INTELSAT V SPACECRAFT TELEMETRY COMMAND AND RANGING

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ABSTRACT

The INTELSAT V communications satellite was designed and assembled by the Ford Aerospace and Communications Corporation of Palo Alto, California, for the International Telecommunications Satellite Consortium (INTELSAT). The Communications Satellite Corporation (COMSAT) is the designated United States representative to INTELSAT and also performs technical service for INTELSAT in monitoring the design, fabrication, and test of communications satellites.

The TT&C subsystem consists of two functionally redundant and independent command and telemetry channels, the major elements of which are shown in Figure 1.

The telemetry subsystem provides two data channels for formatting and transmitting data received from sensors, transducers, and status indicators in the various subsystems of the spacecraft. In addition, the output of a command receiver can be connected to a telemetry transmitter to form a ranging transponder.

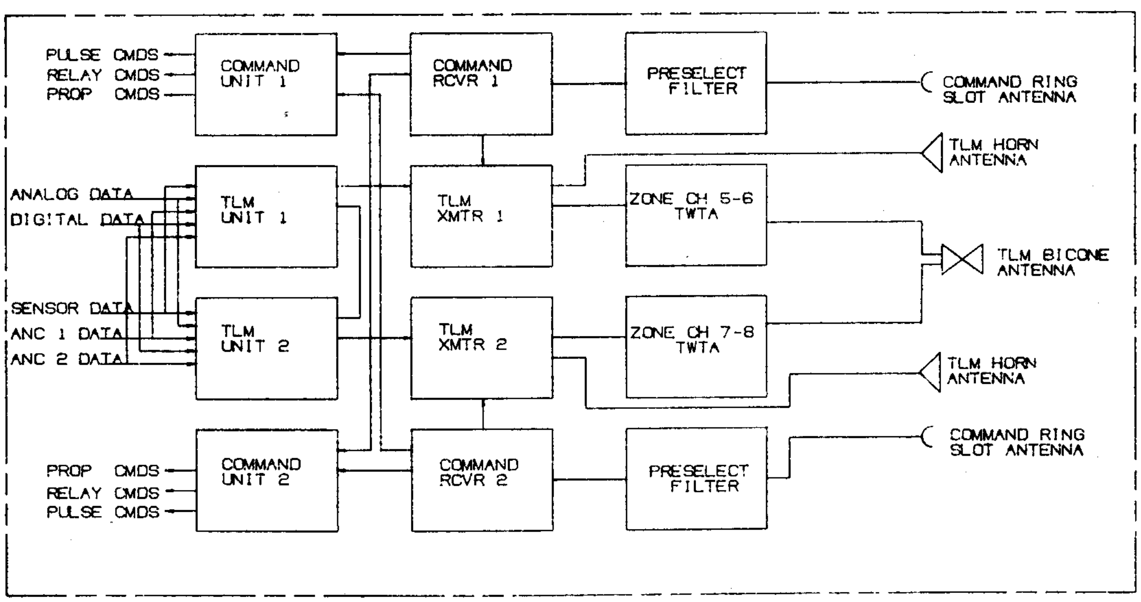
The telemetry unit can provide normal or dwell PCM data in NRZ-M format modulated on a 32 KHz subcarrier. The telemetry transmitter phase modulates one of the data subcarriers or ranging tones on a 4 GHz band downlink carrier. The transmitter output is routed directly to an earth coverage conical horn for transmission at a level of approximately 0.0dbW. The transmitter output can also be routed through a zone communications channel TWTA to a telemetry omni-directional bicone antenna for extended coverage.

Commands and ranging tones are received on a 6 GHz band uplink carrier through dual Omni pattern antennas. The received signal is routed through a passive filter to the two command receivers where the frequency modulated command or ranging tones are

detected. The command tones are routed to the command units for processing. The command transmission is either a command message, consisting of 58 serial bit, or a command execute. The command message includes the address of the command unit which is to be used and what specific command function is to be executed. The command units provide the capability for pulse, discrete relay, and proportional relay command functions required by the various subsystems of the spacecraft.

INTRODUCTION

The Telemetry, Command, and Ranging (TC&R) subsystem of the INTELSAT V spacecraft interfaces with the INTELSAT Tracking, Telemetry, and Control (TT&C) network to provide operational monitoring and control for all spacecraft functions through a microwave link. The subsystem design was made compatible with existing ground equipment except for the command generators. New command generators were designed and manufactured by Ford Aerospace and Communications for each of the eight TT&C ground stations as part of the spacecraft contract.



TELEMETRY, COMMAND AND RANGING SUBSYSTEM
FIGURE 1

TELEMETRY SUBSYSTEM

The INTELSAT V telemetry subsystem consists of two redundant sets of hardware including a telemetry unit, a telemetry transmitter, and a global coverage horn antenna. During transfer orbit, telemetry is also transmitted through two zone communications channels to the telemetry bicone antenna. Table I is the Telemetry Performance Summary.

Unique features of the INTELSAT V telemetry system, as compared to previous INTELSAT communications satellites, include:

a. Each telemetry unit is completely redundant so that only one is on at any one time.

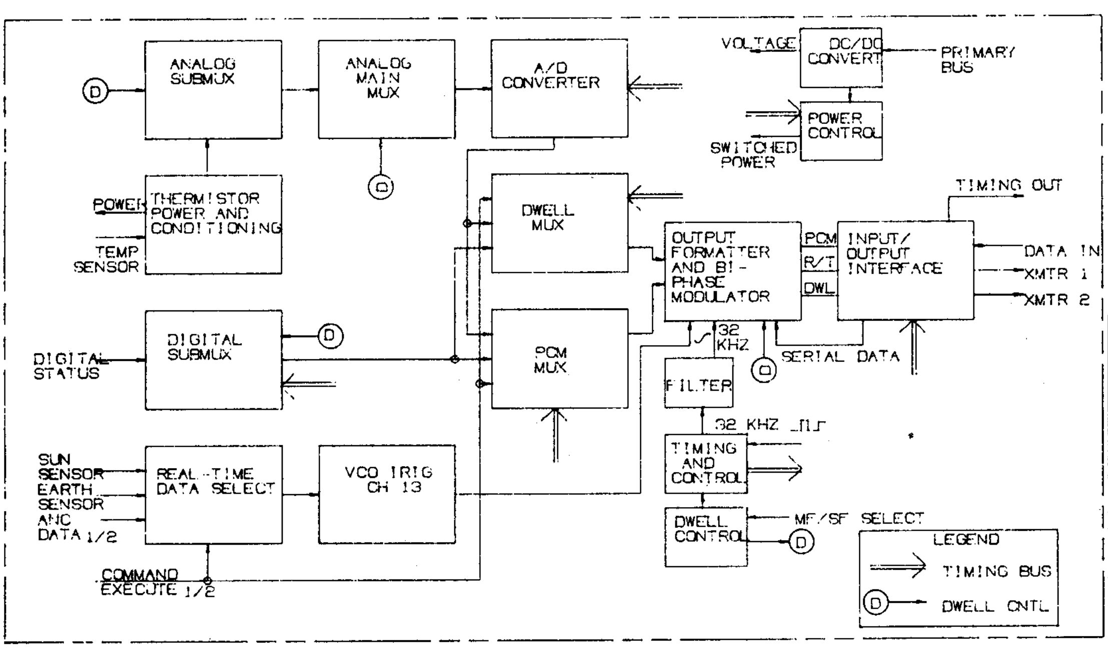
b. A PCM dwell mode is available which allows commendable selection of any main frame or subframe word for presentation on 58 of the 64 main frame words.

c. Up to 32 levels of subcommucation for slowly changing analog and status parameters such as temperature, battery cell voltage, antenna position, and communications switch status.

d. Remote telemetry processors and submultiplexers in other subsystems such as power, attitude determination and control, and antenna position.

e. Ranging through the telemetry and command subsystem instead of through the communications subsystem.

The telemetry unit (Figure 2) provides four types of data which are PCM, PCM dwell, FM nutation accelerometer, and FM sensor/execute pulses. PCM data is always supplied to the primary transmitter which is Transmitter 1 for Telemetry Unit 1 and Transmitter 2 for Telemetry Unit 2. Any one of the four data types can be selected for the alternate transmitter through ground command.

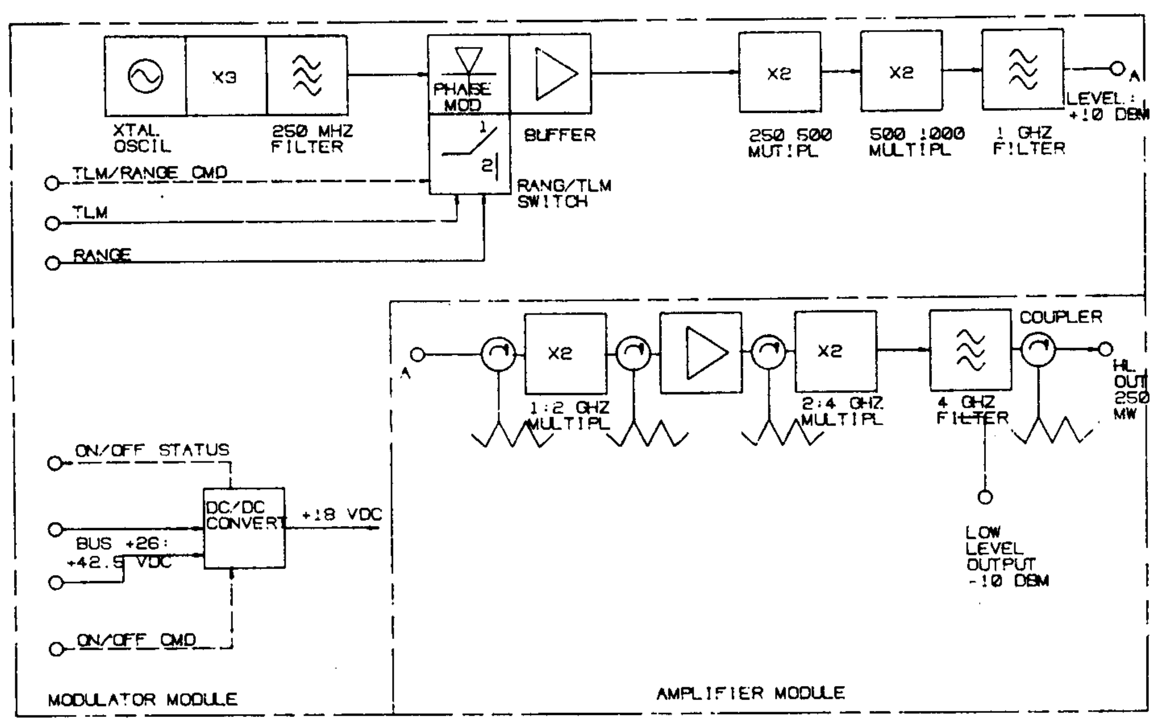


TELEMETRY UNIT
FIGURE 2

The telemetry unit inserts a unique data indentification code into the PCM and the dwell PCM data streams so that the source of all data can be identified when it reaches the ground telemetry data processing centers. The code is hardwired during spacecraft manufacture through a harness connector. The code for Telemetry Unit 1 and 2 on the same spacecraft is identical, but a status bit indicates which telemetry unit is turned on. A status bit in both the PCM and dwell PCM streams identifies the data as normal PCM or dwell. The NRZ-M coded PCM digital streams biphase modulate a 32 kHz subcarrier which is then routed to the telemetry transmitter.

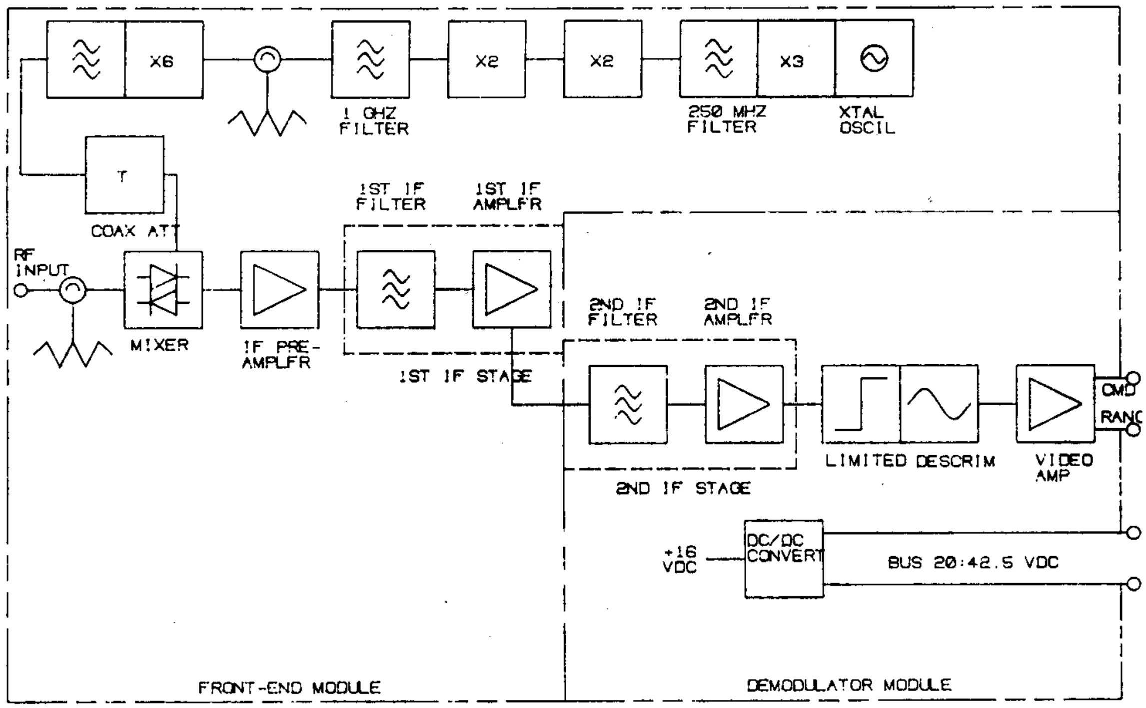
The FM modes are used primarily in transfer orbit operations while the spacecraft is spinning to provide nutation accelerometer or sensor/execute data. In the FM real time mode, pulses from the transfer orbit sun and earth sensors and detected executes from the command unit are ORed and priority selected to frequency modulate the IRIG channel 13 subcarrier. This is then routed to a telemetry transmitter.

The telemetry transmitter (Figure 3) operates at one of two frequencies in the 4 GHz band, determined by the selection of the crystal frequency during manufacture. Either telemetry data or ranging tones from the Side 1 command receiver is channelized to the modulation selection relay in the Side 1 transmitter. The Side 2 command receiver and telemetry transmitter are similarly connected.



TELEMETRY TRANSMITTER
FIGURE 3

Each telemetry transmitter has a +24dbm and a -10dbm output. The higher output is routed directly to an earth coverage conical horn antenna. The lower level output can be routed through one of three selectable communications TWTA's to the telemetry toroidal beam bilrone antenna to provide coverge in a plane perpendicular to the spin (Z) axis.



COMMAND RECEIVER
FIGURE 4

TABLE I TELEMETRY PERFORMANCE SUMMARY

Parameter	Characteristics
Telemetry Transmitters (2)	
Design and Manufacture	Selenia, Italy
Carrier Frequency	One of the two discrete frequencies in the 4 Ghz band.
Power Output	+24dbm and -10dbm.
Type	Frequency multiplication, phase modulation.
Local Oscillator	82 MHz crystal.
Telemetry Antennas	
Design and Manufacture	Selenia, Italy

Transfer orbit	Toroidal beam right hand circularly polarized biconal horn with dual orthogonal input ports, coverage ± 20° from a plane perpendicular to the spin axis.
RF Power Output	
Synchronous orbit	Selenia, Italy
Transfer orbit	Toroidal beam right hand circularly polarized biconal horn with dual orthogonal input ports, coverage ± 20° from a plane perpendicular to the spin axis.
Synchronous orbit	Two conical horns, right hand circularly polarized, average ± 20° from the earth pointing Z-axis.
RF Power Output Synchronous orbit	0.0 dbW e.i.r.p. minimum over the earth coverage region, transmitter +24 dbm output through the conical horns.
Transfer Orbit	Same as synchronous plus 0.0 dbW e.i.r.p. minimum over spin axis perpendicular region, transmitter -10dbm output amplified through 2-zone communications channel +5.4 dbW TWT's.
Modulation	Telemetry from the "on" telemetry unit, or ranging channelized from one command receiver.
Modulation Index	Approximately 1 radian.
Telemetry Units (2) Design	Ford Aerospace and Communications
Manufacture	Mitsubishi Electric Co., Japan
Data Type	Pulse code modulation (PCM) to primary transmitter; PCM, or PCM dwell, or FM accelerometer, or FM sensor/execute (earth sensor, sun sensor, and execute pulses) to secondary transmitter.
PCM Data:	
Data Input Levels:	
Analog	0.0 to +5.1 Vdc
Digital Type A	TTL compatible; 0 level 0.0 to +0.5 Vdc; 1 level + 2.4 to +5.25 Vdc.

Digital Type B	Relay contact or solid state switch; 0 level <50 ohms to return; 1 level >1 megohm to return.
Data Capacity:	
Mainframe	64 8-bit words including 35 differential analog, 37 parallel binary bits, 112 serial binary bits.
Local submultiplexers	2x32 temperature, 1x16 Spot TWTA anode voltage, 1x16 communications status, 1x8 controls status.
Remote submultiplexers	2x32 battery cell voltage, 1x8 antenna positioners, 1x16 attitude control digital data.
Date Format and Rate	Eight bits per word, 64 words per frame, 1000 bits per second.
Main Frame Synchronization	24-bit pattern.
Subframe Synchronization	Subframe number reported in main frame, remote submultiplexers controlled by telemetry unit.
PCM and Dwell PCM Output	NRZ-M serial bit stream biphase modulates a coherent 32kHz subcarrier.
FM Data	Nutation accelerometer on real time sensor/ execute pulses frequency modulated on IRIG Channel 13.

COMMAND SUBSYSTEM

The INTELSAT V command subsystem consists of two redundant sets of hardware including the command antenna, a preselect filter, a command receiver, and a digital command unit. Table II is the command performance summary.

Unique features of the INTELSAT V command subsystem, as compared to previous INTELSAT communication satellites, include:

a. A cardioid command antenna pattern which provides useable coverage in excess of +120 degrees around the spin axis.

b. The use of four baseband tone frequencies for command and execute instead of six.

c. A digital implementation for the tone detectors instead of analog filter circuits.

d. A total command capacity more than twice that of INTELSAT IV reflecting the increased complexity of the spacecraft.

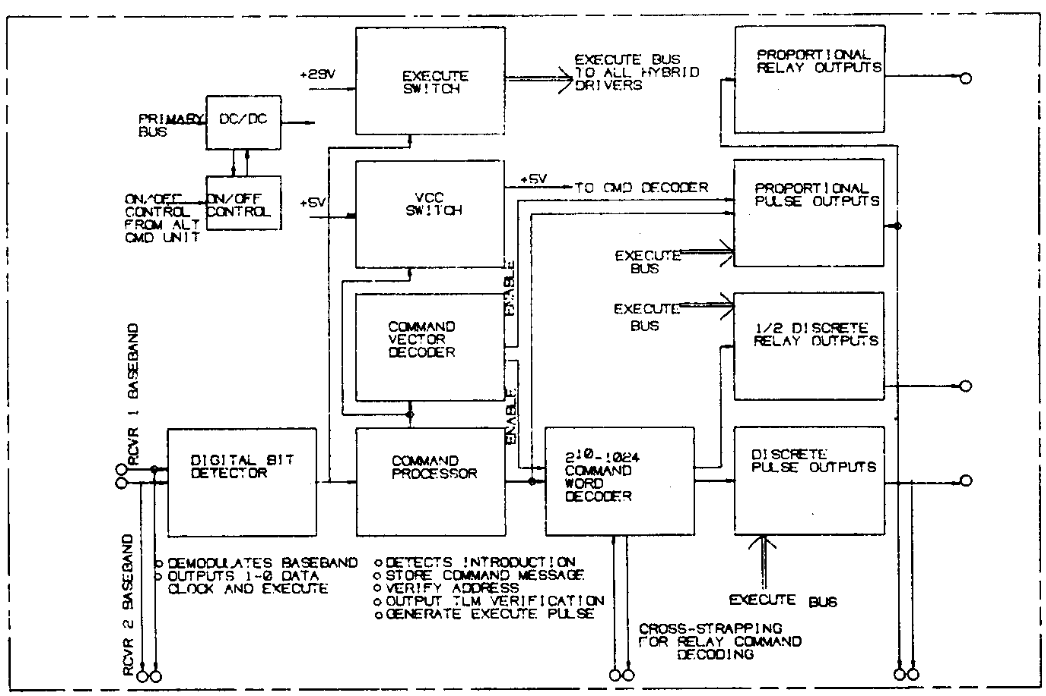
e. The use of proportional commands in addition to discrete commands.

f. An extensive use of relays located in the command unit for command execution.

g. Ranging through the telemetry and command subsystem instead of through the communications subsystem.

The command antenna assembly is located at the top of the antenna tower structure and consists of two ring-slot radiators above a single beam shaping cone. Each radiator is connected through a passive preselect filter to one of the two command receivers. The preselect filter protects the command receiver from the received 6 GHz communications signals and the higher power 4 GHz and 11 GHz transmitters aboard the spacecraft.

The command receiver block diagram is shown in Figure 4. It is a single conversion design employing a crystal oscillator and a balanced mixer to convert the uplink signal to a 70 MHz IF. The demodulator module contains a hard limiter and a Travis discriminator. For simplicity and reliability, AGC or squelch circuits are not used. A very high receiver sensitivity is neither necessary nor desirable since the TT&C ground stations are capable of illuminating the spacecraft with a signal density between -90 and $-54 dW/m^2$.



COMMAND UNIT
FIGURE 5

The command uplink signal is either one of four command tones or one of three ranging tones frequency modulating a 6 GHz command carrier. Commanding and ranging are not conducted simultaneously. The receiver baseband video output is routed to both digital command units for commanding and to one telemetry transmitter where the selection between telemetry or ranging is made through ground command. Both command receivers are operational any time power is available on the spacecraft busses.

Although the output of each receiver is always connected to both command units, the ground operator is able to select which receiver and which command unit is to be used through the selection of tone group and command unit address on the ground command generator. There are two tone groups, each including a “0”, a “1”, and an execute tone. Once the “0_1” tone is detected, Processing is switched to Receiver 1. If a “0_2” tone is detected, processing switched to Receiver 2.

The command unit block diagram is shown in Figure 5. The digital command message contains 58 bits, generated in a PCM-RZ format at a rate of 100 bits per second. Each command message includes an introductory sequence of zeros to switch the receiver selection and to synchronize the bit detector clock, an address, a vector, and a discrete command or proportional data. Each command unit has a unique address which is hardwired during spacecraft assembly through a harness connector. The unit compares the address in the command message the command message identifies the data portion of the message as a discrete command or a specific type of proportional data. The vector and data portions of the message are stored in the command unit, and passed to the telemetry subsystem for use in verification by the ground operator. The command will remain in the command unit until another command message or a clear message, containing only the introductory sequence is received.

Commands stored in the command units are executed upon receipt of the execute tone. The spacecraft execute pulse begins 20 to 30 milliseconds after the receipt of the execute tone and continues as long as the execute tone is being detected. A single execute tone of 300 milliseconds duration is used for most commands. Times or pulse executes are used for manual thruster firing, solar array stewing, and antenna positioner stepping.

Proportional commands are used to load spacecraft storage registers with data such as number of thruster firings, duration of pulse, and firing delay, all used in the store-and-execute function of the Attitude Determination and Control Subsystem (ADCS). They are also used to switch up to 10 functions simultaneously, such as for a Communications subsystem pathway or redundant equipment change. Discrete commands are used for on-off and single state changing functions.

Both command units are normally on whenever power is available on the spacecraft busses. However, either one of the units may be turned off by a command interlocked through the other command unit. The interlock is designed so that both units cannot be turned off. A command unit would only be commanded off if some failure caused interference with the operation of the spacecraft. Each unit also contains an overvoltage detection circuit which can shut off the unit after forcing on the other command unit. These shut off features were incorporated to eliminating a single point failure mode in the spacecraft.

TABLE II   COMMAND PERFORMANCE SUMMARY

Parameter Characteristics	
Command Receivers (2)	
Design and Manufacture	Selenia, Italy
Input Frequency	6 GHz band, both receivers at same frequency.
Dynamic Range	From -70 to -105dbm.
Bandwidth	From 1.0 to 1.5MHz.
Type	Single conversion balanced mixer, 70MHz IF, hard limiter, Travis discriminator, no AGC or Squelch.
Local Oscillator	85 MHz crystal.
Command Antenna	
Design and Manufacture	Selenia, Italy
Type	Stack of two ring slot radiators above a single conical beam-shaping structure.
Coverage	± 120 degrees from the spin (Z) axis, cardiod pattern, left hand circularly polarized.
RF Illumination	
Command	From -65 to -90dbW/m^2 with no response below 1105dbW/m^2.
Ranging	From -65 to -85dbW/m^2.
Modulation	± 400kHz.
Modulation Index	Greater than 10.

Receiver Input	Channelized from a command antenna through a passive preselect filter.
Receiver Output	Each receiver cross-strapped to both command units for commands, and channelized to one telemetry transmitter for ranging.
Command Units (2)	
Design	Ford Aerospace and Communications.
Manufacture	Mitsubishi Electric Co., Japan.
Input Signal	Receives input signal from cross-strapped command receivers.
Command Capacity	560 total
Discrete pulse	242
Discrete relay	268
Proportional	
Attitude control	23 including 4 spares.
Communication pathway	1 combined with 8 discrete relay.
Communication redundance	1 combined with 14 discrete relay.
Telemetry dwell select	1
Critical	4 for enable, apogee kick motor fire, solar array deploy, antenna deploy.
Command Verification	16 bits to telemetry.
Input Signal Modulation	Two groups of 3 tones, PCM-FSK-RZ for one an zero data, continuous tone for executes; Tone Group 1 directs command processing to video from Receiver 1.
Command Bit Rate	100 bits per second.
Command Message Format	58 bits, consisting of introduction, address, vector, discrete command or proportional data.
Execute Duration	Determined by the ground command generator.