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**Access, Terminals, Transmission and Multiplexing (ATTM);
Plastic Optical Fibres;
Part 1: Plastic Optical Fibre System Specifications
for 100 Mbit/s and 1 Gbit/s;
Sub-part 2: 1 Gbit/s and 100 Mbit/s physical layer
for Plastic Optical Fibres**

Reference

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

The present document is part 1, sub-part 2 of a multi-part deliverable covering Plastic Optical Fibre, as identified below:

Part 1: "Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s";

Sub-part 1: "Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s";

Sub-part 2: "1 Gbit/s and 100 Mbit/s physical layer for Plastic Optical Fibres".

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document provides a description of an OSI physical networking layer to communicate data over plastic optical fibre at 100 Mbit/s and 1 000 Mbit/s. A full duplex physical layer is described.

Multi data type interface is proposed, as well as its encapsulation, coding and modulation needed to achieve 1 Gbit/s link over a bandwidth limited optical channel like the plastic optical fibre. Multiple link speeds are handled by this physical layer.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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The following referenced documents are necessary for the application of the present document.

[1] IEC 60793-2-40: "Optical fibres - Part 2-40: Product specifications - Sectional specification for category A4 multimode fibres".

[2] ANSI/EIA/TIA-455-127-1991, FOTP-127/61.1 :"Spectral Characterization of Multimode Laser Diodes".

[3] IEC 61754-20: "Fibre optic interconnecting devices and passive components - Fibre optic connector interfaces - Part 20: Type LC connector family".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ISO/IEC 11801: "Information technology - Generic cabling for customer premises".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

adaptive bit rate: capacity of PHY to adapt the bit rate as a function of the channel conditions and signal quality in coordination with the link partner

bose, ray-chaudhurim hocquenghem: in coding theory the BCH codes form a class of parameterized error-correcting codes, being its main advantage the ease with which they can be decoded using elegant algebraic methods

cyclic redundancy check: error detecting code designed to detect accidental changes to raw data

control cyclic redundancy check: CRC employed to check the integrity of data in PDB.CTRL blocks

data cyclic redundancy check: CRC employed to check the integrity of an encapsulated data packet and which is included in the PDB.CTRL block signalling the end of packet

error vector magnitude: measure of the deviation between the actual signals compared to the ideal signals, commonly defined in statistical terms

extinction ratio: ratio between the maximum and the minimum power of a given optical signal

forward error correction: technique used for controlling errors in data transmission over unreliable or noisy communication channels

jitter: time deviations of the signal arrival from its nominal timing

link: transmission path between any two interfaces of generic cabling, see ISO/IEC 11801 [i.1]

low power idle: time periods where the Physical Layer transmission is switched off to reduce the energy consumption, when no user data is available to transmit

multi-level cosset code: forward error correcting technique consisting on splitting the information bit stream among several levels, for each one a binary component code is employed with an error correction capability according to the reliability experienced by each level in data transmission over noisy channels

optical modulation amplitude: difference between the maximum and the minimum power of a given optical signal

pulse amplitude modulation: form of signal modulation where the message information is encoded in the amplitude of a series of signal pulses

physical data block: minimum data unit of 65 bits used to encapsulate the user information received from any PHY interface

physical control data block: special case of PDB used to carry control information between encapsulator and de-encapsulator to identify parameters of a data packet like length or protocol, and to check the data integrity

physical idle data block: special PDB.CTRL blocks used by encapsulator for continuous transmission over the physical communication channel when no user data are available for encapsulation received from the data interface

physical padding data block: special case of PDB.CTRL block inserted in user data encapsulation to carry out the rate matching between the PHY interfaces and PHY bit-rate, when PHY bit-rate is greater than the interface bit-rate

physical header data: information carried by the header sub-blocks inside the frame structure and used for control and negotiation of PHY parameters between both link ends

physical header subframe: block of 128 symbols prepended and appended by 16 zeroes that represents the minimum transmit unit in which the PHD is divided after encoding and modulation and used to spread the PHD information along one frame

signal to noise ratio: ratio between the average power of signal and the average power of noise in a given point

tomlinson-harashima precoding: coding technique by which the communication transmit signal pre-equalizes a known inter-symbol interference without power penalty, providing communication signal at the output of channel without post-cursor inter-symbol interference

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ABR	Adaptive Bit Rate
AC	Alternate Current
AOP	Average Optical Power
BCH	bose, ray-chaudhurim hocquenghem
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCRC	CRC of current PDB
CMB	Physical Coding and Modulation Blocks

CRC	Cyclic Redundancy Code
CW	Code Word
DAC	Digital to Analogue Converter
DCRC	CRC of Data PDB
EO	Electro Optical Interface
ER	Extinction Ratio
EVM	Error Vector Magnitude
FEC	Forward Error Correction
FER	Frame Error Rate
FS	Symbol Frequency
IDLE	Idle
IEC	International Electrotechnical Commission
IL	Insertion Losses
ISO	International Organization for Standardization
IT	Information Technology
LC	Little Connector
LED	Light Emitting
LFSR	Linear Feedback Shift Register
LPI	Low Power Idle
LSB	Less Significant Bit
MLCC	Multi Level Cosset Code
MLS	Maximum Length Sequence
NMLCC	Length of the MLCC code word in 1D (PAM) symbols
OFF	Off state
OMA	Optical Modulation Amplitude
ON	On state
OSI	Open Systems Interconnection
PAD	Padding
PAM	Pulse Amplitude Modulation
PDB	Physical Data Block
PDB-ER	PDB Error Rate
PHD	Physical Header Data
PHS	Physical Header Subframe
PHY	Physical
POF	Plastic Optical Fibre
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
RMS	Root-Mean-Square
RX	Reception
SF	Scaling Factor
SNR	Signal to Noise Ratio
TH	Tomlinson-Harashima
THP	Tomlinson-Harashima Precoder
TIA	Trans Impedance Amplifier
TX	Transmission
VCSEL	Vertical Cavity Surface-Emitting Laser

4 1 Gbit/s and 100 Mbit/s data rate physical layer for plastic optical fibre

4.1 Physical layer objectives

The following are the objectives of the PHY:

- Provide 1 Gbit/s and 100 Mbit/s full duplex data transmission.
- Provide speeds less than 1 Gbit/s and 100 Mbit/s with adaptive bit rate functionality if communication channel does not provide enough capacity.

- Support operation over Plastic Optical Fibres defined in IEC 60793-2-40 [1] types A4a.2 with the parameters specified in the respective annexes for each PHY.
- Provide a Bit Error Rate (BER) less than or equal to 10^{-12}.
- Provide low power operation mode for power management.

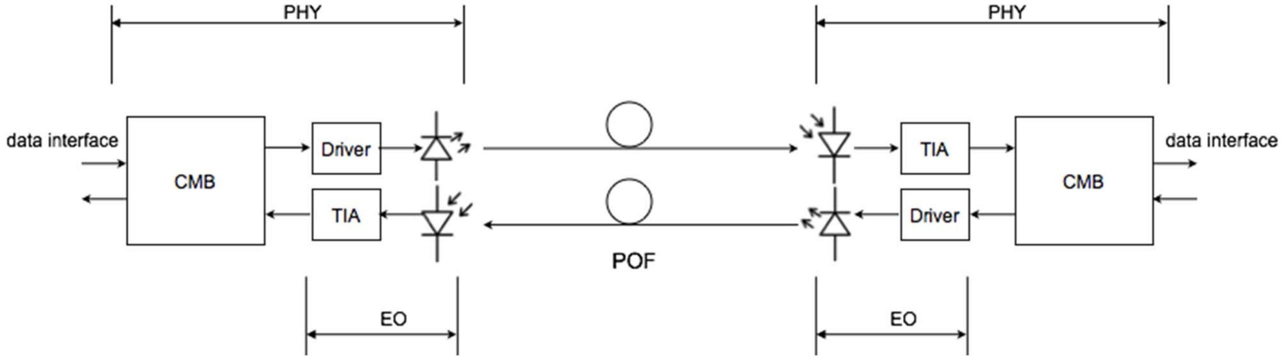

Figure 1: Link topology

Data to be transmitted is provided to the PHY via de TX interface. The PHY generates the linear electrical signal which is converted into optical by the light source via the driver. Optical signal is sent through the fibre and received in the receiver of the other side of the link.

In the receiver the Photo receiver transforms the optical signal into a linear electrical signal with a trans-impedance amplifier (TIA). The PHY transforms back this signal into the transmitted data, and provides it in the Rx interface.

Baseband PAM signalling with a modulation rate that varies with the PHY speed is used. For example, when the speed is 1 000 Mbit/s, the symbol rate is 312,5 MSymbols/s, which results in a symbol period of 3,2 ns. The incoming bits are mapped to PAM symbols using a three level Multi-Level Cosset Code (MLCC). In the first two levels, blocks of bits are encoded using a Bose, Ray-Chaudhuri, Hocquenghem (BCH) code with different coding rates while in the third level bits are not coded.

The PHY can be divided into the following parts:

- Coding and Modulation Blocks (CMB).
- Electro Optical Interface (EO).

4.2 Coding and Modulation Blocks (CMB)

The PHY CMB couples the information in the data interface, to the Electro Optical interface (EO).

The functions performed by the CMB comprise the generation of frames and the mapping of the bits in those frames to PAM symbols using the Multi-Level Cosset Coding technique, and to send them into a Tomlinson-Harashima Precoder (THP), which maps the PAM input into a quasi-continuous discrete time value. Then a power-scaling factor is applied to the symbols and this THP-processed symbol stream is then passed onto a Digital to Analogue Converter (DAC). Finally the analogue signal is sent to the EO interface.

Frames are composed of pilots, a header and data blocks, all of them of fixed length. The pilots are intended to facilitate the receiver initialization and continuous tracking. The header is used to convey physical layer control information. Frames are transmitted continuously to ensure that the receivers are synchronized and the equalizers are aligned to the channel conditions. When no data is being received from the data interface, the blocks of data send the PDB.IDLE pattern described in clause 5.2.3.2. Optionally, the Low Power Idle (LPI) mode can be used together with the PDB.IDLE pattern to reduce energy consumption. The LPI mode is described in clause 5.2.2.

The incoming data is mapped to PAM symbols using a Multi-Level Cosset Coding technique. Depending on the configuration, the bits are divided in up to three levels. In the first two, the incoming bits are encoded using a BCH code while in the third level the bits are left uncoded. Then the resulting bits are mapped to PAM symbols, scrambled and passed to the THP pre-coder and the power adaptation block.

In the transmit direction the CMB receives data packets through the data interface and constructs CMB frames that are then mapped to PAM symbols. In the receive direction, the CMB extracts the information from the received CMB frames and maps them to data packets on the data interface. The receiver is responsible for acquiring symbol timing and equalizing the signal. Both linear and non-linear equalization may be used in the receiver. The reliability of the link is ensured by the CMB Link Monitor function. The CMB PHY Control function controls the CMB operations. PHY Control provides the start-up functions required for successful operation.

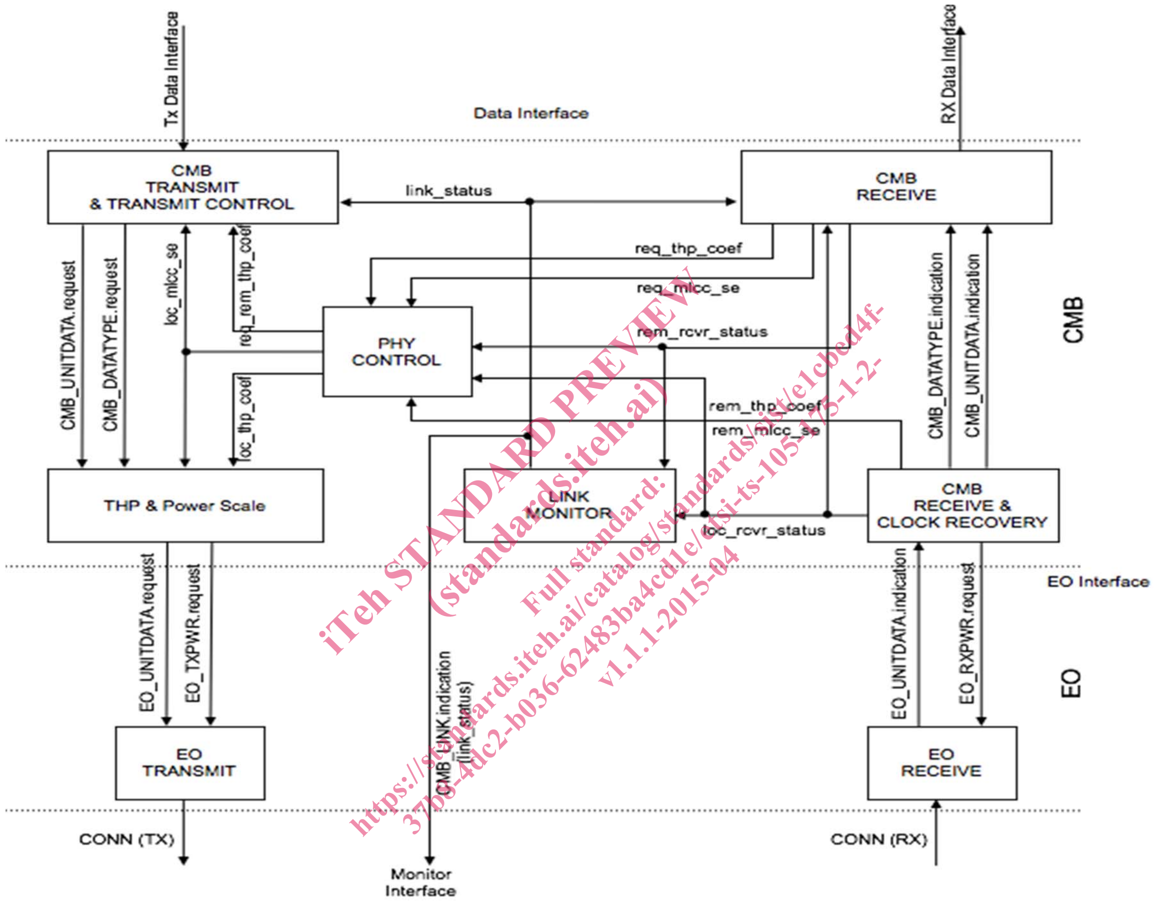

Figure 2: PHY functional block diagram

In figure 2 a block level description of the PHY is shown. Communication between different blocks is also shown. Three different areas are clearly described: the electro optical interface (EO), the coding and modulation blocks (CMB) and the data interface.

4.3 Electro Optical Interface (EO)

The EO specifications detail the characteristics of the optical transmitter and receiver and also of the optical cabling. These are specific for each PHY and are defined in the annexes from A to D specifying each particular PHY.

4.4 Signalling

PHY signalling is performed by the CMB generating symbols to be transmitted on to the EO interface. The signalling scheme achieves a number of objectives including:

a) Forward error correction (FEC) coded symbol mapping for data.

b) Uncorrelated symbols in the transmitted symbol stream.

c) Block framing and other control signals.

d) Energy Efficient operation through the use of the Low Power Idle (LPI) mode.

4.5 Data Interfaces

Several data interfaces can be implemented over the described PHY. The present document does not specify any interface. The present document assumes data transmitted through the data interface is packet oriented vs. continuous stream. On the other hand, there is no limitation on this aspect in the PHY description of the present document.

5 Coding Blocks (CMB)

5.1 CMB introduction

The CMB comprises two functions: CMB transmit and CMB receive.

The CMB couples the data interface to the EO interface. The CMB is defined only in abstract terms and does not imply any particular implementation. Regardless of the implementation used, the optical specifications at the optical output described in clause 7.2 and annexes from A to D shall be met.

The CMB comprises the following functions:

a) CMB Transmit.

b) CMB Receive.

c) PHY Control.

d) Link Monitor.

e) Clock Recovery.

The CMB Receive function receives an electrical signal from the EO and extracts the PAM symbols for the payload and the physical header of the frame. The CMB Receive function is also in charge of equalizing the signal received from the EO. The CMB receive function shall map incoming PAM symbols, decode and unpack the data to be sent to the data interface.

The PHY control function controls the operation of the PHY implementing the state machines for THP coefficients adaptation as well as the optional adaptive bit rate (ABR) to adapt the PHY rate to the channel conditions.

The Link Monitor function determines the status of the link as a function of the local and remote CMB receive status as well as PHY control.

The Clock recovery function is in charge of recovering the transmit clock of the remote PHY from the signal received from the EO, providing a recovered clock valid to properly sample the signal given by the EO_UNITDATA.indication(rx_signal) message.

5.2 CMB transmit function

5.2.1 Introduction to the CMB transmit function

The CMB transmit function maps the incoming data from the data interface onto PAM symbols that are sent to the THP precoder and to the power scaler. The transmission of data at the CMB is structured in frames. The CMB frames consist of pilots, a header and a payload that encodes the user data. All of them are of fixed length. The pilots are intended to aid in the receiver initialization and continuous tracking. The header provides mechanisms for PHY layer signalling between the local and remote devices.

The incoming data from the data interface is encapsulated prior to transmission. Due to the use of the pilots and header, incoming data may need to be buffered before it can be transmitted. The encapsulated data is then scrambled and mapped to PAM symbols using the multilevel cosset coding (MLCC) technique. The CMB Transmit function then, performs THP filtering on the incoming PAM symbols that correspond to the payload data of a frame. Then power scaling is performed to ensure that the Optical Modulation Amplitude (OMA) is the same across the entire frame. Finally, the resulting signal is mapped to an electrical signal that is sent to the EO.

Frames are transmitted continuously in both directions. When there is no data from the data interface the PDB.IDLE pattern is transmitted in the payload of the frame. Optionally, the Low Power Idle (LPI) mode can be used concurrently with the PDB.IDLE pattern to reduce energy consumption.

The CMB Transmit function also carries out the power scaling of all the parts composing the frame, as S1, S2, PHS and payload, as well as the frame building and ordering. Then the resulting signal is mapped to an electrical signal that is sent to the EO.

In addition, the CMB transmit function is in charge of generating the EO_TXPWR.request(tx_pwr) message to the EO, in order to turn off and turn on the transmit optical power when the CMB requests the CMB_DATATYPE.request(PAYLOAD_OFF) message.

5.2.2 Frame structure

A frame comprises pilots, a header and a fixed payload of 225 792 symbols. The pilots and header are divided in sub-blocks and inserted in between the payload sub-blocks. Each header or pilot sub-block is composed of 160 symbols. For pilot and header sub-blocks, the first 16 symbols and the last 16 symbols take value zero. Each payload sub-block is composed of 8 064 symbols that extend an integer number of MLCC code words. The transmission of MLCC code words is aligned with the start of the payload sub-blocks. The code word has a length of 2 016 PAM symbols by default, although this may be configured before CMB initiates the transmission. Other lengths different from 2 016 symbols are reserved for future extensions (see clause 5.2.4.2). For 2 016 symbols length, every payload sub-block consists of 4 MLCC code words.

The frame structure is illustrated in figure 3. The frame is composed of one S1 pilot sub-block, 13 S2 pilot sub-blocks, 14 header sub-blocks and 28 payload sub-blocks. This gives a total of 230 272 symbols. For a symbol frequency of 312,5 MHz the transmission of a frame requires 736,870 4 µs.

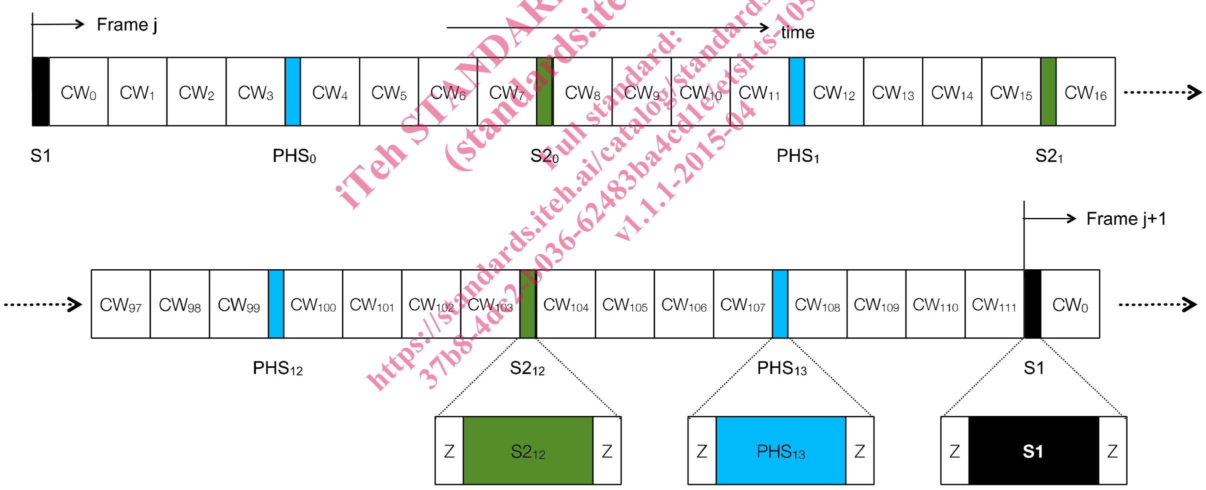

Figure 3: Illustration of the frame structure

As illustrated in figure 3, the pilot (S1, S2x) and header (PHSx) sub-blocks are transmitted once per payload sub-block. The frame always follows the same pattern starting by a S1 block and alternating S2 and PHS sub-blocks, even when the Low Power Idle mode is used.

When both link ends have signalled support for the Low Power Idle mode using the procedure described in clause 5.3.2 the Low Power Idle mode may be used when there is no user data to transmit. The Low Power Idle (LPI) mode shall be signalled by CMB transmit function with parameter tx_type with value PAYLOAD_OFF. The frame with Low Power Idle is illustrated in figure 4. When LPI mode is used all pilot and header sub-blocks are transmitted, but the transmission can be stopped during the payload sub-block frames. This mode always affects complete payload sub-blocks so it is not possible to stop or restart the transmission in the middle of a payload sub-block. The algorithms to determine when to signal LPI as a function of incoming user data from the data interface are left to the implementer.