GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE (GOES)

Telemetry and Communications

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INTRODUCTION

The GOES satellites are multifunctional satellites whose primary function is to provide continuous measurements of the earth’s surface and atmosphere from two geostationary orbit locations: 75°W and 135°W. This objective is accomplished with the Visible infrared spin scan radiometer Atmospheric Sounder (VAS). The atmospheric sounder is a new feature which will add a third dimension to the photographs of the earth seen nightly by TV newscast viewers. The satellite also contains a Space Environment Monitor (SEM) which includes three instruments: a magnetometer, a solar X-ray sensor and an energetic particle sensor (EPS), which monitor solar flares and near earth space environment. The satellite contains a communications system which, in addition to transmitting VAS, SEM and housekeeping data to earth, provides relay capabilities for the stretched VAS and weather facsimile (WEFAX) data, as well as for the Data Collection Platform (DCP). A sketch of the satellite is given in Figure 1.

The telemetry system encompasses two subsystems: RF communications and baseband assemblies. A general diagram of the telemetry system is shown in Figure 2. The telemetry system consists of two functional operations; real time telemetry data which is frequency modulated into IRIG 12 and IRIG B, and PCM data which is phase modulated. The baseband assemblies collect, format and modulate the data. The RF system sums the PCM and IRIG signals, phase modulates it onto both the CDA and STDN carriers, and transmits it to the ground stations. The following sections will describe in further detail the operation of the PCM and real time telemetry functions, and a description of the satellite RF communications system.

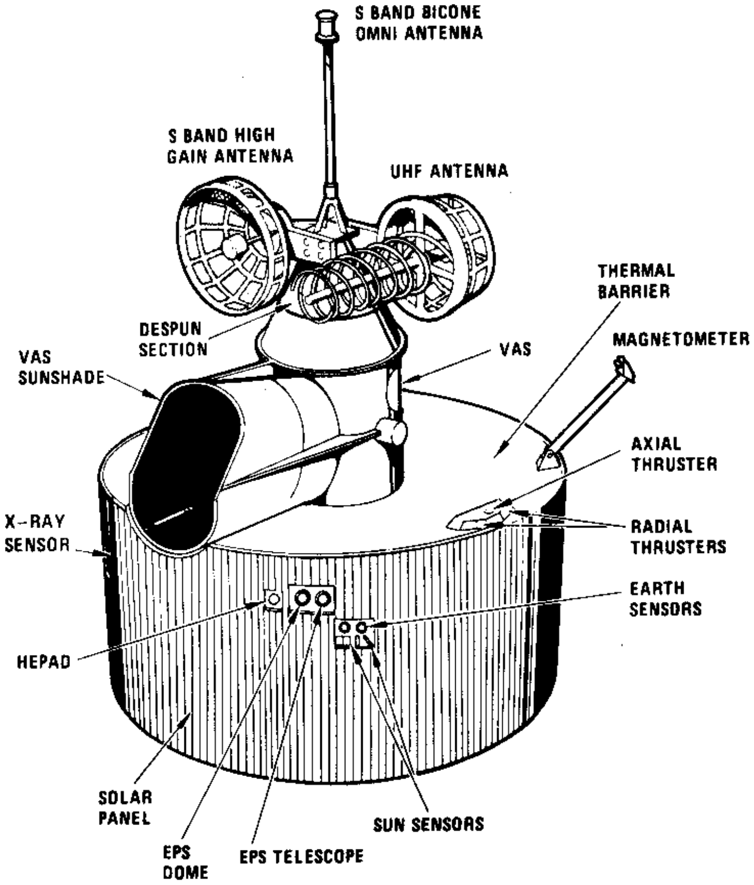


FIGURE 1. GOES SATELLITE

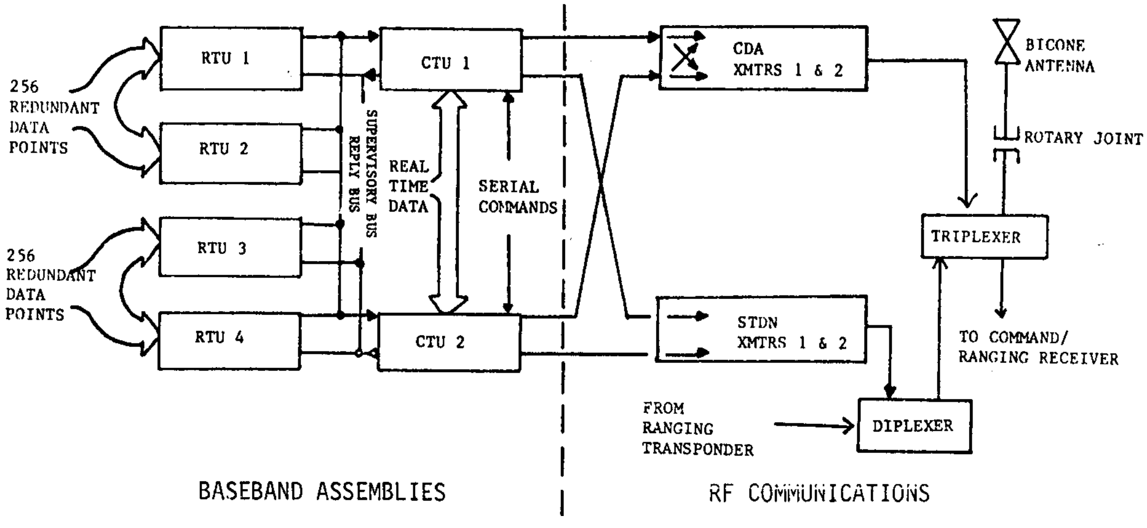


FIGURE 2. TELEMETRY SUBSYSTEM BLOCK DIAGRAM

BASEBAND ASSEMBLIES

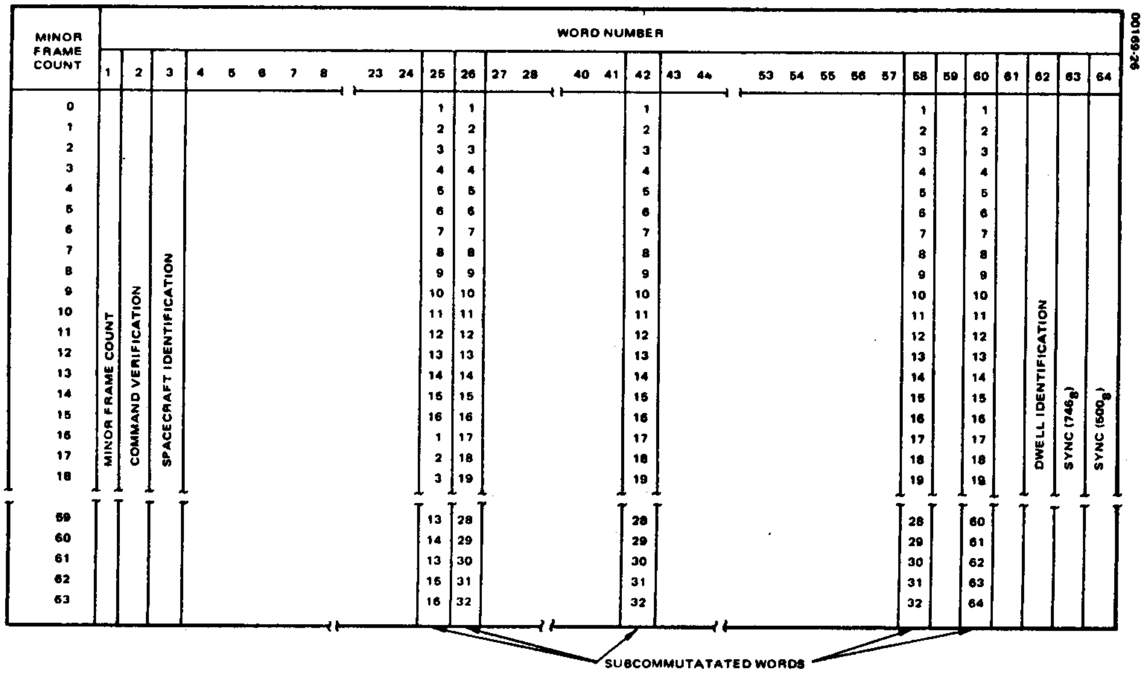
The baseband assemblies consist of two redundant Central Telemetry Units (CTU) and two pairs of redundant Remote Telemetry Units (RTU) which sample the 512 transducers that monitor the general health of the spacecraft. Analog, parallel bilevel digital, and serial digital data are collected by the remote units upon interrogation from the CTU via a supervisory bus. The data is conditioned, multiplexed and A/D converted in the RTUs and the digital data stream is transferred to the CTU via a reply bus. The data is processed, formatted and synchronized into a pulse code modulated (PCM) data stream by the CTU.

Simultaneously, the real time data concerning spacecraft nutation, ABM firing, axial thruster firing, VAS processor data load verification, bus current, command execute, and sun, earth and index pulse occurances are detected and modulated on IRIG 12 and IRIG B subcarriers. The PCM format modes and operational description and the real time telemetry functions are described below.

PCM Telemetry Format

The PCM telemetry downlink provides command verification data, spacecraft configuration information and data concerning the general health of the spacecraft. In addition, VAS and SEM housekeeping and diagnostic data are provided in the PCM data stream. The PCM format is a 64 word by 64 channel major frame shown in Figure 3. Sixty-four nine bit words make up one minor frame, and 64 minor frames make up one major frame. Of the 64 words in the minor frame, 59 are main frame words which have the same channel assignment (are associated with one transducer) for all 64 minor frames. Five of the 64 words are subcommutated into 64 channels such that the data content is associated with a different transducer, depending on the minor frame count. As indicated in Figure 3, word 25 is a 16 channel subcommutated word, so at minor frames 16, 32 and 48 the channels will be repeated sequentially. Consequently, the data content of the 16 channel subcommutated word is updated four times in one major frame. Similarly, words 26, 42 and 58 are 32 channel subcommutated words and therefore are updated twice in one major frame (repeated starting from frame 32). The 64 channel subcommutated word (word 60) is updated only once per major frame.

In addition to the channel subcommutation, several of the words associated with SEM data are subcommutated such that different particle energy counts are serially read out to the RTUs as a function of the minor frame and word number assignment. The logic governing the data accumulation interval and the unique minor frame and word in which the data is to be read out is performed in the EPS electronics. All other channel subcommutation and all word assignments discussed above are formatted by the CTU and are Manchester II coded and phase modulate onto the carrier at 188 bits per second (bps).



BIT RATE - 188.24 bps
ONE WORD (9 BITS) - 47.8 ms
ONE MINOR FRAME 3.06 sec
ONE MAJOR FRAME (64 MINOR FRAMES) = 195.8 sec

FIGURE 3. TELEMETRY MAJOR FRAME FORMAT

PCM Telemetry Modes

The CTU is capable of accepting serial commands which will configure the format of the PCM main frame into one of four operational modes. All four modes - normal, dwell, inhibit and dwell/inhibit - are formatted such that main frame words 1, 2, 3, 62 and 64 appear in each minor frame and are updated every 3.06 seconds.

Normal. In the normal mode the 64 minor frame words are sequentially read out. Upon receipt of the sync words the subcommutator increments the minor frame count by 1 and the next minor frame (64 words) is then read. After completion of one major frame (64 minor frames) the subcommutator resets to zero and the sequence is repeated. In this mode the main frame words are updated four times each major frame (49 seconds), the 32 channel subcommutated words are updated twice each major frame (1.6 minutes) and the 64 channel subcom word is updated once each major frame (3.3 minutes).

Although the word and channel assignments have been allocated to present the data in a manner such that the update periods are related to the frequency of the rate of change of the data content, conditions may occur which require that certain words or channels be monitored at a faster rate than that allowed by the normal update periods. The other three PCM modes allow the flexibility of changing the updates rates.

Dwell. The dwell mode stops the word count at a selected word, thereby increasing the update rate of the word. The dwell mode has the format of sequentially sampling the xth column of the matrix shown in Figure 3, where x is the commanded dwell word execept the first and last three elements of the column are preempted by words 1, 2, 3, 62, 63 and 64. Dwelling on a main frame word would increase the update rate to once per word time (47.8 msec). Dwelling on a 16 channel subcommutated word would increase the update rate to four times per minor frame (764.8 msec). Dwellin on a 32 channel subcommutated word would increase the update period to twice per minor frame (1.53 seconds). Dwelling on the 64 channel subcommutated word increases the update rate to once per minor frame (3.06 seconds). Since the 64 channels are repeated only once per minor frame, the first three and last three words are preempted and therefore are not displayed in this mode. To increase the update rate of these words, another mode must be selected.

Inhibit. The inhibit mode stops the subcommutator from incrementing the minor frame count. In this mode, the words in the yth row of the matrix shown in Figure 3 is sequentially sampled, where y is the commanded minor frame number. This increases the update rate of the selected channel in the subcommutated words. Upon receipt of the sync words, the subcommunator would not increment and the same minor drame would be read out repeatedly until the PCM was commended to another mode. The updated rate for the words in the selected channel is once per minor frame (3.06 seconds). This mode affects the minor frame count (which appears in word one of the mainframe as shown in Figure 3) and all subcommutated words formatted by the CTU, but not the subcommutation of the SEM data performed by the EPS electronics. Although the subcommutated words are inhibited, the data content of the SEM subcommutations will continue to increment during each minor frame.

Dwell/Inhibit. The dwell/inhibit mode is a simultaneous operation of the dwell and inhibit modes in which the word count and minor frame count are both inhibited. Therefore, the selected word/frame is updated once per word time (47.8 msec). Dwelling on a main frame word has the same format as dwell/inhibit on the same main frame word.

Configuring the PCM telemetry into its various operational modes is accomplished using serial commands. These commands configure the CTU into a mode such that the supervisory bus message going to the RTUs is changed and therefore the RTU sampling sequence (and consequently the reply bus data content) is in sequence to the selected mode. Special ground equipment software is required to display the PCM data so that it is compatible with the selected mode.

PCM Telemetry Functional Description

The control logic for the GOES telemetry is the 2901 microprocessor, located in the format generator of the CTU. When power is applied, the processor is loaded from the data proms and establishes the bit rate, bits per word, words per frame and supervisory bus rate. When the selected CTU is powered, two RTU control logic assemblies are also powered. RTU 1 and RTU 2 are a redundant pair and RTU 3 and RTU 4 are a redundant pair. The operational configuration is one RTU from each redundant pair. The eight possible configurations, selectable by ground command, are shown in Table 1.

Combination	CTU	RTU
1	1	1&3
2	1	1&4
3	1	2&3
4	1	2&4
5	2	1&3
6	2	1&4
7	2	2&3
8	2	2&4

Table 1. PCM Telemetry Configurations

The PCM format mode is checked and the processor loads the appropriate supervisory bus message on to the CTU reply bus. The supervisory bus message contains the RTU address, channel location and data type.

The RTU address defines which RTU in the powered pair is being interrogated. Both RTU control logic assemblies decode the address but only the addressed RTU applies power to the multiplexers and the A/D converter.

The channel location message contained in the supervisory bus code instructs the RTU to sample one or more of the 256 multiplexers. Each of the 256 multiplexers are connected to transducers on the spacecraft which provide 512 telemetry monitor points. The design can accommodate additional RTUs (up to 32) without changing the message format by just a simple prom change.

The data type message contained in the supervisory bus code established whether the channel is analog, bilevel or serial digital and whether or not the channel requires conditioning. If the channel requires conditioning, the RTU supplies a 1 mA current. If the data type is analog, the assigned channel is sampled, A/D converted and the resultant 9 bit word is loaded onto the reply bus. If the channel is bilevel the A/D converter is set to a threshold detection mode. The assigned channel is sampled and if it is over half full scale the data is internrptpd as a logic 1. The next eight multiplexers are then sequentially sampled, threshold detected in the same manner, and the resultant 9 bit bilevel word is loaded onto the reply bus. If the data type is serial digital, the RTU samples the sample multiplexer nine times and the transducer serially reads out the data of the RTU clock rate.

There are two (redundant) data reply buses from the RTU to the CTU. The supervisory bus message also instructs the RTU which reply bus to use.

The CTU buffers the reply data and loads the data four and one-half Manchester bits at a time into a downlink holding register (nine logic level bits = four and one-half Manchester bits). Subsequently, the data in the holding registers is serially read out at the bit rate (188 Manchester bits per second) and routed to the transmitters for modulation onto the carrier.

Real Time Telemetry

Simultaneously with the PCM, the CTU receives and processes real time data concerning key spacecraft events, and this data is then frequency modulated onto the Inter-Range Instrumentation Group (IRIG) 12 and B subcarriers.

IRIG 12. Table 2 lists the IRIG 12 operating characteristics. As indicated, the IRIG 12 channel is divided into three groups. Selection among the different input signal groups is accomplished using serial commands. Only one group within the IRIG 12 channel is operating at one time. To prevent interference, a priority scheme is established within each group, allowing only one signal at a time to modulate the subcarrier. Thus, if there is more than one signal in a group present at a given time the highest priority is transmitted.

In Group 1, the ABM Ignite Verification and Active Nutation Control (ANC) axial thruster activation signals are digital (on or off) and therefore are associated with a fixed frequency which is developed by counting down a 4.096 MHz crystal controlled clock. The CTU also receives analog data (nutation data) which frequency modulates an oscillator. The oscillator is driven to various ouput frequencies as a linear function of the magnitude of the signal input. In order to increase the resolution of nutation data during on-orbit operations and increase the range during transfer orbit, the CTU is capable of accepting commands to select between two voltage divider networks in order to obtain the gain factor required for the particular mission phase. As the nutation increases, the ANC threshold is exceeded and the axial jet is automatically fired on each nutation cycle for the duration of the excess nutation. This is continued until the nutation is dampened to a level below the ANC threshold. Since it is useful to monitor the nutation dampening during the ANC operation, the CTU output thruster verify signal occurs for only 20 msec at the rising and falling edge of the thruster fire pulse. A typical time plot of the IRIG 12 Group 1 operation is shown in Figure 4.

Input Signal Group	Signal Priority	Input Signal Source (Event)	Output Signal Type	Output Frequency, Hz
I	1	ABM Ignition pulse verification	Fixed tone	10503 ± 5
	2	ANC thruster actuation pulse	Fixed tone	9990 ± 5
	3	Nutation sensor (acceleration)data	VCO	11000 ± 100
II	NA	Main power bus current data (0 to 14A)	VCO	11287.5 to 9674
III		VAS processor data loading command pulse verification		
	1	Execute tone pulse duration	Fixed tone	10503 ± 5
	2	Hold tone pulse (“0” tone) duration	Fixed tone	9990 ± 5

TABLE 2. IRIG 12 REAL TIME TELEMETRY CHARACTERISTICS

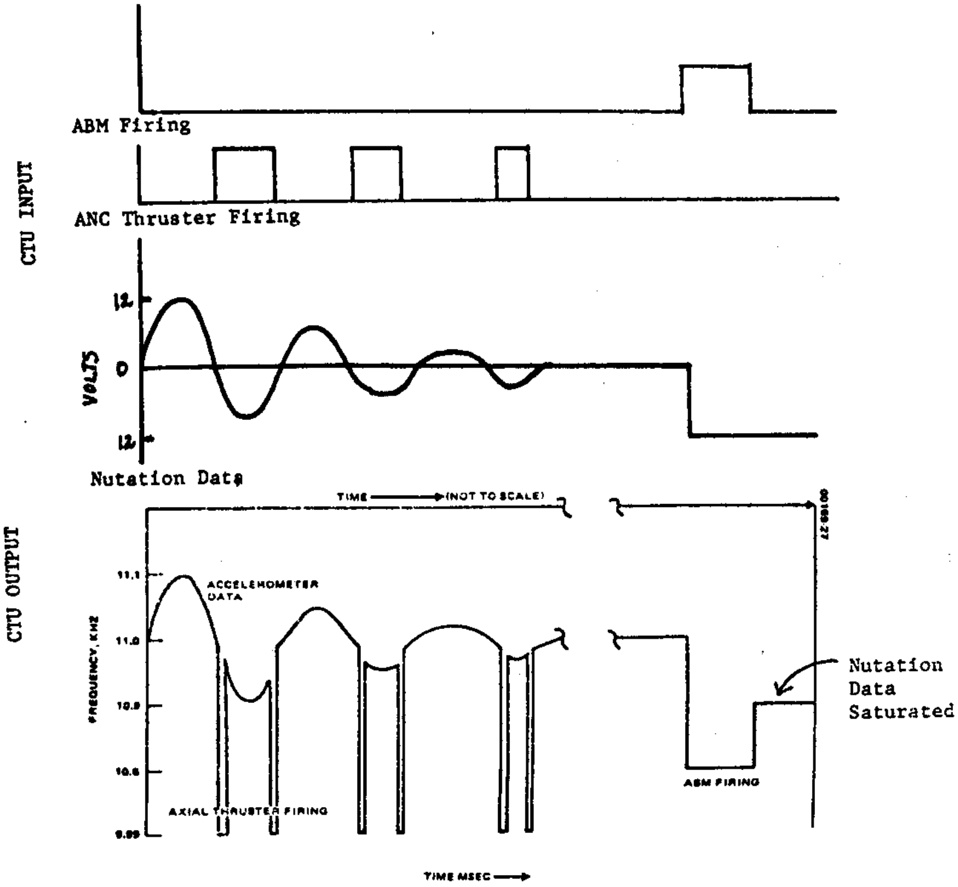


FIGURE 4. IRIG 12 GROUP 1 OPERATION

In Group 2, the main power bus current is frequency modulated by an oscillator. Although this signal is also sampled by the RTUs for modulation onto the PCM data stream, this addional group in IRIG 12 has a faster time constant (10 msec) than that allowed by the PCM modes. This allows the continuous monitoring of bus current at the ground station.

Group 3 is used to verify the data load of the VAS processor. This processor is used to control the VAS into its different operating modes. The VAS processor is capable of accepting a data stream which can configure it to various operational modes. This data stream is a series of execute and hold tones from the demod decoder which is interpreted by the VAS encoder. The VAS encoder also delivers the input signal to the CTU where the execute and hold tones generate fixed frequencies; thereby allowing for ground verification of the processor load data.

IRIG B. Sun pulse, earth pulse, platform index pulses and command execute verify pulses modulate the IRIG B subcarrier. Table 3 lists the IRIG B operating characteristics. Priority gating and command selection operate in the same manner as that used for the IRIG 12 baseband assemblies allowing only one signal to modulate the subcarrier at any given time.

Input Signal Group	Signal Priority	Input Signal Source (Event)	Output Signal Type	Output Frequency, Hz
I	1	Sun sensor pulse	Fixed tone	31508 ± 15
	2	Earth sensor pulse	Fixed tone	26597 ± 1 5
	3	Command execute verify pulse	Fixed tone	28845 ± 15
	4	Idle (rest frequency) tone	Fixed tone	34133 ± 15
II	1	Sun sensor pulse	Fixed tone	31508 ± 15
	2	Earth sensor pulse	Fixed tone	26597 ± 15
	3	DBA index pulses	Fixed tone	28845 ± 15
	4	Idle (rest frequency) tone	Fixed tone	34133 ± 15

TABLE 3 . IRIG B REAL TIME TELEMETRY CHARACTERISTICS

All IRIG B signals are digital in nature and therefore result in a fixed frequency ouput from the CTU. The output signal for IRIG B is as long as the input signal duration. The earth pulse signal is commendable to produce an output tone for inputs from the north earth sensor, south earth sensor, or both.

A typical time plot of the IRIG B group 2 operation is shown in Figure 5. The two baseband real time signals and the PCM data stream are provided separately to the CDA and STDN transmitters. The real time and PCM signals are phase modulated onto the telemetry carriers by the RF communications subsystem, which is described below.

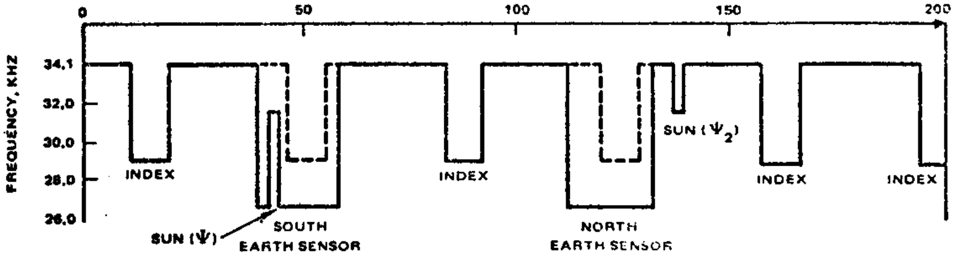


FIGURE 5. IRIG B, GROUP 2 OPERATION

RF COMMUNICATIONS

The PCM data stream and the two real time subcarriers are phase modulated onto the carrier of two pairs of fully redundant telemetry transmitters The Spaceflight Tracking and Data Network (STDN) telemetry transmitter (either primary or redundant) is used during launch, transfer orbit, and ABM firing and is compatible with the STDN ground stations. The CDA telemetry transmitter (either primary or redundant) is used during geostationary satellite operation. This transmitter is compatible with the Command and Data Acquisition (CDA) Station at Wallops Island, Virginia. The telemetry data received at Wallops is transmitted to the Spacecraft Operations and Control Center (SOCC) where the real time telemetry is analyzed and the subsequent attitude control maneuver decisions are generated. Table 3 describes the telemetry transmitter characteristics.

In addition, the telemetry data stream is received at the NOAA Table Mountain Facility at Boulder, Colorado. At this facility, the SEM data is sorted out of the telemetry stream, separated according the instrument type and processed in real time into quantitative form for entry into the Space Environmental Laboratory Data Acquisition and Display (SELDADS) data base.

The VAS data contained in the PCM main frame consists of VAS housekeeping data and blackbody algorithm troubleshooting data. The troubleshooting data is also sampled by the VAS Digital Multiplexer (VDM) along with the earth imaging data. This data stream is modulated for transmission in the S-Band repeater. The VAS data is transmitted at 28 Mbps and received at Wallops Island, Virginia, where it is slowed, or stretched. This stretched VAS data is transmitted from Wallops Island at 1.75 Mbps and relayed via the on board S-Band repeater to Goddard Space Flight Center (GSFC), and the University of

Wisconsin (UW). The data is then relayed to users of the VAS data by ground communications.

Transmitter	CDA	STDN
Downlink Freq, MHz	1694.0	2214.0
EIRP, dBm	33.0	26.0
Antenna Angle	±10°	±30°
Modulation Type		
PCM	PCM/FM	PCM/FM
IRIG 12	FM/PM	FM/PM
IRIG B	FM/PM	FM/PM
Modulation Index, Rad		
PCM	1.0	0.4
IRIG 12	0.5	0.3
IRIG B	0.5	0.75
PCM Bit Rate, bps	188.24*	188.24*

*PCM data are Manchester coded.

TABLE 4. TELEMETRY TRANSMITTER CHARACTERISTICS

The entire communications system includes nine active units, such as transmitters and receivers, with nine more identical units to provide full redundancy for increased reliability. The system also includes seven passive units, such as multiplexers, a rotary joint, and the antennas, plus a myriad of switches to provide the redundancy and crosstrapping capability. coaxial cables are used for interconnections between units, and the sole waveguide device is the noncontacting rotary joint which transfers RF power from the equipment shelf on the spinning portion to the despun antenna assembly. Figure 6 depicts the communications functions and their interface to the various ground stations.

Both telemetry transmitter pairs are located in the spinning portion of the spacecraft and the antennas (including the telemetry bicone) are located on the despun part. The RF energy is transferred from the transmitters through the rotary joint, and to the antenna. The telemetry antenna is a bicone with a toroidal radiation pattern. This antenna is also used for command and ranging during transfer orbit and is not despun until geostationary orbit is attained. Hence, the need for omnidirectional coverage perpendicular to the spin axis during transfer orbit. The gain of bicone antenna varies with frequency and typical characteristics are shown in Table 5.

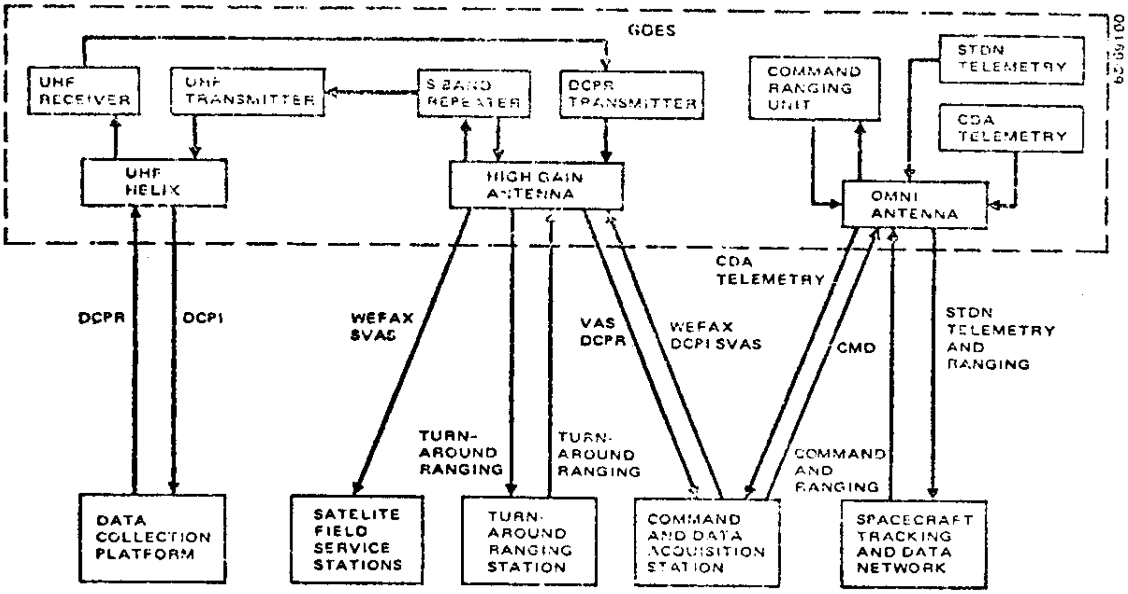


FIGURE 6. COMMUNICATIONS LINKS

Coverage Angle	Uplink	Downlink		
	Command and Ranging (2034 MHz)	(1694 MHz) CDA	Ranging (2209 MHz)	STDN Telemetry (2213 MHz)
0°	1.6	0.8	2.4	1.7
±10°	0.5	-0.1	0.5	0.3
±30°	-4.0	-4.7	-2.5	-2.7
±50°	-8.2	-9.9	-7.2	-7.7

TABLE 5. TYPICAL BICONE ANTENNA GAIN (dBi)

CONCLUSIONS

The telemetry and communications subsystems of the GOES satellite have been designed to support the GOES mission objective - to acquire and diseminate earth and near earth environmental data from geosynchronous orbit. Data from the major payloads, VAS and SEM instrumentation, are provided to the ground station via these subsystems which also provide housekeeping data, nutation data and relay (VAS and DCP) capabilities. The operational modes allow for flexibility with the system and cross strap redundancy minimizes performance risk while potentially increasing spacecraft life.

ACKNOWLEDGEMENT

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