SATELLITE GROUND CONTROL SYSTEM FOR INSAT

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ABSTRACT

The task of controlling and monitoring a domestic communications satellite from transfer orbit injection, through the critical apogee motor firing sequence and the drift orbit to on-station operations is addressed in this paper. The Satellite Ground Control System (SGCS) employs the latest technology, equipment and computer software architecture to perform the necessary tasks of monitoring and controlling the INSAT spacecraft to be launched in 1981. This paper documents an approach which allows cooperation of the host country technological capabilities with the specialized technology required to place a satellite in orbit. A unique feature of this design is the utilization of a single minicomputer to perform both real time telemetry tracking and command (TT&C) and background orbital analysis functions at the Satellite Control Center.

INTRODUCTION

The satellite ground control system consists of the various agencies and facilities composing the network to accomplish the on-station Telemetry, Tracking and Command (TT&C) operations and the orbit-raising TT&C operations. Figure 1 illustrates these GCS elements. The major functions of the SGCS are as follows:

- Control satellite during transfer and drift orbit operations

  - Orbit determination and control
  - Attitude determination and control
  - Subsystem monitoring and control
  - Apogee Kick Motor (AKM) firing
  - Satellite ManeuversPositioning Satellite on station

- Maintain satellite during on-station operations

  - Stationkeeping
  - Orbit determination
  - Orbit and attitude maintenance and control
  - Subsystem health monitoring and control
  - Recordkeeping, analysis and planning

- Coordination of user agencies

  - Meteorological payload control (VHRR & DCP)
  - Broadcast payload control
  - Communications payload control

For on-station operations, the SGCS consists of only one element, the Master Control Facilities (MCF) located at Hassan, India near the city of Bangalore. The MCF represents the central control point for performance of all satellite TT&C operations. The MCF, consisting of redundant India Department of Space (DOS) furnished Satellite Control Earth Stations (SCES) and redundant Ford Aerospace & Communications Corporation (FACC) supplied Satellite Control Centers (SCC's), is self sufficient to independently support two on-station satellites. The MCF is designed so that either SCES can be connected, via 70 MHz IF patching, to operate with either SCC. Figure 2 illustrates the composition of the MCF.

For the orbit-raising operations, the MCF facility is augmented by remote tracking stations (RTS) located in Carvarvon, Australia (RTS 1) and Tangua, Brazil (RTS 2). These temporary elements of the SGCS are provided via a lease agreement with the INTELSAT Consortium. Activities of the two RTS terminals are coordinated through the RTS Control Center located at INTELSAT Headquarters in Washington, D. C. The final two elements of the SGCS, consisting of the Eastern Test Range (ETS) and either the Goddard Space Flight Center for a Delta 3910 launch or the Johnson Space Center for an STS launch, are provided through NASA as part of the MCF system. These SGCS elements operate in unison, under the direction of the MCF in India, to accomplish the orbit-raising operations.

MCF RESPONSIBILITIES

In addition to the complete SCES RF equipment including a 14 meter full tracking monopulse antenna system, DOS is providing the design and implementation of the MCF site facilities, the uninterruptable power system (UPS), a data collection package (DCP) terminal, and an S-band terminal for Broadcast Satellite Service (BSS). FACC is responsible for the SCC design and launch/ orbital operations support. This division of responsibility allows the host country maximum utilization of indigent technology and industry while placing the mission peculiar specialized hardware, software and services with the satellite manufacturer.

SATELLITE CONTROL CENTER (SCC)

Ford Aerospace & Communications Corporation will provide two essentially identical and independent SCC's within the MCF. Either SCC is capable of acting as the central control point for the performance of INSAT mission operations, including the transfer orbit activities and the on-station activities. The major functions of the SCC in the MCF are:

- Central Control for GSCS Network
- Real-time satellite monitor, control and display
  - Initiate and validate all commands
  - Process telemetry
  - Display spacecraft status and control information
  - Perform range measurements
- Orbital Analysis
- Mission and operational planning
- Maintenance of permanent history records
- Satellite evaluation and performance analysis
- User coordination

Each SCC is equipped to interface with either SCES at 70 MHz IF for:

- Generation of satellite command, ranging and test signals
- Processing of satellite telemetry, ranging and test signals
- Reception of Very High Resolution Radiometer (VHRR) and Data Collection Platform (DCP) payload data

Each SCC is also equipped to interface with the other elements of the SGCS via telecommunications equipment for generation and reception of telex messages and voice communications, and for reception of telemetry and tracking data from the remote tracking stations.

Each SCC is provided with all the facilities required to monitor and control the satellite from injection into transfer orbit through satellite orbital life. To meet this requirement and interface with TT&C characteristics of Table I, each SCC comprises the following major subsystems: command, telemetry, ranging, recording, timing, console, monitor/test and computer. An SCC block diagram is presented in Figure 3 and for simplification shows only one SCC without redundancy.

COMPUTER AND PERIPHERALS

In order to support the data processing requirements associated with satellite operations, the SCC contains a fully redundant computer subsystem, consisting of a pair of PDP-11/70 computers, a variety of peripheral equipment, and three functional groups of software.

The PDP-11/70 is designed to operate in large, sophisticated, high performance systems. It is well suited to the INSAT SCC computation and control tasks since it combines capabilities for highspeed, real-time applications with a capacity for multi-user, time-shared applications requiring complex computations and large amounts of addressable memory space. The PDP-11/70 is a 16-bit word machine with many instructions operating also on 8-bit bytes and is, therefore, ideally suited to the INSAT real-time requirement which is primarily hardware control and telemetry data manipulation. Both of these are 8-bit-byte oriented operations. At the same time, by including a floatingpoint processor, the computer is capable of simultaneously performing precision arithmetic calculations involving either 32 or 64 bits (2 or 4 machine words, respectively) for orbital analysis support. Two word calculations yield 7 decimal digits of accuracy; four-word calculations yield 17 decimal digits.

A variety of computer peripherals have been added to the PDP-11/70 CPU to provide the input, output, and bulk storage capabilities required in the SCC application. These peripherals include several alpha-numeric keyboard (ANK) and cathode-ray tube (CRT) terminals for operator interaction, a typewriter for computer-related messages, a disk unit providing up to 33 million words for bulk storage, a magnetic tape unit as a mass storage backup to the disk, three types of printers for dedicated output of commands, real-time data and analysis and planning information, and a number of special purpose interface devices used for communication with the command, telemetry, ranging, timing, and status display subsystems of the SCC as well as with the SCES antennas. Figure 4 shows one of two computer configurations. It is fully capable of supporting two satellites simultaneously.

A unique feature of the FACC designed SCC is the utilization of one computer to perform both real-time and orbital analysis functions at the MCF. Previous ground control systems have used on-site minicomputers for real-time telemetry and command functions, but employed large off-site computer connected by telecommunication lines for all orbital analysis functions.

COMPUTER SOFTWARE

The software associated with the computer subsystem is organized into three functional groups. The first group is the Operating System provided by the computer manufacturer. It provides the executive control of computer operations and also includes several support and utility functions for data management. The second group is the Real-Time Software which supports the real-time and near real-time operations of the SCC. These consist of telemetry processing and display, satellite command generation and verification, tracking data collection, antenna drive control, event recording, and data base management. The third group is the Analysis and Planning Software used for control of the orbital mission and evaluation of performance. It provides support for the tasks of tracking data editing and orbit determination, ephemeris generation and events prediction, apogee boost maneuver planning and evaluation, station acquisition and stationkeeping orbital control, and evaluation of spacecraft operation through telemetry data analysis. A diagram illustrating the functional grouping of the software is presented in Figure 5.

Operating System - The RSX-11M operating system is supplied with each of the SCC computers. The executive is designed to provide a resource-sharing environment ideal for multiple real-time activities. It features multiprogramming, which is the concurrent processing of two or more tasks (program images) residing in memory. Task scheduling is primarily event driven with software priority assigned to each active task.

Real-Time Software - The Real-Time Software has seven major functions which operate under the control of the RSX-11M operating system. The following paragraphs briefly describe each of these functions:

Telemetry Processing - The Real-Time Software must acquire and process two telemetry data streams (one from each satellite) into engineering units data. The acquired data is stored both in core memory and disk files. Analog and status values are monitored on a regular basis to detect actual or potential spacecraft problems. This is accomplished by limit check and CRT display processes. In addition, the raw telemetry data is recorded on the telemetry disk files for subsequent use by the Analysis and Planning Software.

Display Processing - The display function formats data from the telemetry module, data base, and certain disk files generated by the Analysis and Planning Software for display on up to four CRT's. The displays are controlled by an operator who may select which page of data to display. In addition to providing the selected data in an easily readable format (ie, with alphanumeric name fields, engineering units, etc.), other important system conditions such as alarm information and time are regularly updated. The operator has the capability to print a hardcopy of any CRT page on the line printer.

Tracking Control - The tracking function provides the support for both the antenna control unit and the ranging unit. Several different modes of operation may be selected by the operator. These include:

- Range and antenna angle track file collection (used by the Analysis and Planning Software for orbit calculations)

- Program controlled tracking

- Monitor mode

- Search mode

Satellite Commanding - The satellite commanding function allows the operator to send commands to either spacecraft. Commands are entered by a numeric code and the software converts the entry into the correct command generator binary format. Features such as special restricted commands, automatic verification, override, and command execution validation (from the telemetry data) are provided. All command information is printed at a special command log printer.

Data Base Management - This function provides for generation and maintenance of the data base files necessary for the Real-Time Software functions. The data base can be generated or modified by operator entered commands. In addition, commands to save and restore the data base to disk are also supported. Selected data base items may be displayed to the operator in either a page mode or step mode display format.

Event Recording - This function provides for recording important system events. The events are classed into three groups:

- Alarm conditions which require operator attention
- Significant operational events
- Satellite command log

While each class of events has a different recording procedure, all events are tagged with time and printed or displayed to the operator via the CRT's.

Analysis and Planning Software - The Analysis and Planning Software consists of 11 major functions which may be selected via a special executive function operating under control of the RSX-11M operating system. The following paragraphs briefly describe each of these functions:

Executive - The executive function provides the user with a convenient means to control the operation of the various computational processes available in the analysis and Planning Software. It interprets operator requests to initiate the desired function and to transfer parameter values that define the computational conditions.

Data Base Control - A large body of data is used in the Analysis and Planning Software applications. This function provides data management facilities for this data base. Its capabilities include creating, saving, deleting, modifying, or printing selected parts of the data base.

Orbit Parameter Control - This function provides a means of specifying orbit initial conditions and velocity discontinuities representing impulsive maneuvers. Operator inputs in a variety of coordinate systems are accepted, converted to a uniform coordinate system, and stored in the data base.

Tracking Data Edit - This function is used to prepare the raw tracking observations collected via the Real-Time Software for the process of orbit determination. It retrieves the raw measurements of range, azimuth and elevation from a disk file, applies corrections for time delays and atmospheric effects, compact the data at the operator direction and formats the results in another disk file for subsequent use in orbit determination.

Orbit Determination - This function is the basic orbit determination process. Using the processed tracking data it performs a least squares solution to the orbit determination problem via the process of differential correction, iteratively refining an initial estimate of orbit elements, model parameters and observational biases. The operator may select a subset of these solution parameters for a given problem. This function also provides the capability to generate an initial estimate of the orbit elements from the tracking data.

Events - The events output function generates predictions of ephemeris related events and conditions over a specified time span. These include apsis and node crossings, earth and moon eclipses, visibility conditions, spacecraft position and velocity in several coordinate frames, as well as in relation to a ground station and a set of polynomial coefficients for use by the Real-Time Software in controlling antenna pointing.

Ephemeris Generation - The ephemeris generation function serves as the primary source of ephemeris data for the other Analysis and Planning Software applications. It provides a disk file of stored ephemeris information by integrating the equations of motion for a spacecraft subject to a variety of special perturbations - twelfth order harmonics of earth gravity, luni-solar gravity, atmospheric drag, solar radiation pressure, and impulsive velocity changes. Access to the ephemeris information is provided by two subroutines for initialization and retrieval. A special interface with the differential correction function provides integration of variational equations when solving for model parameters.

Apogee Burn - This function provides the calculations required for planning and analyzing the apogee burn maneuver. It calculates the orientation and time of ignition of the spacecraft's apogee motor in order to achieve a drift orbit with operator specified characteristics. The maneuver may be considered in two segments or as a single segment. Parametric variation may be specified to study a range of conditions. Also, the sensitivity of final orbit characteristics to errors in the control variables may be calculated to assist in analysis.

Stationkeeping - The stationkeeping function provides a number of calculation modes in support of maneuver planning in the drift orbit as well as the final orbit. For station acquisition, three modes provide for apsis control (eccentricity management), prediction of spacecraft deviation from its station, and maneuver calculation to arrive on station at a specified time. For east-west stationkeeping, three modes provide planning for the selection of initial conditions, a maneuver calculation for setting radius at one point in the orbit, and a maneuver calculation for setting drift rate. For north-south stationkeeping, two modes provide planning for the selection of an optimum initial node and a maneuver calculation to achieve that node.

Orbit Maneuver Command - This function accepts the maneuver requirements calculated by the stationkeeping function and calculates the appropriate spacecraft command sequence. Using a model of thruster performance characteristics, this program will refer to the data base for current spacecraft properties (mass, fuel pressure) to estimate the control settings to implement the specified velocity change.

Telemetry Analysis - The telemetry analysis function accesses the 30 hour telemetry data file created by the Real-Time Software to retrieve data for tabulation, plotting, and summary reports. Tabulation creates a list of analog data items and change indications for status items. Plots are produced by graphic display of analog data variations with time or as a function of another analog item. Summary reports consist of statistical values for analog items and counts of status changes over a specified time interval.

Sensor Intrusion - This function predicts intrusions of either the sun or the moon into the fields of view of the earth sensors and to within a specified angle of the center line of the VHRR.

SCES DESCRIPTION

The DOS-supplied SCES provides all radio frequency transmission and reception equipment, including tracking antennas, power amplifiers, low noise receivers, and frequency conversion equipment to interface at 70 MHz IF to the FACC-supplied SCC's. Figure 1 shows the MCF definition, including interconnections between DOS-furnished SCES and FACC-provided-SCC. As evident from the figure, both SCES's and SCC's will be cross-strapped for increased reliability and maximum availability. Should major equipments in either SCES or SCC fail, the MCF can continue to meet the INSAT mission requirements.

Each SCES consists of a fully steerable 14 meter cassegrain parabolic antenna, two receive chains for telemetry/ranging, and two uplink transmission chains for command/ranging. In addition, each SCES will be equipped with antennas/receivers/ downconverters to make available two TV transmissions from the satellite in S-band, one Data Collection Platform (DCP) channel at C-band, one VHRR channel at C-band, and one telecommunications test channel at C-band. As part of the SCES, upconverters for transmission of TV and telecommunications test signals in the 6 GHz band are provided. Also a transmit capability at 400 MHz is provided for DCP test and evaluation. All interfaces in the uplink and downlink chains will be at 70 MHz, with patching facilities between each SCES and the appropriate demodulation/modulation baseband equipment of either SCC.

A block diagram of the SCES is shown in Figure 6. A summary of the salient features of the SCES is given in Table II.

REMOTE TRACKING STATION (RTS)

RTS General Description - Remote tracking station services in support of the orbit-raising operations for INSAT launches will be leased from INTELSAT. With one RTS located in Carnarvon, Australia, and another RTS located in Tangua, Brazil, nearly continuous TT&C visibility of a satellite in transfer orbit is available during the initial three orbits. The support requirements for each RTS during these activities provide:

- Tracking and ranging data for the MCF
- Telemetry data for the MCF
- Satellite backup command capability

RTS FUNCTIONAL DESCRIPTION

When an INSAT becomes visible to an RTS, the RTS tracks and performs ranging measurements with the satellite. Resulting data, consisting of station identification, antenna azimuth and elevation angles, satellite range measurement, and data time tag are forwarded to the RTS Control Center (RTS/CC) in Washington, D. C. The RTS also receives the satellite telemetry and records, decommutates, and displays this data while forwarding it to the RTS/CC.

Commands can be generated locally from each RTS for transmission to the satellite; however, because the RTS activities are directed from the RTS/CC, commands are initiated only on instruction from the RTS/CC which would initiate a command sequence only at the direction of the MCF in India.

RTS PERFORMANCE CHARACTERISTICS

Each RTS is a full performance TT&C station with 13 meter full motion antennas and 50°K LNA's. All critical equipments (HPA's, LNA's, converters, receivers, etc.) are redundant.

The antenna is capable of remotely controlled circular, and linear right and left-hand polarization of any angle. Transmission polarization is orthogonal to reception. The antenna servo system is capable of movements of 3°/s in azimuth and elevation in program, manual, and autotrack modes. The station is equipped with synthesizers to provide selection of command and telemetry carriers. Since the INSAT TT&C characteristics are fully comparable with INTELSAT, command, telemetry, and ranging functions can be handled by existing RTS equipments.

Table III presents the performance characteristics of the RTS's.

CONCLUSION

The system described will be the first domestic satellite ground control system to offer complete real-time processing of command/telemetry, and orbital analysis planning in one minicomputer-collocated at a central Master Control Facility. This approach allows efficiency in system implementation and operation by centralizing maintenance, operational, satellite analysis, and orbital analysis personnel at the Satellite Control Center.

ACKNOWLEDGEMENT

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REFERENCES

1. SAHA, M. K., "Salient Features of INSAT-I Space Segment System" AIAA 8th Communications Satellite Systems Conference, Orlando, Florida, AIAA CP802, April 1980, 18-31.

Table I

INSAT TT&C CHARACTERISTICS

Command	
Frequency (MHz)	
Channel 1	6258
Channel 2	6262
Modulation	PCM-FSK-FM
Carrier dev. (kHz)	±400
Data Rate (b/s)	100 ±2%
RF Bandwidth (MHz)	1.56
Link Design BER	10^{-6}
Telemetry	
Frequency (MHz)	
Channel 1	4031
Channel 2	4039
Modulation	PCM-PSK-PM
Carrier dev. (radians)	1 ±0.1
Subcarriers (kHz)	
PCM/PSK	32.0
Data Rate (b/s)	1000

Main Frame Rate	0.512 sec/frame with Dwell mode cap.
Frame Format	64 words (8 bits word length)
EIRP (dBw)	11 dBw max. for sync. orbit
Link Design BER	10^{-4}

Ranging

Modulation	
Uplink	FM
Downlink	PM
Range Tones (kHz)	
No. 1	27.777 or 19.000
No. 2	3.968
No. 3	0.2834
Carrier dev.	
Uplink (kHz)	±400
Downlink (radians)	1 ±0.1
Link Design	
Ranging Error (M)	<50M

Table II

SCES PERFORMANCE CHARACTERISTICS

C-Band (TT&C, VHRR and Comm Test)

Antenna Size	14 Meter Parabolic Dish
Mount	Elevation over azimuth
Antenna Coverage	0 to 90° elevation ±270° azimuth
Feed	Cassegrain with monopulse tracking
Servo Tracking Rate	1°/second
Servo Tracking Acceleration	$0.2°/sec^2$
Servo Slew Rate	2°/second
Tracking Error	.04° RSS peak
Pointing Error	.08° RSS peak
Transmit Band	5855 to 6425 MHz
Receive Band	3700 to 4200 MHz

Polarization	
a) Communication	Rotatable linear with option to use circulator of either sense
b) Tracking	Circular
Antenna Gain	
Transmit	56.0 + 20 log f/6 dB
Receive	53.0 + 20 log f/4 dB
Sidelobes	CCIR Recommendation 965-1
G/T	31.7 dB/°K at 4 GHz and 5° EC
EIRP	85 dBW
EIRP Stability	±0.5 dB/day

S-Band (TV Broadcast Receive)

Antenna	6.1 meter parabolic chicken mesh reflector
Antenna Mount	X-Y
Receive Frequency	2555 to 2635 MHz
Antenna Gain	41.8 dB at 2600 MHz
Sidelobe Level	-20 dB
Receive G/T	13.4 dB/°K at 2600 MHz
Polarization	Left hand circular

UHF (Data Collection Platform Transmit)

Antenna (shared with S-Band)	6.1 meter parabolic chicken mesh reflector
Frequency	402.75 ±0.100 MHz
EIRP	30.0 dBW
Gain	22 dB

Table III

RTS TYPICAL PERFORMANCE CHARACTERISTICS

Frequency	
Uplink	5925 to 6425 MHz
Downlink	3700 to 4200 MHz
Station G/T @ 10° El	33 dB/Hz
System Noise Temperature	100K
EIRP	90 dBW
Antenna Gain	53 dB @ 4 GHz
	56 dB @ 6 GHz
Azimuth Travel	±270°
Elevation Travel	0 to +92°
Tracking Threshold	-134 dBm
RMS Tracking Error	0.02°
Tracking Velocity	3.0°/s
Tracking Acceleration	1.0°/s
Angle Resolution	0.01°
Range Resolution	10m
Time Resolution	1 sec

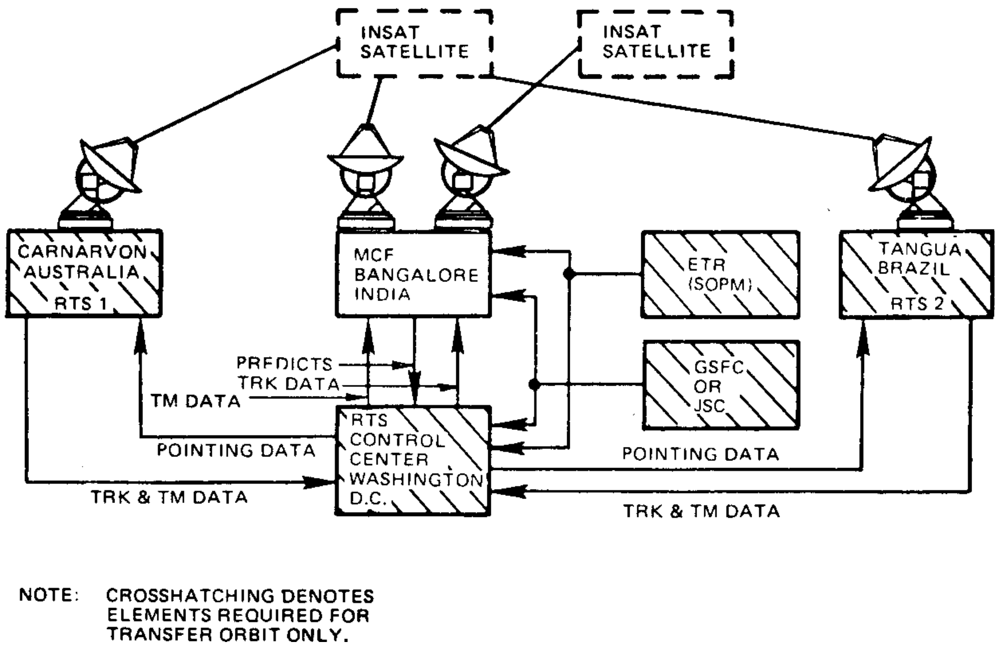

Figure 1. Satellite Ground Control System Elements for INSAT

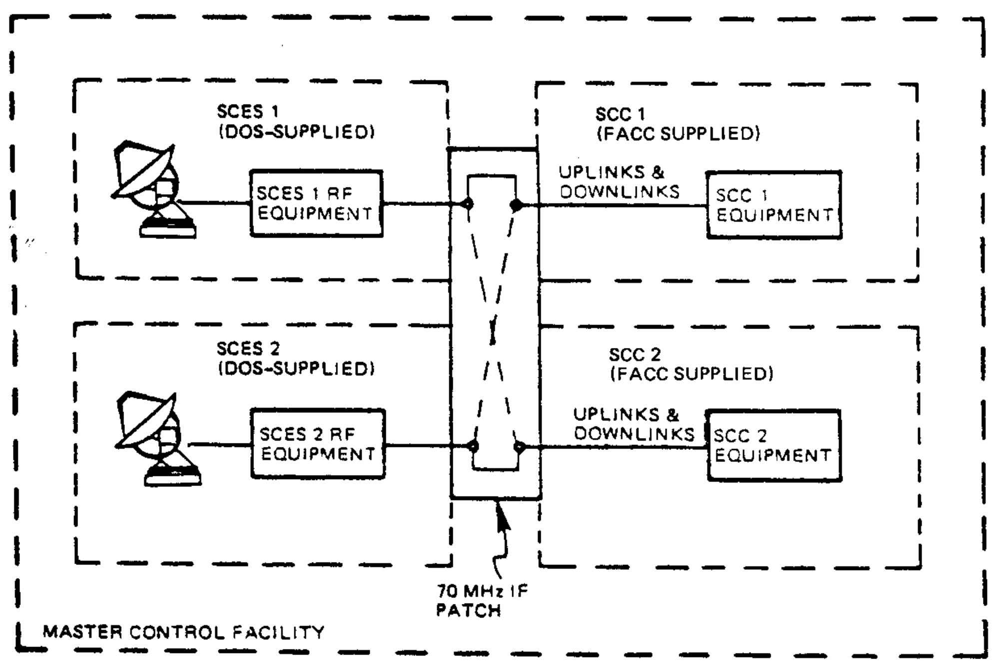

Figure 2. Master Control Facility (MCF) Elements

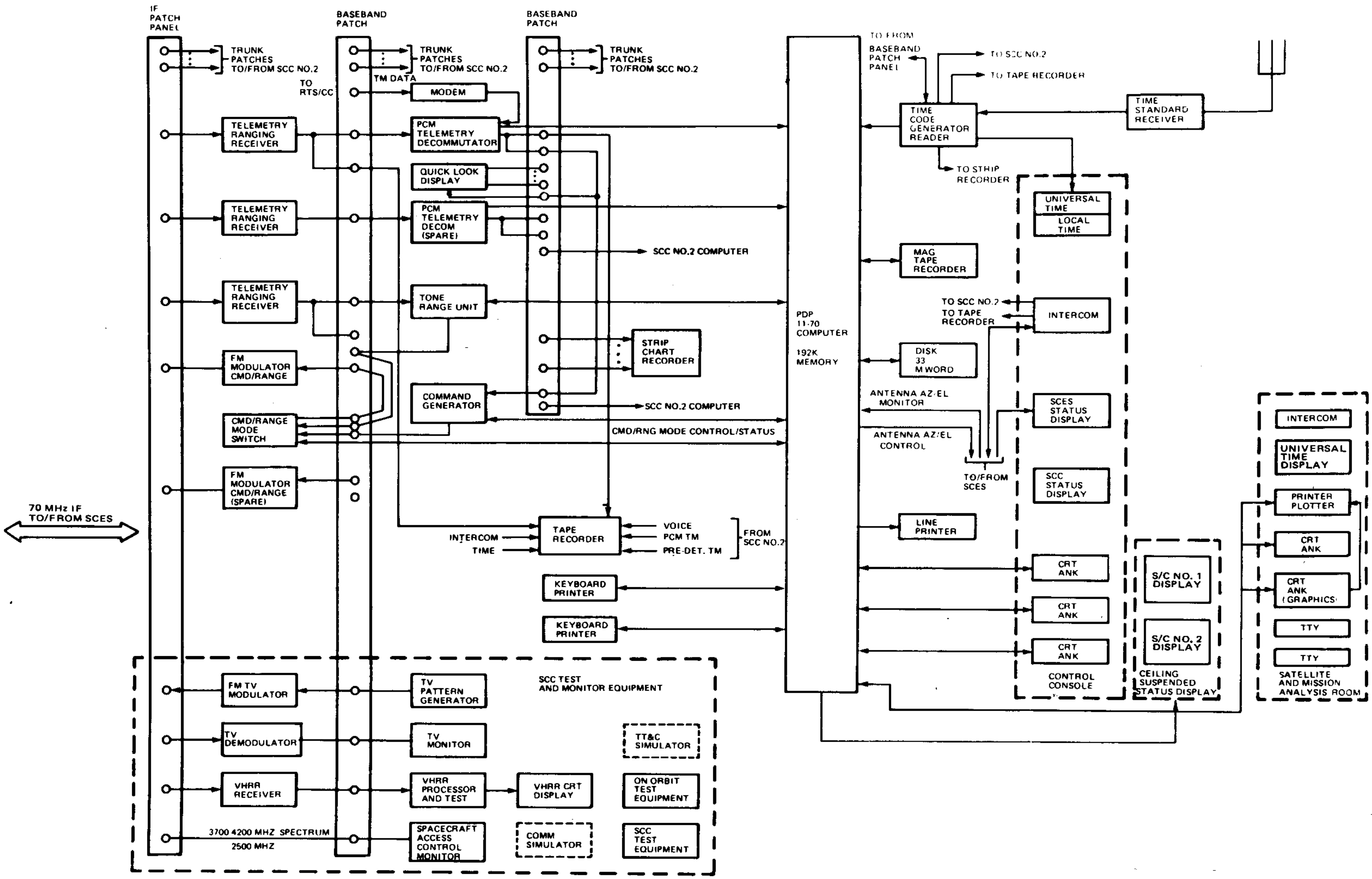

Figure 3. SCC 1 System Block Diagram

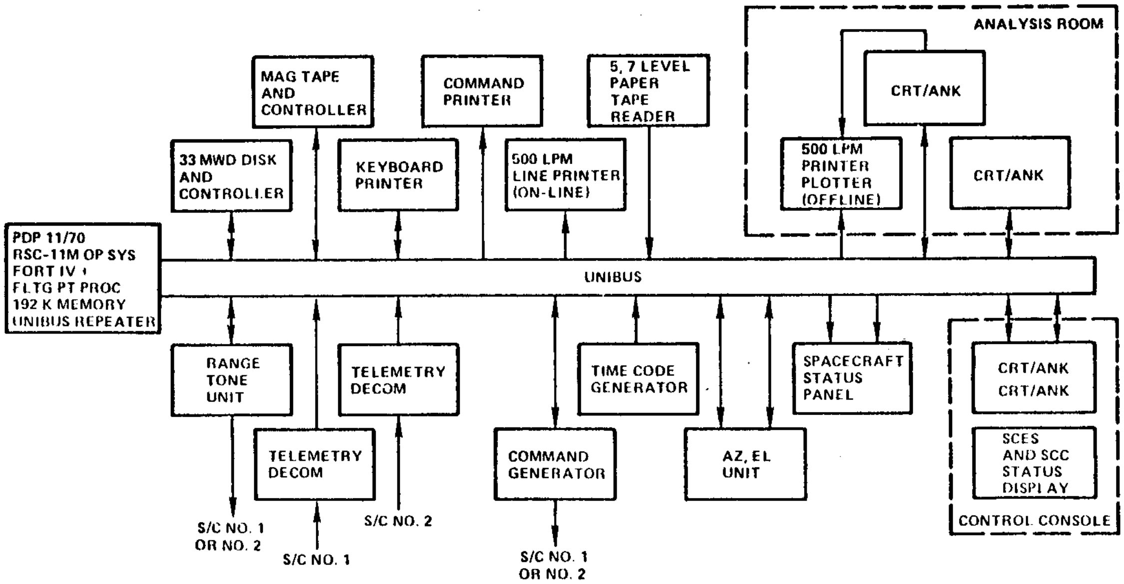

Figure 4. Computer Subsystem Diagram

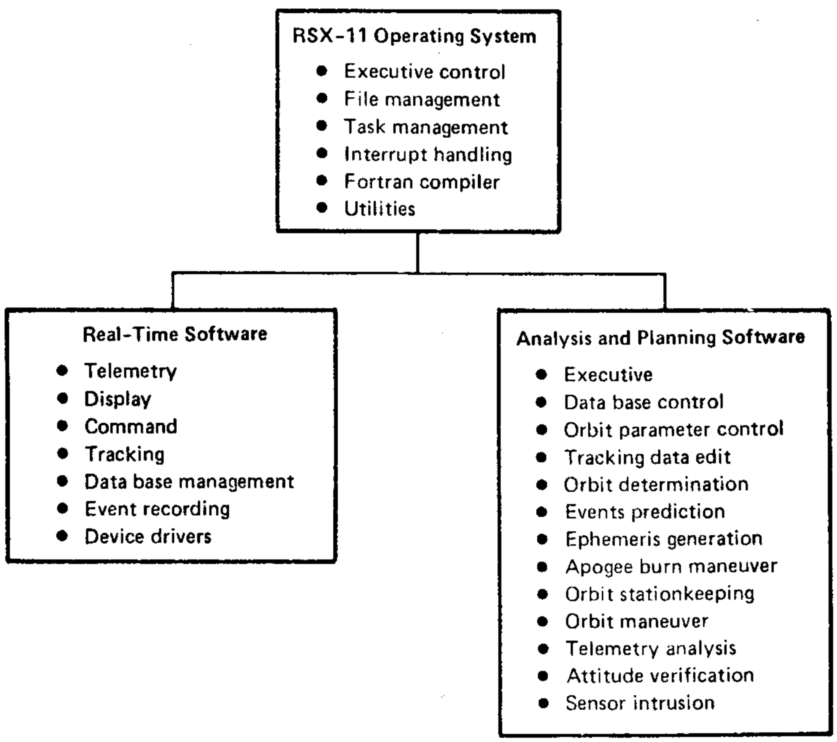

Figure 5. Software Functional Grouping

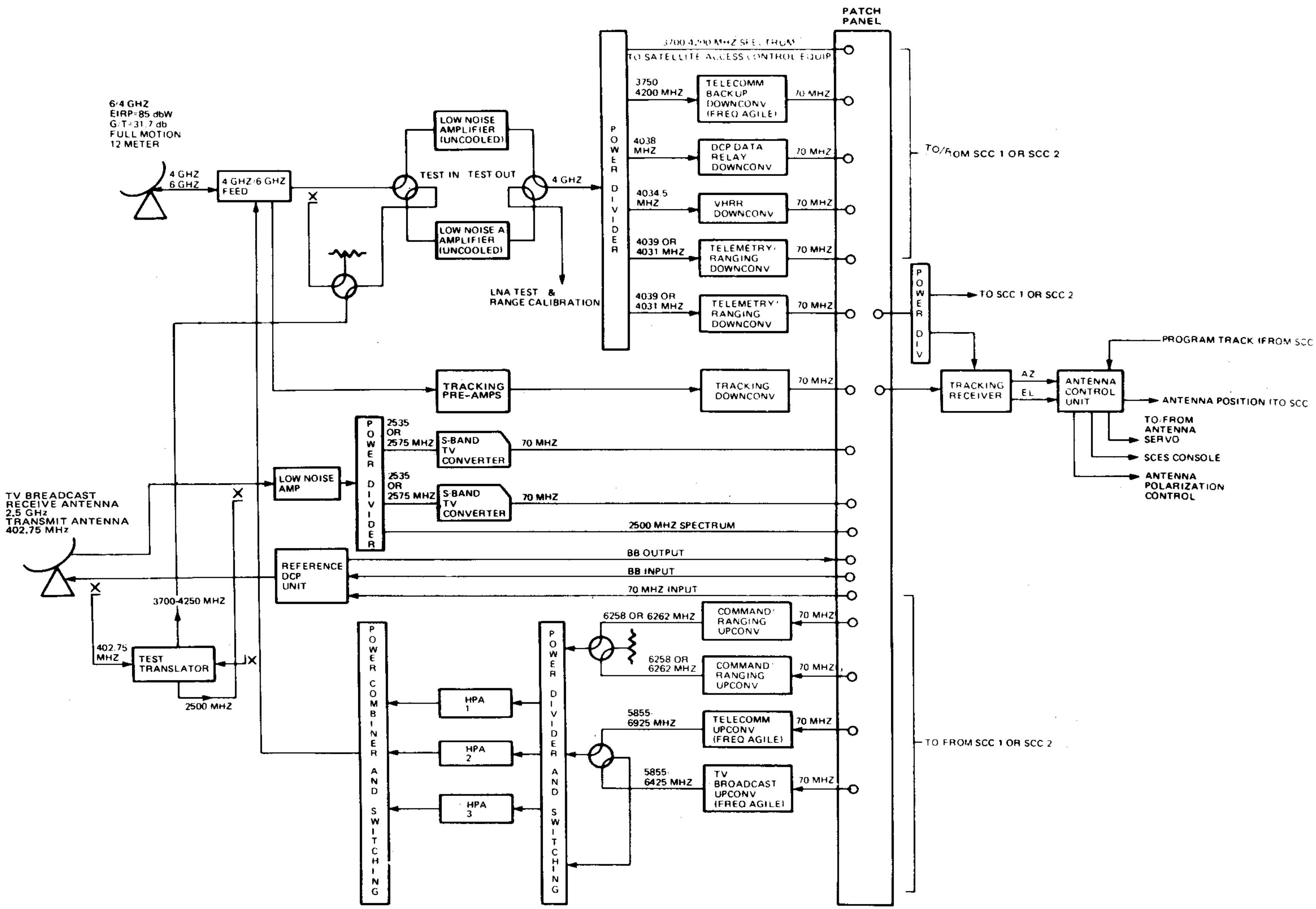

Figure 6. Satellite Control Earth Station (SCES) Functional Block Diagram