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Recommendation G.950

GENERAL CONSIDERATIONS ON DIGITAL LINE SYSTEMS

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

9.5 Digital line systems

1 Introduction

Digital line systems are the means of providing digital line sections. Recommendations on digital line systems may recognize, for digital line sections operating at a given bit rate, specific transmission media and transmission techniques (e.g. coaxial cable, regenerative transmission, etc.). Performance requirements of digital line systems are for the guidance of systems designers and users (equipment design objectives) and may be related to hypothetical digital paths of defined constitution.

All digital line systems operating on the same medium at a given bit rate shall comply with the characteristics of the digital line section at the same bit rate.

2 General requirements for digital line systems

The following general requirements apply to all digital line systems on metallic pair cables and where applicable with appropriate interpretation, also to those on optical fibre cables.

2.1 *Environmental conditions*

2.1.1 *Climatic conditions*

Data concerning the classification of climatic stresses that can be expected for overground equipment is available in IEC Publication series No. 721. Conditions for underground equipment and further details for overground equipment need further study.

Note — Supplement No. 34 contains some information on climatic conditions in underground repeater housing.

2.1.2 *Pressurization*

The repeaters of digital line systems may be operated in pressurized housings.

2.1.3 *Protection against induced voltages and currents caused by lightning and power lines, etc.*

The repeaters, line terminals and the power feeding arrangement should be protected against induced voltages and currents (caused by lightning or other sources) in accordance with Recommendation K.17.

The system shall be physically protected from the above induced voltages and currents so that no damage is sustained. In addition, the performance of the system shall not be adversely affected by steady state induced voltages and currents although it may be affected by surges for the duration of the surge in certain circumstances.

In addition the CCITT Directives [1] give guidance on these problems.

2.1.4 *Protection against interference from other sources*

The performance of Digital Line Systems should not be affected significantly by interference from sources within stations such as fluorescent lamp, tools, ventilation plant, etc., and especially sources giving rise to pulse type interference. Performance degradation due to interferences from radio and broadcast transmitters should also be prevented.

Note — The Supplement No. 27 contains some information on possible measures to reduce effects from interference and measuring methods concerning interference.

2.1.5 *Interference to other systems*

Conducted and radiated emissions must not interfere with other equipment, radio and broadcast services. In particular, digital line systems must coexist in the same cable with other digital and analogue line systems. (Some restrictions might, however, be necessary for joint use of different line systems on symmetrical pair cables.)

Reference

[1] CCITT Manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988.

Recommendation G.951

DIGITAL LINE SYSTEMS BASED ON THE 1544 KBIT/S HIERARCHY

ON SYMMETRIC PAIR CABLES

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 1544 kbit/s hierarchy on symmetric pair cables and includes systems operating at the following bit rates:

1544 kbit/s,

3152 kbit/s,

6312 kbit/s.

2 Transmission medium

The system can be operated on symmetrical pair cables of various wire diameters and cable constructions including those given in Recommendations G.611, G.612, and G.613.

3 Protection against interference from external sources

The digital line system can be disturbed by interference from telephone circuits carried within the same cable and by a switch when repeaters are installed in switching centres. Examples of possible ways of reducing the effect of this type of interference is the reduction of repeater section length near switching centres, segregation of pairs, the use of particular line codes, etc.

4 Overall design features

4.1 *Availability*

The availability objective of the system should be derived taking into account the availability requirement for the hypothetical reference digital section as given in draft Recommendation G.801.

4.2 *Reliability*

MTBF values should be specified for the line system as a whole taking into account the requirements concerning availability.

4.3 *Repeater crosstalk-noise figures*

Repeater crosstalk-nooise figures are defined in Annex A, together with suggested measurement techniques. Crosstalk-noise figures quantify the performance of digital regenerators which are subject to crosstalk interference. They are functions of BER, line system line code, cable characteristics, environmental conditions, and repeater spacing loss A_0(at half the line system baud rate).

At a BER = 10^{D}lF261$^{\mathrm{D}}$lFx and over a loss range A_1 A_0 A_2, crosstalk-noise figures should meet the following specifications:

a) NEXT-Noise Figure [R_N] $CA_0 + D$ *

b) FEXT-Noise Figure [R_F] E *

* It has not been possible to recommend specific values for parameters x , A_1, A_2, C , D and E .

4.4 *Error Performance*

The design objective for the error ratio of the individual repeater should take into account the network performance objectives given in Recommendation G.821.

5 Specific design features

5.1 *Type of power feeding*

Although CCITT does not recommend the use of a specific remote power-feeding system for this symmetrical line system, in practice only the constant current d.c. feeding via the phantom circuits of the two symmetrical pairs of a system is used.

This symmetrical cable system may be subject to induced voltages and currents caused by lightning, power lines, railways, etc.

Precautions must be taken to protect the staff from any possible danger arising from the normal operating voltages and remote power-feed currents as well as from the induced voltages and currents.

Many national Administrations have issued detailed rules and regulations for the protection of persons. It is obligatory in most cases to meet these rules and regulations. In addition the CCITT Directives [1] give guidance on these problems.

Precautions are also needed for the protection of the equipment against induced voltages and currents. The equipment should therefore be designed in such a way that it passes the tests specified in Recommendation K.17 [2].

5.2 *Repeater spacing and cable fill*

The specific repeater spacing cannot be recommended, but general considerations concerning system planning are contained in Annex B to this Recommendation.

5.3 *Maintenance strategy*

5.3.1 *Type of supervision and fault location*

In service monitoring or out-of-service fault location can be used.

5.3.2 *Fault conditions and consequent actions*

The fault conditions and consequent actions in this section should be complementary to those recommended for digital line sections.

ANNEX A

(to Recommendation G.951)

Definition and measurement of repeaters crosstalk noise figures

A.1 *Definition*

a) NEXT-Noise Figure $[R_N]$

$$[R_N] = [I_N] - [N_0]$$

$$I_N = \int_0^{\infty} \left| f/f_0 \right|^{3/2} \left| E(f) \right|^2 P(f)\, df ,$$

I_N = mean square near-end crosstalk (NEXT) voltage produced by a single interfering regenerator that would appear at the decision point if the NEXT loss were 0 dB at half the line system baud rate.

N_0 = mean square NEXT interference voltage at decision point which procedures specified BER, and depends on parameters which affect the decision process and reflects impairments arising from intersymbol interference and offsets from the optimum position of the decision threshold levels and sampling instants at the regenerator decision point.

$E(f)$ = regenerator equalizer frequency transfer function.

$P(f)$ = power spectral density (single sided) of line system line code.

f_0 = half line system baud rate.

Quantities in square brackets are in dB, i.e.

$[X]$ = $10 \log_{10} |X|$.

b) FEXT-Noise Figure $[R_F]$

$$[R_F] = [I_F] - [N_0]$$

$$I_F = \int_0^{\infty} \left| f/f_0 \right|^2 \left| E(f) \right|^2 \left| G(f) \right|^2 P(f)\, df,$$

I_F = mean square far-end crosstalk (FEXT) voltage produced by a single interfering regenerator that would appear at the decision point if the FEXT loss were 0 dB at half the line system baud rate.

N_0 = mean square FEXT interference voltage at decision point which produces specified BER, and depends on parameters which affect the decision process and reflects impairments arising from intersymbol interference and offsets from the optimum position of the decision threshold levels and sampling instants at the regenerator decision points.

$E(f)$, $P(f)$, f_0 as in a), and

$G(f)$ = frequency transfer function of cable.

A.2 *Measurement*

Method a) directly relates to the definition of crosstalk-noise figure and is therefore the reference measuring method. Methods b) and c) are the possible practical alternatives. Method c) avoids the use of a selective filter.

Method a)

The NEXT-Noise Figure and FEXT-Noise Figure can be measured using the configuration shown in Figure A-1/G.951 with the Function Switch in the N and F position, respectively. The measurement consists of equating the r.m.s. voltages at A and A^{1}, setting the artificial line to the desired loss A_0, and then adjusting the variable attenuator until the desired BER = 10$^{\mathrm{D}}$lF261$^{\mathrm{D}}$lFx is achieved. The value of the attenuator, [R] dB, is then the NEXT-Noise Figure or FEXT-Noise Figure for the desired A_0 and BER.

Figure A-1/G.951, (MC) p.

Method b)

The NEXT-Noise Figure [R_N] can be measured using ‘‘input S/N ratio’’ test sets by employing the test set in a ‘‘manual mode’’ and performing external measurements with a selective filter (see Figure A-2/G.951). The measurement consists of:

i) Set artificial line to 0 dB loss and using selective measure test signal power [S_0] dBm.

ii) Set artificial line to desired loss A_0, adjust variable attenuator until desired BER = 10DlF261DlFx is obtained, switch off test signal, and using selective filter, measure noise power [P] dBm.

iii) Then [R_N] = [S_0] — [P] for desired A_0 and BER.

Note — The degrading effect of clock jitter on NEXT-Noise Figure and FEXT-Noise Figure should be measured by superimposing appropriate jitter on the test signal.

Figure A-2/G.951, (M), p.

Method c)

The NEXT-Noise Figure [R_N] can be measured using ‘‘input S/N | ratio’’ test sets in ‘‘manual mode’’ with the insertion of an additional variable attenuator between the test signal and the artificial line, as shown in Figure A-3/G.951).

The measurement procedure is as follows:

i) set the artificial line to 0 dB loss and the additional variable attenuator to A dB loss;

ii) regulate the variable gain amplifier until the power level of the variable attenuator input is equal to [Q1] — A dB, the power level of the artificial line output;

iii) set the artificial line to A dB loss and the additional variable attenuator to 0 dB loss;

iv) adjust the variable attenuator until the desired BER = 10^{-x} is reached. The attenuation value of the attenuator is $[\alpha N]$ dB;

v) calculate $[R_N] = [\alpha N] + A - [W_N]$

where

$$[W_N] = 10 \log_{10} \left[\int_0^{f} P_R(f) df \Big/ \int_0^{f} \left| \frac{f}{f_0} \right|^{3/2} P_R(f) df \right]$$

in which $P_R(f)$ = spectral power density (single sided) of line code.

In would be better to obtain W_N | by measurement. Of course, the value of W_N | can also be calculated according to $P_R(f)$ of AMI or HDB_3 in a certain frequency range, for example, $W_N = -3.59$ dB in the range from 0 to 10 | 40 kHz.

Figure A-3/G.951, (N), p.

ANNEX B
(to Recommendation G.951)

Guidance notes for the satisfactory achievement of the

error performance objectives

B.1 To comply with the Network Performance Objectives (NPO) it is necessary to take into account many interrelated factors. Figure B-1/G.951 illustrates diagrammatically the interrelationship between all the factors that impact on this matter. The basis upon which digital line system installation planning guidelines are formulated is dependent on the circumstances of each Administration. For example, some Administrations may have cables with favourable characteristics, whilst at the same time the network may experience serious levels of unquantifiable interference (network effects). An Administration must, therefore, make a judgement as to the significance of each effect in their network and formulate cable utilization guidelines which satisfy the digital line section error performance requirements.

Figure B-1/G.951, (M), p.

The following notes highlight a number of important considerations concerning the formulation of system installation planning guidelines.

Note 1 — In the process of establishing cable utilization guidelines the crosstalk noise figure is the only parameter describing the intrinsic quality of the regenerator under crosstalk interference conditions. This parameter, which is based on the *average* power spectral density of the total crosstalk interference, provides a useful approximation to the system's immunity to crosstalk from plesiochronous data streams, and is the correct measure for synchronous data streams provided the phases of the disturbing systems are randomized. It is also based on an assumption of random data on the disturbing systems and therefore cannot be applied to the case of repetitive data patterns. However the use of scramblers effectively makes almost all data patterns appear to be random [3].

Note 2 — In an operational environment, regenerators may be subject to other sources of interference which are difficult to quantify and which may induce errors. In some instances specific interference mechanisms have been quantified and appropriate limits and testing procedures are reflected in national specifications. These aspects are currently under study within CCITT and as operational experience is gained it might be possible to introduce further tests that accomodate these other interference mechanisms.

Note 3 — Maximum cable utilization should be based on complying with the network performance objective. To satisfy this objective Administrations may adopt one of the following approaches:

i) In circumstances where Administrations are able to judge the significance of the ''network effects'' cable fill calculations should be based on an objective determined by discounting ''network effects'' from the network performance objective.

ii) In circumstances where Administrations are not able to judge the significance of the network effects, cable fill calculations should be based on the equipment design objective.

Note 4 — The use of a reduced line symbol rate code provides a more favourable crosstalk environment, and this feature will impact on cable fill calculations.

Note 5 — When changing from a plesiochronous to a synchronous network operation, some cable crosstalk couplings and relative phasings of the system clocks lead to increases in system margins whilst others lead to reduced system margins by up to a maximum of 3 dB for practical systems. It is believed that there are more cases with increased margin than reduced margin and that there is therefore no need to introduce any extra margin when changing from plesiochronous to synchronous operations [3].

Scramblers may be used to ensure that the interference from several identical repetitive sequences does not exceed the levels occurring with random data.

References

[1] CCITT Manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988.

[2] CCITT Recommendation *Tests on power-fed repeaters using solid state devices in order to check the arrangements for protection from external interference* , Vol. IX, Rec. K.17.

[3] SMITH, B. | . and POTTER, P. | . [June 1986] — Design Criteria for Crosstalk Interference between Digital Signals in Multipair Cable, *IEEE Trans. Commun.* , Vol. COM-34, No. 6.

Recommendation G.952

DIGITAL LINE SYSTEMS BASED ON THE 2048 kbit/s

HIERARCHY ON SYMMETRIC PAIR CABLES

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 2048 kbit/s hierarchy on symmetric pair cables and includes systems operating at the following bit rates:

2 **|** 48 kbit/s

8 **|** 48 kbit/s

34 **|** 68 kbit/s

The requirement for overall performance and interfaces of the corresponding digital line sections are given in Recommendation G.921.

2 Transmission medium

The system can be operated on symmetrical pair cables of various wire diameters and cable constructions including those given in Recommendations G.611, 612 and 613.

Note — 34 | 68 kbit/s systems should be operated on high performance cables and may require one cable for each direction of transmission.

3 Protection against interference from external sources

The digital line system can be disturbed by interference from telephone circuits carried within the same cable and by a switch when repeaters are installed in switching centres. Examples of possible ways of reducing the effect of this type of interference are the reduction of repeater section length near switching centres, segregation of pairs, the use of particular line codes, etc.

4 Overall design features

4.1 *Availability*

The availability objective of the system should be derived taking into account the availability requirement for the hypothetical reference digital section as given in draft Recommendation G.801.

4.2 *Reliability*

MTBF values should be specified for the line system as a whole taking into account the requirements concerning availability.

4.3 *Repeater crosstalk-noise figures*

Repeater crosstalk-noise figures are defined in Annex A, together with suggested measurement techniques. Crosstalk-noise figures quantify the performance of digital regenerators which are subject to crosstalk interference. They are functions of BER, line system line code, cable characteristics, environmental conditions, and repeater spacing loss A_0(at half the line system baud rate).

At a BER = 10DlF261 ^{x}and over a loss range A_1 A_0 A_2, crosstalk-noise figures should meet the following specifications:

a) NEXT-Noise Figure [R_N] $CA_0 + D$ |

b) FEXT-Noise Figure [R_F] E | .

* It has not been possible to recommend specific values for parameters x , A_1, A_2, C , D , and E .

Examples of the values used by some Administrations for 2 Mbit/s systems are given below:

H.T. [T1.952]

Example	*x*	*A* 1	*A* 2	*C*	*D*	*E*	Test method
i	6	5	40	1.1	14.7	17.5	a
ii	7	10	40	1.0	19 |	—	b
iii	7	7	38	1.0	18 |	—	b

Note 1 — In example ii, a filter with a centre frequency of 1020 kHz and a bandwidth of 3.1 kHz is employed.

Note 2 — The values do not include any allowance for the effects of jitter.

Tableau [T1.952], p.

4.4 *Error performance*

The design objective for the error ratio of the individual repeater should take into account the network performance objectives given in Recommendation G.821.

5 Specific design features

5.1 *Type of power feeding*

Although CCITT does not recommend the use of a specific remote power-feeding system for this symmetrical line system, in practice only the constant current d.c. feeding via the phantom circuits of the two symmetrical pairs of a system is used.

This symmetrical cable system may be subject to induced voltages and currents caused by lightning, power lines, railways, etc.

Precautions must be taken to protect the staff from any possible danger arising from the normal operating voltages and remote power-feed currents as well as from the induced voltages and currents.

Many national Administrations have issued detailed rules and regulations for the protection of persons. It is obligatory in most cases to meet these rules and regulations. In addition the CCITT Directives [1] give guidance on these problems.

Precautions are also needed for the protection of the equipment against induced voltages and currents. The equipment should therefore be designed in such a way that it passes the tests specified in Recommendation K.17 [2].

5.2 *Repeater spacing and cable fill*

A specific repeater spacing cannot be recommended, but general considerations concerning system planning are contained in Annex B to this Recommendation.

5.3 *Maintenance strategy*

5.3.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used.

5.3.2 *Fault conditions and consequent actions*

The following fault conditions should be detected in addition to those specified in Recommendation G.921 for the relevant digital sections, and the associated consequent actions should be taken:

a) failure of remote power feeding —

a prompt maintenance alarm should be generated, if practicable.

b) low error ratio threshold exceeded —

this threshold is 1 | (mu | 0DlF261 5 for systems at 2048 and 8448 kbit/s

thi threshol and 1 | (mu | 0DlF261 6 for systems at higher bit rates;

a deferred maintenance alarm should be generated to signify that performance is deteriorating.

ANNEX A

(to Recommendation G.952)

Definition and measurement of repeaters crosstalk-noise figures

A.1 *Definition*

a) NEXT-Noise Figure $[R_N]$

$$[R_N] = [I_N] — [N_0]$$

$$I_N = \int_0^{\infty} \left| f/f_0 \right|^{3/2} \left| f I E(f) \right|^2 P(f)\, df$$

I_N = mean square near-end crosstalk (NEXT) voltage produced by a single interfering regenerator that would appear at the decision point if the NEXT loss were 0 dB at half the line system baud rate.

N_0 = mean square NEXT interference voltage at decision point which produces specified BER, and depends on parameters which affect the decision process and reflects impairments arising from intersymbol interference and offsets from the optimum position of the decision threshold levels and sampling instants at the regenerator decision point.

$E(f)$ = regenerator equalizer frequency transfer function.

$P(f)$ = power spectral density (single sided) of line system line code.

f_0 = half line system baud rate.

and quantities in square brackets are in dB, i.e.

$[X] = 10 \log_{10} |X|$.

b) FEXT-Noise Figure $[R_F]$

$$[R_F] = [I_F] - [N_0]$$

$$I_F = \int_0^\infty \left| f/f_0 \right|^2 \left| E(f) \right|^2 \left| G(f) \right|^2 P(f)\, df$$

I_F = mean square far-end crosstalk (FEXT) voltage produced by a single interfering regenerator that would appear at the decision point if the FEXT loss were 0 dB at half the line system baud rate.

N_0 = mean square FEXT interference voltage at decision point which produces specified BER, and depends on parameters which affect the decision process and reflects impairments arising from intersymbol interference and offsets from the optimum position of the decision threshold levels and sampling instants at the regenerator decision points.

$E(f)$, $P(f)$, f_0 as in a), and

$G(f)$ = frequency transfer function of cable.

A.2 *Measurement*

Method a) directly relates to the definition of crosstalk-noise figure and is therefore the reference measuring method. Methods b) and c) are the possible practical alternatives. Method c) avoids the use of a selective filter.

Method a)

The NEXT-Noise Figure and FEXT-Noise Figure can be measured using the configuration shown in Figure A-1/G.952, with the Function Switch in the N and F position, respectively. The measurement consists of equating the r.m.s. voltages at A and A_1, setting the artificial line to the desired loss A_0, and then adjusting the variable attenuator until the desired BER = 10^{D}lF261 ^{x} is achieved. The value of the attenuator, [R]dB, is then the NEXT-Noise Figure or FEXT-Noise Figure for the desired A_0 and BER.

Figure A-1/G.952, (MC), p.

Method b)

The NEXT-Noise Figure [R_N] can be measured using ‘‘input S/N ratio’’ test sets by employing the test set in a ‘‘manual mode’’ and performing external measurements with a selective filter, see Figure A-2/G.952. The measurement consists of:

i) set artificial line to 0 dB and using selective measure test signal power [S_0] dBm.

ii) Set artificial line to desired loss A_0, adjust variable attenuator until desired BER = 10^{D}lF261 ^{x}is obtained, switch off test signal, and using selective filter, measure noise power [P] dBm.

iii) Then [R_N] = [S_0] — [P] for desired $A_0$and BER.

Note — The degrading effect of clock jitter on NEXT-Noise Figure and FEXT-Noise Figure should be measured by superimposing appropriate jitter on the test signal.

Figure A-2/G.952, (MC), p.

Method c)

The NEXT-Noise Figure [R_N] can be measured using ‘‘input S/N ratio’’ test sets in ‘‘manual mode’’ with the insertion of an additional variable attenuator between the test signal and the artificial line, as shown in Figure A-3/G.952.

The measurement procedure is as follows:

i) set the artificial line to 0 dB loss and the additional variable attenuator to A dB loss;

ii) regulate the variable gain amplifier until the power level of the variable attenuator input is equal to [Q 1] — A dB, the power level of the artificial line output;

iii) set the artificial line to A dB loss and the additional variable attenuator to 0 dB loss;

iv) adjust the variable attenuator until the desired BER = 10^{D}lF261 ^{x}is reached. The attenuation value of the attenuator is [αN] dB;

v) calculate $[R_N] = [\alpha N] + A — [W_N]$

where

$$[W_N] = 10 \log_{10} \left[\int_0^{\infty} P_R(f)\,df \Big/ \int_0^{\infty} \left| \frac{f}{f_0} \right|^{3/2} P_R(f)\,df \right]$$

in which $P_R(f)$ = spectral power density (single sided) of line code.

In would be better to obtain W_N | by measurement. Of course, the value of W_N | can also be calculated according to $P_R(f)$ of AMI or HDB_3 in a certain frequency range, for example, W_N = —3.59 dB in the range from 0 to 10 | 40 kHz.

Figure A-3/G.952, (N), p.

ANNEX B

(to Recommendation G.952)

Guidance notes for the satisfactory achievement of the

error performance objectives

B.1 To comply with the Network Performance Objectives (NPO) it is necessary to take into account many interrelated factors. Figure B-1/G.952 illustrates diagrammatically the interrelationship between all the factors that impact on this matter. The basis upon which digital line system installation planning guidelines are formulated is dependent on the circumstances of each Administration. For example, some Administrations may have cables with favourable characteristics, whilst at the same time the network may experience serious levels of unquantifiable interference (network effects). An Administration must, therefore, make a judgement as to the significance of each effect in their network and formulate cable utilization guidelines which satisfy the digital line section error performance requirements.

Figure B-1/G.952, (M), p.

The following notes highlight a number of important considerations concerning the formulation of system installation planning guidelines.

Note 1 — In the process of establishing cable utilization guidelines the crosstalk-noise figure is the only parameter describing the intrinsic quality of the regenerator under crosstalk interference conditions. This parameter, which is based on the *average* power spectral density of the total crosstalk interference, provides a useful approximation to the system's immunity to crosstalk from plesiochronous data streams, and is the correct measure for synchronous data streams provided the phases of the disturbing systems are randomized. It is also based on an assumption of random data on the disturbing systems and therefore cannot be applied to the case of repetitive data patterns. However the use of scramblers effectively makes almost all data patterns appear to be random [3].

Note 2 — In an operational environment, regenerators may be subject to other sources of interference which are difficult to quantify and which may induce errors. In some instances specific interference mechanisms have been quantified and appropriate limits and testing procedures are reflected in national specifications. These aspects are currently under study within CCITT and as operational experience is gained it might be possible to introduce further tests that accommodate these other interference mechanisms.

Note 3 — Maximum cable utilization should be based on complying with the network performance objective. To satisfy this objective Administrations may adopt one of the following approaches:

i) In circumstances where Administrations are able to judge the significance of the ''network effects'' cable fill calculations should be based on an objective determined by discounting ''network effects'' from the network performance objective.

ii) In circumstances where Administrations are not able to judge the significance of the network effects, cable fill calculations should be based on the equipment design objective.

Note 4 — The use of a reduced line symbol rate code provides a more favourable crosstalk environment, and this feature will impact on cable fill calculations.

Note 5 — When changing from a plesiochronous to a synchronous network operation, some cable crosstalk couplings and relative phasings of the system clocks lead to increases in system margins whilst others lead to reduced system margins by up to a maximum of 3 dB for practical systems. It is believed that there are more cases with increased margin than reduced margin and that there is therefore no need to introduce any extra margin when changing from plesiochronous to synchronous operations [3].

Scramblers may be used to ensure that the interference from several identical repetitive sequences does not exceed the levels occurring with random data.

References

[1] CCITT Manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988.

[2] CCITT Recommendation *Tests on power-fed repeaters using solid state devices in order to check the arrangements for protection from external interference* , Vol. IX, Rec. K.17.

[3] SMITH, B. | . and POTTER, P. | . [June 1986] — Design Criteria for Crosstalk Interference between Digital Signals in Multipair Cable, *IEEE Trans. Commun.* , Vol. COM-34, No. 6.

Recommendation G.953

DIGITAL LINE SYSTEMS BASED ON THE

1544 kbit/s HIERARCHY ON COAXIAL PAIR CABLES

(Malaga-Torremolinos, 1983; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 1544 kbit/s hierarchy on coaxial pair cables and includes systems conveying the following bit rates:

44 | 36 kbit/s

97 | 28 kbit/s

2 Transmission media

The systems can be operated on coaxial pairs, as defined in the Series G.620 Recommendations, in accordance with Table 1/G.953.

H.T. [T1.953]
TABLE 1/G.953
Transmission media

System (kbit/s)	Cable Recommendation
44 | 36	G.623
97 | 28	G.623

Tableau 1/G.953 [T1.953], p.

3 Overall design features

3.1 *Availability*

The availability objective of the system should be derived taking into account the availability requirement for the hypothetical reference digital section given in Recommendation G.801.

3.2 *Reliability*

MTBF values should be specified for the line system as a whole taking into account the requirements concerning availability.

3.3 *Repeater noise margin*

Repeater Noise Margin is defined in Annex A together with suggested measurement techniques. The Noise Margin quantifies the performance of digital regenerators for coaxial pairs. This is a function of BER and repeater spacing loss A_0(at half the line system baud rate).

At a BER = 10^{D}lF261^{7} *and over the loss range of the system* A_1 A_0 A_2, the Noise Margin should meet the following specification:

Noise Margin (M) ≥" $B + C$ (A_2— A_0)

It has been possible to recommend specific values for parameters A_1, A_2, B and C .

Note — The degrading effect of timing jitter on Noise Margin should be measured by superimposing appropriate jitter on the test signal.

3.4 *Error performance*

The design objective for the error ratio of the individual repeater should take into account the network performance objectives given in Recommendation G.821.

4 Specific design features

4.1 *Type of power feeding*

Although CCITT does not recommend the use of a specific remote power-feeding system for these coaxial line systems, in practice only the constant current d.c. feeding via the inner conductors of the two coaxial pairs of a system is used.

These coaxial cable systems may be subject to induced voltages and currents caused by lightning, power lines, railways, etc.

Precautions must be taken to protect the staff from any possible danger arising from the normal operating voltages and remote power-feed currents as well as from the induced voltages and currents.

Many national Administrations have issued detailed rules and regulations for the protection of persons. It is obligatory in most cases to meet these rules and regulations. In addition the CCITT Directives [1] give guidance on these problems.

Precautions are also needed for the protection of the equipment against induced voltages and currents. The equipment should therefore be designed in such a way that it passes the tests specified in Recommendation K.17 [2].

4.2 *Nominal repeater spacing*

A specific repeater spacing is not recommended but in practice the nominal values indicated in Table 2/G.953 are used by most Administrations:

H.T. [T2.953]
TABLE 2/G.953
Nominal repeater spacings

Nominal repeater spacing (km) System (kbit/s) Cable Recommendation | ua) G.623 }	{
44 | 36	—
97 | 28	4.5

a) Recommendation G.623 refers to 2.6/9.5 mm coaxial pairs.

Tableau 2/G.953 [T2.953], p.

4.3 *Maintenance strategy*

4.3.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used.

4.3.2 *Fault conditions and consequent actions*

The fault conditions and consequent actions should be complementary to those recommended for digital line sections.

ANNEX A

(to Recommendation G.953)

Definition and measurement of repeater noise margin

A.1 *Definition*

The noise margin m_n:

$$m_n = SNR / SNR_{ER} \qquad \text{(A-1)}$$

where:

$$SNR = SNR_{th} \cdot F(t, ER) \qquad \text{(A-2)}$$

.sp 1

The product $SNR_{th} \cdot F(t, ER)$ can be considered the actual signal-to-noise ratio *SNR*, being the measure for the regenerator performance.

SNR_{th} is the theoretical signal-to-noise ratio determined by the system parameters such as output pulse, section loss, noise figure of the regenerator input amplifier, etc.

$F(t, ER)$ is the reduction factor due to an off-set from the optimum timing instant (including phase jitter) in conjunction with the pulse realized $S(t)$, the intersymbol interference $I(t)$ and any other disturbance which causes a corruption in the information signal (I_c).

Note — The intersymbol interference and other disturbances are fluctuating processes with bounded distributions. The ‘‘mean’’ reduction factor depends on *ER*, and, for a ternary signal, is given by:

$$F(t, ER) = \frac{S(t)}{S(0)} - 2\left\{\frac{I(t)}{S(0)} - \frac{I}{S(0)} - I_c\right\} \qquad \text{(A-3)}$$

where $S(0)$ is the realized pulse at $t = 0$ giving the maximum amplitude.

SNR_{ER} is the signal-to-noise ratio required for an error ratio equal to *ER*. For a ternary signal the relation between *ER* and SNR_{ER} is given by the known Gaussian distribution:

ER =

[Formula Deleted]

$P[E]$ =

[Formula Deleted]

$$\int_{SNR_{ER}}^{\infty} e^{-x^2/2}\, dx$$

(A-4)

A.2 *Derived definitions*

The noise marging can be measured by applying an external disturbing signal. For that purpose more practical definitions are derived.

A.2.1 $SNR_{E|R}$ (giving an error ratio ER) can be achieved by injecting sufficient white noise into the input of the regenerator:

$$SNR_{E|R} = \left\{ \frac{N_T}{N_T + N_E} \right\} \times SNR \qquad \text{(A-5)}$$

where

N_T = thermal noise that appears at the decision point during normal operation.

N_E = mean power of the external noise that appears at the decision point to induce an error rate *ER* .

Combining (A-1) and (A-5) results in the noise margin M :

$$M = 20 \log m_n = 10 \log \left(1 + \frac{N_E}{N_T} \right) \qquad \text{(A-6)}$$

$$N_E = N_0 \int_0^{\infty} |E(f)|^2 \, df \qquad \text{(A-7)}$$

$$N_T = kT \int_0^{\infty} |E(f)|^2 \, F(f) \, df \qquad \text{(A-8)}$$

N_0 = power density of the external noise that is superimposed on the signal

$E(f)$ = transfer function of the regenerator’s equalizer

k, T = Boltzmann constant and absolute temperature

$F(f)$ = noise figure of the equalizer amplifier of the regenerator

A.2.2 By injecting a sine wave disturbing signal, a second definition for m_n can be derived.

This disturbance causes a decreasing $F(t, ER)$, which can be defined by:

$$F_d(t, ER) = SNR_{ER}/SNR_{th}$$

Next [in accordane with (A-1) and (A-2)],

$$F(t, ER) = m_n^2 \, SNR_{ER}/SNR_{th}$$

Substraction gives:

$$F(t, ER) - F_d(t, ER) = 2 \frac{I_s}{S(0)} (m_n - 1) \, SNR_{ER}/SNR_{th}$$

where $I_s/S(0)$ is the normalized disturbing signal at the decision point.

Substitution of $SNR_{th} = S(0)/2\sqrt{N_T N_0}$ and some rearrangements results in the noise margin:

$$M = 20 \log \left(1 + \frac{SNR_{ER}}{I_s \sqrt{N_T N_0}} \right)$$

(A-9)

$I_s =$

S_d | (mu | E (

f_d | | (mu | fIa_c

(A-10)

S_d	=	the magnitude of the disturbing signal at the input of the regenerator
f_d	=	the frequency of the disturbing signal
a_c	=	a correction factor taking into account the effect of the disturbance on the peak detector of the automatic equalizer
R_0	=	the real part of the characteristic impedance of the cable.

A.3 *Measurements*

Method A is based on the definition directly related to the noise marging (A-6) and therefore, is the reference test method. Methods B and C are alternative test methods.

Method A (Figure A-1/G.953)

The values of N_E and N_T are measured directly at the decision point. The value of N_T is measured in the absence of both a signal and and externally applied noise. Under these conditions the automatic gain control (AGC) of the equalizer must be externally controlled to a level appropriate to the corresponding cable attenuation. With the signal restored, the level of the externally applied noise is adjusted to give the desired BER. The noise level ($N_T + N_E$) is now measured with the signal removed and with the AGC set at the same value as in the measurement of N_T.

Figure A-1/G.953, (MC), p.

Method B (Figure A-2/G.953)

This method realizes a measurement without the need to access the decision point. The applied noise at the input, to cause a given BER, is measured directly. The corresponding value at the decision point and also the thermal noise (N_T) are evaluated by means of the transfer function and the noise figure of the amplifier equalizer.

Note — Both the transfer and the noise figure of the amplifier equalizer need to be calculated and measured on a sample of repeaters before this method can be applied to a particular repeater design.

Method C (Figure A-2/G.953)

This method is similar to the previous method (B) except that in this case the applied disturbance is a sine wave signal. This applied signal at the input, to cause a given error ratio, is likewise measured directly.

The corresponding disturbance at the decision point (I_s) as well as the thermal noise voltage ($\sqrt{N_T R_0}$) are evaluated by means of the transfer function, the noise figure of the equalizer and the correction factor a_c, which have to be determined.

Note — It follows from (A-8) and (A-9):

$$M = 20 \log (1 + S_d \mu X / SNR_{E/R})$$

$$\text{where } X = \frac{I_E}{f_d} \cdot \frac{\mu a_c}{\sqrt{N_0}}$$

being an unknown factor, which has to be determined on the basis of measurements on a sample of prototype regenerators before this method can be applied to a particular regenerator design.

For this purpose, the noise margin of the prototype regenerator needs to be measured in accordance with the reference test method (A).

Note 2 — This method allows the presence of an LBO-network at the regenerator input. In constrast to method B it is not necessary to insert a complementary filter in the injection path.

Note 3 — To obtain the most accurate measurement the disturbing frequency should be around the Nyquist frequency.

Figure A-2/G.953, (MC), p.

References

[1] CCITT Manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988.

[2] CCITT Recommendation *Tests on power-fed repeaters using solid state devices in order to check the arrangements for protection from external interference* , Vol. IX, Rec. K.17.

Recommendation G.954

DIGITAL LINE SYSTEMS BASED ON THE 2048 kbit/s

HIERARCHY ON COAXIAL PAIR CABLES

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 2048 kbit/s hierarchy on coaxial pair cables and includes systems conveying the following bit rates:

8 | 48 kbit/s

34 | 68 kbit/s

139 | 64 kbit/s

4 × 139 | 64 kbit/s

In the case of $4 \times 139\,264$ kbit/s systems, a digital line muldex equipment combines the functions of multiplexing four digital signals at 139 264 kbit/s and of a line transmission equipment. Details of the digital multiplexing strategy are given in Annex B to this Recommendation.

The requirements for overall performance and interfaces of the corresponding digital line section are given in Recommendation G.921.

2 Transmission media

The systems can be operated on coaxial pairs, as defined in the series G.620 Recommendations, in accordance with Table 1/G.954.

H.T. [T1.954]

TABLE 1/G.954

Transmission media

System (kbit/s)	Cable Recommendation
8 | 48	G.621; G.622
34 | 68	G.621; G.622; G.623
139 | 64	G.622; G.623
4 × 139 | 64	G.623

Tableau [T1.954], p.

3 Overall design features

3.1 *Availability*

The availability objective of the system should be derived taking into account the availability requirement for the hypothetical reference digital section given in Recommendation G.801.

3.2 *Reliability*

MTBF values should be specified for the line system as a whole taking into account the requirements concerning availability.

3.3 *Repeater noise margin*

Repeater Noise Margin is defined in Annex A together with suggested measurement techniques. The Noise Margin quantifies the performance of digital regenerators for coaxial pairs. This is a function of BER and repeater spacing loss A_0(at half the line system baud rate).

At a BER = 10^{D}lF261^{7} and over the loss range of the system A_1 A_0 A_2, the Noise Margin should meet the following specifications:

Noise Margin (M) ≥" $B + C$ (A_2— A_0)

It has not been possible to recommend specific values for parameters A_1, A_2, B and C .

Note — The degrading effect of timing jitter on Noise Margin should be measured by superimposing appropriate jitter on the test signal.

Examples of the values used by some Administrations are given below:

H.T. [T2.954]

A 1 (dB) 8 | 48 kbit/s systems	*A* 2 (dB) 35	*B* (dB) 85	*C* 9,5	 1,5
34 | 68 kbit/s systems 7.5 6.5 12.5 }	34 56 45 0.7 0.5 1.5	84 82 75	{	
139 | 64 kbit/s systems 0.7 0.7 > 1	65 60	84 84	5.5 7.5	{

Note — The values do not include any allowance for the effects of jitter.

Tableau [T2.954], p.

3.4 *Error performance*

The design objective for the error ratio of the individual repeater should take into account the network performance objectives given in Recommendation G.821.

4 Specific design features

4.1 *Type of power feeding*

Although CCITT does not recommend the use of a specific remote power-feeding system for these coaxial line systems, in practice only the constant current d.c. feeding via the inner conductors of the two coaxial pairs of a system is used.

These coaxial cable systems may be subject to induced voltages and currents caused by lightning, power lines, railways, etc.

Precautions must be taken to protect the staff from any possible danger arising from the normal operating voltages and remote power-feed currents as well as from the induced voltages and currents.

Many national Administrations have issued detailed rules and regulations for the protection of persons. It is obligatory in most cases to meet these rules and regulations. In addition the CCITT Directives [1] give guidance on these problems.

Precautions are also needed for the protection of the equipment against induced voltages and currents. The equipment should therefore be designed in such a way that it passes the tests specified in Recommendation K.17 [2].

4.2 *Nominal repeater spacing*

A specific repeater spacing is not recommended but in practice the nominal values indicated in Table 2 are used by most Administrations:

H.T. [T3.954]

TABLE 2/G.954

Nominal repeater spacings

System (kbit/s)	Nominal repeater spacing (km) {		
	G.621	G.622	G.623
8 | 48	4.0	—	—
34 | 68	2.0	4.0 (Note)	—
139 | 64	—	2.0	4.5 (Note)
4 × 139 | 64	—	—	1.5

a) G.621 refers to 0.7/2.9 mm coaxial pairs.

G.622 refers to 1.2/4.4 mm coaxial pairs.

G.623 refers to 2.6/9.5 mm coaxial pairs.

Note — One Administration employs a nominal repeater spacing of 3 km.

Tableau 2/G.954 [T3.954], p.

4.3 *Maintenance strategy*

4.3.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used. For bit rates equal to or above 139 264 kbit/s in-service monitoring is recommended.

4.3.2 *Fault conditions and consequent actions*

The following fault conditions should be detected in addition to those specified in Recommendation G.921 for the relevant digital sections, and the associated consequent actions should be taken:

a) failure of remote power feeding —

a prompt maintenance alarm should be generated, if practicable;

b) low error ratio threshold exceeded —

this threshold is 1 | (mu | 0^{D}lF261^{5} for systems at 8448 kbit/s

this threshol and 1 | (mu | 0^{D}lF261^{6} for systems at higher bit rates;

a deferred maintenance alarm should be generated to signify that performance is deteriorating.

ANNEX A
(to Recommendation G.954)

Definition and measurement of repeater noise margin

A.1 *Definition*

The noise margin m_n |

$$m_n = SNR / SNR_{E\backslash dR} \quad \text{(A-1)}$$

where

$$SNR = SNR_{t\backslash dh} \text{ | (mu | fIF } (t, ER) \quad \text{(A-2)}$$

The product $SNR_{t\backslash dh}$ | (mu | (t, ER) can be considered the actual signal-to-noise ratio *SNR* being the measure for the regenerator performance.

$SNR_{t\backslash dh}$ is the theoretical signal-to-noise ratio determined by the system parameters such as output pulse, section loss, noise figure of the regenerator input amplifier etc.

$F(t, ER)$ is the reduction factor due to an off-set from the optimum timing instant (including phase jitter) in conjunction with the pulse realized $S(t)$, the intersymbol interference $I(t)$ and any other disturbance which causes a corruption in the information signal (I_c).

Note — The intersymbol interference and other disturbances are fluctuating processes with bounded distributions. The ‘‘mean’’ reduction factor depends on *ER* , and, for a ternary signal, is given by:

$$F(t, ER) = \frac{\text{f IS}(t)}{fIS(0)} - 2 \left\{ \frac{\text{f II}(t)}{fIS(0)} - \frac{\text{f II}}{\text{f IS}(0)} \text{f Ic} \right\} \quad \text{(A-3)}$$

where $S(0)$ is the realized pulse at $t = 0$ giving the maximum amplitude.

$SNR_{E\backslash dR}$ is the signal-to-noise ratio required for an error ratio to *ER* . For a ternary signal the relation between *ER* and $SNR_{E\backslash dR}$ is given by the known Gaussian distribution:

ER =
[Formula Deleted]
[Formula Deleted]

$$SNR \int_{fIE\, R}^{(\text{if}} e^{-x^{1/2}} dx$$

(A-4)

A.2 *Derived definitions*

The noise margin can be measured by applying an external disturbing signal. For that purpose more practical definitions are derived.

A.2.1 $SNR_{E\backslash dR}$ | (giving an error ratio ER | can be achieved by injecting sufficient white noise into the input of the regenerator:

$SNR_{E\backslash dR}=$

(A-5) f IN f IT + f N f IE | (mu | fISNR where

N_T = thermal noise that appears at the decision point during normal operation.

N_E = mean power of the external noise that appears at the decision point to induce an error rate ER .

Combining (A-2) and (A-5) results in the noise margin M :

$$M = 20 \log m_n = 10 \log \left(1 + \frac{N_E}{N_T} \right) \tag{A-6}$$

$$N_E = N_0 \int_0^{\infty} |E(f)|^2 \, df \tag{A-7}$$

$$N_T = kT \int_0^{\infty} |E(f)|^2 F(f) \, df \tag{A-8}$$

N_0 = power density of the external noise that is superimposed on the signal

$E(f)$ = transfer function of the regenerator’s equalizer

k, T = Boltzmann constant and absolute temperature

$F(f)$ = noise figure of the equalizer amplifier of the regenerator

A.2.2 By injecting a sine wave disturbing signal, a second definition for m_n | can be derived.

This disturbance causes a decreasing $F(t, ER)$, which can be defined by:

$$F_d(t, ER) = SNR_{E\backslash dR} / SNR_{t\backslash dh}$$

Next [in accordance with (A-1) and (A-2)]

$$F(t, ER) = m_n \cdot SNR_{E\backslash dR} / SNR_{t\backslash dh}$$

Substraction gives:

$$F(t, ER) - F_d(t, ER) = 2 \frac{I_s/S(0)}{SNR_{E\backslash dR}/SNR_{t\backslash dh}} - (m_n - 1)$$

where $I_s/S(0)$ is the normalized disturbing signal at the decision point.

Substitution of $SNR_{t\backslash dh} = S\,(0)/2\,\sqrt{fIN\ \mathrm{f\,IT}\ \mathrm{f\,IR}\ 0}$ and some rearrangements results in the noise margin:

$$M = 20 \log 1\ |\ (\mathrm{mu}\ |\ \left(\frac{fISNR\ \ fIE}{R} \ \mathrm{f\,II}\ |\ (\mathrm{muf}|\mathrm{Is}\sqrt{\mathrm{f\,IN}\ \mathrm{f\,IT}\ \mathrm{f\,IR}\ 0} \right) \tag{A-9}$$

$$I_s = S_d\ |\ (\mathrm{mu}\ |\ E\ (\ f_d\ |\ |\ (\mathrm{mu}\ |\ \mathrm{fIa}_c \tag{A-10}$$

S_d	=	the magnitude of the disturbing signal at the input of the regenerator
f_d	=	the frequency of the disturbing signal
a_c	=	a correction factor taking into account the effect of the disturbance on the peak detector of the automatic equalizer
R_0	=	the real part of the characteristic impedance of the cable.

A.3 *Measurements*

Method A is based on the definition directly related to the noise margin (A-6) and therefore, is the reference test method. Methods B and C are alternative test methods.

Method A | (Figure A-1/G.954)

The values of N_E | and N_T | are measured directly at the decision point. The value of N_T | is measured in the absence of both a signal and an externally applied noise. Under these conditions the automatic gain control (AGC) of the equalizer must be externally controlled to a level appropriate to the corresponding cable attenuation. With the signal restored, the level of the externally applied noise is adjusted to give the desired BER. The noise level ($N_T + N_E$) is now measured with the signal removed and with the AGC set at the same value as in the measurement of N_T.

Figure A-1/G.954, (MC), p.

Method B | (Figure A-2/G.954)

This method realizes a measurement without the need to access the decision point. The applied noise at the input, to cause a given BER, is measured directly. The corresponding value at the decision point and also the thermal noise (N_T) are evaluated by means of the transfer function and the noise figure of the amplifier equalizer.

Note — Both the transfer function and the noise figure of the amplifier equalizer need to be calculated and measured on a sample of repeaters before this method can be applied to a particular repeater design.

Method C | (Figure A-2/G.954)

This method is similar to the previous method (B) except that in this case the applied disturbance is a sine wave signal. This applied signal at the input, to cause a given error ratio, is likewise measured directly.

The corresponding disturbance at the decision point (I_s) as well as the thermal noise voltage ($\sqrt{fIN_{\text{f IT}}\text{ f IR}_0}$) are evaluated by means of the transfer function, the noise figure of the equalizer and the correction factor a_c, which have to be determined.

Note 1 — It follows from (A-8) and (A-9):

$$M = 20 \log (1 + S_d \mid (\text{mu} \mid \text{fIX} / SNR_{E\backslash dR})$$

$$\text{where } X = \mid \text{fIE} \left(\frac{f_d \mid \mid (\text{mu} \mid \text{fIa}_c /}{\sqrt{fIN_{\text{f IT}}\text{ f IR}_0}} \right.$$

being an unknown factor, which has to be determined on the basis of measurements on a sample of prototype regenerators before this method can be applied to a particular regenerator design.

For this purpose, the noise margin of the prototype regenerators needs to be measured in accordance with the reference test method (A).

Note 2 — This method allows the presence of an LBO-network at the regenerator input. In contrast to method B it is not necessary to insert a complementary filter in the injection path.

Note 3 — To obtain the most accurate measurement the disturbing frequency should be around the Nyquist frequency.

Figure A-2/G.954, (MC), p.

ANNEX B
(to Recommendation G.954)

Digital multiplexing strategy for

4 ×139 | 64 kbit/s systems

Figure B-1/G.954, (MC), p.

B.1 *General*

The digital multiplexing strategy is based on the use of positive justification and combines four 139 | 64 kbit/s tributaries into one composite signal.

B.2 *Bit rate*

The nominal bit rate should be 564 | 92 kbit/s. The tolerance on that rate should be ± | 5 parts per million (15 ppm).

B.3 *Frame structure*

Table B-1/G.954 gives:

— the tributary bit rate and the number of tributaries,

— the number of bits per frame,

— the bit numbering scheme,

— the bit assignment,

— the bunched frame alignment signal.

Note — Possible alternative frame structures with the characteristics indicated in Appendix II are left for further study.

B.4 *Loss and recovery of frame alignment*

Loss of frame alignment should be assumed to have taken place when four consecutive frame alignment signals have been incorrectly received in their predicted positions.

When frame alignment is assumed to be lost, the frame alignment device should decide that such alignment has effectively been recovered when it detects the presence of three consecutive frame alignment signals.

The frame alignment device, having detected the appearance of a single correct frame alignment signal, should begin a new search for the frame alignment signal when it detects the absence of the frame alignment signal in one of the two following frames.

Note — As it is not strictly necessary to specify the detailed frame alignment strategy, any suitable frame alignment strategy may be used provided the performance achieved is at least as efficient in all respects as that obtained by the above frame alignment strategy.

H.T. [T4.954]

TABLE B-1/G.954

564 | 92 kbit/s multiplexing frame structure

Tributary bit rate (kbit/s)	139 | 64
Number of tributaries	4
Frame structure	Bit number
	Set I
{ Frame alignment signal (binary content under study) }	1 to 12
Bits from tributaries	13 to 384
	Sets II to VI
{ Justification service bits *C* *(n* = 1 to 5) (see Note) }	1 to 4
Bits from tributaries	5 to 384
	Set VII
{ Remote alarm indication, spare for national use }	1 to 4
{ Bits from tributaries available for justification }	5 to 8
Bits from tributaries	9 to 384
Frame length	2688 bits
Bits per tributary	663 bits
{ Maximum justification rate per tributary }	210 | 90 bit/s
Nominal justification ratio	0.4390

Note — C
| indicates the n^{th} *justification service bit of of the* j^{th} *tributary.*

Tableau B-1/G.954 [T4.954], p.

B.5 *Multiplexing method*

Cyclic bit interleaving in the tributary numbering order and positive justification is recommended. The justification control signal should be distributed and use the C_{jn} bits (n = 1, 2, 3, 4, 5), see Table B-1/G.954. Positive justification should be indicated by the signal 11111, no justification by the signal 00000. Majority decision is recommended.

Table B-1/G.954 gives the maximum justification rate per tributary and the nominal justification ratio.

B.6 *Jitter*

B.6.1 Jitter transfer characteristics (under study).

B.6.2 Tributary output jitter (under study).

B.7 *Service digits*

The first four bits in Set VII of the pulse frame are available for service functions. The first of these bits is used to indicate a prompt alarm condition, see Table C-1/G.954.

Note — A possible solution for scrambler and frame alignment signal is given in Appendix I.

APPENDIX I

(to Annex B of Recommendation G.954)

A possible solution for scrambler and frame

alignment signals for a digital line system at 4 × 139 | 64 kbit/s

I.1 *Reset scrambler*

It is proposed to use a ‘‘reset scrambler’’, i.e. one which is reset at the start of each frame. Advantages of such a scrambler [3] as compared to a free-running or ‘‘self-synchronizing’’ scrambler, are:

— no error multiplication, and

— no necessity to provide additional measures to avoid periodic output signals.

If it is accepted that with an all 1 or all 0 input signal (e.g. with AIS on all four tributaries) the output does not precisely correspond to a $2^n - 1$ pseudorandom sequence but represents an approximately random sequence, fully adequate for timing recovery on the line, a scrambler may be realized (Figure I-1/G.954) which has additional favourable features:

— The scrambler works at = 141 Mbit/s. Four sequences delayed with respect to each other (A0, A2, A5 and A6) are used to scramble the individual tributaries T1 . | | | T4; the four scrambled signals (c, d, e, f) are then multiplexed.

— Simple circuitry, hence easy realization at the high speed involved, and low power consumption.

— After resetting, the scrambler generates the frame alignment signal.

I.2 *Frame alignment signal*

The frame alignment signal, generated at the start of each pulse frame, is

111110100000

and is thus identical to that of the 139 Mbit/s signal according to Recommendation G.751.

The frame alignment signal will not be imitated by all 0 or all 1 signals even if these occur in any combination in the four tributaries.

Figure I-1/G.954, (M), p.

APPENDIX II

(to Annex B of Recommendation G.954)

Possible alternative multiplex frame structures

Other multiplex frame structures at 564 | 92 kbit/s are possible which still retain the same per tributary frame structure as implied by the multiplex frame structure given in Figure I-1/G.954.

These alternative multiplex frame structures are based on the cyclic interleaving of groups of bits from tributaries and such methods of multiplexing can have implementation advantages when alphabetic line codes such as 6B4T are used. Integration of the multiplex and the line code conversion functions can reduce the speed requirements of the associated circuitry.

Equipments based on these alternative multiplex frame structures, provided that they adopt the same multiplex frame length, the same number of bits per tributary, the same maximum justifications rate and the same nominal justification ratio, are consistent with the network performance offered by equipments using the multiplexing method described in the body of this Recommendation.

ANNEX C

(to Recommendation G.954)

Fault conditions
and consequent actions for

digital lines systems at 4 × 139 | 64 kbit/s

C.1 *Fault conditions*

The digital line system 4 × 139 | 64 kbit/s should detect the following fault conditions:

C.1.1 Failure of internal power supply.

C.1.2 Failure of power feeding of regenerators.

C.1.3 Error ratio 1 | (mu | 0^{D}lF261^{3}.

Note — The criteria for activating and deactivating of these alarm indications are under study.

C.1.4 Error ratio 1 | (mu | 0^{D}lF261^{6}.

C.1.5 Loss of incoming line signal.

Note — The detection of this fault condition is required only when it does not result in an indication of loss of frame alignment.

C.1.6 Loss of frame alignment.

C.1.7 Loss of line word alignment when alphabetic line codes are used.

Note — The detection of this fault condition is required only when it does not result in an indication ‘‘Error ratio 1 | (mu | 0^{D}lF261^{3}’’.

C.1.8 Loss of incoming signal on a tributary.

C.1.9 Remote alarm indication.

C.2 *Consequent actions*

Further to the detection of a fault condition, appropriate actions should be taken as specified in Table C-1/G.954.

H.T. [T5.954]

TABLE C-1/G.954

Fault conditions and consequent actions

Equipment	Fault conditions	Maintenance alarms				
		Prompt	Deferred	{	{	
{		Yes, if practicable Yes, if practicable	{			
{	{					
{	{ Yes				Yes	

Note — A *Yes* in the table signifies that a certain action should be taken as a consequence of the relevant fault condition. An *open space* in the table signifies that the relevant action should *not* be taken as a consequence of the relevant fault condition, if this condition is the only one present. If more than one fault condition is simultaneously present the relevant action should be taken if, for at least one of the conditions, a *Yes* is defined in relation to this action.

Tableau C-1/G.954 [T5.954], p.

C.2.1 Prompt maintenance alarm indication generated to signify that performance is below acceptable standards and maintenance attention is required locally.

C.2.2 Deferred maintenance alarm indication generated to signify that performance is deteriorating.

Note — The location and provision of any visual and/or audible alarm activated by the alarm indications given in §§ C.2.1 and C.2.2 above, is left to the discretion of each Administration.

C.2.3 AIS applied to all the tributaries (see Notes 1 and 2 below).

C.2.4 AIS applied to the relevant time slot of the composite signal (see Note 1 below).

C.2.5 Alarm indication to the remote muldex generated.

Note 1 — The equivalent binary content of the Alarm Indication Signal (AIS) is a continuous stream of 1s.

Note 2 — The bit rate of this AIS should be within ± | 5 ppm of the nominal bit rate.

References

[1] CCITT Manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988.

[2] CCITT Recommendation *Tests on power-fed repeaters using solid state devices in order to check the arrangements for protection from external interference* , Vol. IX, Rec. K.17.

[3] MULLER (H), Bit sequence independence through scramblers in digital communication systems, *Nachr. Techn. Z* ., Vol. 27 (1974), pp. 475 to 479.

Recommendation G.955

DIGITAL LINE SYSTEMS BASED ON THE 1544 KBIT/S HIERARCHY ON OPTICAL FIBRE CABLES

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 1544 kbit/s hierarchy on optical fibre cables and includes systems conveying the following bit rates:

1 | 44 kbit/s

3 | 52 kbit/s

6 | 12 kbit/s

32 | 64 kbit/s

44 | 36 kbit/s

n × 44 | 36 kbit/s

97 | 28 kbit/s

4 × 97 | 28 kbit/s.

The aim of this Recommendation is to achieve longitudinal compatibility on elementary cable sections of different digital line systems, i.e. the possibility of installing digital line systems, produced by different manufacturers, on the same optical fibre cable.

For the purpose of this Recommendation, optical fibre digital line systems can be represented as in Figure 1/G.955. The system may have no intermediate regenerators as in Figure 1a/G.955, one intermediate regenerator as in Figure 1b/G.955, or a larger number depending on the system design and route length.

This Recommendation covers requirements for equipment intended to meet the relevant performance objectives of Recommendation G.821 under all normally envisaged operating conditions. In any event Recommendation G.821 remains the overriding performance objective of the network.

Other (synchronous optical) hierarchical rates are presently under consideration. Such rates to be considered in this Recommendation require further study.

Figure 1/G.955, (N), p.

2 Type of transmission medium

Multimode or single-mode optical fibres conforming to Recommendations G.651 or G.652 respectively are considered suitable for these systems. Operation may be in the region of either 850 nm, 1300 nm or 1550 nm or some other wavelength depending on the fibre and system type employed. The attenuation considered the most appropriate for operation at the various bit rates and wavelengths will be chosen by the Administrations in relation to the characteristics of the link to be realized and in accordance with this Recommendation. Similarly, splice losses, connector losses and the cable margin must be chosen together with the attenuation of the optical fibre in order to achieve the overall attenuation specified in § 4.

3 System margin

For the purpose of this Recommendation, the total system margin (Figure 1a/G.955), or regenerator section margin (Figure 1b/G.955), is subdivided into two main contributions. The disposition of these margins is shown in Figure 2/G.955.

3.1 *Cable margin (M*

The cable margin, M_c, covers allowances for:

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

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

iii) degradation of any connector between points S and R when provided.

3.2 *Equipment margin (M*

The equipment margin, M_e, covers allowances for the effect of time and environmental factors on equipment performance (e.g., launched power, receiver sensitivity, equipment connector degradations).

Note 1 — The design margin, which covers the allowance for the tolerances on the characteristics of the various components of the system, is not considered because worst case values for such characteristics are reflected in the specifications of § 4.

Note 2 — The system margin is in relation to a BER threshold of 1 | (mu | 0^{D}lF261^{10} even though for practical reasons the measurements of receiver sensitivity may be carried out at other thresholds.

Note 3 — The worst case approach adopted in this Recommendation leaves some additional margin in operating systems which can be considered as an unallocated margin.

4 System specifications

The optical link of a regenerator section can be represented as in Figure 2/G.955 from the point of the system specifications.

Figure 2/G.955, (N), p.

As a minimum requirement for typical commercially available systems, the transmitter and the receiver shall be designed so that the error performance requirements of § 4.2 are obtained with an optical path as defined in § 4.6 and § 4.7.

4.1 *Regenerator section lengths*

The regenerator section length achievable with the systems specified in this recommendation is related to the fibre characteristics and the specific capabilities of the transmitter/receiver equipment. Exemples are given in Annexes A and B.

For multimode systems, the description of the baseband response with a single value (the —3 dB optical bandwidth) may not be sufficient to determine the suitability of the fibre for the specified system. In some cases, a more detailed description of this characteristic or the description of the impulse response may be necessary. Additionally, the overall —3 dB optical bandwidth is assumed to include modal and chromatic contributions.

For single-mode systems, a principle characteristic is that, for a given section length, they exhibit less pulse broadening than multimode systems, provided that the central wavelength of the laser is sufficiently close to the fibre's zero-dispersion wavelength.

In general, for single-mode fibre systems employing laser sources operating near or below a nominal bit rate of 6×44 | 36 kbit/s, the regenerator section length is expected to be limited by loss and not by dispersion. At higher bit rates, the regenerator section length may be limited by dispersion. Therefore, it is desirable to check whether a regenerator section length is limited by loss or dispersion.

Loss-limited systems: the loss-limited regenerator section length can be calculated taking into account the system gain, the loss introduced by the sum of connector and splice losses, fibre attenuation at the operating wavelength, cable margin, and the additional loss due to any dispersion penalty (including mode partition noise).

Dispersion-limited systems: the dispersion-limited regenerator section length is dependent upon the receiver tolerance to pulse distorsion (e.g., due to the transmitter source spectral characteristics, mode partition noise, and the fibre chromatic dispersion). Administrations should consult with suppliers to determine dispersion-limited lengths for their applications. Dispersion-limited systems require further study.

4.2 *Error performance*

Digital line systems in this Recommendation consider a maximum regenerator section length with a BER not worse than 1 | (mu | 0^{D}lF261^{10}. The error performance should be consistent with the overall performance in Recommendation G.821.

4.3 *Receiver dynamic range*

The optical receiver dynamic range should be at least sufficient to provide a range of automatic gain control to compensate for equipment production tolerances and the effects of temperature and ageing. It is desirable that the dynamic range of the receiver should also minimize the need for line build-out attenuators.

4.4 *Optical source*

Multimode systems may employ either lasers or light-emitting diodes as sources. Single-mode systems generally employ lasers, although light-emitting diodes may have specific applications at certain bit rates. Single-mode systems using light-emitting diodes require further study.

4.5 *Operating wavelength range*

The nominal wavelengths of 850 nm and 1300 nm imply possible use anywhere in the range of 820-910 nm and 1270-1330 nm respectively, for systems operating up to and including nominal bit rates near 3 × 44 | 36 kbit/s. For higher than a nominal bit rate near 3 × 44 | 36 kbit/s the 1300 nm range is reduced to 1285-1330 nm. The range for the region around 1550 nm is under study.

Note 1 — For single-mode systems operating in the 1300 nm range, the lower wavelength limit is determined from consideration of dispersion and cut-off wavelength effects, while the upper wavelength limit is due to consideration of dispersion and attenuation. In particular it should be noted that the range quoted in this Recommendation is restricted compared to the dispersion range of 1270-1340 nm quoted in Recommendation G.652, because of the possibility of OH peak related excess losses. To ensure satisfactory system operation the cut-off wavelength of the shortest length of cabled fibre in a single-mode elementary cable section must not exceed the operating wavelength. The second order ($LP_{1\d1}$) mode should be sufficiently attenuated along the fibre such that at the detector modal noise and bimodal dispersion effects are negligible.

Note 2 — The nominal wavelength ranges specified above are for LEDs and multilongitudinal mode (MLM) lasers. Single longitudinal mode (SLM) lasers require further study.

4.6 *Recommended optical path allowances for multimode fibre systems*

The optical path allowances between points S and R are given in Table 1/G.955 for multimode fibre systems employing LEDs or MLM lasers. These allowances include the cable margin, M_c, and comprise the overall attenuation and 3 dB optical bandwidth. These allowances represent the worst case parameter values derived from current practice within which a given system can be designed. Trade-offs among bandwidth, attenuation, dispersion, coding, etc. can vary these parameters.

The calculation of attenuation between points S and R should consider the variation of the optical fibre loss over the actual wavelength range of the optical fibre.

4.7 *Recommended optical path allowances for single-mode fibre systems*

The optical path allowances between points S and R are given in Table 2/G.955 for single-mode fibre systems employing LEDs or MLM lasers. These allowances include the cable margin, M_c, and comprise the overall attenuation and dispersion. These allowances represent the worst case parameter values derived from current practice within which a given system can be designed. Trade-offs among attenuation, dispersion, coding, etc. can vary these parameters.

The calculation of attenuation between points S and R should consider the variation of the optical fibre loss over the actual wavelength range of the optical source.

H.T. [T1.955]

TABLE 1/G.955

Recommended optical path allowances for digital line systems on multimode optical fibre conforming to Recommendation G.651 with a single optical transmission signal

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	Maximum attenuation (dB)
{			
{			

{				
{ {				
{				

Note 1 — Values given in this table are for source types other than single longitudinal mode (SLM) lasers.

Note 2 — Refer to § 4.1, regenerator section lengths, for other considerations.

Tableau 1/G.955 [T1.955], p.25

H.T. [T2.955]

TABLE 2/G.955

Recommended optical path allowances for digital line systems on single-mode optical fibre conforming to Recommendation G.652 with a single optical transmission signal

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	{ Maximum attenuation (dB)	Maximum dispersion (ps/nm)

Tableau 2/G.955 [T2.955], p.26

4.8 *System margin*

The cable margin, M_c, and equipment margin, M_e, depend on the system characteristics and environmental conditions. Administrations should review the value of these margins, in cooperation with suppliers, relative to their applications and their maintenance strategies. Different maintenance strategies may require different values of margins.

4.9 *Trade-off considerations*

The allowances for digital line systems found in Tables 1/G.955 and 2/G.955 are aimed at specifying minimum requirements for transmission systems with maximized section lengths. However, for applications not requiring maximized section lengths, more economical equipment designs can be used. Parameters for such equipment may differ from those in Tables 1/G.955 and 2/G.955 by allowing trade-offs to be made.

Furthermore, remote power feeding and remote supervision of intermediate regenerators may not be necessary.

4.10 *Wavelength division multiplexing*

The requirements for digital line systems employing wavelength division multiplexing techniques operating either within the same wavelength region or in separate wavelength regions are under study.

5 Power feeding

Power feeding arrangements, if any, require further study.

6 Working conditions

See Recommendation G.950.

7 Overall design features

Under study.

8 Maintenance strategy

8.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used. In the absence of suitable metallic conductors in the optical cable, the supervision of the intermediate regenerator, where appropriate, should be provided by the same two optical fibres used for the line systems, or other fibres within the cable.

8.2 *Fault conditions and consequent actions*

The fault conditions and consequent actions should be complementary to those recommended for digital line sections. For systems with a laser, means to detect laser deterioration is considered advisable. For this fault condition, a deferred maintenance alarm indication is considered adequate.

9 Safety considerations

The Recommendations for guidance for the safe use, maintenance, and service of Fibre Optic Communications Systems (FOCS) utilizing lasers of LEDs with output wavelengths between 400 nm and 3000 nm are currently under study by the IEC. This includes the operating wavelength ranges defined in § 4.5 and will be considered in this Recommendation when completed.

ANNEX A
(to Recommendation G.955)

Example of calculation of the regenerator section length

for a 6 Mbit/s laser-based system operating at 850 nm
on multimode fibre

A.1 The regenerator section length can be calculated considering that at the end of the optical path between points S and R (see Figure 2/G.955) the overall attenuation should not exceed 47 dB and the overall bandwidth should be not less than 17 MHz. In the following example, a nearly equilibrium mode distribution is assumed at point S.

A.2 For loss-limited applications, the maximum regenerator section length can be obtained as an example and without reference to any particular situation, as follows:

— attenuation of the optical fibres at 850 nm 3.0 dB/km

— attenuation of the splices 0.4 dB/km

— cable margin (M_c) 0.4 dB/km Total 3.8 dB/km

Regenerator section length
| 7 | 3.8 = 12.4 km.

The above assumes that no connectors are provided between points S and R.

A.3 Concerning the bandwidth, in order to obtain such a regenerator section length and to respect the overall limit of 17 MHz, fibres with a bandwidth of 106 MHz should be used if the bandwidth addition factor is 0.75. For additional information on the calculation of bandwidth for elementary cable sections, refer to Recommendation G.651.

ANNEX B
(to Recommendation G.955)

Example of calculation of the regenerator section length for a

12 × 45 Mbit/s laser-based system operating at 1300 nm
on single-mode fibre

B.1 The regenerator section length can be calculated considering that at the end of the optical path between points S and R (see Figure 2/G.955 in the text of the Recommendation) the overall attenuation should not exceed 28 dB for systems in the wavelength range of 1270 to 1330 nm.

B.2 Concerning the attenuation, the regenerator section length can be obtained as an example and without reference to any particular situation, as follows:

— attenuation of the optical fibres at 1300 nm 0.40 dB/km

— attenuation of the splices 0.15 dB/km

— cable margin (M_c) 0.15 dB/km Total 0.70 dB/km

Regenerator section length 28 dB/0.7 dB/km = 40 km.

Note 1 — The above assumes that no connectors are provided between the points S and R.

Note 2 — A suitable adjustment should be made to the fibre attenuation in the above budget for systems operating at wavelengths other than 1300 nm to account for the fibre spectral attenuation variation.

B.3 For systems operating at higher bitrates, the regenerator section lengths may be dispersion-limited. A specific illustration is dependent upon several factors (as in § 4.1) and requires further study.

Recommendation G.956

DIGITAL LINE SYSTEMS BASED ON THE 2048 KBIT/S HIERARCHY

ON OPTICAL FIBRE CABLES

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 2048 kbit/s hierarchy on optical fibre cables and includes systems conveying the following bit rates:

$n \times$ 2 **|** 48 kbit/s

$n \times$ 8 **|** 48 kbit/s

$n \times$ 34 **|** 68 kbit/s

$n \times$ 139 **|** 64 kbit/s

$4 \times$ 139 **|** 64 kbit/s (see Note).

Note — Systems at higher bit rates are under study (for the time being, these bit rates are in the area of 1.2 Gbit/s and/or 2.4 Gbit/s).

The requirements for overall performance and interfaces of the corresponding digital line sections are given in Recommendation G.921.

The aim of this Recommendation is to achieve longitudinal compatibility on elementary cable sections of different digital line systems, i.e. the possibility of installing digital line systems, produced by different manufacturers, on the same optical fibre cable.

For the purpose of this Recommendation, optical fibre digital line systems can be represented as in Figure 1/G.956. The system may have no intermediate regenerators as in Figure 1a/G.956, one intermediate regenerator as in Figure 1b/G.956 or a larger number depending on the system design and route length.

This Recommendation covers requirements for equipment intended to meet the relevant performance objectives of Recommendations G.821 and G.921 under all normally envisaged operating conditions. In any event, Recommendation G.821 remains the overriding performance objective of the network.

Figure 1/G.956, (N), p.

2 Type of transmission medium

Multimode or single-mode optical fibres conforming to Recommendations G.651 or G.652 respectively are considered suitable for these systems. Operation may be in the region of either 850 nm, 1300 nm or 1550 nm or some other wavelength depending on the fibre and system type employed. The attenuation considered the most appropriate for operation at the various bit rates and wavelengths will be chosen by the Administrations in relation to the characteristics of the link to be realized and in accordance with this Recommendation. Similarly, splice losses, connector losses and the cable margin must be chosen together with the attenuation of the optical fibre in order to achieve the overall attenuation specified in § 4.

3 System margin

For the purpose of this Recommendation, the total system margin (Figure 1a/G.956), or regenerator section margin (Figure 1b/G.956), is subdivided into two main contributions. The disposition of these margins is shown in Figure 2/G.956.

3.1 *Cable margin (M*

The cable margin, M_c, covers allowances for:

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

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

iii) degradation of any connector between points S and R when provided.

3.2 *Equipment margin (M*

The equipment margin, M_e, covers allowances for the effect of time and environmental factors on equipment performance (e.g., launched power, receiver sensitivity, equipment connector degradations).

Note 1 — The design margin, which covers the allowance for the tolerances on the characteristics of the various components of the system, is not considered because worst case values for such characteristics are reflected in the specifications of § 4.

Note 2 — The system margin is in relation to a BER threshold of 1 | (mu | 0^{D}lF261^{10} even though for practical reasons the measurements of receiver sensitivity may be carried out at other thresholds.

Note 3 — The worst case approach adopted in this Recommendation leaves some additional margin in operating systems which can be considered as an unallocated margin.

4 System specifications

The optical link of a regenerator section can be represented as in Figure 2/G.956 from the point of the system specifications.

Figure 2/G.956, (N), p.

As a minimum requirement for maximum section length, the transmitter and the receiver shall be designed so that the error performance requirements of § 4.2 are obtained with an optical path as defined in § 4.6 or § 4.7.

4.1 *Regenerator section lengths*

The regenerator section length achievable with the systems specified in this Recommendation is related to the fibre characteristics. For loss-limited systems, the regenerator section length can be calculated taking into account splice losses, cable margin, the values of the fibre attenuation at the operating wavelength and the possible presence of connectors between S and R. Examples are given in Annexes A and B.

4.2 *Error performance*

The digital line systems described in this Recommendation are required to provide error performance in accordance with ‘‘section quality classification 1’’, defined in Recommendation G.921. Recognising that systems are required to meet a ‘‘degraded minute’’ threshold of at least 1 | (mu | 0$^{\text{D}}$lF261^{6}, and that future systems should be capable of meeting a ‘‘degraded minute’’ threshold of 1 | (mu | 0$^{\text{D}}$lF261^{7}, the transmitter and receiver shall be designed so that a BER not worse than 1 | (mu | 0$^{\text{D}}$lF261^{10} is obtained when operating over an optical path between points S and R corresponding to the relevant values given in Table 1/G.956 for multimode fibre systems and Table 2/G.956 for single-mode fibre systems.

4.3 *Receiver dynamic range*

The optical receiver dynamic range should be at least sufficient to provide a range of automatic gain control to compensate for equipment production tolerances and the effects of temperatures and ageing. It is desirable that the dynamic range of the receiver should also minimize the need for line building out attenuators.

4.4 *Optical source*

Multimode systems may employ either lasers or light-emitting diodes as sources. Single-mode systems generally employ lasers, although light-emitting diodes may have specific applications at certain bit rates. Single-mode systems using light-emitting diodes require further study.

4.5 *Operating wavelength range*

The nominal wavelength of 850 nm and 1300 nm imply possible use anywhere in the range 820-910 nm and 1270-1330 nm respectively, for systems operating up to and including 140 Mbit/s. For systems at a nominal bit rate of 4 × 140 Mbit/s, the 1300 nm range is reduced to 1285-1330 nm. The range for the region around 1550 nm is under study.

Note — For single-mode systems operating in the 1300 nm range, the lower wavelength limit is determined from consideration of dispersion and cut-off wavelength effects, while the upper wavelength limit is due to consideration of dispersion and attenuation. In particular it should be noted that the range quoted in this Recommendation is restricted compared to the dispersion range of 1270-1340 nm quoted in Recommendation G.652, because of the possibility of OH peak related excess losses. To ensure satisfactory system operation, the cut-off wavelength of the shortest length of cabled fibre in a single-mode elementary cable section must not exceed the operating wavelength. The second order ($LP_{1\backslash d1}$) mode should be sufficiently attenuated along the fibre such that at the detector modal noise and bimodal dispersion effects are negligible.

4.6 *Optical path requirements for multimode fibre systems*

The optical path allowances between points S and R are given in Table 1/G.956 for multimode fibre systems. These allowances include the cable margin, M_c, and comprise the overall attenuation and 3 dB optical bandwidth.

The calculation of attenuation between points S and R should consider the variation of the optical fibre loss over the actual wavelength range of the optical source.

H.T. [T1.956]

TABLE 1/G.956

Recommended optical path allowance for digital line systems on multi-mode optical fibre conforming to Recommendation G.651 with a single optical transmission signal

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	Maximum attenuation (dB)
{			{
{			

{				

a) Values under study.

b) Provisional value.

Note 1 — The description of the baseband response with a single value (the —3 dB optical bandwidth) may not be sufficient to determine the suitability of the fibre for the specified system. A quasi-Gaussian impulse response may be assumed for design purposes but a more detailed description of the fibre response may be necessary in some cases.

Note 2 — In the case of LED systems for the values given in the table the optical fibre is assumed to have a nominal numerical aperture of 0.20-0.21. Additionally the overall —3 dB optical bandwidth (modal + chromatic) is assumed to be measured with an optical source having a maximum linewidth (FWHM) of 60 nm and 100 nm centred at 850 nm and 1300 nm respectively.

Tableau 1/G.956 [T1.956], p.

4.7 *Optical path requirements for single-mode fibre systems*

The optical path allowances between points S and R are given in Table 2/G.956 for single-mode fibre systems. These allowances include the cable margin, M_c, and comprise the overall attenuation and dispersion.

The calculation of attenuation between points S and R should consider the variation of the optical fibre loss over the actual wavelength range of the optical source.

H.T. [T2.956]
TABLE 2/G.956
Recommended optical path allowances for digital line systems on single-mode optical fibre conforming to Recommeandation G.652 with a single optical transmission signal

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	{	
			Maximum attenuation (dB)	Maximum dispersion (ps/nm)

Tableau 2/G.956 [T2.956], p.

4.8 *Equipment margin (M*

The equipment margin as defined in § 3.2 depends on the system characteristics, the environmental conditions and on the maintenance strategy. Administrations will need to choose a suitable value in cooperation with the system supplier for their applications.

A minimum margin of 3 dB is considered appropriate for systems using temperature stabilised lasers and PIN detectors, which operate in a typical station environment.

Greater margins may be necessary in systems using light emitting diodes or non-temperature stabilised lasers, or in systems operating in an outdoor environment.

4.9 *Systems for short haul applications*

The allowances for digital line systems found in Tables 1/G.956 and 2/G.956 are aimed at specifying minimum requirements for transmission systems with maximized section lengths. However, for applications not requiring maximized section lengths, more economical equipment can be used. Parameters for such equipment may differ from those in Tables 1/G.956 and 2/G.956 by allowing trade-offs to be made.

Furthermore, remote power feeding and remote supervision of intermediate regenerators may not be necessary.

4.10 *Wavelength division multiplexing*

The requirements for digital line systems employing wavelength division multiplexing techniques operating either within the same wavelength region or in separate wavelength regions are under study.

5 Power feeding

The use of dependent regenerative repeaters is not generally required for optical fibre systems. It is not, therefore, necessary to recommend a specific remote power-feeding system.

Where remote power-feeding is required for specific applications, only constant current dc feeding should be used.

Where local power feeding is required a dc-voltage is sufficient.

Precautions must be taken to protect staff from any possible danger arising from the normal operating voltages and remote power-feed currents as well as from induced voltages and currents. Appropriate safety measures should be adopted to ensure that under abnormal conditions the requirements of IEC Recommendation 479 are met.

Precautions are also needed for the protection of the equipment against induced voltages and currents.

Note — Precautions against induced voltages and currents require further study. The K-Series Recommendations may be relevant to this study.

6 Working conditions

See Recommendation G.950.

7 Overall design features

Under study.

8 Maintenance strategy

8.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used. For bit rates equal to or above 139 | 64 kbit/s, in-service monitoring is recommended. In the absence of suitable metallic conductors in the optical cable the supervision of the intermediate regenerator, where appropriate, should be provided by the same two optical fibres used for the line systems.

8.2 *Fault conditions and consequent actions*

The following fault conditions should be detected in addition to those specified in Recommendation G.921 for the relevant digital sections, and the associated consequent actions should be taken:

a) failure of remote power feeding (if applicable) —

a prompt maintenance alarm should be generated, if practicable;

b) low error ratio threshold exceeded —

this threshold is 1 | (mu | 0^D^lF261^5^ for systems at 2048 and 8448 kbit/s

this threshol and 1 | (mu | 0^D^lF261^6^ for systems at higher bit rates;

a deferred maintenance alarm should be generated to signify that performance is deteriorating.

Furthermore, for systems with a laser, means to detect laser deterioration are considered advisable. For this fault condition, a deferred maintenance alarm indication is considered adequate.

9 Safety considerations

The recommendations for guidance for the safe use, maintenance and service of Line Systems on Optical Fibre Cables with operating wavelengths between 400 nm and 3000 nm are currently under study by the IEC. This includes the operating wavelength ranges defined in § 4.5 and will be considered in this Recommendation when completed.

ANNEX A

(to Recommendation G.956)

Example of calculation of the regenerator section length

for a 34 Mbit/s laser-based system operating at 1300 nm on multimode fibre

A.1 The regenerator section length can be calculated considering that at the end of the optical path between points S and R (see Figure 2/G.956 in the text of the Recommendation) the overall attenuation should not exceed 35 dB and the overall bandwidth should be not less than 50 MHz. In the following example, a nearly equilibrium mode distribution is assumed at point S.

A.2 Concerning the attenuation, the regenerator section length can be obtained as an example and without reference to any particular situation, as follows:

— attenuation of the optical fibres at 1300 nm 1.0 dB/km

— attenuation of the splices 0.3 dB/km

— cable margin (M_c) 0.3 dB/km Total 1.6 dB/km

Regenerator section length
| 5 | 1.6 = 22 km.

The above assumes that no connectors are provided between points S and R.

Note — If the fibre attenuation at the operating wavelength is different from that at 1300 nm, a suitable allowance should be considered in the above budget.

A.3 Concerning the bandwidth, in order to obtain such a regenerator section length and to respect the overall limit of 50 MHz, fibres with a bandwidth of 500 MHz should be used if the bandwidth addition factor is 0.75. For additional information on the calculation of bandwidth for elementary cable sections, refer to Recommendation G.651.

ANNEX B

(to Recommendation G.956)

Example of calculation of the regenerator section length

for a 4 × 140 Mbit/s laser-based system operating at 1300 nm on single-mode fibre

B.1 The regenerator section length can be calculated considering that at the end of the optical path between points S and R (see Figure 2/G.956 in the text of the Recommendation) the overall attenuation should not exceed 24 dB and the overall dispersion should not exceed 120 ps/nm for systems in the wavelength range 1285-1330 nm.

B.2 Concerning the attenuation, the regenerator section length can be obtained as an example and without reference to any particular situation, as follows:

— attenuation of the optical fibres at 1300 nm 0.40 dB/km

— attenuation of the splices 0.15 dB/km

— cable margin (M_c) 0.15 dB/km Total 0.70 dB/km

Regenerator section length
| 4 | 0.7 = 34 km.

The above assumes that no connectors are provided between points S and R.

Note — A suitable adjustment should be made to the fibre attenuation in the above budget for systems operating at wavelengths other than 1300 nm to account for the fibre spectral attenuation variation.

B.3 Concerning the dispersion the single-mode fibre described in Recommendation G.652 is adequate to obtain such a regenerator section length and to respect the overall limit of 120 ps/nm. Where the fibre dispersion needs to be limited to 100 ps/nm, a restricted wavelength range of 1293-1327 nm would be required for a fibre with the dispersion as specified in Recommendation G.652.

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