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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital terminal equipments – General

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet protocol aspects – Transport

Flexible OTN short-reach interface

Recommendation ITU-T G.709.1/Y.1331.1

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ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
General	**G.700–G.709**
Coding of voice and audio signals	G.710–G.729
Principal characteristics of primary multiplex equipment	G.730–G.739
Principal characteristics of second order multiplex equipment	G.740–G.749
Principal characteristics of higher order multiplex equipment	G.750–G.759
Principal characteristics of transcoder and digital multiplication equipment	G.760–G.769
Operations, administration and maintenance features of transmission equipment	G.770–G.779
Principal characteristics of multiplexing equipment for the synchronous digital hierarchy	G.780–G.789
Other terminal equipment	G.790–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.709.1/Y.1331.1

Flexible OTN short-reach interface

Summary

Recommendation ITU-T G.709.1/Y.1331.1 specifies functions associated with the n x 100 Gbit/s FlexO Group interface application. The intent is to keep it separate from the main ITU-T G.709 text.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.709.1/Y.1331.1	2017-01-12	15	11.1002/1000/13082

Keywords

B100G, FlexO, Flex OTN, IrDI, KP4 FEC, SR or short reach.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Table of Contents

Recommendation ITU-T G.709.1/Y.1331.1

Flexible OTN short-reach interface

1 Scope

This Recommendation specifies a flexible interoperable short-reach OTN interface, over which an OTUCn (n ≥ 1) is transferred, using bonded interfaces. The FlexO interfaces are covered by application codes which are at the time of publication 4I1-9D1F, 4L1-9C1F, C4S1-9D1F and 4L1-9D1F in [ITU-T G.695] and [ITU-T G.959.1]. A FlexO group interface complements the existing functions specified in [ITU-T G.709], such as B100G OTUCn frame, ODUk/flex, with new functions such as physical interface bonding, group management and OTUCn (de)mapping. The intent of the FlexO Recommendation is to capture links to existing [ITU-T G.709]/[ITU-T G.798] functions and to provide specifications for new functions that are applicable to FlexO groups. In addition, some introduction material for the addressed application is included.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.695] Recommendation ITU-T G.695 (2015), *Optical interfaces for coarse wavelength division multiplexing applications*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2016), *Interfaces for the optical transport network.*

[ITU-T G.798] Recommendation ITU-T G.798 (2012), *Characteristics of optical transport network hierarchy equipment functional blocks.*

[ITU-T G.870] Recommendation ITU-T G.870/Y.1352 (2016), *Terms and definitions for optical transport networks (OTN).*

[ITU-T G.872] Recommendation ITU-T G.872 (2017), *Terms and definitions for optical transport networks*.

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2016), *Optical transport network physical layer interfaces.*

[ITU-T G.7041] Recommendation ITU-T G.7041/Y.1303 (2016), *Generic framing procedure (GFP).*

[ITU-T G.8260] Recommendation ITU-T G.8260 (2015), *Definitions and terminology for synchronization in packet networks.*

[IEEE 802.3] IEEE Std. 802.3:2015, *IEEE Standard for Information Technology – Telecommunications and Information Exchange Between Systems – Local and Metropolitan Area Networks – Specific Requirements Part 3: Carrier Sense Multiple Access With Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications.*

[OIF FlexE IA] Optical Interworking Forum, OIF (2016), *FlexEthernet Implementation Agreement.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 Terms defined in [ITU-T G.870]

– completely standardized OTUCn (OTUCn)
– optical data unit (ODUCn)
– optical payload unit (OPUCn)
– optical transport network (OTN)

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 FlexO frame: Consists of frame alignment (markers), OH, FEC and payload area.

3.2.2 FlexO lane: Refers to an electrical/optical lane of a FlexO interface, used to carry OTUC transport signals.

3.2.3 FlexO interface: Refers to an individual interface that is part of a FlexO group. The acronym used for FlexO interface is FOICx.k. The term Cx signifies the FlexO interface rate. The term k refers to the number of lanes in the interface.

NOTE – The terms member and PHY are often used to refer to a FlexO interface.

3.2.4 FlexO group: Refers to the group of m * FlexO interfaces.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AM	Alignment Marker
B100G	Beyond 100G
BMP	Bit-synchronous Mapping Procedure
CAUI	(Chip to) 100 Gb/s Attachment Unit Interface
CM	Common Marker
CRC	Cyclic Redundancy Check
FA	Frame Alignment
FAS	Frame Alignment Signal
FCC	FlexO Communications Channel
FEC	Forward Error Correction
FlexE	Flexible Ethernet
FlexO	Flexible Optical Transport Network
FOIC	FlexO Interface
GFP	Generic Framing Procedure
GID	Group Identification
IA	Implementation Agreement
LSB	Least Significant Bit

MAP PHY Map field

MFAS Multi-Frame Alignment Signal

MS Multiplexed Section

MSB Most Significant Bit

NNI Network Node Interface

ODU Optical Data Unit

OH Overhead

OPU Optical Payload Unit

OSMC OTN synchronization messaging channel

OTL Optical Transport Lane

OTLk.n Group of n Optical Transport Lanes that carry one OTUk

OTLC.n Group of n Optical Transport Lanes that carry one OTUC of an OTUCn

OTN Optical Transport Network

OTU Optical Transport Unit

PCS Physical Coding Sublayer

PHY Physical Layer

PID Physical Identification

PTP Precise Timing Protocol

RES Reserved for future international standardization

RPF Remote Physical Layer Fault

RS Regeneration Section

RS Reed-Solomon

SM Section Monitoring

SSM Source Sync Message

STAT Status

UM Unique Marker

UP Unique Padding

5 Conventions

This Recommendation uses the following conventions defined in [ITU-T G.870]:

– k

– Cn

– m

– n

– r

Transmission order: The order of transmission of information in all the diagrams in this Recommendation is first from left to right and then from top to bottom. Within each byte the most significant bit is transmitted first. The most significant bit (bit 1) is illustrated on the left side of all diagrams.

Value of reserved bit(s): The value of an overhead bit, which is reserved for future international standardization, shall be set to "0".

Value of non-sourced bit(s): Unless stated otherwise, any non-sourced bits shall be set to "0".

6 Introduction and applications

A FlexO (Flexible OTN) group is defined for interoperable interfacing applications. It complements B100G (beyond 100G) [ITU-T G.709] Edition 5, by providing an interoperable interface for OTUCn transport signals. The FlexO group interface provides modularity by bonding standard-rate interfaces (e.g., m * 100G), over which the OTUCn ($n \geq 1$) signal is adapted. The value of m is not standardized. The specification of OTUCn in [ITU-T G.709] excludes interface specific functions such as FEC, scrambling, and bit alignment. The FlexO interface wraps OTUCn, abstracting the transport signal from the interface. FlexO enables ODUflex services >100Gbit/s to be supported across multiple interfaces, ahead of next-gen interface standards (e.g., 400GE [b-IEEE 802.3bs]).

FlexO provides OTN interfaces with comparable functionality as to what was introduced in [OIF FlexE IA] for Ethernet interfaces.

6.1 FlexO considerations

The considerations and capabilities for a FlexO group:

- provides an interoperable system interface for OTUCn transport signals;
- enables higher capacity ODUflex and OTUCn, by means of bonding m standard-rate interfaces;
- provides interface rate modularity and flexibility;
- provides a frame, alignment, deskew, group management, management communication channel, and such functions that are not associated with the OTUCn transport signal; and
- reuses 100G modules (e.g., CFP2, QSFP28) by matching the interface rate to OTU4 as specified in [ITU-T G.709]

The FlexO interface is specified in this recommendation at the external reference point. The logical signal format FOIC can be reused on a system internal interface. These requirements and the optimizations to the FlexO groups (e.g., lower latency by removing FEC) are beyond the scope of this recommendation and covered in [b-ITU-T G-Sup.58].

6.2 Sample applications

FlexO group interfaces can be used for a variety of applications. Example applications for a FlexO interoperable interface are shown in Figure 6-1 and Figure 6-2. An interoperable interface might represent an OTN handoff between router (R) and transport (T) nodes, or could be a handoff between different administrative domains.

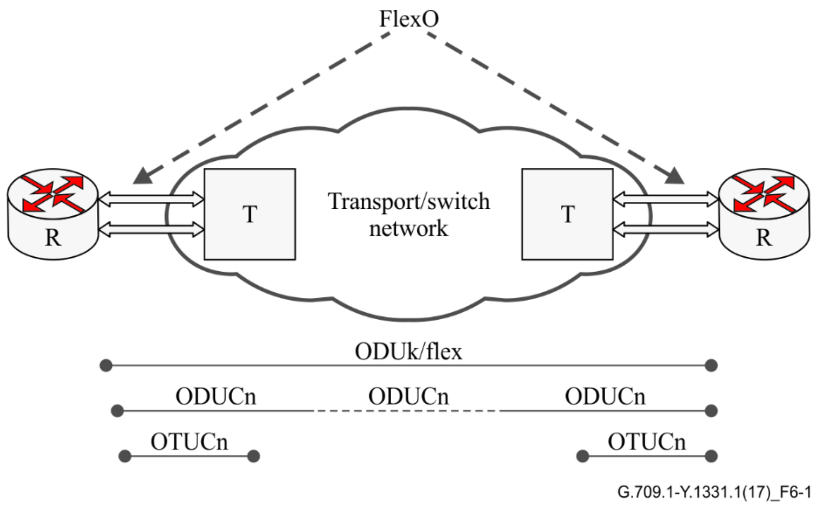

Figure 6-1 – Example FlexO handoff router-transport

The R-T topology is used in Figure 6-1, to draw an analogy between FlexO and FlexE use cases presented in [OIF FlexE IA]. The ODUk/flex (which can be a rate higher than 100Gbit/s) is the transport service (path) and maintenance entity in the OTN transport/switch network. The ODUCn/OTUCn is the section and FlexO provides the interfacing capabilities (e.g., FEC, bonding and scrambling).

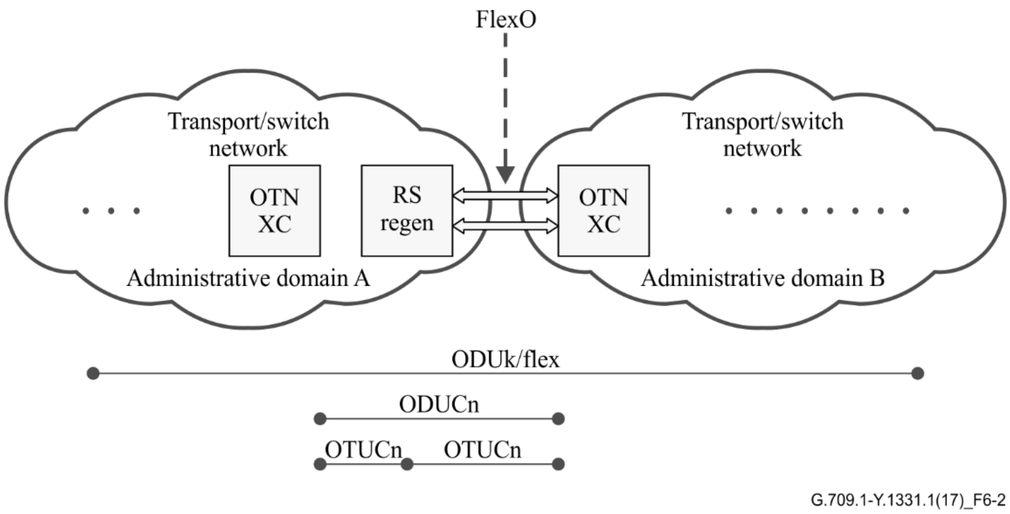

Figure 6-2 – Example FlexO inter-domain handoff

The example of Figure 6-2 shows a FlexO inter-domain interface used as a handoff between two OTN switch/transport administrative domains (A and B). The administrative domains can represent different carriers, different equipment vendors within a carrier or different segments (metro vs core) within a carrier. The OTUCn is the regen section (RS), the ODUCn is the multiplexed section (MS) and the m*OTUC is the FlexO group bonded using m*100G FlexO interfaces.

7 Structure and processes

This clause introduces the functions associated with a FlexO group and the basic signal structure, processes and atomic functions.

7.1 Basic signal structure

The FlexO group interface in this recommendation is only specified for short-reach applications. The FlexO group functional model is specified in [ITU-T G.872]. The physical optical interface specifications are beyond the scope of this recommendation.

The information structure for FlexO groups is represented by information containment relationships and flows. The principal information containment relationship is described in Figure 7-1.

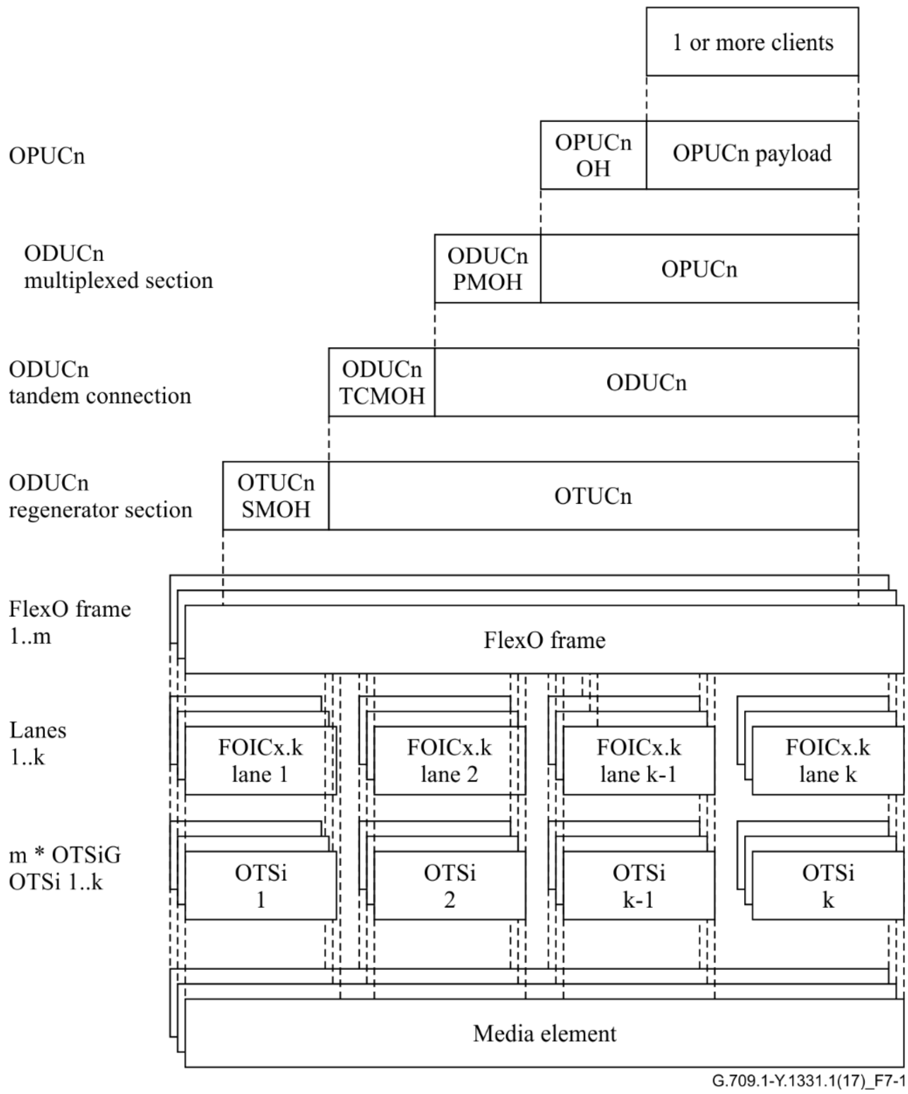

Figure 7-1 – FlexO group principal information containment relationship

7.2 Process flow

Functions and process flows are specified in [ITU-T G.798].

8 FlexO frame

A FlexO frame is associated with a FlexO interface and is independent of an OTUCn frame and transport unit, the latter being specified in [ITU-T G.709]. The OTUCn is the transport unit over OTN interfaces. A FlexO frame consists of frame alignment (markers), OH, FEC and payload area.

The FlexO frames in the different interfaces of a FlexO group are frame/multi-frame aligned at the source.

8.1 Frame structure

The frame structure is shown in Figure 8-1 and consists of 128 rows by 5,440 1-bit columns. It contains a frame alignment marker area in row 1, columns 1 to 960, an overhead area in row 1 columns 961 to 1280, a FEC area in columns 5,141 to 5,440 in every row and a (128 × 5140 – 1280 = 656640 bit) payload area in the remainder of the frame. The FlexO frame period results is ~6.2us.

Each row constitutes a 5,440-bit FEC codeword, with the last 300 bits used for the FEC parity bits. This results in a bit-oriented structure. The MSB in each FEC codeword is bit 1, the LSB is bit 5,440.

NOTE – The FlexO frame structure is derived from 100Gbit/s Ethernet clause 91 [IEEE 802.3-2015] FEC alignment and lane architecture, without any 66b alignment or 256b/257b transcoding functions.

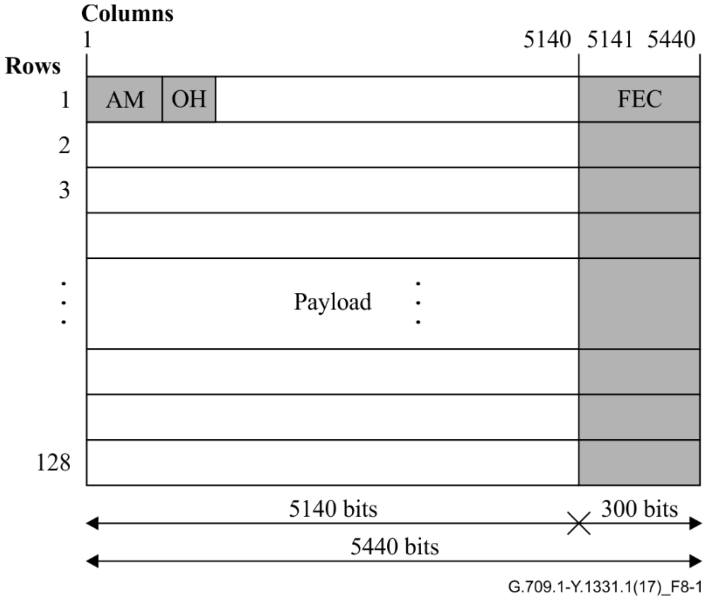

Figure 8-1 – FlexO frame structure

8.2 Multi-frame structure

In order to pad the payload area and provide additional OH field locations, an 8-frame multi-frame structure is defined. The multi-frame structure is shown in Figure 8-2. It uses the three least significant bits of the multi-frame alignment signal (MFAS) overhead to identify the eight frames within the multi-frame.

The multi-frame contains seven fixed stuff locations, each containing 1,280 bits. These fixed-stuff locations are distributed in row 65, columns 1 to 1,280 of the first seven frames within the multi-frame. The last frame within the multi-frame does not contain fixed stuff.

The fixed stuff bits are filled with all-0s and not checked at the receiver sink function.

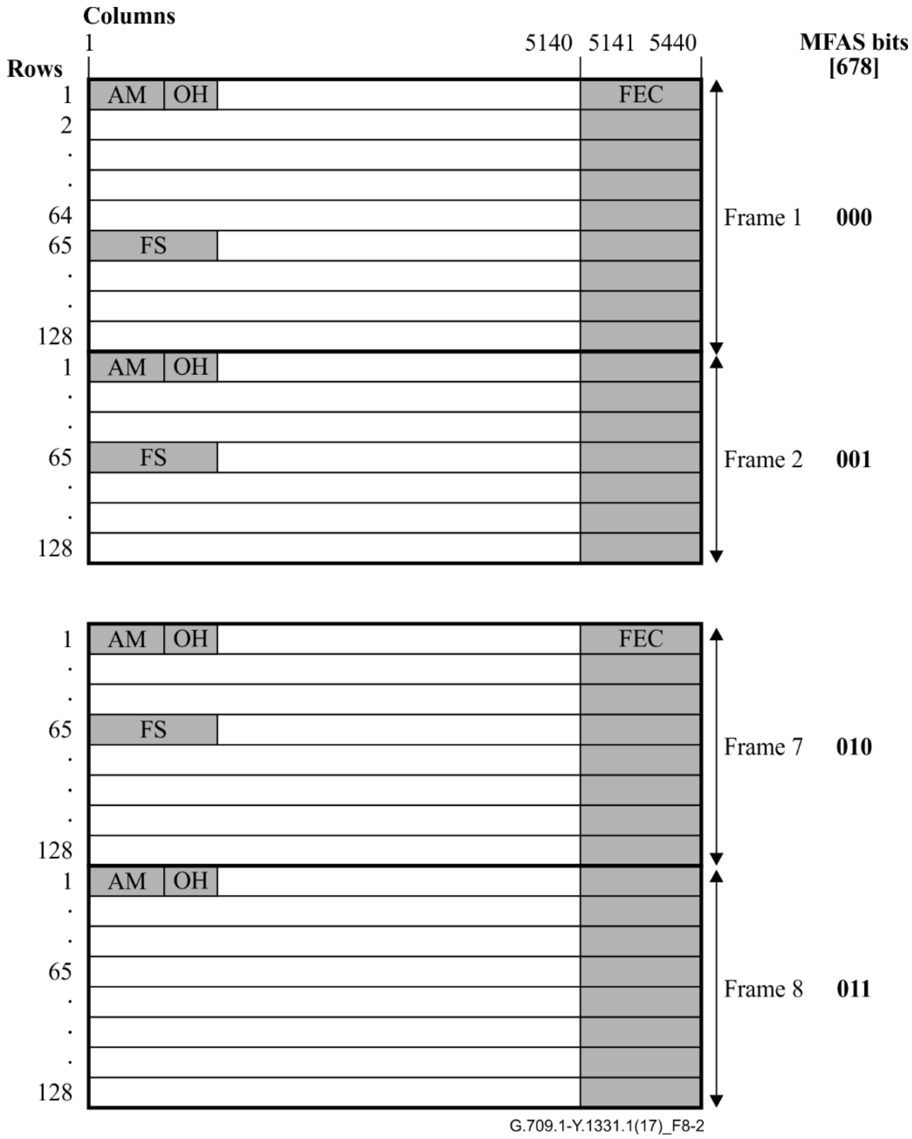

Figure 8-2 – FlexO multi-frame structure

8.3 Bit rates

The FlexO frame payload consists of 5,244,160 bits (655,520 bytes) out of the total 5,570,560 bits (696,320 bytes) per FlexO multi-frame.

FlexO_rate = 256/241 × OTUC_rate

= 256/241 × 239/226 × 99,532,800 kbit/s ±20 ppm

NOTE – The resulting 100G FlexO bit rate is within a -4.46 ppm offset of the OTU4 nominal bit rate.

8.4 FEC

FlexO FEC codewords occupy a row in the FlexO frame. The FlexO frame allocates 300 bits for FEC parity, per row as shown in Figure 8-1. The FEC scheme employs Reed-Solomon code operating over the Galois Field $GF(2^{10})$, where the symbol size is 10 bits.

Reed-Solomon code is denoted as RS(n,k) where k represents the number of message symbols to generate 2t parity symbols, which are appended to the message. The resulting formula is n=k+2t

n=544

k=514

t=15

The FEC encoder processes 20 * 257-bit data blocks, resulting in the 5140 data bits in the FEC codeword (row), and generates 20 * 15 = 300 bits of FEC parity.

NOTE – The FlexO FEC is based on RS10 (544, 514), as specified in clause 91 of [IEEE 802.3-2015] for 100GBASE-KP4 interfaces.

9 Alignment markers and overhead

The FlexO AM and OH areas consist of 1,280 bits, and are part of the FlexO frame structure. It includes information to support group management and alignment functions. The FlexO AM and OH is terminated where the FlexO frame is assembled and disassembled.

An overview of FlexO AM and OH areas is presented in Figure 9-1.

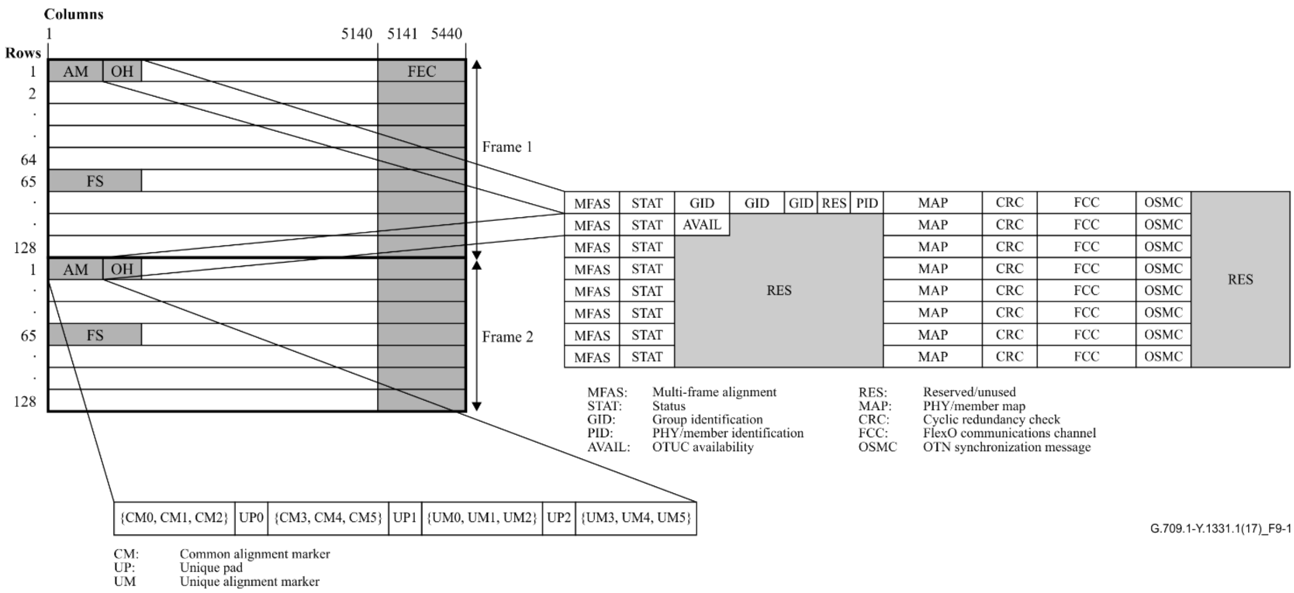

Figure 9-1 – Overhead overview

9.1 Lane alignment markers (AM)

Lane alignment markers are used for lane alignment, lane delineation, lane ordering and lane deskewing.

The AM area length for a FlexO frame is defined as 960 bits, which is a place holder for up to eight 120-bit lane alignment markers.

A lane alignment marker in Figure 9-2 consists of a common portion across all lanes, a unique portion per lane and some pad bits.

– CMx = 8-bit common marker field (common across lanes) – used for aligning lanes

– UMx = 8-bit unique marker field – used for identifying lanes

– UPx = 8-bit unique pad field – used for providing a DC balance when multiplexing lanes

NOTE – Alignment marker area length specified by clause 91 [IEEE 802.3-2015] for 100 Gbit/s Ethernet interfaces, is 1285-bit per AM FEC frame period (every 4096 FEC codewords). It consists of 20 AM blocks of 64-bit, plus 5-bit extra padding required for 257b block alignment. Since the FlexO adaptation method described in this document does not rely on 257b blocks, the five padding bits are unnecessary.

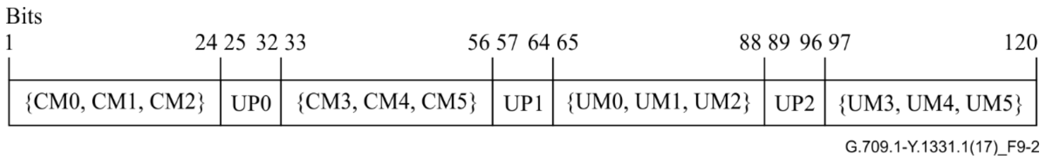

Figure 9-2 – FlexO lane alignment marker format

9.1.1 100G interface alignment markers

The 100G FlexO interface consists of four logical lanes, numbered 0, 1, 2 and 3. Each lane carries a 120-bit lane alignment marker (ami, i = 0,1,2,3) as specified in Table 9-1 plus 120 pad bits (padi, i=0,1,2,3) that have a value of all-0s prior to scrambling. Rows of Table 9-1 give the values of ami transmitted over lane i.

The 960-bit 100G FlexO alignment marker area contains 10-bit interleaved parts of am0, am1, am2, am3, pad0, pad1, pad2 and pad3 as illustrated in Figure 9-3. The first 480 bits contain the 10-bit interleaved parts of am0 to am3 in the order am0, am1, am2, am3, am0, am1, etc. The second 480 bits contain the 10-bit interleaved parts of pad0 to pad3 in the order pad0, pad1, pad2, pad3, pad0, pad1, etc.

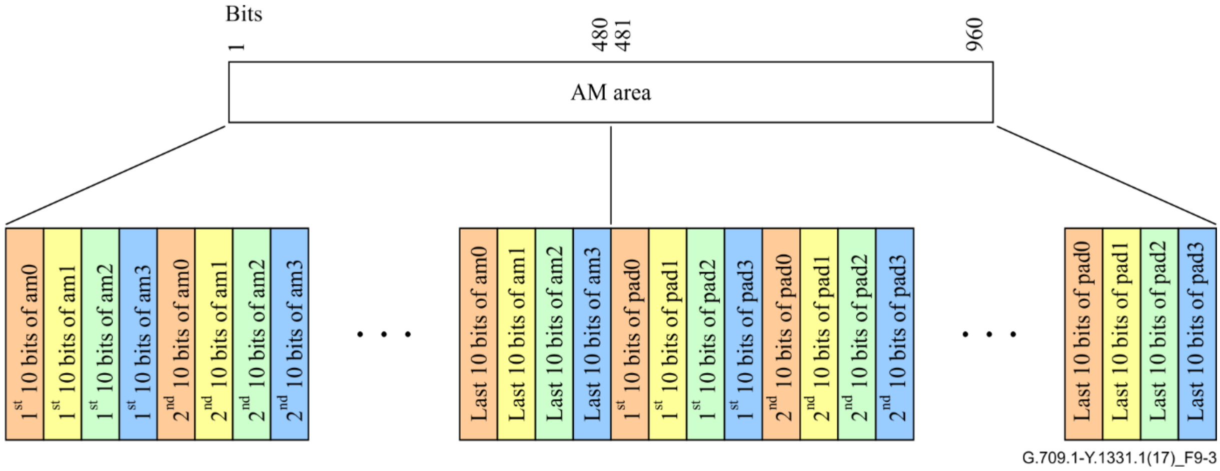

Figure 9-3 – 100G FlexO alignment marker area with four interleaved lane alignment markers and padding

Table 9-1 – 100G FlexO lane alignment marker values

lane	Encoding														
	{CM0, CM1, CM2, UP0, CM3, CM4, CM5, UP1, UM0, UM1, UM2, UP2, UM3, UM4, UM5}														
0	59	52	64	6D	A6	AD	9B	9B	80	8E	CF	64	7F	71	30
1	59	52	64	20	A6	AD	9B	E6	5A	7B	7E	19	A5	84	81
2	59	52	64	62	A6	AD	9B	7F	7C	CF	6A	80	83	30	95
3	59	52	64	5A	A6	AD	9B	21	61	01	0B	DE	9E	FE	F4
NOTE – The value in each byte of this table is in MSB-first transmission order. Note that this per-byte bit ordering is the reverse of AM values found in [b-IEEE 802.bs], which uses an LSB-first bit transmission format.															

9.2 Overhead description

The FlexO OH area is contained in the 320 bits following the FlexO frame AM area. The OH structure amounts to 2,560 bits (320 bytes) and is distributed across an 8-frame multi-frame, as shown in Figure 9-4. Each frame contains 40 OH bytes.

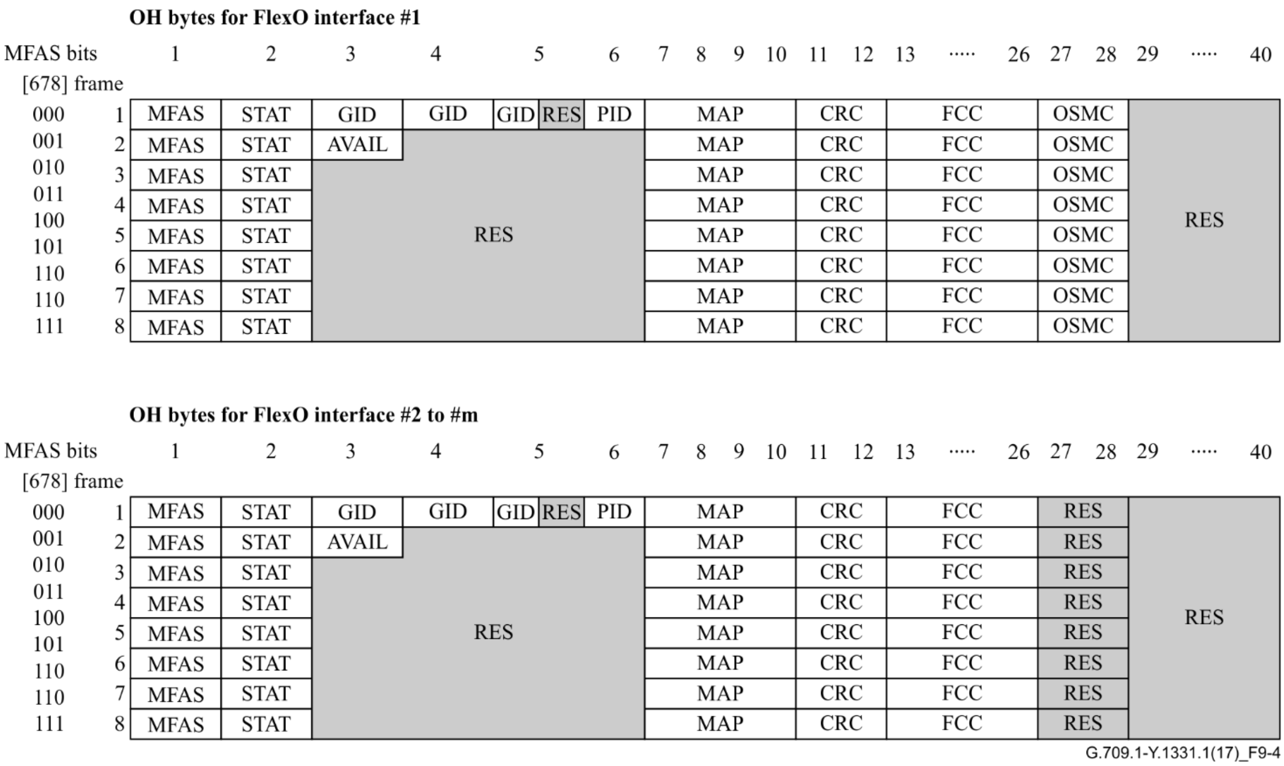

Figure 9-4 – FlexO OH structure

The FlexO OH area contains the following subfields (see Figure 9-4):

– multi-frame alignment signal (MFAS)

– status (STAT)

– group identification (GID)

– PHY identification (PID)

– PHY map (MAP)

– OTUC availability (AVAIL)

– cyclic redundancy check (CRC)

– FlexO management communication channel (FCC)

– bits reserved for future international standardization (RES)

– OTN synchronisation message channel (OSMC)

9.2.1 Multi-frame alignment signal (MFAS)

An 8-bit (1 byte) multi-frame alignment signal field is provided and incremented in every frame. This MFAS field counts 0x00 to 0xFF and provides a 256-frame multi-frame. This central multi-frame is used to lock 2-frame, 4-frame, 8-frame, 16-frame, 32-frame, etc. multi-frame structures of overhead and payload structure to the principal frame.

Figure 9-5 – Multi-frame alignment signal overhead

The MFAS field is located in all frames, in overhead byte 1 immediately following the AM.

9.2.2 Group identification (GID)

A 20-bit (2.5 bytes) FlexO Group Identification field is provided to indicate the FlexO Group instance that the FlexO interface is a member of. The GID provides the ability to check at the receive side that the FlexO interface belongs to the intended FlexO group instance.

The GID field is located in frame 1, in overhead bytes 3, 4 and 5.

The same FlexO Group Identification value is used in both directions of transport.

Non-zero values for GID are valid and the value of "0" is reserved for this field.

A FlexO interface that is not part of any group has its GID value set to "0".

9.2.3 PHY identification (PID)

A FlexO group is composed of m FlexO interfaces, also referred to as members or PHYs. An 8-bit (1 byte) field is provided to uniquely identify each member of a group and the order of each member in the group. This information is required in the reordering process.

The PID values of the interfaces in a FlexO group are not necessarily arranged consecutively. The PID values indicate the order of the interfaces within the FlexO group, from low to high. The first FlexO interface in the group is the one with the lowest PID value.

The PID field is located in frame 1, in overhead byte 6. The values "0" and "255" are reserved for this field.

The same FlexO PHY Identification value is used in both directions of transport.

A FlexO interface that is not part of any group has its PID value default to "0".

9.2.4 PHY map (MAP)

A 256-bit (8 bytes) field is provided to indicate the members belonging to the group. Each bit in the field, is set to "1" indicating a member/PHY is part of the group. The bit position of the MAP corresponds to the PID set for the member FlexO interface, with the MSB corresponding to lowest numbered PID. The remaining unused fields in the MAP are set to "0". The full MAP is sent and received on all members of the group.

The MAP field is located in all frames, in overhead bytes 7, 8, 9 and 10. As shown in Figure 9-6, the MSB of overhead byte 7 in frame 1 is associated with PID #0 and the LSB of overhead byte 10 in frame 8 is associated with PID #255.

PHY MAP bytes

Frame	7								8								9								10							
1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	32	33	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
3	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
4	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
5	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
6	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
7	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
8	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	245	246	247	248	249	250	251	252	253	254	255

G.709.1-Y.1331.1(17)_F9-6

Figure 9-6 – FlexO PHY MAP field

9.2.5 Status (STAT)

An 8-bit (1 byte) field is provided for general purpose status indication.

– Remote PHY Fault

– Reserved

Bits	1	2	3	4	5	6	7	8
	RPF	RES						

G.709.1-Y.1331.1(17)_F9-7

Figure 9-7 – FlexO OH STAT field

The STAT field is located in all frames, in overhead byte 2.

9.2.5.1 Remote PHY fault (RPF)

For section monitoring, a single bit remote PHY fault (RPF) indication to convey the signal fail status detected at the remote FlexO sink function in the upstream direction.

RPF is set to "1" to indicate a remote PHY defect indication; otherwise, it is set to "0".

The RPF field is located in bit 1 of the STAT field as shown in Figure 9-7.

9.2.5.2 Reserved (RES)

Seven bits of the STAT byte are reserved for future international standardization as shown in Figure 9-7. These bits are set to "0".

9.2.6 OTUC availability (AVAIL)

An 8-bit (1 byte) OTUC availability field is provided to indicate the number of valid and available OTUC slices mapped to the FlexO frame. A 100G FlexO frame has a valid count of 0 or 1. This functionality is further specified in clause 10.1.

The AVAIL field is located in frame 2, in overhead byte 3.

9.2.7 Cyclic redundancy check (CRC)

The CRC-16 (2 bytes) is located in overhead bytes 11 and 12 of each FlexO frame. The CRC protects the integrity of the OH fields in bytes 2 to 10 and excludes the MFAS, OSMC and FCC fields. The CRC-16 uses the $G(x) = x^{16} + x^6 + x^5 + x^3 + 1$ generator polynomial, and is calculated as follows:

1) The overhead bytes 2 to 10 of the OH frame are taken in network byte order, most significant bit first, to form a 72-bit pattern representing the coefficients of a polynomial $M(x)$ of degree 71.

2) $M(x)$ is multiplied by x^{16} and divided (modulo 2) by $G(x)$, producing a remainder $R(x)$ of degree 15 or less.

3) The coefficients of $R(x)$ are considered to be a 16-bit sequence, where x^{15} is the most significant bit.

4) This 16-bit sequence is the CRC-16 where the first bit of the CRC-16 to be transmitted is the coefficient of x^{15} and the last bit transmitted is the coefficient of x^0.

The demapper process performs steps 1-3 in the same manner as the mapper process, except that here, the $M(x)$ polynomial of step 1 includes the CRC-16 bits in received order, and has degree 87. In the absence of bit errors, the remainder shall be 0.

9.2.8 FlexO management communications channel (FCC)

An 896-bit (112 bytes) field per multi-frame is provided for a FlexO interface management communications channel. These are allocated across all 8 frames of the multi-frame. This provides a clear channel, and the format and content of the management channel is outside the scope of this recommendation.

NOTE – The FCC is intended for interface management functions and is not a generic communications channel.

The FCC field is located in all frames, in overhead bytes 13 to 26. If unused, the management channel shall be filled with all-0s prior to scrambling. The FCC bytes provide a communication channel per FlexO interface with an approximate bandwidth of 17.98 Mbit/s.

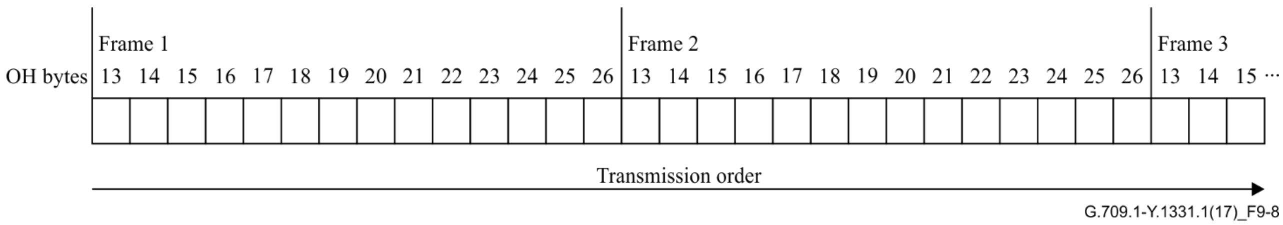

Figure 9-8 – FCC transmission order

9.2.9 FlexO reserved overhead (RES)

123.5 bytes of the FlexO overhead area in the FlexO multi-frame structure are reserved for future international standardization. These bytes/bits are located in frame 1/byte 5, frame 2/bytes 4, 5, 6, frames 3 to 8/bytes 3 to 6 and frames 1 to 8/bytes 29 to 40. These bytes/bits are set to all-0s prior to scrambling.

9.2.10 OTN Sync Message Channel (OSMC)

A 128-bit (16 bytes) field per multi-frame is provided for an OTN synchronization message channel. These are allocated across all eight frames of the multi-frame. This field provides a clear channel, to transport SSM and PTP messages.

The OSMC is only defined on the first FlexO interface (lowest PID value) of a FlexO group. The OSMC field is located in all frames, in overhead bytes 27 and 28. If unused, the OTN synchronization message channel bytes shall be filled with all-0s prior to scrambling. The OSMC bytes are combined to provide a messaging channel, as illustrated in Figure 9-9, with an approximate bandwidth of 2.56 Mbit/s per 100G interface.

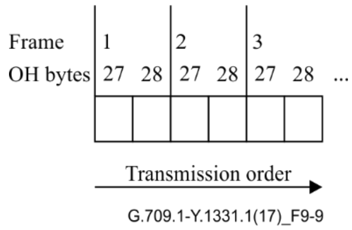

Figure 9-9 – OSMC transmission order

The SSM and PTP messages within a FlexO interface are encapsulated into GFP-F frames as specified into [ITU-T G.7041]. PTP event messages are timestamped and after encapsulation into GFP-F frames, inserted into the OSMC as specified in clause 9.2.9.1. GFP-F encapsulated SSM messages (and PTP non-event messages) are inserted into the OSMC at the earliest opportunity. GFP Idle frames may be inserted between successive GFP frames.

The mapping of generic framing procedure (GFP) frames is performed by aligning the byte structure of every GFP frame with the byte of the OSMC overhead field. Since the GFP frames are of variable length and may be longer than 16 bytes, a GFP frame may cross the FlexO multi-frame boundary.

9.2.10.1 Generation of event message timestamp

The message timestamp point [ITU-T G.8260] for a PTP event message transported over the OSMC shall be the 32-frame multi-frame event (corresponding to MFAS[4:8] = 00000) preceding the beginning of the GFP frame, in which the PTP event message is carried. Since the GFP frames may be longer than 64 bytes, a frame may cross the FlexO 32-frame multi-frame boundary.

All PTP event messages are timestamped on egress and ingress interfaces. The timestamp shall be the time at which the event message timestamp point passes the reference plane [ITU-T G.8260] marking the boundary between the PTP node (i.e., OTN node) and the network.

Event message timestamps are generated at the FlexO Access Point. The message timestamp point is specified below as the 32-frame FlexO multi-frame event corresponding to MFAS[4:8] = 00000. For this application, the FlexO multi-frame event is defined as when the first bit of the first alignment marker, corresponding to MFAS[4:8] = 00000 frame, on a lane crosses between the PTP node (i.e., OTN node) and the network (i.e., the analogous point to Ethernet MDI). In the case of a multi-lane PHY, the PTP path data delay is measured from the beginning of the alignment marker at the reference plane, which is equivalent to Ethernet MDI of the lane with the maximum media propagation delay. In practice:

– On egress interfaces, since the alignment markers for all lanes are transmitted at the same time conceptually, any alignment marker can be used for timestamping.

– On ingress interfaces, alignment markers are present in all the lanes, but different lanes may be skewed from each other. The last received alignment marker across all the lanes shall be used for timestamping.

NOTE 1 – The first byte of a GFP (PTP event message) frame is inserted into the FlexO OSMC between 4 and 31 frames after the 32-frame multi-frame boundary.

NOTE 2 – The guard band of four frames is defined to simplify implementation.

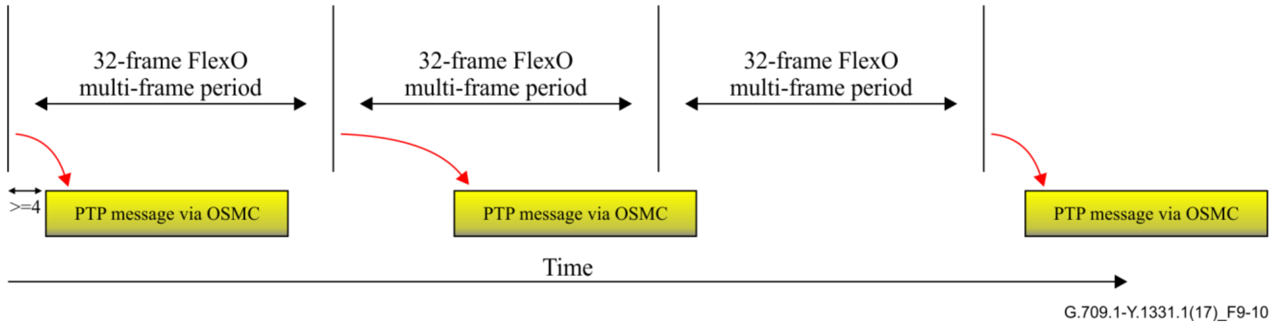

Figure 9-10 – Timing diagram example for OSMC

NOTE 3 – This time synchronization over FlexO interface implementation does not generate event message timestamps using a point other than the message timestamp point [ITU-T G.8260].

In this time synchronization over FlexO interface implementation, the timestamps are generated at a point removed from the reference plane. Furthermore, the time offset from the reference plane is likely to be different for inbound and outbound event messages. To meet the requirement of this subclause, the generated timestamps should be corrected for these offsets. Figure 19 in [IEEE 1588] illustrates these offsets. Based on this model, the appropriate corrections are as follows:

<egressTimestamp> = <egressMeasuredTimestamp> + egressLatency

<ingressTimestamp> = <ingressMeasuredTimestamp> – ingressLatency

where the actual timestamps <egressTimestamp> and <ingressTimestamp> measured at the reference plane are computed from the detected, i.e., measured, timestamps by their respective latencies. Failure to make these corrections results in a time offset between the slave and master clocks.

The PTP timestamp is associated with the first FlexO interface (lowest PID value) of a FlexO group.

10 OTUCn mapping

10.1 Dividing and combining OTUCn

An OTUCn frame structure is specified in clause 11.3 [ITU-T G.709], and contains n synchronous instances of OTUC frame structures. The FlexO source adaptation consists of splitting the OTUCn frame into n * OTUC instances. Similarly, the sink adaptation combines n * OTUC instances into an OTUCn. A single or multiple OTUC instances are then associated to a FlexO interface. Alignment and deskewing are performed on the OTUC instances.

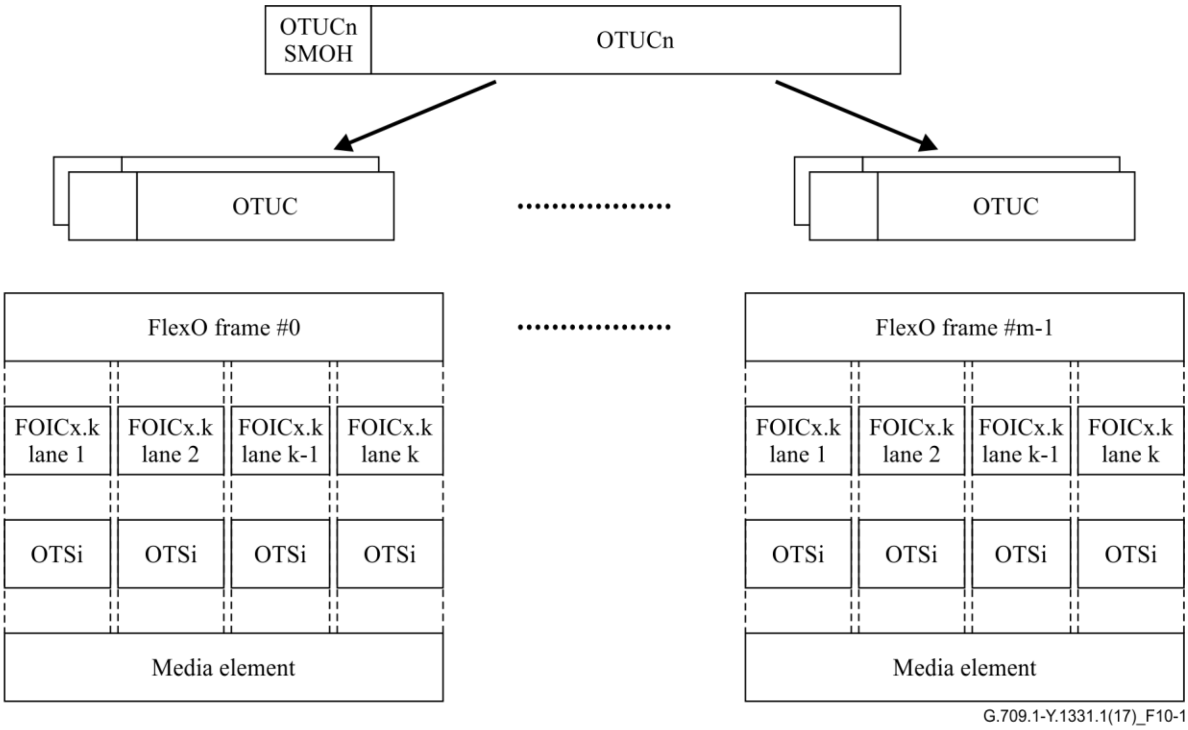

Figure 10-1 – OTUCn divided onto n * OTUC

10.2 FlexO frame payload

The FlexO payload area is divided in 128-bit blocks. The 128-bit blocks are aligned to the start of a FlexO payload area (following AM and OH). The FlexO frame payload consists of 5,120 blocks (frame #1-7 of the multi-frame, with fixed stuff payload) and 5,130 blocks (frame eight of the multi-frame, without fixed stuffing).

NOTE – This 128-bit (16-byte) word/block alignment of the 100G OTUC is analogous to the 66b block alignment of a 100G Ethernet PCS stream that is kept through the clause 91 [IEEE 802.3-2015] adaptation process.

10.3 Mapping of OTUC into FlexO frame

Groups of 128 successive bits (16 bytes) of the OTUC signal are mapped into a 128-bit block of the FlexO frame payload area using a BMP control mechanism as specified in clause 17 of [ITU-T G.709]. The 128-bit group of OTUC is aligned to the OTUC frame structure. The OTUC frame structure is floating in respect to the FlexO frame.

The serial bit stream of an OTUC signal is inserted into the FlexO frame payload so that the bits will be transmitted on the FlexO interface in the same order that they were received at the input of the mapper function.

In clause 8.3, the shown bit rate ratio between FlexO frame and payload is 256/241.

10.3.1 Mapping of OTUC into 100G FlexO frame

There exists a one-to-one relationship between an OTUC and a 100G FlexO interface. The FlexO payload area is segmented in 128-bit blocks. The OTUC is mapped in contiguous 128-bit segments.

There are (5,140*128*8 – 1,280*15) / (239*16*8*4) = 42.85 OTUC frames per FlexO multi-frame. This results in ~5 OTUC frames per FlexO frame, or a new OTUC frame every ~24 FlexO frame rows, as shown in Figure 10-2A.

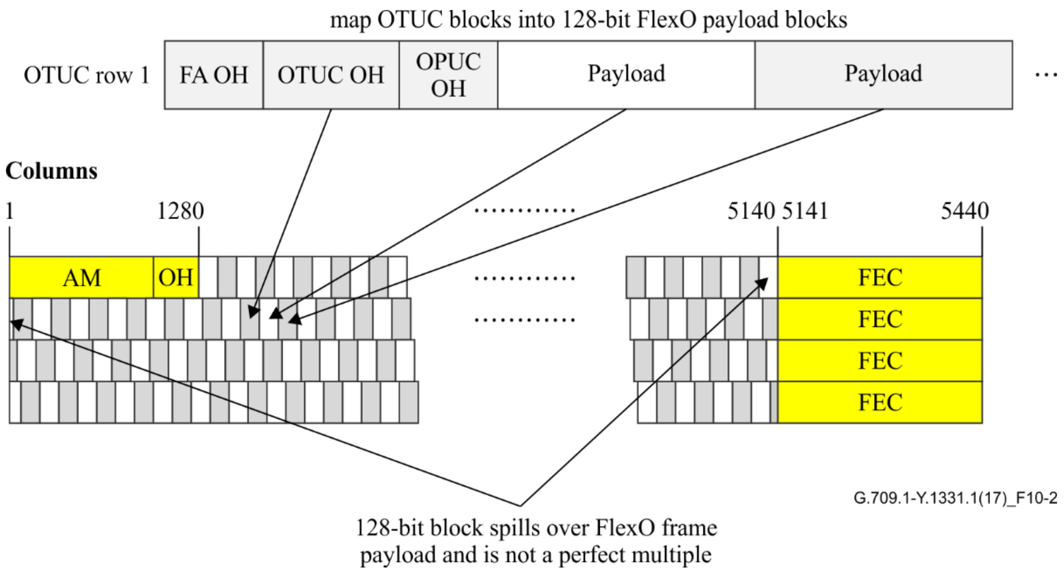

Figure 10-2A – OTUC mapped into 100G FlexO frame payload

The FlexO frame payload does not divide elegantly into 128-bit blocks in a single row. The block will spill over and cross row boundaries as shown in Figure 10-2A. The 128-bit alignment is always consistent across FlexO frames and the first 128-bit block starts immediately following the overhead area.

The AVAIL field indicates whether an OTUC is mapped into the FlexO frame payload (set to "1") or if the FlexO payload is empty (set to "0"). Other AVAIL values are not valid for 100G FlexO interfaces.

10.4 FlexO group alignment and deskewing

FlexO members are identified within a group and reordered using GID, MAP and PID FlexO OH field. The PID sequence is used to recreate an OTUCn in proper sequence order. For example OTUC#1 is mapped into a FlexO frame with the minimum PID number, and so on.

Deskewing in the sink process is performed between OTUC frames within the group, using OTUC FAS as specified in [ITU-T G.709].

The skew requirements are intended to account for variations due to digital mapping and cable lengths. The skew tolerance requirement is 300 ns.

NOTE – These requirements are in line with [OIF FlexE IA] Low Skew applications.

10.5 Scrambling

The FlexO frame payload, AM padding, fixed stuffing and overhead must be scrambled prior to transmission, in order to provide DC balance and proper running disparity on the interface. The ami fields in the AMs are not scrambled and the chosen values have properties of already being DC balanced. The padding padi fields of the AMs as shown in Figure 9-3A are scrambled.

The operation of the scrambler shall be functionally equivalent to that of a frame-synchronous scrambler of sequence 65535 and the generating polynomial shall be $x^{16} + x^{12} + x^3 + x + 1$. (See Figure 11-3 [ITU-T G.709] for an illustration of this scrambler.)

The scrambler resets to 0xFFFF on the most significant bit of the start of frame and the scrambler state advances during each bit of the FlexO frame (Figure 10-3). In the source function, the AM values (ami fields) are inserted after scrambling and before the input to the FEC encoder. In other words, the FEC encoding is performed on unscrambled AM bits (ami fields). The FEC encoder overwrites the

FEC bit fields. The sink then receives unscrambled AM (ami fields) and FEC fields, as illustrated in Figure 10-4.

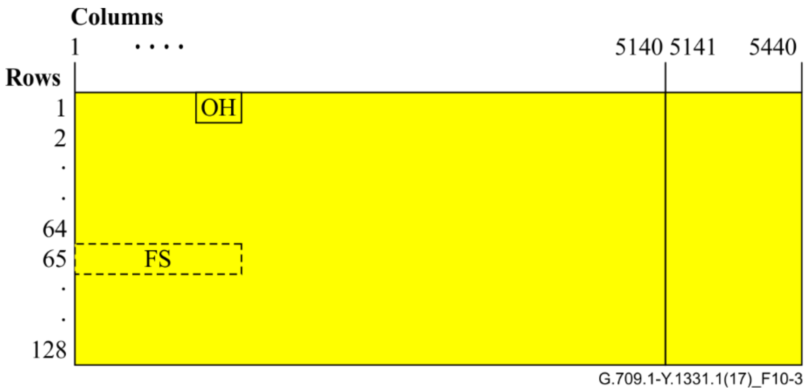

Figure 10-3 – FlexO scrambler

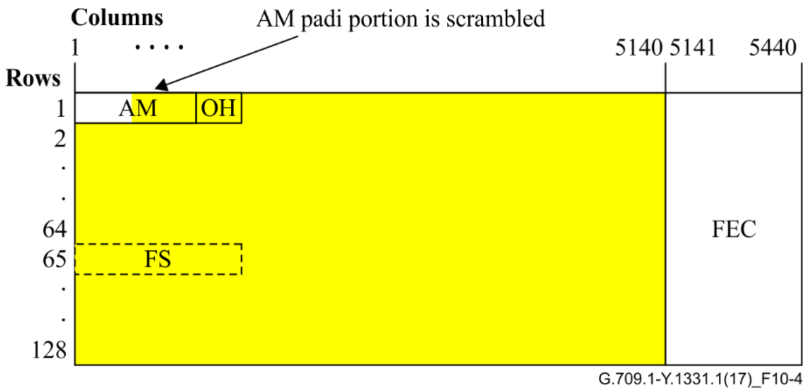

Figure 10-4 – FlexO scrambler after AM and FEC insertion

11 FOIC interface

11.1 FOIC1.4 interface

An FOIC1.4 interface is used as a system interface with 100G optical modules. A FlexO frame is adapted over multi-channel parallel interfaces, using four ~28 Gbit/s physical lanes. No bit-multiplexing is performed.

The alignment markers for the FlexO frame are distributed on four lanes, resulting in 240-bit of data per lane. The alignment marker (AM) values are specified in clause 9.1. Each AM has unique UMx and UPx values. When the four AMs distributed to lanes 0, 1, 2 and 3, the differing values are used for lane reordering in the sink function. The CMx values are replicated on all four lanes to facilitate the searching, alignment and deskewing process.

After FEC encoding, the data and parity bits are distributed to all four lanes, in groups of 10-bits, in a round robin distribution scheme from the lowest to the highest numbered lanes. The resulting per-lane transmitted values of the AM fields are illustrated in Table 11-1 where the transmission order is from left to right. In other words, for example, AM0 is transmitted in Lane 0, AM1 is transmitted in Lane 1, etc., and the bits of each 10-bit word are transmitted MSB first.

NOTE 1 – The inverse multiplexing function is based on clause 91 [IEEE 802.3-2015].

NOTE 2 – The mechanism is compatible and can reuse optical modules being developed for IEEE 100GBASE-R4, with OTU4 rate support.

NOTE 3 – The electrical specifications for an FOIC1.4 25G lane is found in [b-OIF CEI IA].

Table 11-1 – AM bit distribution over the four FOIC1.4 lanes

AM bits	Lane 0 10-bit symbol of AM0	Lane 1 10-bit symbol of AM1	Lane 2 10-bit symbol of AM2	Lane 3 10-bit symbol of AM3
1 – 40	0101100101	0101100101	0101100101	0101100101
41 – 80	0100100110	0100100110	0100100110	0100100110
81 – 120	0100011011	0100001000	0100011000	0100010110
121 – 160	0110100110	0010100110	1010100110	1010100110
161 – 200	1010110110	1010110110	1010110110	1010110110
201 – 240	0110111001	0110111110	0110110111	0110110010
241 – 280	1011100000	0110010110	1111011111	0001011000
281 – 320	0010001110	1001111011	0011001111	0100000001
321 – 360	1100111101	0111111000	0110101010	0000101111
361 – 400	1001000111	0110011010	0000001000	0111101001
401 – 440	1111011100	0101100001	0011001100	1110111111
441 – 480	0100110000	0010000001	0010010101	1011110100
NOTE – Transmission order of each 10-bit word is left-to-right (MSB first). The transmission order within the FlexO frame is left-to-right across the row, and down the table. The transmission order for each lane is per-word and down the table.				

11.1.1 FOIC1.4 skew tolerance requirements

The lane skew tolerance requirement is 180ns.

NOTE – These requirements are in line with CAUI4 [IEEE 802.3-2015].

11.1.2 FOIC1.4 28G lane bit rate

The FOIC1.4 lane is synchronous to the FlexO frame. There are four lanes.

FOIC1.4_lane_rate = 100G_FlexO_rate/4

= 1/4 × 256/241 × 239/226 × 99 532 800 kbit/s ±20 ppm

NOTE – The nominal lane rate is approximately: 27 952 368.611 kbit/s

The 100G_FlexO_rate is specified in clause 8.4.

This results in a FOIC1.4 lane bit rate with a -4.46 ppm offset from the OTL4.4 nominal bit rate.

11.1.3 m*FOIC1.4 interface

The m*FOIC1.4 interface supports multiple optical tributary signals on each of the m single optical spans with 3R regeneration at each end.

An m*FOIC1.4 interface signal contains one OTUCn signal striped across the m optical interfaces and the k=4 lanes per optical interface.

Specifications of the optical tributary signal carrying each FOIC1.4 lane are contained in [ITU-T G.695] and [ITU-T G.959.1].

Bibliography

[b-ITU-T G-Sup.58] ITU-T G-series Recommendations – Supplement 58 (2016), *Optical transport network (OTN) module framer interfaces (MFI).*

[b-IEEE 802.3bs] IEEE Std. 802.3bs/D2.0, *Draft Standard for Ethernet Amendment: Media Access Control Parameters, Physical Layers and Management Parameters for 200 Gb/s and 400 Gb/s Operation*.

[b-OIF CEI IA] OIF, Common Electrical I/O (CEI) (2014), *Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O.*

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