HESSI

High Energy Solar Spectroscopic Imager (HESSI) Spacecraft to Berkeley Ground Station (BGS) Interface Control Document (ICD)

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Distribution List

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1. Introduction

The purpose of the Berkeley Ground Station is to provide primary telemetry and command support for the HESSI mission. The required telemetry data volume is 8 Gbits per day. This document describes the interface between the HESSI spacecraft and the Berkeley Ground Station.

1.1. Document Conventions

In this document, TBD (To Be Determined) means that no data currently exist. A value followed by TBR (To Be Resolved) means that this value is preliminary.

1.2. Applicable Documents

1. HESSI Telemetry Formats, U.C. Berkeley, HSI_SYS_007E, 1999-October-18
2. HESSI Program Telecommand Format Specification, Spectrum Astro, Inc., 1998-August-19
3. Telemetry – Summary of Concept and Rationale, CCSDS 100.0-G-1, December 1987
4. Telemetry Channel Coding, CCSDS 101.0-B-3, May 1992
5. Telecommand Part 1 – Channel Service, CCSDS 201.0-B-2, November 1995
6. Telecommand Part 2 – Data Routing Service, CCSDS 202.0-B-2, November 1992
7. Telecommand Part 2.1 – Command Operation Procedures, CCSDS 202.1-B-1, October 1991
8. Cincinnati Electronics Corporation, HESSI Transponder Documentation, June 1999
9. PTP NT - Programmable Telemetry Processor for Windows NT, User's Manual Version 1.40, Avtec Systems, Inc., November 1998
10. SatTrack Version 4.2 Documentation, Bester Tracking Systems, Inc., August 2000

CCSDS Standards documents may be found at:
http://www.ccsds.org/ccsds/ccsds_home.html

HESSI documents can be found at:
ftp://apollo.ssl.berkeley.edu/pub/hessi/released/icd

Other HESSI related information and a description of the Berkeley Ground Station may be found at: http://hessi.ssl.berkeley.edu/ground_systems

2. Spacecraft Communications System

The communications sub-system on the spacecraft provides the space-to-ground link for retrieval of data and remote commanding.

2.1. General Description

The communications sub-system on the HESSI spacecraft consists of an S-band transceiver, a band reject filter, an antenna switch, a power combiner, four patch antennas with a quasi-hemispherical radiation pattern, and a set of coaxial cables. A block diagram of the HESSI communications sub-system is shown in Figure 1.

The transceiver was manufactured by Cincinnati Electronics Corporation. The term *transceiver* (as opposed to *transponder*) is purposely used to indicate that this unit does not provide a coherent return link and therefore does not allow RF-based verification of the link acquisition and two-way Doppler tracking.

The antenna system consists of four patch antennas, two each for transmit and receive, that were manufactured by Physical Science Laboratory at New Mexico State University.

The lifetime of the transceiver is expected to be at least 5 years in a 600 km circular orbit.

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Figure 1: Block diagram of the HESSI communications sub-system.

2.2. **Telemetry Transmitter**

The telemetry transmitter is crystal controlled and operates on one frequency only, namely 2215.0 MHz. Baseband input data and clock are received from the spacecraft's Communications Interface Board (CIB) via RS-422 interfaces. After waveform conversion from NRZ-L to NRZ-M, the data are BPSK modulated onto the main carrier. The carrier suppression is 35 dB and the maximum data rate is 10 Mbps. Convolutional coding is not used with HESSI.

The transceiver has a DC power consumption of 4.8 W with the transmitter turned off, and 37 W with the transmitter turned on. The DC supply voltage is +28 V. Depending upon temperature, the transmitter generates 5-7 W (37.6-38.5 dBm) of RF output power and can be operated within power and thermal budget constraints for a maximum time of 30 minutes per orbit. A timer will automatically turn the transmitter off after 15 minutes. Conversion curves for the temperature and output power telemetry are shown in Figure 2.

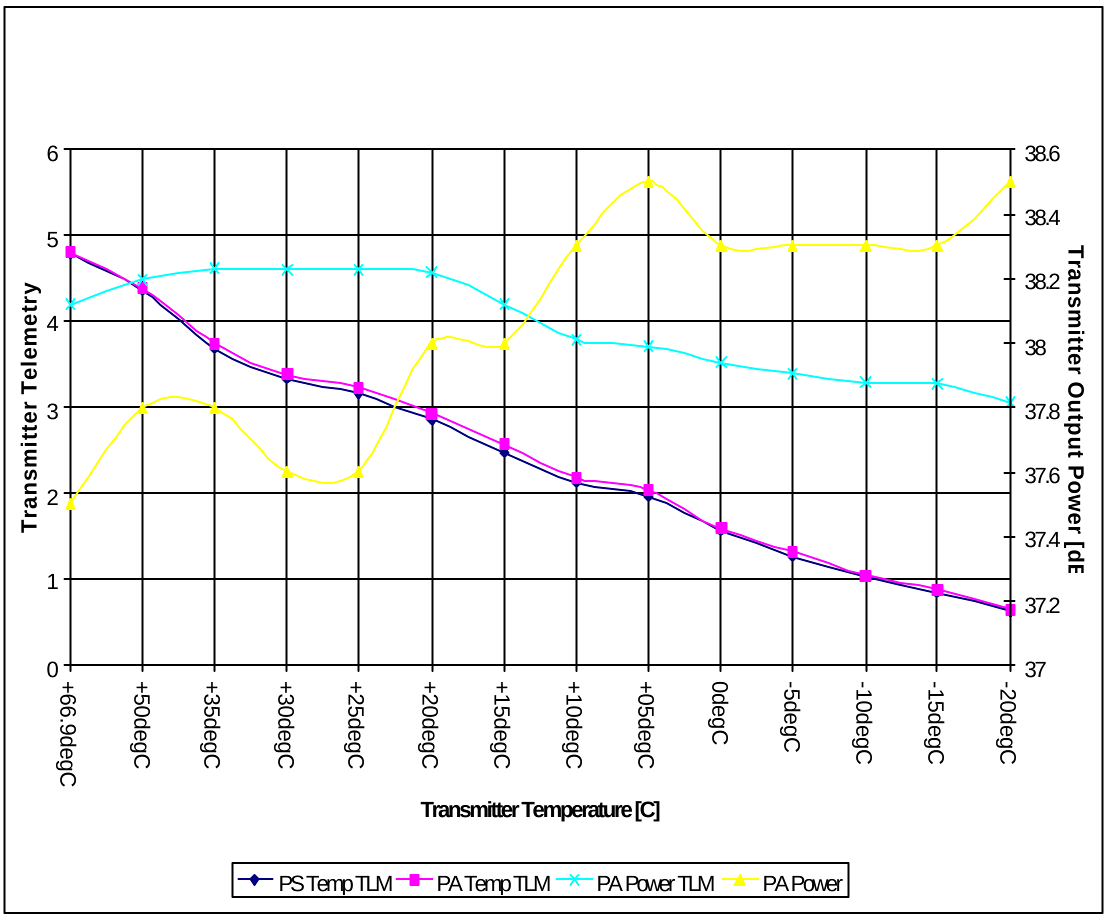

Figure 2: Transmitter temperature and output power telemetry.

2.3. **Command Receiver**

The command receiver on the spacecraft is continuously powered up so that commands can be received at any time. Since the command receiver has no sweep capabilities, the ground station transmitter must be swept for a brief period of time to acquire the command link. The maximum acquisition range is ±120 kHz and, once locked, the maximum tracking range is ±150 kHz. The maximum allowed sweep rate is 35 kHz/s, assuming a continuous analog frequency sweep. The sweep profile must not contain sharp reversals in sweep direction. In other words, a trapezium shaped sweep profile with a short dwell time of at least 0.2 s at the points of reversal or a sinusoidal sweep profile is required. The capture range of the phase-locked loop in the receiver is ±1.5 kHz around the unlocked VCO frequency, which varies with temperature and can be anywhere within ±50 kHz of the nominal receive frequency of 2039.645833 MHz, as shown in Figure 3.

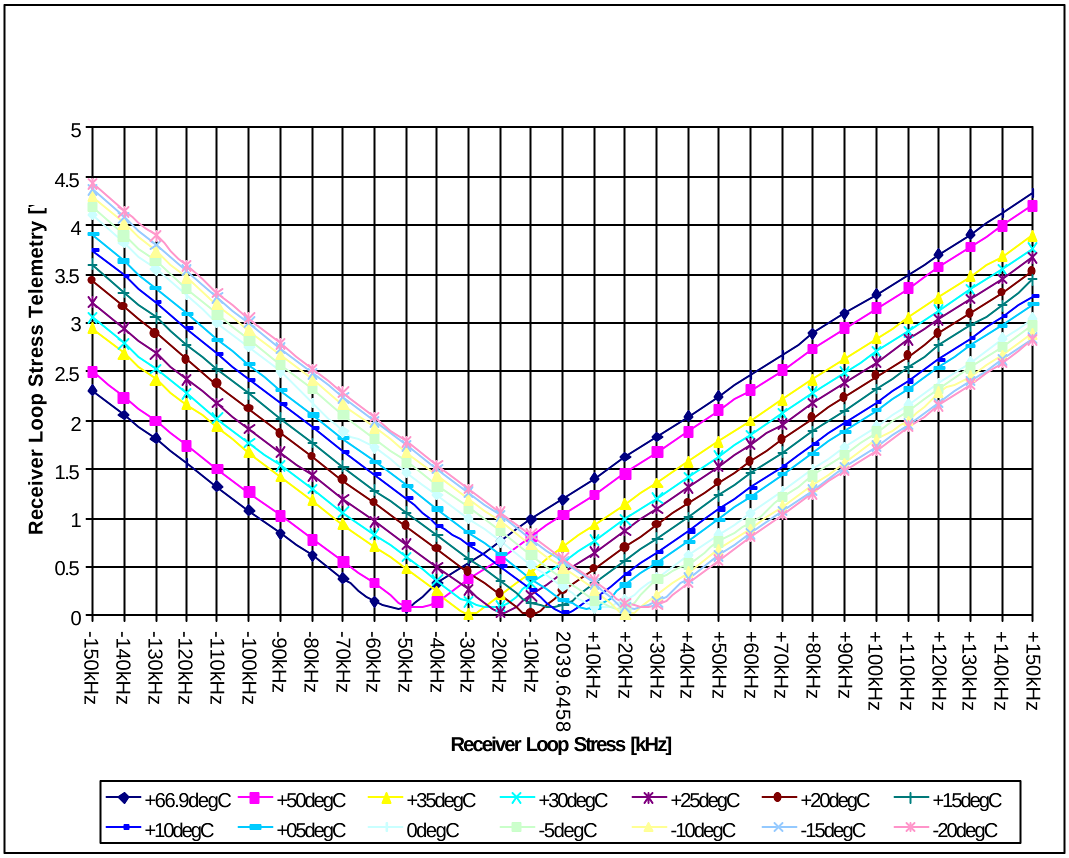

Figure 3: Loop stress of the RF phase-locked loop in the HESSI command receiver.

In case a frequency synthesizer is stepped in frequency to generate the sweep profile, the step size must not exceed 2 kHz. The spacecraft will lock reliably with a sweep profile of 2 kHz steps every 0.1 s. A dwell time of at least 0.2 s at the points of frequency reversal is required. A synthesizer with phase-continuous frequency tuning is recommended.

The command receiver requires a pure carrier input signal of -122 dBm to lock reliably. With sub-carrier modulation, the acquisition threshold level is -115 dBm. A power level of -113 dBm is required to achieve a Bit Error Rate (BER) of 10^{-7} at a data rate of 2 kbps. Under worst case conditions the Berkeley Ground Station will deliver an uplink power level of -95.9 dBm to the command receiver input. Nominally, the maximum allowed input power into the command receiver is -50 dBm. However, the command receiver can withstand an input power level of up to +10 dBm for 10 seconds. The AGC level telemetry conversion curves are shown in Figure 4 below. The voltage-to-power conversion can be approximated linearly between –125 and –75 dBm over a temperature range from +5 to +35 C using the following equation:

$$P\ [\text{dBm}] = -137.3 + 12.78 * U\ [\text{V}]$$

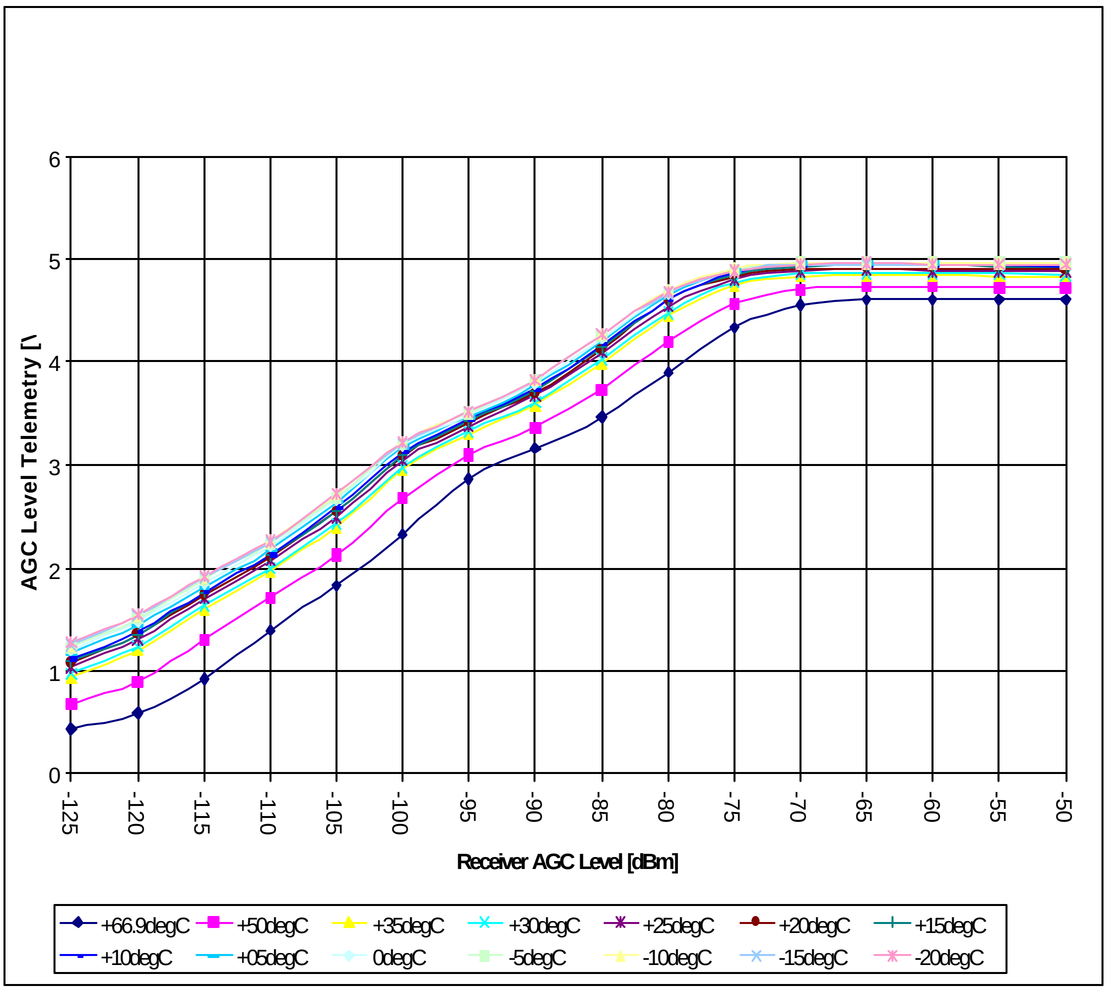

Figure 4: Conversion curves for the receiver AGC level telemetry.

More detailed specifications of frequencies, waveforms and data rates are given in Sections 4 and 5.

2.4. **Antennas**

To provide full spherical coverage, one transmit and one receive antenna is mounted at each the front and the rear of the spacecraft. Both receive antennas are simultaneously connected to the command receiver at all times, which creates a combined antenna pattern with a gain of +6 dBi along the spin axis and -26 dBi perpendicular to the spin axis of the spacecraft. On the other hand, only one of the two transmit antennas is selected at any time using a coaxial RF switch. The transmit antenna gain varies from about +7.0 dBi along the spin axis to -12 dBi perpendicular to the spin axis, as is illustrated in Figure 5. All four HESSI antennas use right-hand circular polarization (RHCP).

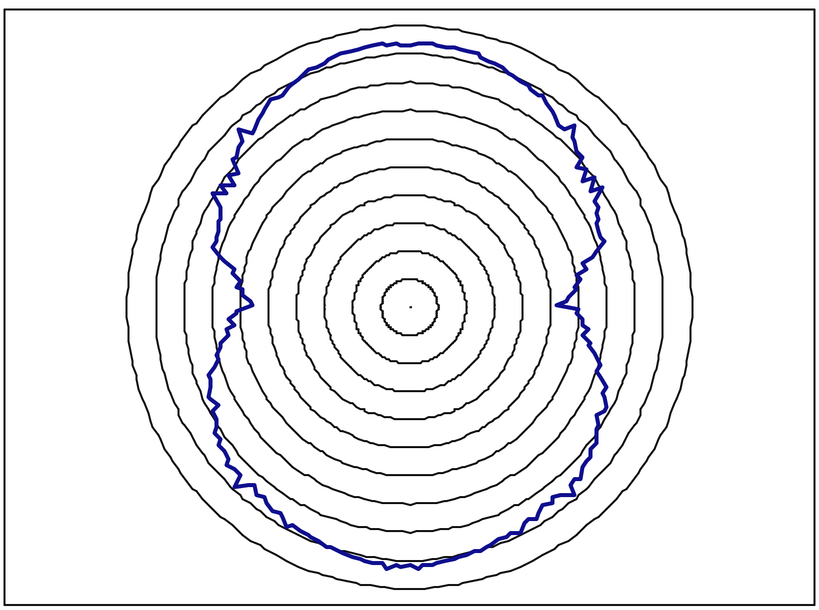

Figure 5: This figure shows the HESSI transmit antenna pattern. Gain circles are spaced by 5 dB, starting at +10 dBi with the outermost circle. The top half is the pattern of the forward transmit antenna, and the bottom half the pattern of the aft transmit antenna on the spacecraft. The spacecraft's spin axis points along an imaginary top-to-bottom line.

3. Berkeley Ground Station

The Berkeley Ground Station is the primary ground-based interface for retrieval of science data and remote commanding of the HESSI spacecraft.

3.1. Geographic Location

The Berkeley Ground Station is located at Space Sciences Laboratory on the campus of the University of California at Berkeley. The coordinates are 37.880 deg north latitude, 122.244 deg west longitude and 400 m altitude. Since the HESSI spacecraft will be launched into a 600 km circular orbit at an inclination of 38 degrees, communications with HESSI can be established through the Berkeley Ground Station up to six times per day. The station mask provides a rather unobstructed view from west to south-east, and a gradual rise in elevation due to the East Bay Hills from zero up to 8 degrees in south-eastern to eastern direction, as is illustrated in Figure 6 below. The duration of passes is variable and can be as long as 11 minutes. The average pass duration is 9.6 minutes.

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other types of printers.

Figure 6: Polar view of the sky, as seen from the Berkeley Ground Station. The station mask contours are shown in dark shaded tones, and the traces represent typical HESSI passes over a 3-day period.

3.2. **Antenna System**

The antenna, shown in Figure 7, was manufactured by L-3 Communications, EMP Systems in Simi Valley, California and consists of a pedestal with a three-axis drive system and an 11-m diameter parabolic reflector with prime-focus feed and autotracking capabilities. The three-axis drive system (azimuth, elevation and cross-elevation) eliminates the keyhole at the zenith. The maximum tracking speed is purposely limited to 8.7 deg/s in azimuth and 3.5 deg/s in elevation. The pointing accuracy is 0.02 deg. The antenna allows full-duplex communications at S-band. The Monitor and Control System for the Berkeley Ground Station was provided by Bester Tracking Systems. Pass schedules, acquisition angles and Doppler files are generated with SatTrack, using NORAD Two-line Element (TLE) sets.

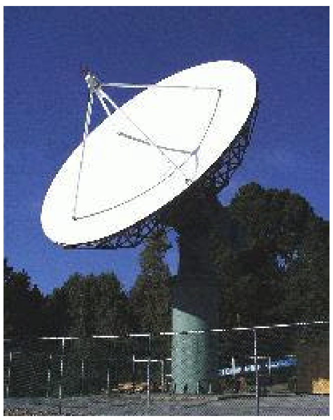

Figure 7: 11-meter antenna of the Berkeley Ground Station.

3.3. **RF Equipment**

The RF equipment comprises two orthogonal receive chains and one transmit chain. The feed system consists of two crossed dipoles, a hybrid to generate two opposite senses of circular polarization, and a diplexer to separate transmit and receive paths.

Two low-noise pre-amplifiers, one each for reception of right-hand and left-hand circular polarized signals, are mounted near the feed point. After amplification the S-band signals are modulated onto an infrared carrier and transferred via fiber-optic cables to the Mission and Science Operations Center (MSOC). The received signals are then demodulated from the infrared carrier and fed into two separate S-band receivers (Microdyne MR-700WB). After demodulation in the receivers, a diversity combiner (Microdyne Model 1620) provides the optimum combined baseband signal. The clear-sky figure of merit (G/T) in the two receive paths is 24.5 dB/K.

For commanding, a sub-carrier generator (GDP Space Systems Model 782) provides the sub-carrier that is modulated with the digital command data. The modulated sub-carrier is then fed into an exciter (Microdyne TSS-2000) that generates the S-band signal. The modulated S-band signal is in turn modulated onto an infrared carrier and transferred from the MSOC to the antenna via optical fiber. The signal is then demodulated from the infrared carrier, amplified locally at the antenna to a high power level and radiated off the feed dipoles. Either left-hand or right-hand circular polarization can be selected.

3.4. **Data Processing Equipment**

The CCSDS data processor in the Berkeley Ground Station is a Programmable Telemetry Processor for Windows NT (PTP NT), manufactured by Avtec Systems. It contains a variety of hardware and software modules that can be configured and linked together to allow for subcarrier demodulation, bit synchronization, Viterbi decoding, bit derandomization, Reed-Solomon decoding, CCSDS virtual channel processing, and distribution of telemetry data streams via TCP/IP socket interfaces. In addition, the PTP NT system contains a serial output interface and a subcarrier modulator for spacecraft command processing. The system also contains an IRIG-B time code processor card to provide an accurate time base.

The PTP NT system acts as the interface between the physical layer of both the forward and the return link, and the ITOS software. ITOS is the spacecraft command and control system and runs on computers in the HESSI Mission and Science Operations Center (MSOC).

4. Telemetry Channel

4.1. **Physical Layer**

The Physical Layer of the telemetry channel provides the communications interface between the spacecraft and the ground data system by means of a radio link.

4.1.1. RF Characteristics

The telemetry frequency for HESSI is 2215.0 MHz. Both transmit antennas are right-hand circular polarized (RHCP). Only one antenna is connected to the transmitter at any time by means of a remote-controlled RF switch.

4.1.2. Modulation

The digital telemetry data are directly modulated onto the main carrier using BPSK. The PCM waveform is NRZ-M.

4.1.3. Data Rates

Telemetry data from the HESSI spacecraft are transmitted at one of three different data rates: 125, 1000 and 4000 kbps. The lowest data rate will be used during the post-launch phase of the mission. Also, the spacecraft automatically selects the lowest data rate when the Communications Interface Board (CIB) is power-cycled.

4.1.4. Data Structures

HESSI uses standard CCSDS telemetry packetization. The Standard Data Structure in the Physical Layer is the Master Frame. Telemetry data are transmitted from the spacecraft to the ground in a continuous stream of Master Frames.

4.2. **Coding Layer**

Each Master Frame is 1279 bytes long and consists of an Attached Synchronization Marker (ASM), one Transfer Frame and a Reed-Solomon Code Trailer. The ASM is a fixed 32-bit pattern (1ACFFC1D hex). The Most Significant Bit (MSB) is transmitted first.

The HESSI telemetry link uses Reed-Solomon (255,223) coding with an interleaving depth I = 5. The Reed-Solomon Code Trailer consists of 1280 check symbols (5 x 32 = 160 bytes) and allows for error detection and correction.

The Transfer Frame plus the Reed-Solomon Code Trailer are also known as the Transmitted Codeblock. A Master Frame consists of the ASM and the Transmitted Codeblock.

Since convolutional coding is not employed, bit randomization is implemented instead to guarantee a minimum bit transition density. The following CCSDS-recommended polynomial is being used to generate the pseudo-random sequence:

$$h(x) = x^8 + x^7 + x^5 + x^3 + 1$$

Bit randomization is applied after Reed-Solomon coding by exclusive-ORing the Transmitted Codeblock, but not the ASM, with the pseudo-random sequence.

4.3. **Transfer Layer**

The Standard Data Structures in the Transfer Layer are Transfer Frames.

4.3.1. Transfer Frame Format

Transfer Frames consist of a Primary Header, a Secondary Header, a Data Field and a Trailer. The total length of a Transfer Frame is 1115 bytes:

Transfer Frame Primary Header:	6 bytes
Transfer Frame Secondary Header:	7 bytes
Transfer Frame Data Field:	1098 bytes
Transfer Frame Trailer:	4 bytes

The Transfer Frame Data Field is made up of Source Packets. Source Packets are sized such that exactly one packet fits into a Transfer Frame.

4.3.2. Virtual Channels

Source Packets originate from one of four different telemetry streams called Virtual Channels. At transmit time, the spacecraft takes data in the form of Source Packets from a selected Virtual Channel and places these into the Transfer Frame Data Field. In addition, a Transfer Frame Header and Trailer are added.

The following Virtual Channels have been implemented on HESSI:

VC0: Real-time State-of-health (SOH) and diagnostic data (first priority)
VC1: Recorded SOH and diagnostic data (second priority)
VC2: Real-time science data (third priority)
VC3: Recorded science data (fourth priority)
VC4: Unused
VC5: Unused
VC6: Unused
VC7: Fill data (default fill pattern is 0xBE)

When the spacecraft transmitter is turned on, only real-time state-of-health data (VC0) and fill data (VC7) are sent out. When more than one Virtual Channel has data ready and has been enabled either by real-time ground command or by on-board time sequence command, these data will be selected based on the above priority scheme.

Details of the Transfer Frame format are described in *High Energy Solar Spectroscopic Imager (HESSI) Telemetry Formats* (see Section 1.2 above for exact reference).

4.4. **Link Budget**

The telemetry link was designed to carry a link margin of 3 dB at a 2400-km range from the Berkeley Ground Station, which corresponds to an elevation angle of 4 deg. The following table summarizes the link calculations, assuming the worst case antenna gain based on spacecraft attitude, and the worst case figure of merit (G/T) of the ground station at low elevation angles.

Table 1: Link Analysis for the HESSI Telemetry Channel

Frequency Wavelength	2215.0 MHz 0.135 m
Satellite Transmit Power Satellite Component Loss Satellite Antenna Gain Satellite EIRP	5 W 1.0 dB -8.0 dB -2.0 dBW
Range Path Loss Atmospheric Loss Polarization Loss Pointing Loss	2400 km 167.0 dB 1.0 dB 0.1 dB 0.5 dB
Ground Antenna Size Ground Antenna Gain Ground Antenna Temperature Ground System Temperature Ground Antenna G/T	11 m 46.2 dB 75.0 K 325.0 K 21.1 dB/K
Data Rate Modulation Coding Bandwidth Bit Error Rate Required E_b/N_0	4000 kbps BPSK Reed-Solomon 4000 kHz 10^{-6} 8.0 dB
Predicted E_b/N_0 Implementation Loss Predicted Link Margin	14.1 dB 1.5 dB 4.6 dB

5. Command Channel

5.1. **Physical Layer**

The Physical Layer of the command channel provides the communications interface between the ground station and the spacecraft for sending commands to the spacecraft by means of a radio link.

5.1.1. RF Characteristics

The command frequency for HESSI is 2039.645833 MHz. Both receive antennas are right-hand circular polarized (RHCP) and are simultaneously connected to the command receiver.

5.1.2. Modulation

The command channel uses a 16 kHz sub-carrier that is PM modulated onto the main carrier with a modulation index of 1.0-1.3 radian. The sub-carrier itself is BPSK modulated with the digital data. The PCM waveform is NRZ-L.

5.1.3. Data Rates

The HESSI command data rate is 2 kbps.

5.1.4. Data Structures

The Standard Data Structures within the Physical Layer are the Acquisition Sequence, the Command Link Transmission Unit (CLTU) and the Idle Sequence.

The Acquisition Sequence consists of 144 bits of alternating ‘ones’ and ‘zeros’, beginning with either a ‘one’ (AA…AA hex) or a ‘zero’ (55…55 hex). The Idle Sequence is a sequence of alternating ‘ones’ and ‘zeros’ with arbitrary length, beginning with a ‘zero’ (5555… hex).

5.2. **Coding Layer**

The Standard Data Structures in the Coding Layer are CLTUs with embedded Telecommand (TC) Codeblocks.

A CLTU consists of a 16-bit Start Sequence (EB90 hex), a TC Data Field which contains a set of Encoded TC Codeblocks, and a 64-bit Tail Sequence (55…55 hex). The maximum length of a CLTU is 306 bytes.

The Encoded TC Codeblocks within a CLTU are 64 bits in length: 56 data bits, 7 parity check bits and one fill bit. The fill bit is always set to 'zero'. TC Codeblocks are block-coded with a (63,56) modified Bose-Chaudhuri-Hocquenghem (BCH) code. The parity bits in the last octet of the code block are the complements of the BCH code parity bits. The 7 parity bits are generated with the following polynomial:

$$g(x) = x^7 + x^6 + x^2 + x^0$$

TC Codeblock encoding is performed on all data, excluding the CLTU Start and Tail Sequence. If the input data do not fit exactly within an integral number of TC Codeblocks, then fill bits are introduced in the encoding process. The fill pattern is an alternating sequence of 'ones' and 'zeros', starting with a 'zero' (55… hex).

Neither convolutional coding nor bit randomization is applied to the command data stream within the Coding Layer.

5.3. **Transfer Layer**

The two Standard Data Structures used in the Transfer Layer are TC Transfer Frames and Command Link Control Words (CLCWs).

TC Transfer Frames can be transmitted to the spacecraft on two Virtual Channels, VC0 and VC1:

- VC0: Command data that are decoded and executed in hardware, e.g. for controlling CPU Power On/Off or VMEbus System Reset
- VC1: All other commands that are decoded and executed in software

Commands transmitted on VC0 are not subjected to frame acceptance testing, whereas VC1 commands are.

The CLCW is used for automated command link verification by the ground data system. It contains 4 bytes of status information and is assembled on the spacecraft and inserted into the telemetry data stream as the Transfer Frame Trailer (see above).

Details of the TC Transfer Frame and CLCW formats are described in *High Energy Solar Spectroscopic Imager (HESSI) Program Telecommand Format Specification* (see Section 1.2 above for exact reference).

5.4. **Link Budget**

The command link was designed such that the Berkeley Ground Station and back-up ground stations with smaller antennas can reliably deliver commands to the spacecraft. For the Berkeley Ground Station, the link margin with the worst-case antenna gain on the spacecraft was calculated to be larger than 20 dB at a range of 2400 km. The following table summarizes the link calculations.

Table 2: Link Analysis for the HESSI Command Channel

Frequency Wavelength	2039.645833 MHz 0.147 m
Ground Transmit Power Ground Component Loss Ground Antenna Size Ground Antenna Gain Ground EIRP	100 W 2.5 dB 11 m 45.5 dB 63.0 dBW
Range Path Loss Atmospheric Loss Polarization Loss Pointing Loss	2400 km 166.2 dB 1.0 dB 0.1 dB 0.5 dB
Satellite Antenna Gain Satellite Component Losses Satellite Receive Power Satellite Antenna Temperature Satellite System Temperature Satellite Antenna G/T	-17.0 dB 3.9 dB -95.8 dBm 300 K 2844 K -51.5 dB/K
Data Rate Modulation Modulation Index Coding Bandwidth Bit Error Rate Required E_b/N_0	2 kbps BPSK/PM 1.0 rad None 2 kHz 10^{-7} 16.8 dB
Predicted E_b/N_0 Implementation Loss Predicted Link Margin	40.2 dB 2.0 dB 21.4 dB

6. Pass Support Procedures

6.1. **Telemetry Link**

This sub-section describes the Physical Layer Operations Procedures (PLOPs) of the telemetry link.

6.1.1. Telemetry Link Activation

During telemetry-only pass supports the spacecraft will select the transmit antenna and turn on the RF carrier at AOS – 30 seconds. This time is pre-programmed in an Absolute Time Sequence (ATS) load and was sent to the spacecraft during a prior command pass. The RF carrier will always be modulated with real-time engineering data (VC0) and fill patterns (VC7). Transmission of real-time science data (VC2) and stored engineering and science data (VC1 and VC3) will typically be enabled 30 seconds after AOS to allow the ground station to lock onto the signal.

At AOS – 2 minutes, the Berkeley Ground Station will have completed its pre-pass configuration and testing. The antenna will be positioned to the pre-calculated acquisition angles and the receivers will be searching for the downlink signal. Once the signal is received, the LHCP receiver will lock up and will send the demodulated bit stream to the bit synchronizer in the PTP NT system. After bit-derandomization and Reed-Solomon decoding, the received Transfer Frames will be annotated with a 10-byte SMEX/LEO-T Telemetry Frame Delivery Header (TFDH). This header contains the ground receive time stamp to an accuracy of 1 ms. Annotated Transfer Frames are 1129 bytes long and consist of the following elements:

Annotation Header:	10 bytes
Attached Synchronization Marker:	4 bytes
Transfer Frame:	1115 bytes

For details regarding the annotation header refer to Avtec's PTP NT User Manual. The annotated VC0-VC3 Transfer Frames will be available for real-time transfer to ITOS via separate TCP/IP socket connections for each Virtual Channel. All annotated Transfer Frames will also be stored locally on the ground station in separate files for each Virtual Channel.

6.1.2. Spacecraft Antenna Switching

Depending upon the angular variation between the spin axis of the spacecraft and the direction towards the ground station, it may be required to switch the transmit antennas on the spacecraft during a pass support. If this situation occurs, the transmitter RF output power is briefly turned off while the antennas are switched. The ATS loads will include these activities and no special action is required on the ground station. The antenna selection and the times of data transmission are based on predicted link margin rather than pure line-of-sight geometry. The dynamic link margin calculation is performed by SatTrack taking into account line-of-sight geometry, spacecraft attitude and resulting antenna pattern, as well as slant range and ground station G/T values.

The ground station will automatically reacquire the carrier from the spacecraft by sweeping the local oscillator in its receiver. Once locked, the phase-locked loop in the receiver will also perform the Doppler compensation.

6.1.3. Telemetry Link Deactivation

Deactivation of the HESSI telemetry link begins with halting the transmission of VC1, VC2 and VC3 data, typically at LOS – 30 seconds. The ground station will stop tracking at LOS and commence with stowing the antenna and post-processing of the received telemetry data. The transmitter on the spacecraft is typically turned off by a stored time sequence command at LOS + 30 seconds. The time intervals will be fine-tuned during on-orbit checkout of the spacecraft. As an additional precaution, the transmitter will be turned off automatically by a timer after 15 minutes.

6.2. **Command Link**

This sub-section describes the Physical Layer Operations Procedures (PLOPs) of the command link.

6.2.1. Command Link Activation

The ground station will generate a sequence of Carrier Modulation Modes (CMMs) in order to acquire the command link. First, the ground station turns on the RF carrier modulated with the plain sub-carrier at AOS plus 1 second. A pre-defined frequency sweep will be started at AOS plus 15 seconds. Sweep rate, sweep amplitude and number of sweep cycles can be adjusted. A typical sweep includes a sweep rate of 20 kHz/s in 10 steps of 2 kHz, sweep amplitude of ±100 kHz and one sweep cycle. With these parameters the acquisition sweep sequence will be completed after approximately 22 seconds. The frequency sweep may be superimposed on the Doppler-corrected uplink frequency to minimize loop stress in the phase-locked loop of the command receiver. As an alternate option, the uplink frequency may not be Doppler-corrected in which case the command receiver on the spacecraft will track the Doppler shift. At the end of the sweep sequence the ground station will be ready for command transmission. In summary, the command link activation and deactivation sequence is as follows:

1. At AOS + 1 s: Raise RF carrier modulated with sub-carrier
2. At AOS + 15 s: Begin acquisition sweep sequence
3. At AOS + 15 + 22 s: Start transmission of command data
4. At LOS – 1 s: Stop commanding, RF carrier down

AOS and LOS times are calculated based on the true station mask. The CCSDS recommendations contain two different procedures, PLOP-1 and PLOP-2. With PLOP-1, the data transmission on the command channel consists of individual CLTUs that are preceded by an Acquisition Sequence. In the second procedure, PLOP-2, an Acquisition Sequence is only transmitted once before the first CLTU is sent out. Optionally, with both PLOP-1 and PLOP-2 the gaps between transmissions of individual CLTUs can be filled with an Idle Pattern that is usually identical to the Idle Sequence. The advantage of the latter is that the Command Decoder Unit (CDU) on the spacecraft will always remain locked. The PTP NT system can be configured to support either PLOP-1 or PLOP-2. The HESSI command decoder can handle both PLOP-1 and PLOP-2 protocols. However, in the latter case a continuous Idle Pattern in between transmissions of individual CLTUs is required. The standard command protocol for HESSI will be PLOP-1 with a continuous Idle Pattern, i.e. each CLTU will be preceded by an Acquisition Sequence and will be followed by an Idle Pattern with variable length, so that there will be no modulation gaps.

During a command support the PTP NT system will receive CLTUs from ITOS in real-time via a TCP/IP socket connection. Each CLTU will be preceded by a 24-byte long SMEX/LEO-T Command Delivery Header (CDH), followed by an 18-byte Acquisition Sequence (AA hex). CLTUs include an Idle Sequence (55 hex). Acquisition Sequence, CLTU and Idle Sequence are then forwarded via a high-speed serial input/output card to the sub-carrier modulator for transmission to the spacecraft. Each command received by the PTP NT system will be archived on the ground station. For details see Avtec PTP NT User's Manual.

6.2.2. Command Verification

ITOS runs the Command Operation Procedure-1 (COP-1) protocol to close the commanding loop. Commands that are transmitted to the spacecraft on VC1 are subject to testing and verification upon arrival, using the Frame Acceptance and Reporting Mechanism (FARM). ITOS receives feedback on the command link status and the frame test results by means of the CLCW, which is part of the received telemetry frames. If commands are out of sequence or were rejected by the spacecraft for other reasons, a retransmission will be initiated automatically by ITOS. The ground station is not involved in the command validation and retransmission process. Command data are merely received by the ground station from ITOS and are forwarded to the spacecraft.

If the RF command link is lost, it can be reacquired either by manual operator control on the ground station or by remote ACQUIRE command from ITOS. The link acquisition sequence will then be repeated, as described above. The Berkeley Ground Station does not monitor the CLCW to initiate autonomous reacquisition of the command link. Reacquisition can be automated using STOL procedures within ITOS that monitor the CLCW and act correspondingly.

The PTP in the Berkeley Ground Station will NOT verify the CCSDS Spacecraft Identifier (SCID) before forwarding a CLTU to the spacecraft. Commands are assumed to be valid and are transmitted, regardless of the SCID. The SCID for HESSI is 167 (A7 hex).

6.2.3. Command Link Deactivation

Deactivation of the HESSI command link begins with blocking the command data channel. Subsequently, the sub-carrier and the main carrier are disabled. Finally, the high-power amplifier is turned off.

7. Temporary Data Storage

All telemetry data received during a pass support will be stored locally on the Berkeley Ground Station in separate files, containing 1129-byte long annotated Transfer Frames for each Virtual Channel. The files are stored on the PTP NT system in the *ptp_user* directory under:

D:\TLM_Data\HESSI\BGS_HESSI_TLM_VCn.dat

The letter *n* designates the Virtual Channel Identifier (VCID). Command data are stored under:

D:\CMD_Data\HESSI\BGS_HESSI_CMD.dat

After a pass support these files need to be renamed or transferred to another computer because otherwise they will be overwritten with each subsequent HESSI pass support. Stored data are typically transferred from the ground station to the MSOC via Internet FTP connections, once a pass support is complete. The maximum data volume received during an 11-minute HESSI pass support is 330 Mbytes.

During a pass support some of the data, e.g. those for VC0 and VC2, are also transferred to the MSOC computers in real-time via TCP/IP connections. The required real-time bandwidth is less than 50 kbps.

A digital data recorder that is currently used for spacecraft integration and testing will eventually be installed on the Berkeley Ground Station. Recording and playback of raw digital base band data will then become possible.

Appendix A: List of Acronyms

AFC	Automatic Frequency Control
AOS	Acquisition of Signal
ASM	Attached Synchronization Marker
BCH	Bose-Chaudhuri-Hocquenghem (Code)
BER	Bit Error Rate
BGS	Berkeley Ground Station
BPSK	Binary Phase Shift Keying
CDH	Command Deliver Header
CDU	Command Decoder Unit
CIB	Communications Interface Board
CCSDS	Consultative Committee for Space Data Systems
CLTU	Command Link Transmission Unit
CLCW	Command Link Control Word
CMM	Carrier Modulation Mode
COP	Command Operation Procedure
EIRP	Effective Isotropic Radiated Power
FARM	Frame Acceptance and Reporting Mechanism
FTP	File Transfer Protocol
GPS	Global Positioning System
HESSI	High Energy Solar Spectroscopic Imager
ICD	Interface Control Document
ITOS	Integrated Test and Operations System
LEO-T	Low Earth Orbiter Terminal
LHCP	Left Hand Circular Polarization
LOS	Loss of Signal
MOC	Mission Operations Center
MSB	Most Significant Bit
MSOC	Mission and Science Operations Center
NRZ-L	Non Return to Zero – Level
NRZ-M	Non Return to Zero – Mark
PACI	Payload and Attitude Control Interface
PCB	Power Control Board
PCM	Pulse Code Modulation
PLOP	Physical Layer Operations Procedure
PM	Phase Modulation
PTP NT	Programmable Telemetry Processor for Windows NT
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
SCID	Spacecraft Identifier
SMEX	Small Explorer
SOH	State of Health
STOL	Spacecraft Test and Operations Language
TBD	To Be Determined
TBR	To Be Resolved
TC	Telecommand
TCP/IP	Transmission Control Protocol / Internet Protocol
TFDH	Telemetry Frame Delivery Header
TLE	Two-line Elements
VC	Virtual Channel
VCID	Virtual Channel Identifier
VCO	Voltage Controlled Oscillator