The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

OPTICAL COMMUNICATIONS PHYSICAL LAYER

DRAFT RECOMMENDED STANDARD

CCSDS 141.0-P-1.1

PINK SHEETS

July 2020

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FOREWORD

This document is a CCSDS Recommended Standard for the Physical Layer of signals to be used in optical communications systems of space missions. ~~It was contributed to CCSDS by NASA.~~ The Physical Layer concepts described herein are intended for missions that are cross supported between Agencies of the CCSDS.

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in the *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). Current versions of CCSDS documents are maintained at the CCSDS Web site:

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Questions relating to the contents or status of this document should be sent to the CCSDS Secretariat at the email address indicated on page i.

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this Recommended Standard is to specify the Physical Layer characteristics of free-space optical communications systems used by space missions. The primary application addressed in this issue of the Recommended Standard is space-to-ground and ground-to-space ~~photon-starved~~ links through an atmospheric channel; use of the Recommended Standard for other applications or operating conditions is not precluded. When provided with a sequence of pulsed and non-pulsed slots produced by the Coding and Synchronization sublayer (see reference [1]), this specification describes the required Physical Layer characteristics of the ~~telemetry, beacon, and optional data transmission accompanying a beacon~~signal transmission.

1.2 SCOPE

This Recommended Standard defines Physical Layer schemes in terms of the signal characteristics and procedures involved in the physical transmission of the optical signals. It does not specify

a) individual implementations or products;

b) the methods or technologies required to perform the procedures; or

c) the management activities required to configure and control the system.

~~Issue 1 of this~~This Recommended Standard provides a specification for two regimes of optical communications. In one regime, High Photon Efficiency (HPE) optical communications, ~~in which~~ the photon-efficiency of the link is of primary concern.[1] Details of the design and implementation of HPE systems can be found in references [D5], [D6], and [D7]. In the second regime, Optical On-Off-Keying (O3K), low complexity is of primary concern. The primary application of O3K focusses on optical downlinks from Low Earth Orbiting (LEO) satellites.

1.3 APPLICABILITY

This Recommended Standard applies to the creation of Agency standards and to the future data communications over optical space links between CCSDS Agencies in cross-support situations. It includes comprehensive specifications of the data formats and procedures for inter-Agency cross support. It is neither a specification of, nor a design for, real systems that may be implemented for existing or future missions.

[1] ~~A subsequent issue of this Recommended Standard may provide a specification for optical on-off keying and/or high-data-rate optical communications.~~

The Recommended Standard specified in this document is to be invoked through the normal standards program of each CCSDS Agency and is applicable to those missions for which cross support based on capabilities described in this Recommended Standard is anticipated. Where mandatory capabilities are clearly indicated in sections of this Recommended Standard, they must be implemented when this document is used as a basis for cross support. Where options are allowed or implied, implementation of these options is subject to specific bilateral cross support agreements between the Agencies involved.

1.4 RATIONALE

The rationale for producing this Recommended Standard is that it facilitates cross support at the physical layer of optical communications systems used by CCSDS member agencies. Such cross support requires specification of a set of allowable center frequencies of transmission, along with other physical layer characteristics of the signal.

The CCSDS believes it is important to document the rationale underlying the recommendations chosen so that future evaluations of proposed changes or improvements will not lose sight of previous decisions. The rationale for the specifications making up this Recommended Standard is expected to be documented in a forthcoming CCSDS Informational Report.

1.5 DOCUMENT STRUCTURE

This document is divided into five numbered sections and four annexes:

a) section 1 presents the purpose, scope, applicability, rationale, document structure, definitions, and references;

b) section 2 provides an overview of the architecture and summary of functions of the Physical Layer;

c) section 3 specifies HPE telemetry signal characteristics;

d) section 4 specifies HPE beacon and optional accompanying data transmission signal characteristics;

e) section 5 specifies O3K telemetry signal characteristics;

f) section 6 specifies O3K beacon signal characteristics;

g) section 7 lists the managed parameters;

h) annex A is a Protocol Implementation Conformance Statement (PICS) Proforma;

i) annex B discusses security issues;

j) annex C lists acronyms used within this document;

k) annex D provides a list of informative references.

2 OVERVIEW

2.1 ARCHITECTURE

Figure 2-1 illustrates the relationship of this Recommended Standard to the Open Systems Interconnection (OSI) reference model (reference [D1]). Two sublayers of the Data Link Layer are defined for CCSDS space link protocols. The Data Link Protocol sublayer provides functions for producing Transfer Frames; possible Space Data Link Protocols using optical communications are the TM Space Data Link Protocol (reference [D2]), the AOS Space Data Link Protocol (reference [D3]), and the Unified Space Data Link Protocol (USLP) (reference [D8]). The Optical Coding and Synchronization protocol (reference [1]) provides the functions of the Coding and Synchronization sublayer of the Data Link Layer for transferring Transfer Frames over an optical space link. The Optical Communications Physical Layer specified in this Recommended Standard provides the required characteristics of the Physical Layer transmission from space to ground and from ground to space.

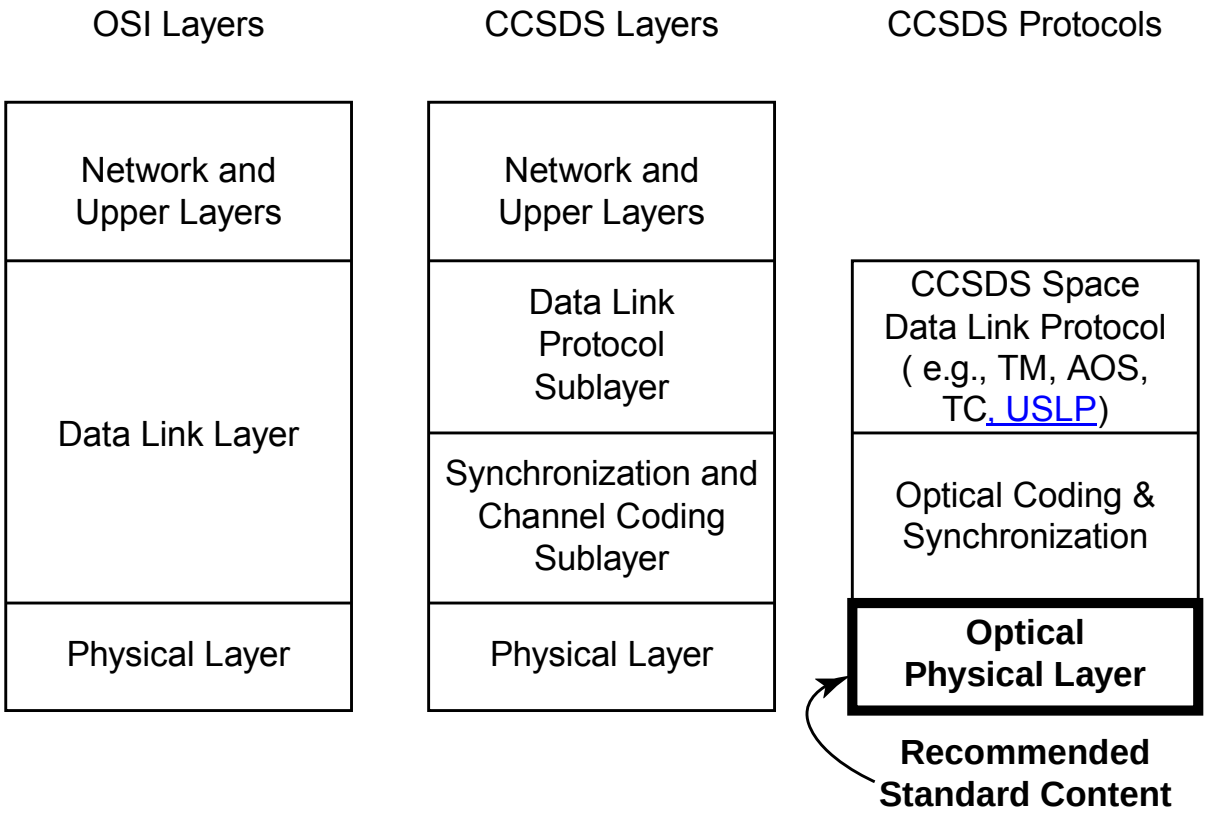

Figure 2-1: Relationship with OSI Layers

2.2 SUMMARY OF FUNCTIONS

The Optical Communications Physical Layer specifies the physical characteristics of the telemetry signal and, separately, the physical characteristics of the beacon and optional telecommand signal. In a typical application, a spacecraft transmits telemetry to a ground

5 OPTICAL ON-OFF KEYING TELEMETRY SIGNAL CHARACTERSTICS

5.1 OVERVIEW

Sections 5 and 6 are intended to enable vendors and operators to provide compatible laser communication equipment and services for O3K systems, mainly for use with, but not limited to, high-speed optical direct-to-Earth telemetry data downlinks. At the sending end, a binary vector is received from the Coding and Synchronization sublayer, as defined in reference [1], indicating a sequence of slots in which light pulses are to be present (1) or absent (0). The physical characteristics of these transmitted pulses are described below. At the receiver, the Physical Layer demodulates the data and delivers statistics to the Coding and Synchronization sublayer for its use in decoding.

5.2 CENTER FREQUENCIES

The center frequency shall be $193.1 + n \times 0.1$ THz, where n is an integer ranging from −18 to 28 for choosing one of 47 optional bands for communications downlink.

NOTES

1 The value of n is a managed parameter.

2 These center frequencies in the optical C-band are a subset of those defined in the ITU-T G.694.1 frequency grid with 100 GHz channel spacing (reference [D4]). The frequencies range from 191.3 THz to 195.9 THz, corresponding to wavelengths in a vacuum ranging from 1530.33 nm to 1567.13 nm.

5.3 CENTER FREQUENCY TOLERANCE

The transmitter center frequency shall be accurate to within a tolerance of ±10 GHz.

5.4 LASER LINE-WIDTH

The modulated laser linewidth shall be less than 10 GHz, measured at full width, half-maximum, over a time scale of 100 ms.

5.5 IN-BAND AND SPILLOVER EMISSIONS

The laser shall transmit 95 percent of its energy within ±20 GHz of its center frequency.

5.6 MODULATION

5.6.1 MODULATION SCHEME

Non-Return-to-Zero On-Off Keying (OOK-NRZ) with equal lengths of ones and zeros slots shall be used as the modulation scheme for telemetry.

5.6.2 PULSE SHAPE/EYE DIAGRAM

The eye-pattern of the transmission shall not impinge on the geometrical shape shown in figure 5-1.

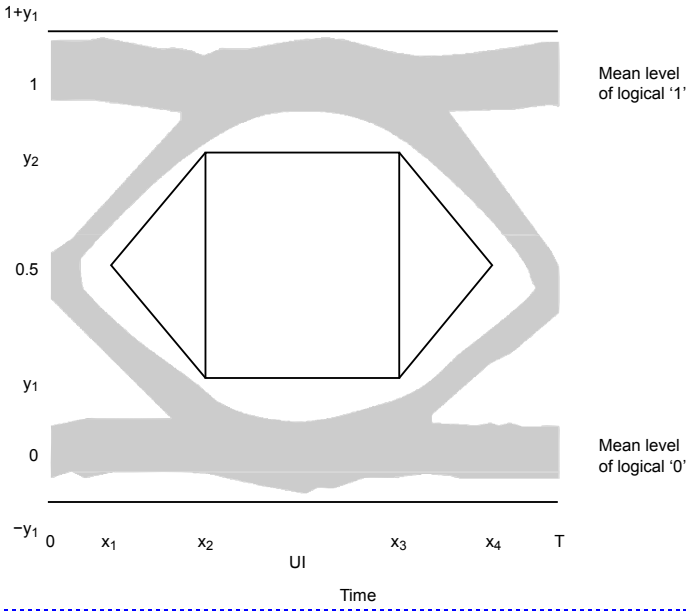

Figure 5-1: Transmit Eye-Pattern

T denotes the OOK slot width. In the figure, x1 = 0.1T, x2 = 0.15T, x3 = 0.85T, x4 = 0.9T, y1=0.10 of the mean level of logical 0, and y2 = 0.90 of the mean level of logical 1.

5.6.3 TIMING JITTER

The RMS pulse timing jitter shall be less than 10 percent of the slot width.

5.6.4 EXTINCTION RATIO

The extinction ratio shall be greater than 10 dB. The ratio is defined to be the ratio of the mean ON level to the mean OFF level.

5.7 SLOT WIDTH

The slot width T shall be one of 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.8, 25.6, 51.2, 102.4, 204.8, 409.6, or 819.2 ns.

NOTES

1 The value of T is a managed parameter.

2 These slot widths correspond to channel symbol rates of $r = 10$ Gsym/s/2^k, with $0 \leq k \leq 13$.

6 OPTICAL ON-OFF KEYING BEACON SIGNAL CHARACTERSTICS

6.1 OVERVIEW

The Coding and Synchronization sublayer produces a binary vector that is to be modulated by the absence (0) or presence (1) of a pulse in the slot by the transmitter at the Physical Layer. The physical characteristics of these transmitted pulses are described below. At the receiver, the Physical Layer demodulates the data and delivers statsistics to the Coding and Synchronization sublayer for its use in decoding.

6.2 CENTER FREQUENCIES

The center frequency shall be one of the following three choices:

a) between 188.350 THz (1591.68 nm) to 188.750 THz (1588.30 nm);

b) between 195.000 THz (1537.40 nm) to 195.900THz (1530.33 nm); or

c) between 281.543 THz (1064.82 nm) to 281.807 THz (1063.82 nm).

6.3 CENTER FREQUENCY TOLERANCE

The center frequency shall be accurate within a tolerance of ±25 GHz for beacon uplink for basic uplink center frequency options a) and b), and ±132.3 GHz for option c).

6.4 LASER LINE WIDTH

The laser linewidth, measured at full width half maximum over a time scale of 100 ms, shall not exceed ±25 GHz for uplink center frequency options a) and b), and shall not exceed ±66 GHz for option c).

6.5 IN-BAND AND SPILLOVER EMISSIONS

The laser shall transmit 95 percent of its energy within ±50 GHz of its center frequency.

6.6 MODULATION

6.6.1 MODULATION SCHEME

Terminal-A shall transmit its beacon signal either unmodulated (Continuous Wave [CW]) or with either rectangular or sinusoidal pulses with a major spectral component at one predefined frequency.

6.6.2 BEACON PULSE REPETITION RATE

6.6.2.1 The beacon signal shall be either unmodulated (CW) or modulated.

6.6.2.2 If the beacon signal is modulated, the modulating frequency shall be in the interval of [0, 20] kHz.

NOTE – The beacon pulse repetition rate is a managed parameter.

6.6.3 TIMING JITTER

The RMS pulse timing jitter shall be less than 10 percent of the slot width.

6.6.4 EXTINCTION RATIO

The extinction ratio shall be greater than 10 dB max/min ratio.

7 MANAGED PARAMETERS

7.1 The managed parameters for HPE signaling shall be those specified in table 7-1.

Table 7-1: Managed Parameters for HPE

Managed Parameter	Allowed Values
n, the telemetry signaling center frequency selection parameter	~~−18 to 28~~Integer in {−18, −17, …, 27, 28}
Telemetry signaling slot width	0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64, 128, 256, or 512 ns
Telemetry signaling polarized transmission	Used or Not Used
Beacon frequency	280.18, 281.72, or 291.06 THz
Data transmission	Used or Not Used

7.2 The managed parameters for O3K signaling shall be those specified in table 7-2.

Table 7-2: Managed Parameters for Optical On-Off Keying

Managed Parameter	Allowed Values
n, the telemetry signaling center frequency selection parameter	Integer in {−18, −17, …, 27, 28}
Telemetry signaling slot width	0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.8, 25.6, 51.2, 102.4, 204.8, 409.6, 819.2, ns
Beacon frequency	a) 188.350 THz to 188.750 THz b) 195.000 THz to 195.900 THz c) 281.543 THz to 281.807 THz
Beacon pulse repetition rate	CW or real number ranging from 0 to 20 kHz

A2.1.4 Identification of Specification

CCSDS 142.0-B-1	
Have any exceptions been required? NOTE – A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is nonconforming.	Yes [ ] No [ ]

A2.1.5 Requirements list

Item	Description	Reference	Status	Values Allowed	Item Supported or Values Supported
PHY-1	HPE or O3K supported	3, 4, 5, 6	1+	N/A	HPE, O3K

HPE Telemetry signaling:

Item	Description	Reference	Status	Values Allowed	Item Supported or Values Supported
HPE-1	Center frequency index	3.2	1+	~~−18 to 28~~Integer in {−18, −17, …, 27, 28}	
HPE-2	Center frequency tolerance	3.3	M	±10 GHz	
HPE-3	Laser linewidth	3.4	M	< 6.25 GHz	
HPE-4	In-band and spillover emissions	3.5	M	95% within ±10 GHz	
HPE-5	Polarized emission	3.6	O	N/A	
HPE-5.1	Polarization type	3.6.1	C:M	RHCP	

O3K Telemetry signaling:

Item	Description	Reference	Status	Values Allowed	Item Supported or Values Supported
O3K-1	Center frequency index	5.2	1+	Integer in {−18, −17, …, 27, 28}	
O3K -2	Center frequency tolerance	5.3	M	±10 GHz	
O3K -3	Laser linewidth	5.4	M	< 10 GHz	
O3K -4	In-band and spillover emissions	5.5	M	95% within ±20 GHz	
O3K -5.1	Modulation	5.6.1	M	OOK	
O3K -5.2	Timing jitter	5.6.3	M	< 10% of slot	
O3K-5.3	Extinction Ratio	5.6.4	M	> 10 dB ON/OFF ratio	
O3K -6	Slot width	5.7	1+	0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.8, 25.6, 51.2, 102.4, 204.8, 409.6, or 819.2 ns	

O3K Beacon signaling:

Item	Description	Reference	Status	Values Allowed	Item Supported or Values Supported
O3K-1	Center frequency	6.2	1+	a) 188.350 THz to 188.750 THz b) 195.000THz to 195.900THz c) 281.543 THz to 281.807 THz	
O3K -2	Center frequency tolerance	6.3	M	±25 GHz for option a) and b) ±132.3 GHz for option c)	

O3K -3	Laser linewidth	6.4	M	±25 GHz for option a) and b) ±66 GHz for option c)	
O3K -4	In-band and spillover emissions	6.5	M	95% within ±50 GHz	
O3K -5.1	Modulation	6.6.1	M	OOK	
O3K-5.2	Beacon Pulse Repetition Rate	6.6.2	M	CW or real number ranging from 0 to 20 kHz	
O3K -5.3	Timing jitter	6.6.3	M	< 10% of slot	
O3K -5.4	Extinction Ratio	6.6.4	M	> 10 dB max-min ratio	