Consultative Committee for Space Data Systems

RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

TELECOMMAND

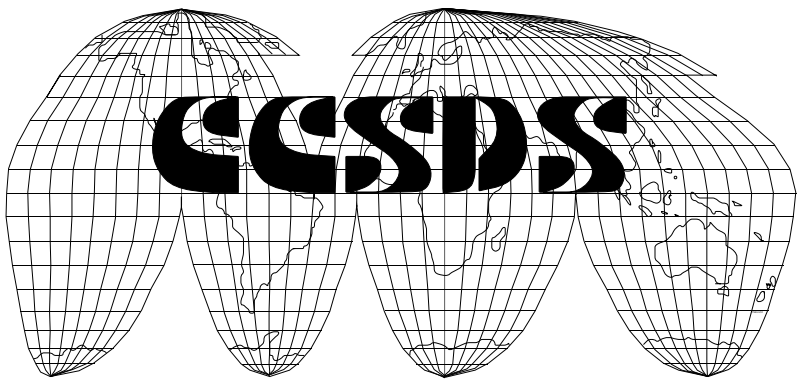
PART 1
CHANNEL SERVICE

ARCHITECTURAL SPECIFICATION

CCSDS 201.0-B-2

BLUE BOOK

November 1995



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The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space Agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommendations** and are not considered binding on any Agency.

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  -- The **standard** itself.

  -- The anticipated date of initial operational capability.

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- Specific service arrangements shall be made via memoranda of agreement. Neither this **Recommendation** nor any ensuing **standard** is a substitute for a memorandum of agreement.

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FOREWORD

This document, which is a technical Recommendation prepared by the Consultative Committee for Space Data Systems (CCSDS), is intended for use by participating space Agencies in their development of space telecommand systems.

This Recommendation allows the implementing organizations within each Agency to proceed coherently with the development of compatible Standards for the flight and ground systems that are within their cognizance. Agency Standards derived from this Recommendation may implement only a subset of the optional features allowed herein, or may incorporate features not addressed by the Recommendation.

In order to establish a common framework within which the Agencies may develop standardized telecommand services, the CCSDS advocates adoption of a layered systems architecture. Within this approach, specific layers of service (including their operational protocol and data structuring techniques) may be selected for implementation according to mission requirements.

The current layered set of CCSDS telecommand Recommendations was developed to match the conventional free-flying mission environment, as characterized by the transmission of command data at relatively low uplink data rates to spacecraft of moderate complexity. The CCSDS is currently examining the extension of these Recommendations (perhaps by defining expanded protocols and data structures within some of the layers) to a more complex mission environment, including the transmission of multiple data types at very high data rates to space vehicles which include extensive onboard data networking capability.

This Recommendation for Telecommand Channel Service was developed within the layered architectural framework, and embraces the standard data structures and data communication procedures which may be used by conventional missions within the lowest telecommand system layers.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommendation is therefore subject to CCSDS document management and change control procedures which are defined in Reference [1].

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DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 201.0-B-1	Recommendation for Space Data System Standards: Telecommand, Part 1: Channel Service, Architectural Specification, Issue 1	January 1987	Original Issue
CCSDS 201.0-B-2	Recommendation for Space Data System Standards: Telecommand, Part 1: Channel Service, Architectural Specification, Issue 2	November 1995	Current Issue – the Tail Sequence has been replaced with a new, more distinctive pattern, which is more reliably recognized at the end of a CLTU; – an option has been added for randomizing the Telecommand data to increase bit transitions, for those command systems that require frequent bit transitions to maintain reliable bit synchronization; – minor format changes have been made based on specifications of the CCSDS Publications Manual.

NOTE – Substantive changes from the previous issue are indicated with change bars in the outside margin.

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to establish a common Recommendation which defines the systems architecture of a spacecraft telecommand "Channel Service". The intent of this architecture is to provide a common framework within which the Agencies participating in the Consultative Committee for Space Data Systems (CCSDS) may implement compatible future spacecraft telecommanding systems.

This Recommendation primarily addresses the data unit formats and functions which are implemented within the Coding layer and the Physical layer of the CCSDS telecommand Channel Service. **THE ASSOCIATED DETAILED OPERATIONAL PROTOCOLS WHICH OPERATE ACROSS THESE LAYERS, AND THE FLOW OF CONTROL INFORMATION REQUIRED TO INITIALIZE THE LAYERS AND DIRECT THE TRANSFER OF DATA BETWEEN THEM, ARE NOT PRESENTLY ADDRESSED WITHIN THIS DOCUMENT: THESE REMAIN ITEMS FOR POTENTIAL EXTENSION OF THIS RECOMMENDATION**.

The operating principles and procedures for the CCSDS are defined in Reference [1]. The context of the Channel Service within the overall Telecommand System is described in Reference [2]. This is a working document, subject to update as experience is gained, which provides an inter-Agency coordination mechanism that ensures that compatible implementations are facilitated.

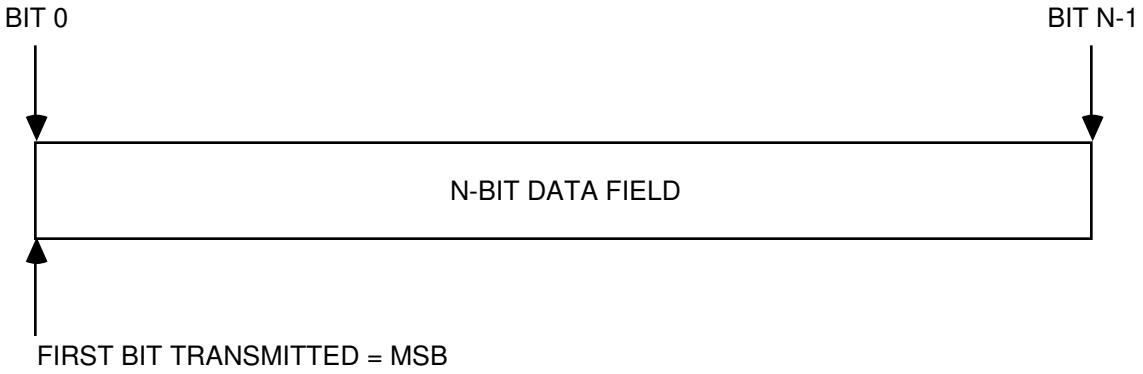
1.2 APPLICABILITY

This Recommendation serves as a guideline for the development of compatible internal Agency standards in the field of spacecraft commanding. This Recommendation is not retroactive, nor does it commit any Agency to implement the recommended telecommand concepts at any future time. Nevertheless, all CCSDS Agencies accept the principle that all future implementations of telecommand which are used in cross-support situations will be based on this Recommendation.

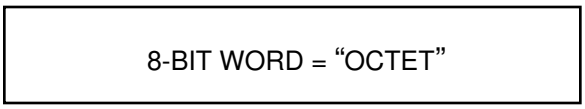
The CCSDS has developed a layered concept for spacecraft telecommanding, which is fully described in Reference [2]. Standard services are defined within each layer, and Agencies will be encouraged to develop corresponding facilities to provide these services in support of Projects. To be fully compatible with the CCSDS concept, a Project's telecommanding architecture should follow this Recommendation for Channel Service, plus the Recommendations for telecommand "Data Management Service" and telecommand "Data Routing Service" which are described in References [3] and [4], respectively. Projects may also elect to be partially compatible with the concept by interfacing with the standard systems at intermediate layers within any of the service specifications.

1.3 BIT NUMBERING CONVENTION AND NOMENCLATURE

In this document, the following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be "Bit 0"; the following bit is defined to be "Bit 1" and so on up to "Bit N-1". When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., "Bit 0".



In accordance with modern data communications practice, spacecraft data fields are often grouped into 8-bit "words" which conform to the above convention. Throughout this Recommendation, the following nomenclature is used to describe this grouping:



By CCSDS convention, all "spare" bits shall be permanently set to value zero.

Note that throughout this document, the word "Telecommand" may be abbreviated as "TC".

1.4 REFERENCES

The following documents are referenced in the text of this Recommendation. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommendation are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommendations.

[1] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-6. Yellow Book. Issue 6. Washington, D.C.: CCSDS, May 1994.

[2] *Telecommand: Summary of Concept and Rationale*. Report Concerning Space Data Systems Standards, CCSDS 200.0-G-6. Green Book. Issue 6. Washington, D.C.: CCSDS, January 1987.

[3] *Telecommand Part 3 — Data Management Service*. Recommendation for Space Data Systems Standards, CCSDS 203.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, January 1987.

[4] *Telecommand Part 2 — Data Routing Service*. Recommendation for Space Data Systems Standards, CCSDS 202.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, November 1992.

[5] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Recommendation for Space Data Systems Standards, CCSDS 401.0-B. Blue Book. Washington, D.C.: CCSDS, May 1996.

The latest issues of these documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

2 TELECOMMAND CHANNEL SERVICE OVERVIEW

A complete summary of the terminology which is used internal to this document is presented in Annex A.

The TC Channel Service (see Figure 2-1) enables an error-controlled data path to be established for the transfer of telecommands to the spacecraft. The service contains two distinct layers of data handling operations:

(1) A **CODING LAYER,** which permits telecommand information bits to be more reliably transmitted through the noisy physical data channel using standard channel coding techniques. The Coding layer also provides information about the beginning of the contents of valid codeblocks and the continuity of the data stream, and it delivers the contents of those codeblocks to the layer above.

(2) A **PHYSICAL LAYER,** which contains the radio frequency and modulation capabilities that may be invoked to establish the physical data channel: these capabilities are fully described in Reference [5] and are only addressed within this document as required for clarity. The Physical layer also contains **PHYSICAL LAYER OPERATIONS PROCEDURES** (PLOPs) which provide the methods of activating and deactivating the physical channel.

A complete, detailed specification of the services provided by each layer within the Channel Service is presented in Annex B. The first-time reader should digest Annex B before proceeding further in this document.

NOTES

1 Figure 2-1 represents a logical view of the TC System and physical implementations may not necessarily correspond to the flow of operations implied by the figure.

2 This Recommendation primarily specifies the data structures and procedures flowing ACROSS the layers from the sending to the receiving end of the TC System, since these have a direct impact on the long lead-time design of future spacecraft hardware and software. Comprehensive definition of the associated operational protocols within each layer and the control instructions, which are required to initialize the layers and to direct the flow of TC data units BETWEEN the layers, remain items for potential future extension of this document.

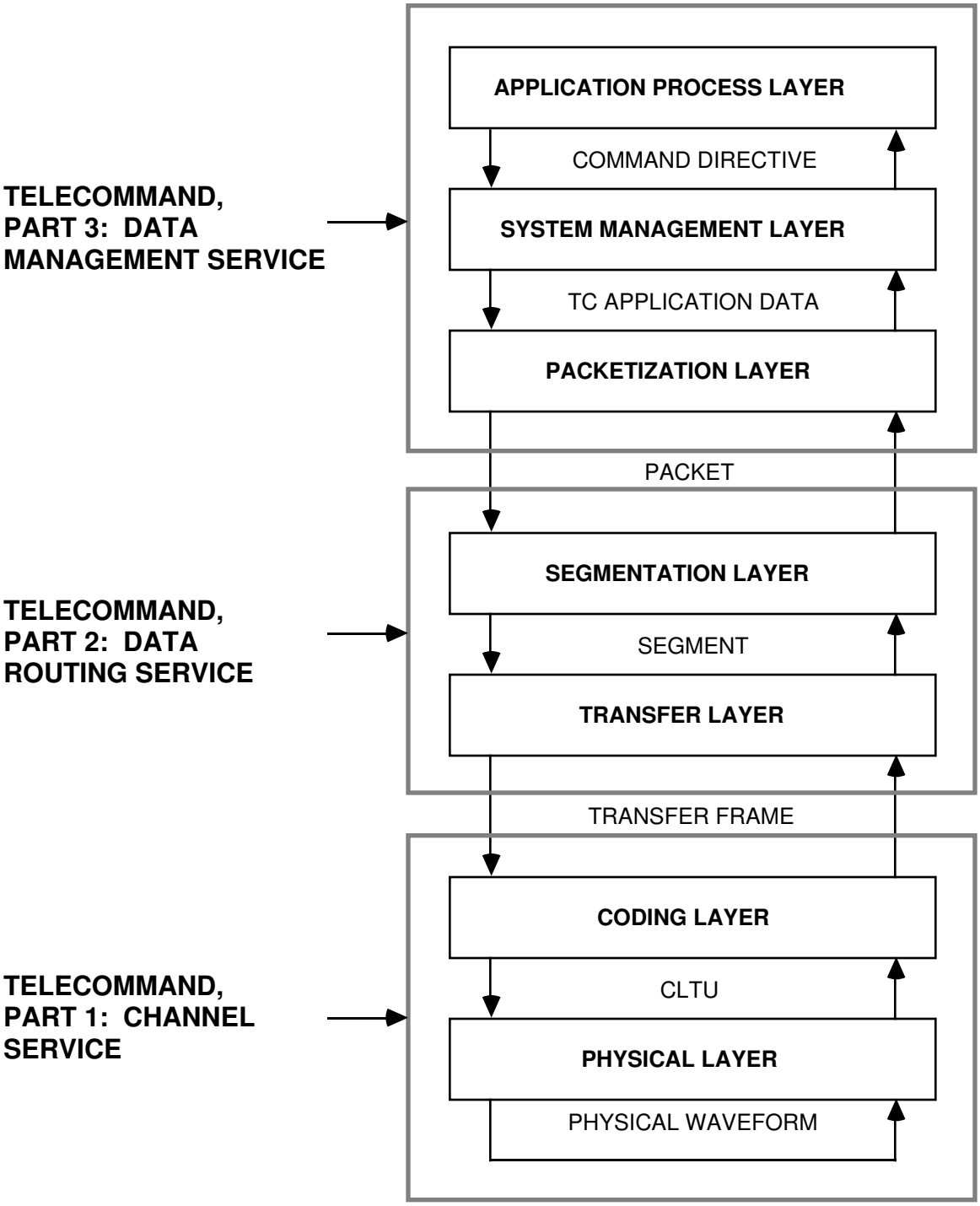


Figure 2-1: Telecommand System

3 CODING LAYER: STANDARD DATA STRUCTURES AND PROCEDURES

3.1 OVERVIEW OF THE CODING LAYER

The Coding layer establishes the reliable, error-controlled data channel through which user telecommand data bits may be transferred. The data are encoded to reduce the effects of noise in the Physical layer channel on the user data. A block code has been chosen to provide this protection. Synchronization for the codeblock and delimiting of the beginning of user data are provided by the Command Link Transmission Unit (CLTU) data structure.

Resolution of data ambiguity (sense of "1" and "0") when receiving the symbol stream shall be a service of the Coding layer. Data ambiguity may result from the modulation technique utilized in the Physical layer such as suppressed-carrier modulation. Ambiguity resolution techniques shall use inherent information in the symbol stream such as either the CLTU start sequence pattern or NRZ-M modulation.

Standard procedures for randomizing, encoding, and handling fill bits are described in 3.3.

3.2 STANDARD DATA STRUCTURES WITHIN THE CODING LAYER

The standard data structures within the Coding layer are the TC Codeblock and the CLTU.

3.2.1 TC CODEBLOCK FORMAT

The TC Codeblock format is a fixed-length data entity shown in Figure 3-1. The codeblock is formulated using a systematic coding technique which contains N information bits in the leading octets and the error control in the last octet. The TC Codeblock contains an integer number of octets with a maximum overall length of 8 octets (64 bits).

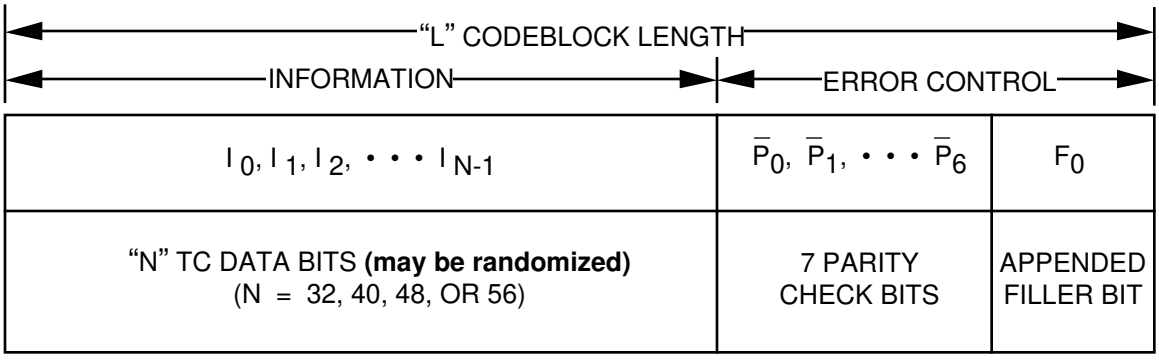


Figure 3-1: Telecommand Codeblock Format

Within any given mission, the overall length "L" of the TC Codeblock shall be fixed and shall be selected from the following standard lengths:

L = 40 bits (N=32)
L = 48 bits (N=40)
L = 56 bits (N=48)
L = 64 bits (N=56)

The preferred length is L = 64 bits.

The COMPLEMENTS of the seven parity check bits, P_0 through P_6, are located in the first seven bits of the last octet of the TC Codeblock. The complements are used to aid in maintaining bit synchronization and detection of bit slippage. The encoding procedure for generating these parity bits is described in 3.3.2.

The last bit of the last octet, F_0, is a filler bit appended to provide an overall Codeblock length which is an integer number of octets. This Filler Bit shall always be a zero.

3.2.2 COMMAND LINK TRANSMISSION UNIT (CLTU) FORMAT

The CLTU is the data structure which carries the TC data as a contiguous series of encoded TC Codeblocks across the Channel Service. The encoded TC data within the CLTU consist of Input Data from the layer above. The CLTU has the structural components shown in Figure 3-2.

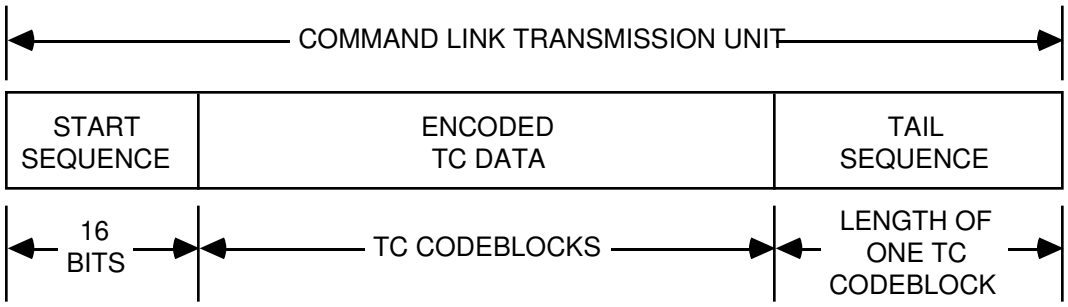
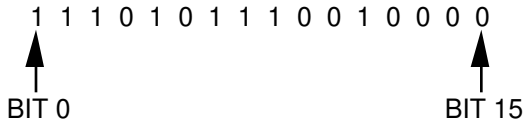


Figure 3-2: Components of the CLTU

3.2.2.1 CLTU Start Sequence. The CLTU Start Sequence field delimits the start of the encoded TC data within the CLTU. It consists of a 16-bit synchronization pattern with low autocorrelation sidelobes and shall have the following pattern:



3.2.2.2 Encoded TC Data. The Encoded TC Data field consists of a set of TC Codeblocks which have been encoded in accordance with the TC Codeblock encoding procedure. In addition to error control bits, these codeblocks contain the Input Data to this layer, plus any fill bits that were appended to meet codeblock length constraints. The encoded TC data field may have been randomized before encoding, or not randomized, as selected for the mission. (For brevity, "random" is used in place of "pseudo-random" throughout this document. See Annex A.)

3.2.2.3 Tail Sequence. The CLTU Tail Sequence field is a data structure which is constructed specifically to be a noncorrectable sequence which delimits the end of a CLTU by stopping the decoding process. The Tail Sequence shall have the same length as the TC Codeblocks that are being used. The Tail Sequence[1] shall consist of leading octets having the pattern 11000101, repeated as necessary until the next-to-last octet of the tail sequence field is reached. The last octet completes the tail sequence field, and always has the pattern 01111001. Therefore, the octet pattern for the standard codeblock lengths may be described as follows:

Codeblock Length L, in Bits	Tail Sequence Pattern
40	11000101 11000101 11000101 11000101 01111001
48	11000101 11000101 11000101 11000101 11000101 01111001
56	11000101 11000101 11000101 11000101 11000101 11000101 01111001
64	11000101 11000101 11000101 11000101 11000101 11000101 11000101 01111001

3.3 STANDARD PROCEDURES WITHIN THE CODING LAYER

The following subsections define the procedures for randomization of Input Data and coding of TC Codeblocks.

[1] A pattern of alternating "zeros" and "ones" identical to the idle sequence throughout the length of a codeblock was defined in the previous issue. The new pattern is preferred for new designs because of its improved performance. See Reference [2].

3.3.1 RANDOMIZATION PROCEDURE

In order to maintain bit (or symbol) synchronization with the received telecommand signal, the incoming signal must have a minimum bit transition density (see Recommendation 2.2.3 in Reference [5]).

If a sufficient bit transition density is not ensured for the channel by other methods (e.g., by use of certain modulation techniques or data that is phase-coherent with the subcarrier) then the randomizer defined in this subsection is required. Its use is optional otherwise.

The presence or absence of randomization is fixed for a physical channel and is managed (i.e., its presence or absence is not signaled but must be known a priori by the spacecraft and ground system). A random sequence is exclusively ORed with the **Input Data** to increase the frequency of bit transitions. On the receiving end, the same random sequence is exclusively ORed with the decoded data, restoring the original data form. The random sequence is generated by the Bit Transition Generator (BTG).

3.3.1.1 Random Sequence. The random sequence shall be generated using the following polynomial:

$$h(x) = x^8 + x^6 + x^4 + x^3 + x^2 + x + 1$$

This sequence repeats after 255 bits, continuing as needed. The first 40 bits of the sequence are

1111 1111 0011 1001 1001 1110 0101 1010 0110 1000
Increasing Time---------->

Figure 3-3 is a basic logical diagram of the BTG.

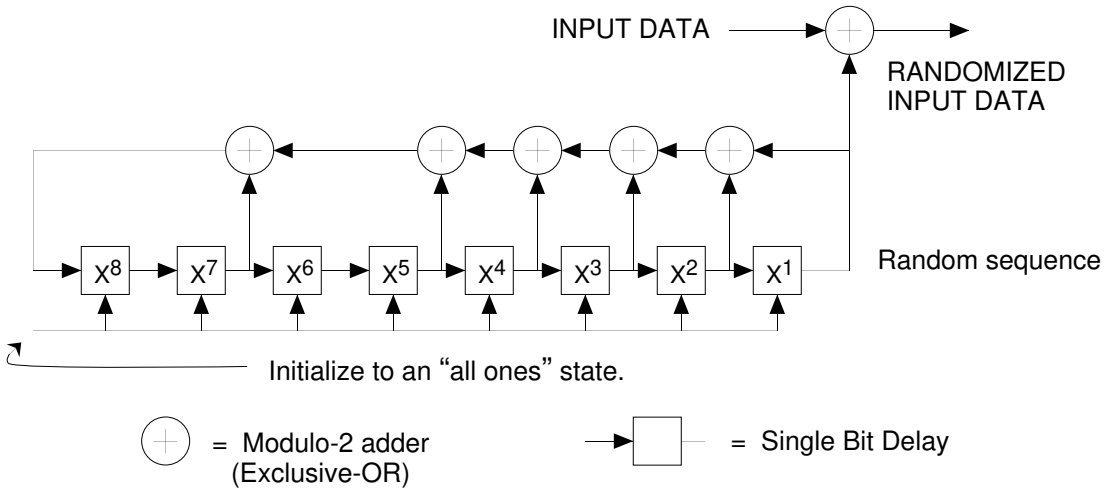


Figure 3-3: Bit Transition Generator Logic Diagram

3.3.1.2 APPLICATION OF THE RANDOMIZER. The randomization is applied at the transmitting end, only to the Input Data. The BTG is preset to the "all-ones" state and then is exclusively ORed, bit by bit, with the Input Data until the process ends with the last bit of the Input Data. The randomization may also be applied to the fill bits added after the end of the Input Data to complete the last codeblock of the CLTU, but this is optional.

At the receiving end, the derandomization is applied to the successfully decoded TC data. The BTG remains in the "all-ones" state until the CLTU Start Sequence has been detected. The BTG pattern is exclusively ORed, bit by bit, to the successfully decoded data (after the Error Control Bits have been removed). The BTG is reset to the "all-ones" state following a failure of the decoder to successfully decode a TC codeblock or other loss of TC data.

3.3.2 TC CODEBLOCK ENCODING PROCEDURE

A systematic block coding procedure is used which always generates 7 parity check bits per codeblock and which is always computed from 56 information bits. The parity check bits are then COMPLEMENTED and placed into the codeblock as shown in Figure 3-1.

The code used is a (63,56) modified Bose-Chaudhuri-Hocquenghem (BCH) code which uses the following generator polynomial to produce the seven parity bits:

$$g(x) = x^7 + x^6 + x^2 + 1$$

It may be desired to shorten the transmitted codeblocks. This is accomplished by reducing the number of TC data bits contained within the transmitted codeblocks. To maintain octet boundaries and reasonable efficiency, 32, 40, and 48 bits are the only shortened TC data field sizes permitted.

The same encoding algorithm shown above for 56 information bits also serves for the shortened cases by forcing the coding algorithm to continue to operate on 56-bit fields. The difference between the shortened TC data field and the 56 bits is treated by the encoder as "virtual fill" (zeros) preceding the TC data. These leading zeros are NOT outputted from the encoder, nor transmitted. In all cases the overall codeblock length is always 8 bits longer than the TC data field. It should be noted that this "virtual fill" is separate and distinct from the fill of 3.3.3 which is used when there is insufficient Input Data to exactly fit the last codeblock.

The code generator implementation is shown in Figure 3-4. Note that the shift registers are initialized to zero. The ganged switch is in position 1 while the N TC data bits are being transmitted, in position 2 for the seven parity bits, and in position 3 for the appended fill bit.

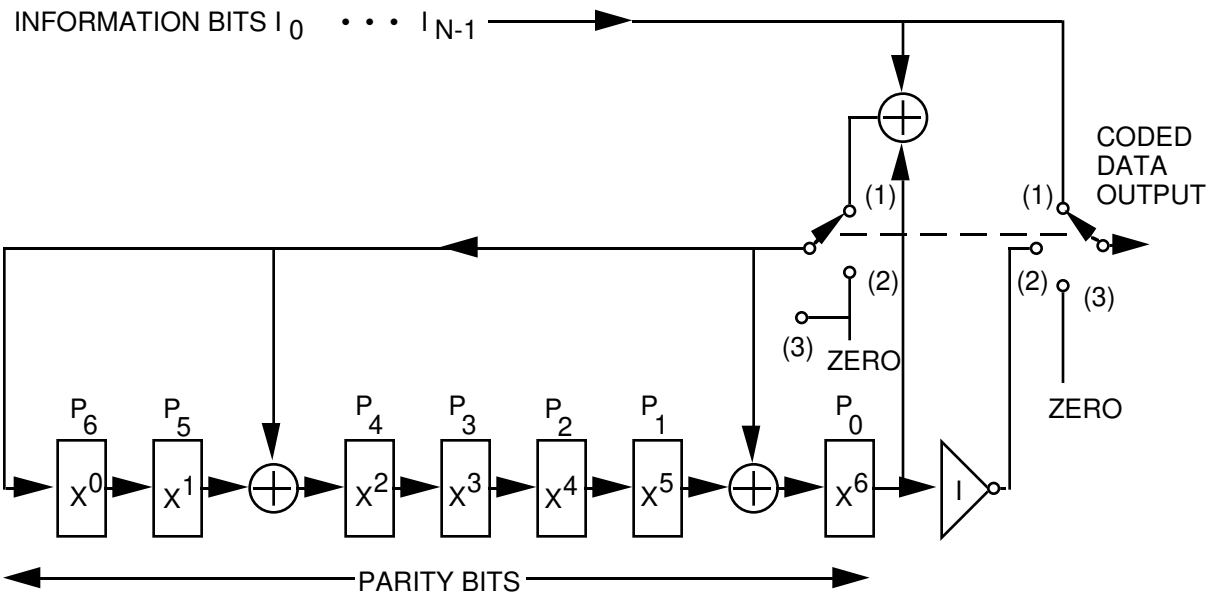


Figure 3-4: (63,56) Modified BCH Code Generator

3.3.3 FILL BITS

If the Input Data do not fit exactly within an integral number of TC Codeblocks, the last octet(s) and ONLY the last octet(s) of the information field of the last Codeblock within the CLTU may contain "Fill" bits. The pattern of the Fill shall consist of a sequence of alternating "ones" and "zeros" starting with a "zero".

The Coding layer may require the introduction of these fill bits in the encoding process; they are not removed by the decoding process. Removal of fill is the responsibility of the layer above, which delimits the end of the Input Data and discards extraneous bits (e.g., fill).

Note – If randomization is being used, any fill octets that were added to the last codeblock of the CLTU will be derandomized even if they were not randomized.

3.3.4 TC CHANNEL SERVICE LOGIC

The TC Channel Service Logic at the receiving end is presented in state diagram form (Figure 3-5). To support the state diagrams, a list of "states" and "events" is given in Tables 3-1 and 3-2. There are three states and four events.

Table 3-1: TC Channel Service States (Receiving End)

State Number	State Name	State Definition
S 1	INACTIVE	The telecommand channel is INACTIVE (i.e., "no bit lock is achieved", or, alternatively, "no bit modulation is detected".
S 2	SEARCH	The incoming bit stream is searched, bit by bit, for the Start Sequence pattern.
S 3	DECODE	TC Codeblocks, which are either free of error or which can be corrected, are received, decoded, and derandomized (if used), and their contents are transferred to the layer above.

Table 3-2: TC Channel Service Events (Receiving End)

Event Number	Event Name	Event Definition
E 1	CHANNEL ACTIVATION	Bit modulation is detected and bit lock is achieved: telecommand bit stream is present.
E 2	CHANNEL DEACTIVATION	Bit lock is lost or telecommand signal is lost: telecommand bit stream is NOT present.
E 3	START SEQUENCE FOUND	The Start Sequence pattern has been detected, signaling the beginning of the first codeblock of the CLTU.
E 4	CODEBLOCK REJECTION	The decoder has indicated uncorrected errors in a codeblock. No data from this codeblock are transferred to the layer above.

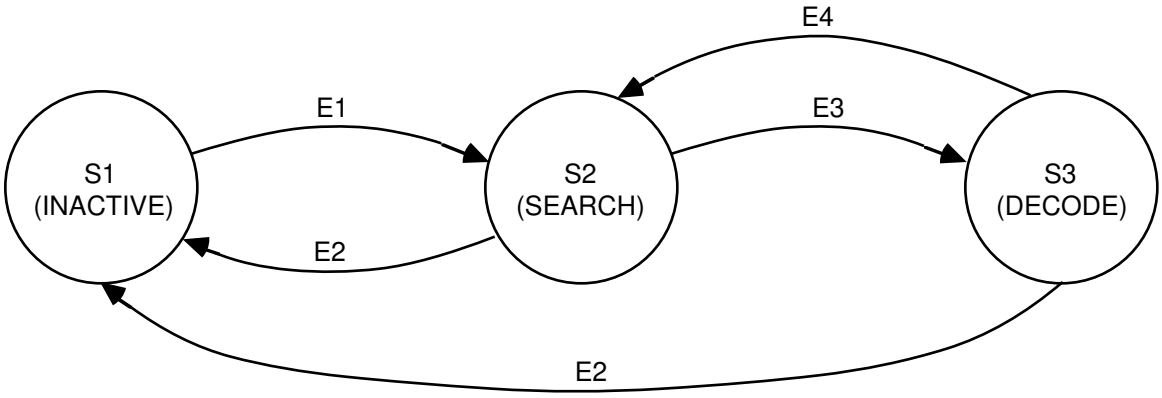


Figure 3-5: TC Channel Service State Diagram (Receiving End)

3.3.5 TC CODEBLOCK DECODING PROCEDURES [2]

Codeblocks that have been encoded using the modified BCH code described in 3.3.2 may be decoded either in an error-detecting mode or in an error-correcting mode, depending on mission requirements. When the error-detecting mode is chosen, one, two or three bits in error will be detected within the codeblock (not counting the appended Filler Bit); when the error-correcting mode is used, one bit in error will be corrected and two bits in error will be detected.

[2] The description to follow assumes a hard-limiting detector before decoding, but a soft-limiting detector is not intended to be precluded.

4 PHYSICAL LAYER: STANDARD DATA STRUCTURES AND PROCEDURES

4.1 OVERVIEW OF THE PHYSICAL LAYER

The Physical layer provides the radio frequency data path which connects the transmitting station to the spacecraft, and its associated Physical Layer Operational Procedures (PLOPs), in order to support the transmission of telecommand data.

4.2 STANDARD DATA STRUCTURES WITHIN THE LAYER

The standard data structures within this layer are the Acquisition Sequence, CLTU, and the Idle Sequence. They are used to provide synchronization of the symbol stream, and are described below.

4.2.1 ACQUISITION SEQUENCE

The Acquisition Sequence is a data structure forming a preamble which provides for initial symbol synchronization within the incoming stream of detected symbols. The length of the Acquisition Sequence shall be selected according to the mission telecommand link performance requirements but the preferred minimum length is 16 octets. The length is not required to be an integral multiple of octets. The pattern of the Acquisition Sequence shall be alternating “ones” and “zeros”, starting with either a “one” or a “zero”.

4.2.2 CLTU

The CLTU is the data structure (symbol sequence) furnished from the layer above, and defined in 3.2.2. It contains the data symbols that are to be transmitted to the spacecraft. Each codeblock within the CLTU, having the format specified in 3.2.1, provides at least 2 data transitions per codeblock. If the spacecraft symbol synchronization design necessitates more frequent transitions, either the CLTU as delivered to the physical layer must have been randomized as described in 3.3.1 or the Physical Layer must invoke a technique (modulation type, phase-coherent data and subcarrier, or other) to guarantee sufficiently frequent transitions for adequate symbol synchronization.

4.2.3 IDLE SEQUENCE

The Idle Sequence is the data structure which provides for maintenance of symbol synchronization in the absence of CLTUs. The bit pattern is a sequence of alternating “ones” and “zeros”.[3] The length of the Idle Sequence is an unconstrained number of bits.

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[3] Previously, the idle sequence was constrained to begin with a “zero” to be continuous with the tail sequence. Because of the improved performance of the tail sequence in this issue, the constraint is no longer necessary.

4.3 STANDARD PROCEDURES WITHIN THE LAYER

Operations within the Physical layer begin with the activation of the physical telecommand channel by invoking the radio frequency carrier and modulation techniques. These techniques include provision of any required command link subcarrier(s) and data modulation in order to establish the physical connection from the transmitting station to the proper spacecraft hardware.

4.3.1 CARRIER MODULATION MODES

Carrier Modulation Modes (CMMs) consist of different states of data modulation upon the RF carrier which creates the physical telecommand channel. The physical methods of modulating the carrier, which may be either spread spectrum (e.g., TDRSS) or subcarrier (e.g., conventional ground station) techniques, are described in Reference [5]. The Carrier Modulation Modes are shown in Table 4-1.

Table 4-1: Carrier Modulation Modes

Mode	State
CMM-1	Unmodulated CARRIER only
CMM-2	CARRIER modulated with ACQUISITION SEQUENCE
CMM-3	CARRIER modulated with TC data (e.g., CLTU)
CMM-4	CARRIER modulated with IDLE SEQUENCE

4.3.2 TELECOMMAND SESSION

During a Telecommand Session, a series of CLTUs is transmitted to a remote spacecraft. The session begins with the initial application of the RF carrier (CMM-1) and ends with the removal of the carrier. The path is further controlled (activated or deactivated) by the selection of appropriate Physical Layer Operations Procedures (PLOPs).

4.3.3 PHYSICAL LAYER OPERATIONS PROCEDURES (PLOPS)

A PLOP consists of a sequential application of the various CMMs in order to activate and deactivate the physical telecommand channel. Two procedures, PLOP-1 and PLOP-2, are currently defined. The selection of PLOPs is mission-specific.

4.3.3.1 PLOP-1. PLOP-1 is a procedure for individually radiating CLTUs, whereby the spacecraft TC decoder is always forced into the INACTIVE state (S1) by deactivating the physical telecommand channel after the end of transmission of each CLTU (or CLTU followed by an Idle Sequence).

PLOP-1 invokes the sequence of CMMs shown in Figure 4-1. Note that "unmodulated" is defined as the state in which no *telecommand* modulation is present.

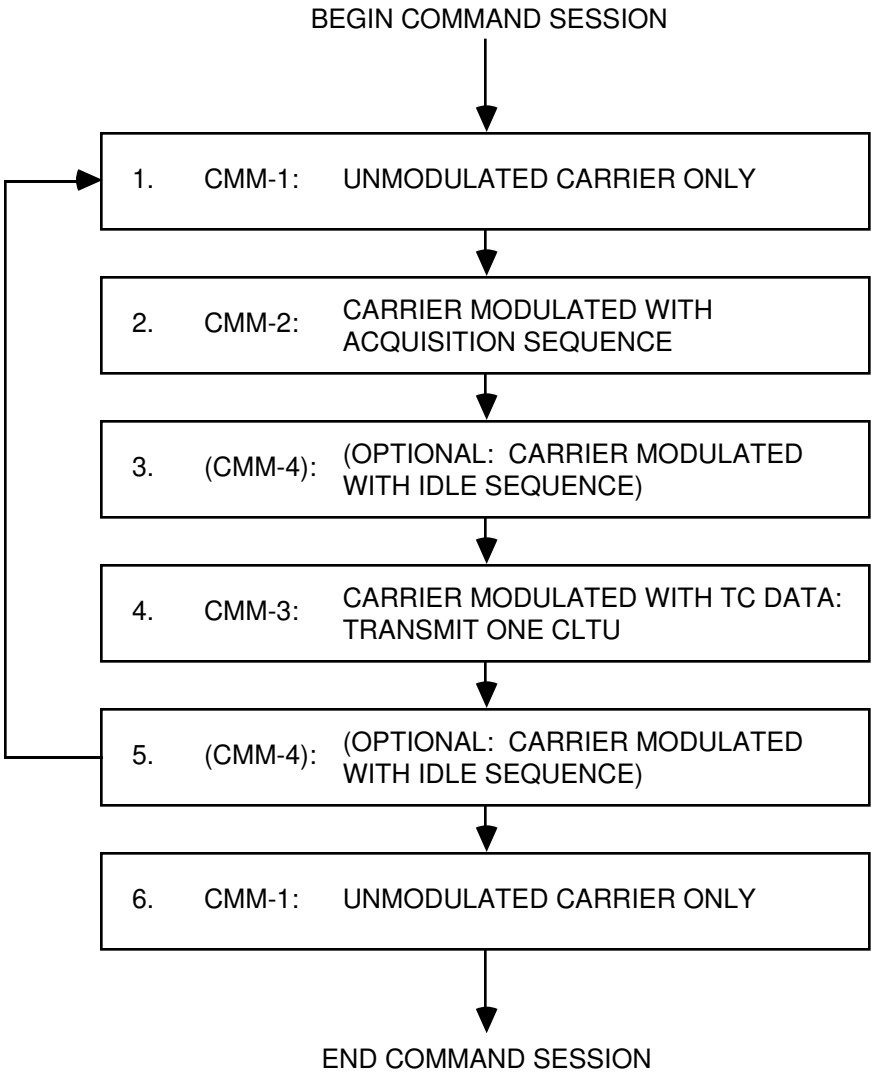


Figure 4-1: Sequence of CMMs Comprising PLOP-1

4.3.3.2 PLOP-2. PLOP-2 is a procedure whereby the physical telecommand channel is not deactivated after each transmitted CLTU. The termination of an individual CLTU is provided only through the data path, using the CLTU Tail Sequence and, optionally, Idle Sequences. This places the decoder in the SEARCH state (S2) after each CLTU. The decoder is forced into the INACTIVE state (S1), by deactivating the physical telecommand channel only at the end of transmission of a series of CLTUs, which may be followed by an Idle Sequence or not.

It should be noted that when operating with PLOP-2, it is recommended to systematically insert a minimum Idle Sequence of one octet between each CLTU to eliminate the small but finite possibility of synchronization lockout. Such a lockout may occur if the start pattern of one CLTU is not detected (leaving the decoder in SEARCH state) and a start pattern exists over the last bits of the last frame of that CLTU and the first bits of its Tail Sequence. This creates an erroneous but temporary CLTU start (DECODE state), causing the true start of the following CLTU to be missed. The added Idle Sequence prevents this from happening.

PLOP-2 invokes the sequence of CMMs shown in Figure 4-2. Note that "unmodulated" is defined as the state in which no *telecommand* modulation is present.

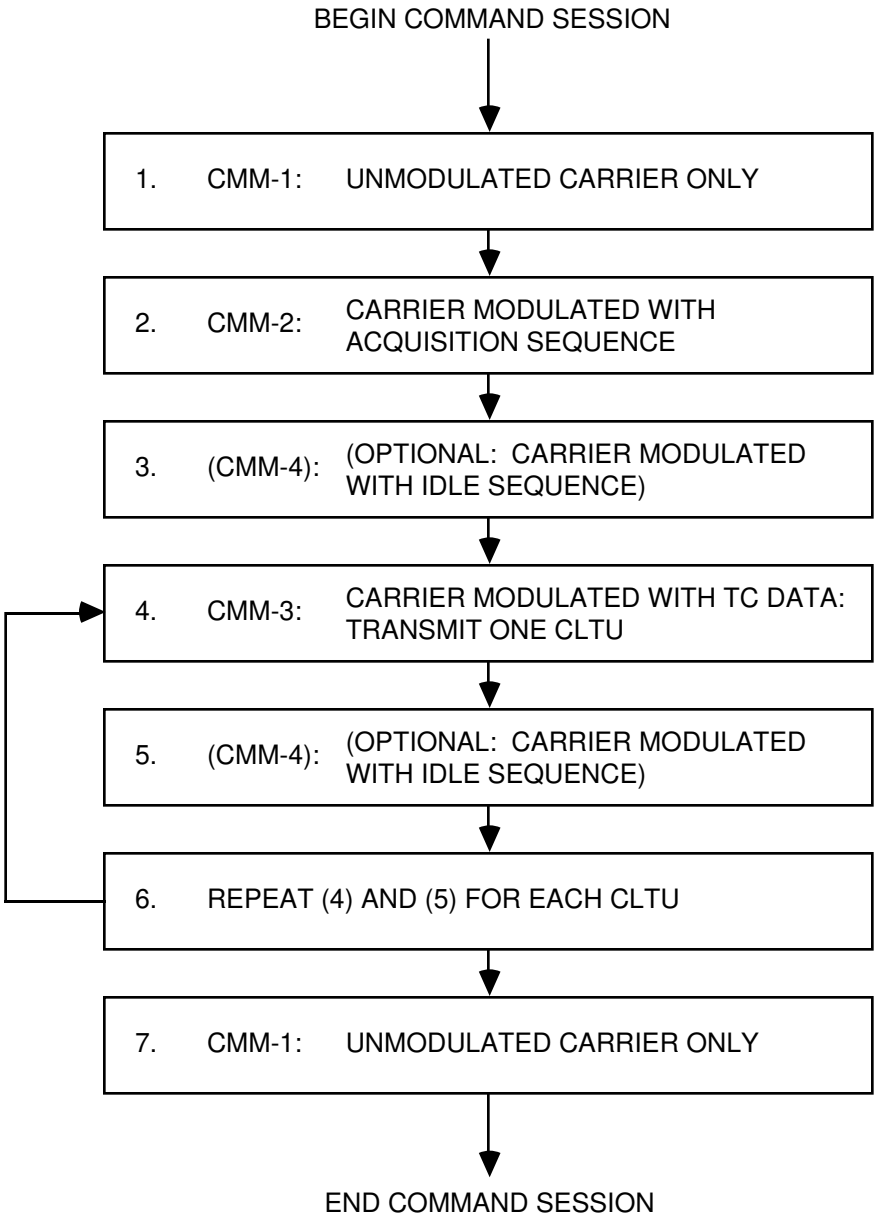


Figure 4-2: Sequence of CMMs Comprising PLOP-2

ANNEX A

CHANNEL SERVICE

ACRONYMS AND TERMINOLOGY

(THIS ANNEX **IS** PART OF THE RECOMMENDATION)

Purpose:

This Annex defines the key acronyms and terms which are used throughout this Recommendation to describe activities within the Channel Service.

ACRONYMS

BCH: BOSE-CHAUDHURI-HOCQUENGHEM
BTG: BIT TRANSITION GENERATOR
CCSDS: CONSULTATIVE COMMITTEE FOR SPACE DATA SYSTEMS
CLTU: COMMAND LINK TRANSMISSION UNIT
CMM: CARRIER MODULATION MODE
MSB: MOST SIGNIFICANT BIT
NRZ-M: NON-RETURN-TO-ZERO-MARK
PLOP: PHYSICAL LAYER OPERATIONS PROCEDURE
TC: TELECOMMAND

TERMINOLOGY

Terminology for the overall CCSDS Telecommand concept is summarized in Reference [2]. Key elements of Channel Service terminology, as used in this document, are defined in this annex. These definitions are meant to be used by the reader as an aid to understanding the concept of Telecommand; no attempt is being made to universally define these terms. Definitions which may be found in a standard English dictionary have been omitted.

ACQUISITION SEQUENCE:

A specific high transition density bit pattern transmitted to permit the receiving end to acquire symbol synchronization.

BIT TRANSITION GENERATOR:

A generator that produces a specific random sequence of 255 bits to be ORed with the input TC data bits to increase the frequency of bit transitions (between “1” and “0”). No additional bits are added by this process.

CARRIER MODULATION MODE:

The data type being used to modulate the RF carrier or subcarrier.

CLEAN DATA BITS:

TC data bits which have been decoded and are outputted from the Coding layer.

CODEBLOCK:

A fixed-length data entity containing information and check bits that have been structured by an encoding algorithm.

CODING LAYER:

That layer of the TC Channel Service which uses a prescribed coding technique to reliably transfer information bits through the potentially noisy Physical layer.

COMMAND LINK TRANSMISSION UNIT:

A Coding layer protocol data entity which is used to synchronize and delimit the beginning of a continuum of bits consisting of a start sequence followed by an integral number of codeblocks.

COMMAND SESSION:

A continuous period of time during which the signal path is established for the communications channel.

COMMAND THRESHOLD:

The telecommand channel operating point at which a deletion rate of 1 frame per 1000 frames is obtained.

DECODER (Hard Decision):

A Coding layer algorithmic process which utilizes the check bits contained in a codeblock for detecting or correcting errors in the information bits. The check bits are then removed before the information bits are outputted.

DECODER (Soft Decision):

A Coding layer algorithmic process which uses quantization of the detector output into n levels for each received bit to decide upon the most likely codeblock and to estimate the reliability of that decision. The check bits are then removed before the best-estimate information bits and any reliability information are outputted.

ENCODED TC DATA:

The TC data contained in a codeblock.

ENCODER:

As used in this document, a Coding layer algorithmic process which adds check bits to a series of information bits to create a codeblock.

EVENT:

As used in this document, an action which causes the TC Channel Service to change states.

FILL:

Bits appended by the Coding layer to the Input Data to enable the data entity to exactly fit an integer number of codeblocks. These fill bits ARE transmitted and must be removed by the layer above.

IDLE SEQUENCE:

A specific high transition density bit pattern transmitted during a command session in the absence of a CLTU to maintain symbol synchronization in the channel.

INPUT DATA:

A discrete collection of data bits provided at the input to the Coding layer from the Data Routing Service.

OCTET:

A contiguous string of 8 bits; an 8-bit word.

PHYSICAL LAYER:

The lower layer of the TC Channel Service which provides the RF channel. At the sending end it provides the radio frequency and modulation techniques required to create and operate the channel. At the receiving end, it provides the reception, demodulation, and symbol synchronization for the channel.

PHYSICAL LAYER OPERATIONS PROCEDURE:

A specific procedure of the Physical layer designed to activate and deactivate the physical telecommand channel by invoking RF carrier and modulation techniques.

PROTOCOL:

A set of procedures, supported by format conventions, that define the orderly exchange of information between entities within a given layer of the TC System or between layers.

PSEUDO-RANDOMIZATION:

Pseudo-Randomization, herein called Randomization, is a bandwidth-efficient technique of algorithmically translating the data bits to insure frequent bit transitions in the communications channel.

RELIABLE:

Meets the quality, quantity, continuity and completeness criteria which are specified by the Telecommand System.

START SEQUENCE:

A specific bit pattern at the beginning of a CLTU having a high autocorrelation function following an idle or acquisition sequence and which: a) synchronizes start of a CLTU; b) delimits start of first codeblock; and c) resolves the sense of a “1” and “0” in the CLTU, if necessary.

SYMBOL:

A bit in an encoded data stream.

TAIL SEQUENCE:

A specific data pattern which delimits the end of a CLTU.

TC DATA:

The data content (after decoding) of the CLTU which is outputted to the Data Routing Service (layer above) and which may include fill.

TC TRANSFER FRAME:

The protocol data unit of the Transfer layer. (See Reference [4], Data Routing Service.)

TELECOMMAND:

A generic term used to describe the process of telecommunicating commands to the spacecraft.

TELECOMMAND CHANNEL SERVICE:

A Telecommand Service which provides error-controlled communications across the space link.

TELECOMMAND DATA ROUTING SERVICE:

A Telecommand Service which provides error-controlled message communications between remote entities.

VIRTUAL FILL:

Added bits which are NOT transmitted, but their presumption in the encoding process must be known for the decoding process (i.e., the decoder must know the codeblock length.)

ANNEX B

CHANNEL SERVICE SPECIFICATION

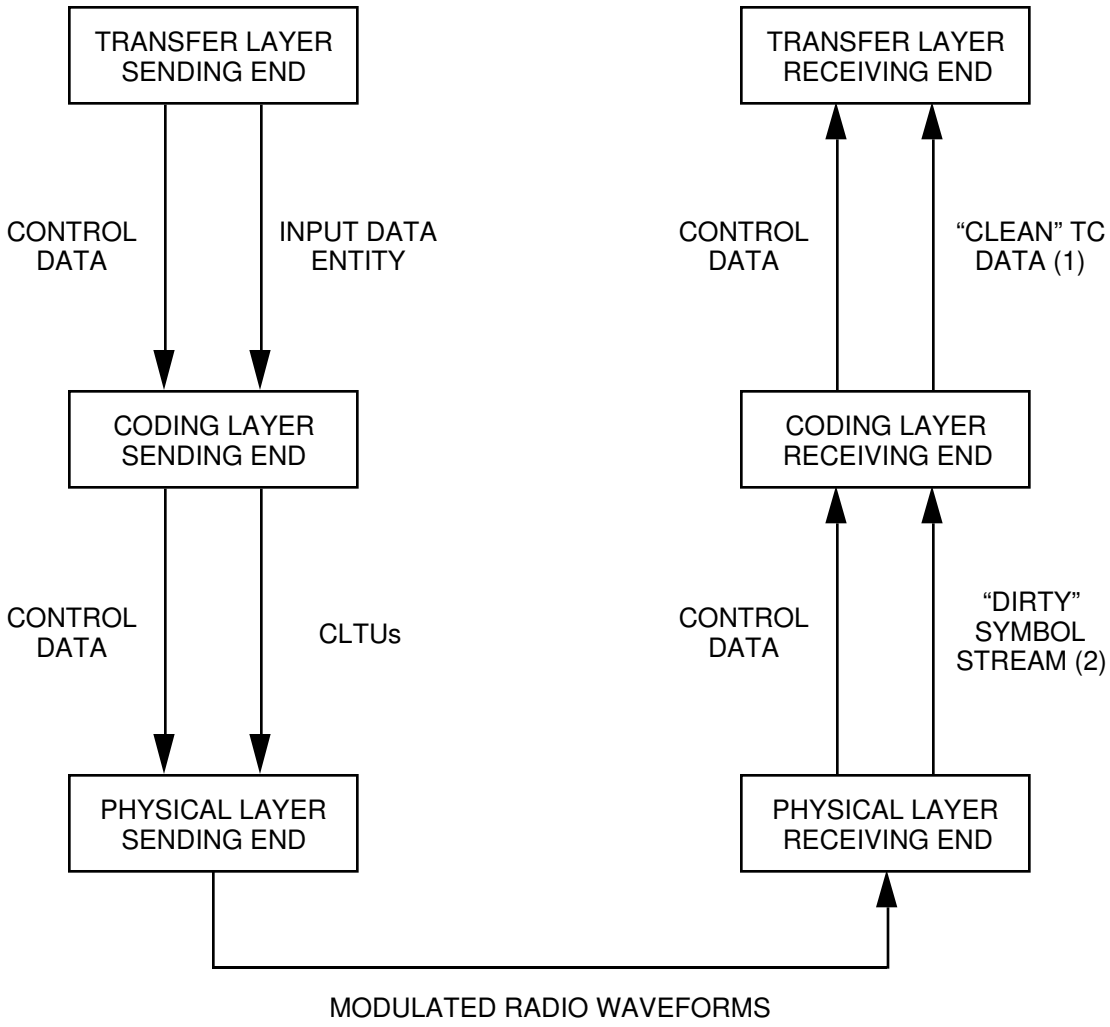
(THIS ANNEX **IS** PART OF THE RECOMMENDATION)

Purpose:

This Annex provides the detailed specification for the service provided by the Coding and Physical layers of the Telecommand System.

B-1 OVERVIEW OF THE LAYERS WITHIN THE TELECOMMAND CHANNEL SERVICE

The TC Channel Service consists of two layers: the Coding layer and the Physical layer. Each of the layers provides services to the layer above (e.g., the CCSDS Transfer layer, Reference [4]) at a "sending end" (located in the region of the user) and at a "receiving end" (located in space). A model of the activities within the Channel Service is presented in Figure B-1.



NOTES: (1) "CLEAN" = ERROR-FREE WITHIN THE PERFORMANCE CAPABILITY OF THE DECODER.

(2) "DIRTY" = SYMBOL STREAM WITH POSSIBLE ERRORS OR SOFT DECISIONS.

Figure B-1: TC Channel Service Model

Within a fully implemented CCSDS Telecommand system, operation of the Channel Service begins when the buffer of information bits corresponding to one or more complete TC Transfer Frames (plus their related operational control information) is delivered from the Transfer layer to the sending end of the Coding layer for radiation through the physical telecommand channel to the spacecraft. (See Figure B-2.)

The TC Transfer Frames are encoded by the Coding layer into short, fixed length TC Codeblocks which provide a noise immunity capability that is compatible with overall TC Frame rejection and undetected error requirements. A TC Transfer Frame is transmitted as a sequential set of TC Codeblocks, with the entire set of Codeblocks being encapsulated by the Coding layer within a "Command Link Transmission Unit" (CLTU) data structure: a CLTU may contain one or more encoded Transfer Frames. If there is a concern that the CLTU does not have adequate symbol transitions to maintain symbol synchronization, then the Input TC data may be randomized using the sequence specified by the BTG in 3.3.1. The CLTU provides the data interface mechanism for passing the TC Codeblocks between the Coding layer and the Physical layer.

To activate the telecommand channel in support of the Coding layer, the services of the sending end Physical layer are invoked. An RF carrier data path is first established, upon which various "Carrier Modulation Modes" (CMMs) may be established to support data transfer. By selecting an appropriate sequence of CMMs, a "Physical Layer Operations Procedure" (PLOP) is formed which activates and deactivates the link so that one or more CLTUs may be transmitted to the spacecraft.

Upon activation of the channel by the selected PLOP, modulated radio waveforms are radiated to the spacecraft. The receiving end of the Physical layer receives this waveform and detects a stream of channel symbols. Control information which indicates the readiness of the channel is passed to the layer above.

The spacecraft telecommand channel decoder within the receiving end of the Coding layer awaits this symbol stream containing an Acquisition sequence, a CLTU Start sequence, and the set of sequential TC Codeblocks which carry the encoded TC Transfer Frame information bits. The Acquisition sequence provides a preamble for symbol synchronization purposes. The CLTU Start sequence marks the start of the first TC Codeblock (which contains the leading bits of a TC Transfer Frame). TC Codeblock decoding begins after the CLTU Start sequence is detected: the TC Codeblocks are sequentially decoded to reconstruct the information (Input TC data) bits which, together with control data, are passed to the layer above which reassembles the TC Transfer Frame. If the Input TC data have been randomized, it is here that they are derandomized before being passed to the layer above. After transmission of all TC Codeblocks contained within the CLTU, a Tail sequence is transmitted which signals the end of the CLTU, and may be followed by an (optional) Idle sequence and more CLTUs. Finally, when the last CLTU has been transmitted (followed or not by an Idle sequence), the link is deactivated by the PLOP.

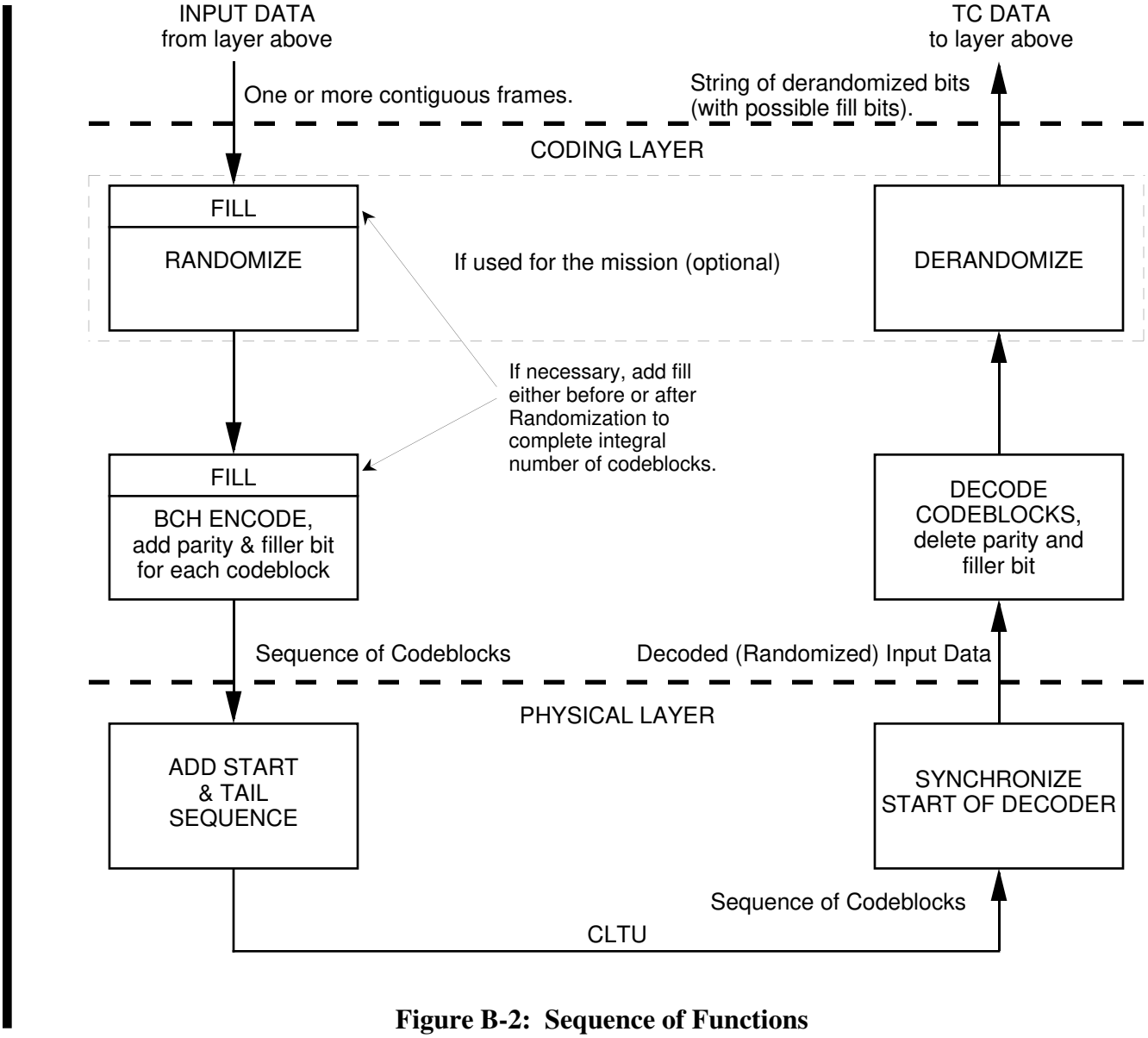


Figure B-2: Sequence of Functions

If the probability of erroneous data (as measured by the channel decoder) is sufficiently high, the spacecraft channel decoder will enter a "Search for Start Sequence" condition until reset by the next CLTU Start sequence or (optionally) by deactivation of the link by the PLOP. (See 4.3.3.2.) In the case where the channel decoder is in the "SEARCH" state, no further data bits will be transferred to the process which reassembles and accepts the TC Transfer Frame (the layer above) until the decoder returns to the DECODE state.

Reporting of individual decoded TC Codeblock acceptance by telemetry will NOT be performed, unless this is implemented on a mission-specific basis for the purposes of spacecraft diagnosis (e.g., via engineering telemetry data). Since no data will be transferred to the spacecraft TC Transfer Frame reassembler in case of TC Codeblock error, the operational reporting of acceptance is performed on a TC Transfer Frame basis via the Frame Acceptance and Reporting Mechanism (FARM) as described in Reference [4].

B-2 CODING LAYER SERVICE SPECIFICATION

The basic Quality of Service of the Coding layer is to provide a reliable, error-controlled data channel through which user telecommand data bits may be transferred.

B-2.1 Coding Layer: Sending End Service Specification

(1) INPUTS

From the layer above:

(a) "Input Data" from the Data Routing Service, to be included in a single CLTU.

(b) Control instructions.

From the layer below:

(c) Status of the physical telecommand channel (i.e., report from the Physical layer).

(2) OUTPUTS

To the layer above:

(a) Status of the physical telecommand channel.

To the layer below:

(b) Command Link Transmission Units (CLTUs).

(c) Control instructions.

(3) INTERNAL FUNCTIONS

(a) Conditions Input TC Data by randomizing it if used by a mission.

(b) Adds fill as necessary to complete the last codeblock of the CLTU (may be done before or after randomizing).

(c) Encodes the Input TC Data or conditioned Input TC Data into TC Codeblocks.

(d) Forms the TC Codeblocks into a CLTU by adding the Start and Tail Sequence.

B-2.2 Coding Layer: Receiving End Service Specification

(1) INPUTS

From the layer below:

(a) Synchronized detected "dirty" symbol stream (with possible errors if hard-decision decoding is used).

(b) Symbol clock (if required).

(c) Control information and status (e.g., physical telecommand channel active or inactive).

(2) OUTPUTS

To the layer above:

(a) "Clean" decoded and derandomized (if used) TC data from each codeblock which have passed the decoder quality check. May include fill from last codeblock of CLTU.

(b) Decode Status, indicating start, continuity, and end of valid TC data.

(c) Control information describing status of the physical telecommand channel (e.g., RF and bit synchronization).

(3) INTERNAL FUNCTIONS

(a) Permits the resolution of the sense of 1 and 0 in the incoming stream of dirty symbols, if not already provided by modulation techniques within the layer below.

(b) Detects the CLTU Start sequence which provides decoder synchronization for the first codeblock; subsequent codeblocks are automatically synchronized by being contiguous. Signals the start of valid TC data.

(c) Within the capability of the decoding algorithm, makes an estimate to determine if an error has probably occurred within the TC Codeblock.

(d) Within the capability of the decoding algorithm, optionally makes an estimate of the correct value of the information bits if errors are suspected to have occurred within the group of symbols that correspond to one TC Codeblock, and continues decoding.

(e) If a TC Codeblock is encountered which is sufficiently likely to contain a detected or uncorrectable error, declares a codeblock error, leaves the DECODE state, enters the SEARCH state and ceases to output further data. Signals the stop of valid TC data.

(f) If the Physical layer signals loss of modulation, leaves the DECODE state, enters the INACTIVE state, ceases to output further data, and signals the stop of valid TC data.

(g) If the mission is randomizing its TC Data, the "Valid TC Data" is derandomized before being passed to the layer above.

(h) Informs the layer above of status of the Channel Service.

B-3 PHYSICAL LAYER SERVICE SPECIFICATION

The basic Quality of Service of the Physical layer is to establish a physical path which connects the sending end of the Telecommand System to the receiving end in space.

B-3.1 Physical Layer: Sending End Service Specification

(1) INPUTS

From the layer above:

(a) Buffers of bits corresponding to a CLTU.

(b) Control information.

(2) OUTPUTS

To the layer above:

(a) Status of the physical telecommand channel.

To the receiving end of the layer:

(b) Modulated radio frequency waveforms, radiated as described in Reference [5].

(3) INTERNAL FUNCTIONS

(a) Establishes the physical radio frequency path to the spacecraft using CMM-1.

(b) Radiates a buffer of data bits serially according to the PLOP requested by the layer above.

B-3.2 Physical Layer: Receiving End Service Specification

(1) INPUTS

From the sending end of the layer:

(a) Modulated radio frequency waveforms which have been radiated by a transmitting station as described and specified in Reference [5].

(2) OUTPUTS

To the layer above:

(a) Synchronized detected "dirty" symbol stream.

(b) Symbol clock (if required).

(c) Channel Active (modulated carrier/subcarrier present); used by layer above to select between Inactive and Search states, to validate the Decode state and in some cases to initiate inter-layer control instructions.

(d) Status of the RF lock and bit synchronization processes.

(3) INTERNAL FUNCTIONS

(a) Receives and detects the modulated carrier/subcarrier.

(b) Performs demodulation and symbol synchronization.

(c) Determines the state of the physical telecommand channel (CHANNEL ACTIVE or CHANNEL INACTIVE).

(d) Performs symbol detection (hard decisions or quantized, soft decisions).

(e) Informs the layer above of status of the Physical layer.

B-4 CHANNEL SERVICE PERFORMANCE SPECIFICATION

The performance of the Channel Service is specified to meet the requirements defined for the layer above. In the case where the layer above is a TC Transfer Frame, the performance specification is given in Reference [4]. The performance provided by the Channel Service depends on the performance of the individual elements and procedures for a CLTU defined in Sections 3 and 4, and as shown in Figure 3-4.

Suggested processing alternatives for each of the elements of a CLTU are shown in Table B-1.

Table B-1: Processing of CLTU Elements

Element	Implementation	Procedure
Modulation Start	Acquisition Sequence	
CLTU "Start"	Start Sequence	A: 0 error in start seq. B: 0 or 1 error in start sequence
CLTU "Data Unit"	Codeblock	A: Triple error detection B: 1-bit error correction
CLTU "Finish"	Tail Sequence Idle Sequence	Codeblock rejection Codeblock rejection
Modulation End	Physical link	Stop modulation (post-CLTU): A: PLOP-1 B: PLOP-2

The overall performance for different combinations of the above strategies (plus variables such as CLTU length) is given in Reference [2]. Accordingly, the recommended Channel Service strategies are as shown in Table B-2.

Table B-2: Recommended Strategies

Strategy	CLTU Start	CLTU Data Unit	Modulation End
1	A	A	A or B
2	B	B	A or B