INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.957

(03/93)

DIGITAL SECTIONS AND DIGITAL LINE SYSTEMS

OPTICAL INTERFACES FOR EQUIPMENTS AND SYSTEMS RELATING TO THE SYNCHRONOUS DIGITAL HIERARCHY

ITU-T Recommendation G.957

(Previously "CCITT Recommendation")

FOREWORD

The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the International Telecommunication Union. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, established the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

ITU-T Recommendation G.957 was revised by the ITU-T Study Group XV (1988-1993) and was approved by the WTSC (Helsinki, March 1-12, 1993).

____

NOTES

1 As a consequence of a reform process within the International Telecommunication Union (ITU), the CCITT ceased to exist as of 28 February 1993. In its place, the ITU Telecommunication Standardization Sector (ITU-T) was created as of 1 March 1993. Similarly, in this reform process, the CCIR and the IFRB have been replaced by the Radiocommunication Sector.

In order not to delay publication of this Recommendation, no change has been made in the text to references containing the acronyms "CCITT, CCIR or IFRB" or their associated entities such as Plenary Assembly, Secretariat, etc. Future editions of this Recommendation will contain the proper terminology related to the new ITU structure.

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

CONTENTS

Page

OPTICAL INTERFACES FOR EQUIPMENTS AND SYSTEMS RELATING TO THE SYNCHRONOUS DIGITAL HIERARCHY

(Geneva, 1990; revised at Helsinki, 1993)

1 Introduction

This Recommendation covers optical interface parameter specifications for equipments and systems supporting the synchronous digital hierarchy (SDH) defined in Recommendations G.707, G.708 and G.709 and operating on single-mode optical fibres conforming to Recommendations G.652, G.653 and G.654.

The purpose of this Recommendation is to provide specifications for the optical interfaces of SDH equipment, described in Recommendations G.782 and G.783, and line systems described in Recommendation G.958, to achieve the possibility of transverse (multivendor) compatibility on elementary cable sections, i.e. the possibility of mixing various manufacturers' equipments within a single optical section. However, the specifications in this Recommendation are also intended to be in accordance with Recommendation G.955 which provides the possibility to achieve longitudinal compatibility for equipment of comparable hierarchical level and application.

The present Recommendation is based on the use of one fibre per direction. Any other optical arrangements may require different specifications and are for further study.

1.1 Abbreviations

For the purposes of this Recommendation, the following abbreviations apply:

BER Bit error ratio

EX Extinction ratio

LED Light-emitting diode

MLM Multi-longitudinal mode

NA Not applicable

NRZ Non-return to zero

ORL Optical return loss

RMS Root-mean-square

SDH Synchronous digital hierarchy

SLM Single-longitudinal mode

STM Synchronous-transport module

UI Unit interval

WDM Wavelength-division multiplexing

2 Classification of optical interfaces

It is expected that optical fibres will be used in SDH-based systems for both inter-office transport between stations and in intra-office applications for connecting equipment within a single station. By appropriate combinations of transmitters and receivers, power budgets for optical fibre line systems can be achieved which are optimized in terms of attenuation/dispersion and cost with respect to the various applications. However, to simplify the development of transverse compatible systems, it is desirable to limit the number of application categories and corresponding sets of optical interface specifications for standardization.

As shown in Table 1, this Recommendation recognizes three broad application categories:

- intra-office corresponding to interconnect distances less than approximately 2 km;
- short-haul inter-office corresponding to interconnect distances of approximately 15 km;
- long-haul inter-office corresponding to interconnect distances of approximately 40 km in the 1310 nm window and approximately 60 km in the 1550 nm window.

TABLE 1/G.957

Classification of optical interfaces based on application and showing application codes

Application		Intra-office	Inter-office				
			Short-haul		Long haul		
Source nominal wavelength (nm)		1310	1310	1550	1310	1550	
Type of fibre		Rec. G.652	Rec. G.652	Rec. G.652	Rec. G.652	Rec. G.652 Rec. G.654	Rec. G.653
Distance (km)[a]		≤ 2	~ 15		~ 40	~ 60	
STM level	STM-1	I-1	S-1.1	S-1.2	L-1.1	L-1.2	L-1.3
	STM-4	I-4	S-4.1	S-4.2	L-4.1	L-4.2	L-4.3
	STM-16	I-16	S-16.1	S-16.2	L-16.1	L-16.2	L-16.3

[a] These are target distances to be used for classification and not for specification.

Within each category, it is possible to consider use of either nominal 1310 nm sources on optical fibre complying with Recommendation G.652 or nominal 1550 nm sources on optical fibre complying with Recommendations G.652, G.653 or G.654. This Recommendation covers both possibilities for the two inter-office applications and considers only nominal 1310 nm sources on G.652 fibre for the intra-office application. Since the overall system characteristics and specific values for the optical parameters generally depend on system bit rate, it is convenient to classify the SDH optical interfaces based on applications considered in this Recommendation using the set of application codes shown in Table 1. This application code is constructed in the following way:

Application – STM level – suffix number

with the application designations being I (Intra-office), S (Short-haul), or L (Long-haul), and the suffix number being one of the following:

- (blank) or 1 indicating nominal 1310 nm wavelength sources on G.652 fibre;
- 2 indicating nominal 1550 nm wavelength sources on G.652 fibre for short-haul applications and either G.652 or G.654 fibre for long-haul applications;
- 3 indicating nominal 1550 nm wavelength sources on G.653 fibre.

NOTE – the use of the term intra-office is not meant to exclude any other applications consistent with the set of optical parameters specified (e.g. B-ISDN user network interfaces – physical layer specifications defined in Recommendation I.432).

The distances chosen for the application codes in Table 1 are based on parameter values that are achievable with present technology and which are thought to suit network requirements. The intra-office and short-haul inter-office application codes have been proposed as low-cost equipment implementations. The long-haul application codes have been proposed to provide maximum length repeater spans consistent with limits set by present technology and the objective of transverse compatibility. The distances proposed may allow for the upgrading of present systems by exploiting the 1550 nm region. The distances in Table 1 represent approximate maximum repeater span distances. Specific distance limits consistent with the attenuation limits given in Tables 2 to 4, but including allowances for extra connectors or margins, can be derived through consideration of maximum fibre attenuation and dispersion values for each application in Tables 2 to 4.

3 Parameter definitions

For the purpose of this Recommendation, optical fibre line system interfaces can be represented as shown in Figure 1. More specific reference configurations which relate the specifications in this Recommendation to actual optical line systems based on the synchronous digital hierarchy are contained in Recommendation G.958. In Figure 1, point S is a reference point on the optical fibre just after the transmitter optical connector (C_{TX}) and point R is a reference point on the optical fibre just before the receiver optical connector (C_{RX}). Additional connectors at a distribution frame (if used) are considered to be part of the fibre link and to be located between points S and R. In this Recommendation, optical parameters are specified for the transmitter at point S, for the receiver at point R, and for the optical path between points S and R.

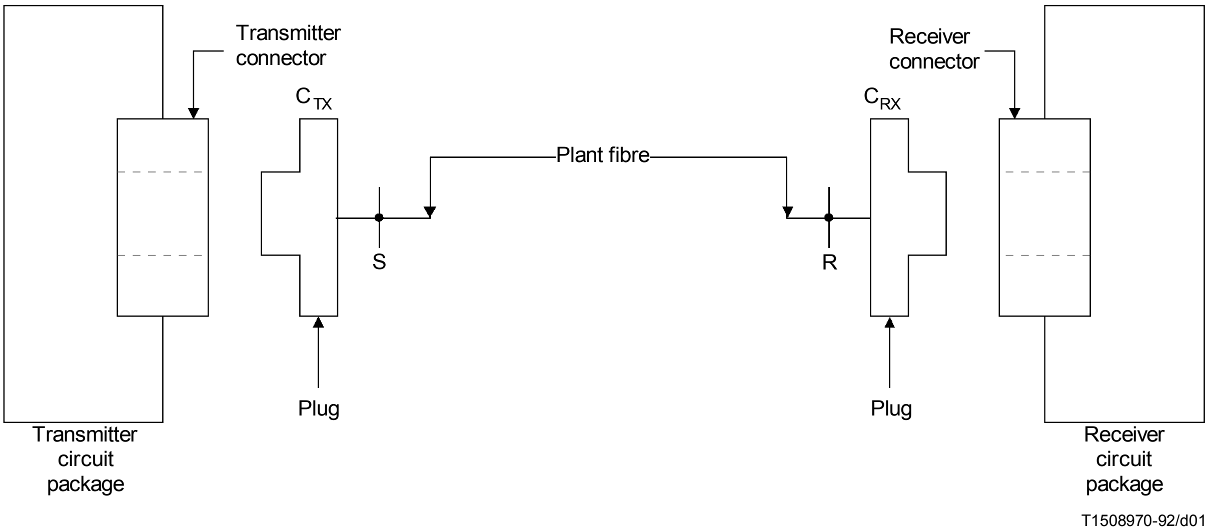


FIGURE 1/G.957

Representation of optical line system interface

All parameter values specified are worst-case values, assumed to be met over the range of standard operating conditions (i.e. temperature and humidity ranges), and they include aging effects. These conditions and effects are for further study. The parameters are specified relative to an optical section design objective of a bit error ratio (BER) not worse than 1×10^{-10} for the extreme case of optical path attenuation and dispersion conditions in each application of Table 1.

The optical line coding used for all system interfaces is binary non-return to zero (NRZ), scrambled according to Recommendation G.709.

TABLE 2/G.957

Parameters specified for STM-1 optical interfaces

	Unit	Values									
Digital signal Nominal bit rate	kbit/s	STM-1 according to Recommendations G.707 and G.958 155 520									
Application code (Table 1)		I-1		S-1.1	S-1.2		L-1.1		L-1.2	L-1.3	
Operating wavelength range	nm	1260[a)]-1360		1261[a)]-1360	1430-1576	1430-1580	1280-1335		1480-1580	1534-1566/ 1508-1580	1480-1580
Transmitter at reference point S											
Source type		MLM	LED	MLM	MLM	SLM	MLM	SLM	SLM	MLM	SLM
Spectral characteristics											
– maximum RMS width (σ)	nm	40	80	7,7	2,5	–	4	–	–	4/2,5	–
– maximum –20 dB width	nm	–	–	–	–	1	–	1	1	–	1
– minimum side mode suppression ratio	dB	–	–	–	–	30	–	30	30	–	30
Mean launched power											
– maximum	dBm	–8		–8	–8		0		0	0	
– minimum	dBm	–15		–15	–15		–5		–5	–5	
Minimum extinction ratio	dB	8.2		8.2	8.2		10		10	10	
Optical path between S and R											
Attenuation range	dB	0-7		0-12	0-12		10-28		10-28	10-28	
Maximum dispersion	ps/nm	18	25	96	296	NA	185	NA	NA	185/296	NA
Minimum optical return loss of cable plant at S, including any connectors	dB	NA		NA	NA		NA		20	NA	
Maximum discrete reflectance between S and R	dB	NA		NA	NA		NA		–25	NA	
Receiver at reference point R											
Minimum sensitivity	dBm	–23		–28	–28		–34		–34	–34	
Minimum overload	dBm	–8		–8	–8		–10		–10	–10	
Maximum optical path penalty	dB	1		1	1		1		1	1	
Maximum reflectance of receiver, measured at R	dB	NA		NA	NA		NA		–25	NA	

a) Some Administrations may require a limit of 1270 nm.

TABLE 3/G.957

Parameters specified for STM-4 optical interfaces

	Unit	Values							
Digital signal Nominal bit rate	kbit/s	STM-4 according to Recommendations G.707 and G.958 622 080							
Application code (Table 1)		I-4		S-4.1	S-4.2	L-4.1		L-4.2	L-4.3
Operating wavelength range	nm	1261[a)]-1360		1293-1334/ 1274-1356	1430-1580	1300-1325/ 1296-1330	1280-1335	1480-1580	1480-1580
Transmitter at reference point S									
Source type		MLM	LED	MLM	SLM	MLM	SLM	SLM	SLM
Spectral characteristics									
– maximum RMS width (σ)	nm	14.5	35	4/2.5	–	2.0/1.7	–	–	–
– maximum –20 dB width	nm	–	–	–	1	–	1	< 1 [b)]	1
– minimum side mode suppression ratio	dB	–	–	–	30	–	30	30	30
Mean launched power									
– maximum	dBm	–8		–8	–8	+2		+2	+2
– minimum	dBm	–15		–15	–15	–3		–3	–3
Minimum extinction ratio	dB	8.2		8.2	8.2	10		10	10
Optical path between S and R									
Attenuation range	dB	0-7		0-12	0-12	10-24		10-24	10-24
Maximum dispersion	ps/nm	13	14	46/74	NA	92/109	NA	b)	NA
Minimum optical return loss of cable plant at S, including any connectors	dB	NA		NA	24	20		24	20
Maximum discrete reflectance between S and R	dB	NA		NA	–27	–25		–27	–25
Receiver at reference point R									
Minimum sensitivity	dBm	–23		–28	–28	–28		–28	–28
Minimum overload	dBm	–8		–8	–8	–8		–8	–8
Maximum optical path penalty	dB	1		1	1	1		1	1
Maximum reflectance of receiver, measured at R	dB	NA		NA	–27	–14		–27	–14

a) Some Administrations may require a limit of 1270 nm.

b) See 3.2.2.

CUADRO 4/G.957

Parámetros especificados para las interfaces ópticas STM-16

	Unidad	Valores					
Señal digital		STM-16 de acuerdo con las Recomendaciones G.707 y G.958					
Velocidad binaria nominal	kbit/s	2 488 320					
Código de aplicación (Cuadro 1)		I-16	S-16.1	S-16.2	L-16.1	L-16.2	L-16.3
Gama de longitudes de onda de funcionamiento	nm	1266[a]-1360	1260[a]-1360	1430-1580	1280-1335	1500-1580	1500-1580
Transmisor en el punto de referencia S							
Tipo de fuente		MLM	SLM	SLM	SLM	SLM	SLM
Características espectrales							
– anchura eficaz máxima (σ)	nm	4	–	–	–	–	–
– anchura a –20 dB máxima	nm	–	1	< 1[b]	1	< 1[b]	< 1[b]
– relación de supresión de modo lateral mínima	dB	–	30	30	30	30	30
Potencia inyectada media							
– máxima	dBm	–3	0	0	0	+1	0
– mínima	dBm	–10	–5	–5	–5	–4	–5
Relación de extinción mínima	dB	8,2	8,2	8,2	10	8,2	10
Trayecto óptico entre S y R							
Gama de atenuación	dB	0-7	0-12	0-12	10-20	10-20	10-20
Dispersión máxima	ps/nm	12	NA	[b]	NA	1194[b]	[b]
Pérdida de retorno óptico mínima de la planta de cable en el punto S, incluidos todos los conectores	dB	24	24	24	24	24	24
Reflectancia discreta máxima entre S y R	dB	–27	–27	–27	–27	–27	–27
Receptor en el punto de referencia R							
Sensibilidad mínima	dBm	–18	–18	–18	–26	–26	–26
Sobrecarga mínima	dBm	–3	0	0	–10	–9	–10
Penalización máxima en el trayecto óptico	dB	1	1	1	1	2	1
Reflectancia máxima del receptor medida en el punto R	dB	–27	–27	–27	–27	–27	–27

a) Algunas Administraciones pueden requerir un límite de 1270 nm.

b) Véase 3.2.2.

3.1 System operating wavelength range

To provide flexibility in implementing transversely compatible systems and future usage of wavelength-division multiplexing (WDM), it is desirable to allow as wide a range as possible for the system operating wavelengths. The choice of operating wavelength range for each of the applications of Table 1 depends on several factors including fibre type, source characteristics, system attenuation range, and dispersion of the optical path. The following general considerations affect the specification of operating wavelength ranges in this Recommendation. More detailed description of the system aspects used to develop the operating wavelength range requirements in this Recommendation is contained in Annex A.

The wavelength regions permitting system operation are partially determined by either the cutoff wavelength values of the fibre or of the fibre cable. For G.652 and G.653 fibres, these values have been chosen to allow single-mode operation of the fibre cable at 1270 nm and above, with values as low as 1260 nm permitted by some Administrations. For G.654 fibre cables, the cutoff wavelength values have been proposed for single-mode operation at 1525 nm (provisional) and above.

The allowable wavelength regions are further defined by the fibre attenuation. Although the intrinsic scattering attenuation generally decreases with increasing wavelength, OH-ion absorption can manifest itself around 1385 nm, and to a smaller extent around 1245 nm. These absorption peaks and the cutoff wavelength therefore define a wavelength region centered around 1310 nm. Dispersion-unshifted fibres complying with Recommendation G.652 are optimized for use in this wavelength region. At longer wavelengths bending attenuation occurs towards 1600 nm or beyond, and infra-red absorption occurs beyond 1600 nm. These attenuations and the 1385 nm water peak therefore define a second operating wavelength region around 1550 nm. Recommendation G.654 for loss-optimized fibre is limited to this region only. However, both G.652 and dispersion-shifted G.653 fibres may be used in this region.

Apart from cutoff wavelength and attenuation that determine the broad operating wavelength regions, the allowable wavelength ranges are determined by the interaction of the fibre dispersion with the spectral characteristics of the transmitter. Parts of this range may lie inside or outside the wavelength range determined by attenuation. The overlap of the two ranges is the permissible wavelength range for system operation.

For SDH networks utilizing optical fibre amplifiers, it might be necessary to limit the operating wavelength of future long-haul systems.

3.2 Transmitter

3.2.1 Nominal source type

Depending on attenuation/dispersion characteristics and hierarchical level of each application in Table 1, feasible transmitter devices include light-emitting diodes (LEDs), multi-longitudinal mode (MLM) lasers and single-longitudinal (SLM) lasers. For each of the applications, this Recommendation indicates a nominal source type. It is understood that the indication of a nominal source type in this Recommendation is not a requirement and that SLM devices can be substituted for any application showing LED or MLM as the nominal source type and MLM devices can be substituted for any application showing LED as the nominal source type without any degradation in system performance.

3.2.2 Spectral width

For LEDs and MLM lasers, spectral width is specified by the maximum root-mean-square (RMS) width under standard operating conditions. The RMS width or value is understood to mean the standard deviation (σ) of the spectral distribution. The measurement method for RMS widths should take into account all modes which are not more than 20 dB down from the peak mode.

For SLM lasers, the maximum spectral width is specified by the maximum full width of the central wavelength peak, measured 20 dB down from the maximum amplitude of the central wavelength under standard operating conditions. Additionally, for control of mode partition noise in SLM systems, a minimum value for the laser side-mode suppression ratio is specified.

There is currently no agreed reliable method for estimating the dispersion penalties arising from laser chirp and finite side-mode suppression ratio for SLM lasers. Because of this, SLM laser linewidths and maximum fibre dispersion values for the L-4.2, S-16.2, L-16.2, and L-16.3 applications are under study. Until this study is complete, transverse compatibility for these systems cannot be guaranteed.

Present indications are that spectral width definitions based on time-averaged spectral measurements can provide necessary, but not sufficient criteria for SLM devices. However, in combination with additional tests such as outlined below, such criteria could provide adequate.

A possible need to specify dynamic laser characteristics more accurately is being recognized, particularly for long-haul systems. This includes associated measurement methods. One possible method is a fibre transmission test. Its configuration consists of a transmitter under test, test fibres with maximum dispersion specified for the maximum system length, and a reference receiver. The dynamic characteristics of the transmitter can then be evaluated using a bit error rate measurement.

The above method could also be adapted for the purposes of laser acceptance testing. Thus, the laser would be evaluated by incorporation into the transmitter of an emulated transmission system. Lasers having acceptable spectral characteristics would be identified on the basis of satisfactory error performance of the emulated system. Any such arrangement, intended for use by laser manufacturers, would need to be made available in a form capable of periodic calibration and, if necessary, repair by a supplier of test equipment. These and alternative methods for characterizing laser dynamic performance are for further study.

3.2.3 Mean launched power

The mean launched power at reference point 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 aging effects. These values allow the calculation of values for the sensitivity and overload point for the receiver at reference point R.

The possibility of obtaining cost-effective system designs for long-haul applications by using uncooled lasers with maximum mean launched powers exceeding those of Tables 2 to 4, necessitating external, removable optical attenuators in low-loss sections, is for further study.

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 according to [1].

3.2.4 Extinction ratio

The convention adopted for optical logic level is

- emission of light for a logical “1”,
- no emission for a logical “0”.

The extinction ratio (*EX*) is defined as:

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

where A is the average optical power level for a logical “1” and B is the average optical power level for a logical “0”. Measurement methods for the extinction ratio are under study.

3.2.5 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 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. Appendix I considers measurement set-ups for determining the eye diagram of the optical transmit signal.

3.3 Optical path

To ensure system performance for each of the applications considered in Table 1, it is necessary to specify attenuation and dispersion characteristics of the optical path between reference points S and R.

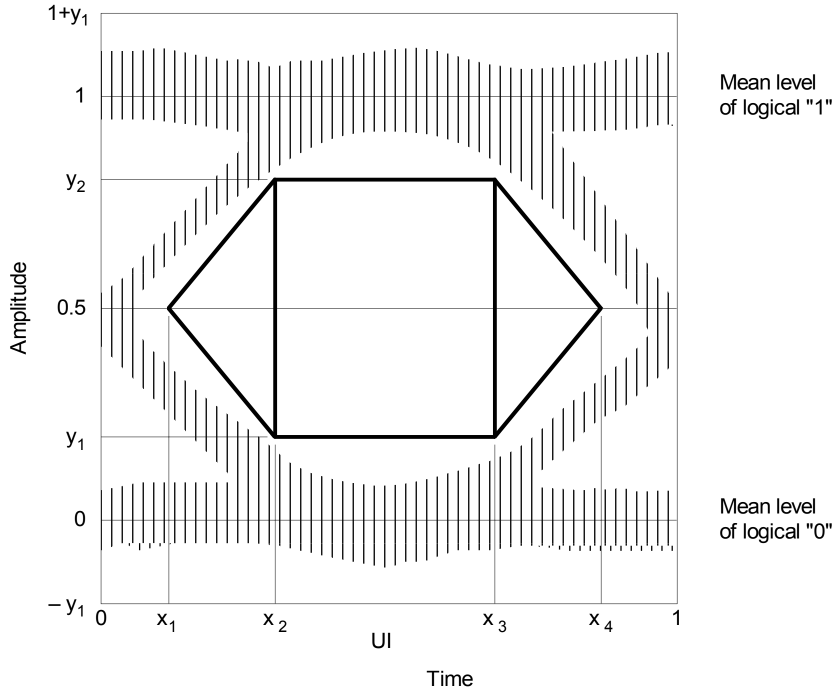
3.3.1 Attenuation

In this Recommendation, attenuation for each application is specified as a range, characteristic of the broad application distances indicated in Table 1. However, to provide flexibility in implementing transverse compatible systems, this Recommendation recognizes some overlap between attenuation ranges between the intra-office applications and the short-haul inter-office applications and between the short-haul inter-office applications and the long-haul inter-office applications. Attenuation specifications are assumed to be worst-case values including losses due to splices, connectors, optical attenuators (if used) or other passive optical devices, and any additional cable margin to cover allowances for

1) future modifications to the cable configuration (additional splices, increased cable lengths, etc.);

2) fibre cable performance variations due to environmental factors; and

3) degradation of any connector, optical attenuators (if used) or other passive optical devices between points S and R, when provided.



	STM-1	STM-4
x_1/x_4	0.15/0.85	0.25/0.75
x_2/x_3	0.35/0.65	0.40/0.60
y_1/y_2	0.20/0.80	0.20/0.80

	STM-16
$x_3 - x_2$	0.2
y_1/y_2	0.25/0.75

T1508980-92/d02

NOTE – In the case of STM-16, x_2 and x_3 of the rectangular eye mask need not be equidistant with respect to the vertical axes at 0 UI and 1 UI. The extent of this deviation is for further study. In view of the frequencies involved in STM-16 systems and the consequent difficulty of realizing this filter, the parameter values for STM-16 may need slight revision in light of experience.

FIGURE 2/G.957

Mask of the eye diagram for the optical transmit signal

3.3.2 Dispersion

Systems considered limited by dispersion have maximum values of dispersion (ps/nm) specified in Tables 2 to 4. These values are consistent with the maximum optical path penalties specified (i.e. 2 dB for L-16.2, 1 dB for all other applications). They take into account the specified transmitter type, and the fibre dispersion coefficient over the operating wavelength range.

Systems considered limited by attenuation do not have maximum dispersion values specified and are indicated in Tables 2 to 4 with the entry NA (not applicable).

3.3.3 Reflections

Reflections are caused by refractive index discontinuities along the optical path. If not controlled, they can degrade system performance through their disturbing effect on the operation of the laser or through multiple reflections which lead to interferometric noise at the receiver. In this Recommendation, reflections from the optical path are controlled by specifying the:

– minimum optical return loss (ORL) of the cable plant at point S, including any connectors, and

– maximum discrete reflectance between points S and R.

The possible effects of reflections on single fibre operation using directional couplers have not been considered in this Recommendation and are for further study.

Measurement methods for reflections are described in Appendix II. For the purpose of reflectance and return loss measurements, points S and R are assumed to coincide with the endface of each connector plug (see Figure 1). It is recognized that this does not include the actual reflection performance of the respective connectors in the operational system. These reflections are assumed to have the nominal value of reflection for the specific type of connectors used.

The maximum number of connectors or other discrete reflection points which may be included in the optical path (e.g. for distribution frames, or WDM components) must be such as to allow the specified overall optical return loss to be achieved. If this cannot be done using connectors meeting the maximum discrete reflections cited in Tables 2 to 4, then connectors having better reflection performance must be employed. Alternatively, the number of connectors must be reduced. It also may be necessary to limit the number of connectors or to use connectors having improved reflectance performance in order to avoid unacceptable impairments due to multiple reflections. Such effects may be particularly significant in STM-16 and STM-4 long-haul systems.

In Tables 2 to 4 the value –27 dB maximum discrete reflectance between points S and R is intended to minimize the effects of multiple reflections (e.g interferometric noise). In Tables 3 and 4, the value –27 dB for maximum receiver reflectance will ensure acceptable penalties due to multiple reflections for all likely system configurations involving multiple connectors, etc. Systems employing fewer or higher performance connectors produce fewer multiple reflections and consequently are able to tolerate receivers exhibiting higher reflectance. As an extreme example, if only two connectors exist in the system, a 14 dB receiver return loss is acceptable.

For systems in which reflection effects are not considered to limit system performance, no values are specified for the associated reflection parameters and this is indicated in Tables 2 to 4 by the entry NA (not applicable). However, when using this Recommendation for a particular application, it should be noted that if upgradability to other applications having more stringent requirements is contemplated, then these more stringent requirements should be used.

The possible need to develop a specification for transmitter signal-to-noise ratio under conditions of worst-case optical return loss for the applications in Tables 2 to 4 is for further study.

3.4 Receiver

Proper operation of the system requires specification of minimum receiver sensitivity and minimum overload power level. These are taken to be consistent with the mean launched power range and attenuation range specified for each application.

3.4.1 Receiver sensitivity

Receiver sensitivity is defined as the minimum acceptable value of average received power at point R to achieve a 1×10^{-10} BER. It takes into account power penalties caused by use of a transmitter under standard operating conditions with worst-case values of extinction ratio, pulse rise and fall times, optical return loss at point S, receiver connector degradations and measurement tolerances. The receiver sensitivity does not include power penalties associated with dispersion, jitter, or reflections from the optical path; these effects are specified separately in the allocation of maximum optical path penalty. Aging effects are not specified separately since they are typically a matter between a network provider and an equipment manufacturer. Typical margins between a beginning-of-life, nominal temperature receiver and its end-of-life, worst-case counterpart are desired to be in the 2 to 4 dB range. An example of a measurement method for determining aging effects on receiver sensitivity is given in Appendix III. The receiver sensitivities specified in Tables 2 to 4 are worst-case, end-of-life values.

3.4.2 Receiver overload

Receiver overload is the maximum acceptable value of the received average power at point R for a 1×10^{-10} BER.

3.4.3 Receiver reflectance

Reflections from the receiver back to the cable plant are specified by the maximum permissible reflectance of the receiver measured at reference point R.

3.4.4 Optical path power penalty

The receiver is required to tolerate an optical path penalty not exceeding 1 dB (2 dB for L-16.2) to account for total degradations due to reflections, intersymbol interference, mode partition noise, and laser chirp.

4 Optical parameter values for SDH applications

Optical parameter values for the applications of Table 1 are given in Table 2 for STM-1, Table 3 for STM-4, and Table 4 for STM-16. Parameters defining the mask of the transmitter eye diagram at reference point S for each of the three hierarchical levels are given in Figure 2. These tables do not preclude the use of systems which satisfy the requirements of more than one application for any given bit rate.

5 Optical engineering approach

The selection of applications and set of optical parameters covered by this Recommendation are chosen to reflect a balance between economic and technical considerations to provide the possibility for transverse compatible systems using the synchronous digital hierarchy. This clause describes the use of the parameters in Tables 2 to 4 to obtain a common system design approach for engineering SDH optical links.

5.1 Design assumptions

To meet the greatest number of application possibilities with the smallest number of optical interface component specifications, three interface categories are assumed for each level of the SDH hierarchy. These are distinguished by different attenuation/dispersion regimes rather than by explicit distance constraints to provide greater flexibility in network design while acknowledging technology and cost constraints for the various applications.

Worst-case, end-of-life parameter values are specified in this Recommendation to provide simple design guidelines for network planners and explicit component specifications for manufacturers. As a result, neither unallocated system margins nor equipment margins are specified and it is assumed that transmitters, receivers, and cable plant individually meet the specifications under the standard operating conditions. It is recognized that, in some cases, this may lead to more conservative system designs than could be obtained through joint engineering of the optical link, the use of statistical design approaches, or in applications and environments more constrained than those permitted under the standard operating conditions.

5.2 Worst-case design approach

For a worst-case design approach, the optical parameters of Tables 2 to 4 are related as shown in Figure 3. In loss-limited applications, a system integrator may determine the appropriate application code and corresponding set of optical parameters by first fixing the total optical path attenuation, which should include all sources of optical power loss and any cable design margin specified by the system integrator. For those situations in which the system attenuation falls within the attenuation overlap region of two applications, then either set of optical parameters would apply. The most economical designs will generally correspond to the application code having the narrower attenuation range. For each installation, it should be verified that the total optical path penalty, which includes combined dispersion and reflection degradations, does not exceed the value given in 3.4.4 and Tables 2 to 4 since a higher value may lead to rapidly deteriorating system performance.

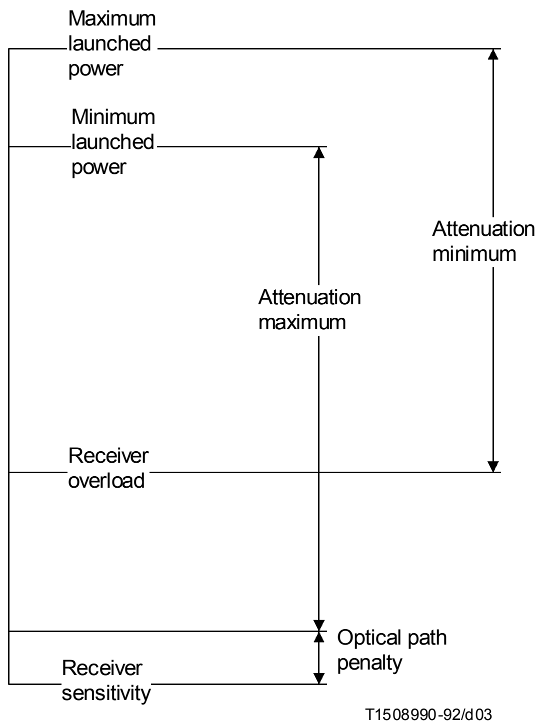


FIGURE 3/G.957

Relationship of the optical parameters

For dispersion-limited systems, the system integrator may select an appropriate application code and corresponding set of optical parameters by determining the total dispersion (ps/nm) expected for the elementary cable section to be designed. The most economical design generally corresponds to the selection of the application having the smallest maximum dispersion value exceeding the dispersion value determined for the system design. Again, the total optical path power penalty should be verified as described above.

5.3 Statistical design approach

The statistical approach is based on designing an enhanced elementary cable section, possibly exceeding the section length obtained by a worst-case design. By admitting a certain probability that the attenuation or dispersion between points S and R is larger than specified system values or that a transverse compatible design may not be obtained, cost savings may be achieved in long-haul high bit-rate optical systems through the reduction of the number of repeaters.

When using the statistical approach, the sub-system parameters are expressed in terms of the statistical distributions, which are assumed to be available from the manufacturers. Such distributions can be handled either numerically (e.g. by Monte Carlo methods) or analytically (e.g. Gaussian averages and standard deviations).

Examples of parameters which can be considered statistical in nature are the following:

- cable attenuation;
- cable zero-dispersion wavelength and zero-dispersion slope;
- splice and connector loss;

– transmitter spectral characteristics (central wavelength, spectral width, etc.);

– available system gain between points S and R (e.g. optical power available at point S and receiver sensitivity at point R. These parameters may need to be considered separately for transverse compatibility considerations).

According to design practices, each of the above parameters can be considered either statistical or worst-case. In a semi-statistical approach, those parameters assumed deterministic may be given a zero-width distribution around the worst-case value. Details are given in Recommendation G.955.

5.4 Upgradability considerations

Two possibilities arise with regard to system upgradability:

1) It may be desired to upgrade from existing plesiochronous systems to SDH systems (e.g. from a 139 264 kbit/s system complying with Recommendation G.955 specifications to an STM-1 system based on this Recommendation);

2) It may be desired to upgrade from one SDH hierarchical level to another (e.g. from STM-1 to STM-4).

It is not always feasible to satisfy both possibilities simultaneously for long-haul applications, and opinions differ on the best approach to be taken for system upgrade. For example, to maintain compatibility with 139 264 kbit/s and 4 × 139 264 kbit/s systems complying with Recommendation G.955, maximum attenuation values for STM-1 and STM-4 long-haul applications in this Recommendation are taken to be 28 dB and 24 dB, respectively. The difference in maximum attenuation for these two levels reflects the current wide-scale availability of STM-4 receivers meeting the sensitivity requirements of the lower attenuation value compared to the current relatively high cost of STM-4 receivers meeting the sensitivity requirements of the higher attenuation value.

Two examples for accomplishing upgradability are described in Appendix IV. Also, 4.3/G.958, addresses the issue of joint engineering to meet not only the upgradability requirements, but any instances where the interface specifications of this Recommendation are not sufficient to meet the requirements of the specific application.

Annex A

System operating wavelength considerations

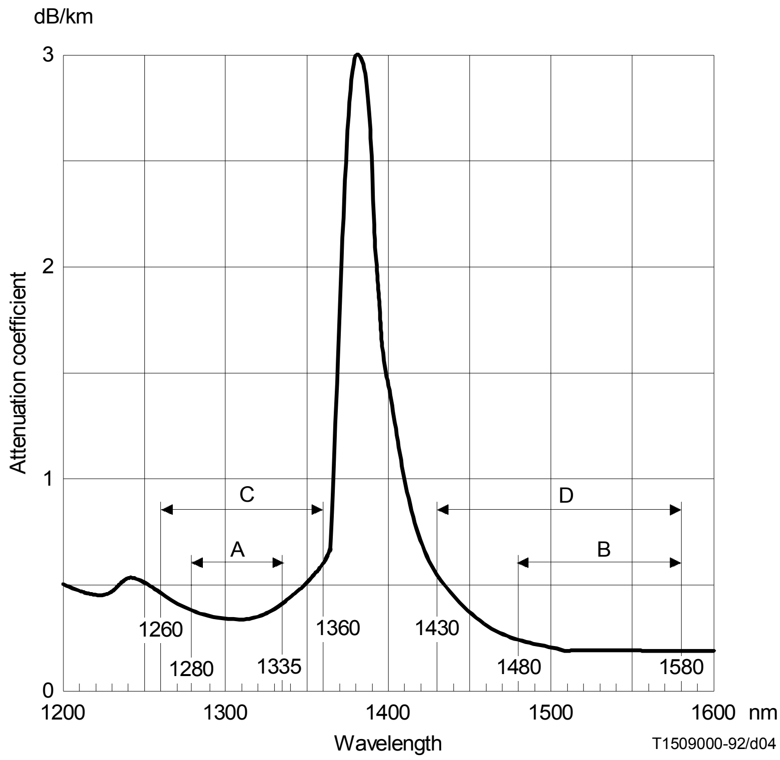
(This annex forms an integral part of this Recommendation)

This annex provides further information on the choice of range of operating wavelengths specified in Tables 2 to 4.

A.1. Operating wavelength ranges determined by fibre attenuation

The general form of attenuation coefficient for installed fibre cable used in this Recommendation is shown in Figure A.1. Included here are losses due to installation splices, repair splices, and the operating temperature range. Recommendation G.652 states that attenuation values in the range 0.3-0.4 dB/km in the 1310 nm region and 0.15-0.25 dB/km in the 1550 nm region have been obtained.

The wavelength ranges indicated in Tables 2 to 4 have been confirmed by data from fibre manufacturers combined with assumptions for a total margin to account for cabling, installation splicing, repair splicing and temperature operating range. Therefore, the following reference maximum attenuation coefficient values are considered appropriate only for systems calculations: 3.5 dB/km in case of intra-office, 0.8 dB/km in case of short-haul, 0.5 dB/km in case of 1310 nm long-haul and 0.33 dB/km in case of 1550 nm long-haul applications. By using these attenuation coefficient values, it is indicated that the approximate target distances in Table 1 are achievable.



Ranges A and B are suitable for long-haul (L-N.x) applications, and ranges C and D are suitable for short-haul (S-N.x) and intra-office (I-N) applications.

FIGURE A.1/G.957

Typical spectral attenuation coefficient for the installed fibre cable between S and R

A.2 Operating wavelength ranges determined by fibre dispersion

For G.652 fibres, the zero-dispersion wavelength lies between 1300 nm and 1324 nm, so the fibre is dispersion-optimized in the 1310 nm region. These wavelengths and corresponding requirements on the zero-dispersion slope result in the maximum permitted absolute value of the dispersion coefficient (as determined by fibres having the minimum or maximum zero-dispersion wavelengths) shown in diagram a) of Figure A.2. However, the G.652 fibres can be used also in the 1550 nm region, for which the maximum dispersion coefficient is comparatively large as shown in diagram b) of Figure A.2.

For G.653 fibre, the permitted range of the zero-dispersion wavelength lies between 1500 nm and 1600 nm, so the fibre is dispersion-optimized in the 1550 nm region. The analytical expressions for the dispersion coefficient result in the maximum permitted values shown in Figure A.3. The G.653 fibres can be used also in the 1310 nm region, for which the maximum dispersion coefficient is comparatively large. However, this possible application is currently not considered in Recommendation G.957.

For G.654 fibres in the 1550 nm region, the dispersion coefficient is similar but slightly larger than that for G.652 fibres. This is still under study and has not been taken into account in Tables 2 to 4.

For G.652 fibres in the 1310 nm region and for G.653 fibres in the 1550 nm region, the dispersion-limited wavelength range is chosen such that the absolute values of the dispersion coefficient at the limiting wavelengths are approximately equal. As can be seen from the shapes of diagram a) of Figure A.2 and Figure A.3, absolute dispersion values are therefore smaller within the operating wavelength range.

For G.654 fibres, and also for G.652 fibres in the 1550 nm region, diagram b) of Figure A.2 shows that dispersion limits the upper operating wavelength while attenuation limits the lower operating wavelength.

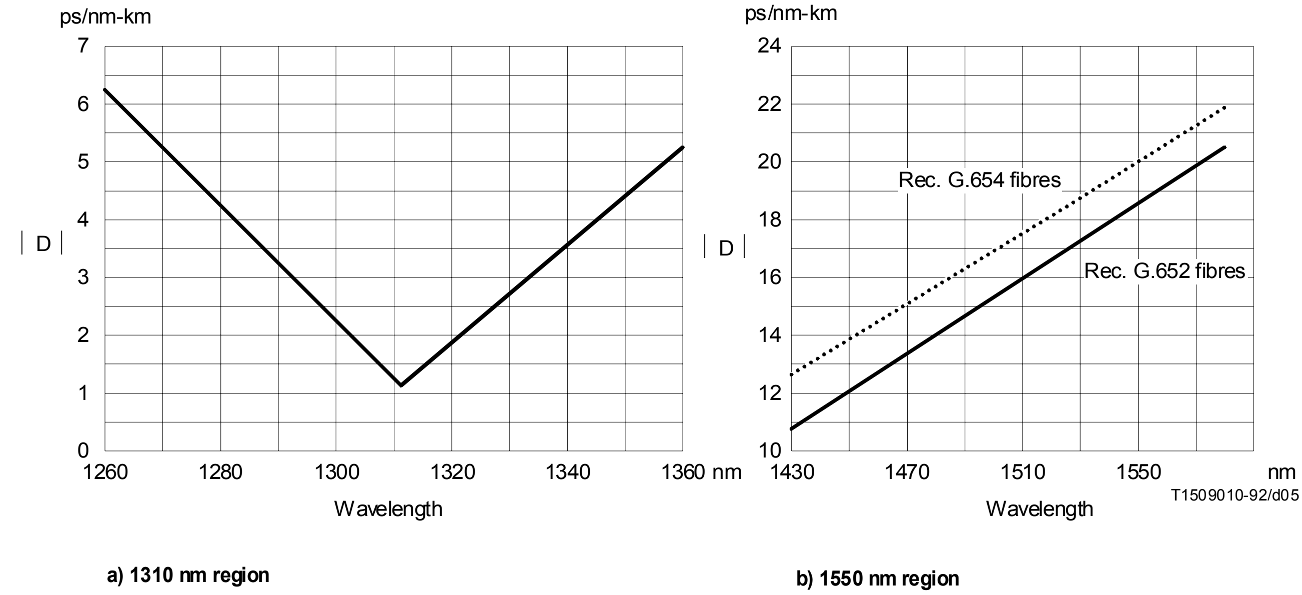


FIGURE A.2/G.957

Maximum absolute value, │ D │, of the dispersion coefficient for G.652 (——) and G.654 fibres (– –)

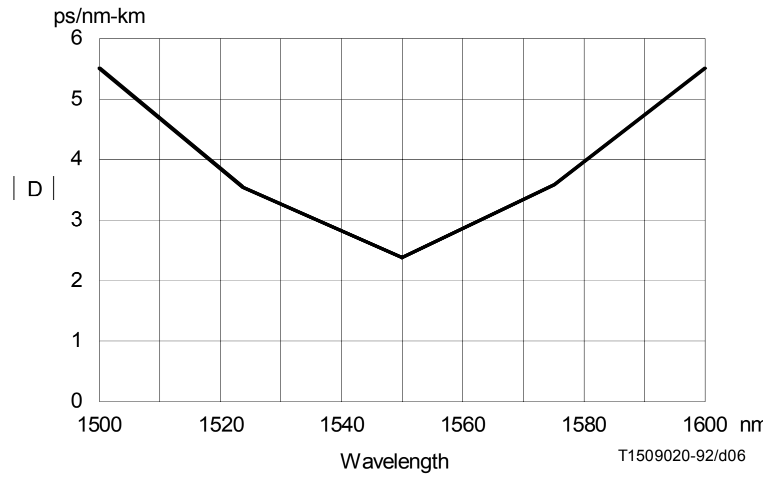


FIGURE A.3/G.957

Maximum absolute values, │ D │, of the dispersion coefficient for G.653 fibres

The interaction between the transmitter and the fibre is accounted for by a parameter epsilon. It is defined as the product of 10^{-6} times the bit rate (in Mbit/s) times the path dispersion (in ps/nm) times the RMS spectral width (in nm). For a 1 dB power penalty due to dispersion, epsilon has a maximum value. For intersymbol interference alone, the value 0.306 is applied to LEDs and SLM lasers. The 20 dB width for SLM lasers is taken as 6.07 times the RMS width. (For L-16.2 only, it is necessary to increase epsilon to 0.491, corresponding to a 2 dB power penalty.) For intersymbol interference plus mode partition noise, the maximum value 0.115 is applied to MLM lasers. (For I-1 and I-4, the large spectral widths may not often occur, but they are retained here for possible cost savings.) For wavelength chirp, no known value is applied to SLM lasers.

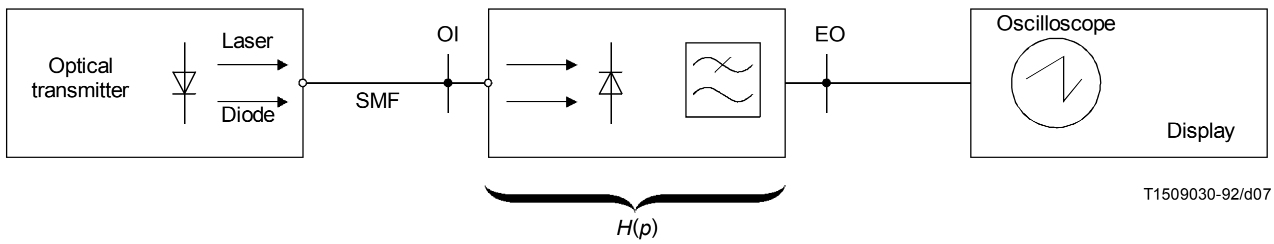
For a particular spectral width, the optical path dispersion is fixed for a particular application code. With the appropriate path distance from Table 1, the maximum allowed dispersion coefficient follows. The spectral dependence of the dispersion coefficient then determines the dispersion-limited wavelength range. (The use of the dispersion coefficient beyond the wavelength ranges stated in Recommendations G.652, G.653 or G.654 is for further study.)

Appendix I
Measurement of the mask of the eye diagram of the optical transmit signal

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

I.1 Measurement set-up

In order to ensure the suitability of the optical transmit signal for the performance of the receiver, a measurement set-up according to Figure I.1 is recommended for the eye diagram of the transmit optical signal. An optical attenuator may be used for level adaptation at the reference point OI. An electrical amplifier may be used for level adaptation at the reference point EO. Values for the mask of the eye diagram in Figure 2 include measuring errors such as sampling oscilloscope noise and manufacturing deviations of the low-pass filter.



H(*p*) Transfer function of optical reference receiver, including photodetector and electrical low-pass filter transfer functions
SMF Less than 10 m of optical fibre according to Recommendations G.652, G.653 or G.654
OI, EO Reference points for optical input (OI) and electrical output (EO)

FIGURE I.1/G.957

Measurement set-up for transmitter eye diagram

I.2 Transfer function of the optical reference receiver

The nominal transfer function of the optical reference receiver is characterized by a fourth-order Bessel-Thomson response according to

$$H(p) = \frac{1}{105}\ (105 + 105\,y + 45\,y^2 + 10\,y^3 + y^4)$$

with

$$p = j\frac{\omega}{\omega_r}, \quad y = 2.1140\,p, \quad \omega_r = 1.5\,\pi f_0, \quad f_0 = \text{bit rate}$$

The reference frequency is $f_r = 0.75\,f_0$. The nominal attenuation at this frequency is 3 dB. The corresponding attenuation and group delay distortion at various frequencies are given in Table I.1. Figure I.2 shows a simplified circuit diagram for the low-pass filter used for measuring the mask of the eye diagram of the optical transmit signal.

NOTE – This filter is not intended to represent the noise filter used within an optical receiver.

TABLE I.1/G.957

Nominal values of attenuation and group delay distortion of the optical reference receiver

f/f_0	f/f_r	Attenuation (dB)	Group delay distortion (UI)
0.15	0.2	0.1	0
0.3	0.4	0.4	0
0.45	0.6	1.0	0
0.6	0.8	1.9	0.002
0.75	1.0	3.0	0.008
0.9	1.2	4.5	0.025
1.0	1.33	5.7	0.044
1.05	1.4	6.4	0.055
1.2	1.6	8.5	0.10
1.35	1.8	10.9	0.14
1.5	2.0	13.4	0.19
2.0	2.67	21.5	0.30

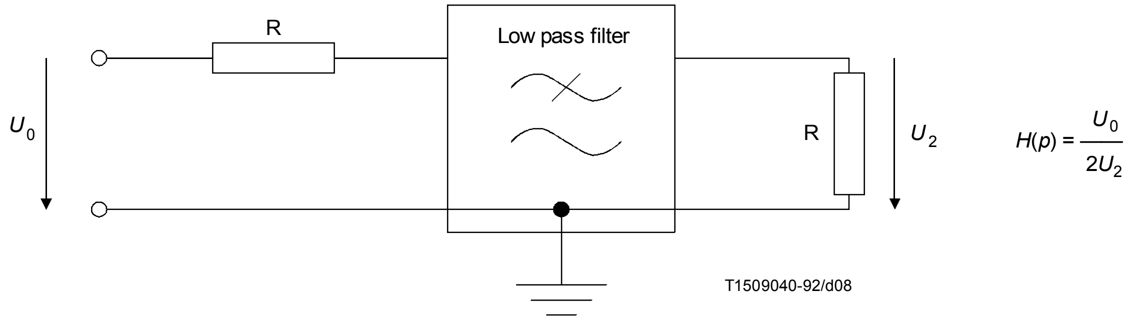


FIGURE I.2/G.957

Low-pass receiver filter for measuring the transmitter eye diagram

In order to allow for tolerances of the optical reference receiver components including the low-pass filter, the actual attenuation should not deviate from the nominal attenuation by more than the values specified in Table I.2. The flatness of the group delay should be checked in the frequency band below the reference frequency. The tolerable deviation is for further study.

TABLE I.2/G.957

Tolerance values of the attenuation of the optical reference receiver

f/f_r	Δa (dB)[a)]		
	STM-1	STM-4	STM-16
0.001 … 1	± 0.3	± 0.3	± 0.5
1 … 2	± 0.3 … ± 2.0	± 0.3 … ± 2.0	± 0.5 … ± 3.0

a) Provisional values.

NOTE – Intermediate values of Δa should be interpolated linearly on a logarithmic frequency scale.

Appendix II
Methods for measuring reflections

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

Two methods are in general use. The optical continuous-wave reflectometer (OCWR) utilizes a continuous or modulated stable light source with a high sensitivity time-averaging optical power meter. It is suitable for measuring the optical return loss of the cable plant at point S or the reflectance of the receiver at point R. The optical time-domain reflectometer (OTDR) utilizes a pulsed source having a low duty cycle along with a sensitive time-resolving optical receiver. It is suitable for measuring discrete reflectances between S and R or the receiver reflectance at R.

Both instruments utilize 2 × 1 optical couplers, and both are available commercially. Instructions contained with the instrument may supersede those given below. Moreover, test procedures are under development.

For calibration purposes, a jumper with a known end reflector may be used. The value of reflectance may be near zero (as obtained with careful index matching and/or a tight bend in the fibre), or about –14.5 dB (as with a good cleave), or some other known reflectance R_0 (as with an imperfect cleave or an applied thin film coating). The connection between the jumper and the instrument must have a low reflectance.

II.1 Optical continuous-wave reflectometer

The coupler nomenclature is shown in Figure II.1, and the following calibration measurement needs to be performed only once. Power P_s is measured by connecting the optical source directly to the power meter. The source is then connected to output port 3 of the coupler, while the power meter measures P_{32} at the input port 2. The source is now connected to input port 1, while the meter measures power P_{13} at port 3. Finally, the non-reflecting jumper is connected to port 3, while power P_0 is measured at port 2.

To measure the reflectance of the detector, the connector at point R is connected to port 3; to measure the ORL of the cable plant, the connector at point S is connected to port 3. In either case, power P_R is measured by the meter at port 2. The reflectance of the detector is

$$R = 10 \log_{10} \frac{P_s (P_R - P_0)}{P_{13} P_{32}}$$

The ORL of the cable plant is

$$ORL = -R$$

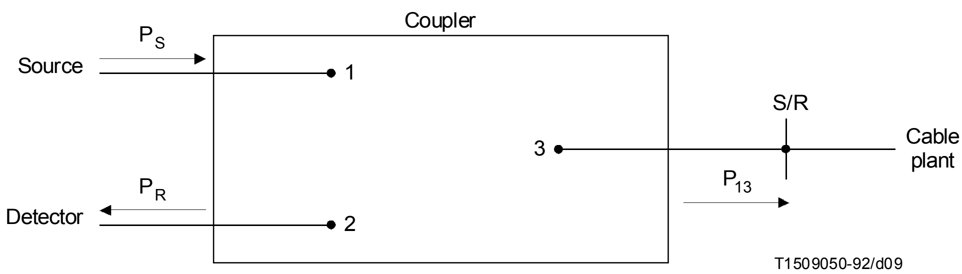


FIGURE II.1/G.957

Coupler arrangement for OTDR and OCWR

II.2 Optical time-domain reflectometer

Here the coupler is usually internal to the instrument. A variable optical attenuator, and a pigtail of length beyond the dead-zone of the instrument are both supplied, if they are not already internal to the instrument. The following calibration measurement needs to be performed only once. A jumper with known reflectance R_0 is attached, giving an OTDR trace schematically shown in Figure II.2. The optical attenuator is adjusted until the reflection peak falls just below the instrumental saturation level, and the peak height H_0 is noted. The calibration factor

$$F = R_0 - 10 \log_{10} \left(10^{\frac{H_0}{5}} - 1 \right)$$

is calculated. (If the temporal duration D of the pulse is measured, the backscatter coefficient of the fibre is $B = F - 10 \log_{10} D$. If D is in ns, B is about –80 dB.)

To measure the maximum discrete reflectance between S and R, the OTDR is connected to point S or R. The peak height H is noted for a particular reflectance. The resulting value is

$$R = F + 10 \log_{10} \left(10^{\frac{H}{5}} - 1 \right)$$

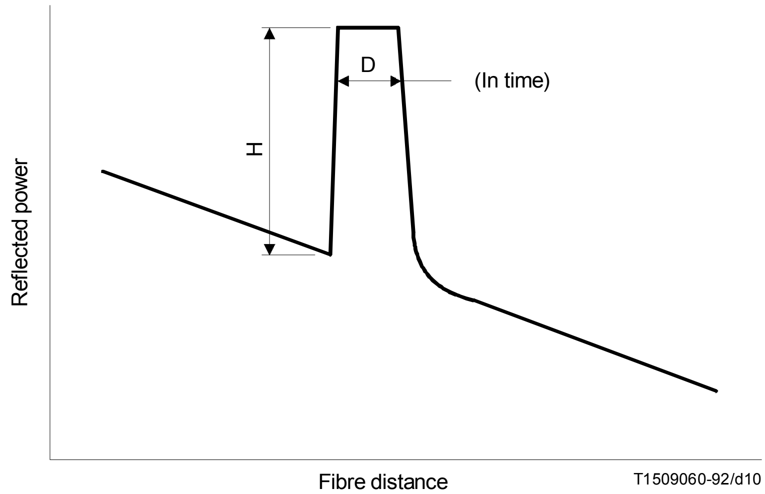


FIGURE II.2/G.957

OTDR trace at a discrete reflector

Appendix III
Possible method for evaluating aging margin contribution in receiver sensitivity specifications

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

This appendix presents a possible method for determining the contribution due to aging effects in the specification of receiver sensitivity used in this Recommendation.

III.1 Receiver sensitivity and eye opening

Figure III.1 shows eye opening at the receiver as a function of optical received power. The eye opening value, E, is the value which is determined by the system designer for operation at a BER of 10^{-10}. The received power P_2 corresponds to the power required for maximum eye opening at the receiver. For stable system operation, the optical received power is typically set to a level higher than P_1 such that, at the end of system life, the specified eye opening, E, is still satisfied. Thus, P_1 is the end-of-life receiver sensitivity and P_0 is the beginning-of-life receiver sensitivity. M is the margin between P_1 and P_0 to account for the effects of receiver aging. The amount of eye margin depends on receiver characteristics and the values, for example, may be $E_1 - E$ and $E_2 - E$ for different receivers (e.g. type I or type II). An appropriate eye margin cannot be obtained if the received power is P_0.

With respect to the effects of aging on receiver performance, it may be assumed that the eye opening as a function of received optical power is shifted parallel to the initial characteristics as shown in Figure III.2. For the purposes of simulating aging effects, it may also be assumed that the shifted curve can be obtained by adding a certain amount of intersymbol interference noise to the signal corresponding to the initial value of eye margin. The test method proposed for evaluation of the eye opening by this technique is the *S*/*X* test.

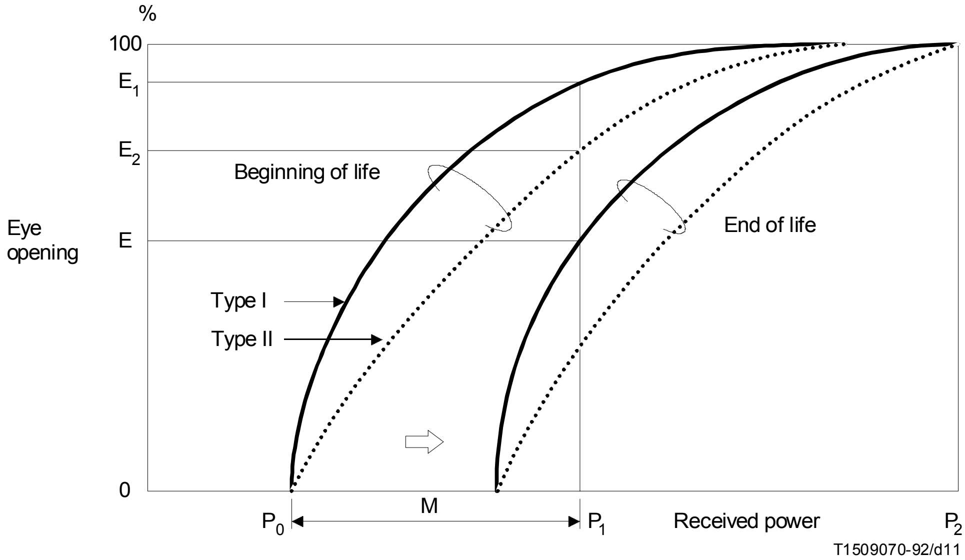


FIGURE III.1/G.957

Eye opening characteristics

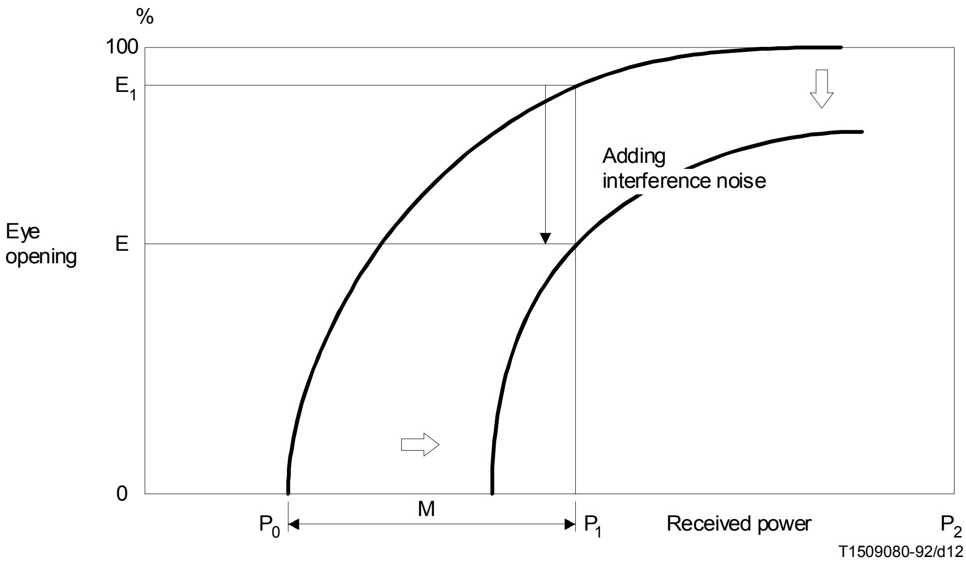


FIGURE III.2/G.957

Eye opening due to intersymbol interference

III.2 *S/X* test method

To simulate intersymbol interference noise, the *S/X* test is performed by using an NRZ signal modulated at a low frequency compared to the system operating bit rate. This interfering signal is combined optically with a normal optical signal and injected into the receiver under test.

In the *S/X* test, the normal optical signal power is usually set to P_1. The amount of the optical power of the interference noise, X, can be determined by a relationship between eye opening and S/X ratio whose characteristics are shown in Figure III.3. From Figure III.3, the *S/X* ratio can be determined as $(S/X)_E$ by the relationship between E_1 and E. The aging margin M and $(S/X)_E$ are given by

$$M = P_1 - P_0$$

$$(S/X)_E = \frac{P_1}{X}$$

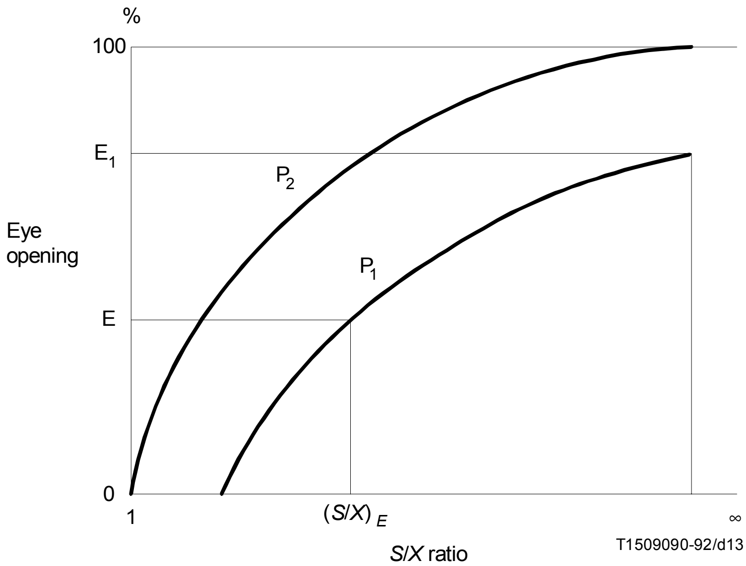


FIGURE III.3/G.957

Eye opening and *S/X* ratio parameter is normal signal power

The test configuration is shown in Figure III.4.

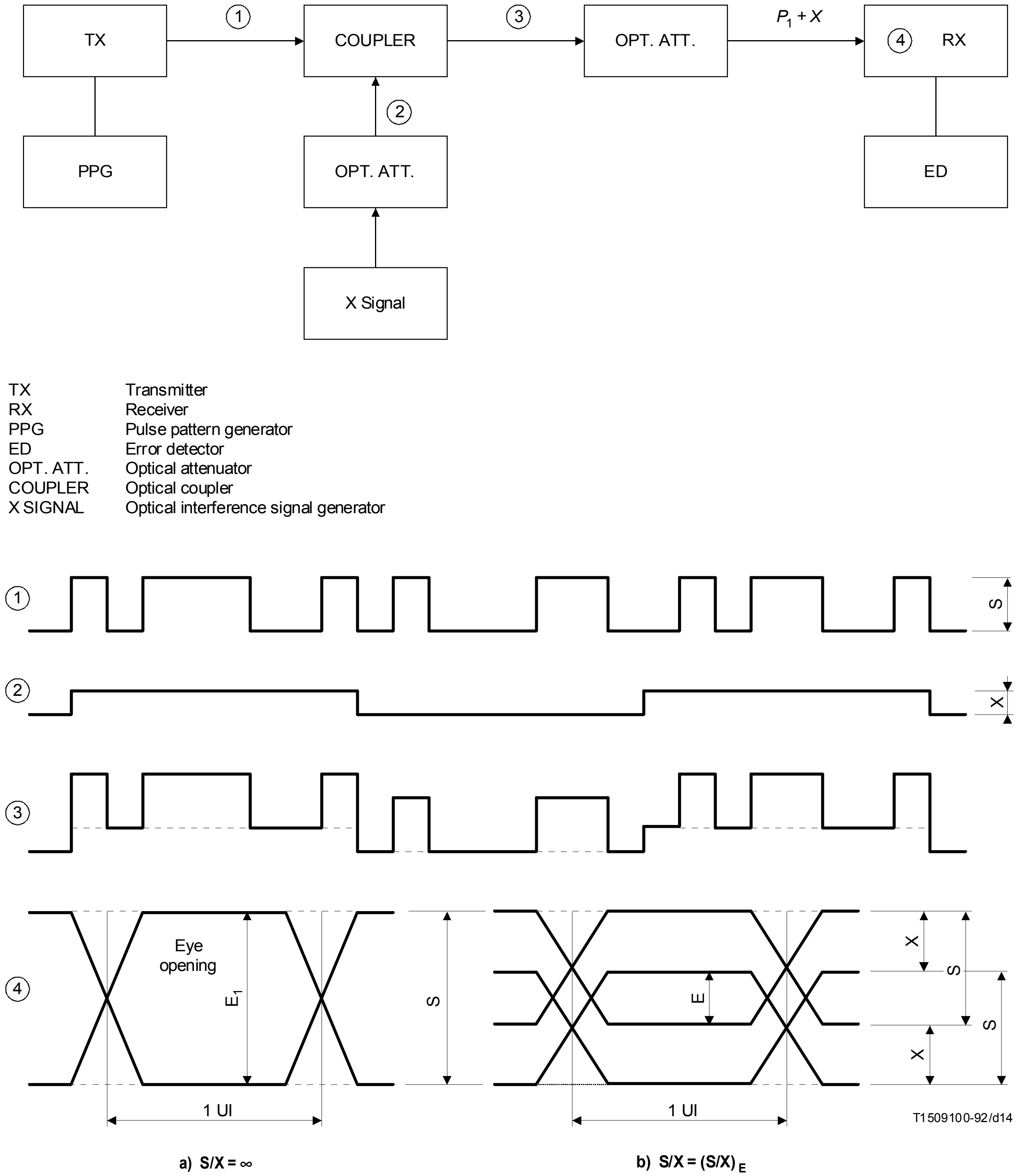


FIGURE III.4/G.957

S/X measurement configurations

Appendix IV
Upgradability examples

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

Two examples for accomplishing upgradability are described below:

Example 1

To realize low-cost designs optimized for a particular hierarchical level by using current, widely available optical components, the following maximum attenuation ranges may be adopted for the long-haul applications:

- STM-1 28 dB
- STM-4 24 dB
- STM-16 20 dB.

For upgrading from one hierarchical level to a higher one when it is desired to maintain regenerator spacings for the original and upgraded system, the following options are available:

i) The original system design may be based on the smallest attenuation (i.e. highest hierarchical level) expected for the upgraded long-haul system.

ii) If the original system operates in the 1310 nm region on G.652 fibre, then the upgraded system may be chosen to operate in the 1550 nm region to obtain lower cable attenuation, although with increased dispersion penalty.

iii) Relatively high-loss components (e.g. connectors) may be replaced with lower-loss components for the upgraded system.

iv) Statistical design approaches may be employed to provide enhanced cable sections for the upgraded system.

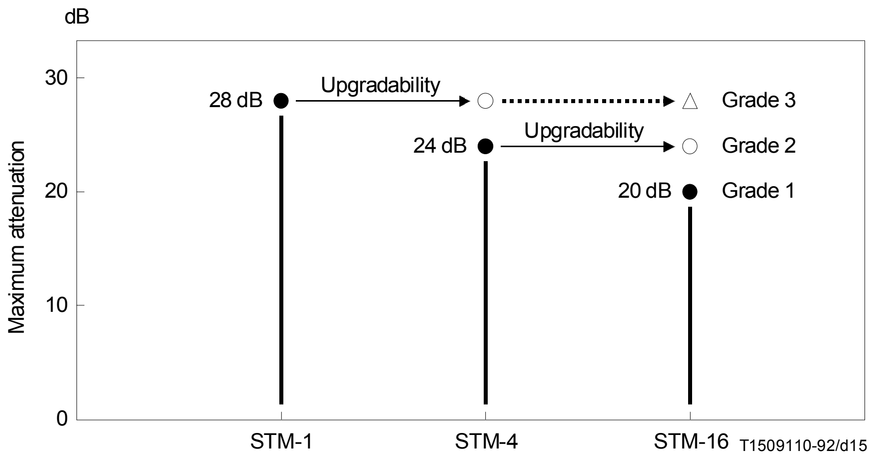
Example 2

Another approach to upgradability is to employ the concept of a set of grades in higher order STM-N systems for the long-haul inter-office interfaces. Table IV.1 and Figure IV.1 show the grade classification based on maximum attenuation. Parameter values for the various grades are for further study. These grades might be applied by users when considering network planning and cost performance, etc. Moreover, higher grade system design should allow incorporation of future technology advances and changing service requirements.

TABLE IV.1/G.957

Grade classification for long-haul applications

Maximum attenuation	STM-1	STM-4	STM-16
28 dB	Grade 1	Grade 2	Grade 3
24 dB	–	Grade 1	Grade 2
20 dB	–	–	Grade 1



● Grade 1

○ Grade 2 (upgrade compatible value from lower STM-level)

△ Grade 3 (full upgrade compatible value)

FIGURE IV.1/G.957

Maximum attenuation for STM-N long-haul inter-office interfaces with three grades

Reference

[1] IEC 825:1984, *Radiation safety of laser products, equipment classification, requirements and user's guide*.

Printed in Switzerland
Geneva, 1994