



BSI Standards Publication

Space engineering — Communication guidelines

National foreword

This Published Document is the UK implementation of CEN/TR 17603-50:2022.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Published by BSI Standards Limited 2022

ISBN 978 0 539 20511 4

ICS 49.140

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2022.

Amendments/corrigenda issued since publication

Date	Text affected
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English version

Space engineering - Communication guidelines

Ingénierie spatiale - Recommandations pour les
systèmes de communications

Raumfahrttechnik - Richtlinien zur Kommunikation

This Technical Report was approved by CEN on 20 April 2022. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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European Foreword

This document (CEN/TR 17603-50:2022) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-50.

This Technical report (CEN/TR 17603-50:2022) originates from ECSS-E-HB-50A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

Introduction

1.1 Purpose

This ECSS handbook is intended to help implementers and users of data handling systems who are adhering to the ECSS E-50 series of standards. The handbook provides an overview of the E-50 standards and related CCSDS Recommended Standards and describes how the individual standards may be used together to form a coherent set of communications protocols. It also evaluates issues which could not be discussed in the Standards documents themselves, and provides guidance on option selection and implementation choices.

1.2 Scope

This handbook provides guidance to the ECSS E-50 series of standards including related CCSDS Recommendations. The information provided is informative and intended to be used as best practice; it is not binding on implementers.

The information contained in this handbook is not part of the ECSS Standards. In the event of any conflict between the ECSS Standards and the material presented in this handbook, the ECSS Standards prevail.

1.3 Document structure

This document is divided into sections and annexes as follows:

- Section 1 (this section) provides intentional and administrative information.
- Section 2 provides the definition and abbreviations of the terms used in the present document.
- Section 3 gives a list of the E-50 series of standards and describes their relationship to CCSDS and other standards bodies. It also provides an overall architectural framework.
- Section 4 provides detailed information on each of the individual ECSS and CCSDS standards covered by the handbook.
- Section 5 addresses individual technical topics related to the ECSS E-50 standards.

- Section 6 provides guidance on selecting appropriate ECSS and CCSDS standards for coherent mission and infrastructure scenarios.
- Section 7 provides a summary of supporting components and products.
- Annex A to Annex F contain draft proforma of the Protocol Implementation Conformance Statement (PICS) for three of the E-50 standards.
- Annex G provides additional performance data for one of the telemetry channel coding options.

Terms, definitions and abbreviations

2.1 Terms and definitions from other documents

For the purpose of this document, the terms and definitions from ECSS-S-ST-00-01 and ECSS-E-ST-50 apply.

2.2 Terms specific to the present document

3.2.1 delimited

<data unit> with a known and finite length.

3.2.2 mission phase

period of a mission during which specified communications characteristics are fixed

NOTE The transition between two consecutive mission phases can cause an interruption of the communications services.

3.2.3 octet

group of eight bits

NOTE The numbering for octets within a data structure starts with 0.

3.2.4 physical channel

stream of bits transferred over a space link in a single direction

2.3 Conventions

2.3.1 Bit numbering and most significant bit

To identify each bit in an N-bit field, the first bit in the field to be transferred (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 an N-bit field is used to express a binary value (such as a counter), the most significant bit (MSB) is the first bit of the field, i.e. bit 0 (see Figure 2-1).

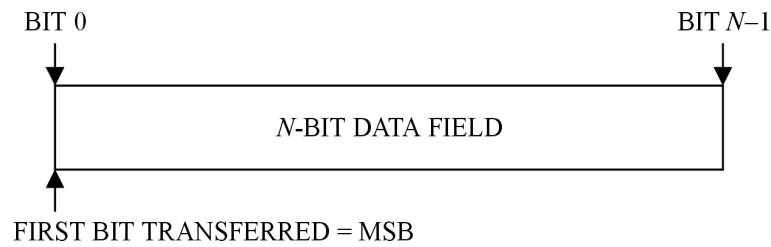


Figure 2-1: Bit numbering convention

2.4 Abbreviated terms

Abbreviation	Meaning
8PSK	phase shift keying of 8 states
AD	acceptance-check and data
AOS	advanced orbiting systems
API	application programming interface
APID	application process identifier
APP	<i>a posteriori</i> probability
ARP	address resolution protocol
ARQ	automatic repeat request
ASIC	application-specific integrated circuit
ASM	analogue signal monitor
ASM	attached sync marker
AWGN	additive white Gaussian noise
BC	bypass (of acceptance check) and control
BCH	Bose-Chaudhuri-Hocquenghem
BD	bypass (of acceptance check) and data
BDM	bi-level discrete monitor
BER	bit error rate
BPSK	binary phase shift keying
BSD	bi-directional serial digital
BSM	bi-level switch monitor
CADU	channel access data unit
CAN	controller area network
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS file delivery protocol
CLCW	communications link control word
CLTU	communications link transmission unit
COP	communications operation procedure

Abbreviation	Meaning
CPDU	command pulse distribution unit
CRC	cyclic redundancy code
dB	decibel
DHCP	dynamic host configuration protocol
DHS	data handling system
DML	data management library
DNS	domain name service
DRD	document requirements definition
DTN	delay tolerant networking
DWT	discrete wavelet transform
EDAC	error detection and correction
EMC	electromagnetic compatibility
EOF	end of file
ESA	European Space Agency
ESOC	European Space Operations Centre
FARM	frame acceptance and reporting mechanism
FDU	frame data unit
FER	frame error rate
FOP	frame operation procedure
FPGA	field-programmable gate array
FQPSK	Feher quadrature phase shift keying
GMSK	Gaussian minimum shift keying
GSTVi	ground systems test and validation infrastructure
HPC	high power command
HSRP	hot standby redundancy protocol
ID	identifier
IDC	image data compression
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISD	input serial digital
ISO	International Organization for Standardization
ISS	international space station
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency

Abbreviation	Meaning
JPEG	Joint Photographic Experts Group
LOS	loss of signal, or, line of sight
LPC	low power command
LVDS	low voltage data signalling
MAP	multiplexer access point
MER	Mars exploration rover
MCID	master channel identifier
MIL	military standard
MPE	multiprotocol encapsulation
MSB	most significant bit
NASA	National Aeronautics and Space Administration
OCF	operational control field
OID	only idle data
OQPSK	offset quadrature phase shift keying
OSD	output serial digital
OSI	open systems interconnection
OSPF	open shortest path first
PAC	packet assembly controller
PCM	pulse code modulation
PDU	protocol data unit
PEP	performance enhancing proxy
PICS	protocol implementation conformance statement
PLOP	physical layer operation procedure
PRL	PICS requirements list
PSNR	peak signal-to-noise ratio
PSS	procedures, specifications and standards
PUS	packet utilization standard
PVN	packet version number
QPSK	quadrature phase shift keying
RAF	return all frames
RCF	return channel frames
RIP	routing information protocol
RMAP	remote memory access protocol
RF	radio frequency
RFC	request for comments
R-S	Reed-Solomon

Abbreviation	Meaning
RTEMS	real-time executive for multiprocessor systems
SAR	synthetic aperture radar
SCID	spacecraft identifier <i>or</i> spacecraft identification
SCOS	spacecraft operating system
SCPS	space communications protocol specification
SEC	single error correction
SFO	store-and-forward overlay
SLE	space link extension
SOIS	spacecraft onboard interface services
SRD	system requirements document
SRRC	square root raised cosine
TC	telecommand
TCM	trellis-coded modulation
TCP	transmission control protocol
TDM	time division multiplexing
TED	triple error detection
TFVN	transfer frame version number
TM	telemetry
TP	transport protocol
TRL	technology readiness level
TSM	temperature sensors monitor
TT&C	telemetry, tracking and command
UDP	user datagram protocol
VCID	virtual channel identifier
VRRP	virtual router redundancy protocol

The E-50 series of standards

3.1 Background

3.1.1 Scope of the ECSS E-50 series

The E-50 series of standards are all related to the end-to-end communications between flight and ground infrastructures. The communications links covered by the E-50 series are the space-to-ground and space-to-space links used during spacecraft operations, and the communications links to the spacecraft used during the assembly, integration and test, and operational phases.

Spacecraft end-to-end communication systems comprise components in three distinct domains: the ground network, the space link and the space network. The E-50 series covers the components of the space link and space network in detail. However, they only cover those aspects of the ground network that are necessary for the provision of the end-to-end communication services. Other aspects of the ground network are covered by the ECSS E-70 series of standards.

Although some of the E-50 standards have been specifically developed under the ECSS authority, many are derived from other standardisation bodies such as the Consultative Committee for Space Data Systems (CCSDS) and the SpaceWire working group.

3.1.2 CCSDS standards

CCSDS was formed in 1982 by the major space agencies of the world to provide a forum for discussion of common problems in the development and operation of space data systems. It is currently composed of ten member agencies, more than 20 observer agencies, and over 100 industrial associates.

CCSDS produces Recommended Standards targeted at cross-support whereby the infrastructure owned by one agency may be utilised by another, for example for telemetry reception. Many CCSDS Recommended Standards are published as standards by ISO (International Organization for Standardization).

CCSDS Recommended Standards (Blue Books) define specific interfaces, technical capabilities or protocols, or provide prescriptive definitions of interfaces, protocols, or other controlling standards such as encoding approaches. The reference number for a Blue Book includes the letter B: for example, CCSDS 131.0-B-1. The last number within the reference number is the issue number.

The publication by CCSDS of a Recommended Standard is not considered binding on any CCSDS member agency. A CCSDS member can choose to endorse or adopt a Recommended Standard or to establish a related standard that is in accord with it. The CCSDS Recommended Standards are referred to in this handbook as “standards” but that should not be taken to imply any adoption by ECSS. Recommended Standards carry on their cover page the words “Recommendation for Space Data System Standards” and are frequently referred to as “CCSDS recommendations” or simply “recommendations”.

Informational Reports (Green Books) form another important category of CCSDS publications. They provide a very broad range of general and background information. They are often published in support of a standard and include high-level overviews, performance data, implementation and testing experience and tutorials. They offer useful informal information, some of which has been used in the preparation of this handbook. The reference number for a Green Book includes the letter G: for example, CCSDS 130.1-G-1.

CCSDS also publishes documents in other categories:

- CCSDS Recommended Practices (Magenta Books) are the consensus results of CCSDS community deliberations and provide a way to capture “best” or “state of the art” approaches for applying or using standards.
- CCSDS Experimental Specifications (Orange Books) are published as part of a research or development effort based on prospective requirements, and as such they are not considered as standards documents. An Experimental Specification is intended to demonstrate technical feasibility in anticipation of a possible future requirement.
- The CCSDS Record (Yellow Books) category includes CCSDS administrative documents such as charters and procedures.
- The CCSDS Historical (Silver Books) designation is applied to approved CCSDS documents that have been superseded by more recent versions or are otherwise considered obsolete. Most of the documents in this category were originally Blue Books but it also includes documents from other categories. When a document is given Silver status, its reference number is extended by appending “-S” at the end.

3.1.3 Relationship to PSS standards

In the past, Recommended Standards developed by CCSDS have generally not been directly adopted by ESA. Rather, minor modifications have been introduced to suit the specific needs of European missions and the modified Recommended Standard has been released under a separate cover. Previously these modified recommendations were released in the ESA Procedures, Specifications and Standards (PSS) series of documents.

The PSS documents related to space communication were typically derived from CCSDS recommendations and included or excluded specific options depending on European preferences.

All PSS documents have now been withdrawn in favour of ECSS standards or CCSDS Recommended Standards.

3.1.4 Relationship of ECSS standards to CCSDS standards

The policy of modifying CCSDS Recommended Standards to suit the specific needs of European missions and publishing them as ECSS standards has continued within ECSS for the core telemetry and telecommand standards. The ECSS standards in this area are generally aligned with the equivalent CCSDS approach with two minor differences:

- The ECSS series of standards includes the *Telemetry and telecommand packet utilization standard*, ECSS-E-ST-70-41, as an application layer protocol. This standard has been developed independently by ESA and ECSS and has not been adopted by CCSDS.
- The ECSS series combines the telecommand protocols into a single standards document, ECSS-E-ST-50-04, whereas CCSDS uses three separate documents. This difference is for historical reasons and the protocols are intended to be equivalent. Some minor differences are described in the section 4.7, about ECSS-E-ST-50-04.

This practice of modifying CCSDS Recommended Standards is now being phased out and in the future they will be directly reused by ECSS thorough adoption notices. The adoption notices may include minor modifications such as the removal of options. It should be noted that not all CCSDS Recommended Standards have been adopted by ECSS.

3.2 Standards covered in this handbook

Table 3-1 lists the ECSS E-50 standards covered by this handbook. Section 4 describes each E-50 standard in some detail and discusses optional features and recommended practices. Where applicable, the differences from equivalent CCSDS Recommended Standards are identified and discussed.

Note that Table 3-1 lists the standards in the numerical order of their reference numbers. This does not reflect the order used within Section 4, so the table shows the appropriate section.

Table 3-2 lists the other standards discussed in Section 4. Most of these are CCSDS Recommended Standards, which can be combined with the ECSS E-50 standards to cover end-to-end communications across the space link and space network.

Table 3-2 also includes ECSS-E-ST-70-41, the telemetry and telecommand packet utilization standard (PUS), which belongs to the ECSS E-70 ground systems and operations series of standards. It is included in Section 4 because it defines the use of fields in CCSDS Space Packets. Other features of the PUS, such as its services, are not discussed in any detail.

Other standards for the ground network are not covered in this handbook, though they are occasionally mentioned for compatibility reasons. For example, these include the Space Link Extension (SLE) services. For a useful introduction to the SLE services, see the informational report CCSDS 910.0-G.

Figure 3-1 shows the standards from Table 3-1 and Table 3-2 and their relationship to the layers of the OSI reference model: these relationships are

discussed in the next section. Within this handbook, the standards from Table 3-1 and Table 3-2 are referred to collectively as “E-50 standards”, although this name strictly applies only those in Table 3-1. However, they all come within the scope described in 3.1.1 and can be used together to achieve end-to-end communications between flight and ground infrastructures.

Table 3-1: ECSS E-ST-50 standards covered in this handbook

Reference	Title	Issue / date		Section
E-ST-50	Space engineering - Communications	C	31 July 2008	4.2
E-ST-50-01	Space engineering - Space data links - Telemetry synchronization and channel coding	C	31 July 2008	4.5
E-ST-50-02	Space engineering - Ranging and Doppler tracking	C	31 July 2008	4.3
E-ST-50-03	Space engineering - Space data links - Telemetry transfer frame protocol	C	31 July 2008	4.6
E-ST-50-04	Space engineering - Space data links - Telecommand protocols, synchronization and channel coding	C	31 July 2008	4.7
E-ST-50-05	Space engineering - Radio frequency and modulation	C	31 July 2008	4.4
E-ST-50-11	Space engineering - SpaceWire protocols		To be published	4.18
E-ST-50-12	Space engineering - SpaceWire - Links, nodes, routers and networks	C	31 July 2008	4.18
E-ST-50-13	Space engineering - MIL 1553 Standard extension	C	15 Nov 2008	4.19
E-ST-50-14	Space engineering - Spacecraft discrete interfaces	C	31 July 2008	4.20

Table 3-2: Other standards covered in this handbook

Reference	Title	Issue / date		Section
CCSDS 121.0-B	Lossless Data Compression	1	May 1997	4.16.2
CCSDS 122.0-B	Image Data Compression	1	Nov 2005	4.16.3
CCSDS 133.0-B	Space Packet Protocol	1	Sep 2003	4.10.2
CCSDS 133.1-B	Encapsulation Service	1	Jun 2006	4.10.3
CCSDS 135.0-B	Space Link Identifiers	3	Oct 2006	4.14
CCSDS 211.0-B	Proximity-1 Space Link Protocol - Data Link Layer	4	Jul 2006	4.9
CCSDS 211.1-B	Proximity-1 Space Link Protocol - Physical Layer	3	Mar 2006	4.9
CCSDS 211.2-B	Proximity-1 Space Link Protocol - Coding and Synchronization Sublayer	1	Apr 2003	4.9
CCSDS 301.0-B	Time Code Formats	3	Jan 2002	4.17
CCSDS 320.0-B	CCSDS Global Spacecraft Identification Field: Code Assignment Control Procedures	5	Sep 2007	4.15
CCSDS 727.0-B	CCSDS File Delivery Protocol (CFDP)	4	Jan 2007	4.13
CCSDS 732.0-B	AOS Space Data Link Protocol	2	Jul 2006	4.8
ECSS-E-ST-70-41	Ground systems and operations - Telemetry and telecommand packet utilization	A	30 Jan 2003	4.12
RFC 791	Internet Protocol, Protocol Specification [1]		Sep 1981	4.11.1
RFC 1883	Internet Protocol, Version 6 (IPv6) Specification		Dec 1995	4.11.3
[1] now known as IPv4				

Section 3.3.2 discusses the Space Data Link Protocols in the Data Link Protocol Sublayer and the related Synchronization and Channel Coding Sublayer. Table 3-3 provides an overview of the associated ECSS and CCSDS standards documents.

Table 3-3: Standards for the TM, TC and AOS Space Data Link Protocols

Space Data Link Protocol	Standards documents		Synchronization and Channel Coding	Standards documents	
	ECSS	CCSDS		ECSS	CCSDS
TM	ECSS-E-ST-50-03	CCSDS 132.0-B	TM	ECSS-E-ST-50-01	CCSDS 131.0-B
AOS	-	CCSDS 732.0-B			
TC	ECSS-E-ST-50-04	CCSDS 232.0-B	TC	ECSS-E-ST-50-04	CCSDS 231.0-B

3.3 ECSS E-50 Protocols

Figure 3-1 shows the ECSS E-50 standards as well as standards from CCSDS and IETF which address areas within the ECSS E-50 purview. It should be noted that not all standards may be applicable to a single project and some standards make reference to other standards.

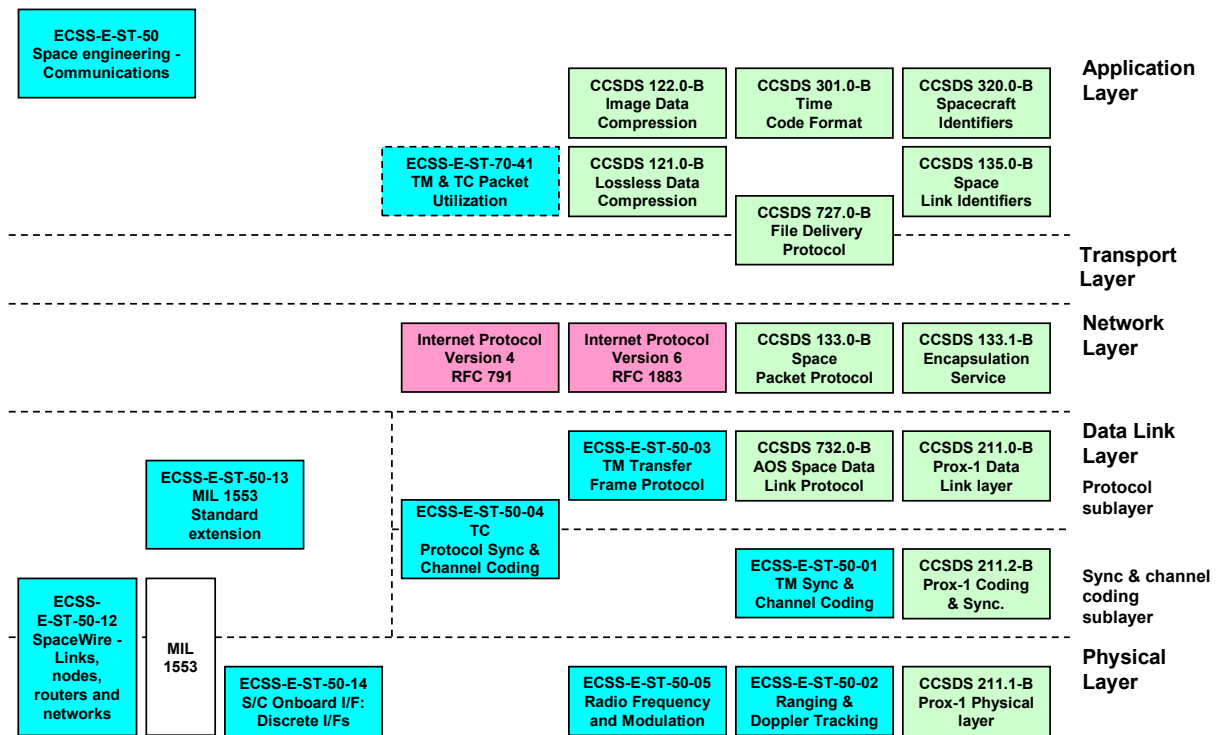
A communications protocol is usually associated with one of the seven layers of the OSI (Open Systems Interconnection) reference model defined in ISO/IEC 7498-1. Although some space link protocols do not fit well with the OSI seven-layer model, ECSS E-50 uses this model for categorizing the space link protocols. The space link protocols are defined for the following five layers of the OSI model:

- Physical Layer
- Data Link Layer
- Network Layer
- Transport Layer
- Application Layer.

As in most terrestrial networks, protocols of the Session and Presentation Layers of the OSI model are rarely or never used over space links. Figure 3-1 shows the space link protocols categorized into the five layers listed above. Figure 3-2 shows some options for combining the protocols.

In Figure 3-1, there are two protocols that do not correspond to a single layer. The CCSDS File Delivery Protocol (CFDP) has the functionality of the Transport and Application Layers, and the Proximity-1 Space Link Protocol has the functionality of the Data Link and Physical Layers.

Although CCSDS and ECSS do not formally define application programming interfaces (APIs) for the space link protocols, most CCSDS standards provide service definitions in the form of primitives following the conventions established by ISO. A primitive is an abstract representation of an API that does not depend on any implementation technology and is suitable for use as the baseline for an API.



V1 - 29/11/2006

Figure 3-1: ECSS E-50 standards and associated layers

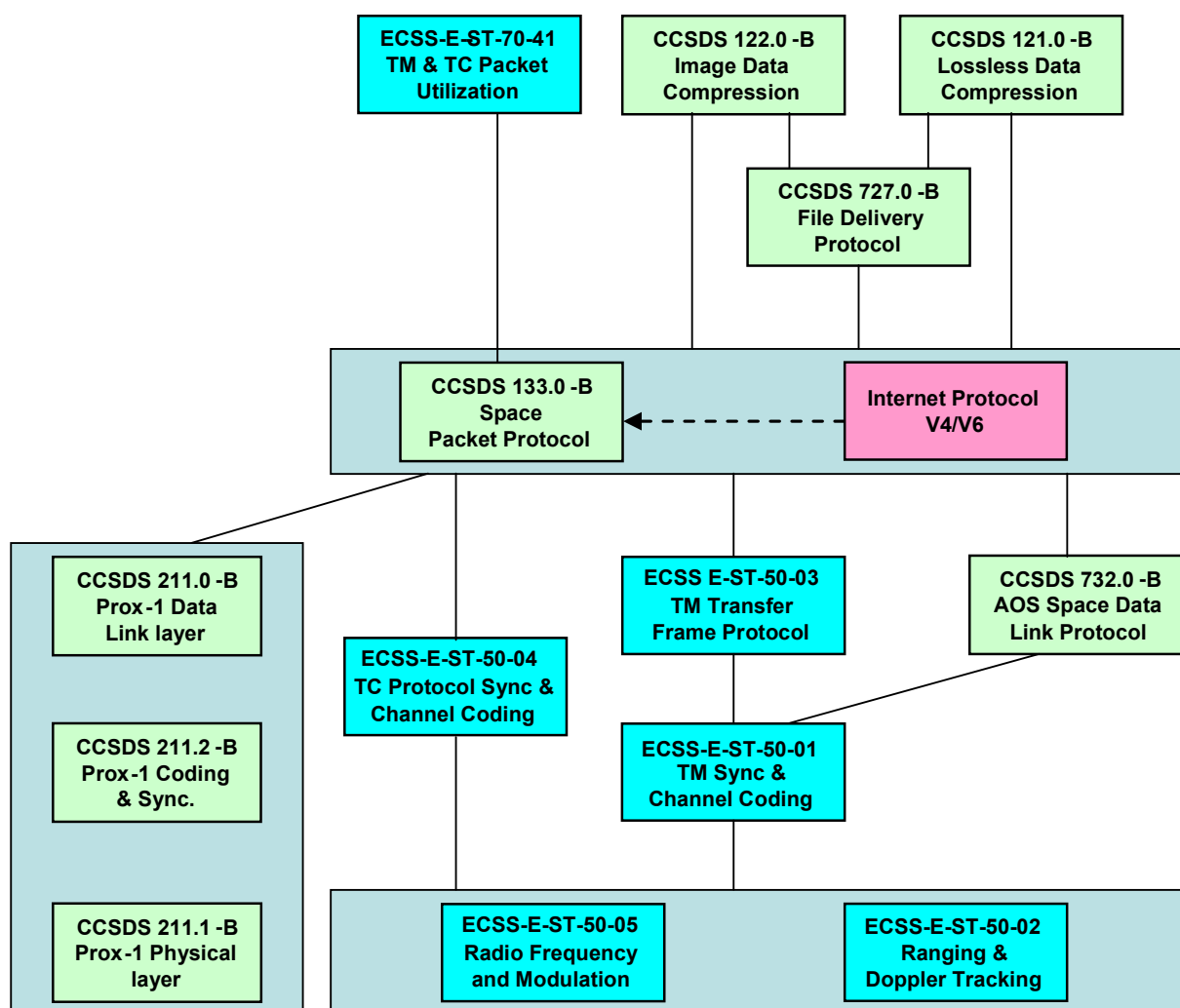


Figure 3-2: Some options for combining the protocols

3.3.1 Physical Layer

ECSS has the standard ECSS-E-ST-50-05, *Radio frequency and modulation*, for the Physical Layer of the space links between spacecraft and ground stations. In addition, CCSDS has a Recommended Standard, CCSDS 211.1-B, for the Physical Layer of the Proximity-1 Space Link Protocol.

3.3.2 Data Link Layer

The Data Link Layer has two sublayers: the Data Link Protocol Sublayer and the Synchronization and Channel Coding Sublayer.

The Data Link Protocol Sublayer specifies methods of transferring data units provided by the higher layer over a space link using data units known as transfer frames. There are three Space Data Link Protocols for the Data Link Protocol Sublayer:

- TM Space Data Link Protocol
- TC Space Data Link Protocol

- AOS Space Data Link Protocol

Each of these protocols provides the capability to send data over a single space link.

The Synchronization and Channel Coding Sublayer specifies methods of synchronization and channel coding for transferring Transfer Frames over a space link. There are two standards for the Synchronization and Channel Coding Sublayer of the Data Link Layer:

- TM Synchronization and Channel Coding
- TC Synchronization and Channel Coding

TM Synchronization and Channel Coding is used with the TM or AOS Space Data Link Protocol, and TC Synchronization and Channel Coding is used with the TC Space Data Link protocol.

In addition, there is the Proximity-1 Space Link Protocol for the Data Link Layer. It also provides a method for transferring data units over a space link using Transfer Frames, but has a more complex subdivision of the Data Link Layer into sublayers. Proximity-1 has its own standard for its Synchronization and Channel Coding Sublayer.

The TM, TC and AOS Space Data Link Protocols and the transfer frame protocol of the Proximity-1 Space Link protocol are called the Space Data Link Protocols in this document.

3.3.3 Network Layer

Space link protocols of the Network Layer provide the function of routing higher-layer data through the entire data system that includes both onboard and ground subnetworks. Three protocols of the Network Layer are discussed in this handbook:

- Space Packet Protocol
- Internet Protocol version 4 (IPv4)
- Internet Protocol version 6 (IPv6)

The packets of a Network Layer protocol are transferred over a space link with the Space Data Link Protocols of the Data Link Layer. The Space Packets of the Space Packet Protocol and the datagrams of IPv4 can be directly transferred as packets by the Space Data Link Protocols. The datagrams of IPv6 must first be encapsulated, for example into a Space Packet.

In some cases, Space Packets are generated and consumed by application processes, and in these cases this protocol is used both as a Network Layer protocol and as an Application Layer protocol.

3.3.4 Transport Layer

Although the transport layer is identified within the architecture, the CCSDS File Delivery Protocol (CFDP) is currently the only protocol defined by ECSS for use over the space link. Other protocols such as UDP may be applicable but generally the unidirectional nature of the TM/TC links coupled with inherent

transmission delays preclude the use of conventional transport layer protocols such as TCP/IP.

Protocol Data Units (PDUs) of a Transport Layer protocol are usually transferred using a protocol of the Network Layer over a space link.

3.3.5 Application Layer

Space link protocols of the Application Layer provide users with end-to-end application services such as file transfer and data compression. Three protocols of the Application Layer are discussed in this handbook:

- Lossless Data Compression
- Image Data Compression
- Telemetry and telecommand packet utilization

The lossless and lossy data compression standards may be used to reduce the volume of data transmitted over the space link. The telemetry and telecommand packet utilization standard defines a set of Application Layer services for spacecraft monitoring and control.

The CCSDS File Delivery Protocol (CFDP) provides the functionality of the Application Layer (i.e. functions for file management), but it also provides functions of the Transport Layer.

Other Application Layer protocols are outside the scope of this handbook. A project can choose to use application-specific protocols to fulfil their mission requirements in the Application Layer over CCSDS space link protocols.

3.4 End to End Aspects

Having listed the various E-50 standards we now examine how these can be assembled as an end to end communication system between space and ground, and space to space. It is not possible to cover all feasible system configurations, either in the elements involved or the protocols utilised but the configurations presented here are generally applicable to any mission.

Figure 3-3 identifies the four elements typically involved in end-to-end communication:

- The onboard end system such as a payload. The onboard end system can be any onboard application, including command and control.
- The onboard relay system represented by the onboard data handling system which includes the TT&C elements and the onboard data buses (subnets).
- The ground relay system composed of the ground station with its telecommand transmission and telemetry acquisition elements, along with the networks used to communicate with the control centre.
- The ground end system represented by the control centre. The ground end system can also be a user application which receives, for example, science telemetry data.

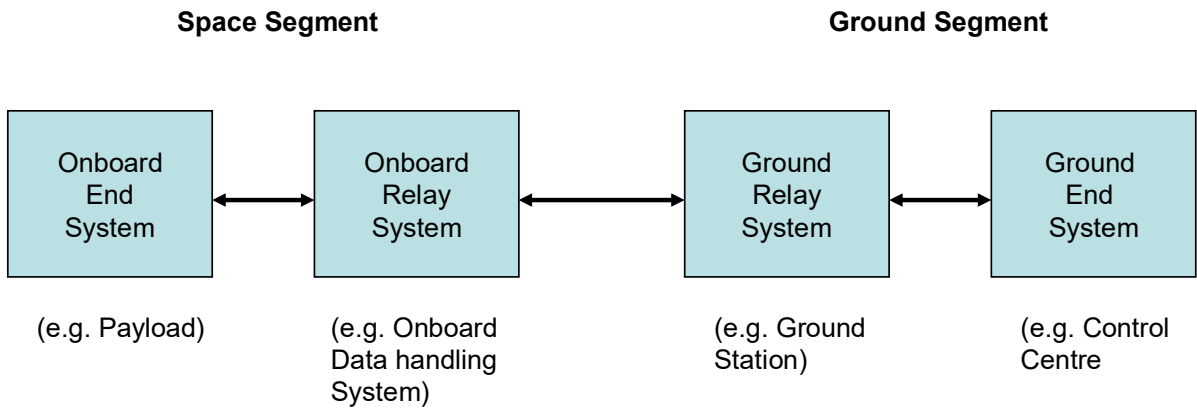


Figure 3-3: Simplified end-to-end communication system

Figure 3-4 takes the same end-to-end communication system and locates the various E-50 standards. The following should be noted:

- The use of onboard subnetwork protocols (typically MIL 1553, CAN and SpaceWire)
- The use of the CCSDS Space Link Extension (SLE) protocols for ground communication.
- The use of the Space Packet Protocol as the end-to-end routing protocol
- The use of CFDP as an example Application Layer protocol

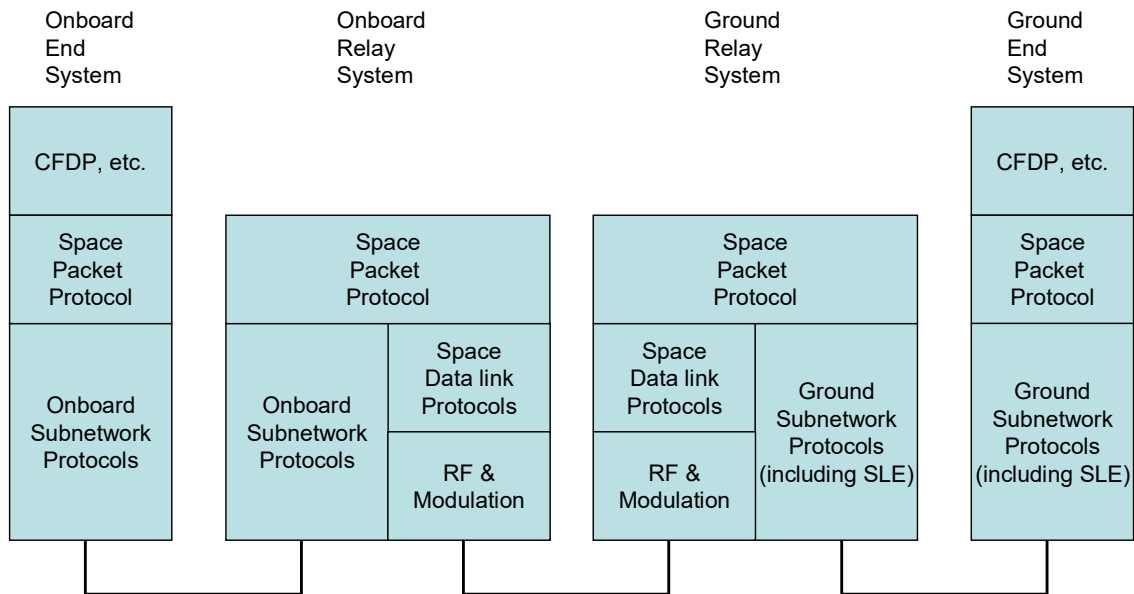


Figure 3-4: End-to-end system with example protocol stacks

Figure 3-5 shows a scenario involving store and forward capability for use in architectures where continuous end-to-end communications is not possible. This is typically the case in planetary exploration missions using orbiting relays. In such a case CFDP provides an end-to-end file transfer capability,

automatically taking custody of data in the orbiter and storing it until an opportunity arises for onward communication.

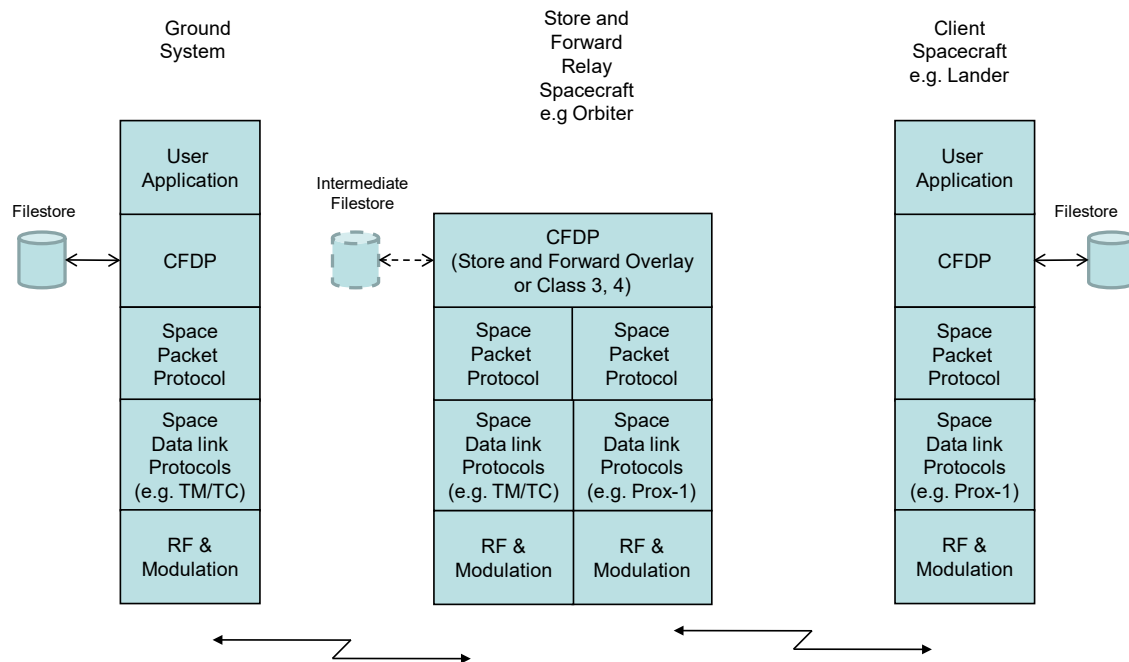


Figure 3-5: Store and forward system with example protocol stacks

Standards overview

4.1 Introduction

This section provides an overview of the standards that are used within the E-50 stack of protocols. See Table 3-1 and Table 3-2 for a list of the standards covered in this section.

For each standard, this section provides information on:

- the purpose of the standard and its intended usage
- the capabilities specified in the standard
- any options within the standard
- recommended practices, and pitfalls to avoid, when applying the standard.

4.2 E-ST-50: Communications

4.2.1 Purpose and usage

The purpose of the ECSS-E-ST-50 standard is to guide the development of the end-to-end data communications system for spacecraft. It defines the activities to be performed as part of the space communication system engineering process, in accordance with the ECSS-E-ST-10 *System engineering* standard. In this respect it is a process oriented standard, which is concerned with the way in which the space communication system is achieved.

The standard also includes specific requirements on space communication systems in respect of functionality and performance.

4.2.2 Description

ECSS-E-ST-50 Clause 4 contains a description of space communication systems and architecture and the communications engineering process. It also discusses spacecraft control considerations.

Clause 5 contains the requirements. Clause 5.2 has requirements for the space communication system engineering process. It specifies activities and the formal project documents to be produced. The remaining clauses specify

requirements on the function and performance of the space communications system:

- clause 5.3: space communication system
- clause 5.4: telecommanding
- clause 5.5: telemetry
- clause 5.6: space link
- clause 5.7: space network
- clause 5.8: ground network

ECSS-E-ST-50 also includes Annexes containing the document requirements definitions (DRDs), which specify the requirements for the contents of the project documents specified in clause 5.2

4.2.3 Options

There are no options associated with ECSS-E-ST-50.

4.2.4 Recommended practice

ECSS-E-ST-50 should be applied to all missions.

4.3 E-ST-50-02: Ranging and Doppler tracking

4.3.1 Purpose and usage

The Ranging and Doppler Tracking standard defines methods of measuring range and range rate of a spacecraft by an Earth station.

Its stated purpose is to:

“Ensure compatibility between space agencies' spacecraft transponders and the ranging and Doppler tracking facilities of the Earth stations for the Space Operation, Space Research and Earth Exploration Satellite services.

Ensure, as far as possible, compatibility between space agencies' spacecraft transponders and other networks from which they request support.

Ensure an adequate level of ranging and Doppler tracking accuracy for missions conforming to this standard.

Facilitate the early design of flight hardware and ensure that the resulting interfaces and system performances are compatible with given ranging and Doppler tracking configurations and specifications.”

The standard applies to projects with unprocessed ranging accuracies of 2,5 ns to 30 ns and Doppler tracking accuracies of 0,1 mm/s to 1 mm/s. Projects with tracking accuracies less stringent than these may use the CCSDS 401.0-B recommendations.

The standard defines the requirements concerning spacecraft transponder and Earth station equipment for the purposes of ranging and Doppler tracking. It also provides criteria for determining the extent to which the accuracy of the measurements is influenced by equipment effects.

4.3.2 Description

The ranging and Doppler tracking system is a spacecraft tracking system capable of providing information on the range and range rate between a spacecraft and an Earth station. It uses an active transponder on-board the spacecraft for the retransmission to the ground of an Earth-to-Space link signal: ranging signal generation and measurement are performed in the Earth station. As a baseline, it is assumed that the spacecraft transponder is used not only for ranging purposes, but also for receiving telecommand signals from Earth and for transmitting telemetry signals to Earth modulated on the same RF carriers. When a transponder is used exclusively for ranging, the requirements in the standard concerning sharing with telecommand and telemetry have no relevance.

Figure 4-1 shows a functional block diagram of the ranging and Doppler tracking process as addressed in the standard.

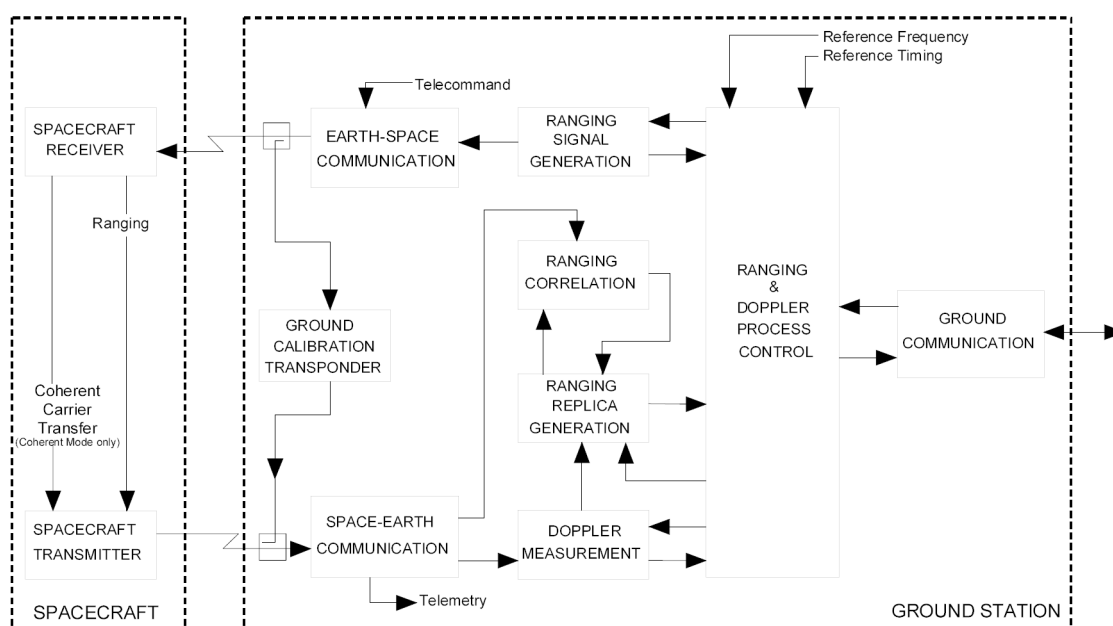


Figure 4-1: Ranging and Doppler tracking - Functional block diagram

The standard describes the functional and performance requirements for:

- the Earth-to-Space link function, employing ground communication, process control, ranging signal generation and Earth-to-Space communication;
- the transponder function, either spacecraft transponder or ground-calibration transponder depending on the application;
- the Space-to-Earth link function, employing Space-to-Earth communication, Doppler measurement, ranging replica generation, ranging correlation, process control and ground communication;
- the link-control function, resident partly in the Space-to-Earth and Earth-to-Space communication and partly in the process control;
- the data-acquisition function, concerned with collection, measurement, processing and transfer of data to the control centre, employing the process control and the ground communication functions.

The standard also describes the process for compatibility testing of implementations. An Annex discusses compatibility with CCSDS-compliant ground station networks.

4.3.3 Options

Table 4-1 presents the options that can be used for ranging and Doppler tracking.

Other ranging and range rate measurement techniques exist such as Differential One-way Ranging and regenerative ranging. However, these techniques are not included in the ECSS-E-ST-50-05 standard. CCSDS are working on recommendations which address these techniques for spacecraft orbital determination.

Table 4-1: Options for Ranging and Doppler tracking

Option	Comment
Tone Frequency	ECSS-E-ST-50-02, "Spectral sharing - Ranging tone selection"
Ranging Code Length	Mission dependent
Simultaneous Ranging and Telecommanding	ECSS-E-ST-50-02, "Modulation – Telecommand and ranging"
RF Frequency and turn-around ratios	ECSS-E-ST-50-05, Clause on "Frequency bands allocated to the Space Radiocommunications services" and Table of "Turnaround frequency ratios for coherent transponder operation"
Transponder Coherency	For deep space operations and for those missions using two-way Doppler measurements
Modulation Index	ECSS-E-ST-50-02, "Spacecraft transponder – Modulation index"

4.3.4 Recommended practice

Ranging tone selection

The nominal ranging tone frequency is selected within the range 100 kHz – 1,5 MHz and in a region of the transponder bandwidth where the group delay is stable within the specified accuracy. The ranging tone frequency selected for a particular mission is usually dependent on whether it is a Near Earth or Deep Space mission. The ranging tone frequency is usually placed at a higher frequency for Deep Space missions than for Near Earth missions due to the ranging accuracy required.

In order to minimise interference between the ranging tone and the telecommand or telemetry signal, careful consideration is required when selecting the subcarriers and tone frequencies as outlined in ECSS-E-ST-50-02, clause on "Spectral sharing – Ranging tone selection – Selection of the frequency: Interference between ranging and telemetry".

4.4 E-ST-50-05: Radio frequency and modulation

4.4.1 Purpose and usage

The ECSS-E-ST-50-05 standard defines the radio communication techniques used for the transfer of information between spacecraft and Earth stations in both directions, and for the tracking systems used for orbit determination. It should be noted that the standard does not apply to:

- other space telecommunication services (i.e. waveforms used by communications satellite payloads);
- spacecraft supported by data relay satellites.

The standard is applicable to all spacecraft supported by Earth stations and to all controlled Earth stations operating in the Space Operation, Space Research and Earth Exploration Satellite services as defined in the International Telecommunication Union (ITU) Radio Regulations. Under the term Earth Exploration Satellite service, Meteorological Satellite services are also included.

The purpose of the standard is to ensure:

- Compatibility of frequency usage and modulation schemes between space agencies' spacecraft and Earth stations for the Space Operation, Space Research and Earth Exploration Satellite services.
- As far as possible, compatibility between the spacecraft and other networks with which they can work.
- Standardization of frequency usage and modulation schemes within the space projects.
- Conformity of spacecraft and Earth station parameters to international radio regulatory provisions (Radio Regulations of the ITU) and with national regulatory provisions (e.g. national frequency plans).
- That the parameters of spacecraft and Earth stations are properly chosen and listed in advance of their use, thus permitting coordination with other interested parties.
- That, within the above limitations, the frequency usage and modulation schemes are optimized.

4.4.2 Description

The standard lists the frequency bands available for Space Operation, Space Research and Earth Exploration Satellite services, discusses specific conditions for the use of certain frequency bands and outlines frequency assignment procedures.

Requirements and constraints are given on transmitted signals concerning, for example, spectral occupation, RF power levels and protection of other radio services. These requirements and constraints ensure that the transmitted signals

do not encroach on other space or non-space communications activities. The standard also defines the permissible modulation methods and parameters.

Annexes discuss, among others:

- Cross support from other networks;
- Protection of the Ariane-5 RF system from interference caused by the Ariane 5 payload spacecraft;
- Specification of the major technical requirements that are relevant for the interface between spacecraft and Earth stations with particular attention to the contents of interface control documentation;
- Conditions where the standard may be deviated from because of mission-specific requirements;
- Differences from CCSDS 401.0-B.

4.4.3 Differences from CCSDS 401.0-B

4.4.3.1 Introduction

This section discusses the differences between ECSS-E-ST-50-05 and the equivalent CCSDS Recommended Standard, CCSDS 401.0-B.

4.4.3.2 Difference 1

4.4.3.2.1 Description

The CCSDS recommendation includes FQPSK-B (Feher QPSK version B), GMSK and baseband filtered/shaped OQPSK modulations. ECSS-E-ST-50-05 only includes GMSK and filtered OQPSK. Furthermore, filtered OQPSK is restricted in ECSS-E-ST-50-05 to specific types of filter with specified roll-off factor whereas the CCSDS recommendation allows an infinite number of filters. It is important to note, however, that these modulations are all of the quaternary offset type and therefore interoperable.

4.4.3.2.2 Rationale

ECSS-E-ST-50-05 has restricted the selection, to avoid including unnecessary modulation schemes with a low likelihood of ever being used. Also, a reduction of the options in the CCSDS recommendation is anticipated: for example, FQPSK-B and shaped OQPSK as well as some filtering options may be removed.

4.4.3.2.3 Potential impact

No impact is to be expected as the FQPSK-B (Feher QPSK version B) and baseband shaped OQPSK modulations are in the process of being removed from the CCSDS 401.0-B RF & Modulation recommendation as no agency intends to make use of them. To be noted also that GMSK and Filtered OQPSK cross-compatibility has been verified and the results are reported in CCSDS 413.0-G, *Bandwidth-Efficient Modulations*.

4.4.3.3 Difference 2

4.4.3.3.1 Description

The CCSDS recommendation includes SRRC-4D 8PSK TCM (available options are 2.0 b/s/Hz, 2.25 b/s/Hz, 2.5 b/s/Hz and 2.75 b/s/Hz; Square Root Raised Cosine filter with $a = 0.35$ or $a = 0.5$), GMSK, and filtered OQPSK (with any type of filters). ECSS-E-ST-50-05 only includes SRRC-4D 8PSK TCM (available options are 2.0 b/s/Hz, and 2.5 b/s/Hz; Square Root Raised Cosine filter with $a = 0.35$ or $a = 0.5$), GMSK, and filtered OQPSK restricted to specific types of filter with specified roll-off factor.

4.4.3.3.2 Rationale

The SRRC-4D 8PSK TCM restriction was agreed in 2002, as two options of value for 'a' were deemed sufficient for the needs of future European missions.

4.4.3.3.3 Potential impact

No impact as ground terminals are flexible enough to support all four options for 'a'. The restriction on the number of options simplifies the onboard design. To be noted that only European agencies have indicated so far their intention of using SRRC-4D 8PSK TCM on a space mission.

4.4.4 Options

The ECSS-E-ST-50-05 standard covers the Earth-space and space-Earth links for all missions of the Space Operations, Space Research (near-Earth and deep space) and Earth Exploration Satellite services. These different services call for different standards options because of ITU requirements. The standard covers all these options and clearly identifies which option is for which service. The main parameters affected by the type of service are:

- Frequency band;
- Requirements on transmitted signals, namely spectral occupancy, RF power levels, protection of other radio services;
- Permissible modulation methods and parameters
- A number of technical requirements that are relevant for the interface between spacecraft and Earth stations;
- Operational aspects, such as signal acquisition.

4.4.5 Recommended practice

4.4.5.1 Frequency allocations

Special conditions on the use of frequency bands are provided in full detail in clause 4.2 of the standard. It is important to note that severe restrictions apply on the use of the 2110-2120 MHz band (deep space) for new frequency assignments. The projects should by all means avoid considering this band for new frequency assignments.

Most Earth Exploration Satellite missions currently operate their high speed payload telemetry data downlink in the 8025-8400 MHz frequency band. The bandwidth limitations, the congestion of the band, and the requirements on out-of-band emissions in the 8400-8450 MHz frequency band make it difficult to use this frequency band for very high data rates. The 25.5-27 GHz is also allocated for the Earth Exploration Satellite missions and should be considered for missions requiring these very high data rates for their payload downlink telemetry.

At the date of publication, there is no ground infrastructure in Europe which supports the frequency bands 25.5-27 GHz, 37-38 GHz and 40.0-40.5 GHz.

When selecting a modulation scheme for the telecommand and the telemetry links, the project must take into account the possible need for a ranging service. This may imply the use of one or more modulation schemes for the telecommand and/or telemetry links in order for the satellite to be compatible with ECSS-E-ST-50-02.

The International Telecommunications Union recognises two categories of Space Science missions which have different frequency band allocations; Deep Space missions which are at a distance greater than 2 million kilometres from the Earth and Near Earth missions which are at a distance of less than 2 million kilometres from the Earth.

NOTE The ECSS-E-ST-50-05 standard provides more details on the TT&C frequency allocations and associated bandwidth constraints.

4.4.5.2 The 'Transponder Dual Lock' issue

For the latest generation of Near Earth and Lagrange point missions, the TT&C receiver subsystem combines the uplink signals from both low gain antennas by using a 3dB hybrid combiner. This ensures that the 'best' TC uplink signal is seen by both the prime and redundant transponder receivers simultaneously. Note that this architecture assumes that it has been checked that any interfering area induced by antennae coupling is out of the nominal LOS (Line Of Sight) domain. The ESA Near Earth mission Cryosat-2 uses this type of TT&C architecture as shown in Figure 4-2. Cryosat-2 is an Earth Exploration Satellite.

This TT&C configuration avoids the situation where one transponder could be potentially operating very close to its receiver telecommand threshold (e.g. at ~ -122 dBm) and therefore not operating at a sufficiently low bit error rate on the telecommand channel to ensure valid telecommands are received and processed by the packet telecommand decoder, whilst at the same time the other transponder receiver is operating well above its telecommand threshold level. This operational scenario is known as the 'Transponder Dual Lock' condition and can potentially cause the rejection of telecommands on the telecommand uplink.

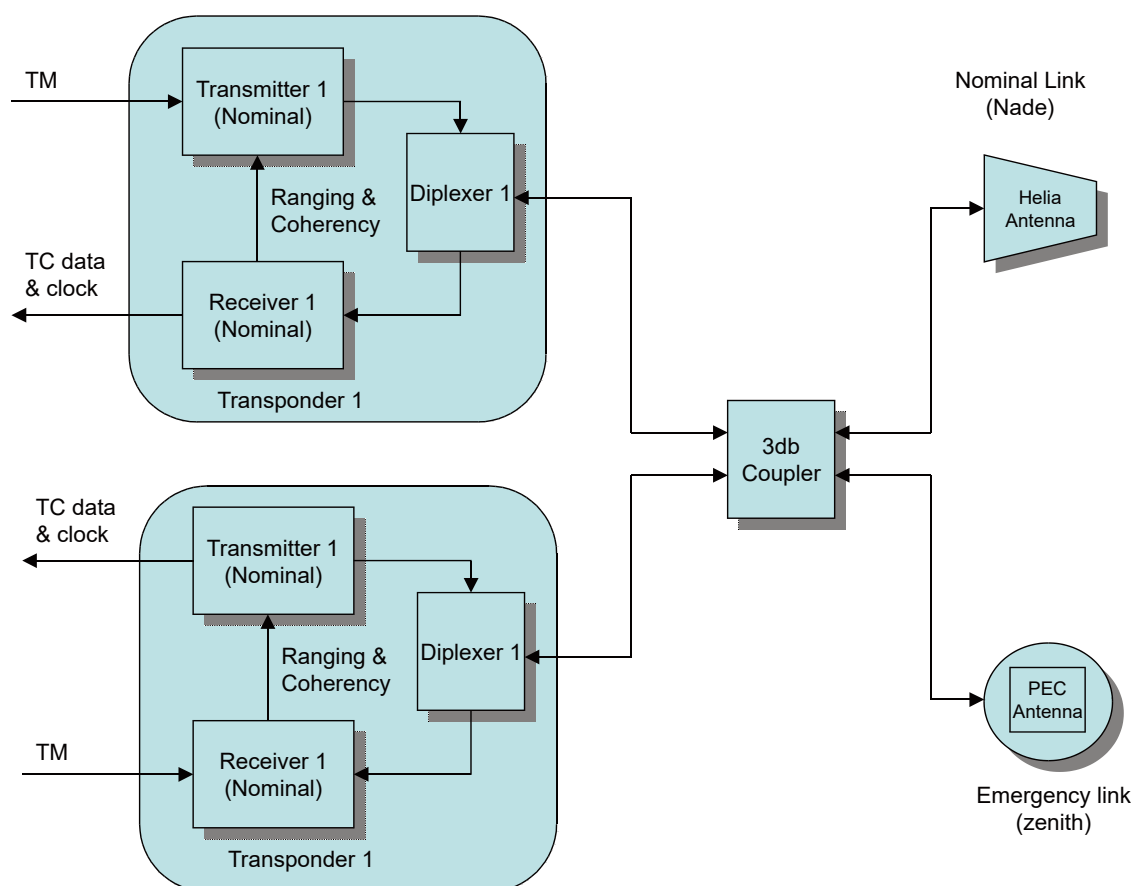


Figure 4-2: Cryosat-2 S-band TT&C subsystem

It is recommended that the COP-1 sequence controlled service (AD mode) should be used for all Near Earth missions in order to ensure a reliable retransmission capability in the case of lost telecommands. It is also strongly recommended that a realistic compatibility test is conducted, prior to launch, using a representative ground station infrastructure. This test configuration needs to include all the elements of the ground station and mission control system which are considered necessary in order to simulate the realistic mission operational scenario.

The operational parameters for the COP-1 protocol need to be tailored for individual missions, based upon the Earth to Satellite distance, in order to optimise the performance. The robustness of the communications uplink when operating in COP-1 sequence controlled service (AD mode) as opposed to expedited service (BD mode), is considered to be the best operational remedy to the problem of frame rejection, which can potentially be caused by the transponder receivers if they are operating in the 'dual lock' condition.

A number of additional recommendations have been proposed, both from an operational perspective and from an on-board system design configuration, which alleviate the 'dual lock' condition for future missions. More information can be found in the report TEC-ETC/2008.66/PMcM "The transponder dual lock issue: Background and recommended remedial actions, June 2008" .

4.5 E-ST-50-01: Telemetry synchronization and channel coding

4.5.1 Purpose and usage

The ECSS-E-ST-50-01 standard, *Space data links - Telemetry synchronization and channel coding*, defines procedures and data structures in the Synchronization and Channel Coding Sublayer of the Data Link Layer discussed in section 3.3.2. The equivalent CCSDS Recommended Standard is CCSDS 131.0-B, *TM Synchronization and Channel Coding*.

ECSS-E-ST-50-01 establishes a common implementation of space telemetry channel coding systems. It addresses:

- coding for improvement of link margin;
- frame synchronization applicable to both coded and uncoded telemetry;
- randomisation to achieve sufficient bit transition density for bit synchronization.

The specification does not attempt to quantify the relative coding gain or the merits of each scheme, nor the design requirements for encoders or decoders. Section 5.2.2 gives some performance data for the coding schemes specified in the standard and further performance details can be found in the informational report CCSDS 130.1-G.

4.5.2 Description

The standard addresses the issue of telemetry channel coding. Telemetry channel coding enables reconstruction of the data with low error probability, thus improving the performance of the channel.

A channel code is the set of rules that specify the transformation of elements of a source alphabet to elements of a code alphabet. The elements of the source alphabet and of the code alphabet are called symbols. Depending on the code, the symbols can consist of one or more bits.

A convolutional code is a code in which a number of output symbols are produced for each input information bit. Each output symbol is a linear combination of the current input bit as well as some or all of the previous $k-1$ bits, where k is the constraint length of the code. The constraint length is the number of consecutive input bits that are used to determine the value of the output symbols at any time.

For telecommunication channels which are bandwidth-constrained and cannot accommodate the increase in bandwidth caused by the basic convolutional code, the standard also specifies a punctured convolutional code which has the advantage of smaller bandwidth expansion.

The Reed-Solomon (R-S) code is a powerful burst error correcting code. In addition, the code has the capability to indicate the presence of uncorrectable

errors, with an extremely low undetected error rate. The Reed-Solomon code has the advantage of smaller bandwidth expansion than the convolutional code.

Concatenation is the use of two or more codes to process data sequentially, with the output of one encoder used as the input of the next. In a concatenated coding system, the first encoding algorithm that is applied to the data stream is called the outer code. To achieve a greater coding gain than the one that can be provided by the convolutional code or Reed-Solomon code alone, a concatenation of the convolutional code with the Reed-Solomon code can be used for improved performance.

A turbo code is a block code formed by combining two component recursive convolutional codes. A turbo code takes as input a block of information bits. The input block is sent unchanged to the first component code and bit-wise interleaved to the second component code. The interleaving process is a fixed bit-by-bit permutation of the entire input block. The output is formed by the parity symbols contributed by each component code plus a replica of the information bits. The turbo codes specified in the standard can be used to obtain even greater coding gain where the environment tolerates the bandwidth overhead.

The methods for synchronization specified in the standard apply to all telemetry channels, coded or uncoded. An attached sync marker (ASM) is attached to the code block or transfer frame. The ASM can also be used for resolution of data ambiguity (sense of '1' and '0') if data ambiguity is not resolved by the modulation method used.

The data unit that consists of the ASM and the Reed-Solomon or turbo codeblock or transfer frame is called the channel access data unit (CADU), as shown in Figure 4-3.

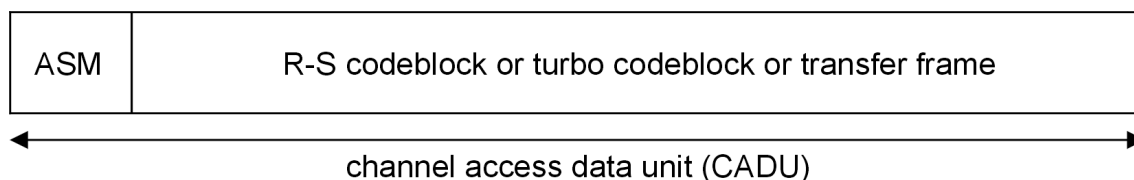


Figure 4-3: Format of channel access data unit (CADU)

Successful bit synchronization at the receiving end depends on the incoming signal having a minimum bit transition density. The standard specifies the method of pseudo-randomizing the data to improve bit transition density.

Figure 4-4 and Figure 4-5 give an overview of how pseudo-randomization and synchronization are combined with the different coding options at the sending and receiving end. At the sending end, the order of convolutional encoding and modulation is implementation dependent. At the receiving end, the order of demodulation, frame synchronization and convolutional decoding is implementation dependent. The figures are not intended to imply any hardware or software configuration in a real system.

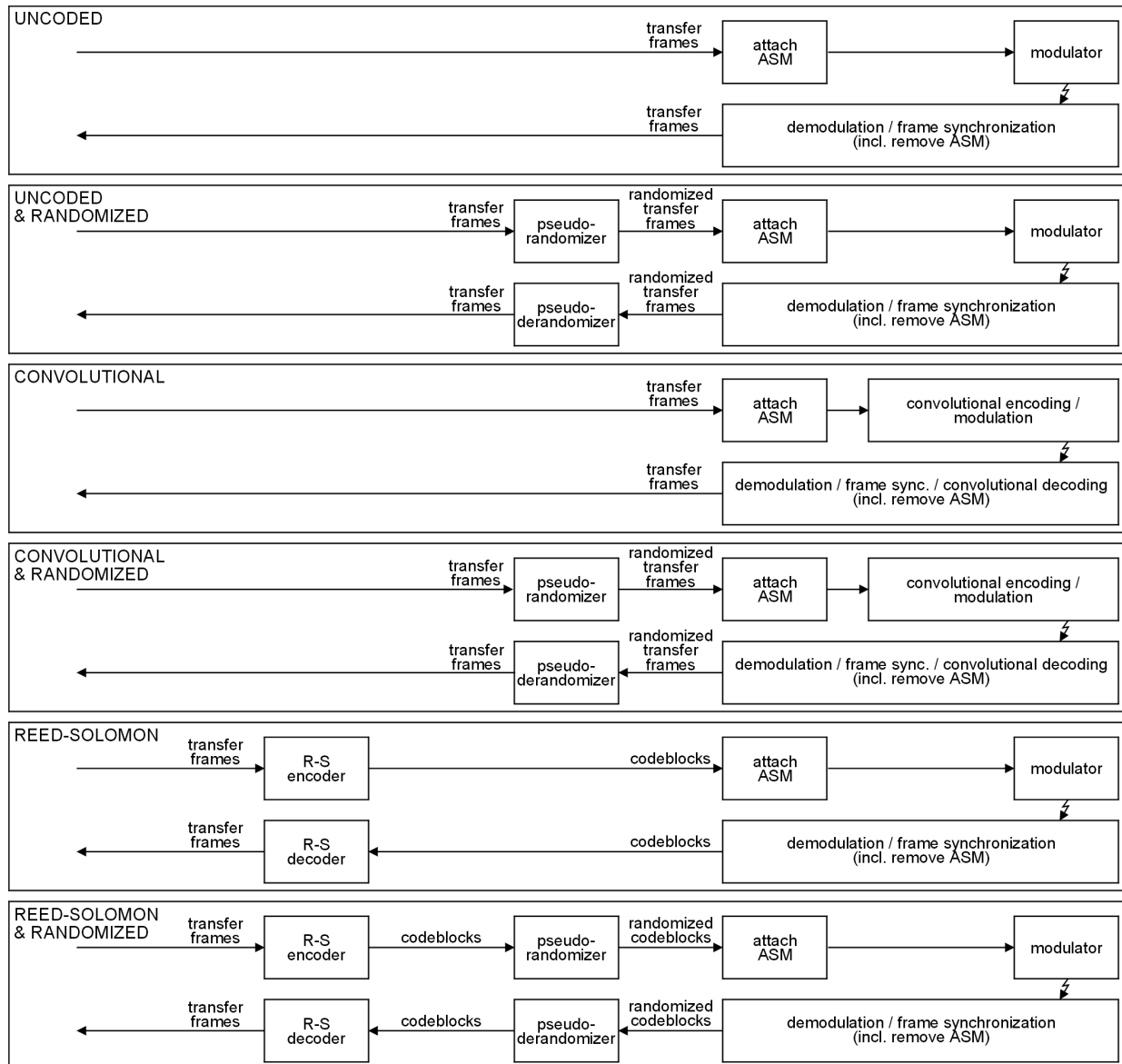


Figure 4-4: Coding, randomization and synchronization configurations (1)

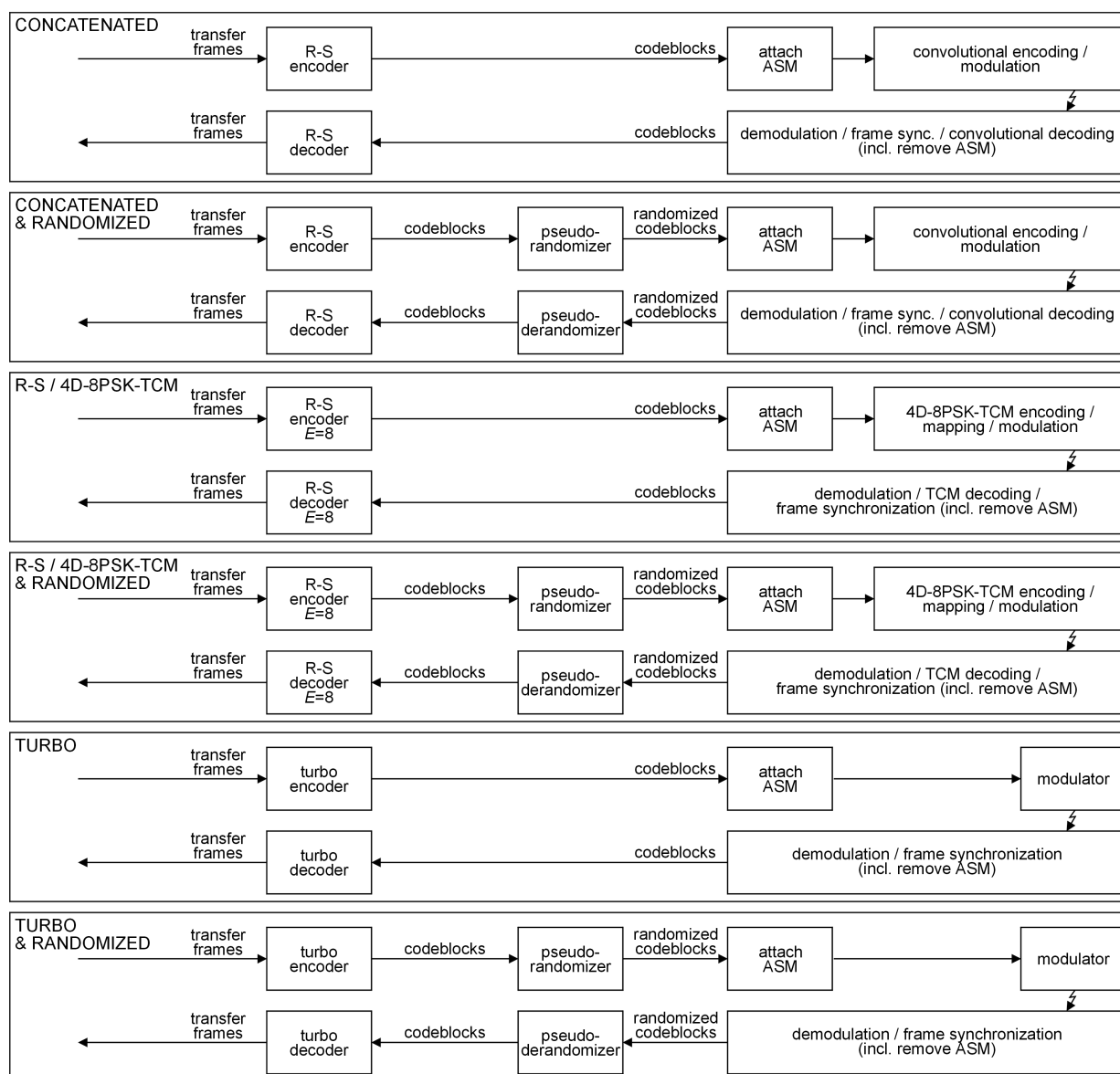


Figure 4-5: Coding, randomization and synchronization configurations (2)

Annexes discuss:

- Reed-Solomon transformations and coefficients;
- telemetry transfer frame lengths compatible with convolutional coding, Reed-Solomon coding and turbo coding;
- application profiles with reference to coding scheme and performances;
- changes from the preceding ESA PSS standard and differences from CCSDS recommendations (see section 4.5.3);
- mission configuration parameters, showing the options and values that can be taken by the parameters specified in ECSS-E-ST-50-01;
- guidance on turbo code patent rights.