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ITU-T G.698.4 (06/2023)

SERIES G: Transmission systems and media, digital systems and networks

Transmission media and optical systems characteristics – Characteristics of optical systems

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Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces

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Recommendation ITU-T G.698.4

Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces

Summary

Recommendation ITU-T G.698.4 provides optical parameter values for physical layer interfaces of dense wavelength division multiplexing (DWDM) systems primarily intended for metro applications, where the tail-end transmitters have the capability to automatically adapt their DWDM channel frequency to the optical demultiplexer/optical multiplexer (OD/OM) or optical add-drop multiplexer (OADM) port. Applications are defined using optical interface parameters and values for single-channel and multichannel interfaces of multichannel DWDM optical systems in point-to-point applications. This Recommendation uses a system architecture comprising a head-end, connecting to the tail-end equipment (TEE) through a black link. The head end houses a set of transmitters and receivers and an OD/OM. A single bidirectional fibre is used to connect the head-end to the black link OD/OM or OADM. The connection between the OD/OM/OADM and the TEE is also bidirectional. This version of the Recommendation includes DWDM applications at 10 Gbit/s and 25 Gbit/s with minimum channel frequency spacing of 50 GHz and 100 GHz, respectively.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T G.698.4	2018-03-16	15	11.1002/1000/13519
1.1	ITU-T G.698.4 (2018) Cor. 1	2018-11-29	15	11.1002/1000/13741
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Keywords

Application codes, bidirectional, black link, DWDM, head-end, message channel, metro, multivendor, OADM, optical, pilot tone, port agnostic, tail-end.

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Recommendation ITU-T G.698.4

Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces

1 Scope

The purpose of this Recommendation is to provide optical interface specifications for the realization of transversely compatible bidirectional dense wavelength division multiplexing (DWDM) systems, primarily intended for metro applications. The tail-end equipment (TEE) transmitters have the capability to automatically adapt their DWDM channel frequency to the optical demultiplexer/optical multiplexer (OD/OM) or optical add/drop multiplexer (OADM) port. They are connected to using feedback from the head-end equipment (HEE) via the head-to-tail message channel (HTMC).

This Recommendation defines and provides values for optical interface parameters of point-to-point DWDM applications on single-mode optical fibres through the use of the "black link" approach with both of the propagation directions sharing the same optical fibre end-to-end.

For the applications in this version of the Recommendation, the black link does not contain optical amplifiers.

This Recommendation describes bidirectional DWDM systems that include the following features:

– minimum channel frequency spacing: 50 GHz for 10 Gbit/s and 100 GHz for 25 Gbit/s;

– bit rate of signal channel: 10 Gbit/s and 25 Gbit/s;

– maximum transmission distance: 20 km for 10 Gbit/s and 10 km for 25 Gbit/s;

– maximum capacity: 40 bidirectional channels at 10 Gbit/s and 20 bidirectional channels at 25 Gbit/s.

Specifications are organized according to the application codes.

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.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.664] Recommendation ITU-T G.664 (2012), *Optical safety procedures and requirements for optical transmission systems*.

[ITU-T G.671] Recommendation ITU-T G.671 (2019), *Transmission characteristics of optical components and subsystems.*

[ITU-T G.694.1] Recommendation ITU-T G.694.1 (2020), *Spectral grids for WDM applications: DWDM frequency grid.*

[ITU-T G.698.1] Recommendation ITU-T G.698.1 (2023), *Multichannel DWDM applications with single-channel optical interfaces*.

[ITU-T G.709.4] Recommendation ITU-T G.709.4/Y.1331.4 (2020), *OTU25 and OTU50 short-reach interfaces*.

[ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.*

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2018), *Optical transport network physical layer interfaces*.

[IEC 60825-1] IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2:2021, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCSs)*.

[IEEE 802.3] IEEE 802.3-2022, *IEEE Standard for Ethernet.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 Terms defined in [ITU-T G.671]:

– channel insertion loss;
– channel spacing;
– dense wavelength division multiplexing (DWDM);
– differential group delay;
– reflectance;
– ripple.

3.1.2 Term defined in [ITU-T G.694.1]:

– frequency grid.

3.1.3 Terms defined in [ITU-T G.957]:

– receiver sensitivity;
– transverse compatibility.

3.1.4 Terms defined in [ITU-T G.959.1]:

– optical tributary signal;
– optical tributary signal class non-return to zero (NRZ) 10G;
– optical tributary signal class NRZ 25G.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BER Bit Error Ratio

DWDM Dense Wavelength Division Multiplexing

HEE Head-End Equipment

HTMC	Head-to-Tail Message Channel
LOS	Loss of Signal
MPI-R_M	Multichannel reference point at the head-end aggregate input
MPI-S_M	Multichannel reference point at the head-end aggregate output
NRZ	Non-Return to Zero
OADM	Optical Add-Drop Multiplexer
OD	Optical Demultiplexer
OM	Optical Multiplexer
R_S	Single-channel reference point at the DWDM network element tributary output
S_S	Single-channel reference point at the DWDM network element tributary input
TEE	Tail-End Equipment
THMC	Tail to Head Message Channel
TOM	Type of Message

5 Conventions

None.

6 Classification of optical interfaces

6.1 Applications

This Recommendation provides the physical layer parameters and values for single-channel and multichannel interfaces of DWDM multichannel optical systems in physical point-to-point single fibre applications where the tail-end transmitters have the capability to automatically adapt their DWDM channel frequency. These DWDM systems are primarily intended to be used in metropolitan area networks for a variety of clients, services and protocols.

The specification method in this Recommendation uses a "black link" approach which means that the optical interface parameters for only (single-channel) optical tributary signals are specified at the tail-end equipment (TEE). Additional specifications are provided for the black link parameters such as maximum attenuation, chromatic dispersion, ripple and polarization mode dispersion. This approach enables transverse compatibility at the single-channel point using a direct wavelength-multiplexing configuration and also transverse compatibility at the head-end multichannel point as shown in Figure 6-1.

6.2 Reference points

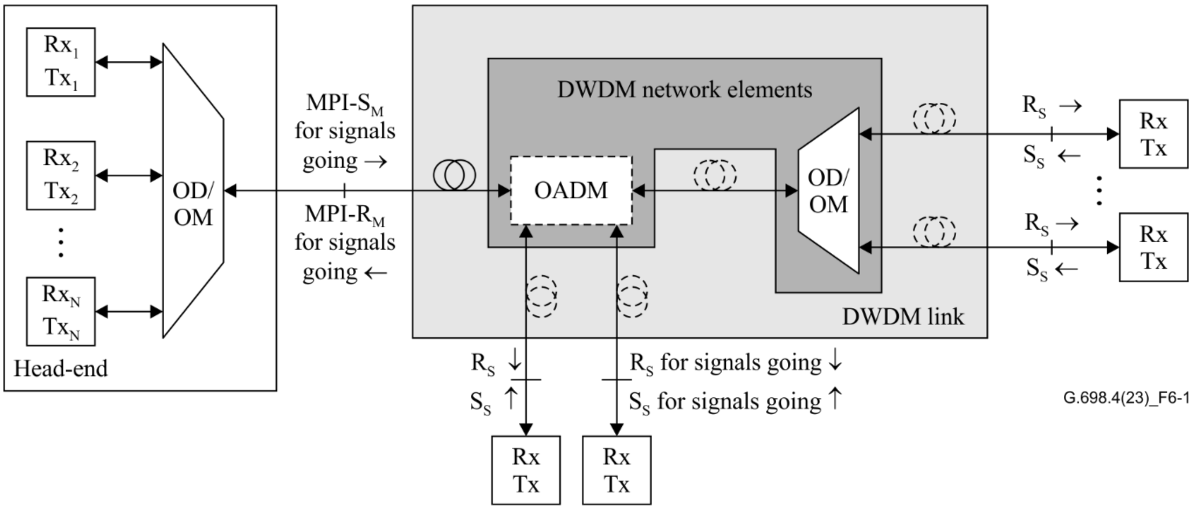

Figure 6-1 – Linear "black link" approach

The system architecture comprises a head-end, connecting to the TEE through a black link. The head-end houses a set of transmitters and receivers and an OD/OM. A single bidirectional fibre is used to connect the head-end to the passive OD/OM as well as the optional OADMs. The connection between the OD/OM or OADM(s) and TEE is also bidirectional. The OD/OM is considered to be part of the black link. The TEE transmitters have the capability to automatically adapt their DWDM channel frequency to the OD/OM or OADM port they are connected to.

The reference points in Figure 6-1 are defined as follows:

– MPI-S_M is a multichannel reference point at the head-end aggregate output;

– MPI-R_M is a multichannel reference point at the head-end aggregate input;

– S_S is a single-channel reference point at the TEE output;

– R_S is a single-channel reference point at the TEE input.

At the MPI-S_M interface, multichannel data signals are transmitted by the head-end.

At the R_S interface, a single channel data signal passes through towards the TEE.

At the S_S interface, a single channel signal is transmitted by the TEE whose wavelength is appropriate to that of the connected OD/OM or OADM port.

At the MPI-R_M interface, a multichannel signal is received by the head-end.

6.3 Nomenclature

The application code notation is constructed as follows:

ADcW-y-tz

where:

AD: is the indicator of metro DWDM applications with port agnostic TEE

c: is the channel spacing in GHz

W: is a letter indicating the span distance, such as:

– ***S*** indicating short-haul

y: indicates the highest class of optical tributary signal supported:

– 2 indicating NRZ 10G;

– 9 indicating NRZ 25G

t: indicates the configuration supported by the application code. In the current version of this Recommendation, the only value used is:

– *D* indicating that the black link does not contain any optical amplifiers

z: indicates the fibre types. In the current version of this Recommendation, the only value used is:

– 2 indicating ITU-T G.652 fibre.

7 Transverse compatibility

This Recommendation specifies parameters in order to enable transverse (i.e., multivendor) compatible line systems for point-to-point applications at single-channel reference points S_S and R_S and multichannel reference points MPI-S_M and MPI-R_M of the black link.

The single-channel reference points S_S and R_S are intended to make multiple tributary interfaces of tunable DWDM TEEs transversely compatible with the head-end. In this case, tributary signal transmitter (Tx λ_i) and receiver (Rx λ_i) pairs may be from different vendors. Similarly, multichannel reference points MPI-S_M and MPI-R_M are intended to make black link and head-end equipment transversely compatible. Thus, TEE, black link and head-end equipment suppliers are not necessarily the same.

Transverse (multivendor) compatibility is enabled for reference points MPI-S_M to R_S and S_S to MPI-R_M of black links having exactly the same application code.

8 Parameter definitions

The parameters in Table 8-1 are defined at the interface points and the definitions are provided in the clauses below.

Table 8-1 – Physical layer parameters for multichannel bi-directional DWDM applications

Parameter	Units	For HEE to TEE defined in:	For TEE to HEE defined in:
General information			
Minimum channel spacing	GHz	8.1.1	8.1.1
Bit-rate / line coding of optical tributary signals	–	8.1.2	8.1.2
Maximum bit-error ratio	–	8.1.3	8.1.3
Fibre type	–	8.1.4	8.1.4
Interface at point S_S or MPI-S_M			
Maximum mean channel output power	dBm	8.2.1	8.2.1
Minimum mean channel output power	dBm	8.2.1	8.2.1
Maximum mean total output power	dBm	8.2.2	NA
Minimum central frequency	THz	8.2.3	8.2.3
Maximum central frequency	THz	8.2.3	8.2.3
Maximum spectral excursion	GHz	8.2.4	8.2.4
Maximum laser drift	GHz/10 min	8.2.5	8.2.5
Minimum channel extinction ratio	dB	8.2.6	8.2.6
Eye mask	–	8.2.7	8.2.7

Table 8-1 – Physical layer parameters for multichannel bi-directional DWDM applications

Parameter	Units	For HEE to TEE defined in:	For TEE to HEE defined in:
Bit rate of the message channel	kbit/s	8.2.8	8.2.8
Maximum frequency tolerance of the message channel	ppm	8.2.8	8.2.8
Maximum modulation depth of the message channel	%	8.2.9	8.2.9
Minimum modulation depth of the message channel	%	8.2.9	8.2.9
Maximum modulation depth of the pilot tone during operation	%	NA	8.2.10
Minimum modulation depth of the pilot tone during operation	%	NA	8.2.10
Minimum modulation depth of the pilot tone during tuning	%	NA	8.2.10
Maximum frequency of pilot tone	Hz	NA	8.2.11
Minimum frequency of pilot tone	Hz	NA	8.2.11
Maximum frequency tolerance of pilot tone	ppm	NA	8.2.11
Minimum frequency spacing of pilot tones	Hz	NA	8.2.11
Maximum combined tolerance of Rx power measurement and Tx power setting at TEE (±)	dB	NA	8.2.12
Optical path from point MPI-S_M to R_S or S_S to MPI-R_M			
Maximum channel insertion loss	dB	8.3.1	8.3.1
Minimum channel insertion loss	dB	8.3.1	8.3.1
Maximum ripple	dB	8.3.2	8.3.2
Maximum chromatic dispersion	ps/nm	8.3.3	8.3.3
Minimum optical return loss at MPI-S_M or S_S	dB	8.3.4	8.3.4
Maximum discrete reflectance between MPI-S_M and R_S or between S_S and MPI-R_M	dB	8.3.5	8.3.5
Maximum differential group delay	ps	8.3.6	8.3.6
Maximum inter-channel crosstalk at R_S	dB	8.3.7	8.3.7
Maximum loss difference between HE-to-TE and TE-to-HE direction	dB	8.3.8	8.3.8
Minimum black link channel width	GHz	8.3.9	8.3.9
Interface at point R_S or MPI-R_M			
Maximum mean channel input power	dBm	8.4.1	8.4.1
Minimum mean channel input power	dBm	8.4.1	8.4.1
Maximum mean total input power	dBm	NA	8.4.2
Receiver sensitivity	dBm	8.4.3	NA
Minimum equivalent sensitivity	dBm	NA	8.4.4
Maximum optical path penalty	dB	8.4.5	8.4.5
Maximum reflectance of receiver or optical network element	dB	8.4.6	8.4.6
Maximum mean channel input power during tuning	dBm	NA	8.4.7
Minimum mean channel input power during tuning	dBm	NA	8.4.7

8.1 General information

8.1.1 Minimum channel spacing

The minimum channel spacing is defined as in [ITU-T G.698.1].

8.1.2 Bit-rate / line coding of optical tributary signals

The bit-rate/line coding of optical tributary signals is defined as in [ITU-T G.959.1].

8.1.3 Maximum bit-error ratio

The maximum bit-error ratio is defined as in [ITU-T G.698.1].

8.1.4 Fibre type

Currently, the only single-mode optical fibre type is that defined in [ITU-T G.652].

8.2 Interface at point S_S or MPI-S_M

8.2.1 Maximum and minimum mean channel output power

The mean channel output power is defined as in [ITU-T G.959.1].

8.2.2 Maximum mean total output power

The maximum mean total output power is defined as in [ITU-T G.959.1].

8.2.3 Minimum and maximum central frequency

The central frequency is defined as in [ITU-T G.698.1].

For each optical channel, different ranges of frequencies are used in the HE-to-TE and TE-to-HE directions. The channel frequencies in the two directions are paired so that their difference is equal to the minimum value compatible with the frequency ranges.

In application code AD100S-2-D2 and AD100S-9-D2, the optical channel frequencies are paired according to Table 8-2.

Table 8-2 – Frequency pairing for AD100S-2-D2 and AD100S-9-D2

HE-to-TE	TE-to-HE
194.1	191.5
194.2	191.6
…	…
196	193.4

In application code AD50S-2-D2 the optical channel frequencies are paired according to Table 8-3.

Table 8-3 – Frequency pairing for AD50S-2-D2

HE-to-TE	TE-to-HE
194.05	191.45
194.1	191.5
…	…
196	193.4

8.2.4 Maximum spectral excursion

The maximum spectral excursion is defined as in [ITU-T G.698.1].

8.2.5 Maximum laser drift

The maximum variation within a time window of 10 minutes of the centroid of the TEE transmitter frequency averaged over 200 ms. The drift is measured without the frequency control feedback from the HEE.

8.2.6 Minimum channel extinction ratio

The minimum channel extinction ratio is defined as in [ITU-T G.698.1].

8.2.7 Eye mask

The eye mask can be measured by means of the set-up in Figure 8-1. The eye mask and limits for this parameter are found in [ITU-T G.959.1].

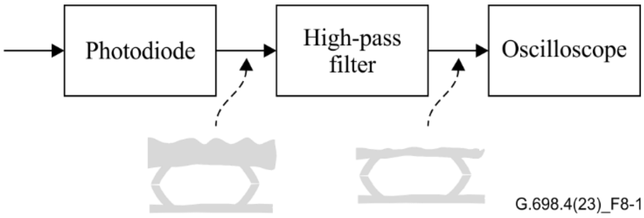

Figure 8-1 – Measurement set-up for the eye mask

NOTE – The cut-off frequency of the high-pass filter is 280 kHz.

8.2.8 Bit rate of the message channel

The bit rate of the message channel that is used to transmit information from the HEE to the TEE or from the TEE to the HEE via envelope modulation of the optical signal.

8.2.9 Minimum and maximum modulation depth of the message channel

The modulation depth of the message channel is the difference between the average optical power in the "ones" of the message channel and the average optical power in the "zeroes", divided by twice the average optical power.

$$m_{MC} = \frac{P(1) - P(0)}{P(1) + P(0)}$$

The average optical powers can be measured by means of the set-up in Figure 8-2 given below.

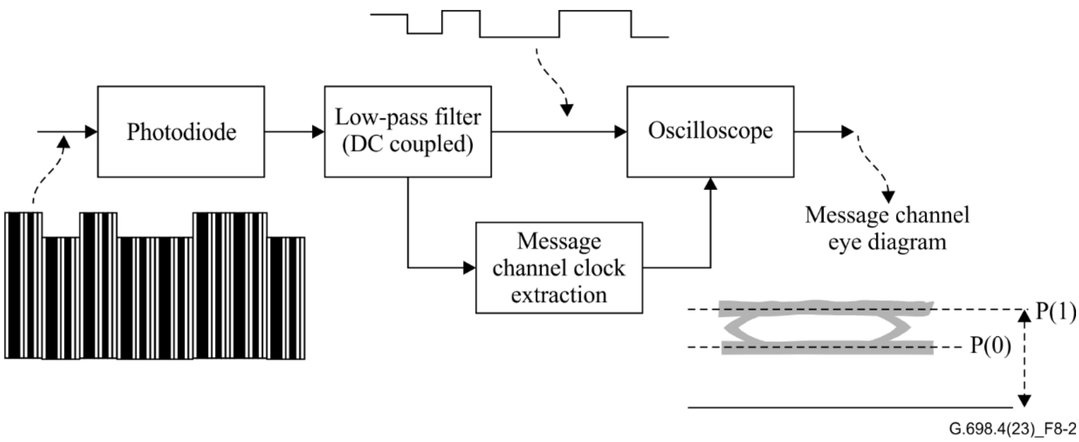

Figure 8-2 – Measurement set-up for the modulation depth of the message channel

8.2.10 Minimum and maximum modulation depth of the pilot tone

The modulation depth of the pilot tone is the peak-to-peak power excursion of the optical signal at the pilot tone frequency, divided by twice the average optical power.

$$m_{PT} = \frac{Pmax - Pmin}{Pmax + Pmin}$$

The average optical powers can be measured by means of the set-up in Figure 8-3.

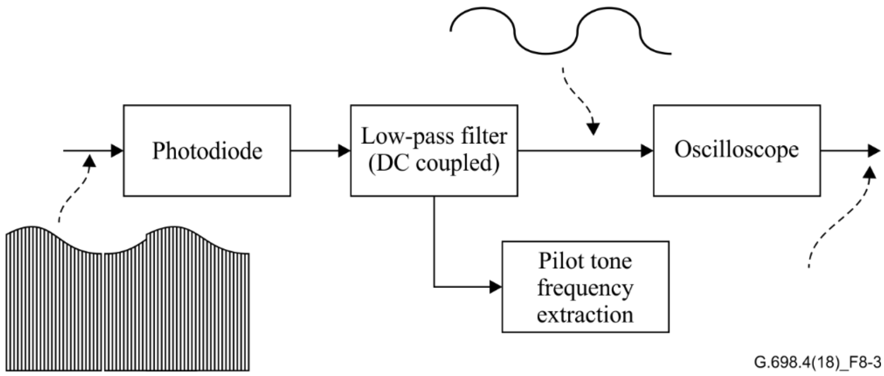

Figure 8-3 – Measurement set-up for the modulation depth of pilot tone

Note that the cut-off frequency of the low-pass filter is different for maximum and minimum modulation depth. To measure the modulation depth against the minimum modulation depth parameter value, the low-pass filter cut-off frequency is 60 kHz. To measure the modulation depth against the maximum modulation depth parameter value the low-pass filter cut-off frequency is 280 kHz.

8.2.11 Minimum and maximum frequency and minimum frequency spacing of the pilot tones

Each pilot tone frequency is the minimum pilot tone frequency plus an integer multiple of the minimum frequency spacing and lies in a range between the minimum and maximum pilot tone frequency.

8.2.12 Maximum combined tolerance of Rx power measurement and Tx power setting at TEE

This is the sum of the tolerances for the receive power measurement at the R_S interface and the transmit power setting at the S_S interface.

The combined tolerance of Rx power measurement and Tx power setting, ΔP_{RxTx}, is determined from the reference power communicated to the TEE, P_{ref}, the received mean channel input power, P_{RS} and the actual output power during tuning, $P_{SS,tune}$, as:

$$\Delta P_{RXTX} = \left| P_{SS,tune} + P_{RS} - P_{ref} \right|$$

Where $|\ldots|$ indicates the absolute value and the power values are given in dBm.

8.3 Optical path from point MPI-S_M to R_S or S_S to MPI-R_M

8.3.1 Maximum and minimum channel insertion loss

The channel insertion loss is defined as in [ITU-T G.698.1].

8.3.2 Maximum ripple

The ripple is defined as in [ITU-T G.698.1].

8.3.3 Maximum chromatic dispersion

The maximum chromatic dispersion is defined as in [ITU-T G.698.1]

8.3.4 Minimum optical return loss at MPI-S_M or S_S

The minimum optical return loss is defined as in [ITU-T G.959.1].

8.3.5 Maximum discrete reflectance between MPI-S_M and R_S or between S_S and MPI-R_M

The maximum discrete reflectance is defined as in [ITU-T G.959.1].

8.3.6 Maximum differential group delay

The maximum differential group delay is defined as in [ITU-T G.698.1]

8.3.7 Maximum inter-channel crosstalk at R_S

The inter-channel crosstalk is defined as in [ITU-T G.698.1].

8.3.8 Maximum loss difference between HE-to-TE and TE-to-HE direction

This parameter defines the maximum absolute difference between the insertion loss of the optical path from point MPI-S_M to R_S for the HEE to TEE wavelength of a channel, and the insertion loss of the optical path from point S_S to MPI-R_M for the TEE to HEE wavelength of the corresponding channel.

8.3.9 Minimum black link channel width

The minimum black link channel width is defined as in [ITU-T G.698.1].

8.4 Interface at point R_S or MPI-R_M

8.4.1 Maximum and minimum mean channel input power

The mean channel input power is defined as in [ITU-T G.959.1].

8.4.2 Maximum mean total input power

The maximum mean total input power is defined as in [ITU-T G.959.1].

8.4.3 Receiver sensitivity

The receiver sensitivity is defined as in [ITU-T G.698.1].

8.4.4 Minimum equivalent sensitivity

The minimum equivalent sensitivity is defined as in [ITU-T G.959.1].

8.4.5 Maximum optical path penalty

The maximum optical path penalty is defined as in [ITU-T G.698.1].

8.4.6 Maximum reflectance of receiver or optical network element

The maximum reflectance of the receiver is defined as in [ITU-T G.698.1]

8.4.7 Minimum and maximum mean channel input power during tuning

The mean channel input power during tuning is the input power of a tuning channel at interface MPI-R_M, when the wavelength of this channel has tuned to the central frequency of the target channel.

9 Parameter values

Table 9-1 shows parameter values from HEE to TEE for 100 GHz spaced applications at 10 Gbit/s.

Table 9-1 – From HEE to TEE for 100 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD100S-2-D2
General information		
Minimum channel spacing	GHz	100
Bit rate / line coding of optical tributary signals	–	NRZ 10G
Maximum bit-error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	−2
Minimum mean channel output power	dBm	−5
Maximum mean total output power	dBm	11
Minimum central frequency	THz	194.1
Maximum central frequency	THz	196
Maximum spectral excursion	GHz	±12.5
Minimum channel extinction ratio	dB	8.2
Eye mask	–	NRZ 10G ratio small
Bit rate of the message channel	kbit/s	50
Maximum frequency tolerance of the message channel	ppm	100
Maximum modulation depth of the message channel	%	8
Minimum modulation depth of the message channel	%	6.5
Optical path from point MPI-S_M to R_S		
Maximum channel insertion loss	dB	14
Minimum channel insertion loss	dB	8
Maximum ripple	dB	2
Maximum chromatic dispersion	ps/nm	400
Minimum optical return loss at MPI-S_M	dB	24
Maximum discrete reflectance between MPI-S_M and R_S	dB	−27
Maximum differential group delay	ps	30
Maximum inter-channel crosstalk at R_S	dB	−16
Maximum loss difference between HE-to-TE and TE-to-HE direction	dB	2
Interface at point R_S		
Maximum mean channel input power	dBm	−10
Minimum mean channel input power	dBm	−19
Receiver sensitivity	dBm	−21.5
Maximum optical path penalty	dB	2.5
Maximum reflectance of the receiver or the optical network element	dB	−27

Table 9-2 shows the parameter values from TEE to HEE for 100 GHz spaced applications at 10 Gbit/s.

Table 9-2 – From TEE to HEE for 100 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD100S-2-D2
General information		
Minimum channel spacing	GHz	100
Bit rate / line coding of the optical tributary signals	–	NRZ 10G
Maximum bit-error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point S_S		
Maximum mean channel output power	dBm	+2
Minimum mean channel output power	dBm	−2
Minimum central frequency	THz	191.5
Maximum central frequency	THz	193.4
Maximum spectral excursion	GHz	±12.5
Maximum laser drift	GHz/10 min	1
Minimum channel extinction ratio	dB	8.2
Eye mask	–	NRZ 10G ratio small
Bit rate of the message channel	kbit/s	50
Maximum frequency tolerance of the message channel	ppm	100
Maximum modulation depth of the message channel	%	8
Minimum modulation depth of the message channel	%	6.5
Maximum modulation depth of the pilot tone during operation	%	8
Minimum modulation depth of the pilot tone during operation	%	5
Minimum modulation depth of the pilot tone during tuning	%	40
Maximum frequency of the pilot tone	Hz	52 500
Minimum frequency of the pilot tone	Hz	47 500
Maximum frequency tolerance of the pilot tone	ppm	100
Minimum frequency spacing of the pilot tones	Hz	50
Maximum combined tolerance of the Rx power measurement and the Tx power setting at TEE (±)	dB	2
Optical path from point S_S to MPI-R_M		
Maximum channel insertion loss	dB	14
Minimum channel insertion loss	dB	8
Maximum ripple	dB	2
Maximum chromatic dispersion	ps/nm	400
Minimum optical return loss at S_S	dB	24
Maximum discrete reflectance between S_S and MPI-R_M	dB	−27
Maximum differential group delay	ps	30
Maximum loss difference between HE-to-TE and TE-to-HE direction	dB	2
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	−6
Minimum mean channel input power	dBm	−16
Maximum mean total input power	dBm	7

Table 9-2 – From TEE to HEE for 100 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD100S-2-D2
Minimum equivalent sensitivity	dBm	−18.5
Maximum optical path penalty	dB	2.5
Maximum reflectance of the receiver or the optical network element	dB	−27
Maximum mean channel input power during tuning	dBm	−19
Minimum mean channel input power during tuning	dBm	−30

Table 9-3 shows the parameter values from HEE to TEE for 50 GHz spaced applications at 10 Gbit/s.

Table 9-3 – From HEE to TEE for 50 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD50S-2-D2
General information		
Minimum channel spacing	GHz	50
Bit rate / line coding of the optical tributary signals	–	NRZ 10G
Maximum bit-error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	−2
Minimum mean channel output power	dBm	−5
Maximum mean total output power	dBm	14
Minimum central frequency	THz	194.05
Maximum central frequency	THz	196
Maximum spectral excursion	GHz	±12.5
Minimum channel extinction ratio	dB	8.2
Eye mask	–	NRZ 10G ratio small
Bit rate of the message channel	kbit/s	50
Maximum frequency tolerance of the message channel	ppm	100
Maximum modulation depth of the message channel	%	8
Minimum modulation depth of the message channel	%	6.5
Optical path from point MPI-S_M to R_S		
Maximum channel insertion loss	dB	14
Minimum channel insertion loss	dB	8
Maximum ripple	dB	2
Maximum chromatic dispersion	ps/nm	400
Minimum optical return loss at MPI-S_M	dB	24
Maximum discrete reflectance between MPI-S_M and R_S	dB	−27
Maximum differential group delay	ps	30
Maximum inter-channel crosstalk at R_S	dB	−16
Maximum loss difference between HE-to-TE and TE-to-HE direction	dB	2

Table 9-3 – From HEE to TEE for 50 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD50S-2-D2
Interface at point R_S		
Maximum mean channel input power	dBm	−10
Minimum mean channel input power	dBm	−19
Receiver sensitivity	dBm	−21.5
Maximum optical path penalty	dB	2.5
Maximum reflectance of the receiver or the optical network element	dB	−27

Table 9-4 shows the parameter values from TEE to HEE for 50 GHz spaced applications at 10 Gbit/s.

Table 9-4 – From TEE to HEE for 50 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD50S-2-D2
General information		
Minimum channel spacing	GHz	50
Bit rate / line coding of the optical tributary signals	–	NRZ 10G
Maximum bit-error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point S_S		
Maximum mean channel output power	dBm	+2
Minimum mean channel output power	dBm	−2
Minimum central frequency	THz	191.45
Maximum central frequency	THz	193.4
Maximum spectral excursion	GHz	±12.5
Maximum laser drift	GHz/10 min	1
Minimum channel extinction ratio	dB	8.2
Eye mask	–	NRZ 10G ratio small
Bit rate of the message channel	kbit/s	50
Maximum frequency tolerance of the message channel	ppm	100
Maximum modulation depth of the message channel	%	8
Minimum modulation depth of the message channel	%	6.5
Maximum modulation depth of the pilot tone during operation	%	8
Minimum modulation depth of the pilot tone during operation	%	5
Minimum modulation depth of the pilot tone during tuning	%	40
Maximum frequency of the pilot tone	Hz	52 500
Minimum frequency of the pilot tone	Hz	47 500
Maximum frequency tolerance of the pilot tone	ppm	100
Minimum frequency spacing of the pilot tones	Hz	50
Maximum combined tolerance of the Rx power measurement and the Tx power setting at TEE (±)	dB	2

Table 9-4 – From TEE to HEE for 50 GHz spaced applications at 10 Gbit/s

Parameter	Units	AD50S-2-D2
Optical path from point S_S to MPI-R_M		
Maximum channel insertion loss	dB	14
Minimum channel insertion loss	dB	8
Maximum ripple	dB	2
Maximum chromatic dispersion	ps/nm	400
Minimum optical return loss at S_S	dB	24
Maximum discrete reflectance between S_S and MPI-R_M	dB	−27
Maximum differential group delay	ps	30
Maximum loss difference between HE-to-TE and TE-to-HE direction	dB	2
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	−6
Minimum mean channel input power	dBm	−16
Maximum mean total input power	dBm	10
Minimum equivalent sensitivity	dBm	−18.5
Maximum optical path penalty	dB	2.5
Maximum reflectance of the receiver or the optical network element	dB	−27
Maximum mean channel input power during tuning	dBm	−19
Minimum mean channel input power during tuning	dBm	−30

Table 9-5 shows the parameter values from HEE to TEE for 100 GHz spaced applications at 25 Gbit/s.

Table 9-5 – From HEE to TEE for 100 GHz spaced applications at 25 Gbit/s

Parameter	Units	AD100S-9-D2
General information		
Minimum channel spacing	GHz	100
Bit rate / line coding of the optical tributary signals	–	25.78125 ± 100 ppm / 25G NRZ
Maximum bit-error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	-1
Minimum mean channel output power	dBm	-7
Maximum mean total output power	dBm	12
Minimum central frequency	THz	194.1
Maximum central frequency	THz	196
Maximum spectral excursion	GHz	±30
Minimum channel extinction ratio	dB	6
Eye mask	–	NRZ 25G ratio
Bit rate of the message channel	kbit/s	50
Maximum frequency tolerance of the message channel	ppm	100

Table 9-5 – From HEE to TEE for 100 GHz spaced applications at 25 Gbit/s

Parameter	Units	AD100S-9-D2
Maximum modulation depth of the message channel	%	8
Minimum modulation depth of the message channel	%	6.5
Optical path from point MPI-S_M to R_S		
Maximum channel insertion loss	dB	11
Minimum channel insertion loss	dB	4
Maximum ripple	dB	2
Maximum chromatic dispersion	ps/nm	200
Minimum optical return loss at MPI-S_M	dB	24
Maximum discrete reflectance between MPI-S_M and R_S	dB	-27
Maximum differential group delay	ps	10
Maximum inter-channel crosstalk at R_S	dB	-16
Minimum black link channel width	GHz	+/- 53
Interface at point R_S		
Maximum mean channel input power	dBm	-5
Minimum mean channel input power	dBm	-18
Receiver sensitivity	dBm	-20.5
Maximum optical path penalty	dB	2.5
Maximum reflectance of receiver or optical network element	dB	-27
NOTE – The bit error ratio (BER) for these application codes is required to be met only after RS10(528,514) has been applied, as in the OTU25u-RS FEC specification in [ITU-T G.709.4].		

Table 9-6 shows the parameter values from TEE to HEE for 100 GHz spaced applications at 25 Gbit/s.

Table 9-6 – From TEE to HEE for 100 GHz spaced applications at 25 Gbit/s

Parameter	Units	AD100S-9-D2
General information		
Minimum channel spacing	GHz	100G
Bit rate / line coding of the optical tributary signals	–	25.78125 ± 100 ppm / 25G NRZ
Maximum bit-error ratio	–	10^{-12} (Note)
Fibre type	–	G.652
Interface at point S_S		
Maximum mean channel output power	dBm	4
Minimum mean channel output power	dBm	-2
Minimum central frequency	THz	191.5
Maximum central frequency	THz	193.4
Maximum spectral excursion	GHz	±30
Minimum channel extinction ratio	dB	6
Eye mask	–	NRZ 25G ratio
Bit rate of the message channel	kbit/s	50

Table 9-6 – From TEE to HEE for 100 GHz spaced applications at 25 Gbit/s

Parameter	Units	AD100S-9-D2
Maximum frequency tolerance of the message channel	ppm	100
Maximum modulation depth of the message channel	%	8
Minimum modulation depth of the message channel	%	6.5
Optical path from point S_S to MPI-R_M		
Maximum channel insertion loss	dB	11
Minimum channel insertion loss	dB	4
Maximum ripple	dB	2
Maximum chromatic dispersion	ps/nm	200
Minimum optical return loss at S_S	dB	24
Maximum discrete reflectance between S_S and MPI-R_M	dB	−27
Maximum differential group delay	ps	10
Minimum black link channel width	GHz	±53
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	0
Minimum mean channel input power	dBm	−13
Maximum mean total input power	dBm	13
Minimum equivalent sensitivity	dBm	−15.5
Maximum optical path penalty	dB	2.5
Maximum reflectance of the receiver or optical network element	dB	−27
NOTE – The BER for these application codes is required to be met only after RS10(528,514) has been applied, as in the OTU25u-RS FEC specification in [ITU-T G.709.4].		

10 Optical safety considerations

See [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2] for optical safety considerations.

11 Method of operation for 10 Gbit/s applications which do not have the ability to tune to the required TEE central frequency on its own

11.1 Optical frequency setting during tuning

11.1.1 Introduction

The tuning procedure described in this section applies to tunable 10 Gbit/s TEE which does not have the ability to tune to the required central frequency on its own. This clause describes the means that are provided to enable the TEE to tune to an appropriate central frequency.

The tuning mechanism relies on a low modulation index[2] amplitude modulation of the HEE to TEE channels (HTMC, head-to-tail message channel).

The head-to-tail message channel (HTMC) is used to provide the information necessary to allow the HEE to automatically set the TEE central frequency and output power while avoiding traffic disruption on other working channels, due to interferometric or interchannel crosstalk.

[2] A low modulation index is used in order to limit the sensitivity penalty at the TEE receiver.

To assist the tuning mechanism, the HEE can command the TEE to transmit a pilot tone at a frequency selected by the HEE.

This Recommendation also specifies the framing and information elements used on the HTMC.

A low modulation index amplitude modulation of the TEE to HEE channels the tail to head message channel (THMC) and can be used to transmit proprietary information. This Recommendation does not specify the structure or content of this information.

11.1.2 HTMC frame structure

The HTMC frame includes:

– an 11-bit field indicating the type of message (TOM);

– a 5-bit checksum field for the TOM;

– a 24-bit field communicating the message content;

– an 8-bit checksum field for the message content.

The frame structure is illustrated in Figure 11-1.

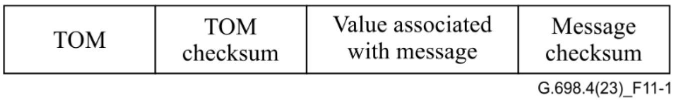

Figure 11-1 – HTMC frame structure

The TOM checksum and the message checksum are generated based on (16,11) and (32,26) Hamming codes, respectively.

The Hamming check bits of the TOM and message value fields are arranged as follows: the bits are ordered from 15 for the TOM, or 31 for the value field, down to 0, to designate the position number of each bit. Positions with power of 2 position number are occupied by Hamming check bits. Position 0 is occupied by the parity bit. The remaining 11 positions for the TOM or 26 positions for the value field are used for data. In the case of the message value field, two "1" bits are appended to the 24 value bits as the two least significant data bits to complete the 26 data bits.

The Hamming check bits are calculated by bit-wise modulo-2 addition of the position numbers of all data bits with value "1". Hamming check bit 0 is located in position 1, Hamming check bit 1 in position 2, Hamming check bit 2 in position 4, Hamming check bit 3 in position 8 and Hamming check bit 4 in position 16 (only for the value field). Finally, to form the parity bit, the modulo-2 sum of all 15 or 31 Hamming codeword bits is calculated, its value is logically inverted and the result is assigned to position 0.

Subsequently, the 16 or 32 bits are ordered such that first the 11 or 24 data bits (most significant to least significant) are transmitted and then the 5 or 8 check bits, fixed bits and parity bit.

An example for the TOM field is shown in Table 11-1.

Table 11-1 – Example of the TOM field

Position	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Position, binary	1111	1110	1101	1100	1011	1010	1001	1000	0111	0110	0101	0100	0011	0010	0001	0000
Content	D10	D9	D8	D7	D6	D5	D4	C3	D3	D2	D1	C2	D0	C1	C0	P
Example	0	0	0	1	1	1	0	1	1	0	0	0	1	0	1	0

In Table 11-1, the checksum bits are calculated by bit-wise modulo-2 addition (denoted by the symbol "$\oplus$") of the position numbers containing data bits with value "1":

1100 (D7)

⊕ 1011 (D6)

⊕ 1010 (D5)

⊕ 0111 (D3)

⊕ 0011 (D0)

────

1001 (C3 | C2 | C1 | C0)

After re-ordering, the 16 TOM and checksum bits are transmitted as

0001 1101 001 1001 0

An example for the value field is shown in Table 11-2.

Table 11-2 – Example of the value field

Position	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Position, binary	11111	11110	11101	11100	11011	11010	11001	11000	10111	10110	10101	10100	10011	10010	10001	10000
Content	D23	D22	D21	D20	D19	D18	D17	D16	D15	D14	D13	D12	D11	D10	D9	C4
Example	1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0
Position	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Position, binary	01111	01110	01101	01100	01011	01010	01001	01000	00111	00110	00101	00100	00011	00010	00001	00000
Value	D8	D7	D6	D5	D4	D3	D2	C3	D1	D0	1	C2	1	C1	C0	P
Example	1	0	1	1	0	0	0	1	1	1	1	0	1	0	1	0

After re-ordering, the 32 value and checksum bits are transmitted as

1001 1100 1001 1101 0110 0011 0110 1010

The HTMC is based on continuous messaging.

Both the HTMC and the THMC are Manchester encoded as specified in clause 7.3.1.1 of [IEEE 802.3].

The HTMC frame is detected by calculating the checksum bits from the received bit stream and comparing them to the bits in the assumed checksum positions. If they do not match, the assumed frame clock is shifted by one bit and a new message channel frame is received. If the expected and the received bits in the checksum fields are identical, the frame clock is maintained. For a successful frame lock, the checksums of two consecutive frames must match the calculated values.

After frame lock is achieved, the frame synchronization is monitored by comparing the checksums of the received frames to the calculated checksums. In the locked state, observing only the checksum of the header and requiring six consecutive checksum mismatches is sufficient to avoid accidental loss-of-lock and to ensure a fast detection of the actual loss-of-lock.

The TOM field allows a maximum number of 2 048 different types of messages. The currently defined messages are listed in Table 11-3.

Table 11-3 – TOM values, message types and content

TOM value	Message type	Message content
0	Idle	
1	Frequency	Nominal optical frequency
2	Tuning power	Tuning power relationship to received power
3	Pilot tone frequency	Frequency to be used for TEE to HEE label pilot tone
4	Start sweep	
5	Turn off	
6	Stop sweep	
7	Change power	New optical power level
8	Change frequency	Change in optical frequency
9	Send traffic	
10	Send pilot tone	
11	Stop sending pilot tone	

Central frequencies are encoded in the message content field as a 2's complement signed integer, as the offset from 193.1 THz with a resolution of 10 MHz[3].

For example, a wavelength value of 1260 nm is first converted in frequency units, namely 237.93052 THz, with an accuracy of 10 MHz. This value is 44.83052 THz (4483052 × 10 MHz) above 193.1 THz, corresponding to 0x4467EC in hexadecimal notation. As a second example, 1560 nm is equivalent to 192.17465 THz, which is 0.92535 THz (92535 × 10 MHz) below 193.1 THz and is encoded as 0xFE9689.

TEE transmitter power is encoded as a 2's complement signed integer representing power values from −30 to 30 dBm with 0.1 dB resolution.

For example, +3 dBm is encoded as +30 which is 0x1E in hexadecimal while −3 dBm is encoded as 0xFFFFE2.

Pilot tone frequencies are encoded in the message content field as unsigned integers representing tone frequency values, with 10 Hz resolution.

For example, 50 kHz is encoded as 5000, which is 0x001388 in hexadecimal and 47.5 kHz is 4750, which is encoded as 0x00128E.

Idle messages (TOM=0) are transmitted when the control of the tail-end equipment does not require the transmission of any other message type over the HTMC. For idle messages, the message content field is not specified, but it can be used to transmit proprietary information between the head-end and the tail-end. This Recommendation does not specify the structure or content of this information.

11.1.3 TEE state machine

The behaviour of the TEE is defined as a state machine operating on the values of the TOM field in the HTMC.

The state machine has six states:

S0: TEE transmitter switched off in standby mode;

S1: TEE transmitter switched off but ready to start the tuning procedure;

S2: TEE transmitter sweeping frequency, transmitting at the required tuning power and sending the pilot tone at the tuning modulation depth;

[3] This makes it possible to encode frequencies with the granularity of 6.25 GHz.

S3: TEE transmitter transmitting within a required channel, sending the pilot tone at the operational modulation depth and adjusting the output power and frequency;

S4: TEE transmitting at the required power and central frequency, sending the pilot tone at the operational modulation depth and sending traffic (i.e., regular operation);

S5: TEE transmitting at the required power and central frequency, sending the THMC and sending traffic (i.e., regular operation).

The state machine behaviour is illustrated in Figure 11-2.

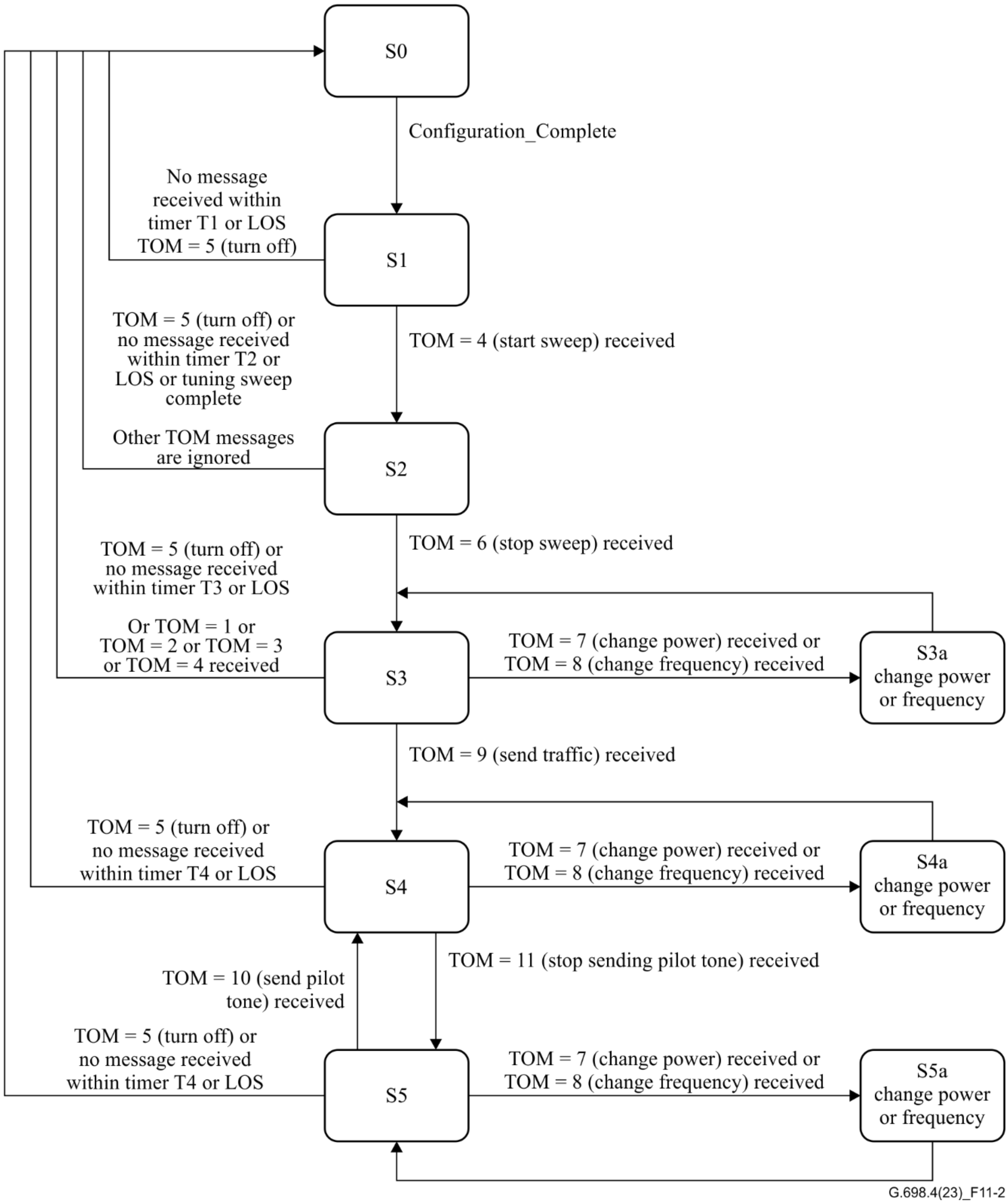

Figure 11-2 – TEE state machine

Configuration_Complete becomes true after at least one of each of the messages TOM = 1, TOM = 2 and TOM = 3 have been received. Configuration_Complete is initialised as false when state S0 is re-entered.

Timers T1 – T4 are used to avoid the TEE operating for an excessive amount of time without receiving control messages from the HEE. The timers T1-T4 are reset, when the TEE enters a respective state according to Figure 11-2 (S1 for T1, S2 for T2, S3 for T3, S4 or S5 for T4) or receives a message with any message type while in the respective state. The timer is reset to the start value of 1 minute for all timers and counts down with time.

An example sequence of messages sent from the HEE to the TEE might be:
TOM=0 (Idle)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=1 (Frequency)
TOM=2 (Tuning power)
TOM=3 (Pilot tone frequency)
TOM=4 (Start sweep)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=0 (Idle)
...
TOM=0 (Idle)
TOM=6 (Stop sweep)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=8 (Change frequency)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=8 (Change frequency)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=7 (Change power)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=9 (Send traffic)
TOM=0(Idle)
TOM=0(Idle)
TOM=11 (Stop sending pilot tone)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=10 (Send pilot tone)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=8 (Change frequency)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=7 (Change power)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=11 (Stop sending pilot tone)
TOM=0 (Idle)
TOM=0 (Idle)
TOM=0 (Idle)
...

When there is no active TEE connected to a particular R_S/S_S port, the message sequence: TOM = 1, 2, 3, 4 is sent periodically to allow a newly connected TEE to start the tuning process.

11.2 Output power setting during tuning

To reduce the crosstalk on working channels during the TEE tuning process, the TEE transmitter output power is reduced with respect to the normal operation.

The TEE output power during tuning is determined from the estimated optical path loss between the TEE and the HEE, which is derived from the mean channel input power at point R_S.

A reference power value, depending on the application code, is communicated from the HEE to the TEE via the HTMC. This reference power level is calculated from the physical layer parameters (Table 8-1) for the application code as:

$$P_{ref} = \frac{(P_{RM,tune,max}+P_{RM,tune,min})}{2} + \frac{(P_{SM,max}+P_{SM,min})}{2}.$$

In this equation, the parameters have the following meaning and are defined in clause 8.

$P_{SM,min}$:	Minimum mean channel output power at MPI-S_M (in dBm)
$P_{SM,max}$:	Maximum mean channel output power at MPI-S_M (in dBm)
$P_{RM,tune,min}$:	Minimum mean channel input power during tuning at MPI-R_M (in dBm)
$P_{RM,tune,max}$:	Maximum mean channel input power during tuning at MPI-R_M (in dBm)

The TEE output power during tuning, $P_{SS,tune}$, is set, based on the communicated reference power, P_{ref} and the measured mean channel input power, P_{RS}:

$$P_{SS,tune} = P_{ref} - P_{RS}.$$

(All values in dBm).

To maintain the estimated and measured loss and power values close to the actual values, the maximum combined tolerance of the Rx power measurement and the Tx power setting at the TEE (ΔP_{RXTX}, clause 8.2.12) is specified, as well as the maximum loss difference of a channel between HEE to TEE and TEE to HEE directions (ΔL, clause 8.3.8).

12 Method of operation for 25 Gbit/s applications which have the ability to tune to the required TEE central frequency on its own

12.1 Introduction

The tuning procedure described in this section assumes a tunable 25 Gbit/s TEE which has the ability to tune to the required central frequency on its own.

This clause describes the means that are provided to enable the TEE to tune to the appropriate central frequency, according to the indications of the HEE.

The tuning mechanism relies on the HTMC and THMC channels, as defined in clause 11.

Applications that rely on a TEE which have the ability to tune to the required central frequency on its own, uses a reduced number of the TOM values and types defined in Table 11-3. These values are listed in Table 12-1.

Table 12-1 – TOM values, message types and content for applications which have the ability to tune to the required TEE central frequency on its own

TOM value	Message type	Message content
0	Idle	
1	Frequency	Nominal optical frequency
4	Start tuning	
8	Change frequency	Change in optical frequency
9	Send traffic	

12.2 State machine for a TEE which has the ability to tune to the required central frequency on its own

The behaviour of a TEE which has the ability to tune to the required central frequency on its own is defined as a state machine operating on the values of the TOM field in the head-to-tail message channel (HTMC). Since the TEE has the ability to tune to the required central frequency on its own, compared to the state machine in Figure 11-2, only a subset of states is used, as follows:

S0: TEE transmitter switched off in standby mode;

S1: TEE transmitter switched off but ready to start the tuning procedure;

S2: TEE transmitter tuning to the nominal optical frequency and turning on to transmit at a power between the minimum and the maximum allowed mean channel output power, sending THMC;

S3: TEE transmitting at central frequency, sending traffic (i.e., regular operation).

The state machine behaviour is illustrated in Figure 12-1.

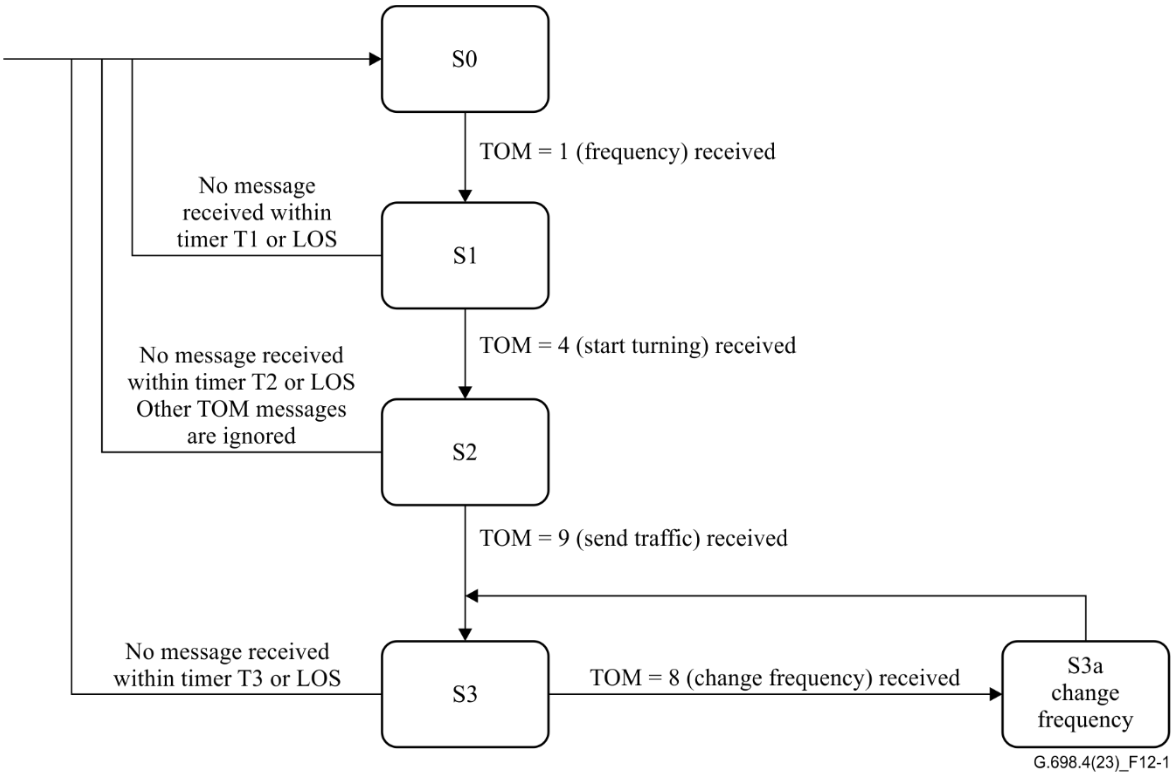

Figure 12-1 – TEE state machine

When there is no active TEE connected to a particular R_S/S_S port, the message sequences: TOM = 1 and TOM = 4 are sent periodically to allow a newly connected TEE to start the tuning process.

Appendix I

Output power setting during tuning

(This appendix does not form an integral part of this Recommendation.)

In order to set the output power during tuning (as in clause 11.2), the application code parameters are chosen to meet the following relation:

$$P_{RM,tune,max} - P_{RM,tune,min} \geq (P_{SM,max} - P_{SM,min}) + 2\Delta L + 2\Delta P_{RXTX}$$

Where:

– $P_{RM,tune,max}$ is the maximum mean channel input power during tuning at MPI-R_M (in dBm), as defined in clause 8.4.7;

– $P_{RM,tune,min}$ is the minimum mean channel input power during tuning at MPI-R_M (in dBm), as defined in clause 8.4.7;

– $P_{SM,max}$ is the maximum mean channel output power at MPI-S_M (in dBm), as defined in clause 8.2.1;

– $P_{SM,min}$ is the minimum mean channel output power at MPI-S_M (in dBm), as defined in clause 8.2.1;

– ΔL is the maximum loss difference of a channel between HE-to-TE and TE-to-HE directions, as defined in clause 8.3.8;

– ΔP_{RXTX} is the maximum combined tolerance of Rx power measurement and Tx power setting at the TEE.

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