THE SPACE SHUTTLE ORBITER COMMUNICATION AND TRACKING SYSTEM

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SUMMARY

During space flight, the communications and tracking system of the Space Shuttle orbiter uses S- and Ku-band links to provide tracking; reception of digitized voice, commands, and printed or diagramatic data at a maximum rate of 216 kilobits a second; and transmission of digitized voice, telemetry, television, and data at a maximum rate of 50 megabits a second. S-band links may be established directly with a ground station and both S- and Ku-band links may be routed through NASA’s Tracking and Data Relay Satellite System A simultaneous capability to communicate with other satellites or spacecraft, using a variety of formats and modulation techniques on more than 850 S-band channels, is provided. UHF is used for communication with extravehicular astronauts. Audio and television subsystems serve on-board needs as well as interfacing with the RF equipment.

During aerodynamic flight following entry, a UHF link provides two-way simplex voice communication with Air Traffic Control facilities. Air navigation aids include TACAN, a microwave scan-beam landing system and radar altimeters.

1. INTRODUCTION

The orbiter communications and tracking (C&T) system is an unusual combination of complexity and simplicity, specialization and versatility, and off-the-shelf and newly developed hardware. it must interface with not only the NASA Space Tracking and Data Network (STDN), but also the NASA Tracking and Data Relay Satellite System (TDRSS), the USAF Satellite Control Facility (SCF), other satellites, crew members performing extravehicular activities (EVA), the Federal Aviation Agency’s (FAA) Air Traffic Control (ATC) voice communications, and FAA and military air navigational aids. in addition, it must interface with the multiple on-board computers of the data processing system, the orbiter displays and controls, and other on-board systems.

On-orbit communication links are depicted in Figure 1. All of the links shown may be employed simultaneously. Links available following entry and emergence from RF blackout are shown in Figure 2.

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The design of the orbiter on-board communications and tracking system was driven by a number of factors; the most important are presented in Table 1.

2. SUBSYSTEM FUNCTIONAL DESCRIPTIONS

The orbiter's communication and tracking system is most conveniently described in terms of those subsystems or equipment groupings shown in Figure 3. In this simplified block diagram many interfaces with other orbiter systems are omitted. Although most of the blocks may be properly thought of as subsystems, the air navigation aids block includes functions that are not interconnected. The ground command interface logic (GCIL) block is a single box interconnected with other equipments to provide system-link functions. The antennas, with each symbol representing a single antenna or group of antennas, are described together only for convenience, as they functionally belong with the subsystem they serve. A similar situation exists in regard to displays and controls (D&C).

UHF

UHF transceivers are provided: (1) for the transmission and reception of voice to allow contact with ATC facilities and chase aircraft during landing operations, and (2) during on-orbit operations for the transmission of voice to and the reception of voice and telemetry from extravehicular space-suited astronauts. The former function is provided during early flights by slightly modified Magnavox ARC-150(v) transceivers; both functions are provided during later flights by a newly developed EVA-ATC communication system being built by RCA under direct contract to NASA.

ARC-150–The ARC-150 is a widely used USAF transceiver capable of transmitting and receiving amplitude-modulated signals on any of 7000 channels in the frequency range of 225.000 to 399.975 MHz. It may also independently monitor 243 MHz (the international emergency frequency) with a separate, internal guard receiver. In receive, it provides 185 milliwatts of audio (at 50 percent modulation), and in transmit, 10 watts of 90 percent amplitude-modulated RF.

There are two Space Shuttle versions of the ARC-150. One was used on orbiter vehicle (OV) 101 during aerodynamic approach and landing tests; the second will be used during early OV-102 orbital flights. They differ internally only in the audio input/output circuitry for compatibility with the different audio systems on the two vehicles, but the OV-102 version is limited by the orbiter control panel to operation on those frequencies utilized by the EVA-ATC communication system.

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

To understand the EVA service, it is necessary to consider the extravehicular communicator (EVC) equipment carried by the EVA astronaut or astronauts. Basic block diagrams of both the orbiter's EVA/ATC transceiver and the EVC are presented in Figure 4.

The extravehicular communicator unit consists of AM transmitters, AM receivers, a telemetry subsystem, a warning system, and an antenna. This equipment is arranged to operate in several different modes. Mode A is the normal mode used by a single EVA astronaut and mode B is the normal mode by a second EVA astronaut. This operation is depicted in Figure 5. Other combinations of receivers and transmitters can provide voice communication in event of equipment failure or interference on normal channels.

In modes A and B, the operating transmitter is modulated by a 5.4-kHz (standard IRG) subcarrier oscillator, which transmits biomedical data (electrocardiographs). Voice, which modulates the carrier directly, is keyed on by voice-operated circuitry (VOX) or a push-to-talk (PTT) switch.

A 1.5-kHz warning tone generator, square wave modulated at 15 Hz, operates in response to a sensor (external to the EVC) to alert the astronaut to conditions requiring his attention.

On the orbiter side of this communication link, receivers and 500-milliwatt transmitters are provided on each of the frequencies shown in Figure 5. Two antennas are provided: one inside the airlock and one on the bottom of the orbiter. The latter is the same used with the ARC-150 during aerodynamic flight tests.

The processing within this system strips the electrocardiograph signals from one or two EVC's and provides them to the orbiter telemetry subsystem. A two-way voice interface with the orbiter's audio distribution system is provided, giving astronaut's performing extravehicular activities access to orbiter voice communications on up to three voice channels. This enables an EVA astronaut to be in direct voice contact with the ground or the orbiter crew or to have his conversations recorded.

Audio Distribution System

The audio distribution system (ADS), designed and manufactured for the orbiter by Telephonics, provides intercom and radio access functions for the various crew stations and hardline “subscribers” involved in an orbital mission. It includes facilities for audio processing, mixing, amplification, volume control, isolation, switching, and distribution. It provides paging capability, communication over various alternative audio bus circuits, distribution of caution and warning signals, and communication with ground crews during preflight vehicle checkout.

The ADS is comprised of six audio terminal units (ATU’s), two speaker-microphone units (SMU’s), one audio central control unit (ACCU), and various interface units, the selection of which depends on the type of headset being used.

These line-replaceable units (LRU’s) (except for the interface units) and their functional relationship are shown in the ADS system block diagram (Figure 6). This block diagram also indicates the relationship of the ADS LRU’s with the radio equipment, recorders, navigation aids (NAVAID’s), and hardline installations that the system serves.

The ADS utilizes hardwire baseband transmission of audio signals and time division multiplexed transmission of control signals. The ACCU acts as a central switchboard for the system; all audio routing is accomplished in the ACCU under control of switching commands originating at the ATU’s. The ATU switching commands are transmitted to ACCU in the form of serial digital data streams arriving independently over dedicated wires, one pair from each ATU. These control signals include channel selections, independent volume levels for each channel, and keying signals.

Air Navigation Aids

The NAVAID’s for aerodynamic flight consist of two radar altimeters, three TACAN’s, and three microwave scan-beam landing system (MSBLS) NAV sets. Rationale for lower redundancy in the altimeters is based on the fact that they are used only during the last few seconds of flight. Outputs of the NAVAID’s are used in redundancy management wherein the computer filters all the outputs. This filtering serves to increase measurement accuracy by applying a middle value select criterion when three LRU’s are used or an average value criterion when only two LRU’s are used. Bad data or failed LRU’s are weeded out by data comparison matrices.

TACAN–The TACAN (tactical air navigation) system is widely used by both military and civilian aircraft; the equipment used in the orbiter is a minor modification of a Hoffman design. It provides navigation updates after deorbit and exit from L-band RF blackout until the navigation aid function is assumed by the MSBLS. In a normal orbiter entry trajectory, the TACAN’s are expected to acquire ground signals at an altitude of about 150,000 feet (45.7 km) at which point the orbiter is about 300 nautical miles (550 km) downrange from the landing site.

Each on-board TACAN set is a combination transmitter, receiver, decoder, and digital processor. In acquisition, it cycles between a top and bottom antenna under internal control and between designated ground stations under data processing system (DPS) control until a signal is received. It then determines the range and bearing to that ground station.

The GN&C (guidance, navigation, and control) computers are recipients of the TACAN navigational data. Range and bearing are also displayed directly to the crew. Channel and mode selection are made via the D&C in a manual mode or by the DPS in an automatic mode.

MSBLS–The MSBLS takes over the final navigation sensor duties from the TACAN and provides the orbiter with range and bearing from about a 10,000-foot altitude through touchdown. The system operates at Ku-band. Data are derived on-board from ground transmitted planner beams scanning in azimuth and elevation (Figure 2) and containing pulse-coded angle data. Ku-band distance measuring equipment (DME) is integrated in the airborne system to provide precise range measurement. The ground system consists of an elevation and an azimuth/DME station.

Within the NAV sets, the pulse-coded signals are converted to digital words that provide elevation angle, azimuth angle, and range information. The data are routed to the guidance, navigation, and control system, which controls the orbiter during approach and landing.

The MSBLS navigation set, a modified U.S. Army AN/ARQ-31 designed and manufactured by AIL, consists of two LRU’s, an RF assembly, and a decoder assembly. The RF assembly receives the incoming Ku-band, angle-coded RF signal and passes it to the decoder assembly. The decoder assembly processes and validates the data. and provides an output in a digital format to the data processing system.

The navigation set complement is configured as triplex with three independent dedicated antennas and data transmission paths. Each string is excited externally to perform a self test prior to deorbit in order to ascertain the system s operating status.

Radar Altimeter–The C-band (4300 MHz) radar altimeter, manufactured by Honeywell. is utilized for precision altitude determination during the final landing approach. If in an automatic landing mode, the GN&C system uses the altimeter output only during approximately the last 100 feet (30 m) of descent. The altimeter output is available for display and is capable of displaying altitude from 2500 feet (760 in) minimum no touchdown.

The altimeters and the MSBLS are designed with a deliberate instability in their pulse repetition rates, which allows multiple units to operate simultaneously without mutual interference.

S-Band System

The orbiter's S-band communication system, designed and manufactured by TRW and subtier contractors, is comprised of two independent subsystems. The network subsystem provides tracking and two-way communication via phase-modulated (PM) links direct to ground or through the TDRSS and transmission of data direct to ground via an 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 11 LRU's. Those not shown as being redundant in Figure 7 are internally redundant, so the subsystem includes two electrically isolated strings with the exception of the reeds and contacts in the switch assembly and the antennas and their coaxial cables. Although some cross-strapping of functional units between strings is possible to improve the capability to withstand failures, this 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 switch assembly services both. Not shown are the interfacing MDM's (multiplexer/demultiplexers) which provide for the telemetry of configuration data and performance parameters and for the transmission of data to and reception of instructions from the DPS computers. The network signal processors (NSP's) can route both received data and data to be transmitted through communication security boxes for decryption or encryption.

The system provides for several modes and data rates (Figure 8) for both the forward link (ground to orbiter) and the return link (orbiter to ground). Coding is used in the TDRS modes to improve bit error rates. The forward link receiving equipment is capable of handling data at two different rates, spread with a pseudorandom noise (PRN) code rate of 11.232 megachips per second or not spread and transmitted on any of four frequencies. Spreading is used on the TDRS mode to reduce TDRS interference to ground-based communications by reducing the power flux density at the earth's surface. The four forward link frequencies accommodate two return link frequencies and two turnaround ratios (ratios of orbiter transmit to receive frequencies). 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. The lower data rate is used when link margins require, as is the case for a large portion of the time when communicating through TDRSS.

In the TDRS low data rate mode, where link margins are in the order of plus 2 to 3 dB, the power amplifier generates about 100 watts and the preamplifier provides a sensitivity of approximately -130dBm. In direct-to-ground communication, although the power amplifier and preamplifier are not used, a transponder output of 2 watts and sensitivity of -118 dBm provide much better link margins because of the reduced range and improved (as compared to TDRS) ground terminal performance.

The FM signal processor and FM transmitters provide a capability for the transmission of data not amenable for incorporation into the limited-rate PCM telemetry data stream. The data to be transmitted via FM include television, digital data from the main engines during launch, wideband (to 4 MHz) payload data, or digital data from recorder playback or payloads.

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, but 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 10 watts. 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.

To enable the transmission of additional data during the development phase of the orbiter program, a development flight instrumentation (DFI), S-band, frequency-modulated transmitter is provided to service an additional PCM telemetry system. This Teledynamics transmitter is multiplexed with the S-band network FM transmitter to either of two wide-beam “hemi” antennas. Both of these transmitters are used for transmission of data directly to the ground and not for relay through the TDRSS. The present plan is to remove the DFI transmitter and its multiplexer following the end of the flight test program (Flight 6) or soon thereafter.

Payload Subsystem–The S-band payload subsystem provides the capability of communicating with a wide variety of satellite communication systems. It will be used for such purposes as checking the operation of a released payload prior to moving from its immediate vicinity and safing a satellite before taking it on board for repair or return to earth.

The receiver and transmitter are packaged in an LRU called the payload interrogator (PI); signal processing in both directions is performed in the payload signal processor (PSP). Redundant LRU’s are carried for both the PI and PSP.

The PI provides 851 duplex channels for simultaneous reception and transmission of information with a noncoherent frequency turnaround ratio of 205/256 in the SGLS mode (20 channels), and 221/240 in the STDN (808 channels) and DSN (23 channels) modes. In addition, it provides four receive-only and six transmit-only RF channels in the DSN (Deep Space Network) mode.

Since payloads are intended to communicate with, in general, the same ground stations as the orbiter, they also receive on the lower end of the space communication band and transmit on the upper end. This means that the interrogator must receive on frequencies near those employed for transmission by the network subsystem and transmit near those on which the network system receives. Careful filtering is employed in both systems to minimize cross interference, and the upper or lower network frequency is selected to maximize separation from the payload channel in use.

Both the transmitter and receiver are capable of performing sweeps and automatically terminating the sweep upon acquisition. Acquisition by a satellite of the sweeping transmit signal must, of course, be determined from the received return signal.

To aid in accommodating the large variation in signal strength, which results from a range that can vary from a few feet to several miles, three manually controlled steps in transmitter output and receiver sensitivity are provided. Maximum transmit power is 2 watts and maximum receive sensitivity is -124 dBm.

The PSP demodulates the subcarrier and provides bit synchronization and frame synchronization based on one of four possible frame sync word lengths. Telemetry from the incoming signal may be at one of five different rates. Demodulated telemetry with clock and frame sync is routed to a payload data interleaver, a part of the instrumentation system, which interleaves it with data from up to four attached payloads for eventual transmission to the ground.

The PSP also receives configuration and payload command messages from the DPS at a burst rate of 1 Mbps. It responds to a configuration message by configuring itself to handle data at the rates and formats designated. Buffered commands PSK-modulate a 16-kHz subcarrier, which is transmitted by RF to a detached payload or by wire to one or more attached payloads.

Ku-Band Radar/Communication System

The Ku-band system, currently scheduled for installation between orbital flights 1 and 2, is designed and manufactured by Hughes. It operates as a radar during space rendezvous, measuring angles, angle rates, range, and range rate. When not so employed, it can be used as a two-way communication subsystem, transmitting through the TDRSS data up to 50 Mbps and receiving at a rate of up to 216 kbps. In both radar and communication modes, it uses a three-foot (0.9 m) parabolic monopulse antenna mounted inside the front of the orbiter's payload bay and deployed by rotation about a single axis after the orbiter is in space and payload bay doors are opened.

The deployed assembly (DA), which includes the antenna and considerable electronics, is mounted on the starboard side of the vehicle. The location of the hardware and radar range, communication modes, and maximum data rates are presented in Figure 9.

In both radar and communication modes, acquisition of the radar target or the communication satellite is aided by designation by the computer of an angle around which a spiral search is conducted. Acquisition thereafter is automatic. Manual entry of antenna angles is also possible.

Hardware common to both radar and communications functions include the antennas (the three-foot dish plus a small acquisition horn), the antenna drive mechanism, drive electronics, traveling wave tube (TWT) transmitter, and receiver front end.

Hardware is packaged in four LRU's (Figure 10). All except the communications signal processor are used for radar and all except electronic assembly 2 (EA-2) are used for communications.

Table II provides some Ku system parameters applicable to both radar and communications.

The parabolic antenna has two uncommon features. it is edge mounted with supports radiating from its mounting point and it is constructed largely of graphite-epoxy to minimize thermal distortion. In angle tracking modes, antenna sum and angular error signals are processed. The elevation and azimuth signals are time multiplexed, eliminating the need for a third processing channel.

Although concern had been originally expressed over the wisdom of combining a communications and radar system, it is now obvious that savings in weight, volume, and developmental costs were attained without significantly degrading either function.

Radar Function–As a rendezvous aid, the Ku-band system operates as a pulse doppler, frequency-hopping radar. The relatively long, 66-microsecond pulses employed at longer ranges provide reasonable efficiency with the peak-power-limited TWT amplifier. Short pulses of 22 nanoseconds are used to provide radar operation down to 100 feet (30 m). Pulse widths and repetition frequencies are selected to provide unambiguous measurement of both range and range rate for uncooperative (skin-tracked) targets to 10 nmi (18.5 km).

Since the orbiter in space performs the latter part of rendezvous and station-keeping by accelerating and braking along the z axis (the axis that runs vertically through the orbiter), the radar normally searches angles within 30 degrees of a straight “upward” pointing position. Tracking, however, may continue through larger angles until the beam is intercepted by orbiter structure.

Radar accuracy characteristics are summarized in Table III. The velocity accuracy requirement led to the choice of a pulse doppler approach. Sixteen doppler filters cover the doppler interval defined by the repetition rate.

Like the S-band payload communication subsystem, the radar must operate over a large dynamic range. In addition to concern over receiver dynamic capability, nearby targets could be damaged by excessive energy from the radar, so three levels of output power are provided: 50 watts full power with -12 and -24 dB steps of attenuation.

An auxiliary (acquisition) antenna provides a convenient source for a guard signal, which is processed and compared to the narrow-beam sum signal to eliminate sidelobe targets. Since the auxiliary antenna gain is 20 dB less than that of the main antenna, and since antenna sidelobes are down 20 dB or more, there is at least a 20-dB difference in the main/guard ratio for mainlobe and sidelobe targets.

Communication Function–Ku communications provide the orbiter with a highly flexible means of transmitting data at the various rates and formats summarized on Figure 9. Except for the 192-kbps channel, which is comprised of the orbiter voice and telemetry (“OPS data”), other rates and bandwidths shown are maximums. From the rate ranges shown in Table IV, it may be seen the capability extends continuously from 16 kbps to 50 Mbps. Similarly, the 4.5 MHz analog channel extends downward to dc. The unusual signal design provides quadraphase shift keying (QPSK) of a subcarrier, and either QPSK or FM of the carrier.

The problem of mutual acquisition of the orbiter and TDRS has received considerable attention. In one acquisition scenario, the orbiter radiates Ku energy at the TDRS through the widebeam acquisition antenna. The TDRS locates this signal and points its narrow (0.36-degree) beam at the orbiter, which searches and acquires with the narrow beam antennas and then switches its transmitter to the narrow-beam antenna. In a similar scenario, the orbiter radiates S-band energy through the appropriate antenna, and the TDRS points its Ku antenna at the S-band source. It even appears possible that available orbital parameters will be good enough to allow both TDRS and orbiter narrow-beam antennas to be pointed at each other with sufficient accuracy to allow acquisition without search.

Failure of the forward link results in a signal being generated in the signal processor, which commands the GCIL to switch the NSP forward link input from the Ku to the S-band receiver. This precludes the possibility of the ground losing communication with the vehicle should a Ku-band forward link problem develop while the crew is asleep.

Television

The television system allows visual monitoring from the ground of on-board activities and provides the crew with the ability to see areas of the payload bay obscured from direct observation. Television signals originating in the orbiter or its payloads can be transmitted to the ground on either of two links–the FM direct S-band link or, when it becomes available, the Ku-band TDRS link. Early flights of the first orbiting vehicle will use an interim TV system, with the operational system coming into use on orbital flight 2 or 3.

Interim System–Flight equipment for the interim TV system consists of two cameras, their lenses and cables, two viewfinder monitors, and a video interface unit (VIU). The cameras, lenses, and monitors are residual Westinghouse equipment from the Apollo-Soyuz program modified to meet Shuttle mission requirements. The VIU, a new piece of equipment, provides the interface between the system and the spacecraft and provides video sync signals.

Each orbiter camera uses a rotating color wheel to generate a field sequential color video signal. One camera is located on the flight deck and the second is located below on the mid deck. Both are hand-held. Wide angle and normal zoom lenses are provided for use with each camera. Several modifications have been made in the original camera configuration, the most significant being a change in the output circuitry to provide a balanced differential output. This change is for compatibility with orbiter wiring designed for the more complex operational TV system, which uses controlled impedance, twisted, shielded, jacketed cable for video and sync signals rather than the more commonly used coaxial cable.

Operational System–The operational television system (Figure 11), designed and manufactured by RCA, will have up to nine on-board cameras, two large-screen monitors, two portable viewfinder monitors, and the associated switching and control logic. Three inputs are provided for television signals from payloads and an output for viewing in an attached manned payload.

All TV cameras are black and white, but may be converted to color with the substitution of a color lens assembly (CLA) for the normal monochrome lens assembly (MLA). This CLA contains a rotating color separation wheel similar to that on the interim system to provide a field sequential color signal. Only the two cameras located inside the cabin are to be equipped for color. One of these same 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 being 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, called the keel camera, at one of four locations on the floor.

The remaining four cameras may be located on the two arms of the remote manipulating system (RMS). These two jointed arms are for use in deploying and retrieving payloads. Cameras are provided at two locations on each arm: one at the “elbow” and one at the “wrist.” The former 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 viewing 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 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.

Video Recorder–A Teac Model V-1000 ABN video recorder will be provided for on-board use. This unit, which can record either black and white or color, uses cassettes to provide 30 minutes of recording time each.

The recorder uses a two-head helical scan system with FM recording. It has its own controls on the front panel, eliminating need for a separate control panel and minimizing orbiter wiring.

Audio response exceeds that of the audio distribution system and video response is at least equivalent to a horizontal resolution of 340 lines (B and W) or 240 lines (color).

Ground Command Interface Logic

The ground command interface logic is an LRU that provides the capability for ground control of many functions of the C&T system and of a portion of the operational instrumentation system. It also provides the logic to allow control of the same functions from either D&C switches (manual commands) or in response to ground-originated commands through either the S-band or Ku-band links. Ground-originated commands flow through the NSP to the general-purpose computers (GPC’s) of the DPS. Commands are sent to the LRU’s, and the command status (from either the GCIL or the LRU’s) is returned to the GPC and routed to the ground through the NSP. The GCIL provides logic to allow the on-board crew to block ground-originated commands.

On-board commands may also be originated through the use of any of several DPS keyboards that enter the command directly in the GPC. A note of clarification: the term GPC includes all five of the DPS computers on board, including those previously referred to as GN&C computers.

The GCIL, in conjunction with the other described equipment, allows a ground crew to operate and monitor the C&T system configuration, freeing the crew for other activities. It also avoids the necessity of having one astronaut awake at all times just to maintain contact with the ground.

Antennas

The antennas associated with each subsystem (except the UHF airlock and the deployable Ku-band) are flush mounted and placed as shown in Figure 12. The locations were chosen to favor the desired direction of coverage within the constraints of the available “real estate.”

All flush antennas are overlaid with thermal protective material, which covers that part of the orbiter surface that otherwise would be unable to survive the heat of entry. Thermal protective material is thickest on the bottom; that over the lower antenna is as thick as 2-1/2 inches. This material has electrical characteristics somewhat similar to polyurethane foam, and has required special attention where the patterns are critical (quads), the wavelength is in the order of material thickness (MSBLS), and where isolation is important (radar altimeter).

Basic data on the antennas are presented in Table V. MSBLS antennas require a reasonably smooth pattern to avoid introducing measurement errors that would otherwise result from signal amplitude variations as the vehicle attitude changes. The four 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 roll provide overlapping roll coverage; fore-aft coverage is in the order of 120 degrees.

3. DISPLAYS AND CONTROLS

Communication control panels in the orbiter are not too different from their counterparts in large commerical aircraft and previous manned spacecraft, and much effort has resulted in highly reliable components. All panels (not just C&T) are designed and manufactured by the orbiter prime contractor, Rockwell International, to ensure commonality of component use and standard layout and nomenclature.

The S-band control panel (Figure 13) makes use of some block diagramming to aid in understanding switch functions, a technique that also shows on the bottom of the Ku-band control panel (Figure 14). The signal strength meter on the Ku panel is shared between the S-band PM (network) subsystem, the S-band payload subsystem, and the Ku subsystem. The striped “barber poles” are two-state displays more reliable and easier to view under various lighting conditions than pilot lights.

Additional information on the C&T system is available on the DPS cathode-ray display. Most interesting of the data that can be called up is the antenna status display, the center of which is shown in Figure 15. This display shows the volume around the vehicle as if a tube had been placed around the fuselage, split along the bottom, and flattened. The nose is a line across the top of the figure, the tail the line across the bottom of the figure, and both sides of the figure represent the bottom fore-aft center line of the vehicle. The oddly shaped figures are the outlines of the angles within which the Ku beam would be blocked by the vehicle. Moving symbols E, W, and S are the directions to east and west TDRS and to the nearest ground station. Obviously, they are not all always on the display. The square around the W indicates the Ku antenna is pointing toward TDRS west. The pairs of letters along the top of the display indicate the S-band quad that best serves those 90-degree quadrants (LL = lower left, LR = lower right, etc.). This center display is surrounded by other antenna status and signal strength data.

4. SYSTEM PHYSICAL DESCRIPTION

The C&T system utilizes both 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 in the order of 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 cover or base provides contact with water-cooled shelves on which or under which it mounts (Figure 16). Holddown is by captive fasteners. Connectors are on the front panel. Physical design was greatly influenced by the sealing requirement, conduction cooling, and by the design vibration requirement of 0.09 g^2 per Hertz.

Off-the-shelf NAVAID's are of standard aircraft configuration, with both the MSBLS and TACAN LRU's being vibration isolated. These LRU's are cooled by air. Forced circulation is used because of the lack of convection in space.

Most C&T LRU's are mounted in equipment bays located at the fore and aft ends of the mid deck along with LRU's of other orbiter systems. 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.

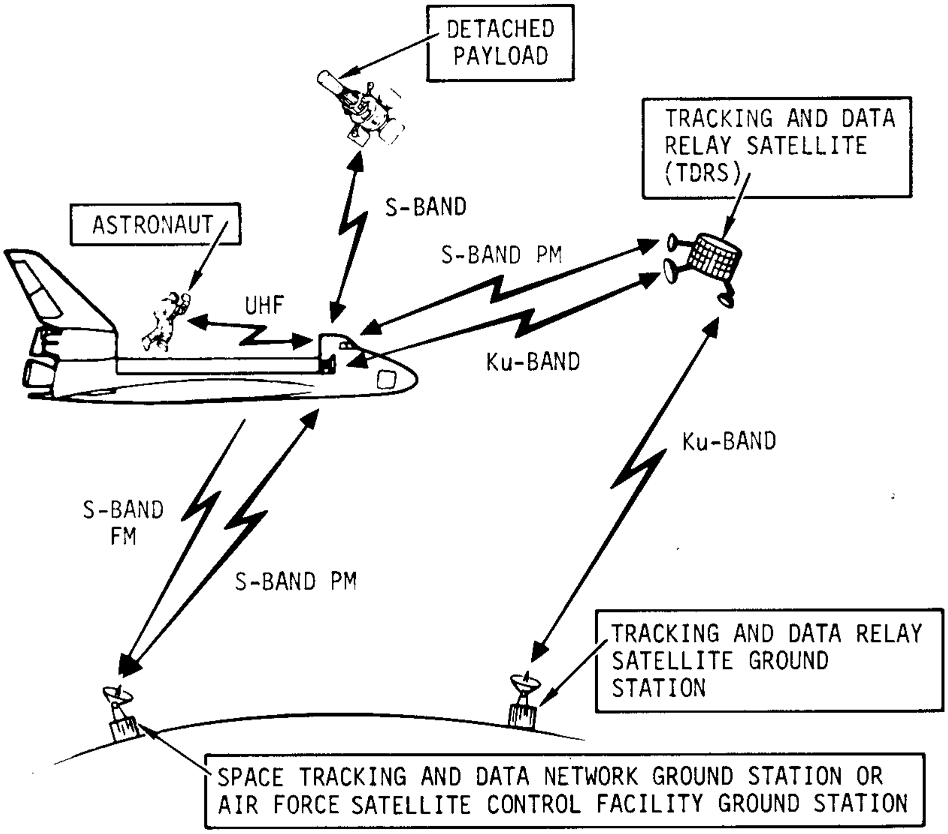


Figure 1 - Orbital Communication Links

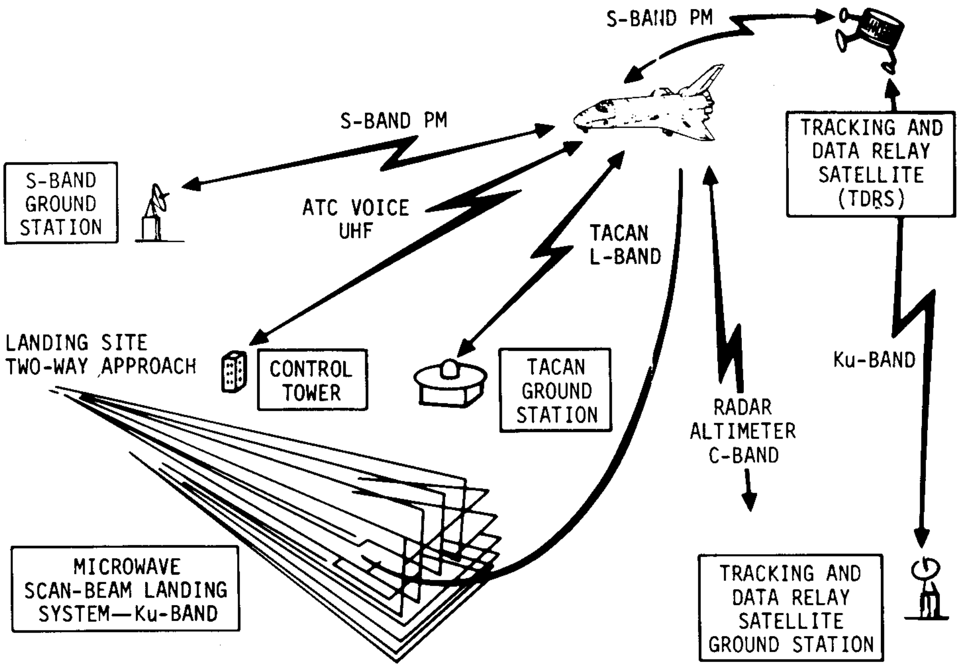


Figure 2 - Atmospheric Flight Links

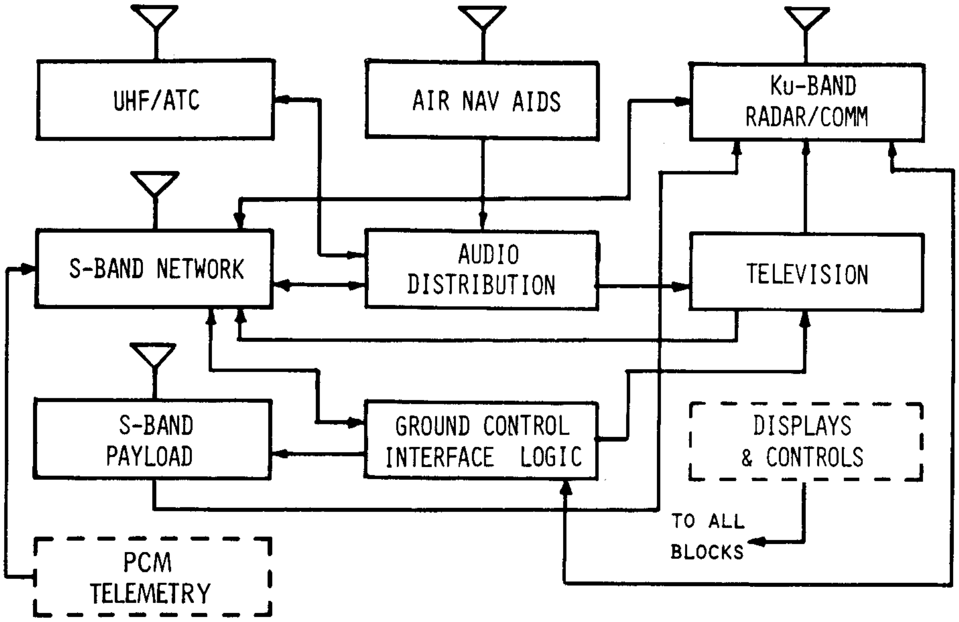


Figure 3 - Subsystems and Hardware Groupings

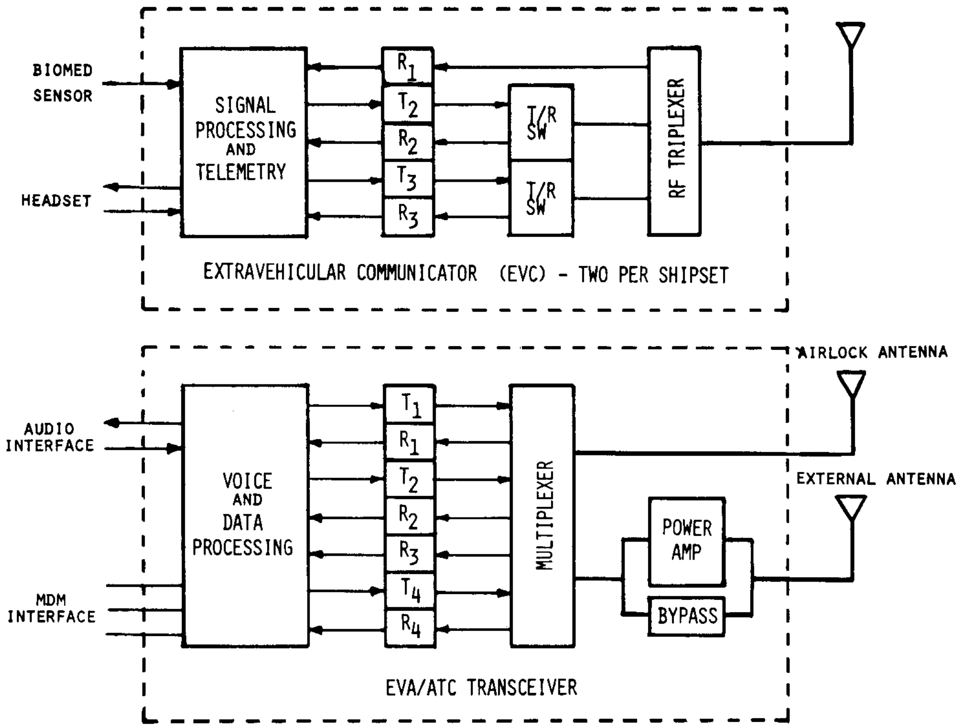


Figure 4 - EVA/ATC Communication System Block Diagram

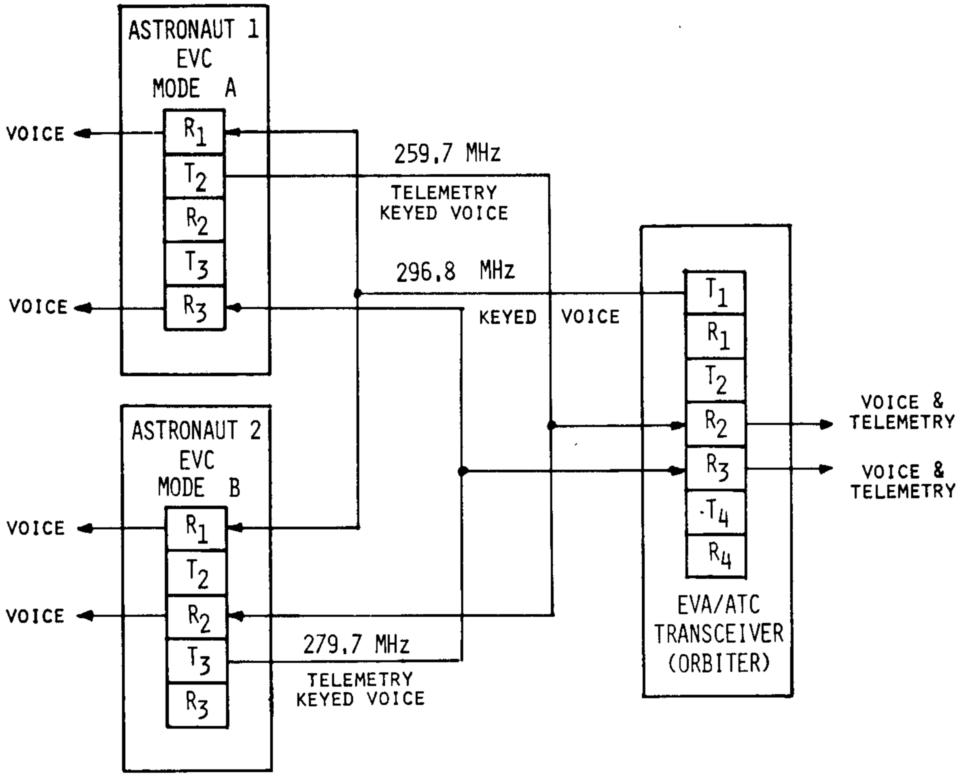


Figure 5 - Normal EVA Communications

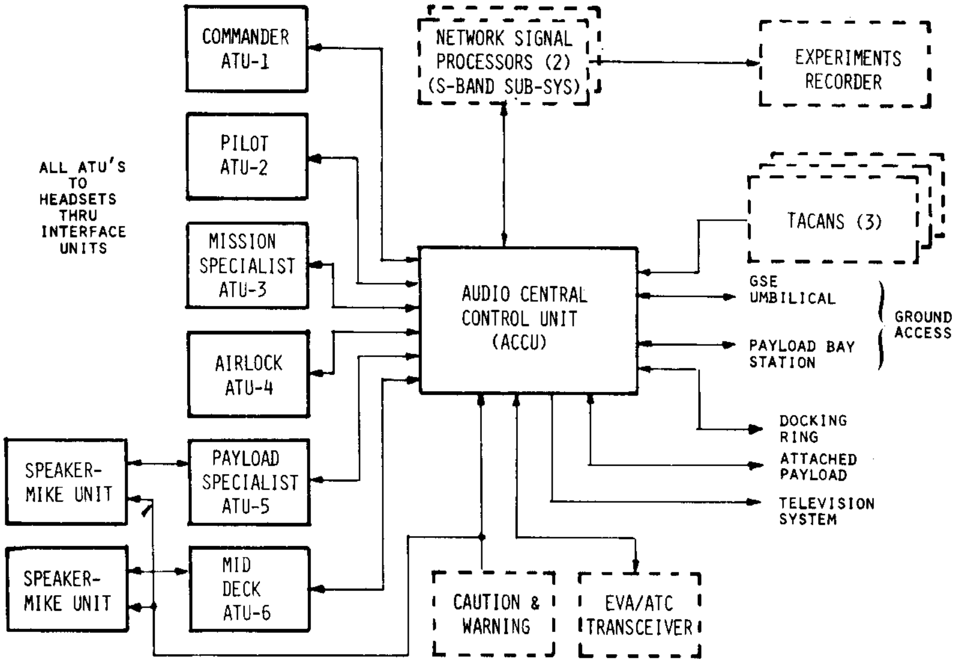


Figure 6 - Audio Distribution System Block Diagram

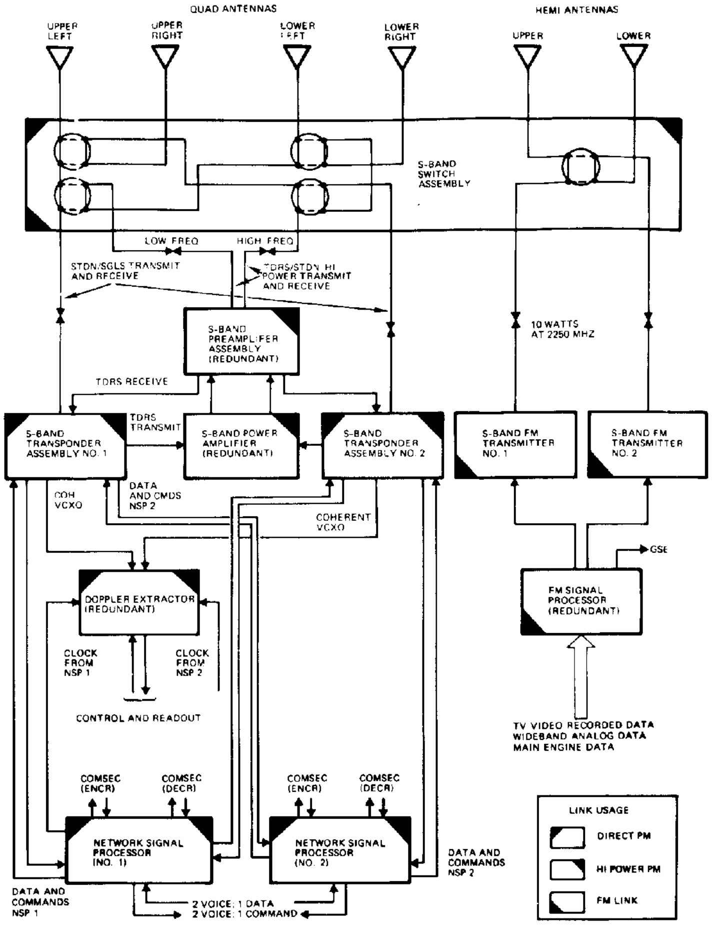


Figure 7 - S-Band Network System Block Diagram

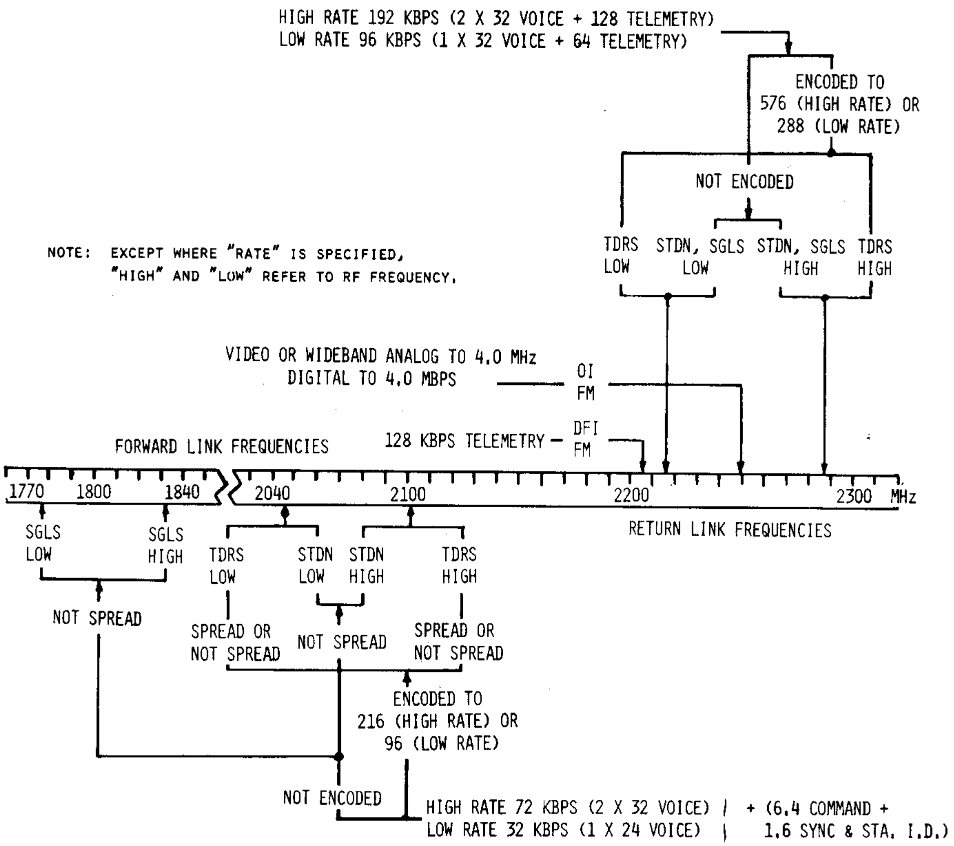


Figure 8 - S-Band Network Frequencies, Modes, and Data Rates

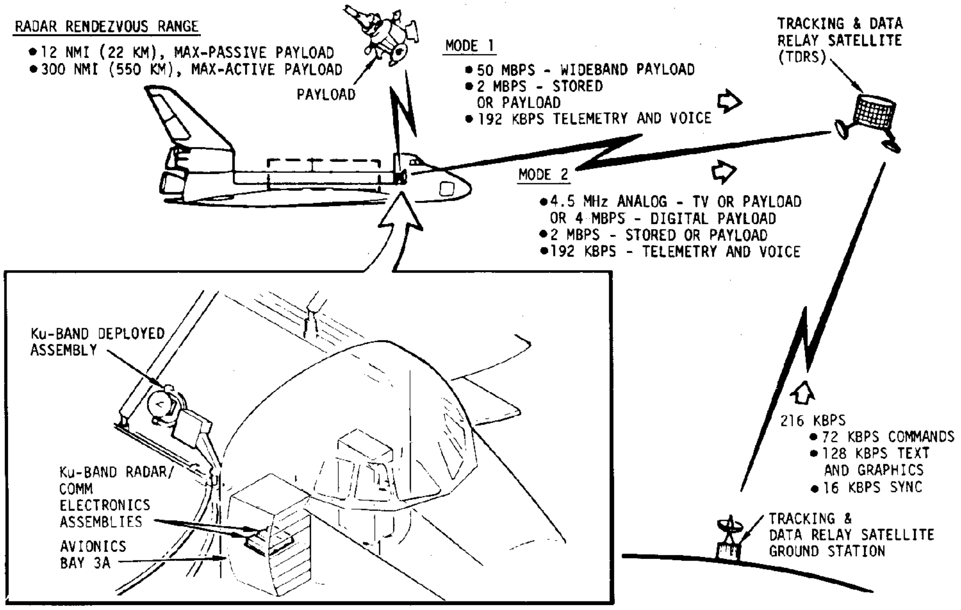


Figure 9 - Ku-Band Radar/Communication Subsystem

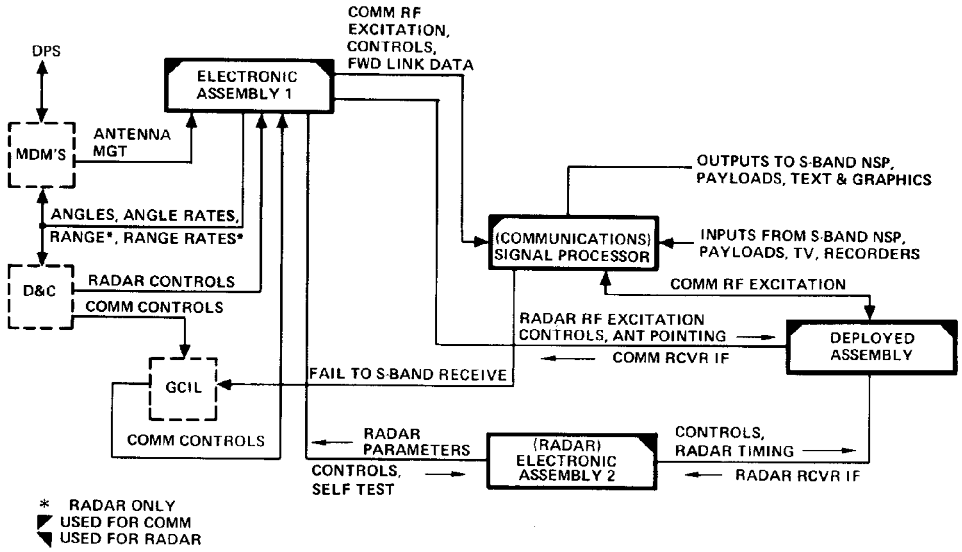


Figure 10 - Ku-Band Subsystem Block Diagram

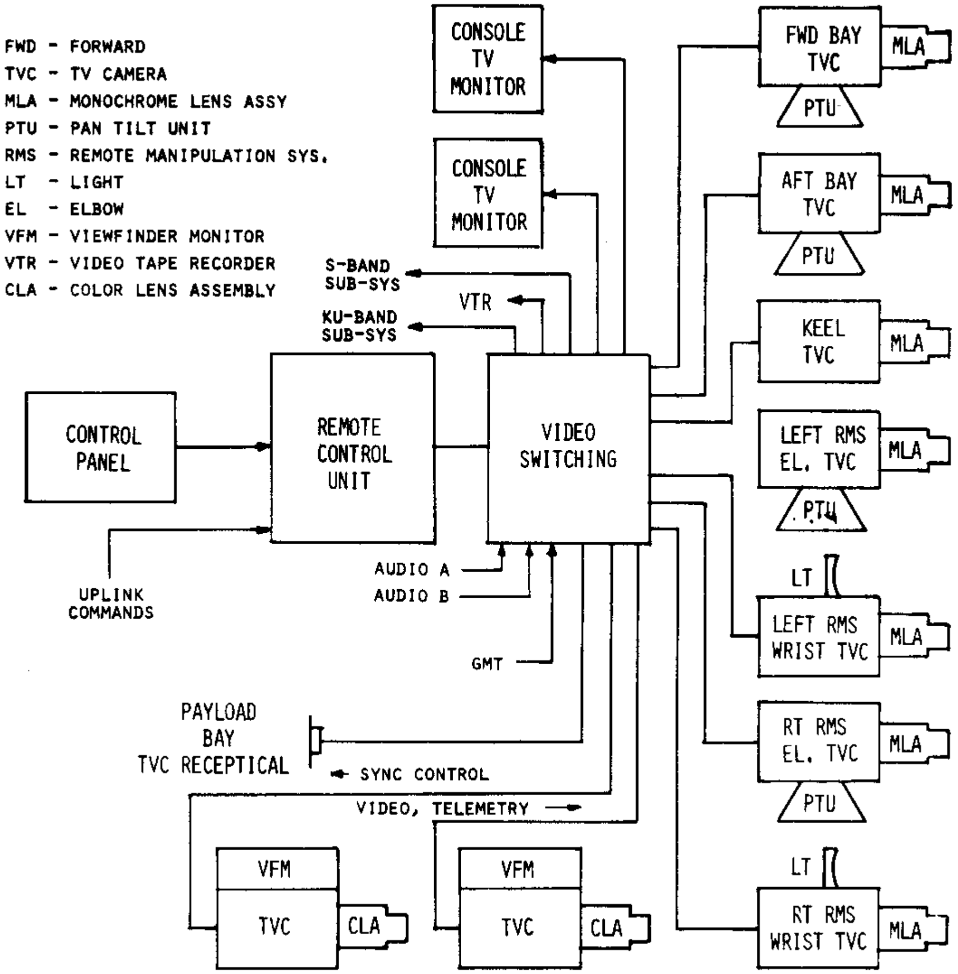


Figure 11 - Operational TV System Block Diagram

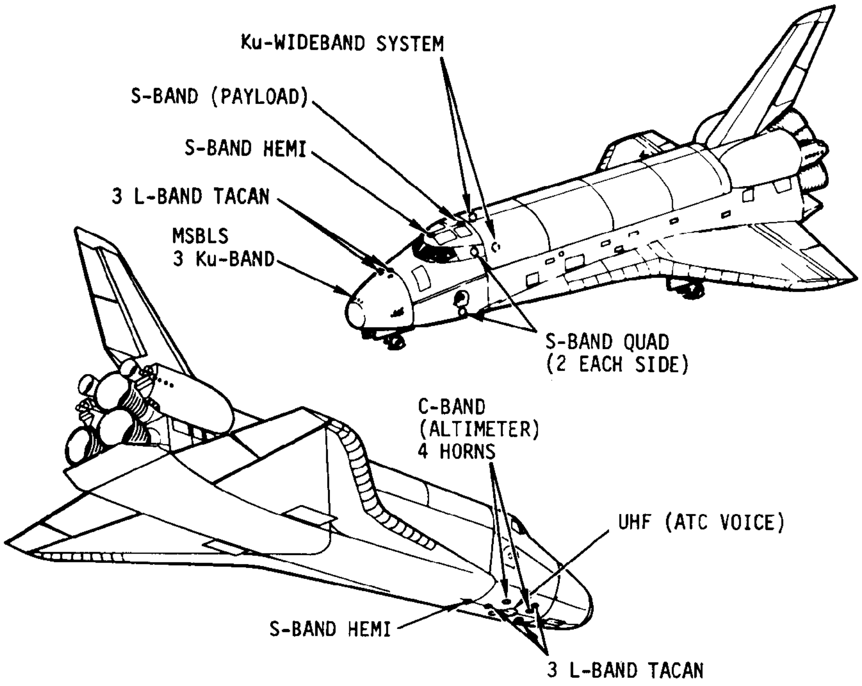


Figure 12 - Antenna Locations

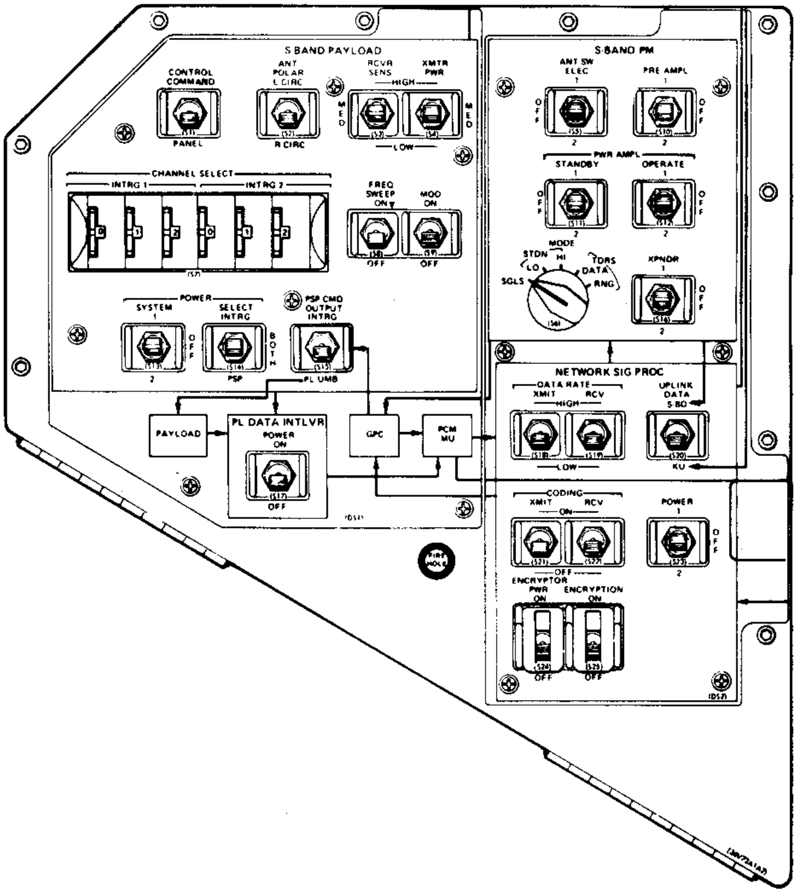


Figure 13 - S-Band Controls

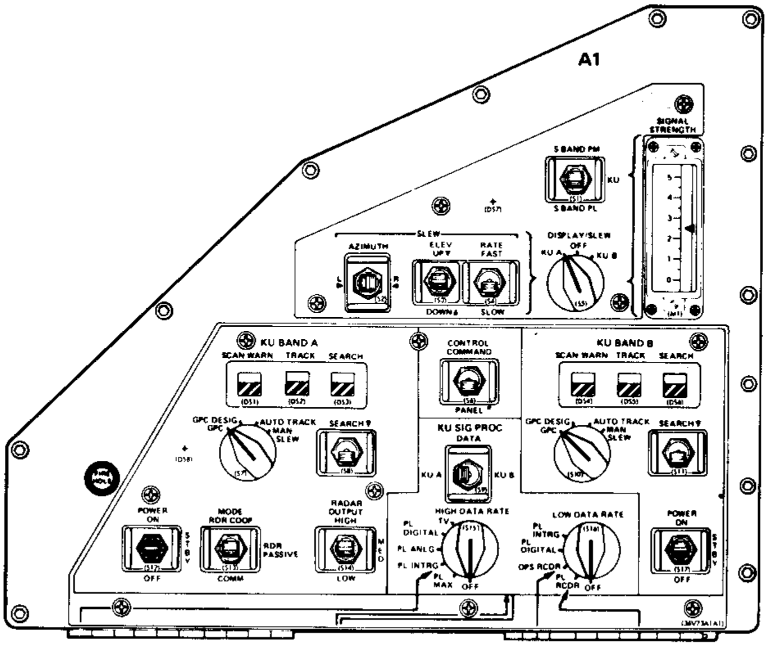


Figure 14 - Ku-Band Displays and Controls

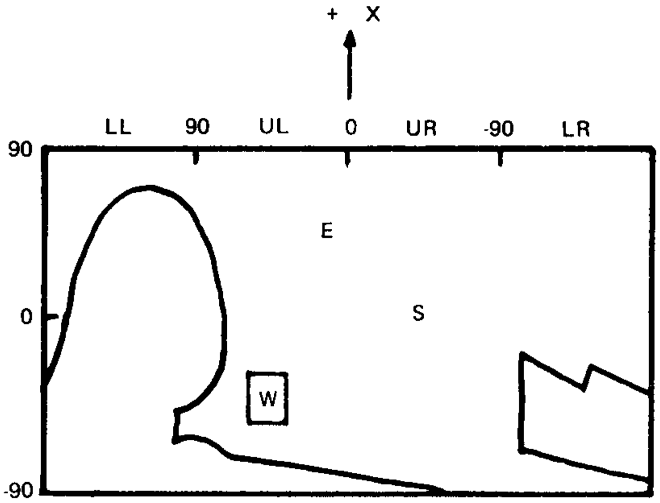


Figure 15 - Center of Antenna Display

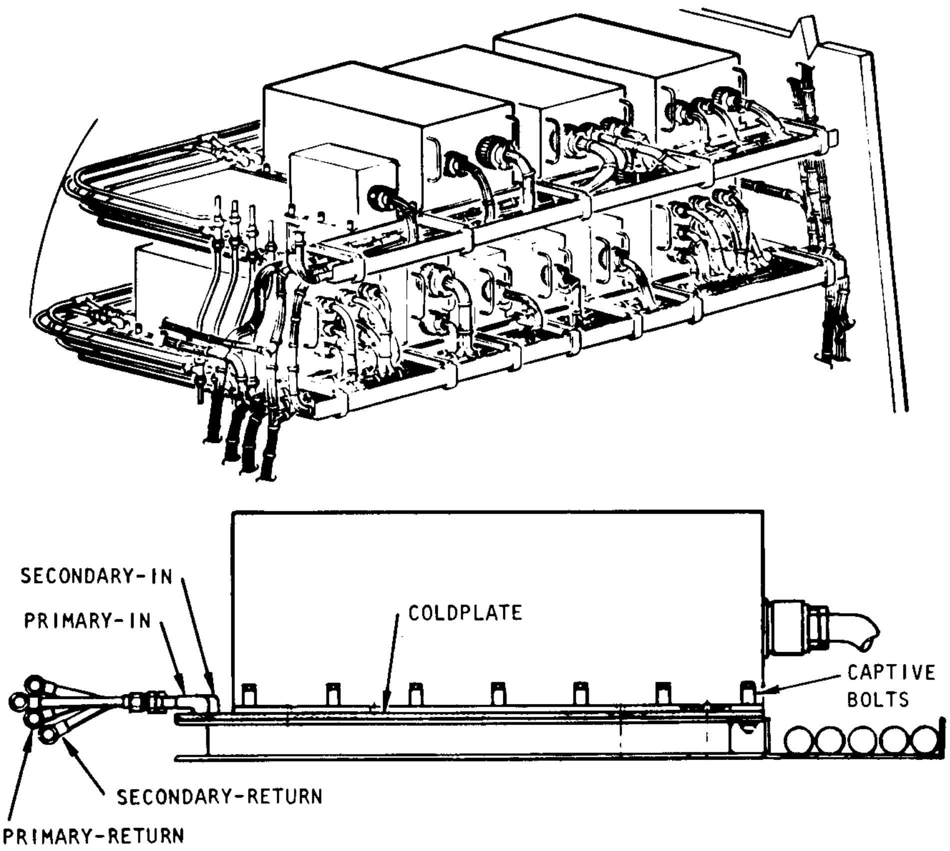


Figure 16 - Typical Avionics Installation

Table I - Source and Impact of Design Drivers

Design Driver	Source	Impact
Cost	Objective to make Shuttle a low-cost launching system	• Compatability 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 groung networks and interface with a wide variety of payload communication	• 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
Atonomy	Requirement to be independent of ground support (operate without radiating)	Development of doppler extractor to obtain navigation data from stable ground-transmitted signal
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 ro minimize losses and improve aantenna and receiver/transmitter performance

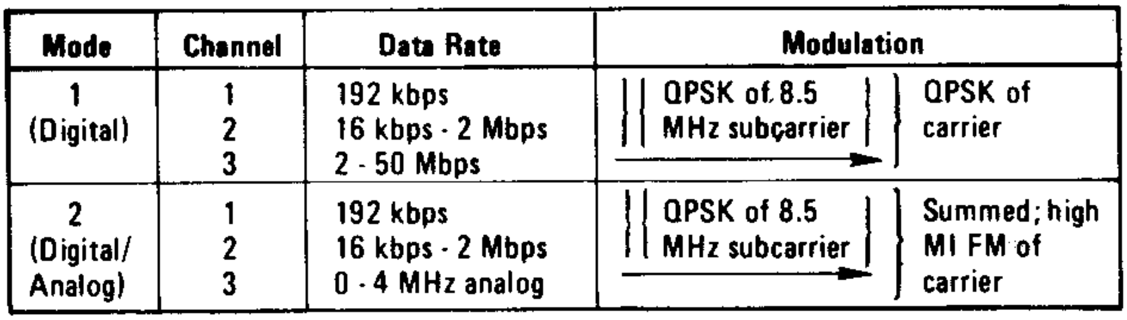
Table II - Key Ku System Parameters

Narrow Beam Antenna	
Type	Prime feed parabolic
Peak gain	38.4 - 38.9 dB*
3 dB beamwidth	1.57 - 1.68°
Polarization	RHCP/linear
Wide Beam Antenna	Horn
Type	18 dB
Gain	20°
Beamwidth	Linear
Polarization	
Common Parameters	50 W
TWT output	5 dB max.
Receiver NF	28 vdc
Prime power	
*Frequency dependent	

Table III - Radar Accuracy

Range accuracy (3σ)	80 feet or 1 percent
Velocity accuracy (3σ)	1 ft/s
Angle accuracy (3σ)	8 milliradians
Angle rate accuracy (3σ)	0.14 milliradians/sec

Table IV - Return Link Signal Design



Mode	Channel	Data Rate	Modulation	
1 (Digital)	1 2 3	192 kbps 16 kbps - 2 Mbps 2 - 50 Mbps	QPSK of 8.5 MHz subcarrier →	QPSK of carrier
2 (Digital/ Analog)	1 2 3	192 kbps 16 kbps - 2 Mbps 0 - 4 MHz analog	QPSK of 8.5 MHz subcarrier →	Summed; high MI FM of carrier

Table V - Orbiter Antennas

Antenna	Quantity	Freq.	Polar	Type	Reason for Selection
TACAN	6	L	LV	Annular slot	High efficiency; broad angular coverage
MSBLS	3	Ku	LV	Waveguide horn	Selected beamwidth; smooth pattern
Radar altimeter	4	C	LV	Horn	Beam-shaping; isolation
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	SS	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	
Ku system	1 or 2	Ku	L radar CP comm	Parabolic	High gain; low sidelobes