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DSN Command System Mark IV-85

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This article presents a functional description of the Deep Space Network Command System and its subsystems as implemented in 1985.

I. Mark IVA Network Implementation

A. General

The Mark IVA Network implementation, completed in 1985, provides a Signal Processing Center (SPC) at each of the three Deep Space Communications Complexes (Goldstone, California; Canberra, Australia; and Madrid, Spain). The Ground Communications Facility (GCF) provides communications between JPL and each SPC. The Networks Consolidation Program (Ref. 1) required the Mark IVA Network to support high-apogee Earth-orbital missions in addition to the deep space missions.

Figure 1 is a block diagram of the DSN Command System Mark IV-85. Each Deep Space Communications Complex (DSCC) has a 64-m antenna with deep space uplink, a 34-m antenna with both deep space and Earth-orbiter uplinks, and a 26-m, former Ground Spacecraft Tracking and Data Network (GSTDN) antenna with Earth-orbiter uplink. (A decision to incorporate the 26-m, instead of the 9-m, GSTDN antennas in the Networks Consolidation Program was made after the publication of Refs. 1 and 2.)

B. DSN Command System Implementation

The DSN Command System Mark IV-85 was implemented approximately in accordance with the plan described in Ref. 2. The Mark IVA configuration at each complex includes four strings of DSCC command subsystem equipment. The DSCC Monitor and Control Subsystem, as shown in Fig. 1, provides operation of any three strings.

C. Performance Requirements

Support of the Mark IVA mission set requires Command System performance characteristics compatible with the NASA standard transponders, which are to be used on future spacecraft, and also compatible with current inflight spacecraft and certain planned spacecraft that do not use the standard transponder. Some of the required capabilities are listed below:

(1) Data rates. Data rates from 1 to 2000 bits/s are provided.

(2) Subcarrier frequencies. Sine-wave and square-wave subcarriers are generated at frequencies of 100 Hz to 16 kHz.

(3) Subcarrier data modulation. Selection is provided for phase-shift-keyed (PSK) or frequency-shift-keyed (FSK) modulation of the subcarrier by a pulse-code-modulated NRZ-L command symbol stream. An option for amplitude modulation (AM) of the FSK subcarrier is also provided.

(4) Carrier modulation. The command-modulated subcarrier is phase-modulated on an S-band carrier for radiation to the spacecraft. Control of modulation index angle is provided over a range from 0.35 to 1.5 rad.

(5) Carrier frequencies. Generation of the uplink carrier at S-band frequencies assigned for deep space missions is provided at the 64-m and 34-m antennas. S-band frequencies assigned for Earth orbit missions are provided at the 34-m and 26-m antennas.

II. Store-and-Forward Command Functions for Deep Space Missions

Many of the spacecraft supported by the DSN have onboard storage and sequencing capabilities that permit command sequences to be sent well in advance of the actions to be taken by the spacecraft. Thus, fewer direct action (real-time) commands are needed. Ground system capabilities providing massive storage of spacecraft commands, multimission operating functions, and standardized protocol were incorporated in the DSN Command System in 1978 (Ref. 3). These capabilities are continued in the Mark IV-85 system configuration.

A. Operational Functions

End-to-End spacecraft command operations are represented functionally in Fig. 2. Command sequences for one or more spacecraft are generated and stored at a Mission Operations Center (MOC). Commands for a particular spacecraft are selected from the command files, formatted into messages, and stored for transmittal to a specified link of a DSCC. Command data are extracted from the message received and are stored and queued until radiated. Finally, the commands arrive at the spacecraft and are either executed immediately or stored aboard for later execution.

The functions of the DSN Command System in this process include the following:

(1) Establishing the DSCC configuration for the specified spacecraft.

(2) Receiving and storing command data at the DSCC.

(3) Queuing command data to be radiated to the spacecraft.

(4) Radiating the command data to the spacecraft.

(5) Monitoring system status and reporting events and alarms.

B. Operational Procedure

The key onsite input to the DSCC Command (DCD) Subsystem is the spacecraft number (SCN). This input causes the Command Processor Assembly (CPA) software to transfer a specified configuration and standards and limits table from disk storage to memory, and to configure the Command Modulator Assembly (CMA) according to the table. Standards and limits changes may later be made by messages from the Network Operations Control Center (NOCC) via the GCF (or by keyboard entries at the Link Monitor and Control Console in an emergency).

Prior to the beginning of the scheduled spacecraft track, the control of DSCC command functions is transferred to NOCC. Configuration standards and alarm/abort limits can be updated by GCF transmission of messages from the NOCC Command Subsystem (NCD) real-time monitor processor. The standards and limits are derived from files compiled in the NOCC Support Subsystem. Spacecraft-dependent parameters, such as data rate, subcarrier frequency, alarm limits, and abort limits, are established via these messages. After the proper configuration standards and limits have been established, test commands are transmitted through the system to ensure that the system can accept spacecraft commands via GCF, temporarily store the commands, and confirm radiation. During this test the transmitter output is radiated into a dummy load. After the Network Operations Control Team (NOCT) has established that the system is operating properly, the station operator switches the transmitter to space radiation, and the NOCT transfers command data control to the flight project's MOC for loading of actual spacecraft command sequences to be radiated to the spacecraft during the track period.

At the time for radiation of each command element, the subsystem advances to the active mode (see Fig. 3 for description of the various modes) and command data are transferred from the CPA to the CMA for radiation via the Receiver-Exciter, Transmitter, Microwave, and Antenna Subsystems.

C. Command Data Handling

The DCD Subsystem design allows mission operations to prepare large files of spacecraft commands in advance and then to forward several files to the DSCC link at the beginning of a spacecraft track. The design also provides real-time system status monitoring and control. For protection of data integrity, every message block to or from the CPA contains a block checksum, in addition to the GCF error detection provisions.

1. **Command files.** Each file may consist of up to 256 GCF data blocks. The content of each data block is a file element. The first block in a file contains the *header element* and each subsequent block contains a *command element*. Each command element may consist of up to 800 bits of spacecraft command data. Up to 8 files for a given mission can be stored by the CPA. Thus, the available storage is over 1.6 million command bits.

The header element contains file identification information, file processing instructions, and a file checksum. The file processing instructions include optional file radiation open and close window times, and an optional file bit 1 radiation time. File open and close window times specify the time interval during which a command file may be radiated (i.e., a mission sequence may demand that specific commands not be sent before or after a certain time). The bit 1 radiation time allows the project to specify the exact time at which the file is to begin radiation to the spacecraft. The file checksum is created at the time of file generation and is passed intact to the CPA. It adds reliability to ensure that no data were dropped or altered in the transfer of the file from one facility to another. (This is in addition to the previously mentioned block checksums.)

The command elements each contain command bits, file identification, element number, element size, and an optional "delay time" (interval from start of previous element). If delay time is not specified, the element will start radiating immediately after the end of the previous element.

2. **Receiving and storing command data at a DSCC.** Normally, the files of commands to be radiated to the spacecraft will be sent from the MOC to the specified DSCC link at the beginning of a spacecraft track period. However, files may be sent to the DSCC link at any time during the spacecraft track period. The first step in receiving and storing command data at a DSCC is the process of opening a file area on the CPA disk. The MOC accomplishes this by sending a header element, which serves as a *file-open* directive. After the CPA acknowledges receipt of the header element, the MOC sends the remainder of the file (up to 255 command elements) and follows it with a *file-close* directive. The CPA acknowledges the file-close instruction and indicates whether the file loading was successful or unsuccessful. If the file loading was unsuccessful, the acknowledge message contains the reason for the failure and from what point in the file the command elements are to be retransmitted. When the file is successfully closed, the MOC may proceed to send additional files until the eight-file directory in the CPA is full.

3. **Queuing the command data for radiation.** After the files are stored at the CPA, the MOC then sends a *file-attach* directive for each of up to five file names to be placed in the radiation queue. The Mission Control Team determines in which order the files are to be attached. The order in which the file-attach directives are received at the CPA determines the sequence in which the files will be radiated; that is, first attached, first to radiate to the spacecraft

4. **Command radiation to the spacecraft.** The first command element in the top (prime) file in the queue begins radiation to the spacecraft immediately after attachment or as soon as all optional file instructions (such as bit 1 radiation time) are satisfied. Upon completion of radiation of the first command element, the second command element begins radiation either immediately or when the optional delay time has been satisfied. The process continues until all command elements in the file have been radiated. After the first file completes radiation, the second file in the queue automatically becomes the prime file and the command radiation process is repeated. After the second file completes radiation, the third file becomes prime, etc. This process is repeated until all files in the queue are exhausted. The MOC can attach new files to the queue whenever space is available.

Confirmations of prime-file command-element radiations are reported in *event* messages to the MOC and NOCC once per minute, or after five elements have been radiated, whichever occurs first. If a command element is aborted, an event message is sent immediately.

Status messages are sent to the MOC and NOCC once per minute and whenever an alarm occurs.

5. **Additional data processing.** The foregoing descriptions of the DSCC functions of storing the command files, attaching the files to the queue, and radiating the commands to the spacecraft assume nominal (standard) operation. Additional data processing functions are provided for non-nominal operations and failure recovery. Control of these functions is normally exercised remotely from the MOC. However, emergency control is also available at the SPC.

a. File erase. A file can be deleted from storage at the CPA by means of a *file erase* directive, if the file is not attached to the radiation queue.

b. Clearing the queue. As previously stated, the order of file radiation to the spacecraft is dependent on the order of files in the queue. To rearrange the order, a *clear-queue* directive must be sent, followed by file-attach directives in the desired order.

c. Suspend radiation. If the Mission Control Team desires to stop command radiation, a *suspend* message can be sent to the CPA. This message suspends command radiation to the spacecraft upon completion of the current element. When the prime file is suspended in this manner, the DCD remains in the Idle 2 mode.

d. Resume command radiation. To restart radiation of a suspended file (either suspended intentionally or from an abort), messages can be sent to *resume* radiation *at* any specified unconfirmed element in the file. The suspend and resume-at directives can be used for skipping elements of the prime file, if desired.

e. Command abort. As each command bit is radiated to the spacecraft, numerous checks are made to ensure validity of the command data. If a failure is detected during the radiation, the command element is automatically aborted immediately, the prime file is suspended, and radiation is terminated until a mode update directive and a resume-at directive are received

In addition to the automatic abort function, there is provision for the MOC to send an *abort-and-suspend* directive to terminate command radiation immediately without waiting for completion of an element.

f. Close-window time override. If a close-window time is specified in a file header element, and the Mission Operations Team later decides to extend the permissible time for radiation of the file, an *override* message can be sent (after the file becomes prime), which instructs the CPA to ignore the close-window time.

D. Data Records

All message blocks received by the CPA and all blocks sent from the CPA are logged at the DSCC on the Original Data Record (ODR). Message blocks from the DSCC are also recorded at the GCF central communications terminal (CCT).

The DSCC original data records and the CCT recording provide information for fault isolation in case problems occur in the Command System operation.

III. Throughput Command Functions for Earth-Orbiter Missions

The Mark IV-85 Network provides support for several low Earth Orbiters and geosynchronous orbiters that were not included in the original networks consolidation programs. Former GSTDN data processing and communication equipment has been retained in the 26-m antenna control centers for such missions (Ref. 4). Spacecraft commanding is handled by the Spacecraft Command Encoder (SCE) with real-time, "throughput command" protocol.

The command-modulated subcarrier output from the SCE is usually routed to the 26-m antenna exciter, but can be sent to the 34-m antenna exciter for emergency backup.

Command data are communicated via NASCOM to the SCE from the flight project's MOC for immediate radiation to the spacecraft. The data are formatted in message blocks containing up to 4592 bits each. The SCE can buffer up to 5 blocks before starting radiation of a block sequence.

Upon receipt of each throughput command data block, the SCE checks the block for correctness and, if the block is acceptable, returns a "command echo block" to the MOC. If a block is not acceptable to the SCE, it is discarded, and the MOC must try again.

Monitoring of command system status and alarms in the 26-m antenna control center is done by a local operator who reports by voice to the Network Operations Control Team.

IV. Subsystems Configurations for Mark IV-85 System

Modifications and reconfiguration of subsystems for the DSN Command System Mark IV-85 are summarized below.

A. Antenna Mechanical Subsystem

At Canberra and Madrid all antennas are located near the SPC. At Goldstone, the 64-m antenna is located near the SPC. The Goldstone 34-m S-band uplink antenna and the Goldstone 26-m former GSTDN antenna remain at their original locations, and are connected to the SPC via the GCF intersite analog communications subsystem. In addition to their SPC cross-support connections, all of the 26-m antenna stations retain their own control, processing, and NASCOM communications equipment for support of Earth-orbiter missions.

B. Antenna Microwave Subsystem

For the 64-m antenna at each complex, the Antenna Microwave Subsystem uplink frequency range is 2090 to 2120 MHz to provide command coverage in the upper end of the Earth-orbiter S-band and all of the deep space S-band allocation. The Microwave Subsystem of the 34-m S-band antenna will handle uplinks over the range of Earth-orbiter and deep space frequency allocations (2025–2120 MHz). The 26-m Antenna Microwave Subsystem also covers the 2025- to 2120-MHz range, for routine support of Earth orbiters and for post-launch initial acquisition of deep space mission spacecraft.

The 64-m Antenna Microwave Subsystem provides selection of linear, right-circular, or left-circular polarization of the S-band uplink. The 34-m and 26-m antennas are provided selection of right-circular or left-circular polarization.

C. Transmitter Subsystem

The 64-m antenna has a high-power and low-power transmitter. The high-power transmitter provides up to 400 kW at frequencies of 2110 to 2120 MHz and up to 300 kW at 2090 MHz. A 100-kW Klystron tube is also available as a spare. The low-power transmitter provides up to 20 kW in the 2110- to 2120-MHz range.

The 34-m and 26-m antennas have tunable transmitters for the 2025- to 2120-MHz frequencies. Tuning is in 20-MHz steps. Maximum operating power is 20 kW on the 34-m antenna and 10 kW on the 26-m antenna.

D. Receiver–Exciter Subsystem

Functions of the Receiver–Exciter Subsystem include sending on/off messages to the DCD, receiving the command-modulated subcarrier from the DCD, phase-modulating that baseband signal on the uplink carrier, and returning a baseband verification signal to the DCD.

The Block 4 S-band exciter for the 64-m antenna covers a frequency range equal to that of the Antenna Microwave Subsystem. Minor modifications of the verification detector circuitry were made to provide an acceptable interface to the new CMA. The Block 3 exciter for the 34-m stations was upgraded to cover the full range of Earth-orbiter and deep space uplink frequencies. The GSTDN S-band exciter is retained for the 26-m antenna.

E. DSCC Command Subsystem

In the Mark IVA Network configuration the Command Subsystem in the SPC at each complex is implemented as shown in Fig. 1. The new Command Switch Assembly permits any of the exciters to be connected to any CMA under control of the Complex Monitor and Control console. New CMAs were implemented to accommodate the Mark IVA mission support requirements. The CPAs use existing Modcomp II-25 computers with core memory increased to maximum capacity. CPA software was upgraded to satisfy new mission support requirements, to modify the CMA interface functions, and to provide required functions for interfacing with the new DSCC Monitor and Control Subsystem.

F. DSCC Monitor and Control Subsystem

New equipment was implemented for the DSCC Monitor and Control Subsystem (DMC) at each complex in the Mark IVA Network configuration. Assignment of command equipment (antenna, transmitter, exciter, and command modulator-processor combinations) to a given "link," for each scheduled spacecraft pass or for a scheduled test, is accomplished by the DMC along with telemetry and tracking equipment assignments. Prepass countdown is controlled by inputs at the Link Monitor and Control console.

The DMC receives antenna pointing and uplink frequency predictions and relays them to the appropriate subsystems. The DMC sends link status information to the CPA, and the CPA sends command system status information to the DMC for link console displays.

G. GCF Subsystems

In the Mark IVA Network configuration, the GCF Digital Communication (GDC) Subsystem replaces the Mark III GCF High-Speed Data and GCF Wideband Data Subsystems. Command data blocks are communicated at a line rate of 56 kb/s, between the Central Communications Terminal at JPL and the Area Routing Assembly at each DSCC.

At the Goldstone DSCC the GCF Intersite Analog Communications Subsystem communicates the CMA signal from the SPC to the DSS 12 and DSS 16 exciters.

H. NOCC Command Subsystem

The NOCC Command Subsystem Real-Time Monitor software was upgraded to accommodate new destination codes, spacecraft identifiers, standards and limits tables, and test command tables. The NOCC Support Subsystem provides capability for generating test command files and configuration standards and limits tables.

V. Mark IV-88 X-Band Uplink

The Mark IVA Network configuration includes a 34-m, high-efficiency (HEF), downlink-only antenna at Goldstone and at Canberra. Another HEF antenna is to be completed at Madrid in 1986.

A task is in progress to provide deep space X-band uplink (7145–7235 MHz) capability on the 34-m HEF antennas at Canberra and Madrid, for support of Galileo and Magellan mission experiments. Spacecraft command capability on the X-band uplink is scheduled for completion in 1988. Implementation of X-band uplink command capability on the Goldstone 34-m HEF antenna is anticipated at a later date.

References

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4. Gordon, D. D., "Mark IVA DSN 26-Meter Subnet," *TDA Progress Report 42-79*, pp. 152–164, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1984.

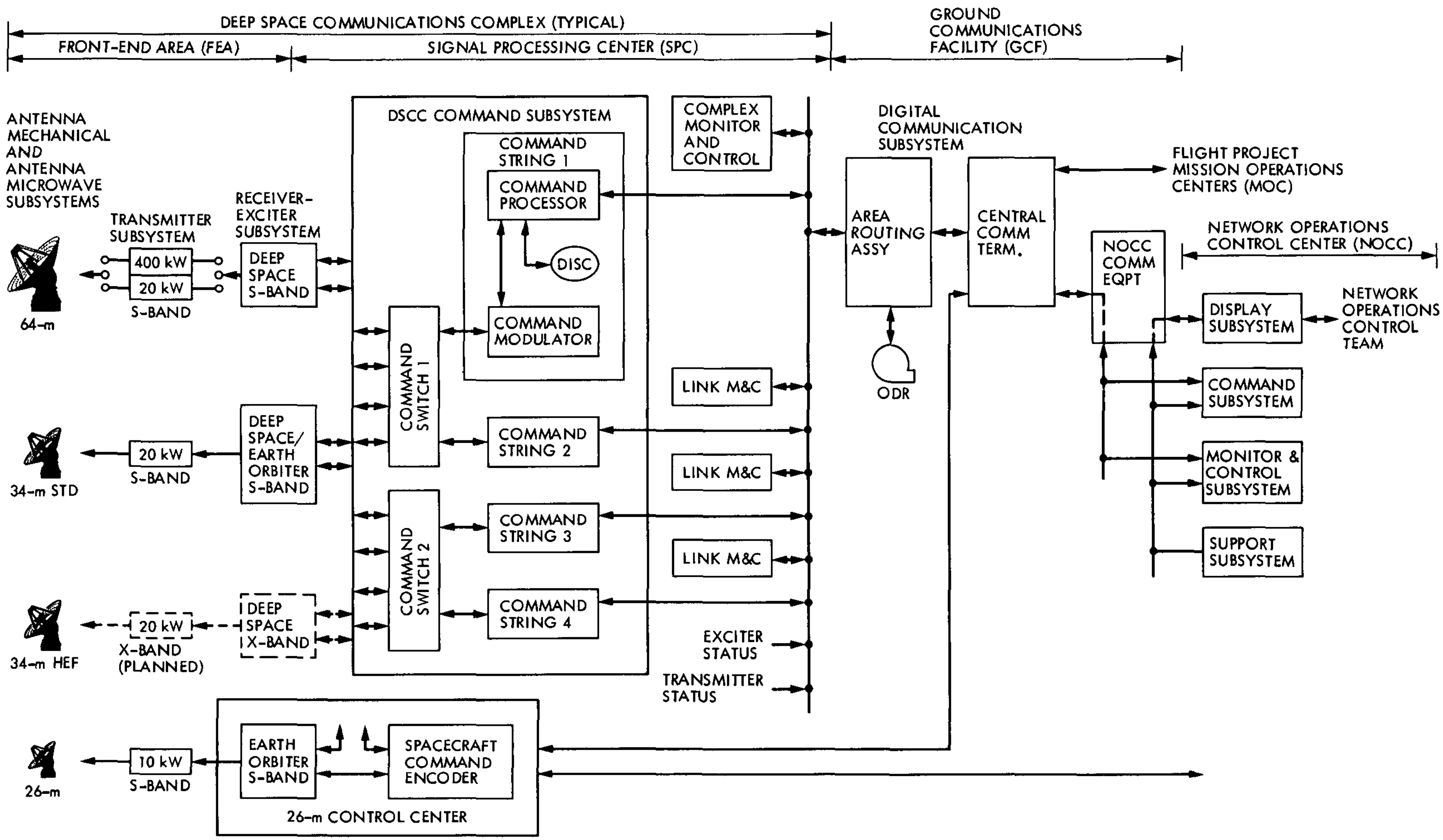


Fig. 1. DSN Command System Mark IV-85 block diagram

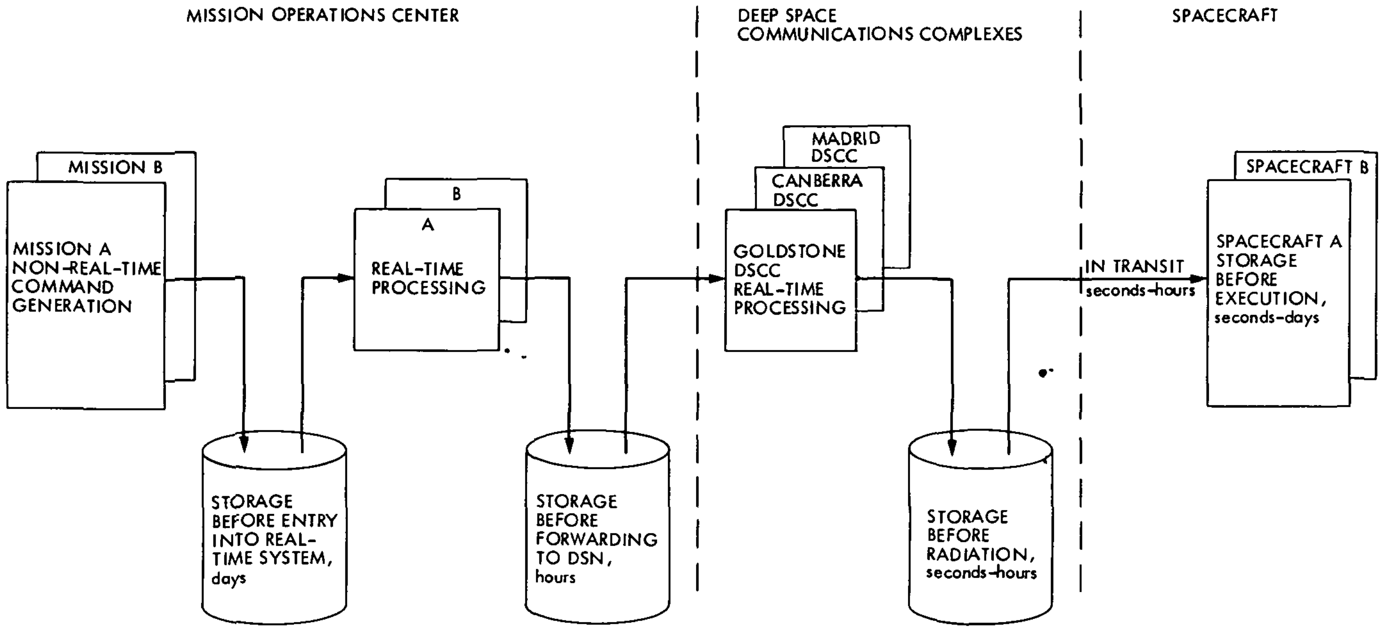
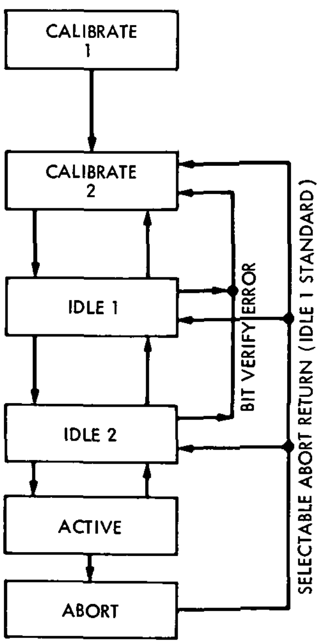


Fig. 2. End-to-end command data flow with typical storage times

SUBSYSTEM MODE



SUBSYSTEM MODE	PRIME PURPOSE	DATA ACCEPTED VIA GCF	COMMENTS
CALIBRATE 1	ALLOWS DSS OPS PERSONNEL TO PERFORM INITIALIZATION TASKS	CONFIGURATION, STANDARDS AND LIMITS, MODE CONTROL, RECALL	WHEN RUN DIRECTIVE IS INPUT, THE CALIBRATE 2 MODE WILL BE ENTERED
CALIBRATE 2	STANDARD MODE FOR UPDATING STANDARDS AND LIMITS AND CONFIGURATION DATA VIA GCF PRIOR TO SPACECRAFT ACQUISITION	CONFIGURATION, STANDARDS AND LIMITS, MODE CONTROL, RECALL	MULTIMISSION STANDARD PROCEDURES STATE THAT THIS MODE IS TO BE ENTERED FOR CHANGING SUBCARRIER FREQUENCY, BIT RATE
IDLE 1	SAFE MODE - CANNOT COMMAND. PROVISION FOR IDLE/ACQUISITION SEQUENCE. NORMAL MODE FOR COMMAND FILE LOADING	CONFIGURATION, STANDARDS AND LIMITS, MODE CONTROL, RECALL	ALL STANDARDS AND LIMITS AND CONFIGURATION DATA PARAMETERS WILL TAKE IMMEDIATE EFFECT IN THIS MODE
IDLE 2	ALLOWS ENTRY INTO ACTIVE MODE. PROVIDES IDLE/ACQUISITION SEQUENCE DURING COMMAND PERIODS	RECALL AND MODE CONTROL DATA ONLY	MODE CONTROL INFORMATION CONTAINED IN THE COMMAND ELEMENT BLOCK
ACTIVE	COMMAND TRANSMISSION	RECALL AND MODE CONTROL DATA ONLY	
ABORT	PROVIDES ABORT INSTRUCTION TO CMA	RECALL AND MODE CONTROL DATA ONLY	

NOTES: 1. COMMAND DATA MESSAGES ARE ACCEPTED IN ALL MODES
2. ALARM MESSAGES/ALARM DATA ARE TRANSMITTED TO THE MOC IN ALL MODES EXCEPT ABORT

Fig. 3. DSCC Command Subsystem modes