Satellite Telemetry, Tracking and Control Subsystems

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Overview

- The telemetry, tracking and control subsystem provides vital communication to and from the spacecraft
- TT&C is the only way to observe and to control the spacecraft's functions and condition from the ground

Outline

- TT&C functions and trades
- Command System functions
  - Encoding/Decoding
  - Messages
  - Interfaces
- Telemetry systems
  - Sensors and transducers
  - ADC
  - Formats
  - Concerns/Design principles

TT&C Functions

- Carrier tracking
- Command reception and detection
- Telemetry modulation and transmission
- Ranging
- Subsystem operations

Carrier Tracking

- Two-way coherent communication
  - Transmitter phase-locks to the received frequency
  - Transmitted frequency is a specific ratio of the uplink frequency
- Easy to find and measure the frequency received on the ground
- Doppler shift provides range rate

Ranging

- Uplink pseudo-random code is detected and retransmitted on the downlink
- Turnaround time provides range
- Ground antenna azimuth and elevation determines satellite angular location

Subsystem Operations

- Receive commands from Command and Data Handling subsystem
- Provide health and status data to CD&H
- Perform antenna pointing
- Perform mission sequence operations per stored software sequence
- Autonomously select omni-antenna when spacecraft attitude is lost
- Autonomously detect faults and recover communications using stored software sequence

TT&C Trades

- Antenna size vs transmitter power
- Solid state amplifiers vs traveling wave tube amplifiers
- Spacecraft complexity vs ground complexity

TT&C Interfaces

Subsystem	Requirement
Attitude Determination and Control	Antenna pointing
Command and Data Handling	Command and telemetry data rates Clock, bit sync,and timing requirements Two-way comm requirements Autonomous fault detection and recovery Command and telemetry electrical interface
Electrical Power Subsystem	Distribution requirements
Thermal/Structural	Heat sinks for TWTAs Heat dissipation of all active boxes Location of TT&C subsystem electronics Clear field of view and movement for all antennas
Payload	Storing mission data RF and EMC interface requirements Special requirements for modulation and coding

Command System

- Reconfigures satellite or subsystems in response to radio signals from the ground
- Command timing
  - Immediate
  - Delayed
  - Priority driven (ASAP)

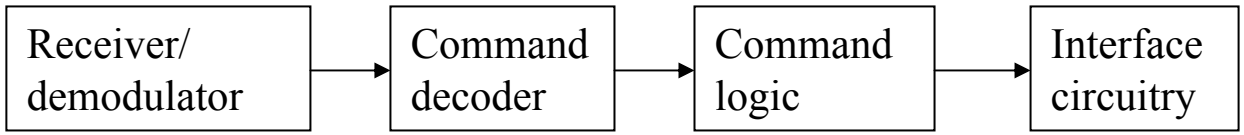
Command Functions

- Power on/off subsystems
- Change subsystem operating modes
- Control spacecraft guidance and attitude control
- Deploy booms, antennas, solar cell arrays, protective covers
- Upload computer programs

Command System RF Performance

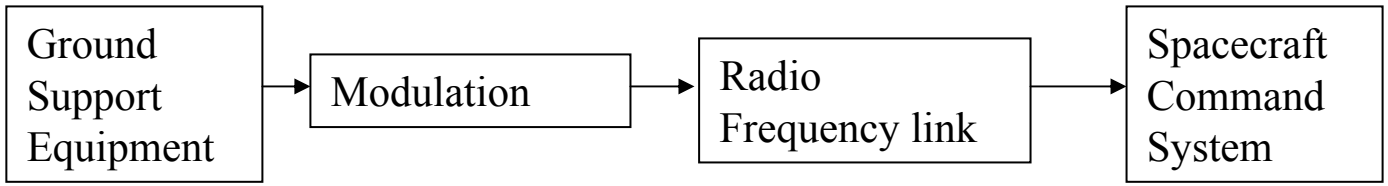
- Frequencies
  - S-band (1.6 – 2.2 GHz)
  - C-band (5.9 – 6.5 GHz)
  - Ku-band (14.0 – 14.5 GHz)
- BER = 10^{-6}

Spacecraft Command System Block Diagram



- Decoders reproduce command messages and produce lock/enable and clock signals
- Command logic validates the command
  - Default is to reject if any uncertainty of validity
  - Drives appropriate interface circuitry

Complete Command System



- GSE operator selects command mnemonic
- Software creates command message in appropriate format and encodes it
- Batch commands/macros
- Pulse code modulation (PCM)
- Phase shift keying (PSK)
- Frequency shift keying (FSK)

Command Decoders

- Detects PCM encoding and outputs binary stream in non-return-to-zero format
- Outputs clock signal
- Outputs lock/enable signal
- Activates downstream command subsystem components
- Decentralized decoding reduces harness mass

Secure Command Links

- Encryption
- Authentication

Command Message Components

- Input checkerboard bits
- Synchronization (Barker word) bits
- Command bits
- Error detection bits

Command Messages

- Spacecraft address
- Command type
  - Relay commands
  - Pulse commands
  - Level commands
  - Data commands
- Command select
- Error detection and correction
- Multiple commands

Command Logic

- Decodes command
- Validates command
  - Correct address
  - EDAC
  - Valid command
  - Valid timing
  - Authenticated
- Activates circuitry

Interface Circuitry

- Latching relays with telltales
- Pulse commands
- Level commands
- Data commands
  - Serial (enable, data and clock)
  - Parallel

Telemetry Systems

- Measure physical properties from afar
  - Status of spacecraft resources, health, attitude, and operation
  - Scientific data
  - Spacecraft orbit and timing data for ground navigation
  - Images
  - Tracked object location
  - Relayed data

Telemetry System RF Performance

- Frequencies
  - S-band (2.2 – 2.3 GHz)
  - C-band (3.7 – 4.2 GHz)
  - Ku-band (11.7 – 12.2 GHz)
- BER = 10^{-5}

Sensors and Transducers

- Sensors change state as a function of an external event
- Transducers convert energy from one form to another
- Outputs can be
  - Resistance
  - Capacitance
  - Current
  - Voltage

Signal Conditioning and Selection

- Conditioning ensures proper level, dynamic range, frequency response, impedance, ground reference, common mode rejection
- Commutation selects the proper sensor at a given time
- Sampling frequency determined by the Nyquist criteria

Analog to Digital Conversion

- Converts voltages (0 – 5.1 v, or -2.56 to 2.54 v) to 2^n-1 discrete values
- Quantization error decreases as n increases

Type	Conversion Rate	Word Size	Power
High Speed ADC	$50*10^6$ /sec	8 bit	2.5 W
High Resolution ADC	$1*10^5$ /sec	16 bit	1.5 W
Low Power ADC	$2.5*10^4$ /sec	8 bit	0.005 W

Telemetry Processing

- Compression
- Analysis for autonomous systems
- Formatting
- Storage

Telemetry Formats

- Synchronization
- Frame count
- Spacecraft identification
- EDAC
- Frame format identification
- Spacecraft time

Multiplexing

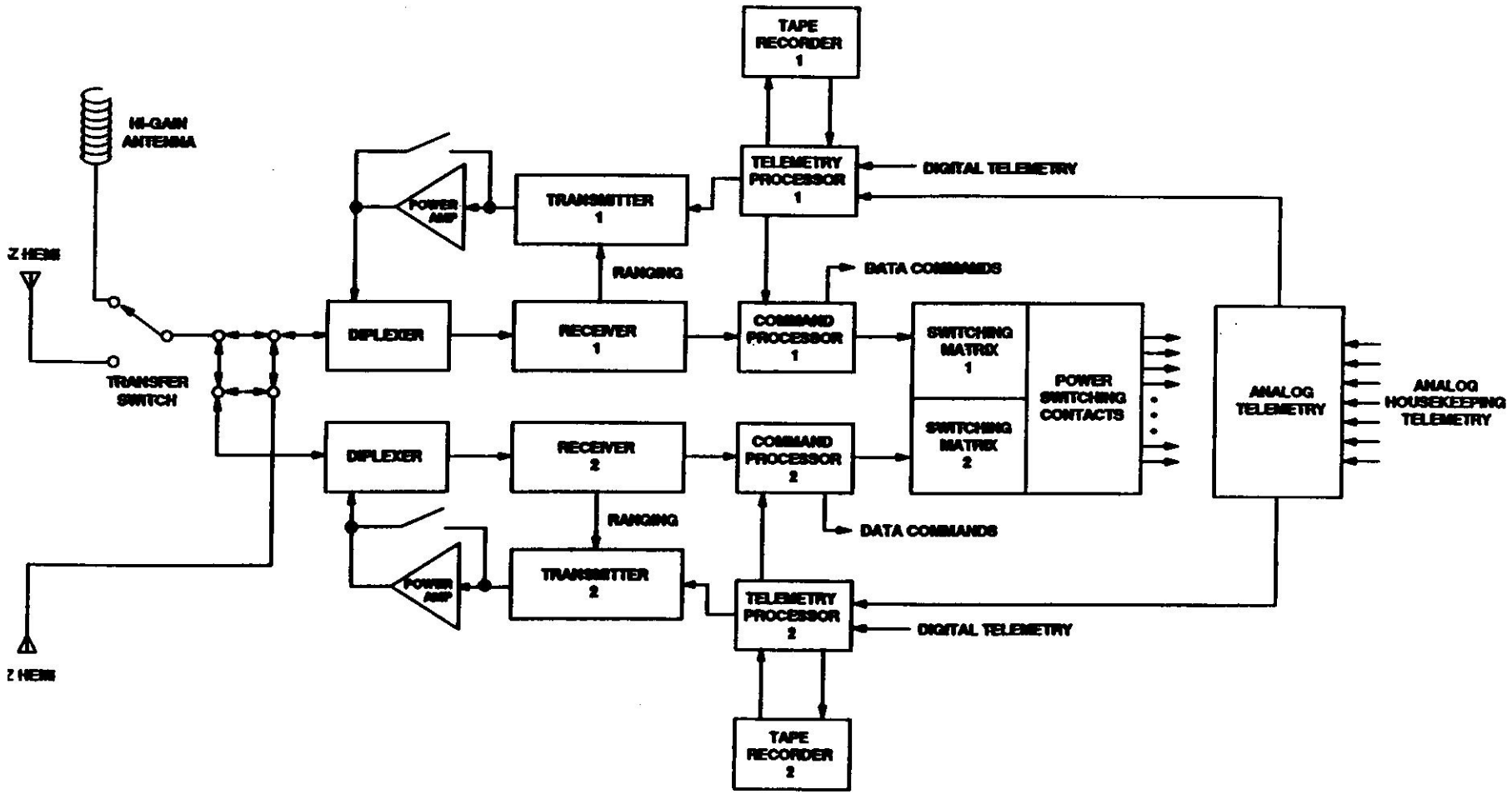
- Frequency division multiple access
- Time division multiple access
- Code division multiple access

Commutation in Data Formats

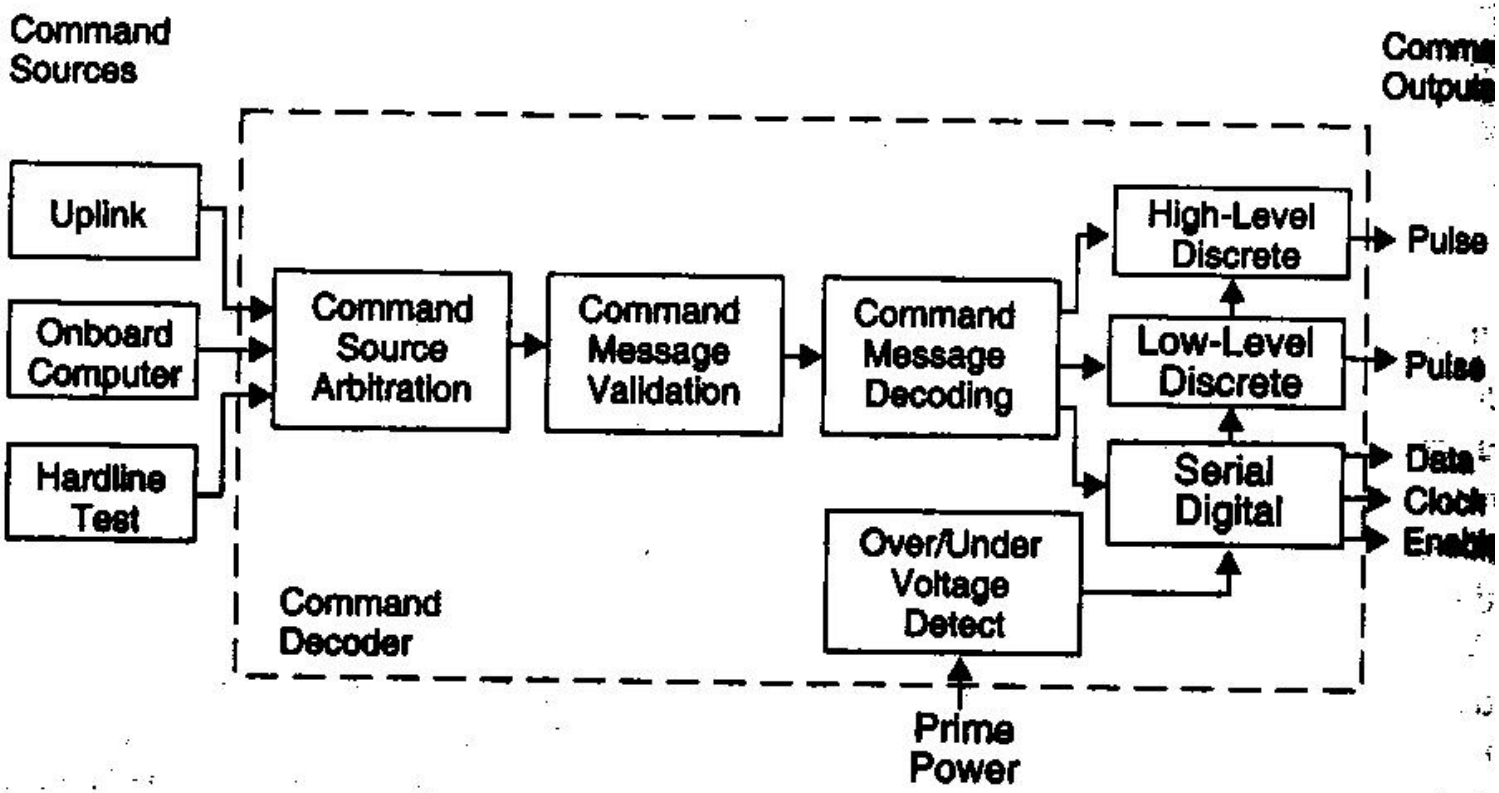
Data type no. 1 bits	Type no. 2 bits	Type no. 3 bits	Type no. 4 bits	Type no. 5 bits	Type no. 6 bits	Type no. 7 bits

- Commutation – sequential data time sampling
  - Data includes major and minor frame identification and EDAC
- Sub-commutated data – given element represents different data in different frames
- Super-commutated data – given element is found more than once per frame

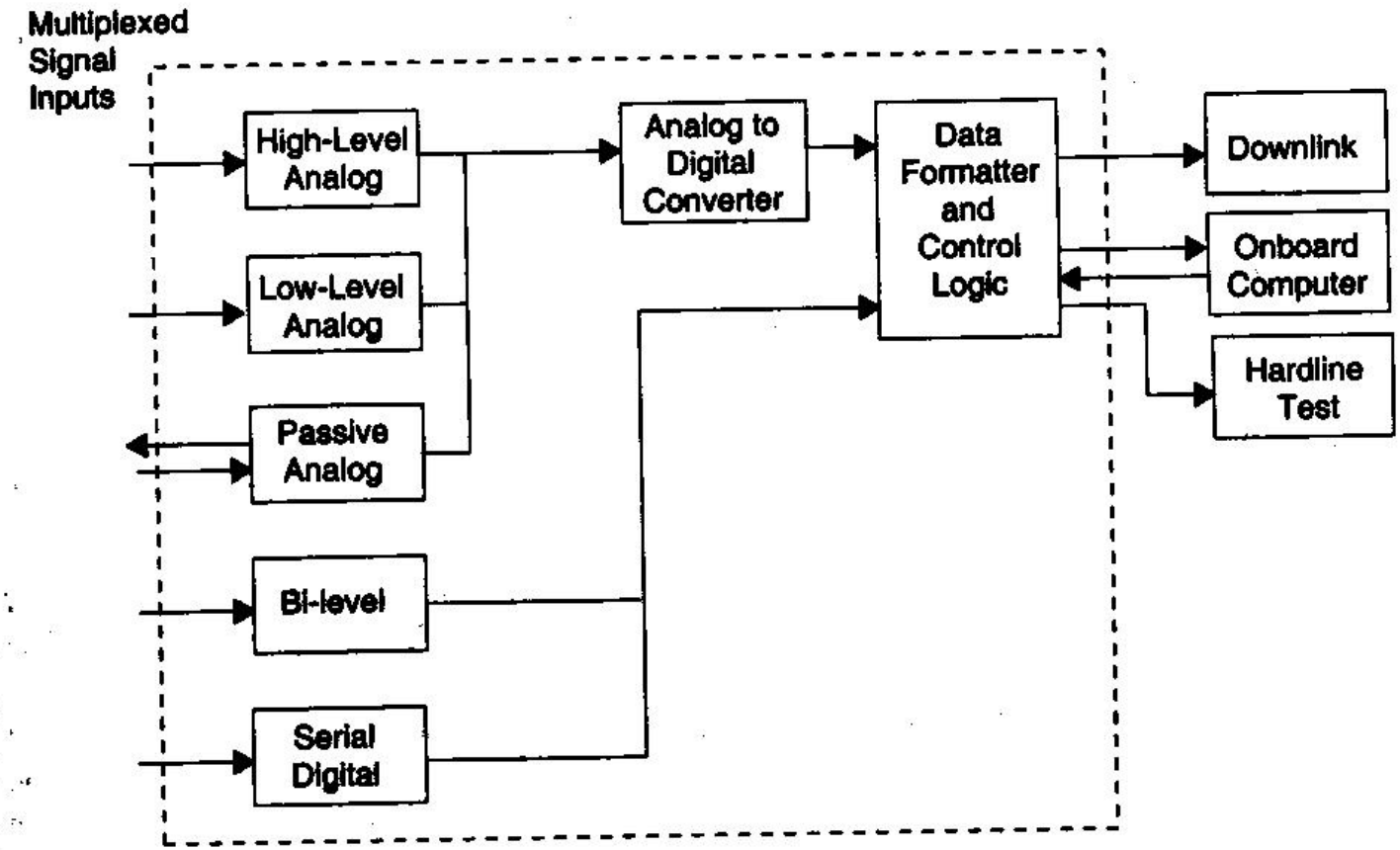
Telemetry and Command System Block Diagram



Command Decoder Block Diagram



Data Handling Unit Block Diagram



Command and Data Handling Concerns

- Interfaces to other subsystems must protect the command decoder
- No commands or transient signals may appear on command outputs during application or removal of prime power or during under/over voltage conditions
- If a commands integrity is in doubt, reject it

Command and Data Handling Concerns (continued)

- Multiple commands are required for critical/ dangerous operations
- No single component failure can result in unintended operation
- No commands shall interrupt the uplink source to the command decoder

References

- Pisacane, Vincent L. and Robert C. Moore, Fundamentals of Space Systems, Oxford University Press, New York, 1994
- Wertz, James R. and Wiley J. Larson, Space Mission Analysis and Design, Third edition, Microcosm Press, Torrance Ca, 1999