MONTAGE: REC. G.812 EN TETE DE CETTE PAGE

Recommendation G.821

ERROR PERFORMANCE OF AN INTERNATIONAL DIGITAL CONNECTION FORMING PART OF AN INTEGRATED SERVICES

DIGITAL NETWORK

(Geneva, 1980; further amended)

The CCITT,

considering

(a) that services in the future may expect to be based on the concept of an Integrated services digital network (ISDN);

(b) that errors are a major source of degradation in that they affect voice services in terms of distortion of voice, and data type services in terms of lost or inaccurate information or reduced throughout;

8.2 Quality and availability targets

(c) that while voice services are likely to predominate, the ISDN is required to transport a wide range of service types and it is therefore desirable to have a unified specification;

(d) that an explanation of network performance objectives and their relationship with design objectives is given in Recommendation G.102,

recommends

that within the following scope and definitions the requirements set out in Table 1/G.821 and subsequent paragraphs should be met.

1 Scope and definitions

1.1 The performance objectives are stated for each direction of a 64 kbit/s circuit-switched connection used for voice traffic or as a ‘‘Bearer Channel’’ for data-type services.

1.2 Recommendation I.325 gives reference configurations for the ISDN connection types listed in Recommendation I.340. In the context of error performance of 64 kbit/s circuit-switched connection types and the allocation of performance to the connection elements, an all digital hypothetical reference configuration (HRX) is given in Figure 1/G.821. It encompasses a total length of 27 | 00 km and is a derivative of the standard hypothetical reference configuration given in Figure 1/G.801 and of the reference configuration given in Figure 3/I.325.

1.3 The performance objective is stated in terms of **error performance parameters** each of which is defined as follows:

‘‘The percentage of averaging periods each of time interval T_0 during which the bit error ratio (BER) exceeds a threshold value. The percentage is assessed over a much longer time interval T_L’’ (see Note 3 to Table 1/G.821).

It should be noted that total time (T_L) is split into two parts, namely, time for which the connection is deemed to be available and that time when it is unavailable (see Annex A).

Requirements relating to the permissible percentage of unavailable time will be the subject of a separate Recommendation.

1.4 The following BERs and intervals are used in the statement of objectives:

a) a BER of less than 1 | (mu | 0$^{\mathrm{D}}$lF261^{6} for T_0 = 1 minute;

b) a BER of less than 1 | (mu | 0$^{\mathrm{D}}$lF261^{3} for T_0 = 1 second;

c) zero errors for T_0 = 1 second (equivalent to the concept of error free seconds EFS).

These categories equate to those of Table 1/G.821. In assessing these objectives, periods of unavailability are excluded (see Annexes A and B).

1.5 The performance objectives aim to serve two main functions:

a) to give the user of future national and international digital networks an indication as to the expected error performance under real operating conditions, thus facilitating service planning and terminal equipment design;

b) to form the basis upon which performance standards are derived for transmission equipment and systems in an ISDN connection.

1.6 The performance objectives represent a compromise between a desire to meet service needs and a need to realize transmission systems taking into account economic and technical constraints. The performance objectives, although expressed to suit the needs of different services are intended to represent a single level of transmission quality.

The performance objective for degraded minutes [Table 1/G.821 (a)] as stated, is based on an averaging period of one minute. This averaging period and the exclusion of errors occurring within severely errored seconds which occur during this one minute period (see Table 1/G.821, Note 2), may allow connections with frequent burst errors to meet this particular part of the overall objective, but such events will be controlled to a certain extent by the severely errored seconds objective [Table 1/G.821 (b)]. However, there is some doubt as to whether the objectives are adequate for proper operation of real-time video services with relatively long holding times, and this is the subject of further study.

1.7 Since the performance objectives are intended to satisfy the needs of the future digital network it must be recognized that such objectives cannot be readily achieved by all of today's digital equipment and systems. The intent, however, is to establish equipment design objectives that are compatible with the objectives in this Recommendation. These aspects are currently the subject of discussion within the CCITT and CCIR.

It is further urged that all technologies, wherever they appear in the network, should preferably be designed to better standards than those indicated here in order to minimize the possibility of exceeding the end-to-end objectives on significant numbers of real connections.

1.8 The objectives relate to a very long connection and recognizing that a large proportion of real international connections will be shorter, it is expected that a significant proportion of real connections will offer a better performance than the limiting value given in § 2. On the other hand, a small percentage of the connections will be longer and in this case may exceed the allowances outlined in this Recommendation.

Note — Controlled slips, which may be perceived as short bursts of errors, are not included in the calculations of the error performance objectives in this Recommendation. Therefore, users should be aware that error performance measurements which include controlled slip effects may produce poorer performance than would be indicated by this Recommendation. Users are directed to Recommendation G.822, which specifies the controlled slip rate objectives, for guidance in estimating the possible effects on their applications.

1.9 The error performance objectives detailed in §§ 2 and 3 of this Recommendation apply to a 64 kbit/s circuit switched connection (as defined in § 1.2). However, it is recognized that in practical situations these objectives will need to be evaluated from measurements made at higher bit rates.

Therefore, Annex D defines preliminary guidelines for estimating 64 kbit/s error performance parameter information from measurements made at the primary and higher bit rates.

2 Performance objectives

The performance objectives for an international ISDN connection as identified in §§ 1.1 and 1.2 are shown in Table 1/G.821. It is intended that international ISDN connections should meet all of the requirements of Table 1/G.821 concurrently. The connection fails to satisfy the objective if any of the requirements is not met.

3 Allocation of overall objectives

Since the objectives given in § 2 relate to an overall connection it is necessary to sub-divide this to constituent parts. This paragraph outlines the basic principles and strategy for apportioning the performance objectives.

The overall apportionment philosophy involves the use of two slightly different strategies, one applicable to the degraded minutes requirement and the errored seconds requirement [see classifications a), c)] and the other applicable to the severely errored seconds requirement [see classification b)].

H.T. [T1.821]

TABLE 1/G.821

Error performance objectives for international ISDN connections

Performance classification	Objective (Notes 3, 5)

{
(a)
(Degraded minutes)
(Notes 1, 2)
}
Fewer than 10% of one-minute intervals to have a bit error ratio worse than 1 | (mu | 0^{D}lF261^{6} (Note 4)
}
	{

{
(b)
(Severely errored seconds)
(Note 1)
}
Fewer than 0.2% of one-second intervals to have a bit error ratio worse than 1 | (mu | 0^{D}lF261^{3}
}
	{

{
(c)
(Errored seconds)
(Note 1)
}
Fewer than 8% of one-second intervals to have any errors (equivalent to 92% error-free seconds)
}
	{

Note 1 — The terms ‘‘degraded minutes’’, ‘‘severely errored seconds’’ and ‘‘errored seconds’’ are used as a convenient and concise performance objective ‘‘identifier’’. Their usage is not intended to imply the acceptability, or otherwise, of this level of performance.

Note 2 — The one-minute intervals mentioned in Table 1/G.821 and in the notes (i.e. the periods for M | | in Annex B) are derived by removing unavailable time and severely errored seconds from the total time and then consecutively grouping the remaining seconds into blocks of 60. The basic one-second intervals are derived from a fixed period.

Note 3 — The time interval *T , over which the percentages are to be assessed has not been specified since the period may depend upon the application. A period of the order of any one month is suggested as a reference.*

Note 4 — For practical reasons, at 64 kbit/s, a minute containing four errors (equivalent to an error ratio of 1.04 × 10^{D}lF261^{6}) is not considered degraded. However, this does not imply relaxation of the error ratio objective of 1 | (mu | 0^{D}lF261^{6}.

Note 5 — Annex B illustrates how the overall performance should be assessed.

TABLEAU 1/G.821 [T1.821], p.1

3.1 *Basic apportionment principles*

Apportionment is based on the assumed use of transmission systems having qualities falling into one of a limited number of different classifications.

Three distinct quality classifications have been identified representative of practical digital transmission circuits and are independent of the transmission systems used. These classifications are termed local grade, medium grade and high grade and their usage generally tends to be dependent on their location within a network (see Figure 1/G.821).

Figure 1/G.821,

The following general assumptions apply to the apportionment strategy that follows:

— in apportioning the objectives to the constituent elements of a connection it is the ‘‘% of time’’ that is subdivided;

— an equal apportionment of the objectives applies for both the degraded minutes and errored seconds requirements [classifications a), c)];

— the error ratio threshold is not sub-divided. The rationale for this is based on the assumption that the performance of real circuits forming the parts of the HRX (Figure 1/G.821) will normally be significantly better than the degraded minute threshold (see Note to § 3.1);

— no account is taken of the error contribution from either digital switching elements or digital multiplex equipments on the basis that it is negligible in comparison with the contribution from transmission systems.

These quality classifications for different parts of the connection are considered to represent the situation for a large proportion of real international connections. Administrations are free to use whatever transmission systems they wish within their own networks and these other arrangements are considered as being completely acceptable provided that the overall performance of the national portion is no worse than it would have been if the standard CCITT arrangements had been employed.

It should be noted that a small percentage of connections will be longer than the 27 | 00 km HRX. By definition the extra connection length will be carried over high-grade circuits and hence the amount by which such connections exceed the total allowance envisaged in this Recommendation will be proportional to the amount by which the 25 | 00 km section is exceeded. Administrations should note that if the performance limits in the various classifications could be improved in practical implementations, the occurrence of these situations could be significantly reduced.

Note — For terrestrial systems the apportionment of the ‘‘degraded minute’’ performance classification to smaller entities (e.g. hypothetical reference digital section) may require sub-division of the error ratio objective, as well as the sub-division of ‘‘% of time’’, with distance. This is the subject of further study.

3.2 *Apportionment strategy for the degraded minutes* and *errored seconds requirements*

The apportionment of the permitted degradation, i.e. 10% degraded minutes and 8% errored seconds, is given in Table 2/G.821. The derived network performance objectives are given in Annex C.

H.T. [T2.821]

TABLE 2/G.821

Allocation of the degraded minutes and errored seconds objectives for the three circuit classifications

Circuit classification Allocation of the degraded minutes and errored seconds objectives given in Table 1/G.821 }	{
Local grade (2 ends) 15% block allowance to each end (Notes 1, 4 and 5) }	{
Medium grade (2 ends) 15% block allowance to each end (Notes 2, 4 and 5) }	{
High grade 40% (equivalent to conceptual quality of 0.0016% per km for 25 | 00 km, but see Note to § 3.1) (Notes 3, 6 and 7) }	{

Note 1 — The local grade apportionment is considered to be a block allowance, i.e. an allowance to that part of the connection regardless of length.

Note 2 — The medium grade apportionment is considered to be a block allowance, i.e. an allowance to that part of the connection regardless of length. The actual length covered by the medium grade part of the connection will vary considerably from one country to another. Transmission systems in this classification exhibit a variation in quality falling between the other classifications.

Note 3 — The high grade apportionment is divided on the basis of length resulting in a conceptual per kilometre allocation which can be used to derive a block allowance for a defined network model (e.g. Hypothetical Reference Digital Link). For practical planning purposes of links in network models, link allowances based on the number of 280 km sections nominally 280 km (as specified in Table 2/G.921) can be used in place of the per kilometre allocation specified in this Recommendation. For longer sections which are not an exact integer multiple of 280 km, the next highest integer multiple is used.

Note 4 — The local grade and medium grade portions are permitted to cover up the first 1250 km of the circuit from the T-reference point (see Figure 1/G.821) extending into the network. For example, in large countries this portion of the circuit may only reach the Primary Centre whilst in small countries it may go as far as the Secondary Centre, Tertiary Centre or the International Switching Centre (see Figure 1/G.821).

Note 5 — Administrations may allocate the block allowances for the local and medium grade portions of the connection as necessary within the total allowance of 30% for any one end of the connection. This philosophy also applies to the objectives given for local and medium grades in Table 3/G.821.

Note 6 — Based on the understanding that satellite error performance is largely independent of distance, a block allowance of 20% of the permitted degraded minutes and errored second objectives is allocated to a single satellite HRDP employed in the high-grade portion of the HRX.

Note 7 — If the high-grade portion of a connection includes a satellite system and the remaining distance included in this category exceeds 12 | 00 km or if the high-grade portion of a non-satellite connection exceeds 25 | 00 km, then the objectives of this Recommendation may be exceeded. The occurrence of such connections is thought to be relatively rare and studies are continuing in order to investigate this. The concept of satellite equivalent distance (the length of an equivalent terrestrial path) is useful in this respect and it has been noted that a value in the range 10 | 00 to 13 | 00 km might be expected.

Note 8 — For subscriber premises installation, between the T-reference point and terminal equipment, no specific requirements are given. However careful attention should be paid to the choice of the subscriber equipment since the overall performance of the connection depends heavily, not only on the network performance, but also on the quality of the terminal installation.

Table 2/G.821 [T2.821], p.

3.3 *Apportionment strategy for severely errored seconds*

The total allocation of 0.2% severely errored seconds is subdivided into each circuit classification (i.e. local, medium, high grades) in the following manner:

a) 0.1% is divided between the three circuit classifications in the same proportions as adopted for the other two objectives. This results in the allocation as shown in Table 3/G.821.

H.T. [T3.821]

TABLE 3/G.821

Allocation of severely errored seconds

Circuit classification Allocation of severely errored seconds objectives }	{
Local grade 0.015% block allowance to each end (Note 5 to Table 2/G.821) }	{
Medium grade 0.015% block allowance to each end (Note 5 to Table 2/G.821) }	{
High grade	0.04% (Notes 1, 2)

Note 1 — For transmission systems covered by the high grade classification each 2500 km portion may contribute not more than 0.004%.

Note 2 — For a satellite HRDP operating in the high grade portion there is a block allowance of 0.02% severely errored seconds (see also Note 6 to Table 2/G.821).

Table 3/G.821 [T3.821], p.

b) The remaining 0.1% is a block allowance to the medium and high grade classifications to accommodate the occurrence of adverse network conditions occasionally experienced (intended to mean the worst month of the year) on transmission systems. Because of the statistical nature of the occurrence of worst month effects in a world-wide connection, it is considered that the following allowances are consistent with the total 0.1% figure:

— 0.05% to a 2500 km HRDP for radio relay systems which can be used in the high grade and the medium grade portion of the connection;

— 0.01% to a satellite HRDP (the CCIR are continuing studies on severely errored seconds performance for satellites systems and this value may eventually need to be increased).

ANNEX A

(to Recommendation G.821)

Available and unavailable time

A period of unavailable time begins when the bit error ratio (BER) in each second is worse than 1 | (mu | 0^{D}lF261^{3} for a period of ten consecutive seconds. These ten seconds are considered to be unavailable time. A new period of available time begins with the first second of a period of ten consecutive seconds each of which has a BER better than 10^{D}lF261^{3}.

Definitions concerning availability can be found in Recommendation E.800-series.

ANNEX B
(to Recommendation G.821)

Guidelines concerning the interpretation of Table 1/G.821

Figura, p.

ANNEX C
(to Recommendation G.821)

Allocation of objectives to constituent parts

H.T. [T4.821]

TABLE C-1/G.821
{
Allocation of % degraded minute intervals and errored seconds objectives
}

{	{	
	% degraded minutes	% errored seconds
Local grade	1.5	1.2
Medium grade	1.5	1.2
High grade	4.0	3.2

Table C-1/G.821 [T4.821], p.

ANNEX D
(to Recommendation G.821)

Preliminary guidelines for the assessment of the

performance of higher bit rate systems

D.1 *Interim guidelines*

Recognizing the need for interim guidance, the formulas below are offered prior to the results of further study. They may be used to provide a normalized estimate (to the 64 kbit/s parameters cited in this Recommendation) of the error performance. It should be noted that the measurement may only be valid at the bit rate at which the measurement was made; this concern applies especially for certain types of bursty error distribution. Hence an assessment of system error performance by means of these formulas does not assure *compliance* with this Recommendation.

In order to estimate error performance normalized to 64 kbit/s in terms of:

— % errored seconds;

— % degraded minutes; and

— % severely errored seconds,

from error performance measurements at primary bit rates and above, the following provisional formulas are provided.

D.1.1 *Errored seconds*

The percentage errored seconds normalized to 64 kbit/s is given by:

Formula F1.821 to be inserted here.

where:

i) n | is the number of errors in the i^{th} second at the measurement bit rate;

ii) N | is the higher bit rate divided by 64 kbit/s;

iii) j | is the integer number of one second periods (excluding unavailable time) which comprises the total measurement period;

iv) the ratio $\left(\frac{f\,In}{f\,IN}\right)$ i for the i th seconds is

$$\frac{f\,In}{f\,IN}$$
, if $0 < n < N$, or

1, if $n \geq$" N

D.1.2 *Degraded minutes (see Note 1)*

The percentage of degraded minutes normalized to 64 kbit/s can be taken directly from measurements at primary bit rates and above, i.e. X % degraded minutes at the primary rate or above yields X % degraded minutes at 64 kbit/s.

D.1.3 *Severly errored seconds (see Note 1)*

The percentage of severly errored seconds normalized to 64 kbit/s that can be assessed from measurements made at primary bit rates and above is given by:

$$Y\,\% + Z\,\%$$

where:

Y percentage severly errored seconds at the measurement bit rate; and

Z percentage of non severely errored seconds at the measurement bit rate containing one or more loss of frame alignment at the measurement bit rate.

Note 1 — The calculation of the bit error ratio at the measurement bit rate (e.g. 10^{D}lF261^{6} for degraded minutes) will sometimes result in non-integral values of errors over the integration period. For clarification purposes, the next integer number of errors above the calculated value is considered to exceed the threshold of the performance objective (e.g. 123 errors over a minute for a bit rate of 2048 kbit/s, resulting in a BER worse than 10^{D}lF261^{6}, is considered as a degraded minute).

Note 2 — In order to assure the proper operation of:

— higher bit rate services (e.g. TV);

— 64 kbit/s services,

it is necessary to determine performance requirements for higher bit rate systems (i.e. above 64 kbit/s). While it is not clear which of these services has the most demanding requirements, in both cases it appears to be necessary to determine performance requirements for the higher bit rate systems either by using integration period much shorter than one second or by applying more stringent limits for severely errored seconds.

For 64 kbit/s services, the need for shorter integration periods or more stringent limits arises from the operation of the de-multiplexing equipment and in particular from the operation of the justification control and re-framing processes in the presence of error bursts much shorter than one second. For example, errors which do not result in severely errored seconds at the 64 kbit/s level as a result of loss of frame alignment in higher order multiplexers.

Reference

[1] CCITT Recommendation *Transmission performance objectives and recommendations* , Vol. III, Rec. G.102.

CONTROLLED SLIP RATE OBJECTIVES | ON AN INTERNATIONAL DIGITAL CONNECTION

(Geneva, 1980; further amended)

1 General

This Recommendation deals with end-to-end *controlled octet slip rate* objectives for 64-kbit/s international digital connections. The objectives are presented for various operational conditions in relation to the evaluation of connection quality.

Under design conditions for digital network nodes and within defined normal transmission characteristics, it may be assumed that there are zero slips in a synchronized digital network. However, the defined transmission characteristics can be exceeded under operating conditions and cause a limited number of slips to occur even in a synchronized network.

Under temporary loss of timing control within a particular synchronized network, additional slips may be incurred, resulting in a larger number of slips for an end-to-end connection.

With plesiochronous operation, the number of slips on the international links will be governed by the sizes of buffer stores and the accuracies and the stabilities of the interconnecting national clocks.

2 Scope and considerations

2.1 The end-to-end slip rate performance should satisfy the service requirements for telephone and non-telephone services on a 64-kbit/s digital connection in an ISDN.

2.2 The slip rate objectives for an international end-to-end connection are stated with reference to the standard digital Hypothetical Reference Connection (HRX) of Figure 1/G.801 [1] of 27 | 00 km in length.

2.3 It is assumed that international switching centres (ISC) are interconnected by international links which are operating plesiochronously, using clocks with accuracies as specified in Recommendation G.811. It is recognized that one slip in 70 days per plesiochronous interexchange link is the resulting maximum theoretical slip rate, taking into account clock accuracies according to Recommendation G.811 only, and provided that the perfor mance of the transmission and switching requirements remain within their design limits.

2.4 In the case where the connection includes all of the 13 nodes identified in the HRX (Recommendation G.801) and these nodes are all operating together in a plesiochronous mode, the nominal slip performance of a connection could be 1 in 70/12 days or 1 in 5.8 days. However, since in practice some nodes in such a connection would be part of the same synchronized network a better nominal slip performance can be expected (e.g. where the National Networks at each end are synchronized. The Nominal Slip Performance of the connection would be 1 in 70/4 or 1 in 17.5 days).

Note — These calculations assume a maximum of four international links.

2.5 In a practical international end-to-end connection containing both international and national portions, the slip rate may significantly exceed the value computed from *n* plesiochronous interexchange links due to various design, environmental and operational conditions in international and national sections. These include:

a) configuration of the international digital network,

b) national timing control arrangements,

c) wander due to extreme temperature variations,

d) operational performance characteristics of various types of switches and transmission links (including diurnal variations of satellite facilities),

e) temporary disturbances on transmission and synchronization links (network rearrangements, protection switching, human errors, etc.).

Note — The maximum number, *n* , of plesiochronous interexchange links is under study.

2.6 A threshold of slip performance is a suitable compromise between desired service requirements and normally achievable performance. Slip levels according to category (b) (see Table 1/G.822) exceeding this threshold will begin to affect performance and can cause some services to be considered degraded. In order to ensure that a trend of performance has been identified, the threshold rate must be measured over a sufficient period to record a significant number of slips. An objective limit is placed on the total time that the threshold is exceeded during the period of one year. The performance objectives are intended to represent a uniform set of specifications.

Slip is one of several contributing factors to impairment of a digital connection. The performance objectives for the rate of octet slips on an international connection of 27 | 00 km in length or a corresponding bearer channel are given in Table 1/G.822. Further study is required to confirm that these values are compatible with other objectives, e.g. the error performance as listed in Recommendation G.821.

H.T. [T1.822]
TABLE 1/G.822
Controlled slip performance on a 64 kbit/s international connection or bearer channel

Performance category	Mean slip rate	Proportion of time (Note 1)
(a) (Note 2)	| slips in 24 hours	> 98.9%
(b) > | slips in 24 hours | nd | 0 slips in 1 hour }	{ < 1.0%	
(c)	> | 0 slips in 1 hour	< 0.1%

Note 1 — Total time ≥" | year.

Note 2 — The nominal slip performance due to plesiochronous operation alone is not expected to exceed 1 slip in 5.8 days (see § 2.4).

Table 1/G.822 [T1.822], p.

3 Allocation of impairments

3.1 The probability of more than one section of the network experiencing excessive slips which will simultaneously affect any given connection, is low. Advantage is taken of this factor in the allocation process.

3.2 Because the impact of slips occurring in different parts of a connection will vary in importance depending upon the type of service and the level of traffic affected, the allocation process includes placing tighter limits on slips detected at international and national transit exchanges and less stringent limits on small local exchanges.

3.3 The recommended allocation process is based on subdividing the percentage of time objectives for performance categories (b) and (c) (Table 1/G.822). A provisional allocation is made to the various portions of the HRX as shown in Table 2/G.822.

H.T. [T2.822]
TABLE 2/G.822
Allocation of controlled slip performance objectives

{		(c)	
{ International transit portion }	8.0 |	0.08 |	0.008 |
{ Each national transit portion (Note 2) }	6.0 |	0.06 |	0.006 |
Each local portion (Note 2)	40.0 |	0.4 |	0.04 |

Note 1 — The portions of the HRX are defined in Figure 1/G.822. They are derived from but not identical to Recommendation G.801.

Note 2 — The allocation between national transit portion and local portion is given for guidance only. Administrations are free to adopt a different apportionment provided the total for each national portion (local plus transit) does not exceed 46%.

Note 3 — Performance levels are defined in Table 1/G.822.

Note 4 — Total time ≥" | ne year.
} _

Tableau 2/G.822 [T2.822], p.8

Figure 1/G.822, p.9

Reference

[1] CCITT Recommendation *Digital transmission models* , Vol. III, Rec. G.801, Figure 1/G.801.

Recommendation G.823

THE CONTROL OF JITTER AND WANDER |
WITHIN DIGITAL NETWORKS

WHICH ARE BASED ON THE 2048 KBIT/S HIERARCHY

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

The CCITT,

considering

(a) that jitter, which is defined as the short-term variations of the significant instants of a digital signal from their ideal positions in time, can arise in digital networks;

(b) that, if proper control is not exercised, then under certain circumstances, jitter can accumulate to such an extent that the following impairments can arise:

i) an increase in the probability of introducing errors into digital signals at points of signal regeneration as a result of timing signals being displaced from their optimum position in time;

ii) the introduction of uncontrolled slips into digital signals through store spillage and depletion in certain types of terminal equipment incorporating buffer stores and phase comparators, e.g. jitter reducers and certain digital multiplex equipment;

iii) a degradation of digitally encoded analogue information as a result of phase modulation of the reconstructed samples in the digital to analogue conversion device at the end of the connection;

(c) that, unlike some other network impairments, jitter can be reduced in magnitude by the use of jitter reducers. Depending upon the size and complexity of networks, it might be necessary to employ such devices in certain circumstances;

(d) that wander, which is defined as the long-term variations of the significant instants of a digital signal from their ideal position in time, can arise as a result of changes in the propagation delay of transmission media and equipments;

(e) that it is necessary to accommodate wander at the input ports of digital equipments if controlled or uncontrolled slips are to be minimized,

recommends

that the following guidelines and limits should be applied in the planning of networks and in the design of equipment.

1 The control of jitter in digital networks — basic philosophy

The jitter control philosophy is based on the need:

— to recommend a maximum network limit that should not be exceeded at any hierarchical interface;

— to recommend a consistent framework for the specification of individual digital equipments;

— to provide sufficient information and guidelines for organizations to measure and study jitter accumulation in any network configuration.

2 Network limits for the maximum output jitter and wander at any hierarchical interface

2.1 *Network limits for jitter*

The limits given in Table 1/G.823 represent the maximum permissible levels of jitter at hierarchical interfaces within a digital network. The limits should be met for all operating conditions and regardless of the amount of equipment preceding the interface. These network limits are compatible with the minimum tolerance to jitter that all equipment input ports are required to provide.

In operational networks, account needs to be taken of the fact that signals at an interface can contain jitter up to the maximum permissible network limit. This is particularly important in the design of equipments incorporating jitter reducers where this jitter together with any additional jitter generated in the system prior to the jitter reducer, needs to be accommodated. In circumstances where the maximum permissible jitter amplitude occurs at an interface between two countries, it is left to the discretion of national Administrations to take the appropriate remedial action. This situation is unlikely to occur very often.

The arrangements for measuring output jitter at a digital interface are illustrated in Figure 1/G.823. The specific jitter limits and values of filter cut-off frequencies for the different hierarchical levels are given in Table 1/G.823. The frequency response of the filters associated with the measurement apparatus should have a roll-off of 20 dB/decade. Suitable test apparatus is described in Recommendation O.171.

H.T. [T1.823]

TABLE 1/G.823

Maximum permissible jitter at a hierarchical interface

<table>
<tr><th>{</th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td>| 64 (Note 1)</td><td>0.25</td><td>0.05</td><td>20 Hz</td><td>3 kHz</td><td>20 kHz</td></tr>
<tr><td>2 | 48</td><td>1.5</td><td>0.2</td><td>20 Hz</td><td>18 kHz (700 Hz)</td><td>100 kHz</td></tr>
<tr><td>8 | 48</td><td>1.5</td><td>0.2</td><td>20 Hz</td><td>3 kHz (80 kHz)</td><td>400 kHz</td></tr>
<tr><td>34 | 68</td><td>1.5</td><td>0.15</td><td>100 Hz</td><td>10 kHz</td><td>800 kHz</td></tr>
<tr><td>139 | 64</td><td>1.5</td><td>0.075</td><td>200 Hz</td><td>10 kHz</td><td>3500 kHz</td></tr>
</table>

Note 1 — For the codirectional interface only.

Note 2 — The frequency values shown in parenthesis only apply to certain national interfaces.

Note 3 — UI = Unit Interval:

for 64 kbit/s 1 UI = 15.6 µs for 2048 kbit/s 1 UI = 488 ns for 8448 kbit/s 1 UI = 118 ns for 34 | 68 kbit/s 1 UI = 29.1 ns for 139 | 64 kbit/s 1 UI = 7.18 ns
} _

Tableau 1/G.823 [T1.823], p.10

Figure 1/G.823, p.11

For systems in which the output signal is controlled by an autonomous clock (e.g. quartz oscillator) more stringent output jitter values may be defined in the relevant equipment specifications (e.g. for the muldex in Recommendation G.735, the maximum peak-to-peak output jitter is 0.05 UI).

2.2 *Network units for wander*

A maximum network limit for wander at all hierarchical interfaces has not been defined. Actual magnitudes of wander, being largely dependent on the fundamental propagation characteristics of transmission media and the ageing of clock circuitry (see Recommendation G.811, § 3), can be predicted. Studies have shown that, provided input ports can tolerate wander in accordance with the input tolerance requirements of § 3.1.1, then slips introduced as a result of exceeding the input tolerance, will be rare. For interfaces to network nodes the following limits apply:

The MTIE (see Recommendation G.811) over a period of *S* seconds shall not exceed the following:

1) $S < 10^4$; this region requires further study;

2) (10^{D}lF261^{2} S + 10 | 00) ns: applicable to values of S greater than 10^4.

Note — The resultant overall specification is illustrated in Figure 2/G.823.

Figure 2/G.823, p.

2.3 *Jitter and wander considerations concerning synchronized networks*

It is assumed that, within a synchronized network, digital equipment provided at nodes will accommodate permitted phase deviations on the incoming signal, together with jitter and wander from the transmission plant thus under normal synchronized conditions, slips will not occur. However, it should be recognized that, as a result of some performance degradations, failure conditions, maintenance actions and other events, the relative time interval error (TIE) between the incoming signal and the internal timing signal of the terminating equipment may exceed the wander and jitter tolerance of the equipment which will result in a controlled slip.

At nodes terminating links interconnecting independently synchronized networks (or where plesiochronous operation is used in national networks), the relative TIE between the incoming signal and the internal timing signal of the terminating equipment may eventually exceed the wander and jitter tolerance of the equipment in which case slip will occur. The maximum permissible long-term mean controlled slip rate resulting from this mechanism is given by Recommendation G.811, i.e. one slip in 70 days.

3 Jitter limits appropriate to digital equipments

3.1 *Basic specification philosophy*

For individual digital equipments it is necessary to specify their jitter performance in three ways:

3.1.1 *Jitter and wander tolerance of digital input ports*

In order to ensure that any equipment can be connected to any recommended hierarchical interface within a network, it is necessary to arrange that the input ports of all equipments are capable of accommodating levels of jitter up to the maximum network limit defined in Table 1/G.823.

For convenience of testing, the required tolerance is defined in terms of the amplitude and frequency of sinusoidal jitter which, when modulating a test pattern, should not cause any significant degradation in the operation of the equipment. It is important to recognize that the test condition is not, in itself, intended to be representative of the type of jitter to be found in practice in a network. However, the test does ensure that the ‘‘*Q* associated with the timing signal recovery of the equipments input circuitry is not excessive and, where necessary, that an adequate amount of buffer storage has been provided.

Thus, all digital input ports of equipments should be able to tolerate a digital signal having electrical characteristics in accordance with the requirements of Recommendation G.703 but modulated by sinusoidal wander and jitter having an amplitude-frequency relationship defined in Figure 3/G.823. Table 2/G.823 indicates the appropriate limits for the different hierarchical levels.

In principle, these requirements should be met regardless of the information content of the digital signal. For test purposes, the equivalent binary content of the signal with jitter modulation should be a pseudo-random bit sequence as defined in Table 2/G.823.

In deriving these limits, the wander effects are considered to be predominant at frequencies below f_1, and many transmission equipments, such as digital line systems and asynchronous muldexes using justification techniques, are effectively transparent to these very low frequency changes in phase. Notwithstanding this, it does not need to be accommodated at the input of certain equipments (e.g. digital switches and synchronous muldexes). The requirement below f_1 is not amenable to simple practical evaluation but account should be taken of the requirement at the design stage of the equipment.

Unlike that part of the mask between frequencies f_1 and f_4, which reflect the maximum permissible jitter magnitude in a digital network, that part of the mask below the frequency f_1 does not aim to represent the maximum permissible wander that might occur in practice. Below the frequency f_1, the mask is derived such that where necessary, the provision of this level of buffer storage at the input of an equipment facilitates the accommodation of wander generated in a large proportion of real connections.

A short-term reversal of the relative TIE between the incoming signal, and the internal timing signal of the terminating equipment shortly after the occurrence of a controlled slip should not cause another slip. In order to prevent such a slip, the equipment should be designed with a suitable hysteresis for this phenomenon. This hysteresis should be at least 18 microseconds.

Figure 3/G.823, p.

H.T. [T2.823]

TABLE 2/G.823

Parameter values for input jitter and wander tolerance

{	{ Frequency	{						
	A 0	*A* 1	*A* 2	*f* 0	*f* 1	*f* 2	*f* 3	*f* 4
| 64 (Note 1) 2^{11} — 1 (Rec. O.152) }	1.15 (18 µs)	0.25	0.05		20 Hz	600 Hz	3 kHz	20 kHz
2 | 48 2^{15} — 1 (Rec. O.151) }	36.9 (18 µs)	1.5	0.2	1.2×10^{D}lF261^{5} Hz	2.4 kHz (93 Hz)	18 kHz (700 Hz)	100 kHz	{
8 | 48 2^{15} — 1 (Rec. O.151) }	152 (18 µs)	1.5	0.2	1.2×10^{D}lF261^{5} Hz	20 Hz	400 Hz (10.7 kHz)	3 kHz (80 kHz)	400 kHz
34 | 68 2^{23} — 1 (Rec. O.151) }	*	1.5	0.15	*	100 Hz	1 kHz	10 kHz	800 kHz
139 | 64 2^{23} — 1 (Rec. O.151)	*	1.5	0.075	*	200 Hz	500 Hz	10 kHz	3500 kHz

* Values under study.

Note 1 — For the codirectional interface only.

Note 2 — For interfaces within national networks the frequency values (*f* 2 and *f* 3) shown in parenthesis may be used.

Note 3 — UI = Unit Interval:

For 64 kbit/s 1UI = 15.6 µs

For 2048 kbit/s 1UI = 488 ns

For 8448 kbit/s 1UI = 118 ns

For 34 | 68 kbit/s 1UI = 29.1 ns

For 139 | 64 kbit/s 1UI = 7.18 ns

Note 4 — The value for *A* 0 (18 µs) represents a relative phase deviation between the incoming signal and the internal timing local signal derived from the reference clock. This value for *A* 0 corresponds to an absolute value of 21 µs at the input to a node (i.e. equipment input port) and assumes a maximum wander of the transmission link between two nodes of 11 µs. The difference of 3 µs corresponds to the 3 µs allowed for long-term phase deviation in the national reference clock [Recommendation G.811, § 3c].

Tableau 2/G.823 [T2.823], p.

3.1.2 *Maximum output jitter in the absence of input jitter*

It is necessary to restrict the amount of jitter generated within individual equipments. Recommendations dealing with specific systems define the maximum levels of jitter that may be generated in the absence of input jitter. The actual limits applied depend upon the type of equipment. They should be met regardless of the information content of the digital signal. In all cases the limits never exceed the maximum permitted network limit. The arrangement for measuring output jitter is illustrated in Figure 1/G.823.

3.1.3 *Jitter and wander transfer characteristics*

Jitter transfer characteristics define the ratio of output jitter to input jitter amplitude versus jitter frequency for a given bit rate. When jitter is present at the digital input port of digital equipment, in many cases some portion of the jitter is transmitted to the corresponding digital output port. Many types of digital equipment inherent attenuate the higher frequency jitter components present at the input. To control jitter in cascaded homogeneous digital equipment, it is important to restrict the value of jitter gain. The jitter transfer for a particular digital equipment can be measured using a digital signal modulated by sinusoidal jitter.

Figure 4/G.823 indicates the general shape of a typical jitter transfer characteristics. The appropriate values for the levels *x* and —*y* dB and the frequencies *f* , f_5, f_6 and f_7 can be obtained from the relevant Recommendation.

Because the bandwidth of phase smoothing circuits in asynchronous digital equipment is generally above 10 Hz, wander on the input signal may appear virtually unattenuated on the output. However, in certain particular digital equipments (e.g. nodal clocks) it is necessary that wander be sufficiently attenuated from input to output. CCITT Recommendations dealing with synchronous equipment will ultimately define limiting values for particular wander transfer characteristics.

Figure 4/G.823, p.

3.2 *Digital sections*

To ensure that the maximum network limit (§ 2) is not exceeded within a digital network, it is necessary to control the jitter contributed by transmission systems.

The jitter limits for digital sections are found in Recommendation G.921.

3.3 *Digital muldexes*

The jitter limits for digital multiplexers and demultiplexers are found in the appropriate equipment Recommendations.

4 Guidelines concerning the measurement of jitter

There are two clearly identifiable categories under which jitter measurement may be classified:

— measurements using an undefined traffic signal which may generally be considered as quasi-random (generally applicable under operational circumstances);

— measurements using specific test sequencies (generally applicable during laboratory, factory and commissioning circumstances).

4.1 *Measurements using an undefined traffic signal*

Because of the quasi-random nature of jitter and its possible dependency on traffic loading, accurate peak-to-peak measurements in operational networks need to be made over long periods of time. In practice it is expected that, with experience of particular systems, it will be possible to identify abnormalities measured over a shorter measurement period which would indicate that the maximum permissible limit might be exceeded over a longer measurement interval.

The network limits recommended in § 2 are so derived that the probability of exceeding such levels is very small. The practical observation of such a magnitude with a high degree of confidence requires an unacceptable measurement interval. To take account of such an effect it may be necessary to introduce a smaller, but related, limit which has a greater probability of occurrence, facilitating its measurement over a reasonably short measurement interval. These aspects are the subject of further study.

4.2 *Measurements using a specific test sequence*

Given that it is advantageous to assess the jitter performance of digital line equipment using a specific pseudo-random binary sequence (PRBS), it is necessary to derive limits appropriate to this unique test condition. Although the use of such deterministic test signals is extremely useful for factory acceptance tests and commissioning tests, the results need to relate to an operational situation in which the information content of the signal is likely to be more random (e.g. a telephony type signal). Based on practical experience, it is usually possible to relate a traffic-based measurement to a PRBS-based measurement by the application of an appropriate correction factor (Annex A).

The use of a PRBS in the measurement of jitter may have shortcomings in that for the measurement to be valid the PRBS must have adequate spectral content within the jitter bandwidth of the system being measured. In circumstances where the spectral content is insufficient, a suitable correction must be applied if a measured value is to be meaningfully compared with specified limits. This aspect is the subject of further study (Annex A).

4.3 *Test signal interaction with signal processing devices integral to transmission systems*

The inclusion of additional signal processing devices integral to a transmission system often influences the observed jitter performance. Studies have shown that the transmitted signal, particularly if it is pseudo-random or highly structured, interacts with digital scramblers and line code converters to produce interesting effects which are observed as changes in the performance of such equipments. All interaction effects result in a modification to the statistics of the transmitted signal causing a consequential change in the pattern-sensitive jitter generated within each repeater. A typical manifestation is that successive measurements on a transmission system incorporating these devices, using an identical test signal on each occasion, yield a widely varying range of peak-to-peak and r.m.s. jitter amplitudes.

Studies have shown that the following factors influence the observed jitter performance:

— the feedback connections on both the PRBS test signal generator and the transmission system’s scrambler;

— the number of stages on the PRBS test signal generator and the transmission system’s scrambler;

— the presence of a code converter in the transmission system.

Consequently, considerations concerning the choice of test signal for equipment validation purposes should take account of the following points:

a) It is inadvisable to use a PRBS test signal generator with a cycle length that has common factors with the scrambler incorporated in the transmission system.

b) The equal configuration of the PRBS test signal generator and the transmission system's scrambler should be avoided if a random signal is required.

5 Jitter accumulation in digital networks

The variability of network configurations prevents the consideration of every possible case. To analyse a particular network configuration, it is necessary to use the information about the jitter characteristics of individual equipments in conjunction with appropriate jitter accumulation models. Annex B aims to provide sufficient information to enable organizations to carry out such evaluations.

ANNEX A

(to Recommendation G.823)

The use of a pseudo-random binary sequence (PRBS) for jitter measurements on digital line,

radio and optical fibre systems

A.1 *The relationship between a random traffic-based measurement and a PRBS-based measurement*

It is often convenient to emulate a random type traffic signal using a pseudo-random binary sequence (PRBS). However, jitter measurements using such a test signal tend to give optimistic values when compared with an identical measurement using a traffic signal in which the information content is more random. This disparity arises because the traffic signal, which is generally non-deterministic in nature, is able to cause the generation of

an almost unrestricted range of jitter amplitudes, whereas the quasi-random nature of a PRBS means that it is only able to cause the generation of a finite range of jitter amplitudes. Based on operational experience to date, a correction factor relating the two types of measurement has been determined, but it is extremely difficult to establish an accurate value for every conceivable practical situation. Its actual value is dependent on many interrelated aspects such as the measurement period, system length, the value of the timing recovery circuit Q , the sequence length, and the presence of scramblers. To relate a random traffic-based measurement (made over a relatively short interval) to a specific PRBS, it is necessary to use the following correction factors which are believed to represent a good practical choice for most circumstances:

— 1.5 at 2048 kbit/s and 8448 kbit/s (based on the use of a $2^{15} — 1$ PRBS generated in accordance with Recommendation O.151);

— 1.3 at 34 | 68 kbit/s and 139 | 64 kbit/s (based on the use of a $2^{23} — 1$ PRBS generated in accordance with Recommendation O.151).

Therefore:

Estimated jitter amplitude Measured jitter

when transmitting = correction factor × amplitude using

random signal (traffic) a specific PRBS.

A.2 *Spectral content of the PRBS*

By its very nature, the PRBS is cyclical and is therefore characterized by a power spectrum with spectral lines occurring at regularly spaced intervals. For the achievement of a meaningful result, in which the measurement error is acceptable, it is necessary to ensure that the PRBS used when measuring output jitter, has adequate spectral content within the jitter bandwidth of the system being measured. The bandwidth of the jitter spectrum at the output of a chain of digital regenerators is shown to be a function of the Q factor of the timing recovery circuit and the number of generators in tandem [1].

Now:

$$\text{Jitter bandwidth} = \frac{f\,I\,f}{f\,I\,Q \times \frac{1}{n}} \text{ [Hz] for large } n$$

where

f_1 = frequency of the timing signal that is extracted from the incoming signal by the timing recovery circuit

Q = Q factor of one repeater

n = number of cascaded repeaters

and

$$\text{PRBS repetition rate} = \frac{f}{L} \ \text{[Hz]}$$

where

f	=	bit rate
L	=	sequence length

For adequate spectral content, the pattern repetition frequency should be less than [Formula Deleted] of the jitter bandwidth of the system under test. (The value for *y* requires further study).

Thus

$$\frac{f}{L} \le \frac{f_1}{y \times Q \times n}$$

and

$$L \ge y \times n \times Q \times \frac{f}{f_1}$$

Exemples:

For line code B6ZS $f = f_1$ and $L \ge y \times n \times Q$

For a Non-Redundant Quaternary line code [Formula Deleted]

If the system uses a scrambler or a code translation technique (e.g. 4B3T), this may be taken into account in order to reduce the length of the test sequence.

ANNEX B
(to Recommendation G.823)

B.1 *Jitter accumulation in digital networks*

B.1.1 *Jitter accumulation relationships for cascaded homogeneous digital equipments*

B.1.1.1 *Digital line, radio and optical fibre systems*

With this type of equipment, the relationship applicable is critically dependent on the content of the transmitted signal, the physical implementation of timing recovery, the inclusion of a scrambler/descrambler combination, etc. A number of relationships are identified.

a) *Cascaded homogeneous regenerators*

Most digital repeaters currently in use are fully regenerative and self-timed; that is, the output signal is retimed under the control of a timing signal derived from the incoming signal. The most significant form of jitter arises from imperfections in the circuitry, which cause jitter that is dependent on the sequence of pulses in the digital signal being transmitted, termed pattern-dependent jitter. The mechanisms that generate jitter within a regenerator, that have been extensively studied, are principally related to imperfections in the timing-recovery circuit. [2], [3], and [4].

Since pattern-dependent jitter from regenerated sections is the dominant type of jitter in a network, the manner in which it accumulates must be considered. For jitter purposes, a regenerative repeater acts as a low-pass filter to the jitter present on the input signal, but it also generates jitter, which can be represented by an additional jitter source at the input. If this added jitter were truly random, as distinct from pattern dependent, then the total r.m.s. jitter, J_N, present on the digital signal after N regenerators would be given by the approximate relationship:

$$J_N = J \times \sqrt{N} \qquad (1)$$

where J is the r.m.s. jitter from a single regenerator due to uncorrelated jitter sources. This equation assumes that the jitter added at each regenerator is uncorrelated.

However, most of the jitter added is pattern dependent and, since the pattern is the same at each regenerator, it can be assumed that the same jitter is added at each regenerator in a chain of similar regenerators. In this case, it can be shown that the low-frequency components of the jitter add linearly, whereas the higher-frequency components are increasingly attenuated by the low-pass filtering effect of successive regenerators. If a random signal is being transmitted, the r.m.s. jitter J_N, present on the signal after N regenerators would be given by the approximate relationship.

$$J_N = J_1 \times \sqrt{N} \quad \text{for large values of } N \qquad (2)$$

where J_1 is the r.m.s. jitter from a single regenerator due to pattern-dependent mechanisms [1].

Note 1 — Based on operational experience to date, values for J_1 in the range 0.4 to 1.5% of a unit interval are achievable using cost-effective designs.

Note 2 — The implementation of timing recovery using a phase-locked loop causes the rate of accumulation to be marginally greater, as given by the approximate relationship:

$$J_N = J_1 \times \sqrt{NA} \qquad (3)$$

where A is a factor dependent upon both the number of regenerators and the phase-locked loops damping factor. The latter parameter is generally chosen, in this application, such that A has an amplitude marginally greater than unity.

Note 3 — The implementation of timing recovery using a transversal surface acoustic filter produces a rate of accumulation approaching that obtained for uncorrelated jitter sources. This favourable jitter accumulation arises because of the large inherent delay which reduces the correlation between the recovered timing signal and the data stream. Systematic pattern-dependent jitter is therefore effectively randomized and tends to accumulate in a manner similar to that obtained from uncorrelated jitter sources. The only noticeable side-effect is a marginal degradation in the alignment jitter. This favourable jitter accumulation is not exhibited by surface acoustic wave resonators due to their different mode of operation [9].

Note 4 — Repeaters incorporating circuitry involving pattern transformations effectively represent uncorrelated jitter sources causing a non-systematic jitter accumulation. For example, a pattern transformation based on the modulo 2 addition of a signal and its delayed version (Huffman sequence) causes the r.m.s. jitter to accumulate approximately with the fourth root of the number of repeaters [8].

Equations (1) and (2) demonstrate two important results:

a) pattern-dependent jitter accumulates more rapidly than non-pattern-dependent jitter, as the number of regenerators is increased, and

b) the amplitude of jitter produced by a chain of regenerators increases without limit, as the number of regenerators is increased.

The jitter produced by a random pattern is itself random in nature, the amplitude probability distribution function of which is considered to be close to gaussian. Hence, for a given r.m.s. amplitude (standard deviation), the probability of exceeding any chosen peak-to-peak amplitude can be calculated. A peak-to-peak to r.m.s. ratio of between 12 and 15 is often assumed for specification purposes, which has a very low probability of being exceeded.

In contrast, when the signal being transmitted is composed of two repetitive patterns, alternating at low frequency, the jitter appears as a low-frequency repetitive wave, having an amplitude proportional to the number of regenerators. This could lead to very large amplitudes of jitter. In such instances, the maximum peak-to-peak jitter amplitude ($J_{N,P}$) is described by the following relationship:

$$J_{N,P} = d \times N \tag{4}$$

where d is the Pattern Sensitive Jitter (PSJ) produced by a single regenerator when subjected to alternating repetitive patterns. This relationship assumes that the repetition rate is sufficiently low so that steady states are attained. The actual value is dependent on the pattern used.

This situation is very unlikely in normal operation because the signal transmitted is generally made up of traffic from a number of different sources, although not necessarily so at the primary line rate, together with a frame alignment signal and justification control digits, etc. Furthermore, the probability of fixed patterns occurring can be reduced still further by the use of digital scramblers, which tend to randomize the signal.

b) *Cascaded homogeneous digital line, radio and optical fibre systems incorporating scramblers and jitter reducers*

The inclusion of a scrambler/descrambler combination in a digital line, radio or optical fibre system needs to be considered when such homogeneous systems are connected in cascade. In such situations, the jitter contributed to each system is uncorrelated and is therefore found to accumulate in accordance with the fourth root of the number of cascaded systems. Therefore, the r.m.s. jitter, J_M, present on the digital signal after M digital line, radio or optical fibres systems is given by the approximate relationship:

$$J_M = J_S \times \sqrt[2K]{M} \tag{5}$$

where J_S is the r.m.s. jitter from a single system and K is a constant with a value between 1 and 2. For large values of M, $K = 2$.

Where jitter reducers are provided in addition to scramblers, the same accumulation relationship may apply, except that the value for J_S is then significantly reduced. In such circumstances, the r.m.s. jitter, J_S, is given by the following approximate relationship:

$$J_S = 2N\,J\sqrt{\frac{f_c}{B}} \quad \text{for large } N \tag{6}$$

where J is the r.m.s. jitter from a single repeater, N is the number of cascaded repeaters, f_c is the cut-off frequency of the jitter reducer and B is the half bandwidth of a single repeater $\left(B \approx \frac{f_0}{2Q}\right)$.

Note — The validity of the relationships given in this section requires further study. Particularly in the case where jitter reducers are incorporated, as the degree of randomization, produced by the length of scrambler commonly considered acceptable, may not be sufficient to ensure that the jitter contributions, within the bandwidth of the jitter transfer functions expected, are uncorrelated to the extent that fourth root accumulation is dominant.

B.1.1.2 *Muldex equipments*

With this type of equipment, the only type of jitter that is likely to accumulate to any significant extent is the variable low frequency waiting time jitter which may have components at frequencies within the passband of the demultiplexers phase-locked loop. The expectations are that the accumulation of waiting time jitter will be at a rate between $\sqrt{N}$ and $\sqrt[4]{N}$, where N is the number of cascaded multiplexer/demultiplexer pairs [5], [6], and [7].

Further study is required to determine a more exact relationship.

B.2 *Guidelines concerning the practical application of jitter accumulation relationships in a digital network*

(These aspects require further study.)

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Recommendation G.824

THE CONTROL OF JITTER AND WANDER WITHIN DIGITAL NETWORKS

WHICH ARE BASED ON THE 1544 kbit/s HIERARCHY

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

The CCITT,

considering

(a) that timing jitter and alignment jitter can arise in digital networks;

(b) that, if proper control is not exercised, then under certain circumstances jitter can accumulate to such an extent that the following impairments can arise;

i) an increase in the probability of introducing errors into digital signals at points of signal regeneration as a result of timing signals being displaced from their optimum position in time;

ii) the introduction of uncontrolled slips into digital signals resulting from either data overflow or depletion in digital equipment incorporating buffer stores and phase comparators, such as jitter reducers and certain digital multiplex equipment;

iii) a degradation of digitally encoded analogue information as a result of phase modulation of the reconstructed samples in the digital-to-analogue conversion device at the end of the connection, which may have significant impact on digitally encoded video signals;

(c) that unlike some other network impairments, jitter can be reduced in magnitude by the use of jitter reducers, and in complex networks, it may be necessary to employ such devices;

(d) that wander can arise due to variations in transmission characteristics of the media and equipment, including disruptions in synchronization reference distribution;

(e) that it is necessary to accommodate wander at the input ports of digital equipment if controlled or uncontrolled slips are to be minimized;

recommends

that the following guidelines and limits be applied in the planning of networks and in the design of equipment.

1 Basic jitter and wander control philosophy

The goal of the strategy outlined in this Recommendation is to minimize impairments due to jitter and wander in digital networks. The strategy provides the following elements:

a) specification of network limits not to be exceeded at any hierarchical interface;

b) a consistent framework for the specification of individual digital equipment;

c) information and guidelines to predict and analyze jitter and wander accumulation in any network configuration, facilitate satisfactory control of the impairments due to this accumulation, and to provide insight into the jitter and wander performance of individual digital equipments;

d) measurement methodology to facilitate accurate and repeatable jitter and wander measurements.

Suggestions for measurement of parameters recommended below can be found in Supplement No. 3.8 of the O-Series (for jitter) and Supplement No. 35 (for wander).

2 Network limits for maximum output at hierarchical interfaces and wander at synchronous network nodes

2.1 *Network limits for jitter*

Specification of maximum permissible values of output jitter at hierarchical network interfaces is necessary to enable the interconnection of digital network components (line section, multiplex equipment, exchanges) to form a digital path or connection. These limits should be met regardless of the number of interconnected network components preceding the interface. The limits are intended to be compatible with the minimum jitter tolerance of all equipment operating at the same hierarchical level.

The limits given in Table 1/G.824 represent maximum permissible output jitter limits at hierarchical interfaces of a digital network. In circumstances where the maximum permissible jitter amplitude occurs at an interface between two countries, it is left to the discretion of national Administrations to take the appropriate remedial action. This situation is unlikely to occur very often.

H.T. [T1.824]

TABLE 1/G.824

{ Maximum permissible output jitter at hierarchical interfaces }		
Network limit (UI peak-to-peak) } Band-pass filter having a lower cut-off frequency *f* 1 or *f* 3 and a minimum upper cut-off frequency *f* 4 }	{ {	

Digital rate (kbit/s)	B 1	B 2	*f* 1 (Hz)	*f* 3 (kHz)	*f* 4 (kHz)
1 | 44	5.0	0.1 (Note)	10	8	| 40
6 | 12	3.0	0.1 (Note)	10	3	| 60
32 | 64	2.0	0.1 (Note)	10	8	| 00
44 | 36	5.0	0.1	10	30	| 00
97 | 28	1.0	0.05	10	240	1 | 00

UI Unit Interval.

Note — This value requires further study.

Table 1/G.824 [T1.824], p.

For systems in which the output signal is controlled by an autonomous clock (e.g., quartz oscillator) more stringent output jitter values may be defined in the relevant equipment specifications (e.g., for the muldex in Recommendation G.743, output jitter should not exceed 0.01 UI r.m.s).

The arrangements for measuring output jitter at a digital interface are illustrated in Figure 1/G.824. The specific jitter limits and values of filter cut-off frequencies are given in Table 1/G.824.

Figure 1/G.824, p.

2.2 *Network limits for wander*

Network output wander specifications at synchronous network nodes are necessary to ensure satisfactory network performance (e.g. slips, error bursts). For network nodes the following limits are specified, based on the assumption of a non-ideal synchronizing signal (containing jitter, wander, frequency departure, and other impairments) on the line delivering timing information. The maximum time interval error (MTIE) (see Recommendation G.811) over a period of S seconds shall not exceed the following:

1) $S < 10^4$, this region requires further study;

2) (10^{D}lF261^{2} | fIS + 10 | 00) ns; applicable to values of S greater than 10^4.

Note — The resultant overall specification is illustrated in Figure 2/G.824.

Figure 2/G.824, p.

Further study is required to quantify the difference in limits for transit and local nodes. In addition, wander accumulation in networks is closely tied to the stability specifications contained in Recommendations G.811, G.812, Q.511.

3 Framework for the specification of individual digital equipments

3.1 *Basic specification philosophy*

Jitter and wander control inherently depends on both network and equipment design. Network considerations are discussed in § 2. The principal parameters of importance when considering the jitter and wander performance of digital equipment are:

i) the amount of jitter and wander that can be tolerated at the input;

ii) the proportion of this input jitter and wander which filters through to the output; and

iii) the amount of jitter and wander generated by the equipment.

The intention of this section is to provide a foundation for the development of equipment requirements which will ensure that the various network equipments are compatible from the standpoint of jitter and wander performance.

3.1.1 *Jitter and wander tolerance of input ports*

In order to ensure that any equipment will operate satisfactorily when connected to a hierarchical interface within the network, it is necessary that the equipment input ports be capable of accommodating levels of network output jitter up to the maximum network limits specified in Table 1/G.824. Specification of input jitter tolerance in terms of a single Recommendation applicable to all categories of digital equipment ensures that a certain minimum jitter tolerance is satisfied by all network elements. Most specifications of equipment input tolerance are in terms of the amplitude of sinusoidal jitter that can be applied at various frequencies without causing a designated degradation of error performance. The simplicity of this form of specification has great appeal, since it is easily verified with conventional test equipment. However, it is important to recognize that the test condition is not, in itself, intended to be representative of the type of jitter to be

found in practice in a network. For some equipment, therefore, it may be necessary to specify supplemental jitter tolerance tests, and reference to the individual equipment Recommendation should always be made.

As a minimum guideline for equipment tolerance, it is recommended that all digital input ports of equipments be able to tolerate the sinusoidal jitter and wander defined by Figure 3/G.824 and Table 2/G.824. The limits are to be met in an operating environment.

In deriving the specifications contained in Table 2/G.824 for frequencies above f_3, the effects of the amount of alignment jitter of the equipment clock decision circuit are considered to be predominant. Measurements carried out to verify compliance with these specifications may provide environment dependent results, hence allowing some ambiguity in their interpretation. Account should be taken of the requirement at the design stage of the equipment; Supplement No. 3.8 (O-Series) provides guidance regarding environment independent measurements.

In deriving these specifications, the wander effects are considered to be predominant at frequencies below f_1, and many transmission equipments, such as digital line systems and asynchronous muldexes using justification techniques, are effectively transparent to these very low

frequency changes in phase. However, such phase variation does need to be accommodated at the input of certain equipments (e.g. digital exchanges and synchronous muldexes). The requirement contained in Table 2/G.824 for frequencies below f_1 is not amenable to simple practical evaluation, but account should be taken of the requirement at the design stage of the equipment.

Equipment wander tolerance must be compatible with network output wander limits specified in Figure 2/G.824. Insufficient wander tolerance at synchronous equipment input ports may result in controlled or uncontrolled slips, depending on the specific slip control strategy employed.

Figure 3/G.824, p.

H.T. [T2.824]

TABLE 2/G.824

Jitter and wander tolerance of input ports

(Provisional values) (Note 1)

Bit rates (kbit/s)	{ Frequency A 0 (µs)	Test signal A 1 (UI)	A 2 (UI)	f 0 (Hz)	f 1 (Hz)	f 2 (Hz)	f 3 (kHz)	f 4 (kHz)	
1 | 44 2^{20} | (em | (Note 3) }	18 (Note 2)	5.0	0.1 (Note 2)	$1.2 \times 10^{\text{D}}$lF261^{5}	10	| 20	6.	40	{
6 | 12 2^{20} | (em | (Note 2) }	18 (Note 2)	5.0	0.1	$1.2 \times 10^{\text{D}}$lF261^{5}	10	| 50	2.5	60	{
32 | 64 2^{20} | (em | (Note 3) }	18 (Note 2)	2.0	0.1	$1.2 \times 10^{\text{D}}$lF261^{5}	10	| 00	8.	400	{
44 | 36 2^{20} | (em | (Note 2) }	18 (Note 2)	5.0	0.1 (Note 2)	$1.2 \times 10^{\text{D}}$lF261^{5}	10	| 00	30.	400	{
97 | 28	18 (Note 2)	2.0	0.1	$1.2 \times 10^{\text{D}}$lF261^{5}	10	12 | 00	240	1000	2^{23} | (em | (N

Note 1 — Reference to individual equipment specifications should always be made to check if supplementary input jitter tolerance requirements are necessary.

Note 2 — This value requires further study.

Note 3 — It is necessary to suppress long zero strings in the test sequence in networks not supporting 64 kbit/s transparency.

Note 4 — The value A 0 (18 µs) represents a relative phase deviation between the incoming signal and the internal local timing signal derived from the reference clock.

Table 2/G.824 [T2.824], p.

3.1.2 *Jitter and wander transfer characteristics*

Jitter transfer characteristics define the ratio of output jitter to input jitter amplitude versus jitter frequency for a given bit rate. When jitter is present at the digital input port of digital equipment, in many cases some portion of the jitter is transmitted to the corresponding digital output port. Many types of digital equipment inherently attenuate the higher frequency jitter components present at the input. CCITT Recommendations dealing with particular equipment will ultimately define limiting values for its particular jitter transfer characteristics. To control jitter in cascaded homogeneous digital equipment situations, it is important to restrict the value of jitter gain.

Because the bandwidth of phase smoothing circuits in asynchronous digital equipment is generally above 10 Hz, wander on the input signal may appear virtually unattenuated on the output. However, in certain particular digital equipments (e.g. nodal clocks) it is necessary that wander be sufficiently attenuated from input to output. CCITT Recommendations dealing with synchronous equipment will ultimately define limiting values for particular wander transfer characteristics.

3.1.3 *Intrinsic jitter and wander generation*

Intrinsic jitter and wander generation is defined as output jitter and wander in the absence of input jitter and wander. It is necessary to restrict the amount of intrinsic jitter and wander generated within individual digital equipments to provide control over network jitter and wander accumulation from cascaded network elements. Limits for output jitter and wander for individual digital equipments are defined in the specific CCITT equipment Recommendations. The actual limits applied depend upon the type of equipment.

3.2 *Digital line sections*

To ensure that the maximum network limit (§ 2.1) is not exceeded within a digital network, it is necessary to control the jitter and wander contributed by transmission systems.

The jitter specifications for digital line sections will ultimately be found in Recommendations G.911 to G.915.

3.3 *Digital muldexes*

To ensure that the maximum network limit (§ 2.1) is not exceeded within a digital network, it is necessary to control the jitter and wander contributed by transmission systems.

The jitter specifications for digital muldexes using positive justification are found in Recommendations G.743 and G.752.

3.4 *Digital exchanges*

To ensure that the maximum network limit (to be specified in § 2.2) is not exceeded within a digital network, it is necessary to control jitter and wander transfer and generation, as appropriate, for digital exchanges.

Output wander specifications for primary reference clocks are addressed in Recommendation G.811. The jitter and wander specifications for digital transit exchanges and digital local exchanges are found in Recommendation Q.541.

4 Jitter and wander accumulation in digital networks

The variability of network configurations presents a multitude of connection possibilities. To analyze a particular network configuration, it is necessary to use the information about the jitter characteristics of individual equipments in conjunction with appropriate jitter accumulation models. Supplement No. 36 provides information to aid organizations in carrying out such evaluations.

MONTAGE: PAGE 56 = PAGE BLANCHE

SECTION 9

DIGITAL SECTIONS AND DIGITAL LINE SYSTEMS

9.0 General

Recommendation G.901

GENERAL CONSIDERATIONS ON DIGITAL SECTIONS AND DIGITAL LINE SYSTEMS

(Geneva, 1980; further amended)

1 Digital sections and digital systems

The term digital section is used in these Recommendations as a general term to include digital line section and digital radio section. This term is defined in Recommendation G.701 (see also Figure 1/G.701 and Figure 2/G.960). Digital sections are defined as component parts of digital links operating at particular bit rates and may be regarded as ‘‘black boxes’’. For digital sections used in digital hierarchy (network) applications the inputs and outputs are recommended in the form of ‘‘equipment interfaces’’ (i.e. in Recommendation G.703 for hierarchical bit rates or in the Recommendation G.931 for non-hierarchical bit rates). For digital sections used for ISDN customer access the ‘‘section boundaries’’ are at the T reference point and the appropriate V reference point. User-network interfaces which may be used at the T reference point are recommended in the I.400 series of Recommendations and the exchange interfaces which may be used at the V reference points are recommended in the Q.500-Series of Recommendations. Digital section Recommendations contain the common network-related requirements applicable to digital radio, metallic and optical transmission systems. The performance requirements relate to network performance objectives.

Digital line and radio systems are the means of providing digital sections. Recommendations on digital line and radio systems may recognize, for digital sections operating at a given bit rate, specific transmission media and transmission techniques. Performance requirements of digital line and radio systems are for the guidance of system designers (equipment design objectives) and may be related to hypothetical reference digital sections of defined constitution.

All digital line and radio systems operating at a given bit rate and for use in a particular part of the network shall comply with the characteristics of the digital section appropriate for that network application.

Digital radio system requirements are covered in CCIR Recommendations.

2 International interconnections

For international interconnections CCITT recommends:

1) as preferred solution interconnections at equipment interfaces operating at hierarchical bit rates, the connections shown in Figures 1a)/G.901 and 2a)/G.901;

2) as second priority solution interconnections at equipment interfaces operating at non-hierarchical bit rates, the connections shown in Figure 2b)/G.901;

3) that line interfaces as indicated in Figure 1b)/G.901 and Figure 2c)/G.901 are not intended to be used as international interconnection points.

All parameters necessary for interconnection at equipment interfaces will be covered by that part of the Recommendation that deals with ‘‘Characteristics of digital line sections’’.

Equipment interfaces as used in the following Recommendations refer to interfaces as specified in Recommendation G.703 and may either refer to a direct connection between terminating equipments or to a connection at a digital distribution frame.

Figure 1/G.901, p.

Figure 2/G.901, p.

3 ISDN customer access

Digital sections and digital line systems for the ISDN customer access are recommended specifically for those applications and are not part of the ‘‘digital hierarchy’’. Whereas other digital section and digital line system Recommendations are symmetrical (i.e. the line terminations have the same functionality at each end), those for the ISDN customer access are asymmetrical in respect of certain functions (i.e. bit timing, octet timing, activation/deactivation, power feeding, operations and maintenance). This is because of the inherent asymmetry of the local line distribution network and different requirements of exchange interfaces to user-network interfaces.

Bibliography

CCITT Recommendation | fITransmission performance objectives and *Recommendations* , Vol. III, Rec. G.102.

9.1 Digital line sections at hierarchical bit rates based on a primary rate of 1544 kbit/s

Recommendations G.911 to G.915 have been deleted.

9.2 Digital sections at hierarchical bit rates based on a primary bit rate of 2048 kbit/s

Recommendation G.921

DIGITAL SECTIONS BASED ON THE 2048 kbit/s HIERARCHY

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

1 Characteristics of digital sections

1.1 *General features*

1.1.1 *Bit rate*

The digital sections based on the 2048 kbit/s hierarchy should be able to transmit signals at the nominal bit rates with their corresponding tolerances as indicated in Table 1/G.921.

H.T. [T1.921]

TABLE 1/G.921

Tolerances on transmitted signals

Nominal bit rate (kbit/s)	2048	8448	34 | 68	139 | 64
Tolerance (ppm) | 15 *Note* — The 2048 kbit/s digital sections may be operating synchronously or plesiochronously within the same environment. }	| 50	| 30	| 20	{

Table 1/G.921 [T1.921], p.

1.1.2 *Special properties*

The digital sections based on the 2048 kbit/s hierarchy should be bit sequence independent.

1.2 *Characteristics of interfaces*

The digital interfaces should comply with Recommendation G.703.

1.3 *Performance standards*

The performance requirements (e.g. errors, jitter and availability) are specified in terms of a Hypothetical Reference Digital Section (HRDS). Such a model is defined in Recommendation G.801.

1.3.1 *Error performance*

Depending on the various applications in the differenct parts of a connection as specified in Recommendation G.821, different section quality classes have been defined in Table 2/G.921.

1.3.2 *Jitter*

To ensure that the maximum network limit of jitter (see § 2 of Recommendation G.823) is not exceeded within a digital network it is necessary to control the jitter contributed by transmission systems.

1.3.2.1 *Introduction*

The jitter specifications relate to hypothetical reference digital sections (HRDS) defined in Table 2/G.921.

The limits given below have been derived on the basis that only a few digital sections will be connected in cascade and, moreover, no account has been taken of jitter originating from asynchronous multiplexing equipment. However, in certain real network configurations some Administrations may find it necessary to have more sections in cascade along with many asynchronous digital multiplex. For effective jitter control in these situations it might be necessary to satisfy more demanding limits and/or to use other means of jitter minimization.

All the limits given below for digital sections are to be satisfied for all sections regardless of length and the number of repeaters.

It is important to note that the limits must be met regardless of the transmitted signal. In such circumstances the choice for a test sequence is left to the discretion of national Administrations. The measurement guidelines given in § 4 of Recommendation G.823 should be taken into account.

1.3.2.2 *Lower limit of tolerable input jitter*

The requirements given in Figure 2/G.823 and Table 2/G.823 should be met.

Note — It is recognized that for 2048 kbit/s line sections and under practical conditions of interference the permissible maximum input jitter may have to be reduced in the frequency range f_3 to f_4 (but retaining the existing 20 dB/decade slope below the frequency f_3 which would result in a slightly lower value for frequency f_2). Considering that these sections are used in the lowest levels of the network and that actual 2048 kbit/s sources have very low output jitter in the high frequency range (cf. Recommendations G.732, G.742 and Q.551), the resulting performance will be entirely satisfactory.

1.3.2.3 *Jitter transfer characteristics*

The maximum gain of the jitter transfer function should not exceed the value of 1 dB.

Note 1 — The low frequency limit should be as low as possible taking into account the limitations of measuring equipment. A value in the order of 5 Hz is considered acceptable.

Note 2 — For line sections at 2048 kbit/s complying with the alternative national interface option (Note 2 to Table 2/G.823), a jitter gain of 3 dB is permitted.

H.T. [T2.921]

TABLE 2/G.921

Digital section quality classifications for error performance

{ Section quality classification }	HRDS length (km) (see Figure 4/G.801) (Note 2)	} Allocation (Notes 3, 4)	To be used in circuit classification (see Figure 1/G.821) (Notes 5 and 6) }
1	280	0.45%	High grade
2	280	2%	Medium grade
3	50	2%	Medium grade
4	50	5%	Medium grade

Note 1 — There is no intention to confine any quality classification to any specific bit rate. The possibility of introducing additional options (for instance concerning length) requires further study.

Note 2 — The indicated values of length are those identified in Recommendation G.801. They should be understood to correspond to maximum lengths of real digital sections. If a real digital section is shorter, there will be no reduction of the bit error allocation (i.e. percentage value in the third column). This takes into account that:

— in many line systems (especially on copper wire pairs) most bit errors occur at the ends of the system;

— in the interest of econmy, short-haul systems may be designed with greater per-kilometre error ratio than long-haul systems.

If a real digital section is longer (e.g. 450 km), its overall allocation should correspond to that of an integer number of HRDSs (of the same quality classification) the combined lengths of which are at least as long as the real section length (e.g. 2 × 280 km).

Note 3 — The values in this column are percentages of the overall degradation (at 64 kbit/s) specified in Recommendation G.821; i.e. of the 8% errored seconds, of the 10% degraded minutes and of the 0.1% severely errored seconds which are allocated according to the same rules as the two other parameters.

Note 4 — To obtain 64 kbit/s error performance data from error measurement at primary bit rates and above, the method described in Recommendation G.821, Annex D, should be used.

Note 5 — May also be used within a lower grade portion of the connection as defined per Figure 1/G.821.

Note 6 — To take account of adverse propagation conditions on radio systems as detailed in Recommendation G.821, an additional percentage of 0.05% of severely errored seconds has been allocated to a 2500 km radio-relay HRDP for systems operating in the high and medium grade quality part of the HRX. This corresponds for a 280 km section to a value of 0.0055% to be added to section quality classification 1 and 2 allocation when applied to severely errored seconds.

This would result in an additional allowance of 0.025% of severely errored seconds available for the medium grade part of the connection if it is realized entirely with class 1 radio sections. Where the medium grade portion of the network is realized with a mixture of different classifications, part of this additional allowance may be allocated to classes 3 and 4 at the discretion of Administrations.

To be consistent with the statistical assumptions made in G.821 § 3.3 |) regarding the munber of radio sections in the HRX, and the occurrence of worst month effects it may be necessary to take into account the probability of worst month effects occurring simultaneously for all radio sections in a connection. A statistical model to be used for network planning and performance evaluation to assess the consistency of a given connection to the overall objective of G.821 is under study.

Tableau 2/G.921 [T2.921], p.24

1.3.2.4 *Output jitter in the absence of input jitter*

The maximum peak-to-peak jitter in the absence of input jitter, for any valid signal condition, should not exceed the limit given in Table 3/G.921.

H.T. [T3.921]
TABLE 3/G.921
The maximum output jitter in the absence of input jitter for a digital section
(Measurements are made in accordance with the method shown in Figure 1/G.823)

{						
2 | 48 .	50 .	0.75 .	0.2 .	20 Hz .	18 kHz (700 Hz)	| 00 kHz .
8 | 48 .	50 .	0.75 .	0.2 .	20 Hz .	3 kHz (80 kHz)	| 00 kHz .
34 | 68	50	0.75	0.15	100 Hz	10 kHz	| 00 kHz
34 | 68	280	0.75	0.15	100 Hz	10 kHz	| 00 kHz
139 | 64 3 | 00 kHz *Note* — For interfaces within national networks the frequency values (*f* 2 and *f* 3) shown in parenthesis may be used. }	280	0.75	0.075	200 Hz	10 kHz	{

Table 3/G.921 [T3.921], p.

1.3.3 *Availability*

Under study.

This performance requirement will be defined taking into account Recommendations G.821, E.800 and CCIR Recommendation 557.

1.4 *Fault conditions and consequent actions*

1.4.1 *Fault conditions*

The digital sections should detect the following fault conditions.

1.4.1.1 *Internal power failure of the line terminal equipment*

Note — Line refers to both cable and radio-relay equipments.

1.4.1.2 *Error ratio > | | (mu | 0* ^{3}

The consequent actions should be taken when the bit error ratio is considered to exceed 1 | (mu | 0^{D}lF261^{3}. Some form of persistence check should be employed to establish with appropriate confidence that a fault condition does exist. In any case, the alarm indication should be given with 500 ms of the start of the fault condition; this period includes the detection and any persistence check time.

The alarm indication should be removed once it has been established, with appropriate confidence, that the fault condition has disappeared.

1.4.1.3 *Loss of the signal at the receiving terminal*

Note — The detection of this fault condition is required only when it does not result in an indication ‘‘error ratio > | | (mu | 0DlF2613’’.

1.4.1.4 *Loss of alignment when alphabetic line codes or additional frames are used*

Note — The detection of this fault condition is required only when it does not result in an indication ‘‘error ratio > | | (mu | 0DlF2613’’.

1.4.1.5 *Loss of incoming interface signal*

1.4.2 *Consequent action*

Further to the detection of a fault condition, appropriate actions should be taken as specified in Table 4/G.921.

H.T. [T4.921]

TABLE 4/G.921

Fault conditions and consequent actions for digital sections based on the 2048 kbit/s hierarchy

Maintenance alarms	prompt	deferred (see Note) AIS to	Line side	Interface side	
Line terminal equipment	Internal power failure	yes		if practicable	if practicable
	yes		yes	{	
{	yes		yes	{	
	yes		yes		
Interface side only	Loss of incoming signal	yes		yes	

Note — As far as network performance objectives are concerned, criteria to activate deferred maintenance alarm are needed. They should be provided by the systems if possible.

Table 4/G.921 [T4.921], p.

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

Note — The location and provision of any visual and/or audible alarm activated by the alarm indications given in § 1.4.2.1 above, is left to the discretion of each Administration.

1.4.2.2 AIS applied to the line side (see Notes 1 and 2).

1.4.2.3 AIS applied to the interface side.

Note 1 — The equivalent binary content of the alarm indication signal (AIS) is a continuous stream of ones.

Note 2 — The bit rate of this AIS should be within the tolerance limits defined in Table 1/G.921.

Note 3 — In the case of power failure apply AIS only if practicable.

1.4.3 *Time requirements for application of AIS*

In general, the AIS should be transmitted coincident with the detection of the fault conditions given in Table 4/G.921, except for AIS under the fault condition ‘‘error ratio > | | (mu | 0^{D}lF261^{3}’’; in this latter case the time requirements given in § 1.4.1.2 should be respected.

Note — For wholly national digital sections and, with the agreement of the countries involved digital sections which cross international boundaries, an option to delay the transmission of an AIS of up to a few seconds may be needed when the application of an AIS is controlled by means of a G.921 threshold monitoring process based on the severely errored second G.821 parameter. Short downstream alarms in international digital links which are routed via wholly national digital sections may appear during these few seconds.

9.3 Digital line transmission systems on cable at non-hierarchical bit rates

Recommendation G.931

DIGITAL LINE SECTIONS AT 3152 KBIT/S

(former Recommendation G.921 of Volume III of the Yellow Book)

1 Characteristics of interfaces

The digital interfaces at 3152 kbit/s should comply with the interface specification given in Annex A.

2 Performance standards

2.1 *Error performance*

Under study.

2.2 *Jitter*

2.2.1 *Lower limit of maximum tolerable jitter at the input*

Under study.

2.2.2 *Maximum output jitter*

Under study.

2.2.3 *Maximum output jitter in the absence of input jitter*

Under study.

2.2.4 *Jitter transfer function*

Under study.

2.3 *Availability*

Under study.

3 Fault conditions and consequent actions

Under study.

ANNEX A

(to Recommendation G.931)

Interface at 3152 kbit/s

A.1 Interconnection of 3152-kbit/s signals for transmission purposes is accomplished at a digital distribution frame.

A.2 The signal shall have a bit rate of 3152 kbit/s ± 30 ppm.

A.3 One balanced twisted pair shall be used for each direction of transmission. The distribution frame jack connected to a pair bringing signals to the distribution frame is termed the in-jack.

The distribution frame jack connected to a pair carrying signals away from the distribution frame is termed the out-jack.

A.4 Test load impedance shall be 100 ohms, resistive.

A.5 A bipolar (AMI) code shall be used. In order to guarantee adequate timing information, the minimum pulse density taken over any 130 consecutive time slots must be 1 in 8. The design intent is that the long-term pulse density be equal to 0.5. In order to provide adequate jitter performance for systems, timing extracting circuits should have a Q of 1200 ± 200 that is representable by a single tuned network.

A.6 The shape for an isolated pulse measured at either the out- or in-jack shall meet the requirements of Table A-1/G.931. There is no necessity for pulse overshoot for this interface.

A.7 The peak-to-peak voltage within a time slot containing a zero (space) produced by other pulses meeting the specifications of Table A-1/G.931 should not exceed 0.1 of the peak pulse amplitude.

H.T. [T1.931]

TABLE A-1/G.931

Digital interface at 3152 kbit/s

Location	Digital distritution frame
Bit rate	3152 kbit/s ± 30 ppm
{ Pair(s) in each direction of transmission }	One balanced twisted pair
Code	Bipolar (AMI)
Test load impedance	100 ohms, resistive
Nominal shape	Rectangular
Nominal amplitude	3.0 volts
Width (at 50% amplitude)	159 ± 30 ns
{ Rise and fall times (20-80% of amplitude) } 50 ns (difference between rise and fall times shall be 0 ± 20 ns) }	{
{ Signal power (all is signal, measured over 10 MHz bandwidth) } 16.53 ± 2 dBm [ratio of (power in + pulses) to (power in — pulses) shall be 0 ± 0.5 dB] }	{
Pour Montage:	Pulse characteristics

Tableau A-1/G.931 [T1.931], p.

9.4 Digital line systems provided by FDM transmission bearers

Recommendation G.941

DIGITAL LINE SYSTEMS PROVIDED BY FDM TRANSMISSION BEARERS

(Geneva, 1980; further amended)

The CCITT,

considering

(a) that there is an urgent need to provide long-haul facilities mainly for nontelephony services (e.g. data, facsimile, visual telephony) for national use and for international interworking, and these non-telephony services need digital transmission at a low and medium bit rate (e.g. primary and secondary hierarchical levels);

(b) that long-haul digital links begin to be available, but that nevertheless the implementation of these facilities on a general basis will take some time;

(c) that it is possible to use analogue FDM links specified in Recommendation G.211 [1], or the frequencies within or over the bandwidth used by analogue FDM line systems specified in Section 3 of the Series G Recommendations to carry a digital stream, and that some realizations are already available,

recommends

that the digital line systems provided by FDM transmission bearers should comply with the following requirements:

1 General characteristics

Two basic methods can be used for the transmission of digital signals on FDM transmission bearers:

— the first method consists of using either a part or the whole of the band normally employed for FDM systems [Data-in-Voice (DIV)],

— the second method consists of using a band outside the one normally employed for FDM systems [Data-over-Voice (DOV)].

The international interconnection should be performed at digital hierarchical levels using the interfaces specified in Recommendation G.703.

Since these digital line systems on FDM transmission bearers could form part of a digital path, their performance standards in terms of error rate, jitter and availability should be in accordance with the relevant Recommendations in Section 9 of the Series G Recommendations concerning digital line sections at the corres ponding bit rates.

The systems should be designed in such a way that the quality requirements given in the relevant Recommendations for the analogue circuit are still met.

Administrations intending to use digital line systems provided by FDM bearers in their networks should ensure that compatible designs of equipment are used at each end of a link. For international links the systems to be used should be by the agreement of the Administrations concerned.

The application of digital line systems provided by FDM transmission bearers for the interconnection of digital and analogue networks is covered in Supplement No. 28.

2 Data-in-Voice systems

2.1 Characteristics of DIV systems providing digital transmission at hierarchical bit rates on analogue carrier-transmission systems specified in Recommendation G.211 [1].

Note — Examples of hierarchical DIV digital line systems are given in Annex A. Examples of DIV digital line systems at non-hierarchical levels either in the analogue or in the digital interfaces are given in Annex B.

2.1.1 *Digital interface*

The DIV system digital interface should conform to the appropriate sections of the Recommendation G.703.

2.1.2 *Analogue interface*

2.1.2.1 *Frequency band*

The DIV signal frequency band should be displaced into the frequency band specified in Recommendation G.211, § 1.

2.1.2.2 *Power level*

The relative power level at the distribution frame should conform to the appropriate §§ of the Recommendation G.233.

The mean power level of the wideband signal over the frequency band specified in § 2.1.2.1 should not exceed —15 + 10 $\log_{10}$ *n* dBm0, *n* being the total number of telephone channels in the analogue system which are replaced by the data channels.

In order to limit cross modulation effects, the power level of any individual spectral component in the frequency band specified in § 2.1.2.1 should not exceed —10 dBm0.

2.1.3 *Disturbances of the analogue signal by the DIV signal*

The total distributed noise produced by the DIV signal measured in any 3.1 kHz bandwidth corresponding to a telephone channel outside the frequency band specified in the Recommendation G.211, § 1 should be less than —73 dBm0p.

The single tone interference should be less than —73 dBm0.

2.1.4 *DIV system performance*

The performance relating to error rate, jitter and availability should conform to the appropriate Recommendations of the G.900 series.

2.2 *Characteristics of the analogue link to carry the DIV signal*

The analogue link used to carry the DIV signal should include no more than three through connections. It could be necessary to avoid certain positions of the DIV signal band in the analogue carrier transmission system.

Note — Reference to H series Recommendations could be made concerning characteristics such as attenuation distortion, phase jitter and group-delay distortion.

3 Data-over-voice systems

3.1 *Characteristics of DOV systems providing 2048-kbit/s digital transmission on analogue FDM line systems defined by Recommendations G.332* [2], *G.334* [3], *G.344* [4], *G.345* [5] *and G.346* [6]

3.1.1 *Digital interface*

The digital interface of the DOV system should be as specified in Recommendation G.703, § 6.

3.1.2 *Disturbances of the analogue signal by the DOV signal*

The increase to the total distributed noise due to the DOV signal measured in any 4 kHz bandwidth should be less than 750 pW0p for a reference length of 2500 km (less than 0.3 pW0p/km).

Note — The total distributed noise of the line when analogue and DOV signals are present should be below 7500 pW0p for a reference length of 2500 km (less than 3 pW0p/km).

The level of single tone interference should be less than —70 dBm0.

3.1.3 *DOV system performance*

The performance relating to error rate, jitter and availability should be in accordance with Recommendation G.921.

3.2 *Characteristics of the FDM line systems used to carry the DOV signal*

To allow the through-connection of DOV signals on FDM line systems, spurious analogue signals within the frequency band of the DOV signal should be suppressed before the coupling point up to a power level of —60 dBm0 within 4 kHz bandwidth.

ANNEX A
(to Recommendation G.941)

Examples of hierarchical DIV systems

H.T. [T1.941]

Administration	Digital interface	Analogue interface	DIV system performance
NTT 1544 kbit/s Rec. G.703, § 2 }	{ Mastergroup (812-2044 kHz)	Rec. G.911	
FRG 2048 kbit/s Rec. G.703, § 6 }	{ Mastergroup (812-2044 kHz)	Rec. G.921	
NTT 6312 kbit/s Rec. G.703, § 3 }	{ Mastergroup (812-2044 kHz)	Rec. G.912	
FRG 8448 kbit/s Rec. G.703, § 7 } Supermastergroup (8516-12 | 88 kHz) }	{ { Rec. G.921		
Italy 8448 kbit/s Rec. G.703, § 7 } 15 supergroup assem. (312-4028 kHz) }	{ { Rec. G.921		

Table [T1.941], p.

ANNEX B
(to Recommendation G.941)

Examples of systems other than those recommended

in Recommendation G.941
(see Note 1)
H.T. [T2.941]

Administration Design bit error ratio for regeneration section }	Bit rate (kbit/s)	Analogue interface	{
France (see Note 2)	704	Supergroup (312-552 kHz)	10DlF2618
Netherlands	2048	2 supergroups	10DlF2618

Note 1 — Modems for the transmission of digital signals at 48-72 kbit/s or twice these bit rates are covered in Recommendations V.36 and V.37.

Note 2 — The digital interface of this DIV equipment is at 2048 kbit/s according to Recommendation G.703 § 6, and with a frame structure according to Recommendation G.704 § 3.3.1. Only 11 (including TS0) among the 32 time slots are effectively used: the

useful bit rate is then equal to 10 times 64 kbit/s. The other characteristics of the DIV system satisfy to § 2 of this Recommendation.
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Table [T2.941], p.

References

[1] CCITT Recommendation *Make-up of a carrier link* , Vol. III, Rec. G.211.

[2] CCITT Recommendation *12-MHz systems on standardized 2.6/9.5-mm coaxial cable pairs* , Vol. III, Rec. G.332.

[3] CCITT Recommendation *18-MHz systems on standardized 2.6/9.5-mm coaxial pairs* , Vol. III, Rec. G.334.

[4] CCITT Recommendation *6-MHz systems on standardized 1.2/4.4-mm coaxial cable pairs* , Vol. III, Rec. G.344.

[5] CCITT Recommendation *12-MHz systems on standardized 1.2/4.4-mm coaxial cable pairs* , Vol. III, Rec. G.345.

[6] CCITT Recommendation *18-MHz systems on standardized 1.2/4.4-mm coaxial cable pairs* , Vol. III, Rec. G.346.

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