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DIGITAL SYSTEMS AND NETWORKS

Transmission media characteristics – Characteristics of
optical components and subsystems

Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers

ITU-T Recommendation G.691



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ITU-T Recommendation G.691

Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers

Summary

This Recommendation provides parameters and values for optical interfaces of single-channel long-haul STM-4, STM-16 and STM-64 systems utilizing optical preamplifiers and/or optical booster amplifiers. Furthermore, it provides optical interface parameters for single-channel STM-64 intra-office and short-haul systems without optical amplification

Source

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ITU-T Recommendation G.691

Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers

1 Scope

The purpose of this Recommendation is to provide optical interface specifications to enable transverse (multi-vendor) compatibility of single-channel STM-4, STM-16, and STM-64 inter-office systems using optical preamplifiers and/or optical booster amplifiers. Specifications to enable transversely compatible single-channel STM-64 intra-office and short-haul systems not requiring optical amplification are also included.

The use of line amplifiers is not within the scope of this Recommendation.

This Recommendation is based on the use of one fibre per direction.

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.

- [1] ITU-T Recommendation G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.
- [2] ITU-T Recommendation G.653 (2003), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.
- [3] ITU-T Recommendation G.655 (2006), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
- [4] ITU-T Recommendation G.662 (2005), *Generic characteristics of optical amplifier devices and subsystems*.
- [5] ITU-T Recommendation G.663 (2000), *Application related aspects of optical amplifier devices and subsystems*.
- [6] ITU-T Recommendation G.664 (2006), *Optical safety procedures and requirements for optical transport systems*.
- [7] ITU-T Recommendation G.671 (2005), *Transmission characteristics of optical components and subsystems*.
- [8] ITU-T Recommendation G.693 (2005), *Optical interfaces for intra-office systems*.
- [9] ITU-T Recommendation G.707/Y.1322 (2003), *Network node interface for the synchronous digital hierarchy (SDH)*.

- [10] ITU-T Recommendation G.955 (1996), *Digital line systems based on the 1544 kbit/s and the 2048 kbit/s hierarchy on optical fibre cables.*
- [11] ITU-T Recommendation G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.*
- [12] ITU-T Recommendation G.959.1 (2006), *Optical transport network physical layer interfaces.*

3 Terms and definitions

3.1 Definitions

This Recommendation defines the following terms:

3.1.1 main (optical) path: The fibre plant between the S point of the transmitter equipment and the R point of the receiver equipment. The main path does not include any auxiliary paths.

3.1.2 main path interfaces: The interfaces to the fibre plant specified in this Recommendation.

3.1.3 auxiliary (optical) path: The optical interconnection between a non-amplified transmitter or receiver and an (stand-alone) optical pre- or booster-amplifier device. An auxiliary path is not included in the main path.

3.1.4 (optical) transponder: A transmitter-receiver combination with or without pulse shaping and retiming that converts an optical signal into another optical signal by a conversion into the electrical domain.

3.2 Terms defined in other Recommendations

This Recommendation uses the following terms defined in other ITU-T Recommendations:

Booster amplifier:	(ITU-T Rec. G.662)
Erbium doped fibre amplifier:	(ITU-T Rec. G.661)
Joint engineering:	(ITU-T Rec. G.957)
Longitudinal compatibility:	(ITU-T Rec. G.955)
Optical amplifier device:	(ITU-T Rec. G.662)
Optical amplifier subsystem:	(ITU-T Rec. G.662)
Optical amplifier:	(ITU-T Rec. G.662)
Optical fibre amplifier:	(ITU-T Rec. G.662)
Optical return loss:	(ITU-T Rec. G.957)
Optically amplified receiver:	(ITU-T Rec. G.662)
Optically amplified transmitter:	(ITU-T Rec. G.662)
Pre-amplifier:	(ITU-T Rec. G.662)
S/R reference points:	(ITU-T Rec. G.955)
Transverse compatibility:	(ITU-T Rec. G.957)

4 Abbreviations

This Recommendation uses the following abbreviations:

APD	Avalanche Photo Diode
ASE	Amplified Spontaneous Emission
ASK	Amplitude Shift Keying
BER	Bit Error Ratio
DA	Dispersion Accommodation
DGD	Differential Group Delay
DST	Dispersion Supported Transmission
EX	Extinction ratio
FEC	Forward Error Correction
ffs	For Further Study
FM	Frequency Modulation
FSK	Frequency Shift Keying
FSR	Free Spectral Range
FWHM	Full Width at Half Maximum
I	Intra-Office
IM	Intensity Modulation
L	Long-Haul
MLM	Multi-Longitudinal Mode
MPI	Main Path Interface
MPN	Mode Partition Noise
NA	Not Applicable
NRZ	Non-Return to Zero
ORL	Optical Return Loss
PCH	Prechirp
PDC	Passive Dispersion Compensator
PIN	"p-type" – intrinsic – "n-type"
PMD	Polarization Mode Dispersion
PRBS	Pseudo-Random Binary Sequence
PSP	Principal State of Polarization
RMS	Root Mean Square
S	Short-Haul
SDH	Synchronous Digital Hierarchy
SLM	Single-Longitudinal Mode
SMSR	Side Mode Suppression Ratio
SNR	Signal to Noise Ratio

SOP	State of Polarization
SPM	Self Phase Modulation
STM-N	Synchronous Transport Module of order N
U	Ultra Long-Haul
V	Very Long-Haul
WDM	Wavelength Division Multiplex

5 Classification of optical interfaces

5.1 Applications

This Recommendation defines optical interfaces for single-channel inter-office line systems for terrestrial long-distance applications from STM-4 to STM-64. It is an extension of ITU-T Rec. G.957 based on the addition of optical amplifiers and the STM-64 data rate. Systems with line amplifiers are not within the scope of this Recommendation.

The definitions of the application codes are extended from ITU-T Rec. G.957 as:

Application – STM level.suffix number,

where "application" corresponds to the target distance: I- (Intra-office), S- (Short-haul), L- (Long-haul), V- (Very long-haul), and U- (Ultra long-haul).

The suffix number denotes:

- 1 the use of nominally 1310 nm sources on G.652 (standard) fibre;
- 2 the use of nominally 1550 nm sources on G.652 fibre;
- 3 the use of nominally 1550 nm sources on G.653 (dispersion shifted) fibre;
- 5 the use of nominally 1550 nm sources on G.655 (non-zero dispersion shifted) fibre.

For some I-64 codes an "r" is added after the suffix number to indicate a reduced target distance. These application codes which belong to the intra-office family are dispersion limited. The same target distance can be achieved by means of other technological solutions, which are for further study (e.g., parallel interface approach).

The target distances are based on approximately 40 km intervals for 1550 nm and 20 km intervals for 1310 nm, except for the very short reach and intra-office applications. The target distances are to be used for classification only and not for specification. They are estimated using the assumption of 0.275 dB/km installed fibre loss including splices and cable margins for 1550 nm systems, and 0.55 dB/km for 1310 nm systems. From a practical point of view, attenuation spans of 11 dB/20 km at 1310 nm and 11 dB/40 km at 1550 nm are defined, except for very short reach and intra-office applications. In practice, these values may not apply to all fibre cables, in which case the realistic distances that can be reached may be shorter.

The primary specifications are the attenuation range and the maximum dispersion tolerance of the system. The main use of the target distance is to define the dispersion tolerance, which is calculated as the maximum fibre dispersion times the target distance. This gives added tolerance to the systems, as well as enabling the full utilization of low attenuation fibre plants. Tables 1a, 1b and 1c summarize the application codes described in this Recommendation.

Table 1a/G.691 – Classification of optical interfaces based on application and showing I application codes

Applications						
Source nominal wavelength [nm]	1310	1310	1550	1550	1550	1550
Fibre type	G.652	G.652	G.652	G.652	G.653	G.655
Targ dist. [km]	0.6	2	2	25	25	25
STM-64	I-64.1r	I-64.1	I-64.2r	I-64.2	I-64.3	I-64.5
Parameters given in	G.693	G.693	G.693	G.959.1	G.959.1	G.959.1
As code	VSR600-2R1	VSR2000-2R1	VSR2000-2L2	P1I1-2D2	P1I1-2D3	P1I1-2D5
NOTE 1 – The target distances are approximate and are to be used for classification only and not for specification.						
NOTE 2 – I, S and L codes for STM-1, -4 and -16 are defined in ITU-T Rec. G.957.						

Table 1b/G.691 – Classification of optical interfaces based on application and showing S and L application codes

Applications						
Source nominal wavelength [nm]	1310	1550	1550	1550	1310	1550
Fibre type	G.652	G.652	G.653	G.655	G.652	G.653
Targ dist. [km]	20	40	40	40	40	80
STM-64	S-64.1	S-64.2	S-64.3	S-64.5	L-64.1	L-64.3
Parameters given in	G.959.1	G.959.1	G.959.1	G.959.1	G.959.1	Table 5c
As code	P1S1-2D1	P1S1-2D2	P1S1-2D3	P1S1-2D5	P1L1-2D1	
NOTE 1 – The target distances are approximate and are to be used for classification only and not for specification.						
NOTE 2 – I, S and L codes for STM-1, -4 and -16 are defined in ITU-T Rec. G.957.						

Table 1c/G.691 – Classification of optical interfaces based on application and showing V and U application codes

Applications					
Source nominal wavelength [nm]	1310	1550	1550	1550	1550
Fibre type	G.652	G.652	G.653	G.652	G.653
Targ dist. [km]	60	120	120	160	160
STM-1	–	–	–	–	–
STM-4	V-4.1	V-4.2	V-4.3	U-4.2	U-4.3
Parameters given in	Table 3	Table 3	Table 3	Table 3	Table 3
Targ dist. [km]	60	120	120	160	160
STM-16	–	V-16.2	V-16.3	U-16.2	U-16.3
Parameters given in		Table 4	Table 4	G.959.1	G.959.1
As code				P1U1-1A2	P1U1-1A3
Targ dist. [km]	60	120	120		
STM-64	–	V-64.2	V-64.3	–	–
Parameters given in		Table 5d	Table 5d		
NOTE – The target distances are approximate and are to be used for classification only and not for specification.					

5.2 Reference and physical configurations

The focus of this Recommendation is to specify the main path interfaces (MPIs). The MPIs are the interfaces to the long-distance fibre plant. The properties of the main path set the requirements on the terminal equipment. The terminal equipment can, in principle, be organized in different ways in order to meet the required specifications of the MPIs. This concerns such aspects as integration level, dispersion accommodation method, or the use of stand-alone optical amplifiers.

Due to the multiplicity of active and passive equipment in the optical path (amplifiers, multiplexers, etc.) in the Recommendations for single- and multichannel systems with optical amplifiers, the S and R reference points must be interpreted in a generic sense, and have to be detailed for each system. To distinguish the MPI-S and -R points from other reference points (e.g., S in ITU-T Rec. G.957) the transmit and receive ends of the main path are denoted MPI-S and MPI-R respectively, when used in a general sense.

The optical interconnection paths (patchcords) between any optical devices within the terminal equipment, if present, are termed "auxiliary paths". For the purpose of this Recommendation, optical fibre line system interfaces can therefore be represented as shown in Figure 1.

In Figure 1, the transmitter side is illustrated using a transmitter, connected through an auxiliary path to a stand-alone optical amplifier device, whereas on the receiver side an optically amplified receiver directly interfaces with the main path.

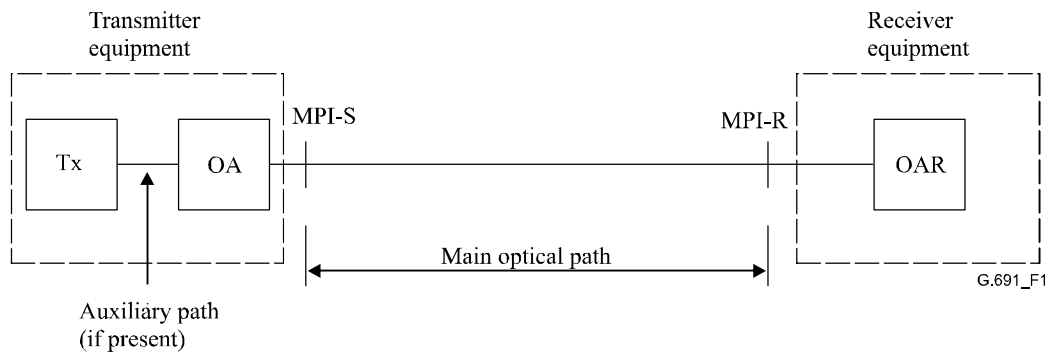


Figure 1/G.691 – An example of an optical link showing the interface points defined in this Recommendation

6 Parameter definitions

All parameter values are worst-case values, assumed to be met over the range of standard operating conditions (i.e., temperature and humidity ranges), and they include ageing effects. The parameters are specified relative to an optical section design objective of a bit error ratio (BER) not worse than 10^{-12} for any combination of parameters within the ranges given in the tables for each specified system.

The optical line coding used for system interfaces up to, and including, STM-64 is binary non-return to zero (NRZ) scrambled according to ITU-T Rec. G.707/Y.1322.

6.1 System operating wavelength range

The operating wavelength range is the maximum allowable range for source wavelength. Within this range, the source wavelength can be selected for different amplifier implementations and different fibre-related impairments. The receiver must have a minimum operating wavelength range that corresponds to the maximum allowable range for the source wavelength.

The operating wavelength range of fibre optic transmission systems is basically determined by the attenuation and dispersion characteristics of the various fibre and source types. A detailed discussion of these aspects can be found in ITU-T Rec. G.957. In the long-distance systems with optical amplifiers considered in this Recommendation, the operating wavelength range is further restricted by the optical amplifiers themselves.

NOTE – When a wavelength-fixed or tunable filter to eliminate amplified spontaneous emission (ASE) is used before the receiver, the operating wavelength band may be limited, and the transverse compatibility may not be guaranteed.

6.2 Transmitter

6.2.1 Spectral characteristics

It is not expected that spectral measurements alone will be able to guarantee transverse compatibility, and these parameters should be viewed as necessary, but not sufficient, for that purpose. Presently, few values for the spectral parameters are given. Until these values are available, transversal compatibility cannot be guaranteed for these systems.

6.2.1.1 Maximum spectral width for SLM sources

For single-longitudinal mode (SLM) sources, the spectral width is defined as the full width of the largest spectral peak, measured 20 dB down from the maximum amplitude of the peak.

The maximum time-averaged spectral width is mainly used to guard against excessive chirp in directly modulated lasers. Such sources would primarily be intended for the low-dispersion

applications (e.g., STM-4, and systems on G.653 fibre), but may also be used in some high-dispersion systems.

High dispersion systems (mainly STM-16, or -64 on G.652 fibre) will usually employ modulator sources. Particularly STM-64 systems on G.652 fibre operate near to or at the typical dispersion limit. Their source power spectra must therefore, by definition, be practically ideal. The maximum spectral width definition, although still valid, then becomes less useful, and the most important parameter for modulator sources instead becomes the chirp parameter.

6.2.1.2 Maximum spectral width for MLM sources

The maximum root mean square (RMS) width or the standard deviation σ (in nm) of the spectral distribution of a multi-longitudinal mode (MLM) laser considers all laser modes, which are not more than 20 dB down from the peak mode. Only a system with an MLM laser at 1310 nm requires this specification.

6.2.1.3 Chirp parameter

The source frequency chirp parameter (also known as the α -parameter) is defined as:

$$\alpha = \frac{\frac{d\phi}{dt}}{\frac{1}{2P} \cdot \frac{dP}{dt}}$$

where ϕ is the optical phase of the signal, and P its power. It should be noted that with this definition, the chirp parameter is not constant during a pulse. Therefore, a pulse may have zero average chirp parameter value, but still not be chirp free.

A positive chirp parameter corresponds to a positive frequency shift (blueshift) during the rising edge of a pulse, and to a negative frequency shift (redshift) during the falling edge of the pulse. A modulator typically has a chirp parameter of -1 to $+1$ rad, whereas the turn-on transient of a standard laser may have a chirp factor of 10-100 rad.

Since several systems in this Recommendation operate at or near to the typical dispersion limit, their source spectra must be close to ideal. The frequency chirp specification is needed to control and describe the phase behaviour of the signal, which is hardly visible in the power spectrum defined by the other parameters.

The phase behaviour of the signal can be used to "peak" the performance of a system, e.g., by employing chirp induced pulse compression. It can also be used to modify the behaviour of power-induced non-linearities. This interaction is complicated, and the allowed ranges of this parameter may therefore vary with the application code and other system parameters.

A test method for source chirp is discussed in Appendix IV.

6.2.1.4 Side mode suppression ratio

The side mode suppression ratio (SMSR) is defined as the ratio of the largest peak of the total source spectrum to the second largest peak. The spectral resolution of the measurement shall be better (i.e., the optical filter bandwidth shall be less) than the maximum spectral width of the peak, as defined above. The second largest peak may be next to the main peak or far removed from it.

NOTE – Within this definition spectral peaks that are separated from the largest peak by the clock frequency are not considered to be side modes.

The SMSR specification is intended to minimize the occurrence of BER degradations due to mode partition noise (MPN). Since MPN is a transient effect with low probability, SMSR measurements on PRBS or continuous signals may underestimate the MPN. The SMSR specification is relevant only to SLM laser sources.

6.2.1.5 Maximum spectral power density

The maximum (optical) spectral power density is defined as the highest time-averaged power level per 10 MHz interval anywhere in the modulated signal spectrum. The measurement must therefore be made with a resolution of better (i.e., the optical filter bandwidth shall be less) than 10 MHz FWHM.

This parameter is used to avoid entering into the Brillouin scattering regime for high-power sources with potentially narrow inherent linewidths, such as laser-modulator-amplifier combinations. The specification, however, applies to all source types.

6.2.2 Mean launched power

The mean launched power at point MPI-S is the average power of a pseudo-random data sequence coupled into the fibre by the transmitter. It is given as a range to allow for some cost optimization and to cover allowances for operation under the standard operating conditions, transmitter connector degradations, measurement tolerances, and ageing effects. These values allow the calculation of values for the sensitivity and overload point for the receiver at reference point MPI-R.

In the case of fault conditions in the transmit equipment, the launched power and maximum possible exposure time of personnel should be limited for optical fibre/laser safety considerations.

6.2.3 Extinction ratio

The minimum admitted value of the extinction ratio (EX) is defined as:

$$EX = 10 \times \log_{10}(A/B)$$

where A is the average optical power level at the centre of a logical "1", and B is the average optical power level at the centre of a logical "0". The convention adopted for optical logic levels is:

- emission of light for a logical "1";
- no emission for a logical "0".

6.2.4 Eye pattern mask

In this Recommendation, general transmitter pulse shape characteristics including rise time, fall time, pulse overshoot, pulse undershoot, and ringing, all of which should be controlled to prevent excessive degradation of the receiver sensitivity, are specified in the form of a mask of the transmitter eye diagram at point MPI-S. For the purpose of an assessment of the transmit signal, it is important to consider not only the eye opening, but also the overshoot and undershoot limitations. The parameters specifying the mask of the transmitter eye diagram are shown in Figure 2. Annex A considers further aspects of the eye mask definitions.

For systems employing dispersion accommodation techniques based on predistortion of the signal, the eye mask in the above sense can only be defined at points with undistorted signals. These points, however, do not coincide with the main path interfaces, and may thus not even be accessible. This definition is for further study.

For systems employing non-linear effects for dispersion accommodation (presently L-64.2b and V-64.2b), the eye mask may be different from the eye mask employed for linear systems.

Additionally, for systems that are subject to self phase modulation (SPM) due to high power output, a specification of the minimum rise time to avoid the SPM breakdown is required. The minimum rise time (10% to 90% value of the single pulse) for systems with transmitter power levels of +12 to +15 dBm has to be 30 ps. For lower power levels such as +10 to +13 dB this value and the interaction with the signal chirp is for further study.