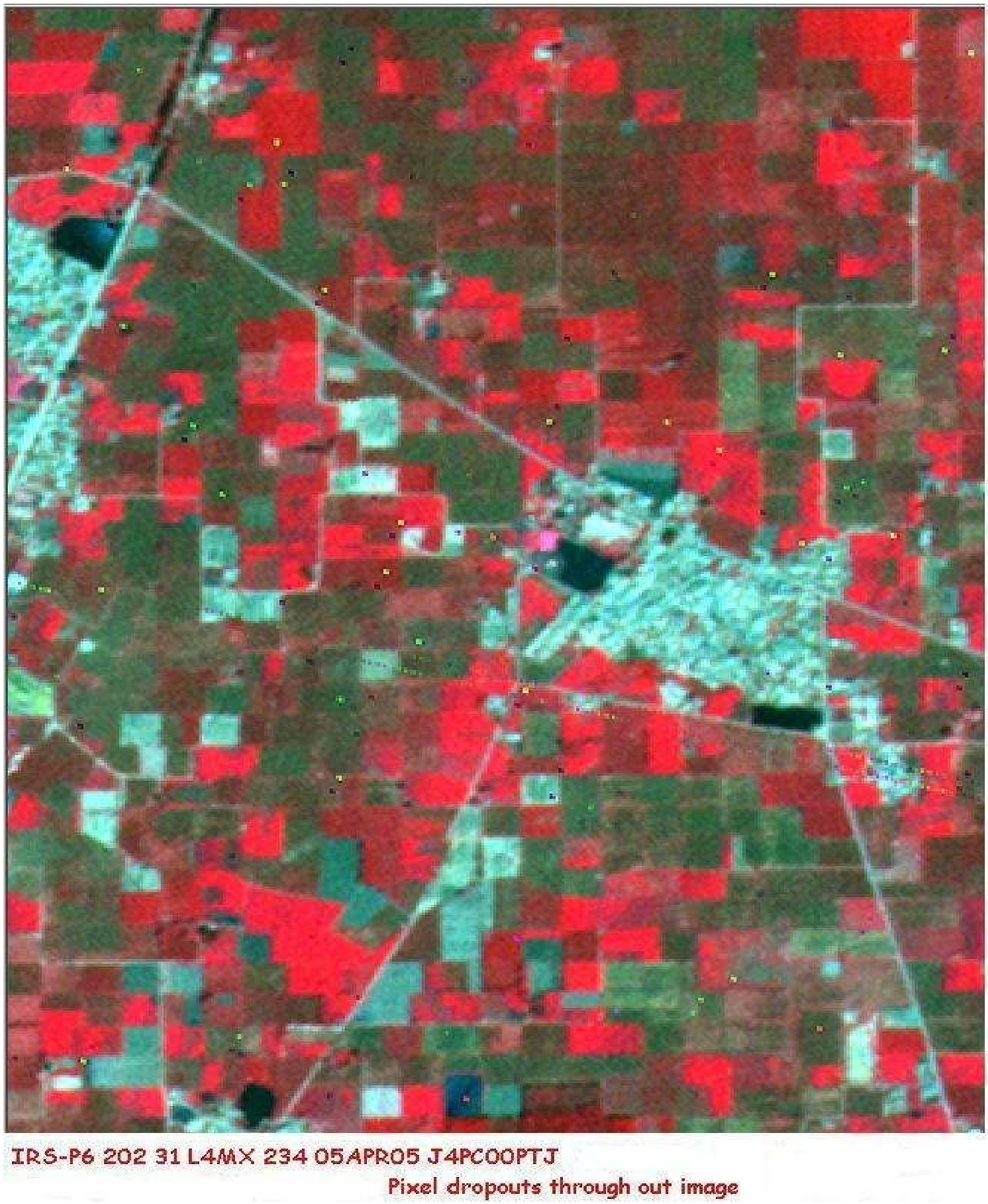


Figure3.3 **Image showing the pixel dropouts**

3.5 **BER Measurement through Statistical Approach** [39-41,44,45]

3.5.1. Introduction

The quality of the BER estimation increases as the total number of bits increase. In the limit, as the number of bits approaches infinity, the BER becomes a perfect estimate of the true error probability. Most bits in real systems are the result of random noise and therefore in a well designed system BER performance is limited by random noise and/or random jitter. The number of errors that occur over the life time of the system is a random variable. The main issue is how many bits must be transmitted through the system for a perfect BER test is therefore unbounded. Since practical BER testing requires finite test times, we must accept less than perfect estimation and can be done using the concept of statistical confidence levels. The calculations for the confidence level are based on the use of statistical methods involving the binomial distribution function and Poisson theorem. For a given application based on the allowable errors the confidence levels can be derived. For the satellite systems where the data transmission formats are fixed, the number of bits transmitted is known. One common method of shortening the test time involves intentional reduction of the Signal to Noise (SNR) by a known quality during testing and the relationships between SNR and BER can be modelled for a given system.

The Remote Sensing Satellites transmit the image data (images) during the imaging modes specific to each satellite. The image data being dynamic does not provide the means to attach the quality tags with respect to the data quality or the data reception channel performance. The evaluation of image data validation can happen in near real time and does not provide the opportunity to tune the systems for the online improvement, if necessary. It also becomes a limitation for automated testing and remote management of systems.

Therefore the authors have developed a methodology for the real time estimation of Data Reception chain quality through statistical means based on the system performance. The statistical BER measurement does not determine the actual BER. Instead it checks whether the data received complies with a specified minimum quality. However classifying a good quality receiver as bad is less problematic than rating a bad as good. Hence the concept developed derives the measurement times through statistical means while the actual system performance model at the instant of testing is used to provide the BER in a closed loop function to cater to (a) provide Real time assessment of Data reception channel (b) implement the automated test and diagnostics process as a closed loop function and the remote management.

Many components in digital communication systems must meet a minimum specification for the probability of bit error ($P(\varepsilon)$). For a given system, ($P(\varepsilon)$) can be estimated by comparing the output bit pattern with a predefined pattern applied to the input. Any discrepancy between the input and output bit streams is flagged as an error and the ratio of detected bit errors (ε) to total bits transmitted (n) is P(ε), where the prime character signifies an estimate of the actual P(ε). The quality of this estimate improves with the total number of bits transmitted. The relationship can be expressed as

$$P(\varepsilon) = \frac{\varepsilon}{n} \underset{n\to\infty}{\longrightarrow} P(\varepsilon) \qquad \text{(eq: 1)}$$

It is important to transmit enough bits through the system to ensure that P(ε) is a reasonable approximation of the actual P(ε) (i.e. the value to be obtained if the test could proceed for an infinite amount of time). For a reasonable limit on test time, therefore, we must know the minimum number of bits that yields a statistically valid test.

In many cases, we must verify only that P(ε) is at least as good as some predefined standard. In other words, it is sufficient to prove that P(ε) is less than some upper limit. For example, the P(ε) required in many telecommunication systems is 10^{-10} or better (an upper limit of 10^{-10}). The statistical idea of associating a *confidence level* with an upper limit can be used to postulate, with quantifiable confidence, that the actual P(ε) is less than the specified limit. As a primary advantage, this method lets you trade test time for measurement accuracy.

3.5.2 Definition of the statistical confidence level

The statistical confidence level is defined as the probability, based on a set of measurements, that the actual probability of an event is better than some specified level. (For the purpose of this definition, actual probability means the probability that is measured in the limit as the number of trials tends toward infinity). When applied to P(ε) estimation, the definition of statistical confidence level can be restated as the probability (based on ε detected errors out of n bits transmitted) that the actual P(ε) is better than a specified level γ (such as 10^{-10}).

Mathematically, this can be expressed as

$$CL = P[P(\varepsilon) < \gamma\ [e,n] \qquad \text{(eq:2)}$$

Where P[ ] indicates probability and CL is the confidence level. Because confidence level is a probability by definition, the possible values range from 0% to 100%.

After computing the confidence level, we can say we have CL percent confidence that the P(ε) is better than γ. As another interpretation, if we repeat the bit-error test many times and recompute P(ε) = ε/n for each test period, we expect P(ε) to be better than γ for CL percent of the measurements.

3.5.3 Determination of the confidence level

Calculations of the confidence level are based on the binomial distribution function described in many statistics texts . The binomial distribution function is generally written as

$$P_n(k) = \frac{n!}{k!(n-k)!} p^k q^{n-k} \qquad \text{(eq:3)}$$

Equation [3] gives the probability that k events (ie. bit errors) occur in n trials (i.e. n bits transmitted), where p is the probability of event occurrence in a single trial (i.e. a bit error), and q is the probability that the event does not occur in a single trial (i.e. no bit error). Note that the binomial distribution model events that have two possible outcomes, such as success/failure, heads/tails, or error/no error. Thus, p+q=1.

When we are interested in the probability that N or fewer events occur in trials (or, conversely, that greater than N events occur), then the cumulative binomial distribution function of Equation 4 is useful.

$$P(\varepsilon \le N) = \sum_{k=0}^{N} P_N(k) = \sum_{k=0}^{N} \left[\frac{n!}{k!(n-k)!}\right] P^k q^{n-k}$$

$$P(\varepsilon > N) = 1 - P(\varepsilon \le N) \sum_{k=N+1}^{n} \left[\frac{n!}{k(n-k)!}\right] P^k q^{n-k} \qquad \text{(eq:4)}$$

Where

n = Total number of trials (i.e. total bits transmitted)

k = Number of events occurring in n trials (i.e. bit errors)

p = Probability that an event occurs in one trial (i.e., probability of bit error)

q = Probability that an event does not occur in one trial
(i.e. probability of no bit error)

P + q = 1

$$CL = 1 - \sum_{K=0}^{N} P_n^{(k)}$$

In a typical confidence-level measurement, we start by choosing a satisfactory level of confidence and hypothesizing a value for p (the probability of bit error in transmitting a single bit). We represent the chosen p value as p_h. In general, we choose these values according to a limit imposed by specification (e.g., if the specification is $P(\varepsilon)\leq 10^{-10}$, we choose $p_h = 10^{-10}$ and a confidence level of, say, 99%).

We can then use Equation 4 to determine the probability of $P(\varepsilon > N / p_h)$, that more than N bit errors will occur when n total bits are transmitted. If, during actual testing, less than N bit errors occur (even though $P(\varepsilon > N / p_h)$ is high), then one of two conclusions can be made: (a) we just got lucky, or (b) the actual value of p is less than p_h. If we repeat the test over and over and continue to measure less than N bit errors, then we become more and more confident in conclusion (b).

The quantity $P(\varepsilon > N / p_h)$ defines our level of confidence in conclusion (b). If $p_h = p$,, we have a high probability of detecting more bit errors than N. When we measure less than N errors, we conclude that p is probably less than p_h, and we define as the confidence level this probability that our conclusion is correct. In other words, we are CL% confident that $P(\varepsilon)$ (the actual probability of bit error) is less than p_h.

In terms of the cumulative binomial distribution function, the confidence level is defined as

$$CL = P(\varepsilon > N \mid p_h) = 1 - \sum_{K=0}^{N} \left[\frac{n!}{k!(n-k)!}\right] (P_n)^k (1-P_h)^{n-k} \qquad \text{(eq:5)}$$

Where CL is the confidence level in terms of percent.

As noted above, when using the confidence-level method we generally choose a hypothetical value of p (p_h) along with a desired confidence level (CL), and then solve Equation 5 to determine how many bits (n) we must transmit through the system (with N or fewer errors) to prove our hypothesis. Solving for n and N can prove difficult unless approximations are made.

If np>1 (i.e. we transmit at least as many bits as the mathematical inverse of the bit error rate), and k has the same order of magnitude as np, then the Poisson theorem provides a conservative estimate of the binomial distribution function.

$$Pn(k) = \left[\frac{n!}{K!(n-k)!}\right] p^k q^{n-k} \xrightarrow[n-\infty]{} \frac{(np)^k}{k!} e^{-np} \qquad \text{.. (eq.6)}$$

then

$$\sum_{k-0}^{N} P_n(k) = \sum_{K=0}^{N} \frac{(np)^k}{k!} e^{-np} \qquad \text{.. (eq.7)}$$

Combining eq. 5 & 7

$$\sum_{K=0}^{N} P_n(k) = 1-CL$$

$$\sum_{K=0}^{N} \frac{(np)^k}{k!} e^{-np} = 1-CL$$

$$-np = +\ln(1-CL) - \ln \sum_{K=0}^{N} \frac{(np)}{k!}$$

OR $$np = -\ln(1-CL) + \ln \sum_{K=0}^{N} \frac{(np)}{k!}$$

$$n = \frac{1}{P}\left[-\ln(1-CL) + \ln \sum_{K=0}^{N} \frac{(np)}{k!}\right]$$

In other words

$$n = \frac{1}{BER}\left[-\ln(1-CL) + \ln \sum_{K=0}^{N} \frac{(np)}{k!}\right]$$

Where n=Total Bits transmitted
BER = Bit Error Rate or Probability of bit error
N = No. of errors detected
ℓn = natural logarithm

When the number of errors detected are zero is N=0 then the 2nd term in the above equation will be zero, then the above equation will be

$$N = -(\ln(1-CL)) / BER$$

OR $$N \times BER = -\ln(1-CL)$$

From the above for zero errors $N \times BER = -\ln(1-CL)$ for CL = 95% N = 3/BER.

This results in a simple rule of thumb which is that the transmission of 3 times the reciprocal of the specified BER without an error gives a 95% confidence level that the system meets the BER specifications. Similar calculations show that n = 2.3/ BER for 90% confidence level and 4.6/BER for 99% confidence level for zero errors.

The graph below illustrates the relationship between the number of bits transmitted versus the confidence level for zero, one and two bit errors. The confidence levels are taken from 70% to 99%. To use the graph select the desired confidence level and draw a vertical line up from that point on the horizontal axis until it intersects the curve for the number of errors detected during the test. From the intersection point draw a horizontal line to the left until it intersects the vertical axis to determine the number of bits that must be transmitted nx BER. Divide this number by specified BER to get the number of bits that must be transmitted for desired confidence level.

3.5.4 Calculation of n x BER for different Confidence levels

n : No. of bits transmitted=10^{10}
Bit Error Rate(BER) =1 x 10^{-8}

For Zero Errors

Confidence Level	n x BER
70	1.2039
75	1.38629
80	1.60943
85	1.89712
90	2.3025
95	2.9954
98	3.9120
99	4.60517

Table 3.9 Calculation of n x BER for zero errors

For 1 Error

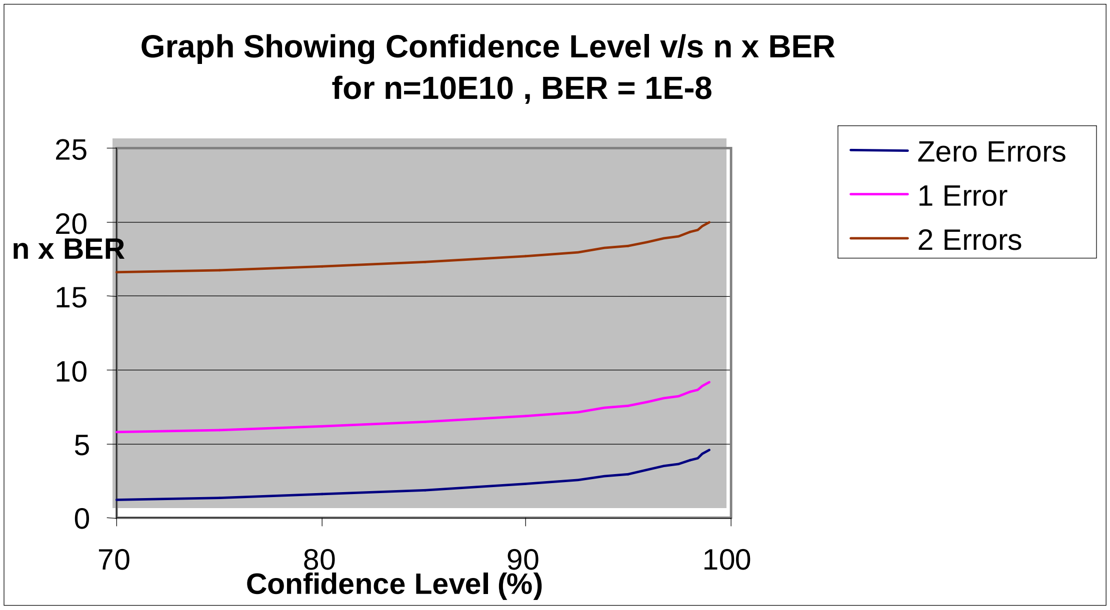
Confidence Level	n x BER
70	5.80907
75	5.99146
80	6.2146
85	6.50229
90	6.90767
95	7.60087
98	8.51717
99	9.21034

Table 3.10 Calculation of n x BER for one error

For 2 Errors

Confidence Level	n x BER
70	16.6288
75	16.81124
80	17.034377
85	17.322069
90	17.72744
95	18.42064
98	19.3369
99	20.030

Table 3.11 Calculation of n x BER for two errors



Plot 3.12 Relation between n x BER and CL for different errors

Test Time

The test time is defined by simple means as the ratio of the total bits transmitted to the rate at which the data is transmitted.

$$\text{Test Time } T = \frac{n}{R}$$

Where T : Time in seconds

n : no. of bits transmitted (bits)

R : Data rate (bits/sec)

As a sample for100 Mb/S data rates the Test times are derived for the above data sets and tabulated below.

3.5.5 Deduction of Test Time from Confidence Level for zero errors

Data rate(R) = 100 Mbps

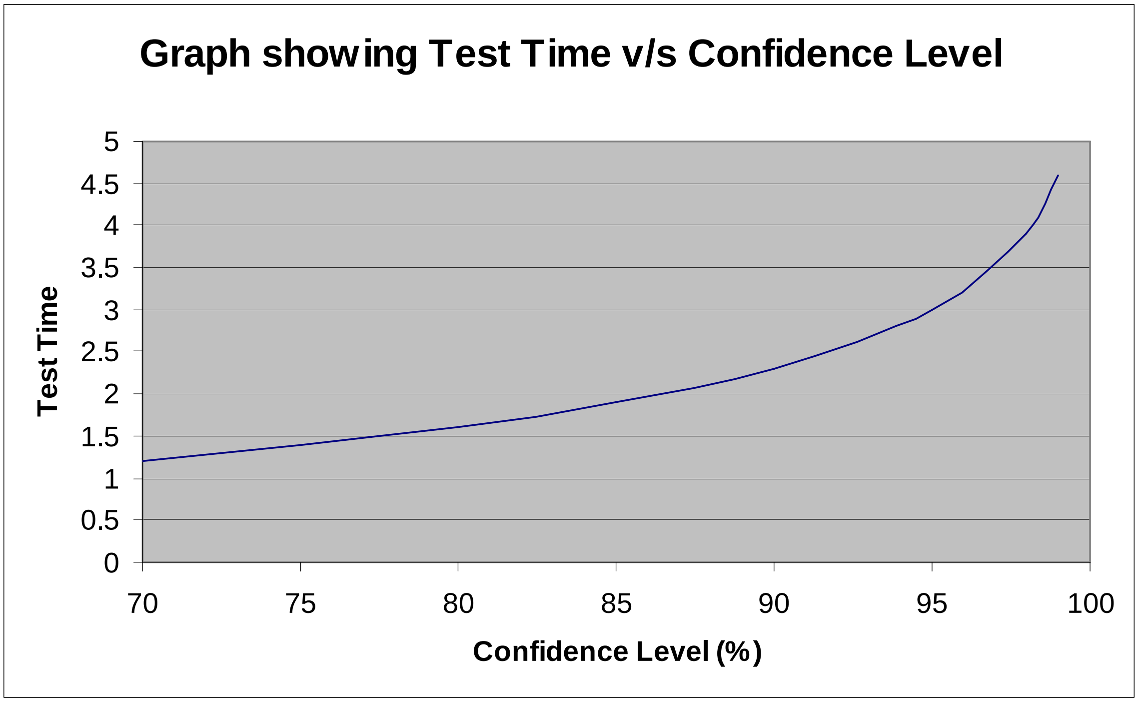
No. of bits transmitted(n) = 10^{10}

Bit Error Rate(BER) = 1 x 10^{-8}

Confidence Level	n/BER	Test Time T=n/R
70	1.2039 x 10^8	1.2039 sec
75	1.38629 x 10^8	1.38629 sec
80	1.60943 x 10^8	1.60943 sec
85	1.89712 x 10^8	1.89712 sec
90	2.3025 x 10^8	2.3025 sec
95	2.9957 x 10^8	2.9957 sec
98	3.9120 x 10^8	3.9120 sec
99	4.60517 x 10^8	4.60517 sec

Table 3.13 Test times for different CL's

It is also evident from the model that the test time increases with the increase in confidence level and reaches infinite as it approaches 100% CL.



Plot 3.14 Relation between Test time and CL

Stressing the System to reduce the test time

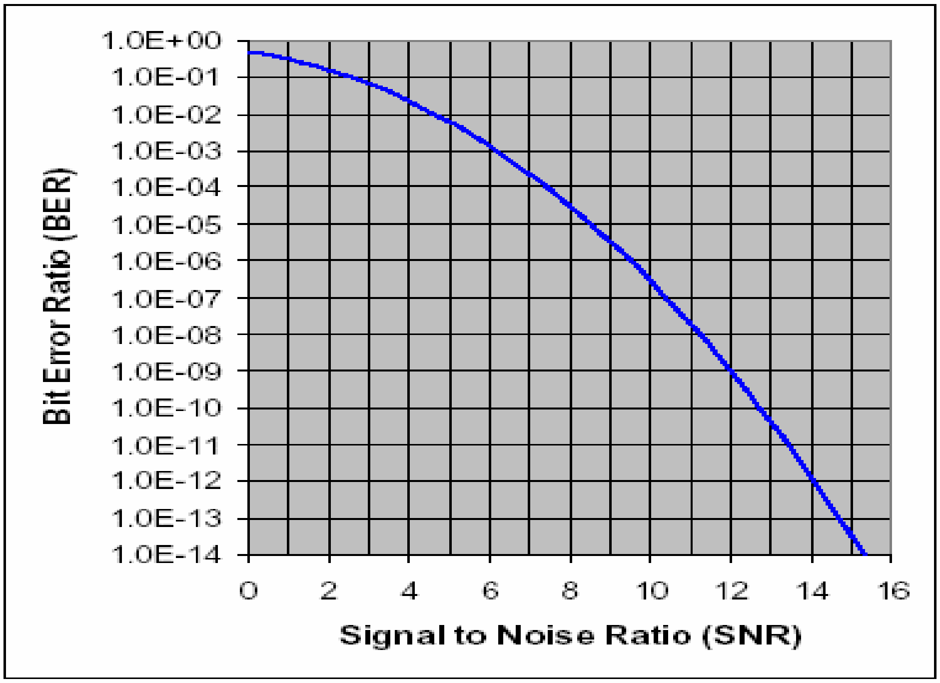
Dan Wolener has documented the method for reducing the test time by stressing the system. It is based on an assumption that the dominant cause of bit errors in thermal (Gaussian) noise at the input of the receiver. This assumption excludes Jitter and other potential causes of the error which are clearly known for a given system. For the system in which this assumption is valid, the signal-to-noise (SNR) ratio can be reduced by inserting a fixed alternation (for the signal) in the transmission path and the probability of bit error can be calculated.

$$P(\varepsilon) = Q\left\{\sqrt{\frac{SNR}{2}}\right\}$$

Where Q is the complementary error function

This equation shows that the probability of bit error increases as the SNR decreases. The reduction in SNR results in more bit errors and quicker measurement of the resulting degraded BER (ref.). If we know the relationship between SNR and BER, then the degraded BER results can be extrapolated to estimate the BER of interest. Implementation of this method is based on the assumption that the thermal (Gaussian) noise at the input to the receiver is the dominant cause of the bit errors in the system. The relationship between the

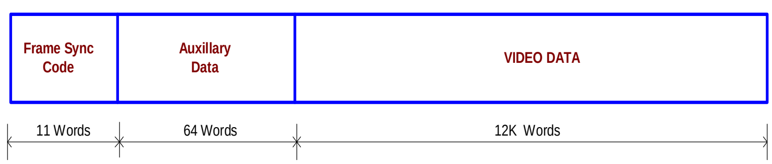
SNR and BER can be derived using Gaussian statistics and is documented in text books (ref.).
BER = 1-NORMS DIST (SNR/2)



Plot 3.15 **The relationship between BER and SNR**

3.6 Application of this approach to Indian Remote Sensing Satellites [32-34,82]

The Remote Sensing Satellites transmit image data during the imaging modes. The data is transmitted in a given format specific to each satellite. The data is transmitted in the form of image data lines which is called as a frame. Each frame/line consists of frame sync code; auxiliary data and image data as follows:



Word Size: 8 /10/12 bit ; Aux Data contains DH ON/OFF STATUS,LBT (HK) Data, Line Count, OBT Count. SPS Data, Video Data (mono/ multiband data), Multi Band Video Data.

The frame sync code is specified for each satellite. The auxiliary information is embedded in the video data stream contains the Telemetry, channel ID and value, satellite health parameters like temperatures, status of important elements, attitude information based on each sensors, star sensors, satellite positioning systems, gyro information, payload modes and associated cameras onboard times and related parameters etc. The video data in a specific format for each satellite contains single band data in case of Panchromatic Sensor and multiband data in case of multiband sensor with different lengths from 4k to 12k. The auxiliary data is a dynamic information from the satellite with sampling period of each type of data varying from 32m sec to 1 sec. Some of the data parameters in Auxiliary data get repeated for some frames as it is a slow data and also provide redundancy for the data availability at the ground to ensure error free reception at the ground so that these data volumes can be used for data processing without any error. The video data is an image of the ground and hence totally dynamic. The stream also contain the line count to represent each line of data with unique and incrementing number in the satellite visibility. At the time of realtime, data acquisition, Universal Time (UTC) will be embedded to each line of data so that UTC or the line count can work as a reference for the data.

The data transmission rates from the remote sensing satellites are as follows:

Sat ID	Data rate
IRS-1A	20.8Mbps+5.2Mbps
IRS-1B	20.8Mbps+5.2Mbps
IRS-P2	20.8Mbps
IRS-P3	5.2Mbps
IRS-1C	84.9 Mbps
IRS-P4	20.8 Mbps
IRS-1D	84.9Mbps
Resourcesat-1	105Mbpsx2
Cartosat-I	105MbpsX2
Cartosat-II	105MbpsX1
ERS-1	105Mbps
ERS-2	105Mbps

Table 3.16 Data rates from Remote Sensing Satellites

The frame/line length of Image data varies from satellite to satellite depending upon the CCD's that are used. It varies from 4K pixels to 12K pixels

Sat ID	Sensor	Image frame/line length
IRS-1C	PAN	12K pixels
IRS-1D	PAN	12K pixels
IRS-1C/1D	WIFS	4 K pixels
IRS-P6 (Resourcesat)	L-IV	4 K pixels in multiband mode 12k pixels in mono mode
IRS-P5 (Cartosat-I)	PAN	12K pixels
Cartosat-II	PAN	12K pixels

Table 3.17 Image frame lengths of Remote Sensing Satellites

Based on the above, the line integration times change from Sensor to Sensor as per the table given below:

Sat ID	Sensor	Data Rate (Mbps)	CCD length (Pixels)	Line Integration (m sec)
IRS-1C/1D	PAN LISS-III+WIFS	84.9 42.45	12K 6K/band 4K/band	0.8836 3.36
IRS-P4	OCM	20.8	6K/band	34.8
Resourcesat (IRS-P6)	LISS-IV Multiband Mono AWIFS	 105Mbps 105Mbps 52.5Mbps	 4K/band 12K 6K/band	 0.878 9.958
Cartosat-I	PAN A/F	105MbpsX2	12K	0.3659
Cartosat-II	PAN	105Mbps	12K	0.3659

Table 3.18 Line Integration times of different cameras

3.6.1 Reduction in measurement times and system modelling

Tests that require a high confidence level and/or low BER may take a long time particularly for low data rate systems. Consider a 99% confidence level test for a BER of 10^{-8} on a 105 Mbps system. The required number of bits from the above is 4.61 x 10^8 for zero errors. At 105 Mbps, the test time would be 4.6 x 10^8 bits/105 x 10^6 bits/sec = 4.38 sec. The Test times required for the different Indian Remote Sensing Satellite Data Rates is given in the table below:

Data Rate Mbps	Test Times in Seconds (CL = 99 %)
20.80	22.11
42.452	10.83
84.903	5.41
52.50	8.76
105.00	4.38

Table 3.19 Test Times for different data rates

The Remote Sensing Satellites are visible to any ground station for about 10 to 15 minutes depending upon the altitude and further tests depending upon the camera switch on times. The volume of data depends on the data rates for the above visibility periods.

Sat ID	Sensor	Data Rate	Data Volume for 10 minutes pass duration (GB)
IRS-1C	PAN L-III+WIFS	84.9 Mbps 42.45	6.3
IRS-P4	OCM	20.8 Mbps	1.5
Cartosat-I	PAN A&F	105 MbpsX2(comp)	50.4
Cartosat-II	PAN	105 Mbps (comp)	25.2
Resourcesat	L-IV L-III+AWIFS	105MbpsX2	15.75

Table 3.20 Data volumes for different sensors

As explained above, as a rule of thumb, 3n bits to be transmitted in place of n bits for the probability of few errors. Hence the same concept is used to check 3 consecutive frames in the frame sync detection for arriving at the stable data acquisition. Frame sync detection is done through the digital correlators and described in the subsequent pages.

The error probability is a function of SNR and the bit errors increase as SNR decreases. Hence by varying the signal the system behavior can be modeled for different SNRs. As there can be variations (however minor it is) in the system performance time to time, system performance is logged on the fly to generate an operating point reference. Based on the operating point, the BER and the corresponding test times are derived on the fly to initiate online measurement of BER for a selected exponent while the CL is programmable.

3.7 System Development

Based on the mathematical model, the system has been developed by the authors. Basic formats of IRS data are fixed and hence the no. of bits transmitted and the data rates are drawn from the system data base as per the given satellite/sensor. The confidence levels are user programmable and 99% programmed as default. Based on these, reduced measurement times are derived and loaded into the look up table. The system performance characteristics are taken from the system in real time to choose the operating point of signal strength and derive the BER. Subsequently the measurement times are derived from the look up tables and get loaded to the BER measurement counter in the correlator part of the system. Other selections like BER window (Exponent) are selected by the system in auto mode as per the above environmental parameters. System hardware has been realized in Xilinx environment using CPLD’s with total in house software.

The frame sync correlation is the basis for the detection of errors in realtime. Therefore high speed digital correlators are developed as described in the subsequent pages at 3.8

3.7.1 **Functional Flow**

1. System behavior model available from the offline tests BER vs. SNR (Lookup Table)
2. ON line Signal Strength is available from the data acquisition and based on this BER is derived from the above LUT
3. From the chosen BER (from LUT) programmed satellite, sensor and confidence level, Test time is derived
4. Test the system for the derived Time
5. Set the BER counter exponent for the above derived BER
6. Look at the actual BER as per the Test Time
7. The results are fine tuned based on the day to day system functionality
8. Output

   Actual BER value during Image data download
   (a) in the system as a file
   (b) as a counter output for viewing and
   The hardware is also programmed to provide totalized errors

3.7.2 **Design Validation**

It has been developed in Xilinx platform using the CPLDs in the first version. Subsequently it is redesigned using vertex FPGAs.

For the purpose of design validation, it has been tested for different satellites. The BER that has taken based on the operating point was used as an input for selecting the test time and to select the exponent in the BER display while taking the confidence level always as 99%. The results are as follows:

Sat ID	**Expected BER**	**CL**	**Test Time sec**	**Actual BER**
IRS-1C	10^{-8}	99%	10.83	10^{-8}
IRS-1D	10^{-8}	99%	5.41	10^{-8}
IRS-P6	10^{-8}	99%	8.76	10^{-8}
IRS-P5	10^{-8}	99%	4.38	10^{-9}

Table 3.21 Results of validation of BER actual/designed

3.8 Design of High Bit Rate Digital Correlator *[35,37,43]*

3.8.1 Introduction

Correlation is a mathematical technique widely used in Communications, Instrumentation, Computers, Signal processing and Pattern Recognition. This technique can be applied to digital signals as well as to analog signals. The Correlation involve comparison of two sequences for a match by sliding against each other and then attempting to determine how closely the sequences resemble as they move with respect to each other in time scale. The Correlation of a function with a time-delayed replica of itself is called autocorrelation.

Satellite Communications experienced rapid growth in the past 3 to 4 decades. The Bandwidth requirements have increased multifold along with the data volumes. Therefore the speed requirements for the digital Correlators are much beyond the Correlators that are available in the world market resulting in need for high speed digital Correlators with all desirable properties with respect to reliability, maintainability and cost using the VLSI technology. The application of multiplexing techniques to digital Correlator is used to increase the operating speed. To configure M-bit digital Correlator using n-fold multiplexing resulted in N sub-Correlators, which are summed up to form the desired Correlator. In addition to multiplexing; synchronization, design optimization to achieve the desired speed are the important elements of this design. The authors have used new design techniques so that the Correlators can be used for all the remote sensing satellites that are in the road map for next decade and to cater to the full bandwidth capabilities for remote sensing applications. The design has been realized and certified.

3.8.2 Frame Sync Insertion and its detection

Frame synch words are inserted into the PCM data stream as a time marker for the receiver synchronization. This frame sync work as a synchronizing code word at regular time intervals and is useful for the recognition and retrieval of the information. The information theory indicates that the number of bits required to specify the beginning of the frame is $L = (\log_2 M)$ where L is the minimum number of frame sync bits required for error-free channel for a proper signal to noise ratio and M is the frame length in number of bits. The problems of noisy channel and the probability of random data having the appearance as frame sync code indicate the need for frame sync code with a length and 2 to 5 times L in order to achieve rapid frame sync acquisition. The specific values selected for a system would depend upon the worst case operating conditions of the signal-to-noise ratio. The Correlators of TRW range of 40 to 60 MHz use Pseudo random linear code generator references of length $N = 2^n - 1$ to shorten Correlation length.

3.8.3 Theoretical Background of Frame Sync Correlation

The Frame Sync correlation takes place in two modes viz. Search Mode and Maintenance Mode. The time interval during which the correlation gets established is called **SEARCH** mode. After the correlation the logic has to continue in the correlated mode and continue the correlation in the lock state. This is called **MAINTENANCE** mode. However due to the channel noise the logic looses the lock and reenters the search mode which continuously monitors for correlation between the received framing pattern and the expected frame pattern. If the maintenance mode detects a loss of synchronization, a loss of frame synchronization is declared and the search mode is reentered. Therefore the receiver framing circuit can be viewed as a two state machine, either searching for the synch word location or maintaining its temporal position once the synch word has been identified. When the channel errors corrupt the bit stream no events occur with certainty and a probabilistic model must be used for analysis.

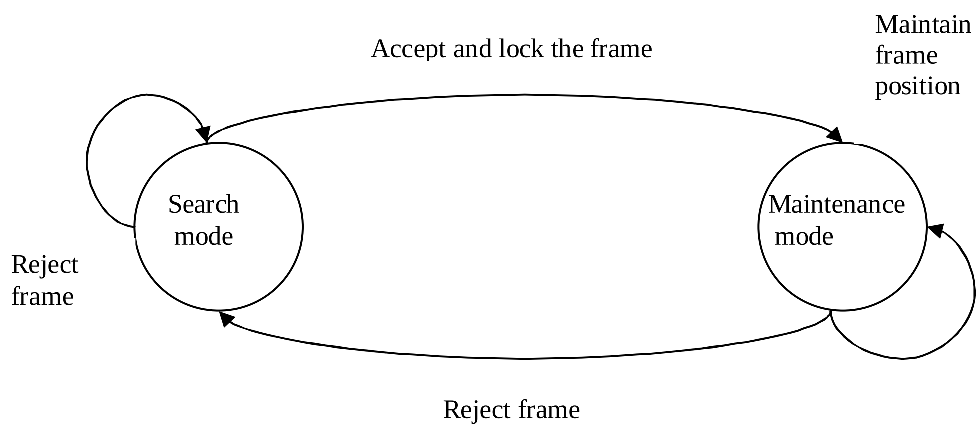


Fig.3.4 State diagram for frame sync detection

Frame synchronization performance is characterized by specifying:

- The time to acquire initial synchronization or frame acquisition time
- The time that frame synchronization is maintained as a function of BER, or time to loss of frame alignment
- The time to reacquire frame synchronization after a loss of synchronization or frame reacquisition time to be complete, a specification must state the transmission bit error rate and the required probabilities of acquisition, maintenance or reacquisition within the specified times.

Channel bits are assumed equally likely and statistically independent that is, for binary transmission, P(0) = P(1) = ½. Therefore the probability that a channel bit will match a frame synchronization bit is equal to ½. Bit errors are also assumed statistically independent, thus allowing use of Bernoulli trials formulation where the bit error probability P_e .is constant.

3.8.4 Frame Search Mode

The search mode provides a sequential search comparing each bit frame alignment position with the known frame pattern until a proper match is found. For the distributed frame structure each bit position is scanned one bit at a time at *F* bit intervals for up to *N* times, where *F* is the frame length and *N* is the number of frames in the pattern. The criterion for acceptance of a bit position is that the *N*-bit comparison must yield e or fewer errors while rejection occurs for more than e errors. When acceptance occurs, the frame maintenance mode is activated; for rejection the search mode shifts one bit position and tests the next bit position using the same accept/reject criterion. This operation of the search mode can be conveniently described in terms of a set of states (bit positions) and probabilities of transitions between these states (accept/reject probabilities). Thus there are four transition probabilities:

1. Probability of accepting a false position (P_{AF}):

$$P_{AF} = \sum_{i=0} \binom{N}{i} (0.5)^N$$

2. Probability of rejecting a false position (P_{RF})

$$P_{RF = 1 -}\ P_{AF}$$

$$P_{AF} = \sum_{i=\varepsilon+1}^{N} \binom{N}{i} (0.5)^N$$

3. Probability of accepting the true position (P_{AT}) :

$$P_{AF} = \sum_{i=0}^{t} \binom{N}{i} (1-p_e)^{N-i} p_e^i$$

4. Probability of rejecting the true position (P_{RT}) :

$$P_{RF = 1 -}\ P_{AT}$$

$$P_{AF} = \sum_{i=\varepsilon+1}^{N} \binom{N}{i} (1-p_e)^{N-i} p_e^i$$

The probability of acquiring true alignment during the first search of all possible bits is the probability of rejecting all random bit positions and accepting the true frame position. Should no match be found during the first search, even at the true frame position, additional searches are made until a match is found.

3.8.5 Frame Maintenance Mode :

Each frame pattern is first tested against a pass/fail criterion similar or identical to the accept/reject criterion used in the search mode. The maintenance mode reject criterion is based on more than one frame pattern comparison, which results in lower probability of inadvertent loss of frame synchronization. This protection against false loss of synchronization is known as hysteresis or flywheel provided by the maintenance mode.

Hence the first scheme is to go for 'r' successive tests fail before the search mode is initiated. The second is based on an up/down count, which is initially set at highest count M+i. For each test of the received frame pattern agreement results in an increment of 1 and disagreement results in a decrement of D.

If the count is already at its maximum value, succeeding agreements leave the count at its max. value when a loss of frame is declared through disagreement the count gets decremented. Continuation of loss state continues the count decrement till its zero state where the search mode gets activated. In general the calculation of the number of tests 'n' required before the zero state is reached depends on the environment. The number of tests required before the maintenance mode declares loss of frame depends upon the scheme employed based on the system environment and can be obtained by recursive techniques using the Markcov Chain Mode.

Digital Correlators with Parallel Pipes for improved speeds

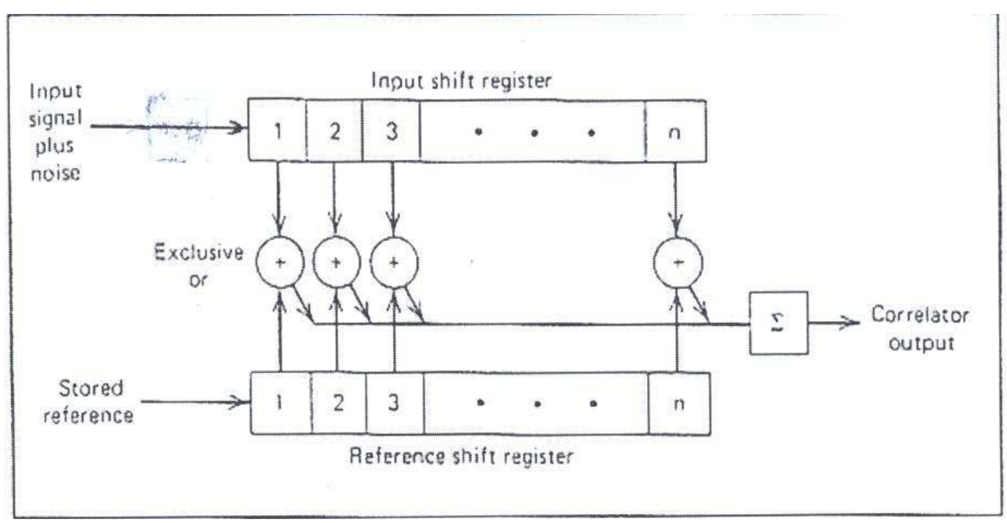


Fig.3.5 Diagram of digital correlator

A simplified logic diagram of a digital Correlator is shown above. An N-bit reference sequence is serially loaded into N-bit reference register R. A signal sequence is then clocked into N-bit register S. Each pair of corresponding bits Si, ri, in two registers is compared and the results of comparison of each position are summed to produce the Correlator output corresponding to the number of bit agreements A in th N-bit signal and reference sequences.

Using the VLSI design concepts, the correlators are part of a single FPGA/CPLD wherein the speed gets limited to the speed at which the chip can work. In order to improve the speed of the Correlator to handle high speed data streams, Parallel Pipe Correlation techniques are adapted. To configure an N-bit digital Correlator using K-Parallel pipes involve the use of K N/K bit digital Correlator devices designated as pipes or subcorrelators. The K sub Correlator outputs are summed up to form the overall multiplexed Correlator output. In practice, N/K will be power of 2 with k generally chosen for convenience as power of 2, N will also be some power of 2. The sub Correlator are designed as Serial load or Parallel load. In the serial load, the parallel K-subcorrelator outputs would be summed up in a binary adder as given bellow where (a) corresponds to a serial Correlator,(b) corresponds to timing diagram and (c) corresponds to ideal auto correlation function.

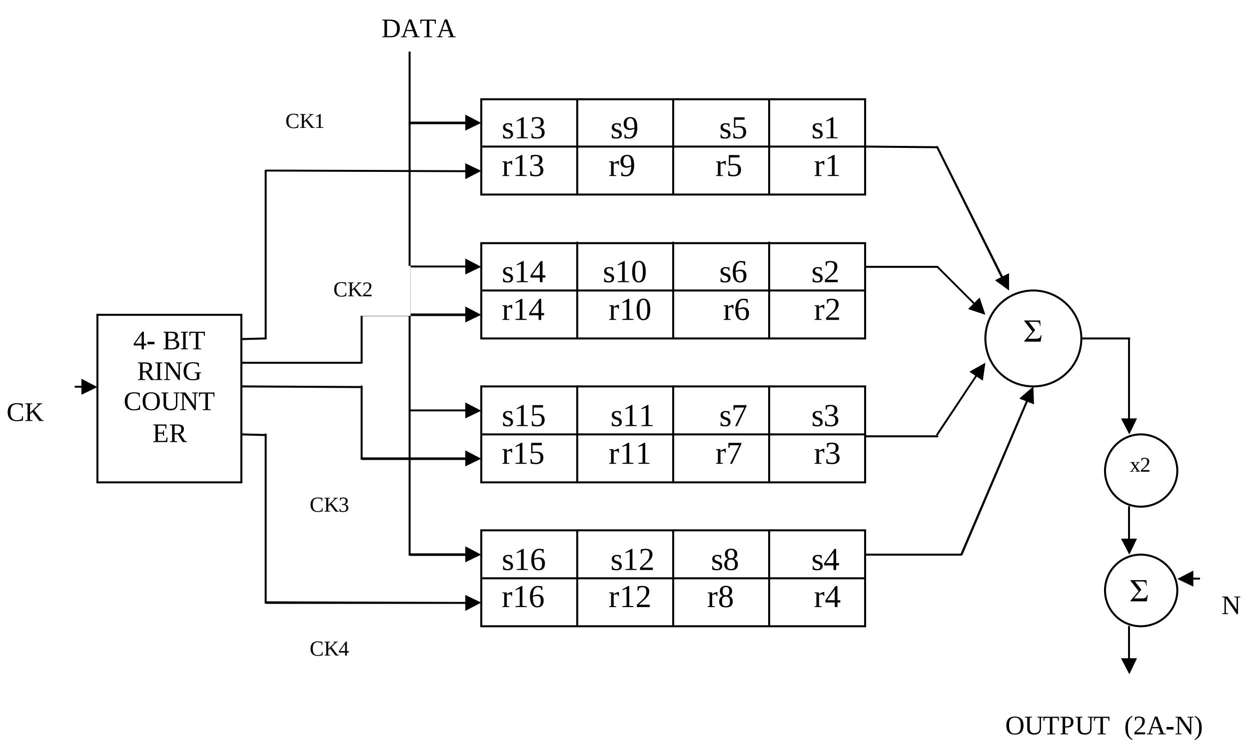
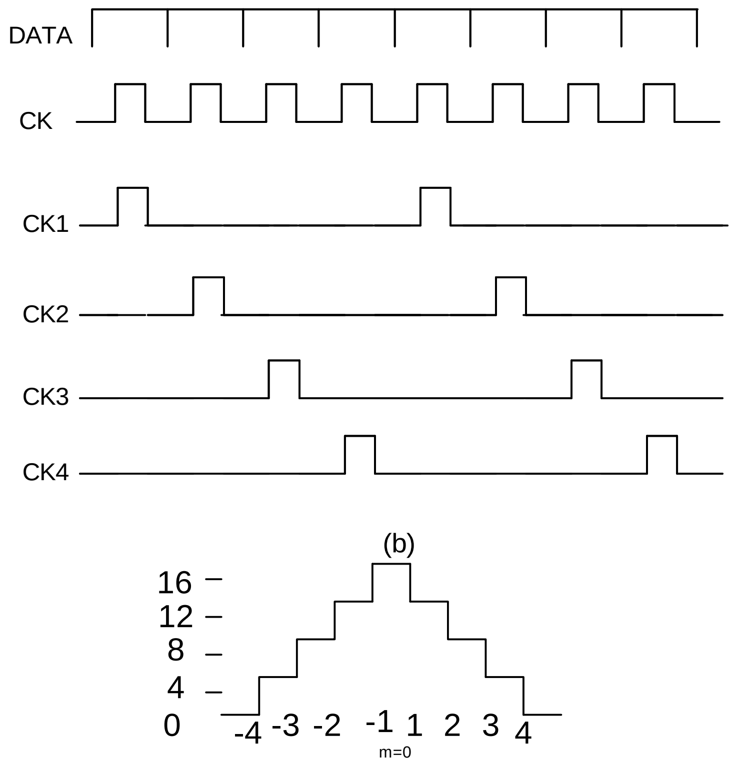


Fig.3.6 **Parallel Correlators**



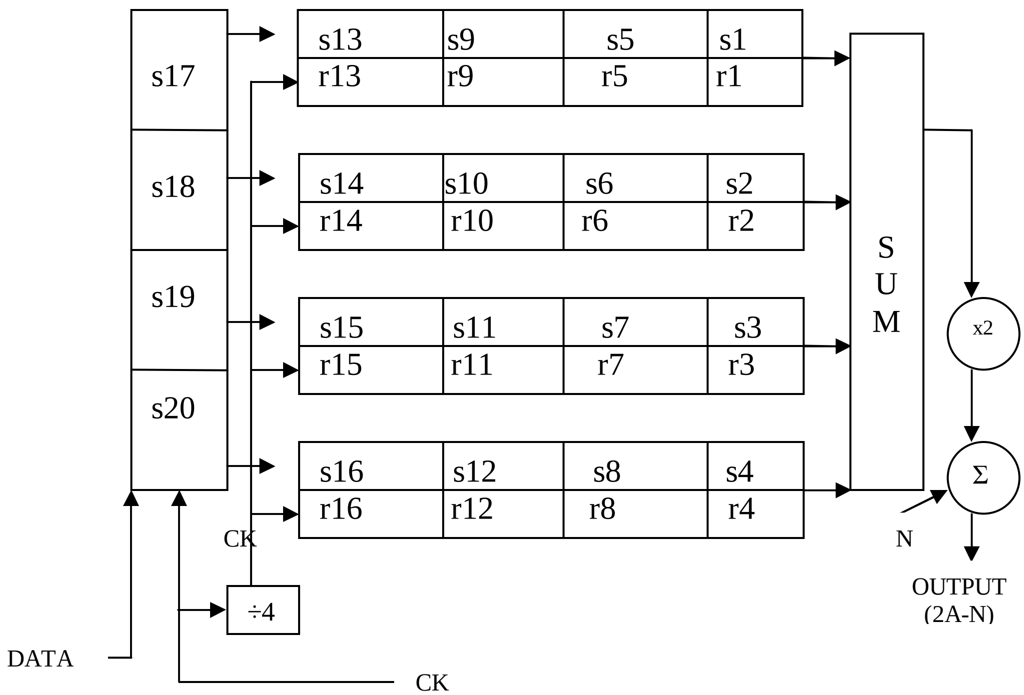
Parallel Correlators

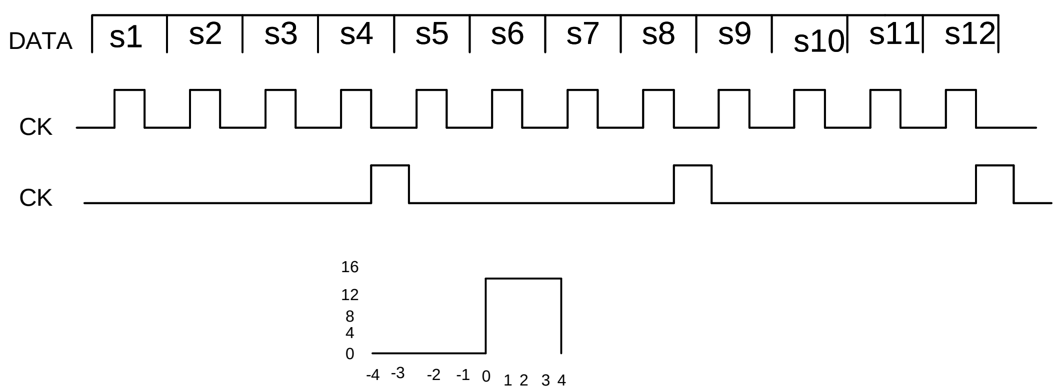
(c)

Fig.3.6 **Parallel Correlators**

The parallel load Correlator is given below fig 3.7 where the basic clock is divided in frequency by so that each subcorrelator is operated at clock <u>c/k.</u>

Both these approaches require exact synchronization of the signal sequence with the clock for proper positioning of the S registers in order for auto correlation to occur. The synchronization in the serial load case occurs only where the first bit of a reference code replica in the signal sequence corresponds to a clock pulse of subcorrelator 1. Synchronization in the parallel load case occurs only when the first bit of the reference code replica in the sequence corresponds to the first basic clock pulse following a reduced rate clock pulse. This is achieved through a data selector.





Parallel Correlators with Clock C/K

Fig.3.7 **Parallel Correlators with clock C/K**

3.8.7 Design Description

The overall block diagram of the system is shown below. The Frame Synchronization process is made more reliable by the flywheel logic.

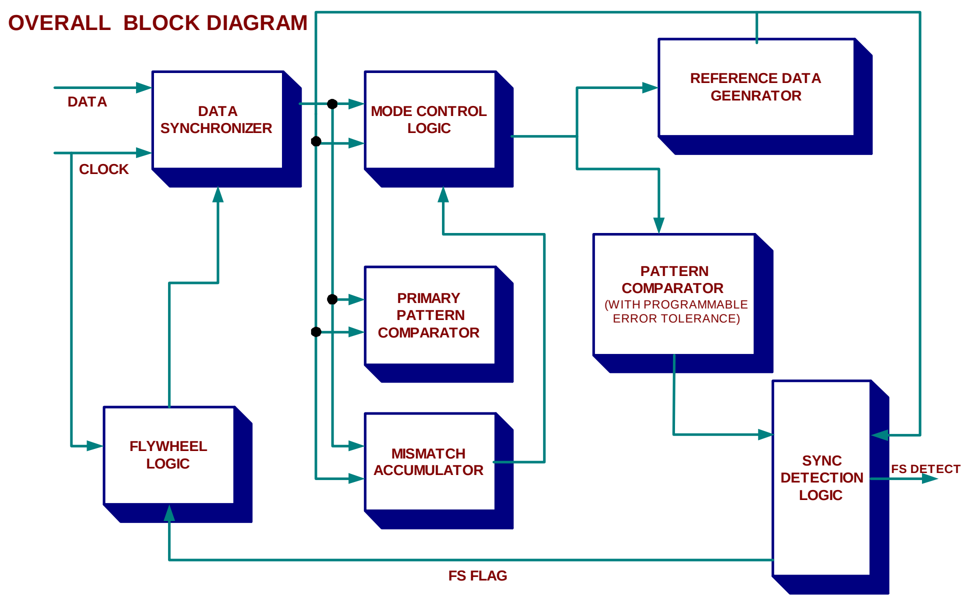


Figure3.8 Block Diagram of digital Correlator

The circuit at power on assumes the search mode of operation. After the initial data synchronization, the serial data bits from the incoming data are used as seed words to load the internal reference data generator. The Primary Comparator checks for the initial consecutive agreements and the Mismatch accumulator resets the logic once the error tolerance is violated. If consecutive agreements occur, the Pattern Comparator will compare the next stream of bits with those from the reference data. Since the communication channel is error prone, for robust operation the system has programmable error tolerance. Once the required agreements occur, the sync code word end bits from the reference data generator are gated and the gate output is enabled at the end of the frame sync word, resulting in the system going from search mode to Lock/Maintenance mode.

The circuit continues in the maintenance mode, searching for frame sync code words at regular intervals at which they are inserted by the formatter. In the maintenance mode, the flywheel logic helps in achieving the above operation.

3.8.8 Validation of the Design :

In each mode of operation of the system, a received serial bit is compared to a reference serial data bit. Each bit comparison may be considered to be a Bernoulli trial so that the number of bit mismatches in the code word as the

binomial distribution with parameter P_e , which is the probability of channel error rate for a sync word length of N bits and error tolerance of x bits.
The probability of error occurrence in the sync code word P is

$$P = {}^{N}C_{x} \; (P_e)^{x} (1 - P_e)^{N-x} \qquad \rightarrow \qquad \text{Equation 1.0}$$

For a Channel with $P_e = 1 X 10^{-6}$

The pattern comparator checks 64-bits of received data, after excluding the seed word bits, the remaining 56-bits can be grouped as eight equal groups.
If more than seven bit errors occur randomly within the 8 groups the initial seven consecutive bit agreements may not occur. If we proceed to calculate the probability of occurrence of these types of errors, we have

$$N = 56, x = 8 \text{ and } P = 10^{-6}$$

Substituting in the equation 1.0 we have

$$P_8 = 1.4025 \ X \ 10^{-39}$$

Thus P_8 gives the Probability of the system missing the initial consecutive seven bit agreements. Thus the probability of the system locking to the initial consecutive seven bits is

$$P_{lock} = 1 - (P_8 + P_9 + \ldots + P_{56})$$

but P_9 to P_{56} being infinitesimally small, hence are ignored.

$$P_{lock} = 1 \quad \text{(CERTAIN TO LOCK)} \qquad \rightarrow \qquad \text{Equation 1.1}$$

Therefore this design approach is certain in locking to the initial consecutive seven bits. The above calculations pertained to the 56 bits; the probability calculation for the remaining 64 bits is as follows. For a test case assuming the error tolerance of one error

$$X=2; \qquad P_e = 10^{-6}; \qquad N=64;$$

Substituting in Eqn. 1.0 we have

$$P_2 = 2.016 \ X \ 10^{-9}$$

As given in the equation 1.1 the probability of the system locking to initial consecutive 7-bits is ‘1’ i.e. Certain. Thus the overall probability of the system missing the frame synchronization (P_{MFS}) is

$$\mathbf{P_{MFS} = 2.016 \ X \ 10^{-9}}$$

Thus the design proves to be four times robust than the conventional correlation approach adopted by commercially available ICs whose probability of missing frame synchronization is 8 X 10^{-9}.

3.8.9 Performance in Maintenance Mode

Two measures of performance are used when the receiver is in frame Synchronism. The first is the expected time maintaining false sync before it is rejected (T_{MFS}) and the second is the expected time of maintaining true synchronism (T_{MTS}). In the later case, random channel errors will eventually cause the true code word to be rejected and search mode will be re-entered.
While the receiver is in the maintenance mode, each multi frame code word is verified to detect a possible loss of synchronism. When synchronism is lost due to channel errors, information bits are presented for code word verification. In

most cases, the false code word is immediately rejected (1 - P_{MF}) and the receiver is returned to the search mode. In some cases, random information bits can resemble the code word and false synchronism may be maintained for several multi frames. When measured from the correct word, the expected time to maintain false synchronism may be calculated by the following equation:

$$T_{MFS} = (N_F * T_B) / (1- P_{MF}) \quad \rightarrow \quad \text{Equation 2.0}$$

N_F is the number of bits in a multi frame
T_{MFS} is the average maintenance time of false synchronism
(1 – P_{MF}) is the possibility of rejecting a false sync word
T_B is the time per transmitted bit
For a test case with a Channel Error Rate of $1 * 10^{-6}$, N_F = 37500 Bits
& T_B =23.5565 ns
Substituting in equation 2.0, we have

$$T_{MFS} = 0.88364 \text{ ms}$$

A receiver in correct synchronism may falsely initiate search mode when the code word has been severely corrupted with channel errors. The average time to reject the true sync word is the maintenance time of true synchronism.

$$T_{MTS} = (N_F * T_B) / (1- P_{MT}) \quad \rightarrow \quad \text{Equation 2.1}$$

T_{MTS} is the average maintenance time of true synchronism
(1- P_{MT}) is the probability of rejecting the true sync word.
For the above test case we have

$$\mathbf{T_{MTS} = 122 \text{ Hrs}}$$

3.8.10 Performance in Search Mode

In search mode each bit position of the incoming data is tested for the synchronizing code word. In testing the NF – 1 false locations of the multi frame random data may resemble the sync word and cause sync maintenance in a false location. When the maintenance word fails to verify the next sync word, the process returns to search mode. When the correct sync location is encountered, the maintenance mode is usually entered although random errors can cause continuation in the search mode. If the search procedure is assumed to start in the worst possible location, the equation below calculates the maximum average search time.

$$T_{FTS} = (N_F * T_B) / P_{AT}) \quad \rightarrow \quad \text{Equation 2.1}$$

Where P_{AT} is Probability of accepting the True Sync word.
For the test case of above we have

$$T_{FTS} = 0.88364 * 10^{-3} \text{ sec}$$

fig. 3.9 Digital Correlator PCB

3.8.11 Conclusions

The digital correlators designed and developed using the Xilinx CPLDs by the author has been tested and certified upto 160 MHz. The developments using Vertex are certified beyond 200 MHZ. The design has been proven to be four times more reliable than the commercially available Correlators. The design has the flexibility to adapt to scalable parallelism for higher performance, though the current design meet the requirements for all the satellites to be launched in the next decade. The synchronization approaches used for parallel pipes is a real challenge to the designers.

This technology has been developed as a Technology development project at Data Archival and Real time Systems Division of NRSA, Department of Space, Govt. of India, to facilitate the reception chain performance validation in real time in auto mode, and of immense use to all the remote sensing community. The results have been validated with pre-pass performance values and are matching consistently, providing the accuracy and confidence to the methodology. With the advent of VLSI technology, software methodologies and convergence of networks, automated testing and Remote management of systems has become a reality. As a part of this approach the above system has been developed to enable automated testing of the total chain with remote configurability and diagnostics support. With the other associated developments remote configuration and control of remote sensing satellite ground station has been made as a reality.

3.8.12 Design Implementation Results Correlator

```
XACT:  version M1.4.12                                  Xilinx Inc.
                                   Fitter Report
   Design Name: fssync
Fitting Status: Successful                                 Date:  3- 9-2004,
4:29PM

****************************  Resource Summary
****************************

Design        Device            Macrocells     Product Terms   Pins
Name          Used              Used           Used            Used
fssync        XC95108-7-PC84    28 /108 ( 25%) 58 /540 ( 10%)  3  /69
(  4%)

PIN RESOURCES:

Signal Type    Required     Mapped  |  Pin Type            Used
Remaining
------------------------------------|---------------------------------
-----
Input         :    1           1    |  I/O              :     2
61
Output        :    1           1    |  GCK/IO           :     1
2
Bidirectional :    0           0    |  GTS/IO           :     0
2
GCK           :    1           1    |  GSR/IO           :     0
1
GTS           :    0           0    |
GSR           :    0           0    |
                 ----        ----
        Total      3           3

GLOBAL RESOURCES:

Signal 'CLKINPAD' mapped onto global clock net GCK1.
Global output enable net(s) unused.
Global set/reset net(s) unused.

POWER DATA:
There are 28 macrocells in high performance mode (MCHP).
There are 0 macrocells in low power mode (MCLP).
There are a total of 28 macrocells used (MC).End of Resource Summary
```

Flywheel

```
XACT:  version M1.4.12                              Xilinx Inc.
                                  Fitter Report
   Design Name: fssync
Fitting Status: Successful                           Date:  3- 9-2004,
4:43PM

************************ Resource Summary ****************************

Design        Device             Macrocells      Product Terms    Pins
Name          Used               Used            Used             Used
fssync        XC95108-7-PC84     29 /108 ( 26%) 61 /540 ( 11%)   5  /69
(  7%)

PIN RESOURCES:

Signal Type    Required     Mapped  |  Pin Type        Used   Remaining
------------------------------------|----------------------------------
Input         :    1           1    |  I/O              :     4
59
Output        :    3           3    |  GCK/IO           :     1
2
Bidirectional :    0           0    |  GTS/IO           :     0
2
GCK           :    1           1    |  GSR/IO           :     0
1
GTS           :    0           0    |
GSR           :    0           0    |
                 ----        ----
        Total      5           5

GLOBAL RESOURCES:

Signal 'CLKINPAD' mapped onto global clock net GCK1.
Global output enable net(s) unused.
Global set/reset net(s) unused.

POWER DATA:
There are 29 macrocells in high performance mode (MCHP).
There are 0 macrocells in low power mode (MCLP).
There are a total of 29 macrocells used (MC).

End of Resource Summary
```

Frame Synch

```
XACT:  version M1.4.12                              Xilinx Inc.
                                 Fitter Report
   Design Name: fssync
Fitting Status: Successful                            Date: 3- 9-2004 ,
4:01PM

****************************  Resource Summary
****************************

Design        Device            Macrocells     Product Terms   Pins
Name          Used              Used           Used            Used
fssync        XC9536-5-PC44    27 /36  ( 75%) 50 /180 ( 27%)  3  /34  (
8%)

PIN RESOURCES:

Signal Type    Required     Mapped  |  Pin Type           Used
Remaining
------------------------------------|---------------------------------
-----
Input         :    1          1     |  I/O              :     2
26
Output        :    1          1     |  GCK/IO           :     1
2
Bidirectional :    0          0     |  GTS/IO           :     0
2
GCK           :    1          1     |  GSR/IO           :     0
1
GTS           :    0          0     |
GSR           :    0          0     |
                 ----       ----
        Total      3          3

GLOBAL RESOURCES:

Signal 'CLKINP' mapped onto global clock net GCK1.
Global output enable net(s) unused.
Global set/reset net(s) unused.

POWER DATA:

There are 27 macrocells in high performance mode (MCHP).
There are 0 macrocells in low power mode (MCLP).
There are a total of 27 macrocells used (MC).
End of Resource Summary
```

Chapter- 4

Computer Controlled Tracking Systems

Abstract :

Auto track system for Remote Sensing Satellite data reception has certain limitations with reference to low and high elevation angles. In order to overcome these limitations and to have the total knowledge about the tracking systems, it is necessary to have Computer Controlled programmed mode of tracking. This calls for the Controller to have the full knowledge about the tracking systems and the accurate knowledge of the true position of the satellite at all times. Development of such system involve (a) Development of software for the automated operations of the station functions. (b) Characterization of the station for its tracking (c) Development of tracking software and (d) Fine tuning of the integrated system for a reliable programme track. (e) Extension of this to handle multi-terminals and to make it netcentric for remote management. These developments were implemented and the results of one year error free data acquisition is provided as a sample.

4.1 **Introduction**: [46-48,53-58]

Satellite tracking in Auto track is the most common form. When implemented for remote sensing satellites with S & X band tracking provision, auto diversity helps the systems to track in S-band initially and switch over to X band as per the availability. This concept helps the systems to have one tracking as a back up to the other. However due to environmental reasons and due to system limitations, satellite tracking gets lost irrespective of the tracking carrier used either S or X. Another approach is to have programmed mode of tracking wherein the tracking system is driven by the pre-determined trajectory of the satellite. In order to implement such a system the tracking system behavior is required to be modelled precisely so that the program track system can be fine tuned to have errors less than 0.1^{o} in both elevation and azimuth. A fine tuned system over a period of time can be as efficient as an auto track system while overcoming loss of tracking conditions like environmental conditions and the system limitations etc., Therefore the fine tuned programme track system can be a top layer under the tracking environment with full efficiency. As the tracking system is basically driven by a computer, the total parameters and the status of the tracking system is fully known to the computer which in turn helps for the automation and remote management. This concept is used for the development of the programme track system for the remote sensing satellites by name Station Control Computer (SCC) associated with the software that is used in tracking by name “TRACK” were developed and also supplied to the national and international customers under the IRS Programme of Department of Space for the establishment of Ground Stations elsewhere.

This system has provided 100% efficiency after the full implementation as brought out in this chapter along with the statistical details.

In order to handle multiple earth stations in a given location and to facilitate remote management, Net Centric Station Computer Systems were designed, developed and implemented as described below.

4.2 Station Control System (SCS)Description [54]

The Station Control System(SCS) controls and monitors the Data Reception System. It is the main interface between the operator and the antenna system to program the system to track automatically the Remote Sensing Satellites. This along with Station Automation System configures, controls, monitors various instruments viz. Antenna Control Unit (ACU), Time Code Translator (TCT), Demodulators (DEMOD) and Bit Synchronizers. The TRACK Software computes the trajectory of the satellite to be tracked and commands the antenna in a scheduled environment.

Station Control Computer(SCC) for multi-terminal support is configured in similar lines with common interface files shared across the network. There will be separate system for each Terminal and all are networked. For a two terminal system the configuration will be as follows:

SCC- PC1 for Terminal–I , SCC–PC2 for Terminal-2 and Station Automation PC (SAC) are networked. Pass Schedule is generated for both the terminals on any of the SCC PC's and this information is shared across other systems.

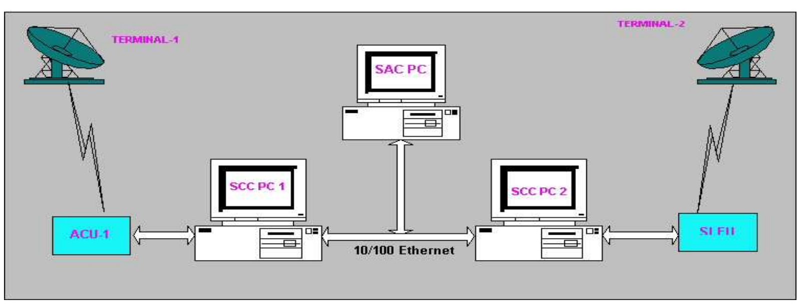


Fig.4.1 Two terminal SCC

Station Automation Computer (SAC) is interfaced through GPIB/USB interface to all key systems in Data Chain which have GPIB/USB interfaces.. The system monitors the status of Demodulators and Bit Synchronizers and configures the Data Path Controller as per the requirement. The software developed provides user friendly GUI.

The SCC system is configured around PC with necessary hardware and software support to handle these tasks. The basic functions of this system are briefly illustrated below.

- Synchronizing the System Time with Station Time

- Generation of Pre Pass Planner(PPP) reports & Pass Information
- Clash Analysis of visible passes in the multisatellite/multi terminal environment.
- Scheduling passes as per pass support
- Automatic Positioning using sector information of the Antenna for initial Acquisition prior to Appearance of Satellites (AOS)
- Program Tracking of the Satellite
- Positioning of Antenna to Bore-sight Radiation for loop checks.
- Positioning of Antenna to STOW position
- Reading Time Code from the Time Code Translator and display

4.3 Software Development [49-53]

The Tracking Software of Station Control computer is primarily designed to handle critical real-time tasks of tracking the Satellite through ACU and monitoring the status of RF systems in the Data Reception Chain during the Satellite pass . The ACU and the RF Systems are interfaced through GPIB to SCC.

The Tracking Software consists of following modules

- **Scheduler**
    - Schedule
        - Clash Analysis
        - Pre-Pass Positioning
        - Program Track during Pass Time
    - Quit

- **Utilities**
    - Satellite State Vectors(SVs) Update
    - PPP Generation
    - STOW Position
    - Bore sight Position
    - Set Time
    - Read Time
    - RF chain
    - Data Path Controller
    - BERT System
    - Satellite Data Format Simulator
    - Antenna Control Unit
    - Sun-Moon track

The functional description with Data Flow Diagram (DFD) for above modules are described in detail below.

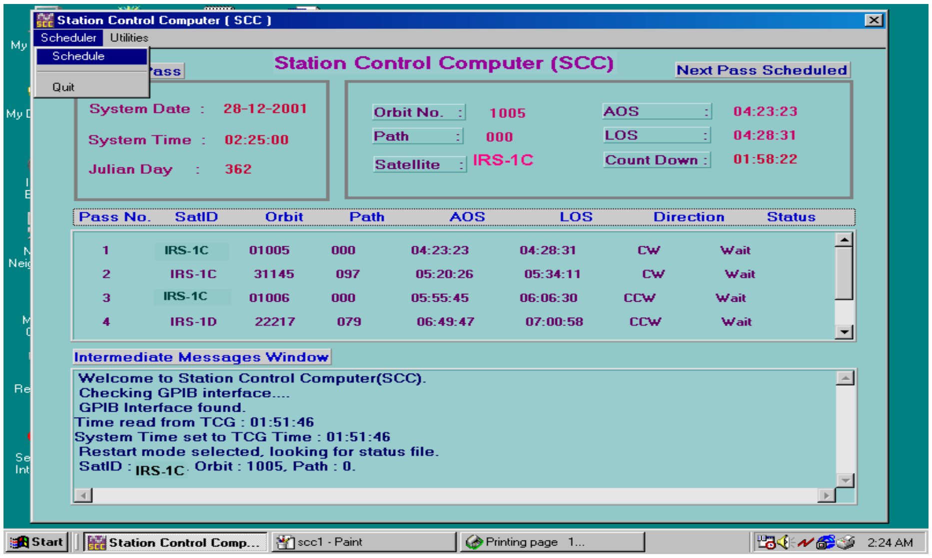


Fig.4.2 GUI for SCC

4.3.1 Scheduler:

4.3.1.1 Functional Description:

- Scheduler schedules and coordinates various activities based on the System Timer Events. Ensures State Vectors are updated with DOP-1 epoch and PPP's are generated for the Date of Operation (Date of Pass).
- Synchronizes the system time to Station Time through GPIB interface
- Provides AUTO & RESTART scheduling
- Provides Mission Support option in AUTO mode of scheduling
- Generates pass information for supported missions, performs clash analysis on this and generates report. The AOS/LOS timings are derived for 3 deg. Elevation position.
- Based on the clash analysis report, user is allowed to resolve the clashes either by deselecting one of the clashing missions or by changing AOS/LOS timings in certain overlap pass cases.
- Scheduler selects the pass from scheduled list sorted in ascending order with reference to pass timings. If the pass time is less than the system time, it is scheduled, otherwise it skips and next pass is selected and this is repeated until all passes are checked The countdown is enabled for the scheduled pass. This selection process is repeated for every pass until all passes are completed.

4.3.1.2 Schedule Process

- Scheduler invokes Program Track module (PTM) at countdown time 10 minutes
- The Program Track module performs
    - Initializes ACU parameters

- Pre-pass positioning of antenna to initial look angles derived with respect to AOS time of the pass selected
- At countdown 30 seconds, the Antenna Control Unit (ACU) will be switched from Standby mode to Position mode, and at countdown 5 seconds, the Auto Track is enabled.
- At AOS, Real-time control module will sends predicted AZ & EL angles to ACU and reads the Actual Values, computes Error and displays in the **Real Time Tracking panel**. The process continues till LOS.
- On exit from Real-time control module, the Post-pass positioning of antenna to initial angles is performed and it exits from PTM module

- After exit from PTM module, next supported pass is scheduled and countdown is updated for the pass. The above processes of scheduling are repeated until all the passes are over in selected list of schedule.

Fig.4.3 GUI for clash analysis

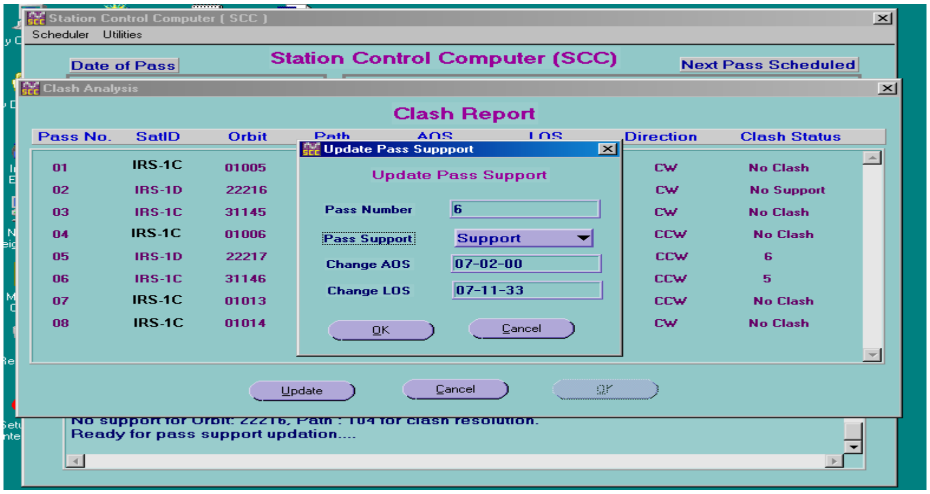


Fig.4.4 GUI for clash report

4.3.1.3 Data Flow Diagram:

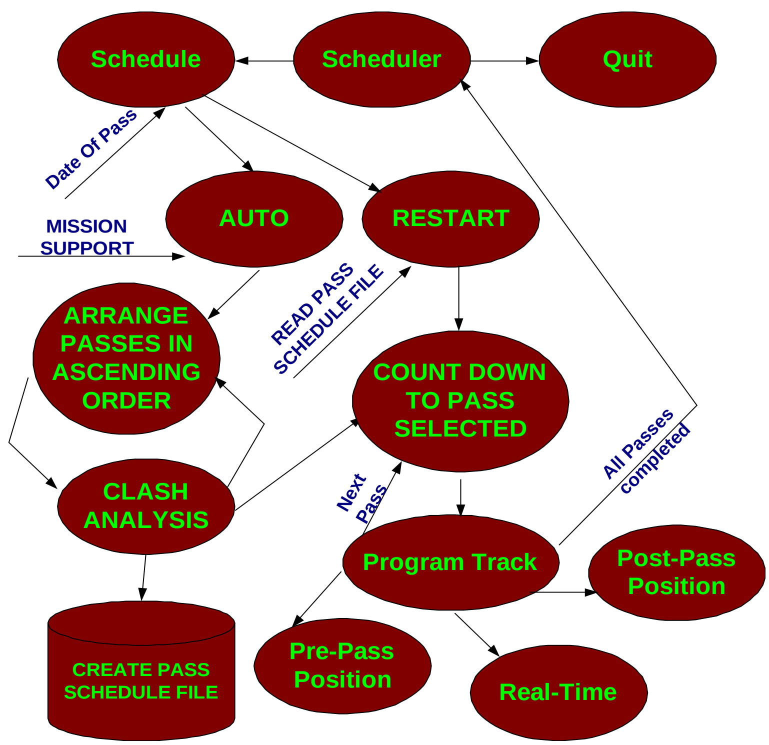


Fig.4.5 DFD for SCC

Inputs : Date Of Operation, Mission Support, Pass Schedule File, Pass support

Outputs: Create Pass Schedule File, Pre-pass position, Post-pass position, Real-time Tracking of Satellite , Display Tracking errors

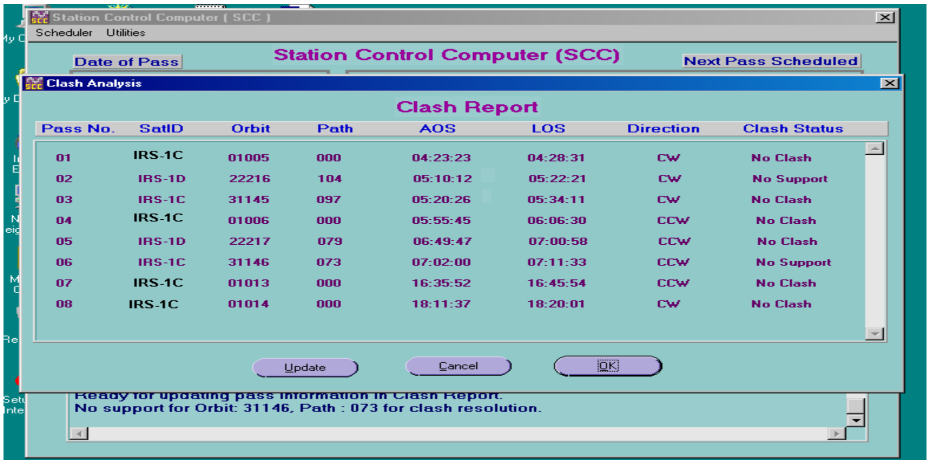


Fig. 4.6 GUI for Pass Support file

4.3.1.4 Quit :

Functional Description:

On click of this button , the TRACK software exits from the scheduler and returns to the windows desktop.

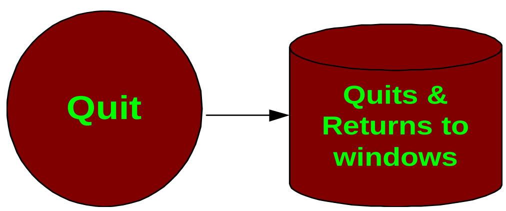


Fig.4.7 DFD for quit

Inputs : User selection

Outputs: Quits the scheduler and returns to the windows

4.3.2 Utilities :

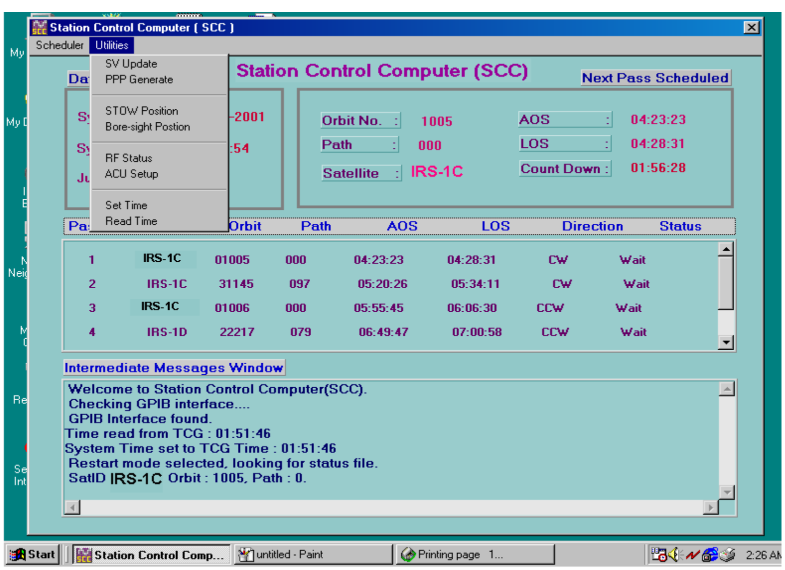


Fig.4.8 GUI for Utilities

4.3.2.1 SV (State Vector) Update :

Functional Description:

This utility updates the State Vectors from user inputs or from a file. User has to provide Date of Operation , Satellite ID, State Vectors corresponding to selected Satellite ID & Epoch Date. If State Vectors are available as text file , then user has to select Read text file or else manual entry of all elements of State Vectors. Once all the entries are completed, on click of UPDATE button , the process updates all the user entries and creates a formatted output text file required for PPP Generation module.

Data Flow Diagram:

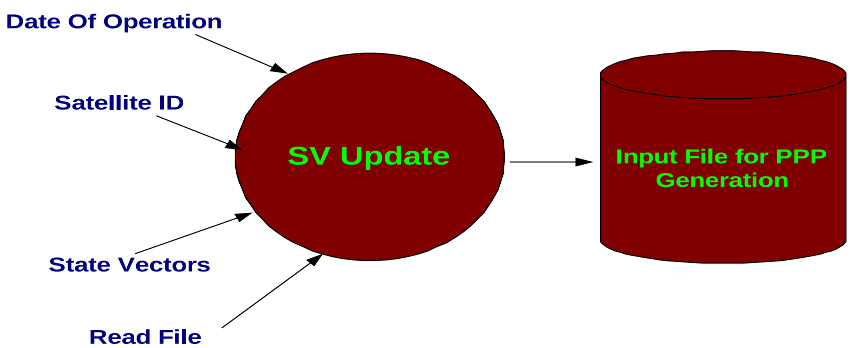


Fig.4.9 DFD for SV update

Inputs : Date Of Operation, Satellite ID , State Vectors

Outputs: a text file of the format : SEPH_Iss.ddd

Where ss - Satellite ID ex. 1C , 1D

ddd - Day number within the year ex. 365

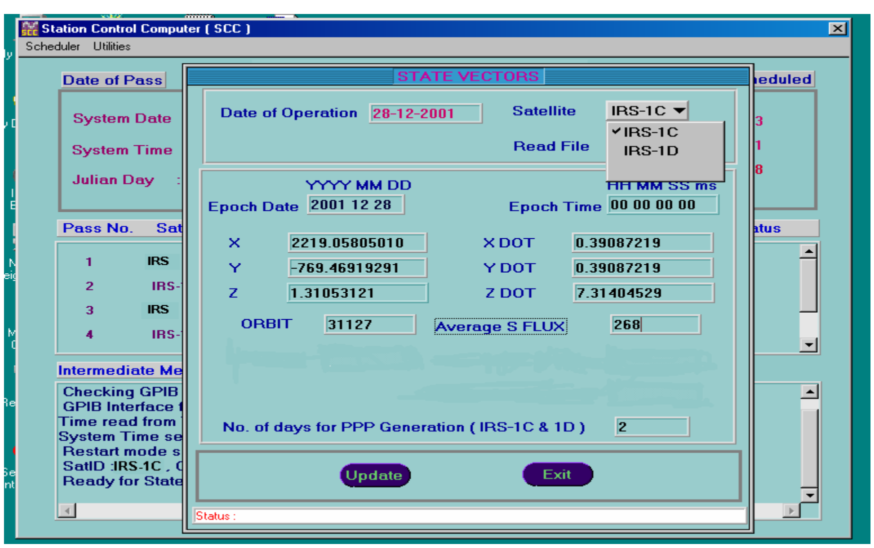


Fig.4.10 GUI for SV's update

4.3.2 .2 PPP (Pre Pass Planner) Generation :

Functional Description:

This utility generates pass information for selected Satellites.

This process takes Satellite ID input from user and reads State Vector information from PPP Gen Input file and generates Ephemeris for all orbits. For the given station co-ordinates generates pass information for visible passes and look angle information orbit wise at specified intervals

Data Flow Diagram:

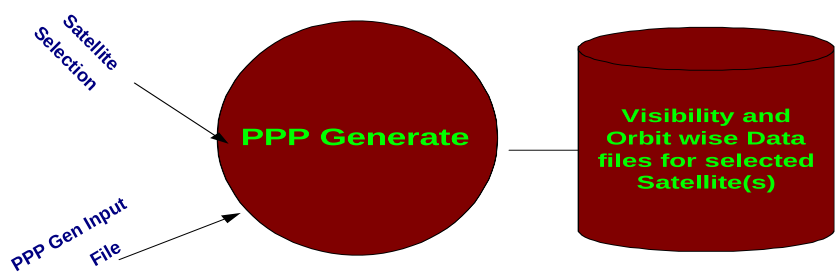


Fig.4.11 DFD for PPP gen.

Inputs : a text file of the format : SEPH_Iss.ddd and Satellite ID selection

Outputs: Visibility File & Orbit wise files of the format

Vsbtms_iss.ddd

Iss_PPPooooo.dat

Where ss - Satellite ID ex. 1C , 1D

ddd - Day number within the year ex. 365

ooooo - 5 digits Orbit number

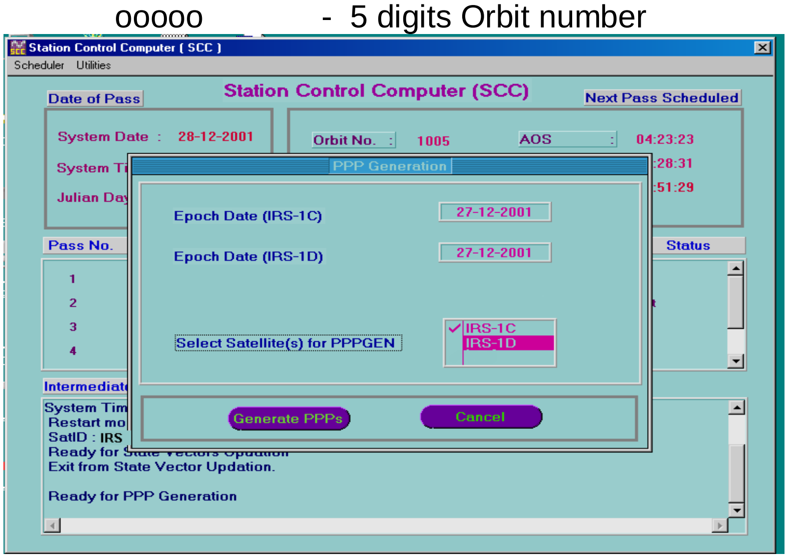


Fig.4.12 GUI for PPP gen.

4.3.2.3 STOW Position :

Functional Description:

This utility positions the antenna to STOW postion. This process sends antenna position angles of STOW POSITION to Antenna Control Unit (ACU) and uses Rate mode for coarse and Position mode for fine positioning until the antenna reaches the desired angle. Ex. STOW position angles are

Azimuth ~ 356.64 ^{O}

Elevation ~ 90.208 ^{O}

Data Flow Diagram:

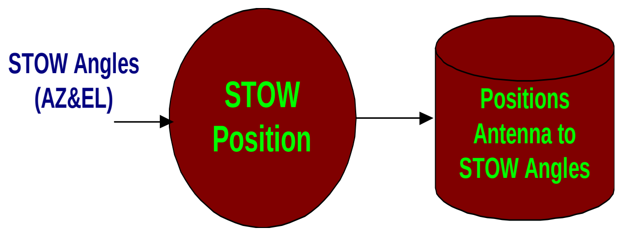


Fig.4.13. DFD for Stow

Inputs : Stow Angles (Azimuth & Elevation)

Outputs: Positioning of the Antenna to STOW angles

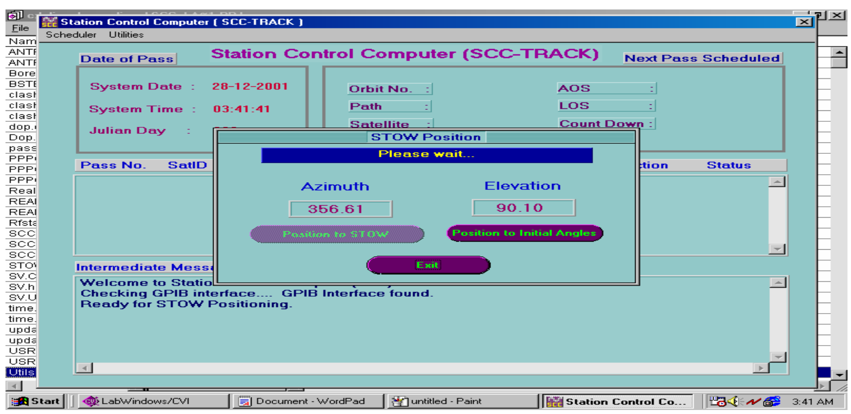


Fig.4.14 GUI for Stow

4.3.2.4 Boresight Position :

Functional Description:

This utility positions antenna to Boresight position and provides pointing accuracy and position offset information. This process sends antenna position angles of BORE SIGHT to Antenna Control Unit (ACU) and uses Rate mode for coarse and Position mode for fine positioning until the antenna reaches the desired angle. Ex. BORE SIGHT position angles are

Azimuth ~ 121.60 ^{O}

Elevation ~ 359.45 ^{O}

For Local loop tests feed back to scheduler will be provided for corrective measures.

Data Flow Diagram:

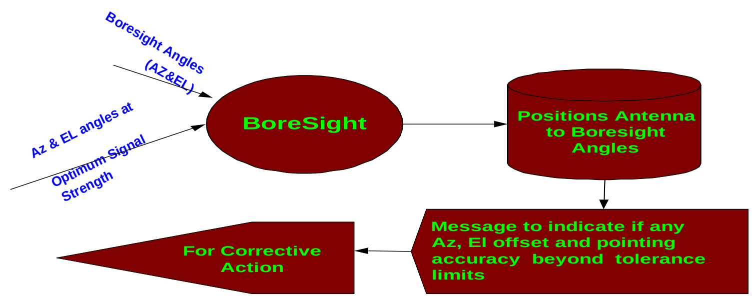


Fig.4.15 DFD for Boresight Position

Inputs : BORE SIGHT Angles (Azimuth & Elevation)

Outputs: Positioning of the Antenna to BORE SIGHT angles

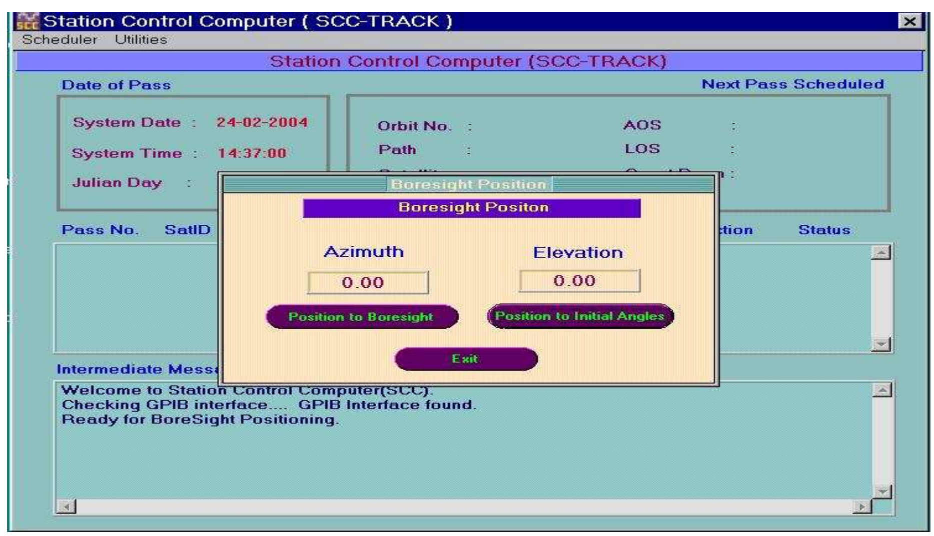


Fig.4.16 GUI for Boresight position

4.3.2.5 Set Time :

Functional Description:

This utility sets the system time to Station time. This process to synchronize system time with station time, it reads IRIG-A Time Code from TCT GPIB interface, in any of the formats ASCII or PACKED BCD and sets the PC system time accordingly.

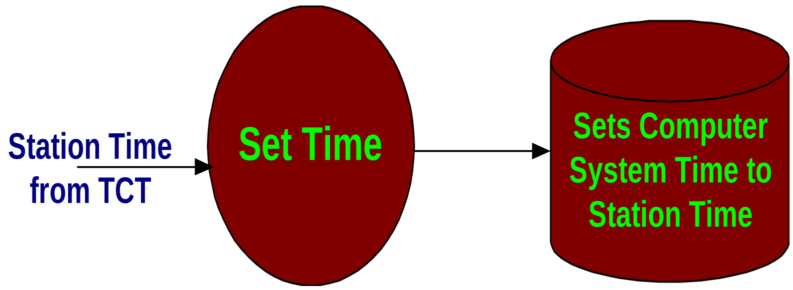


Fig.4.17 DFD for Set time

Inputs : IRIG-A Station Time from TCT through GPIB interface

Outputs: Synchronizes the PC system time to Station time from TCT

4.3.2.6 Read Time :

Functional Description:

This utility reads Station time. This process reads IRIG-A Time Code from TCT GPIB interface, in any of the formats ASCII or PACKED BCD and displays the read time in message intermediate message window of scheduler

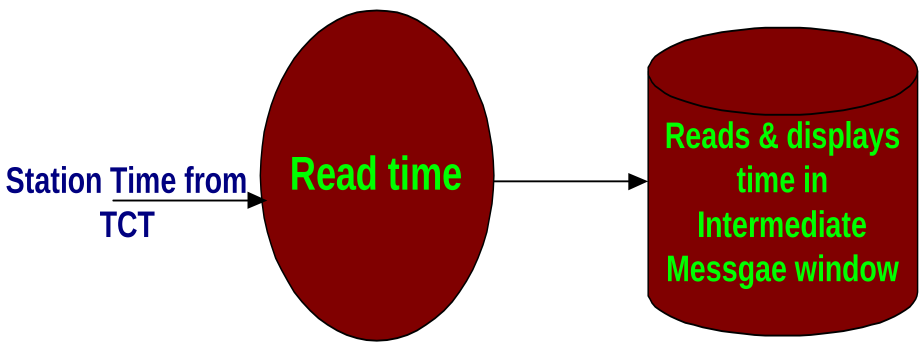


Fig. 4.18 DFD for Realtime

Inputs : IRIG-A Station Time from TCT through GPIB interface

Outputs: Reads and displays in intermediate message window of scheduler

4.3.2.7 RF Chain

Functional Description:

This module is a Utility function developed as a GUI function. This process monitors the status of Demodulators and Bit Synchronizers in Real-time. The main functions are

- Monitoring the carrier lock/loss status of demodulators
- Monitoring Clock Lock/Loss status of Bit Sync
- LO Frequency programming

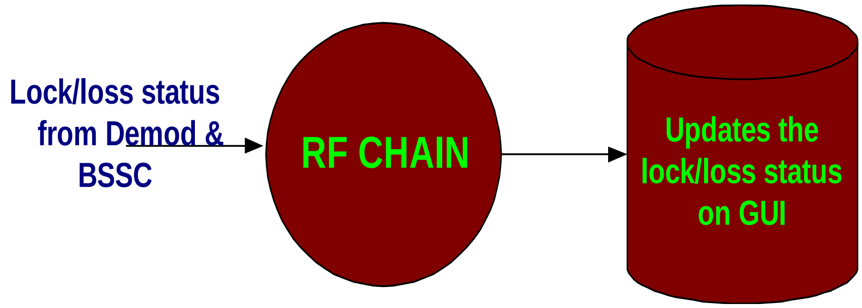


Fig.4.19 DFD for RF chain status

Inputs: *Lock/Loss status from Demods and BSSC*

Outputs: The Lock/Loss status displayed on the GUI.

4.3.2.8 Antenna Control Unit (ACU) [53]

Functional Description:

This utility configures the ACU and tests different functions of the ACU. This process configures the ACU and selects different modes of operation for offline testing of Servo system

- Rate / Position mode selection
- Rate / Position values
- Position Angles readout

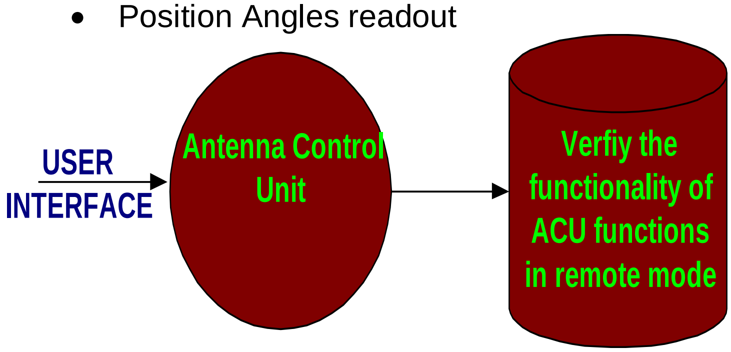


Fig.4.20 DFD for ACU

Inputs: Enter the configuration through GUI

Outputs: Verify the functionality of ACU functions in remote mode

4.3.2.9 SUN-MOON Track

Functional Description:

- This utility Generates SUN & MOON look angles for the given time period and positions the antenna to respective angles. The AUTO acquisition is enabled if the antenna locks to SUN or MOON. The user interface contains
    - Selection of SUN or MOON
    - Time Period for which PPP's to be generated and integration time
    - Station Co-ordinates selection and modification

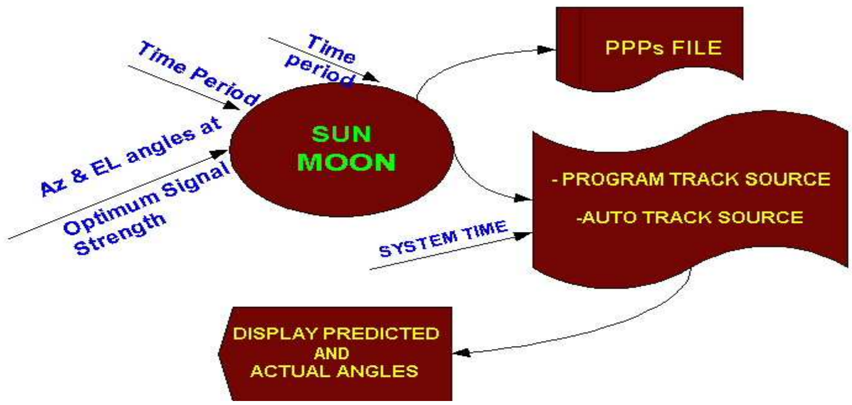


Fig.4.21 DFD for Sun Moon Track

Inputs: Enter the configuration through GUI

Outputs: Verify the functionality of ACU functions in remote mode

- The program positions the antenna to angles with respect to time for selected source (SUN or MOON) and tracks the source in Program Track Mode at the time interval chosen. During this process, if the signal strength of source is sufficient enough then it enables Auto Track and tries to track in AUTO mode. The predicted and actual angles along with time are displayed for user information

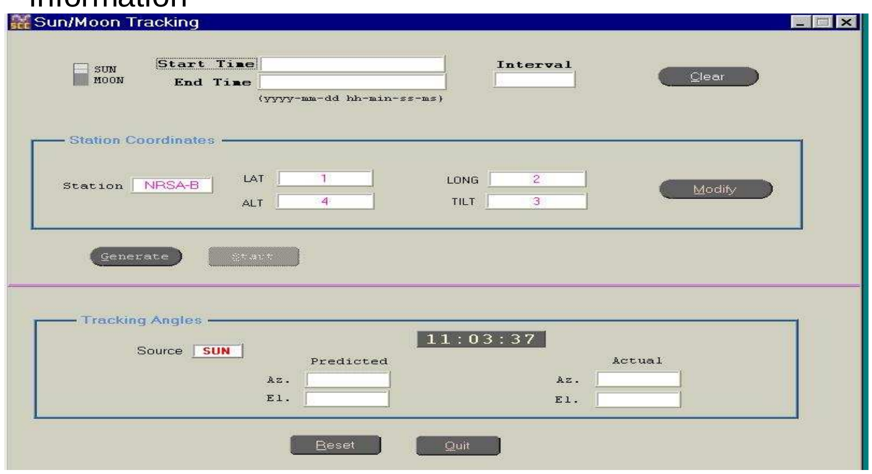
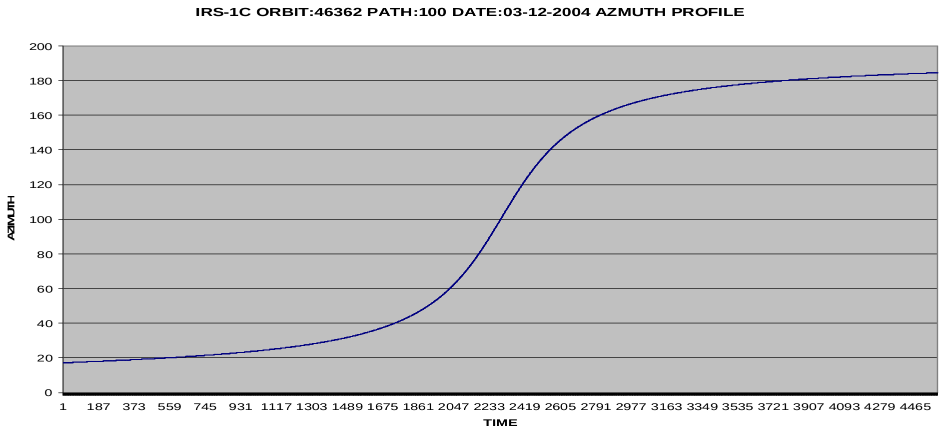


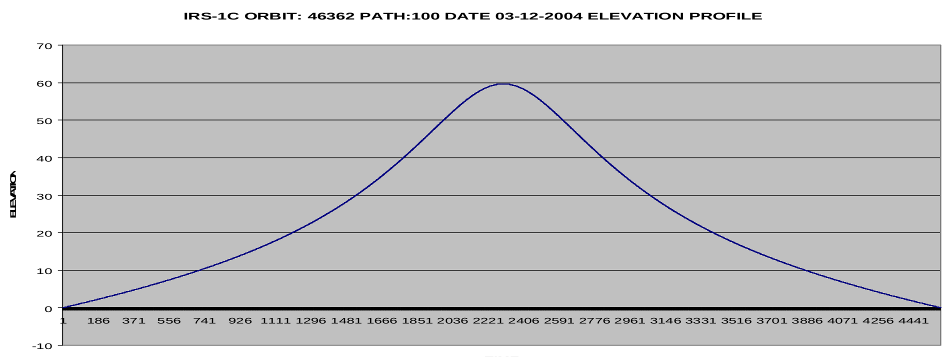
Fig.4.22 GUI for Sun Moon Track

4.4 System Modelling and fine tuning of the program track

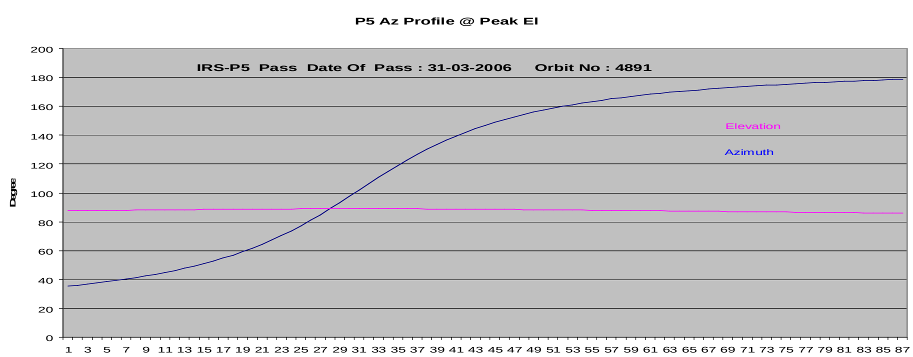
Satellite State Vectors are used for the orbit determination. Sample outputs are annexed to this chapter pertaining to IRS1C dated oct 04,2006 for orbit nos 55881&55882. The determined orbit is compared with the auto track results both in Azimuth and Elevation. The sampling of Az and El. Values in auto track is based on the system model. The orbit determination is fine tuned for best possible errors both in Az and El. The Az and El. Profiles generated for IRS-1C and IRS-P5 are enclosed as a sample.



Plot No.4.1 Azimuth Profile



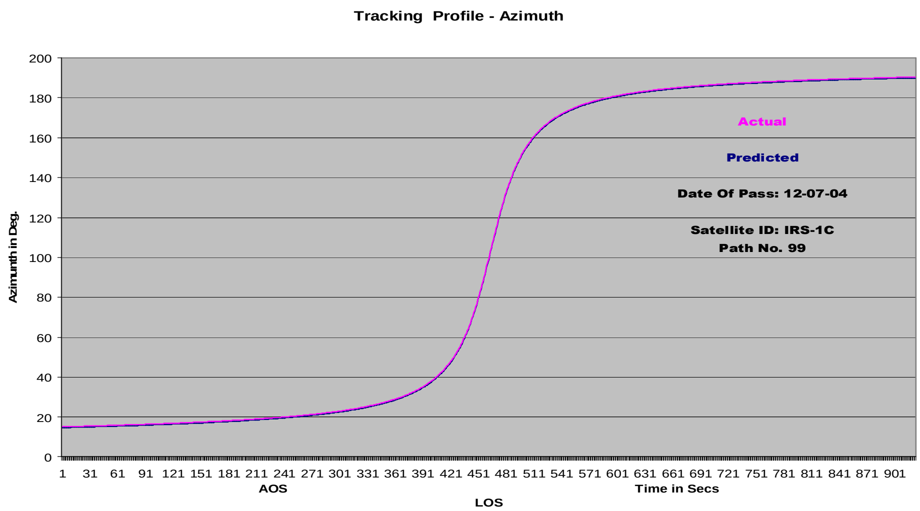
Plot No.4.2 Elevation Profile



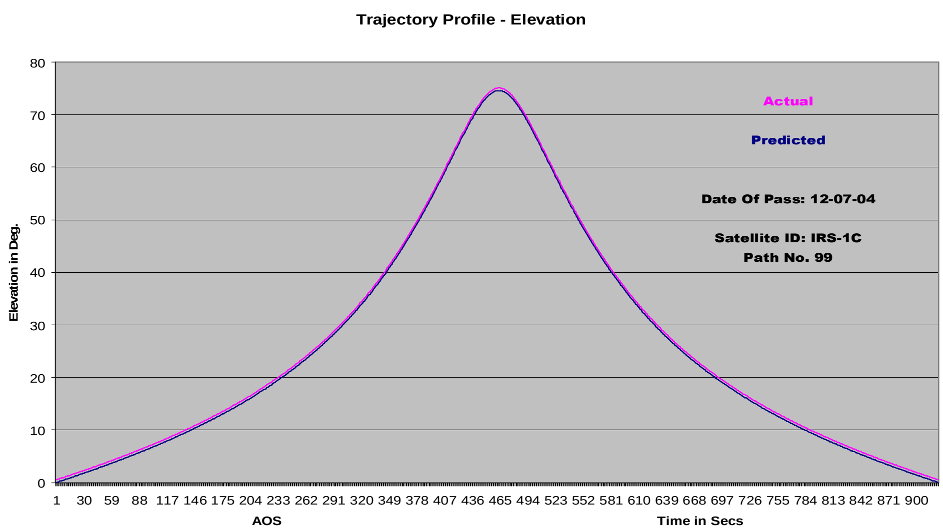
Plot No.4.3 AZ & EL Profiles

4.5 Design Validation

The program track software was fine tuned by changing the sampling rate as per the servo system to obtain the errors less than 0.1^{o} in both Az and El. Sample results are enclosed for the data 12.7.04, IRS-1C Path No.99 showing both predicted and actual in Az and El. The system has been working for all the satellites to provide error tracking. In both the profiles the expected and actual values are very close and hence are seen as almost coinciding.



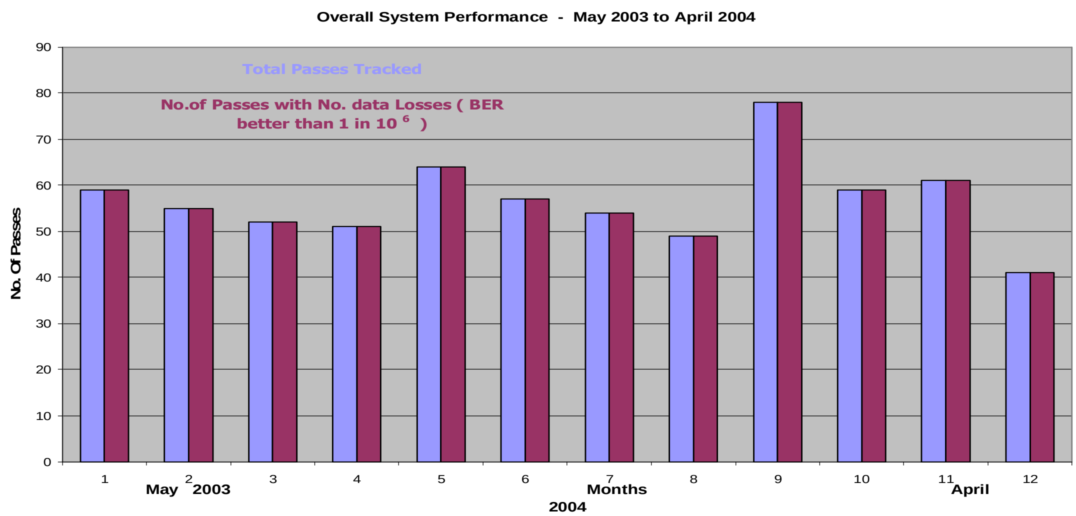
Plot No.4.4 AZ Profile Actual/Predicted



Plot No.4.5 EL Profile Actual/Predicted

4.6 Results

The system developed has been providing 100% efficiency for the data acquisition for the remote sensing satellites. The Table below provides the error-free data acquisition for one year period as a sample.



Plot No. 4.6 System Performance

4.7 Conclusion

This system was initially developed after characterizing the antenna and tracking system at Delhi and operationalised it. The system was found to be 100% reliable with program track mode. Therefore the systems along with the software by name "TRACK" was supplied internationally to IRAN etc., under the Indian Remote Sensing Satellite Program to International Ground Stations from Department of Space through Antrix Corporation. It is proved to be reliable at all locations globally. This development of SCS has made the system status transparent to the computer with appropriate storage in realtime. This is one of the key developments for station automation. This is being improved with few FPGA's based ACU and USB for interfacing.

4.8 Sample Pre Pass Planner Reports

```
                    P A Y L O A D   P A S S   PPPs
                    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

         LOOK ANGLES OF SATELLITE    :IRS - 1C          GROUND STATION : SHADNAGR

         P A S S   S U M M A R Y:
         PASS NO.:   1         REV NO.:055881                     PATH NO.:114
          DAY WITHIN CYC:14                 CYC NO:0164
        DATE(YY-MM-DD):2006-10-04  AOS(HH-MM-SS.SSS):02-06-00.968
        LOS(HH-MM-SS.SSS):02-19-21.372  DURATION(MM-SS.SS):13  20.4
         NUMBER OF VISIBLE ROWS:  27        STARTING ROW NO.:  46
                                             ENDING ROW NO.:  72
```

L O O K   A N G L E S   A N D   G R O U N D   T R A C K   I N F O R M A T I O N

ROW NO.	TIME(UT) (HH-MM-SS.S)	AZIMUTH (DEG)	ELEVN. (DEG)	RANGE (KM)	LATITUDE DEG	LATITUDE MIN	LONGITUDE DEG	LONGITUDE MIN
46	02-07- 0.8	41.61	3.10	3012.25	34	28.4	97	49.5
47	02-07-21.0	43.42	4.20	2905.49	33	17.3	97	29.2
48	02-07-41.3	45.36	5.31	2801.24	32	6.3	97	9.4
49	02-08- 1.5	47.46	6.44	2699.86	30	55.1	96	49.9
50	02-08-21.7	49.72	7.59	2601.72	29	44.0	96	30.7
51	02-08-42.0	52.17	8.75	2507.26	28	32.8	96	11.9
52	02-09- 2.2	54.81	9.92	2416.98	27	21.5	95	53.3
53	02-09-22.4	57.68	11.08	2331.39	26	10.3	95	35.1
54	02-09-42.7	60.77	12.23	2251.09	24	59.0	95	17.1
55	02-10- 2.9	64.11	13.35	2176.71	23	47.6	94	59.4
56	02-10-23.2	67.71	14.42	2108.91	22	36.2	94	41.9
57	02-10-43.4	71.57	15.43	2048.39	21	24.8	94	24.6
58	02-11- 3.6	75.68	16.34	1995.85	20	13.4	94	7.5
59	02-11-23.9	80.03	17.14	1951.96	19	2.0	93	50.5
60	02-11-44.1	84.59	17.78	1917.36	17	50.5	93	33.8
61	02-12- 4.3	89.33	18.26	1892.56	16	39.0	93	17.2
62	02-12-24.6	94.18	18.54	1877.99	15	27.5	93	0.7
63	02-12-44.8	99.10	18.62	1873.89	14	15.9	92	44.4
64	02-13- 5.1	104.00	18.49	1880.34	13	4.4	92	28.2
65	02-13-25.3	108.84	18.16	1897.24	11	52.8	92	12.1
66	02-13-45.5	113.54	17.64	1924.31	10	41.3	91	56.1
67	02-14- 5.8	118.06	16.95	1961.14	09	29.7	91	40.1
68	02-14-26.0	122.35	16.12	2007.16	08	18.1	91	24.3
69	02-14-46.2	126.40	15.18	2061.76	07	6.5	91	8.5
70	02-15- 6.5	130.19	14.15	2124.26	05	54.9	90	52.8
71	02-15-26.7	133.73	13.06	2193.96	04	43.3	90	37.1
72	02-15-47.0	137.00	11.92	2270.17	03	31.6	90	21.4

Report :4.7   PPP report - 1

P A Y L O A D   P A S S   PPPs

LOOK ANGLES OF SATELLITE :IRS - 1C   GROUND STATION : SHADNAGR

P A S S S U M M A R Y:
PASS NO.: 2   REV NO.:055882   PATH NO.:090
DAY WITHIN CYC:14   CYC NO:0164
DATE(YY-MM-DD):2006-10-04 AOS(HH-MM-SS.SSS):03-45-25.710
LOS(HH-MM-SS.SSS):03-59-52.551 DURATION(MM-SS.SS):14 26.8
NUMBER OF VISIBLE ROWS: 23   STARTING ROW NO.: 38
ENDING ROW NO.: 60

L O O K   A N G L E S   A N D   G R O U N D   T R A C K   I N F O R M A T I O N

ROW NO.	TIME(UT) (HH-MM-SS.S)	AZIMUTH (DEG)	ELEVN. (DEG)	RANGE (KM)	LATITUDE DEG	LATITUDE MIN	LONGITUDE DEG	LONGITUDE MIN
38	03-45-39.4	355.71	0.78	3253.96	43	54.5	75	30.4
39	03-45-59.7	354.74	1.97	3127.74	42	44.0	75	5.5
40	03-46-19.9	353.69	3.20	3002.47	41	33.4	74	41.4
41	03-46-40.1	352.54	4.48	2878.34	40	22.7	74	18.0
42	03-47- 0.3	351.27	5.82	2755.55	39	11.9	73	55.1
43	03-47-20.6	349.87	7.20	2634.35	38	1.1	73	32.9
44	03-47-40.8	348.32	8.66	2515.04	36	50.3	73	11.2
45	03-48- 1.0	346.60	10.17	2397.95	35	39.3	72	50.0
46	03-48-21.3	344.69	11.76	2283.48	34	28.4	72	29.3
47	03-48-41.5	342.54	13.43	2172.10	33	17.3	72	9.0
48	03-49- 1.7	340.12	15.17	2064.35	32	6.3	71	49.1
49	03-49-22.0	337.39	16.98	1960.90	30	55.1	71	29.6
50	03-49-42.2	334.30	18.87	1862.50	29	44.0	71	10.5
51	03-50- 2.4	330.79	20.80	1770.04	28	32.8	70	51.6
52	03-50-22.7	326.80	22.76	1684.55	27	21.5	70	33.1
53	03-50-42.9	322.27	24.70	1607.17	26	10.3	70	14.9
54	03-51- 3.1	317.16	26.57	1539.17	24	59.0	69	56.9
55	03-51-23.4	311.43	28.27	1481.86	23	47.6	69	39.1
56	03-51-43.6	305.10	29.72	1436.54	22	36.2	69	21.6
57	03-52- 3.9	298.25	30.81	1404.40	21	24.8	69	4.3
58	03-52-24.1	291.02	31.44	1386.36	20	13.4	68	47.2
59	03-52-44.3	283.62	31.56	1382.98	19	2.0	68	30.3
60	03-53- 4.6	276.28	31.16	1394.36	17	50.5	68	13.6

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CHAPTER – 5

Modelling of Zenith Passes and implementation through program tracking

Abstract

Very high Azimuth velocities are required for tracking target trajectories that pass near the zenith position due to the singular behavior and hence auto tracking of Remote Sensing Satellite gets lost when azimuth spatial pointing direction lags the satellite position by an angle exceeding the antenna beam width. This lag is a result of the maximum azimuth velocity limitations of the pedestal. The computer simulations for number of overhead passes has resulted in a possible solution, while adopting Linear Orbit Approximation (LOA) by deriving the trajectories around peak elevation, for specified periods of time upto 5 seconds either side, such that the systems performance was optimized to reduce errors to a minimum. This is possible by having the accurate knowledge of the true position of the satellite at all times. Using this information the optimum trajectory is derived while taking the positioners physical limitations and the specified RF Performance into consideration. The tracking angle information in the form of AZ and EL. Angles etc., in the pre-determined trajectory gets replaced with the newly derived values as per the computer simulations for the window periods so derived around the peak elevation. This composite trajectory information is used for tracking the satellite in program track mode totally. This system has been implemented based on the models derived and in providing 100% efficiency for all the high elevation passes. This concept is a break through for tracking remote sensing satellites and also helping the program track system to have full knowledge of the tracking.

5.1 Introduction to zenith passes

Control of the Station by Station Control Computer System(SCS) was described in Chapter 4. The SCS was optimized based on the station model to track the satellite under the program track and provide full reliability. The program track is based on the trajectory information derived from the Satellite State Vectors and refined to provide least possible errors in autotrack as described in Chapter-4. Further satellite passes having more than 87^{o} EL, the velocity requirement in AZ crosses the limits specifications of the system. Therefore such passes are required to be identified and to be handled totally by the program track mode and not by auto track mode through a modified trajectory as per the model derived in this chapter. This chapter deals with the system that was developed to handle such passes.

The solution provided is based on the thorough computer analysis of the high elevation passes with respect to AZ and EL velocity requirements for the pedestal, generation of different azimuth trajectories that fall within the antenna beam and the pedestal driving limits. Therefore based on these computer simulations, a model was developed to cater to each elevation adopting the Linear Orbit Approximation (LOA) throughout. Computer simulations and the solution offered are brought out in this chapter.

5.2 Background Theory [54-59]

The normal mode of operation for the system can be either in program track or in the servo control loop in autotrack. The computed orbital parameters are used to predict the occurrence of an overhead pass. During this phase, angles are sampled for close intervals of time and used to drive the system under the Computer Control as per the AZ and EL values derived by the overhead pass controller.

Zenith pass programmer predicts a zenith(over head) pass based on the trajectory predictions, it will then calculate a time for programmer control to begin. At the proper moment in the pass, the Zenith Pass Controller (ZPC) commands the servo control unit into zenith pass mode, and outputs the precalculated trajectory coordinates. During this time, the elevation will be observed to continue smoothly to peak angle of 89-90^0 and decrease. Azimuth will enter a rapid condition as the Programmer commands position along the optimum trajectory. The zenith programmer will continue to output the trajectory coordinates until the end of the calculated-control period. The ZPC then checks for the presence of an acquire level from the tracking converter. If the acquire level is not present, the programmer continues and retains the servo control in the zenith pass mode. Under normal operation, the acquired level will be present throughout the control period and the programmer can return control to autotrack at the end of this period. Having completed its function, the zenith pass programmer provides a status flag so that system can continue to complete the pass either in autotrack or in program track mode after the status.

5.3 Elevation-over-Azimuth Tracking Limitations

The spherical geometry coverage offered by an elevation-over-azimuth positioner has several advantages over other positioner geometries, including as a few, mechanical simplicity, full hemispherical coverage, ease of operator control, and direct relationships with coordinate systems traditionally employed in navigational and scientific fields. Since any positioner is a mechanical device, some constraints will be placed on the freedom of axis motion by the positioner's physical construction. As will be seen in the following discussion, this choice of positioner coordinate system results in large azimuth velocities for tracking target trajectories that pass near the zenith position. This is true also for positioners using alternate gimbal geometries, although the singular behavior will occur for other typical tracking trajectories. Since we are concerned here primarily with the behavior of the positioner around the zenith position, it can be assumed that the target trajectory is approximately rectilinear through the small special angular range to be investigated with little loss of generaility. The linear orbit approximation (LOA) is adopted throughout.

Assuming the target trajectory is parallel to the x-axis of a Cartesian system defined as in figure below with the z-axis directed along the Earth centered radial direction, the transformation between this Cartesian system and the associated spherical elevation-over-azimuth system of the spoitioner can be written as shown in the following.

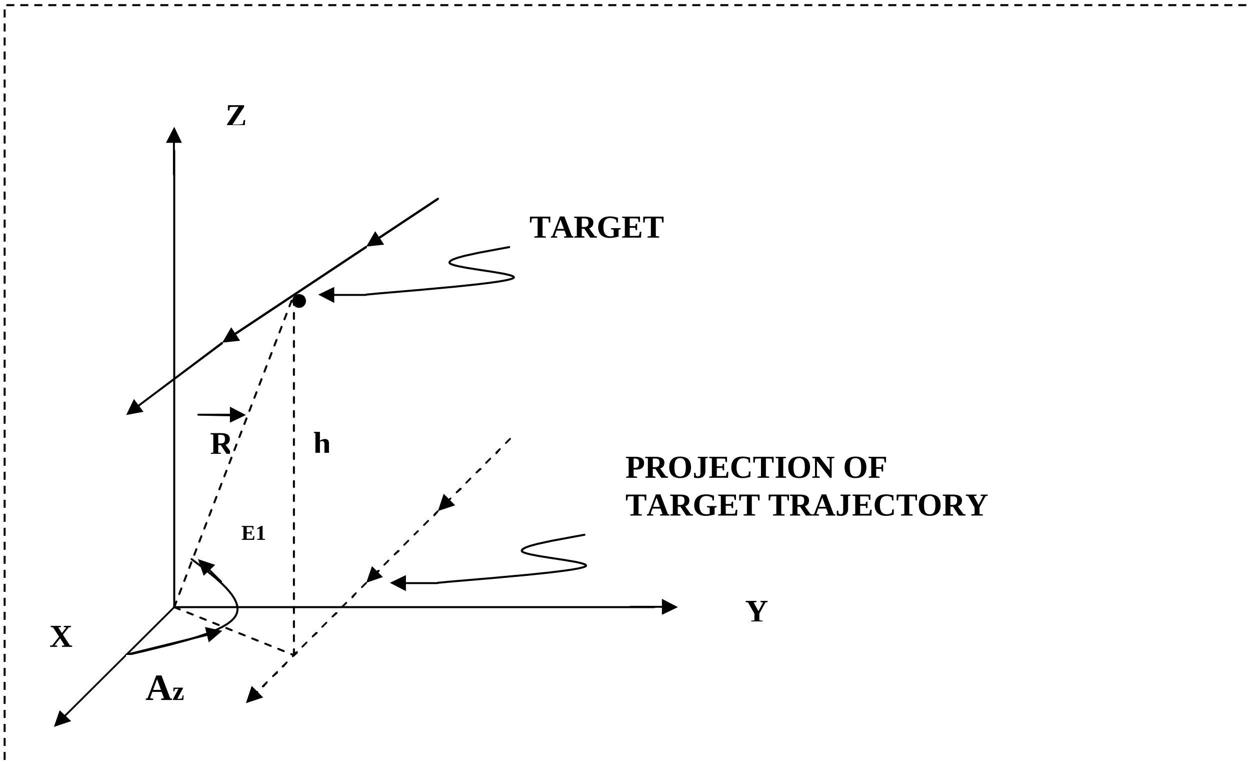


Fig.5.1 Representation of Satellite in Cartesian Coordination System

The Cartesian vector matrix describing the target trajectory as a function of time for target velocity (v_t) at a height (h) is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} v_t * (t-t_o) \\ h * \cot(E\ell_m) \\ h \end{bmatrix}$$

Where t_o = time origin at which the elevation angle is maximum

$E\ell_m$ = maximum elevation angle that will be achieved during the pass
h = height
v_t = Target Velocity

The transformations to the spherical coordinates of elevation and azimuth are accomplished by the angular rotation matrices:

$$M_z(Az) = \begin{bmatrix} \cos Az \; \sin Az & 0 \\ -\sin Az \; \cos Az & 0 \\ 0 \quad 0 & 1 \end{bmatrix}$$

and

$$M_y(E\ell) = \begin{bmatrix} \cos E\ell & 0 & \sin E\ell \\ 0 & 1 & 0 \\ -\sin E\ell & 0 & \cos E\ell \end{bmatrix}$$

Then $\begin{bmatrix} x \\ y \\ z \end{bmatrix} = M_z(-Az)\, M_y(-E\ell) \begin{bmatrix} R \\ 0 \\ 0 \end{bmatrix}$

is the matrix equation yielding

$$\frac{1}{[x^2+y^2+z^2]}^{1/2} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos Az \cos E\ell \\ \sin Az \cos E\ell \\ \sin E\ell \end{bmatrix}$$

or:

$$Az = \text{arc tan} \left[\frac{h * \cot (E\ell_m)}{Vt^* (t-t_o)} \right]$$

$$E\ell = \text{arc tan} \; \{[v_t * (t-t_o) \big)^2 + \cot^2 E\ell_m]^{-1/2}\}$$

These equations relate the elevation and azimuth angles of the pedestal to the trajectory of the target as a function of time.

The required pedestal axis velocities can be found by differentiation:

$$Az = \frac{d}{dt} Az = \frac{-h^*\cot E\ell_m}{vt^*(t-to)^2} \cos^2 E\ell$$

and:

$$E\ell = \frac{d}{dt} E\ell = \frac{-h^*\cot E\ell_m^*}{\sqrt{(vt^2(t-t_o)^2+h^2\cot^2 \text{ø}m)^3}}$$

Consider the azimuth velocity:

$$Az = \frac{-h*\cot E\ell_m * v_t}{[v_t^2*(t-t_o)^2+h^2*(\cot^2 E\ell_m)]}$$

Then the maximum azimuth velocity will obviously occur at $t = t_o$ when the elevation angle is maximum,

So that $$Az\Big|_{max} = \frac{-v_t}{h*\cot(E\ell_m)}$$

This equation exhibits the fact that the transformation requires an infinite azimuth velocity to track a direct overhead pass ($E\ell_m = 90^o$)for Satellite Auto tracking. The very high azimuth velocities required to precisely follow even a slow moving (large orbit radius) satellite in a high elevation pass cause limitations on the maximum elevation angle pass that the positioner is able to effectively track. It should be noted that it is not necessary for the positioner to have the exact azimuth angle during a high elevation pass in order to remain locked onto the target. This is a result of the geometrical correction between the azimuth position error and the effective special pointing error, commonly referred to as the secant correction. The effect is easily understood when a pointing direction directly overhead is considered. At that point, the azimuth position of the pedestal is irrelevant to the special pointing direction. The effect is to correct the azimuth positioning error by the cosine of the elevation angle to obtain the special pointing error.

In a typical high elevation pass, as the elevation angle nears 90^o , the azimuth velocity will track the required position until the maximum velocity of the positioner axis is reached. The positioner will then fall behind the true azimuth position of the satellite until the special pointing error exceeds the antenna beamwidth and the tracking signal is lost. If the beam width of the antenna is large enough, or if the pedestal velocities are high enough, it is possible that the special error will not exceed the beamwidth. In that case, auto tracking will be possible for nearly direct overhead passes.

The desirability of using an elevation-over-azimuth pedestal for satellite tracking has prompted a more detailed analysis of the overhead pass problem and its possible solution.

5.4 Computer Simulations

Based on the theory, the orbit predictions were done for passes having maximum elevation of (a) 85.522^o (b) 87.62^o (c) 87.62^o (d) 88.04^o (e) 89.0^o (f) 89.83^o for the actual orbit of IRS.

As the orbital predictions are long files, the predicted values around the peak elevation code are given below along with the following graphs for each (a) AZ and EL profiles (Y-axis) with respect to time (in X-axis) (b)AZ &EL rate profiles with respect to time.

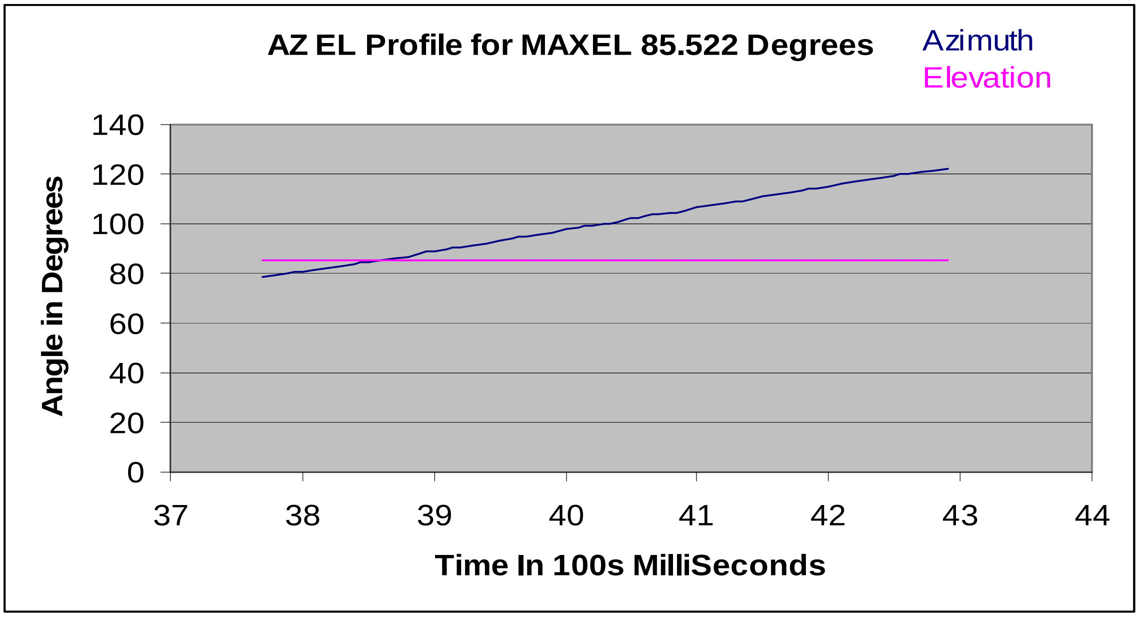
5.4.1 Pass with 85.522° Elevation

The prediction clearly shows that the AZ rate does not cross the single digit value.

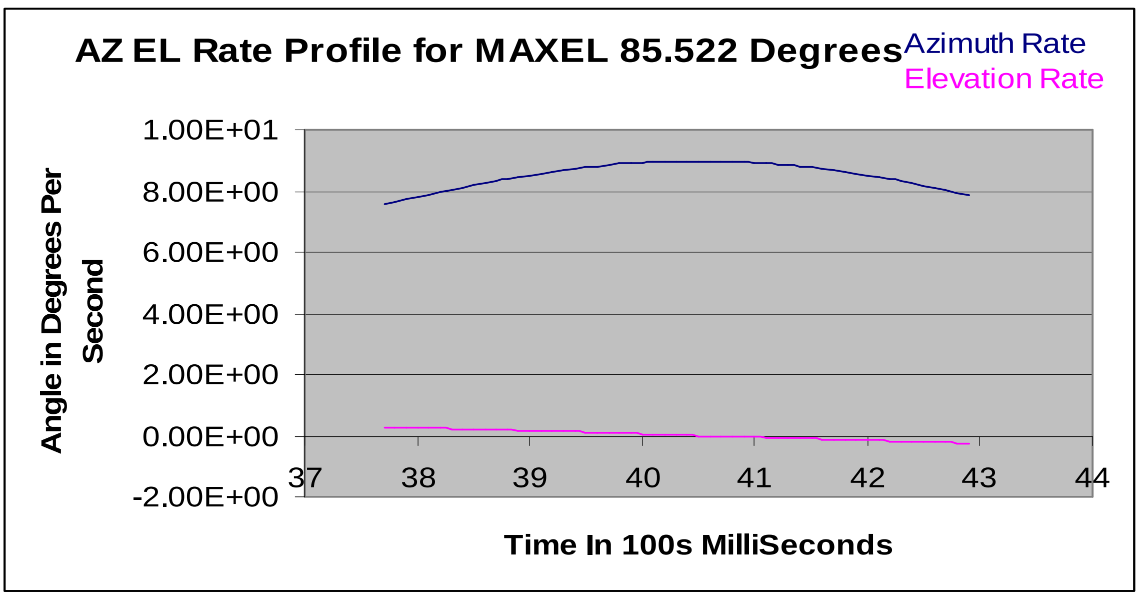
Table 5.1 Satellite Trajectory Report for 85.522° EL

	Data For	MaxEl 85.522	Degrees	
Time In MilliSec	**Azimuth**	**Elevation**	**Azimuth Rate**	**Elevation rate**
37.7	78.20987	85.118244	7.55E+00	2.79E-01
37.8	78.968793	85.145705	7.63E+00	2.70E-01
37.9	79.73625	85.17231	7.72E+00	2.62E-01
38	80.512106	85.198045	7.80E+00	2.53E-01
38.1	81.296211	85.222896	7.88E+00	2.44E-01
38.2	82.088398	85.246848	7.96E+00	2.35E-01
38.3	82.888487	85.269888	8.04E+00	2.26E-01
38.4	83.69628	85.292001	8.12E+00	2.16E-01
38.5	84.511562	85.313176	8.19E+00	2.07E-01
38.6	85.334104	85.333398	8.26E+00	1.97E-01
38.7	86.16366	85.352655	8.33E+00	1.88E-01
38.8	86.999969	85.370934	8.40E+00	1.78E-01
38.9	87.842752	85.388225	8.46E+00	1.68E-01
39	88.691717	85.404515	8.52E+00	1.58E-01
39.1	89.546555	85.419794	8.58E+00	1.48E-01
39.2	90.406943	85.434051	8.63E+00	1.37E-01
39.3	91.272544	85.447277	8.68E+00	1.27E-01
39.4	92.143007	85.459463	8.73E+00	1.17E-01
39.5	93.017969	85.470599	8.77E+00	1.06E-01
39.6	93.897052	85.480679	8.81E+00	9.55E-02
39.7	94.779871	85.489694	8.85E+00	8.48E-02
39.8	95.666028	85.497639	8.88E+00	7.41E-02
39.9	96.555115	85.504507	8.90E+00	6.33E-02
40	97.446717	85.510295	8.93E+00	5.24E-02
40.1	98.340413	85.514996	8.95E+00	4.16E-02
40.2	99.235772	85.518609	8.96E+00	3.07E-02
40.3	100.132361	85.521129	8.97E+00	1.97E-02
40.4	101.029745	85.522556	8.98E+00	8.80E-03
40.6	102.825133	85.522126	8.97E+00	-1.31E-02
40.7	103.722258	85.52027	8.97E+00	-2.40E-02
40.8	104.618418	85.51732	8.96E+00	-3.50E-02

40.9	105.513177	85.513279	8.94E+00	-4.59E-02
41	106.406103	85.508151	8.92E+00	-5.67E-02
41.1	107.296771	85.501938	8.89E+00	-6.75E-02
41.2	108.184759	85.494647	8.87E+00	-7.83E-02
41.3	109.069657	85.486281	8.83E+00	-8.90E-02
41.4	109.95106	85.476846	8.80E+00	-9.97E-02
41.5	110.828575	85.466351	8.75E+00	-1.10E-01
41.6	111.701819	85.454801	8.71E+00	-1.21E-01
41.7	112.570421	85.442206	8.66E+00	-1.31E-01
41.8	113.434022	85.428574	8.61E+00	-1.41E-01
41.9	114.292276	85.413914	8.55E+00	-1.52E-01
42	115.144852	85.398236	8.50E+00	-1.62E-01
42.1	115.991432	85.381552	8.43E+00	-1.72E-01
42.2	116.831714	85.363871	8.37E+00	-1.82E-01
42.3	117.66541	85.345206	8.30E+00	-1.92E-01
42.4	118.49225	85.325568	8.23E+00	-2.01E-01
42.5	119.311978	85.30497	8.16E+00	-2.11E-01
42.6	120.124354	85.283425	8.09E+00	-2.20E-01
42.7	120.929154	85.260945	8.01E+00	-2.29E-01
42.8	121.726171	85.237545	7.93E+00	-2.39E-01
42.9	122.515215	85.213237	7.85E+00	-2.48E-01



Plot 5.2 Az. & EL. Profile for max.EL of 85.522°



Plot 5.3 Az. & EL. Rate Profile s for max. EL of 85.522°

5.4.2 Passes with 86.7° EL

The azimuth rate has gone up to a maximum of 12.2°/Sec. as given below:

Table 5.2 Satellite Trajectory Report for 86.7o

Data For Max EL 86.7 Degrees

Time In MilliSec	Azimuth	Elevation	Azimuth Rate	Elevation rate
36.9	67.328968	85.990092	8.27E+00	3.96E-01
37	68.164077	86.029253	8.43E+00	3.87E-01
37.1	69.015683	86.06756	8.60E+00	3.79E-01
37.2	69.883891	86.104987	8.77E+00	3.70E-01
37.3	70.768783	86.141508	8.93E+00	3.61E-01
37.4	71.67041	86.177096	9.10E+00	3.51E-01
37.5	72.588792	86.211726	9.27E+00	3.41E-01
37.6	73.523915	86.245369	9.43E+00	3.31E-01
37.7	74.475731	86.277999	9.60E+00	3.21E-01
37.8	75.44415	86.309589	9.77E+00	3.11E-01
37.9	76.429044	86.340111	9.93E+00	3.00E-01
38	77.43024	86.369539	1.01E+01	2.89E-01
38.1	78.447521	86.397845	1.03E+01	2.77E-01
38.2	79.480619	86.425001	1.04E+01	2.66E-01
38.3	80.529222	86.450982	1.06E+01	2.54E-01
38.4	81.592961	86.475761	1.07E+01	2.42E-01
38.5	82.671419	86.499313	1.09E+01	2.29E-01
38.6	83.764124	86.521612	1.10E+01	2.17E-01
38.7	84.870551	86.542633	1.11E+01	2.04E-01
38.8	85.990119	86.562354	1.13E+01	1.91E-01
38.9	87.122194	86.58075	1.14E+01	1.77E-01
39	88.266089	86.597802	1.15E+01	1.64E-01
39.1	89.421066	86.613487	1.16E+01	1.50E-01
39.2	90.586335	86.627788	1.17E+01	1.36E-01
39.3	91.761058	86.640686	1.18E+01	1.22E-01
39.4	92.944351	86.652164	1.19E+01	1.08E-01
39.5	94.135291	86.662208	1.19E+01	9.32E-02
39.6	95.332913	86.670805	1.20E+01	7.87E-02
39.7	96.536219	86.677944	1.21E+01	6.41E-02
39.8	97.744183	86.683615	1.21E+01	4.93E-02
39.9	98.955753	86.68781	1.21E+01	3.46E-02
40	100.169857	86.690524	1.22E+01	1.97E-02
40.2	102.601325	86.691496	1.22E+01	-1.00E-02
40.3	103.816502	86.689753	1.21E+01	-2.49E-02
40.4	105.029853	86.686526	1.21E+01	-3.97E-02
40.5	106.240297	86.681819	1.21E+01	-5.44E-02
40.6	107.44677	86.675639	1.20E+01	-6.91E-02
40.7	108.648227	86.667994	1.20E+01	-8.37E-02
40.8	109.843651	86.658895	1.19E+01	-9.82E-02

40.9	111.032056	86.648352	1.18E+01	-1.13E-01
41	112.212491	86.636381	1.18E+01	-1.27E-01
41.1	113.384045	86.622996	1.17E+01	-1.41E-01
41.2	114.545851	86.608214	1.16E+01	-1.55E-01
41.3	115.697086	86.592053	1.15E+01	-1.68E-01
41.4	116.836978	86.574533	1.13E+01	-1.82E-01
41.5	117.964807	86.555675	1.12E+01	-1.95E-01
41.6	119.079904	86.535502	1.11E+01	-2.08E-01
41.7	120.181652	86.514035	1.09E+01	-2.21E-01
41.8	121.269492	86.4913	1.08E+01	-2.34E-01
41.9	122.342915	86.46732	1.07E+01	-2.46E-01
42	123.401469	86.442121	1.05E+01	-2.58E-01
42.1	124.444754	86.41573	1.04E+01	-2.70E-01
42.2	125.47242	86.388172	1.02E+01	-2.81E-01
42.3	126.484171	86.359475	1.00E+01	-2.93E-01
42.4	127.479757	86.329665	9.87E+00	-3.04E-01
42.5	128.458976	86.298769	9.71E+00	-3.14E-01
42.6	129.421671	86.266815	9.54E+00	-3.25E-01
42.7	130.367726	86.233831	9.38E+00	-3.35E-01
42.8	131.297069	86.199842	9.21E+00	-3.45E-01
42.9	132.209661	86.164877	9.04E+00	-3.54E-01
43	133.105501	86.128962	8.87E+00	-3.64E-01
43.1	133.984621	86.092124	8.71E+00	-3.73E-01
43.2	134.847083	86.054388	8.54E+00	-3.82E-01
43.3	135.692975	86.015782	8.38E+00	-3.90E-01

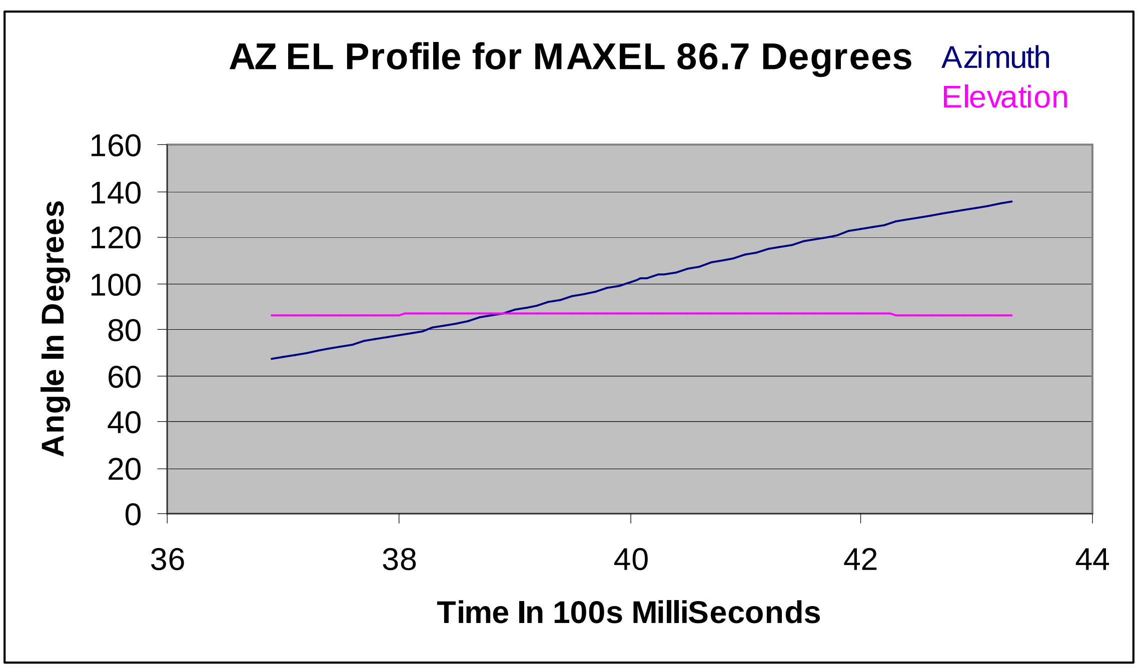


Fig.5.4 AZ. & EL. Profiles for max.EL of 86.7°

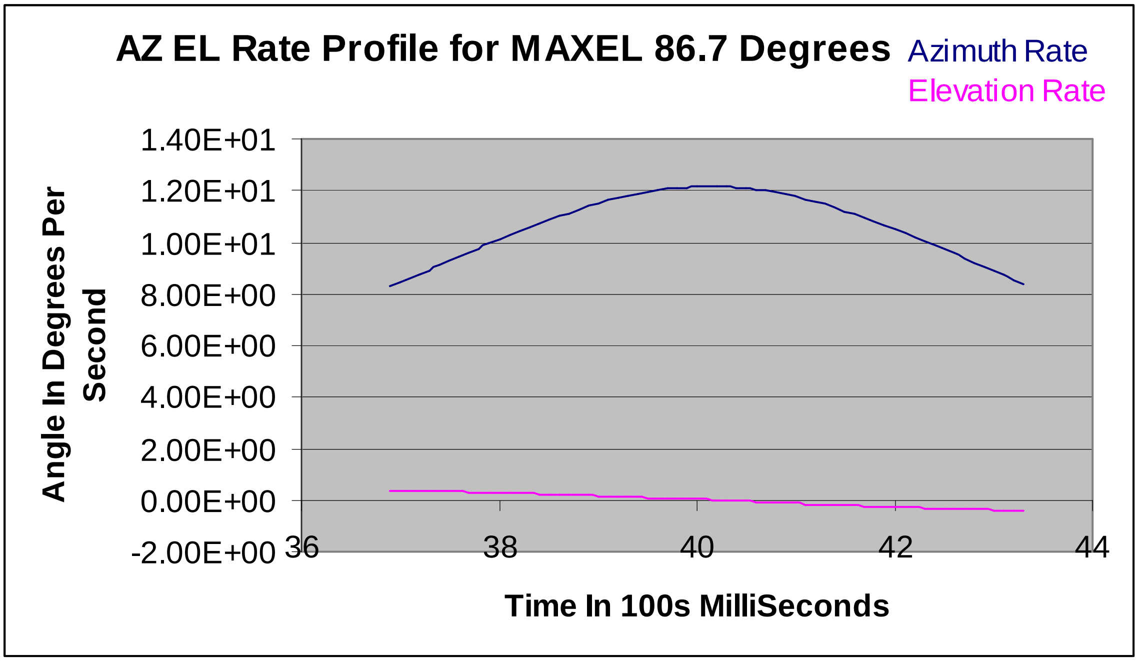


fig.5.5 AZ. & EL. Rate Profiles for max.EL of 86.7°

5.4.3 Passes with 87.62° EL

The azimuth rate has gone upto 16.9°/Sec. as given in the predictions.

Table 5.3 Satellite Trajectory Report for 87.6°

	Data For MaxEL 87.62 Degrees			
Time In MilliSec	**Azimuth**	**Elevation**	**Azimuth Rate**	**Elevation rate**
36.5	57.060664	86.654308	8.54E+00	4.93E-01
36.6	57.927417	86.703253	8.80E+00	4.86E-01
36.7	58.82013	86.751426	9.06E+00	4.78E-01
36.8	59.739536	86.798792	9.33E+00	4.70E-01
36.9	60.686355	86.845316	9.61E+00	4.61E-01
37	61.66129	86.890957	9.89E+00	4.52E-01
37.1	62.665023	86.935677	1.02E+01	4.42E-01
37.2	63.698207	86.979433	1.05E+01	4.33E-01
37.3	64.761454	87.022184	1.08E+01	4.22E-01
37.4	65.855331	87.063884	1.11E+01	4.12E-01
37.5	66.980351	87.104488	1.14E+01	4.00E-01
37.6	68.136956	87.143948	1.17E+01	3.89E-01

37.7	69.325515	87.182217	1.20E+01	3.77E-01
37.8	70.546304	87.219244	1.24E+01	3.64E-01
37.9	71.799499	87.254978	1.27E+01	3.51E-01
38	73.085162	87.28937	1.30E+01	3.37E-01
38.1	74.403225	87.322365	1.33E+01	3.23E-01
38.2	75.753483	87.353912	1.37E+01	3.08E-01
38.3	77.135575	87.383958	1.40E+01	2.93E-01
38.4	78.548976	87.41245	1.43E+01	2.77E-01
38.5	79.992985	87.439337	1.46E+01	2.61E-01
38.6	81.466714	87.464566	1.49E+01	2.44E-01
38.7	82.969082	87.488087	1.52E+01	2.27E-01
38.8	84.498809	87.509853	1.54E+01	2.09E-01
38.9	86.05441	87.529816	1.57E+01	1.90E-01
39	87.634199	87.547932	1.59E+01	1.72E-01
39.1	89.23629	87.564159	1.61E+01	1.53E-01
39.2	90.858605	87.57846	1.63E+01	1.33E-01
39.3	92.498881	87.5908	1.65E+01	1.13E-01
39.4	94.154691	87.601149	1.66E+01	9.34E-02
39.5	95.823457	87.60948	1.67E+01	7.32E-02
39.6	97.50247	87.615773	1.68E+01	5.27E-02
39.7	99.188922	87.62001	1.69E+01	3.21E-02
39.8	100.879926	87.622182	1.69E+01	1.14E-02
39.9	102.572549	87.622283	1.69E+01	-9.36E-03
40	104.26384	87.620311	1.69E+01	-3.01E-02
40.1	105.950862	87.616273	1.68E+01	-5.07E-02
40.2	107.630724	87.610179	1.68E+01	-7.12E-02
40.3	109.300606	87.602045	1.66E+01	-9.15E-02
40.4	110.957791	87.59189	1.65E+01	-1.12E-01
40.5	112.599687	87.579742	1.63E+01	-1.31E-01
40.6	114.223849	87.565629	1.61E+01	-1.51E-01
40.7	115.828001	87.549587	1.59E+01	-1.70E-01
40.8	117.410044	87.531652	1.57E+01	-1.89E-01
40.9	118.968074	87.511866	1.55E+01	-2.07E-01
41	120.500384	87.490273	1.52E+01	-2.25E-01
41.1	122.005472	87.466919	1.49E+01	-2.42E-01
41.2	123.482036	87.441853	1.46E+01	-2.59E-01
41.3	124.928976	87.415125	1.43E+01	-2.75E-01
41.4	126.345386	87.386785	1.40E+01	-2.91E-01
41.5	127.730547	87.356887	1.37E+01	-3.07E-01
41.6	129.083917	87.325483	1.34E+01	-3.21E-01
41.7	130.405122	87.292625	1.31E+01	-3.36E-01
41.8	131.693939	87.258366	1.27E+01	-3.49E-01
41.9	132.95029	87.222759	1.24E+01	-3.63E-01
42	134.174223	87.185854	1.21E+01	-3.75E-01
42.1	135.365904	87.147703	1.18E+01	-3.88E-01
42.2	136.5256	87.108355	1.14E+01	-3.99E-01
42.3	137.653671	87.067859	1.11E+01	-4.11E-01
42.4	138.750554	87.026263	1.08E+01	-4.21E-01
42.5	139.816754	86.983611	1.05E+01	-4.32E-01
42.6	140.852833	86.939949	1.02E+01	-4.42E-01

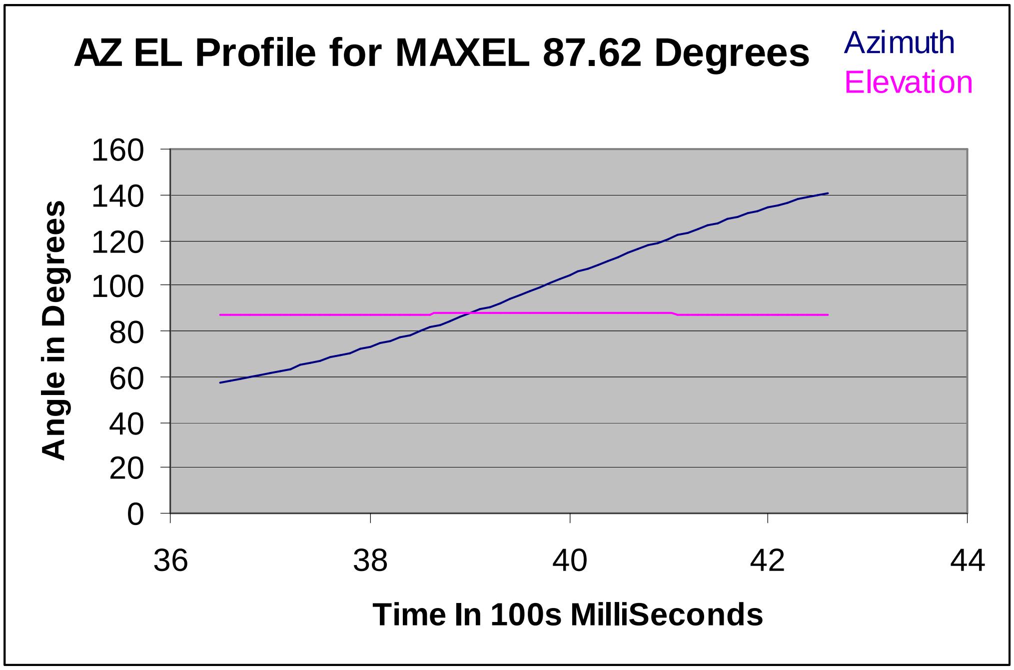


Fig.5.6 AZ. & EL. Profiles for max.EL of 87.62°

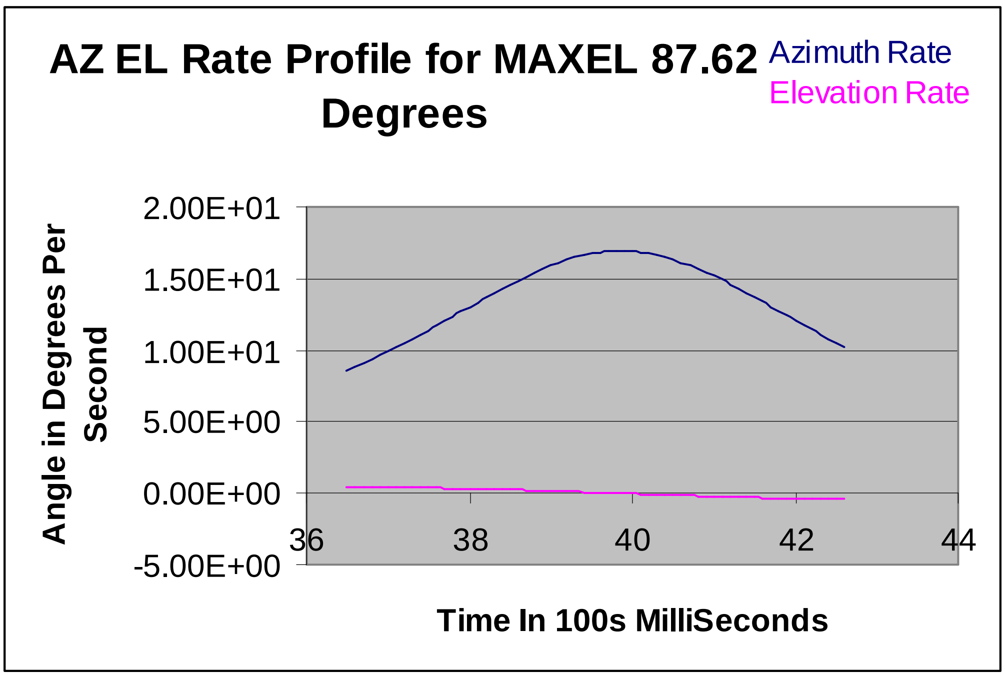


Fig.5.7 AZ. & EL. Rate Profiles for max. EL of 87.62°

5.4.4 Passes with 88.04° EL

The azimuth rate has gone upto 20.6°/Sec. as given in the predictions.

Table 5.4 Satellite Trajectory Report 88.04°EL.

Data For MaxEl88.04 Degrees

Time In MilliSec	Azimuth	Elevation	Azimuth Rate	Elevation rate
36.4	319.775482	87.527864	1.29E+01	4.31E-01
36.5	318.467579	87.570289	1.33E+01	4.18E-01
36.6	317.113871	87.611405	1.38E+01	4.04E-01
36.7	315.713501	87.651146	1.42E+01	3.90E-01
36.8	314.265776	87.689439	1.47E+01	3.75E-01
36.9	312.770197	87.72621	1.52E+01	3.60E-01
37	311.226492	87.761384	1.57E+01	3.44E-01
37.1	309.63465	87.794885	1.62E+01	3.26E-01
37.2	307.994959	87.826635	1.66E+01	3.08E-01
37.3	306.308035	87.856554	1.71E+01	2.90E-01
37.4	304.574857	87.884567	1.76E+01	2.70E-01
37.5	302.796799	87.910595	1.80E+01	2.50E-01
37.6	300.975649	87.934563	1.84E+01	2.29E-01
37.7	299.113633	87.956399	1.88E+01	2.07E-01
37.8	297.213419	87.976033	1.92E+01	1.85E-01
37.9	295.278125	87.9934	1.95E+01	1.62E-01
38	293.3113	88.008442	1.98E+01	1.39E-01
38.1	291.316908	88.021104	2.01E+01	1.15E-01
38.2	289.299291	88.03134	2.03E+01	9.01E-02
38.3	287.26312	88.039114	2.04E+01	6.53E-02
38.4	285.213342	88.044394	2.05E+01	4.03E-02
38.5	283.155106	88.047161	2.06E+01	1.51E-02
38.7	279.034431	88.045123	2.06E+01	-3.54E-02
38.8	276.982616	88.040325	2.05E+01	-6.05E-02
38.9	274.943429	88.03303	2.03E+01	-8.54E-02
39	272.921861	88.023265	2.01E+01	-1.10E-01
39.1	270.922642	88.011067	1.99E+01	-1.34E-01
39.2	268.950181	87.99648	1.96E+01	-1.58E-01
39.3	267.008518	87.979556	1.93E+01	-1.81E-01
39.4	265.101284	87.960353	1.89E+01	-2.03E-01
39.5	263.231681	87.938936	1.85E+01	-2.25E-01
39.6	261.402465	87.915373	1.81E+01	-2.46E-01
39.7	259.615945	87.889736	1.76E+01	-2.66E-01
39.8	257.873994	87.862099	1.72E+01	-2.86E-01
39.9	256.178063	87.83254	1.67E+01	-3.05E-01
40	254.529206	87.801137	1.63E+01	-3.23E-01
40.1	252.928106	87.767967	1.58E+01	-3.40E-01
40.2	251.375111	87.733108	1.53E+01	-3.57E-01
40.3	249.870266	87.696638	1.48E+01	-3.73E-01
40.4	248.413345	87.658632	1.43E+01	-3.87E-01
40.5	247.003893	87.619164	1.39E+01	-4.02E-01

40.6	245.641249	87.578307	1.34E+01	-4.15E-01
40.7	244.324586	87.536128	1.29E+01	-4.28E-01
40.8	243.052939	87.492697	1.25E+01	-4.40E-01
40.9	241.825227	87.448076	1.21E+01	-4.52E-01

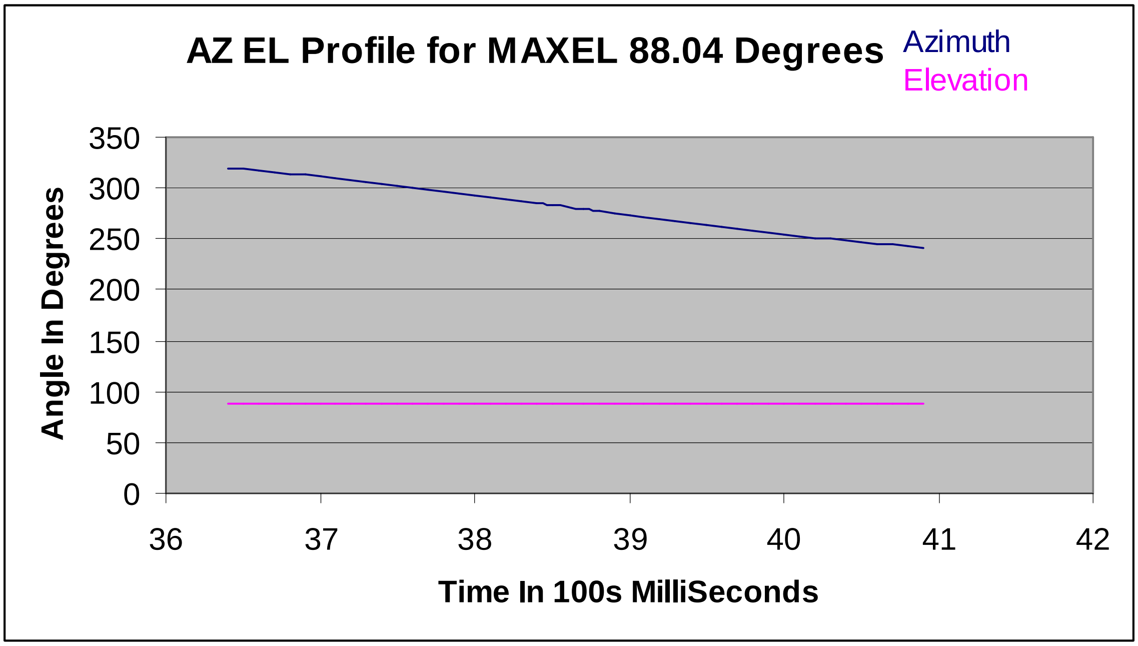


Fig.5.8 AZ. & EL. Profiles for max.EL of 88.04°

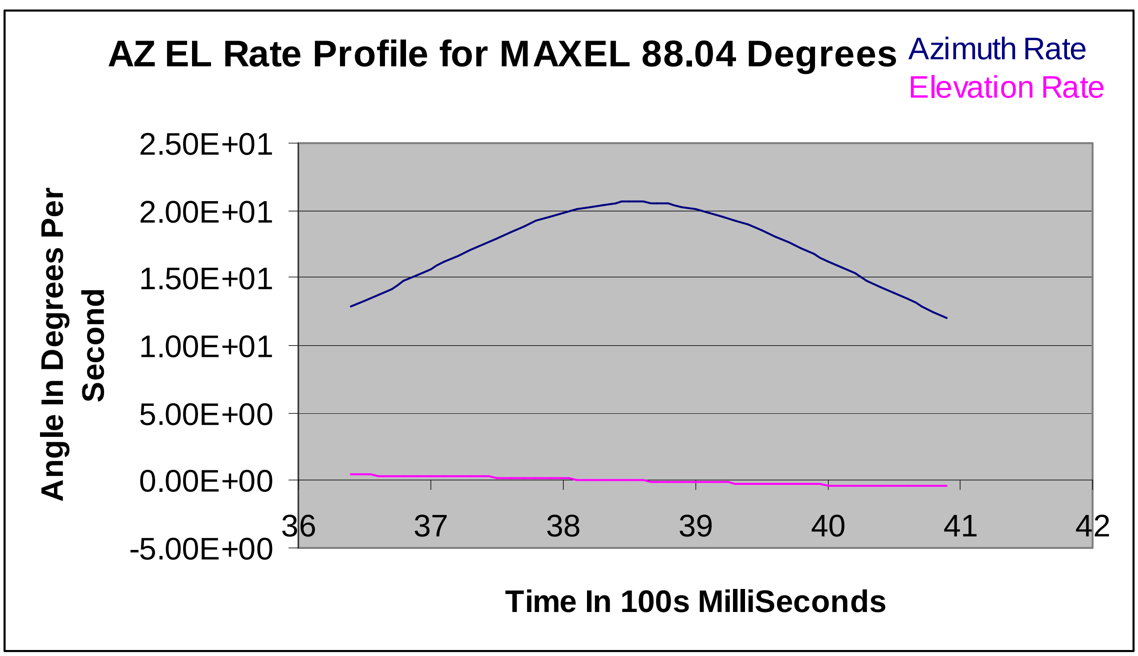


Fig.5.9 AZ. & EL. Rate Profiles for max. EL of 88.04°

5.4.5 Passes with 89.0^o EL

Table 5.5 Satellite Trajectory Report for 89.0^{o}EL.

The AZ rate requirements have gone upto 40.6^o/Sec. as given below:

Data For MaxEl 89.0 Degrees

Time In MilliSec	Azimuth	Elevation	Azimuth Rate	ElevationRate
35.6	348.443749	87.512459	6.44E+00	6.44E-01
35.7	347.782912	87.576667	6.78E+00	6.40E-01
35.8	347.086155	87.64054	7.16E+00	6.37E-01
35.9	346.350692	87.704051	7.56E+00	6.33E-01
36	345.573471	87.767167	7.99E+00	6.29E-01
36.1	344.751144	87.829853	8.46E+00	6.25E-01
36.2	343.880038	87.89207	8.97E+00	6.20E-01
36.3	342.956122	87.953775	9.52E+00	6.14E-01
36.4	341.974971	88.014919	1.01E+01	6.08E-01
36.5	340.931731	88.075449	1.08E+01	6.02E-01
36.6	339.821078	88.135303	1.15E+01	5.95E-01
36.7	338.637182	88.194414	1.22E+01	5.87E-01
36.8	337.373671	88.252706	1.31E+01	5.79E-01
36.9	336.023597	88.310093	1.40E+01	5.69E-01
37	334.579414	88.366479	1.49E+01	5.59E-01
37.1	333.03297	88.421757	1.60E+01	5.47E-01
37.2	331.375514	88.475805	1.72E+01	5.34E-01
37.3	329.597745	88.528487	1.84E+01	5.19E-01
37.4	327.68989	88.57965	1.98E+01	5.03E-01
37.5	325.641858	88.629125	2.12E+01	4.86E-01
37.6	323.443459	88.67672	2.28E+01	4.66E-01
37.7	321.084733	88.722226	2.44E+01	4.44E-01
37.8	318.556394	88.76541	2.62E+01	4.19E-01
37.9	315.850426	88.806021	2.80E+01	3.92E-01
38	312.96082	88.843787	2.98E+01	3.62E-01
38.1	309.884461	88.878419	3.17E+01	3.30E-01
38.2	306.622117	88.90962	3.35E+01	2.94E-01
38.3	303.179454	88.937086	3.53E+01	2.55E-01
38.4	299.567955	88.96052	3.69E+01	2.13E-01
38.5	295.805567	88.979646	3.83E+01	1.69E-01
38.6	291.916912	88.994216	3.94E+01	1.22E-01
38.7	287.932874	89.004031	4.02E+01	7.38E-02
38.9	279.826226	89.008898	4.06E+01	-2.54E-02
39	275.78368	89.003878	4.02E+01	-7.49E-02
39.1	271.801256	88.993963	3.94E+01	-1.23E-01
39.2	267.914907	88.979296	3.83E+01	-1.70E-01
39.3	264.155398	88.960079	3.69E+01	-2.14E-01
39.4	260.547213	88.936559	3.53E+01	-2.56E-01
39.5	257.108165	88.909013	3.35E+01	-2.95E-01

39.6	253.849608	88.877738	3.17E+01	-3.30E-01
39.7	250.777097	88.843038	2.98E+01	-3.63E-01
39.8	247.891311	88.80521	2.79E+01	-3.93E-01
39.9	245.189065	88.764543	2.61E+01	-4.20E-01
40	242.664301	88.721308	2.44E+01	-4.44E-01
40.1	240.308969	88.675757	2.27E+01	-4.66E-01
40.2	238.113764	88.62812	2.12E+01	-4.86E-01
40.3	236.068718	88.578608	1.97E+01	-5.04E-01
40.4	234.163639	88.527411	1.84E+01	-5.20E-01
40.5	232.388441	88.474699	1.71E+01	-5.34E-01
40.6	230.733359	88.420624	1.60E+01	-5.47E-01
40.7	229.189104	88.365321	1.49E+01	-5.59E-01
40.8	227.746936	88.308913	1.39E+01	-5.69E-01
40.9	226.398715	88.251505	1.30E+01	-5.79E-01
41	225.136909	88.193195	1.22E+01	-5.87E-01
41.1	223.954581	88.134067	1.14E+01	-5.95E-01
41.2	222.84537	88.074198	1.07E+01	-6.02E-01
41.3	221.803458	88.013654	1.01E+01	-6.09E-01
41.4	220.82353	87.952497	9.51E+00	-6.14E-01
41.5	219.900742	87.89078	8.96E+00	-6.20E-01
41.6	219.030677	87.828551	8.45E+00	-6.25E-01
41.7	218.209312	87.765855	7.98E+00	-6.29E-01
41.8	217.432981	87.702729	7.55E+00	-6.33E-01
41.9	216.698343	87.63921	7.15E+00	-6.37E-01
42	216.00235	87.575328	6.78E+00	-6.41E-01
42.1	215.342223	87.511112	6.43E+00	-6.44E-01
42.2	214.715421	87.446588	6.11E+00	-6.47E-01
42.3	214.119622	87.38178	5.81E+00	-6.49E-01
42.4	213.552703	87.316708	5.53E+00	-6.52E-01

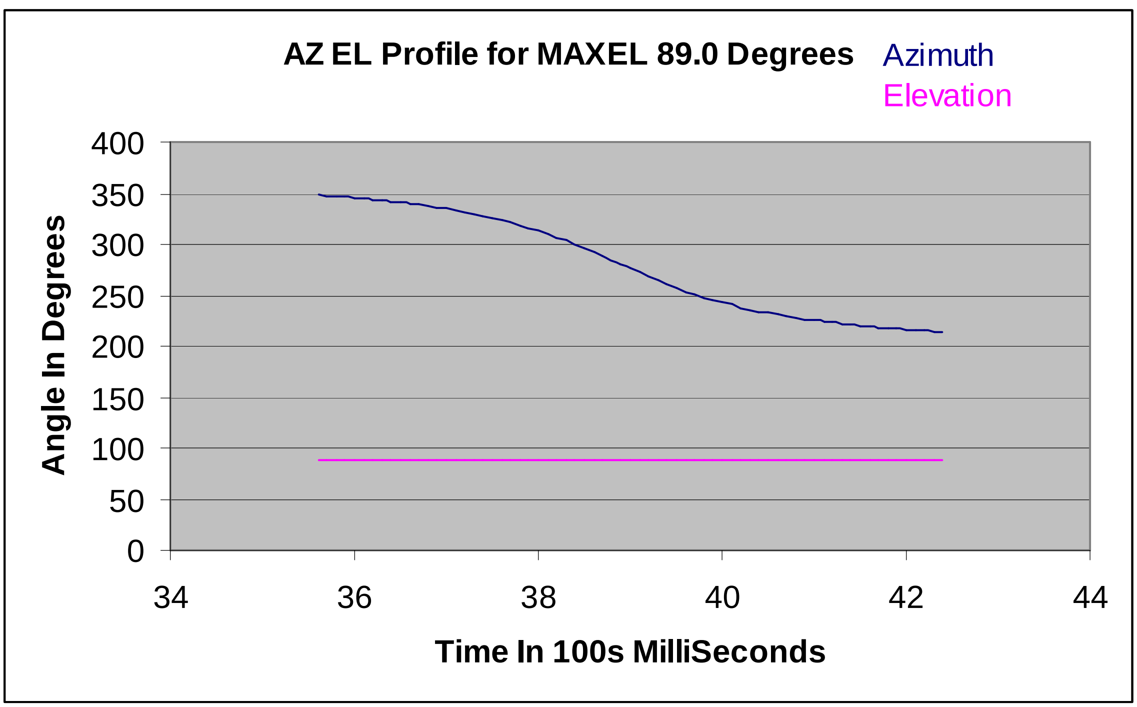


Fig.5.10 AZ. & EL. Profiles for max. EL. Of 89.0°

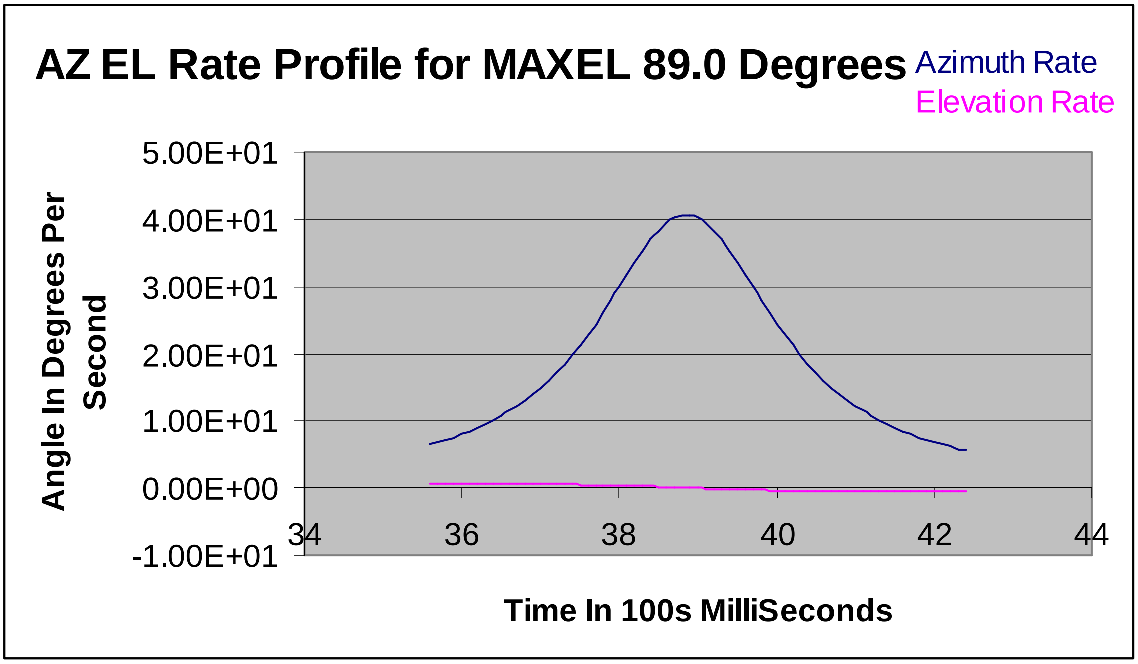


Fig.5.11 AZ. & EL. Rate Profiles for max. EL. Of 89.0°

5.4.6 Passes with 89.83° EL

The AZ rate requirements are very high calling for 264° /Sec. at the peak value as given below:

Table 5.6 Satellite Trajectory Report for max. EL. Of 89.83°

	Data For	MaxEl 89.83	Degrees	
Time In MilliSec	**Azimuth**	**Elevation**	**Azimuth Rate**	**ElevationRate**
37.2	18.08257	88.592943	3.10E+00	6.98E-01
37.3	18.408685	88.662749	3.43E+00	6.98E-01
37.4	18.770709	88.73251	3.82E+00	6.97E-01
37.5	19.174885	88.802218	4.28E+00	6.97E-01
37.6	19.628987	88.871862	4.82E+00	6.96E-01
37.7	20.142806	88.941428	5.48E+00	6.95E-01
37.8	20.728853	89.010901	6.27E+00	6.94E-01
37.9	21.403363	89.080257	7.25E+00	6.93E-01
38	22.187765	89.149467	8.48E+00	6.91E-01
38.1	23.110924	89.218492	1.00E+01	6.89E-01

38.2	24.212599	89.287277	1.21E+01	6.86E-01
38.3	25.54901	89.355744	1.48E+01	6.83E-01
38.4	27.202082	89.423779	1.85E+01	6.78E-01
38.5	29.295451	89.491208	2.37E+01	6.70E-01
38.6	32.023399	89.557752	3.14E+01	6.60E-01
38.7	35.70557	89.622943	4.32E+01	6.43E-01
38.8	40.894102	89.685935	6.22E+01	6.14E-01
38.9	48.581467	89.745092	9.44E+01	5.63E-01
39	60.527265	89.797031	1.49E+02	4.64E-01
39.1	79.152887	89.834799	2.25E+02	2.71E-01
39.2	104.304258	89.847475	2.64E+02	-2.99E-02
39.4	145.844475	89.788245	1.37E+02	-4.88E-01
39.5	156.829073	89.734587	8.71E+01	-5.75E-01
39.6	163.950631	89.674539	5.79E+01	-6.21E-01
39.7	168.803572	89.61105	4.06E+01	-6.47E-01
39.8	172.277138	89.545561	2.97E+01	-6.62E-01
39.9	174.868739	89.478825	2.26E+01	-6.72E-01
40	176.868907	89.411267	1.77E+01	-6.79E-01
40.1	178.455795	89.343141	1.42E+01	-6.84E-01
40.2	179.74367	89.274608	1.17E+01	-6.87E-01
40.3	180.808771	89.205773	9.73E+00	-6.90E-01
40.4	181.703726	89.13671	8.23E+00	-6.92E-01
40.5	182.465944	89.06747	7.06E+00	-6.93E-01
40.6	183.122701	88.99809	6.11E+00	-6.94E-01
40.7	183.694331	88.928598	5.35E+00	-6.95E-01
40.8	184.196284	88.859015	4.71E+00	-6.96E-01
40.9	184.640506	88.789357	4.19E+00	-6.97E-01
41	185.036372	88.719638	3.74E+00	-6.97E-01
41.1	185.39134	88.649868	3.37E+00	-6.98E-01
41.2	185.711415	88.580054	3.04E+00	-6.98E-01
41.3	186.001485	88.510204	2.76E+00	-6.99E-01
41.4	186.265568	88.440323	2.52E+00	-6.99E-01

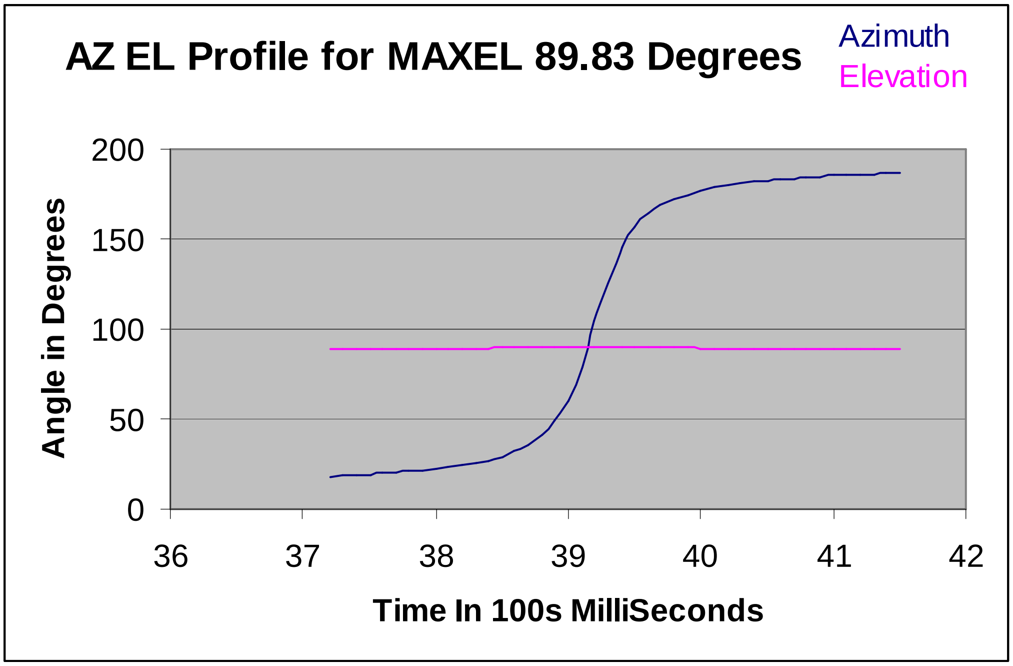


Fig.5.12 AZ & EL profiles for max. EL of 89.83°

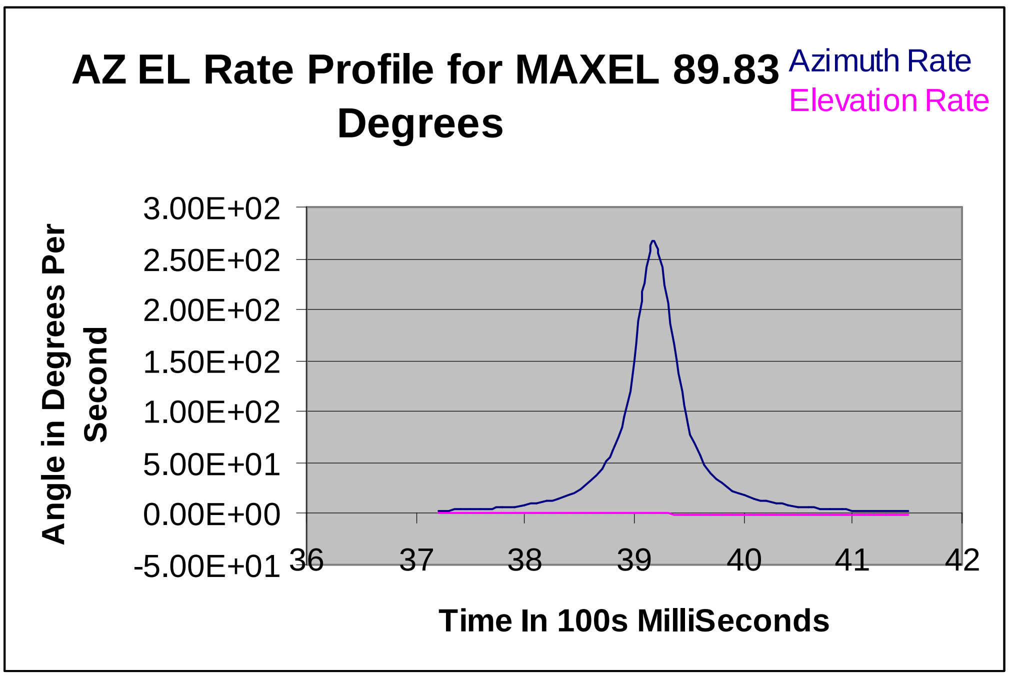


Fig.5.13 AZ & EL rate profiles for max. EL of 89.83°

5.5 **Conceptual Predictive Control Theory**

The computer analysis of the overhead pass problem resulted in a possible solution to the tracking problem. As has been noted, a sufficiently high azimuth positioner velocity limit will allow the positioner to track within the antenna beamwidth and receive data through the pass. For small beamwidths, however, this becomes an unrealistic and expensive requirement.

It is possible, using the trajectory calculation program, to construct a family of azimuth trajectories that fall within the antenna beamwidth limits for a high overhead pass. A plot of this limiting band about the true satellite coordinates was also derived for the -3 dB beamwidth of a 10-meter parabolic dish used for tracking the satellite.

It was also seen that it is possible to anticipate the high azimuth velocities at zenith and "lead" the true position before cross-over and "lag" after cross-over and still remain within the -3dB boundary. The most efficient trajectory possible to minimize the required azimuth velocities is one that tracks the true azimuth coordinate to a prescribed position and then moves at maximum velocity to the symmetry position at the opposite side of the crossover position before reverting to true coordinate tracking while limiting the speed requirement within the specifications. The peak minimum velocity occurs in a direct overhead pass.

5.6 Theory of the Model Developed [60]

Along with derivation of the satellites Trajectory information, it is possible to derive the velocity requirements of the satellite passes having elevation greater than 87^o. During the computer simulation the following were taken into account and observed for zenith passes (a) very high Azimuth velocities are required during the overhead pass (b) Elevation velocities are very small during the overhead pass (c) Auto tracking is lost when the Azimuth pointing direction lags the satellite position by an angle exceeding the antenna beamwidth (d)This lag is a result of maximum azimuth velocity limitation of the pedestal. It means sufficiently high azimuth velocity will allow the position to track within the antenna bandwidth and receive the pass. For small beamwidths, however, this becomes an unrealistic requirement. For a given antenna beam width for a 10 mtr. Antenna, based on the different elevation passes, family of azimuth trajectories could be constructed that fall within the beam width for overhead pass. This plot should limit the band about the true satellite coordinates for -3dB bandwidth as explained above. During this period the tracking is totally through programmed mode of operations so that the antenna tracking is controlled by the system as per the predetermined model. Even through an auto tracking system may still loose track of the satellite as a result of velocity limitations and signal degradation, the programme controlled need only to remain within $\pm 0.7^o$ of the pointing error of the target to receive the acceptable data. This approach uses the concept of limiting the speed to a maximum of around 20 to 22deg sec for a programmed trajectory. The analysis was done for IRS series of satellites where the pedestal is assumed to within 0.7deg cone during zenith passes result in signal degradation upto 6db. The model developed provides a method of control for the antenna in the programmed mode near overhead and zenith passes. This is called as Zenith Pass Controller (ZPC) and becomes active only for Zenith passes and further designed window period around the peak elevation. Based on the trajectory studies, the velocity requirements increase with the increase in the elevation angle. Based on this, the controlling periods too vary around the zenith to cater to their requirements. The table below provides an idea of the controlling windows around the zenith and the velocity requirements for each window for azimuth.

Azimuth velocity requirements for High Elevation Passes

The Velocities to be handled by the ZPC for the specific windows around the peak elevation.

Elevation	**± 5 Sec. around Zenith**	**± 4 Sec. around Zenith**	**± 3 Sec. around Zenith**
89.85^{o} peak EL.	17.5046^{o}/Sec.	21.7^{o}/Sec.	28.62^{o}/Sec.
89^{o} Peak EL.	14.85^{o}/Sec.	17.64^{o}/Sec.	23.276^{o}/Sec.
88^{o} Peak EL.	12.1856^{o}/Sec.	13.80^{o}/Sec.	15.727^{o}/Sec.

The S/W flow is as given below:

Steps involved for Zenith Passes

1. Derive the Satellite Trajectory containing Time (UTC), Azimuth, Elevation, Azimuth rate, Elevation rate in addition to the other information like Date of Pass, Sat ID, Orbit NO., Path No., revolution no. in a cycle. Cycle No, day since launch, AOS time, LOS time etc., at regular intervals of time around 20 Sec.

2. If the peak elevation is more than $87.5^{o,}$, the sampling interval of this report is changed to 200msec..

3. Then Derive the highest elevation.

4. The Azimuth rate is required to be verified for the crossovers, beyond the system specifications, the start point (UTC and the rate) and the end point (UTC and the rate)

5. Based on the above model, intentional offset is provided for the tracking based on the model and generate the new Azimuth and Elevation angles

around the peak elevation(approx upto 5 to 6 sec either side) as per the above table.

6. Replace the old Azimuth and Elevation angles with the newly derived model based values for the specified window period.

7. The new Constructed Pre-pass Planner Report generated as above containing the zenith pass AZ & EL values and will be used by the SCS to derive the tracking systems in programmed mode of operation.

8. SCS derives the system as per the above predicted values and will have a known deterioration in the signal during zenith pass but tracking never gets lost.

9. As the System is program controlled, all the status details are available and recorded by the station automation system described in the forth coming chapters

5.7 Software Development

The analysis of the high elevation pass problem results in several requirements for the Station Control System (SCS) that is to assume command of the pedestal during the overhead portion of the track. It is apparent that the system must have an analytical feature that will allow it to:

a. Anticipate the occurrence of an overhead pass.

b. Generate the optimum coordinate trajectories to minimize pointing errors.

c. Command the positioner to the prescribed trajectory as a function of time.

The requirement that the system performance be optimized to reduce errors to a minimum requires the SCS to have highly accurate knowledge of the true position of the satellite at all times derived from the Satellite State Vectors. The software derives the Azimuth, Elevation, Azimuth Rate, Elevation Rate with reference to UTC as provided in the above pages. For the high elevation passes, beyond 88^o, the azimuth rate will be going beyond the system specifications. SCS detects this and identifies the start point of Zenith Pass and the end point too with respect to UTC. This information allows the SCS to deduce the optimum trajectory for the coordinates, taking the positioner's physical limitations into consideration and generate the modified AZ and EL values and fit into the original trajectory file. Thus the pre -pass planning file for zenith passes will have modified values. The SCS then assumes programmed mode of operation and programs the positioner along the optimum path during the overhead portion of the pass, using the curve-fit trajectory parameters to generate the true target position. At the end of the zenith, the programmer can pass the control back to the auto track circuitry or it can continue the program track mode of operation. As these models were tested thoroughly, programmed mode of operation of all the passes is convenient to the user.

5.8 Results:

The program track system has been fine tuned to work close to auto track resulting in the least possible errors both in Azimuth and Elevation. The predicted and the actual Az and EL match very closely. It took sometime to model and fine tune the behavior of the system. After the final implementation the results are excellent and the systems are working error free for all the remote sensing satellites.

This above zenith passes model has been tested with Cartosat (IRS-P5) tracking for 6 passes with the Elevation angles 85.5^{o}, 86.7^{o}, 87.62^{0}, 88^{o}, 89^{o} and 89.8^{o}. The performance was good. It was observed to be fine for all other satellite passes also.

Therefore with the help of this model the zenith passes were handled by the system very efficiently without loosing the satellite with a tolerable deterioration in the data quality. This development has provided the way for the automation of the tracking system in total with least human subjectivities.

5.9 Conclusion :

In order to implement and realize the automation of the remote sensing satellite ground station, it is necessary to have elevation independent tracking or in other words non-interruptive tracking of the passes without any human interaction. Therefore it is very important to have the zenith passes programme tracked and controlled irrespective of the elevation angle. This was implemented and also functional without any failures. This is one of the critical and important achievements for the automation. The systems status is transparent to the controlling computer, error handling and diagnosis has also become easy and thus leading the systems to go for remote diagnostics concepts.

Chapter- 6

Development of Systems for the automated operations of the ground station

Abstract

In order to implement remote control, configuration and management of the data acquisition system, it is necessary to have automated station operations. It calls for extensive Hardware and Software developments. This has motivated to increase the adoption of programmable architectures through FPGAs, CPLDs and programmable non-volatile memories such as EEPROM and FLASH in the designs etc.,. In order to extend this concept, the systems are required to be redesigned for on line configuration using reconfigurable systems etc. This called for the development of high speed switching systems with remote programmability. It also called for process automation and intelligent software for diagnostics. This chapter deals with (a)Development of remote controlled high speed switching matrices catering to current and future remote sensing satellite data rates(b)Development of remote control/configurable interfaces for all the devices in the remote sensing Ground Station viz.. RF systems, BER systems, Simulators, Timing systems etc..(c)Development of scheduling software interlinking all the above systems/modules for total automation and remote management(d)Development of Automated report Generation System with the associated data bases for the systems and satellites status. These systems were developed and supplied to several National /International agencies and all are working fine.

6.1 Introduction :

The Station Automation System (SAS) automate the remote sensing satellite ground station operations by configuring/controlling various sub systems in the satellite data reception chain. It monitors and records the status of each equipment/function for the purpose of report generation, diagnostics and for recovery mechanisms. These concepts are introduced to enable the remote management of the system including the multi-mission satellite operations.
The advanced developments in VLSI, development of high speed network interfaces partially reconfigurable FPGAs and the concepts of process automation have provided the path for the development of automated and reconfigurable systems. In order to implement these concepts some new systems were developed. Hence this chapter deals with the systems and the softwares that were developed for SAS.

6.2 Systems connectivity in Data Reception for automation :

The basic systems connectivity diagram of Data Reception systems for automation is shown in Fig.6.1. It provides the connectivity between different subsystems in the Reception chain. The Down Converter takes the data from the Antenna Subsystem and gives out Intermediate Frequency(IF) data. The output of the Down Converter is fed to IF Data Path Controller to route the Data to the required Demodulators and Bit synchronizers and Signal Conditioners(BSSC). The Data and Clock from these BSSCs are routed by Digital Data Path Controller to different Realtime Computer for data archival.

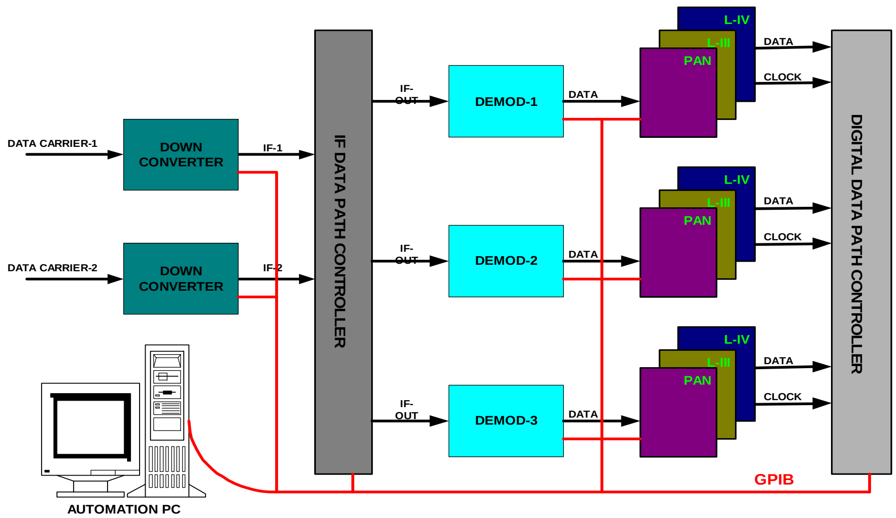


Fig. 6.1 Functional diagram of Reception System

All the above subsystems needs to be configured to receive the data from each satellite in Real-time and may need to be changed based on the requirement.

6.3 Systems Development

For the implementation of SAS the following systems were developed(a)Data Path Controller(b)Remote interfaces for down converter, demodulators ,BSSCs, phase shifter. Some of the equipments like BER Test Systems (BERTS),Satellite Data Format Simulators(SDFS) were already detailed in the previous chapters.

6.3.1 Development of Data Path Controller

After the successful launch of IRS-1B Satellite, there was a need for handling data from multi sensors imaging satellites. The requirement got multiplied in the presence of multi satellite terminals under the satellite visibility clashes. Under this environment, there was need to develop a device that can switch the multiple input data streams from different satellites / sensors / terminals and to feed the respective data and clock channels to the real-time recording and pre-processing systems while taking into account the main and back up options too for each of the channels. The device switching speeds should be high to avoid Data break in creating the National Archives. The development of such switching device has become more and more imminent subsequent to the launch of IRS-P2, 1C etc. The requirement of channel band widths also increased along with the sensors' band widths. The number of input and output channels has increased with the increase in the number of satellites. In order to cater to this requirement, the Matrix Switching Device of 32 X 32 was developed with a band width of more than 200 MHz per channel. The Real-time data acquisition systems call for the automation of the Matrix Switching Device operations through RS 232 / GPIB / USB Interfaces. This system is being used operationally. This technological development has resulted in a quality certified product of international standard with MTBF better than One Hundred Thousand hrs. The references were drawn from net[61-62,69] , text books[65-68], and the author's paper [70].

6.3.1 **Description**

The heart of the Digital Switching System is a cross point switch . The cross point switch will provide the connectivity of one to any / many all output channels while ensuring the identical signal status to all the channels upto a data rate of 200 Mbps. Per channel from DC. The functional block Diagram is shown in fig. The system is divided into

a) Input / Out Put Signal conditioners
b) Differential Switching matrix
c) Front Panel Interface
d) RS 232 /GPIB /USB remote Interface
e) Graphic LCD Display

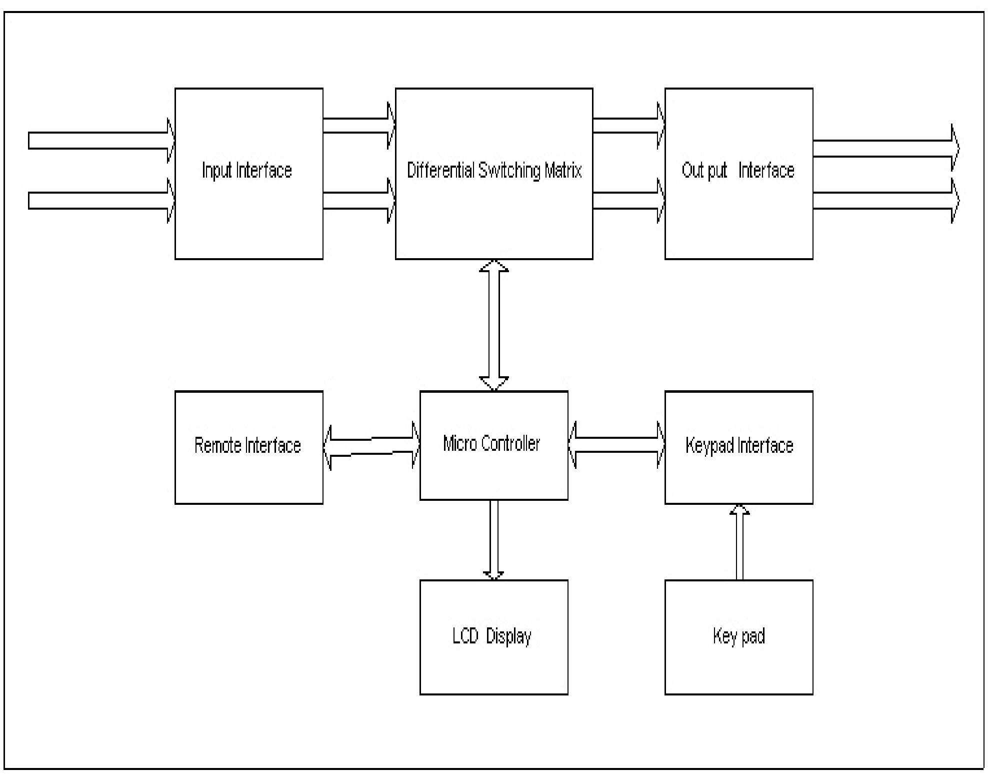


Fig 6.2 Block diagram of Data Path Controller

a) **Input / Output Signal Conditioner :**

It Provides Line terminations, Signal level conversions for supporting different frequencies and ensures signal integrity. Provides flexibility for the user to operate either ECL or PECL levels. Unterminated outputs are provided to the user.

b) **Differential Switch Matrix** :

This is the heart of the system and the matrix is designed to handle 16X16 I/Os. The design accommodates to have cascading of such 16X16 signal pairs to cater to the higher matrix for future requirements. The Bandwidth is extendable to 300 Mbps per channel.

c) Front Panel Interface :

The main function of the Front Panel interface is to provide a user friendly Keypad and Graphics LCD Screen. They were used to configure and display the existing configuration. The Firmware is developed to have a default configuration with a flexibility to select/modify for the desired configuration. The nomenclature of each port programmed in the system will be displayed along with each port number. The default configuration is programmable as per requirement

d) **Remote Interfaces:**

The RS 232 / GPIB / USB Interfaces enable the remote configuration of the switching matrix the remote interface facilitates to configure as well as to read the existing configuration thus classifying the command messages as read or write to carry out all the functions.

e) Graphics LCD display Controller.

The Graphics dot matrix LCD display (240 X 128) with The Graphics controller HD 61830 is used with 4 X 4 membrane Key pad for user interface This graphics controller chip is designed to control small to medium size graphics Liquid Crystal Display modules. It is interfaced with a number of 8 bit microprocessor units (MPU). This graphics controller provides the necessary interface between the MPU and the Video RAM (VRAM). It also generates the necessary timing and data signals for the liquid crystal driver circuits. It has a built in 192 Character Generator ROM (CG-ROM) and character generator circuits.

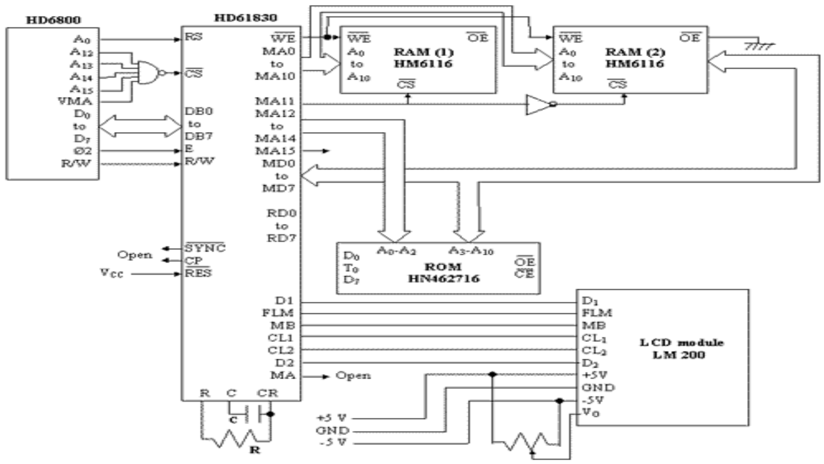
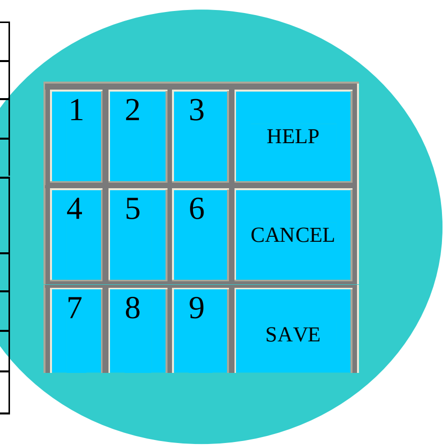


Fig.6.3 LCD Interface for DPC

The 4 X 4 Keypad contains numeric as well as function keys for operator selection in local mode. The cursor movement is controlled by arrow keys.

KEYS	FUNCTION
1 – 8	To select DPC ports and its inputs
0 & 9	Not in use
ENTER	Puts the display into EDIT mode
SAVE	Configures the Port & puts cursor to HOME position
CANCEL	Goes back to DISPLAY mode
HELP	Not in use
→	Not in use
←	Not in use



Typical Operational configuration :

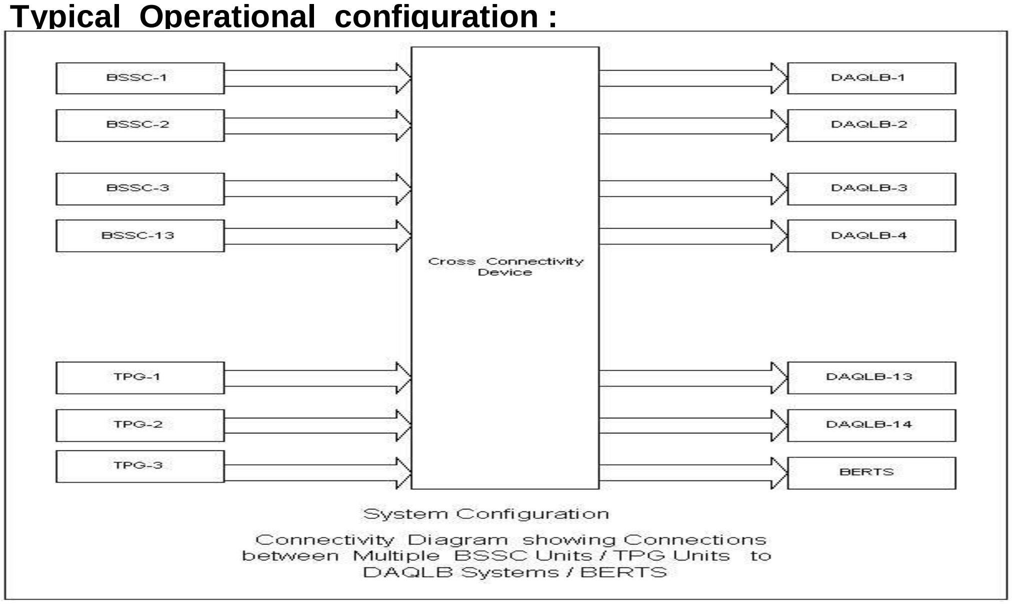


Fig.6.4 System Configuration for DPC

The diagram of the device in the operational environment as an example is given above. This configuration connects one set of data and clock pertaining to a given sensor/satellite from the data reception system to one realtime data archival system. For the purpose of redundancy the backup systems can be configured in the same manner. During the satellite launch time as the data is required to be analyzed in short period of time, one to many connectivity concept is used. The system is designed to cater to all such combinations. One of the greatest advantages of the system is saving of bandwidth in case of multicast and broadcast modes of operations. In both the cases only one input is connected to many outputs through hardware implementation unlike the switches in the networking.

Default configurations are stored in the memory and selectable either locally or remotely. As this is a key element in the total data chain, remote diagnosis , fault finding and rectification are being implemented with additional hardware and software in the system.

6.3.1.2 Fabrication Aspects :

While designing the PCB and chassis , specific precautions were taken to make unit usable at high frequencies . Standards are followed for the EMC compliance associated with equipment chassis shielding / grounding and cabling . At higher frequencies, traces on a PCB act as a monopole or Loop antenna. Differential mode radiation is the electromagnetic radiation caused by currents consisting of harmonic frequency components flowing in a loop in the PCB. The radiation is proportional to the current loop area and the square of the frequency of the signal. Common mode radiation is the electromagnetic radiation caused by the current flowing in the unterminated trace and may require appropriate load terminating resistors to eliminate reflections. The radiation resembles that of a monopulse antenna and the magnitude is proportional to the current per line length and frequency. The high frequency components of the fundamental radiate more rapidly and the amplitude of the harmonic frequency components decrease as the frequency increases. The radiated power frequency varies depending upon the trace characteristics. The transmission line effects become an important design consideration when the trace length approaches 1/7 . of the wave length of the signal being transported. If the clock frequency is 300 M Hz, the wave length in Fr 4 is about 0.5 m.. Multilayer PCBs with ground and power were distributed as separate layers with signal conductors embedding as planes in the substrate. The return currents for the signal traces flow through the reference plane which is in close proximity to the plane and use of planes provide low impedance power distribution necessary for good supply decoupling. Enclosing the signal traces between the ground and power supply planes provide shielding and reduce radiation. In the PCB, radiated fields from the outward flowing currents tend to cancel which reduces and synchronizes propagation delays throughout the board. For the system to perform correctly at high speeds, a well controlled propagation time is required and adjustments with timing, skew for some signals may be necessary. Alternatively, trace lengths can be equalized manually to avoid skew by appropriate routing. Author has published a paper on the fabrication considerations [71].

6.3.1.3 System Specifications

Techinical

Data Rate	: 0 - 200 MBPS
No. Of Inputs	: 32
No. Of Channels	: 32
Data & clock input	:P ECL
Data & clock output	:P ECL (unterminated)
Key Pad	: 4 x 4 Matrix type
LCD screen	: 20 x 4 Characters
Remote interface	: GPIB/RS232
Type of GPIB device	: Talker/Listener
Adj channel rejection	:60 db

Environment

Operating

Temperature	: +5 ^{0}C to +35 ^{0}C
Humidity	: 10 to 80%RH (Non Condensing)

Storage

Temperature	: -10 ^{0}C to +60 ^{0}C
Humidity	: 10 to 95%RH (Non Condensing)

Mechanical

Chasis Height	: 7”
Chasis Width	: 17”
Chasis Depth	: 20”

POWER SUPPLY (External)

Input Power Supply	: 230V +/- 10%AC @ 50Hz +/- 0 . 5Hz
Operating voltage	: +5V DC @ 5 A and -5V DC @20 A

6.3.1.4 Results

(a) The designers have taken care for delay equalization , synchronization and wave form improvement The delay is adjusted to be identical on all the three connectivities One to One, Cross Connectivity, and One to Many or broadcast mode. All the modes were certified and one typical input and output wave form is as follows:

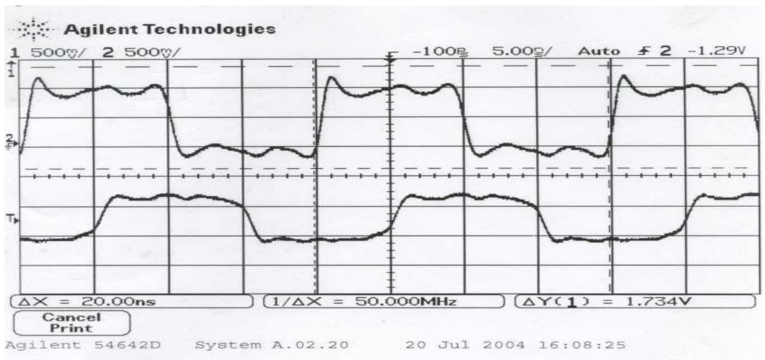


Fig.6.5 Data and Clock output waveforms of DPC

The frequency and the rise time of the signal are related as rise time Tr in nano seconds = 0.35/freq in GHz.

(b) All channels in the system for all the above types of connectivities /configurations were tested for Bit Error Rate (BER) using the PN sequences of 2^7-1 through 2^{23}-1 System was certified for ZERO Bit Errors all through the band of operation for all the configurations all the time. The typical BER response of the cross point switch is as follows:

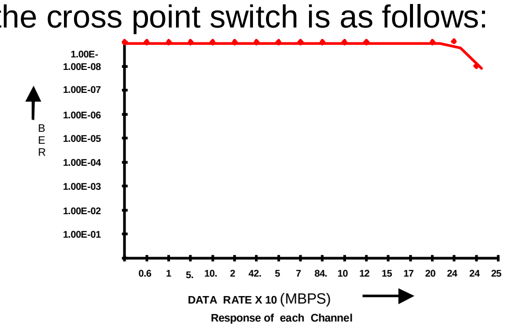


Fig. 6.6 BER response of each DPC Channel

(c) Eye diagram is a simple technique that compresses the results of long simulation into a single,easy to digest and interpret the picture. Eye diagrams are easy to create by chopping the high speed serial PRBS

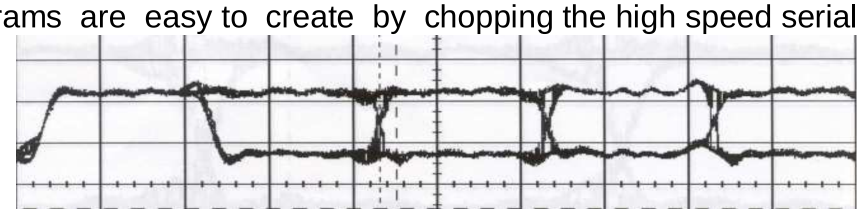


Fig.6.7 Typical Eye Pattern – DPC response

data wave form at regular intervals related to bit time, place each chopped segment on the top of the previous segment and view all the overlaid data in one overlaid picture. Small eye opening spells disaster for the signal path. Openness of the eye tells whether the data stream is acceptable or not. Small eye opening refers to the bad drifting of received bits in both time and voltage. Wider trace while maintaining characteristic impedence improves the signal quality.

(d) In order to maintain equal trace lengths all 64 pairs of signals, radial signal routing concept is used. Typical layout is as follows:

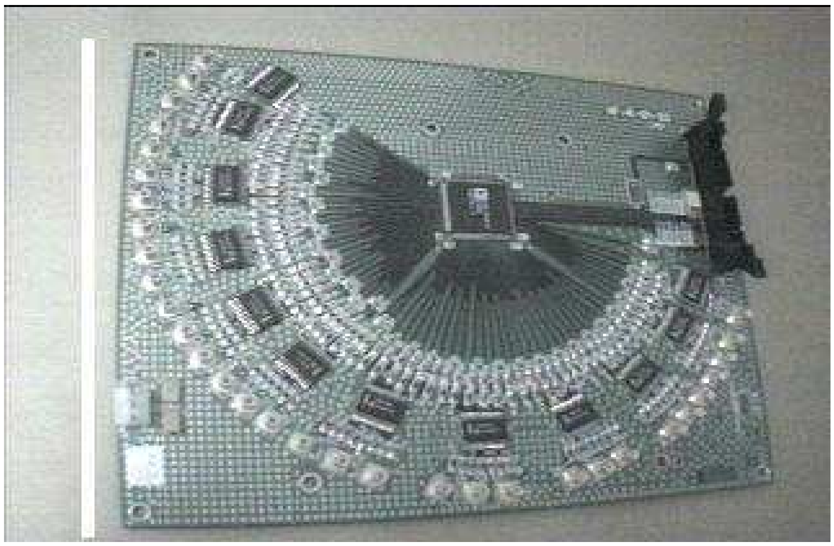


Fig. 6.8 PCB photo of DPC

(e) Design considerations with respect to multi layer PCBs, interconnections, fabrication, integration and engineering aspects were carefully designed and implemented covering all the issues related to EMI/EMC too. Typical result is as follows:

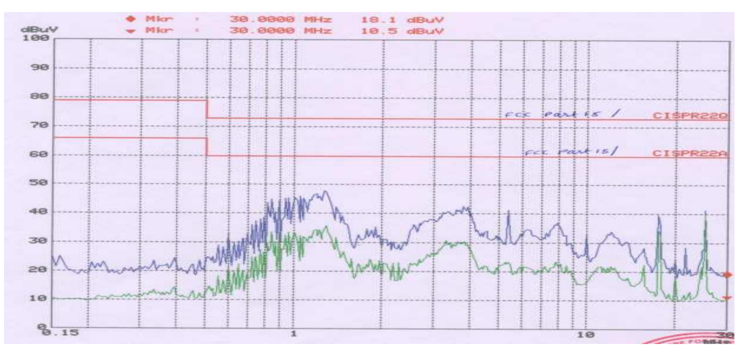


Fig. 6.9 EMI response of DPC

(f) Photograph of the instrument which is reliably working for the last five to six years without a single failure is given below:

Fig.6.10 Front panel photo of DPC

(g) The unit has been developed as a specific requirement of realtime data acquisition System. This concept was also extended by the authors to develop analog crosspoint switches for the spread spectrum applications. Use is envisaged in several applications in communications, computer networking , etc. The concept plays an excellent role in the switching systems for high frequency applications. As the interfaces are taking serial form, it has wider applications with appropriate intelligence built in.. The unit is being augmented for LVDS, online built-in diagnostics with remote evaluation facility etc.

6.3.2 Development of Satellite Data Simulator. This was described in Chapter 2.

6.3.3 Development of BER Test Systems This was already covered in Chapter2

6.3.4 Development of IRIG Time Code Translator [71].

The time from GPS with accuracies better than 1 µsec. is used as a reference time in the Ground Station. Universal Coordinated Time (UTC) in IRIG-A format is used with the help of different Timing Instruments viz., Time Code Generator, Time Code Translator, Parallel and Serial Time Distribution Units, remote display systems etc.. that were developed in-house as per the QA standards. These systems were supplied to more than 2 doz. countries from Department of Space as a part of Indian Remote Sensing Satellite Program through Antrix Corporation.

6.4 **Software Development for SAS**: [63-65,72-80]

Station Automation System configures and controls different sub systems of the Data Reception Chain. All these functions are controlled by GUI based software called Station Automation System (SAS).The SAS is primarily designed to schedule the satellite passes in realtime as per the UTC while taking the satellite pass schedules from station control systems. In addition to handling the realtime functions through scheduler, a set of utilities were developed to test the functions independently and also to carry out the various activities that are required for Station and as well as Scheduler.

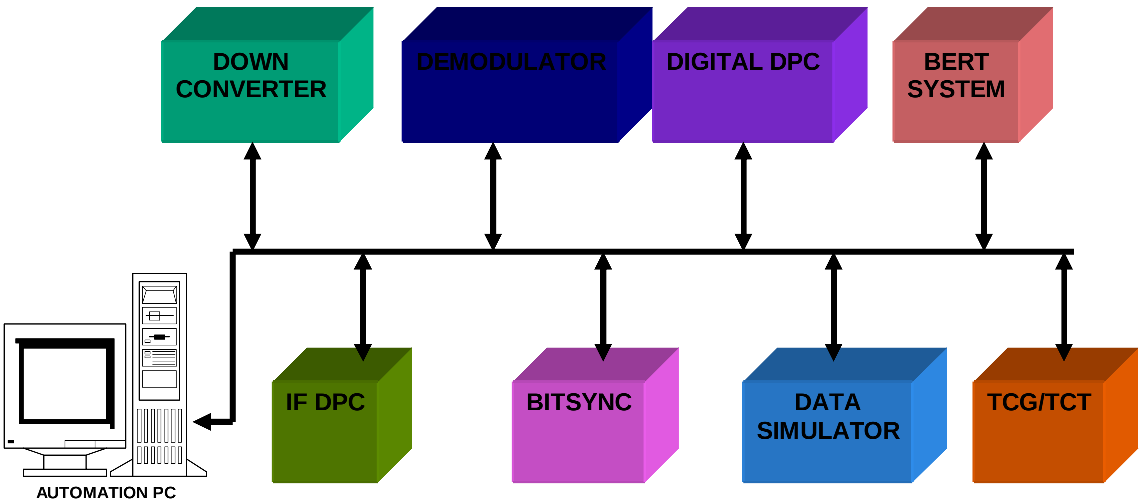


Fig. 6.11 SAS Configuration

6.4.1 Scheduler

The main objective of the scheduler is to schedule and monitor status of sub systems and also to log the signal strength of both the chains through spectrum analyzer. This information is logged on to the computer system in raltime while updating the status on the realtime panel of Scheduler. The main functions of the scheduler are

- Synchronizes the system time to Station UTC Time
- Schedule and coordinate various activities based on the System Timer
- Receives the Pass Schedule file from Station Control Computer
- Configures all the devices and provide electronic paths for data acquisition
- Scheduling the passes as per the Pass Schedule file
- Provides Auto Mode of scheduling till LOS (Loss of Satellite) of the pass
- Monitoring and logging the lock loss status of Demodulators, Bit Synchronizers, Tracking Receiver etc.
- Logging of the Signal Strength of both the streams through spectrum analyzer

6.4.2 **Pass Scheduling**

The execution of the scheduler gets performed from SAS window based on the System Timer. The Scheduler initially synchronizes the system time to UTC by reading the BCD time from time code translator.Then it reads the schedule file and schedules all the passes based on the Pass status flag. It displays Pass status against the 'Status' filed on the scheduler window as over or in progress or Wait. The Scheduler checks the possibility of scheduling passes as per the system time with 'Wait' flag. If the system time crosses the LOS of pass time, a message popup is generated saying that 'Pass scheduling is not possible' and the scheduler updates the status with 'Skip' against the status field in the pass table and the scheduler looks immediate next pass for schedule. If the system time crosses the AOS but not LOS, then the scheduler updates status with 'Progress' against the status filed in the pass table and starts scheduling real-time events.If the System time has not cross AOS, then it schedules the realtime events at AOS-60 secs. The process will continue for all the scheduled passes till last pass in the pass Table. At the time of Scheduler exits the information in the pass table is updated in the pass schedule file.

6.4.3 **Scheduling of Real Time Events** :

The scheduler starts scheduling the Realtime events few minutes before AOS. It starts scheduling the passes by displaying a Prepass input window to configure the Down Converter, BSSCs, demodulator etc... It also configures both the spectrum analyzers that are connected to the Station Automation Computer.

After the completion of devices configuration, it displays the Real time panel where the countdown for AOS updates will be seen at regular intervals based on the system time. This will continue till AOS. At AOS the realtime data logging starts and it will continue till LOS. During realtime the following activities will be carried out by timer event.

- Monitoring and logging the lock loss status of Demodulators, Bit Synchronizers, Tracking Receiver etc.
- Reading and recording the Signal Strength of both the streams through spectrum analyzer
- Logging the status on to the system
- Countdown for LOS on the realtime panel
- Exit at LOS

6.4.4 **Utilities**

A set of Utilities was provided to carry out the independent activities as and when required.

- Data Path Controller
- Time Code Translator
- Remote Interface for RF systems
- Down Converter Unit
- Satellite Data Simulator
- Bit Error Rate Test Systems
- Get Pass Schedule file from SCC
- System Time Synchronization
- DPC Defaults
- DPC Port map
- BER logging during link checks
- Backup management
- Report Generator

6.4.4.1 **Data Path Controller** :

The main function of the Data Path Controller utility is to establish the connectivity between different source and destination equipment. After invoking this utility, it checks for the GPIB interface and DPC unit. Once it is identified as DPC, it prompts the user to put the unit into remote mode and starts reading the status of DPC ports at regular intervals of time based on the system timer. This will automatically reflect the configuration changes that were done in the local mode subsequently. The device errors will be reported in the Intermediate message window. The main features of this utility are\

- Device identification and Recognition
- Programming of selected ports
- Programming to default configuration
- Customization DPC port labels
- Updating port status

6.4.4.2 **Time Code Translator** :

The main function of the utility is to read the time from Time Code Translator. After invoking this utility, initially it checks for the GPIB interface and TCT unit. Once it is identified it starts reading the Time and updating time in Time Window on TCT panel for every one second. Apart from this, it also reads the time upto 1/10th of msec for a specified no. of samples with a given time interval. All the device/interface errors that will come across during time read are reported in the intermediate message window. IRIG-A Time Code Translators were developed in-house by the author and supplied these systems done internally (QA certified) to around 2 dozen countries. The unit has been developed GPIB/RS232 external interfaces. The unit photographs are given below.

Fig.6.12 Front Panel for TCT

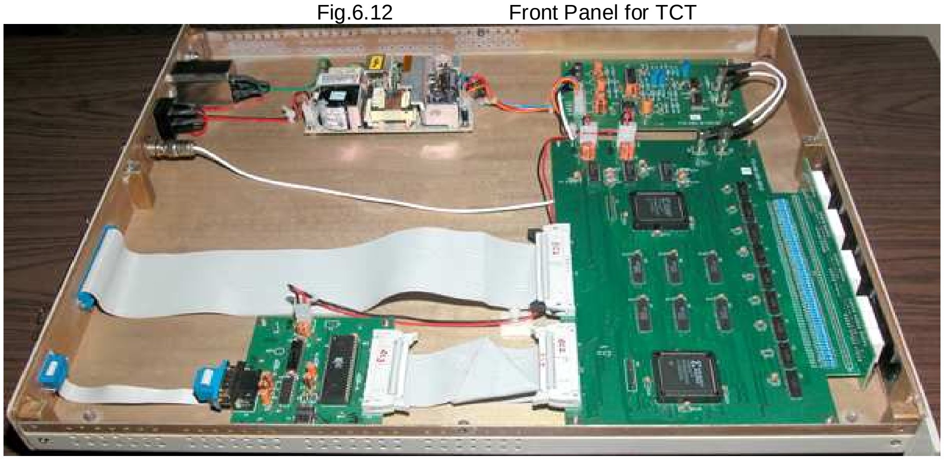


Fig. 6.13 Internal layout of TCT

6.4.4.3 **RF Chain** :

The main function of this utility is to read the lock/loss status Demodulators, Bit Synchronizers, Tracking receivers etc. After invoking the utility, it checks for the GPIB interface and RFMON unit. Once it is identified it starts reading the lock/loss status of configured RF system through 'RFMON' and updating it on the status window of RFMON Panel at a regular intervals of time.

6.4.4.4 **Down Converter** :

The main function of this utility is to program the LO frequency of the three channel down converter. One channel is used for tracking and the other two channels for Data. The main features of the utility are

a. Channel wise Independent programming of Down converter to any frequency
b. Programming the LO frequency based on the Sensor/Satellite
c. Simultaneous Programming of two data and one tracking carrier to the required frequency

6.4.4.5 **Satellite Data Simulator**

The main function of the utility is to configure both the streams of Satellite Data Simulator remotely based on the type of Satellite pas. It has got modes TPG and PRBS. In TPG mode, each stream simulates Satellite Data Pattern based on the Satellite. Again each stream has got an option to select different pattern lengths in the video portion of the Data format. In PRBS mode it stimulates the PRBS data of 7, 15, 20 and 23 code lengths at realtime speed of the sensor. The main features of the utility are

1. Two modes :TPG/PRBS
2. Selection of Sensor/Satellite (IRS-1C/1D/P4/TES/P6/P5
3. Selection of mode (RT/SSR/CAL)
4. Selection of data pattern for both the streams
5. FS error injection

6.4.4.6 **Bit Error Rte Test System**

The main function of the utility is to configure both the transmitter and receiver modules of the Bit Error Rate Test System. The main features of the utility are

1. Selection of Code length both for Transmitter and Receiver
2. Error injection for Transmitter
3. Reading the BER from Receiver
4. Setting the BER Exponent of the Receiver
5. Logging of BER values with reference to UTC

6.4.4.7 **Programmable Defaults**:

Using this utility user can program the default configuration that is required for DPC regularly. Whenever this utility is invoked, it displays the existing default configuration that is being used by DPC. It provides the user to modify and save the default configuration as per the requirement. The same configuration will be used by DPC whenever it programs to default configuration.

6.4.4.8 **DPC Port Map**

Using this utility user can customize the labels of both input and output ports of the DPC based on the systems connected. These labels will be used and displayed on the DPC panel whenever custom mode option is exercised on DPC. In the Custom mode of configuration these labels will be displayed instead of generic names in the DPC configuration window.

6.5 **Operational Procedure** :

These operations of the Station Automation system totally controlled by GUI based software called Station Automation User Interface (STATUS) and broadly categorized into two types of Scheduler and Utilities.

6.5.1 Scheduler

STEP 1 : Starting a STATUS

To start a STATUS click on ‘STATUS’ icon from Desktop. It displays the following Panel with continuous time updation in the GMT window for every one second. It also opens the Device configuration file and initializes the GPIB device addresses for different systems.

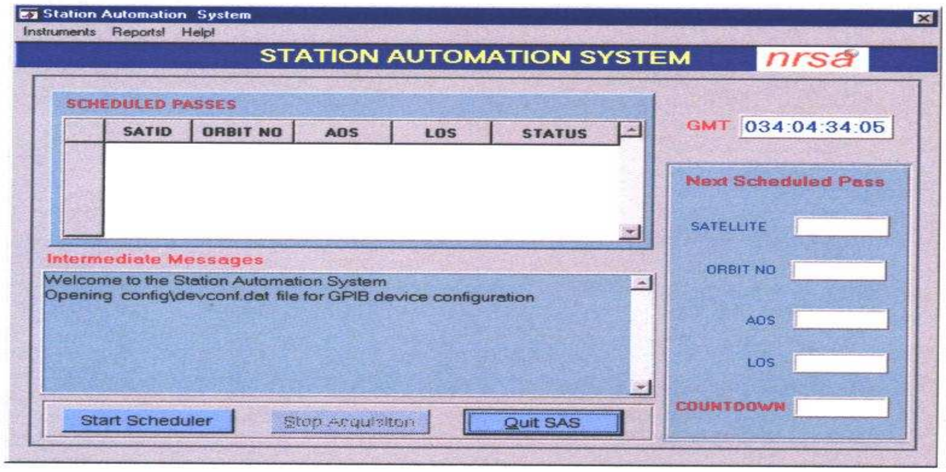


Fig. 6.14 Start of Pass GUI for SAS

Click on 'Start Scheduler' button to start the scheduler for a given Day or Night. Immediately 'Start Scheduler' button toggles into 'Stop Scheduler'.

STEP 2: Enter Date of Pass

Enter the Date in Date of Operation (in case data is different from the system data) Panel and then press 'OK' button to run the scheduler. Press 'CANCEL' button to cancel the scheduler operation. *By default it shows the System Date.*

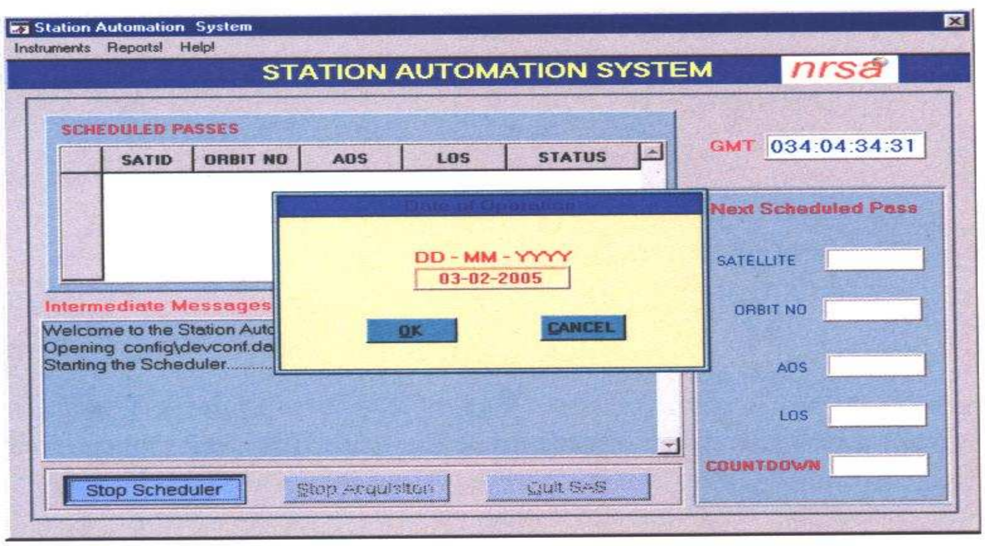


Fig. 6.15 GUI for Pass entry - SAS

After entering the Date of Pass, press 'OK' button to accept the date.

STEP 3: Scheduling of Passes :

First, it reads the time from Time Code Translator to synchronize the System Time to Station Time. In case of any problem it prompts the user to enter the time in Time Popup Window.

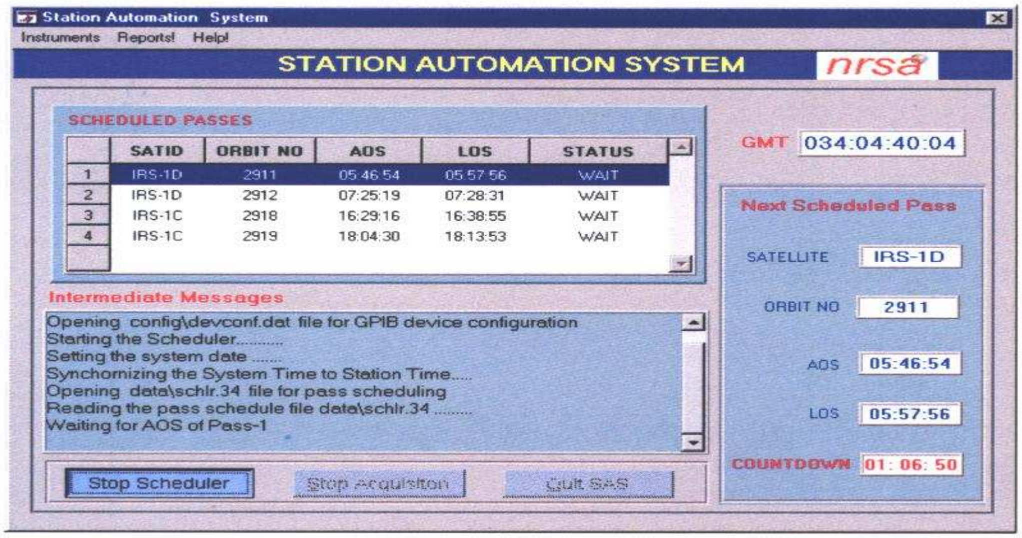


Fig. 6.16 GUI for Passes scheduling

Now it reads the pass information from Pass schedule file and updates pass information in 'SCHEULED PASSES' window of the STATUS panel. It schedules the passes based on the system time and updates the countdown and System Time for every one second in the Scheduler window.This will continue till countdown reaches less than or equal to 60 seconds.

STEP 4 : Pre pass input selection :
At (AOS-60) sec, the scheduler prompts for the selection of pre pass inputs through a pre pass input window. After the selection of inputs for both the steams press OK button to configure the Sub system.

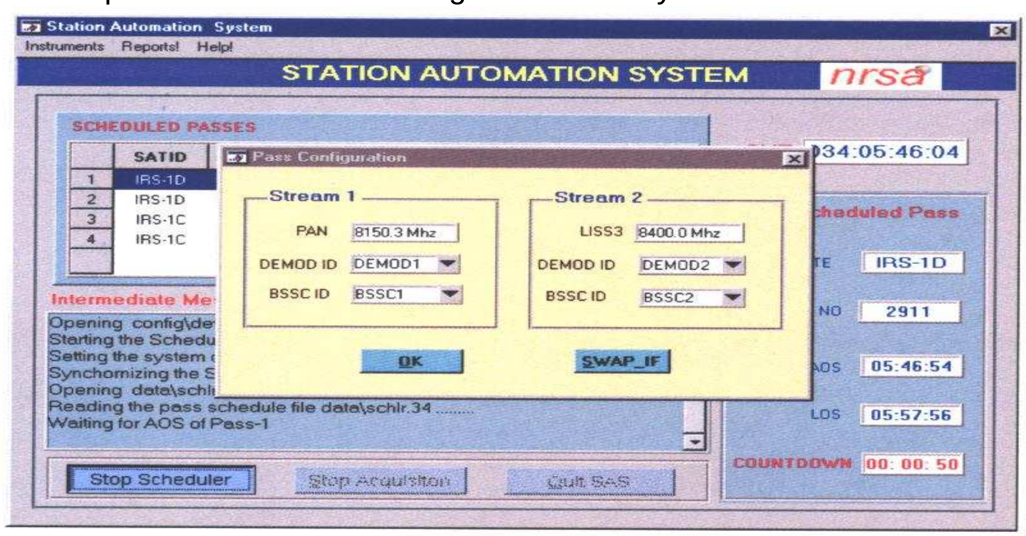


Fig.6.17 GUI for Pre-pass Selection

Based on the Satellite pass LO frequencies of both the streams are selected. By using 'SWP_IF' user can swap the IF of both the streams if required.Select the Demod and BSSC ids for both the Streams and then press 'OK' button.

STEP 5 : Configuring the Sub Systems

After pressing OK button, the scheduler to configures all the sub systems and displays the real time panel.

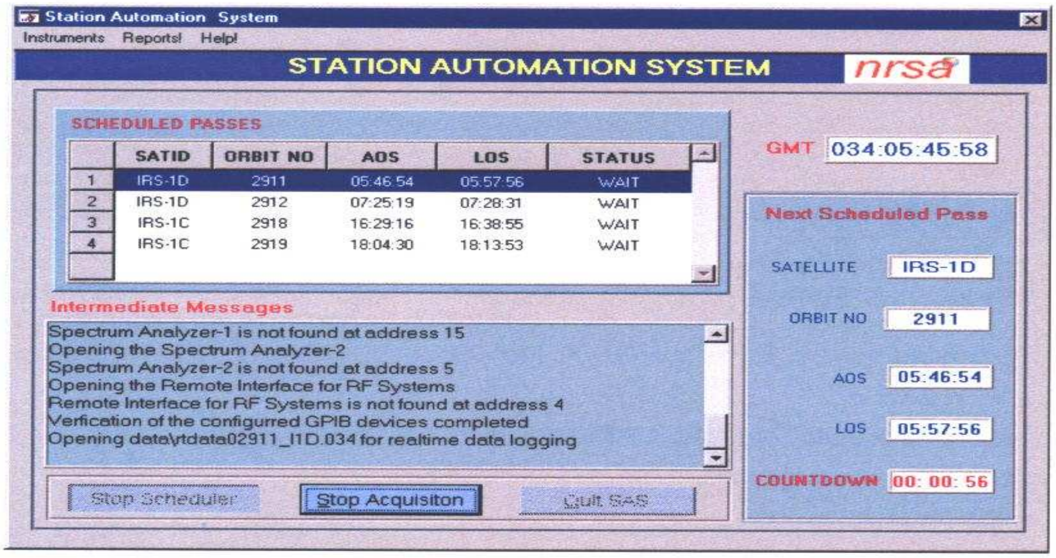


Fig.6.18 GUI for Data Acquisition

STEP 6 : Scheduling Real-time events :

In the real time panel, the time and AOS countdown will be updated for every timer event till AOS.

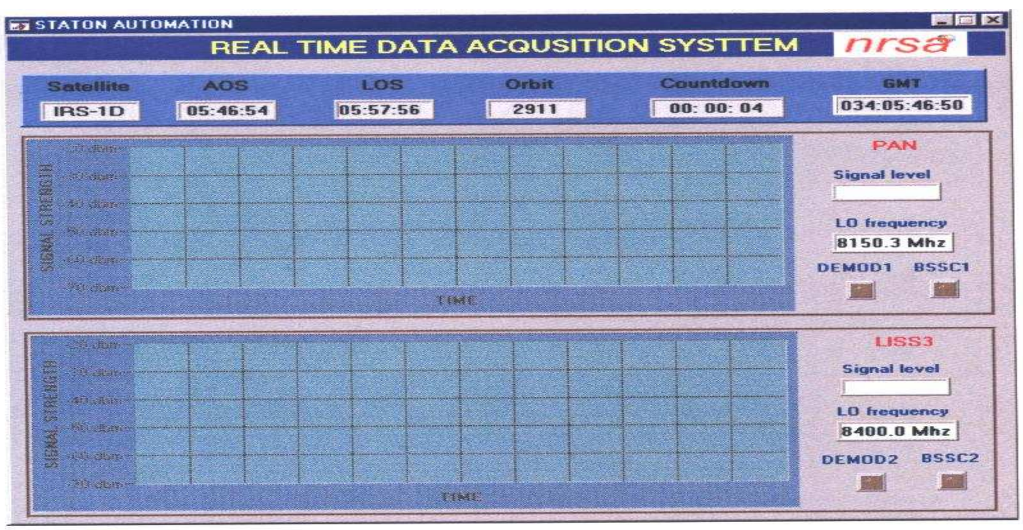


Fig. 6.19 GUI for Realtime events

In this panel, the top and bottom Strip charts corresponds to the Stram-1 and Stream-2 respectively. The DEMOD and BSSC LEDs indicate the lock/loss status.

STEP 7 : Initiating Data logging at AOS :

At exactly AOS, the status will be updated with 'Progress' for the scheduled pass in the 'SCHEDULED PASSES' window of STATUS panel. Then it initiates the realtime data logging.

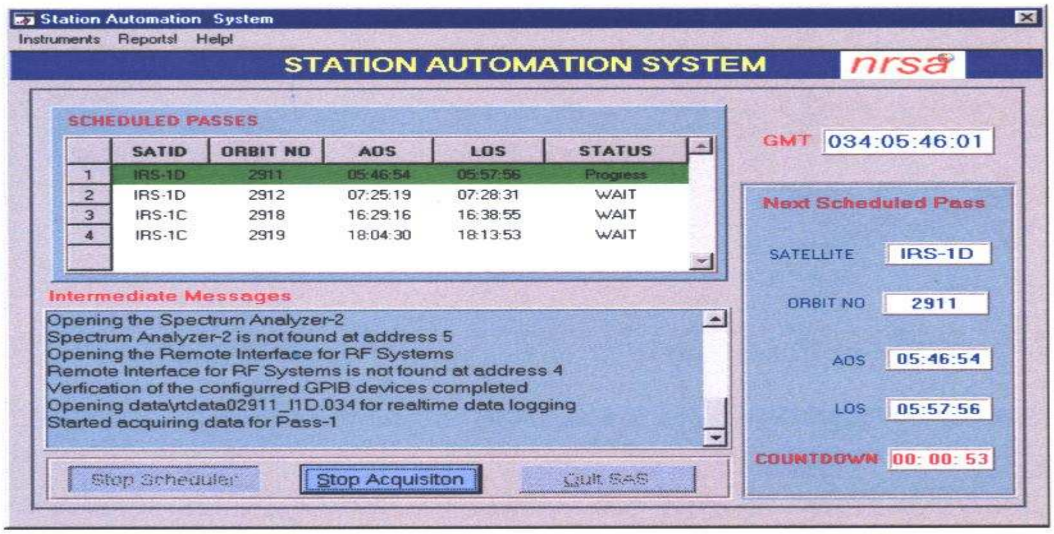


Fig.6.20 GUI for Pass in Progress

STEP 8 : Real time data logging and RT panel updation :

At exactly AOS it starts logging the data from different sub systems and will be stored on to computer system apart from updating the status in the Realtime panel for every timer event based on the System timer. This proves will continue till AOS of the pass.

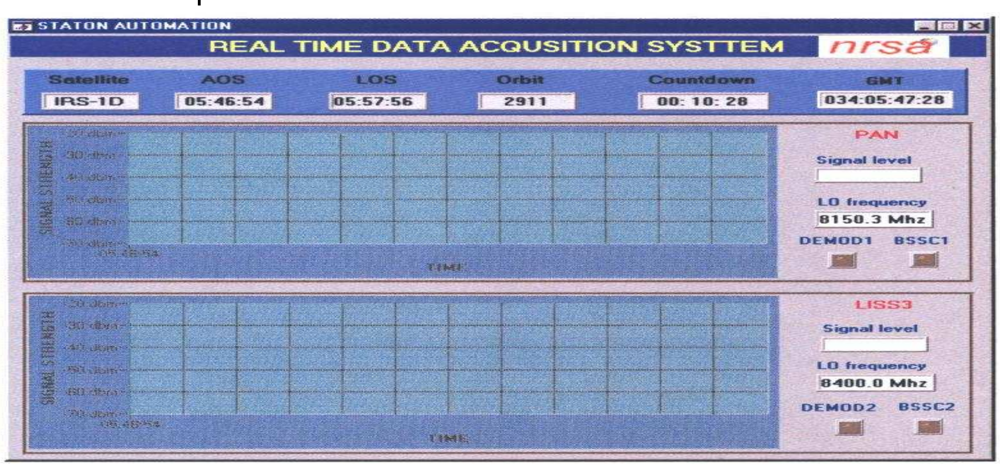


Fig. 6.21 GUI for RT data logging

In each stream there are two Traces. The Red trace indicates the threshold level and Blue trace corresponds to actual signal level. In general the signal trace will be above the threshold level trace, which indicates receive data is good. If the signal trace falls below the threshold trace, which indicates data is bad. Similarly the Red indication on any LED indicates loss condition and Green indicates Lock condition. In this manner the process will continue till LOS of the pass.

STEP 9 : Scheduling next immediate pass :

After the LOS, it immediately goes to schedule the next pass. STEP2 to STEP7 will be repeated.

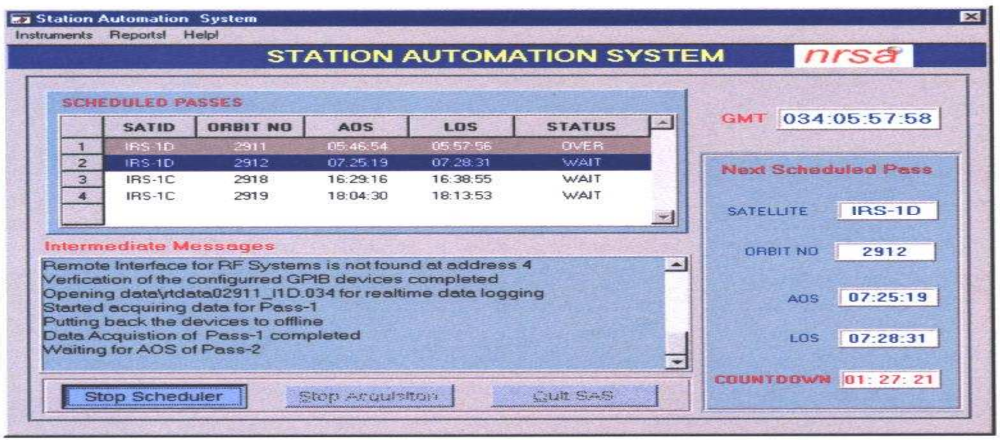


Fig. 6.22 Scheduling of next Pass

In this manner, all the scheduled passes will be completed. After the completion of the last pass the scheduler will exit automatically.

6.5.2 Utilities :

The Utilities provided by the STATUS are invoked from STATUS Panel. The first window after the Title bar is the Menu. It has got three menus namely Instruments, Reports and Help. All these utilities are standalone utilities it does not send or receive any information from the Scheduler.

6.5.2.1 Data Path Controller :

The DPC utility is invoked from Instruments menu of STATUS Panel. It has got three windows namely Status, Selections and Command Window. The status window displays the current configuration of the DPC. The Selections window provides the user to select port configurations for each port of DPC independently. The command allows the user to give different commands .There are four commands Config, Default, Status and Generic/Custom. The description of each is given below

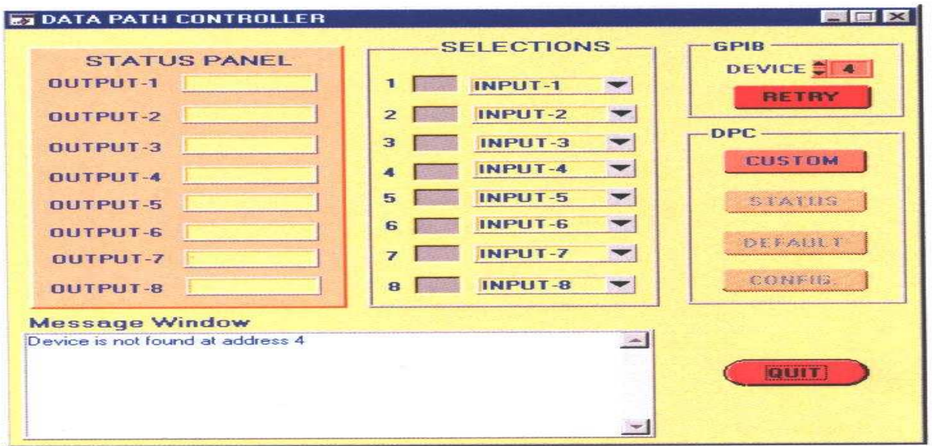


Fig.6.23 GUI for DPC Ports Configuration

a. Port Configuration

Whenever user wants to configure a particular port, one has to select the input source from the appropriate 'List Box' from selection window. Immediately after selection a "Tick mark" will appear in the check box adjacent to it, which indicates the user that the port is ready for configuration. Later if the user wants to deselect the port for configuration, it can be cancelled simply by clicking on the check box. (The tick mark will disappear). In this manner all the required ports can be selected for configuration. Once the selection is over by clicking the *'Configure'* button all the selected ports (which has got tick mark) will be configured immediately and the updated configuration will appear on the Status window. After the successful configuration the tick mark will disappear automatically.

b. **Default Configuration** :

Whenever 'Default' button is clicked it loads the default configuration in the 'selection' window. It also Prompt the user through a Confirmation Popup 'Do you want to configure DPC to Default?'. Then the user has to press 'Yes' button on the Popup window to configure DPC after looking at the default configuration otherwise press 'No' button to abort the operation.

c. Get Status

By exercising this option, it reads the configuration port configuration from DPC and updates the status on Status Window.

d. **Generic/Custom**:

It displays the DPC configuration either in Generic or in Custom option. In Generic mode, by default all the input ports are displayed as Input 1, Input 2 etc., and the output ports are displayed as Output-1, Output-2 etc. In Custom mode, all the DPC ports are displayed with appropriate labels. This Custom information is available in the form of a file that has been generated from DPC Labels Utility.

6.5.2.2 Time Code Translator

The Time Code Translator utility is invoked from Instruments menu of STATUS Panel. Again it has got an option to select NRSA TCT & Datum TCT.Initially it checks for the GPIB interface and TCT unit. Once it is identified it starts reading the Time and updating time in Time Window on TCT panel for every one second.

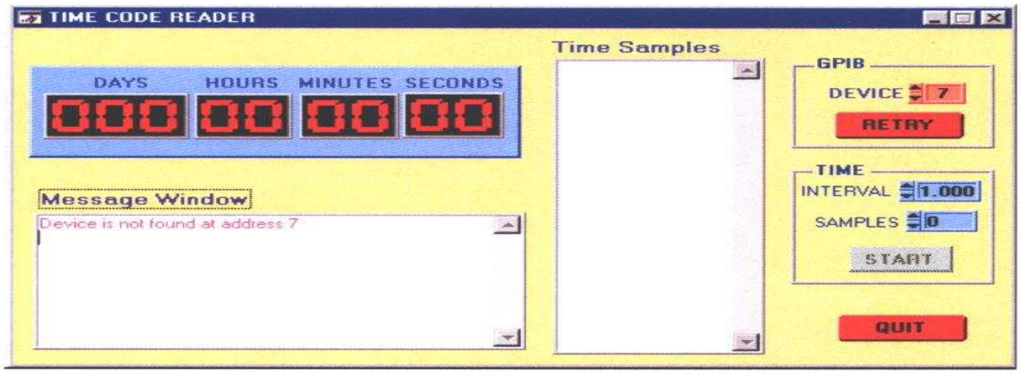


Fig. 6.24 GUI for Status Panel of Time

Apart from this, it also reads the time upto 1/10th of msec for a specified no. of samples with a given time interval. By default the Interval window show 1.000 seconds and samples window show no. of samples as 0. After the selection of both, press the 'Start' button to start reading the time for a given no. of samples. All the device/interface errors that will come across during time read are reported in the intermediate message window..

6.5.2.3 RF Chain

The RF chain utility is invoked from Instruments menu of STATUS Panel. After invoking the utility it checks for the presence of the unit. If the unit is available it reads the status and updates in the status panel. Each LED has got three states. The Green colour indicates lock condition, Red colour indicates loss condition and Grey colour indicates unit is powered OFF. The status gets updated at regular intervals based on the system timer. Apart from this it has got one more command button to get the status 'Get Status', which reads and updates the status immediately.

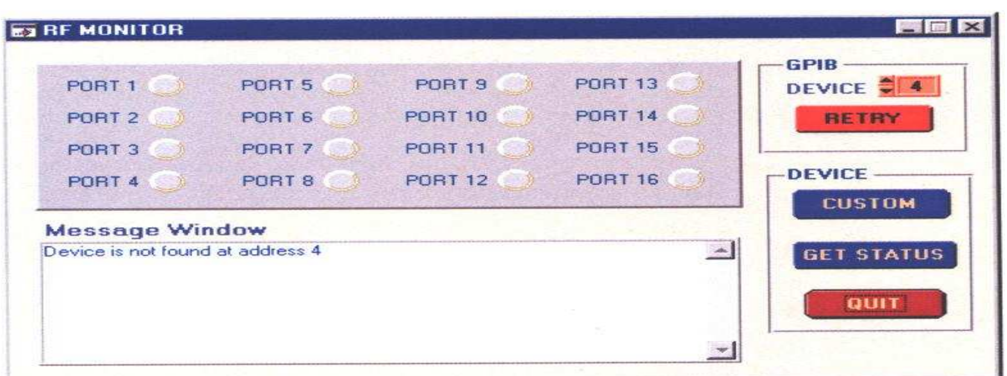


Fig. 6.25 GUI for RF System Status Monitoring

6.5.2.4 Down Converter

The Down Converter Utility is invoked from Instruments menu of STATUS Panel. All the sensor/satellite frequencies are already programmed so the user need not remember the actual LO frequencies. The Selection window has got a provision to select the LO frequency of each channel of down converter separately. If you want to program any frequency other than Standard sensors/satellite, user has to select 'Custom' option so that user can enter the required frequency in the frequency window.

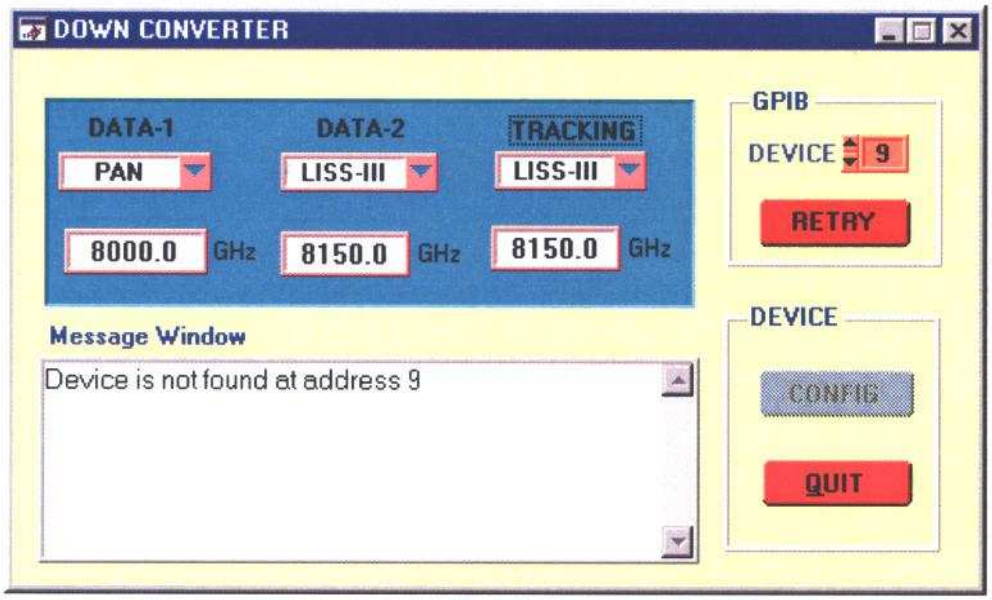


Fig.6.26 GUI for Down Converter LO Freq. Selection

Whenever the user changes the frequency, the corresponding window changes to green color, which indicates the user the new frequency is about to be programmed. Whenever the 'Config' key is pressed the modified channels, which are displayed in green color will be programmed. After the successful completion the sensor window turns to white color.

6.5.2.5 Satellite Data Simulator :

The Satellite Data Simulator is invoked from Instruments menu of STATUS Panel. First user has to select the Mode TPG/PRBS. In TPG mode once again user has to select Satellite ID from the satellite window. Now based on the mode selection the user has to select the stream and pattern. The selected FS error is applicable to both the streams. The N value is valid only in L-IV MX stream. Like any other utility, by clicking the 'Config' button the unit will be programmed. The function of the default button is to load and configure the default frequency.

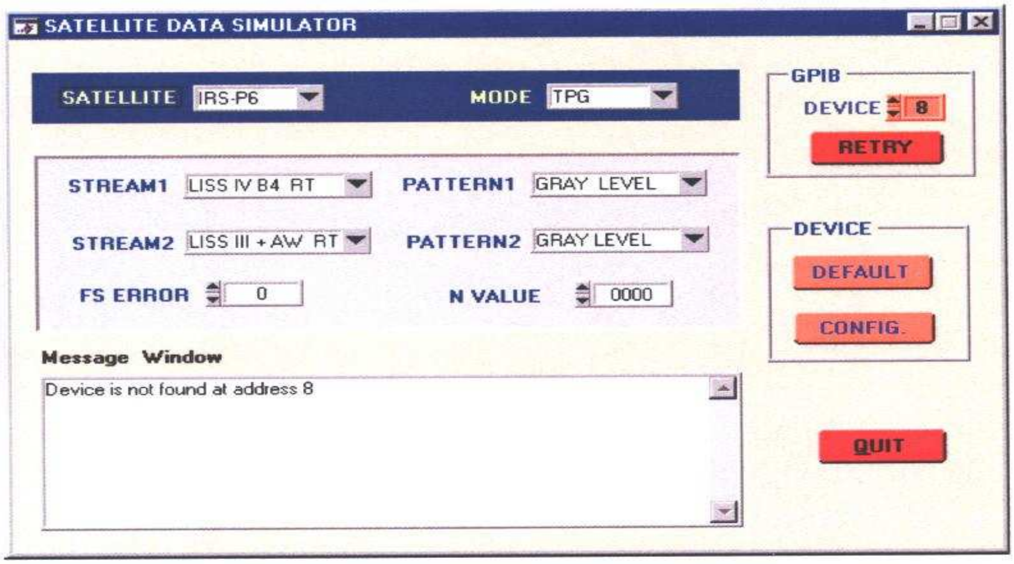


Fig.6.27 GUI for Data Simulator Configuration

6.5.2.5 **Bit Error Rate Test System** :

The Bit Error Rate Test System utility is involved from Instruments menu of STATUS Panel. The different parameters of Clock Source, Data Generator and Reader are selected through a Combo Box. With the mouse click on 'config' button the unit will be programmed to the required configuration.

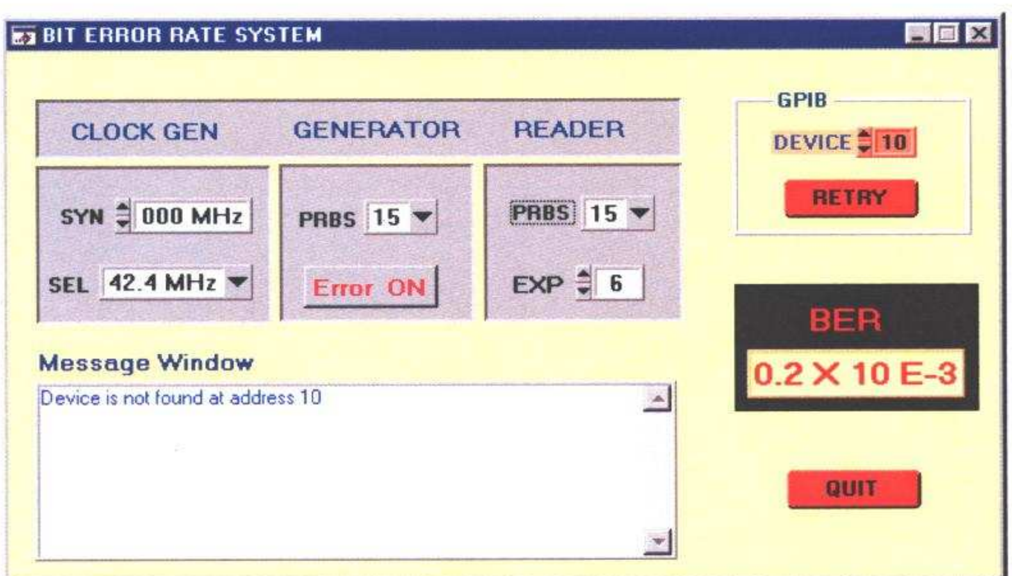


Fig.6.28 GUI for BERT Configuration

6.5.2.7 Programmable Defaults :

The main function of the utility is to modify the default configuration for DPC as per the requirement. The utility is invoked from Instruments menu of STATUS Panel. It immediately loads and displays the existing default configuration.

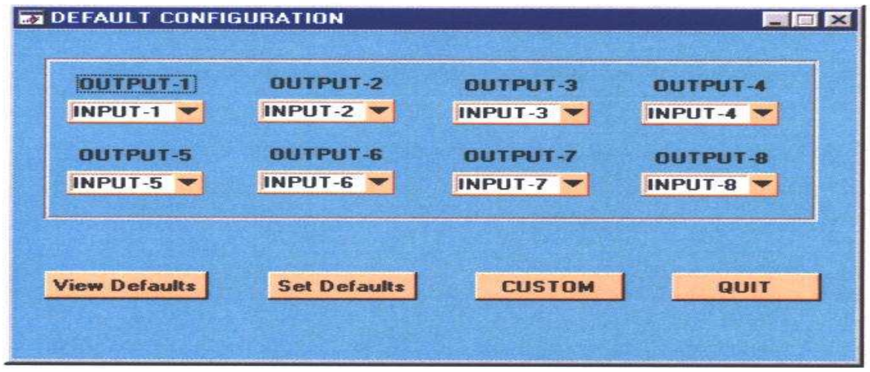


Fig.6.29 GUI for DPC Programmable Defaults

It has got four buttons View Defaults, Set Defaults, Generic/Custom and Quit. The function of each button is given below:

a. View Defaults: It loads and display the default configuration
b. Set Defaults: Saves the default configuration
c. Generic/Custom: Displays the labels either in Generic or Custom mode
d. Quit: Exits the User Interface

6.5.2.8 DPC Port map :

The utility is involved from Instruments menu of STATUS Panel. It immediately loads and displays the existing default configuration. The main function of the utility is to modify the default configuration for DPC as per the requirement.

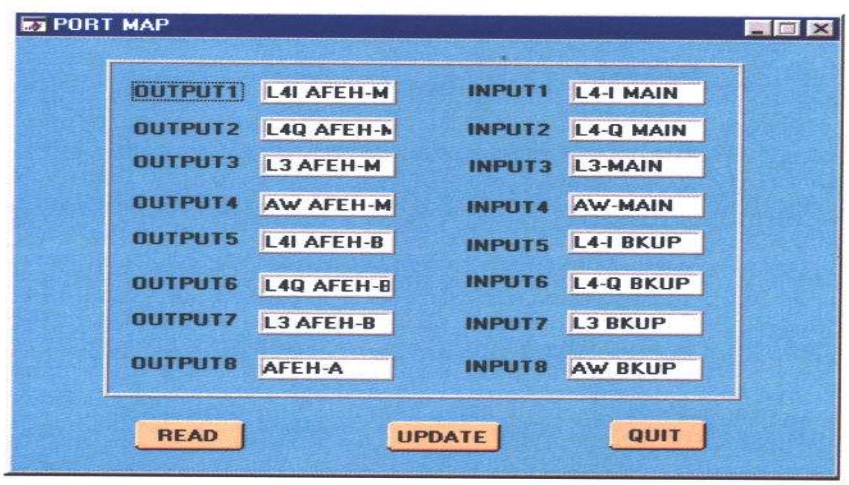


Fig.6.30 GUI for DPC Port Map

It has got three buttons Read, Update and Quit. The function of each button is given below:

a. Read/Load: It loads and displays the default configuration
b. Save: Saves the default configuration
c. Quit: Exit the user interface.

6.6 Reception Information and Report Generation System (RIRGS) [84]

6.6.1 Introduction

The realtime satellite signal strengths are recorded in the system with reference to UTC for each satellite pass by the Station Automation System for both S and X bands as per the availability. Sample file format is as follows:

Sat ID: P6 Date : Sat, Mar 05, 2005

Time	L-3 (dBm)	L-4 (dBm)
05 03 49	-63.21	-62.96
05 03 50	-64.35	-63.22
05 03 51	-63.97	-63.02
05 03 52	-61.34	-63.47
05 03 53	-62.47	-62.58
05 03 54	-64.76	-62.26
05 03 55	-63.25	-62.06
05 03 56	-62.87	-61.59
05 03 57	-64.19	-64.33
05 03 58	-62.80	-62.19
05 03 59	-63.54	-62.05
05 04 00	-61.76	-62.43
05 04 01	-62.75	-62.34
05 04 02	-63.93	-62.18
05 04 03	-63.63	-62.17
05 04 04	-62.65	-61.72
05 04 05	-62.98	-63.55
05 04 06	-63.58	-63.86
05 04 07	-62.25	-63.22
05 04 08	-63.10	-62.61
05 04 09	-61.37	-61.75
05 04 10	-64.62	-62.56
05 04 11	-64.62	-62.91

6.6.2 Software Development

The above information gets stored as a file and the information system handles these files to generate the acquired data reports. As a pre-operation, the values recorded in the dat files to be validated for each entry in the files for each pass/satellite. Post operation of this validation includes (a) storing this data in a format in a data base (b) generation of signal strength graphs with respect to UTC (c) generation of Signal Strength graphs with respect to Az and. El.

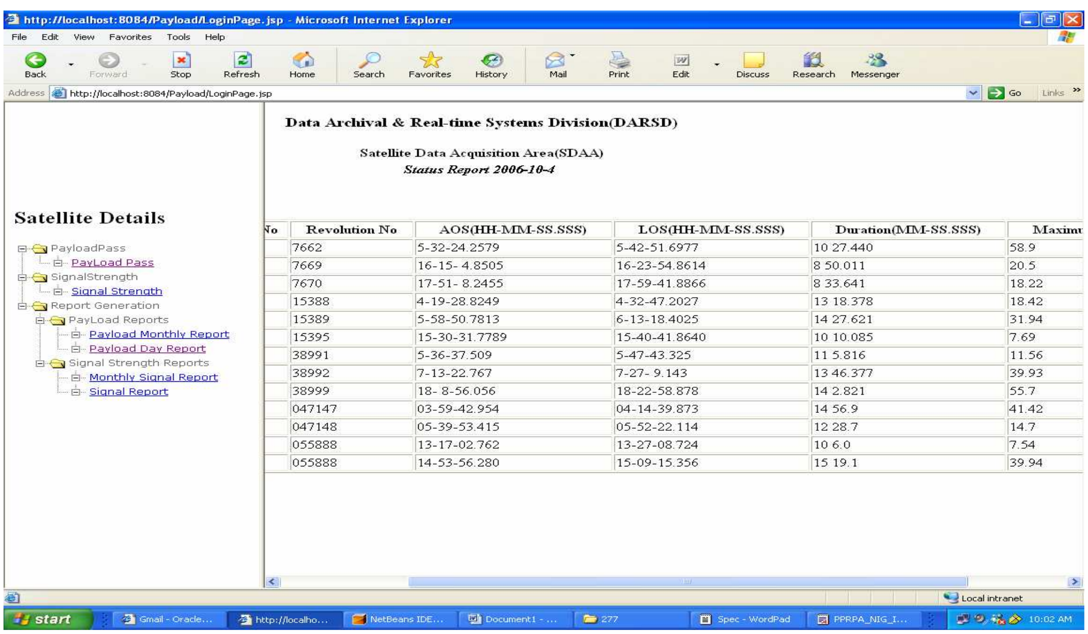
As the information is stored in data bases, the system also helps to generate the monthly reports etc., as per the satellite/requirement.

Therefore this software has 3 different modules depending on the operations performed.

1. Payload Passes Status
2. Signal Strength Status
3. Report Generation

6.6.2.1 <u>Payload Passes Status</u>

The information is extracted from the pre pass planning reports derived from satellite state vectors. The information contains date of pass, sat ID, orbit no, path no, AOS time, LOS time pass duration and maximum elevation. The data is stored in this format and a sample is given below.



No	Revolution No	AOS(HH-MM-SS.SSS)	LOS(HH-MM-SS.SSS)	Duration(MM-SS.SSS)	Maximu
	7662	5-32-24.2579	5-42-51.6977	10 27.440	58.9
	7669	16-15- 4.8505	16-23-54.8614	8 50.011	20.5
	7670	17-51- 8.2455	17-59-41.8866	8 33.641	18.22
	15388	4-19-28.8249	4-32-47.2027	13 18.378	18.42
	15389	5-58-50.7813	6-13-18.4025	14 27.621	31.94
	15395	15-30-31.7789	15-40-41.8640	10 10.085	7.69
	38991	5-36-37.509	5-47-43.325	11 5.816	11.56
	38992	7-13-22.767	7-27- 9.143	13 46.377	39.93
	38999	18- 8-56.056	18-22-58.878	14 2.821	55.7
	047147	03-59-42.954	04-14-39.873	14 56.9	41.42
	047148	05-39-53.415	05-52-22.114	12 28.7	14.7
	055888	13-17-02.762	13-27-08.724	10 6.0	7.54
	055888	14-53-56.280	15-09-15.356	15 19.1	39.94

Fig.6.31 GUI for Payload Pass Status

6.6.2.2 Signal Strength Status:

This module deals with Uploading of Signal Strength dat file to the database

Functional Description:

Step1: validating x-band and s-band values of the Signal Strength dat files

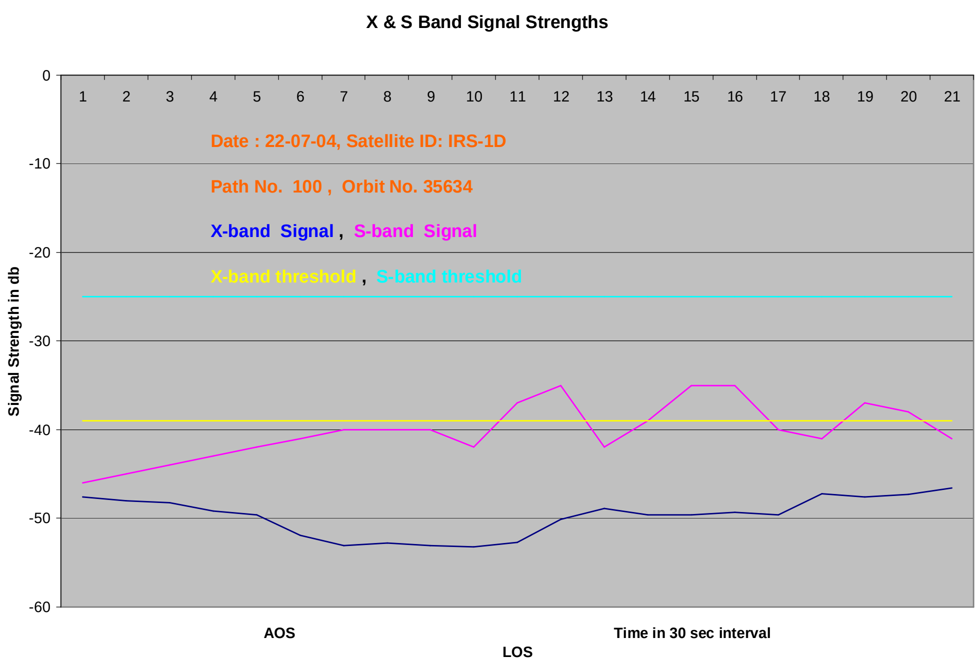
Step2: Storing the necessary Information(sat id ,date ,path no ,orbit no/revolution no ,path no.. signal strength etc.,) from the dat files into the xml file .

Step3: Generation of Graphs using SVG Technologies

Step4**:**Converting .svg files to .jpeg file using Batik Processor

Step5**:** Storing The Necessary Status Reports along with graphs(.jpeg) into Portable Document Files(PDF) which is mailed to the clients as an attachment The sample graph is as follows.

PLOT :6.32



6.6.2.3 **Report Generation:**

This Module deals with Daily and Monthly Reports.

In Generating Date Reports ,User Selected date is validated and the corresponding reports are generated by retrieving the values from the database on the selected date. Similarly Monthly Reports are retrieved from database on the selected To and From dates. GUI is as follows.

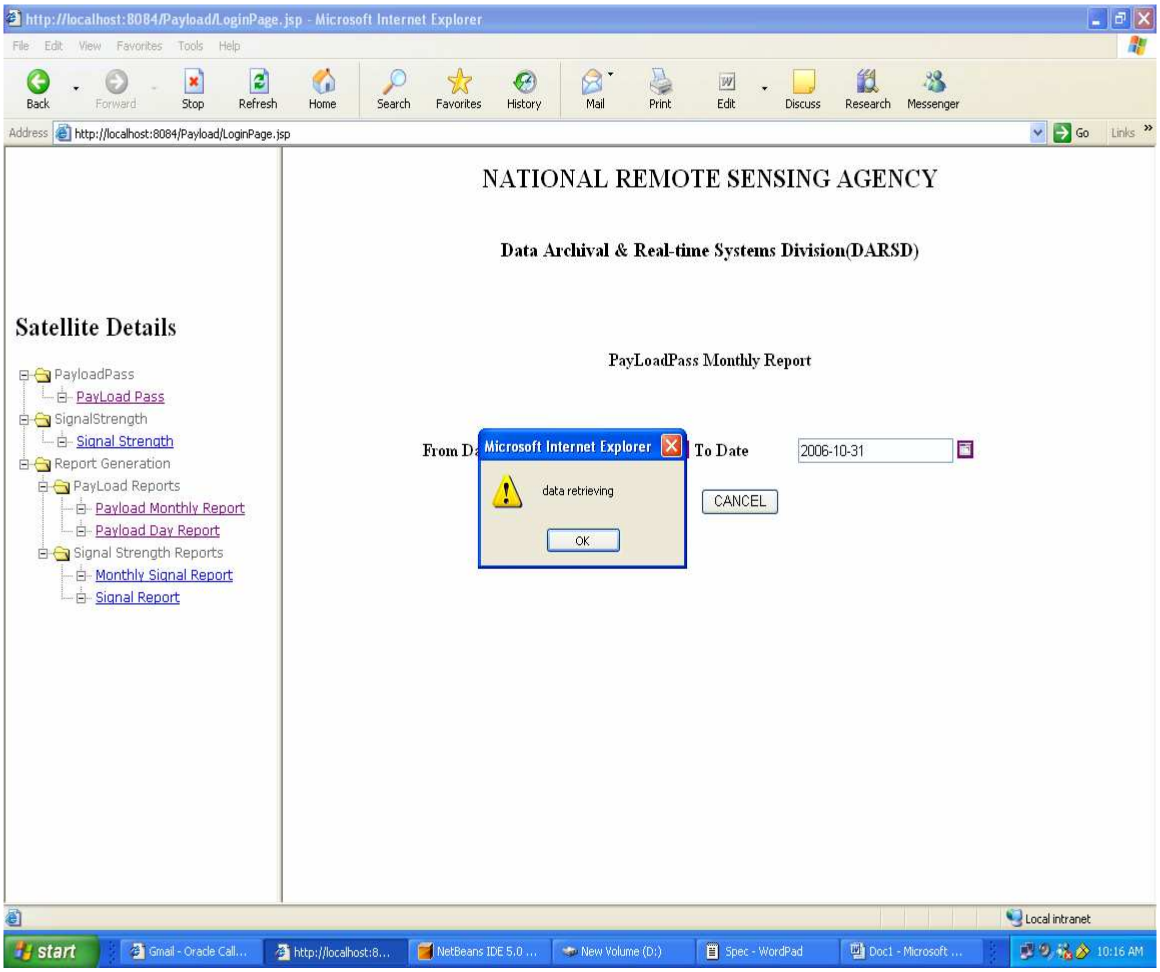
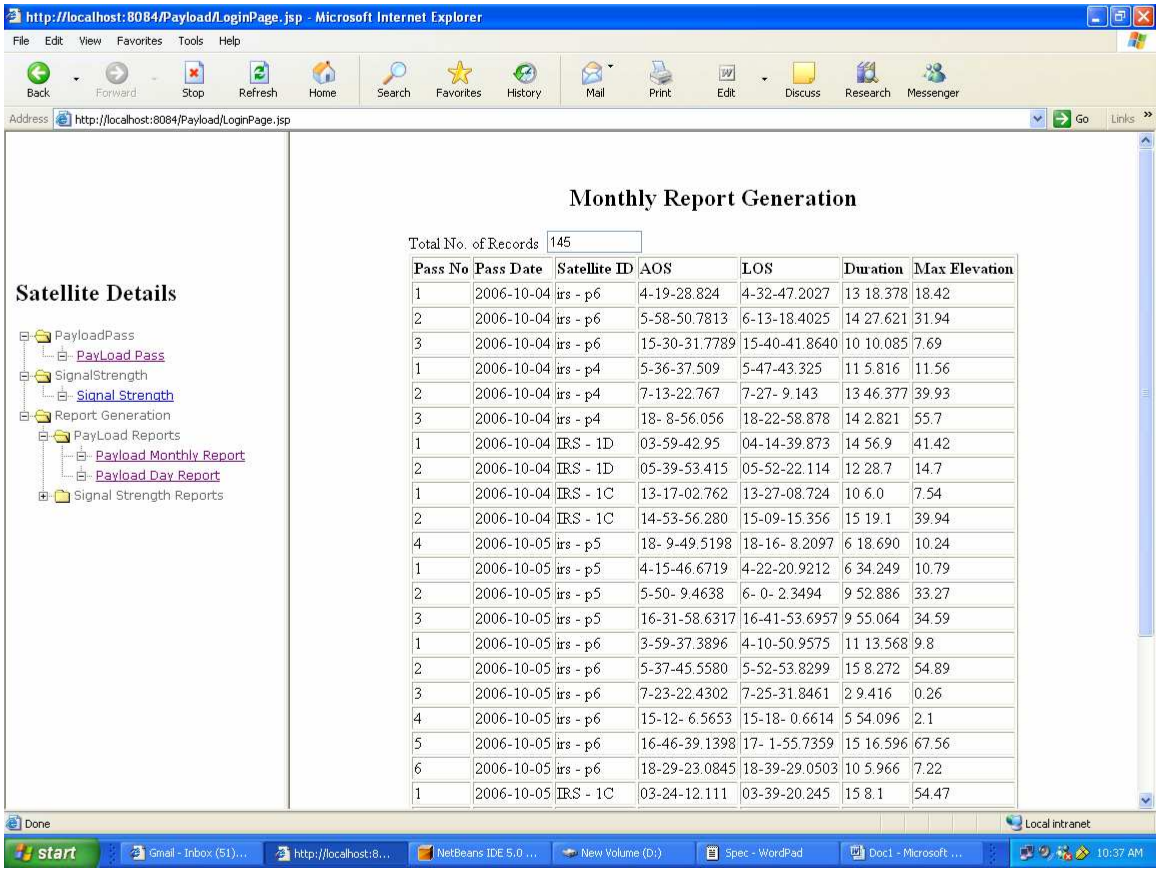


Fig. 6.33 GUI for Payload Passes Monthly Report



Pass No	Pass Date	Satellite ID	AOS	LOS	Duration	Max Elevation
1	2006-10-04	irs - p6	4-19-28.824	4-32-47.2027	13 18.378	18.42
2	2006-10-04	irs - p6	5-58-50.7813	6-13-18.4025	14 27.621	31.94
3	2006-10-04	irs - p6	15-30-31.7789	15-40-41.8640	10 10.085	7.69
1	2006-10-04	irs - p4	5-36-37.509	5-47-43.325	11 5.816	11.56
2	2006-10-04	irs - p4	7-13-22.767	7-27- 9.143	13 46.377	39.93
3	2006-10-04	irs - p4	18- 8-56.056	18-22-58.878	14 2.821	55.7
1	2006-10-04	IRS - 1D	03-59-42.95	04-14-39.873	14 56.9	41.42
2	2006-10-04	IRS - 1D	05-39-53.415	05-52-22.114	12 28.7	14.7
1	2006-10-04	IRS - 1C	13-17-02.762	13-27-08.724	10 6.0	7.54
2	2006-10-04	IRS - 1C	14-53-56.280	15-09-15.356	15 19.1	39.94
4	2006-10-05	irs - p5	18- 9-49.5198	18-16- 8.2097	6 18.690	10.24
1	2006-10-05	irs - p5	4-15-46.6719	4-22-20.9212	6 34.249	10.79
2	2006-10-05	irs - p5	5-50- 9.4638	6- 0- 2.3494	9 52.886	33.27
3	2006-10-05	irs - p5	16-31-58.6317	16-41-53.6957	9 55.064	34.59
1	2006-10-05	irs - p6	3-59-37.3896	4-10-50.9575	11 13.568	9.8
2	2006-10-05	irs - p6	5-37-45.5580	5-52-53.8299	15 8.272	54.89
3	2006-10-05	irs - p6	7-23-22.4302	7-25-31.8461	2 9.416	0.26
4	2006-10-05	irs - p6	15-12- 6.5653	15-18- 0.6614	5 54.096	2.1
5	2006-10-05	irs - p6	16-46-39.1398	17- 1-55.7359	15 16.596	67.56
6	2006-10-05	irs - p6	18-29-23.0845	18-39-29.0503	10 5.966	7.22
1	2006-10-05	IRS - 1C	03-24-12.111	03-39-20.245	15 8.1	54.47

Fig.6.34 GUI for Monthly Report

6.7 Conclusion

The station automation is the primary issue to reduce human subjectivity. This could be fulfilled by redesigning all the equipments and its interfaces through the configurable hardware's and softwares using the derived system behavior models. This called for extensive hardware and software developments while going through the revolutionary concepts of process automation. The system was designed and implemented as a sample in Delhi and improved for error-free operations and management. Subsequently the system was also supplied to international users under Indian Remote Sensing Program for the International Ground Station through Antrix Corporation of the Department of Space. Finally it has resulted as reliable software for the remote sensing community in the globe.

Chapter- 7

Realtime Data Acquisition Information System for Remote Sensing Satellites

Abstract

Remote Sensing Satellite data Acquisition Systems acquire the data in real time from the sun synchronous low earth polar orbiting satellites during the period of visibility. As the functions are extremely complex for this process, it is necessary to have an information system covering the above processes catering to the status information, mission parameters, satellite orbital information, attitude information, data quality etc., to enable the satellite controllers, operators and users to have access to the above parameters for the necessary processing. As these mechanisms are required on the operational basis in the Indian Remote Sensing Satellite programmes, the authors have developed and oparationalised information system for the real time data acquisition and referred as “Level-‘0’ ” information system in software documentation. This is a server based web enabled system providing the databases for all the status of parameters of the Indian Remote Sensing Satellite missions on daily basis. The system is developed around the client/Server environment. The server program contains the basic logics for the databases generation and management. The client program caters to all the functional requirements of the information system, with appropriate GUI’s for the user interaction and inputs for uploading the server and processor. Specific design techniques were used for the optimization of the load on server and the client. The software developed is operational and working error free. The software is updated every time when a new remote sensing satellite is added. The system also caters to several automatic reporting mechanisms such as status reports at regular intervals, error diagnosis, corrective mechanisms etc., The system not only extracts and generates the data bases to provide national archives for all the satellite missions in a automatic matter with the least manual interaction. The system is an in-house development and operational for all the Indian Remote Sensing Satellite Programmes at NRSA Department of Space and then to foreign satellites.

7.1 Introduction

Remote sensing Satellites are of the class low earth, sun synchronous and polar orbiting satellites. They are visible to the ground station tracking the same about 10 –15 minutes in a given orbit. The satellites will be serving the user imaging requirements in different orbits globally as per the visibilities. The imaging requirements beyond a given users coverage can get handled through Onboard Solid state recorders. During the period of visibility of a given ground station, the imaging data from the satellite get transmitted to the ground station and therefore the short visibility periods are very important and the systems are required to demonstrate 100% availability and efficiency on 24/7 basis throughout. The status of all the systems, satellite parameters including the imaging details is an important task for diagnosis, corrective mechanism and processing the data. The volume of the data handled per day is upto a TB and the turn around time for handling the data to meet the disaster requirements is expected to be realtime, therefore the process requires the development of system generated Information data bases and the associated reporting mechanisms in an automatic manner. Hence an automated system was developed along with report generation system and implemented first time in remote sensing community in the world. The chapter deals with the information system that is necessary to handle the real time image data for the above purpose. It is a web-enabled system to cater to the multiple satellite missions and to make it accessible to all the designers in different centers of Department of Space. The real time data acquisition systems handle the raw data from the satellite without changing its status while producing various products. In the remote sensing terminology, the raw data handling is referred as "Level-'0'". Therefore the software, the documentation and the associated GUIs reflect the term "Level-0".

In the Client/Server configuration, the server is connected to all Direct Archival & Quick Look Browse (DAQLB) systems for raw data ingest of Remote Sensing Satellites. There are more than ten DAQLB systems to support IRS series Satellites staring from IRS-P3 to Cartosat-1. The server side program contains the basic logic for Database management and the Client side program caters for pre processing of user inputs before uploading to Server. Data Extraction module is developed to process the Ancillary Data Information (ADIF) to extract information related to Acquisition of Satellite, Loss of Satellite, Data on/off & other relevant pass information, orbital information will be used by the server program as base data for the given date of operation. This software has been augmented with utilities such as Monthly progress, Weekly progress reports, sorting based on problems, etc as derivatives.

The level-0 report generation software generates level-0 daily operational reports for IRS, ERS, and LANDSAT Missions. The Data Extraction module will extract the necessary information from the output files (i.e. ADIF summary file, pre-pass planner report file, MDID file, Sharp Summary file) automatically. This extracted information (i.e. extracted variables) will be appended to an HTML file for all the IRS Satellites for the given date of pass.

The information in the HTML file will be exported to the java Web Server through the session. The session variables are validated and, collected by the individual java script programs running in the java web server. These scripts will extract the information and put that data into the ORACLE database using SQL queries. The data in database can be modified, deleted or inserted using the Graphic user interface developed in HTML forms. The data stored in the database can used for future use.

The Level-0 information system basically provides the following system functionality information extracted and processed.

- Multiple reports formatting and archival as detailed.
- Make the report available on online
- Online access to the database for accessing old reports

- Dissemination of the reports to the specified destination
- Periodical status report generation

7.2 **Basic Design Approach**

The software package can be divided into three components.

1. Data Extraction
2. Server processing
3. Client processing

7.2.1 Data Extraction: This module is coded in c++ to extract satellite related information from Ancillary Data from all Satellite data acquisition workstations. The workstations are programmed to acquire payload & ancillary data from Indian Remote sensing series of satellites. The ancillary data information extracted contains

- Direct archival and quick look system Ids.
- Date of acquisition of pass (satellite visibility /orbit)
- Pass information and orbit & scene information for all sensors & satellites
- Satellite/Sensor specific attitude data, data quality information and browse information
- Histogram data of all sensors

The module creates an HTML file containing the information extracted as above, and exports this data to java web server through a session.

The Ancillary Data Information (ADIF) gets generated on Direct Archival system configured around higher end workstations. The data is collected on different workstations in real time, and ADIF is generated as end product.

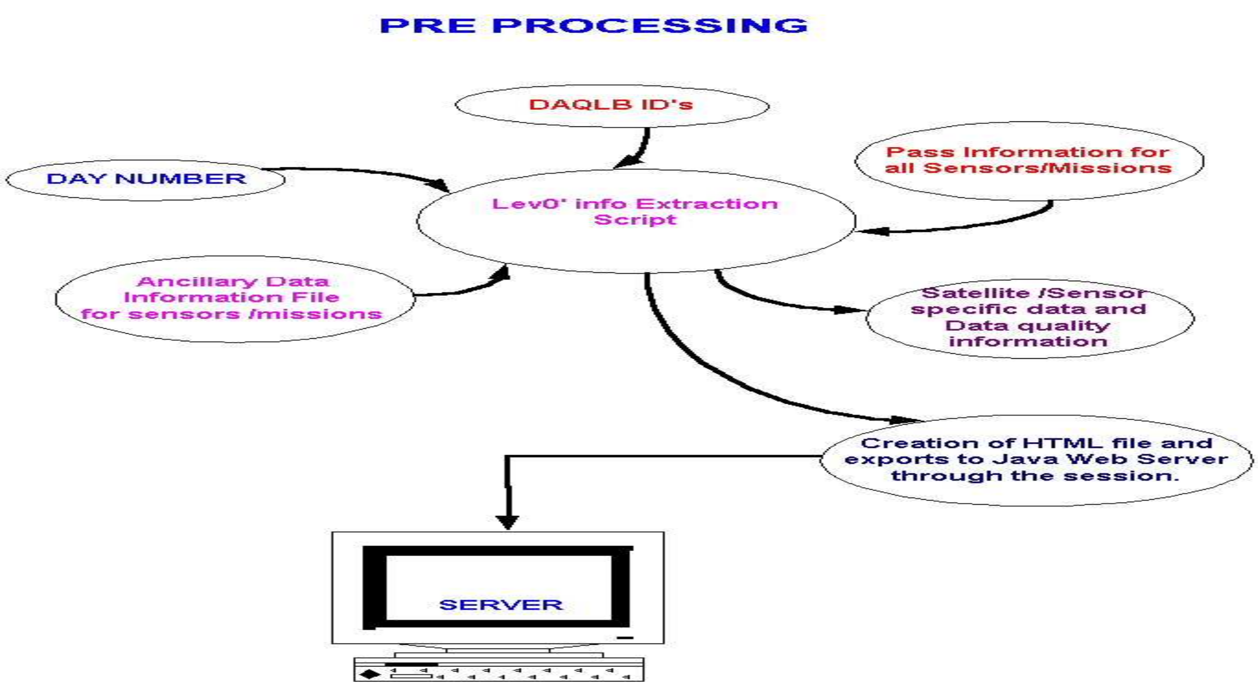


Fig.7.1 RADIS – Preprocessing

7.2.2 Server Processing: This module is coded in Java Server pages (JSP) and HTML forms. This module takes information of all satellites /Sensors from the HTML file, validate this data and inserts into the ORACLE Database using SQL queries and JSP scripts automatically. This module apart from automatic updation, it provides facility to add information about satellite or sensor, which are not covered/not completed in automatic updation.
The information such as

- Station readiness through simulated process sensor/satellite wise
- Network transfers
- Pending products
- Product generated
- Hardware and software status
- Data quality information
- Operational information

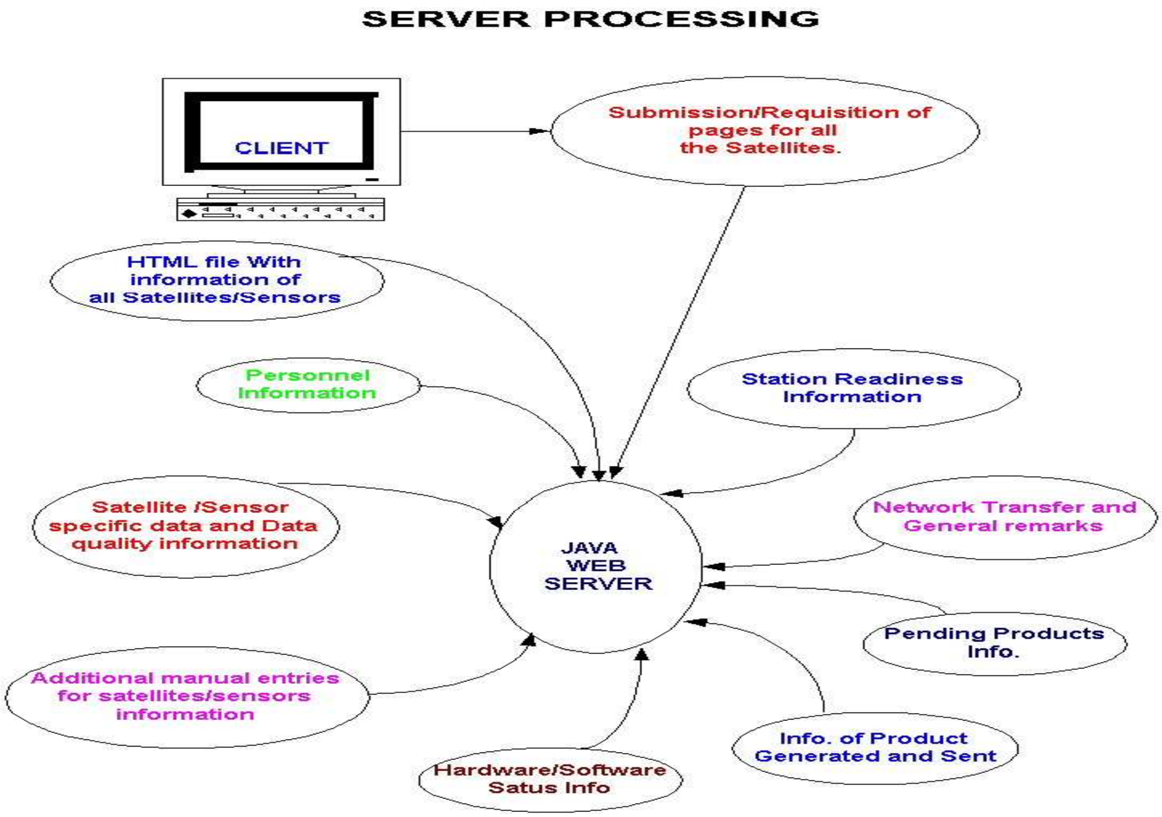


Fig.7.2 RADIS Server Processing

7.2.3 Client processing: This module coded in java server pages (JSP) and HTML form. This module takes initializes the page variables, Defines necessary functions and submits the client pages to the server

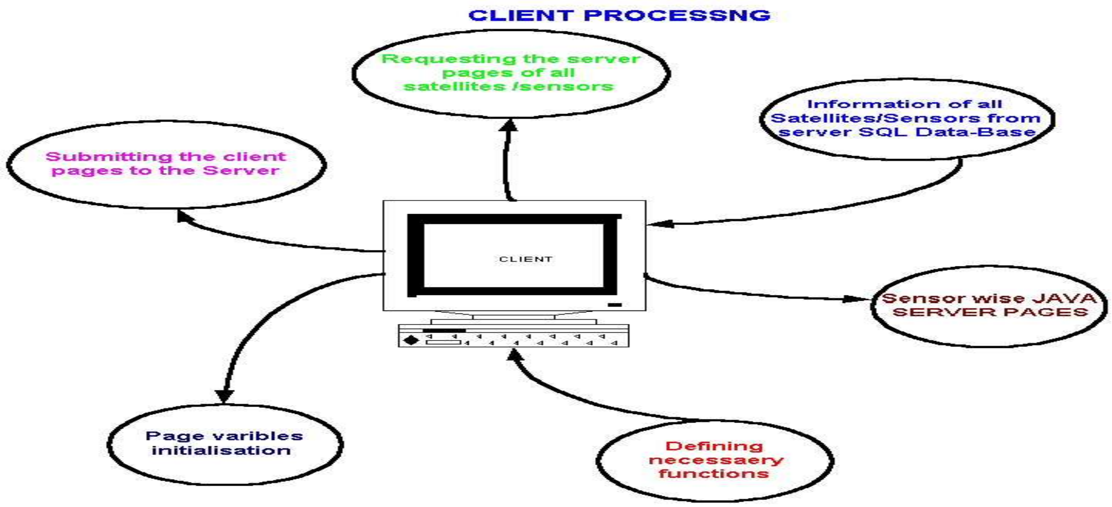


Fig.8.3 RADIS Client Processing

7.3 Functionality

Data flow diagram for Data extraction
Functional description: This module process the ADIF from all IRS satellites like IRS-1C, 1D, P3, P4, P5,P6,C2 and TES. And extract relevant pass information fields, which are important for future reference in database. The extracted information is for the given date of pass.

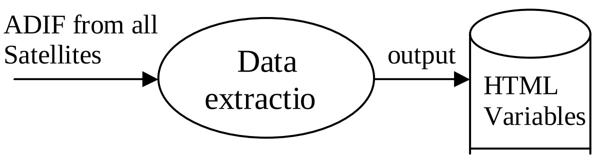


Fig.7.4

Inputs: Ancillary data information from all satellites

Outputs: Data variables available in HTML form

Data flow diagram for exporting data to web server
Functional description:_ The extracted variables will be put into the Java web server-using HTML through the browser post method by the client computer system.

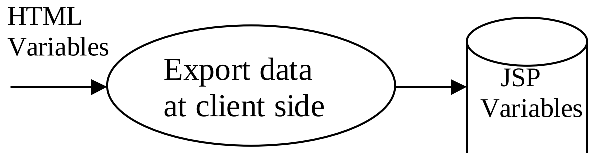


Fig.7.5

Inputs: Data information available in HTML
Outputs: Data variables available in JSP form

Data flow diagram for user authentication

Functional description:_ The Java Web Server will extract data posted by the client Browser. Java script developed at the server side, which takes username and password and date of pass and validate the user authentication. The HTML variables converted into JSP variables, will be extracted by the various JAVA scripts for different satellites and inserted into the ORACLE database using several SQL queries. The inserted data in the database can be modified, deleted and updated at any point of time using GUI based java scripts.

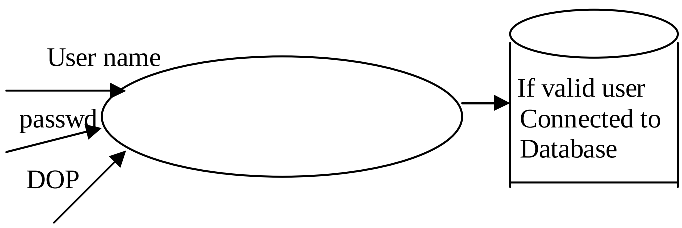


Fig.7.6

Inputs: Username, Password, Date of pass

Outputs: Access to database

Data flow diagram for updating the database:

Functional description: User authentication will be checked validated and the process proceeds further for extraction of session variables into temporary JSP variables for all the satellites. These are unique throughout the application. This data will be validated and updated in the ORACLE database using java script programs and SQL queries.

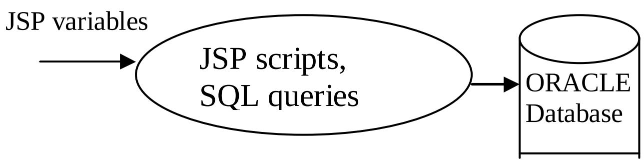


Fig.7.7

Inputs: Data variables available in JSP form

Outputs: Data available ORACLE database

Data flow diagram for user manual entries:

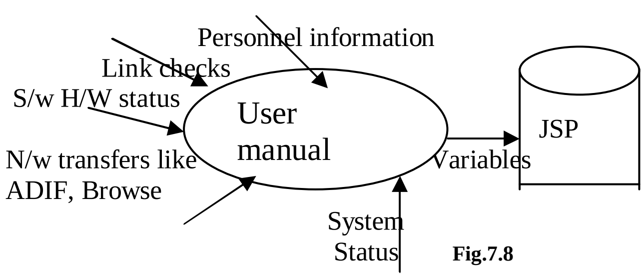


Fig.7.8

Functional description:
There is a provision for some of the information like pre-pass link checks status , and Software / Hardware status for user manual updates.
Inputs: Manual entries for Personnel, link checks, S/w H/w status, N/w transfer status, System status information

Outputs: Data available in ORCALE database
Data flow diagram for client post process:
Functional description: The client will have all requested information for each satellite available in the form of JSP scripts. This output is available in HTML form as well as Text form.

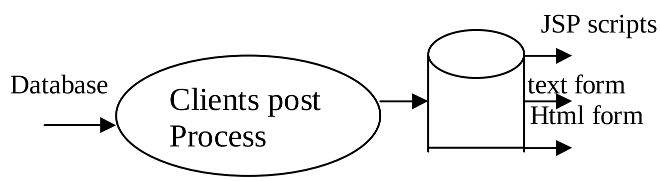


Fig.7.9

Inputs: Data available in ORACLE database

Outputs: Text, HTML documents as output

7.4 Benefits

- Automatic system generated Level-'0' report on daily basis is a novel concept to provide non subjective, error free and dependable information for Satellite Controllers/users by archiving the critical mission parameters for all the satellite missions for each mission life .
- Information pertaining to critical real time data acquisition , status of all the processes can be obtained.
- Problematic analysis of critical parameters like attitude, orbit can be performed
- Quantitative analysis for trouble shooting of system performance can lead to problem solution

7.5 Results

Some of the GUI's generated by this package are given below. There are about 20 GUI's generated to process all the required information and update to database. This is one of the well appreciated reports by all the concerned in the Dept. of Space.

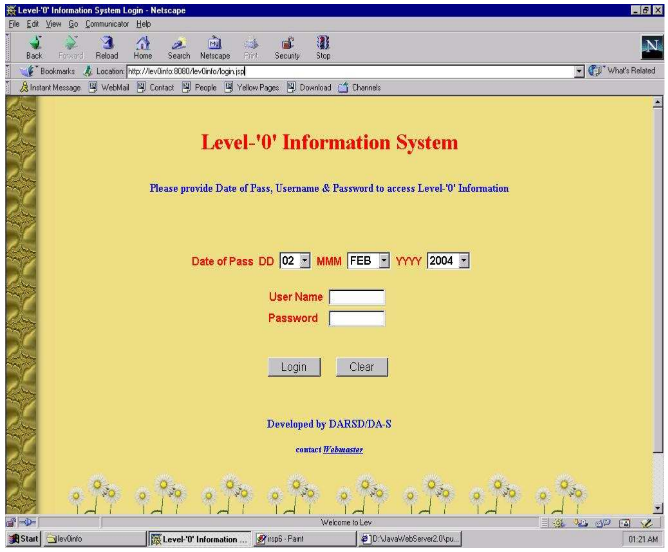


FIG.7.10 GUI for RDAIS Start-up

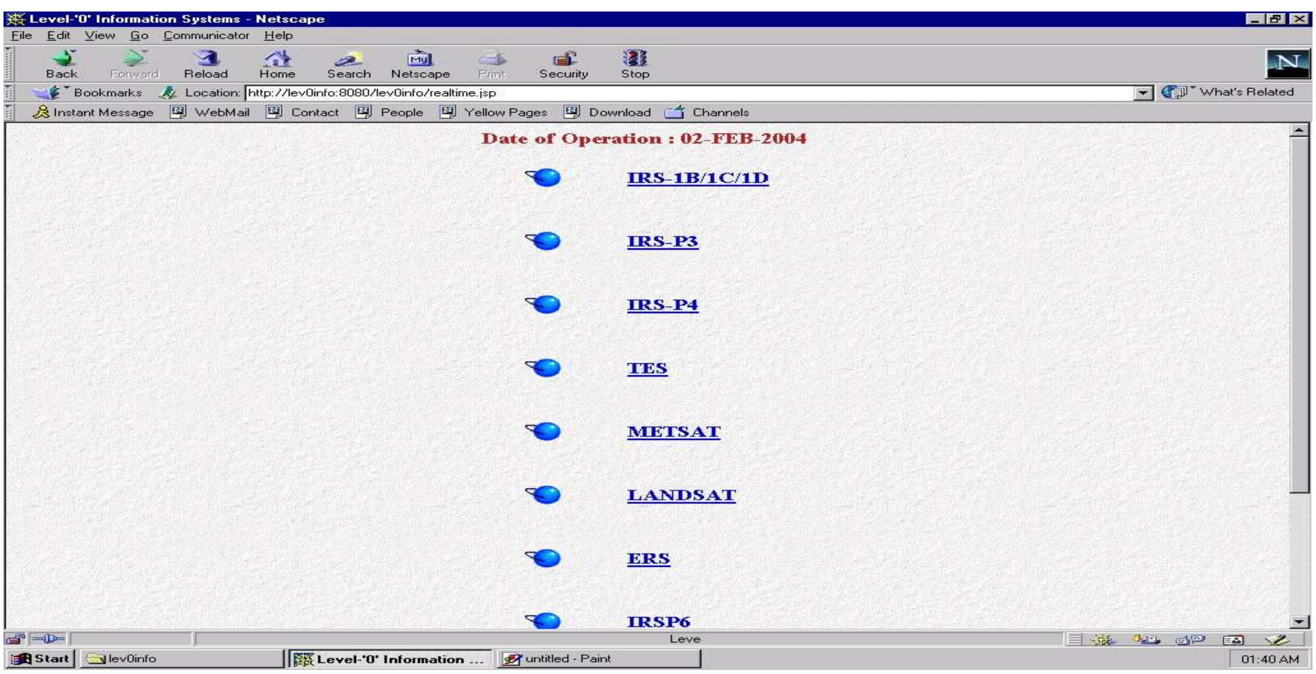


Fig.7.11 GUI for RDAIS Satellite Selection

2. Pre-pass Link Status

Satellite	Sensor	Loop	Terminal	Chain	System	Remarks

3. Passes Supported Information

Satellite	Sensor	Pass Type	Orbit	Path	Config.	Mode	System	Sim.	Row Nos.	Data Qua
IRS-1C	PAN	PAYLOAD	42099	112	T-1/MAIN	RT	DAQLB2	Not Done	44-58	Good da
IRS-1D	LISS-3	PAYLOAD	33256	122	T-1/MAIN	RT	DAQLB1	Not Done	51-75	Near AC
IRS-1D	LISS-3	PAYLOAD	33257	97	T-1/MAIN	RT	DAQLB1	Not Done	38-81	Good da
IRS-1D	PAN	PAYLOAD	33256	122	T-1/MAIN	RT	DAQLB1	Not Done	51-75	Near AC
IRS-1D	PAN	PAYLOAD	33257	97	T-1/MAIN	RT	DAQLB1	Not Done	38-81	Good da
IRS-P4	OCM-RT	PAYLOAD	24912	10	T-1/MAIN	RT	DAQLB3	Not Done	12-14	Good da
IRS-P4	OCM-RT	PAYLOAD	24913	8	T-1/MAIN	RT	DAQLB3	Not Done	13-14	Good da
IRS-P6	L3+AWIFS-PB	SSR	1613	-	T-3/MAIN	PB	DAQLB6	Not Done	-	Good dat
IRS-P6	L3+AWIFS-RT	PAYLOAD	1606	112	T-3/MAIN	RT	DAQLB6	Not Done	-	Good da
IRS-P6	L3+AWIFS-RT	PAYLOAD	1607	88	T-3/MAIN	RT	DAQLB6	Not Done	-	Good da
IRS-P6	L4MN-RT	PAYLOAD	1606	112	T-3/MAIN	RT	DAQLB6	Not Done	-	Good da
IRS-P6	L4MX-RT	PAYLOAD	1607	-	T-3/MAIN	RT	DAQLB6	Not Done	-	Good da

4. Passes NotSupported/Skipped Information

Satellite	Sensor	Pass Type	Orbit	Path	Support Status	Remarks
IRS-1D	LISS-3	PAYLOAD	33258	75	No Support(ARS)	
IRS-1D	PAN	PAYLOAD	33258	75	No Support(ARS)	

FIG.7.12 GUI for RDAIS link and Satellite Information

5. Products Generated & Dispatched

Satellite	Sensor	Media	Product ID	Product Status	Dispatched By	Browse Status	Dispatched By	Re
IRS-1C	PAN	DAY DLT	PC010038	Generated	Spl. vehicle	Generated	Spacenet	
IRS-1D	LISS-3	DAY DLT	LD008038	Generated	Spl. vehicle	Generated	Spacenet	
IRS-1D	PAN	DAY DLT	PD008038	Generated	Spl. vehicle	Generated	Spacenet	
IRS-P4	OCM-RT	DAY DLT	4P006038	Generated	Spl. vehicle	Generated	Spacenet	
IRS-P6	L3+AWIFS-RT	DAY DLT	L6002038	Generated	Spl. vehicle	Generated	Spacenet	
IRS-P6	L3+AWIFS-RT	NIG DLT	L6102038	Generated	H on 08/02/04	Generated	Spacenet	
IRS-P6	L4MX+MN-RT	DAY DLT	M6002038	Generated	Spl. vehicle	Generated	Spacenet	

6. Gate Pass Information

Gate Pass Date	Gatepass No.	Vehicle	Date of Product
07-FEB-2004	9294	Spl. vehicle	07-FEB-2004
07-FEB-2004	9295	H veh on 08/02/04	07-FEB-2004

Fig.7.13 GUI for RDAIS Data Products Information

7. Network Transfer Status

View [Network Transfer Report for 07-FEB-2004]

8. Hardware & Software Status

Type	Remarks

9. Pending products Information till 07-FEB-2004

DOP	Satellite	Sensor	Prod. ID	Module	Error Code	Remarks
22-DEC-2003	IRS-P6	L3+AWIFS-PB	L6101356	ADIFVAL_SSR	190	ADIFVAL_SSR:Came out with error: ADIF File contains stars in some field. DLTs are generated. ADIF & Browse are pending.

7.14 GUI for Network data transfers, Status and Pending Products

10. Systems Status

System	Status
DAQLB 6	On PC linux system screen was locked and not responded. After the
DAQLB4	OK
TM/ERS FS UNITS	OK
OTHER O2s AND PCs	OK
NETWORK PRINTERS/LOCAL PRINTER	OK
LAN MS-900 SWITCH	OK
MULTIMISSION DATA SIMULATOR	OK
IRS-P4 DATA SIMULATOR	OK
SCHEMACS WORKSTATION	OK
LEVEL-0 INFORMATION SYSTEM	OK
DAQLB1	OK
ALPHA 3000/800 LEV0P3 SYSTEM	OK
IRIG Time Display	Ok
TCG/TCT (DARSD Make)	Ok
DAQLB2	OK
DAQLB3	OK
TES Data Simulator	OK
MSMR Data Simulator	OK
SMART SYSTEM	OK
DATA LINK TO SCC	OK
DATA LINK TO NDC/IMS/NRSA	OK
Internet	OK
Spacenet	OK
TekHind Oscilloscope	Not Working
DAQLB5	OK
AC Plant of IRS/1C/1D computer room	Ok.
FUEL Work Station	OK
QLBPC	ok
Internet pc	Monitor was replaced with a spare by maintanace agency.
DAQLB6	OK
Station Time Synchronization	118 micro secs lagging, Corrected to 3 microsec.

FIG.7.15 GUI for Systems Status

7.6 Information System through Net

The system generated reports are transmitted to all the authorized users in Department of Space through DOS Intranet. As this information is very useful and critical, the reports are also accessible through intranet to the authorized for all the satellite missions for the mission life.

7.7 Conclusion

In order to bring down the human subjectivity to least values and to make the status parameter information flow automatic to all the concerned, the above system was designed and operationalised. The system is working error-free and also getting updated for the satellites that are getting launched subsequently. Therefore the system currently caters to all the Indian Remote Sensing Programmes that are in operation at NRSA. For all the satellites from the date of operationalisation, the system is working reliably with 100% availability and therefore appreciated by all the concerned. The outputs of the system are backed up for the mission life of each satellite. Similar approaches are being extended for all the critical systems to have the least manual subjectivity and to support online information and parameter flow in order to aid remote management of the systems. One of the sample outputs are given below.

7.8 Data Archival & Real-time Systems Division (DARSD)

Satellite Data Acquisition Area (SDAA)

Level-'0' Status Report for 04-FEB-2007

---

1. Staff

DARSD Staff

Name	Duty	Remarks
K.KOTESWARA RAO	D	
S.YADAGIRI	DN	
B. VANI JAHNAVI	DN	
N. ASHOK KUMAR	DN	
RADHA NAYANI	H	
T.SRIHARI	H	
M.SURYANARAYANA	H	

Maintenance Engineers

Name	Agency
Sandeep	CMA

Computer Room Contract Staff

Name	Shift
Srinu	A&B
Sekhar	N

---

2. Pre-pass Link Status

Satellite	Sensor	Loop	Chain	Remarks
IRS-1C/1D	LISS-3	Local Loop	BACKUP	Not available
IRS-1C/1D	LISS-3	Local Loop	MAIN	OK
IRS-1C/1D	PAN	Local Loop	MAIN	OK
IRS-1C/1D	PAN	Local Loop	BACKUP	Not available
IRS-P4	OCM_RT	Local Loop	MAIN	OK
IRS-P4	OCM_RT	Local Loop	BACKUP	OK
IRS-P5	PANAFT	Local Loop	BACKUP	OK
IRS-P5	PANAFT	Local Loop	MAIN	OK
IRS-P5	PANFORE	Local Loop	BACKUP	OK
IRS-P5	PANFORE	Local Loop	MAIN	OK
IRS-P6	L3+AW	Local Loop	BACKUP	OK
IRS-P6	L3+AW	Local Loop	MAIN	OK
IRS-P6	LISS-4	Local Loop	BACKUP	OK
IRS-P6	LISS-4	Local Loop	MAIN	OK

3. Passes Supported Information

Sensor	Pass Type	Orbit	Path	Config.	Mode	System	Sim.	Row Nos.	Data Quality Rema
LISS-3	PAYLOAD	57630	81	T-1/MAIN	RT	DAQLB2	Not Done	42-64	Good Data
PAN	PAYLOAD	57630	81	T-1/MAIN	RT	DAQLB2	Not Done	42-64	Good Data
LISS-3	PAYLOAD	48908	116	T-1/MAIN	RT	DAQLB1	Not Done	46-72	Good Data

LISS-3	PAYLOAD	48909	91	T-1/MAIN	RT	DAQLB1	Not Done	40-76	Good Data
PAN	PAYLOAD	48908	116	T-1/MAIN	RT	DAQLB1	Not Done	46-72	Good Data
PAN	PAYLOAD	48909	91	T-1/MAIN	RT	DAQLB1	Not Done	40-76	Good Data
OCM-RT	PAYLOAD	40760	11	T-1/MAIN	RT	DAQLB3	Not Done	14-15	Good Data
L3+AWIFS-PB	SSR	17143	-	T-2/MAIN	RT	DAQLB7	Not Done	-	Good data.
L3+AWIFS-RT	PAYLOAD	17136	105	T-3/MAIN	RT	DAQLB7	Not Done	-	Good Data
L3+AWIFS-RT	PAYLOAD	17137	81	T-3/MAIN	RT	DAQLB7	Not Done	-	Good Data
L4MN-RT	PAYLOAD	17136	105	T-3/MAIN	RT	DAQLB7	Not Done	-	Good Data
L4MN-RT	PAYLOAD	17137	81	T-3/MAIN	RT	DAQLB7	Not Done	-	Good Data
L4MX-RT	PAYLOAD	17136	105	T-3/MAIN	RT	DAQLB7	Not Done	-	Good Data
PANF+PANA	PAYLOAD	9484	596	T-3/BACKUP	RT+SSR	DAQLB8	Not	-	Good Data
PANF+PANA	SSR	9485	722	T-2/MAIN	RT	DAQLB8	Not Done	-	Good data.
PANF+PANA	SSR	9492	-	T-3/MAIN	SSR	DAQLB8	Not	-	Good Data

3A. HST Information

Satellite	Sensor	Orbit	Payloadssr	Status	Remarks
IRS-P6	ALL	17136	PAYLOAD	NORMAL	ALL PORTS OK
IRS-P6	ALL	17137	PAYLOAD	NORMAL	ALL PORTS OK
IRS-P5	PAN-AFT	9484	PAYLOAD	DEVOBS	In Ports P1 & P5
IRS-P5	PA+PF	9485	PAYLOAD	NORMAL	ALL PORTS OK

3B. IRS-P6 SPS Information

Satellite	Adifmode	Orbit	SpsPbOn	SpsPbOff	Remarks
IRS-P6	L	17136	--	--	null
IRS-P6	L	17137	null	null	No Data

3C. RS-Encoding Uncorrectable Errors

Satid	StreamId	daynig	Orbit	Segment1	Segment2	Segment3	Segment4
IRS-P5	PAN-AFT-I	DAY	9484	0	161		

IRS-P5	PAN-AFT-Q	DAY	9484	0	176		
IRS-P5	PAN-FORE-I	DAY	9484	3	19		
IRS-P5	PAN-FORE-Q	DAY	9484	3	21		
IRS-P5	PAN-AFT-I	DAY	9485	0	-	-	-
IRS-P5	PAN-AFT-Q	DAY	9485	1	-	-	-
IRS-P5	PAN-FORE-I	DAY	9485	1	-	-	-
IRS-P5	PAN-FORE-Q	DAY	9485	1	-	-	-
IRS-P5	PAN-AFT-I	NIGHT	9492	4	1	0	2
IRS-P5	PAN-AFT-Q	NIGHT	9492	4	1	0	2
IRS-P5	PAN-FORE-I	NIGHT	9492	6	3	6	5
IRS-P5	PAN-FORE-Q	NIGHT	9492	6	3	5	5

---

4. Passes NotSupported/Skipped Information

Satellite	Sensor	Pass Type	Orbit	Path	Pass Status;	Remarks

5. Products Generated & Dispatched

ite	Sensor	Media	Product ID	Product Status	Dispatched By	Browse Status	Dispatched By	Remarks
C	LISS-3	DAY DLT	LC013035	Generated	Spl vehicle	Generated	Spacenet	
C	PAN	DAY DLT	PC013035	Generated	Spl vehicle	Generated	Spacenet	
D	LISS-3	DAY DLT	LD011035	Generated	Spl vehicle	Generated	Spacenet	
D	PAN	DAY DLT	PD011035	Generated	Spl vehicle	Generated	Spacenet	
P4	OCM-RT	DAY DLT	4P009035	Generated	Spl vehicle	Generated	Spacenet	
P5	PANF+PANA	DAY DLT	P500303501	Generated	G vehicle	Generated	Spacenet	
P5	PANF+PANA	NIG DLT	P510303501	Generated	H on 05.02.07	Generated	Spacenet	
P6	L3+AWIFS-PB	NIG DLT	L6105035	Generated	H on 05.02.07	Generated	spacenet	
P6	L3+AWIFS-RT	DAY DLT	L6005035	Generated	G vehicle	Generated	Spacenet	
P6	L4MN-RT	DAY DLT	M6005035	Generated	G vehicle	Generated	Spacenet	

P6	L4MX-PB	NIG DLT	M6105035	Generated	H on 05.02.07	Generated	spacenet	

6. Gate Pass Information

Gate Pass Date	Gatepass No.	Vehicle	Date of Product	Remarks
04-FEB-2007	14624	H vehicle	04-FEB-2007	null
04-FEB-2007	14625	Spl vehicle	04-FEB-2007	null
04-FEB-2007	14626	G vehicle	04-FEB-2007	null

7. Network Transfer Status

The following data files are transferred from Level'0' systems through Spacenet to DP Server. The transfer is derived as complete after perfect correlation of the file sizes between the transferred files at DP Server and the source files at Level'0' Systems .The system generates this report in AUTO mode after the above processes for all the satellites. Therefore this report certifies the existence of all the below mentioned files at DP Server as per the time mentioned against each .

```
Sent by: Mr.N.AshokKumar, DARSD, on Sun 04-Feb-2007 at 06:02:22 (GMT)
from DAQLB9
 The following CARTO2(DAY) files are available at NDCIRIS after
transfer from Level-'0' Systems
----------------------------------------------------------------------
---------
----------------------------------------------------------------------
---------
Sno. Date Of Pass Type  Size  Date        File Name
----------------------------------------------------------------------
---------
1 04-Feb-2007 ADIF
           10190867 Feb  4 11:37
/usr1/people/spacenet/data/adif/c02/atpd00371_SAN_c02_2007.035
              51234 Feb  4 11:37
/usr1/people/spacenet/data/adif/c02/atpd00371_SAN_c02_sum_2007.035
2 04-Feb-2007 BROWSE
      00371      2570240 Feb  4 11:38 abRpPAN00371_SAN_c02.035
      00371         3672 Feb  4 11:38 brogen_00371_SAN_c02rep.035
 3 04-Feb-2007 HIST
      00371       197408 Feb  4 11:38 hstpd0037101011_SAN_c02.035
      00371       197408 Feb  4 11:39 hstpd0037101021_SAN_c02.035
      00371       197408 Feb  4 11:39 hstpd0037101031_SAN_c02.035
      00371       197408 Feb  4 11:39 hstpd0037101041_SAN_c02.035
      00371         6191 Feb  4 11:39 hstpd00371SAN_c02_summ_db.035
      00371        15178 Feb  4 11:39 hstpd00371SAN_c02_summarynrt.035
      00371        35555 Feb  4 11:39 hstpd00371SAN_c02_tablenrt.035
      00371       798720 Feb  4 11:39 hstrd00371_SAN_c02.035
 ---------------------------------------------------------------------
----------
```

```
Sent by: Mr.N.Ashokkumar,DARSD On Sun 04-Feb-2007 at 07:37:08 (GMT)
 The following IRS-1C (PAN) files are available at NDCIRIS, after
transfer from Level-'0' Systems
-----------------------------------------------------------------------
--------------------------
Sno. Date Of Pass Type  Path/Orbit  Size  Time        File Name
-----------------------------------------------------------------------
--------------------------
1 04-Feb-2007      ADIF
                               80555 Feb  4 13:13 acmpaacctp_i1c.035
                              374906 Feb  4 13:13 actpaacctp_i1c.035
                               45827 Feb  4 13:14 scenerep1c_pp.035

2 04-Feb-2007     BROWSE
                  081        1259520 Feb  4 13:14 P1CPN00081.035
-----------------------------------------------------------------------
-----------
Sent by: Mr.N.Ashokkumar,DARSD On Sun 04-Feb-2007 at 07:39:14 (GMT)
 The following IRS-1C (LISS-3+WiFS) files are available at NDCIRIS,
after transfer from Level-'0' Systems
-----------------------------------------------------------------------
----------------------------------
Sno. Date Of Pass Type  Path/Orbit  Size  Time        File Name
-----------------------------------------------------------------------
----------------------------------
1 04-Feb-2007      ADIF
                               35590 Feb  4 13:15 acmpaacctl_i1c.035
                              374906 Feb  4 13:15 actpaacctl_i1c.035
                                7117 Feb  4 13:15 scenerep1c_lp.035

2 04-Feb-2007     BROWSE
                  081         655360 Feb  4 13:16 P1CL300081.035
                  081         163840 Feb  4 13:16 P1CWI00081.035
-----------------------------------------------------------------------
----------
Sent by: Mr.N.Ashokkumar,DARSD On Sun 04-Feb-2007 at 07:42:14 (GMT)
 The following IRS-1D (PAN) files are available at NDCIRIS, after
transfer from Level-'0' Systems
-----------------------------------------------------------------------
--------------------------
Sno. Date Of Pass Type  Path/Orbit  Size  Time        File Name
-----------------------------------------------------------------------
--------------------------
1 04-Feb-2007      ADIF
                              222956 Feb  4 13:17 acmpaacctp_i1d.035
                              767277 Feb  4 13:18 actpaacctp_i1d.035
                              127008 Feb  4 13:18 scenerep1d_pp.035

2 04-Feb-2007     BROWSE
                  091        2263040 Feb  4 13:19 P1DPN00091.035
                  116        1689600 Feb  4 13:19 P1DPN00116.035
-----------------------------------------------------------------------
----------
Sent by: Mr.N.Ashokkumar,DARSD On Sun 04-Feb-2007 at 07:45:37 (GMT)
 The following IRS-1D (LISS-3+WiFS) files are available at NDCIRIS,
after transfer from Level-'0' Systems
```

```
--------------------------------------------------------------------------------
-------------------------
Sno. Date Of Pass Type     Path/Orbit   Size   Time         File Name
--------------------------------------------------------------------------------
-------------------------
1 04-Feb-2007      ADIF
                                  97836 Feb  4 13:20 acmpaacctl_i1d.035
                                 766977 Feb  4 13:21 actpaacctl_i1d.035
                                  19295 Feb  4 13:21 scenerep1d_lp.035

2 04-Feb-2007     BROWSE
                    091         1536000 Feb  4 13:22 P1DL300091.035
                    116         1116160 Feb  4 13:22 P1DL300116.035
                    091          337920 Feb  4 13:23 P1DWI00091.035
                    116          307200 Feb  4 13:23 P1DWI00116.035

--------------------------------------------------------------------------------
--
Sent by: Mr.N.Ashokkumar, DARSD,on Sun 04-Feb-2007 at 07:46:31 (GMT)
 The following IRS-P4 files are available at NDCIRIS, after transfer from
Level-'0' Systems
--------------------------------------------------------------------------------
-----------
Sno. Date Of Pass Type     Path/Orbit   Size   Time         File Name
--------------------------------------------------------------------------------
-----------
1 04-Feb-2007 ADIF
                                   3487 Feb  4 13:23 acmpaaccdo_ip4.035
                                  93973 Feb  4 13:23 actpaaccdo_ip4.035

2 04-Feb-2007 BROWSE
                    11            92160 Feb  4 13:24 RP4OC00011.035

--------------------------------------------------------------------------------
-
Sent by: Mr.N.Ashokkumar, DARSD, on 04-Feb-2007  at 07:53:44 (GMT)
 The following IRS-P6 files are available at NDCIRIS after transfer from Level-
'0' Systems
--------------------------------------------------------------------------------
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Sno. Date Of Pass Type     Path/Orbit   Size   Time         File Name
--------------------------------------------------------------------------------
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1 04-Feb-2007 ADIF
                                6436920 Feb  4 13:26 atpdadayws_HYD_ip6.035
                                 744103 Feb  4 13:26 atpdadayws_HYD_ip6_sum.035

2 04-Feb-2007 BROWSE
                    000         5416960 Feb  4 13:28 abrp000mx17136_hyd_ip6.035
                    081          296960 Feb  4 13:28 abrp081aw00000_hyd_ip6.035
                    081         1423360 Feb  4 13:28 abrp081ls00000_hyd_ip6.035
                    081         1320960 Feb  4 13:29 abrp081mn00000_hyd_ip6.035
                    105          296960 Feb  4 13:29 abrp105aw00000_hyd_ip6.035
                    105         1505280 Feb  4 13:30 abrp105ls00000_hyd_ip6.035

3 04-Feb-2007 HIST
                  17136 17137 450560       Feb             4       13:31
```

```
hstrd17137_hyd_ip6.035
                                  4080 Feb  4 13:31 hstrls_hyd_ip6.summ_db.035
                                  5011 Feb  4 13:31
hstrls_hyd_ip6.summarynrt.035
                                 10468 Feb  4 13:31 hstrls_hyd_ip6.tablenrt.035
                                  2051 Feb  4 13:31 hstrmn_hyd_ip6.summ_db.035
                                  4127 Feb  4 13:31
hstrmn_hyd_ip6.summarynrt.035
                                  9474 Feb  4 13:31 hstrmn_hyd_ip6.tablenrt.035
                                  3059 Feb  4 13:31 hstrmx_hyd_ip6.summ_db.035
                                  3995 Feb  4 13:31
hstrmx_hyd_ip6.summarynrt.035
                                  8624 Feb  4 13:31 hstrmx_hyd_ip6.tablenrt.035

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OBTGRT FILES AVILABLE AT DPSERVER AFTER TRANSFER TODAY 035

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OBTGRT FILES AVILABLE AT DPSERVER AFTER TRANSFER TODAY 035

total 384
-rwxr-xr--    1 spacenet user      102256 Feb  4 16:28 OBTGRTCorrelateFile.ip6
-rwxr-xr-x    1 spacenet user       43200 Feb  4 16:28
OBTGRTCorrelateFile_I.ip5
-rwxr-xr-x    1 spacenet user       43120 Feb  4 16:28
OBTGRTCorrelateFile_Q.ip5
-rwxr-xr-x    1 spacenet user          57 Dec 14 11:16 xfer_obt.txt
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Sent by: Mr.N.AshokKumar, DARSD, on Sun 04-Feb-2007 at 10:58:14 (GMT) from
DAQLB8
 The following IRS-P5(DAY) files are available at NDCIRIS after transfer from
Level-'0' Systems
-------------------------------------------------------------------------------
-
-------------------------------------------------------------------------------
-
Sno. Date Of Pass Type     Path/Orbit   Size   Time          File Name
-------------------------------------------------------------------------------
-
1 04-Feb-2007 ADIF
            2074617 Feb  4 16:29
/usr1/people/spacenet/data/adif/p5/atpddayws_HYD_ip5.035
              88259 Feb  4 16:29
/usr1/people/spacenet/data/adif/p5/atpddayws_HYD_ip5_sum.035
            4443142 Feb  4 16:30
/usr1/people/spacenet/data/adif/p5/atsddayws_HYD_ip5.035
             125853 Feb  4 16:30
/usr1/people/spacenet/data/adif/p5/atsddayws_HYD_ip5_sum.035
```

```
2 04-Feb-2007 BROWSE

      0596       2426880 Feb  4 16:31 abrp0596pa000000_hyd_ip5.035

      0596       1740800 Feb  4 16:32 abrp0596pf000000_hyd_ip5.035

      0000       1658880 Feb  4 16:32 abrs0000pa009484_hyd_ip5.035

      0000       4096000 Feb  4 16:33 abrs0000pa009485_hyd_ip5.035

      0000       1587200 Feb  4 16:33 abrs0000pf009484_hyd_ip5.035

      0000       4085760 Feb  4 16:34 abrs0000pf009485_hyd_ip5.035

3 04-Feb-2007 HIST
      04076       04083        09484       798720 Feb  4 16:35
hstrd09484_HYD_ip5.035
      09485       399360 Feb  4 16:35 hstrd09485_HYD_ip5.035

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-
Sent by: Mr.N.Ashokkumar, DARSD, on Sun 04-Feb-2007  at 18:21:31 (GMT)
 The following IRS-P6(NIG) files are available at NDCIRIS after transfer from
Level-'0'Systems
------------------------------------------------------------------------------
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Sno. Date Of Pass Type    Path/Orbit   Size   Time         File Name
------------------------------------------------------------------------------
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1 04-Feb-2007 ADIF
                               4157604 Feb  4 23:56 atsnadayws_HYD_ip6.035
                                175631 Feb  4 23:56 atsnadayws_HYD_ip6_sum.035

2 04-Feb-2007 BROWSE
                   057          133120 Feb  4 23:56 abrs057aw00000_hyd_ip6.035
                   057          645120 Feb  4 23:57 abrs057ls00000_hyd_ip6.035
                   278          163840 Feb  4 23:57 abrs278aw00000_hyd_ip6.035
                   278          675840 Feb  4 23:58 abrs278ls00000_hyd_ip6.035
                   278         1300480 Feb  4 23:58 abrs278mn00000_hyd_ip6.035

------------------------------------------------------------------------------
-
Sent by: Mrs.B.VaniJahnavi, DARSD, on Sun 04-Feb-2007 at 18:57:00 (GMT) from
DAQLB8
 The following IRS-P5 (NIG) files are available at NDCIRIS after transfer from
Level-'0' Systems
------------------------------------------------------------------------------
-
Sno. Date Of Pass Type    Path/Orbit   Size   Time         File Name
------------------------------------------------------------------------------
-
1 04-Feb-2007 ADIF
                               7794214 Feb  5 00:31
/usr1/people/spacenet/data/adif/p5/atsndayws_HYD_ip5.035
                                138960 Feb  5 00:31
/usr1/people/spacenet/data/adif/p5/atsndayws_HYD_ip5_sum.035
```

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2 04-Feb-2007 BROWSE
                    09492       2928640 Feb  5 00:32
/usr1/people/spacenet/data/browse/p5/abrs0000pa009492_hyd_ip5.035
                    09492       2795520 Feb  5 00:33
/usr1/people/spacenet/data/browse/p5/abrs0000pf009492_hyd_ip5.035

3 04-Feb-2007 HIST
                    09492       1986560 Feb  5 00:34
/usr1/people/spacenet/data/hist/p5/hstrn09492_HYD_ip5.035
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-
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8. Hardware/Software/Network Status

Type	Remarks
General	IRS-P6 USDA scenes for path 57, rows 95D and 99B are generated and sent.

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9. Pending products Information till 04-FEB-2007

Date	Satellite	Sensor	Prod. ID	Module	Error Code	Remarks
11-JAN-2007	IRS-P6	L3+AWIFS-RT	L6005011		-	Adifval exited with an error "line count discripency found the adif scene block". Hence Adif & Browse not generated DLTs generated and dispatched by G Veh.
11-JAN-2007	IRS-P6	L4MN-RT	M6005011		-	Adifval exited with an error "line count discripency found the adif scene block". Hence Adif & Browse not generated DLTs generated and dispatched by G Veh.

10. Systems Status

System	Status
OTHER O2s AND PCs	OK
NETWORK PRINTERS/LOCAL PRINTER	OK
SMART SYSTEM	OK
Internet pc	OK
line Printers	OK
MDAQLB	OK
LISQLD	OK
WIFSQLD	OK
SCHEMACS WORKSTATION	OK.
ALPHA 3000/800 LEV0P3 SYSTEM	OK
ERS Direct Archival System	OK
LAN MS-900 SWITCH	OK
WIFSQLD MONITOR	OK
DAQLB4	OK
DAQLB8	OK
IRS-P4 DATA SIMULATOR	OK
MSMR/SPS Data Simulator	OK
TES Data Simulator	OK
FUEL Work Station	OK
TCTs (DARSD Make)	Ok
HP Oscilloscope	OK
DATA LINK TO NDC/IMS/NRSA	OK
32x32 DATA PATH CONTROLLER	OK
DAQLB3	OK
DAQLB5	OK
DAQLB6	OK
AC in IRS-1B Control Room	OK
AC In IRS-1C/1D Control Room	Ok
DATA SERIALIZER	OK
Spacenet	OK
DATA PATH CONTROLLER (1C & 1D)	OK
MULTIMISSION DATA SIMULATOR	OK
2 MBPS FO Line	OK
Voice Link to SCC	OK

DAQLB1	OK
DAQLB2	OK
IRIG Time Display	OK
DAQLB7	OK
Internet	OK
DAQLB-9	OK
TCG2	15 micro seconds time difference adjusted to less than 2 micro seconds.

Chapter – 8

Important Conclusions of the Thesis and Future work

8.1 Introduction

This chapter summarizes the important conclusions of this thesis. The Data Acquisition systems were characterized for their functionality with respect to RF systems, tracking systems, realtime systems etc., to build the intelligent functions. Development of the model for each function is the first step and the second step is to design each system with field upgradability. The field upgradability within FPGA's addresses embedded programming, reconfigurability, Input/Output status preservability and device status control etc.,

The third important aspect is to develop the designs with the ability for remote upgrade through network etc., This part is brought out as a future work. This addresses the requirements that are necessary for the field upgradability in the form of PROMS, FLASH memories on the PCB, the test bus controller that is used for interfacing the system in a PCB with the external world through IEEE bus, extension of the same concepts in handling the multi PCB systems for remote upgradability and finally the deployment of Hardware for reconfigurability.

The combination of design complexity, component size and the use of multiple FPGA's in target systems increase the number of design versions used by customer products. A method for handling remote hardware upgrades in the field is necessary for a successful configurable product line. The object oriented nature of hardware objects eliminates the need to handle the low level issues with hardware interfacing designs, JTAG or select-Map programming allowing the end user's application.

8.2 Important conclusions of the research

- New concepts in the development of satellite data format simulators by incorporating programmability to suit the multi satellite/sensor missions. The method uses the reconfigurable FPGAs, injection of realistic/simulated ancillary data to the data stream to create the actual environment like satellite for simulation while considering all the parameters for the subsequent image handling and processing. Also introduced the approach of injecting the compressed/uncompressed image into the serial data stream of the simulator instead of simple data patterns using zeros, ones etc.. This has simplified the validation/end-to-end tests of the entire data handling chains of the ground segment.
- Modelling of bit errors and development of the associated systems for the validation of the data reception chains in a computer controlled environment.

- Characterization of the reception systems through simulation and fine tuning of the same for realtime performance. Automation of the simulation process based on time tagging as per the sequence in a given day.
- BER validation of the reception chain during image data download is another new challenge through statistical modelling while using the system functional models derived from simulations.
- Major issue of data reception from horizon to horizon has been resolved by developing an efficient program track system to track the satellite. This was augmented with a specific elevation dependant tracking model for tracking high elevation satellite passes. This development enables the remote sensing data acquisition systems to be totally remote configurable/controllable.
- Development of high speed cross point switches for 8X8,16X16,32X32 signal pairs.
- Developed the computer controlled systems, processes for the automated operations with appropriate Hardwares and softwares.
- Developed automated report generation systems for the operational events and status and make these information services available to all users through net.

8.3 Some Important End Results

- This research has resulted in the development of several systems using reconfigurable approaches viz.. Bit Error Test Systems, Data Path Controllers, Timing systems, Station Control Systems for automated tracking, Satellite Data Format Simulators, Realtime Data Archival systems, Automated Report Generation and Information Management Systems for data acquisition etc.. These systems are supplied to several National and International remote sensing satellite ground stations under the Indian Remote Satellite program from department of space through Antrix Corporation. The international users are Iran, Algeria, Norman-USA, Euromap-Germany, China, Scanex-Russia, UAE, Taiwan, Mynamar, Svalbard(Notherlands) etc... The Indian users are ministry of defense and ministry of home affairs.
- This research enables the user to locate the data acquisition systems even in remote inaccessible areas.
- This has resulted in publication of 30 papers. The paper published and presented by the author in an international seminar ICSCN2007 on Elevation independent tracking system for remote sensing satellites has got the best paper award.

8.4 Future Work [87-99]

An emerging issue for the system designer is the desire for configurable products. This has motivated designers to increase the adoption of programmable architectures that utilize programmable logic devices such as FPGAs and CPLDs, and programmable non-volatile memories, such as

EEPROM and FLASH. Designing the systems with the ability to remotely upgrade the programmable logic and non-volatile memory of the system, which in the field, is a typical approach to address the requirements. However, obtaining access to all the programmable devices is increasingly more difficult especially for PCBs with mezzanine card or multi PCB backplane based systems.

Traditionally, the approach used to embed the test into PCBs and systems by storing the functional diagnostic code as a part of the unit in CPUs memory etc. These embedded tests are used to test the integrated systems, both in manufacturing and in the field. The systems with these concepts grow more complex.

The following provide some background on methods that are used for facilitating product reconfiguration and for embedded test of PCBs and systems.

8.4.1 Reconfiguration of Programmable Devices

The method that in predominantly used to configure FPGA logic employs application specific configuration PROMS. These PROMS are programmed. With the configuration data for the design, which is then loaded into the FPGAs configuration memory at power up.

In large FPGA, on an average, requires upto four configuration PROMS for single design. In some cases based on the design Bit file size the PROMs requirement may go beyond 4 and upto 7. But the numbers of PROMS that can be configured are in some way limited. Sometimes it may be desirable to load different protocols or algorithms into an FPGA based on the target communication medium or the geographical location where the product is used. Another important issue is that the configuration PROMS employ a proprietary method for programming FPGAs so that they are not interchangeable between different programmable vendors. Also the PROMS will require an onboard mechanism that enables them to be reconfigured in-system. Another issue with reconfiguration PROM method is integration of FPGA configuration with board and system test. Currently FPGAs support various I/O logic families such as HSTC, PECC, LVDs etc. The FPGA based PCBs need to be tested in at least two scenarios, with FPGA I/O configured and with I/O unconfigured. This PROM based configuration resulted in designers having their own custom configuration which is again not cost-effective due to added verification and debug time, lack of support by commercial design and test tools, added integration costs, reuse in next version etc.,

Another approach to configure programmable devices is to interface the system processor to an IEEE 1149.1. Test Bus Controller (TBC) IC, and then use this mechanism to reconfigure the FPGA PROMS as given in the figure below:

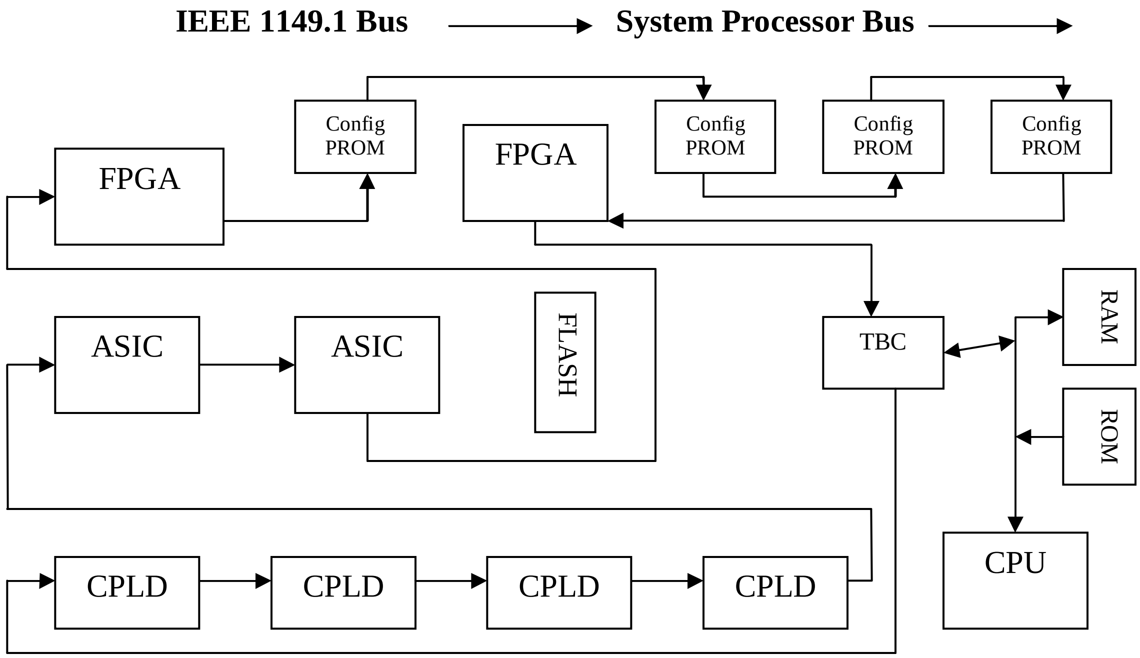


Fig. 8.1 Traditional CPU and Test Bus Controller

This has TBC as an additional component and hence call for additional code, validation debugging etc. including the proprietary related issues. Interfacing the CPU is an involved process requiring additional glue logic around CPU and also around TBC to access PROMs and FPGAs. Another approach is to use mission mode processor to program FPGAs directly for low speed applications. The dedicated configuration and test browser will be a suitable solution to manage multiple system configurations. Examples in this category are network processors, audio processors, digital signal processors and video processors. For these tasks, dedicated processors offer many advantages, as embedded test enables testing of the general purpose CPU and its support logic, and logging of all failures without the need for the system to function. In other words a dedicated embedded configuration and test processor (C&T processor) will function as a centralized manager for configuration and testing PCBs and systems.

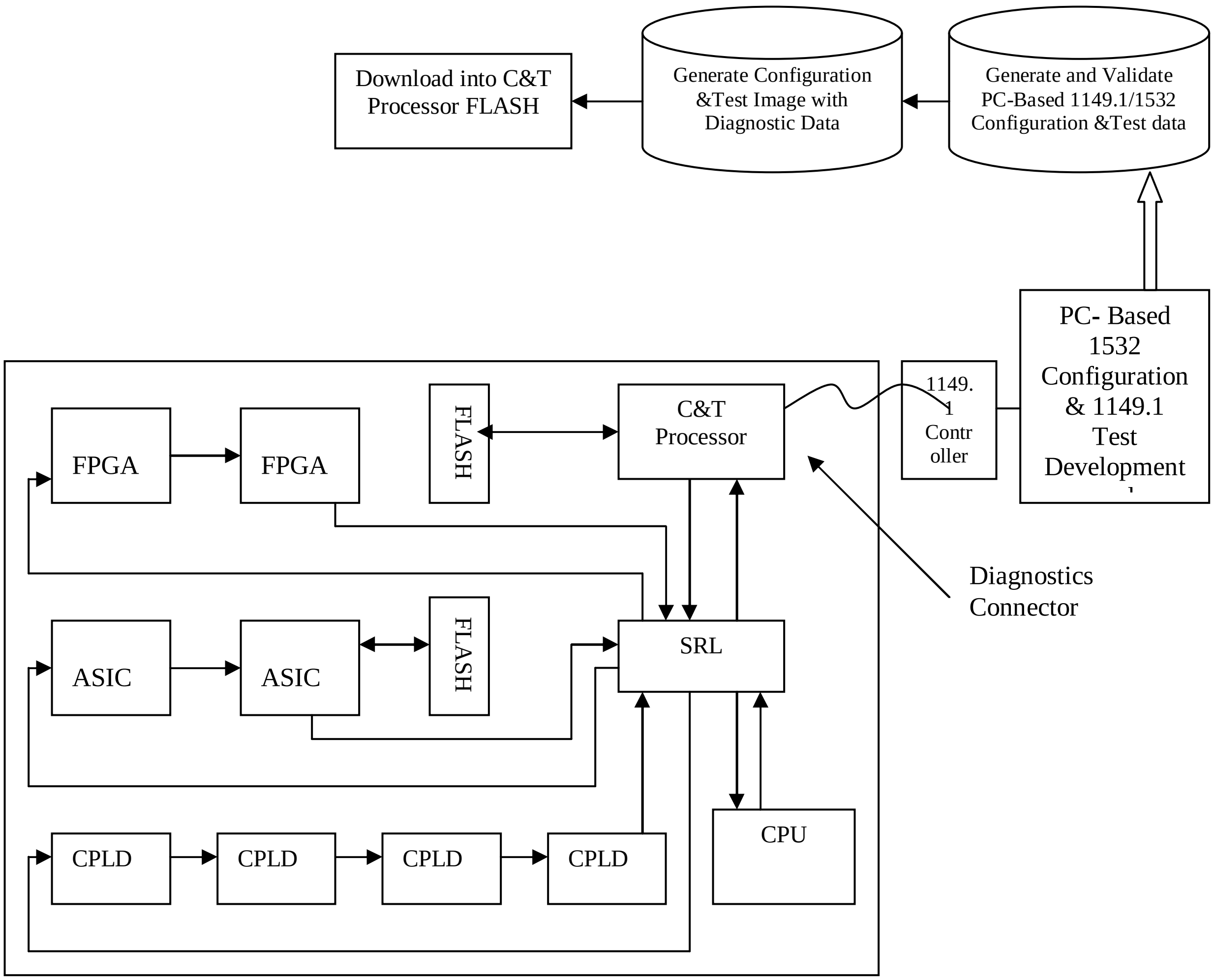


Fig. 8.2 Embedded Configuration and Test (C&T) Processor for a single PCB System

A single configuration and test processor at power up can automatically run the entire manufacturing test stream, including scan tests, logic BIST, memory BIST and board/system interconnect tests – as well as configure all the programmable logic devices in the system. The following figure shows how the configuration and test processor connects externally to automated development tools that are used for developing and validating configuration data and test programs.

The above concept shows how the configuration and test processes can be used at the board level. It also illustrates how the configuration and Test processor connects externally to automated development tools that are used for developing and validating configuration data and test programs. The architecture uses PC-based IEEE 1149.1 software tools for ATPG and debug. The development environment interfaces with an IEEE 1149.1 controller which connects to the processor on the PCB. The embedded Test and Configuration processor then interfaces with an optional Scan Ring Linker (SRL) that partitions the scan paths at the board level. In this, the embedded configuration and Test Processor replaces the configuration. PROMS and interfaces to a FLASH memory device. The FLASH starts the test and configuration suites of the processor and the processor drives 1149.1 scan chains on the board, in this example via an SRL. This process also interfaces with an external IEEE 1149.1 connector, which allows communication to and from the PC based tools. This interface is used to develop and validate configuration and test vectors using the development and validation tools. This is a major advantage in that the external Boundary Scan tools can communicate through the processor directly. Therefore, this guarantees the equivalent drive and signal integrity for the on-board embedded configuration and test mechanism, as was achieved with the external PC-based tools. The external tools and the embedded processor essentially contain the same 'engine' for interpreting the scan test data and the FPGA configuration data, so their behavior is exactly the same, including critical timing elements needed for CPLD programming. The result is that only one configuration and test validation step is needed, eliminating the need to re-validate the vectors in the embedded environment. After the test and configuration suites are finalized through the external connector and tools, they are downloaded into the FLASH for embedded execution. Then the external IEEE 1149.1 equipment is disconnected from the PCB and the processor assumes control of running the embedded test suites and programming the FPGAs.

PC based Design Tools

The PC based design software tools enable the developer to create test and configuration suites that hold an unlimited number of test vectors, test scripts, flow scripts and FPGA configuration data files. The PC based software and C&T processor can hold upto 16 suites at one time. The suites can be like Reset suite, BIST suite, interconnect suite, standard design suites etc., The storage depends on the size of FLASH.

Using the C&T Processor at System level

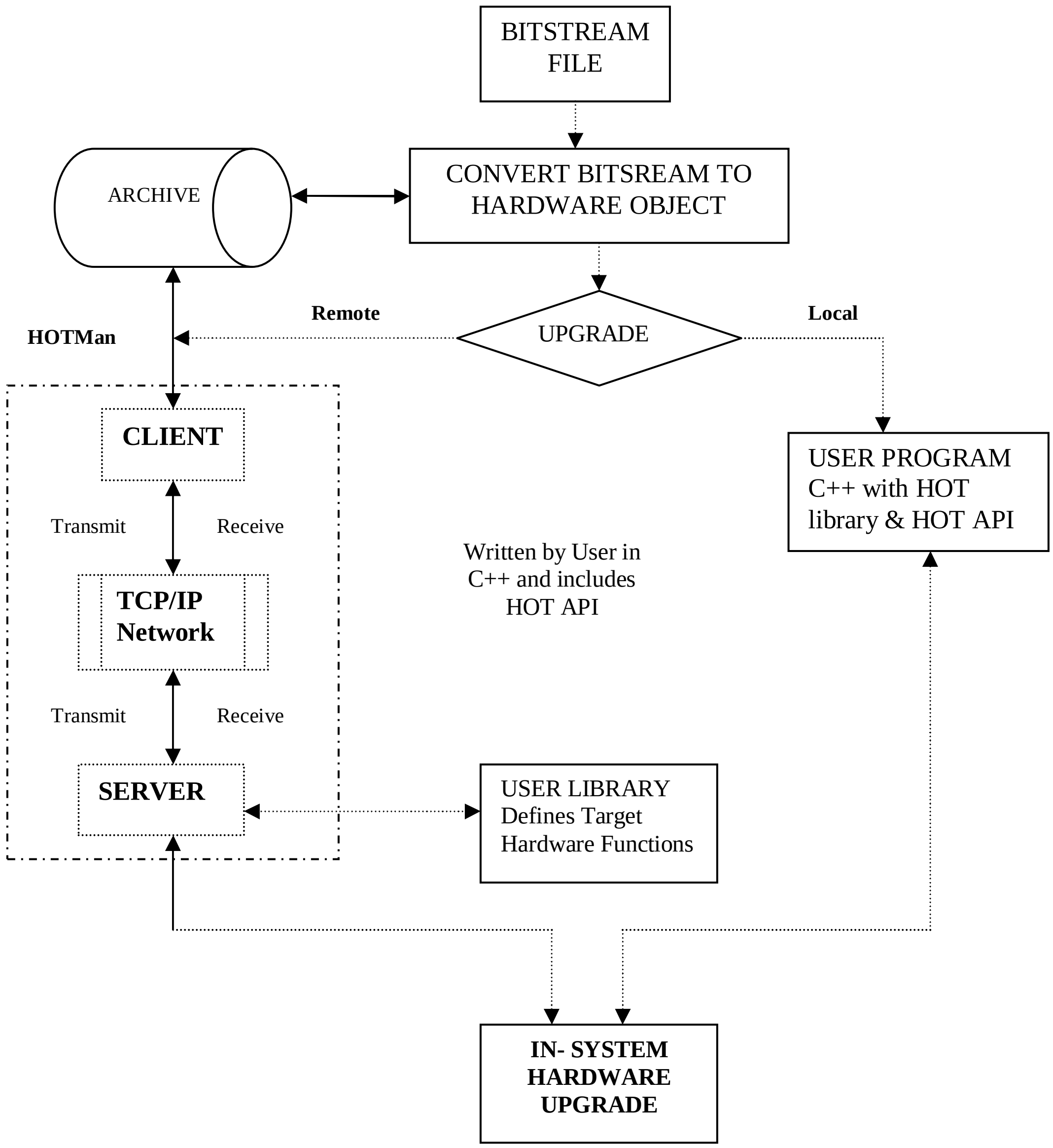
The configuration and test processor can also be used at the system level having multiple boards. This system uses a multi drop 1149.1 bus called the Parallel Test Bus (PTB) along with an addressable Parallel Test Bus Controller (PTBC) on each board. In this configuration, only the master/slave PCB has an embedded Configuration and Test Processor. This provides a single, centralized processor that is dedicated for managing all system configuration and test. Engineers can use the external IEEE 1149.1 Controller and embedded processor for validation before embedding the configuration and test data. The architecture enables embedding test and configuration at the system level, including PCB self test of master board, Parallel Configuration and Test of the slave boards and system level Interconnect test. This configuration provides the diagnostics status with reference to time etc., which can be used for Field Replaceable Unit (FRU) identification and PCB level repair etc. The Test messages and error codes enable the customer or field service person to diagnose the problem done to FRU with low cost PDA. Tests can be made granular, plug-in daughter cards and socket components. PCB level standby units can be configured in case of problems which the faulty PCB can be sent back to the factory for repair.

8.4.2 Deploying Hardware for in-system upgrades

Hardware remote upgrades need a robust methodology for managing and delivering bit streams. Object-Oriented Programming (OOP) is a revolutionary concept in computer programme development. An object is a bundle of variables and related methods. By applying object programming techniques bit stream files, one gets a bit stream file that includes bit stream data, other resource data and methods for management of bit stream itself. This bit stream configuration file alone is not enough to facilitate remote upgrading. It needs other data such as version history for tracking and maintenance, network protocol data, target location information, programmed commands and other commands and the essential data for use within execute programme. This makes bit stream intelligent. The Intelligent Bit Stream includes all the information required for delivery, verification and use.

The Intelligent Bit Stream is called a Hardware Object and the Hardware Object Technology (HOT) provides the transportation link between bit stream generation and Run-time use of bit stream within executable programs. The HOT application program creates the Hardware Object file from a used selected bit file. It outputs a static array file or a dynamic file. The Hardware Object (HOT file) is used with HOT API, JAVA and a C++ Compiler to provide program control and delivery. The Hardware Object contains the compressed Bit stream data as well as number of data fields as follows:

(i) The bit stream in the bit format is converted to bit stream control input. The bit stream control input contains compressed bit file, bit file name, source path, size of uncompressed bit stream and compressed bit stream (ii) The bit stream control input goes through the process of documentation control which contains author information, creation data, comments, security field as well as options for auto mission/revision numbers. (iii) The next step is generation of Target ID containing Name of the target system, Name of the Target board, Name of the Target daughter board, Number of the Target device, Part Number derived from the bit stream (iv) The further step is to have the Network Development Protocol inputs containing Destination address on network where the target resides, message and acknowledgement from the server, server commands like upgrade, verify etc., Port No. User library to be loaded on the server (v) The final step is to generate the Hardware Object and then compile the same to make it as a Run-time loadable format.



THE APPLICATION PROGRAMMING INTERFACE

Fig. 8.3 Design Flow for Creation & Use of Hardware Objects

Hardware Object Design flow

The conversion of the standard bit stream to a Hardware Object provides foundation for a well-managed bit stream delivery solution. The Hardware object is a bit stream that knows where to go, knows what to do when it gets to target and report back on its status. The figure 8.3 shows the design flow for a Hardware Object use. Hot Man is an easy to use cost-effective tool for advanced FPGA based IP network deployment management.

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