SPACE SHUTTLE ORBITER TELEMETRY/COMMAND DESIGN ASPECTS AND FLIGHT TEST RESULTS

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ABSTRACT

During the first flight of Columbia (STS-1), the Instrumentation, Communications, and Tracking Subsystems (I-C&TSS) of the Space Shuttle orbiter used S-band links to provide (in addition to tracking) reception of digitized voice, commands, and printed or diagrammatic data at a maximum rate of 72 kilobits per second (kbps). The subsystem also provided a transmission capability for digitized voice, telemetry, television, and real-time and recorded data. Communication was via S-band directly to the ground stations; ultra-high frequency (UHF) voice was used for communication with the landing site and some ground stations and for providing a backup link for state vector update. Audio and television subsystems served on-board needs and interfaced with the radio frequency (RF) equipment. Provisions were provided to record on-board data for post-flight playback. During aerodynamic flight following entry, the S-band link was used to supplement the UHF link that provides two-way simplex voice communication with air traffic control facilities. The I-C&T subsystem for STS-1 operated with almost textbook performance; exceptions were a dedicated signal conditioner redundancy failure, failure of the development flight instrumentation PCM recorder, and some measurement sensor failures.

INTRODUCTION

The orbiter's Instrumentation, Communication, and Tracking Subsystem (I-C&TSS) is an unusual combination of complexity and simplicity, specialization and versatility, and off-the-shelf and newly developed hardware. It interfaces not only with NASA's Space Tracking and Data Network (STDN), but also with USAF Space Ground Link Subsystem (SGLS), satellites, crew members performing extravehicular activities (when required), and the Federal Aviation Agency's (FAA) air traffic control (ATC) voice communications. In addition, it must interface with the multiple on-board computers of the data processing subsystem, the orbiter displays and controls, other on-board subsystems, and payloads (Table 1).

Because of the complexity of the I-C&TSS, this paper is restricted to an overview of design and the flight results. In cases where existing papers describe subsystems (S-band or antennas); those subsystems are only summarized here (see References 1, 2, 3, and 4).

SUBSYSTEM FUNCTIONAL DESCRIPTIONS

The I-C&TSS is most easily described in terms of subsystems or equipment groupings (Figure 1). Functional descriptions of these subsystems or equipment groupings are provided in the following paragraphs.

S-Band Subsystem

The orbiter's S-band communication subsystem was designed and manufactured by TRW and subtier contractors. It comprises two independent subsystems: the network subsystem and the payload communication subsystem. The network subsystem provides tracking and two-way communication via phase-modulated (PM) links directly to the ground, as well as transmission of data directly to the ground via frequency modulation (FM) link. The payload communication subsystem, like a flying ground station, provides two-way communication with unmanned orbiting spacecraft.

Network Subsystem - The network subsystem consists of seven line-replaceable units (LRU's). Those not shown as being redundant (Figure 2) are internally redundant. Therefore, the subsystem includes two electrically isolated strings (with the exception of the reeds and contacts in the switch assembly), the antennas, and their coaxial cables. Although cross-strapping of functional units between strings is possible to improve the capability to withstand failures, the flexibility is limited to minimize orbiter wiring complexity and weight.

As may be seen from the block diagram, the FM and PM functions are separate, except that the LRU antenna switch assembly services both. Not shown are the interfacing multiplexer/demultiplexers (MDM's) that provide telemetry of configuration data, performance parameters, and transmission and reception of data to and from the data processing subsystem (DPS) computers. The network signal processors (NSP's) can route both data received and data transmitted through communication security boxes for decryption or encryption.

Table 1. Design Drivers

Design Driver	Source	Impact
Cost	Objective to make Shuttle a low-cost launching system	• Compatibility with existing ground facilities • Use of off-the-shelf navigation aids • Limited new component development
Reuse	Objective to reuse orbiter up to 100 times	• Many environmentally sealed boxes • Extended environmental testing
Reliability	Requirement that two failures not endanger crew or vehicle and a single failure not force mission termination	• Triple redundant navigation aids (except radar altimeter) • Almost completely redundant communication
Flexibility	Requirement to interface with both DOD and NASA ground networks and interface with a wide variety of payloads communication systems	• Two “turnaround” ratios • Multiple payload data rates, formats, and operating frequencies
Flush or deployable antennas	Protruding antennas would burn off during entry	Considerable difficulty in meeting performance requirements
Power and weight	Objective to maximize vehicle payload capability	More complex development trades and design effort
Long RF coax runs	Large size of orbiter	Special efforts to minimize losses and improve antenna and receiver/transmitter performance

The subsystem provides for several modes and data rates (Figure 3) for both the forward link (ground-to-orbiter) and the return link[*] (orbiter-to-ground). The forward link receiving equipment is capable of handling data at two different rates and receiving on any of four frequencies. The four forward link frequencies accommodate two return link frequencies and two turnaround ratios (ratios of orbiter transmit-to-receive frequencies). Two return link frequencies, which operate in the 1.7 to 2.3 GHz band, are used to minimize interference to payload communications. Two turnaround ratios correspond to those used by NASA (240/221) and DOD (256/205).

Two data rates are available for the return link, accommodating, as in the forward link, one or two voice channels, and, in addition, two different telemetry rates (Figure 3). The lower data rate is used when link margins are limited to less than 3 dB. The power amplifier generates over 100 watts with an effective isotropic radiated power (EIRP) of 17.7 dBW, and the preamplifier provides a sensitivity of approximately -130 dBm at the LRU. The antenna gain-to-noise (G/T) value is approximately -27.3 dB°K with the dual beam antennas. In direct-to-ground communication, although the power amplifier and preamplifier were used at launch, the output of 2 watts and sensitivity of -118 dBm provided strong link margins of more than 30 dB during STS-1 flight. The very efficient bit sync performance (Figure 4) operated at less than 1 dB from the theoretical values.

FM Subsystem (Operational) - The FM subsystem consists of three LRU’s (Figure 2). The FM signal processor and FM transmitters provide a capability for the transmission of data not amenable for incorporation into the limited-rate pulse code modification (PCM) telemetry data stream. The data transmitted via FM includes television, digital data from the main engines during launch, wideband (to 5MHz) payload data, and digital data from recorder playback.

Conditioning and multiplexing for FM transmission occur in the FM signal processor. Video and wideband digital and analog signals are routed to the FM transmitter with only matching and filtering. Narrower band digital engine data are placed on subcarriers at 576, 768, and 1024 kHz.

The FM transmitter operates at 2250 MHz with an output power of 4.1 dBW at the antenna. Both baseband and RF filtering is provided to reduce out-of-channel interference to the PM and payload receivers. Nominal RF bandwidth is 10 MHz. A DFI FM transmitter operates at 2205 MHz in conjunction with the DFI data sources.

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*The forms, forward and return links, were adopted in preference to up and down to avoid the confusion resulting from the usage of a relay satellite at a synchronous altitude where signals in both directions rollow paths going both up and down.

Television Subsystem

The television subsystem allowed visual monitoring from the ground of on-board activities. It provided the crew with the ability to see areas of the payload bay obscured from direct observation. Television signals originating in the orbiter, near the orbiter, and its payloads were transmitted to the ground on the FM direct S-band link.

The operational television subsystem (Figure 5), designed and manufactured by RCA, will have up to nine on-board cameras, two large-screen monitors, two portable viewfinder monitors, and the the associated switching and control logic.

All TV cameras were black and white, but can be converted to color with the substitution of a color lens assembly (CLA) for the normal monochrome lens assembly (MLA). The CLA contains a rotating color separation wheel to provide a field sequential color signal. Only the two cameras located inside the cabin are to be equipped for color. One of these cameras may be carried by an EVA astronaut outside the crew compartment. These cabin cameras are the only cameras equipped with viewfinder monitors; the pointing of all other cameras is either fixed or remotely controlled from the console television monitors (CTM).

Up to three cameras may be located in the payload bay: one at the forward end, one at the aft end, and one (keel camera) at any of four locations on the floor. The remaining four cameras may be located on the two arms of the remote manipulating system (RMS) one at the elbow and one at the wrist. The three jointed arms are for deploying and retrieving payloads. The elbow camera is mounted on a remotely controlled pan-tilt unit to adjust its pointing as desired. This same pan-tilt unit is provided for the forward and aft payload bay cameras. The camera at the wrist is fixed-mounted, but has a light atop it for aid in viewing shadowed areas.

The two black and white CTM’s are located at the aft-end of the flight deck near the television control panel. Each has the capability for split-screen viewing, thus allowing monitoring of up to four cameras simultaneously.

These cameras and monitors are interconnected through a video switching unit (VSU), which performs switching in response to signals from the remote control logic unit (RCU). Commands are decoded by the RCU and multiplexed on the sync signal along with a camera ID. The camera’s electronics decode these signals and drive the lens and pan/tilt motors. The camera multiplexes its ID number, temperature, pan/tilt angles, and angle rates on the composite video to the VSU.

In addition to its switching function, the VSU multiplexes Greenwich Mean Time from the orbiter's master timing unit on the downlink or record video and encodes one of two audio channels on the video sync signal.

Ground Command Interface Logic Controller (GCILC)

GCILC is an LRU that provided the capability for ground control of many functions of C&TSS and a portion of the operational instrumentation subsystem. It also provided the logic to allow control of the same functions from either D&C switches (manual commands) or in response to ground-originated commands through the uplink. Ground-originated commands flowed through the NSP to the general-purpose computers (GPC's) of the DPS to the GCILC and were sent to the LRU's. Then the command status (from either the GCIL or the LRU's) was returned to the GPC and routed to the ground through the pulse code modulation (PCM) data stream. The GCILC provided logic to allow the on-board crew, if required, to block ground-originated configuration commands.

On-board commands were also originated through the use of any of several DPS keyboards that enter the command directly in the GPC.[**]

The GCILC, in conjunction with the other described equipment, allowed a ground crew to operate and monitor the I-C&TSS configuration, freeing the crew for other activities. It also avoided the necessity of having one astronaut awake at all times just to maintain contact with the ground.

Instrumentation System

The orbiter's instrumentation system comprises two independent subsystems: Developmental Flight Instrumentation (DFI) and Operational Instrumentation (OI). The OI subsystem enables real-time data monitoring using on-board displays, STDN ground station reception. and decommutation of S-band PM. In addition, data were recorded during periods when the orbiter was out of ground station range for later playback. The DFI system allows the recording of data for post-flight analysis and the transmission of real-time DFI pulse code modulation data to ground stations by means of S-band frequency modulation. The OI and-DFI subsystems obtain timing information from a common orbiter timing unit.

OI Subsystem - The OI subsystem (Figure 6) consists of transducers, signal conditioners, pulse code modulation encoding equipment, digital and analog recorders, and timing

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[**] The term GPC includes all five of the operations (OPS) computers, including those previously referred to as guidance, navigation, and control (GN&C) computers.

equipment. Transducers to monitor vibration, temperature, pressure, strain. quantity, flowrates, current, and position are distributed throughout the orbiter. Table II is a breakdown of orbiter vehicle measurements.

Table 11. Orbiter Measurements

Type	Quantity (approx)	
	Analog	Discrete
OI PCM sensors (downlink)	1,025	1,875
OI GPC sensors (downlink)	421	1,245
OI GPC-derived (downlink)	7,900	7,995
DFI wideband sensors	675	N/A
DFI PCM sensors	2,535	90

The OI is required to sense, acquire, condition, digitize, format, and distribute data for display, telemetry, recording, and checkout. It provides PCM recording, voice recording, and master timing for on-board systems. The equipment consists of two PCM master units (PCMMU’s), two operational recorders, one payload recorder, one master timing unit (MTU), 13 dedicated signal conditioners (DSC’s), eight multiplexer/demultiplexers (MDM’s), and various sensors.

Dedicated Signal Conditioner - The DSC receives sensor data and buffers, amplifies, converts, or attenuates the inputs as necessary, and provides two isolated outputs for all sensors except AC discrete (Figure 7). The DSC modules are available in a variety of ranges to accommodate standard inputs. The DSC has a maximum of 32 modules, each module having from three to eight channels. The DSC has redundant power supplies. The module mix is determined by the measurements assigned to a DSC on a box-by-box basis.

Multiplexer/Demultiplexer - The MDM’s receive sensor data from the DSC’s, digitize, and transmit serial biphase Manchester II to the PCMMU upon request. The MDM’s have redundant power supplies, sequence control units (SCU), analog to digital (A/D) converters, and serial multiplexer interface adapters (MIA) (Figure 8).

The MDM receives sensor input data by means of the non-redundant input/output cards. The MIA/serial data bus is the interface between the MDM and the PCMMU’s. Upon request for data by the PCMMU, the MDM digitizes, converts the digitized data into biphase Manchester II, adds parity and sync, and transmits the data to the PCMMU for further processing.

Pulse Code Modulation - Master Unit - There are two identical PCMMU's, of which only one is active at any given time. The PCMMU is responsible for acquiring parameter data (designated as downlink data) from the MDM's, storing the data in memory, structuring the telemetry format, inserting stored data into the telemetry format, and providing data to the GPC for display and systems management functions (Figure 9).

Parameter acquisition is under control of the OI and PL fetch programmable read-only memory. This "fetch PROM" establishes maximum parameter sample rates and directs the received data into specific random access memory (data RAM) for storage. The GPC's transmit data to the PCMMU to be stored in a computer data RAM. This computer data RAM is a double buffer memory which allows asynchronous reception of GPC data while synchronously outputting previously received data. This arrangement guarantees the homogeneity of GPC data.

PCM output data are formatted into a serial digital output stream for telemetry, recording, or GSE. The output data stream operates at 128 kilobits per second (kbps) and 64 kbps. A format PROM is used for a fixed format and cannot be altered by the GPC's. The fixed format is used following initial power-up. A separate RAM memory is used for each of the programmable 128-kbps and 64-kbps formats. These formats are loaded into the RAM by GPC from the mass memory. The formats can then be changed for different mission phases and ground checkout. The fixed format serves as a ready backup in the event of power loss to the PCMMU, which would result in loss of data from the volatile RAM.

Formats have been developed for the ascent phase, on orbit phase, entry phase, and ground checkout. Telemetry format load (TFL) data are output from a ground-based compiler. This TFL is then loaded in the mass memory for GPC use.

Master Timing Unit (MTU) - The MTU generates a stable frequency and is the GMT and MET source for avionics subsystems. The MTU has dual-redundant temperature-control led oscillators and triple-redundant GMT and MET time accumulators (Figure 10).

Oscillator selection is accomplished either manually by panel switch, or by internal selection based upon oscillator performance. One oscillator drives all of the frequency and time accumulators of the MTU at a given time. Frequency, GMT, and MET IRIG outputs are available continuously. GMT and MET are also available on a demand basis by the GPC and PCMMU in biphase Manchester II format. The GPC and the ground controllers can reset or update the GMT or MET accumulators.

Operational Recorders - Two identical recorders are used for continuous recording of the OI PCM data with or without digitized voice. One 14-track serial recorder records data while the data on the second recorder are selectively dumped to STDN ground stations via uplink control. The recorder functions are alternated throughout the mission.

One operational recorder is dedicated to parallel recording of the three 60-kbps main engine digital data during the ascent period. The second operational recorder simultaneously records the OI PCM data interleaved with one or two digitized voice channels (192 kbps).

Payload Experiment Recorder - The payload recorder is similar in design to the operational recorders. Payload data recording is provided via the payload station distribution patch panel. Pre-mission patch panel wiring permits digital recording in either parallel or serial (up to 14 tracks) or a combination of digital and analog parallel data (up to 14 tracks). Data ranges associated with the 14 tape speeds are pre-mission selectable to provide for selection of four tape speeds during a given mission.

DFI Subsystem - The DFI subsystem (Figure 6) consists of transducers, signal conditioners, pulse code modulation encoding equipment, digital and analog recorders, frequency division multiplexers, and timing equipment.

The DFI, scheduled for development flights only, provides additional instrumentation (similar to OI) to support certification and verification programs. The DFI is required to monitor, acquire, condition, digitize, format, frequency-multiplex, distribute, and record data. The equipment consists of two PCMMU’s, three recorders, nine frequency division multiplexers, seven MDM’s, various signal conditioners, and sensors.

The DFI PCMMU’s, MDM’s, signal conditioners, and sensors perform the same functions as the OI counterparts and are therefore not discussed here.

Frequency Division Multiplexer (FDM) - The FDM’s consist of four 15-channel multiplexers each. One multiplexer output is transmitted in real-time through the S-band FM subsystem. FDM data are recorded during specific mission phases on the wideband ascent or mission recorders.

PCM Recorder (DFI Development flight measurement data are processed by a PCMMU and recorded on a continuous or automatic sample basis by the PCM recorder dedicated to DFI. The DFI PCM recorder records data at 128 kbps from the DFI PCMMU either continuously or in timed intervals, depending on recorder controls selected. The 14 tracks are used to record in a track-to-track serial sequence, the serial recording providing up to eight hours of recording at a speed of 15 ips. The data are played back via hard line to GSE only. Serial playback is at the rate of eight to one.

Wideband Recorder (DFI) - Continuous frequency data, such as vibration, acoustic, and flutter measurements are frequency-multiplexed and recorded on the wideband recorder. The DFI wideband recorder provides up to 14 tracks for recording frequency-multiplexed wideband analog data from the FDM outputs. Total recording time is 32 minutes at a programmed operating speed of 15 ips. The recorder can be operated continuously or in a manual data sampling mode. Data are played back to GSE at a one-to-one rate, relative to the record speed, and all 14 tracks are dumped simultaneously.

MISSION RECORDER (DFI)

A second wideband recorder is used to provide 28 tracks for recording additional FDM outputs. The recorder can be operated continuously or in a manual data-sampling mode. The total recording time on this recorder is two hours. At 15 ips, data are played back at a one-to-one rate relative to record speed. All 28 tracks are outputted simultaneously. The playback electronics are contained in a carry-on GSE unit which interconnects between the on-board recorder and the vehicle umbilical wiring.

UHF

UHF transceivers are provided for the transmission and reception of voice to allow contact with ATC facilities and chase-aircraft during landing operation. They are provided during on-orbit operations for the transmission of voice to, and the reception of voice and telemetry from, extravehicular space-suited astronauts. Both functions are provided by a newly developed EVA-ATC communication subsystem being built by RCA under direct contract to NASA.

EVA/ATC Communication System - The EVA/ATC communication subsystem is designed primarily to support extravehicular activities, but it also provides ATC voice communication capabilities, thus allowing it to replace the ARC-150 used on Orbiter 101. In the ATC service, it provides two-way RF links on either of two frequencies (296.8 or 259.7 MHz) with a transit power of 10 watts at the LRU output. In addition, emergency communication is provided by a 243-MHz guard channel transmitter and receiver.

Antennas

The antennas associated with each subsystem (except the UHF airlock and the deployable Ku-band) are flush mounted (Figure 11). The locations were chosen to favor the desired direction of coverage within the constraints of the space available on-board the orbiter.

All flush antennas are overlaid with the thermal protection subsystem (TPS), which covers that part of the orbiter surface that otherwise would be unable to survive the heat of entry. TPS is thickest on the bottom where the depth over the lower antennas reaches 2.5 inches. TPS has electrical characteristics somewhat similar to polyurethane foam. It has required special attention where the patterns are critical (quads). Basic data on the antennas are presented In Table III.

The quad antennas are placed in the roll plane of the vehicle at 45 degrees to the orbiter horizontal plane. The patterns of about 100 degrees In the roll plane provide overlapping coverage; fore-aft coverage is on the order of 130 degrees. More details on orbiter antennas and patterns may be found in References 1, 3, and 4.

Displays and Controls (D&C's)

I-C&TSS control panels in the orbiter are not very different from their counterparts in large commercial aircraft and previously manned spacecraft. All panels (not just I-C&TSS) are designed and manufactured by the orbiter prime contractor, Rockwell International, to ensure commonality of component usage and standard layout and nomenclature.

The S-band control panel (Figure 12) makes use of block diagramming to aid in understanding switch functions.

Instrumentation controls are located throughout the flight deck panels (Figure 13). The configuration and functions are similar to the S-band controls as seen in the recorder controls in Figure 12.

SUBSYSTEM PHYSICAL DESCRIPTION

The I-C&TSS utilizes both environmentally sealed and unsealed LRU's, with most of those specifically designed for the orbiter being sealed as an aid toward meeting the goal of a ten-year life. A typical box is approximately 7.6 inches (19 cm) high and no longer than 20 inches (51 cm), with width being determined by the volume needed. A flat thermal base provides contact with water-cooled shelves on which or under which it mounts (Figure 14). Hold-down is by captive fasteners. Connectors are on the front panel. The physical design was greatly influenced by the sealing requirement, by conduction cooling, and by the design vibration requirement.

Table III. Orbiter Antennas

Antenna	Quantity	Freq	Polar	Type	Reason for Selection
UHF	1	UHF	LV	Annular slot	High efficiency, broad angular coverage
S-band quads	4	S	RHCP	Crossed dipole fed cavity fixed array	Beam shaping, gain, efficiency
S-band hemi's	2	S	RHCP	Crossed dipole fed cavity	High-efficiency, broad, continuous coverage
S-band payload	1	S	RH & LH CP	Cross dipole fed cavity	Polarization switching, shaped beam
UHF-airlock	1	UHF	L	Microstrip	Total coverage in the airlock cylinder

A summary of subsystem weight and power consumption is provided in Table IV. Power dissipation is about the same as consumption except for those LRU'S that generate significant amounts of RF. Power consumption is not totaled because all of the subsystems are never on at the same time. In addition to the powers listed, there are short-term switching transients as latching relays are switched and intermittent heater-power for TV cameras, which are external to the temperature-controlled crew compartment.

Most of the LRU's of the I-C&TSS are mounted in equipment bays located at the fore and aft ends of the mid deck along with LRU's of other orbiter subsystems. In these bays, wires to LRU connectors are in trays in front of the equipment for easy repair and modification. Where feasible, redundant LRU's are mounted in separate bays for damage control.

STS-1 FLIGHT TEST RESULTS

Orbiter I-C&TSS performance for flight STS-1 was near perfect. However, a dedicated signal conditioner and the DFI PCM recorder experienced anomalies during the ascent phase. Also some measurements failed or outputted questionable data during the flight.

One of two circuit breakers supplying power to two dedicated signal conditioners blew at T + 10 minutes. This occurrence coincided with an indication of a momentary current spike on an orbiter main bus, and no attempt was made to reset the breaker. This failure did not result in any data loss, due to the redundant power bus and redundant power supplies in the conditioner. Post-flight teardown revealed a foreign object in one of the two conditioner power supplies which caused a power short to ground. Under the zero-g environment, the object moved into a position causing the short.

The DFI PCM recorder operated for 31 minutes prior to failure. As the nature of the recorder problem was unknown, an attempt was made to record entry data. Post-flight tape dump revealed that only 31 minutes of ascent data was recorded. Post-flight teardown revealed an extraneous object in the recorder drive mechanism. Limited data were lost because DFI PCM S-band was recorded over ground stations. No data were available during blackout. Additionally, 300 milliseconds of data was lost at SRB ignition due to tape/head separation as a result of SRB overpressure shock.

Four OI measurements became inoperative during the flight. A small percentage of DFI measurements failed to operate properly or provided data which were in question. All measurement anomalies are being investigated prior to STS-2, and all problems identified are being repaired.

The closed-circuit television (CCTV) equipment was operated from the cabin or via the S-band command link. All of the CCTV hardware was exercised during the STS-1 mission, and performance was normal.

The UHF transceiver was operated in the high-power simplex mode at 296.8 MHz throughout the mission. In this mode, the unit communicated directly with ground stations during ascent and while on orbit and with chase aircraft and landing facilities during landing. The performance of the transceiver was normal.

The ground command interface logic controller (GCILC) performance was normal.

The S-band RF equipment operated within its design limits for the entire mission in textbook performance. The S-band PM equipment was in high power for launch and switched to the space ground link system (SGLS) mode for the Indian Ocean Station pass. It was then changed to the space flight tracking and data network (STDN) low-power high-frequency mode. This configuration was maintained for the remainder of the mission with the exception of the two station passes used for special communication tests and the remaining passes over the Indian Ocean Station. There were no problems during prelaunch or the mission for the S-band PM equipment. The S-band FM equipment launch configuration transmitted main engine data. During the remainder of the mission, the system was used for TV (real-time and playback) and operational instrumentation recorder dumps. There were no problems during prelaunch or mission for the S-band FM equipment.

Table IV. Power Consumption and Weight of Subsystems

Subsystem	Quantity of LRU's	Power Consumption* (watts)	Weight** [lb	(kg)]
UHF-ATC transceiver	1	160	18	(8)
S-band network	13	797	218	(99)
Television	18	528***	279	(127)
Ground command Interface logic	1	60	39	(18)
Antennas	22	-	76	(35)
Operational instrumentation				
DSC	13	328	234	(106)
MDM	7	359	465	(211)
PCMMU	2	55	56	(25)
Recorders	3	168	122	(55)
MTU	1	31	27	(12)
Developmental flight instrumentation				
DSC	16	374	349	(158)
MDM	7	359	465	(211)
PCMMU	2	55	56	(25)
Recorders	3	134	135	(61)
FDM	9	450	165	(75)
WBSC	389	232	117	(53)
Total	507	4,090	2,821	(1,279)

*Sum of LRU's that normally operate simultaneously
**LRU's only -- excludes wiring, coax, and Interfacing hardware
***All cameras on

The S-band antenna switch assembly was under computer control for the entire mission. The appropriate S-band quadrature and hemi-antennas were selected as the attitude of the orbiter changed with respect to the ground station. The configuration of the S-band network equipment was managed by either uplink real-time or stored program commands.

Minimum anomaly data analysis and hardware/subsystem retest were considered necessary. The performance of the communication and tracking subsystem was rated “excellent” In the NASA STS-1 flight report.

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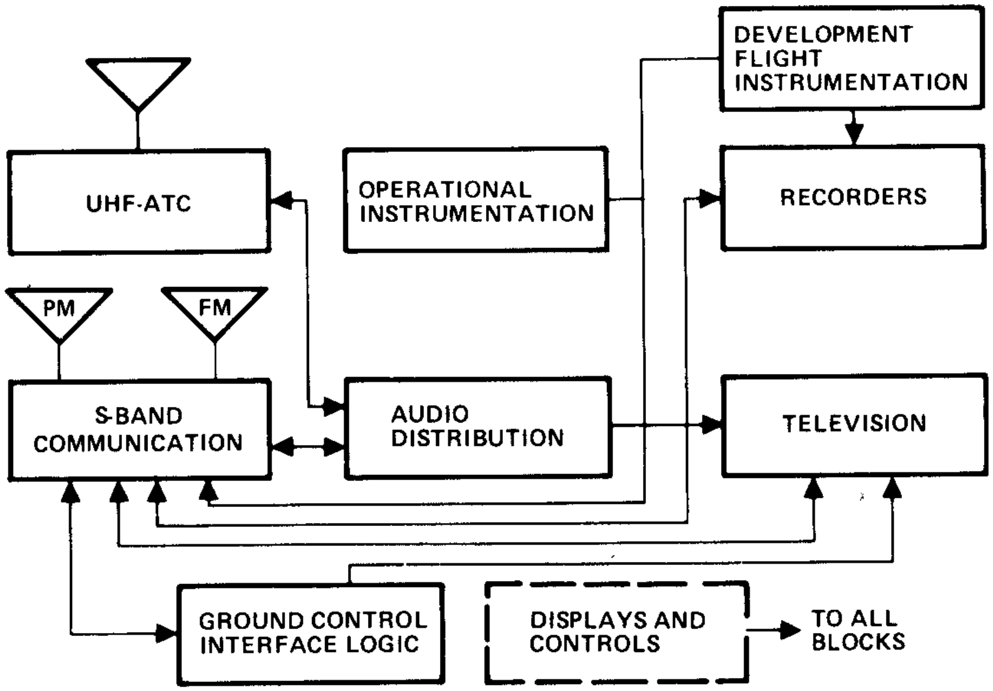

NOTE: Interfaces with other subsystems are not presented. Each antenna symbol represents one antenna, or a group of them are together for convenience. They belong with the subsystem they serve, and a similar situation exists for displays and controls.

Figure 1 -- Subsystem Groupings

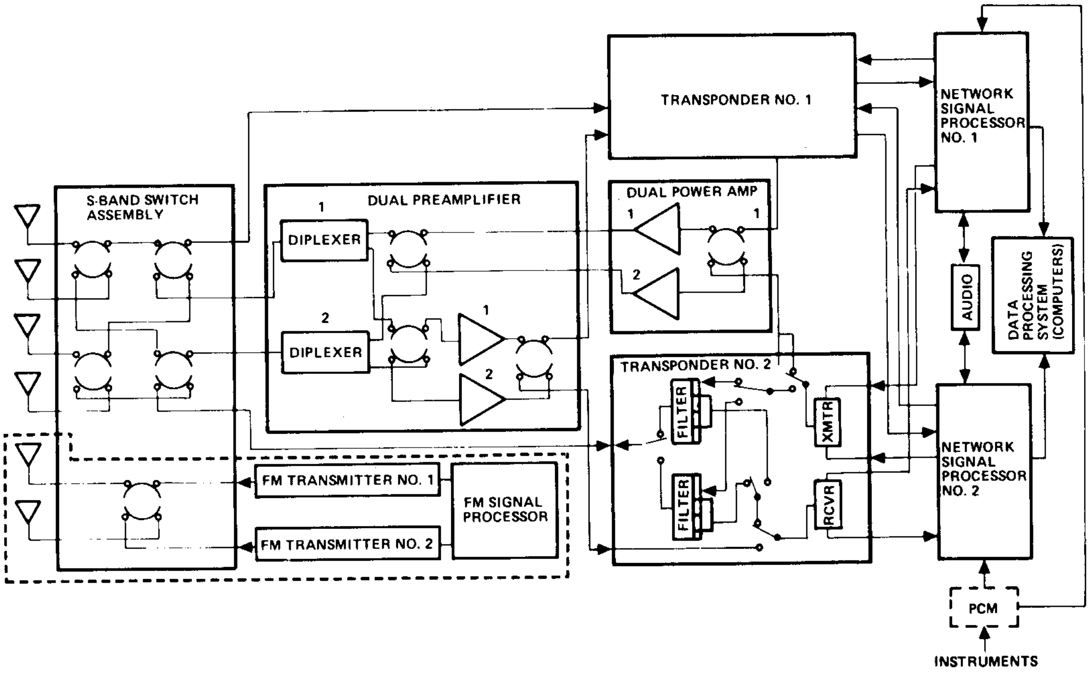

Figure 2 - I-C&TSS Block Diagram

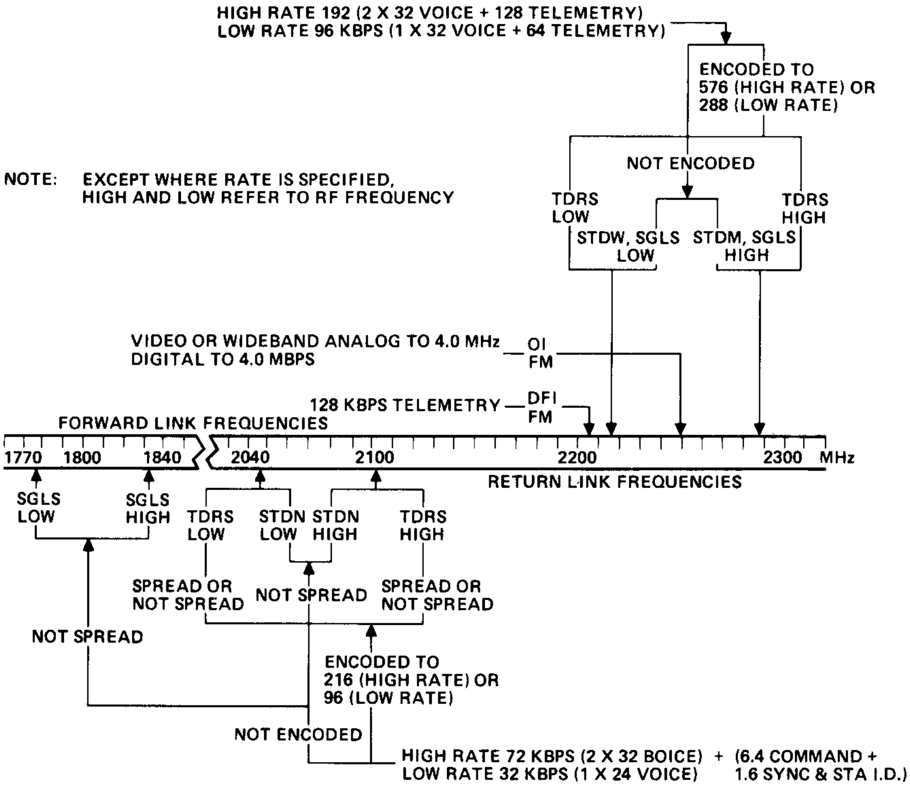

Figure 3 -- S-Band Frequencies, Modes, and Data Rates

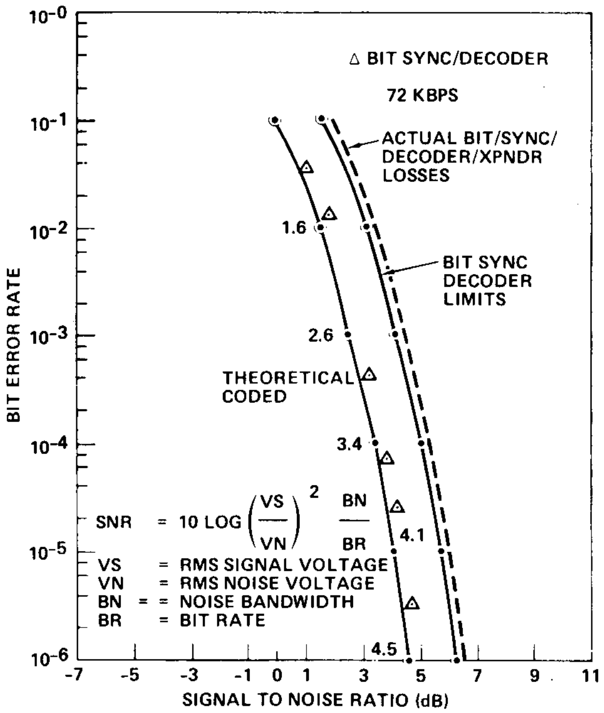

Figure 4 -- Bit Error Versus Signal-to-Noise Ratio

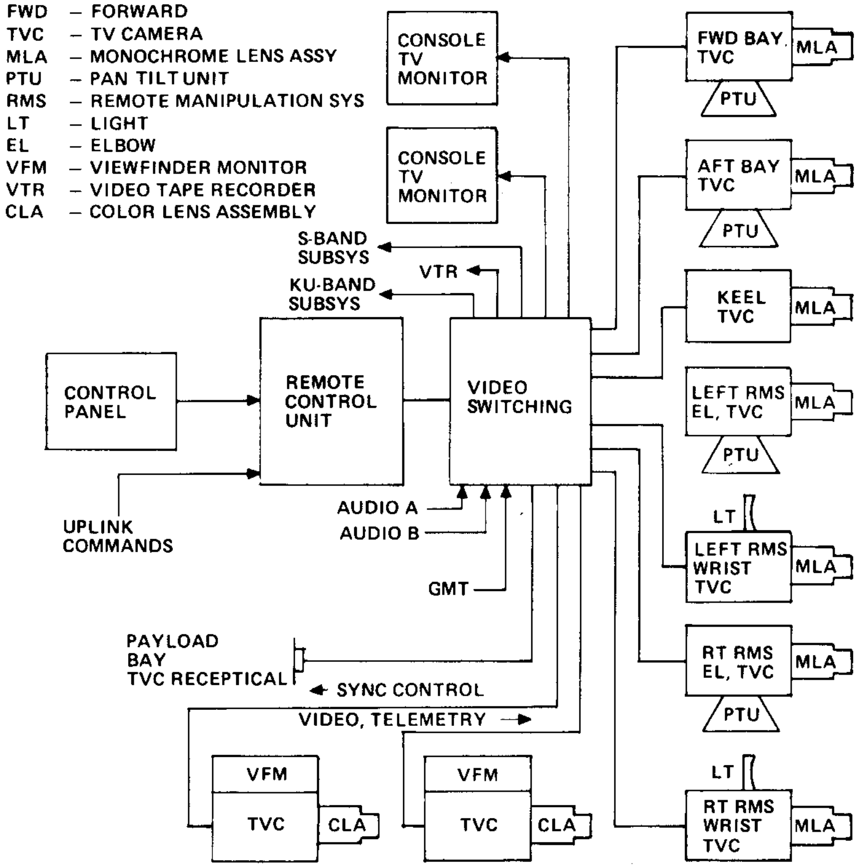

Figure 5 -- Operational TV Subsystem Diagram

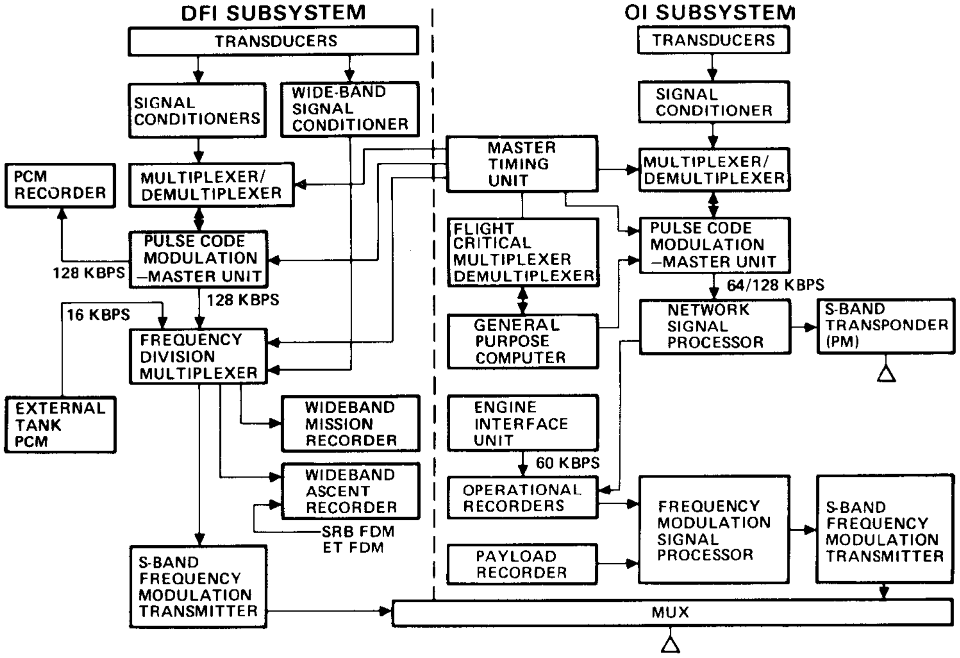

Figure 6 -- OI/DFI Block Diagram

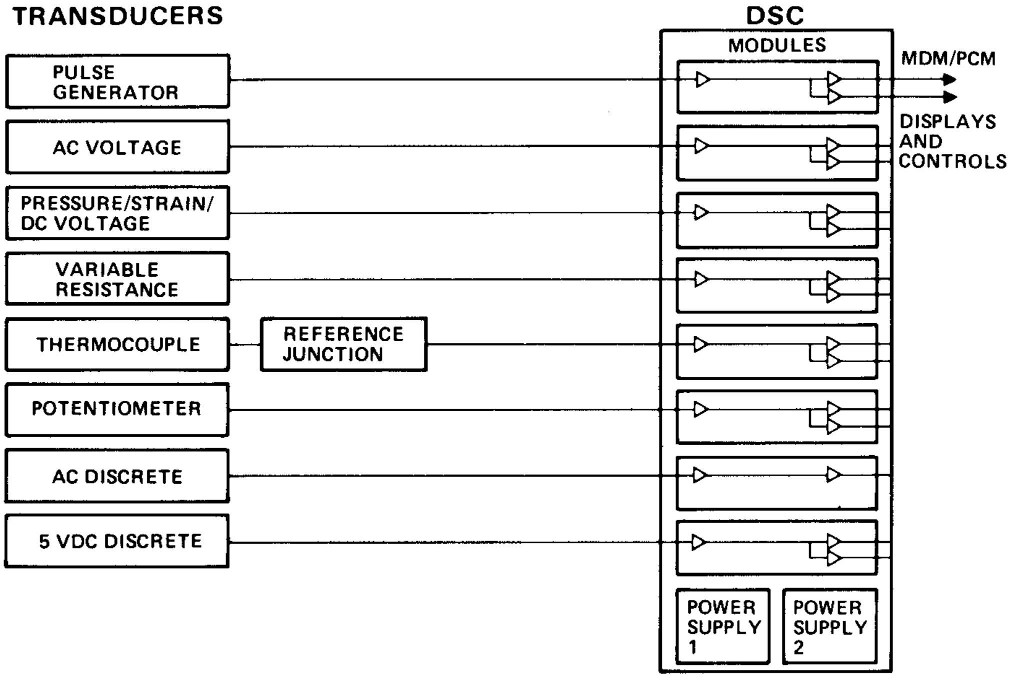

Figure 7 -- Dedicated Signal Conditioner Block Diagram

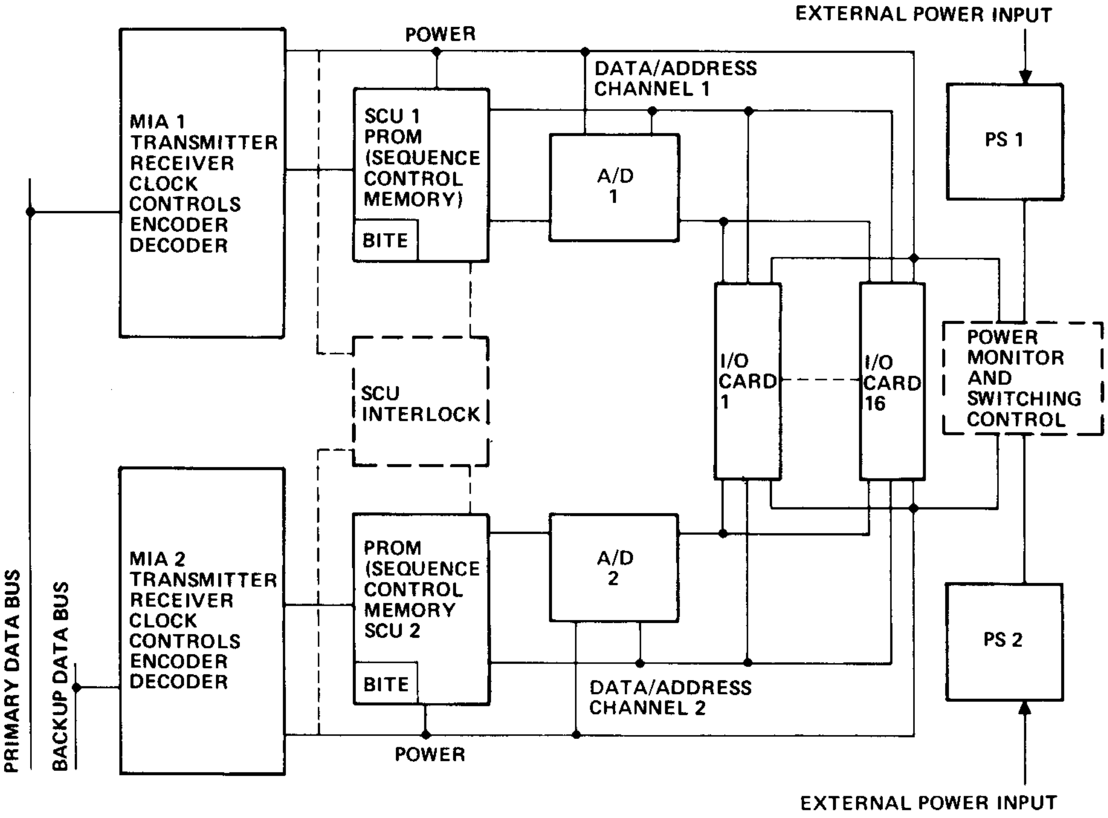

Figure 8 -- MDM System Block Diagram

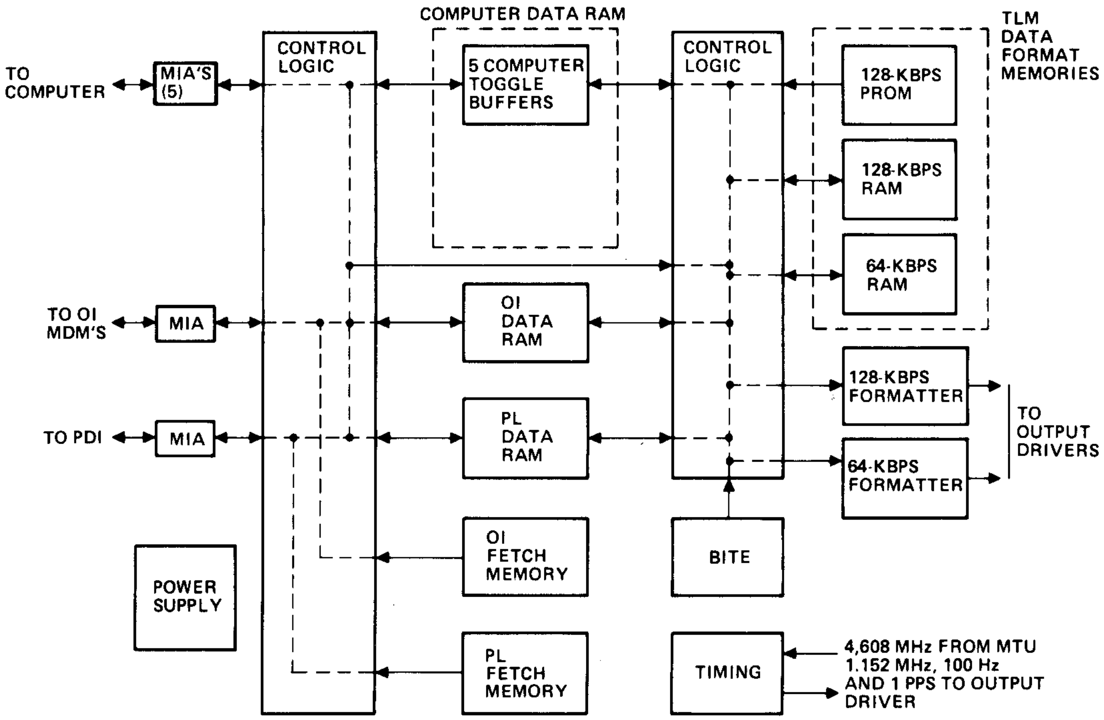

Figure 9 -- PCMMU Block Diagram

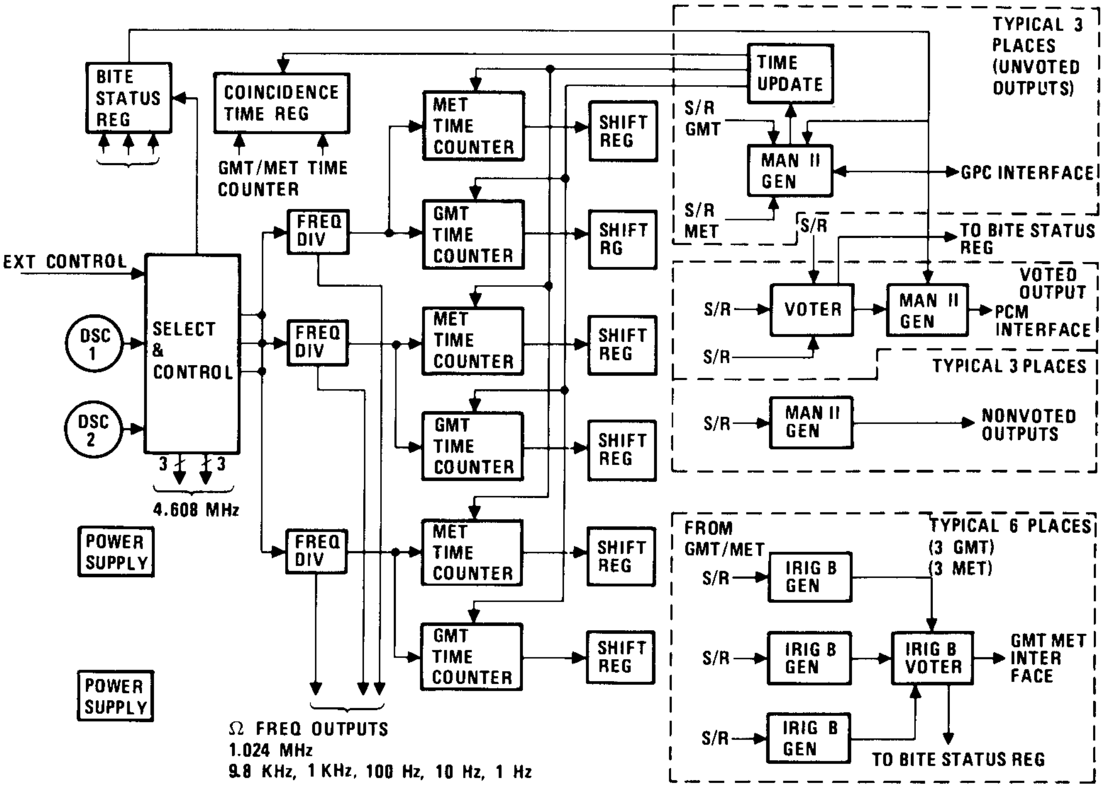

Figure10 -- Master Timing Unit Block Diagram

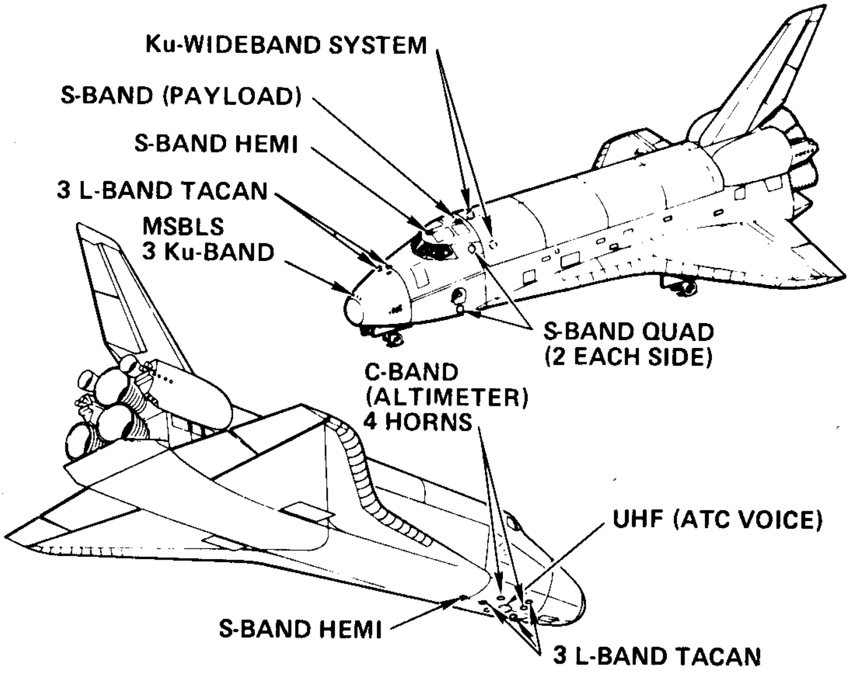

Figure 11 -- Antenna Locations

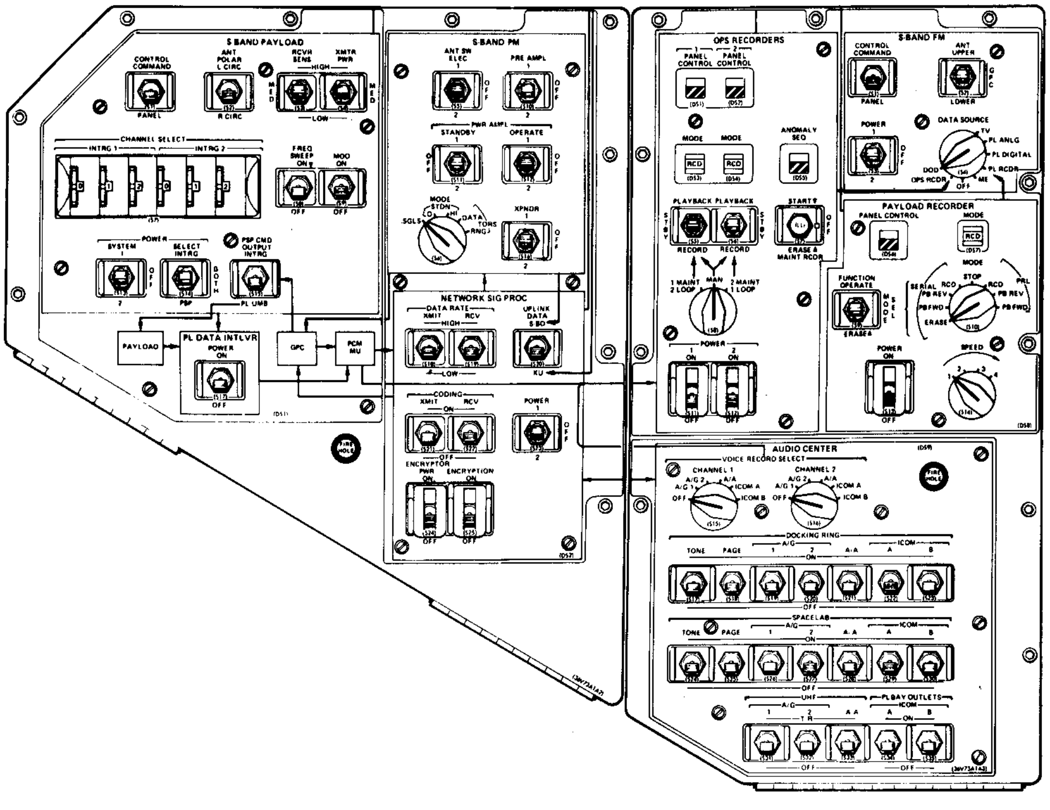

Figure 12 -- Communications and Tracking Control Panels

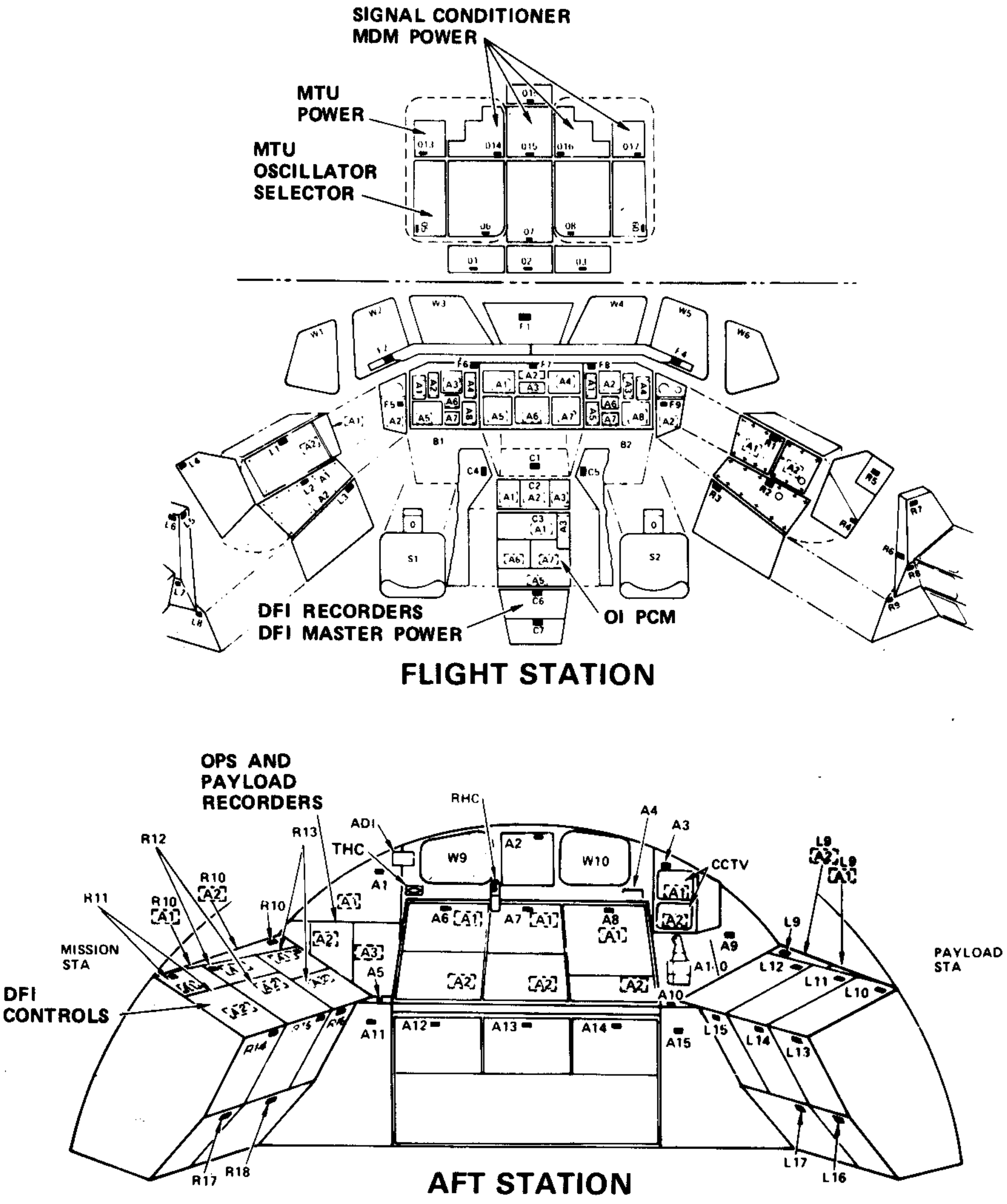

Figure 13 -- Instrumentation Control Panels

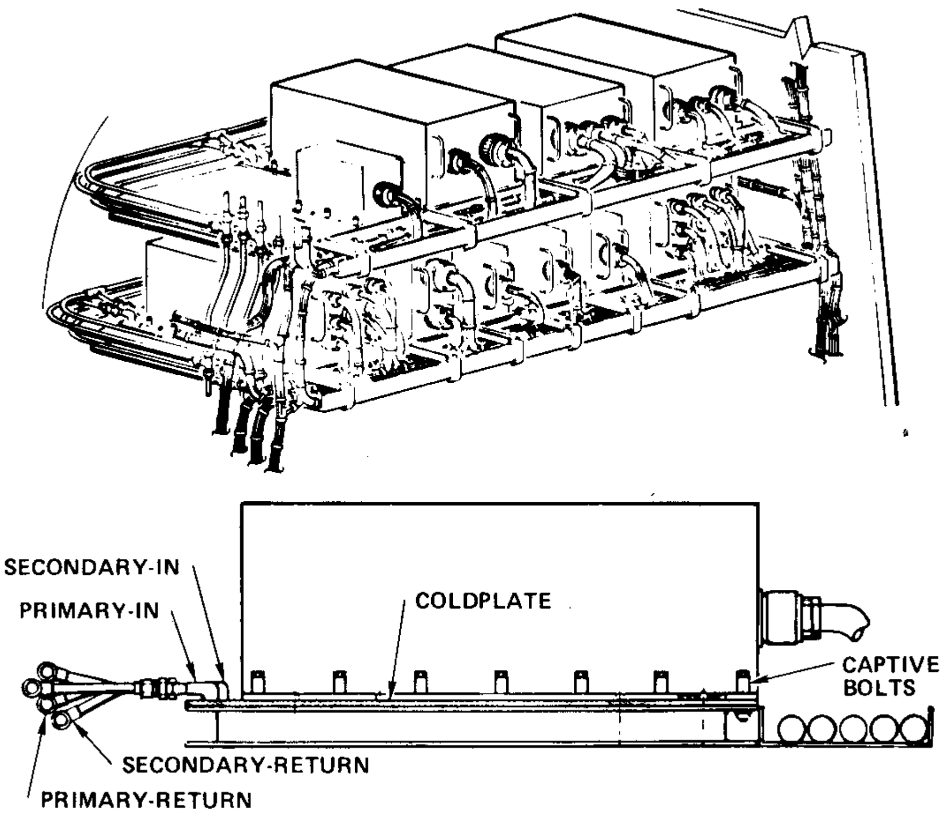

Figure 14 --Typical Avionics Installation