INTERNATIONAL TELECOMMUNICATION UNION

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THE INTERNATIONAL
TELEGRAPH AND TELEPHONE
CONSULTATIVE COMMITTEE

BLUE BOOK

VOLUME III – FASCICLE III.5

DIGITAL NETWORKS, DIGITAL SECTIONS AND DIGITAL LINE SYSTEMS

RECOMMENDATIONS G.801-G.961

IXTH PLENARY ASSEMBLY
MELBOURNE, 14-25 NOVEMBER 1988

Geneva 1989

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Digital networks, digital sections and digital line systems

PRELIMINARY NOTE

In this fascicle, the expression «Administration» is used for shortness to indicate both a telecommunication Administration and a recognized private operating agency.

FASCICLE III.5

Recommendations G.801 to G.961

DIGITAL NETWORKS, DIGITAL SECTIONS AND DIGITAL LINE SYSTEMS

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SECTION 8

DIGITAL NETWORKS

8.0 General aspects of digital networks

Recommendation G.801

DIGITAL TRANSMISSION MODELS

(Malaga-Torremolinos, 1984)

The CCITT

considering

(a) that digital networks support a wide variety of connections for which digital transmission impairments and other performance parameters need to be controlled;

(b) that, if proper control is not exercised, then under certain circumstances, digital transmission impairments cause unacceptable service degradations;

(c) that various network performance objectives need to be allocated to the elements of a digital network;

(d) that equipment design objectives need to be formulated for individual digital elements;

(e) that networks need to be configured to a level of transmission quality consistent with the needs of different services (voice and non-voice) and in particular of services in the ISDN;

(f) that Administrations need to examine the effect on transmission quality of possible changes of impairment allocation in national networks;

(g) that there is a need to test national rules for prima facie compliance with any impairment criteria which may be recommended by the CCITT for national and international systems;

(h) that guidelines need to be formulated governing the use of certain digital elements (e.g. satellite links, transcoders, digital pads, circuit multiplication devices, etc.),

recommends

that in the study of digital transmission impairments and other performance parameters, the following network models and associated guidelines should be applied.

1 Introduction

Digital transmission network models are hypothetical entities of a defined length and composition for use in the study of digital transmission impairments (e.g. bit errors, jitter and wander, transmission delay, availability, slip, etc.). The diversity of possible network situations requires that individual models can only represent a small portion of typical real entities. However, a limited number of such models (e.g. 2 or 3) together may be sufficiently representative to provide a useful tool upon which studies may be based.

The network models, where applicable, take account of the following features:

a) physically reflect the length of the overall connection with some indication of frequency of occurrence,

b) identify boundaries between switching and transmission elements,

c) give no indication of the means of implementing transmission between switching elements (e.g. metallic, optical, radio media, satellite etc.),

d) describe in detail the user/network access arrangement in the local portion (i.e. customer to local exchange),

e) take account of all possible usages or be independent of them,

f) reflect the use of additional digital processing elements required in particular network configurations (e.g. A-μ converters, digital pads, transcoders, etc.).

This Recommendation makes no statement in respect of the electrical and physical environment in which the network models operate. These aspects are currently the subject of study. In the application of these network models to the study of specific digital impairment (e.g. errors) arbitrary judgements may need to be made concerning the significance, in particular, of the electrical environment.

2 Hypothetical reference connection (HRX)

A digital HRX is a model in which studies relating to overall performance may be conducted, thereby facilitating the formulation of standards and objectives. In order to initiate studies directed at the performance of an ISDN, an all digital 64 kbit/s connection is considered. Since the overall network performance objectives for any performance parameter need to be consistent with user requirements, such objectives, in the main, should relate to a network model which is representative of the very long connection. The HRX shown in Figure 1/G.801 serves this purpose. It does not represent the rare worst case connection; although it does aim to encompass the vast majority of connections for each relation. Moreover, the difficulty of identifying every conceivable practical implementation of a connection and the undesirability of producing too many options naturally requires that this "standard HRX" may need to be appropriately modified in composition to suit the particular task in hand. A situation can be envisaged where many similar HRXs exist to serve specific functions, but in all cases they are derivatives of the "standard HRX". The potential proliferation of HRXs prevent their inclusion in this Recommendation. Any departure from the "standard HRX" may need to be shown in the Recommendation appropriate to that impairment or performance parameter. For example, see Recommendation G.821. They are not intended to be used for the design of transmission systems.

The diversity in composition is particularly apparent when a distinction is made between average size and large countries and, therefore no one HRX can possibly accommodate such variations. In the process of apportionment the demarcation between national and international portions is unimportant as in most instances the intrinsic quality of circuit comprising both portions is the same. In contrast, however, the overall length is regarded as being critical and its choice is "country size" independent. Accordingly, the level of impairment actually experienced over a real connection is considered satisfactory if compatible with that stipulated for the longest HRX, taking due account of differences between the construction of the hypothetical and real connections. For a large proportion of real connections configured using equipment designs recommended by CCITT, the actual performance is likely to be significantly better. Those CCITT compliant connections which exceed the longest HRX in either length or complexity may not have controlled levels of performance; however, their impairment levels are unlikely to exceed those of the longest HRX by more than a factor of 2 and the design margins provided with individual items of equipment may well bring the impairment to within CCITT end-to-end performance specifications.

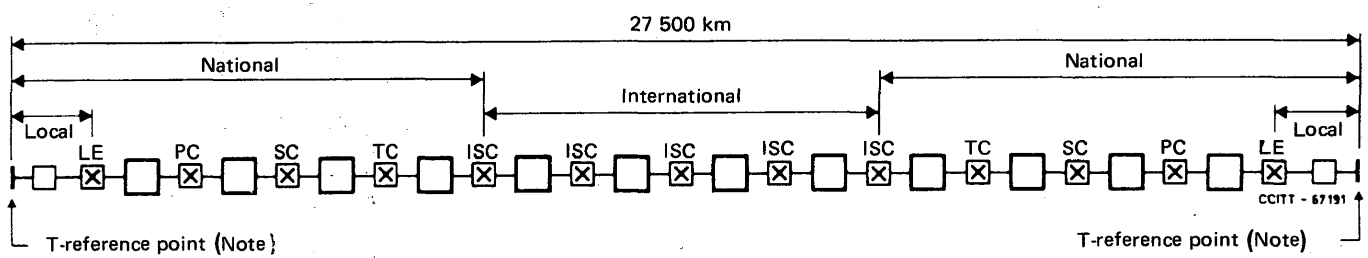
In formulating the above HRX no account was taken of the following aspects:

– maritime applications,

– semi-automatic connections (i.e. auto-manual),

– standby routing in case of failure.

Two other HRXs have been included to facilitate studies over shorter connections with a view to establishing the typical performance levels likely to be achieved over frequently realized international circuits. These are given in Figures 2/G.801 and 3/G.801.



LE Local exchange
PC Primary centre
SC Secondary centre
TC Tertiary centre
ISC International switching centre

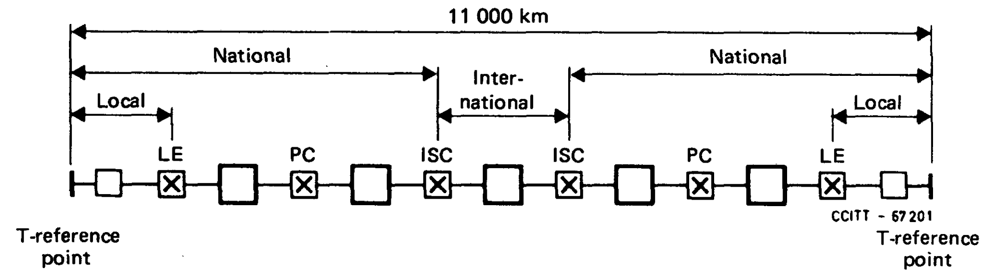
☐ Digital link

☒ Digital exchange

Note – Recommendation I.411 (applicable to ISDN only).

FIGURE 1/G.801

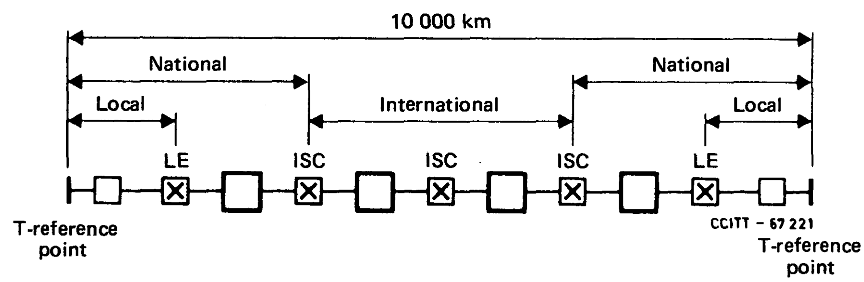
Standard digital hypothetical reference connection (longest length)



Note – See Figure 1/G.801 for legend.

FIGURE 2/G.801

Standard digital hypothetical reference connection (moderate length)



Note – See Figure 1/G.801 for legend.

FIGURE 3/G.801

Standard digital hypothetical reference connection (moderate length with subscriber situated near the International Switching Centre (ISC))

3 Hypothetical reference digital link (HRDL)

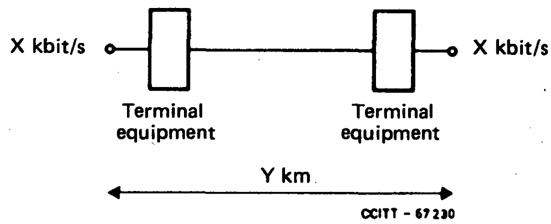
To facilitate the study of digital transmission impairments (e.g. bit errors, jitter and wander, slip, transmission delay) it is necessary to define network models comprising a combination of different types of transmission elements (e.g. transmission systems, multiplexers, demultiplexers, digital pads, transcoders). Such a model is defined as a Hypothetical Reference Digital Link (HRDL). The exact length and composition in respect of the number, type and disposition of equipments will depend on the digital impairment under study. For example, in the analysis of jitter accumulation in a network both transmission systems and muldexes would need to be included to take account of the different jitter characteristics exhibited by such equipment types. In addition the HRDL can be regarded as a constituent element of an HRX thus permitting the apportionment of overall performance objectives to a shorter model. A length of 2500 km is considered as a suitable distance for a HRDL.

The formulation of such models is the subject of further study.

In CCIR Recommendations the term Hypothetical Reference Digital Path (HRDP) is sometimes used. This is equivalent to a Hypothetical Reference Digital Link (see Definition 3005 in Recommendation G.701).

4 Hypothetical reference digital section (HRDS)

To accommodate the performance specification of transmission systems (i.e. digital line and radio systems) it is necessary to introduce a Hypothetical Reference Digital Section (HRDS). Such a model is defined in Figure 4/G.801 for each level in the digital hierarchies defined in Recommendation G.702. The input and output ports are the recommended interfaces as given in Recommendation G.703 for hierarchical bit rates. The lengths have been chosen to be representative of digital sections likely to be encountered in real operational networks, and are sufficiently long to permit a realistic performance specification for digital radio systems. The model is homogeneous in that it does not include other digital equipments such as multiplexers/demultiplexers. This entity can form a constituent element of a HRDL.



Note — The appropriate value for "Y" is dependent on the network application. For now the lengths of 50 km and 280 km have been identified as being necessary (see Recommendation G.921).

FIGURE 4/G.801

Hypothetical reference digital section

It is possible to relate the two following types of performance requirement to an HRDS:

- the Network Performance Objectives (NPO) which are the objectives to be realized in a real network;
- the Equipment Design Objectives (EDO) which provide guidance to the designer of systems using specific transmission media and transmission techniques.

Note 1 – The Equipment Design Objectives which normally appear in the appropriate transmission and switching system recommendations are formulated to ensure compatibility with the corresponding network performance objectives.

Note 2 – An explanation of a Network Performance Objective and an Equipment Design Objective is given in Recommendation G.102.

Note 3 – The formulation of a homogeneous entity of a realistic length permits specification and commissioning acceptance testing under real operational conditions.

In a similar manner CCIR and CMTT have formulated media and application orientated models for use in their studies. The following recommendations describe the relevant models.

- Recommendation 502-2 (Draft). Hypothetical Reference Circuit for Sound Programme Transmission. (Terrestrial systems and systems in the fixed-satellite service).
- Recommendation 521-1. Hypothetical Reference Digital Path for systems using digital transmission in the fixed-satellite service.
- Recommendation 556. Hypothetical Reference Digital Path for radio-relay systems for telephony.

ANNEX A

(to Recommendation G.801)

The application of Hypothetical Reference Models in the formulation of equipment design objectives

An important use of hypothetical reference models is to facilitate the apportionment of network performance objectives to constituent elements, prior to the derivation of equipment design objectives. To satisfactorily achieve this objective a diagrammatic representation of the approach adopted by CCITT in the formulation of equipment design objectives is shown in Figure A-1/G.801.

The approach recognizes that it may be necessary to derive from the "standard HRX" a more appropriate HRX which better takes into account both the usage and the specific network performance parameter under study. The adoption of this approach will facilitate the formulation of rules governing the use of certain digital elements such as satellite links, transcoders, digital pads, etc.

National Administrations are advised to develop their own representative network models reflecting the features of their evolving national digital network in order to validate prima facie compliance with international standards.

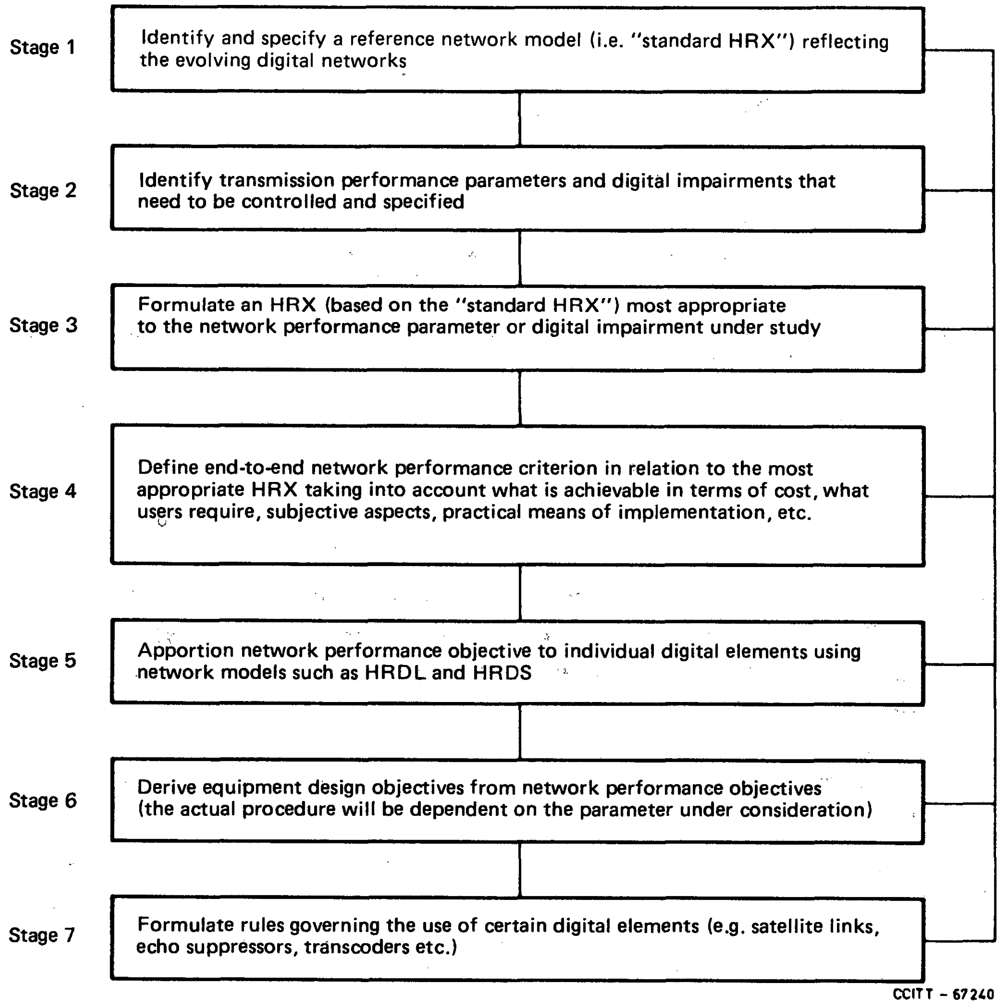


FIGURE A-1/G.801

The derivation of equipment design objectives based on the use of network models

Recommendation G.802

INTERWORKING BETWEEN NETWORKS BASED ON DIFFERENT DIGITAL HIERARCHIES AND SPEECH ENCODING LAWS

(former Recommendations G.722 of Volume III of the Yelow Book, further amended)

1 Introduction

This Recommendation deals with the following aspects of interworking between networks for transport of 64 kbit/s digital information:

– encoding law and conversion rule for interworking between networks using the different encoding laws based on Recommendations G.711, G.721 and G.722;

– interworking hierarchy between networks which incorporate the different digital hierarchies based on Recommendation G.702;

– interworking arrangements between networks incorporating the different hierarchies and encoding laws; and,

– interconnection by plesiochronous operation between networks which each has an independent synchronization.

This Recommendation is applicable also to ISDNs for transport of B channels specified in Recommendation I.412.

Note – The future specifications on channels and their bit rates to support ISDN broadband services for customer-to-customer applications may require additional interworking arrangement specifications other than those specified below.

2 Terms and definitions

The terms used in this Recommendation and not defined below are described in Recommendations G.701 or I.112.

2.1 z-operation

Conversion of the μ-law character signal "00000000" (all-zero octet) into the μ-law character signal "00000010", where "1" is the bit numbered seven in the octet (see Recommendation G.711).

Note – Bit number indicates the chronological order of transmission of bits in serial processing.

2.2 1.5/2 Mbit/s multiplex system conversion (1.5/2 Mbit/s MSC)

A function which embodies the following properties:

1) termination of a digital link operating at a digital hierarchical level of 1544 kbit/s;
2) termination of a digital link operating at a digital hierarchical level of 2048 kbit/s; and,
3) rearrangement of 64 kbit/s channels between 1544 kbit/s and 2048 kbit/s digital terminations.

Note – The hierarchical levels and the frame structures are specified in Recommendations G.702 and G.704, respectively.

2.3 pulse density requirement (PDR) at 1544 kbit/s

The minimum requirement for an entire 1544 kbit/s digital signal is that there should be no more than 15 binary "0"s between successive binary "1"s and that there should be an average binary "1"s density of at least one in every eight bits. This requirement is due to the design of a number of existing systems (see Recommendation G.703.)

Moreover, the requirement for an octet-structured source in a 1544 kbit/s digital link is that at least one binary "1" should be contained in any octet.

3 Unrestricted 64 kbit/s transfer capability of a digital link

Newly introduced digital transmission systems should have the capability to provide bit sequence independence for 64 kbit/s digital links. This capability should be activated as soon as unrestricted 64 kbit/s transfer capability can be practically realized.

During a transition period, however, 56 kbit/s bit sequence independent transfer capability may be provided by bilateral agreement. (Important constraints on the data formats transmitted by source data terminal equipment are given in Annex 1 to this Recommendation.)

4 Encoding law conversion between A-law and μ-law

4.1 *Encoding law on an international digital link*

International digital links between countries which have adopted different PCM encoding laws (A-law or μ-law) should carry signals encoded in accordance with the A-law specified in Recommendation G.711.

Where both countries have adopted the same law, that law should be used on digital links between them.

4.2 *Conversion rule*

A-law/μ-law conversion necessary between countries which have adopted different PCM encoding laws will be performed according to Recommendation G.711 by the μ-law country. The conversion includes the even-bit inversion of the A-law character signal.

Note – Location of the conversion function in a μ-law country is a national matter depending upon the structure of domestic digital networks, and is left to the discretion of the Administrations in the μ-law country.

4.3 *Control of conversion function*

In switched public network applications enabling/disabling of the conversion function should be under control of the international switching system, and will be carried out on a call-by-call or during-a-call basis depending upon the service category requested by the signalling protocol.

It should also be possible to enable/disable this conversion function manually and/or via an operator terminal on a per-channel or semi-permanent basis. This capability would be necessary for configuring leased line circuits not passing through the international switching system, or if the international switching system were not capable of controlling this function.

Note – Control of conversion function in ISDN environment is specified in I.300-series and I.500-series Recommendations.

5 Interworking hierarchy

For international interworking between networks using different digital hierarchies specified in Recommendation G.702, the following interworking hierarchy should be employed:

2048 – 6312 – 44 736 – 139 264 kbit/s.

For interworking between networks with different digital hierarchies but with 1544 kbit/s primary level, however, levels other than those specified for the above interworking hierarchy may be employed (e.g. 1544 kbit/s).

Note 1 – National networks with a 1544 kbit/s primary level may offer transit of international traffic of 6312 kbit/s composed of three 2048 kbit/s signals or of 44 736 kbit/s containing twenty-one 2048 kbit/s signals. These networks will provide the property of bit sequence independence at 6312 and 44 736 kbit/s and hence at 2048 kbit/s.

Note 2 – The frame structures for 2048-6312 kbit/s, 6312-44 736 kbit/s and 44 736-139 264 kbit/s multiplexing stages are specified in Recommendations G.747, G.752 and G.755, respectively.

6 Interworking arrangements

Based on the general specifications described in the previous Sections, establishment of an international digital interconnection between networks using the different digital hierarchies and speech encoding laws should conform to the interworking arrangements specified in Table 1/G.802.

7 Transport of a 1544 kbit/s signal within a G.704-structured 2048 kbit/s signal

For international leased line applications, the transmission of 1544 kbit/s signals may be considered using a special mapping into point-to-point 2048 kbit/s signals. Annex B to this Recommendation specifies the method for this mapping.

Note – The possible development of specific mappings of 8448 or 34 368 kbit/s signals into 44 736 kbit/s signals is not precluded.

8 Synchronization of an international digital link

8.1 *Links not synchronized to the national networks*

Where independently synchronized national networks are interconnected via an international digital link, the timing of which is independent of the national networks, the link should be operated in a plesiochronous mode with the accuracy specified in Recommendation G.811.

8.2 *Links synchronized to the network in the transmitting country*

Where independently synchronized national networks are interconnected via an international digital link, the timing of which is synchronized to the national network in the transmitting country, the plesiochronous operation will be performed in the receiving country.

TABLE 1/G.802

Interworking arrangements

Type of information	Voice or voiceband data						Non-voice information		Signalling information (Note 1)	
Encoding law at IRP (Note 2) / Function	PCM G.711		ADPCM G.721		SB-ADPCM G.722		------		------	
Network (Note 3)	A	B	A	B	A	B	A	B	A	B
1.5/2 Mbit/s MSC	–	X	–	X	–	X	–	X	–	X
A/μ and μ/A conversion	–	X	–	–	–	–	–	–	–	–
Z-operation	–	X (Note 4)	–	X (Notes 4 and 5)	–	X (Notes 4 and 6)	–	X (Note 4)	–	–
Transcoding	–	–	X	X	–	–	–	–	–	–

– Not allowed

X May be applied

Note 1 – Signalling information is transferred on unrestricted channels between International Switching Centers (ISCs).

Note 2 – IRP = Interworking reference point between Network A and Network B.

Note 3 – "A" is a network within the country incorporating the A-law and 2048 kbit/s-based digital hierarchy. "B" is a network within the country incorporating the μ-law and 1544 kbit/s-based digital hierarchy.

Note 4 – Z-operation in the μ-law country will be applied when the link in that country contains transmission systems that have to meet PDR; in this case unrestricted 64 kbit/s transfer capability cannot be provided due to PDR and the bit sequence independent transfer capability is restricted to 56 kbit/s.

Note 5 – 32 kbit/s digital signals, which are voice or voiceband data signals encoded in accordance with the ADPCM algorithm specified in Recommendation G.721, do not contain a "0000" code word. (See Recommendation G.721.) This implies that even when PDR exists in the μ-law country, these signals will not be affected by the z-operation and will be transferred transparently.

Note 6 – 64 kbit/s audio signals, where the audio signals having the bandwidth of 50 to 7000 Hz are encoded at 64, 56 or 48 kbit/s in accordance with the coding algorithm specified in Recommendation G.722, do not contain an all-zero octet. (See Recommendation G.722.) This implies that even when PDR exists in the μ-law country, these signals will not be affected by the z-operation and will be transferred transparently.

ANNEX A

(to Recommendation G.802)

Impact on terminal equipment designed to work with 56 kbit/s bit sequence independent transfer capability

During a transition period 56 kbit/s bit sequence independent transfer capability may be provided by bilateral agreement. In this case a 56 kbit/s bit sequence independent transfer capability requires that the source data terminal equipment (DTE) fix the eighth bit of each octet to binary "1". This must be done on both ends of the digital connection even if one portion of the connection has unrestricted 64 kbit/s transfer capability. Failure to keep the eighth bit fixed to binary "1" will cause any all-zero octet to be converted to "00000010" by z-operation in the μ-law country.

ANNEX B

(to Recommendation G.802)

Mapping method of a 1544 kbit/s signal into a G.704-structured 2048 kbit/s signal

The following is a means of accommodating a bit synchronous 1544 kbit/s signal, which may be unstructured or structured, within a G.704-structured 2048 kbit/s frame, for the purpose of providing leased line applications at 1544 kbit/s only. The 1544 kbit/s signal is transmitted transparently without regard to its frame structure within the 2048 kbit/s signal.

The 193 bits of an arbitrary 125 μs period of the 1544 kbit/s signal should be accommodated within a G.704-structured 2048 kbit/s frame as follows:

TS 0:	Frame alignment signal according to Recommendation G.704
TS 1-15 TS 17-25 Bit 1 in TS 26	193 contiguous bits of the 1544 kbit/s signal
TS 16, 27-31:	Reserved for possible accommodation of additional information at up to 384 kbit/s (Note 2)

Note 1 – In cases where only the 1544 kbit/s signal is to be transported, the timing of the 1544 kbit/s (or 2048 kbit/s) outgoing signal should be derived from the 2048 kbit/s (or 1544 kbit/s) incoming signal for each direction of transmission.

Note 2 – In some cases, e.g. where information is transported by the reserved time-slots, the timing of the outgoing signal should be traceable to the national reference clock conforming to Recommendation G.811. This will require the use of 125 μs slip buffers.

Note 3 – The maximum capacity available to end-users for transparent transport of their information is 1536 kbit/s and not 1544 kbit/s. Depending on the national regulations some network operators may offer the user of part of the 8 kbit/s overhead associated with a 1544 kbit/s signal for performance monitoring and its reporting.

8.1 Design objectives for digital networks

Recommendation G.810

CONSIDERATIONS ON TIMING AND SYNCHRONIZATION ISSUES

(Melbourne, 1988)

1 General

This Recommendation provides information and guidance concerning the various timing and synchronization Recommendations as well as insight into the fundamental related issues.

2 Definitions

primary reference clock

A reference clock that provides a timing signal with long term frequency departure maintained at $1 \cdot 10^{-11}$ or better with verification to Universal Time Coordinated (UTC). Requirements for primary reference clocks are given in Recommendation G.811.

Note 1 – The primary reference clock may generate a timing signal completely autonomous of other references or alternatively, the primary reference clock may not have a completely autonomous implementation, in which case it may employ direct control from standard UTC-derived frequency and time sources.

Note 2 – This clock is sometimes referred to as a Stratum 1 clock (i.e. the highest quality clock in the network).

synchronous network node

A geographical location at which there are one or more interconnected synchronous digital equipments.

transit node

A synchronous network node which interfaces with other nodes and does not directly interface with customer equipment.

local node

A synchronous network node which interfaces directly with customer equipment.

slave clock

A clock whose timing output is phase-locked to the timing signal received from a higher quality clock. Requirements for slave clocks are given in Recommendation G.812.

Note – The highest quality slave clock is sometimes referrred to as a transit node clock, or a Stratum 2 clock. The second highest quality slave clock is sometimes referred to as a local node clock, or a Stratum 3 clock.

jitter

Short-term variations of the significant instants of a digital signal from their reference positions in time.

timing jitter

The short term variations of the significant instants of a digital signal from their ideal positions in time (where short term implies these variations are of frequency greater than or equal to 10 Hz).

alignment jitter

The short term variations between the optimum sampling instants of a digital signal and a sampling clock derived from it.

wander

The long term variations of the significant instances of a digital signal from their ideal positions in time (where long term implies that these variations are of frequency less than 10 Hz).

Note – For the purposes of this Recommendation and the following related Recommendations, this definition of wander does not include integrated frequency departure.

frequency departure

An underlying offset in the long term frequency of a timing signal from its ideal frequency.

slip

The repetition or deletion of a block of bits in a synchronous or plesiochronous bit stream due to a discrepancy in the read and write rates at a buffer.

3 Description of phase variation components

Phase variation is commonly separated into three components: jitter, wander and integrated frequency departure. In addition, phase discontinuities due to transient disturbances such as network re-routing, automatic protection switching, etc., may also be a source of phase variation.

4 Impairments caused by phase variation

4.1 *Types of impairments*

4.1.1 *Errors*

Errors may occur at points of signal regeneration as a result of timing signals being displaced from their optimum positions in time.

4.1.2 *Degradation of digitally encoded analogue information*

Degradation of digitally encoded analogue information may occur as a result of phase variation of the reconstructed samples in the digital to analogue conversion device at the end of the connection. This may have significant impact on digitally encoded video signals.

4.1.3 *Slips*

Slips arise as a result of the inability of an equipment buffer store (and/or other mechanisms) to accommodate differences between the phases and/or frequencies of the incoming and outgoing signals in cases where the timing of the outgoing signal is not derived from that of the incoming signal. Slips may be controlled or uncontrolled depending on the slip control strategy.

4.2 *Control of impairments*

4.2.1 *Errors*

The intent of both network and equipment jitter specifications is to ensure that jitter has no impact on the error performance of the network.

4.2.2 *Degradation of digitally encoded analogue signals*

The intent of jitter specifications is to provide sufficient information to enable equipment designers to accommodate the expected levels of phase variation without incurring unacceptable degradations.

4.2.3 *Slips*

Slips may occur in asynchronous multiplexes and various synchronous equipments. Given the specified levels of phase variation, slip occurrences may be minimised in asynchronous muldexes by appropriate choice of justification and muldex buffer capacity within. For synchronous equipments, slip occurrences may be minimised by appropriate choice of buffer capacity as well as rigorous specification of clock performance.

It should be noted that it is impossible to eliminate slips when there is a frequency difference between the incoming and outgoing timing signals. Controlled slip performance objectives for an international connection are given in Recommendation G.822.

Various forms of aligning equipment may be used to minimise the impact of slips. The following two forms of aligning equipment are suitable for the termination of digital signals:

- frame aligner;
- time-slot aligner.

4.2.3.1 Where a frame aligner is used, a slip will consist of the insertion or removal of a consecutive set of digits amounting to a frame. In the case of frame structures defined in Recommendation G.704 the slip can consist of one complete frame. It is of importance that the maximum and mean delays introduced by the frame aligner should be as small as possible in order to minimize delay. It is also of importance that, after the frame aligner has produced a slip, it should be capable of absorbing substantial further changes in the arrival time of the frame alignment signals before a further slip is necessary.

4.2.3.2 Where a slot aligner is used, a slip will consist of the insertion or removal of eight consecutive digit positions of a channel time slot in one or more 64 kbit/s channels. Because slips may occur on different channels at different times, special control arrangements will be necessary in switches if octet sequence integrity of multiple time-slot services is to be maintained.

5 Purpose of phase variation specifications

5.1 *Jitter*

Jitter requirements given in Recommendations G.823 and G.824 fall into two basic categories:

- specification of the maximum permissible jitter at the output of hierarchical interfaces;
- sinusoidal jitter stress test specifications to ensure the input ports can accommodate expected levels of network jitter.

Additional jitter requirements for individual equipments may be found in the appropriate equipment Recommendations.

5.2 *Wander and long term frequency departure*

Relevant wander requirements fall into the following categories:

i) maximum permissible wander at the output of synchronous network nodes;

ii) stress tests to ensure that synchronous equipment input ports can accommodate expected levels of network wander;

iii) wander specifications for primary reference and slave clocks may include:

   a) intrinsic output wander under ideal conditions;

   b) intrinsic output wander under free-running conditions;

   c) output wander under stress test conditions;

   d) wander transfer characteristic.

The purpose of these Recommendations is not only to provide limits for the allowance wander accumulation along the transmission paths but also for the wander accumulation along the synchronization distribution paths arising from cascaded clocks.

6 Structure of synchronization networks

6.1 *Synchronization modes*

International networks usually work in the plesiochronous mode one with another.

The synchronization of national networks may be of the following types:

- fully synchronized, controlled by one or several primary reference clocks;
- fully plesiochronous;
- mixed, in which synchronized sub-networks are controlled by one or several primary reference clocks functioning plesiochronously one with another.

6.2 *Synchronization networks*

There are two fundamental methods of synchronizing nodal clocks:

- master-slave synchronization;
- mutual synchronization.

The master-slave synchronization system has a single primary reference clock to which all other clocks are phase-locked. Synchronization is achieved by conveying the timing signal from one clock to the next clock. Hierarchies of clocks can be established with some clocks being slaved from higher order clocks and in turn acting as master clocks for lower order clocks.

In a mutual synchronization system, all clocks are interconnected; there is no underlying hiearchical structure or unique primary reference clock.

Some practical synchronization strategies combine master-slave and mutual synchronization techniques.

Recommendation G.811

TIMING REQUIREMENTS AT THE OUTPUTS OF PRIMARY REFERENCE CLOCKS SUITABLE FOR PLESICHRONOUS OPERATION OF INTERNATIONAL DIGITAL LINKS

(Melbourne, 1988)

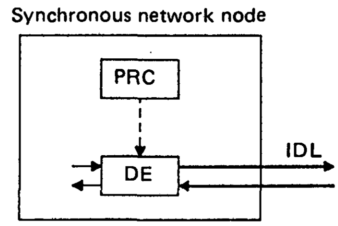
1 General

1.1 *International connections and network synchronization considerations*

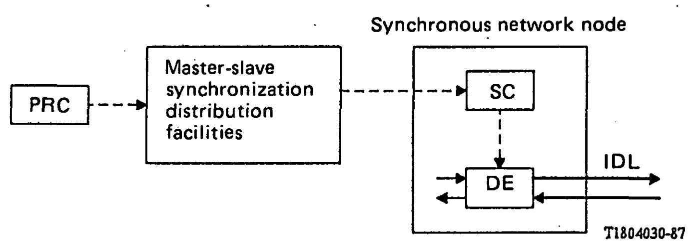
National digital networks, which may have a variety of internal synchronization arrangements, will usually be connected by international links which operate plesiochronously. International switching centres (ISCs) will be interconnected directly or indirectly via one or more intermediate ISCs, as indicated in the hypothetical reference connection (HRX) shown in Figure 1/G.801.

International connections terminate on synchronous network nodes that may or may not be co-located with a primary reference clock. Such network nodes may include slave clocks. Therefore, synchronous network node clock specifications are essential to ensure satisfactory operation of plesiochronous international digital links.

Figure 1/G.811 illustrates the two alternative international connections described above.



a) Case 1 – Synchronous network node including primary reference clock



b) Case 2 – Synchronous network node including slave clock

PRC Primary reference clock
SC Slave clock
DE Digital equipment such as digital exchange or digital muldex
IDL International digital link

Note – Other cases are for further study.

FIGURE 1/G.811

International connections terminating on synchronous network nodes

1.2 *Purpose of this Recommendation*

The purpose of this Recommendation is to specify requirements for primary reference clocks, promote understanding of associated timing requirements for plesiochronous operation of international digital links, and to clarify the relationship of the requirements for synchronous network nodes, constituent clocks and the use of satellite systems.

Administrations may apply this Recommendation, at their own discretion, to primary reference clocks other than those used in connection with international traffic.

1.3 *Interaction between plesiochronous and synchronous international operation*

It is important that the Recommendations for plesiochronous operation should not preclude the possibility of the later introduction of international synchronization.

When plesiochronous and synchronous operations coexist within the international network, the nodes will be required to provide for both types of operation. It is therefore important that the synchronization controls do not cause short-term frequency departures of the clocks which are unacceptable for plesiochronous operation. The magnitudes of the short-term frequency departures should satisfy the specifications in § 2.2.

1.4 *Maximum time interval error and relationship with frequency departure*

Maximum time interval error (MTIE) is the maximum peak-to-peak variation in the time delay of a given timing signal with respect to an ideal timing signal within a particular time period (Figure 2/G.811), i.e. MTIE(S) = max $x(t)$-min $x(t)$ for all t within S.

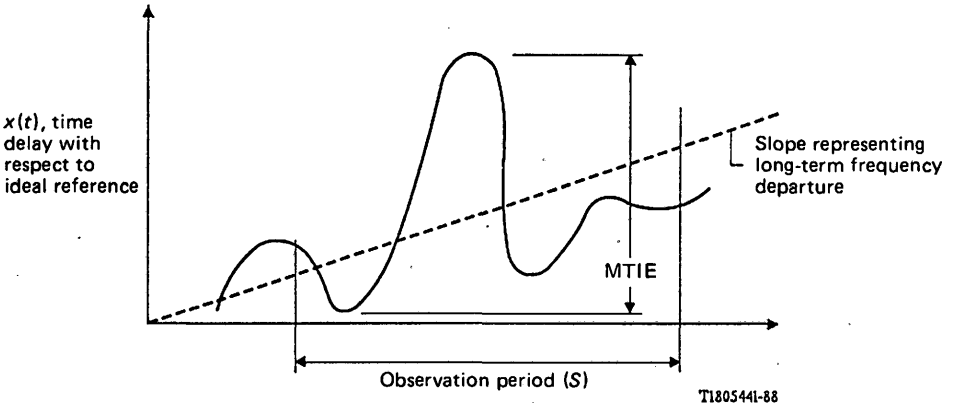


FIGURE 2/G.811

Definition of maximum time interval error

Long-term frequency departure ($\Delta f/f$) is determined by the MTIE divided by the observation interval S, as S increases.

Note – The rigorous definition and measurement of long-term frequency departure for clocks is a subject for further study.

2 Long-term frequency departure and phase stability of primary reference clocks

A primary reference clock controls the synchronization performance of the overall network. It is necessary to specify the long-term frequency departure and phase stability of a primary reference clock, and to provide guidance concerning issues associated with degradation and unavailability performance. The definition of a primary reference clock is given in Recommendation G.810.

2.1 *Long-term frequency departure*

A primary reference clock should be designed for a long-term frequency departure of not greater than 1×10^{-11}. The long-term frequency departure of 1×10^{-11} is about two orders of magnitude larger than the uncertainty of Coordinated Universal Time (UTC). Therefore UTC should be the reference for long-term frequency departure (see CCIR Report 898).

The theoretical long-term mean rate of occurrence of controlled frame or octet slips (i.e. the design rate of slips based on ideally undisturbed conditions) in any 64 kbit/s channel is consequently not greater than one in 70 days per digital international link (see Recommendation G.822).

Note 1 – Some Administrations support a primary reference clock long-term frequency departure of not greater than 7×10^{-12} based upon current primary reference clock technology.

Note 2 – Caesium-beam technology is suitable for primary reference clocks complying with the above specification.

2.2 *Phase stability*

The phase stability of a clock can be described by its phase variations, which in turn can be separated into a number of components:

- phase discontinuities due to transient disturbances;
- long-term phase variations (wander and integrated frequency departure);
- short-term phase variations (jitter).

A phase stability model for primary reference clocks is described in the annex to this Recommendation.

2.2.1 *Phase discontinuities*

Primary reference clocks need a very high reliability and are likely to include replication of the equipment in order to ensure the continuity of output. However, any phase discontinuity, due to internal operations within the clock, should only result in a lengthening or shortening of the timing signal interval and must not cause a phase discontinuity in excess of 1/8 of a unit interval at the clock output. (This refers to output signals at 1544 kbit/s or 2048 kHz, see § 4. Specification of other interfaces is under study.)

2.2.2 *Long-term phase variations*

The maximum permissible long-term phase variation of the output of a primary reference clock (whether sinusoidal or pulse) is expressed in MTIE.

The MTIE over a period of S seconds shall not exceed the following limits:

a) $100\ S$ ns for the interval $0.05 < S \leq 5$

b) $(5\ S + 500)$ ns for the interval $5 < S \leq 500$

c) $(0.01\ S + X)$ ns for values of $S > 500$.

The asymptote designated 10^{-11} refers to the long-term frequency departure specified in § 2.1.

The value of X is under study. It is provisionally recommended that $X = 3000$ ns. Certain Administrations support a value of 1000 ns.

Note 1 – For measurement of long-term phase variations, the use of a 10 Hz low-pass filter is suggested.

Note 2 – The MTIE Recommendation requires further study.

Note 3 – The overall specification is illustrated in Figure 3/G.811.

2.2.3 *Short-term phase variations*

Clock implementations exist today which may have some high-frequency phase instability components. The specification of maximum permissible short- term phase variation of a primary reference clock due to jitter is under study.

3 **Degradation of the performance of a primary reference clock**

To achieve the required high reliability a primary reference clock includes redundancy, i.e. by incorporating several (caesium beam) oscillators, the output of only one of these being used at any given time. If a clock frequency departs significantly from its nominal value, this should be detected and switching to an undegraded oscillator should then be effected. This switching should be accomplished before the MTIE specification is exceeded.

With current technology, the performance of a primary reference clock is statistically well below the MTIE specification of Figure 3/G.811.

4 **Interfaces**

The preferred interface for the timing output is in accordance with Recommendation G.703, § 10, i.e. an interface at 2048 kHz. By agreement between operators or manufacturers of equipment, the timing signal may also be delivered at various other physical interfaces (e.g., 1544 kbit/s primary rate signal, 1 MHz, 5 MHz, or 10 MHz).

5 **Use of satellite systems in an international plesiochronous digital network**

It is recommended that the link be operated in a plesiochronous mode using high accuracy (1×10^{-11}) source for the satellite TDMA timing. The international satellite links will be terminated on network nodes whose timing is in accordance with Recommendations G.823 and G.824.

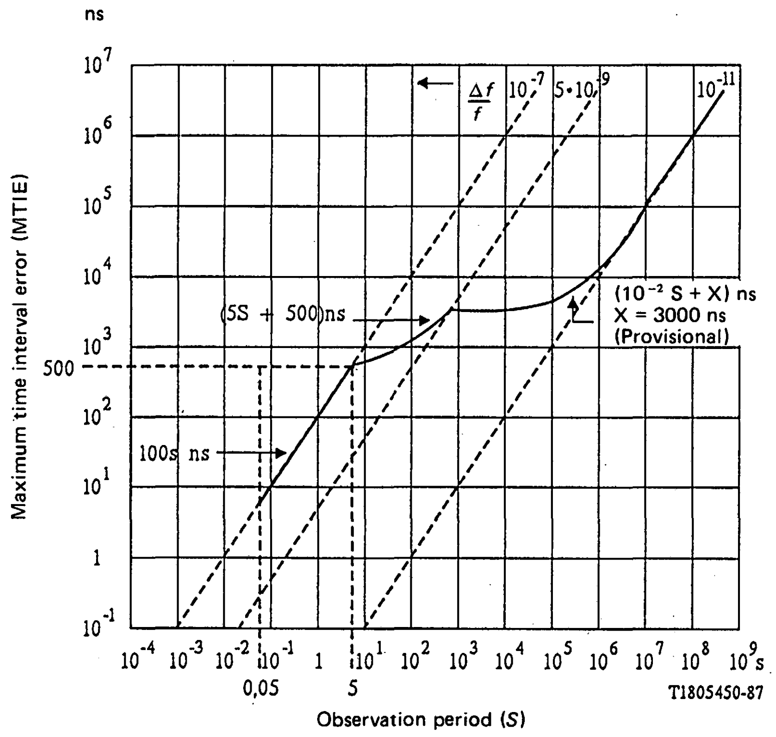


FIGURE 3/G.811

Permissible maximum time interval error (MTIE) due to long-term phase variation as a function of observation period *S* for a primary reference clock

6 Guidelines concerning the measurement of jitter and wander

Verification of compliance with jitter and wander specifications requires standardized measurement methodologies to eliminate ambiguities in the measurements and in interpretation and comparison of measurement results. Guidelines concerning the measurement of jitter and wander are contained in Supplement No. 3.8 (O-Series) and Supplement No. 35 at the end of this Fascicle.

ANNEX A

(to Recommendation G.811)

Characterization of primary reference clock phase stability

The following phase stability model may be employed to characterize primary reference clocks. Let $x(t)$ represent the time interval error of a clock synchronized at $t = 0$, and free-running against UTC thereafter. $x(t)$ may be defined as:

$$x(t) = y_0 t + \left(\frac{D}{2}\right) t^2 + e(t)$$

where:

D is the normalized linear frequency drift per unit time (ageing),

y_0 is the initial frequency departure with respect to UTC, and

$e(t)$ is the random error component.

The estimate of the standard deviation of $x(t)$ may be obtained, and used for characterization of phase instability.

$$\sigma_x(t) = \left(\frac{D}{2}\right) t^2 + t \sqrt{\sigma_{y_0}^2 + \sigma_y^2 (\tau = t)}$$

where:

σ_y^2 is the two-sample variance of the initial frequency departure, and

$\sigma_y^2 (\tau)$ is the two-sample Allan variance describing the random frequency instability of the clock.

Recommendation G.812

TIMING REQUIREMENTS AT THE OUTPUTS OF SLAVE CLOCKS SUITABLE FOR PLESIOCHRONOUS OPERATION OF INTERNATIONAL DIGITAL LINKS

(Melbourne, 1988)

1 General

1.1 *Purpose of this Recommendation*

The purpose of this Recommendation is to specify requirements for slave clocks, and promote understanding of associated timing requirements for plesiochronous operation of international digital links.

Note – Administrations may apply this Recommendation, at their own discretion, to slave clocks other than those used in connection with international traffic. Supplement No. 35 gives guidance on one suitable method for the measurement of clock performance with respect to this Recommendation.

1.2 *Maximum relative time interval error*

The concept of maximum relative time interval error (MRTIE) is useful in specifying slave clock performance. MRTIE is analogous to MTIE as defined in Recommendation G.811 but with reference to a practical high-performance oscillator instead of UTC.

2 Phase stability of slave clocks

The phase stability of a slave clock can be described by its phase variations which in turn can be separated into a number of components:

- phase discontinuities due to transient disturbances;
- long-term phase variations (wander and integrated frequency departure);
- short-term phase variations (jitter).

A phase stability model for slave clocks is described in Annex A to this Recommendation.

2.1 *Phase discontinuity*

In cases of infrequent internal testing or rearrangement operations within the slave clock, the following conditions should be met:

- the phase variation over any period up to 2^{11} UI should not exceed 1/8 of a UI;
- for periods greater than 2^{11} UI in the phase variation for each interval or 2^{11} UI should not exceed 1/8 UI up to a total amount of 1 µs,

Where the UI corresponds to the reciprocal of the bit rate of the interface.

2.2 *Long-term phase variations*

Slave clock phase stability requirements must account for clock behaviour in real network environments. Impairments such as jitter, error bursts, and outages are intrinsic characteristics of timing distribution facilities. The following specifications are based on the slave clock phase stability model contained in the Annex. This model characterizes actual clock performance, reflecting the stress conditions in real networks under which clocks should perform acceptably. There are three categories of clock operation which require specification:

i) ideal,

ii) stressed, and

iii) holdover.

2.2.1 *Ideal operation*

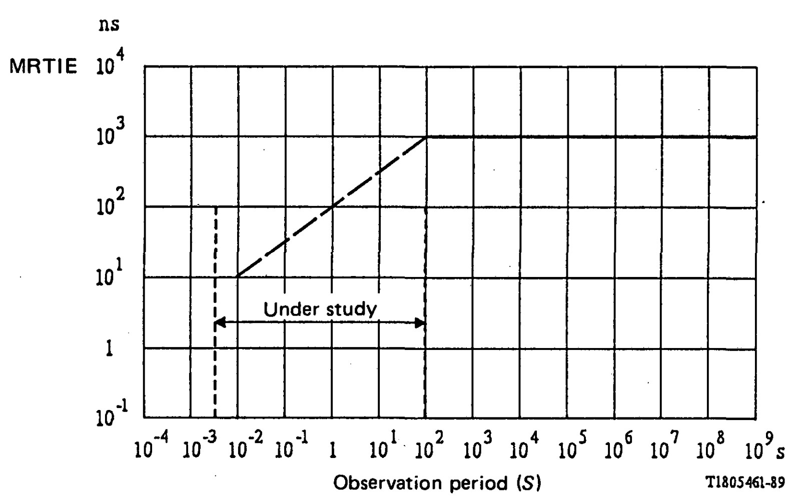
This category of operation reflects the performance of a clock under conditions in which there are no impairments on the input timing reference(s).

The MRTIE at the output of the slave clock should not, over any period of S seconds, exceed the following provisional limits:

1) $0.05 < S < 100$: this region requires further study;

2) 1000 ns for $S \geqslant 100$.

The resultant overall specification is summarized in Figure 1/G.812.



Note – For measurement of long-term variations the use of a 10 Hz low-pass filter with a 20 dB/dec roll-off is suggested.

FIGURE 1/G.812

Permissible maximum relative time interval error (MRTIE) due to long-term phase variations vs. observation period *S* for a slave clock under ideal operation

2.2.2 *Stressed operation*

This category of operation reflects the actual performance of a clock considering the impact of real operating (stressed) conditions. Stressed conditions include the effects of jitter, protection switching activity, and error bursts. The result of such stressed conditions is timing impairments, as discussed in the Annex.

The requirements for stressed operation are under study.

2.2.3 *Holdover operation*

This category of operation reflects the performance of a clock for the infrequent times when a slave clock will lose reference for a significant period of time.

The MRTIE (see § 1.2 and Recommendation G.811) at the output of the slave clock should not, over any period of S seconds, exceed the following provisional limits.

$$\text{For } S \geqslant 100, \text{ MRTIE}(S) = (\text{a}S + 1/2\ \text{b}S^2 + c) \text{ ns}$$

where parameters a, b, c are proposed provisionally in Table 1/G.812 (Note 5):

TABLE 1/G.812

	Transit node clock [a] (stratum 2 clock)	Local node clock [a] (stratum 3 clock)
a	0.5 (Note 1)	10.0 (Note 3)
b	1.16×10^{-5} (Note 2)	2.3×10^{-4} (Note 4)
c	1000 (Note 6)	1000 (Note 6)

[a] See Recommendation G.810 for definitions.

Note 1 – Corresponds to un initial frequency offset of 5×10^{-10}.

Note 2 – Corresponds to a frequency drift of 1×10^{-9}/day.

Note 3 – Corresponds to an initial frequency offset of 1×10^{-8}.

Note 4 – Corresponds to a frequency drift of 2×10^{-8}/day.

Note 5 – Temperature effects: the effect of changes in environmental temperature on the performance of a slave clock in holdover mode requires further study.

Note 6 – Takes care of any MRTIE that might have existed at the beginning of holdover operation, and of effects of internal configuration, etc. in the clock (and timing distribution, if applicable). In any case, a smooth transition between "ideal" and "holdover" operations is stipulated.

The resultant overall specification is summarized in Figure 2/G.812.

2.3 *Short-term phase variations*

Clock implementations exist which may have some high frequency phase instability components. The maximum permissible short-term phase variation of a slave clock due to jitter is under study.

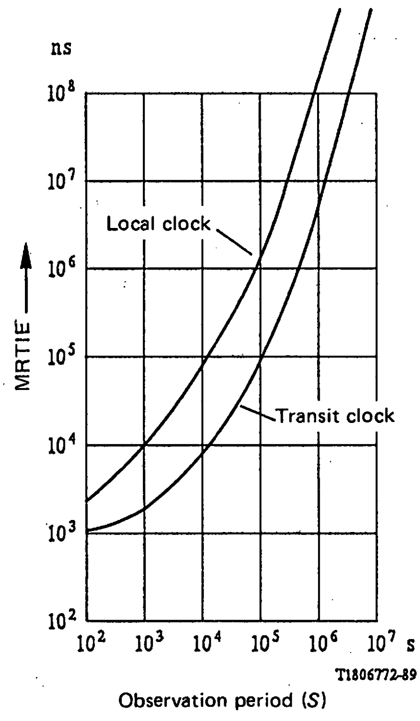


FIGURE 2/G.812

Permissible maximum relative time interval error (MRTIE) due to long-term phase variations vs. observation period *S* for a slave clock under holdover operation

ANNEX A

(to Recommendation G.812)

Characterization of slave clock phase stability

A.1 The slave clock model is described by the following equation:

$$x(t) = y_{\text{bias}} \cdot t + \left(\frac{D}{2}\right) t^2 + e_{\text{pm}}(t) + \int_{\tau=0}^{\tau=t} e_{\text{fm}}(\tau)\, d\tau$$

where,

$x(t)$ is the phase-time output relative to the reference input (dimension time);

y_{bias} is a residual fractional frequency offset which can arise from disruption events on the reference input (dimensionless);

D is the linear frequency drift component when the clock is in holdover condition (dimension 1/time);

$e_{pm}(t)$ is a white noise phase modulation (PM) component associated with the short-term instability of the clock (dimension time);

$e_{fm}(\tau)$ is a white noise fractional frequency modulation (FM) component associated with the disruption process of the reference (dimensionless).

The clock model is best understood by considering the three categories of clock operation:

– ideal operation;

– stressed operation;

– holdover operation.

A.1.1 *Ideal operation*

For short observation intervals outside the tracking bandwidth of the PLL, the stability of the output timing signal is determined by the short term stability of the local synchronizer time base. In the absence of reference disruptions, the stability of the output timing signal behaves asymptotically as a white noise PM process as the observation period is increased to be within the tracking bandwidth of the PLL. The output of the clock can be viewed as a superposition of the high frequency noise of the local oscillator riding on the low frequency portion of the input reference signal. In phase locked operation the high frequency noise must be bounded, and is uncorrelated (white) for large observation periods relative to the bandwidth of the phase locked loop.

Under ideal conditions, the only non-zero parameter of the model is the white noise PM component.

A.1.2 *Stressed operation*

In the presence of interruptions, the stability of the output timing signal behaves as a white noise FM process as the observation period is increased to be within the tracking bandwidth of the PLL. The presence of white noise FM can be justified based on the simple fact that in general, network clocks extract time interval, rather than absolute time from the time reference. An interruption is by nature a short period during which the reference time interval is not available. When reference is restored there is some ambiguity regarding the actual time difference between the local clock and the reference. Depending on the sophistication of the clock phase build-out there can be various levels of residual phase error which occur for each interruption. There is a random component which is independent from one interruption event to the next which results in a random walk in phase, i.e. a white noise FM noise source.

In addition to the white noise FM component, interruption events can actually result in a frequency offset between the clock and its reference. This frequency offset (y_{bias}) results from a bias in the phase build-out when reference is restored. This is a critical point. The implications of this effect are that in actual network environments there is some accumulation of frequency offset through a chain of clocks. Thus, clocks controlled by the same primary reference clock are actually operating plesiochronously to some degree.

To summarize, under stress conditions the non-zero parameters of the clock model are the white noise FM component (e_{fm}) and the frequency offset component (y_{bias}). The stressed category of operation reflects a realistic characterization of what "normal" operation of a clock is.

A.1.3 *Holdover operation*

In holdover, the key components of the clock model are the frequency drift (D) and the initial frequency offset (y_{bias}). The drift term accounts for the significant ageing associated with quartz oscillators. The initial frequency offset is associated with the intrinsic setability of the local oscillator frequency.

A.2 *Relationship of slave clock model to TIE performance*

It is useful to consider the relationship between the clock model and the Time Interval Error (TIE) that would be expected. It is proposed that the two sample Allan variance be used to describe the stochastic portion of the clock model. The following equations apply for the three categories of operation:

Ideal

$$\sigma_{TIE} = \sqrt{3\sigma_y^2 (\tau = t) \cdot t}$$

Stressed

$$\sigma_{TIE} = \sqrt{\sigma_{bias}^2 + \sigma_y^2 (\tau = t) \cdot t}$$

Holdover

$$\sigma_{TIE} = \left(\frac{D}{2}\right) t^2 + \sqrt{\sigma_{bias}^2 + \sigma_y^2 (\tau = t) \cdot t}$$

where,

σ_{TIE} is the standard deviation of the relative time interval error of the clock output compared to the reference over the observation time t;

$\sigma_y(\tau)$ is the two sample standard deviation describing the random frequency fluctuation of the clock, and

σ_{bias} describes the two sample standard deviation of the frequency bias.

A.3. *Guidelines concerning the measurement of jitter and wander*

Verification of compliance with jitter and wander specifications requires standardized measurement methodologies to eliminate ambiguities in the measurements and in the interpretation and comparison of measurement results. Guidance concerning the measurement of jitter and wander is contained in Supplement No. 35.

8.2 Quality and availability targets

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;

(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 27 500 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 $1 \cdot 10^{-6}$ for $T_0 = 1$ minute;

b) a BER of less than $1 \cdot 10^{-3}$ 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)].

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 $1 \cdot 10^{-6}$ (Note 4)
(b) (Severely errored seconds) (Note 1)	Fewer than 0.2% of one-second intervals to have a bit error ratio worse than $1 \cdot 10^{-3}$
(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 $M > 4$ 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_L, 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.

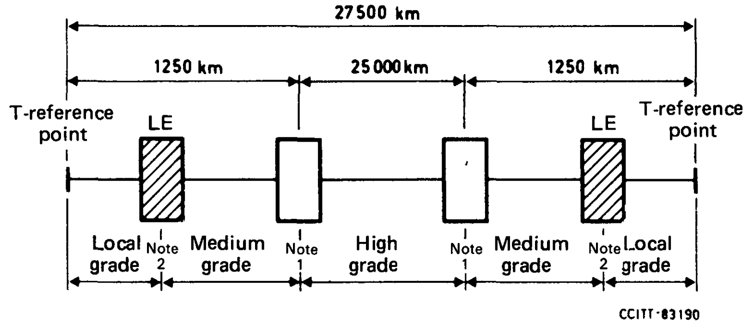
Note 4 – For practical reasons, at 64 kbit/s, a minute containing four errors (equivalent to an error ratio of 1.04×10^{-6}) is not considered degraded. However, this does not imply relaxation of the error ratio objective of $1 \cdot 10^{-6}$.

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

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).



Note 1 – It is not possible to provide a definition of the location of the boundary between the medium and high grade portions of the HRX. Note 4 to Table 2/G.821 provides further clarification of this point.

Note 2 – LE denotes the local exchange or equivalent point.

FIGURE 1/G.821

Circuit quality demarcation of longest HRX

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 27 500 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 25 000 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.

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 25 000 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 12 500 km or if the high-grade portion of a non-satellite connection exceeds 25 000 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 10 000 to 13 000 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.

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.

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).

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

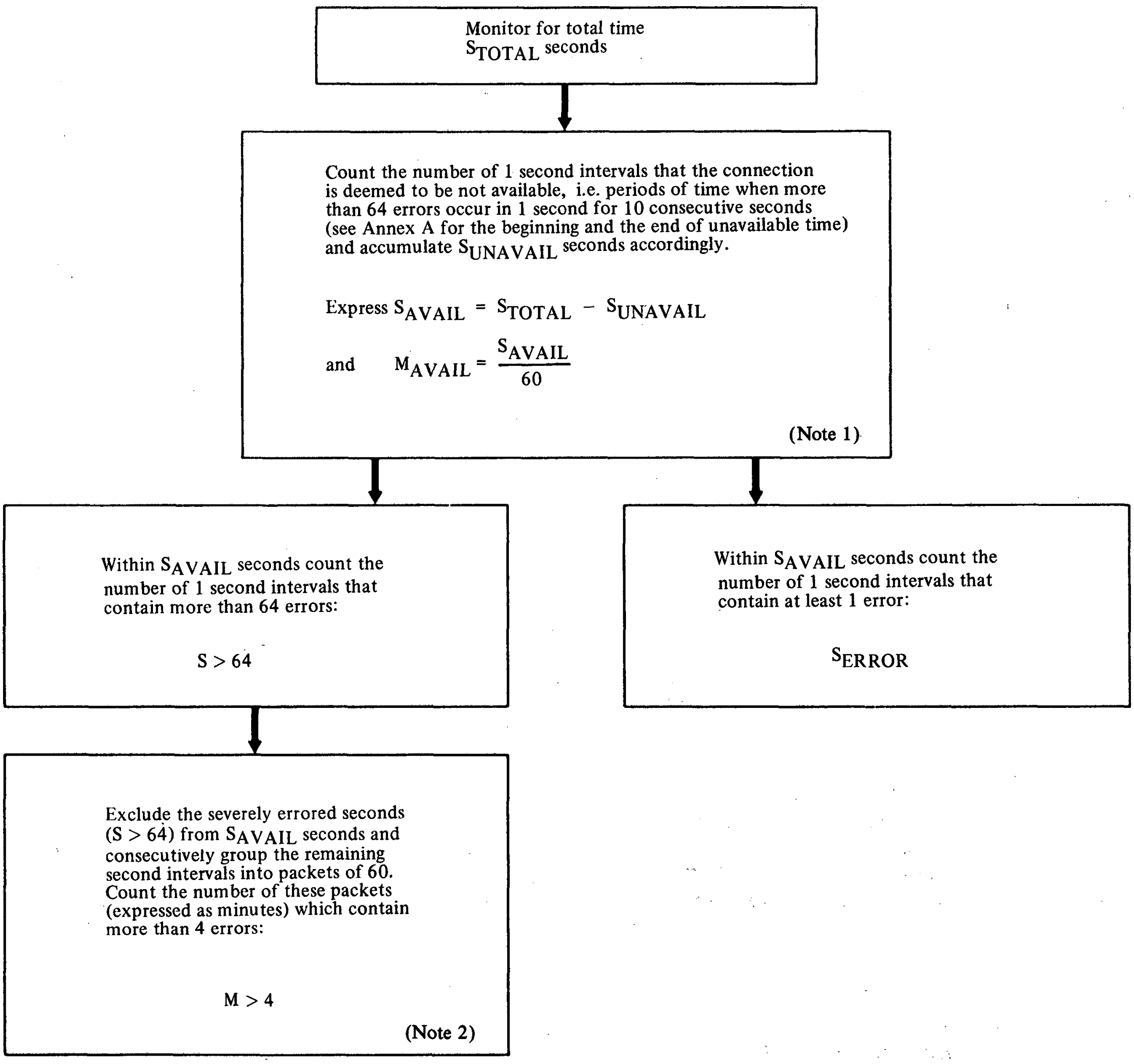
A period of unavailable time begins when the bit error ratio (BER) in each second is worse than $1 \cdot 10^{-3}$ for a period of ten consecutive seconds. These ten seconds are considered to be unavailable time. A new period of available time begins with the first second of a period of ten consecutive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



Note 1 — The result is rounded off to the next higher integer.

Note 2 — The last packet which may be incomplete is treated as if it were a complete packet with the same rules being applied.

Performance classification (see Table 1/G.821)	Objective
(a)	$\frac{M > 4}{M_{AVAIL}} < 10\%$
(b)	$\frac{S > 64}{S_{AVAIL}} < 0.2\%$
(c)	$\frac{S_{ERROR}}{S_{AVAIL}} < 8\%$

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ANNEX C

(to Recommendation G.821)

Allocation of objectives to constituent parts

TABLE C-1/G.821

Allocation of % degraded minute intervals and errored seconds objectives

Circuit classification (see Figure 1/G.821)	Network performance objectives at 64 kbit/s	
	% degraded minutes	% errored seconds
Local grade	1.5	1.2
Medium grade	1.5	1.2
High grade	4.0	3.2

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:

$$\frac{1}{j} \sum_{i=1}^{i=j} \left(\frac{n}{N}\right)_i \times (100\%)$$

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 $\left(\frac{n}{N}\right)_i$ for the i^{th} seconds is

$$\frac{n}{N}, \text{ if } 0 < n < N, \text{ or}$$

$$1, \text{ if } n \geqslant N$$

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^{-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^{-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 27 500 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 performance 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 27 500 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.

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)	≤ 5 slips in 24 hours	> 98.9%
(b)	> 5 slips in 24 hours and ≤ 30 slips in 1 hour	< 1.0%
(c)	> 30 slips in 1 hour	< 0.1%

Note 1 – Total time ≥ 1 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).

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.

TABLE 2/G.822

Allocation of controlled slip performance objectives

Portion of HRX derived from Figure 1/G.801 [1]	Allocated proportion of each objective in Table 1/G.822	Objectives as proportion of total time	
		(b)	(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 ⩾ one year.

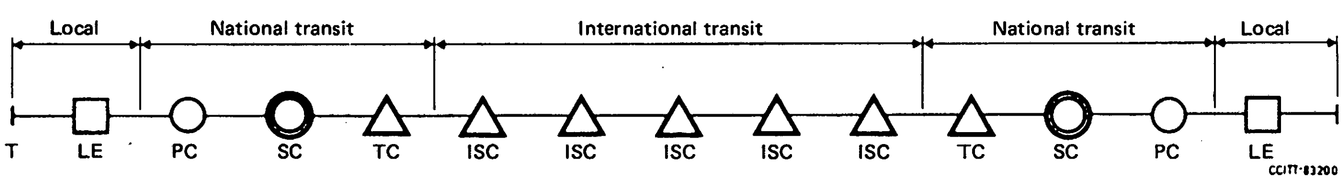

FIGURE 1/G.822

Subdivision of the HRX for the purpose of allocation of slip performance objectives

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.

TABLE 1/G.823

Maximum permissible jitter at a hierarchical interface

Parameter value / Digit rate (kbit/s)	Network limit		Measurement filter bandwidth		
	B_1 unit interval peak-to-peak	B_2 unit interval peak-to-peak	Band-pass filter having a lower cutoff frequency f_1 or f_3 and an upper cutoff frequency f_4		
			f_1	f_3	f_4
64 (Note 1)	0.25	0.05	20 Hz	3 kHz	20 kHz
2 048	1.5	0.2	20 Hz	18 kHz (700 Hz)	100 kHz
8 448	1.5	0.2	20 Hz	3 kHz (80 kHz)	400 kHz
34 368	1.5	0.15	100 Hz	10 kHz	800 kHz
139 264	1.5	0.075	200 Hz	10 kHz	3500 kHz

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 34 368 kbit/s 1 UI = 29.1 ns
for 139 264 kbit/s 1 UI = 7.18 ns

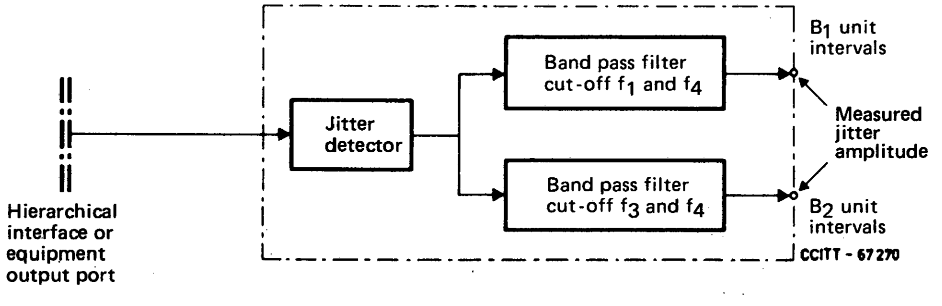

FIGURE 1/G.823

Measurement arrangements for output jitter from a hierarchical interface or an equipment output port

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) $(10^{-2}\ S + 10\,000)$ ns: applicable to values of S greater than 10^4.

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

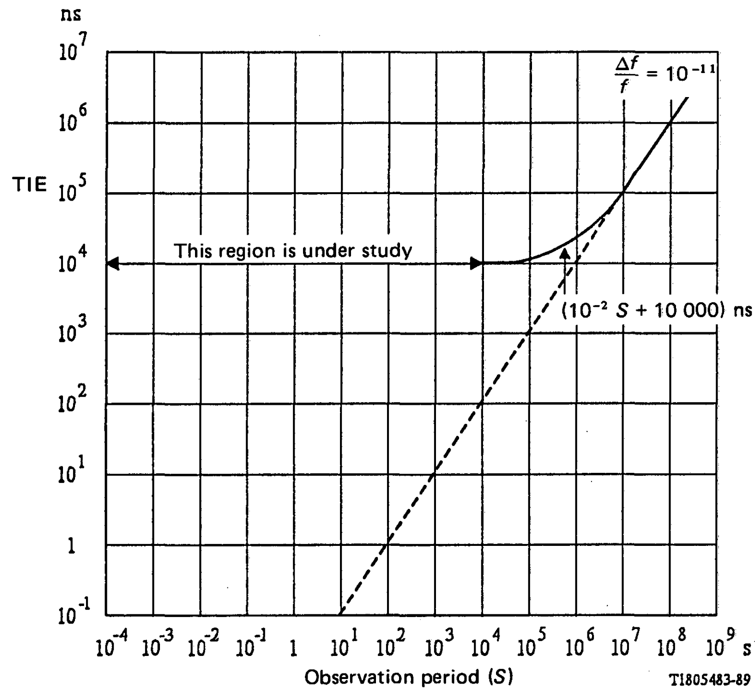

FIGURE 2/G.823

Permissible maximum time interval error (MTIE) versus observation period S for the output of a network node

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*" factor 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.

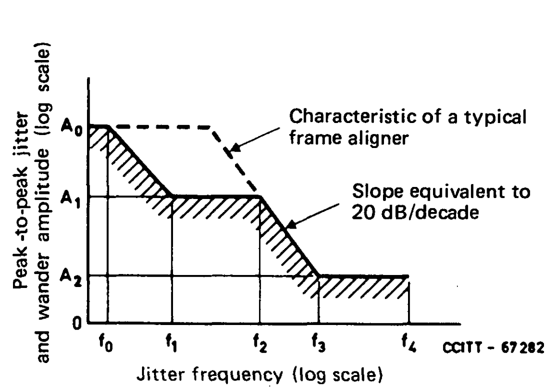

FIGURE 3/G.823

Lower limit of maximum tolerable input jitter and wander

TABLE 2/G.823

Parameter values for input jitter and wander tolerance

Parameter value / Digit rate kbit/s	Peak-to-peak amplitude unit interval			Frequency					Pseudo-random test signal
	A_0	A_1	A_2	f_0	f_1	f_2	f_3	f_4	
64 (Note 1)	1.15 (18 μs)	0.25	0.05	1.2×10^{-5} Hz	20 Hz	600 Hz	3 kHz	20 kHz	$2^{11} - 1$ (Rec. O.152)
2 048	36.9 (18 μs)	1.5	0.2		20 Hz	2.4 kHz (93 Hz)	18 kHz (700 Hz)	100 kHz	$2^{15} - 1$ (Rec. O.151)
8 448	152 (18 μs)	1.5	0.2	1.2×10^{-5} Hz	20 Hz	400 Hz (10.7 kHz)	3 kHz (80 kHz)	400 kHz	$2^{15} - 1$ (Rec. O.151)
34 368	*	1.5	0.15	*	100 Hz	1 kHz	10 kHz	800 kHz	$2^{23} - 1$ (Rec. O.151)
139 264	*	1.5	0.075	*	200 Hz	500 Hz	10 kHz	3500 kHz	$2^{23} - 1$ (Rec. O.151)

* 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 1 UI = 15,6 μs
For 2048 kbit/s 1 UI = 488 ns
For 8448 kbit/s 1 UI = 118 ns
For 34 368 kbit/s 1 UI = 29,1 ns
For 139 264 kbit/s 1 UI = 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].

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.

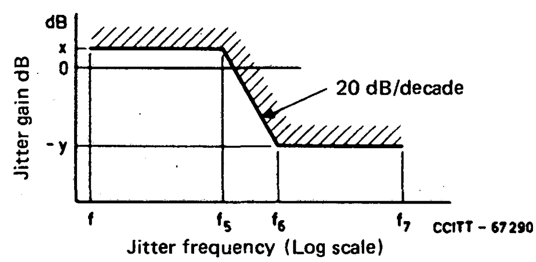

FIGURE 4/G.823

Typical jitter transfer characteristics

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 34 368 kbit/s and 139 264 kbit/s (based on the use of a $2^{23} - 1$ PRBS generated in accordance with Recommendation O.151).

Therefore:

$$\left[\begin{array}{l}\text{Estimated jitter amplitude}\\ \text{when transmitting}\\ \text{random signal (traffic)}\end{array} = \text{correction factor} \times \begin{array}{l}\text{Measured jitter}\\ \text{amplitude using}\\ \text{a specific PRBS.}\end{array}\right]$$

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:

$$\text{Jitter bandwidth} = \frac{f_1}{Q \times n} \text{ [Hz] for large } n$$

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 $\frac{1}{y}$ of the jitter bandwidth of the system under test. (The value for y requires further study).

Thus

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

and

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

Exemples:

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

For a Non-Redundant Quaternary line code $\frac{f}{f_1} = \frac{2}{1}$ and $L \geqslant y \times n \times Q \times 2$

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:

$$J_N \simeq J \times \sqrt[4]{N} \tag{1}$$

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.

$$J_N \simeq J_1 \times \sqrt{2N} \text{ for large values of } N \tag{2}$$

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:

$$J_N = J_1 \times \sqrt{2NA} \tag{3}$$

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_{NP}) is described by the following relationship:

$$J_{NP} = d \times N \tag{4}$$

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:

$$J_M \simeq J_S \times \sqrt[4]{KM} \tag{5}$$

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:

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

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 $\left(B = \dfrac{W_0}{2Q}\right)$.

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 $\sqrt[4]{N}$ and $\sqrt[2]{N}$, 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.

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)
1 544	5.0	0.1 (Note)	10	8	40
6 312	3.0	0.1 (Note)	10	3	60
32 064	2.0	0.1 (Note)	10	8	400
44 736	5.0	0.1	10	30	400
97 728	1.0	0.05	10	240	1 000

UI Unit Interval.

Note – This value requires further study.

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.

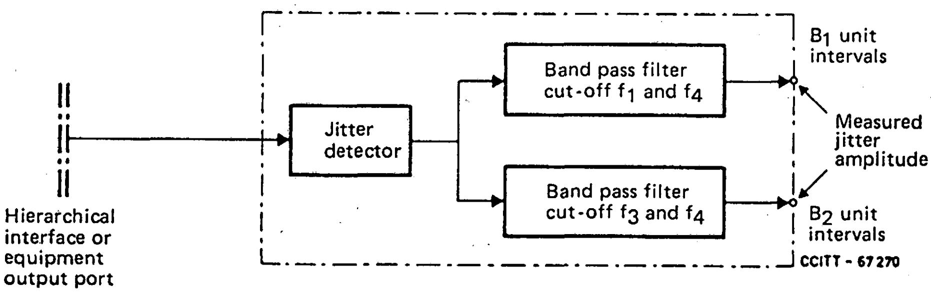

FIGURE 1/G.824

Measurement arrangements for output jitter from a hierarchical interface or an equipment output port

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) $(10^{-2}\,S + 10\,000)$ ns; applicable to values of S greater than 10^4.

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

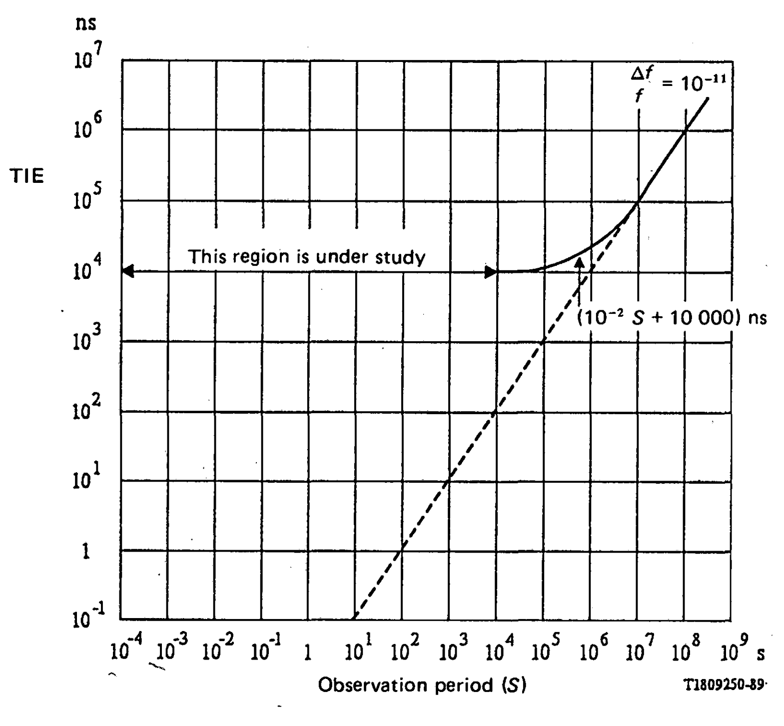

FIGURE 2/G.824

Permissible maximum time interval error (MTIE) versus observation period S for the output of a network node

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.

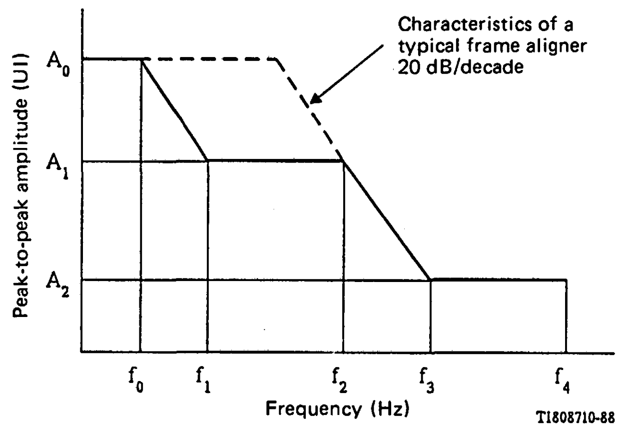

FIGURE 3/G.824

Mask of peak-to-peak jitter and wander which must be accommodated at the input of a node in a digital network
(Measurement method – refer to Supplement No. 3.8 (O-Series) and Supplement No. 35)

TABLE 2/G.824

Jitter and wander tolerance of input ports (Provisional values) (Note 1)

Bit rates (kbit/s)	Jitter amplitude (peak-to-peak)			Frequency					Test signal
	A_0 (μs)	A_1 (UI)	A_2 (UI)	f_0 (Hz)	f_1 (Hz)	f_2 (Hz)	f_3 (kHz)	f_4 (kHz)	
1 544	18 (Note 2)	5.0	0.1 (Note 2)	1.2×10^{-5}	10	120	6	40	$2^{20} - 1$ (Note 3)
6 312	18 (Note 2)	5.0	0.1	1.2×10^{-5}	10	50	2.5	60	$2^{20} - 1$ (Note 2)
32 064	18 (Note 2)	2.0	0.1	1.2×10^{-5}	10	400	8	400	$2^{20} - 1$ (Note 3)
44 736	18 (Note 2)	5.0	0.1 (Note 2)	1.2×10^{-5}	10	600	30	400	$2^{20} - 1$ (Note 2)
97 728	18 (Note 2)	2.0	0.1	1.2×10^{-5}	10	12 000	240	1000	$2^{23} - 1$ (Note 2)

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.

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.

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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.

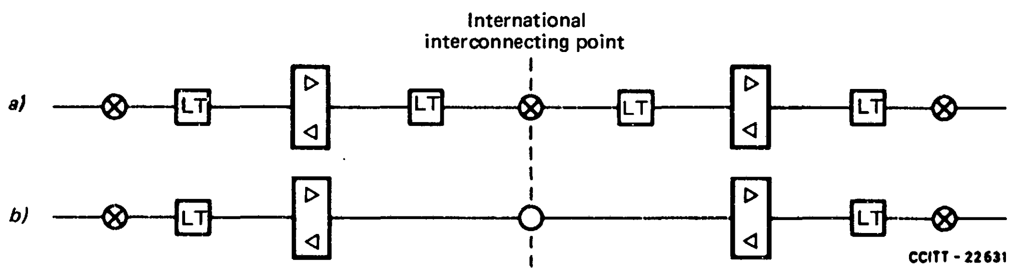


FIGURE 1/G.901

Alternatives for interconnection of line transmission systems operating at hierarchical bit rates

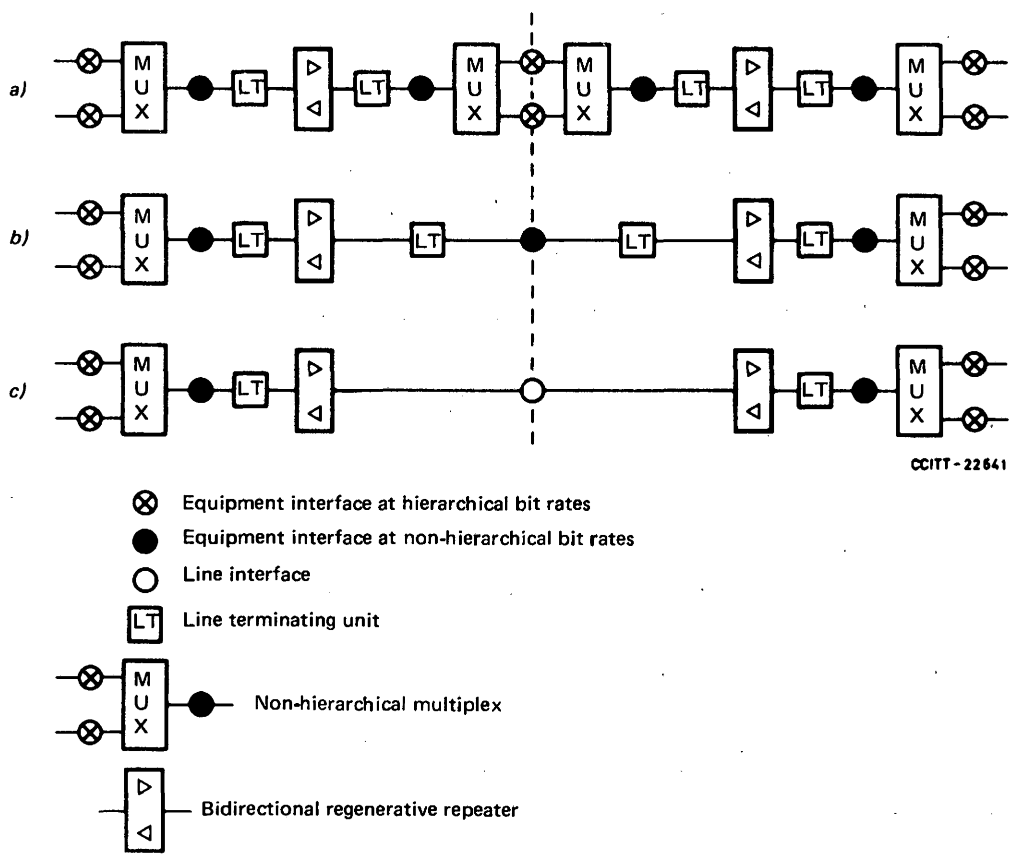


FIGURE 2/G.901

Alternatives for interconnection of line transmission systems operating at non-hierarchical bit rates

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 *Transmission 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.

TABLE 1/G.921

Tolerances on transmitted signals

Nominal bit rate (kbit/s)	2048	8448	34 368	139 264
Tolerance (ppm)	50	30	20	15

Note – The 2048 kbit/s digital sections may be operating synchronously or plesiochronously within the same environment.

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.

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 b) 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.

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.

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)

Bit rate (kbit/s)	HRDS length (km)	Maximum output jitter for a digital section		Measurement filter bandwidth		
		Low frequency limit (f_1-f_4) unit interval peak-to-peak	High frequency limit (f_3-f_4) unit interval peak-to-peak	Band-pass filter having a lower cut-off frequency f_1 or f_3 and an upper cut-off frequency f_4		
				f_1	f_3	f_4
2 048	50	0.75	0.2	20 Hz	18 kHz (700 Hz)	100 kHz
8 448	50	0.75	0.2	20 Hz	3 kHz (80 kHz)	400 kHz
34 368	50	0.75	0.15	100 Hz	10 kHz	800 kHz
34 368	280	0.75	0.15	100 Hz	10 kHz	800 kHz
139 264	280	0.75	0.075	200 Hz	10 kHz	3 500 kHz

Note – For interfaces within national networks the frequency values (f_2 and f_3) shown in parenthesis may be used.

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* $> 1 \cdot 10^{-3}$

The consequent actions should be taken when the bit error ratio is considered to exceed $1 \cdot 10^{-3}$. 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 $> 1 \cdot 10^{-3}$".

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 $> 1 \cdot 10^{-3}$".

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.

TABLE 4/G.921

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

Equipment	Fault conditions	Maintenance alarms		AIS to	
		prompt	deferred (see Note)	Line side	Interface side
Line terminal equipment	Internal power failure	yes		if practicable	if practicable
Line side only	Error ratio $> 1 \cdot 10^{-3}$	yes			yes
	Loss of the signal at the receiving terminal	yes			yes
	Loss of alignment when alphabetic line codes or additional frames are used	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.

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 $> 1 \cdot 10^{-3}$"; 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.

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
Pulse characteristics	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]

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 corresponding 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

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 (8516-12 388 kHz)	Rec. G.921
Italy	8448 kbit/s Rec. G.703, § 7	15 supergroup assem. (312-4028 kHz)	Rec. G.921

ANNEX B

(to Recommendation G.941)

Examples of systems other than those recommended in Recommendation G.941
(see Note 1)

Administration	Bit rate (kbit/s)	Analogue interface	Design bit error ratio for regeneration section
France (see Note 2)	704	Supergroup (312-552 kHz)	10^{-8}
Netherlands	2048	2 supergroups	10^{-8}

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.

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.

9.5 Digital line systems

Recommendation G.950

GENERAL CONSIDERATIONS ON DIGITAL LINE SYSTEMS

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

1 Introduction

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

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

2 General requirements for digital line systems

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

2.1 *Environmental conditions*

2.1.1 *Climatic conditions*

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

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

2.1.2 *Pressurization*

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

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

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

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

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

2.1.4 *Protection against interference from other sources*

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

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

2.1.5 *Interference to other systems*

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

Reference

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

Recommendation G.951

DIGITAL LINE SYSTEMS BASED ON THE 1544 KBIT/S HIERARCHY ON SYMMETRIC PAIR CABLES

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

1 General

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

1544 kbit/s,

3152 kbit/s,

6312 kbit/s.

2 Transmission medium

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

3 Protection against interference from external sources

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

4 Overall design features

4.1 *Availability*

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

4.2 *Reliability*

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

4.3 *Repeater crosstalk-noise figures*

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

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

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

b) FEXT-Noise Figure $[R_F] \leqslant E$*

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

4.4 *Error Performance*

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

5 Specific design features

5.1 *Type of power feeding*

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

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

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

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

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

5.2 *Repeater spacing and cable fill*

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

5.3 *Maintenance strategy*

5.3.1 *Type of supervision and fault location*

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

5.3.2 *Fault conditions and consequent actions*

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

ANNEX A

(to Recommendation G.951)

Definition and measurement of repeaters crosstalk noise figures

A.1 *Definition*

a) NEXT-Noise Figure $[R_N]$

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

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

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

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

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

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

f_0 = half line system baud rate.

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

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

b) FEXT-Noise Figure $[R_F]$

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

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

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

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

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

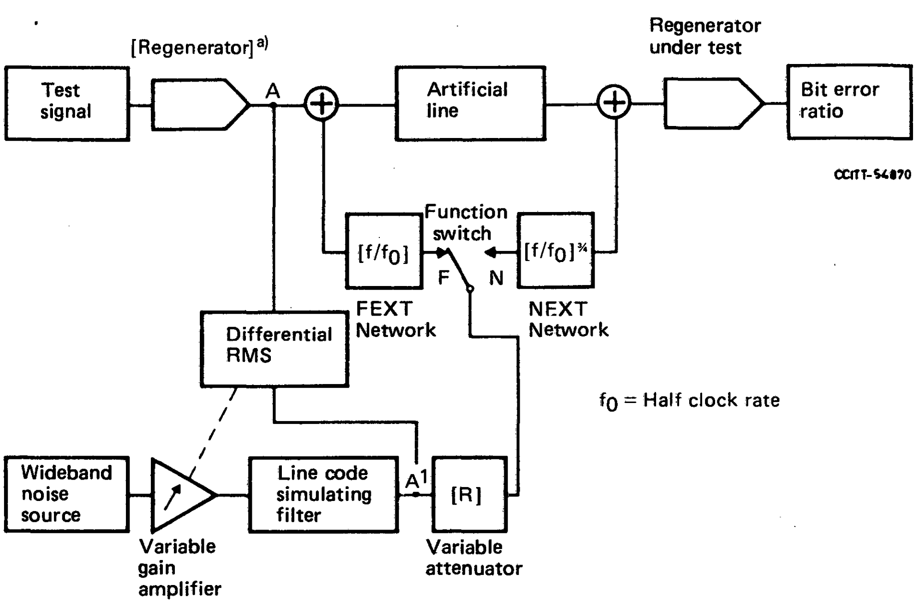
$G(f)$ = frequency transfer function of cable.

A.2 *Measurement*

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

Method a)

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



a) The regenerator can be omitted if the test signal generator provides the appropriate pulseshape.

FIGURE A-1/G.951

NEXT and FEXT-Noise Figure measurement

Method b)

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

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

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

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

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

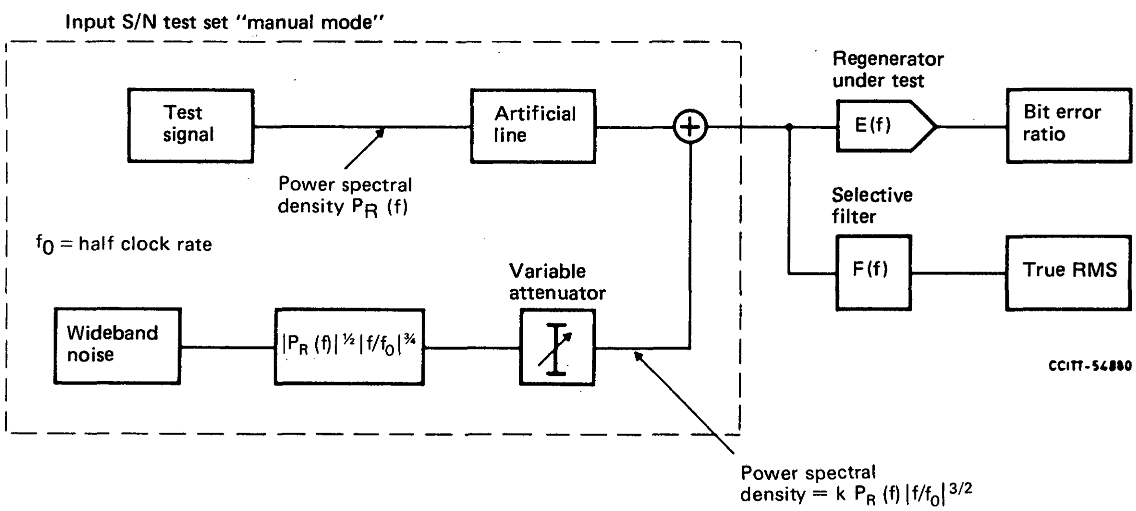


FIGURE A-2/G.951

NEXT-noise figure measurement using input S/N test set

Method c)

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

The measurement procedure is as follows:

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

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

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

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

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

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

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

In would be better to obtain W_N by measurement. Of course, the value of W_N can also be calculated according to $P_R(f)$ of AMI or HDB_3 in a certain frequency range, for example, $W_N = -3.59$ dB in the range from 0 to 10 240 kHz.

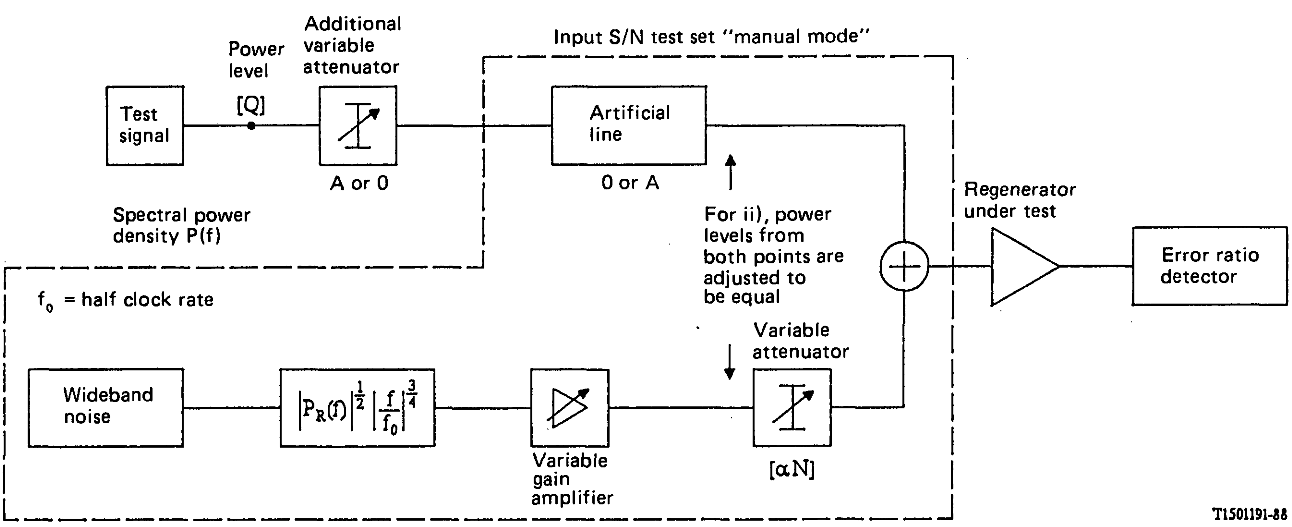


FIGURE A-3/G.951

NEXT-noise figure measurement using input S/N test set

ANNEX B

(to Recommendation G.951)

Guidance notes for the satisfactory achievement of the error performance objectives

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

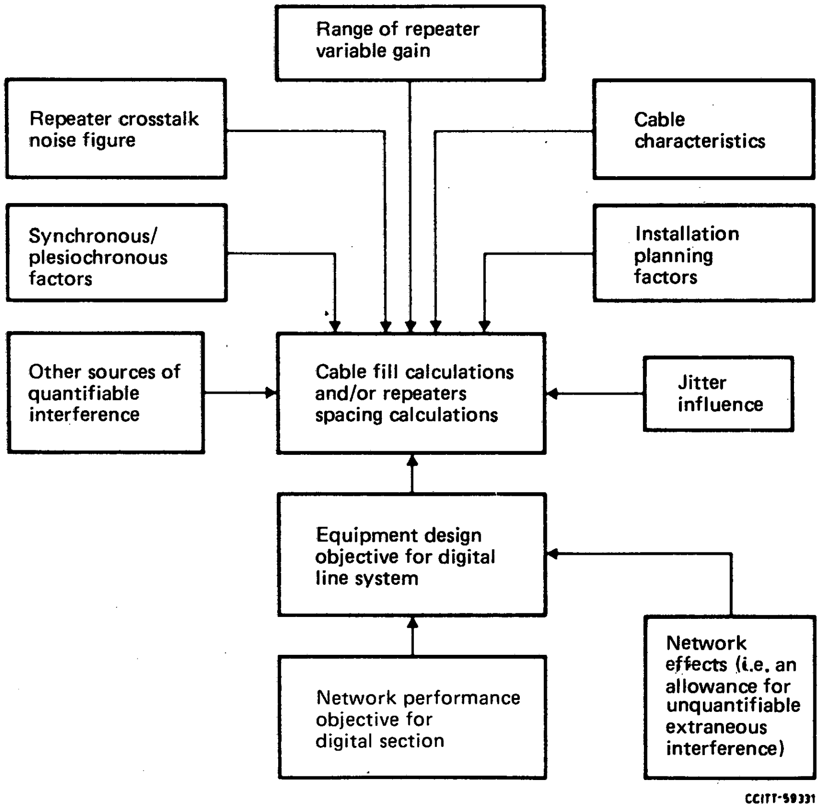


FIGURE B-1/G.951

Factors impacting on the error performance of a digital line system on symmetrical pairs

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

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

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

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

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

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

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

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

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

References

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

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

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

Recommendation G.952

DIGITAL LINE SYSTEMS BASED ON THE 2048 kbit/s HIERARCHY ON SYMMETRIC PAIR CABLES

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

1 General

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

2 048 kbit/s

8 448 kbit/s

34 368 kbit/s

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

2 Transmission medium

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

Note – 34 368 kbit/s systems should be operated on high performance cables and may require one cable for each direction of transmission.

3 Protection against interference from external sources

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

4 Overall design features

4.1 *Availability*

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

4.2 *Reliability*

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

4.3 *Repeater crosstalk-noise figures*

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

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

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

b) FEXT-Noise Figure $[R_F] \leqslant E$*.

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

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

Example	x	A_1	A_2	C	D	E	Test method
i	6	5	40	1.1	14.7	17.5	a
ii	7	10	40	1.0	19	–	b
iii	7	7	38	1.0	18	–	b

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

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

4.4 *Error performance*

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

5 Specific design features

5.1 *Type of power feeding*

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

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

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

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

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

5.2 *Repeater spacing and cable fill*

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

5.3 *Maintenance strategy*

5.3.1 *Type of supervision and fault location*

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

5.3.2 *Fault conditions and consequent actions*

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

a) failure of remote power feeding –
a prompt maintenance alarm should be generated, if practicable.

b) low error ratio threshold exceeded –
this threshold is $1 \cdot 10^{-5}$ for systems at 2048 and 8448 kbit/s
and $1 \cdot 10^{-6}$ for systems at higher bit rates;

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

ANNEX A

(to Recommendation G.952)

Definition and measurement of repeaters crosstalk-noise figures

A.1 *Definition*

a) NEXT-Noise Figure $[R_N]$

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

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

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

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

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

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

f_0 = half line system baud rate.

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

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

b) FEXT-Noise Figure $[R_F]$

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

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

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

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

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

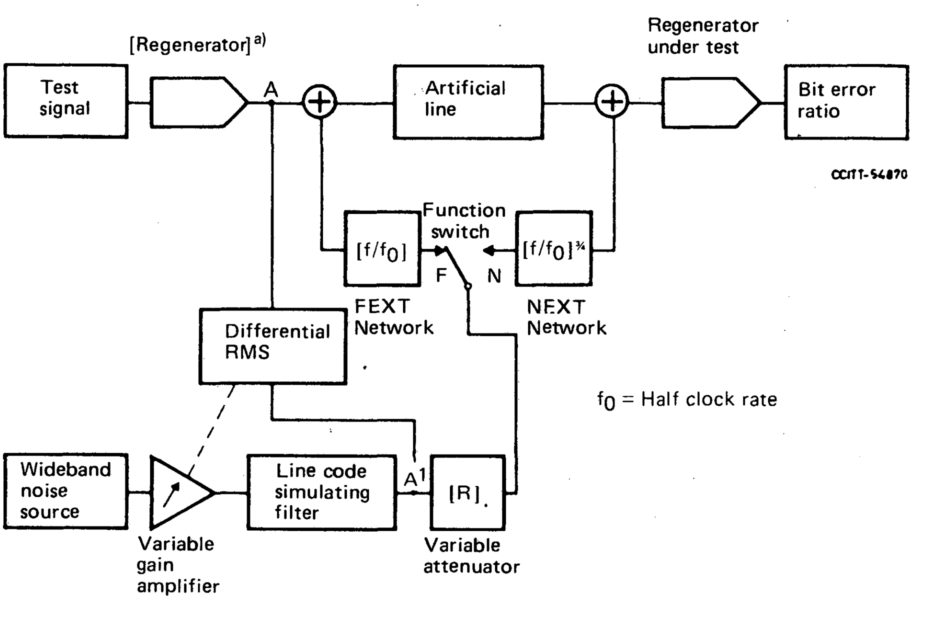
$G(f)$ = frequency transfer function of cable.

A.2 *Measurement*

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

Method a)

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



a) The regenerator can be omitted if the teste signal generator provides the appropriate pulseshape.

FIGURE A-1/G.952

NEXT and FEXT-Noise Figure measurement

Method b)

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

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

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

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

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

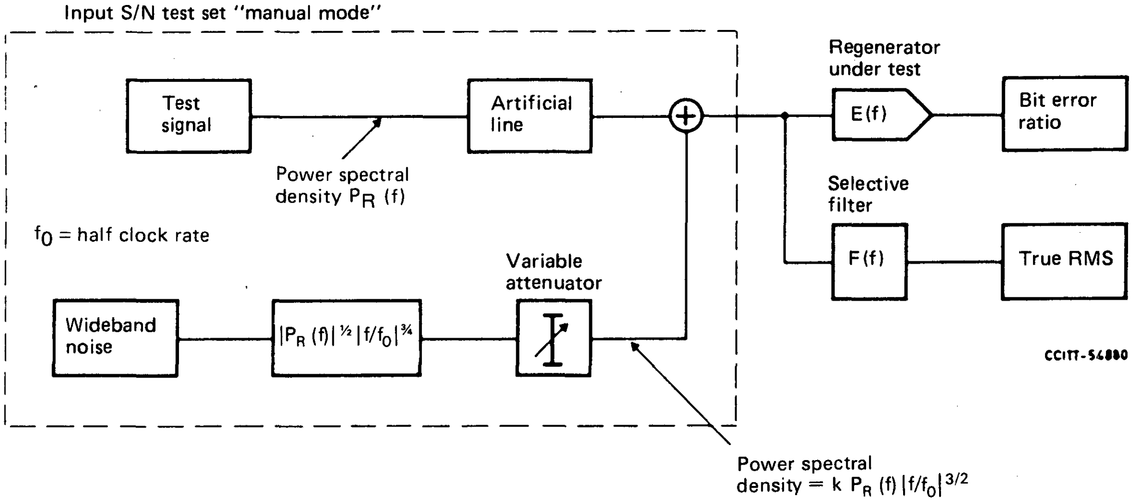


FIGURE A-2/G.952

NEXT-noise figure measurement using input S/N test set

Method c)

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

The measurement procedure is as follows:

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

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

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

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

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

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

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

In would be better to obtain W_N by measurement. Of course, the value of W_N can also be calculated according to $P_R(f)$ of AMI or HDB_3 in a certain frequency range, for example, $W_N = -3.59$ dB in the range from 0 to 10 240 kHz.

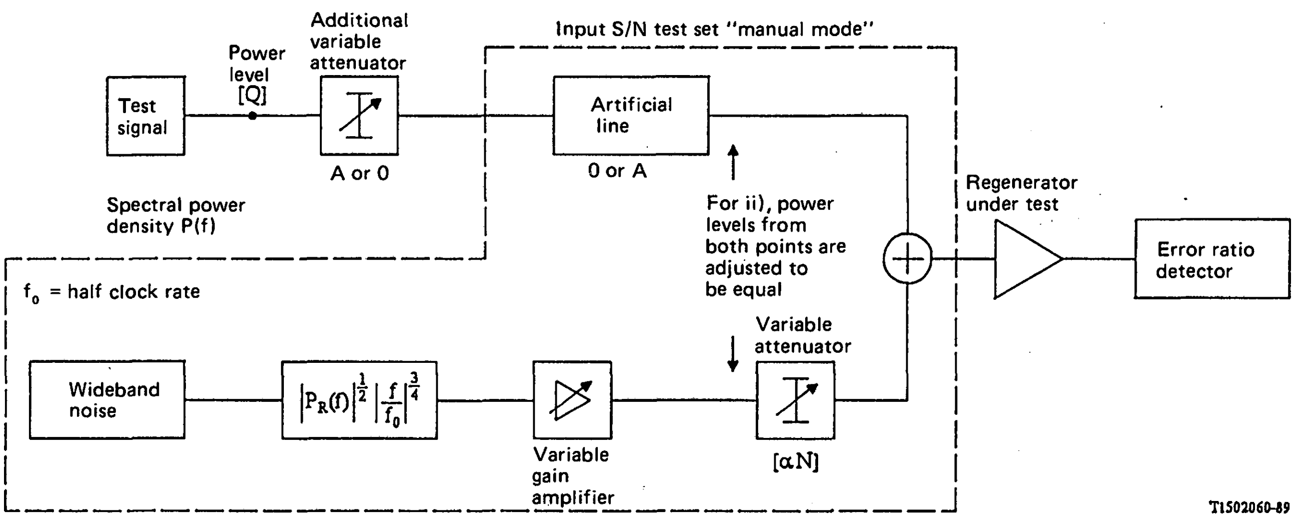


FIGURE A-3/G.952

NEXT-noise figure measurement using input S/N test set

ANNEX B

(to Recommendation G.952)

Guidance notes for the satisfactory achievement of the error performance objectives

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

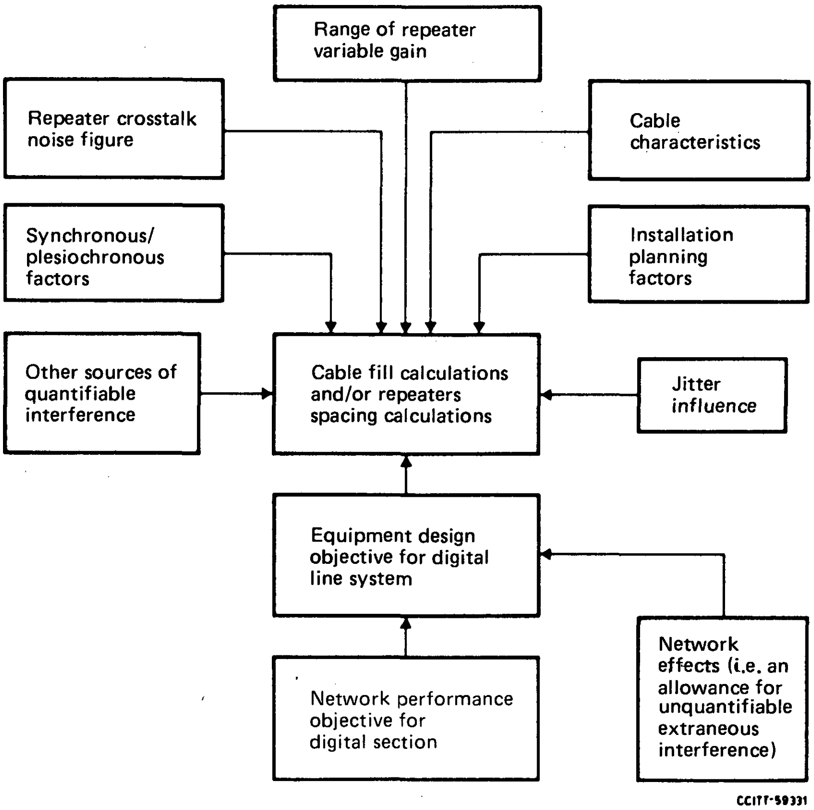


FIGURE B-1/G.952

Factors impacting on the error performance of a digital line system on symmetrical pairs

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

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

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

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

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

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

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

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

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

References

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

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

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

Recommendation G.953

DIGITAL LINE SYSTEMS BASED ON THE 1544 kbit/s HIERARCHY ON COAXIAL PAIR CABLES

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

1 General

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

44 736 kbit/s

97 728 kbit/s

2 Transmission media

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

TABLE 1/G.953

Transmission media

System (kbit/s)	Cable Recommendation
44 736	G.623
97 728	G.623

3 Overall design features

3.1 *Availability*

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

3.2 *Reliability*

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

3.3 *Repeater noise margin*

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

At a BER = 10^{-7} and over the loss range of the system $A_1 \leqslant A_0 \leqslant A_2$, the Noise Margin should meet the following specification:

Noise Margin $(M) \geqslant B + C(A_2 - A_0)$

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

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

3.4 *Error performance*

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

4 Specific design features

4.1 *Type of power feeding*

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

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

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

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

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

4.2 *Nominal repeater spacing*

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

TABLE 2/G.953

Nominal repeater spacings

	Nominal repeater spacing (km)
System (kbit/s)	Cable Recommendation [a)] G.623
44 736	–
97 728	4.5

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

4.3 *Maintenance strategy*

4.3.1 *Type of supervision and fault location*

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

4.3.2 *Fault conditions and consequent actions*

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

ANNEX A

(to Recommendation G.953)

Definition and measurement of repeater noise margin

A.1 *Definition*

The noise margin m_n:

$$m_n = SNR/SNR_{ER} \tag{A-1}$$

where:

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

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

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

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

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

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

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

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

$$ER = \frac{4}{3}\ P[E] = \frac{4}{3\sqrt{2\pi}} \int_{SNR_{ER}}^{\infty} e^{-x^{1/2}}\, dx \tag{A-4}$$

A.2 *Derived definitions*

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

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

$$SNR_{ER} = \left\{\frac{N_T}{N_T + N_E}\right\} \cdot SNR \tag{A-5}$$

where

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

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

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

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

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

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

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

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

k, T = Boltzmann constant and absolute temperature

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

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

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

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

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

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

Substraction gives:

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

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

Substitution of $SNR_{th} = S(0)/2\sqrt{N_T R_0}$ and some rearrangements results in the noise margin:

$$M = 20 \log 1 \cdot \left(\frac{I_s}{SNR_{ER} \cdot \sqrt{N_T R_0}} \right) \tag{A-9}$$

$$I_s = S_d \cdot |E(f_d)| \cdot a_c \tag{A-10}$$

S_d = the magnitude of the disturbing signal at the input of the regenerator

f_d = the frequency of the disturbing signal

a_c = a correction factor taking into account the effect of the disturbance on the peak detector of the automatic equalizer

R_0 = the real part of the characteristic impedance of the cable.

A.3 *Measurements*

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

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

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

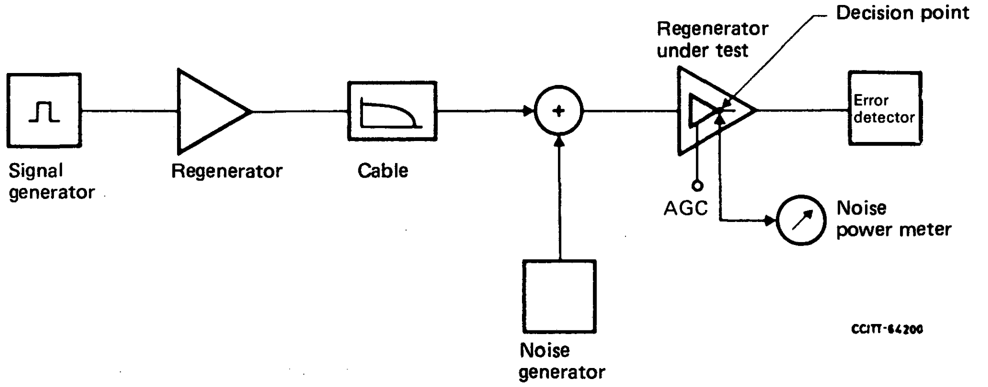


FIGURE A-1/G.953

Measurement of noise margin (Method A)

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

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

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

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

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

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

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

$$M = 20 \log (1 + S_d \cdot X / SNR_{ER})$$

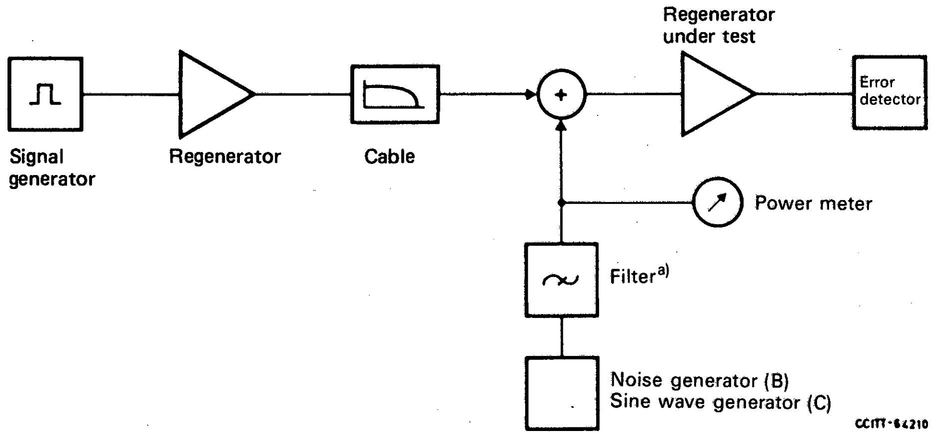
$$\text{where } X = |E(f_d)| \cdot a_c / \sqrt{N_T R_0}$$

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

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

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

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



a) Can be deleted in Method C.

FIGURE A-2/G.953

Measurement of noise margin (Methods B and C)

References

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

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

Recommendation G.954

DIGITAL LINE SYSTEMS BASED ON THE 2048 kbit/s HIERARCHY ON COAXIAL PAIR CABLES

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

1 General

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

8 448 kbit/s
34 368 kbit/s
139 264 kbit/s
4 × 139 264 kbit/s

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

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

2 Transmission media

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

TABLE 1/G.954

Transmission media

System (kbit/s)	Cable Recommendation
8 448	G.621; G.622
34 368	G.621; G.622; G.623
139 264	G.622; G.623
4 × 139 264	G.623

3 Overall design features

3.1 *Availability*

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

3.2 *Reliability*

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

3.3 *Repeater noise margin*

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

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

Noise Margin $(M) \geqslant B + C(A_2 - A_0)$

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

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

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

	A_1 (dB)	A_2 (dB)	B (dB)	C
8 448 kbit/s systems	35	85	9	1
34 368 kbit/s systems	34 56 45	84 82 75	7.5 6 12	0.7 0.5 1
139 264 kbit/s systems	65 60	84 84	5.5 7.5	0.7 0.7 → 1

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

3.4 *Error performance*

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

4 Specific design features

4.1 *Type of power feeding*

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

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

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

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

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

4.2 *Nominal repeater spacing*

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

TABLE 2/G.954

Nominal repeater spacings

System (kbit/s)	Nominal repeater spacing (km)		
	Cable Recommendation [a]		
	G.621	G.622	G.623
8 448	4.0	–	–
34 368	2.0	4.0 (Note)	–
139 264	–	2.0	4.5 (Note)
4 × 139 264	–	–	1.5

[a] G.621 refers to 0.7/2.9 mm coaxial pairs.
G.622 refers to 1.2/4.4 mm coaxial pairs.
G.623 refers to 2.6/9.5 mm coaxial pairs.

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

4.3 *Maintenance strategy*

4.3.1 *Type of supervision and fault location*

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

4.3.2 *Fault conditions and consequent actions*

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

a) failure of remote power feeding –
a prompt maintenance alarm should be generated, if practicable;

b) low error ratio threshold exceeded –
this threshold is $1 \cdot 10^{-5}$ for systems at 8448 kbit/s
and $1 \cdot 10^{-6}$ for systems at higher bit rates;

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

ANNEX A

(to Recommendation G.954)

Definition and measurement of repeater noise margin

A.1 *Definition*

The noise margin m_n:

$$m_n = SNR/SNR_{ER} \tag{A-1}$$

where

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

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

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

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

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

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

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

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

$$ER = \frac{4}{3} P[E] = \frac{4}{3\sqrt{2\pi}} \int_{SNR_{ER}}^{\infty} e^{-x^{2}/2}\, dx \tag{A-4}$$

A.2 *Derived definitions*

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

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

$$SNR_{ER} = \left\{\frac{N_T}{N_T + N_E}\right\} \cdot SNR \tag{A-5}$$

where

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

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

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

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

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

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

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

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

k, T = Boltzmann constant and absolute temperature

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

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

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

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

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

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

Substraction gives:

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

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

Substitution of $SNR_{th} = S(0)/2\sqrt{N_T R_0}$ and some rearrangements results in the noise margin:

$$M = 20 \log 1 \cdot \left(\frac{I_s}{SNR_{ER} \cdot \sqrt{N_T R_0}}\right) \tag{A-9}$$

$$I_s = S_d \cdot |E(f_d)| \cdot a_c \tag{A-10}$$

S_d = the magnitude of the disturbing signal at the input of the regenerator

f_d = the frequency of the disturbing signal

a_c = a correction factor taking into account the effect of the disturbance on the peak detector of the automatic equalizer

R_0 = the real part of the characteristic impedance of the cable.

A.3 *Measurements*

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

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

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

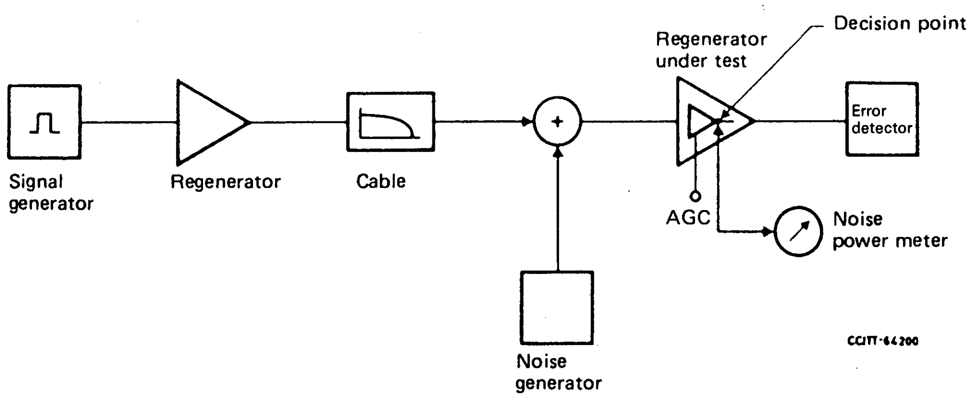


FIGURE A-1/G.954

Measurement of noise margin (Method A)

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

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

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

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

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

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

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

$$M = 20 \log (1 + S_d \cdot X/SNR_{ER})$$

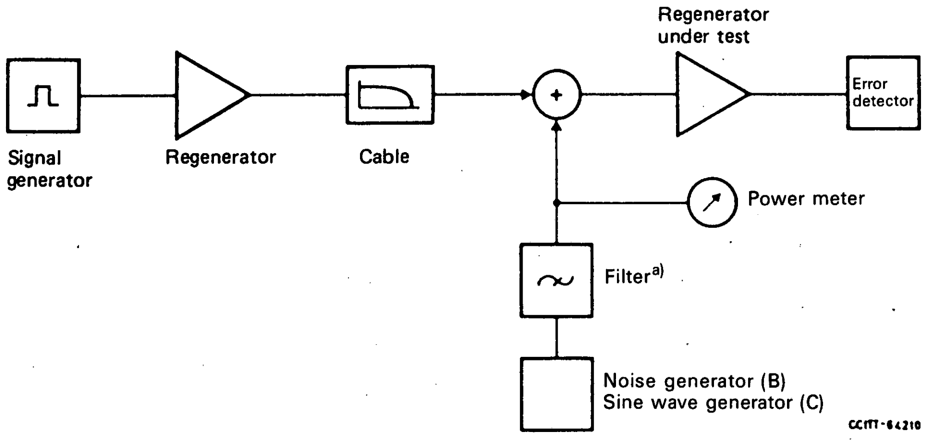
$$\text{where } X = |E(f_d)| \cdot a_c/\sqrt{N_T R_0}$$

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

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

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

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



a) Can be deleted in Method C.

FIGURE A-2/G.954

Measurement of noise margin (Methods B and C)

ANNEX B

(to Recommendation G.954)

Digital multiplexing strategy for 4 × 139 264 kbit/s systems

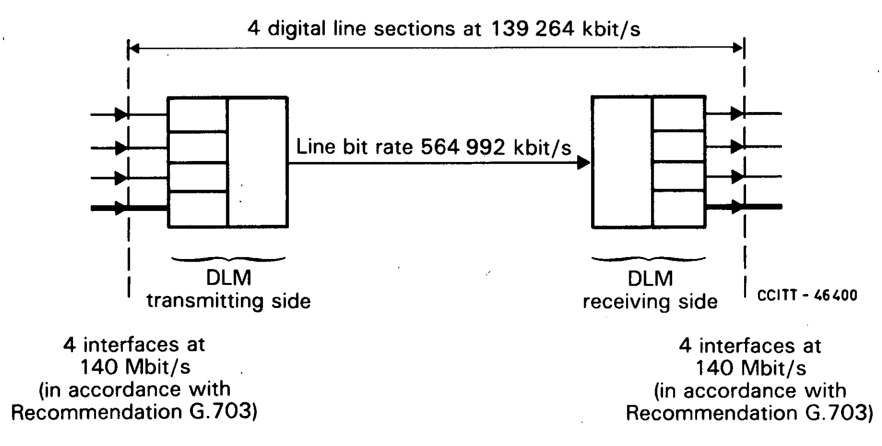


FIGURE B-1/G.954

DLM digital line muldex

B.1 *General*

The digital multiplexing strategy is based on the use of positive justification and combines four 139 264 kbit/s tributaries into one composite signal.

B.2 *Bit rate*

The nominal bit rate should be 564 992 kbit/s. The tolerance on that rate should be ± 15 parts per million (15 ppm).

B.3 *Frame structure*

Table B-1/G.954 gives:

- the tributary bit rate and the number of tributaries,
- the number of bits per frame,
- the bit numbering scheme,
- the bit assignment,
- the bunched frame alignment signal.

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

B.4 *Loss and recovery of frame alignment*

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

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

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

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

TABLE B-1/G.954

564 992 kbit/s multiplexing frame structure

Tributary bit rate (kbit/s)	139 264
Number of tributaries	4
Frame structure	Bit number
 Frame alignment signal (binary content under study) Bits from tributaries	*Set I* 1 to 12 13 to 384
 Justification service bits C_{jn} (n = 1 to 5) (see Note) Bits from tributaries	*Sets II to VI* 1 to 4 5 to 384
 Remote alarm indication, spare for national use Bits from tributaries available for justification Bits from tributaries	*Set VII* 1 to 4 5 to 8 9 to 384
Frame length Bits per tributary Maximum justification rate per tributary Nominal justification ratio	2688 bits 663 bits 210 190 bit/s 0.4390

Note – C_{jn} indicates the nth justification service bit of of the jth tributary.

B.5 *Multiplexing method*

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

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

B.6 *Jitter*

B.6.1 Jitter transfer characteristics (under study).

B.6.2 Tributary output jitter (under study).

B.7 *Service digits*

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

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

APPENDIX I

(to Annex B of Recommendation G.954)

A possible solution for scrambler and frame alignment signals for a digital line system at 4 × 139 264 kbit/s

I.1 *Reset scrambler*

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

- no error multiplication, and
- no necessity to provide additional measures to avoid periodic output signals.

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

- The scrambler works at ≈ 141 Mbit/s. Four sequences delayed with respect to each other (A0, A2, A5 and A6) are used to scramble the individual tributaries T1 ... T4; the four scrambled signals (c, d, e, f) are then multiplexed.
- Simple circuitry, hence easy realization at the high speed involved, and low power consumption.
- After resetting, the scrambler generates the frame alignment signal.

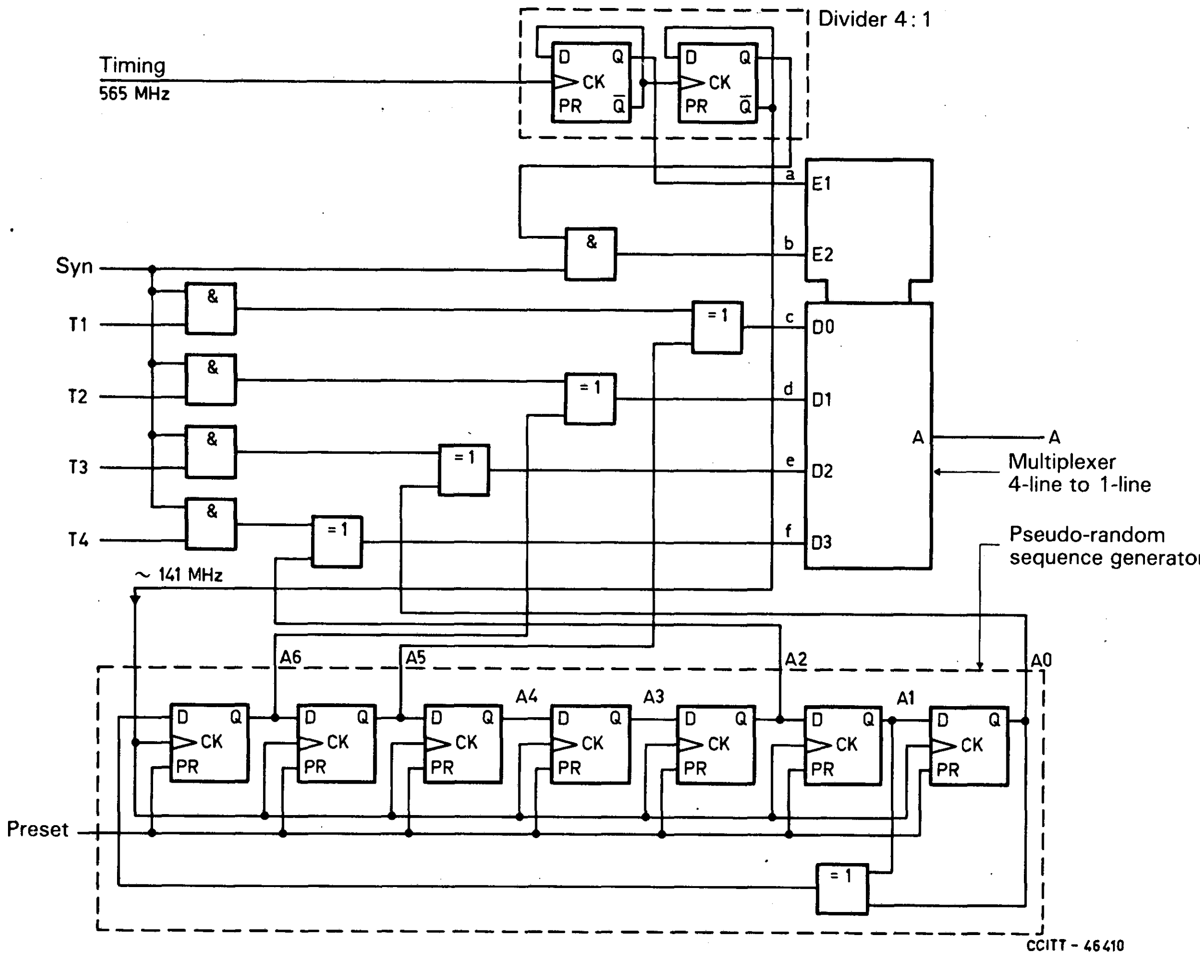
I.2 *Frame alignment signal*

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

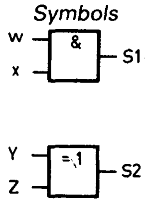
111110100000

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

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



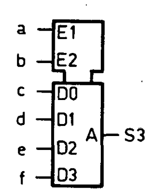
Symbols



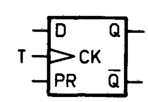
Truth tables

w	x	S1
0	0	0
1	0	0
0	1	0
1	1	1

Y	Z	S2
0	0	0
1	0	1
0	1	1
1	1	0



a	b	S3
0	0	c
1	0	d
0	1	e
1	1	f



PR	T	D	0
0	X	X	1
1	↑	a	a

Note – T represents the timing signal. The positive-going transition is the active transition.

Time t_n	A6	A5	A4	A3	A2	A1	A0	Preset	Syn	Multiplexed scrambler output signal	A	
0	1	1	1	1	1	1	1	0	0	A5 A6 A5 A6	1 1 1 1	Frame alignment word
1	0	1	1	1	1	1	1	1	0	A5 A6 A5 A6	1 0 1 0	
2	0	0	1	1	1	1	1	1	0	A5 A6 A5 A6	0 0 0 0	
3	0	0	0	1	1	1	1	1	1	A5 A6 A0 A2	T1 T2 $\overline{T3}$ $\overline{T4}$	Scrambled ↓
4	0	0	0	0	1	1	1	1	1	A5 A6 A0 A2	T1 T2 $\overline{T3}$ $\overline{T4}$	
5	0	0	0	0	0	1	1	1	1	A5 A6 A0 A2	T1 T2 $\overline{T3}$ T4	
6	0	0	0	0	0	0	1	1	1	A5 A6 A0 A2	T1 T2 $\overline{T3}$ T4	
7	1	0	0	0	0	0	0	1	1	A5 A6 A0 A2	T1 $\overline{T2}$ T3 T4	
8	0	1	0	0	0	0	0	1	1	A5 A6 A0 A2	$\overline{T1}$ T2 T3 T4	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

FIGURE I-1/G.954

Reset scrambler and multiplexer

APPENDIX II

(to Annex B of Recommendation G.954)

Possible alternative multiplex frame structures

Other multiplex frame structures at 564 992 kbit/s are possible which still retain the same per tributary frame structure as implied by the multiplex frame structure given in Figure I-1/G.954.

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

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

ANNEX C

(to Recommendation G.954)

Fault conditions and consequent actions for digital lines systems at 4 × 139 264 kbit/s

C.1 *Fault conditions*

The digital line system 4 × 139 264 kbit/s should detect the following fault conditions:

C.1.1 Failure of internal power supply.

C.1.2 Failure of power feeding of regenerators.

C.1.3 Error ratio $1 \cdot 10^{-3}$.

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

C.1.4 Error ratio $1 \cdot 10^{-6}$.

C.1.5 Loss of incoming line signal.

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

C.1.6 Loss of frame alignment.

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

Note – The detection of this fault condition is required only when it does not result in an indication "Error ratio $1 \cdot 10^{-3}$".

C.1.8 Loss of incoming signal on a tributary.

C.1.9 Remote alarm indication.

C.2 *Consequent actions*

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

TABLE C-1/G.954

Fault conditions and consequent actions

Equipment	Fault conditions	Maintenance alarms		Alarm indication to the remote line muldex generated	AIS applied, see § C.2	
		Prompt	Deferred		to all the tributaries	to the relevant time slot of the composite signal
Muldex	Failure of internal power supply	Yes			Yes, if practicable	
	Failure of power feeding of regenerators	Yes			Yes, if practicable	
Receiving side only of line muldex (See Figure 2/G.901)	Error rate 1×10^{-3}	Yes		Yes	Yes	
	Error rate 1×10^{-6}		Yes			
	Loss of incoming signal	Yes		Yes	Yes	
	Loss of frame alignment	Yes		Yes	Yes	
	Loss of line word alignment when alphabetic line code is used	Yes		Yes	Yes	
	Detection of remote alarm indication					
Transmitting side only of line muldex (See Figure 2/G.901)	Loss of incoming signal on a tributary	Yes				Yes

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

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

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

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

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

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

C.2.5 Alarm indication to the remote muldex generated.

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

Note 2 – The bit rate of this AIS should be within ± 15 ppm of the nominal bit rate.

References

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

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

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

Recommendation G.955

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

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

1 General

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

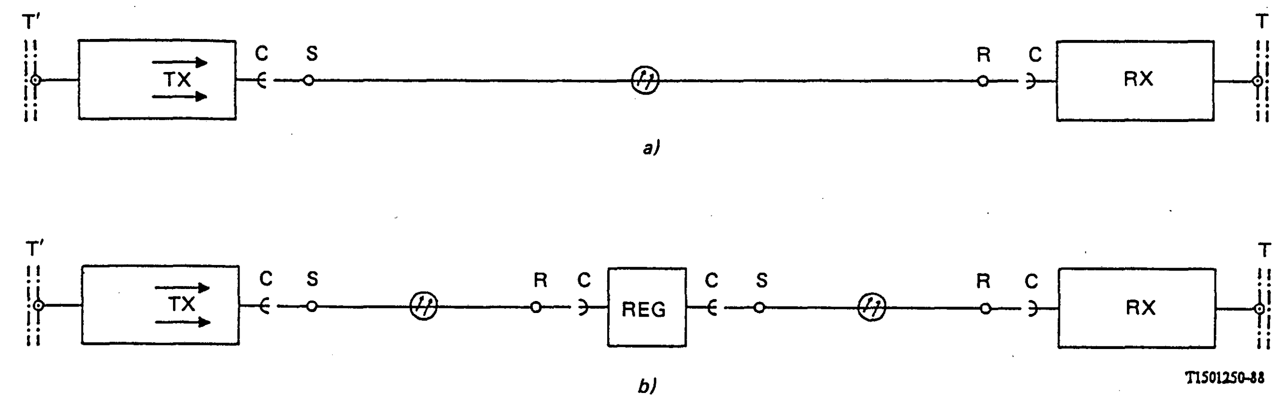
1 544 kbit/s
3 152 kbit/s
6 312 kbit/s
32 064 kbit/s
44 736 kbit/s
$n \times$ 44 736 kbit/s
97 728 kbit/s
4 × 97 728 kbit/s.

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

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

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

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



T, T′ Equipment interface in accordance with Recommendation G.703.
S Point on the optical fibre just after the transmitter (TX) or the regenerator (REG) optical connector (C).
R Point on the optical fibre just before the receiver (RX) or the regenerator (REG) optical connector (C).

Note – Additional connectors at a distribution frame (if used) are considered to be part of the fibre link and to be located between points S and R.

FIGURE 1/G.955

2 Type of transmission medium

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

3 System margin

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

3.1 *Cable margin (M_c)*

The cable margin, M_c, covers allowances for:

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

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

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

3.2 *Equipment margin (M_e)*

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

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

Note 2 – The system margin is in relation to a BER threshold of $1 \cdot 10^{-10}$ even though for practical reasons the measurements of receiver sensitivity may be carried out at other thresholds.

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

4 System specifications

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

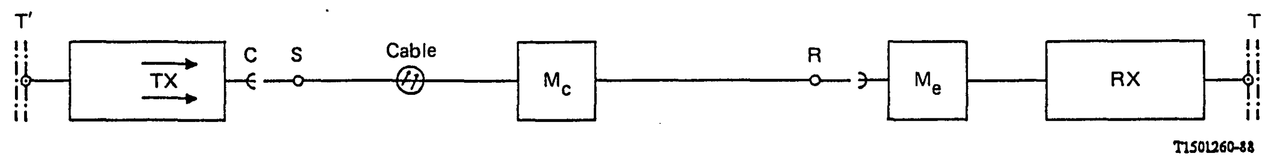


FIGURE 2/G.955

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

4.1 *Regenerator section lengths*

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

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

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

In general, for single-mode fibre systems employing laser sources operating near or below a nominal bit rate of 6 × 44 736 kbit/s, the regenerator section length is expected to be limited by loss and not by dispersion. At higher bit rates, the regenerator section length may be limited by dispersion. Therefore, it is desirable to check whether a regenerator section length is limited by loss or dispersion.

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

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

4.2 *Error performance*

Digital line systems in this Recommendation consider a maximum regenerator section length with a BER not worse than $1 \cdot 10^{-10}$. The error performance should be consistent with the overall performance in Recommendation G.821.

4.3 *Receiver dynamic range*

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

4.4 *Optical source*

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

4.5 *Operating wavelength range*

The nominal wavelengths of 850 nm and 1300 nm imply possible use anywhere in the range of 820-910 nm and 1270-1330 nm respectively, for systems operating up to and including nominal bit rates near 3 × 44 736 kbit/s. For higher than a nominal bit rate near 3 × 44 736 kbit/s the 1300 nm range is reduced to 1285-1330 nm. The range for the region around 1550 nm is under study.

Note 1 – For single-mode systems operating in the 1300 nm range, the lower wavelength limit is determined from consideration of dispersion and cut-off wavelength effects, while the upper wavelength limit is due to consideration of dispersion and attenuation. In particular it should be noted that the range quoted in this Recommendation is restricted compared to the dispersion range of 1270-1340 nm quoted in Recommendation G.652, because of the possibility of OH peak related excess losses. To ensure satisfactory system operation the cut-off wavelength of the shortest length of cabled fibre in a single-mode elementary cable section must not exceed the operating wavelength. The second order (LP_{11}) mode should be sufficiently attenuated along the fibre such that at the detector modal noise and bimodal dispersion effects are negligible.

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

4.6 *Recommended optical path allowances for multimode fibre systems*

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

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

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

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

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

TABLE 1/G.955

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

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	Allowances between S and R at 1×10^{-10} BER	
			Maximum attenuation (dB)	Minimum overall −3 dB optical bandwidth (MHz)
6 312	850	Laser	47	17
		LED	34	17
	1300	Laser	34	17
		LED	21	17
32 064	850	Laser	[a]	[a]
		LED	[a]	[a]
	1300	Laser	33	65
		LED	[a]	[a]
44 736	850	Laser	42	62
		LED	29	62
	1300	Laser	33	62
		LED	21	62
2 × 44 736	850	Laser	42	90
		LED	[a]	[a]
	1300	Laser	30	81
		LED	[a]	[a]
97 728	850	Laser	[a]	[a]
		LED	[a]	[a]
	1300	Laser	31	100
		LED	[a]	[a]
3 × 44 736	850	Laser	[a]	[a]
		LED	[a]	[a]
	1300	Laser	28	120
		LED	[a]	[a]

[a] Values under study.

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

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

TABLE 2/G.955

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

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	Allowances between S and R at 1×10^{-10} BER	
			Maximum attenuation (dB)	Maximum dispersion (ps/nm)
44 736	1300	Laser	32	N/A
	1550	Laser	a)	a)
2 × 44 736	1300	Laser	28	N/A
	1550	Laser	a)	a)
97 728	1300	Laser	31	a)
	1550	Laser	a)	a)
3 × 44 736	1300	Laser	28	N/A
	1550	Laser	a)	a)
4 × 44 736	1300	Laser	26	N/A
	1550	Laser	a)	a)
6 × 44 736	1300	Laser	26	(Note 2)
	1550	Laser	a)	a)
4 × 97 728	1300	Laser	28	(Note 2)
	1550	Laser	a)	a)
9 × 44 736	1300	Laser	26	(Note 2)
	1550	Laser	a)	a)
12 × 44 736	1300	Laser	24	(Note 2)
	1550	Laser	a)	a)
18 × 44 736	1300	Laser	24	(Note 2)
	1550	Laser	a)	a)
24 × 44 736	1300	Laser	24	(Note 2)
	1550	Laser	a)	a)
36 × 44 736	1300	Laser	23	(Note 2)
	1550	Laser	a)	a)

a) Values under study.

N/A – Not applicable.

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

Note 2 – Regenerator section lengths may be dispersion-limited. Specific values are dependent upon several factors and require further study. Refer § 4.1, regenerator section lengths, for other considerations.

4.8 *System margin*

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

4.9 *Trade-off considerations*

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

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

4.10 *Wavelength division multiplexing*

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

5 **Power feeding**

Power feeding arrangements, if any, require further study.

6 **Working conditions**

See Recommendation G.950.

7 **Overall design features**

Under study.

8 **Maintenance strategy**

8.1 *Type of supervision and fault location*

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

8.2 *Fault conditions and consequent actions*

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

9 **Safety considerations**

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

ANNEX A

(to Recommendation G.955)

Example of calculation of the regenerator section length for a 6 Mbit/s laser-based system operating at 850 nm on multimode fibre

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

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

– attenuation of the optical fibres at 850 nm		3.0 dB/km
– attenuation of the splices		0.4 dB/km
– cable margin (M_c)		0.4 dB/km
	Total	3.8 dB/km

Regenerator section length $\frac{47}{3.8} = 12.4$ km.

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

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

ANNEX B

(to Recommendation G.955)

Example of calculation of the regenerator section length for a 12 × 45 Mbit/s laser-based system operating at 1300 nm on single-mode fibre

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

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

– attenuation of the optical fibres at 1300 nm		0.40 dB/km
– attenuation of the splices		0.15 dB/km
– cable margin (M_c)		0.15 dB/km
	Total	0.70 dB/km

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

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

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

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

DIGITAL LINE SYSTEMS BASED ON THE 2048 KBIT/S HIERARCHY ON OPTICAL FIBRE CABLES

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

1 General

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

2 048 kbit/s

8 448 kbit/s

34 368 kbit/s

139 264 kbit/s

4 × 139 264 kbit/s (see Note).

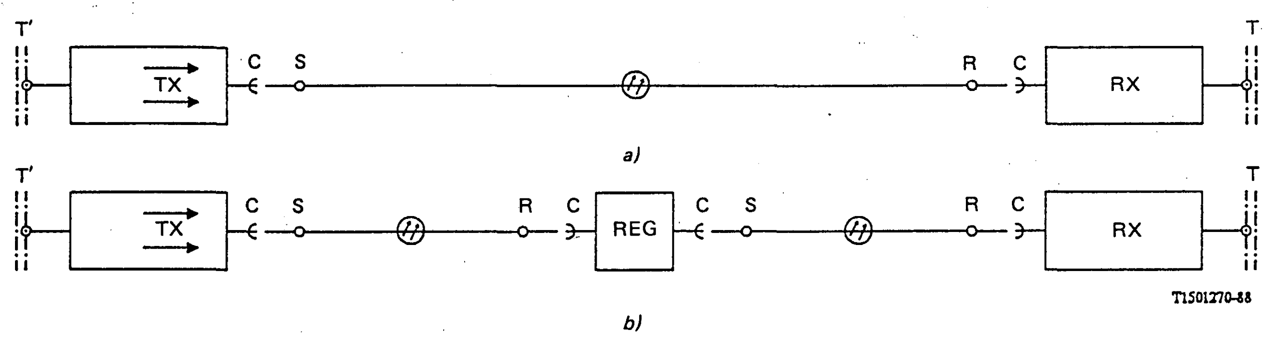
Note – Systems at higher bit rates are under study (for the time being, these bit rates are in the area of 1.2 Gbit/s and/or 2.4 Gbit/s).

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

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

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

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



T, T' Equipment interface in accordance with Recommendation G.703.
S Point on the optical fibre just after the transmitter (TX) or the regenerator (REG) optical connector (C).
R Point on the optical fibre just before the receiver (RX) or the regenerator (REG) optical connector (C).

Note – Additional connectors at a distribution frame (if used) are considered to be part of the fibre link and to be located between points S and R.

FIGURE 1/G.956

2 Type of transmission medium

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

3 System margin

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

3.1 *Cable margin (M_c)*

The cable margin, M_c, covers allowances for:

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

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

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

3.2 *Equipment margin (M_e)*

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

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

Note 2 – The system margin is in relation to a BER threshold of $1 \cdot 10^{-10}$ even though for practical reasons the measurements of receiver sensitivity may be carried out at other thresholds.

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

4 System specifications

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

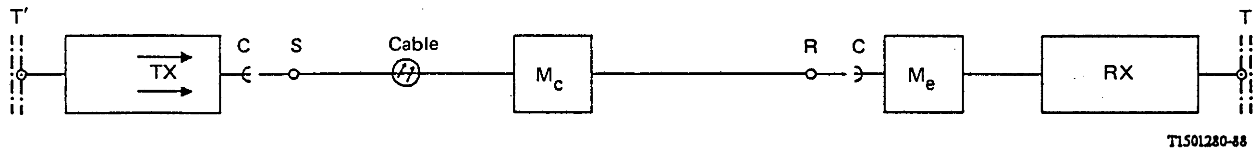


FIGURE 2/G.956

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

4.1 *Regenerator section lengths*

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

4.2 *Error performance*

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

4.3 *Receiver dynamic range*

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

4.4 *Optical source*

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

4.5 *Operating wavelength range*

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

Note – For single-mode systems operating in the 1300 nm range, the lower wavelength limit is determined from consideration of dispersion and cut-off wavelength effects, while the upper wavelength limit is due to consideration of dispersion and attenuation. In particular it should be noted that the range quoted in this Recommendation is restricted compared to the dispersion range of 1270-1340 nm quoted in Recommendation G.652, because of the possibility of OH peak related excess losses. To ensure satisfactory system operation, the cut-off wavelength of the shortest length of cabled fibre in a single-mode elementary cable section must not exceed the operating wavelength. The second order (LP_{11}) mode should be sufficiently attenuated along the fibre such that at the detector modal noise and bimodal dispersion effects are negligible.

4.6 *Optical path requirements for multimode fibre systems*

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

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

TABLE 1/G.956

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

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	Allowances between S and R at 1 × 10^{-10} BER	
			Maximum attenuation (dB)	Minimum overall −3 dB optical bandwidth (MHz)
2 048	850	Laser	51	10
		DEL	[a]	10
	1300	Laser	46	10
		DEL	30	10
8 448	850	Laser	47	20
		DEL	[a]	[a]
	1300	Laser	[a]	[a]
		DEL	[a]	[a]
34 368	850	Laser	41	50
		DEL	[a]	[a]
	1300	Laser	35	50
		DEL	22 [b]	50
139 264	850	Laser	35	100
		DEL	[a]	[a]
	1300	Laser	27	100
		DEL	18 [b]	100

[a] Values under study.

[b] Provisional value.

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

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

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

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

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

TABLE 2/G.956

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

Nominal bit rate (kbit/s)	Nominal wavelength (nm)	Source type	Allowances between S and R at 1 × 10^{-10} BER	
			Maximum attenuation (dB)	Maximum dispersion (ps/nm)
2 048	1300	Laser	46	N/A
	1550	Laser	a)	a)
8 448	1300	Laser	40	N/A
	1550	Laser	a)	a)
34 368	1300	Laser	35	N/A
	1550	Laser	a)	a)
139 264	1300	Laser	28 (Note 2)	300 (Note 3)
	1550	Laser	a)	a)
4 × 139 264	1300	Laser (Fabry-Perot)	24	120 (Note 1)
	1550	Laser	a)	a)

a) Values under study.

N/A Not applicable.

Note 1 – This value indicates the maximum permissible dispersion for 4 × 139 264 kbit/s systems at the limits of the operating wavelength range specified (1285 and 1330 nm). The system supplier will need to determine any resultant design penalty considering the effect of mode partition noise, chromatic dispersion, etc. due to the spectral characteristics of the optical source. For reliable operation of systems it may be necessary to limit the maximum dispersion at the system operating wavelength to less than 100 ps/nm; this can be achieved by confining the system operating wavelength to a reduced wavelength range close to the fibre dispersion zero.

Note 2 – For application in which the chief objective is to maximize the regenerator section length, values could be higher than 28 dB (e.g. 31 dB).

Note 3 – This value indicates the maximum possible dispersion for 139 264 kbit/s systems at the limit of the operating wavelength range specified (1270-1330 nm). To optimize the system design it may be necessary to limit maximum dispersion at the system operating wavelength to less than 300 ps/nm. This can be achieved by confining the system operating wavelength to a reduced wavelength range close to the fibre dispersion zero.

4.8 *Equipment margin (M_e)*

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

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

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

4.9 *Systems for short haul applications*

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

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

4.10 *Wavelength division multiplexing*

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

5 Power feeding

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

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

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

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

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

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

6 Working conditions

See Recommendation G.950.

7 Overall design features

Under study.

8 Maintenance strategy

8.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used. For bit rates equal to or above 139 264 kbit/s, in-service monitoring is recommended. In the absence of suitable metallic conductors in the optical cable the supervision of the intermediate regenerator, where appropriate, should be provided by the same two optical fibres used for the line systems.

8.2 *Fault conditions and consequent actions*

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

a) failure of remote power feeding (if applicable) –
a prompt maintenance alarm should be generated, if practicable;

b) low error ratio threshold exceeded –
this threshold is $1 \cdot 10^{-5}$ for systems at 2048 and 8448 kbit/s
and $1 \cdot 10^{-6}$ for systems at higher bit rates;

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

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

9 Safety considerations

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

ANNEX A

(to Recommendation G.956)

Example of calculation of the regenerator section length for a 34 Mbit/s laser-based system operating at 1300 nm on multimode fibre

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

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

– attenuation of the optical fibres at 1300 nm	1.0 dB/km
– attenuation of the splices	0.3 dB/km
– cable margin (M_c)	0.3 dB/km
Total	1.6 dB/km

Regenerator section length $\frac{35}{1.6} = 22$ km.

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

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

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

ANNEX B

(to Recommendation G.956)

Example of calculation of the regenerator section length for a 4 × 140 Mbit/s laser-based system operating at 1300 nm on single-mode fibre

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

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

– attenuation of the optical fibres at 1300 nm		0.40 dB/km
– attenuation of the splices		0.15 dB/km
– cable margin (M_c)		0.15 dB/km
	Total	0.70 dB/km

Regenerator section length $\frac{24}{0.7} = 34$ km.

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

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

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

9.6 Digital section and digital transmission systems for ISDN customer access

Recommendation G.960

DIGITAL SECTION FOR ISDN BASIC RATE ACCESS

(Melbourne, 1988)

1 General

1.1 *Scope*

This Recommendation describes the characteristics of a digital section for the ISDN basic rate access between the user network interface (at T reference point, defined in Recommendation I.411) and the local exchange (at V_1 reference point defined in Recommendation Q.512) supporting the recommended channel structure 2B + D and the required additional functions.

In this Recommendation and unless otherwise indicated, the term TE is used to indicate terminating layer 1 aspects of TE1, TA and NT2 functional groups.

When the term TE indicates terminating layer 1 aspects of TE1, then according to Figure 2/I.411, the S and T reference points coincide.

The terminology used in this Recommendation is very specific and not contained in the relevant terminology Recommendations. Therefore Annex B to this Recommendation provides terms and definitions used in this Recommendation.

1.2 *Configuration*

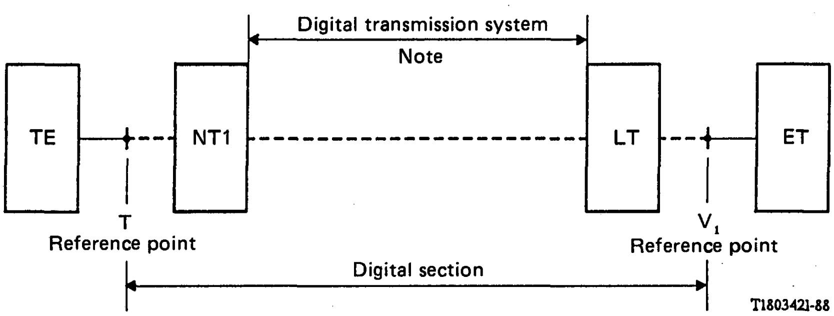
Figure 1/G.960 shows the boundaries of the digital section in relation to the digital system definition.

The concept of the digital section is used in order to allow a functional and procedural description and a definition of the network requirements.

Note that reference point T and V_1 are not identical and therefore the digital section is not symmetric.

The concept of a digital transmission system is used in order to describe the characteristics of a implementation, using a specific medium, in support of the digital section.

Note – The T and V reference points are defined in Recommendations I.411 and Q.512.



ET Exchange termination
LT Line termination
NT Network termination
TE Terminal equipment

Note – Digital transmission system refers to either a line system using metallic pairs, optical fibres or radio systems.

FIGURE 1/G.960

Digital section and transmission system boundaries

1.3 *Application*

The basic access digital section may be applied as given in Figure 2/G.960 for:

– direct access to the local exchange (V_1-reference point);

– access via a basic access multiplex equipment (V_4-interface) to the local exchange;

– access via a basic access concentrator (V_2-interface) to the local exchange;

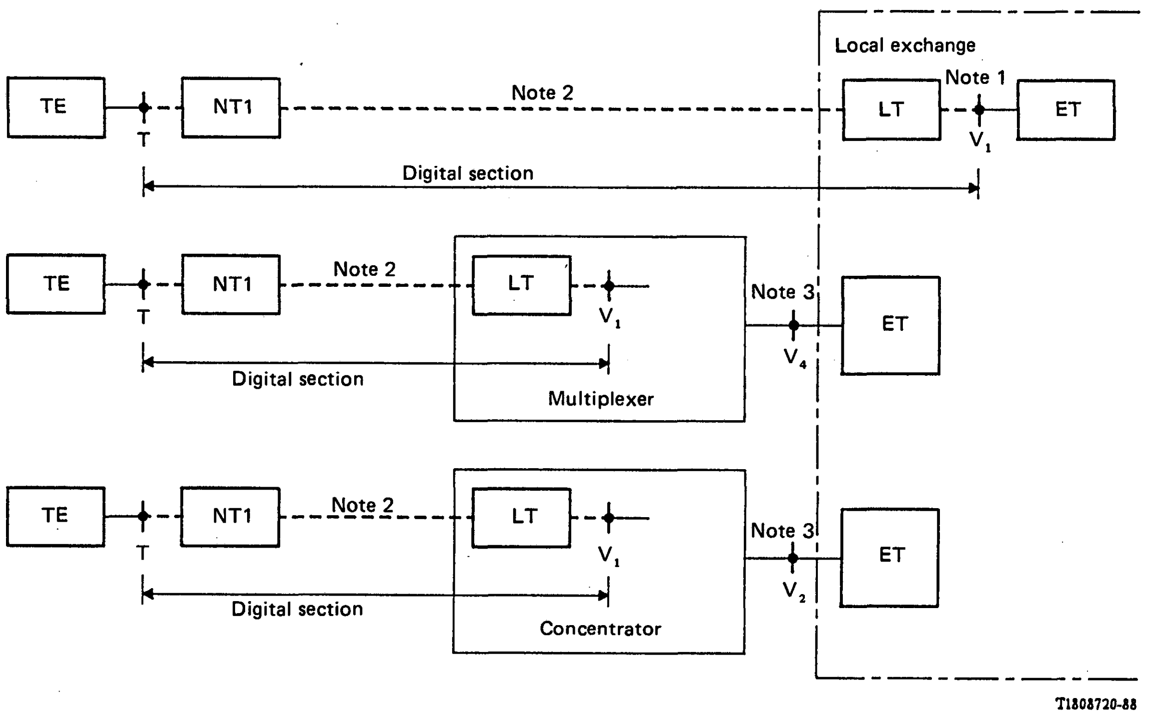
1.4 *Abbreviations*

A number of abbreviations are used in this Recommendation. Some of them are commonly used in the ISDN reference configuration while others are created only for this Recommendation. The last one are given in the following:

C_{V1}	Control Channel at V_1 reference point
DS	Digital Section
FE	Function Element used between ET and LT
FII	Failure Indication Information
INFO	Information element defined at the user network interface
SIG	Signal between LT an NT1

2 Modelling and relationship between the digital section and the ET

The general model shown in Figure 3/G.960 depicts the whole ISDN customer access layer 1 and adjacent entities and provides the basis to describe the functions performed by the digital section and those performed by TE, ET and system management and how various functions are grouped. In particular, according to this model the activation/deactivation procedures and maintenance functions specified in this Recommendation are not confined to functions performed by the digital section but include functions associated with ET layer 1.



Note 1 – The LT may be integrated together with the ET or separate (as integral part or outside of the local exchange).

Note 2 – In case of a digital section using a digital transmission system for metallic pairs the application of one regenerator may be foreseen.

Note 3 – Local and remote applications are envisaged. For the remote case a transparent link between the remote multiplexer or concentrator and the local exchange will be used.

FIGURE 2/G.960

Application of the digital section

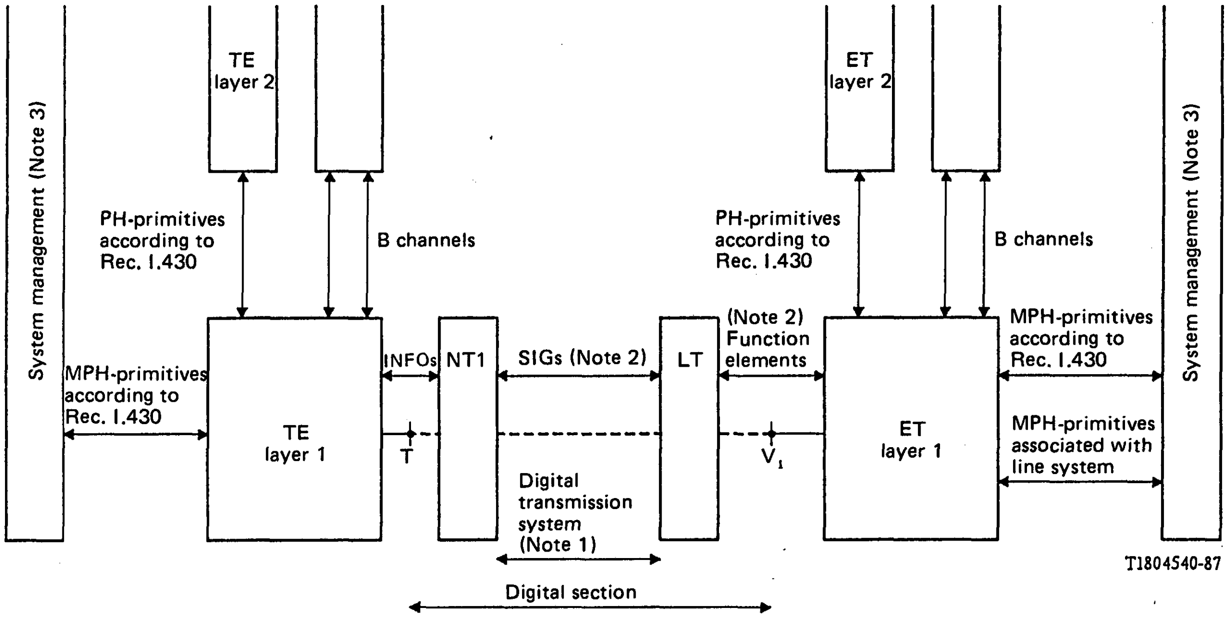
This model includes primitive procedures between ET layer 1, ET layer 2 and system management:

i) I.430 to I.440/I.441 interactions between ET layer 1 and ET layer 2, and ET layer 1 and system management based on PH and MPH primitives, respectively, as defined in Recommendation I.430. These interactions are for the support of functions specified in Recommendations I.440 and I.441;

ii) interactions between ET layer 1 and system management for the support of functions associated with the digital section, based on MPH primitives.

The primitive procedures within TE comply with the specification according to Recommendation I.430.

This model does not constrain layer 1 arrangements between LT and NT1, (it is also applicable to remote access as shown in Figure 2/G.960), or the digital transmission system technology.



Note 1 – The digital transmission system refers to either a digital line transmission system using a metallic pair of wires, optical fibre or radio system.

Note 2 – SIG, FE and primitives refer to an exchange of information. It does not imply any specific coding nor implementation. Some of these functions may be terminated in the LT and do not pass the digital transmission system.

Note 3 – The term system management corresponds to both system management and layer management as defined in Recommendation Q.940.

FIGURE 3/G.960

General model of ISDN customer access layer 1 and adjacent entities

3 Functions

Figure 4/G.960 shows the functions which have to be supported by the basic access digital section.

3.1 *B channel*

This function provides, for each direction of transmission, two independent 64 kbit/s channels for use as B Channels (as defined in Recommendation I.412).

3.2 *D channel*

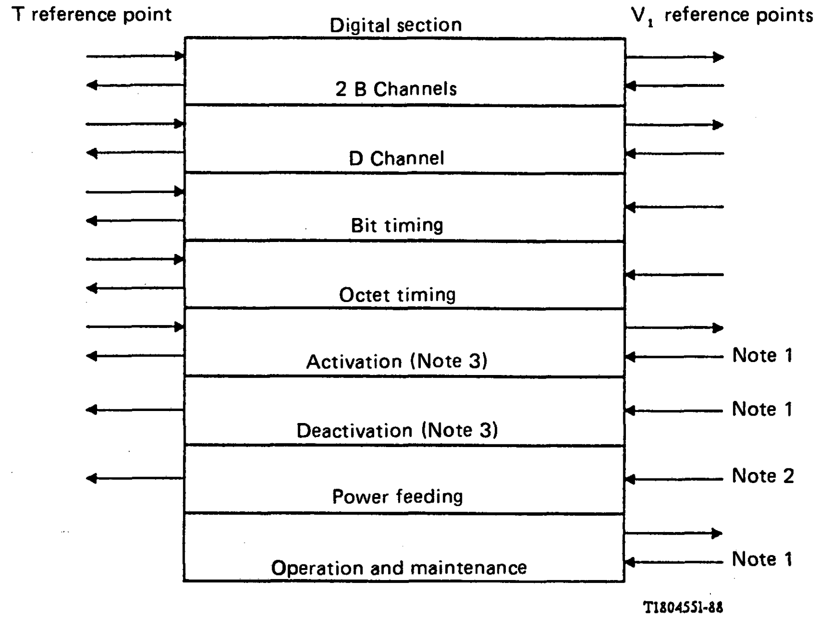
This function provides, for each direction of transmission, one D Channel at a bit rate of 16 kbit/s (as defined in Recommendation I.412).

3.3 *Bit timing*

This function provides bit (signal element) timing to enable the receiving equipment to recover information from the aggregate bit stream. Regarding the V_1 reference point, the bit timing function is used for both transmit and receive data.

3.4 *Octet timing*

This function provides 8 kHz octet timing for the B Channels.



Note 1 – These functions are conveyed by the C_{V1} channel across the V_1 reference point.

Note 2 – This function is optional.

Note 3 – The activation and deactivation functions are concerned with the operation of the digital section and the user-network interface. However, for consistency with Recommendations I.430, they are described as separate functions.

FIGURE 4/G.960

Functions of the digital section

3.5 *Activation*

3.5.1 *Activation from ET*

This function places all the functions of the digital section into a normal operating mode and supports the activation of the interface at the T reference point according to Recommendation I.430. This takes into account:

- power down mode;
- initial power up;
- a failure condition.

The procedures and exchange of information are described in § 5 of this Recommendation.

An activation should be possible to a state which allows maintenance actions to be performed in the digital section even when there is no customer equipment connected to the T reference point.

In the case of a basic access digital section making use of a digital transmission system for a metallic line one additional mode of operation may be applied for activation/deactivation, which is to activate/deactivate the digital section only. This is optional.

3.5.2 *Request for activation from TE*

This function supports activation of the digital section and of the interface at the T reference point according to Recommendation I.430.

These functions are conveyed by the C_{V1} channel (see § 7).

3.6 *Deactivation*

This function is specified in order to permit the interface at the T reference point and the digital section to be placed in a low power consumption mode. The procedures and exchange of information are described in § 5 of this Recommendation.

Deactivation should be initiated only by the exchange (ET).

This function is conveyed by the C_{V1} channel (see § 7).

3.7 *Power feeding*

This function provides for remote power feeding of NT1 and optionally the TE via the user network interface in accordance with Recommendation I.430, § 9.

3.8 *Operation and maintenance*

This function supports required actions and information for operating and maintaining the digital section controlled by the ET as defined in Recommendation I.603.

Four categories of functions have been identified:

- commands regarding LT, regenerator, or NT1;
- information from LT, regenerator, or NT1;
- indications of fault conditions;
- control of digital section power feeding.

These functions are conveyed by the C_{V1} channel (see § 7).

4 Network performance

4.1 *Availability*

The definition of availability is given in Annex A of Recommendation G.821. The availability objective of the digital section should be consistent with the availability requirement for the hypothetical reference digital section as given in Recommendations G.801 and I.350.

4.2 *Signal transfer delay*

Signal transfer delay is specified for B Channels and is defined as absolute signal delay between T and V_1 reference points for each direction of transmission. The value is for further study. The relevant Recommendations have to be taken into account (e.g. signal transmission delay when the signal represents speech must be taken into account as one component of the end-to-end delay requirement of Recommendation G.114).

4.3 *Error performance*

Error performance must be consistent with the requirements given in Recommendation G.821.

4.4 *Jitter*

4.4.1 *Output/input jitter at T reference point*

The requirements are defined in § 8 of Recommendation I.430.

4.4.2 *Jitter at V_1 reference point*

The input jitter limits are for further study.

5 *Activation/deactivation*

5.1 *Functional capabilities*

The digital section provides the layer 1 signalling capability and the necessary procedures to enable:

5.1.1 *Customer equipment at the user side of reference point T*

to activate the layer 1 of the user-network interface at reference point T and, if not already activated, the digital section.

5.1.2 *Equipment at the network side of V_1 reference point to*

a) activate:

1) the layer 1 of the user-network interface at reference point T and, if not already activated, the digital section (this activation is related to call control), or

2) the digital section only (this activation is related to controlling the configuration of the access; it is a network opinion),

b) deactivate:

1) the layer 1 of the user-network interface at reference point T and the digital section, or

2) the layer 1 of the user-network interface at reference point T only.

The functional capabilities defined in § 5.1.2 a) 2) allow maintenance actions in the digital section which do not impact the deactivated user-network interface at reference point T to be performed and make provision for the implementation of a non-transparent loopback 2. If required in some applications, they also permit the digital section to be placed in a mode where the full information transfer capability is available while the user-network interface at reference point T remains deactivated.

The procedures for the activation or deactivation of the layer 1 of the user-network interface at reference point T comply with the Recommendation I.430, § 6.2. These procedures are based on a repertoire of INFO signals as defined in Recommendation I.430 (Table 2/I.430).

The procedures at V_1 reference point are based on a repertoire of function elements (FEs). These FEs have specific relationships to primitives between the ET layer 1 and ET layer 2, and ET layer 1 and system management for the activation or deactivation of the layer 1 of the user-network interface in accordance with Recommendation I.430, § 6.2 and Recommendation I.440 and I.441. The means for defining these interactions are the primitive procedures (see Figure 5/1.430) based on a repertoire of PH- and MPH-primitives.

5.2 *Modelling*

5.2.1 *General*

The model for activation/deactivation procedures is given in § 2.

It is recognized that activation/deactivation is a process between customer equipment and local exchange requiring appropriate functionality at both ends. The model contained in § 2 includes the functional blocks relevant to activation/deactivation and depicts the primitives related to the activation/deactivation procedures.

5.2.2 *Partitioning of functions*

Recommendation I.430 defines the network side of the user-network interface at reference point T as one functional block which supports the layer 1 activation/deactivation procedures across the T reference point and the primitive procedures at the ET layer 1/ET layer 2 boundary and ET layer 1/system management boundary. This block includes the functional groupings NT1, LT and ET layer 1.

This concept is described in terms of a state machine, called the G state machine in Recommendation I.430.

In order to describe the relationship between signals across the user-network interface at reference point T and function elements across reference point V_1, and the relationship between function elements across reference point V_1 and primitives, two state machines are defined. One in the digital section (DS virtual state machine), and one at the network side of the V_1 reference point (ET layer 1 virtual state machine). Figure 5/G.960 illustrates this approach.

In addition to primitives defined in Recommendation I.430 and I.441 related to call control, Figure 5/G.960 also introduces a new set of primitives related to configuration control and the control of loopbacks. Partitioning of activation/deactivation procedures between two state machines is used for the convenience of easy and accurate description. The ET layer 1 state machine is to be viewed as virtual, not intended to imply any particular implementation.

However, in order to implement a customer access the virtual DS state machine has to be partitioned further. Figure 6/G.960 shows the partition of the DS state machine into NT1 state machine (NT-states) and LT state machine (LT-states).

The NT1 state machine supports user-network interface procedures in accordance with Recommendation I.430 based on the INFOs, and interacts with the LT state machine by means of a signal repertoire (SIGs) which has to be supported by the line transmission system. The LT state machine interacts with the ET layer 1 state machine by means of a set of function elements (FEs). The ET layer 1 state machine contains those states which represent the local exchange view of the status of the interface at reference point T and the digital section. It supports the already specified primitive procedures to provide services to ET layer 2 and system management in accordance with Recommendation I.430, and additional primitive procedures for the support of functions associated with the digital section.

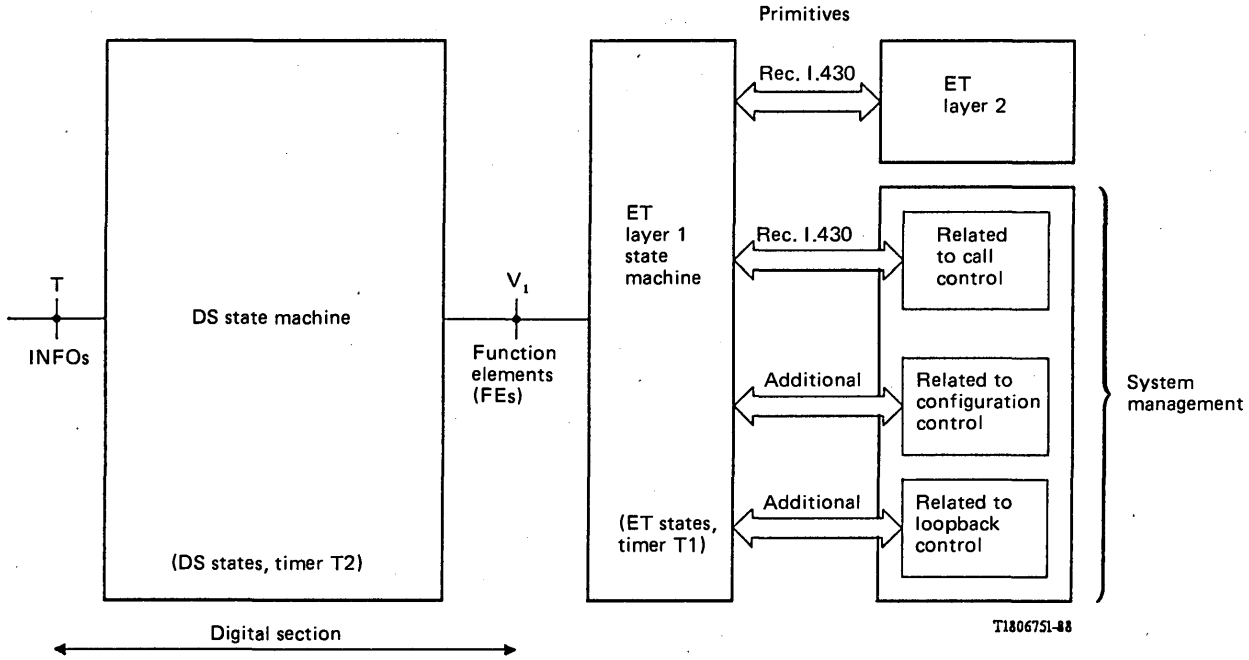


FIGURE 5/G.960

State machines

Figure 6/G.960 provides information for the description of the transmission system which is given in Recommendation G.961.

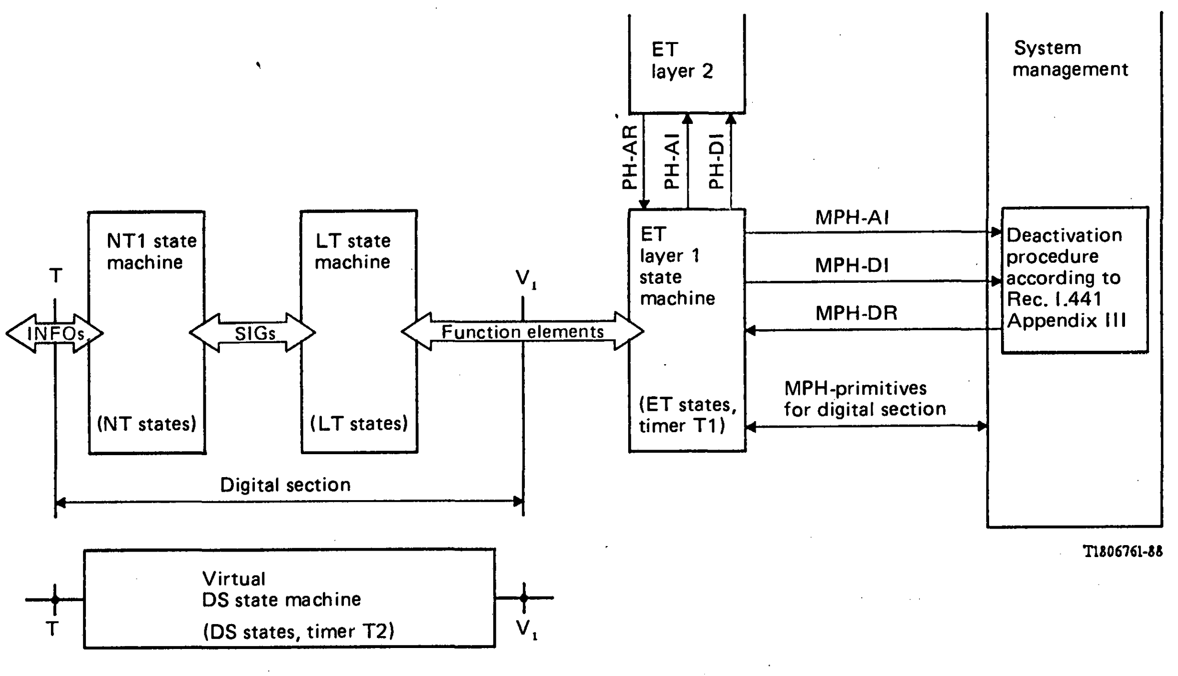


FIGURE 6/G.960

Partitioning of the DS state machine

5.2.3 *Location of timers T1 and T2*

In the following description of the DS and ET layer 1 state machines, timer T1 will be associated with ET layer 1 (ET layer 1 state machine) while timer T2 will be associated with the digital section (DS state machine).

The association of timer T1 with layer 1 of the ET is applied for the convenience of easy description but may be implemented anywhere while being functional part of the ET. The exact location of timer T2 within the digital section does not impact the description of the DS state machine.

5.3 *Activation/deactivation procedures*

The procedures allow the activation/deactivation of the user-network interface at reference point T. The activation may be invoked by either side while deactivation may only be invoked by the network. The overall activation/deactivation procedures can be divided into three classes:

a) basic procedures for call control used to activate the layer 1 of the user-network interface at the T reference point and if not already activated, the digital section;

b) procedures to control loopbacks;

c) procedures to control the configuration.

5.3.1 *Basic characteristics of the procedures*

5.3.1.1 *Priority*

Priority refers to contention resolution between activation/deactivation requests which have been invoked concurrently.

If contention between conflicting activation/deactivation requests from layer 2 and system management occurs it is resolved in the ET layer 1 state machine, which will then pass to the V_1 reference point a coordinated set of Function Elements (FEs). Table 1/G.960 shows the ET layer 1 state machine priority order.

TABLE 1/G.960

Priority order of request in the ET layer 1 state machine

Type of request	Priority order
Deactivation request	3 (highest)
Loopback	2
Call control activation request	1
Digital section only activation/deactivation request from the ET side	0 (lowest)

If contention between conflicting activation/deactivation requests from ET side and user side occurs it is resolved in the DS state machine. Table 2/G.960 shows the DS state machine priority order.

TABLE 2/G.960

Priority order of requests in the DS state machine

Type of request	Priority order
Request from ET side except digital section only activation	2 (highest)
Call control activation request from user side	1
Digital section only activation/deactivation request from the ET side	0 (lowest)

5.3.1.2 *System management*

Some assumptions related to the system management are described in Annex A.

5.3.1.3 *Loopbacks*

In case a transparent loopback 2 is applied, the NT1 shall send INFO 4 frames toward the user with the D-echo-channel set to binary ZERO.

With a transparent loopback 1, the NT1 (when able to activate the user-network interface at the T reference point) shall send INFO 4 frames toward the user with the D-echo-channel set to binary ZERO or operating normally.

5.3.1.4 *Protection of layer 2 frames*

According to Recommendation I.430 § 6.2.6.1 a TE is allowed to take up to 100 ms to synchronize on INFO 2, no lower time limit is defined. The different time each TE may take to synchronize on INFO 2 affects the offering of an incoming call in layer 1 multiple terminal arrangements. The fastest TE notifies to the network that the access is activated and the message offering the incoming call (SETUP) may be transmitted (TE ready to receive the message) while other TEs are not yet ready to receive the message.

This could result in the slow TEs loosing all or part of the incoming messages (layer 2 frames).

The protection mechanism is for further study.

5.3.1.5 *Structure of the tables*

Both the DS state transition table and the ET layer 1 state transition table are structured such that the three classes of the activation/deactivation procedures described at the beginning of § 5.3 are clearly separated. This allows implementation of the basic procedure only.

5.3.1.6 *Transmission of INFO 2*

In the following procedures two different internal events of the digital section are considered to start transmission of INFO 2:

a) the transmission system is synchronized in the direction LT to NT1

b) the transmission system is synchronized in both directions of transmission (see Note 2, Table 3/G.960)

5.4 *Description of the state transtition tables*

5.4.1 *Description of the DS state transition table*

5.4.1.1 *Digital section states (DS-states)*

Hereafter are defined the states that the digital section may enter as a result of: INFOs received across reference point T, function elements (FEs) received across reference point V_1, or internal events.

The DS-states are classified according to the functionality they support as follows:

i) DS 1.X states for the support of functionality according to Recomendation I.430;

ii) DS 2.X states for the support of functionality related to loopbacks (these states complement DS 1.X states);

iii) DS 3.X states for the support of functionality related to digital section only activation/deactivation (these states complement DS 1.X states).

The X represents the specific state within each mode. Some values of X are not used in mode 2 and 3 in order to have a consistent use of them.

5.4.1.1.1 State DS 1.0 (fully deactivated): in this state state, the digital section is in a non-operational mode and as seen from the user side of reference point T, the network side is in state G1 according to Recommendation I.430 § 6.2.1.2.1.

5.4.1.1.2 State DS 1.1 (pending activation access): this transitional state is entered when an activation of the access was requested by the network (by means of either the PH- or MPH-ACTIVATE-REQUEST primitive) or the user (by means of INFO 1 across T reference point) while the digital section was in the state DS 1.0. An awake process takes place to establish the digital section conditions which allow the transmission of INFO 2 across T reference point. As seen from the user side of reference point T, the network side is in state G1 according to Recommendation I.430 § 6.2.1.2.1.

5.4.1.1.3 State DS 1.2 (transitional state access activation): when entering this transitional state the network initiates transmission of INFO 2 across reference point while waiting for the digital section to be fully synchronized and the receipt of INFO 3. As seen from the user side of reference point T, the network side is in state G2 according to Recommendation I.430 § 6.2.1.2.2.

5.4.1.1.4 State DS 1.3 (digital section fully activated): in this transitional state, the digital section is synchronized in both directions of transmission and the network sends INFO 2 across T reference point while waiting for INFO 3. As seen from the user side of reference point T, the network side is in state G2 according to Recommendation I.430 § 6.2.1.2.2. This state is also entered if loss of synchronization occurs at reference point T while in the state DS 1.5.

5.4.1.1.5 State DS 1.5 (interface at T activated): this is the normal active stable state where the layer 1 service is available to the higher layers. The network sends INFO 4 across T reference point and as seen from the user side, the network side is in state G3 according to Recommendation I.430 § 6.2.1.2.3.

5.4.1.1.6 State DS 1.6 (pending deactivation access): this transitional state is entered if the system management instructed the digital section to deactivate the access. As seen from the user side of reference point T, the network side is in state G4 according to Recommendation I.430 § 6.2.1.2.4.

5.4.1.1.7 State DS 1.7 (transitional state access deactivation): in this transitional state, the interface at reference point T is already deactivated. The deactivation of the digital section is in progress. As seen from the user side of reference point T, the network side is in state G1 according to Recommendation I.430 § 6.2.1.2.1.

5.4.1.1.8 State DS 1.8 (transitional state access deactivation): in this transitional state, the digital section is already deactivated. The deactivation of the interface at reference point T is in progress. As seen from the user side of reference point T, the network side is in state G4 according to Recommendation I.430 § 6.2.1.2.4.

5.4.1.1.9 States DS 2.X: for further study.

5.4.1.1.10 State DS 3.1 (pending activation digital section only): this transitional state is entered when an activation of the digital section only was requested by the network (by means of the MPH-DIGITAL SECTION ACTIVATE-REQUEST primitive, MHP-DSAR). The digital section was previously in the state DS 1.0 or a deactivation of the access was previously in progress. As seen from the user side of reference point T, the network side is in state G1 according to Recommendation I.430 § 6.2.1.2.1.

5.4.1.1.11 State DS 3.2 (transitional state digital section activation): this transitional state is entered when an activation of the digital section only was requested by the network (by means of the MPH-DIGITAL SECTION ACTIVATE-REQUEST primitive, MPH-DSAR). The deactivation of the access was previously in progress. As seen from the user side of reference point T, the network side is in state G4 according to Recommendation I.430 § 6.2.1.2.4.

5.4.1.1.12 State DS 3.3 (digital section only activated): in this stable state, the digital section is synchronized in both directions of transmission and this has been notified to the system management by means of the MPH-DIGITAL SECTION ACTIVATE-INDICATION primitive (MPH-DSAI). The network sends INFO 0 across T reference point. As seen from the user side of reference point T, the network side is in state G1 according to Recommendation I.430 § 6.2.1.2.1.

5.4.1.1.13 State DS 3.4 (pending activation interface): this transitional state is entered when an activation of the interface was requested by the network (by means of either the PH- or MPH-ACTIVATE-REQUEST primitive) or the user (by means of INFO 1 across the T reference point) while the digital section was already in the activated state, state DS 3.3. The network immediately transmits INFO 2 across the T reference point. As seen from the user side of reference point T, the network side is in state G2 according to Recommendation I.430 § 6.2.1.2.2.

5.4.1.1.14 State DS 3.6 (pending deactivation interface): this transitional state is entered if the system managemnt instructed the digital section to deactivate the interface at reference point T but to remain activated. As seen from the user side of reference point T, the network side is in state G4 according to Recommendation I.430 § 6.2.1.2.4.

5.4.1.2 *Repertoire of signals across the user-network interface at the T reference point*

The definition of INFO signals is contained in Recommendation I.430 § 6.2.2.

5.4.1.3 *Repertoire of function elements at the V_1 reference point*

The function elements represent input signals which are consumed if a state transition occurs, even if it is a null transition (remain in the same state), and are not longer available to initiate one more state transition.

The following repertoire of function elements associated with the activation/deactivation procedures is defined:

- FE 1 (LT ← ET): activation request for the interface at reference point T
- FE 2 (LT → ET): request to start timer T1 within ET layer 1
- FE 3 (LT → ET): the digital section is activated
- FE 4 (LT → ET): user-network interface at the T reference point is activated or loopback is operated
- FE 5 (LT ← ET): deactivation request for the digital section and interface at reference point T
- FE 6 (LT → ET): the digital section is deactivated and the interface at reference point T will be or has been deactivated
- FE 7 (LT → ET): error indication
- FE 8 (LT ← ET): activation request for loopback 2
- FE 9 (LT ← ET): activation request for loopback 1
- FE 10 (LT ← ET): activation request for loopback 1A
- FE 11 (LT ← ET): request to enter a state where the digital section only is activated

5.4.1.4 *Specification of the procedures*

5.4.1.4.1 *Procedures across the user-network interface at reference point T*

The digital section supports the procedures across the user-network interface at reference point T in accordance with Recommendation I.430 § 6.2.

5.4.1.4.2 *Digital section state transition table*

The state transition table, see Table 3/G.960, specifies the procedures. It includes the actions to be taken on various events while in a specific state (see § 5.4.1.1 for the definition of the states). In particular, the actions to support the activation/deactivation procedures across the reference point T in accordance with Recommendation I.430 (sequence of INFOs in compliance with I.430). The procedures for loopback operation require further study.

TABLE 3/G.960

State transition table of digital section (DS state machine)

State number	DS 1.0	DS 1.1	DS 1.2 (Note 2)	DS 1.3 (Note 2)	DS 1.5	DS 1.6	DS 1.7 (Note 3)	DS 1.8 (Note 3)
INFO SENT	INFO 0	INFO 0	INFO 2	INFO 2	INFO 4	INFO 0	INFO 0	INFO 0
FE 1	DS 1.1	na	na	na	na	DS 1.1	DS 1.1	DS 1.1
FE 5	na	Start T2 DS 1.6	Start T2 DS 1.6	Start T2 DS 1.6	Start T2 DS 1.6	na	na	na
Receiving INFO 0 (Note 1)	–	–	–	–	FE 7 DS 1.3	DS 1.7	–	DS 1.0
Receiving INFO 0	FE 2 DS 1.1	–	–	–	/	–	FE 2 DS 1.1	–
Receiving INFO 3	/	–	–	FE 4 DS 1.5	–	–	/	/
Lost framing at T (Note 1)	/	–	–	–	FE 7 DS 1.3	–	/	/
Expiry of timer T2	–	–	–	–	–	DS 1.7	–	DS 1.0
Ready to transmit INFO 2	–	DS 1.2	–	–	–	–	–	–
Digital section fully activated	–	–	FE 3 DS 1.3	–	–	–	–	–
Digital section fully deactivated	–	–	–	–	–	FE 6 DS 1.8	FE 6 DS 1.0	–

DS-states related to loopbacks	DS 3.1	DS 3.2	DS 3.3	DS 3.4	DS 3.6
INFO SENT	INFO 0	INFO 0	INFO 0	INFO 2	INFO 0
FE 1	DS 1.1	na	DS 3.4	na	DS 3.4
FE 5	DS 1.7	DS 1.6	DS 1.7	–	DS 1.6
Receiving INFO 0 (Note 1)	–	DS 3.1	–	–	DS 3.3
Receiving INFO 0	FE 2 DS 1.1	–	FE 2 DS 3.4	–	–
Receiving INFO 3	–	–	–	FE 4 DS 1.5	–
Lost framing at T (Note 1)	–	–	–	/	–
Expiry of timer T2	–	DS 3.1	–	–	DS 3.3
Ready to transmit INFO 2	–	–	–	–	–
Digital section fully activated	FE 3 DS 3.3	FE 3 DS 3.6	–	–	–
Digital section fully deactivated	–	–	–	–	–

TABLE 3/G.960 *(cont.)*

State number	DS 1.0	DS 1.1	DS 1.2 (Note 2)	DS 1.3 (Note 2)	DS 1.5	DS 1.6	DS 1.7 (Note 3)	DS 1.8 (Note 3)	DS-states related to loopbacks	DS 3.1	DS 3.2	DS 3.3	DS 3.4	DS 3.6
INFO sent	INFO 0	INFO 0	INFO 2	INFO 2	INFO 4	INFO 0	INFO 0	INFO 0		INFO 0	INFO 0	INFO 0	INFO 2	INFO 0
FE 8														
FE 9														
FE 10														
FE 11	DS 3.1	–	–	Start T2 DS 3.6	Start T2 DS 3.6	DS 3.2	DS 3.1	DS 3.1		na	na	na	Start T2 DS 3.6	na

Note 1 – In the case of the receipt of INFO 0 or lost framing at the T reference point, FE 7 may not be provided in some networks in accordance with Recommendation I.430 (see Note 3 to Table 4/I.430).

Note 2 – If transmission of INFO 2 starts when the digital section is synchronized in both directions, the events "ready to transmit INFO 2" and "digital section fully activated" coincide and state DS 1.2 and DS 1.3 can be merged.

Note 3 – The states DS 1.7 and DS 1.8 have been included to reflect the full scope of possible deactivation procedures. Three possible implementations have been considered:

1) The sequence of events ("digital section fully deactivated", "expiry of timer T2 or "receiving INFO 0") is not determined. Then both states, DS 1.7 and DS 1.8 have to be considered.

2) The sequence of events is determined as the "digital section fully deactivated" condition always occurs after "expiry of timer T2" or "receiving INFO 0". Then state DS 1.7 ony has to be considered.

3) The "digital section fully deactivated" condition always occurs prior to "expiry of timer T2" or "receiving INFO 0". Then direct transition from state DS 1.6 to state DS 1.0 on "expiry of timer T2" or "receiving INFO 0" may be considered. If this case applies, the digital section has to make provision that FE6 is issued.

– No state change, no action when event occurs.

/ Impossible event due to intrnal reasons or peer-to-peer procedures.

na No action; this event may occur or may be impossible.

FE.. Issue function element FE.. across V_1 reference point.

DS a.b. Enter state DS a.b.

5.4.2 *Description of the ET layer 1 state transition table*

5.4.2.1 *ET layer 1 states (ET-states)*

Hereafter are defined the states that the ET layer 1 may enter as a result of: function elements (FEs) received across reference point V_1, service primitives received (PH-, MPH-primitives), or internal events.

The ET-states are classified according to the functionality they support as follows:

i) ET 1.X states for the support of functionality according to Recommendation I.430;

ii) ET 2.X states for the support of functionality related to loopbacks (these states complement ET 1.X states);

iii) ET 3.X states for the support of functionality related to digital section only activation/deactivation (these states complement ET 1.X states).

5.4.2.1.1 State ET 1.0: the access (interface at reference point T and digital section) is in a stable state (deactivated or activated). Timer T1 is not running.

5.4.2.1.2 State ET 1.1: an activation has been initiated to establish a call. Timer T1 is running.

5.4.2.1.3 State ET 2.0: the access is in a loopback state. Timer T1 is not running.

5.4.2.1.4 State ET 2.1: a loopback request has been issued. Timer T1 is running.

5.4.2.1.5 State ET 3.0: the access is in a stable state. The digital section only is activated while the interface at the T reference point is deactivated or activated. Timer T1 is not running.

5.4.2.1.6 State ET 3.1: an activation has been initiated to establish a call. When the activation of the interface at the T reference point was invoked, the digital section was already activated. Timer T1 is running.

5.4.2.1.7 State ET 3.2: this is a transitional state which is entered when the digital section only activation has been invoked. Timer T1 is running.

5.4.2.2 *Repertoire of PH- and MPH-primitives within ET for the suppport of functions specified in Recommendations I.440 and I.441. They are related to call control*

The repertoire of these primitives is defined in Recommendations I.430 § 6.2.1 and I.441 § 4.1.

The MPH-EI primitive used in this Recommendation includes the MPH-EI primitive as defined in Recommendation I.430, § 6.2.1.5. In addition, it notifies to the system management configuration control an error condition if the activation or loopback operation attempt failed (see § 5.4.2.3).

5.4.2.3 *Repertoire of MPH-primitives within ET for the support of functions associated with the digital section*

The primitives below permit the digital section to change between two modes. In the first one, full information transfer capability of the digital section is available whatever the status of the user-network interface at reference point T is. In the second one, full information transfer capability of the digital section is available only if the user-network interface at reference point T has to be or is activated. They are related to configuration control.

i) MPH-DIGITAl SECTION ACTIVATE-REQUEST (MPH-DSAR)
The MPH-DSAR primitive is used to request the digital section to maintain the full information transfer capability disregarding the state of the T reference point. The configuration control has to make provision that this primitive is issued only if the access is deactived.

ii) MPH-DIGITAL SECTION ACTIVATE-INDICATION (MPH-DSAI)
The MPH-DSAI primitive is used to indicate that the digital section is in a mode capable to maintain the full information transfer capability whatever the status of the user-network interface at reference point T is.

iii) MPH-DIGITAL SECTION DEACTIVATE-REQUEST (MPH-DSDR)
The MPH-DSDR primitive is used to restore the mode where the status of the digital section is controlled by those primitives (PH-ACTIVATE-REQUEST, or MPH-ACTIVATE-REQUEST as appropriate, and MPH-DEACTIVATE-REQUEST) which are used for the activation/deactivation of the interface at reference point T. This includes the deactivation of the digital section if the interface at reference point T has previously been deactivated. The configuration control has to make provision that this primitive is issued only if the interface at reference point T is deactivated.

iv) MPH-DIGITAL SECTION DEACTIVATE-INDICATION (MPH-DSDI)
This primitive supports a confirmed deactivation service. It is issued when the digital section is fully deactivated. Depending on deactivation procedures the interface at the T reference point is already or not yet deactivated.

v) MPH-ERROR-INDICATION (MPH-EI)
The MPH-EI primitive is used to notify the system management if the activation or loopback operation attempt failed.

vi) MPH-AWAKE-INDICATION (MPH-AWI)
This primitive notifies the network side management that the activation of the interface at reference point T has been invoked by the user side. It may be used by the ET to assign the resources required to support layer 2.

The primitives below are associated with maintenance functions based on loopbacks. The activate request primitives include the activation of the digital section and possibly the user-network interface at reference point T. The establishment of the requested loopback is notified to the requester by means of the MPH-AI primitive. The deactivation of a loopback is invoked by means of the MPH-DSDR primitive, or alternatively the MPH-DR primitive, as appropriate.

MPH-L2AR: activation request for loopback 2

MPH-L1AR: activation request for loopback 1

MPH-L1AAR: activation request for loopback 1A

The primitives below are used for other test purposes than loopbacks (continuidy test).

MPH-AR: activation request of the interface at the T reference point and the digital section for continuity test purpose.

MPH-AI: activation indication of the interface at the T reference point and of the digital section.

5.4.2.4 *ET layer 1 state transition table*

The state transition table, Table 4/G.960, specifies the procedures. It includes the actions to be taken on various events while in a specific state (see § 5.4.2.1 for the definition of the states). It specifies the interactions with ET layer 2 and system management which are required to support the layer interface procedures in accordance with Recommendation I.430 (sequences of PH- and MPH-primitives in compliance with I.430) and the interactions across the layer interface between ET layer 1 and system management for the support of functions associated with the digital section (see § 5.4.2.3 for the definition of the related MPH-primitives).

TABLE 4/G.960

State transition table of ET layer 1
(ET layer 1 state machine)

Event \ State	ET 1.0	ET 1.1	ET 2.0	ET 2.1	ET 3.0	ET 3.1	ET 3.2
PH-AR/ MPH-AR	Start T1 FE 1 ET 1.1	–	PH-DI –	PH-DI –	Start T1 FE 1 ET 3.1	–	Restart T1 FE 1 ET 3.1
MPH-DR	PH-DI FE 5 –	|	FE 5 ET 1.0	|	PH-DI FE 11 –	|	|
FE 2	Start T1 MPH-AWI ET 1.1	(Note 3) MPH-AWI –	/	–	Start T1 MPH-AWI ET 3.1	(Note 3) MPH-AWI –	Restart T1 MPH-AWI ET 3.1
Expiry of timer T1	/	MPH-EI ET 1.0	/	MPH-EI ET 1.0	/	MPH-EI ET 3.0	MPH-EI ET 1.0
FE 3	(Note 4) MPH-DSAI –	MPH-DSAI –	To be specified	To be specified	(Note 4) MPH-DSAI –	MPH-DSAI –	Stop T1 MPH-DSAI ET 3.0
FE 4	(Note 4) MPH-AI –	Stop T1 PH-AI MPH-AI ET 1.0	To be specified	Stop T1 MPH-AI ET 2.0	(Note 4) –	Stop T1 PH-AI MPH-AI ET 3.0	/
FE 6	MPH-DSDI –	/	To be specified	To be specified	/	/	/
FE 7	MPH-DI MPH-EI	/	To be specified	To be specified	MPH-DI MPH-EI	/	/
MPH-L2AR	Start T1 FE 8 ET 2.1	|	|	|	|	|	|
MPH-L1AR	Start T1 FE 9 TC 2.1	|	|	|	|	|	|
MPH-L1AAR	Start T1 FE 10 TC 2.1	|	|	|	|	|	|
MPH-DSAR (Note 1)	Start T1 FE 11 ET 3.2	(Note 2) ET 3.1	|	|	|	|	|
MPH-DSDR (Note 1)	(Note 5) FE 5 –	|	FE 5 ET 1.0	|	FE 5 ET 1.0	|	|

– No state change, no action when event occurs
| Impossible event by the definition of the layer 1 service
/ Impossible event due to internal reasons or peer-to-peer procedures

PH-AI	Issue PH-ACTIVATE-INDICATION primitive
PH-DI	Issue PH-DEACTIVATE-INDICATION primitive
MPH-AWI	Issue MPH-AWAKE-INDICATION primitive
MPH-AI	Issue MPH-ACTIVATE-INDICATION primitive
MPH-DI	Issue MPH-DEACTIVATE-INDICATION primitive
MPH-DSDI	Issue MPH-DIGITAL SECTION DEACTIVATE-INDICATION primitive
MPH-EI	Issue MPH-ERROR-INDICATION primitive
FE..	Issue function element FE.. across V1 reference point
ET ab	Enter state ET a.b

Note 1 – The primitives MPH-DSAR and MPH-DSDR are allowed only if the T reference point is deactivated. The management has to meet this requirement.

Note 2 – This event occurs in the case of a collision between the MPH-DSAR primitive and the MPH-AWI primitive (or the MPH-DSAI primitive, if management ignores the MPH-AWI primitive) at the boundary between ET layer 1 and management. This collision has been caused by concurrent invokation of digital section only activation and access activation from the user side.

Note 3 – This event occurs in the case of a collision between the function elements FE 1 and FE 2 at reference point V1. This collision has been caused by concurrent invokation of an activation of the interface from the user side and network side.

Note 4 – These events occur if timer T1 expires concurrently with the completion of a task which the digital section indicates fo ET layer 1 by means of the appropriate function element (FE 3 and FE 4). It is a situation caused by excessive delay within the digital section. In some cases it is advantageous to issue the appropriate primitive to notify to management the status of the customer access subsequent to the error indication which would have been conveyed in an MPH-EI primitive. This provides the management with the information to initiate the optimum recovery procedure.

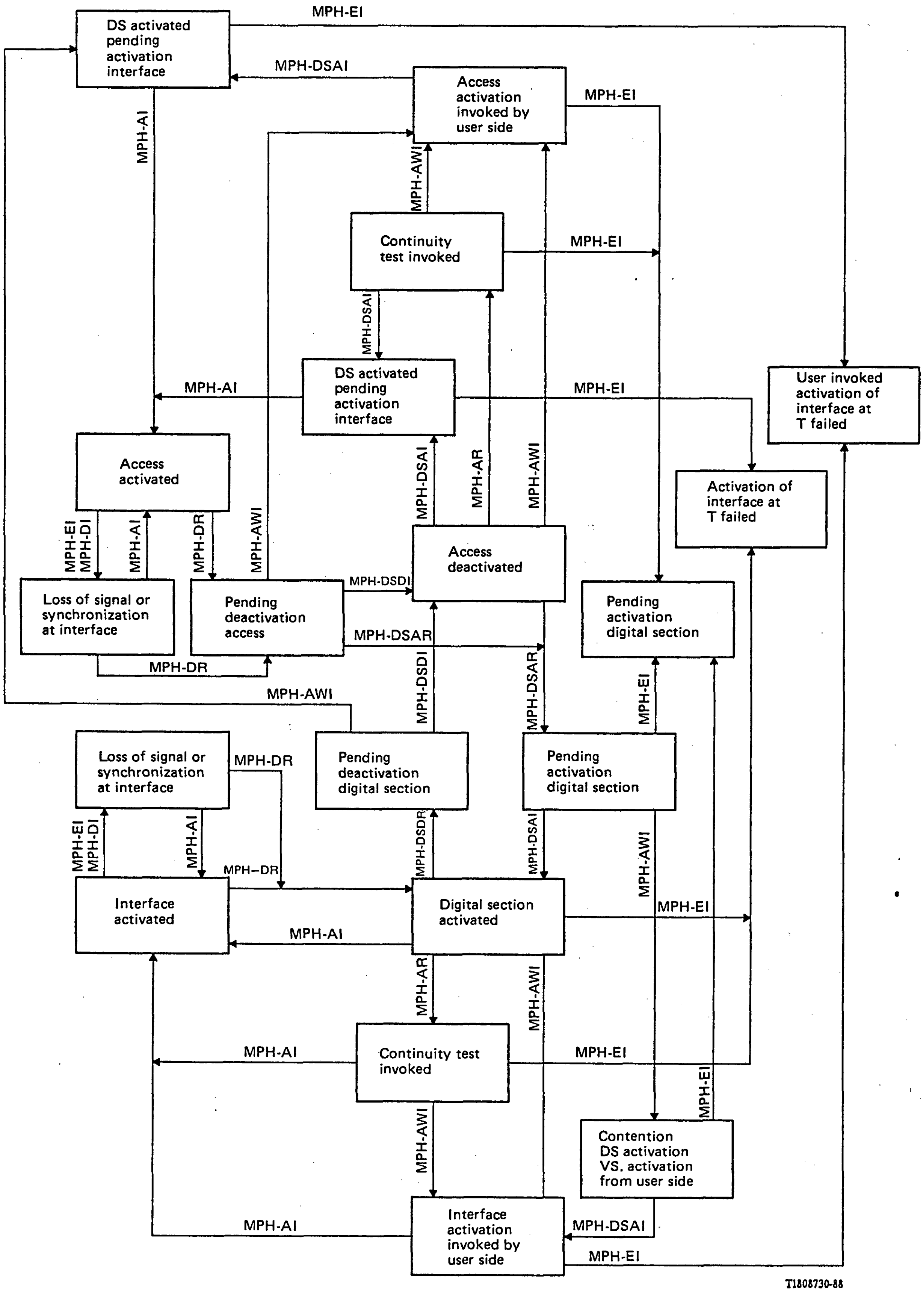
Note 5 – This event occurs if timer T1 expired and management invokes a deactivation as a consequence of the receipt of the MPH-EI primitive. In particular this recovery seems to be useful in case of excessive delays (see Note 4).

5.4.2.5 *Primitive procedures for the support of functions specified in Recommendations I.440 and I.441*

The sequences of PH- and MPH-primitives which are valid between ET layer 1 and ET layer 2. and ET layer 1 and system management, respectively, for the support of functions specified in Recommendations I.440 and I.441 and the ET layer 1 states as perceived by ET layer 2 and system management as a result of primitives transferred between entities are specified in Recommendation I.430 § 6.2.1.6.

5.4.2.6 *Primitve procedures for the support of functions associated with the digital section*

The allowed sequences of MPH-primitives between ET layer 1 and system management for the support of functions associated with the digital section are specified in the state transition diagram, Figure 7/G.960. This state transition diagram defines the ET layer 1 states that system management perceives ET layer 1 to be in as a result of primitives transferred across the corresponding layer interface.



Note – The actions to be taken when entering the states "Loss of signal or synchronization at interface", "Activation of digital section failed", "Activation of interface at T failed" and "User invoked activation of interface at T failed" require further study.

FIGURE 7/G.960

Valid MPH-primitive sequences and ET layer 1 states as perceived by system management configuration control

5.5 *Activation time*

For activation from the user side the activation time is measured at the T reference point between the initiation of the sending of INFO 1 to the interface at the T reference point and the receipt of INFO 4 from the digital section.

For activation from the network side the activation time is defined between Functional Element 1 and Functional Element 4 at the V_1 reference point.

The activation time is specified for a digital section on which a bit error rate lower than the value x (see Note 1) can be achieved when activated.

5.5.1 *Maximum activation time (see Note 2) for activation occuring immediately after a deactivation (without any intervening loopback or powering action) (see Note 4)*:

Metallic pair cable transmission system

i) without regenerator:	300 ms
ii) with regenerator:	600 ms

5.5.2 *Maximum activation time (see Note 2) for activation occurring after the first powering on of a digital section:*

i) without regenerator:	10 sec
ii) with regenerator:	10 sec

Note 1 – The exact test conditions are for further study.

Note 2 – The specified value for activation time is understood as a 95%-value. This means that for 95% of performed activations the activation time must be lower than the specified value.

Note 3 – The values take into account the response time of TE for sending INFO 3 on receipt of INFO 2.

Note 4 – Timer T1 being a functional part of the ET it may be physically implemented in the ET. In this case, its value may be adjusted according to the characteristics of the transmission system between the ET and the digital section when it exists (e.g. in case of a satellite transmission system a value of 1000 ms has to be taken into account).

6 **Operation and maintenance**

6.1 *General*

This paragraph describes the operation and maintenance functions for the digital section of the ISDN basic rate access. For the time being only functions for a digital transmission system for a metallic line are defined.

Operation functions related to activation/deactivation procedure are specified in § 5.

Further assumptions regarding the system management are given in Annex A.

The maintenance functions recommended in I.603 provide the capability to maintain the digital section to the level of Network Performance given in § 4 of this Recommendation.

It must be possible to test and maintain the digital section in accordance with Recommendation I.603 regardless of the customer equipment.

The main features are:

a) control of maintenance and test support facilities;
b) monitoring of the functional elements to provide operating and performance information and fault condition indications;
c) maintenance communication facility.

6.2 *Control facilities*

6.2.1 *Loopbacks*

6.2.1.1 Loopback implementation

The location and characteristics of loopbacks are defined in Recommendation I.603.

6.2.1.2 *Loopback procedure*

The loopbacks are controlled by ET system management.

A normal call activation request cannot override a request for loopback 1, 1a or 2.

The procedure for loopback operation always starts from the deactivated state of the digital section.

One possible sequence is:

a) ET generates an operation command for the required loopback;
b) ET receives MPH-AI;
c) ET performs the test;
d) ET generates a release command;
e) ET receives MPH-DI.

6.2.2 *Auxiliary equipment line switchover*

The function provides control of switchovers across the V_1 reference point:

a) to switch the line from the LT to a line measurement device;
b) to switch the line from the normal LT to a standby LT;
c) to switch the LT to test NT1 located in the local exchange.

This function is optional. The function definition, control options and procedures are for further study.

6.2.3 *Control of functions in the NT1*

This function allows control of specific functions within the NT1 and is for further study.

An example of such a function: control of switching between normal and restricted power at the user network interface.

6.2.4 *Information request*

This function allows the ET to request from the LT, regenerator and NT1 specific status reports.

6.2.5 *Power switch on/off to the line*

This function allows switching of the power to the line, and may be automatically applied upon reception of a power feed failure indication.

6.2.6 *Continuity test*

The continuity test is described in Recommendation I.603.

The continuity test is controlled by the ET and is initiated by MPH-AR. System management decides when the test is passed (i.e. on reception of MPH-DSAI or MPH-AI). When the system management receives MPH-EI (expiry T1) the test is considered to be failed. See also Annex A to this Recommendation.

6.3 *Monitoring*

6.3.1 *Functions*

The following operational conditions are monitored throughout the section:

a) the defect conditions;
b) the power feed arrangements;
c) transmission performance.

6.3.2 *Implementation aspects*

Monitoring capabilities must be provided in the digital section (see Recommendation I.603). The handling and processing of the information is implementation dependent. For example:

a) the use of registers/counters in functional groups, the use of explicit commands and responses to establish status reports;
b) the transfer of information to the exchange, either when a defect condition occurs or on a regular basis. This information is then processed by entities outside the digital section.

6.3.3 *Anomaly and defect conditions and consequent action*

6.3.3.1 *Defect conditions*

The following defect conditions are examples:

i) excessive error rate;

ii) loss of incoming signal;

iii) loss of frame alignment;

iv) power feed failure.

Note — One example of an anomaly is a transmission error.

6.3.3.2 *Consequent actions*

Further to the detection of a defect condition appropriate actions should be taken as specified in Table 5/G.960.

Defect indication information (FII) is automatically transmitted from the digital section to the ET.

TABLE 5/G.960

Defect conditions and consequent actions

Equipment	Defect conditions	Consequent actions		
		FII	Signal at V_1	Signal at T
LT Line side	Excessive error rate (Note 1) Loss of signal Loss of frame	Yes Yes Yes	FFS FE 7 (Note 4) FE 7 (Note 4)	FFS INFO (Note 5) INFO (Note 5)
NT Line side	Excessive error rate (Note 1) Loss of signal Loss of frame	Yes Yes Yes	FFS Not applicable Not applicable	FFS INFO (Note 5) INFO (Note 5)
NT at T	Loss of signal Loss of frame	Yes (Note 3) Yes (Note 3)	FE 7 (Note 4) FE 7 (Note 4)	Not applicable (Note 3) Not applicable
NT	Loss of power	Yes (Note 2)	FFS	INFO 0

FFS For further study

Note 1 — If processed in the digital section.

Note 2 — Depending on power feed arrangements, optional.

Note 3 — Optional.

Note 4 — This signal is defined in § 5.

Note 5 — Whether an existing INFO as defined in Recommendation I.430 may be used is for further study.

6.3.4 *Error performance monitoring*

6.3.4.1 *General*

Provision has to be made in order to monitor the error performance of the digital section and to report on such performance.

6.3.4.2 *Error performance parameters*

The digital section must deliver to the ET the necessary information to allow it to evaluate the error performance parameters defined in Recommendation G.821.

6.3.5 *Status report functions*

Status report functions cover information which relate to the overall operation and performance of the digital section. The information may be transmitted either automatically or under request of ET.

Listed below are descriptions of the status report functions:

i) *Transmission errors*
This information, derived in the digital section, allows the ET to evaluate the transmission error performance.

ii) *Loopback 1 status*
This information, sent from the LT, gives the status of loopback 1.

iii) *Loopback 1A status*
This information, sent from the regenerator, gives the status of loopback 1A.

iv) *Loopback 2 status*
This information, sent from the NT1, gives the status of loopback 2.

v) *User network interface power feed status*
This information indicates the status of the user network interface at T reference point power feed, e.g. normal or restricted power feed mode.

vi) *User network interface power feed fault*
This information indicates a failure of the normal or restricted power source.
This function may be split into two reports.
This information is reported on request of the ET.

vii) *User network interface power feed overload*
This information indicates that the power drawn from any source within the NT1 exceeds the maximum power that is available.
This information is reported on request of the ET.

viii) *Defect indication information*
This information is transmitted automatically under conditions specified in § 6.3.3.1.

TABLE 6/G.960

Status report functions

Function	Location	Mandatory/optional
Transmission errors	LT REG. NT	M O O
Loopback 1 status (Note)	LT	M
Loopback 1A status (Note)	REG.	M
Loopback 2 status (Note)	NT1	M
T reference point power feed status	NT1	O
T reference point power feed fault	NT1	O
T reference point power feed overload	NT1	O
FII	LT REG. NT	M M M

Note – The information may be implicit (e.g., activation indication).

6.3.6 *System dependent status report functions*

These status reports will be dependent upon the type of digital transmission system used and require further study.

Some examples of a particular system are given in Table 7/G.960.

TABLE 7/G.960

System dependent status report functions

Function	Location
Line test relay state	LT
LT test relay state	LT
Remote power switch state	LT
Remote power feed	LT
Induced overvoltage on line	LT
Abnormal current condition	LT
Receive eye opening	LT REG. NT1
Echo cancellation coefficients	LT REG. NT1
Battery test	NT

7 Control channel C_{V1}

This control channel provides, for each direction of transmission, the capability to transfer the commands, status report information and FII.

Although described as a single channel, the control channel may be realized by a number of sub-channels which may use different transport mechanisms (as appropriate to the functions). Even though some of the functions mentioned in § 6 have optional status, the C_{V1} channel shall have the capability to convey all the control information to allow their implementation.

ANNEX A

(to Recommendation G.960)

SYSTEM MANAGEMENT REQUIREMENTS

A.1 *Introduction*

This Recommendation specifies the required functions of the digital section and the ET layer 1. In order to ensure correct operation, it is necessary to take into account the assumptions made about the management functions involved. It is assumed that the structure of the management is as given in CCITT Recommendation Q.940.

In this Recommendation, distinction is made between ET layer 1 and system management only. Where the term system management is used it corresponds to both system management and layer management as defined in Recommendation Q.940.

A.2 *System management requirements*

A.2.1 *General*

System management shall not initiate more than one action at a time towards the ET layer 1. An action is delimited by the primitive which is issued by system management and the corresponding primitive which confirms completion of the task.

A.2.2 *Error indications*

The management entity takes account of the sequence of primitives before and after the reception of MPH-EI. From the sequence of the primitives, the system management may determine the cause of the MPH-EI primitive (e.g. unsuccessful activation of the interface, unsuccessfull activation of the access, loss of synchronization or signal at the interface at reference point T).

Upon the occurence of an error, the ET layer shall notify this event to the system management by means of the primitive MPH-EI. The system management must decide which appropriate actions should be taken (e.g. hold or abandon call, initiate MPH-DR or MPH-DSDR).

A.2.3 *Loopback operations*

The system management should take into account that when the ET layer 1 is in loopback operation it does not send any primitives to ET layer 2.

If a primitive is sent by ET layer 2 to ET layer 1 during loopback operation, it will be ignored by ET layer 1.

The setting of a loopback is initiated by the system management by issuing a primitive MPH-LxAR where by x indicates the type of loopback 2, 1 or 1A.

The setting of the loopbacks 1, 2 and 1A is confirmed to the system management by means of the MPH-AI primitive. The system management should be able to interpret this MPH-AI as a loopback confirmation and not as a normal activation indication by taking into account the sequence of the primitives.

A.2.4 *Continuity test*

The continuity test is initiated by the system management using the primitive MPH-AR. The system management must decide when the test is passed (i.e. on reception of MPH-DSAI or MPH-AI). If the system management receives MPH-EI (expiry T1) the test is considered to be failed.

If the test is passed, the system management should check whether a call establishment has been progressed or if there is a call available before sending MPH-DR.

A.2.5 *Information to be sent in the D channel during loopback operation*

The information sent in the D channel should not imitate any HDLC pattern. However, it is in the responsibility of the system management to decide to send the required pattern for fault localisation.

A.2.6 *Configuration control*

The system management shall ensure that any action related to configuration control will be issued only when the T reference point is deactivated.

ANNEX B

(to Recommendation G.960)

Vocabulary of terms used in connection with Recommendations I.430, I.431, G.960 and G.961

Introduction

This Annex provides a vocabulary of terms and definitions that are appropriate to layer 1 aspects of the ISDN customer access for basic access and primary rate access.

It should be considered in relation to Recommendations I.430, I.431, G.960 and G.961 since its scope is limited to these Recommendations. It is provided for a clear understanding of these Recommendations and will be reviewed during the next Study Period for alignment with Recommendations produced by other bodies.

A small number of terms in this Annex are duplicated in other Recommendations (e.g. Recommendation I.112 and/or Recommendation G.701). References to these are given in parenthesis as an aid to ensuring consistency between the Recommendations in the event of future amendments (e.g. "complete loopback {M.125}"). Where the term is defined differently, but the spirit is maintained, the reference is shown as in the following example: "functional group [{I.112, 419}]".

According to the conventions applied in this Annex any term in common usage, but whose use is deprecated in the sense defined, is shown after the recommended term as in the following example: "line [loop]".

Where a truncated term is widely used in an understood context the complete term is quoted following the colloquial form, for example: "multiplex, digital multiplex equipment".

Paragraph B.7 contains an alphabetical list of all of the terms contained in this Recommendation.

Paragraph B.8 illustrates the general aspects of the terminology.

Paragraph B.9 explains the V reference point, V interface, and interface point concept.

B.1 *General*

101 **basic access, basic rate access**

A user-network access arrangement that corresponds to the interface structure composed of two B-channels and one D-channel. The bit rate of the D-channel for this type of access is 16 kbit/s.

102 **primary rate access**

A user-network access arrangement that corresponds to the primary rates of 1544 kbit/s and 2048 kbit/s. The bit rate of the D-channel for this type of access is 64 kbit/s. The typical primary rate interface structures are as given in Recommendations I.412 and I.431.

103 **local exchange, ISDN local exchange**

The exchange which, in addition to the switching function, contains the exchange termination for the ISDN customer accesses.

104 **line termination (LT) (abbreviated)**

The functional group containing at least the transmit and receive functions terminating one end of a digital transmission system.

105 **exchange termination (ET) (abbreviated)**

The functional group containing at least the layer 2 and layer 3 network side functions of the I.420 interface at the T reference point.

Note 1 – This may not be true if concentrators or other intelligent equipment are located in the local line distribution network.

Note 2 – The ET is not the switching function. The extent to which the ET supports call control processing and management is not defined.

106 **network termination (NT) (abbreviated)**

The functional group on the network side of a user-network interface.

Note – In Recommendations I.430 and I.431, "NT" is used to indicate network terminating layer 1 aspects of NT1 and NT2 functional groups.

107 **terminal equipment (TE) (abbreviated)**

The functional group on the user side of a user network interface.

Note – In Recommendations I.430 and I.431, "TE" is used to indicate terminal terminating layer 1 aspects of TE1, TA and NT2 functional groups.

108 **functional group** [{I.112, 419}]

A set of functions that may be performed by a single equipment.

Note 1 – The transmission medium is not part of any functional group.

Note 2 – Regenerators, multiplexers and concentrators are functional groups which are outside the scope of Recommendation I.411.

109 **access connection element [subscriber access]** [{I.324}]

The equipment providing the concatenation of functional groups between and including the exchange termination and the NT1. The term should be qualified by the type of access supported. That is:

- basic access connection element
- primary rate access connection element.

110 **customer equipment [subscriber installation]** [{I.324}]

The concatenation of equipment on the user side of the T reference point (i.e. TAs, TE2s, TE1s NT2 and associated transmission media). In the case of multiple access, the customer equipment includes all the equipment on the user side of all those accesses comprising the multiple access.

Note 1 – This term should not imply or restrict ownership or responsibility for providing equipment.

Note 2 – The terms "user equipment" and "subscriber equipment" are deprecated.

111 **ISDN customer access [ISDN subscriber access]**

The equipment providing the concatenation of all functional groups relevant to an individual or group of related access connection elements (i.e. customer equipment and access connection element).

Note – This term should not imply or restrict ownership or responsibility for providing equipment.

112 **direct access, direct access connection element**

A specific access connection element in which the basic access digital section or primary rate access digital section is directly connected to the exchange termination at a V_1 or V_3 reference point respectively.

113 **remote access, remote access connection element**

A specific access connection element in which the digital section is not directly connected to the exchange termination but is connected through a multiplexer or concentrator.

114 **reference point** {I.112, 420}

A conceptual point at the conjunction of two non-overlapping functional groups.

Note – Each reference point is assigned a prefix letter, for example: T reference point.

115 **interface, physical interface** {I.112, 408; G.701, 1008}

The common boundary between physical equipment.

116 **user network interface [customer network interface]** {I.112, 409}

An interface, at which the access protocols apply, and which is located at the S or T reference point.

117 **V interface**

A digital interface which usually coincides with the V reference point.

Note 1 – A specific V interface is denoted by a suffix number.

Note 2 – The V interfaces are internal network interfaces.

118 **V_1 reference point**

A V reference point at the network side of a basic access digital section for the provision of a single basic access.

Note – The V_1 interface is a functional boundary between the exchange termination and the line termination and may or may not exist as a physical interface. The V_1 interface structure is comprised of two B-channels, one D-channel, and a C_{V1}-channel.

119 **V_2 reference point**

A V reference point at the network side of a concentrator for the provision of a number of basic and/or primary rate accesses.

120 **V_3 reference point**

A V reference point at the network side of a primary rate access digital section for the provision of a single primary rate access.

121 **V_4 reference point**

A V reference point at the network side of a multiplexer supporting several basic access digital sections.

B.2 *Digital transmission*

201 **Digital link, digital transmission link** [{I.112, 302; G.701, 3005}]

The whole of the means of digital transmission of a digital signal of specified rate between specified reference points.

Note – A digital link comprises one or more digital sections and may include either a multiplexer or concentrator, but not switching.

202 **digital access link**

A digital link between the T reference point and the V reference point in the case of remote access only.

203 **digital section [section]** [{G.701, 3007}]

The whole of the means of digital transmission of a digital signal of specified rate between two consecutive reference points. The term should be qualified by the type of access supported, or by a prefix denoting the V interface at the digital section boundaries. For example:

- basic access digital section;
- primary rate access digital section;
- V_x digital section.

204 **digital section boundaries**

The reference points at the near and far ends of the digital section.

205 **digital system, digital transmission system [system]** [{G.701, 3014}]

A specific means of providing a digital section.

Note – For a specific type of system this term may be qualified by the insertion of the name of the transmission medium employed by that specific system. Some examples are:

- digital line transmission system;
- digital radio system;
- digital optical transmission system.

206 **transmission method**

The technique by which the transmission system transmits and receives signals via the transmission medium.

207 **echo cancellation**

A transmission method used in digital transmission systems in which bi-directional transmission occurs simultaneously on the same line and in the same frequency band. An echo canceller is required to attenuate the echo of the near-end transmission.

208 **time compression multiplex [burst mode]**

A transmission method used in digital transmission systems in which bi-directional transmission occurs in non-overlapping uni-directional bursts.

209 **multiplex, digital multiplex equipment** [{G.701, 4017}]

The combination of a digital multiplexer and a digital demultiplexer at the same location, operating in opposite directions of transmission.

210 **static multiplex [fixed multiplex]**

A multiplex where each tributary channel is assigned to one or more main-stream time-slots and the assignment is fixed.

211 **dynamic multiplex [statistical multiplex]**

A multiplex where signalling information of some or all tributary D-channels is assigned to a lesser number of main-stream time-slots on a statistical basis, but the assignment of other channels is fixed.

212 **concentrator, digital concentrator**

Equipment containing the means to combine, in one direction, a number of basic accesses, and/or primary rate accesses into a lesser number of time-slots by omitting the idle channels and/or redundancy, and to perform the corresponding separation in the contra-direction.

B.3 *Signalling*

301 **INFO**

A defined layer 1 signal with specified meaning and coding at a basic access user-network interface.

302 **SIG**

A signal representing an exchange of layer 1 information between line terminations of a digital transmission system for basic access.

303 **function elements (FEs) (abbreviated)**

A signal representing a functional exchange of layer 1 information at the V_1 interface.

304 **control channel; C-channel [service channel]**

Additional dedicated transmission capability provided at a reference point or interface, or transported by a digital transmission system, to support the execution of management functions.

Note – The control channel at a specific reference point, interface or type of transmission system is denoted by an appropriate suffix. For example:

– C_{v1}: channel – the control channel at the V_1 interface

– C_L: channel – the control channel at the line.

B.4 *Activation/deactivation*

401 **deactivation**

A function which places a system, or part of a system, into a non-operating or partially operating mode where the power consumption of the system may be decreased (low power consumption mode).

402 **activation**

A function which places a system, or part of a system, which may have been in a low power consumption mode during deactivation, into its fully operating mode.

403 **permanent activation**

Activation of a system, or part of a system, that will not be deactivated even when it is not required to be fully operating.

404 **line activation**

The function which requires the digital line transmission system to be activated but which may also activate the user-network interface.

405 **line-only activation**

The function which requires the activation of only the digital line transmission system and does not activate the user-network interface.

406 **one-step activation**

A type of activation which invokes a sequence of actions to activate the digital line transmission system and user-network interface from a single command.

407 **two-step activation**

A type of activation which is initiated by one command to invoke a sequence of actions to activate the digital line transmission system and continued by a second command to invoke a sequence of actions to activate the user-network interface.

408 **one-step deactivation**

Deactivation of the digital line transmission system and user-network interface invoked by a single command.

409 **user-network interface only deactivation**

Deactivation of the user-network interface which does not deactivate the digital line transmission system.

B.5 *Loopbacks*

501 **loopback, digital loopback** {M.125} **[test loop]** [{I.112 G}]

A mechanism incorporated into a piece of equipment whereby a bi-directional communication path may be connected back on itself so that some or all of the information contained in the bit stream sent on the transmit path is returned on the receive path.

502 **loopback type**

The characteristic of a loopback which specifies the relationship between information entering the loopback and the information leaving the loopback in the contra-direction.

503 **complete loopback** {M.125}

A physical layer 1 mechanism which operates on the full bit stream. At the loopback point, the receive bit stream shall be transmitted back towards the transmitting station without modification.

Note – The use of the term "complete loopback" is not related to implementation since such a loopback may be provided by means of active logic elements or controlled unbalance of a hybrid transformer, etc. At the control point only the information channels may be available.

504 **partial loopback** {M.125} **[echoing loopback]**

A physical layer 1 mechanism which operates on one or more specified channels multiplexed within the full bit stream. At the loopback point, the received bit stream associated with the specified channel(s) shall be transmitted back towards the transmitting station without modification.

505 **logical loopback** {M.125}

A loopback which acts selectively on certain information within a specified channel or channels and may result in some specified modification of the looped information. Logical loopbacks may be defined to apply at any layer, depending on the detailed maintenance procedures specified.

506 **loopback point** [{M.125}]

The precise location of the loopback.

507 **loopback control mechanism [control mechanism]** {M.125}

The means by which the loopback is operated and released from the loopback control point.

508 **loopback control point [control point]** {M.125}

The point which has the ability to directly control loopbacks. The loopback control point may receive requests for loopback operation from several loopback requesting points.

509 **loopback requesting point** [{M.125}]

The point which requests the loopback control point to operate loopbacks.

510 **loopback application** {M.125}

The maintenance phase for which the loopback operation is used.

511 **forward signal**

The signal transmitted beyond the loopback point.

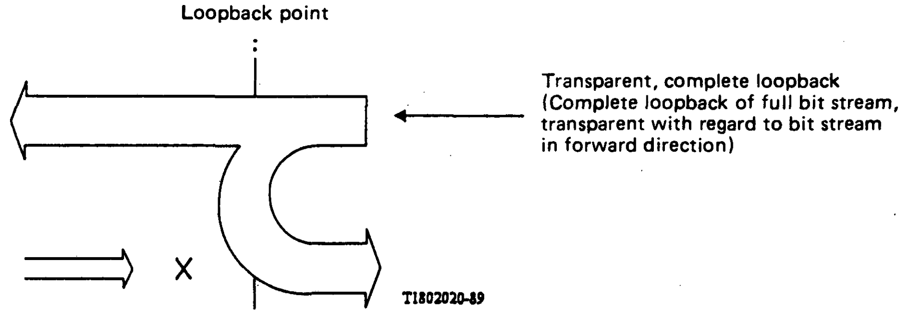
Note – The forward signal may be a defined signal or unspecified.

512 **loopback test pattern** [{M.125}]

The information transmitted during the operation of the loopback in the channel or channels which are to be redirected by the loopback.

513 **transparent loopback** {M.125}

A transparent loopback is one in which the signal transmitted beyond the loopback point (the forward signal) when the loopback is activated, is the same as the received signal at the loopback point. See Figure B-1/G.960.

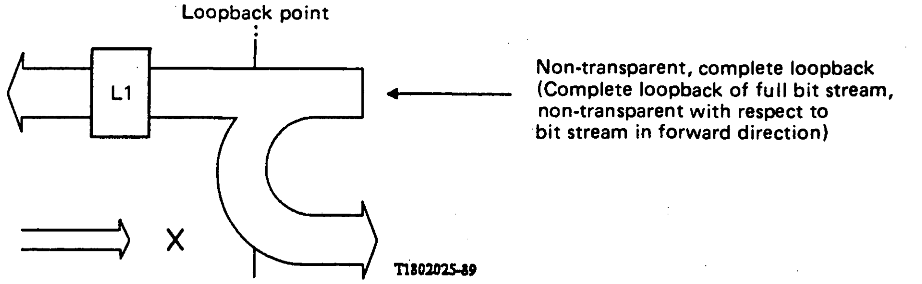


X Signal inhibited in order to avoid interference with looped signal

FIGURE B-1/G.960

514 **non-transparent loopback** {M.125}

A non-transparent loopback is one in which the signal transmitted beyond the loopback point (the forward signal) when the loopback is activated is not the same as the received signal at the loopback point. The forward signal may be a defined signal or unspecified. See Figure B-2/G.960.



X Signal inhibited in order to avoid interference with looped signal
L1 Device which changes or inhibits the transferred signal

FIGURE B-2/G.960

B.6 *local line distribution network*

601 **local line distribution network**

A network of cables and wires which are currently installed between a local exchange and customer premises.

602 **twisted pair**

A line or part of a line which has each (insulated) conductor twisted around the other to reduce the effect of induction from stray electromagnetic and/or electrostatic fields.

Note – This definition also applies to twisted quad except that two pairs are twisted together.

603 **exchange cable**

A cable forming part of the local line distribution network, used in the local exchange between the line termination and main distribution frame.

604 **main cable**

A cable used in the local line distribution network between the main distribution frame and a cross connection point.

605 **distribution cable**

A cable used in the local line distribution network between the cross connection point and a distribution point.

606 **installation cable [subscriber cable]**

A cable or single pair of metallic wires used in the local line distribution point and the customer premises.

607 **bridged tap**

A length of unused open circuit line that is "T"ed to the customer line to provide flexibility in the local line distribution network.

Note – Bridged taps are not used in all local line distribution networks.

608 **open wire**

A pair of suspended and often uninsulated metallic wires which run parallel to each other.

Note – Overhead installation cables in common use between distribution poles and customer premises are not open wires.

609 **loading coil**

A device used to modify the electric characteristics of a line to give relatively constant attenuation over the voice-frequency range, but which gives relatively high attenuation beyond that range.

610 **crosstalk**

A phenomenon by which an unwanted signal is introduced into a line through coupling to one or more other lines.

611 **intrasystem crosstalk**

Crosstalk between lines sharing the same cable on which the same type of transmission system is used on each line.

612 **intersystem crosstalk**

Crosstalk between lines sharing the same cable and on which different types of transmission systems are used on each line.

613 **near-end crosstalk (NEXT) (abbreviated)**

Crosstalk where the coupling is occurring at or near to the transmitter.

614 **far-end crosstalk (FEXT) (abbreviated)**

Crosstalk where the coupling is occurring at or near to the end of the line furthest from the transmitter.

615 **line [loop]**

The transmission medium between line terminations. The term may be qualified by the type of medium used, for example:

- metallic line: a pair of metallic (usually copper) wires,
- optical line: one optical fibre (bi-directional transmission), or one pair of fibres (uni-directional transmission).

616 **local line [subscriber line]**

An individual line which is continuous between the line termination (LT) and the customer premises, passing through the exchange, main, distribution and installation cables.

617 **digital local line**

A local line which is used by a digital transmission system.

Note – Regenerators are not part of the line but may be inserted between two line lengths.

B.7 *Alphabetical list of terms contained in this Annex*

B.8 *Illustration of the general aspects of the terminology ISDN customer access*

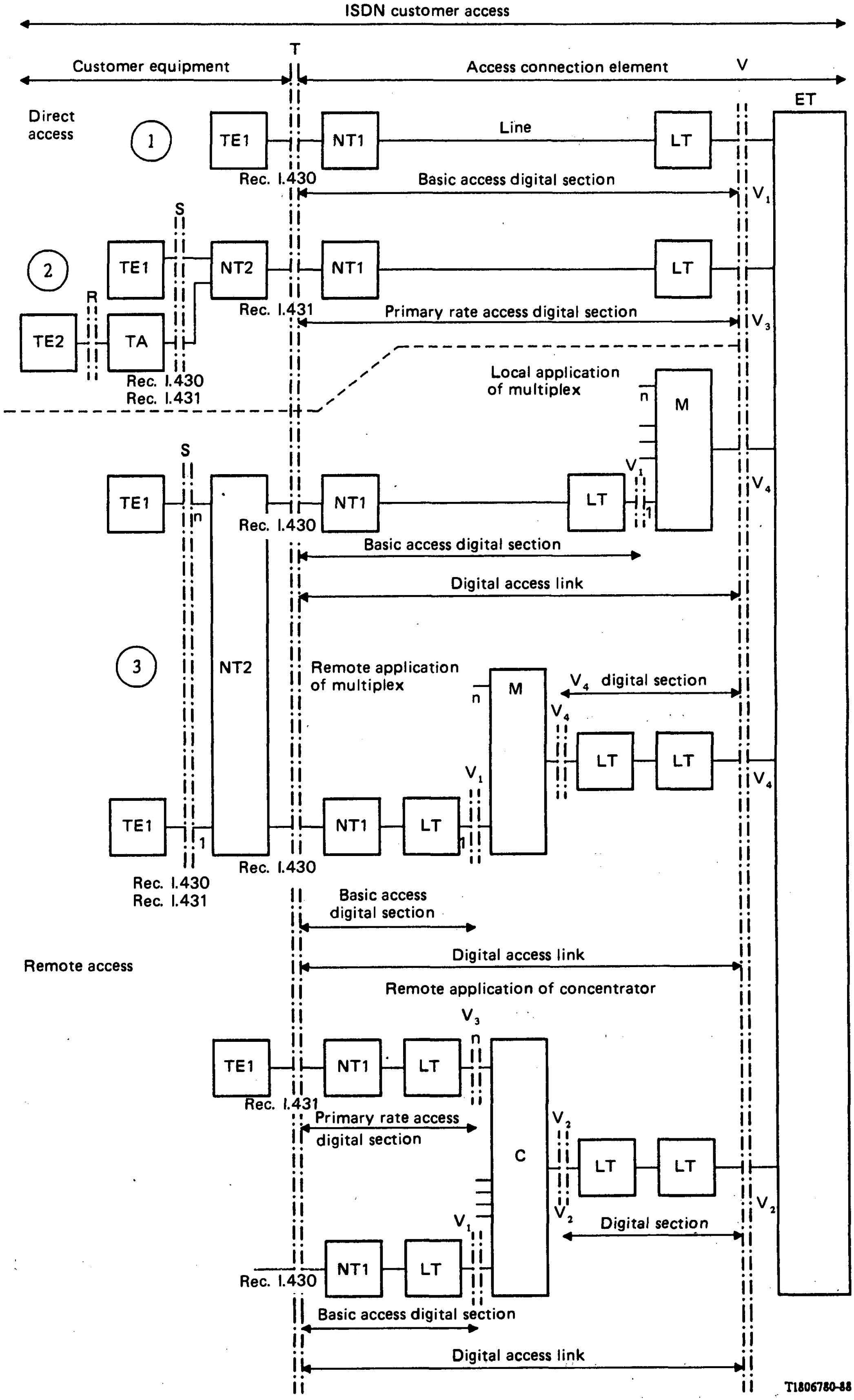


FIGURE B-3/G.960

B.9 *Clarification of the V reference point, V interface, and interface point concept*

B.9.1 The V_1 reference point and the V_3 reference point are always on the network side of the line termination and are applicable to individual (low order) accesses.

A reference point, when physically realized by an interface, requires the specification of at least two interface points. See Figure B-4/G.960.

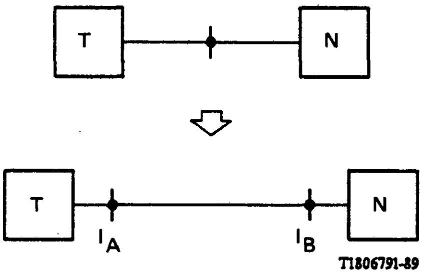
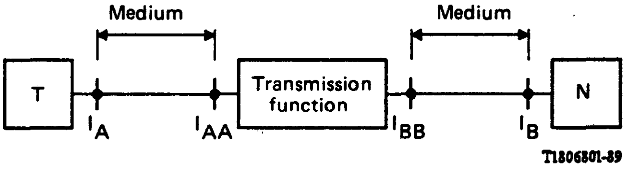


FIGURE B-4/G.960

B.9.2 *Interface point*

One of at least two physical locations associated with an interface. The interface points mark the end of the transmission medium which supports the interface and may be the location of connectors (if used).

The reach of any interface may be extended by the use of a transmission system, providing that the transmission system is transparent in regards to the functions transported by the interface. In such a case, two further interface points would be required. See Figure B-5/G.960.



Note – The insertion of a transmission system to a specific interface may be limited by performance related requirements.

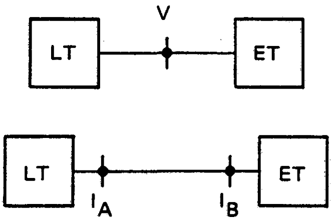
FIGURE B-5/G.960

B.9.3 A group of individual accesses may be multiplexed or concentrated together to comprise a higher order access (i.e. V_2 or V_6 for basic access higher order interfaces).

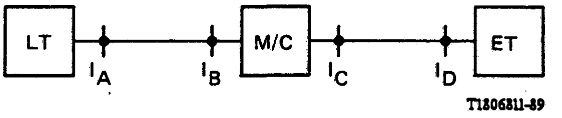
There is only one V reference point at which the V interfaces may be implemented (between LT and ET). See Figure B-6/G.960.

This approach aligns with the use of I_B and I_A interface points in Recommendations I.430 and I.431.

– with the modelling technique used so far;
– with the terminology used so far;
– with the fact that an S or T reference point may support a range of interfaces (Recommendations I.430/I.431);
– does not contradict Recommendation Q.512.



a) Low order interface application



b) High order interface application

M/C Multiplexer or concentrator

Note – I_B and I_A are the interface points supporting V_1 or V_3 interfaces. I_C and I_D are the interface points supporting V_2 or V_4 interfaces.

FIGURE B-6/G.960

Recommendation G.961

DIGITAL TRANSMISSION SYSTEM ON METALLIC LOCAL LINES FOR ISDN BASIC RATE ACCESS

(Melbourne, 1988)

1 General

1.1 *Scope*

This Recommendation covers the characteristics and parameters of a digital transmission system at the network side of the NT1 to form part of the digital section for the ISDN basic rate access.

The system will support the

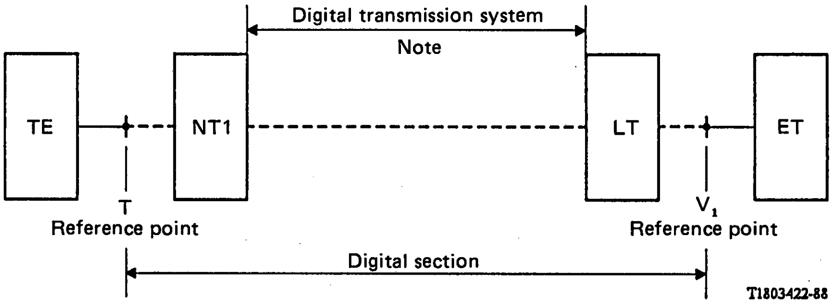
- full duplex;
- bit sequence independent

transmission of two B-channels and one D-channel as defined in Recommendation I.412 and the supplementary functions of the digital section defined in Recommendation I.603 for operation and maintenance.

The terminology used in this Recommendation is very specific and not contained in the relevant terminology Recommendations. Therefore Annex B to Recommendation G.960 provides a number of terms and definitions used in this Recommendation.

1.2 *Definition*

Figure 1/G.961 shows the boundaries of the digital transmission system in relation to the digital section.



Note – In this Recommendation digital transmission system refers to a line system using metallic lines. The use of one intermediate regenerator may be required.

FIGURE 1/G.961

Digital section and transmission system boundaries

The concept of the digital section is used in order to allow a functional and procedural description and a definition of the network requirements. Note that the reference points T and V_1 are not identical and therefore the digital section is not symmetric.

The concept of a digital transmission system is used in order to describe the characteristics of an implementation, using a specific medium, in support of the digital section.

1.3 *Objectives*

Considering that the digital section between the local exchange and the customer is one key element of the successful introduction of ISDN into the network the following requirements for the specification have been taken into account:

- to meet the error performance specified in Recommendation G.960;
- to operate on existing 2-wire unloaded lines, open wires being excluded;
- the objective is to achieve 100% cable fill for ISDN basic access without pair selection, cable rearrangements or removal of bridged taps (BT) which exist in many networks;
- the objective to be able to extend ISDN basic access provided services to the majority of customers without the use of regenerators. In the remaining few cases special arrangements may be required;
- coexistence in the same cable unit with most of the existing services like telephony and voice band data transmission;
- various national regulations concerning EMI should be taken into account;
- power feeding from the network under normal or restricted conditions via the basic access shall be provided where the Administration provides this facility;
- the capability to support maintenance functions shall be provided.

1.4 *Abbreviations*

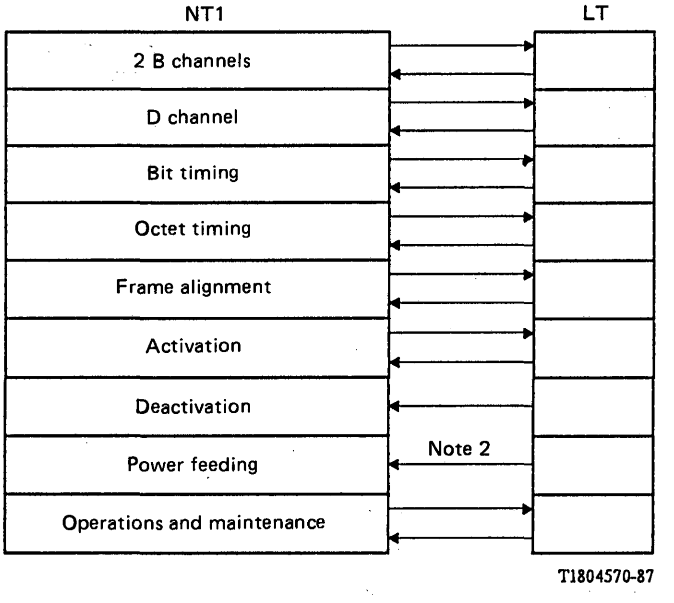
A number of abbreviations are used in this Recommendation. Some of them are commonly used in the ISDN reference configuration while others are created only for this Recommendation. The last one is given in the following:

BER	bit error ratio
BT	bridged tap
CISPR	Comité international spécial de perturbation radioélectrique (now part of IEC)
CL	control channel of the line system
ECH	echo cancellation

EMI electro-magnetic interference
DLL digital local line
DTS digital transmission system
NEXT near-end crosstalk
PSL power sum loss
TCM time compression multiplex
UI unit interval

2 Functions

Figure 2/G.961 shows the functions of the digital transmission system on metallic local lines.



Note 1 – The optional use of one regenerator must be foreseen.
Note 2 – This function is optional.

FIGURE 2/G.961

Functions of the digital transmission system

2.1 *B-channel*

This function provides, for each direction of transmission, two independent 64 kbit/s channels for use as B-channels (as defined in Recommendation I.412).

2.2 *D-channel*

This function provides, for each direction of transmission, one D-channel at a bit rate of 16 kbit/s, (as defined in Recommendation I.412).

2.3 *Bit timing*

This function provides bit (signal element) timing to enable the receiving equipment to recover information from the aggregate bit stream. Bit timing for the direction NT1 to LT shall be derived from the clock received by the NT1 from the LT.

2.4 *Octet timing*

This function provides 8 kHz octet timing for the B-channels. It shall be derived from frame alignment.

2.5 *Frame alignment*

This function enables the NT1 and the LT to recover the time division multiplexed channels.

2.6 *Activation from LT or NT1*

This function restores the Digital Transmission system (DTS) between the LT and NT1 to its normal operational status. Procedures required to implement this function are described in § 6 of this Recommendation.

Activation from the LT could apply to the DTS only or to the DTS plus the customer equipment. In case the customer equipment is not connected, the DTS can still be activated.

Note – The functions required for operation and maintenance of the NT1 and one regenerator (if required) and for some activation/deactivation procedures are combined in one transport capability to be transmitted along with the 2B + D-channels. This transport capability is named the CL-channel.

2.7 *Deactivation*

This function is specified in order to permit the NT1 and the regenerator (if it exists) to be placed in a low power consumption mode or to reduce intrasystem crosstalk to other systems. The procedures and exchange of information are described in § 6 of this Recommendation. This deactivation should be initiated only by the exchange (ET). See Note in § 2.6.

2.8 *Power feeding*

This optional function provides for remote power feeding of one regenerator (if required) and NT1. The provision of wetting current is recommended.

Note – The provision of line feed power to the user-network interface, normal or restricted power feeding as defined in Recommendation I.430 is required by some Administrations.

2.9 *Operations and maintenance*

This function provides the recommended actions and information described in Recommendation I.603.

The following categories of functions have been identified:

- maintenance command (e.g., loopback control in the regenerator or the NT1);
- maintenance information (e.g., line errors);
- indication of fault conditions;
- information regarding power feeding in NT1.

See Note in § 2.6.

3 **Transmission medium**

3.1 *Description*

The transmission medium over which the digital transmission system is expected to operate, is the local line distribution network.

A local line distribution network employs cables of pairs to provide services to customers.

In a local line distribution network, customers are connected to the local exchange via local lines.

A metallic local line is expected to be able to simultaneously carry bi-directional digital transmission providing ISDN basic access between LT and NT1.

To simplify the provision of ISDN basic access, a digital transmission system must be capable of satisfactory operation over the majority of metallic local lines without requirement of any special conditioning. Maximum penetration of metallic local lines is obtained by keeping ISDN requirements at a minimum.

In the following, the term Digital Local Line (DLL) is used to describe a metallic local line that meets minimum ISDN requirements.

3.2 *Minimum ISDN requirements*

a) No loading coils;

b) No open wires;

c) When BTs are present, some restrictions may apply. Typical allowable BT configurations are discussed in § 4.2.1.

3.3 *DLL physical characteristics*

In addition to satisfying the minimum ISDN requirements, a DLL is typically constructed of one or more twisted-pair segments that are spliced together. In a typical local line distribution network, these twisted-pair segments occur in different types of cables as described in Figure 3/G.961.

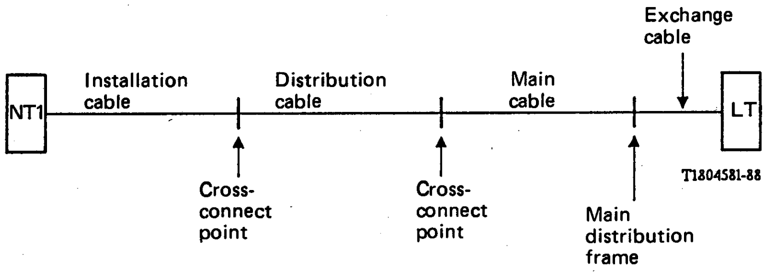


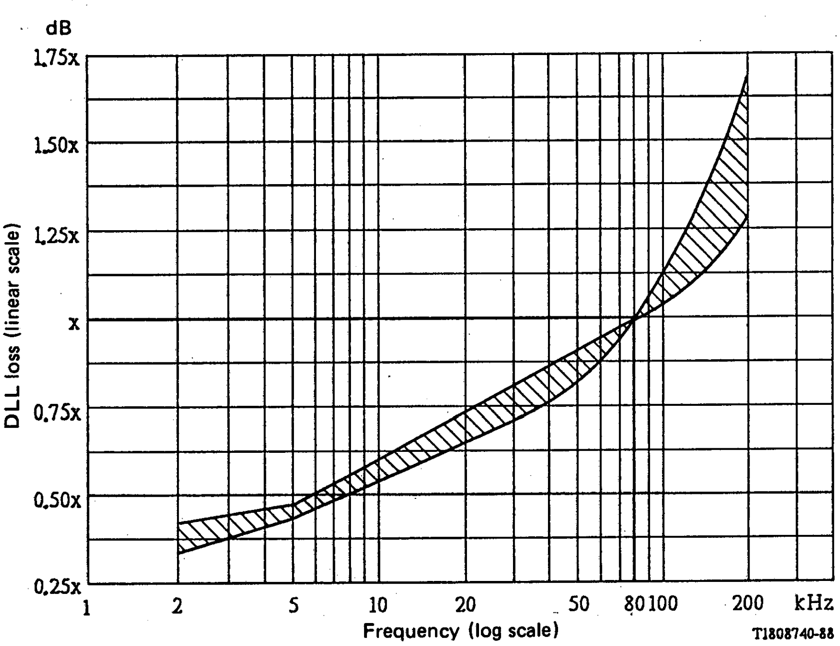
FIGURE 3/G.961

DLL physical model

3.4 *DLL electrical characteristics*

3.4.1 *Insertion loss*

The DLL will have non-linear loss versus frequency characteristic. For any DLL of a particular gauge mix, with no BTs and with an insertion loss of x dB at 80 kHz, the typical behaviour of its insertion loss versus frequency is depicted in Figure 4/G.961.



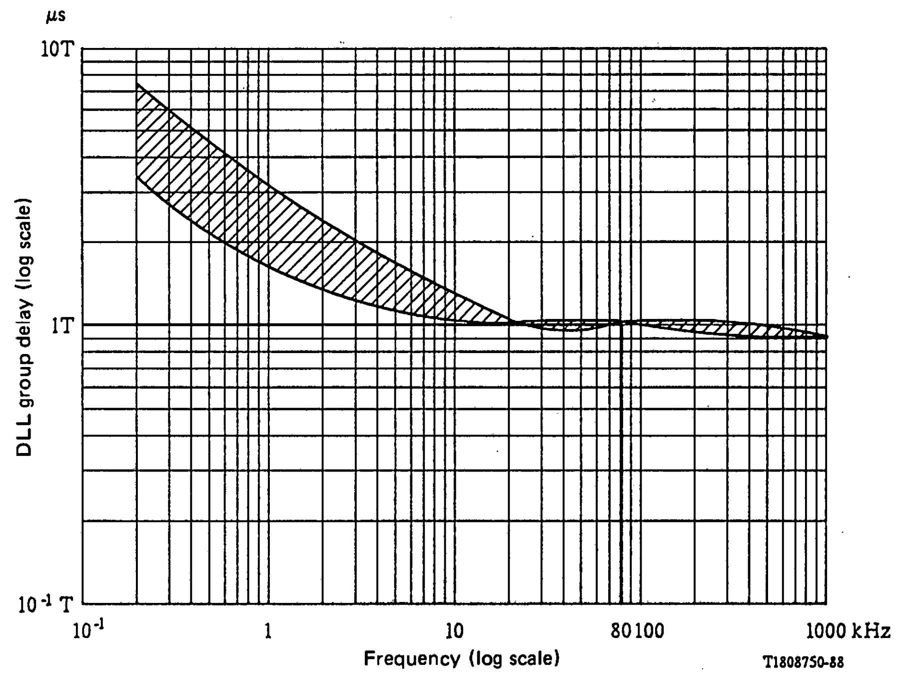
Note – The maximum value of x ranges from 37 dB to 50 dB at 80 kHz. The minimum value could be close to zero.

FIGURE 4/G.961

Typical insertion loss characteristic without presence of BTs

3.4.2 *Group delay*

Typical ranges of values of DLL group delay as a function of frequency are shown in Figure 5/G.961.



Note — The maximum value of one-way group delay (T) ranges from 30 to 60 microseconds at 80 kHz.

FIGURE 5/G.961

Typical group delay characteristic

3.4.3 *Characteristic impedance*

Typical ranges of values of the real and imaginary parts of the characteristic impedance of twisted pairs in different types of cables are shown in Figure 6/G.961.

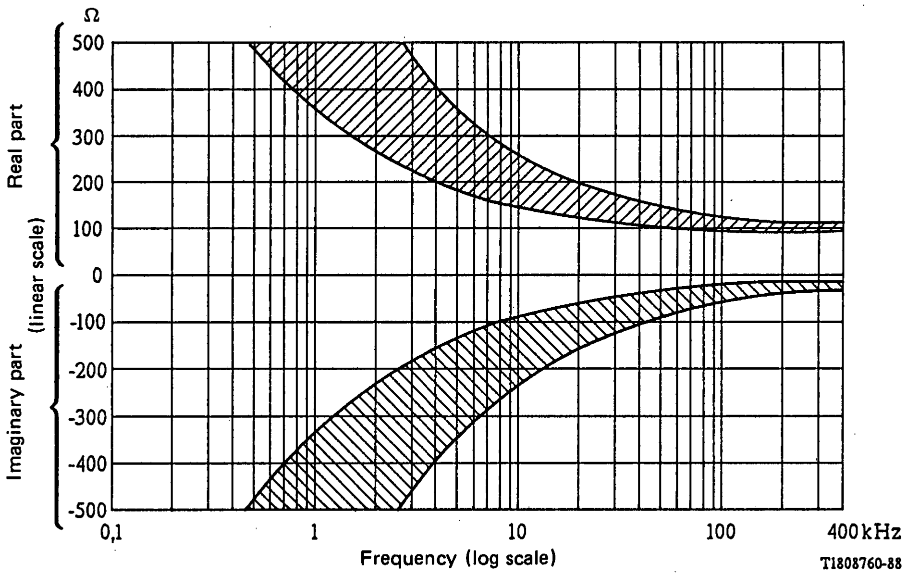


FIGURE 6/G.961

Typical ranges of values of real and imaginary parts of characteristic impedance

3.4.4 *Near-end crosstalk (NEXT)*

The DLL will have finite crosstalk coupling loss to other pairs sharing the same cable. Worst-case NEXT power sum loss (PSL) varies from 44 to 57 dB at 80 kHz (refer to § 4.2.2).

The DLL loss and PSL ranges have been independently specified. However, it is not required that all points in both ranges be satisfied simultaneously. A combined DLL loss/PSL representation is shown in Figure 7/G.961 to define the combined range of operation.

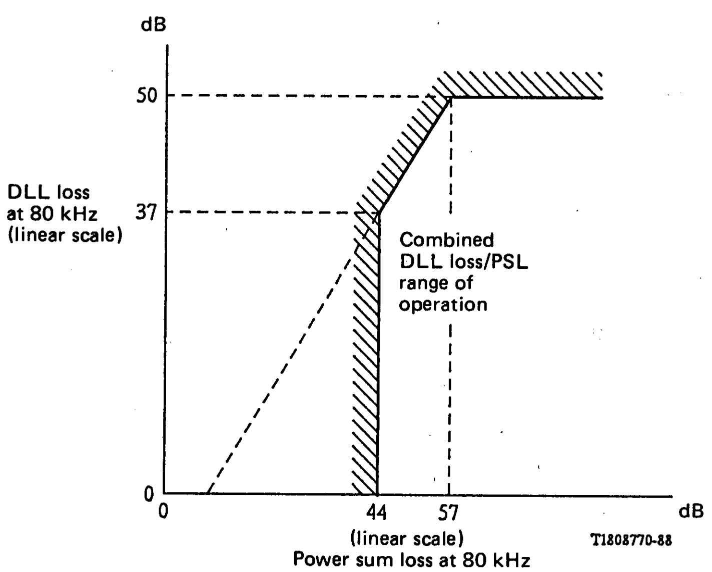


FIGURE 7/G.961

Combined representation of DLL loss/PSL range of operation

3.4.5 *Unbalance about earth*

The DLL will have finite balance about earth. Unbalance about earth is described in terms of longitudinal conversion loss. Worst-case values are shown in Figure 8/G.961.

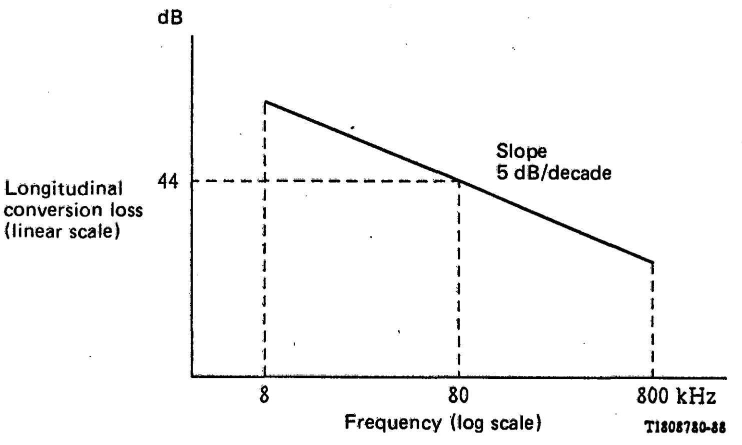


FIGURE 8/G.961

Worst-case longitudinal conversion loss versus frequency

3.4.6 *Impulse noise*

The DLL will have impulse noise resulting from other systems sharing the same cable as well as from other sources.

4 System performance

4.1 *Performance requirements*

Performance limits for the digital section are specified in § 4 of Recommendation G.960. The digital transmission system performance must be such that these performance limits are met. For that purpose, a digital transmission system is required to pass specific laboratory performance tests that are defined in the next sections.

4.2 *Performance measurements*

Laboratory performance measurement of a particular digital transmission system requires the following preparations:

a) definition of a number of DLL models to represent physical and electrical characteristics encountered in local line distribution networks;

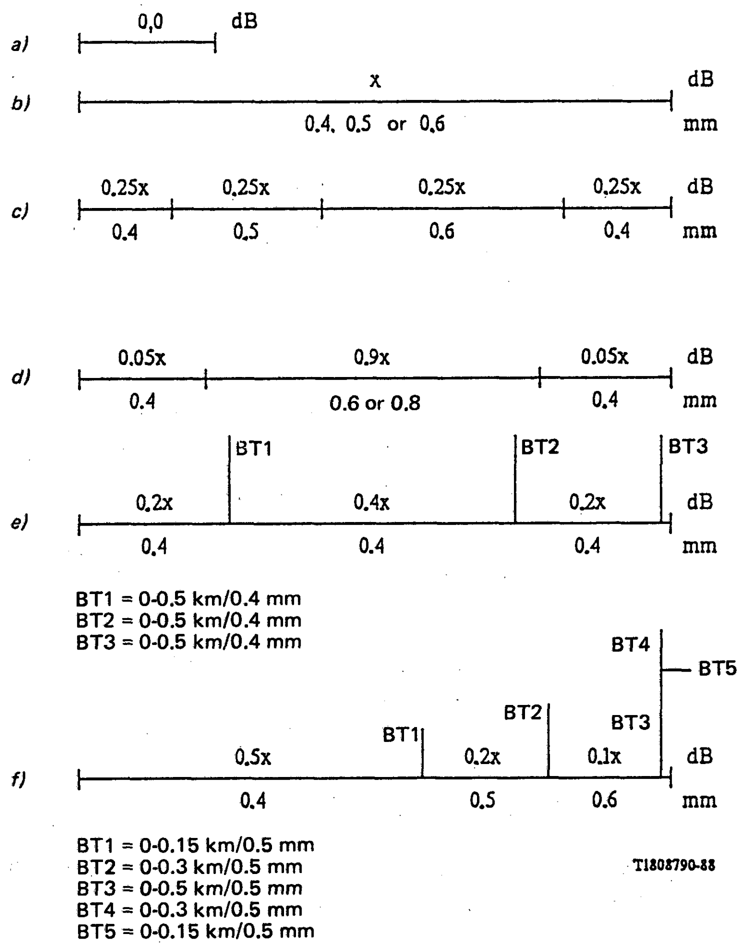
b) simulation of the electrical environment caused by finite crosstalk coupling loss to other pairs in the same cable;

c) simulation of the electrical environment caused by impulse noise;

d) specification of laboratory performance tests to verify that the performance limits referred to in § 4.1 will be met.

4.2.1 *DLL physical models*

For the purposes of laboratory testing of performance of a digital transmission system providing ISDN basic access, some models representative of DLLs to be encountered in a particular local line distribution network are required. The maximum loss in each model is optionally set between 37 and 50 dB at 80 kHz to satisfy requirements of the particular network. Similarly, the lengths of BTs are optionally set within the range defined in Figure 9/G.961.



Note 1 – The value of x varies from 37 to 50 dB at 80 kHz.

Note 2 – Equivalent gauges can be used. For example 0.6 mm is equivalent to AWG 22. AWG stands for American Wire Gauge.

FIGURE 9/G.961

DLL physical models for laboratory testing

4.2.2 *Intrasystem crosstalk modelling*

4.2.2.1 *Definition of* **intrasystem crosstalk**

Crosstalk noise in general results due to finite coupling loss between pairs sharing the same cable, especially those pairs that are physically adjacent. Finite coupling loss between pairs causes a vestige of the signal flowing on one DLL (disturber DLL) to be coupled into an adjacent DLL (disturbed DLL). This vestige is known as crosstalk noise. Near-end crosstalk (NEXT) is assumed to be the dominant type of crosstalk. Intrasystem NEXT or self NEXT results when all pairs interfering with each other in a cable carry the same digital transmission system. Intersystem NEXT results when pairs carrying different digital transmission systems interfere with each other. Definition of intersystem NEXT is not part of this Recommendation.

Intrasystem NEXT noise coupled into a disturbed DLL from a number of DLL disturbers is represented as being due to an equivalent single disturber DLL with a coupling loss versus frequency characteristic known as PSL. Worst-case PSL encountered in a local line distribution network is defined in Figure 10/G.961. All DLLs are assumed to have fixed resistance terminations of *Ro* ohms. The range of *Ro* is 110 to 150 ohms.

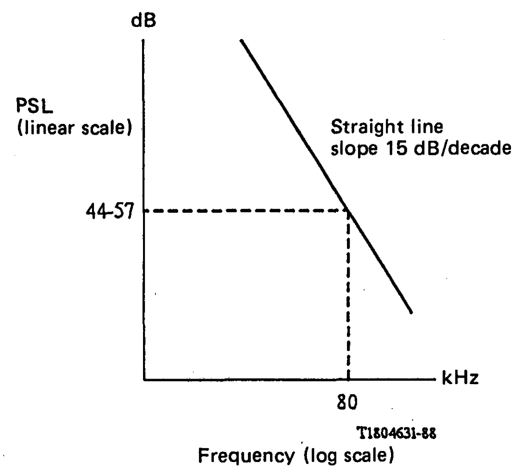


FIGURE 10/G.961

Worst-case power sum loss (PSL)

4.2.2.2 *Measurement arrangement*

Simulation of intrasystem NEXT noise is necessary for performance testing of digital transmission systems. Intrasystem noise coupled into the receiver of the disturbed DLL depends on:

a) Power spectrum of the transmitted digital signal. The power spectrum is a function of the line code and the transmit filter.

b) Spectrum shaping due to the PSL characteristic of Figure 10/G.961.

The measurement arrangement of Figure 11/G.961 can be used for testing of performance with intrasystem crosstalk noise.

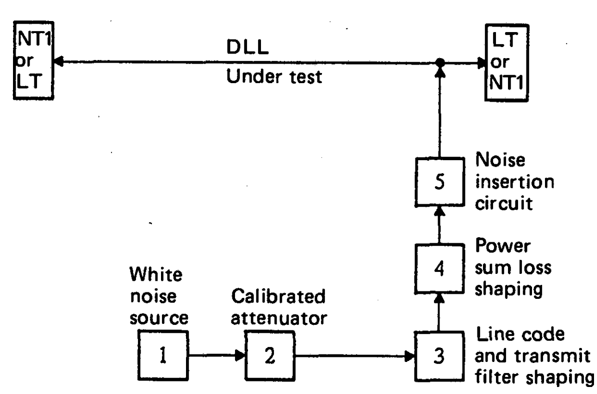


FIGURE 11/G.961

Crosstalk noise simulation and testing

The measurement arrangement in Figure 11/G.961 is described in the following:

a) Box 1 represents a white noise source of constant spectral density. Spectrum is flat from 100 Hz to 500 kHz rolling off afterwards at a rate ⩾ 20 dB/decade.

b) Box 2 is a variable attenuator.

c) Box 3 is a filter that shapes the power spectrum to correspond to a particular line code and a particular transmit filter.

d) Box 4 is a filter that shapes the power spectrum according to the PSL characteristic of Figure 10/G.961.

e) Box 5 is a noise insertion circuit which couples the simulated crosstalk noise into the DLL without disturbing its performance. The insertion circuit therefore must be of sufficiently high output impedance relative to the magnitude of the characteristic impedance of the DLL under test. A value of ⩾ 4.0 kΩ in the frequency range 0 to 1000 kHz is recommended.

Boxes 3, 4 and 5 in Figure 11/G.961 are conceptual. Dependent on the particular realization, they could possibly be combined into one circuit. The measurement arrangement in Figure 11/G.961 is calibrated according to the following steps:

a) By terminating the output of Box 5 with a resistor of a value of $Ro/2$ ohm, and measuring the true r.m.s. (root-mean-square) voltage across it in a bandwidth extending from 100 Hz to over 500 kHz. The power dissipated in the $Ro/2$ resistor is 3 dB higher than the power coupled into the receiver of the DLL under test.

b) The shape of the noise spectrum measured across the $Ro/2$ resistor should be within:

   – ± 1 dB for values within 0 dB to 10 dB down from the theoretical peak;

   – ± 3 dB for values within 10 dB to 20 dB down from the theoretical peak;

   for measurement purposes a resolution bandwidth of ⩽ 10 kHz is recommended.

c) The peak factor of the noise voltage across the $Ro/2$ resistor should be ⩾ 4. This in turn fixes the dynamic range requirements of the circuits used in the measurement arrangement.

With the specified calibrated measurement arrangement, intrasystem crosstalk noise due to a worst-case PSL can be injected into the DLL under test while monitoring its performance. The noise level can be increased or decreased to determine positive or negative performance margins.

4.2.3 *Impulse noise modelling*

4.2.3.1 *Definition of impulse noise*

Impulse noise energy appears concentrated in random short time intervals during which it attains substantial levels. For the rest of the time impulse noise effects are negligible.

4.2.3.2 *Measurement arrangement*

Figure 12/G.961 shows a possible arrangement for impulse noise testing.

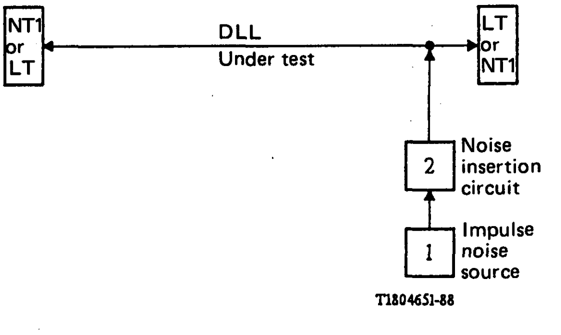
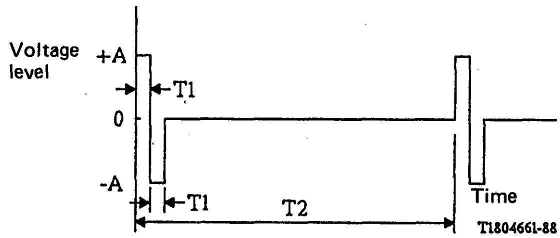


FIGURE 12/G.961

Impulse noise simulation and testing

The impulse noise source in Figure 12/G.961 is for further study. Two possible classes of impulse noise signals are described in the following:

- white noise of flat spectral density level of 5-10 $\mu V/\sqrt{Hz}$ and a bandwidth > 4 times the Nyquist frequency of the particular system. The peak factor of the noise must be > 4;
- a particular waveform, as represented in Figure 13/G.961.



A Peak level, provisionally set to 100 mV
T1 Pulse width, provisionally set to 3 baud periods
T2 Period ≫ T1

Note – In some local line distribution networks and as a national option, crosstalk noise performance tests are considered sufficient to evaluate a particular digital transmission system. In such cases proper DLL engineering rules are applied to guard against impulse noise.

FIGURE 13/G.961

Possible waveform to simulate impulse noise

4.2.4 *Performance tests*

Five types of tests are required to describe the overall performance of a particular digital transmission system to qualify it for operation over the local line distribution network modelled in this Recommendation.

4.2.4.1 *Dynamic range*

Dynamic range performance describes the ability of a particular digital transmission system to operate with received signals varying in level over a wide range. DLL models 1 and 2 in Figure 9/G.961 have a loss varying from very low (0 dB) to very high (37-50 dB at 80 kHz).

When testing with DLL models 1 and 2 in Figure 9/G.961, no errors should be observed in any 15 minutes (provisional) measuring interval when monitoring any B-channel.

Specification of data sequences to be used for this measurement are for further study.

4.2.4.2 *Immunity to echoes*

The remaining DLL models in Figure 9/G.961 are used to test performance of digital transmission systems in the presence of BTs and/or diameter changes.

In each model, no errors should be observed in any 15 minutes (provisional) measuring interval when monitoring any B-channel.

Specification of data sequences to be used for this measurement are for further study.

4.2.4.3 *Intrasystem crosstalk*

Using the crosstalk arrangement described in § 4.2.2.2 with simulated crosstalk noise injected in each DLL model in Figure 9/G.961 the observed bit error ratio (BER) should be $\leqslant 10^{-6}$ (provisional).

When BER measurements are performed in a B-channel, a measuring interval of at least 15 minutes (provisional) is required.

In each DLL model, performance margins are determined. Definition of a minimum positive performance margin is left for further study. This is required to account for additional DLL loss due to splices, and environmental effects (e.g. temperature change).

Specification of data sequences to be used for this measurement are for further study.

4.2.4.4 *Impulse noise*

For further study.

4.2.4.5 *Longitudinal voltages induced from power lines*

For further study.

5 Transmission method

The transmission system provides for duplex transmission on 2-wire metallic local lines. Duplex transmission shall be achieved through the use of ECHO CANCELLATION (ECH) or TIME COMPRESSION MULTIPLEX (TCM). With the ECH method, illustrated in Figure 14/G.961, the echo canceller produces a replica of the echo of the transmitted signal that is subtracted from the total received signal. The echo is the result of imperfect balance of the hybrid and impedance discontinuities in the line.

With the TCM or "burst mode" method, illustrated in Figure 15/G.961, transmissions on the DLL are separated in time (bursts). Blocks of bits (bursts) are sent alternatively in each direction. Bursts are passed through buffers at each transceiver terminal such that the bit stream at the input and output of the TCM transceiver terminal is continuous at the rate R. The bit rate on the line is required to be greater than 2R to provide for an idle interval between bursts which is necessary to allow for the transmission delay and transmitter/receiver turn-around (switching of Sn and Se in Figure 15/G.961).

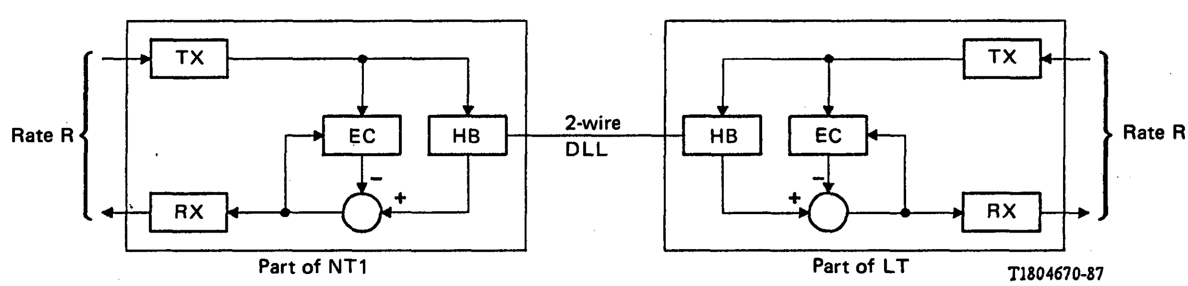
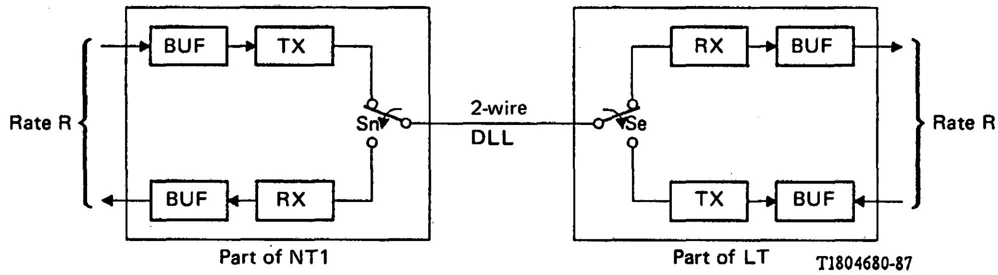


FIGURE 14/G.961

ECH method functional diagram



TX Transmitter
RX Receiver
EC Echo canceller
HB Hybrid
BUF Buffer

FIGURE 15/G.961

TCM method functional diagram

6 Activation/deactivation

6.1 *General*

The functional capabilities of the activation/deactivation procedure are specified in Recommendation G.960. The transmission system has to meet the requirements specified in Recommendation G.960. In particular, it has to make provision to convey the signals defined in Recommendation G.960 which are required for the support of the procedures.

6.2 *Physical representation of signals*

The signals used in the digital transmission system are system dependent and can be found in Annex A and in the Appendices to this Recommendation.

7 Operation and maintenance

7.1 *Operation and maintenance functions*

The operation and maintenance functions in the digital transmission system using metallic local lines for the ISDN basic rate access, are defined in Recommendation G.960.

7.2 *CL channel*

7.2.1 **CL channel** *definition*

This channel is conveyed by the digital transmission system in both directions between LT and NT1. It is used to transfer information concerning operation, maintenance and activation/deactivation of the digital transmission system and of the digital section.

7.2.2 *CL channel requirements*

For further study.

The minimum number of functions (optional or mandatory) the CL channel should support is for further study.

7.3 *Transfer mode of operation and maintenance links*

For further study.

8 Power feeding

8.1 *General*

This section deals with power feeding of the NT1, one regenerator (if required), and the provision of power to the user-network interface according to Recommendation I.430 under normal and restricted conditions.

When activation/deactivation procedures are applied, power down modes at the NT1, regenerator (if required) and the LT are defined.

8.2 *Power feeding options*

Power feeding options under normal and restricted conditions are considered. For this purpose, a restricted condition is entered after failure of AC mains power at the NT1 location.

a) Power feeding of NT1 under normal conditions will be provided using one of the following options:
   - AC mains powering;
   - remote powering from the network (or via a regenerator, if required).

   In both cases the NT1 may provide power to the user-network interface according to Recommendation I.430. This power is derived from AC mains or remotely from the network.

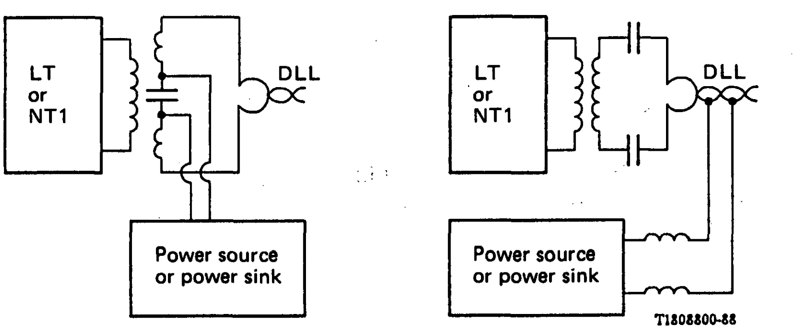
b) Power feeding of NT1 under restricted conditions, when provided, employs one of the following optional sources:
   - back-up battery;
   - remote powering from the network (or via a regenerator, if required).

In both cases the NT1 may provide power to the user-network interface according to Recommendation I.430.

Power feeding options are chosen to satisfy national regulations.

8.3 *Power feeding and recovery methods*

Two power feeding and recovery methods are possible and are described in Figure 16/G.961.



a) Series power feeding and recovery

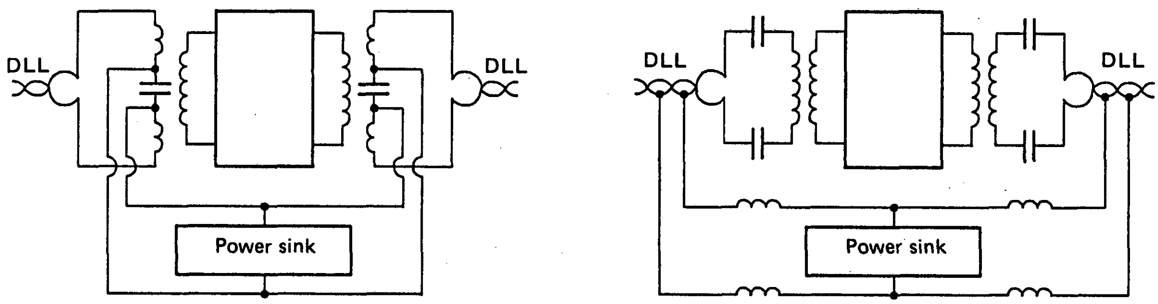
b) Parallel power feeding and recovery

FIGURE 16/G.961

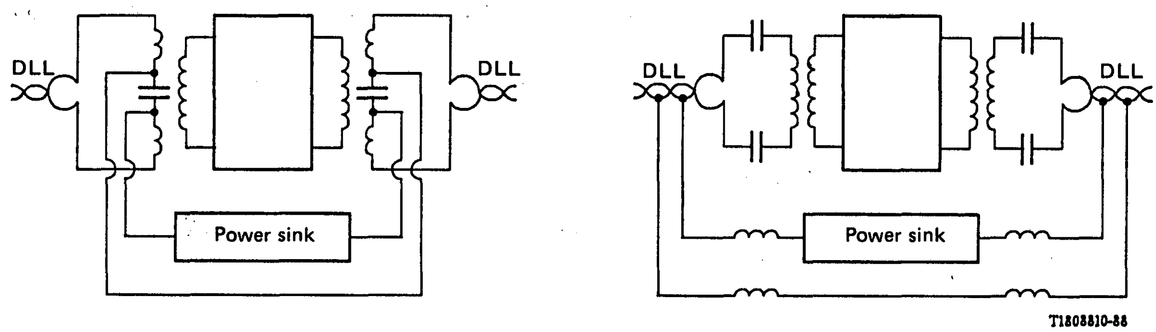
Power feeding and recovery methods

When no regenerator is present on the DLL connecting the LT and the NT1, for each case in Figure 16/G.961 the power source could be either a constant voltage source with current limiting or a constant current source with voltage limiting.

When a regenerator is present, both methods of power feeding and recovery in Figure 16/G.961 remain applicable. However, when a constant voltage source is used at the LT, the regenerator power sink is connected in parallel to the DLLs and when a constant current source is used at the LT, the regenerator power sink is connected in series with the DLLs. The resulting configurations are shown in Figure 17/G.961.



a) Regenerator powering from constant voltage source at LT



b) Regenerator powering from constant current source at LT

FIGURE 17/G.961

Powering at regenerator

8.4 *DLL resistance*

This parameter is a particular subject of the individual local network and therefore out of the scope of this Recommendation. Its maximum value depends on the LT output voltage, the power consumption of the NT1 and regenerator (if required) and the power feeding arrangement for the user-network interface.

8.5 *Wetting current*

The NT1 shall provide a DC termination to allow a minimum wetting current to flow (the value has to be defined) including the power down mode or in case of local power feeding of the NT1.

8.6 *LT aspects*

A current limitation for voltage source configuration or a voltage limitation for current source configuration is required. The values shall take into account the relevant IEC Publications and national safety regulations.

Short-term overload of the feeding current may be tolerated (charging condition of the capacitor of DC/DC converter in NT1).

8.7 *Power requirements of NT1 and regenerator*

8.7.1 *Power requirements of NT1*

a) active state without powering of user-network interface: to be defined;

b) active state including restricted powering of the user-network interface as defined in Recommendation I.430: to be defined;

c) active state including normal powering of user-network interface as defined in Recommendation I.430: to be defined;

d) power down mode: to be defined.

8.7.2 *Power requirements of regenerator*

For further study.

8.8 *Current transient limitation*

The rate of change of current drawn by the NT1 or regenerator from the network shall not exceed X mA/µs. The value of X is to be defined.

9 **Environmental conditions**

9.1 *Climatic conditions*

Climatograms applicable to the operation of NT1 and LT equipment in weather protected and non-weather protected locations can be found in IEC Publication 721-3. The choice of classes is under national responsibility.

9.2 *Protection*

9.2.1 *Isolation*

Isolation between various points at the NT1 can be identified:

- between line interface and T reference point;
- between line interface or T reference point and AC mains (this is generally defined in IEC Guide 105 and IEC Publication 950 but the test requirements may be different in various countries);
- between line interface and the protective ground of AC mains.

9.2.2 *Overvoltage protection*

- To conform with Recommendations K.12, K.20 for LT.
- To conform with Recommendations K.12, K.21 for NT1.

9.3 *Electromagnetic compatibility*

9.3.1 *Susceptibility, radiated and conducted emission levels for LT or NT1 equipment*

This is outside of the scope of this Recommendation. CISPR Publication 22 and national regulations have to be considered.

9.3.2 *Limitation of the output power to the line*

Due to limited longitudinal conversion loss of the line at high frequencies and the limitation of radiation according to CISPR Publication 22 and national regulations, the output power shall be limited. The specific values are outside the scope of this Recommendation.

ANNEX A

(to Recommendation G.961)

General structure for an Appendix on electrical characteristics

A.0 *Electrical characteristics*

Short general characterization of the digital transmission system.

Note – The content of this Annex is a guideline for the presentation of the description of the digital transmission systems and is not intended to constrain any of the systems which will be included.

A.1 *Line code*

For both directions of the transmission the line code is ... And the coding scheme will be ... .

A.2 *Symbol rate*

The symbol rate is determined by the line code, the bit rate of the information stream and the frame structure. The symbol rate is ... kbaud.

A.2.1 *Clock requirements*

A.2.1.1 *NT1 free running clock accuracy*

The accuracy of the free running clock in the NT1 shall be ± ... ppm.

A.2.1.2 *LT clock tolerance*

The NT1 and LT shall accept a clock accuracy from the ET of ± ... ppm.

A.3 *Frame structure*

The frame structure contains a frame word, *N* times (2B + D) and a CL channel.

Frame word	*N* times (2B + D)	CL channel

A.3.1 *Frame length*

The number *N* of (2B + D) slots in one frame is ...

A.3.2 *Bit allocation in direction LT-NT1*

In Figure A-1/G.931 the bit allocation is given.

TO BE PREPARED FOR EVERY SPECIFIC CASE

FIGURE A-1/G.961

Bit allocation in direction LT-NT1

A.3.3 *Bit allocation in direction NT1-LT*

In Figure A-2/G.961 the bit allocation is given.

TO BE PREPARED FOR EVERY SPECIFIC CASE

FIGURE A-2/G.961

Bit allocation in direction NT1-LT

A.4 *Frame word*

The frame word is used to allocate bit positions to the 2B + D + CL channels. It may, however, also be used for other functions.

A.4.1 *Frame word in direction LT-NT1*

The code for the frame word will be ...

A.4.2 *Frame word in direction NT1-LT*

The code for the frame word will be ...

A.5 *Frame alignment procedure*

A.6 *Multiframe*

To enable bit allocation of the CL channel in more frames next to each other a multiframe structure may be used. The start of the multiframe is determined by the frame word. The total number of frames in a multiframe is ...

A.6.1 *Multiframe word in direction NT1-LT*

The multiframe will be identified by ...

A.6.2 *Multiframe word in direction LT-NT1*

The multiframe will be identified by ...

A.7 *Frame offset between LT-NT1 and NT1-LT frames*

The NT1 shall synchronize its frame on the frame received in the direction LT to NT1 and will transmit its frame with an offset.

A.8 *CL channel*

A.8.1 *Bit rate*

A.8.2 *Structure*

A.8.3 *Protocols and procedures*

A.9 *Scrambling*

Scrambling will be applied on 2B + D channels and the scrambling algorithm shall be as follows:

– In direction LT to NT1

– In direction NT1 to LT.

A.10 *Activation/deactivation*

Description of system activation/deactivation procedure including options that are supported and options that are not supported.

See also Recommendation G.960, § 5.

A.10.1 *Signals used for activation*

A list and definition of the signals used for activation/deactivation (SIGs).

- signals used for start-up (CL not available);
- bits in CL channel in an already established frame.

A.10.2 *Definition of internal timers*

A.10.3 *Description of the activation procedure* (based on arrow sequence for the error-free case)

- activation from the network side;
- activation from the user side.

A.10.4 *State transition table NT1 as a function of INFOs, SIGs, internal timers*

The description of loop backs and options supported is given in such a way that the minimum implementation may be clearly identified.

A.10.5 *State transition table LT as a function of FEs, SIGs, internal timers*

The description of loop backs and options supported is given in such a way that the minimum implementation may be clearly identified.

A.10.6 *Activation times*

See Recommendation G.960, §§ 5.5.1 and 5.5.2.

A.11 *Jitter*

Jitter tolerances are intended to ensure that the limits of Recommendation I.430 are supported by the jitter limits of the transmission system on local lines. The jitter limits given below must be satisfied regardless of the length of the local line and the inclusion of one regenerator, provided that they are covered by the transmission media characteristics (see § 3). The limits must be met regardless of the bit patterns in the B, D and CL channels.

A.11.1 *NT1 input signal jitter tolerance*

The NT1 shall meet the performance objectives with wander/jitter at the maximum magnitudes (J_1, J_2) indicated in Figure A-3/G.961, for single jitter frequencies in the range of F_1 Hz to F_3 kHz ($F_3 = 1/4\ F_6$, F_6 = symbol rate frequency), superimposed on the test signal source. The NT1 shall also meet the performance objectives with wander per day of up to ... UI peak-to-peak where the maximum rate of change of phase is ... UI/hour.

A.11.2 *NT1 output jitter limitations*

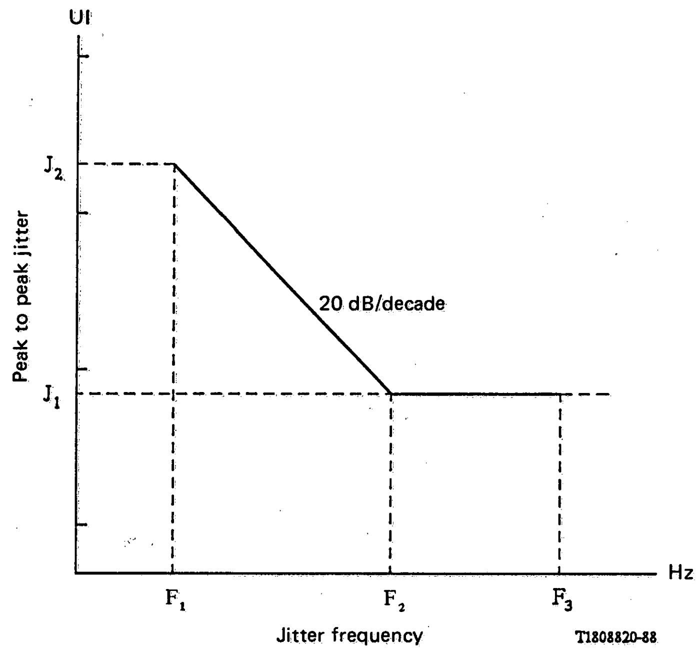
With the wander/jitter as specified in § A.11.1 superimposed on the NT1 input signal, the jitter on the transmitted signal on the NT1 towards the network shall conform to the following:

a) The jitter shall be equal to or less than ... UI peak-to-peak and less than ... UI r.m.s. when measured with a high-pass filter having a 20 dB/decade roll-off below $M \cdot F_2$ Hz ($M \geq 1$).

b) The jitter in the phase of the output signal relative to the phase of the input signal (from the network) shall not exceed ... UI peak-to-peak or ... UI r.m.s. when measured with a band-pass filter having a 20 dB/decade roll-off above $N \cdot F_2$ Hz ($N \geq 2$) and a 20 dB/decade roll-off below $K \cdot F_k$ ($F_k \ll 1$). This requirement applies with superimposed jitter in the phase of the input signal as specified in § A.11.1 for single frequencies up to F_2 Hz.

A.11.3 *Test conditions for jitter measurements*

Due to bidirectional transmission on the 2-wire and due to severe intersymbol interference no well defined signal transitions are available at the NT1 2-wire point.



Note — Two possible solutions are proposed:

a) A test point in the NT1 is provided to measure jitter with an undisturbed signal.

b) A standard LT transceiver including an artificial local line is defined as a test instrument.

FIGURE A-3/G.961

Minimum tolerable jitter on NT1 input signal

A.12 *Transmitter output characteristics of NT1 and LT*

The following specifications apply with a load impedance of ...

A.12.1 *Pulse amplitude*

The zero to peak nominal amplitude of the largest pulse shall be ... V and the tolerance shall be ± ... %.

A.12.2 *Pulse shape*

The pulse shape shall meet the pulse mask of Figure ...

A.12.3 *Signal power*

The average signal power shall be between ... dBm and .. dBm.

A.12.4 *Power spectrum*

The upper bound of the power spectral density shall be within the template in Figure ...

A.12.5 *Transmitter signal nonlinearity*

This is a measure of the deviations from ideal pulse heights and the individual pulse nonlinearity.

The measurement method is for further study.

A.13 *Transmitter/receiver termination*

A.13.1 *Impedance*

The nominal input/output impedance looking toward the NT1 or LT respectively shall be ...

A.13.2 *Return loss*

The return loss of the impedance shall be greater than shown in the template Figure ...

A.13.3 *Longitudinal conversion loss*

The minimum longitudinal conversion loss shall be as follows:

... kHz ... dB

... kHz ... dB

APPENDIX 1

(to Recommendation G.961)

Electrical characteristics of an MMS 43 transmission system

I.1 *Line code*

For each direction of transmission the line code is a Modified Monitoring State Code mapping 4 bits into 3 ternary symbols with levels +, 0 or − (MMS 43). Details of the coding scheme are given in Figure I-1/G.961. Note that the numbers in the columns for each of the 4 alphabets S1 ... S4 give the numbers of the alphabet to be used for the coding of the next block of 4 bits. The bits and symbols standing left are those transmitted or received first.

	S1	S2	S3	S4
0001	0 − + 1	0 − + 2	0 − + 3	0 − + 4
0111	− 0 + 1	− 0 + 2	− 0 + 3	− 0 + 4
0100	− + 0 1	− + 0 2	− + 0 3	− + 0 4
0010	+ − 0 1	+ − 0 2	+ − 0 3	+ − 0 4
1011	+ 0 − 1	+ 0 − 2	+ 0 − 3	+ 0 − 4
1110	0 + − 1	0 + − 2	0 + − 3	0 + − 4
1001	+ − + 2	+ − + 3	+ − + 4	− − − 1
0011	0 0 + 2	0 0 + 3	0 0 + 4	− − 0 2
1101	0 + 0 2	0 + 0 3	0 + 0 4	− 0 − 2
1000	+ 0 0 2	+ 0 0 3	+ 0 0 4	0 − − 2
0110	− + + 2	− + + 3	− + + 2	− − + 3
1010	+ + − 2	+ + − 3	+ − − 2	+ − − 3
1111	+ + 0 3	0 0 − 1	0 0 − 2	0 0 − 3
0000	+ 0 + 3	0 − 0 1	0 − 0 2	0 − 0 3
0101	0 + + 3	− 0 0 1	− 0 0 2	− 0 0 3
1100	+ + + 4	− + − 1	− + − 2	− + − 3

Note — A received ternary block 000 is decoded as binary 0000.

FIGURE I-1/G.961

MMS43-Code

I.2 *Symbol rate*

The symbol rate is 120 kbaud.

I.2.1 *Clock symbol requirements*

I.2.1.1 *NT1 free running clock accuracy*

The tolerance of the free running NT1 clock is ± 100 ppm.

I.2.1.2 *LT clock tolerance*

The tolerance of the clock signal provided at the LT is ± 1 ppm.

I.3 *Frame structure*

Each frame contains a frame word, 2B + D data and the CL-channel. Multiframes are not used.

I.3.1 *Frame length*

The length of each frame is 120 ternary symbols corresponding to 1 ms. Each frame has 108 symbols (corresponding to 144 bits) carrying 2B + D data.

I.3.2 *Symbol allocation LT to NT1*

In the direction LT to NT1 the 120 symbols of each frame are used as follows:

- Symbols 1 to 84: 2B + D;
- Symbol 85: CL-channel;
- Symbols 110 to 120: frame word.

I.3.3 *Symbol allocation NT1 to LT*

In the direction NT1 to LT, the frame structure is identical to that of the direction LT to NT1.

The frame transmitted by the NT1 is synchronized to that received from the LT.

I.4 *Frame word*

I.4.1 *Frame word in direction LT to NT1*

The frame word in the direction LT to NT1 is:

$+ + + - - - + - - + -$

I.4.2 *Frame word in direction NT1 to LT*

The frame word in the direction NT1 to LT is:

$- + - - + - - - + + +$

I.5 *Frame alignment procedure*

The transmission system is considered to be synchronous if the frame word has been identified in the same position for 4 immediately succeeding frames. Loss of synchronization is assumed, if the detected frame position does not coincide with the expected position during 60 ... 200 successive frames.

I.6 *Multiframe*

Not used.

I.7 *Frame offset at NT1*

On the line at the NT1 the frame word transmitted by the NT1 occurs 60 ± 1 symbols (0.5 ms) later than that received at the NT1 input, measured between the first symbols of each frame word.

I.8 *CL-channel*

I.8.1 *Bit rate*

The bit rate for the CL-channel (maintenance-channel) is 1 kbit/s.

I.8.2 *Structure*

No specific structure is defined for transparent messages.

I.8.3 *Protocols and procedures*

Transparent messages in the CL-channel use "0" and "−" polarity of the CL-symbol of the line signal. "0" and "+" polarity are used to request a loopback 2B + D in the NT1 or an intermediate repeater. Transparent use of the CL-channel may override these loopback commands.

I.9 *Scrambling*

In order to minimize correlation between incoming and transmitted symbols scrambling is used. Scrambling is applied only to the 2B + D-channels.

The scrambling polynomial is different in both NT1 to LT and LT to NT1 directions.

– In direction LT to NT1: $1 \oplus x^{-5} \oplus x^{-23}$

– In direction NT1 to LT: $1 \oplus x^{-18} \oplus x^{-23}$.

where $\oplus$ is the modulo two sum and x^{-k} is the scrambled data delayed by k symbol intervals.

I.10 *Activation/deactivation*

Activation/deactivation is provided to enable the use of a power down state especially for applications, where the NT1 is powered from the LT via the local line. Activation from the power state may be initated from both ends usig a 7.5 kHz burst signal. Collisions are handled through appropriate duration and repetition rate of these bursts.

The procedures on the line system support the procedures at reference point T for call control in accordance with Recommendation I.430 and the operation of loopbacks 1 (in the LT), 1A (in the regenerator) and 2 (in the NT1) in accordance with Recommendation I.603. The loopbacks are transparent.

Timer 1 and timer 2, as defined in Recommendation I.430, are located as follows:

– Timer 1 in the ET layer 1 or the ET,

– Timer 2 in the NT1.

The activation of the line system for maintenance purposes e.g. error performance monitoring, is possible, even if no TE is connected to the interface at T reference point.

Transmission of INFO 2 on the interface of T reference point is initiated when the line system is synchronized in the direction LT to NT1.

I.10.1 *Signals used for activation*

To provide means to control/indicate progress during activation/deactivation across the local line the following signal elements are used:

SIG 0 — NT1 to LT and LT to NT1
No signal.

SIG 1W — NT1 to LT
Awake signal (7.5 kHz tone); signals the layer 1 entity in the local exchange that it has to enter the power-up state and provide for the activation of the line system and the interface at T reference point.
This signal is also used as awake acknowledge on the receipt of SIG 2W.

SIG 2W — LT to NT1
Awake signal (7.5 kHz tone); signals the NT1 that it has to enter the power-up state and prepare for synchronization on an incoming signal from the LT.
This signal is also used as awake acknowledge on the receipt of SIG 1W.

SIG 1 NT1 to LT
Signal which contains framing information and allows the synchronization of the receiver in the LT. It informs the LT that the NT1 has synchronized on SIG 2.

SIG 2 LT to NT1
Signal which contains framing information and allows the synchronization of the receiver in the NT1.

SIG 1A NT1 to LT
Signal similar to SIG 1 but without framing information.

SIG 3 NT1 to LT
Signal which contains framing information and allows the synchronization of the receiver in the LT. It indicates to the ET that the interface at T reference point is synchronized in both directions of transmission (except in the case of loopback 2 and 1A).

SIG 4H LT to NT1
Signal which requires the NT1 to establish full layer 1 information transfer capability in both directions of transmission.

SIG 4 LT to NT1
Signal which contains framing information and operational data on B and D channels.

SIG 5 NT1 to LT
Signal which contains framing information and operational data on B and D channels.

SIG 2-L2 LT to NT1
Signal similar to SIG 2, but includes a loopback 2 request.

SIG 4H-L2 LT to NT1
Signal which requires the NT1 to operate loopback 2 and to establish layer 1 information transfer capability in the direction LT to TE (transparent loopback 2).

SIG 4-L2 Signal similar to SIG 4, but includes a loopback 2 request.

All SIGs, except SIG 1W and SIG 2W, are continuous signals. The awake signals SIG 1W and SIG 2W are sent for a specified period of time only, but may be repeated if no acknowledgement is received. The repetition times are specified in a way to assure a proper interworking with the normal activation procedure.

The loopback requests are transmitted making use of the CL channel. All other SIGs do not require the CL channel.

The CL channel is provided with all SIGs except SIG 0, SIG 1W, SIG 2W and SIG 1A.

I.10.2 *Definition of internal timers*

In the state transition tables and arrow diagrams the following internal timers are used:

Tn1 =	13 ms:	timer to supervise repetition of the awake signal SIG 2W from the LT
Tl1 =	7 ms:	timer to supervise repetition of the awake signal SIG 1W from the NT1
Tl2 =	1 ms:	timer which defines the duration of SIG 4H and SIG 4H-L2
Tl3 =	1 ms:	timer which assures that, under non-failure conditions, the PH-AI is passed first in the TE and then in the LT/ET. This protects the first layer 2 frame (layer 3 – SETUP message) from the network side.
Tl4 =	12 ms:	timer used to start transmission of SIG 2 when loopback 1 is requested.
Tl5 =	0.1 ... 1 s:	timer to supervise the deactivation procedure (within ET).

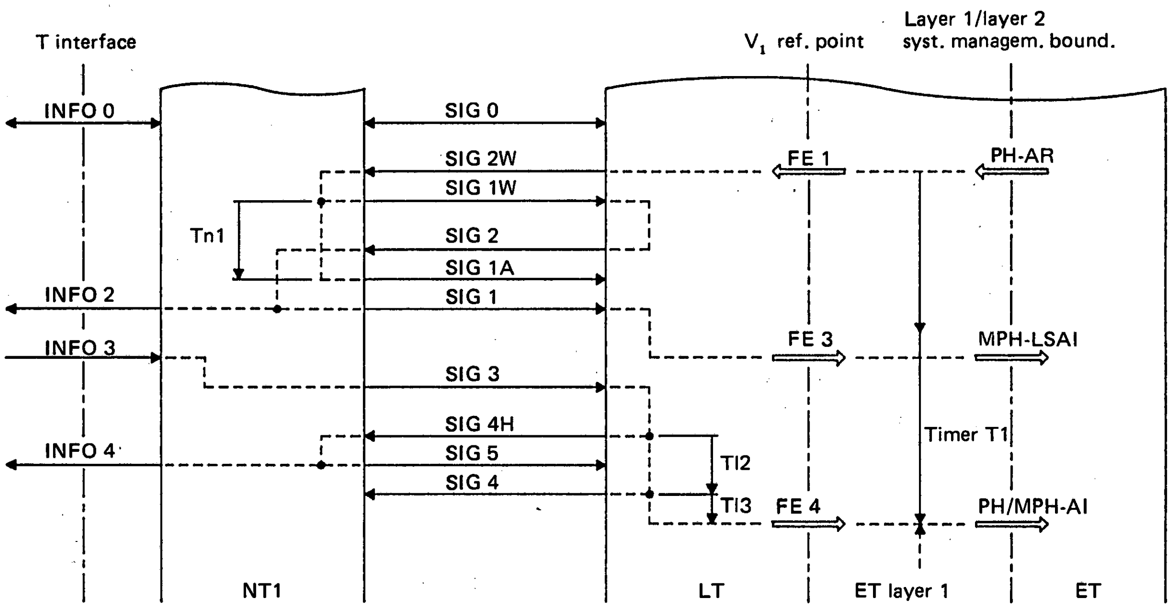
I.10.3 *Description of the activation procedure*

In Figure I-2/G.961 the activation/deactivation procedures are described for the non-failure situation.

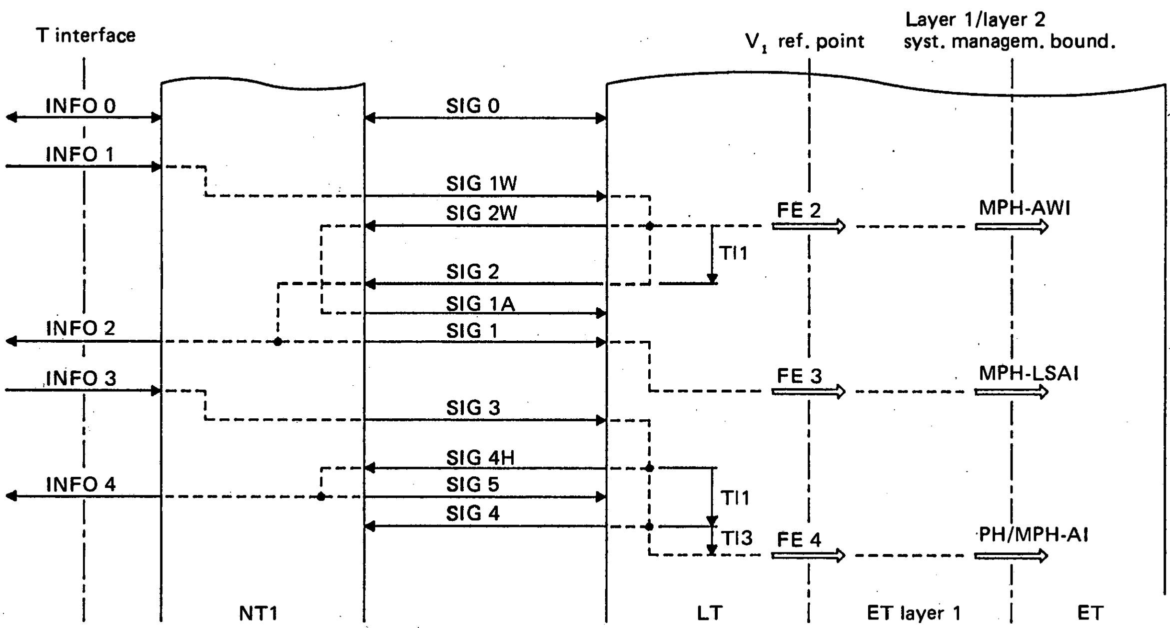
Timer T1 (located in ET layer 1) and Timer T2 (located in NT1) are as specified in Recommendation I.430; the Functional Elements (FE) are defined in Recommendation G.960, § 5.4.1.3, and the primitives in Recommendation G.960, § 5.4.2.2 and § 5.4.2.3.

I.10.4 *NT1 state transition table*

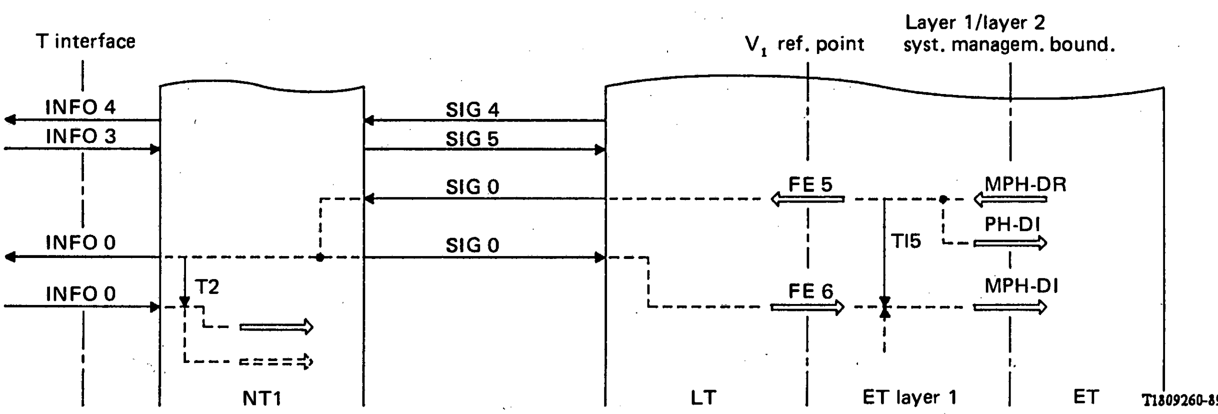
The NT1 state transition table is described in Table I-1/G.961. INFOs on the interface at T reference point are related to SIGs on the line system and vice versa.



a) Activation from network side



b) Activation from user side



c) Deactivation

FIGURE I-2/G.961

Activation/deactivation procedures: arrow diagrams (non-failure situations)

TABLE I-1/G.961

NT1 state transition table

State	NT 1.1	NT 1.2	NT 1.3	NT 1.4	NT 1.5	NT 1.6	NT 1.7	NT 1.8	NT 1.9	NT 1.10	NT 2.1	NT 2.2
Transmit signal	INFO 0	INFO 0	INFO 0	INFO 0	INFO 2	INFO 2	INFO 4	INFO 0	INFO 2	INFO X (Note 2)	INFO 2	INFO 4 (Note 4)
Receive signal	SIG 0	SIG 1W	SIG 1W	SIG 1A	SIG 1	SIG 3	SIG 5	SIG 0	SIG 5	SIG 0 (Note 3)	SIG 3	SIG 5 (Note 5)
INFO 0	–	–	–	–	–	–	NT 1.9	NT 1.1	–	–	–	–
INFO 1	NT 1.2	–	–	–	–	–	/	–	–	/	–	/
INFO 3	/	/	/	/	NT 1.6	–	–	–	NT 1.7	/	–	–
SIG 0	–	–	–	ST.T2; NT 1.8	ST.T2; NT 1.8	ST.T2; NT 1.8	ST.T2; NT 1.8	–	ST.T2; NT 1.8	ST.T2; NT 1.8	ST.T2; NT 1.8	ST.T2; NT 1.8
SIG 2W	ST. TN1; NT 1.3	NT 1.4	/	/	/	/	/	–	/	/	/	/
SIG 2	/	–	–	NT 1.5	–	–	/	/	/	/	NT 1.6 or –	/
SIG 4H	/	/	/	/	/	NT 1.7	–	/	/	/	NT 1.7	/
SIG 4	/	/	/	/	/	/	–	/	–	–	/	NT 1.7
Exp. of T2 (Note 1)	–	–	–	–	–	–	–	NT 1.1	–	–	–	–
Lost framing T interface	/	/	/	/	/	–	NT 1.9	–	–	–	/	/
Lost framing line system	/	/	/	/	NT 1.10	NT 1.10	NT 1.10	/	NT 1.10	–	NT 1.10	NT 1.10
Exp. of internal timer Tn1	/	/	NT 1.4	/	/	/	/	/	/	/	/	/

TABLE I-1/G.961 *(cont.)*

State	NT 1.1	NT 1.2	NT 1.3	NT 1.4	NT 1.5	NT 1.6	NT 1.7	NT 1.8	NT 1.9	NT 1.10	NT 2.1	NT 2.2
Transmit signal	INFO 0	INFO 0	INFO 0	INFO 0	INFO 2	INFO 2	INFO 4	INFO 0	INFO 2	INFO X (Note 2)	INFO 2	INFO 4 (Note 4)
Receive signal	SIG 0	SIG 1W	SIG 1W	SIG 1A	SIG 1	SIG 3	SIG 5	SIG 0	SIG 5	SIG 0 (Note 3)	SIG 3	SIG 5 (Note 5)
SIG 2-L2	/	–	–	NT 2.1	NT 2.1 or –	NT 2.1 or –	/	/	/	/	–	/
SIG 4H-L2	/	/	/	/	/	NT 2.2	–	/	/	/	NT 2.2	–
SIG 4-L2	/	/	/	/	/	/	NT 2.2	/	NT 2.2	NT 2.2	/	–

– No state change.

/ Impossible by the definition of peer-to-peer physical layer procedures or system internal reasons.

ST.Tx; NTy Start Timer x; enter state NT y.

Note 1 – Timer T2 as defined in Recommendation I.430.

Note 2 – INFO X: signal with no framing information i.e. binary ZERO's.

Note 3 – Any other signal which produces an error indication on the LT side is allowed, especially loss of framing or excessive error rate.

Note 4 – The D-Echo bit is set to binary ZERO.

Note 5 – The B- and D-channels are looped back to the network side.

The following states are used:

NT 1.1 Deactivated state (low power consumption mode). No signal is transmitted.

NT 1.2 The NT1 sends the awake signal SIG 1W to the LT, on the receipt of INFO 1 from the user side, and waits for the receipt of the awake acknowledge signal SIG 2W from the LT.

NT 1.3 On receipt of the awake signal SIG 2W, the NT1 responds with SIG 1W and starts transmission of SIG 1A on expiry of timer Tn1, unless a new awake signal SIG 2W from the LT is received.

NT 1.4 After completion of the awake procedure, the NT1 waits for SIG 2 to synchronize its receiver.

NT 1.5 The receiver on the network side is synchronized. The NT1 sends SIG 1 to the LT and INFO 2 to the user side to initiate the activation of the interface of reference point T. It waits for the receipt of INFO 3.

NT 1.6 The interface at T reference point is synchronized in both directions of transmission. The NT1 sends SIG 3 to the LT and waits for the receipt of SIG 4H.

NT 1.7 The NT1 is fully active and sends INFO 4 to the user side and SIG 5 to the LT. The B and D channels are operational.

NT 1.8 Pending deactivation state. The NT1 sends INFO 0 to the user side to deactivate the interface at reference point T and SIG 0 to the LT. It waits for the receipt of INFO 0 or expiry of timer T2 to enter state NT1.1.

NT 1.9 This state is entered on loss of signal or loss of framing at the T interface. No indication is sent to the LT, in accordance with Note 3 to Table 4/I.430.

NT 1.10 This state is entered on loss of framing at the line side. An indication is forwarded to the user side (INFO X) and to the network side (SIG 0).

The following states support activation when loopback 2 is requested:

NT 2.1 The receiver on the network side is synchronized. The NT1 sends SIG 3 to the LT and INFO 2 to the user side (transparent loopback). It waits for the receipt of SIG 4H-L2 from the LT.

NT 2.2 The NT1 is fully active and sends INFO 4 to the user side (transparent loopback) and SIG 5 to the LT. Loopback 2 is operated and receive data 2B + D are sent to the LT.

I.10.5 *LT state transition table*

The LT state transition table is described in Table I-2/G.961. SIGs on the line sysem are related to Functional Elements (FEs) on the V_1 reference point.

The following states are used:

LT 1.1 Deactivated state. No signal is transmitted.

LT 1.2 On receipt of the awake signal SIG 1W, the LT responds with SIG 2W and starts transmission of SIG 2 on expiry of timer Tl1, unless a new awake signal SIG 1W from the NT1 is received.

LT 1.3 The LT sends the awake signal SIG 2W to the NT1, on the receipt of FE 1, and waits for the awake acknowledge signal SIG 1W from the NT1.

LT 1.4 The LT sends SIG 2 to the NT1 and waits for SIG 1 or SIG 3 to synchronize its receiver. When the LT is synchronized and has detected SIG 1, it issues FE 3.

LT 1.5 The line transmission system is synchronized in both directions of transmission. The LT waits for the receipt of SIG 3.

LT 1.6 The line transmission system and the interface at T reference point are synchronized in both directions of transmission. The LT sends SIG 4H until the expiry of timer Tl2.

LT 1.7 Fully active state. The LT sends SIG 4 to the NT1 and issues FE 4. The B and D channels are fully operational.

LT 1.8 Pending deactivation state. The LT sends SIG 0 to the NT1 to deactivate the line system and the interface at T reference point. It waits for the receipt of SIG 0 to enter state LT 1.1 and to issue FE 6.

TABLE I-2/G.961

LT state transition table

State	LT 1.1	LT 1.2	LT 1.3	LT 1.4	LT 1.5	LT 1.6	LT 1.7	LT 1.8	LT 2.1	LT 2.2	LT 2.3	LT 2.4
Transmit signal / Receive signal	SIG 0	SIG 2W	SIG 2W	SIG 2	SIG 2	SIG 4H	SIG 4	SIG 0	SIG 2W	SIG 2	SIG 4H	SIG 4
FE 1	LT 1.3	–	–	–	–	–	–	–	–	–	–	–
FE 5	:	LT 1.8	LT 1.8	LT 1.8	LT 1.8	LT 1.8	LT 1.8	–	LT 1.8	LT 1.8	LT 1.8	LT 1.8
SIG 0	–	–	–	–	FE 7; –	FE 7; –	FE 7; –	FE 6; LT 1.1	–	–	–	–
SIG 1W	ST.TI1, FE 2; LT 1.2	:	LT 1.4	/	/	/	/	–	–	/	/	/
SIG 1	/	/	/	FE 3; LT 1.5	–	/	/	–	/	–	–	–
SIG 3	/	/	/	ST.TI2; LT 1.6	ST.TI2; LT 1.6	–	–	–	/	–	–	–
Exp. of intern. timer TI1	–	LT 1.4	–	–	–	–	–	–	–	–	–	–
Exp. of intern. timer TI2	–	–	–	–	–	FE 7; LT 1.4	–	–	–	–	FE 4; LT 2.4	–
Lost framing line system	/	/	/	/	FE 7; –	FE 7; –	FE 7; –	–	/	/	/	/

TABLE I-2/G.961

State	LT 1.1	LT 1.2	LT 1.3	LT 1.4	LT 1.5	LT 1.6	LT 1.7	LT 1.8	LT 2.1	LT 2.2	LT 2.3	LT 2.4
Transmit signal / Receive signal	SIG 0	SIG 2W	SIG 2W	SIG 2	SIG 2	SIG 4H	SIG 4	SIG 0	SIG 2W	SIG 2	SIG 4H	SIG 4
FE 4	ST.T14; LT 2.1	–	LT 2.2 or –	LT 2.2 or –	LT 2.2 or –	–	–	LT 2.1	:	:	:	:
Exp. of itern. timer T14	–	–	–	–	–	–	–	–	LT 2.2	–	–	–
Rec. synch. on looped b. sig.	/	/	/	–	–	–	–	–	/	ST.T12; LT 2.3	–	–

– No state change.

/ Impossible by the definition of peer-to-peer physical layer procedures or system internal reasons.

: Impossible by the definition of the physical layer.

a, b; LTx Perform action/issue message a and b; enter state LTx.

ST.T1x Start Timer T1x.

The following states support activation when loopback 1 is requested:

LT 2.1 The LT sends the awake signal SIG 2W to the NT1 (transparent loopback), on the receipt of FE 9, and starts transmission of SIG 2 on expiry of timer Tl4.

LT 2.2 The LT has operated loopback 1 and is synchronizing its receiver on the looped back signal.

LT 2.3 The LT sends SIG 4H until the expiry of timer Tl2.

LT 2.4 The LT is fully active and sends SIG 4 to the NT1 (transparent loopback). Loopback 1 is operated.

The LT state transition table is not affected by loopback 2 and 1A requests. The corresponding control signals are transferred across channels C_{V1} and CL.

I.10.6 *Activation times*

For definition of activation times see Recommendation G.960, § 5.5.

a) Maximum activation time for activation occuring immediately after a deactivation:
   - without regenerator: 210 ms.
   - with regenerator: 420 ms.

b) Maximum time for activation occuring after the first powering of a line
   - without regenerator: 1.5 s.
   - with regenerator: 3 s.

I.11 *Jitter*

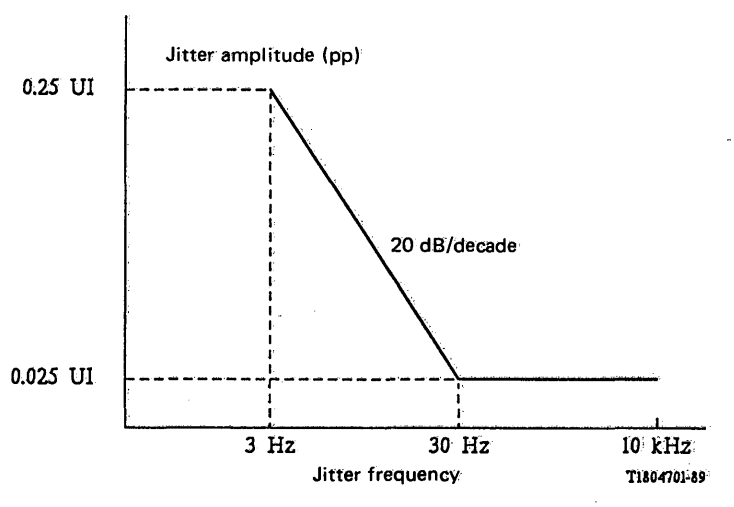
Jitter tolerances shall assure that the maximum network limit of jitter (see Recommendation G.823) is not exceeded.

Furthermore, the limits of Recommendation I.430 must be supported by the jitter limits of the transmission system on local lines.

The jitter limits given below must be satisfied regardless of the length of the local line and the inclusion of repeaters, provided that they are covered by the transmission media characteristic (see § 3). The limits must be met regardless of the transmitted signal. A suitable test sequence is for further study (see Recommendation G.823, § 4).

I.11.1 *Limits of maximum tolerable input jitter*

The amplitude of the jitter at the NT1 input shall be limited by the template given in Figure I-3/G.961.



1 UI = 1/120 kHz = 8.$\overline{3}$ μs

FIGURE I-3/G.961

Minimum tolerable sinusoidal input jitter

I.11.2 *Output jitter of NT1 in absence of input jitter*

When measured with a highpass filter with a 30 Hz cut-off frequency, the jitter at the output of the NT1 shall not exceed 0.02 UIpp. Without a filter, the jitter shall not exceed 0.1 UIpp.

I.11.3 *Timing extraction jitter*

The jitter at the output of the NT1 shall closely follow the input jitter. Therefore, the jitter transfer function of the NT1 shall be less than ± 1 dB in the frequency range 3 Hz to 30 Hz.

I.11.4 *Test conditions for jitter measurements*

For further study.

I.12 *Transmitter output characteristics*

I.12.1 *Pulse amplitude*

The amplitude of a transmitted single pulse shall be 2V ± 0.2V with a load impedance of 150 ohm.

I.12.2 *Pulse shape*

The shape of a transmitted single pulse shall fit the mask given in Figure I-4/G.961.

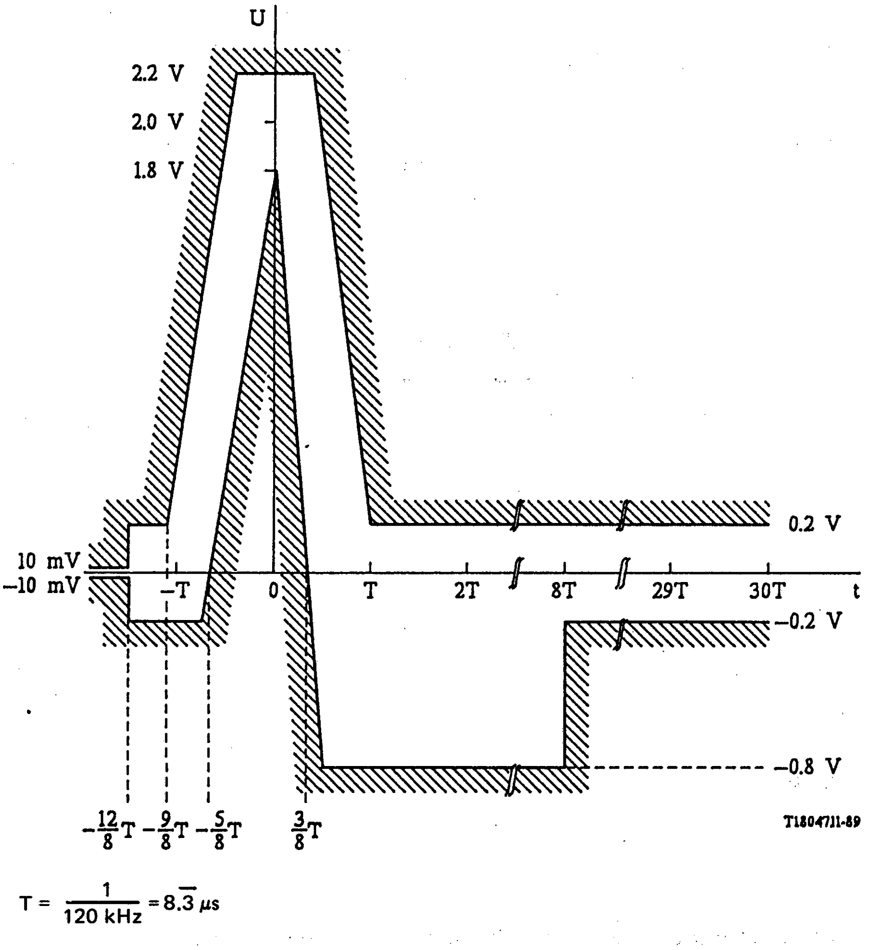


FIGURE I-4/G.961

Pulse mask for transmitted single pulse

I.12.3 *Signal power*

Not specified.

I.12.4 *Power spectrum*

The upper bound of the power spectral density shall be limited according to Figure I-5/G.961.

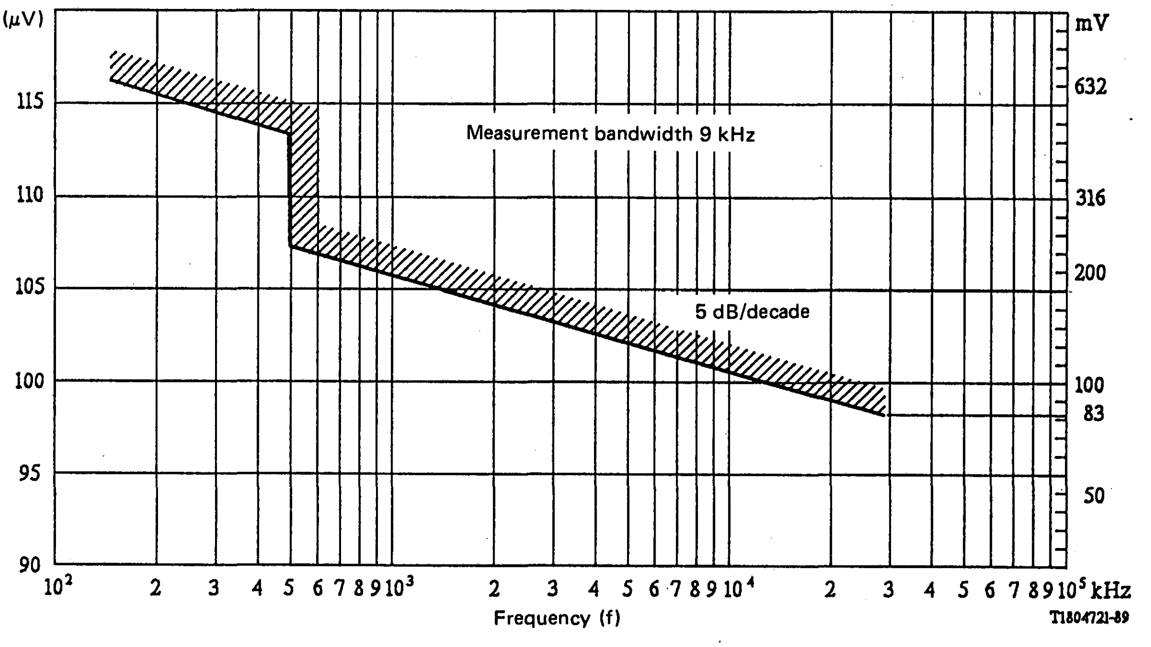


FIGURE I-5/G.961

Limits of transmit power spectrum

I.12.5 *Transmitter signal nonlinearity*

Not specified.

I.13 *Transmitter/receiver termination*

I.13.1 *Impedance*

The nominal output/input impedance of the NT1 and LT shall be 150 ohm.

I.13.2 *Return loss*

The return loss agains 150 ohm ± 1% measured for NT1 or LT shall exceed the limits given in Figure I-6/G.961.

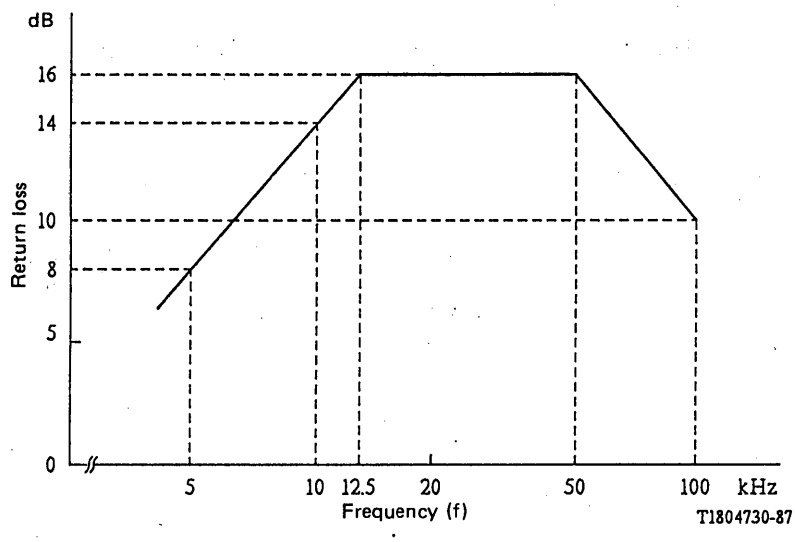


FIGURE I-6/G.961

NT1 and LT return loss

I.13.3 *Longitudinal conversion loss*

The longitudinal conversion loss at the line interface for LT and NT1 shall exceed the limits given in Figure I-7/G.961.

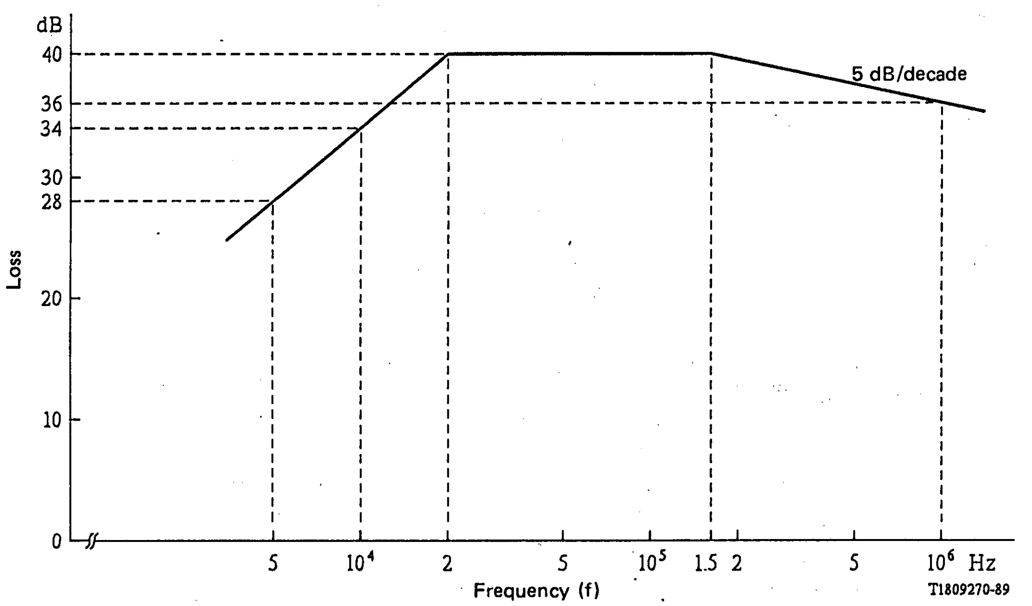


FIGURE I-7/G.961

Longitudinal conversion loss

APPENDIX II

(to Recommendation G.961)

Electrical characteristics of a 2B1Q transmission system

II.1 *Line code*

The line code shall be 2B1Q (2 binary, 1 quaternary). This is a 4-level code and is used without redundancy.

The bit stream entering the NT1 from the interface at reference point T (or entering the LT from the ET) shall be grouped into pairs of bits for conversion to quaternary symbols that are called quats. Figure II-1/G.961 shows the relationship of the bits in the B and D channels to quats. The B- and D-channel bits are scrambled before coding. M_1 through M_6 bits of the CL channel are also paired, coded and scrambled in the same way.

	Time →								
Data	B_1				B_2				D
Bit pairs	$b_{11}b_{12}$	$b_{13}b_{14}$	$b_{15}b_{16}$	$b_{17}b_{18}$	$b_{21}b_{22}$	$b_{23}b_{24}$	$b_{25}b_{26}$	$b_{27}b_{28}$	d_1d_2
Quat # (relative)	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9
# Bits	8				8				2
# Quats	4				4				1

b_{11} First bit of B_1 octet received at reference point T

b_{18} Last bit of B_1 octet received at reference point T

b_{21} First bit of B_2 octet received at reference point T

b_{28} Last bit of B_2 octet received at reference point T

d_1d_2 Consecutive D-channel bits
(d_1 is first bit of pair as received at reference point T)

q_1 Ith quat relative to start of given 18-bit 2B + D data field

Note – There are 12 2B + D 18-bit fields per 1.5 ms basic frame.

FIGURE II-1/G.961

2B1Q encoding of 2B + D bit fields

Each successive pair of scrambled bits in the binary data stream is converted to a quaternary symbol to be output from the transmitters, as specified below:

First bit (sign)	Second bit (magnitude)	Quaternary symbol (quat)
1	0	+ 3
1	1	+ 1
0	1	– 1
0	0	– 3

At the receiver, each quaternary symbol is converted to a pair of bits by reversing the table above, descrambled, and formed into a bit stream representing B and D channels and a CL channel containing M bits for maintenance and other purposes. The bits in the B and D channels are properly placed by reversing the relationship in Figure II-1/G.961.

II.2 *Line baud rate*

The line symbol rate is 80 kbauds.

II.2.1 *Clock tolerance*

II.2.1.1 *NT1 clock tolerance*

The tolerance of the free running NT1 clock is ± 100 ppm.

II.2.1.2 *LT clock tolerance*

The tolerance of the clock provided at the LT is ± 5 ppm.

II.3 *Frame structure*

A frame shall be 120 quaternary symbols transmitted within a nominally 1.5 ms. interval. Each frame contains a frame word, 2B + D data and CL channel bits shown in Figure II-2/G.961.

		← 1.5 ms →	
Frame	FW/IFW	12 × (2B + D)	CL
Function	Frame word	2B + D	Overhead
# Quats	9	108	3
Quat positions	1-9	10-117	118-120
# Bits	18	216	6
Bit position	1-18	19-234	235-240

quat Quaternary symbol = 1 baud

−3, −1, +1, +3 Symbol names

2B + D Customer data channel B_1, B_2 et D

FW Frame Word (9-Symbol Code) = +3 +3 −3 −3 −3 +3 −3 +3 +3

IFW Inverted (or complementary) Frame Word = −3 −3 +3 +3 +3 −3 +3 −3 −3

CL M-Channel Bits M_1-M_6

Note – Frames in the NT1-to-Network direction are offset from frames in the Network-to-NT1 direction by 60 ± 2 quats.

FIGURE II-2/G.961

Frame structure of 2B1Q transmission system

II.3.1 *Frame length*

The number of 2B + D slots in a frame is 12. Each slot contains 18 bits.

II.3.2 *Bit allocation in direction LT-NT1*

The bit allocation of the frames are shown in Figures II-1/G.961 and II-2/G.961.

II.3.3 *Bit allocation in direction NT1-LT*

See § II.3.2.

II.4 *Frame word*

The frame word is used to allocate bit positions to the B, D, and CL channels. It may be also used for baud synchronization.

II.4.1 *Frame word in direction LT-NT1*

The code for the frame word in all frames except the first in a multiframe shall be:

$$\mathrm{FW} = +3\ +3\ -3\ -3\ -3\ +3\ -3\ +3\ +3$$

The code for the frame word of the first frame of a multiframe shall be an inverted frame word (IFW):

$$\mathrm{IFW} = -3\ -3\ +3\ +3\ +3\ -3\ +3\ -3\ -3$$

II.4.2 *Frame word in direction NT1-LT*

See § II.4.1.

II.5 *Frame alignment procedure*

Not specified.

II.6 *Multiframe*

To enable the allocation of the CL channel bits over more than one frame, a multiframe is used. The start of the multiframe is determined by the inverted frame word (IFW). The number of frames in a multiframe is 8.

II.6.1 *Multiframe word in direction NT1-LT*

See § II.4.1.

II.6.2 *Multiframe word in direction LT-NT1*

See § II.4.1.

II.7 *Frame offset between LT-NT1 and NT1-LT frames*

The NT1 shall synchronize transmitted frames with received frames (LT-NT1 direction). Transmitted frames shall be offset with respect to received frames by 60 ± 2 quaternary symbols (i.e., about 0.75 ms).

II.8 *CL channel*

II.8.1 *Bit rate*

The bit rate for the CL channel is 4 kbit/s.

II.8.2 *Structure*

Forty eight bits of a multiframe are used for the CL channel and are referred to as M bits.

Twenty four bits per multiframe (2 kbit/s) are allocated to an embedded operations channel (EOC) which supports operations communications needs between the network and the NT1.

Twelve bits per multiframe (1 kbit/s) are allocated to a cyclic redundancy check (CRC) function.

Twelve bits per multiframe (1 kbit/s) are allocated to other functions and spare bits as shown in Figure II-3/G.961.

		Framing	2B + D	CL (overhead) bits $M_1 - M_6$					
	Quat positions	1-9	10-117	118s	118m	119s	119m	120s	120m
	Bit positions	1-18	19-234	235	236	237	238	239	240
Multi-frame #	Basic frame #	Frame word	2B + D	M_1	M_2	M_3	M_4	M_5	M_6
		LT to NT1							
A	1	IFW	2B + D	EOC_{a1}	EOC_{a2}	EOC_{a3}	ACT	1	1
	2	FW	2B + D	EOC_{dm}	EOC_{i1}	EOC_{i2}	DEA	1	FEBE
	3	FW	2B + D	EOC_{i3}	EOC_{i4}	EOC_{i5}	1	CRC_1	CRC_2
	4	FW	2B + D	EOC_{i6}	EOC_{i7}	EOC_{i8}	1	CRC_3	CRC_4
	5	FW	2B + D	EOC_{a1}	EOC_{a2}	EOC_{a3}	1	CRC_5	CRC_6
	6	FW	2B + D	EOC_{dm}	EOC_{i1}	EOC_{i2}	1	CRC_7	CRC_8
	7	FW	2B + D	EOC_{i3}	EOC_{i4}	EOC_{i5}	1	CRC_9	CRC_{10}
	8	FW	2B + D	EOC_{i6}	EOC_{i7}	EOC_{i8}	1	CRC_{11}	CRC_{12}
B, C, . . .									
		NT1 to LT							
1	1	IFW	2B + D	EOC_{a1}	EOC_{a2}	EOC_{a3}	ACT	1	1
	2	FW	2B + D	EOC_{dm}	EOC_{i1}	EOC_{i2}	PS_1	1	FEBE
	3	FW	2B + D	EOC_{i3}	EOC_{i4}	EOC_{i5}	PS_2	CRC_1	CRC_2
	4	FW	2B + D	EOC_{i6}	EOC_{i7}	EOC_{i8}	NTM	CRC_3	CRC_4
	5	FW	2B + D	EOC_{a1}	EOC_{a2}	EOC_{a3}	CSO	CRC_5	CRC_6
	6	FW	2B + D	EOC_{dm}	EOC_{i1}	EOC_{i2}	1	CRC_7	CRC_8
	7	FW	2B + D	EOC_{i3}	EOC_{i4}	EOC_{i5}	1	CRC_9	CRC_{10}
	8	FW	2B + D	EOC_{i6}	EOC_{i7}	EOC_{i8}	1	CRC_{11}	CRC_{12}
2, 3, . . .									

1	Reserve = bit for future standard; set = ONE
EOC	Embedded operations channel a Address bit dm Data/message indicator i Information (data/message)
FW	Frame word
IFW	Inverted frame word
s	sign bit (first) in quat
m	Magnitude bit (second) in quat
ACT	Activation bit (set to ONE during activation)
PS_1, PS_2	Power status bits (set to ZERO to indicate power problems)
NTM	NT1 in Test Mode bit (set to ZERO to indicate test mode)
CSO	Cold-start-only bit (set to ONE to indicate cold-start-only)
CRC	Cyclic redundancy check: covers 2B + D and M4 1 Most significant bit 2 Next most significant bit etc.
DEA	Deactivation bit (set to ZERO to announce deactivation)
FEBE	Far end block error bit set to ZERO for errored multiframe)

Note 1 – NT1-to-Network multiframe delay offset from Network-to-NT1 multiframe by 60 ± 2 quats (about 0.75 ms). All bits other than the frame word are scrambled.

Note 2 – 8 × 1.5 ms basic frames → 12 ms multiframe.

FIGURE II-3/G.961

2B1Q multiframe technique and overhead bit assignments

II.8.3 *Protocol and procedures*

The CL-channel functions (M bits) specified below are based on the bit allocation for the multiframe defined in Figure II-3/G.961.

II.8.3.1 *Error monitoring function*

II.8.3.1.1 *Cyclic redundancy check (CRC)*

The CRC bits are the M_5 and M_6 bits in frames 3 through 8 of the multiframe. The CRC is an error detection code that shall be generated from the appropriate bits in the multiframe and inserted into the bit stream by the transmitter. At the receiver a CRC calculated from the same bits shall be compared with the CRC value received in the bit stream. If the two CRCs differ, there has been at least one error in the covered bits in the multiframe.

II.8.3.1.2 *CRC algorithms*

The Cyclic Redundancy Check (CRC) code shall be computed using the polynomial:

$$P(x) = x^{12} \oplus x^{11} \oplus x^3 \oplus x^2 \oplus x \oplus 1$$

where

$\oplus$ = modulo 2 summation.

One method of generating the CRC code for a given multiframe is illustrated in Figure II-4/G.961. At the beginning of a multiframe all register cells are cleared. The multiframe bits to be covered by the CRC are then clocked into the generator from the left. During bits which are not covered by the CRC (FW, IFW, M_1, M_2, M_3, M_5, M_6) the state of the CRC generator is frozen and no change in state of any of the stages takes place. After the last multiframe bit to be covered by the CRC is clocked into register cell 1, the 12 register cells contain the CRC code of the next multiframe. Between this point and the beginning of the next multiframe, the register cell contents are stored for transmisssion in the CRC field of the next multiframe. Notice that bit CRC1 resides in register cell 12, CRC2 in register cell 11, etc.

Note – The binary ONEs and ZEROs from the interface at the T reference point, and corresponding bits from the network (across the V_1 reference point), must be treated as binary ONEs and ZEROs, respectively, for the computation of the CRC.

II.8.3.1.3 *Bits covered by the CRC*

The CRC bits shall be calculated from the bits in the D channel, both B channels, and the M_4 bits.

II.8.3.2 *Other M-bit functions*

A number of transceiver operations and maintenance functions are handled by M_4, M_5, and M_6 bits in the multiframe. These bits are defined in the following paragraphs.

II.8.3.2.1 *Far end block error (FEBE) bit*

A single bit in each multiframe is allocated to carrying the Far End Block Error (FEBE) bit. The FEBE bit shall be set to ONE if there are no CRC errors in the multiframe and ZERO if the multiframe contains a CRC error. The FEBE bit shall be placed in the next available outgoing multiframe and transmitted back to the originator. The FEBE bits may be monitored to determine the performance of the far end receiver.

II.8.3.2.2 *The act bit*

The act bit is the M_4 bit in the first frame of multiframes transmitted by either transceiver. The act bit is used as a part of the start-up sequence to communicate readiness for layer 2 communication progress (see § II.10.5).

II.8.3.2.3 *The DEA Bit*

The DEA bit is the M_4 bit in the second frame of multiframes transmitted from the LT (see § II.3 and Figure II-3/G.961). The DEA bit is used by the LT to communicate to the NT1 its intention to deactivate (see § II.10.1.5.2). To permit reliable detection of the DEA bit when indicating the intention to deactivate, its corresponding status (binary ZERO) shall be transmitted in three successive multiframes before terminating transmission of signal.

II.8.3.2.4 *NT1 power status bits*

Two bits of each multiframe (Figure II-3/G.961) shall be used to indicate NT1 power status. Table II-1/G.961 shows the power status bit assignments and the corresponding messages and definitions.

The NT1 must have sufficient energy storage to transmit the dying gasp indication for a minimum of 3 multiframes.

II.8.3.2.5 *NT1 test mode indicator bit*

One bit, NTM, of each multiframe (Figure II-3/G.961) from the NT1 to the LT shall be used to indicate that the NT1 is in a customer initiated test mode. The NT1 is considered to be in a test mode when the D channel or either one of the B channels are involved in a customer locally-initiated maintenance action. While in test mode, the NT1 may be unavailable for service or the NT1 may be unable to perform actions requested by EOC messages. The bit shall be a binary ONE to indicate normal operation and a binary ZERO indicate test mode.

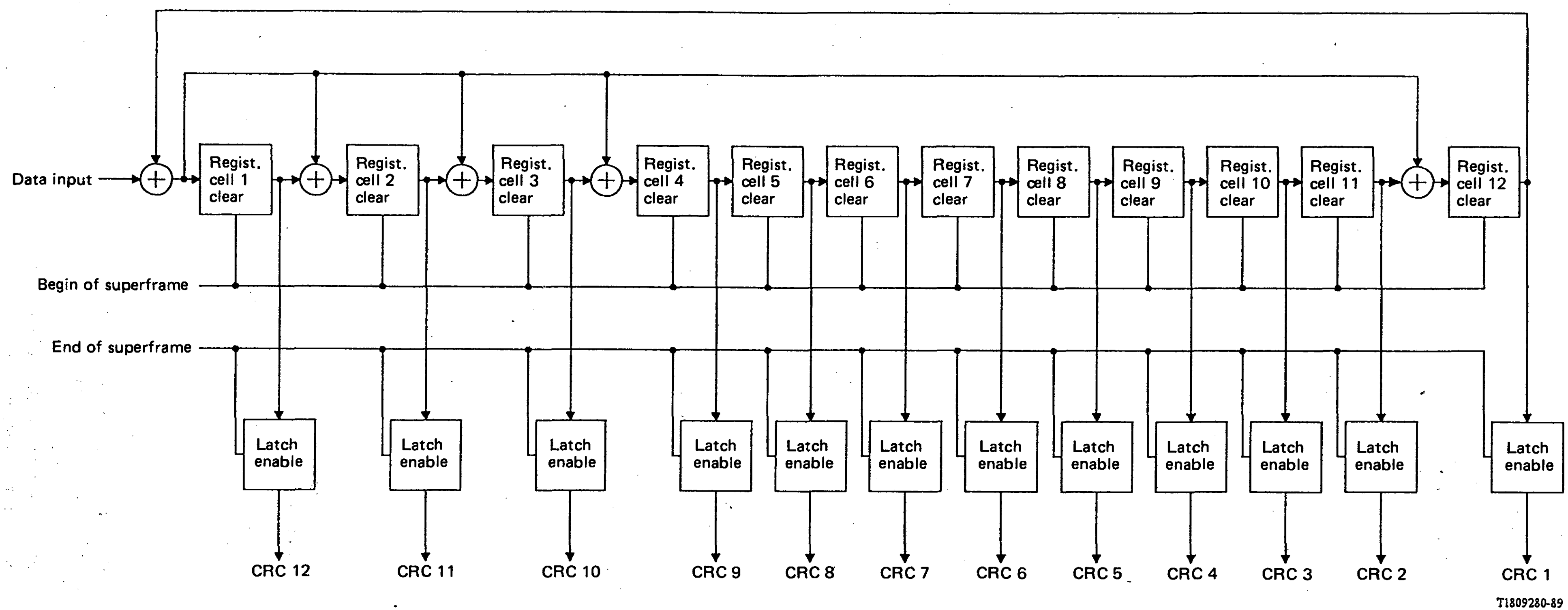


FIGURE II-4/G.961

CRC-12 generator

TABLE II-1/G.961

Power status bit assignments and messages

NT1 status	ps_1 ps_2 binary values	Definition
All power normal	11	Primary and secondary power supplies are both normal
Secondary power out	10	Primary power is normal, but the secondary power is marginal, unavailable, or not provided
Primary power out	01	Primary power is marginal or unavailable, secondary power is normal
Dying gasp	00	Both primary and secondary power are marginal or unavailable. The NT1 may shortly cease normal operation

II.8.3.2.6 *Cold-start-only bit*

The CSO bit is the M_4 bit in the fifth frame of the multiframe transmitted by an NT1. It shall be used to indicate the start-up capabilities of the NT1 transceiver. If the NT1 has a cold-start-only transceiver, as defined in part 4) of § II.10, this bit is set to ONE. Otherwise, this bit shall be set to ZERO in SN3.

II.8.3.2.7 *Reserved bits*

All bits in M_4, M_5, and M_6 not otherwise assigned are reserved for future standardization. Reserved bits shall be set to ONE before scrambling.

II.8.3.3 *Embedded operations channel (EOC) functions*

Twenty-four bits per multiframe (2 kbps) are allocated to an embedded operations channel (EOC) which supports operations communications needs between the network and the NT1.

II.8.3.3.1 *EOC frame*

The EOC frame shall be composed of 12 bits synchronized to the multiframe:

Bits	3	1	8
Functions provided	Address field	Data msg indicator	Info field

The three-bit Address Field may be used to address up to 7 locations. Only the specification of addresses of messages for the NT1 are within the scope of this Recommendation. The additional addresses are for intermediate network elements where the system is used to extend access involving carrier systems.

The Data/Message Indicator bit shall be set to ONE to indicate that the Information Field contains an operations message; it shall be set to ZERO to indicate that the Information Field contains numerical data. Up to 256 messages may be encoded in the information field.

Exactly two EOC frames shall be transmitted per multiframe consisting of all M_1, M_2, and M_3 bits (see Figure II-3/G.961).

II.8.3.3.2 *Mode of operation*

The EOC protocol operates in a repetitive command/response mode. Three identical properly-addressed consecutive messages shall be received before an action is initiated. Only one message, under the control of the network shall be outstanding (not yet acknowledged) on a complete basic access EOC at any one time.

The network shall continously send an appropriately addressed message. In order to cause the desired action in the addressed element, the network shall continue to send the message until it receives three identical consecutive EOC frames from the addressed device that agree with the transmitted EOC frame. When the network is trying to activate an EOC function, autonomous messages from the NT1 will interfere with confirmation of receipt of a valid EOC message. The sending by the NT1 and receipt by the network of three identical consecutive properly addressed Unable to Comply messages constitutes notification to the network that the NT1 does not support the requested function, at which time the network may abandon its attempt.

The addressed element shall initiate action when, and only when, three identical, consecutive, and properly addressed EOC frames, that contain a message recognized by the addressed element, have been received. The NT1 shall respond to all received messages. The response should be an echo of the received EOC frame towards the network with two exceptions described below. Any reply or echoed EOC frame shall be in the next available returning EOC frame, which allows a processing delay of approximately 0.75 ms.

If the NT1 does not recognize the message in a properly addressed EOC frame, rather than echo, on the third and all subsequent receipts of that same correctly addressed EOC frame it shall return the Unable to Comply message in the next available EOC frame.

If the NT1 receives EOC frames with addresses other than its own address (000), or the broadcast address (111), it shall, in the next available EOC frame, return an EOC frame toward the network containing the hold state message and its own address (the NT1, address, 000).

The protocol specificaiton has made no provision for autonomous messages from the NT1.

All actions to be initiated at the NT1 shall be latching, permitting multiple eoc-initiated actions to be in effect simultaneously. A separate message shall be transmitted by the network to unlatch.

II.8.3.3.3 *Addressing*

An NT1 shall recognize either of two addreses, an NT1 and a broadcast address. These addresses are as follows:

	Node	Address
	NT1	000
Broadcast	(all nodes)	111

An NT1 shall use the address 000 in sending the Unable to Comply message.

II.8.3.3.4 *Definition of required EOC functions*

1) *Operate 2B + D loopback:* This function directs the NT1 to loopback the user-data (2B + D) bit stream toward the network. This loopback is complete and may be transparent or non-transparent but in either case will continue to provide sufficient signal to allow the TE to maintain synchronization to the NT1.

2) *Operate B1-Channel (or B2-Channel) loopback:* This function directs the NT1 to loopback an individual B channel toward the network. The individual B-channel loopback can provide per-channel maintenance capabilities without totally disrupting service to the customer. This loopback is transparent.

3) *Return to normal:* The purpose of this message is to release all outstanding EOC controlled operations and to reset the EOC processor to its initial state.

4) *Unable to comply acknowledgement:* This will be the confirmation that the NT1 has validated the receipt of an EOC message, but that the EOC message is not in the menu of the NT1.

5) *Request corrupt CRC:* This message requests the sending of corrupt CRCS toward the network, until cancelled with Return to Normal.

6) *Notify of corrupted CRC:* This message notifies the NT1 that intentionally corrupted CRCS will be sent from the network until cancellation is indicated by Return to Normal.

7) *Hold state:* This message is sent by the network to maintain the NT1 EOC processor and any active EOC controlled operations in their present state. This message may also be sent by the NT1 toward the network to indicate that the NT1 has received an EOC frame with an improper address.

II.8.3.3.5 *Codes for required EOC functions*

Table II-2/G.961 shows the codes for each of the EOC functions defined in § II.8.3.3.4 above.

TABLE II-2/G.961

Messages required for command response EOC mode

Message	Message code	Origin (o) & destination (d)	
		Network	NT1
Operate 2B + D loopback	0101 0000	o	d
Operate B_1-channel loopback	0101 0001	o	d
Operate B_2-channel loopback	0101 0010	o	d
Request corrupted CRC	0101 0011	o	d
Notify of corrupted CRC	0101 0100	o	d
Return to normal	1111 1111	o	d
Hold state	0000 0000	d/o	o/d
Unable to comply acknowledgement	1010 1010	d	o

Sixty-four EOC messages have been reserved for non-standard applications in the following four blocks of 16 codes each (x is ONE or ZERO): 0100 xxxx, 0011 xxxx, 0010 xxxx, 0001 xxxx. All remaining codes not defined in Table II-2/G.961 and not reserved for non-standard applications are reserved for future standardization. Thus, 184 codes associated with the NT1 (000) and broadcast (111) addresses, are available for future standardization, i.e., 256 total codes minus 8 defined codes from the table minus 64 codes for non-standard applications.

Note – The reservation of codes for non-standard applications does not in any way endorse their use. Any use of such messages shall not interfere with the EOC protocol. An NT1 and an LT that support messages for non-standard applications may not function properly together.

II.9 *Scrambling*

The data stream in each direction of transmission shall be scrambled with a 23rd-order polynomial (see Figure II-5/G.961) prior to the insertion of FW.

In the LT-NT1 direction the polynomial shall be:

$$1 \oplus x^{-5} \oplus x^{-23}$$

where

$\oplus$ = modulo 2 summation.

In the NT1-LT direction the polynomial shall be:

$$1 \oplus x^{-18} \oplus x^{-23}$$

where

$\oplus$ = modulo 2 summation.

The binary data stream shall be recovered in the receiver by applying the same polynomial to the scrambled data as was used in the transmitter.

Note – Binary ONEs and ZEROs entering the NT1 receiver from the interface at reference point T or entering the LT side transceiver from the network must appear as binary ONEs and ZEROs respectively, at the input of the scrambler. Also, during transmission/reception of the frame word or inverted frame word, the state of the scrambler must remain unchanged. (Caution: It is common for the input bits to be all ONEs, e.g., during idle periods or during start-up. For the ONEs to become scrambled, the initial state of the scrambling shift register must not be all 1s.)

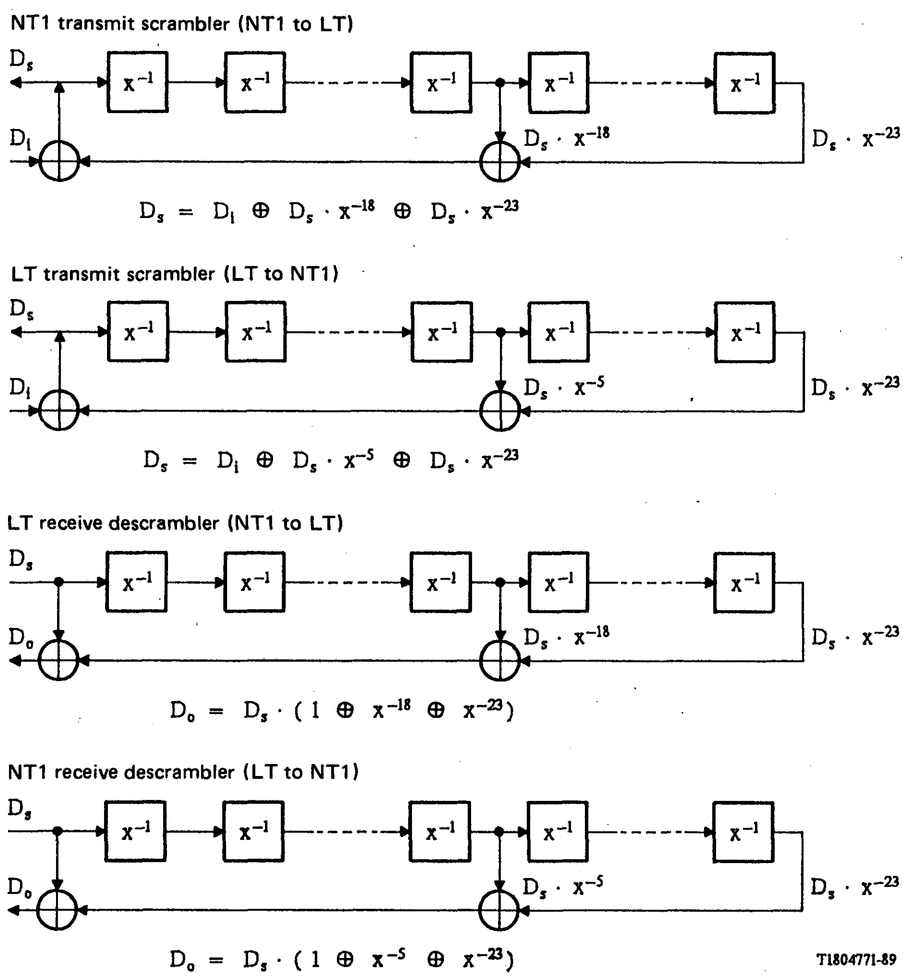


FIGURE II-5/G.961

Scrambler and descrambler

II.10 *Activation/deactivation*

This section gives requirements and examples supporting activation/deactivation requests, indicators of activation and deactivation, and indicators of errors. The transmission system is capable of loopbacks but these are not illustrated by examples. The transmission system is also capable of being activated without activating the interface at reference point T. There are no provisions for the support of activation of the transmission system without activating the interface at reference point T, but such a capability is not precluded (e.g., by use of spare CL channel bits).

The following definitions are for the purpose of clarifying requirements that are to follow:

1) *Start-up:* A process characterized by a sequence of signals produced by the LT and by the NT1. Start-up results in establishment of the master-slave mode, i.e., synchronization of the receivers and the training of equalizers and echo cancelers to the point that two-way transmission requirements are met.

2) *Warm start:* The start-up process that applies to transceivers meeting the optional warm-start activation-time requirements after they have once been synchronized and have subsequently responded to a deactivation request. Warm start applies only if there have been no changes in line characteristics and equipment. Transceivers that meet warm-start requirements are called warm-start transceivers.

3) *Cold-start:* The start-up process that applies to transceivers that either do not meet optional warm-start activation-time requirements, or have not been continuously in a deactive state that resulted from a deactivation request to the NT1. Cold start also applies if there have been changes in line characteristics or equipment or both. A cold start shall always start from the RESET state.

4) *Cold-start-only* (CSO): NT1 transceivers that do not meet optional warm-start activation-time requirements (see § II.10.6) are called cold-start-only transceivers.

5) *Reset:* The reset state consists of two sub-states: the receive reset and the full reset states. In other sections of this Recommendation, the term reset is used to refer to the full reset state.

   Reset has no implications about the state of convergence of the equalizer or echo canceler coefficients of the transceiver. The reset states are applicable to cold-start-only as well as warm-start transceivers.

   For specific transceiver implementations, reset states (or sub-states) may mean different and possibly multiple internal states.

6) *Full Reset:* The full reset state is one in which a transceiver has detected the loss of signal from the far-end and is not transmitting (sending signal to the loop).

   The full reset state shall also be entered following power-up.

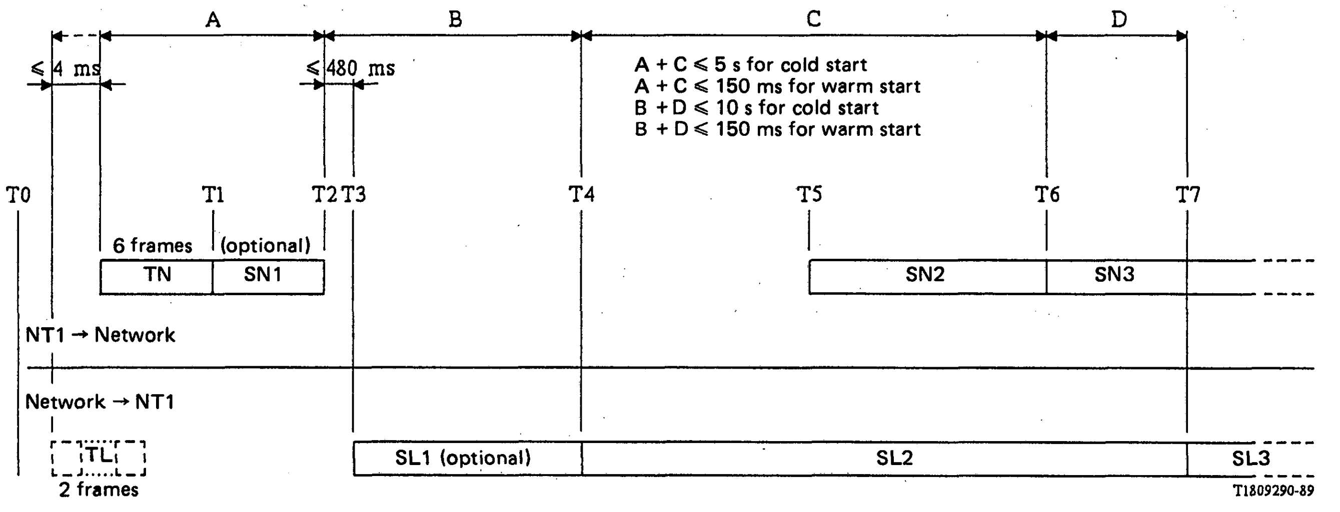
   While in full reset, NT1s may initiate transmission only to request service. Under all other conditions, where the interface has been deactivated, the NT1s shall remain quiet, i.e., they shall not start transmitting any signal until the NT1 has received the TL signal from the network.

7) *Receive reset:* The receive reset state is a transient state in which NT1 has detected the loss of signal from the far-end and is not transmitting (sending signal to the loop) and, in addition, is not permitted to initiate the start-up sequence (send wake-up tone) but shall be capable of responding to the start-up sequence (detecting wake-up tone). An NT1 must remain in this state for at least 40 ms, after detecting the loss of received signal, as specified in § II.10.1.5.2 and II.10.2, after which time, the transceiver shall enter the full reset state.

II.10.1 *Signals used for activation*

II.10.1.1 *Signals during start-up*

Figure II-6/G.961 defines the signals produced by the transceivers during start-up. These signals apply during both types of start-up; i.e., cold start, and warm start. During start-up, all signals at the interface shall consist of sequences of symbols of the shape defined in § II.12.2.



Time description of event or state:

T0 Reset state.
T1 Network and NT1 are awake.
T2 NT1 discontinues transmission, indicating that the NT1 is ready to receive signal.
T3 Network responds to termination of signal and begins transmitting signal toward the NT1.
T4 Network begins transmitting SL2 toward the NT1, indicating that the network is ready to receive SN2.
T5 NT1 begins transmitting SN2 toward the network, indicating that NT1 has acquired FW frame and detected SL2.
T6 NT1 has acquired multiframe marker, and is fully operational.
T7 Network has acquired multiframe marker, and is fully operational.

FIGURE II-6/G.961

State sequence for transceiver start-up

With the exception of the wake-up tones (TN and TL), the scrambler shall be used in the normal way in formulating the signals. For example, Figure II-7/G.961 shows ONEs for B and D channel bits and the overhead bits in the signal SN1. These ONEs are scrambled before coding, producing random pulses in these positions at the interface.

Except where noted otherwise in Figure II-7/G.961, all the pulse sequences, are framed and multiframed in accordance with the normal frame structure shown in Figures II-1/G.961, II-2/G.961, and II-3/G.961, and all pulses represent scrambled bits except those in the frame word. The signals TN and TL are 10 kHz tones generated by repeating the following unscrambled and unframed symbol pattern:

$$\ldots +3\ +3\ +3\ +3\ -3\ -3\ -3\ -3 \ldots$$

II.10.1.2 *Line rate during start-up*

During start-up, the network shall produce symbols at the nominal line rate within the tolerance specified in § II.2.1.2.

The symbol rate from the NT1 shall be 80 kbauds ± 100 ppm.

Signal	Frame word (FW)	Multiframe (IFW)	2B + D	M	Start	Stop	Time (frames)
TN	± 3‡	± 3‡	± 3‡	± 3‡	†	†	6
SN1	Present	Absent	1	1	T1	T2	–
SN2	Present	Absent	1	1	T5	T6	–
SN3	Present	Present	Normal+	Normal	T6	*	–
TL	± 3‡	± 3‡	± 3‡	± 3‡	†	†	2
SL1	Present	Absent	1	1	T3	T4	–
SL2	Present	Present	0	Normal	T4	T7	–
SL3	Present	Present	Normal+	Normal	T7	*	–

‡ Tones have alternating pattern of four +3 symbols followed by four −3 symbols, and no FW

† See Figure II-6/G.961 and § II.10.1.3 for start and/or stop time of this signal

TN, TL Tones produced by NT1 or LT, respectively (see § II.10.1.1)

SNx, SLx Pulse patterns produced by NT1 or LT, respectively

Tx Notation refers to transition instants defined in Figure II-6/G.961

Absent Under Multiframe this notation means only that FW is transmitted instead of IFW

Normal Normal means that the M bits are transmitted onto the 2-wire line as required during normal operation; e.g., valid CRC bits, EOC bits, and indicator bits are transmitted

Normal+ Except to perform a loopback, 2B + D bits shall remain in the previous state (SN2 or SL2) until both act bits indicate full transparency of the B and D channels (i.e., the 2B + D bits of SN3 and SL3 shall remain set to ONE and ZERO, respectively, until transparency is achieved at both ends of the DLL)

* Signals SN3 and SL3 continue indefinitely (or until deactivation)

FIGURE II-7/G.961

Definitions of signals during start-up

II.10.1.3 *Start-up sequence*

Figure II-6/G.961 shows the sequence of signals at the interface that are generated by the transceivers. The transition points in the sequence are also defined in Figure II-7/G.961. For further information on the events at the interface at reference point T, the reader is referred to Recommendation I.430.

II.10.1.4 *Wake-up*

When transceivers meeting the optional warm-start activation-time requirements, or when cold-start-only NT1s having the optional capability of initiating start-up, are in the RESET state or are deactive as a result of responding to a deactivation request, either transceiver may initiate start-up by sending a tone as defined in Figure II-7/G.961.

II.10.1.5 *Progress indicators*

II.10.1.5.1 *Activation*

In the NT1 to LT direction, the act bit remains set to ZERO until the customer equipment indicates progress in getting ready to transmit. The corresponding action at the T reference point in the customer equipment is receipt of the signal INFO3. To communicate this progress indication, act from the NT1 is set to ONE. Assuming INFO3 occurs before T6 and T7, this progress indication shall not affect overhead symbols at the interface until T6, when the NT1 overhead bits are allowed to be normal, and may not be detected by the LT until T7.

After event T7 (Figure II-6/G.961) and after act = ONE is received from the NT1, the LT sets the act bit to ONE to communicate readiness for layer 2 communication (see § II.8.3.2.2).

II.10.1.5.2 *Deactivation*

Transceivers in the active state that meet optional warm- start activation-time requirements shall cease transmission on the basis of the DEA bit (see § II.8.3.2.3) and subsequent loss of received signal. The DEA bit from the LT shall be set to ONE before activation is initiated. The LT shall announce deactivation by setting DEA to ZERO.

The LT shall send DEA = ZERO in at least three multiframes before ceasing transmission. It shall cease transmission before sending a DEA bit in the multiframe following the multiframe in which DEA = ZERO is sent the last time. During the multiframes with DEA = ZERO the NT1 has time to prepare for deactivation. The NT1 shall, upon the detection of loss of signal from the LT, cease transmission, enter the receive reset state and deactivate. Its response time to a loss of received signal shall be such that the NT1 will enter the receive reset state within 40 ms. of the occurrence of the transition to no signal at its interface. As specified in the definitions given at the beginning of §II-10, it shall not initiate the transmission of wake-up tone for a period of at least 40 ms. after it ceases transmission and then it shall enter the full reset state. The LT shall enter the full reset state upon the detection of the loss of received signal.

LT transceivers not implementing optional warm-start activation-time requirements shall continuously set DEA to ONE.

II.10.2 *Timers*

Timers shall be used to determine entry into the reset states. Upon the occurrence of any of the following conditions:

1) failure to complete start-up within 15 s. (warm or cold start),
2) loss of received signal for more than 480 ms., or
3) loss of synchronization for more than 480 ms.,

a transceiver shall respond as follows: Upon satisfying conditions 1) or 3), it shall cease transmission and then, upon the subsequent detection of the loss of received signal, the transceiver shall enter the receive reset state. Its response time to a loss of signal (after conditions 1) or 2) have been satisfied) shall be such that it shall enter the receive reset state and be capable of responding to the initiation of wake-up tone by the far-end transceiver within 40 ms. after the far end transceiver ceases transmission. Upon satisfying condition 2), the transceiver shall immediately enter the receive reset state. As specified in part 7) of § II.10, a transceiver shall remain in the receive reset state for at least 40 ms., after which it shall enter the full reset state. The transciever may not initiate transmission of wake-up tone in the receive reset state.

For conditions 2) and 3), the requirements apply to transceivers after start up, i.e., after multiframe synchronization is achieved (see T6 and T7 in Figure II-6/G.961 for NT1 and LT transceivers, respectively).

In addition, an NT1 shall enter the full reset state if signal is not received within 480 ms. after it ceases the transmission of TN, or SN1 if it is sent (see T2 to T3 in Figures II-6/G.961 and II-7/G.961).

II.10.3 *Description of the activation procedure*

II.10.3.1 *Activation from customer equipment*

While the NT1 and LT remain in the deactive state as a result of receiving and responding to a deactivation request, or while they are in RESET, a request for activation from the customer equipment shall result in the TN signal (tone) being sent from the NT1 toward the LT. The LT, on receiving TN shall remain silent until detection of cessation of signal from the NT1. The rest of the sequence then follows as indicated in Figures II-6/G.961 and II-7/G.961. If the LT happens to try to activate at the same time it may send a TL tone during the TN tone without harm.

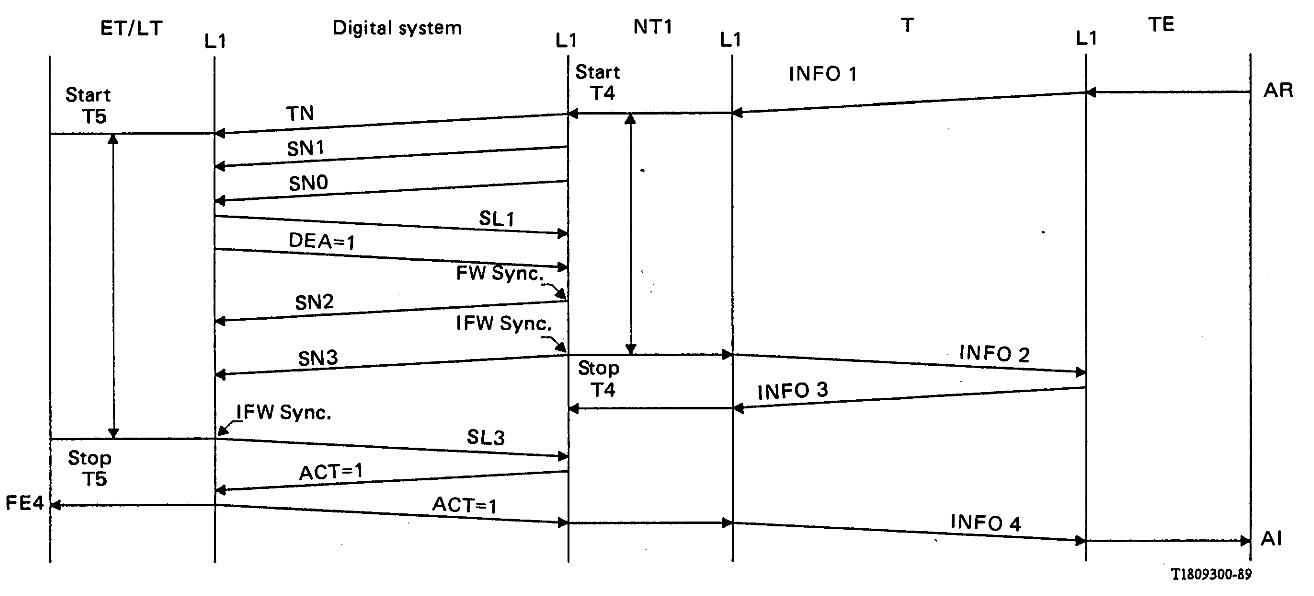
While in the reset state, NT1 may initiate transmission only to request service. Under all other conditions where the system has been deactivated, the NT1 shall remain quiet, i.e., they shall not start transmitting any signal until the NT1 has received the TL signal from the LT.

II.10.3.2 *Activation from the network*

While the NT1 and LT remain in the deactive state as a result of receiving and responding to a deactivation request, or while they are in RESET, a request for activation from the LT shall result in the TL signal being sent from the LT toward the NT1. The NT1, on receiving TL shall respond with TN within 4 ms from the beginning of TL. The rest of the sequence then follows as indicated in Figures II-6/G.961 and II-7/G.961.

II.10.3.3 *Sequence charts*

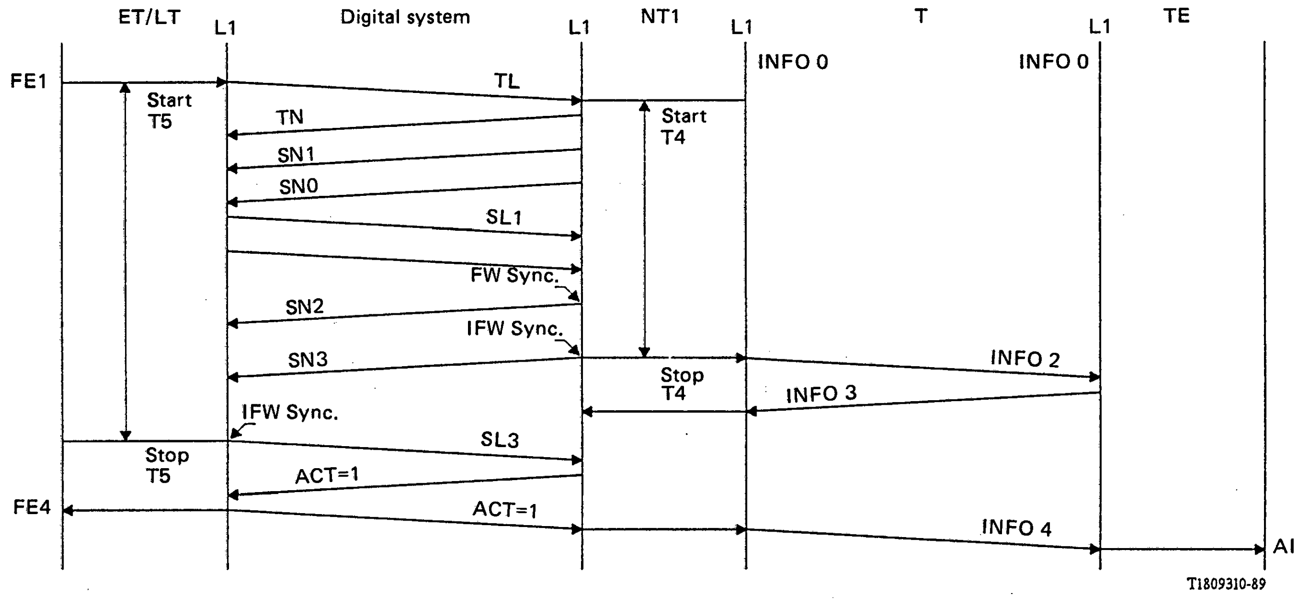
Examples of sequence charts for activation by both terminal and ET equipment are given in Figures II-8/G.961 and II-9/G.961.



Note – Receipt of INFO 3 and SL3 at the NT1 can theoretically occur in either order.

FIGURE II-8/G.961

Activation initiated by terminal equipment



Note – Receipt of INFO 3 and SL3 at the NT1 can theoretically occur in either order.

FIGURE II-9/G.961

Activation initiated by the exchange

II.10.3.4 *Transparency*

Transparency of the transmission in both directions by the NT1 shall be provided after the NT achieves full operational status (T6), and both act = ONE form the LT and DEA = ONE. Full operational status of the NT1 means that the NT1 has:

1) acquired bit timing and frame synchronization from the incoming signal from the LT,
2) recognized the multiframe marker from the LT,
3) fully converged both its echo canceler and equalizer coefficients.

Transparency of the transmission in both directions at the LT shall be provided when the LT:

1) achieves full operational status (T7),
2) detects the presence of the multiframe marker from the NT1,
3) receives act = ONE from the NT1.

Full operational status at the LT means that the LT has:

1) acquired bit timing phase of the incoming signal from the NT1, and frame synchronization,
2) recognized the multiframe marker from the NT1,
3) fully converged both its echo canceler and equalizer coefficients.

After both the LT and the NT1 achieve transparency in both directions, the act bits shall continue to reflect the state of readiness of the LT and the terminal equipment for layer 2 communication. The act bit in the LT-to-NT1 direction shall reflect the status of the LT side of the interface. The act bit in the NT1-to-LT direction shall reflect the status of the NT1 side of the interface. Whenever either end, for any reason, loses its readiness to communicate at layer 2 (e.g., the terminal is unplugged), that end shall set its transmitted act bit to ZERO. A change of status of this bit shall be repeated in at least three consecutive transmitted multiframes.

II.10.4 *State transition table for the NT1*

Table II-3/G.961 provides an example of a state transition table for the NT1 as a function of INFOs, SIGs, and Timers.

TABLE II-3/G.961

State transition table for the NT1 as a function of INFOs, SIGs and timers

Event													
State name	Power off	Full reset	Alerting	EC training	EC cnvrg'd	FW sync.	IFW sync.	Pending active	Active	Pending deact'n	Tear down	TE inactive	Rcv. reset
State code	NT0	NT1 (T0)	NT2	NT3 (T1)	NT4 (T2)	NT5 (T5)	NT6 (T6)	NT7	NT8	NT9	NT10	NT11	NT12
Tx	SN0	SN0	TN	SN1	SN0	SN2	SN3 ACT=0	SN3 ACT=1	SN3 ACT=1	SN3 (Note 7)	SN0	SN3 ACT=0	SN0
(Note 6)	INFO 0	INFO 0	INFO 0	INFO 0	INFO 0	INFO 0	INFO 2	INFO 2	INFO 4		INFO 0	INFO 2	INFO 0
Power on	NT1	–	–	–	–	–	–	–	–	–	–	–	–
Loss of power	–	NT0	NT0	NT0	NT0	NT0	NT0	NT0	NT0	NT0	NT0	NT0	NT0
Received T INFO 1 signal (Notes 1 and 2)	/	ST.T4 NT2	–	–	–	–	–	–	/	/	–	/	–
Received T INFO 3 signal (Notes 1 and 3)	/	/	/	/	/	/	NT7	–	–	–	–	NT7	/
Received T INFO 0 signal (Notes 1 and 4)	/	–	–	–	–	–	–	NT11	NT11	–	–	/	–
End of tone TN (9 ms)	/	/	NT3	–	/	/	/	/	/	/	/	/	/
Received tone TL	/	ST.T4 NT2	–	/	/	/	/	/	/	/	/	/	ST.T4 STP.T6 NT2
Echo canceler converged	/	–	–	NT4	–	–	–	–	–	–	–	–	–
Basic frame sync (FW)	/	/	/	/	NT5	–	–	–	–	–	–	–	–
Multiframe sync (IFW)	/	/	/	/	/	STP.T4 NT6	–	–	–	–	–	–	–
Received DEA = 0 (Note 6)	/	/	/	/	/	/	NT9	NT9	NT9	–	–	NT9	–
Received ACT = 0	/	/	/	/	/	/	–	–	NT7	–	–	–	–
Received ACT = 1 and DEA = 1	/	/	/	/	/	/	–	NT8 AI	–	–	–	–	–
Loss of synchronization (> 480 ms)	/	/	/	/	/	/	NT10	NT10	NT10	–	–	NT10	–
Loss of signal (> 480 ms)	/	/	/	/	ST.T6 NT1	ST.T6 NT12	ST.T6 NT12	ST.T6 NT12	ST.T6 NT12	/	/	ST.T6 NT12	–
Expiry of timer T4 (15 seconds)	/	–	NT10	NT10	NT10	NT10	/	/	/	/	–	/	–
Loss of signal (< 40 ms)	/	/	/	/	/	/	/	/	/	ST.T6 NT12	ST.T6 NT12	/	/
Expiry of timer T6 (40 ms)	/	–	/	/	/	/	/	/	/	/	/	/	NT1

Note – For symbols and abbreviations, see Table II-4/G.961.

II.10.5 *State transition table for the LT*

Table II-4/G.961 provides an example of a state transition table for the LT as a function of FEs, SIGs, and Timers.

TABLE II-4/G.732

State transition table for the LT as a function of FEs, SIGs and timers

Event	State name	Power off	Full reset	Alerting	Awake	EC training	EC cnvrg'd	FW sync.	IFW sync.	Active	Deact'n alert	Tear down	Pending deact'n	Rev. reset
	State code	LT0	LT1 (T0)	LT2	LT3 (T1)	LT4 (T3)	LT5 (T4)	LT6	LT7 (T7)	LT8	LT9	LT10	LT11	LT12
	Tx	SL0	SL0	LT	SL0	SL1	SL2 DEA=1 ACT=0	SL2 DEA=1 ACT=0	SL3 DEA=1 ACT=0	SL3 DEA=1 ACT=1	SL3 DEA=0 ACT=0	SL0	SL0	SL0
Power on		LT1	–	–	–	–	–	–	–	–	–	–	–	–
Loss of power		–	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0 FE7	LT0
Activation request (FE1)		/	ST.T5 LT2	–	–	–	–	–	–	/	/	–	–	–
Deactivation request (FE5) (Note 8)		/	–	–	–	–	–	–	LT9 FE7	LT9	–	–	–	–
End of tone TL (3 ms)		/	/	LT3	–	/	/	/	/	/	/	/	/	/
Received tone TN		/	ST.T5 LT3	–	–	/	/	/	/	/	/	/	/	ST.T5 STP.T7 LT3
Loss of signal energy		/	–	–	LT4	–	/	/	/	/	/	/	/	–
Echo canceler converged		/	–	–	–	LT5	–	–	–	–	–	–	–	–
Basic frame sync. (FW)		/	/	/	/	/	LT6	–	–	–	–	–	–	–
Multiframe sync. (IFW)		/	/	/	/	/	/	STP.T5 LT7	–	–	–	–	–	–
Received ACT = 0		/	/	/	/	/	/	/	–	LT7 FE6,7	–	–	–	–
Received ACT = 1		/	/	/	/	/	/	/	LT8 FE4	–	–	–	–	–
Loss of synchronization (> 480 ms)		/	/	/	/	/	/	/	LT10 FE7	LT10 FE6,7	–	–	–	–
Loss of signal (> 480 ms)		/	/	/	/	/	/	ST.T7 LT12 FE7	ST.T7 LT12 FE7	ST.T7 LT12 FE6,7	–	/	/	/
End of last multiframe with DEA = 0 (Note 9)		/	/	/	/	/	/	/	/	/	LT11	/	/	/
Expiry of timer T5 (15 seconds)		/	–	LT10 FE7	LT10 FE7	LT10 FE7	LT10 FE7	LT10 FE7	/	–	/	–	/	/
Loss of signal (< 40 ms)		/	–	/	/	/	/	/	/	/	/	ST.T7 LT12	LT1	–
Expiry of timer T7 (40 ms)		/	/	/	/	/	/	/	/	/	/	/	/	LT1

Symbols, abbreviations, and Notes for Tables II-3/G.961 and II-4/G.961

–	No change, no action
/	Impossible situation
FE1	Function element – corresponds to primitive Activation request – PH-AR
FE4	Function element – corresponds to primitive Activation indication – PH/MPH-AI
FE5	Function element – corresponds to primitive Deactivation request – MPH-DR
FE6	Function element – corresponds to primitive Deactivation indication – MPH-DI
FE7	Function element – corresponds to primitive Error indication
NTn	Go to state "NTn"
LTn	Go to state "LTn"
ST.Tn	Start timer Tn
STP.Tn	Stop timer Tn
SL0	No signal

Note 1 – These events are initiated by the "G" Finite State Matrix (FSM), as defined in Recommendation I.430, and communicated to the "NT" FSM through messages.

Note 2 – This condition acts as an "Activation Request" event.

Note 3 – This condition indicates that the user data path (2B + D channels) in the TE-to-NT1 direction is transparent to user data.

Note 4 – This condition indicates that the user data path (2B + D channels) in the TE-to-NT1 direction is not transparent to user data.

Note 5 – This event takes priority over received act = ZERO for warm-start NT1s. This event could be ignored for NT1s not wishing to deactivate (cold-start-only NT1s).

Note 6 – Although the INFO signals at the T reference point are shown as transmit signals in the "NT" FSM, the "NT" FSM does not directly control these signals. They are included for information only.

Note 7 – The signals output in this state remain unchanged from signals output during the preceding state (e.g., act = ZERO if NT6 or NT11 preceded, or act = ONE if NT7 or NT8 preceded).

Note 8 – This event will cause deactivation of the NT1 independent of whether the transmitter is cold-start-only or warm-start.

Note 9 – This event must occur after receiving at least three multiframes. See § II.10.1.5.2.

II.10.6 *Activation times*

The LT and the NT1 shall complete the start-up process, including synchronization and training of equalizers to the point of meeting performance criteria within the following lengths of time: Cold-start-only transceivers shall synchronize within 15 s. Transceivers meeting optional warm-start activation-time requirements shall synchronize within 300 ms. on warm starts and within 15 s on cold starts. The 15-second cold-start time requirement is apportioned such that the NT1 is allowed 5 s. and the LT is allowed 10 s. For warm starts the 300 ms. start-up time requirement is apportioned equally between the NT1 and the LT, 150 ms. each. See Figure II-6/G.961 for details.

Note – The 300 ms. requirement applies to laboratory tests only. No 300 ms. timer is involved in actual in-service loops. (See definitions in § II.10 for warm and cold starts.)

As indicated in Figure II-6/G.961, the start time requirements cover the time span from wake-up tone to T7, and do not include time for activation of customer terminal equipment. All activation times apply only to the DLL, and do not apply to the entire customer access link where carrier systems may be involved.

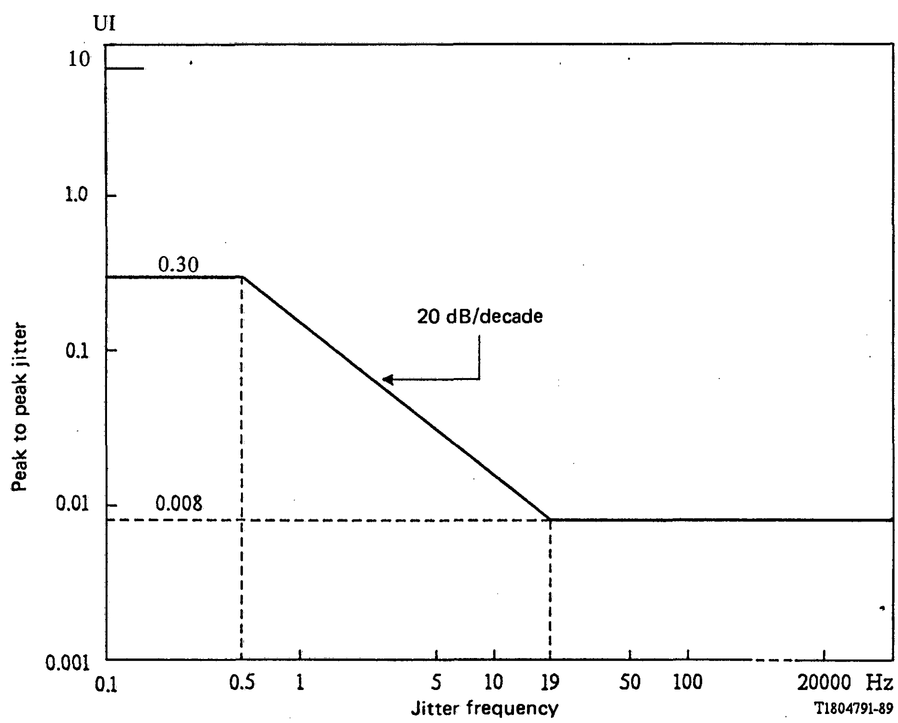
Note – The value in Recommendation G.960 is 10 s. This is a 95% value.

II.11 *Jitter*

To assure support of the jitter requirements of Recommendation I.430, the jitter of the timing signal recovered at the clock of the NT1 shall not exceed the limits given in Figure 9/I.430 and § 8.3.1 of Recommendation I.430. Jitter tolerances are intended to ensure that the limits of Recommendation I.430 are supported by the jitter limits of the transmission system on subscriber lines. The jitter limits given below must be satisfied regardless of the length of the subscriber line and the inclusion of one repeater, provided that they are covered by the transmission media characteristics. The limits must be met regardless of the transmitted signal. In this Recommendation, jitter is specified in terms of unit intervals (UI) of the nominal 80 kbauds signal (12.5 μs.).

II.11.1 *Input signal jitter tolerance*

The NT1 shall meet the performance objectives with wander/jitter at the maximum magnitude indicated in Figure II-10/G.961, for single jitter frequencies in the range of 0.1 Hz to 20 kHz, superimposed on the test signal source with the received signal symbol rate in the range of 80 kbauds ± 5 ppm. The NT1 shall also meet the performance objectives with wander per day of up to 1.44 UI peak-to-peak where the maximum rate of change of phase is 0.06 UI/hour.



Note – Unit interval (UI) = 12.5 μs.

FIGURE II-10/G.961

Permissible sinusoidal NT1 input signal jitter

II.11.2 *NT1 output jitter limitations*

With the wander/jitter as specified in § II.11.1, except as noted, superimposed on the NT1 input signal, the jitter on the transmitted signal from the NT1 towards the LT shall conform to the following, with the received signal symbol rate in the range of 80 kbauds ± 5 ppm, as described in § II.2:

1) The jitter shall be equal to or less than 0.04 UI peak-to-peak and less than 0.01 UI rms when measured with a high-pass filter having a 6 dB/octave roll-off below 100 Hz.

2) The jitter in the phase of the output signal (the signal transmitted towards the LT) relative to the phase of the input signal (from the LT) shall not exceed 0.05 UI peak-to-peak and 0.015 UI rms when measured with a band-pass filter having a 6 dB/octave roll-off above 40 Hz and below 1.0 Hz. (Note that the 1.0 Hz cut-off assures that the average difference in the phase of the input and output signals is substracted.) This requirement applies with superimposed jitter in the phase of the input signal as specified in § II.11.1 for single frequencies up 19 Hz.

3) The maximum (peak) departure of the phase of the output signal from its nominal difference (long term average) from the phase of the input signal (from the LT) shall not exceed 0.1 UI. This requirement applies during normal operation including following a "warm start". (Note that this means that, if deactivated and subsequently activated in conformance with the "warm start" requirements, the long term average difference in phase of the ouput signal from the phase of the input signal shall be essentially unchanged.)

II.11.3 *Test conditions for jitter measurements*

Due to bidirectional transmission on the 2-wire and due to severe intersymbol interference, no well defined signal transitions are available at the NT1 2-wire point.

Two possible solutions are proposed:

1) A test point in the NT1 is provided to measure jitter with an undisturbed signal.

2) A standard LT transceiver including an artificial transmission line is defined as a test instrument.

II.12 *Transmitter output characteristics of NT1 and LT*

The following specifications apply with a load impedance of 135 ohms resistive over a frequency band of 0 Hz to 160 kHz.

II.12.1 *Pulse amplitude*

The nominal peak of the largest pulse shall be 2.5 Volts (see Figure II-11/G.961).

II.12.2 *Pulse shape*

The transmitted pulse shall have the shape specified in Figure II-11/G.961. The pulse mask for the four quaternary symbols shall be obtained by multiplying the normalized pulse mask shown in Figure II-11/G.961 by 2.5 V, 5/6 V, −5/6 V or −2.5 V. When the signal consists of a framed sequence of symbols with a synchronization word and equiprobable symbols in all other positions, the nominal average power is 13.5 dBm.

II.12.3 *Signal power*

The average power of a signal consisting of a framed sequence of symbols with a frame word and equiprobable symbols at all other positions should be between 13.0 dBm and 14.0 dBm over the frequency band from 0 Hz to 80 kHz.

II.12.4 *Power spectral density*

The upper bound of the power spectral density of the transmitted signal shall be as shown in Figure II-12/G.961.

II.12.5 *Transmitted linearity*

II.12.5.1 *Requirements*

This is a measure of the deviations from ideal pulse heights and the individual pulse non-linearity. The transmitted and received signals shall have sufficient linearity so that the residual rms non-linearity is at least 36 dB below the rms signal at the interface.

Normalized level		Quaternary symbols +3	+1	−1	−3
A	0.01	0.025 V	0.00833 V	−0.00833 V	−0.025 V
B	1.05	2.625 V	0.8750 V	−0.8750 V	−2.625 V
C	1.00	2.5 V	5/6 V	−0.5/6 V	−2.5 V
D	0.95	2.275 V	0.79167 V	−0.79167 V	−2.275 V
E	0.03	0.075 V	0.025 V	−0.025 V	−0.075 V
F	−0.01	−0.025 V	−0.00833 V	0.00833 V	0.025 V
G	−0.12	−0.3 V	−0.1 V	0.1 V	0.3 V
H	−0.05	−0.125 V	−0.04167 V	0.04167 V	0.125 V

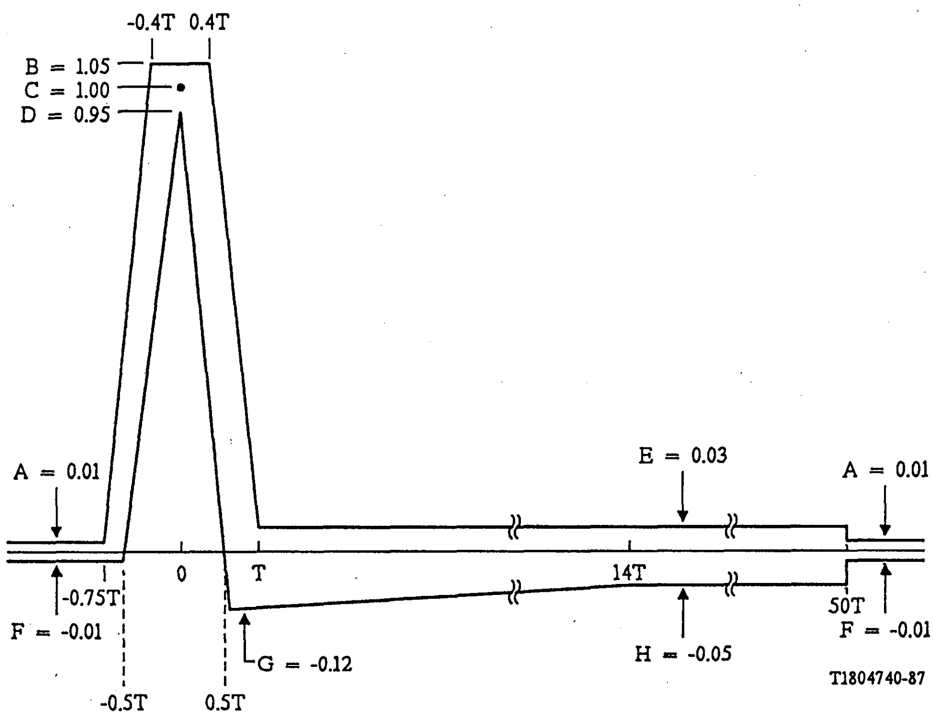


FIGURE II-11/G.961

Normalized output pulse from NT1 or LT

II.12.5.2 *Linearity test method*

With the transceiver (LT or NT1) terminated in a 135/ohm resistance through a zero-length loop, and driven by an arbitrary binary sequence, the voltage appearing across the resistance is filtered (anti-alias), sampled and converted to digital form (V_{out}) with a precision of no less than 12 bits (see Figure II-13/G.961). These samples are compared with the output of an adjustable, linear filter, the input of which is the scrambled, framed, and linearly encoded transmitter input. The signals at the substractor may both be in digital form, or they may both be in analog form.

The linear digital filter input ("Quaternary Input Data" in Figure II-13/G.961) can be considered a linearity standard. It may be produced from the transmitter output by an errorless receiver (with no descrambler), or from the scrambled transmitter input data if it is available. If the samples input to the adjustable filter are available in digital form, no additional A/D converter is required. Whether analog or digital, these samples are required to be in the ratio 3:1:−1:−3, to an accuracy of at least 12 bits.

The sampling rate of the samplers and filters may be higher than the symbol rate, and generally will be several times the symbol rate for good accuracy. Alternatively, the sample rate may be at the symbol rate, but the rms values are obtained by averaging over all sample phases relative to the transmitter signal.

Because the anti-alias filter, sampler, and A/D converter operating on the transmitter output may introduce a loss or gain, proper calibration requires determining $< V_{out}^2 >$ at the filter output, as shown in Figure II-13/G.961, rather than the mean-squared value of the transmitter output itself.

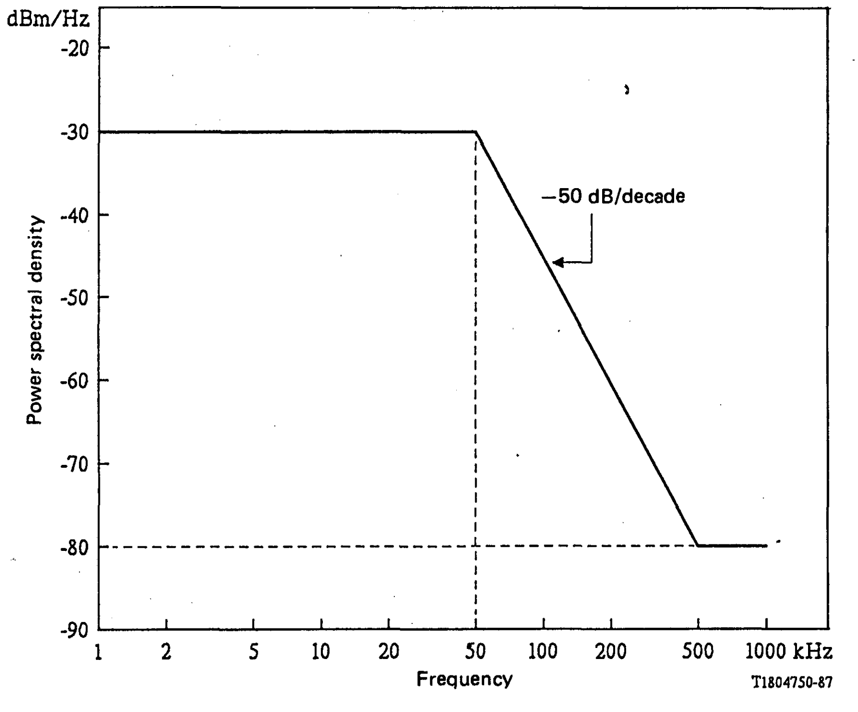


FIGURE II-12/G.961

Upper bound of power spectral density of signal from NT1 and LT

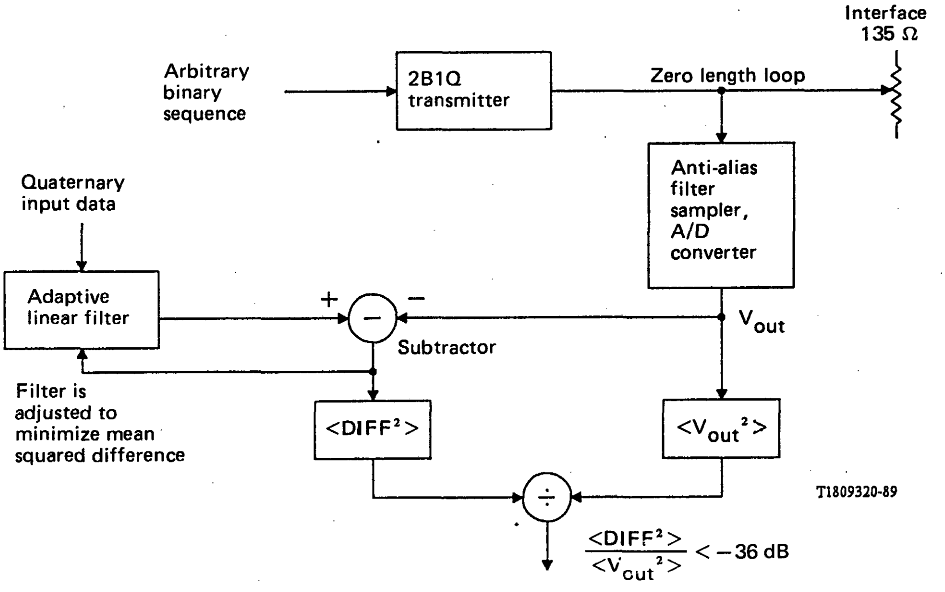


FIGURE II-13/G.961

Measurement of transmitter linearity

II.13 *Transmitter/receiver termination*

II.13.1 *Impedance*

The nominal driving point impedance at the interface toward the NT1 shall be 135 ohms.

II.13.2 *Return loss*

The return loss with respect to 135 ohms, over a frequency band from 1 kHz to 200 kHz, shall be as shown in Figure II-14.G.961.

II.13.3 *Longitudinal conversion loss*

II.13.3.1 *Longitudinal Balance*

The longitudinal balance (of impedance to ground) is given by:

$$LBal = 20 \log \left| \frac{e_l}{e_m} \right| dB$$

where

e_l is the applied longitudinal voltage (referenced to the building green or green wire ground of the NT1).

e_m is the resultant metallic voltage appearing across a 135 ohms termination.

The balance shall be > 60 dB at frequencies up to 4 kHz and > 55 dB at higher frequencies up to 160 kHz.

Figure II-15/G.961 defines a measurement method for longitudinal balance. For direct use of this test configuration, measurement should be performed with the NT1 powered up but inactive (no transmitted signal).

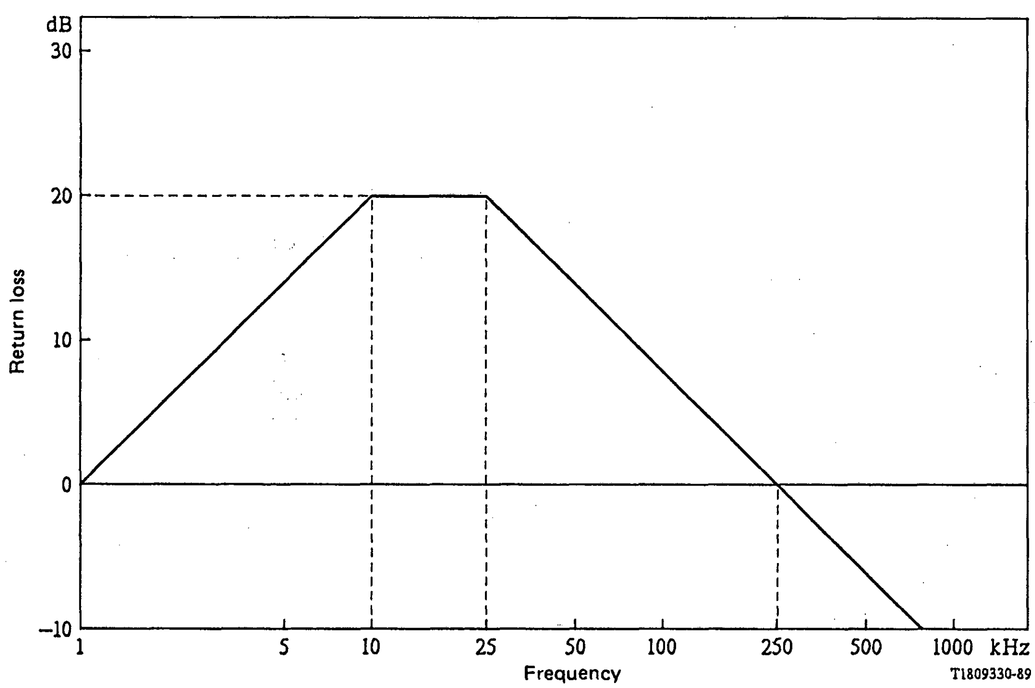
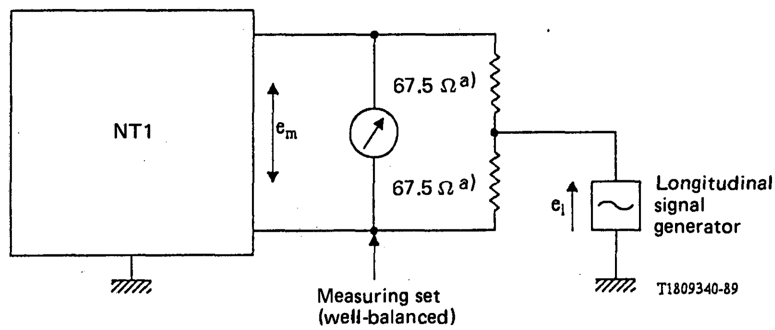


FIGURE II-14/G.961

Minimum return loss



a) These resistors to be matched to better than 0.03% tolerance.

FIGURE II-15/G.961

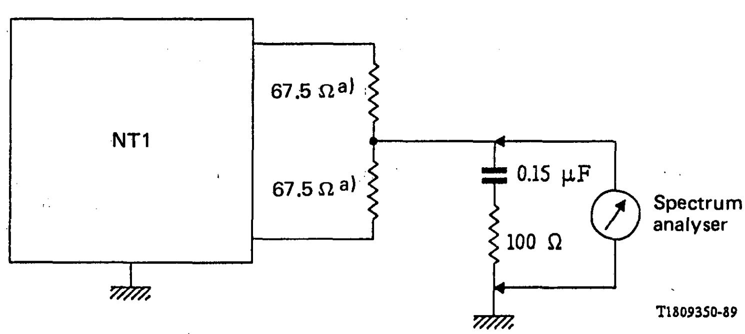
Measurement method for longitudinal balance

II.13.3.2 *Longitudinal output voltage*

The longitudinal component of the NT1 output signal shall have an rms voltage, in any 4 kHz bandwidth averaged in any 1 second period, less than −50 dBv over the frequency range 100 Hz to 170 kHz, and less than −80 dBv the range from 170 kHz to 270 kHz. Compliance with this limitation is required with a longitudinal termination having an impedance equal to or greater than a 100 ohm resistor in series with a 0.15 uF capacitor.

Figure II-16/G.961 defines a measurement method for longitudinal output voltage. For direct use of this test configuration, the NT1 should be able to generate a signal in the absence of a signal from the LT.

The ground reference for these measurements shall be the building ground.



a) These resistors to be matched to better than 0.1% tolerance.

FIGURE II-16/G.961

Measurement method for longitudinal output voltage

APPENDIX III

(to Recommendation G.961)

Electrical characteristics of an AMI transmission system

III.0 *General*

The system will support the full duplex, transparent transmission of the two 64 kbit/s B channels and one 16 kbit/s D channel, as defined in Recommendation I.412. The bidirectional transmission over symmetric pair cables is based on the echo cancelling techniques. An extra 16 kbit/s capacity is added to the resulting 144 kbit/s data information, to provide a CL channel (for control, supervisory and maintenance purposes) and other transmission facilities.

The frames of the transmitted signal contain framewords which include a time period of absence of line signal. This frame format allows, when the relative offset between the frames in the two transmission direction is lesser than the values specified in § III.7, to simplify the timing recovery, the line equalizer setting and the echo canceller updating.

III.1 *Line code*

For both directions of transmission the line code is AMI.

The binary bit stream shall be coded according to the following rule:

– a binary ONE is represented by no line signal

– a binary ZERO is alternately represented as a positive or a negative pulse.

III.2 *Symbol rate*

The symbol rate is determined by the line code, the bit rate of the information stream and the frame structure. The symbol rate is 160 kbauds.

III.2.1 *Clock requirements*

III.2.1.1 *Free running NT1 clock accuracy*

The accuracy of the free running clock in the NT1 shall be ± 50 ppm.

III.2.1.2 *LT clock tolerance*

The NT1 and the LT shall accept a clock accuracy from the ET of ± 1 ppm.

III.3 *Frame structure*

The frame structure contains a frame word, 32 times (2B + D) and a CL channel, besides an auxiliary and a stop bit. In both transmission directions the general structure of the frame is as follows:

Frame word	A	4 [8 (2B + D) + CL]	P

A = Auxiliary bit

The A bit of the frame is used to distinguish the directions of transmission and to signal the correct establishment of the activation procedure by the polarity inversion.

P = Parity bit

The P bit is used to get an even number of binary ZEROs in the frame; so it is set to binary ZERO or binary ONE according to the number of binary ZEROs if the frame is odd or even respectively.

III.3.1 *Frame length*

The number of (2B + D) slots in one frame is 32; whereas the number of CL bits is 4.

III.3.2 *Bit allocation in direction LT-NT1*

In Figure III-1/G.961 the bit allocation is given.

Bit position	Use		
1-58	Frame word		
59	Auxiliary bit		
60-67	B1 channel	First slot	
68-75	B2 channel	(2B + D)	
76-77	D channel		
.			
.			First block
.			[8 (2B + D) + CL]
.			
186-193	B1 channel		
194-201	B2 channel	Eighth slot	
202-203	D channel	(2B + D)	
204	CL channel		
.			
.	.	.	
.	.	.	
.	.	.	
.			
492-493	B1 channel	First slot	
494-508	B2 channel	(2B + D)	
509-510	D channel		
.			Fourth block
.			[8 (2B + D) + CL]
.			
621-628	B1 channel		
629-636	B2 channel	Eighth slot	
637-638	D channel	(2B + D)	
639	CL channel		
640	Parity bit		

FIGURE III-1/G.961

Bit allocation in direction LT-NT1

III.3.3 *Bit allocation in direction NT1-LT*

Same as § III.3.2.

III.4 *Frame word*

The frame word is used to allocate bit positions to the 2B + D + CL channels and to the A and P bits. It may also be used for timing recovery, echo canceller updating and line equalizer setting.

III.4.1 *Frame word in direction LT-NT1*

The code for the frameword shall be 57 consecutive binary ONE (coded as line absence of signal) and one binary ZERO (positive line pulse).

III.4.2 *Frame word in direction NT1-LT*

Same as § III.4.1.

III.5 *Frame alignment procedure*

The frame alignment procedure shall be as follows:

III.5.1 *State 1: correct frame alignment*

To enter the correct alignment state the frame word, the auxiliary bit and the parity bit must be detected correctly three times consecutively.

III.5.2 *State 2: prealarm for frame alignment*

To enter the prealarm state it is sufficient not to detect the frame word, the auxiliary bit and the parity bit for one time.

III.5.3 *State 3: out of frame alignment*

To enter the out of alignment state eight consecutive negative checks of the condition defined under state 1 must be detected.

III.6 *Multiframe*

To enable bit allocation of the CL channel in more frames next to each other, a multiframe structure shall be used. The start of the multiframe is determined by the content of the CL channel in a frame word as described in § III.6.1. The total number of frames in a multiframe is 4.

III.6.1 *Multiframe word in direction NT1-LT*

The multiframe will be identified by detecting the CL channel bits. CL channel is synchronous with the frame, and the start of a multiframe is assumed when odd parity is verified on the four CL bits in a frame. There are four of CL bits in a frame, coded as follows:

CL channel structure

I	I	I	O	First frame
I	I	I	P	Second frame
I	I	I	P	Third frame
P	P	P	P	Fourth frame

Where I stands for Information bits and P, O for parity check bits. The P bits of the fourth frame are dedicated to vertical parity of the previous frames, while O is the odd parity of the first frame. The parity evaluation is performed considering the binary ONE's. The first CL frame is also used for multiframing alignment. In the condition of out of multiframe alignment the CL channel shall be disregarded.

III.6.2 *Multiframe word in direction LT-NT1*

Same as § III.6.1.

III.6.3 *Multiframe alignment procedure*

The multiframe alignment is based on a correct detection of the parity (odd and even) of the CL channel. The correct multiframe alignment is assumed when the four parity bits satisfy the horizontal sequence Odd, Even, Even, Even and vertical sequence Even (see § III.6.1). When such sequence is not detected a prealarm multiframe alignment state is assumed, then if the correct detection is not available, out of multiframe alignment is assumed. From the state of out of multiframe alignment or from prealarm multiframe alignment condition only one correct detection of the right sequence enters the system in correct multiframe alignment state.

III.7 *Frame offset between LT-NT1 and NT1-LT frames*

The NT1 shall synchronize its frame with the frames received in the direction LT to NT1 and will transmit its frame with the offset specified in § III.7.1.

In LT the offset between the frames in the two transmission directions shall not exceed the value specified in § III.7.2.

III.7.1 *Relative frame position at the NT1 input output*

The first bit of each frame transmitted from a NT1 towards the LT shall be delayed, nominally, by 583 bit periods with respect to the first bit of the frame received from the LT. Figure III-2 /G.961 illustrated the relative bit positions for both transmitted and received frames.

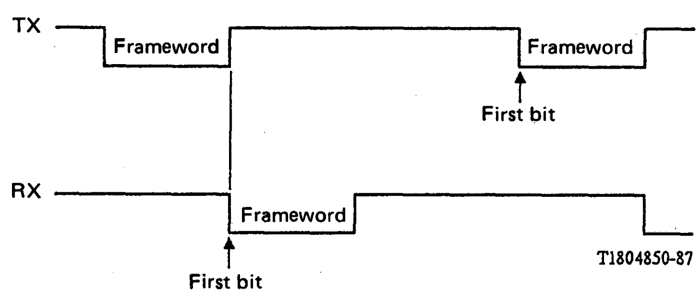


FIGURE III-2/G.961

Timing diagram in NT1

III.7.2 *Relative frame position at the LT input/output*

The time delay between the first bit of each frame transmitted from a LT towards the NT1 and the first bit of each frame received from NT1 shall not exceed 583 + 13 bit periods. Figure III-3/G.961 shows the relative bit positions for both transmitted and received frames.

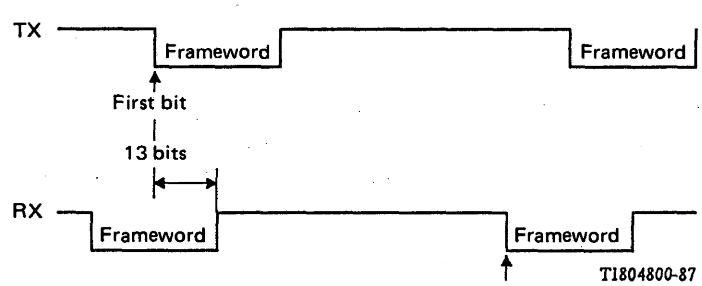


FIGURE III-3/G.961

Timing diagram in LT

III.8 *CL channel*

CL channel shall be used to carry information for activation/deactivation, testing and maintenance purposes.

III.8.1 *Bit rate*

The bit rate for the CL channel is 1 kbit/s.

III.8.2 *Structure*

The informations to be transmitted are organized in frames of 16 bit (four quadruplets in a multiframe). Each sixteen bits frame contains:

- 9 information bits;
- 7 bits for parity checks and error detection and multiframe alignment purposes.

Denoting by I the information bits and by O and P the bits for odd and even parity, the generic frame may be represented as indicated in § III.6.1.

III.8.2.1 *CL channel performance*

The performance of the CL channel shall be the following:

With a bit error rate of 10^{-3}

- the frame simulation probability shall be less than 10^{-10}
- the probability of not detecting a right frame in 100 ms shall be less than 10^{-10}

III.8.3 *Protocols and procedures*

The messages on the CL channel may be split into two categories, namely:

a) messages concerned with the activation/deactivation procedure and spontaneous report of maintenance information not sollicited by the ET.

b) auxiliary messages for maintenance purposes. These functions imply actions that can be started only by the ET and that can be performed during the full active state.

The messages of the category a) are present in a continuous mode; this means that they are transmitted continuously on the CL channel until a new message has to be transmitted.

The messages used for the transmission of these messages allows the transmission of both single byte information and multi byte information.

The procedure, that may be started only by LT/ET, shall be as follows:

- The LT/ET sends in a continuous mode the first message containing the first information byte. The first information byte always contains the address of the destination equipment in a downstream direction (regenerator, NT1,). The message is transmitted continuously until the reception of an acknowledged message from the destination equipment.
- The LT/ET sends, in the same way the following messages each containing a byte information. Each message sent by LT/ET is acknowledged by the destination equipment.
- The ET/LT sends and end-message which is acknowledged as any other message.
- When the destination equipment has to send answer information, the procedure is the same as above. In this case it is not necessary to provide the address as the destination equipment is LT/ET.

III.9 *Scrambling*

Scrambling will be applied on (2B + D + CL) channels. The scrambling polynomial is $1 \oplus x^{-9} \oplus x^{-11}$ in both transmission directions.

Scrambling with a two thresholds guard circuit is used to avoid long sequences of binary ONE's.

Figures III-4/G.961 and III-5/G.961 show the scrambling and descrambling circuit respectively.

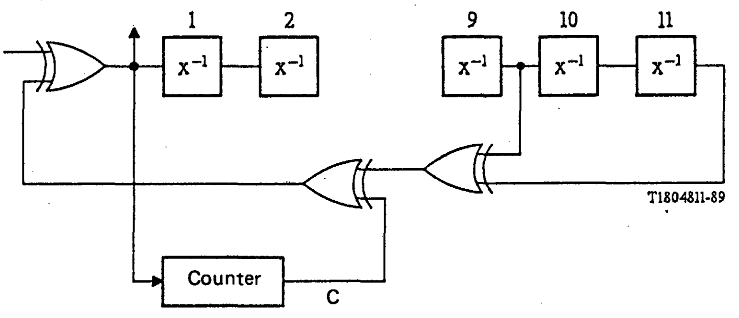


FIGURE III-4/G.961

Scrambling circuit

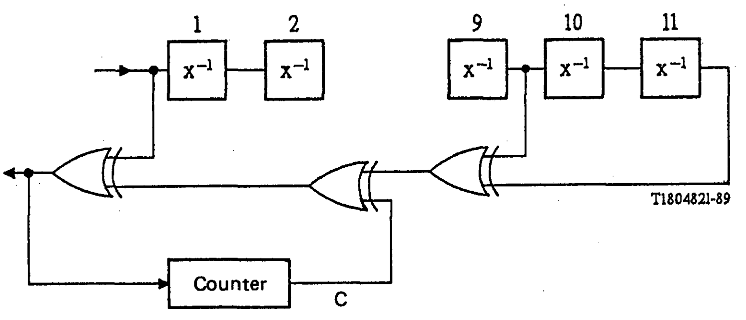


FIGURE III-5/G.961

Descrambling circuit

The counter C is incremented at each transmitted binary ONE and cleared at each transmitted binary ZERO. The counter sends a binary ZERO when 16 consecutive ONEs have been transmitted and sets its threshold to 2 if a binary ONE appears again at its input. In this condition, the counter sends a binary ZERO every two consecutive binary ONEs at its inputs. The threshold is resetted to 16 at the first binary ZERO transmitted.

III.10 *Activation/deactivation*

The guidelines taken into account in the definition of activation/deactivation procedures can be summarized as follows:

- In the deactivated state, no signal is present on the line.
- During activation appropriate signals are sent to speed up the convergence of the equalizer, the bit and frame synchronization and the echo canceller convergence.

A master/slave relationship is assumed between LT and NT1, so that, even if NT1 starts to request an activation, it is always the LT (under the ET acknowledgment), that assumes the initiative of continuing the procedure and then the transmission.

The system will support the activation of both the transmission system and the interface at T reference point, the activation of the transmission system only, interface, the deactivation of both the transmission system and the interface at T reference point or of the interface at T reference point only.

Cold and warm activations are possible. Cold activation starts after the power off – power on transition or after some specific maintenance procedures. Cold start refers to NT1 and LT which do not have stored any information about the echo canceller coefficients or equalizers setting, so a long time for activation is expected. Warm activation apply when LT and NT1 contain full information about the echo canceller coefficients and the line equalizers setting, so a short activation time is expected.

Power down mode refers to a state with very low power consumption of both LT and NT1 and with the absence of any line signal, this state allows to statistically reduce the power feeding from the central office. Of course some parts of the system, in particular the receiving sections, are always active to detect the incoming activation requests.

III.10.1 *Signals used for activation*

III.10.1.1 *Signals used for start up (CL not available)*

During the activation/deactivation procedures the following specific signals (SIGS) are exchanged on the line between LT and NT:

Down stream (LT → NT1)

INFO U0 (IU0): No signals on the line.

INFO U12 (IU12): 20 kHz burst tone. This line signal is obtained by repeating 72 times the following pattern of 8 line symbols (+ + + + – – – –) every 8 ms. The burst tone is sent in half-duplex way.

INFO U22 (IU22): 80 kHz burst tone. This line signal is obtained by repeating 291 times the following pattern of 2 line symbols (+ –) every 8 ms. The burst tone is sent in half-duplex way.

INFO U4 (IU4): Full-duplex transmission. The line signal has the same frame structure of the useful signal but with B1, B2, D and CL bit channels at the binary value ZERO. The binary stream is scrambled with a pseudorandom sequence and encoded according to the AMI rule. The second bit of the frame is set to the binary value ZERO.

INFO U6 (IU6): Full-duplex transmisison of operative data on the B and D channels; CL channel is used to convey layer 1 activation/deactivation, testing and maintenance information. The second bit of the frame is set to the binary value ONE.

Upstream (NT1 → LT)

INFO U0 (IU0): No signals on the line.

INFO U11 async.: 20 kHz burst tone. This line signal is obtained by repeating 72 times the following pattern of 8 line symbols (+ + + + – – – –) every 16 ms. The burst tone is sent in half-duplex way.

INFO U11 sync.: 20 kHz burst tone. This line signal is obtained by repeating 72 times the following pattern of 8 line symbols (+ + + + – – – –) every 8 ms. The burst tone is sent in half-duplex way synchronized to the IU12 coming from LT.

INFO U21 (IU21): 80 kHz burst tone. This line signal is obtained by repeating 291 times the following pattern of 2 line symbols (+ –) every 8 ms. The burst tone is sent in half-duplex way.

INFO U3 (IU3): Full-duplex transmission. The line signal has the same frame structure of the useful signal but with B1, B2, D and CL bit channels at the binary value ZERO. The binary stream is scrambled with a pseudorandom sequence and encoded according to the AMI rule. The second bit of the frame is set to the binary value ONE.

INFO U5 (IU5): Full-duplex transmission of operative data on the B and D channels; CL channel is used to convey layer 1 activation/deactivation, testing and maintenance information. The second bit of the frame is set to the binary value ZERO.

III.10.1.2 *Bits in the CL channel*

The I bits (see § III.6.1) of the CL channels are used to convey both activation/deactivation commands and testing and maintenance commands/reports, while P and O bits are employed for parity checking and error detecting and coded consequently. Only the activation/deactivation signals that are exchanged between LT and NT1 and conveyed through the CL channel are listed below.

I bits of CL Channel from LT to NT1

000010001 ACTIVATE REQUEST (AR)
Request to activate all the layer 1, both transmission system and interface at T reference point are activated

000001111 TRANSMISSION SYSTEM ACTIVATE REQUEST (UAR)
Request to activate the transmission system only. As in case of an AR command, the activation procedure is automatically performed. In the case in which the interface at T reference point is active, it will be deactivated.

000010011 ACTIVATE REQUEST with LOOPBACK 2 (AR2)
Request to activate with loopback 2 in NT1.

000000001 DEACTIVATE REQUEST (DR)
Request to deactivate the transmission system. The LT and NT1 automatically perform the deactivation procedure.

I bits of CL Channel from NT1 to LT

000001001 RESYNCHRONIZATION (RSY)
The RSY indication is input by the T interface when the synchronization on the interface at T reference point has been lost and not valid data are available.

000011001 ACTIVATE INDICATION (AI)
The activation procedure at the interface at T reference point has been successfully completed up to the terminal equipments when the AI is active.

000011101 ACTIVATE INDICATION with LOOPBACK 2 (AIL)
The connection through loopback 2 at the T-interface has been established. After an ARL command, the AIL indicate signal acknowledges the the receiving of an AI.

000001111 TRANSMISSION SYSTEM ACTIVATION INDICATION (UAI)
The transmission system is activated in NT1 and this information is transferred to LT/ET. The interface at T reference point is not activated.

III.10.2 *Definition of internal timers*

During the activation/deactivation procedures the following timers shall be used:

- *Timer A:* This timer is located in NT1. It has two different meanings: during the activation procedure its value is 8 seconds and is an upper limit for the activation time. Whenever, the activation is reached its value is 500 ms as a guard time to prevent unwanted deactivations due to interruption of signal or loss of line frame coming from LT.
- *Timer 2:* This timer is located in NT1. Its value is fixed in 50 ms and its purpose is to prevent from unwanted reactivations from a TE.

III.10.3 *Description of the activation procedure*

III.10.3.1 *Description of the activation procedure from LT*

Figure III-6/G.961 based on arrow sequence summarizes the activation procedure originated from ET. The activation procedure is started from an Activation request (FE1) coming from the ET. LT starts the procedure with an FE2 to ET and transmitting (IU12) on the line. At the reception of (IU11) from NT1, LT transmits (IU22) towards NT1. (IU22) is used by the NT1 for line equalizer setting (only for cold starts), fast timing recovery and AMI decision threshold setting. Once that NT1 finished its training procedure, it transmits towards LT (IU21). This SIG is used by LT for line equalizer setting (only cold starts), timing recovery and AMI decision thresholds setting. Then LT transmits (IU4) which is used by the NT1 for echo canceller updating (short training period for warm starts, longer for cold starts). At the end of this training period, NT1 sends (IU3) which is used by LT for the same purposes just explained for the NT1. Whenever all the training periods are over, LT sends (IU6) (operative B and D channels) in which the I bits of the CL channel carry FE1 command. NT1 answers with (IU5) (operative B and D channels) with FE3 code in the CL I bits if the interface at T reference point is not active and then (IU5) with FE4 when the interface at T reference point is active.

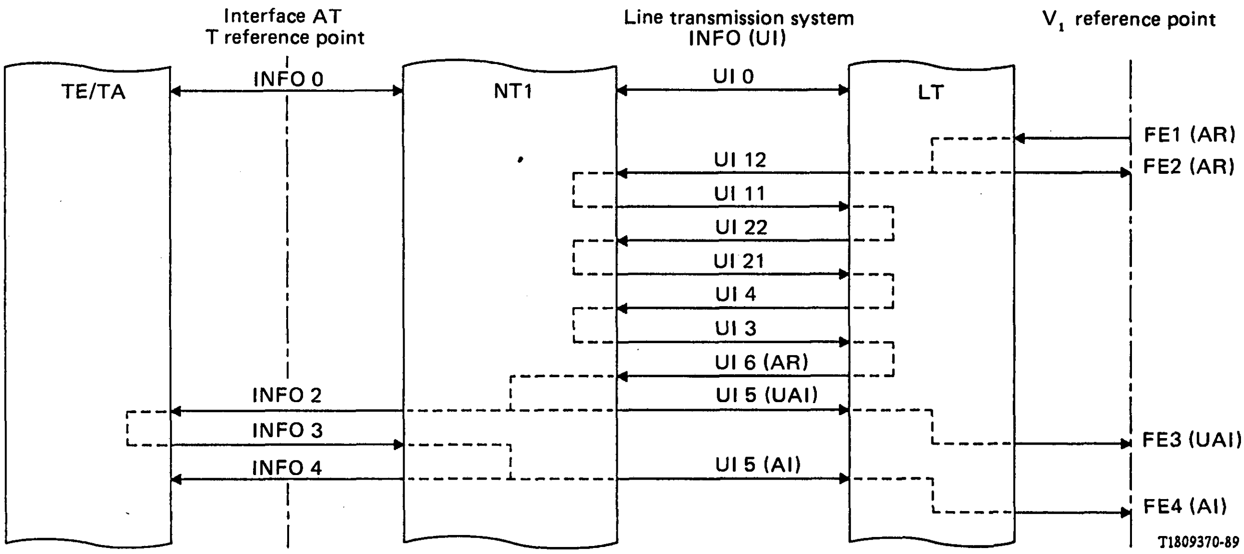


FIGURE III-6/G.961

Layer 1 activation from the network side

III.10.3.2 *Description of the activation procedure from NT1*

Figure III-7/G.961 based on arrow sequence summarizes the activation procedure originated from the user side. The activation procedure is started from an activation request INFO1 coming from the interface at T reference point. NT1 starts the procedure transmitting IU11asyn towards LT. LT passes this information to the ET with FE2 and waits for the ET FE1 to continue the activation procedure. If ET gives its acknowledgment with FE1, then the activation procedure resumes and is equal to that shown in § III.10.3.1.

III.10.3.3 *Description of the deactivation procedure*

The deactivation of the layer 1 is physically performed only under complete control of the LT/ET. The deactivation is started from ET with FE3 to LT. LT transmit (IU6) with the command DR in the I bits of the CL channel. NT1 send INFO 0 to the interface at T reference point and (IU0) back to LT. Figure III-8/G.961 based on arrow sequence summarizes the deactivation procedure.

III.10.4 *NT1 state transition table*

The detailed behaviour of the activation/deactivation procedure in NT1 is described in the Table III-1/G.961 as a function of INFOs, SIGs and internal timers.

Loopback 2 shall be originated only from a deactivated state, and no transitions from loopback 2 to active state shall be possible.

III.10.5 *LT state transition table*

The detailed behaviour of the activation/deactivation procedure in LT is described in the Table III-2/G.961 as a function of INFOs, SIGs and internal timers.

Loopback 1 shall be originated only from a deactivated state, and no transitions from loopback 1 to active state shall be possible. Loopback 1 shall be transparent or not. It is possible that after loopback 1 a long activation (cold start) will be required, as the system could loose all the information about the line equalizer, echo canceller coefficients and so on.

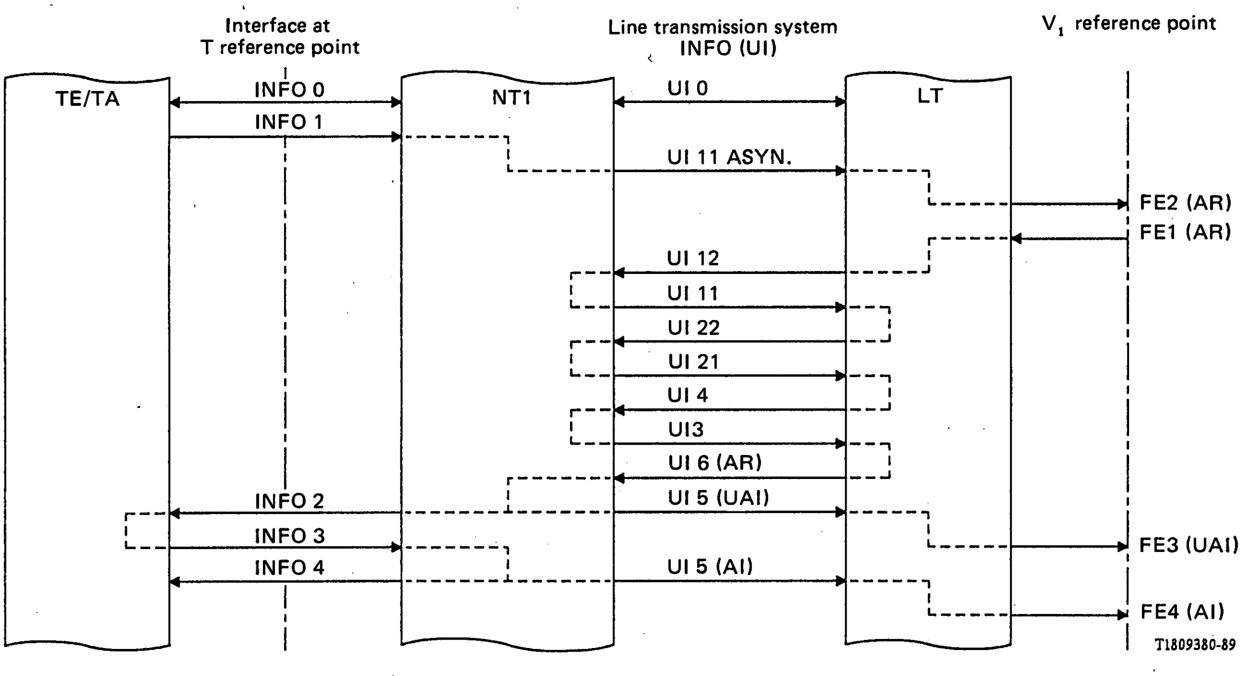


FIGURE III-7/G.961

Layer 1 activation from the user side

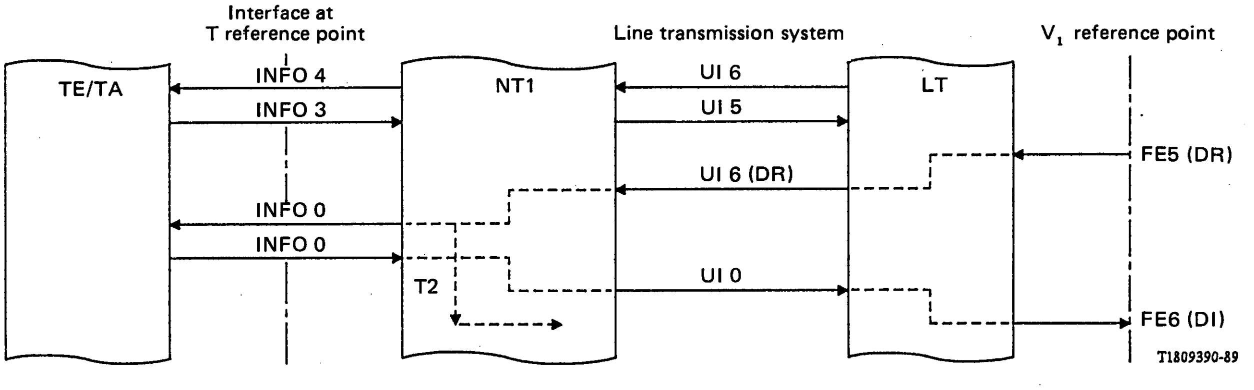


FIGURE III-8/G.961

Layer 1 deactivation

TABLE III-1/G.961

State transition table NT1 (NT-states matrix)

<table>
<tr><td></td><td>State</td><td>NT1</td><td>NT2</td><td>NT3</td><td>NT4</td><td>NT5</td><td>NT6</td><td>NT7</td><td>NT8</td><td>NT9</td><td>NT10</td><td>NT11</td><td>NT12</td><td>NT13</td><td>NT14</td><td>NT15</td></tr>
<tr><td></td><td>Name</td><td>Deactivation</td><td>Pending activation step 1</td><td>Pending activation step 2</td><td>Pending activation step 3</td><td>Pending activation step 4</td><td>Line only active</td><td>Pending activation T int.</td><td>T interf + line active</td><td>Lost of frame at U in NT6</td><td>Lost of frame at U in NT8, 9</td><td>Pending deactivat. exp. TA</td><td>Pending deactivat. IU6 (DR)</td><td>U inter. active loop 2</td><td>Loop 2 active</td><td>Loss of fr. at U loop 2</td></tr>
<tr><td></td><td>Signals Tx — Line INFO</td><td>IU0</td><td>IU11 asy</td><td>IU11</td><td>IU21</td><td>IU3</td><td>IU5 + UAI on CL</td><td>IU5 + X on CL</td><td>IU5 + AI on CL</td><td>IU0</td><td>IU0</td><td>IU0</td><td>IU5 + X on CL</td><td>IU5 + UAI or RSY</td><td>IU5 + AI on CL</td><td>IU0</td></tr>
<tr><td></td><td>New event Rx — S/T</td><td>INFO 0</td><td>INFO 0</td><td>INFO 0</td><td>INFO 0</td><td>INFO 0</td><td>INFO 0</td><td>INFO 2</td><td>INFO 4</td><td>INFO 0</td><td>INFO X</td><td>INFO 0</td><td>INFO 0</td><td>INFO 2</td><td>INFO 4</td><td>INFO X</td></tr>
<tr><td rowspan="5">S/T</td><td>INFO 0</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>NT7</td><td>–</td><td>–</td><td>NT1</td><td>NT1</td><td>/
/</td><td>NT13</td><td>–</td></tr>
<tr><td>INFO 1</td><td>NT2</td><td>–</td><td>–</td><td>–</td><td>–</td><td>- - -
(Note)</td><td>–</td><td>NT7</td><td>–</td><td>–</td><td>–</td><td>–</td><td>|
|</td><td>|
|</td><td>|
|</td></tr>
<tr><td>INFO 2</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>NT14</td><td>–</td><td>–</td></tr>
<tr><td>INFO 3</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>NT8</td><td>–</td><td>/
/</td><td>–</td><td>–</td><td>–</td><td>/
/</td><td>–</td><td>–</td></tr>
<tr><td>Loss of frame align. at T int.</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>NT7</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>/
/</td><td>NT13</td><td>/
/</td></tr>
<tr><td></td><td>Expiry T2</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>NT1</td><td>NT1</td><td>/
/</td><td>/
/</td><td>/
/</td></tr>
<tr><td></td><td>Expiry TA</td><td>/
/</td><td>ST.T2
NT11</td><td>ST.T2
NT11</td><td>ST.T2
NT11</td><td>ST.T2
NT11</td><td>/
/</td><td>/
/</td><td>/
/</td><td>NT1</td><td>ST.T2
NT11</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>ST.T2
NT11</td></tr>
<tr><td rowspan="10">LINE</td><td>IU0</td><td>–</td><td>–</td><td>ST.TA</td><td>ST.TA</td><td>ST.TA</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>IU12</td><td>NT3</td><td>NT3</td><td>–</td><td>ST.TA</td><td>ST.TA</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>/
/</td></tr>
<tr><td>IU22</td><td>/
/</td><td>/
/</td><td>Stop TA
NT4</td><td>–</td><td>ST.TA</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>/
/</td></tr>
<tr><td>IU4</td><td>/
/</td><td>/
/</td><td>ST.TA</td><td>Stop TA
NT5</td><td>–</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>/
/</td></tr>
<tr><td>IU6 + AR on CL</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>Stop TA
NT7</td><td>NT7</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>/
/</td></tr>
<tr><td>IU6 + UAR on CL</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>Stop TA
NT6</td><td>–</td><td>/
/</td><td>NT6</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>/
/</td></tr>
<tr><td>IU6 + AR2 on CL</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>Stop TA
NT13</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>–</td><td>–</td><td>/
/</td></tr>
<tr><td>IU6 + DR on CL</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>NT1</td><td>ST.T2
NT12</td><td>ST.T2
NT12</td><td>/
/</td><td>/
/</td><td>–</td><td>–</td><td>ST.T2
NT12</td><td>ST.T2
NT12</td><td>/
/</td></tr>
<tr><td>Loss of frame align. at U int.</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>ST.TA
NT9</td><td>ST.TA
NT10</td><td>ST.TA
NT10</td><td>–</td><td>–</td><td>/
/</td><td>/
/</td><td>ST.TA
NT15</td><td>ST.TA
NT15</td><td>–</td></tr>
<tr><td>Recovery from loss of frame align. at U int.</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>Stop TA
NT6</td><td>Stop TA
NT7 ou
NT8</td><td>/
/</td><td>/
/</td><td>/
/</td><td>/
/</td><td>Stop TA
NT13 or
NT14</td></tr>
</table>

Note – For symbols and abbreviations, see Table III-2/G.961.

TABLE III-2/G.961

State transition table LT (LT-states matrix)

	State	LT1	LT2	LT3	LT4	LT5	LT6	LT7	LT8	LT9	LT10	LT11	LT12	LT13
	Name	Deactivation	Wait activation	Pending activat. step 1	Pending activat. step 2	Pending activat. step 3	Pending activat. step 4	Line only active	T int. or loop 2 active	Loss of frame at U in LT8	Loss of frame at U in LT7	Remote error indication	Loss of frame at U in LT11	Pending deactivation
	Signals Tx — Line INFO	IU0	IU0	IU12	IU22	IU4	IU6 + FE on CL	IU6 + FE on CL	IU6 + FE on CL	IU6 + FE on CL	IU6 + FE on CL	IU6 + FE on CL	IU6 + FE on CL	IU6 + FE on CL
	New event Rx — V_1	FE 6 (DI)	FE 2 (AR)	FE 2 (AR)	FE 2 (AR)	FE 2 (AR)	FE 2 (AR)	FE 3 (UAI)	FE 4 (AI)	FE 7 (RSY)	FE 7 (RSY)	FE 7 (RSY)	FE 7 (RSY)	FE receiv. from CL
V_1	FE 1 (AR)	LT3	LT3	–	–	–	–	–	–	–	–	–	–	–
V_1	FE 11 (UAR)	LT3	/ /	–	–	–	–	–	–	–	–	–	–	–
V_1	FE 9 (ARL)	LT4	/ /	/ /	–	–	–	–	–	–	–	–	–	–
V_1	FE 8 (AR2)	LT3	/ /	–	–	–	–	–	–	–	–	–	–	–
V_1	FE 10 (AR4)	LT3	/ /	–	–	–	–	–	–	–	–	–	–	–
V_1	FE 5 (DR)	–	–	LT1	LT1	LT1	LT1	LT13	LT13	LT1	LT1	LT13	LT1	–
LINE	IU11 asyn.	LT2	–	–	–	–	–	–	–	–	–	–	–	–
LINE	IU11	/ /	LT1	LT4	–	–	–	–	–	–	–	–	–	–
LINE	IU21	/ /	LT1	–	LT5	–	–	–	–	–	–	–	–	–
LINE	IU3	/ /	LT1	–	–	LT6	–	–	–	–	–	–	–	–
LINE	IU5 + UAI on CL	/ /	TL1	–	–	–	LT7	–	LT7	–	–	LT7	–	–
LINE	IU5 + AI on CL	/ /	LT1	–	–	–	LT8	LT8	–	–	–	LT8	–	–
LINE	IU5 + AR on CL	/ /	/ /	/ /	/ /	/ /	/ /	LT6	/ /	/ /	/ /	/ /	/ /	/ /
LINE	IU0	–	LT1	–	–	–	–	–	–	–	–	LT8	–	LT1
LINE	IU5 + RSY on CL	/ /	LT1	–	–	–	–	LT11	LT11	–	–	–	–	–
LINE	Loss of frame align. at U int.	/ /	/ /	/ /	/ /	/ /	/ /	LT10	LT9	–	–	LT12	–	LT1
LINE	Recovery from loss of frame at U int.	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /	LT8	LT7	/ /	LT11	/ /

/	Impossible event
–	No change state
|	Impossible event by the definition of the layer 1 service
INFO IU5 + X	Line signal with X-message on CL channel
INFO IU6 + X	Line signal with X-message on CL channel
ST.T2	Start timer T2
ST.TA	Start timer TA
INFO U6 + FE	Line signal with a message on CL channel related with FE and V1 interface coming from ET1.

Note – NT1 transmits on the CL channel AR instead of UAI.

III.10.6 *Activation times*

The activation time from a warm start shall be less than 300 ms.

The activation time from a cold start shall be less than 4 seconds.

III.11 *Jitter*

Jitter tolerances are intended to ensure that the limits of Recommendation I.430 are supported by the jitter limits of the transmission system on local lines. The jitter limits given below must be satisfied regardless of the length of the line and the inclusion of one regenerator, provided that they are covered by the transmission media characteristics (see § 3). The limits must be met regardless of the transmitted bit patterns in the B, D and CL channel.

III.11.1 *NT input signal jitter tolerance*

The NT1 shall meet the performances objectives with wander/jitter at the maximum magnitudes indicated in Figure III-9/G/961 for single jitter frequencies in the range of 1 Hz to 40 kHz, superimposed on the test signal source. The NT1 shall also meet the performance objectives with wander per day of up to 3 UI peak to peak where the maximum rate of change of phase is 0.6 UI/hour.

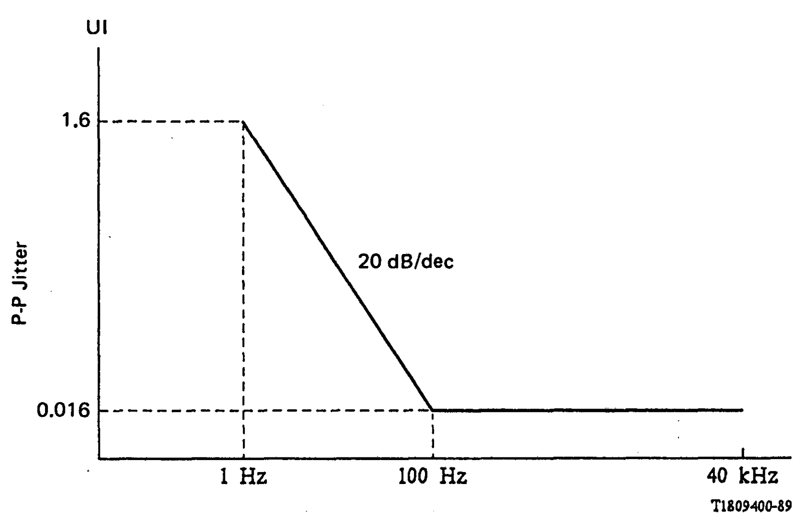


FIGURE III-9/G.961

Minimum tolerable jitter on NT1 input signal

III.11.2 *NT output jitter limitation*

With the wander/jitter as specified in § III.11.1 superimposed on the NT1 input signal, the jitter on the transmitted signal on the NT1 towards the network shall conform the following:

a) The jitter shall be equal to or less than 0.08 UI peak-to-peak and less than 0.02 UI rms when measured with a high-pass filter having a 20 dB/dec roll-off below 100 Hz.

b) The jitter in the phase of the output signal relative to the phase of the input signal (from the network) shall not exceed 0.08 UI peak-to-peak or 0.02 UI rms when measured with a band-pass filter having a 20 dB/decade roll-off above 200 Hz and a 20 dB/decade roll-off below 0.1 Hz. This requirement applies with a superimposed jitter in the phase of the input signal as specified in § III.11.1 for single frequencies up to 100 Hz.

III.11.3 *Test conditions for jitter measurements*

The jitter measurements have been performed using test points.

III.12 *Transmitter output characteristics of NT1 and LT*

The following specifications apply with a load impedance of 130 ohms.

III.12.1 *Pulse amplitude*

The zero to peak nominal amplitude of the largest pulse shall be 2 V and the tolerance ± 10%.

III.12.2 *Pulse shape*

The pulse shape shall meet the mask of Figure III-10/G.961.

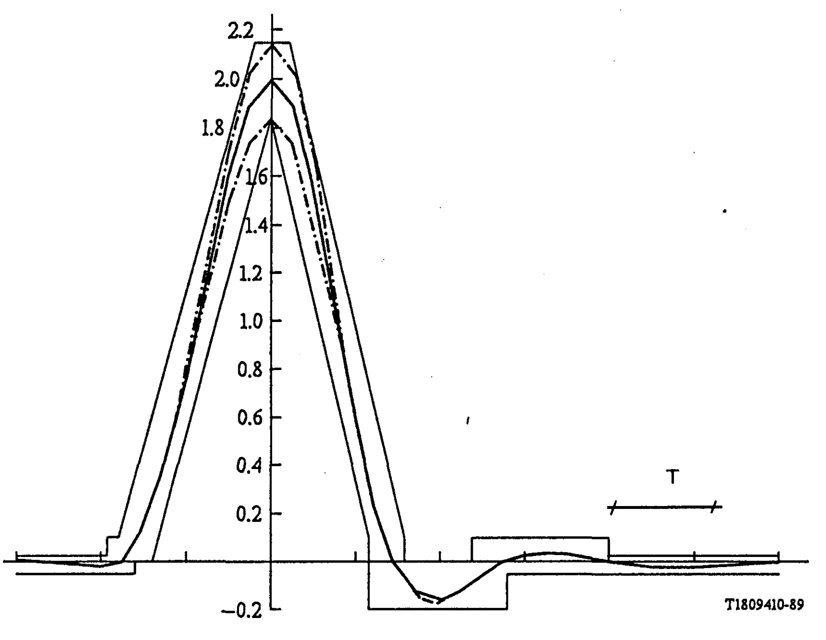


FIGURE III-10/G.961

Transmit pulse mask

III.12.3 *Signal power*

The average signal power shall be between 8 dBm and 9 dBm.

III.12.4 *Power spectrum*

The upper bound of the power spectral density shall be within the template of Figure III-11/G.961.

III.12.5 *Transmitter signal nonlinearity*

The transmitter signal nonlinearity shall be less than 1%.

III.13 *Transmitter/receiver termination*

III.13.1 *Impedance*

The nominal input/output impedance looking towards to the NT1 or LT respectively shall be 130 ohms.

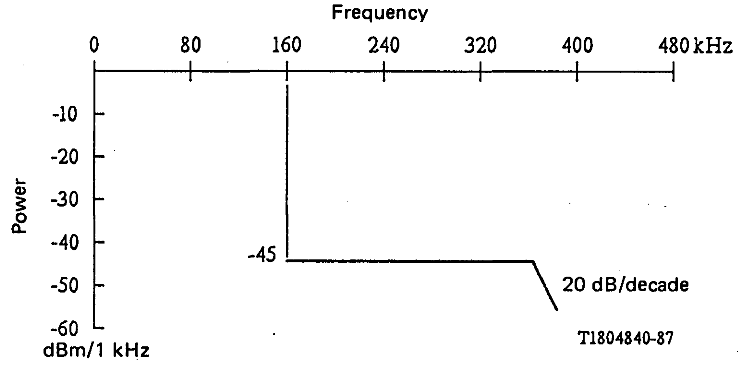


FIGURE III-11/G.961

Template of the transmitted power spectral density

III.13.2 *Return loss*

The return loss of the impedance shall be greater than 11 dB in the frequency range 5 to 60 kHz and greater than 16 dB in the frequency range 60 to 100 kHz.

III.13.3 *Longitudinal conversion loss*

The minimum longitudinal conversion loss shall be as follows:

- up to 80 kHz 45 dB;
- above 80 kHz 40 dB.

APPENDIX IV

(to Recommendation G.961)

Electrical characteristics of an AMI transmission system using a TCM method

IV.1 *Line code*

For both directions of the transmission, the line code is AMI. The coding scheme will be performed in such a way that a binary ZERO is represented by no line signal, while a binary ONE is represented by a positive or negative pulse alternately.

IV.2 *Symbol rate*

The symbol rate is determined by the line code, rate of the information stream and the frame structure. The bit symbol rate is 320 kbauds.

IV.2.1 *Clock requirements*

IV.2.1.1 *NT1 free running clock accuracy*

The accuracy of the free running clock in the NT1 shall be ± 50 ppm.

IV.2.1.2 *NT1 clock tolerance*

The NT1 shall accept a clock accuracy from the LT of ± 10 ppm.

IV.2.1.3 *LT clock tolerance*

The LT shall accept a clock accuracy from the ET of ± 10 ppm.

IV.3 *Frame structure*

The frame structure contains a frame word, N times (2B + D) and a CL channel.

← 2.5 ms →

Frame word	CL channel	*N* times (2B + D)	P	Space

P Parity bit: The P bit is used to get an even number of binary ONEs in a frame; so it is set to binary ONE or binary ZERO when the number of binary ONEs in a frame is odd or even respectively

IV.3.1 *Frame length*

The number *N* of (2B + D) slots in one frame is twenty.

IV.3.2 *Bit allocation in direction LT-NT1*

In Figure IV-1/G.961, the bit allocation is given.

IV.3.3 *Bit allocation in direction NT1-LT*

In Figure IV-2/G.961, the bit allocation is given.

Bit positions	1~8	9	10	11~13	14~16	XX (Note)	YY (Note)	ZZ (Note)	VV (Note)	377	378~800
Functions	Frame word	Control bit	Multiframe bit	Control bits	CRC bits	B_1 channel	D channel	B_2 channel	D channel	Parity bit	Space (No line signal)
		CL channel									

Note – XX = (17 + 18n) until (24 + 18n); where n = 0~19.
YY = 25 + 18n ; where n = 0~19.
ZZ = (26 + 18n) until (33 + 18n); where n = 0~19.
VV = 34 + 18n ; where n = 0~19.

FIGURE IV-1/G.961

Bit allocation in direction LT-NT1

Bit positions	1 ~ 8	9	10	11 ~ 13	14 ~ 16	XX (Note)	YY (Note)	ZZ (Note)	VV (Note)	377	378 ~ 800
Functions	Frame word	Information bit	Multiframe bit	Information bits	CRC bits	B_1 channel	D channel	B_2 channel	D channel	Parity bit	Space (No line signal)
		CL channel									

Note – XX = (17 + 18n) until (24 + 18n); where n = 0 ~ 19.
YY = 25 + 18n ; where n = 0 ~ 19.
ZZ = (26 + 18n) until (33 + 18n); where n = 0 ~ 19.
VV = 34 + 18n ; where n = 0 ~ 19.

FIGURE IV-2/G.961

Bit allocation in direction NT1-LT

IV.4 *Frame word*

The frame word is used to allocate bit position to the 2B + D + CL channels. It may, however, also be used for other functions.

IV.4.1 *Frame word in direction LT-NT1*

The code for the frame word will be "100000M0"; M is "1"/"0" alternating bit in every frame.

IV.4.2 *Frame word in direction NT1-LT*

The code for the frame word will be "1000000M"; M is "1"/"0" alternating bit in every frame.

IV.5 *Frame alignment procedure*

The frame alignment procedure is defined as follows.

a) *Frame alignment state*

The transmission system is considered to be frame alignment state if the frame word has been identified in the same position for three consecutive frames.

b) *Loss of frame alignment state*

The transmission system is considered to be loss of frame alignment state if the frame word has not been identified in the expected frame position for six frames before identifying the frame word in the frame position for twelve frames.

IV.6 *Multiframe*

To enable bit allocation of the CL channel in more frames next to each other, a multiframe structure may be used. The start of the multiframe is determined by the frame word. The total number of frames in a multiframe is four.

IV.6.1 *Multiframe word in direction LT-NT1*

The multiframe is identified by the multiframe bit allocated in the CL channel. The code for the multiframe word, which is defined by the multiframe bits in four consecutive frames under the frame alignment state, is "1000".

IV.6.2 *Multiframe word in direction NT1-LT*

The same as IV.6.1.

IV.7 *Frame offset between LT-NT1 and NT1-LT frames*

The NT1 shall synchronize its frame on the frame received in the direction LT to NT1 and will transmit its frame with an offset. Relative frame position at the NT1 input/output is as follows. The first bit of each frame transmitted from the NT1 toward the LT shall be delayed by 383 up to 384 bit periods with respect to the first bit of the frame received from the LT.

IV.8 *CL channel*

IV.8.1 *Bit rate*

The bit rate for the CL channel is 3.2 kbit/s.

IV.8.2 *Structure*

a) Thirty two bits (3.2 kbit/s) are allocated in a multiframe for the use of CL channel.

b) Four bits (0.4 kbit/s) are allocated to multiframe bits.

c) Sixteen bits (1.6 kbit/s) are allocated to maintenance and operational control functions in direction LT to NT1, and to maintenance and operational information functions in direction NT1 to LT.

d) Twelve bits (1.2 kbit/s) are allocated to a cyclic redundancy check (CRC) function.

IV.8.3 *Protocols and procedures*

Protocols and procedures of maintenance/operational control/information are as follows.

a) Transfer modes are bit-oriented.

b) Sending modes are continuous.

c) Identification is confirmed by identical bits receiving for three consecutive multiframes under the frame alignment state.

d) Duration of control invocations is as long as sending control is identified.

e) Duration of information invocations is as long as causing event is identified.

IV.9 *Scrambling*

Scrambling will be applied on 2B + D channels and the scrambling algorithm shall be as follows.

– In direction LT-NT1: $x^9 \oplus x^5 \oplus 1$

– In direction NT1-LT: $x^9 \oplus x^5 \oplus 1$

IV.10 *Activation/deactivation*

Activation/deactivation is defined in Recommendation G.960, § 5. Applications provided by the transmission system are described as follows.

IV.10.1 *Signals used for activation*

Definition of the signals used for activation/deactivation (SIGs) are listed below. Signals used for start-up (bits in the CL channel are not available) and bits in the CL channel (in already established frames) are defined.

a) Signals used for start-up (CL not available):

– SIG 0 (NT1 to LT and LT to NT1): No line signal.

– SIG 1 (LT to NT1): A signal which deactivates the line and the interface at T reference point.

– SIG 2 (NT1 to LT): An awake signal to invoke the LT layer 1 that it has to enter the power up state and provide for the activation of the line and the interface at T reference point. It is invoked by receiving the signal INFO 1 across the T reference point in case of the activation from the user side. This signal is also used as awake acknowledgement on receiving of the signal SIG 3 in case of the activation from the network side.

– SIG 3 (LT to NT1): An awake signal to invoke the NT1 layer 1 that it has to enter the power up state and prepare for synchronization on an incoming signal from the LT. This signal is also used as awake acknowledgement on receiving of the signal SIG 2 in case of the activation from the user side.

– SIG 4 (LT to NT1): A signal which contains framing information and allows the synchronization of the receiver in the NT1.

– SIG 5 (NT1 to LT): A signal which contains framing information and allows the synchronization of the receiver in the LT. It informs the LT that the NT1 has synchronized on the signal SIG 4.

b) Bits in CL channel in already established frame:

– SIG 6 (LT to NT1): A signal which requires the NT1 to establish the full layer 1 information transfer capability available between the NT1 and LT, and requires the NT1 to activate the T interface by sending the signal INFO 2 across the T reference point.

– SIG 7 (LT to NT1): A signal which requires the NT1 to establish the full layer 1 information transfer capability available between TE and the ET by sending the signal INFO 4 across the T reference point.

– SIG 8 (NT1 to LT): A signal which indicates that the interface at T reference point is activated, and requires the LT to provide the full layer 1 information transfer capability available between TE and the ET. It is invoked by receiving of the signal INFO 3 across the T reference point.

– SIG 9 (LT to NT1): A signal which requires the NT1 to establish the full layer 1 information transfer capability available between the NT1 and LT, and requires the NT1 to activate the loopback 2.

– SIG 10 (NT1 to LT): A signal which indicates that the loopback 2 is activated in the NT1, and requires the LT to provide the full layer 1 information transfer capability available between the NT1 and ET.

– SIG 11 (LT to NT1 and NT1 to LT): A synchronization signal which contains framing information and 2B + D + CL channels.

- SIG 12 (NT1 to LT): A signal which indicates that the receiver on the T interface side of the NT1 has entered lost framing state.
- SIG 13 (LT to NT1): A signal which indicates that the receiver on the line side of the LT has entered lost framing state. This signal also contains a function as the signal SIG 4.
- SIG 14 (NT1 to LT): A synchronization signal which contains framing information and 2B + D+ CL channels; bits in the 2B + D channels are set to be idle.

Note – Definition of the function element (FEs) across the V reference point is described in Recommendation G.960, § 5.4. FEs used for activation/deactivation are relisted in Table IV-1/G.961.

TABLE IV-1/G.961

The repertoire of function elements associated with the activation/desactivation procedures

FEs	Direction	Repertoire
FE 1	ET to LT	Activation request for the interface at T reference point
FE 5	ET to LT	Deactivation request for the line and the interface at T reference point
FE 9	ET to LT	Activation request for loopback 1
FE 8	ET to LT	Activation request for loopback 2
FE 4	LT to ET	The T interface is activated or a loopback is provided respectively
FE 3	LT to ET	The line is activated
FE 6	LT to ET	The line and the interface at T reference point are deactivated
FE 7	LT to ET	Error indication
FE 2	LT to ET	Request to start timer T1 within the ET layer 1

IV.10.2 *Definition of internal timers*

Timer T2 (see Recommendation I.430, § 6) resides within the LT layer 1.

IV.10.3 *Description of the activation procedure*

a) Activation from the network side: See Figure IV-3/G.961.

b) Activation from the user side: See Figure IV-4/G.961.

c) Deactivation from the network side: See Figure IV-5/G.961.

d) Activation of loopback 2: See Figure IV-6/G.961.

Note 1 – Activating the line system only, where the full information transfer capability is available while the interface at T reference point remains deactivated, is not provided.

Note 2 – A non-transparent loopback 1 is provided where no line signal is transmitted at the LT 2-wire point.

Note 3 – A non-transparent loopback 2 is provided where INFO 0 is sent from the NT1 at the interface at T reference point.

Note 4 – A repeater is not applicable.

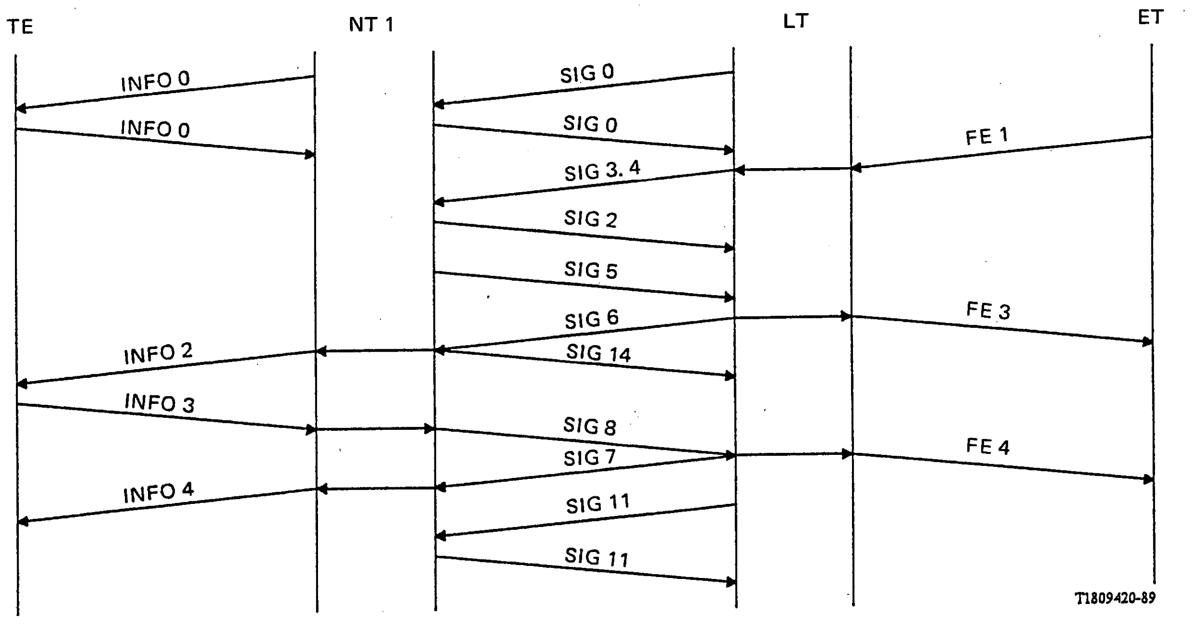


FIGURE IV-3/G.961

Activation from the network side

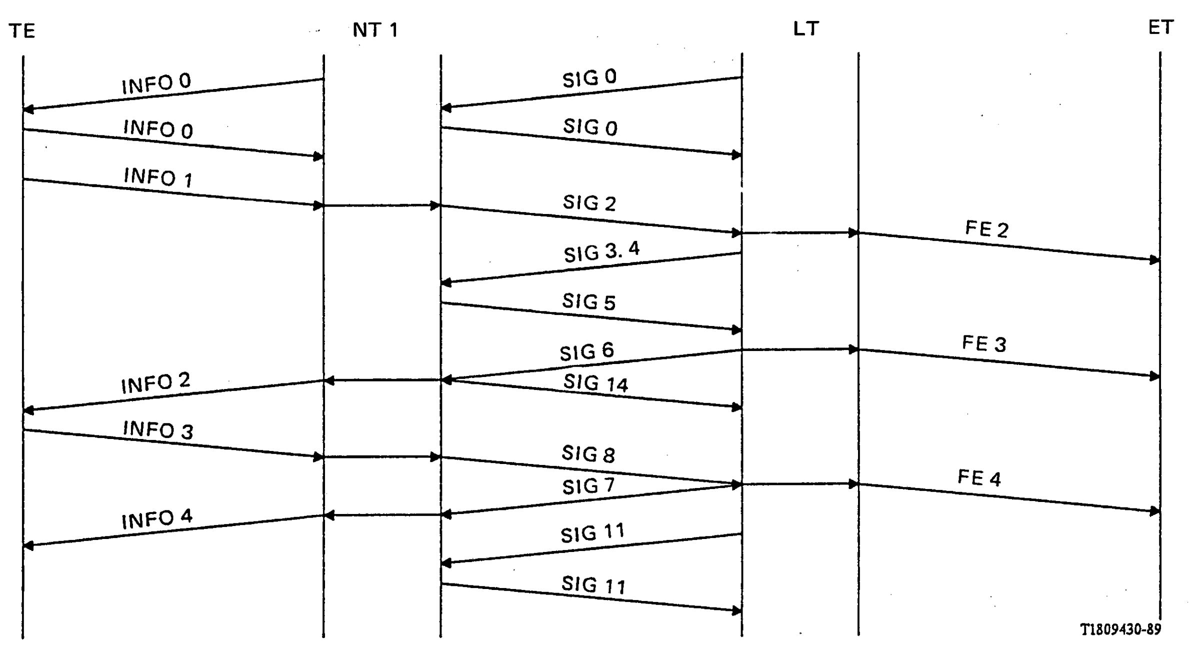


FIGURE IV-4/G.961

Activation from the user side

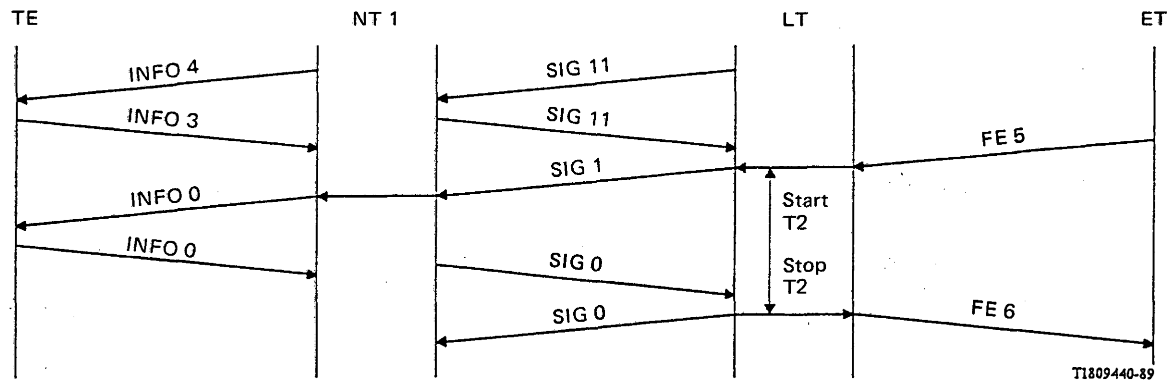


FIGURE IV-5/G.961

Deactivation from the network side

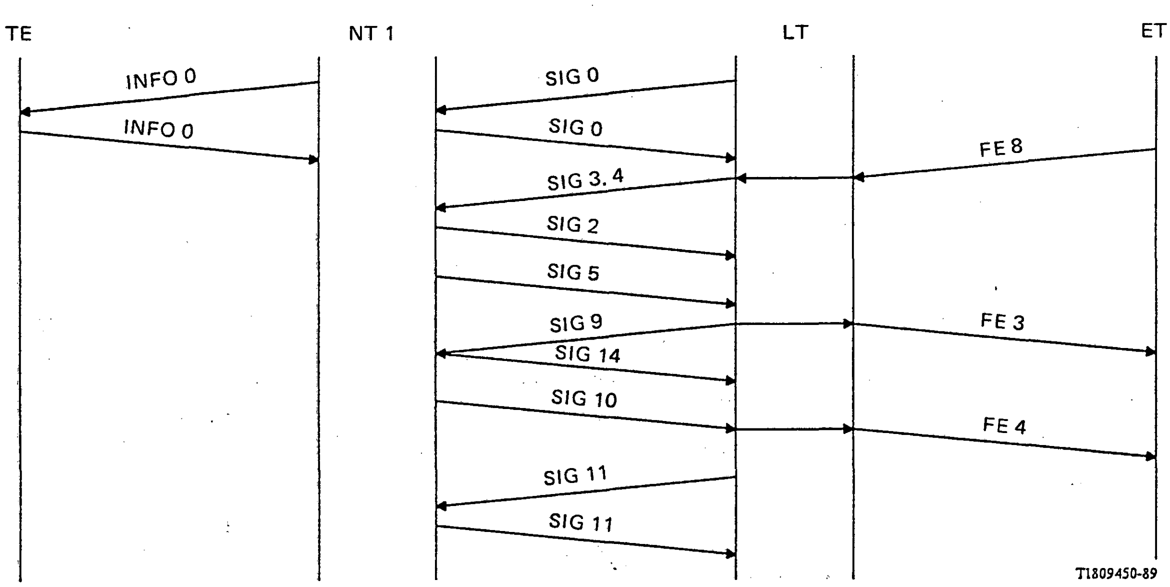


FIGURE IV-6/G.961

Activation of loopback 2

IV.10.4 *State transition table NT1*

State transition table NT1 as a function of INFOs and SIGs is defined in Table IV-2/G.961.

IV.10.5 *State transition table LT*

State transition table LT as a function of FEs, SIGs and the internal timer T2 is defined in Table IV-3/G.961.

TABLE IV-2/G.961

State transition table NT1

Event / State name	Deactive	Pending power activation	Pending activation of line at NT1 side	Pending activation of line at LT side	Line active	T- interface pre-active	T- interface active	Lost framing of T- interface	Ligne active	Loopback 2 active
State code	NT 1.0	NT 1.1	NT 1.2	NT 1.3	NT 1.4	NT 1.5	NT 1.6	NT 1.7	NT 2.1	NT 2.2
Tx	INFO 0	INFO 0	INFO 0	INFO 0	INFO 2	INFO 2	INFO 4	INFO 2	INFO 0	INFO 0
	SIG 0	SIG 2	SIG 2	SIG 5	SIG 14	SIG 8	SIG 11	SIG 12	SIG 14	SIG 10 SIG 11
SIG 1	/	NT 1.0	NT 1.0	NT 1.0	NT 1.0	NT 1.0	NT 1.0	NT 1.0	NT 1.0	NT 1.0
SIG 3	NT 1.2	NT 1.2	–	–	/	/	/	/	/	/
Line of NT1 side active	/	/	NT 1.3	–	–	–	–	–	–	–
SIG 6	/	/	/	NT 1.4	–	–	–	–	–	–
SIG 7	/	/	/	/	/	NT 1.6	–	–	/	/
SIG 9	/	/	/	NT 2.1	/	/	/	/	–	–
SIG 13	/	/	/	–	NT 1.3	NT 1.3	NT 1.3	NT 1.3	NT 1.3	NT 1.3
Lost framing of T interface	/	/	/	/	/	NT 1.7	NT 1.7	–	/	/
Lost framing of line at NT1 side	/	/	/	NT 1.2	NT 1.2	NT 1.2	NT 1.2	NT 1.2	NT 1.2	NT 1.2
Receiving INFO 1	NT 1.1	–	–	–	–	/	/	/	–	–
Receving INFO 3	/	/	/	/	NT 1.5	–	–	NT 1.5	/	/
Loopback 2 established	/	/	/	/	/	/	/	/	NT 2.2	–

/ Impossible event

– No state change

TABLE IV-3/G.961

State transition table LT

Event									
State name	Deactive	Pending activation of line	Line active	T- interface active	Pending deactivation	Lost framing of line	Pending activation of line	Line active	Loopback 2 active
State code	LT 1.0	LT 1.1	LT 1.2	LT 1.3	LT 1.4	LT 1.5	LT 2.1	LT 2.2	LT 2.3
Tx	SIG 0	SIG 3 SIG 4	SIG 6	SIG 7 SIG 11	SIG 1	SIG 13	SIG 3 SIG 4	SIG 9	SIG 11
SIG 2	FE 2 LT 1.1	–	–	/	/	–	–	/	/
Line fully active	/	FE 3 LT 1.2	–	–	–	FE 3 LT 1.2	FE 3 LT 2.2	–	–
SIG 8	/	/	FE 4 LT 1.3	–	–	/	/	/	/
SIG 10	/	/	/	/	/	/	/	FE 4 LT 2.3	–
Lost framing of line	/	/	FE 7 LT 1.5	FE 7 LT 1.5	–	–	/	FE 7 LT 2.1	FE 7 LT 2.1
SIG 12	/	/	/	FE 7 LT 1.2	–	/	/	/	/
Expiry of timer T2	/	/	/	/	LT 1.0	/	/	/	/
FE 1	LT 1.1	/	/	/	/	/	/	/	/
FE 5	/	ST.T2 LT 1.4	ST.T2 LT 1.4	ST.T2 LT 1.4	/	ST.T2 LT 1.4	ST.T2 LT 1.4	ST.T2 LT 1.4	ST.T2 LT 1.4
FE 8	2.1	/	/	/	/	/	/	/	/

/ Impossible event

– No state change

IV.10.6 *Activation times*

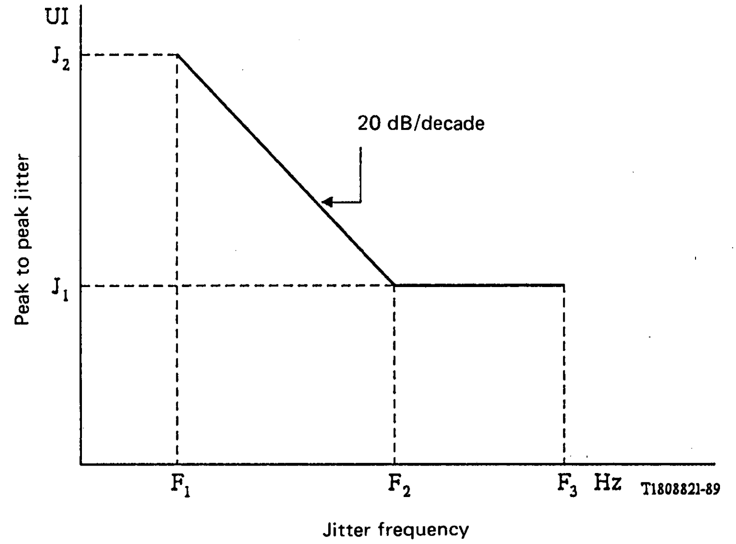
See Recommendation G.960, §§ 5.5.1 and 5.5.2.

IV.11 *Jitter*

Jitter tolerance is intended to ensure that the limits of Recommendation I.430 are supported by the jitter limits of the transmission system on local lines. The jitter limits given below must be satisfied regardless of the length of the local line and the inclusion of one regenerator, provided that they are covered by the transmission media characteristics (see § 3). The limits must be met regardless of bit patterns in the B, D and CL channels.

IV.11.1 *NT1 input signal jitter tolerance*

The NT1 shall meet the performance objective with wander/jitter at the maximum magnitudes indicated in Figure IV-7/G.961, for single jitter frequencies in the range of 3 Hz to 80 kHz, superimposed on the test signal source. The NT1 shall also meet the performance objectives with wander per day of up to 0.1 UI peak-to-peak where the maximum rate of change of phase is 1.0 UI/hour.



$$1 \text{ IU} = \frac{1}{320 \text{ kHz}} = 3.125 \text{ µs}$$

F_1	F_2	F_3	J_1	J_2
3 Hz	30 Hz	80 kHz	0.1 UI	1.0 UI

FIGURE IV-7/G.961

Minimum tolerable jitter on NT1 input signal

IV.11.2 *NT1 output jitter limitations*

With the wander/jitter as specified in IV.11.1 superimposed on the NT1 input signal, the jitter on the transmitted signal on the NT1 toward the network shall conform to following:

a) The jitter shall be equal to or less than 0.1 UI peak-to-peak and less than 0.25 UI rms when measured with a high-pass filter having a 20 dB/decade roll-off below 90 Hz.

b) The jitter in the phase of the output signal relative to the phase of the input signal (from the network) shall not exceed 0.12 UI peak-to-peak or 0.025 UI rms when measured with a band-pass filter having a 20 dB/decade roll-off above 90 Hz and a 20 dB/decade roll-off below 0.3 Hz. This applies with superimposed jitter in the phase of the input signal as specified in § IV.11.1 for single frequency up to F_2 Hz.

IV.11.3 *Test conditions for jitter measurements*

Due to bidirectional transmission on the 2-wire and due to severe intersymbol interference no well defined signal transitions are available at the NT1 2-wire point.

Note – Two possible solutions are proposed:

a) A test point in the NT1 is provided to measure jitter an undisturbed signal.

b) A standard LT transceiver including an artificial local line is defined as a test instrument.

IV.12 *Transmitter output characteristics of NT1 and LT*

The following specification apply with a load impedance of 110 ohms.

IV.12.1 *Pulse amplitude*

The zero to peak nominal amplitude of the largest pulse shall be 6 V and the tolerance shall be ± 10%.

IV.12.2 *Pulse shape*

The pulse shape shall meet the pulse mask of Figure IV-8/G.961.

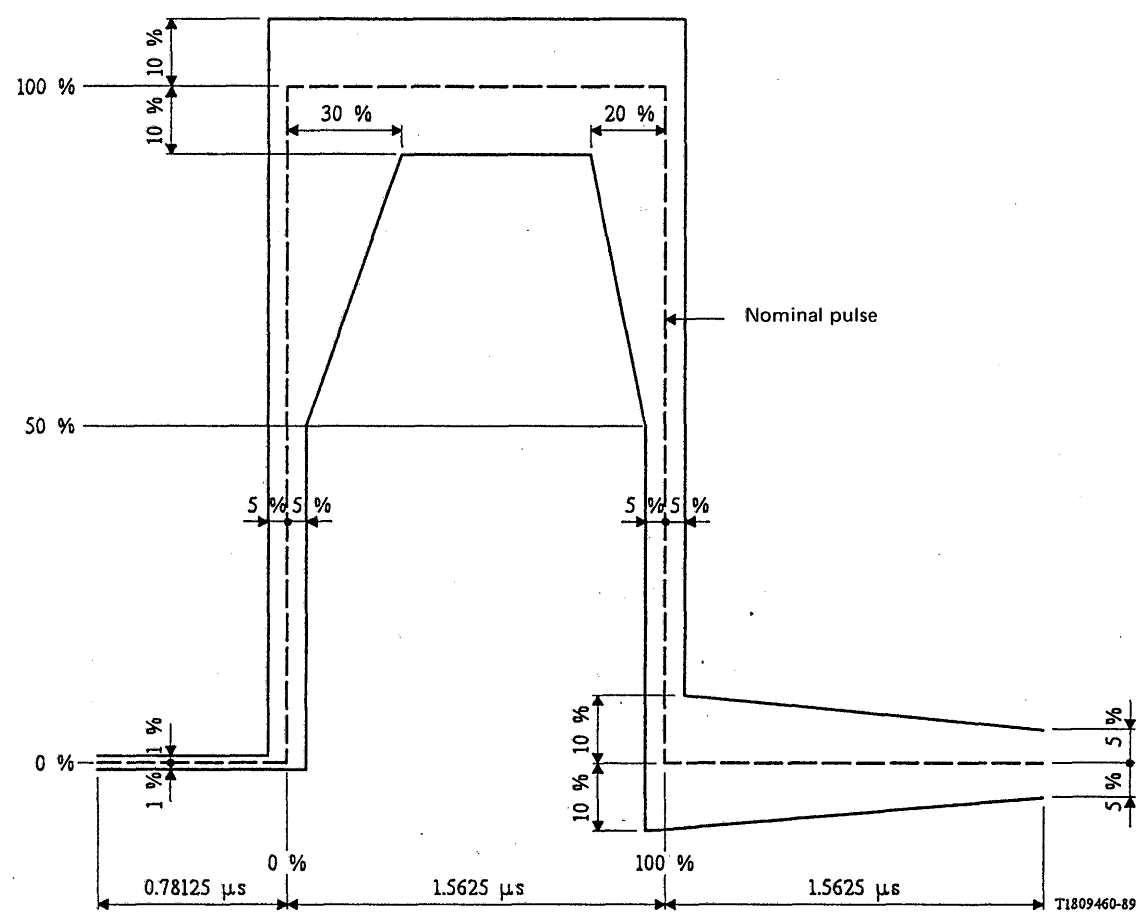


FIGURE IV-8/G.961

Transmitter output pulse mask

IV.12.3 *Signal power*

The average power shall be between 14.5 dBm and 17.1 dBm.

IV.12.4 *Power spectrum*

The upper bound of the power spectral density shall be within the template in Figure IV-9/G.961.

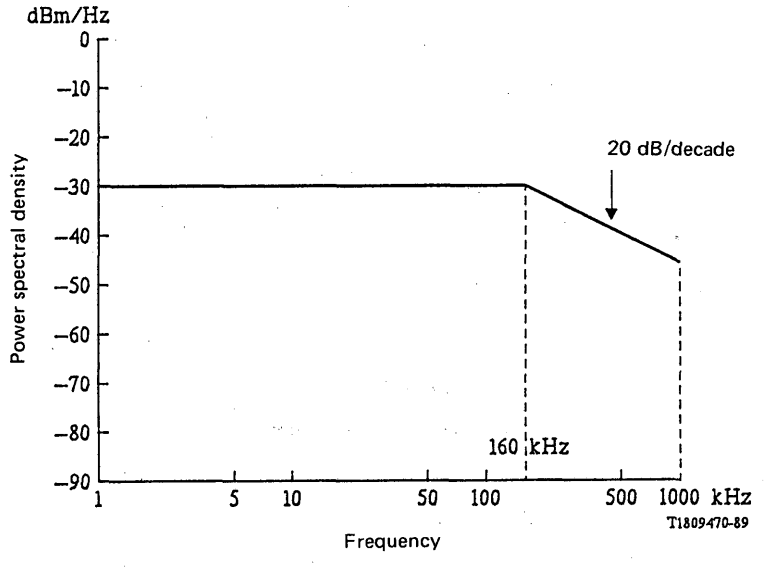


FIGURE IV-9/G.961

Upper bound of power spectral density of signal

IV.12.5 *Transmitter signal nonlinearity*

This is a measure of the deviations from ideal pulse heights and the individual pulse nonlinearity.

The deviation between positive and negative pulse heights shall be less than 5%.

The measurement method is for further study.

IV.13 *Transmitter/receiver termination*

IV.13.1 *Impedance*

a) The nominal input impedance looking toward the NT1 or LT respectively shall be 110 ohms.

b) The nominal output impedance looking toward the NT1 or LT respectively shall be less than 30 ohms when driving pulses, and shall be 110 ohms when not driving pulses.

IV.13.2 *Return loss*

The return loss of the impedance shall be greater than shown in the template Figure IV-10/G.961.

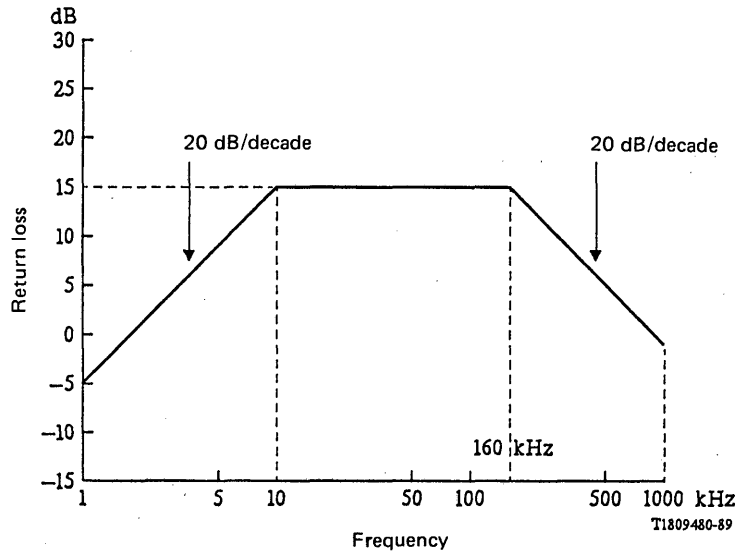


FIGURE IV-10/G.961

Minimum return loss of impedance

IV.13.3 *Longitudinal conversion loss*

The minimum longitudinal conversion loss shall be greater than shown in the template Figure IV-11/G.961.

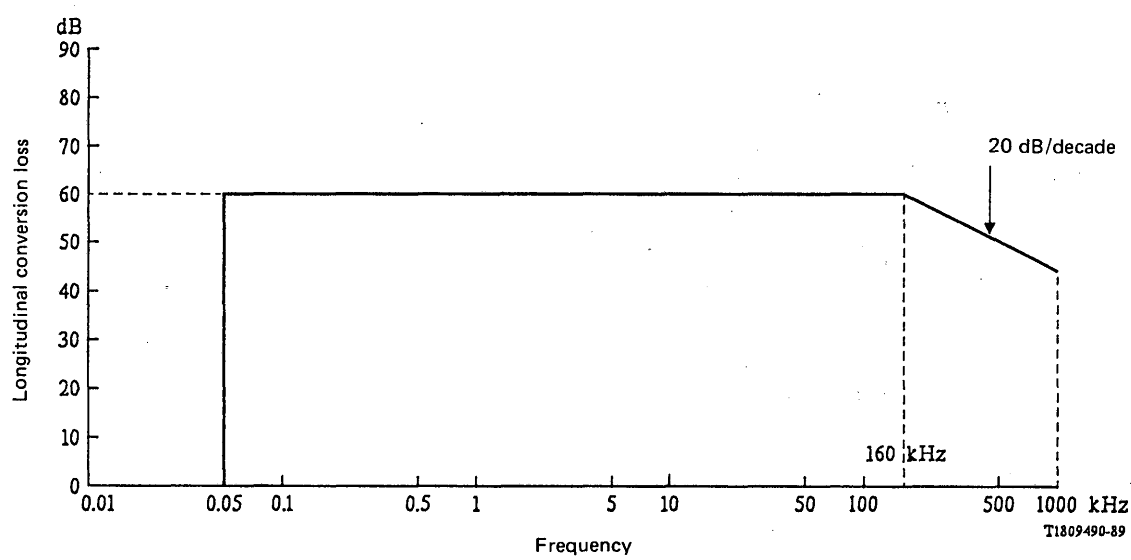


FIGURE IV-11/G.961

Minimum conversion loss

APPENDIX V

(to Recommendation G.961)

A digital line system for ISDN basic rate access using binary bi-phase line code

V.0 *Electrical characteristics*

This appendix describes a 160 kbit/s transparent transmission system using echo cancelling techniques. The transmission rate will support 64 kbit/s B channels and one 16 kbit/s D channel as defined in Recommendation I.412. The remaining 16 kbit/s capacity will allow for framing and auxiliary channel information.

Data scrambling is performed on the entirety of the framed data using different polynomials at exchange end and subscriber end. Bi-phase coding is used for the line code. The encoded signal is filtered and transmitted to the line at a symbol rate of 160 kbauds. The bi-phase signalling element transitions allow data-derived clock extraction with low jitter, and equalisation can be accomplished by a short decision-feedback structure. Binary decision-making gives best immunity to residual inter-symbol interference and residual echo and simplifies receiver design by not requiring AGC/decision references.

V.1 *Line code*

For both the directions of transmission the line code is bi-phase. The coding scheme is as follows.

Binary ZERO is represented by a negative transition in the middle of the bit period.

Binary ONE is represented by a positive transition in the middle of the bit period.

Transitions at the bit boundary occur if successive binary data bits are identical.

The encoded binary signal is then shaped to effectively filter out the high frequency components.

V.2 *Symbol rate*

The symbol rate is determined by the line code, the bit rate of the information stream and the frame structure. The symbol rate is 160 kbauds.

V.2.1 *Clock requirements*

V.2.1.1 *NT1 free running clock accuracy*

The accuracy of the free running clock in the NT1 shall be ± 230 ppm.

V.2.1.2 *LT clock tolerance*

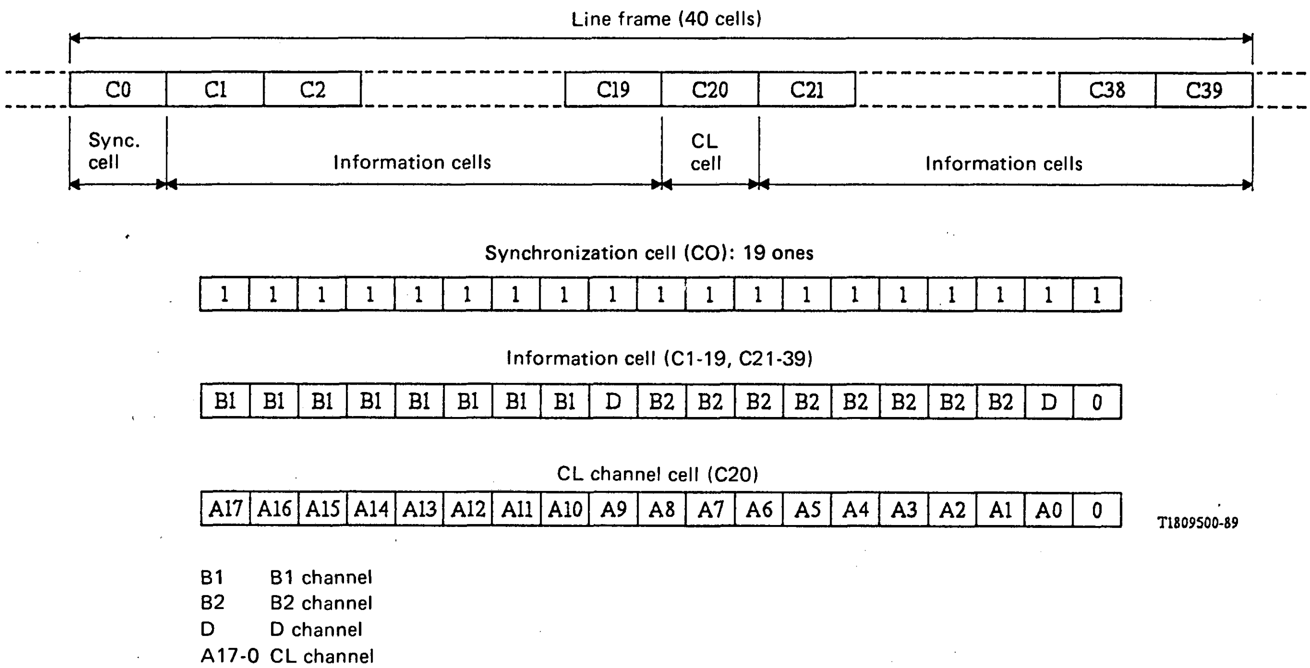
The NT1 and LT shall accept a clock accuracy from the ET of ± 50 ppm in compliance with Recommendation G.703.

V.3 *Frame structure*

The frame structure contains a frame word, *N* times (2B + D) and a CL channel.

As shown in Figure V-1/G.961, a line frame is defined as 40 "cells" C0 to C39, each containing 19 bits at the transmission bit rate. Cell C0 contains a frame synchronization pattern.

Cells C1 to C19 and C21 to C39 contain the subscriber B1, B2, and D channels. Cell C20 contains a CL channel.



Note – Transmission order is from left to right.

FIGURE V-1/G.961

Frame structure

V.3.1 *Frame length*

The defined frame structure and line rate results in a line frame of 760 bits and of 4.75 ms duration.

V.3.2 *Bit allocation in direction LT-NT1*

As defined in § V.3.

V.3.3 *Bit allocation in direction NT1-LT*

As defined in § V.3.

V.4 *Frame word*

V.4.1 *Frame word in direction LT-NT1*

The frame word occupies cell C0 in the frame structure, and it consists of 19 consecutive ones, which is unique within the frame bit sequence. This is ensured by defining the 19th bit in cells C1 to C39 to be permanently set to zero.

V.4.2 *Frame word in direction NT1-LT*

As defined in § V.4.1.

V.5 *Frame alignment procedure*

A 20-bit alignment pattern of 19 consecutive ones immediately preceded by a zero shall be searched for in the incoming data stream. "Frame alignment" is defined as the correct reception of three consecutive frames containing the alignment pattern in the expected positions within the frames.

V.5.1 *Frame alignment monitoring*

"Loss of frame alignment", is defined as the detection of 3 consecutive frames each with one or more errors in the alignment pattern. The monitoring of frame alignment shall be a continuous process.

V.5.2 *Line polarity detection*

In the NT1, a mechanism is provided for the automatic detection of the line polarity. An 80 ms timer is started only by the inactive to active transition of the "line signal detect" signal, from the transmission system. The timer is held reset when "frame alignment" is achieved. The expiry of the timer causes the incoming and outgoing data polarity to be reversed. Once the line polarity is determined it is retained as the initial polarity for subsequent detection operations. The timer duration of 80 ms is chosen to allow for the convergence of the transmission system, plus the time required to obtain "frame alignment".

In order to avoid duplication of the alignment pattern by a data sequence in a data stream from a reversed line, the B1, B2 and D channels, in the LT to NT1 direction, are to be set to all ones during that part of the activation procedure before operational data is switched through. In addition, at least one bit of the auxiliary channel must also be set to a one during the activation procedure.

V.6 *Multiframe*

There is no multiframe structure.

V.7 *Frame offset between LT-NT1 and NT1-LT frames*

The LT-NT1 and NT1-LT frames at the NT1 can be in any alignment but the LT is required to align with any offset of the received line frames relative to the transmitted line frames.

V.8 *CL channel*

The purpose of the CL channel is to convey maintenance information as well as "date valid" and "ready for data" flags.

V.8.1 *Bit rate*

The bit rate of the CL channel is 3.8 kbit/s.

V.8.2 *Structure*

Figure V-2/G.961 shows the CL channel format in the two directions LT-NT1 and NT1-LT, which is divided into the following field types:

a) M3-0: A 4 bit field for the conveyance of a "maintenance command" to a remote transmission termination. The termination identity is included in the command coding.

b) R3-0: A 4 bit field for the conveyance of a "maintenance response" to the LT.

c) DV: A "data valid" flag which indicates that, in the LT to NT1 direction, the B1, B2 and D channels contain operational data.

d) RFD: A "ready for data" flag which indicates that, in the NT1 to LT direction, the B1, B2 and D channels contain operational data.

e) D7-0: An 8 bit field for the conveyance of any "maintenance data" that may be associated with a "maintenance response".

f) K4-0: A 5 bit cyclic check code which operates on the auxiliary cell bits A17 to A5 inclusive.

	A17	A16	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	
Towards NT1	M3	M2	M1	M0	DV	X	X	X	X	X	X	X	X	K4	K3	K2	K1	K0	0

	A17	A16	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	
Towards LT	R3	R2	R1	R0	RFD	D7	D6	D5	D4	D3	D2	D1	D0	K4	K3	K2	K1	K0	0

T1809510-89

A17-0 CL channel cell bit position – refer to Figure V-1/G.961
M3-0 Maintenance command
R3 Maintenance response
DV Data valid flag
RFD Ready for data flag
D7-0 Maintenance data
K4-0 Cyclic check
X Unused (set to one)

FIGURE V-2/G.961

CL channel format

V.8.3 *Protocols and procedures*

Maintenance operations are based on a repetitive command/echo-response protocol. A maintenance operation is initiated by the continuous transmission of the required "maintenance command" from the LT. When the appropriate termination receives the validated command, it is continuously echoed back to the LT as a "maintenance response", and the command is acted upon. If the command demands data, then this is simultaneously returned in the "maintenance data" field. The termination continues to echo the command and provide any data for as long as it receives appropriate validated commands. For responses which are not accompanied by data, the "maintenance data" field is undefined. The LT assumes the conclusion of the maintenance operation when it receives a validated response that matches the transmitted command.

Loopbacks are applied using maintenance commands, and transmission system performance data is returned using the maintenance data field. Maintenance operations can be performed whenever the Digital Section is activated.

V.8.4 *Security*

A security mechanism operates on CL channel bits A17 to A0 inclusive.

The validation procedure consists of two stages:

a) A 5 bit cyclic redundancy code K4-0 operates on CL channel bits A17 to A5 inclusive. The generator of the code is:

$$g(x) = (1 \oplus x)(1 \oplus x \oplus x^4)$$

This is a Hamming code which gives single bit error detection and single bit error correction.

b) A set of CL channel bits A17 to A5 are only accepted as valid if they have been successfully checked/corrected and they match the previous two sets which were successfully checked/corrected. Note that these three sets need not necessarily have come from consecutive line frames.

V.9 *Scrambling*

The entirety of the framed binary data stream is scrambled as follows:

a) NT1 to LT scramble polynomial

$$1 \oplus x^{-14} \oplus x^{-15}$$

b) LT to NT1 scramble polynomial

$$1 \oplus x^{-1} \oplus x^{-15}$$

($\oplus$ = EXCLUSIVE OR)

V.10 *Activation/deactivation*

One bit of the CL channel is allocated for use during the activation and deactivation procedures. These are the "data valid" flag in the LT to NT1 direction and the "ready for data" flag in the NT1 to LT direction. These bits are not included in the maintenance protocol described above, and operate as simple unsollicited indications.

V.10.1 *Signals used for activation/deactivation*

The signals (SIGs) used for activation/deactivation are:

LT-NT1 direction

Signal	Frame word	2B + D	M	DV	K
I0	Absent	Absent	Absent	Absent	Absent
I2	Normal	1	1	0	Normal
I4	Normal	Normal	Normal	1	Normal

NT1-LT direction

Signal	Frame word	2B + D	R	RFD	D0-D7	K
I0	Absent	Absent	Absent	Absent	Absent	Absent
I1	0	0	0	0	0	0
I31	Normal	0	1	0	Normal	Normal
I3	Normal	Normal	Normal	1	Normal	Normal

V.10.2 *Definition of internal timers*

The following timers are located within the LT:

- Timer 2 (T2) prevents unintentional reactivation from the TE.
- Timer A (TA) is started if, from the layer 1 active state (LT4), SIG I31 is received, indicating loss of SIG I3. If SIG I3 is not subsequently received before expiry of Timer A, deactivation is initiated.
- Timer B (TB) is started upon loss of framing. If frame recovery is not achieved before expiry of Timer B, deactivation is initiated.

Durations of internal timers are for further study.

V.10.3 *Description of activation/deactivation procedures*

Figure V-3/G.961 (sheet 1 of 3) illustrates the method of activation from the network. PH ACTIVATE REQUEST causes SIG I2 to be transmitted from the network towards NT1. NT1 achieves line signal detect and frame synchronization status. At this point NT1 sends INFO 2 towards the TE and simultaneously sends SIG I31 towards the network. In time, the network achieves in synchronization status and the TE replies to INFO 2 with INFO 3. The latter event is signalled to the network from NT1 by sending SIG I3. At the network this results in ACTIVATE INDICATION. The network responds by sending SIG I4 towards NT1. Upon receipt of this signal NT1 sends INFO 4 towards the TE, thus completing the activation procedure.

Figure V-3/G.961 (sheet 2 of 3) illustrates activation from the user side. The activation process is essentially similar to that for activation from the network side, except that INFO 1 from the TE begins the process. In this case NT1 starts the process by sending SIG I1 towards the network. Line signal detect status is achieved at the network. The network sends SIG I2 towards NT1. From here on the process is as described above.

Figure V-3/G.961 (sheet 3 of 3) illustrates the method of deactivation. DEACTIVATE REQUEST causes transmission from the network to NT1 to cease (SIG I0). The NT1, on detecting this, sends SIG I1 back to the network, and INFO 0 towards the TE. The TE responds by sending INFO 0 back to the NT1, and on receipt of this, the NT1 ceases transmitting to the network (SIG I0). At the network, this results in DEACTIVATE INDICATION, thus completing the deactivation procedure.

Definitions for SIGs are given in V.10.1 and for definitions for INFOs refer to Recommendation I.430.

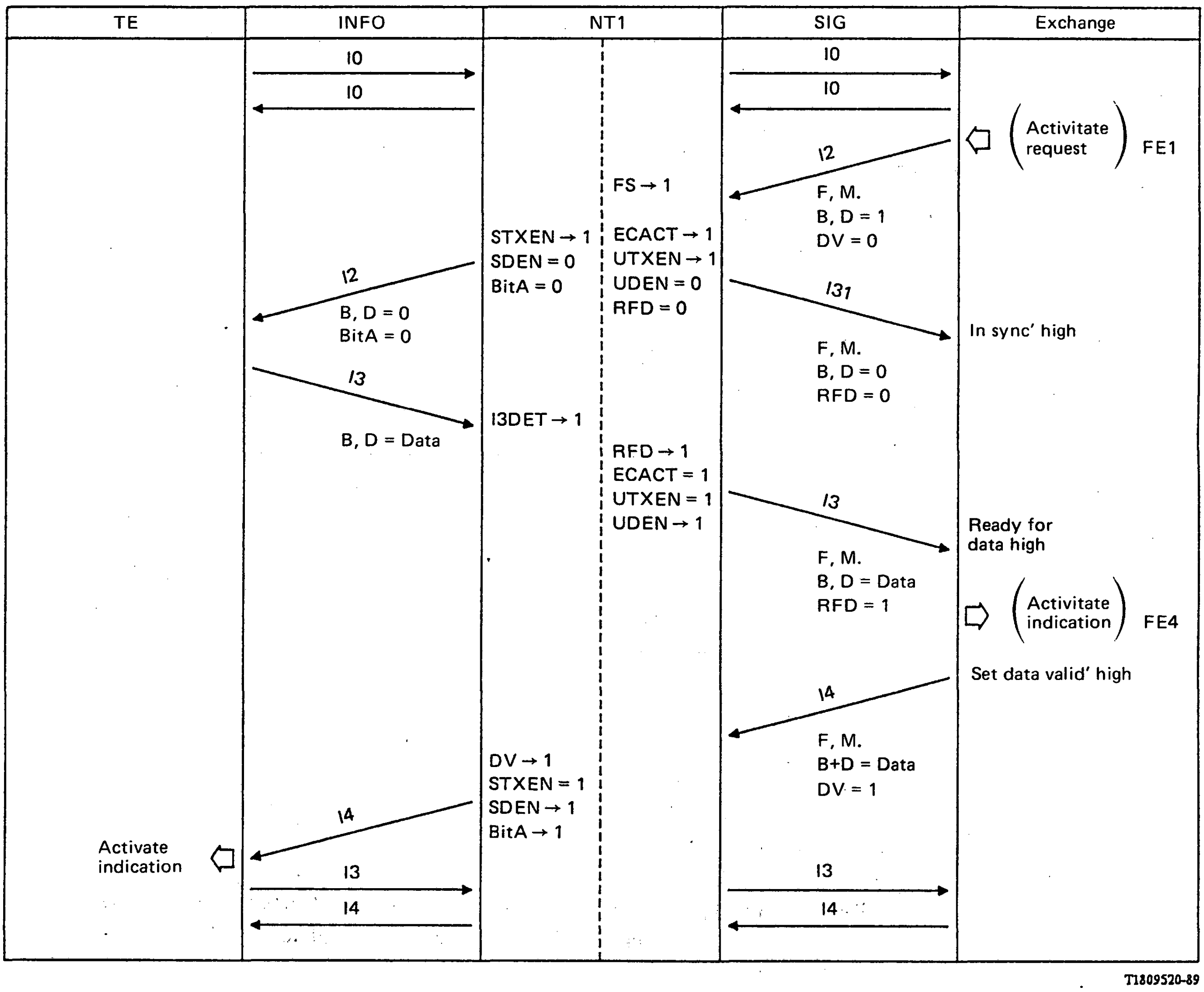


FIGURE V-3/G.961 (Sheet 1 of 3)

Activation from network side – activation initiated by exchange

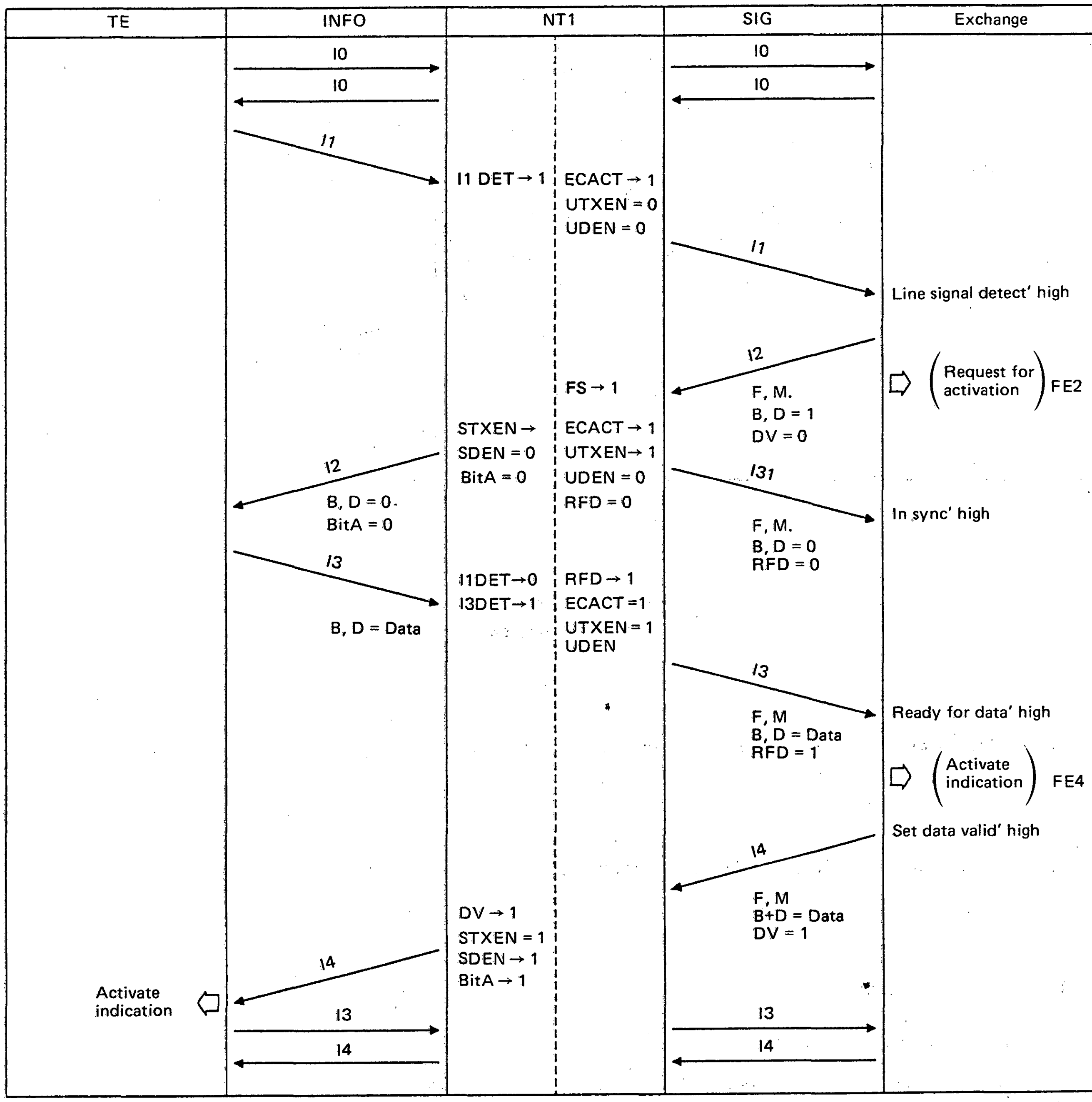


FIGURE V-3/G.961 (Sheet 2 of 3)

Activation from user side – activation initiated by terminal

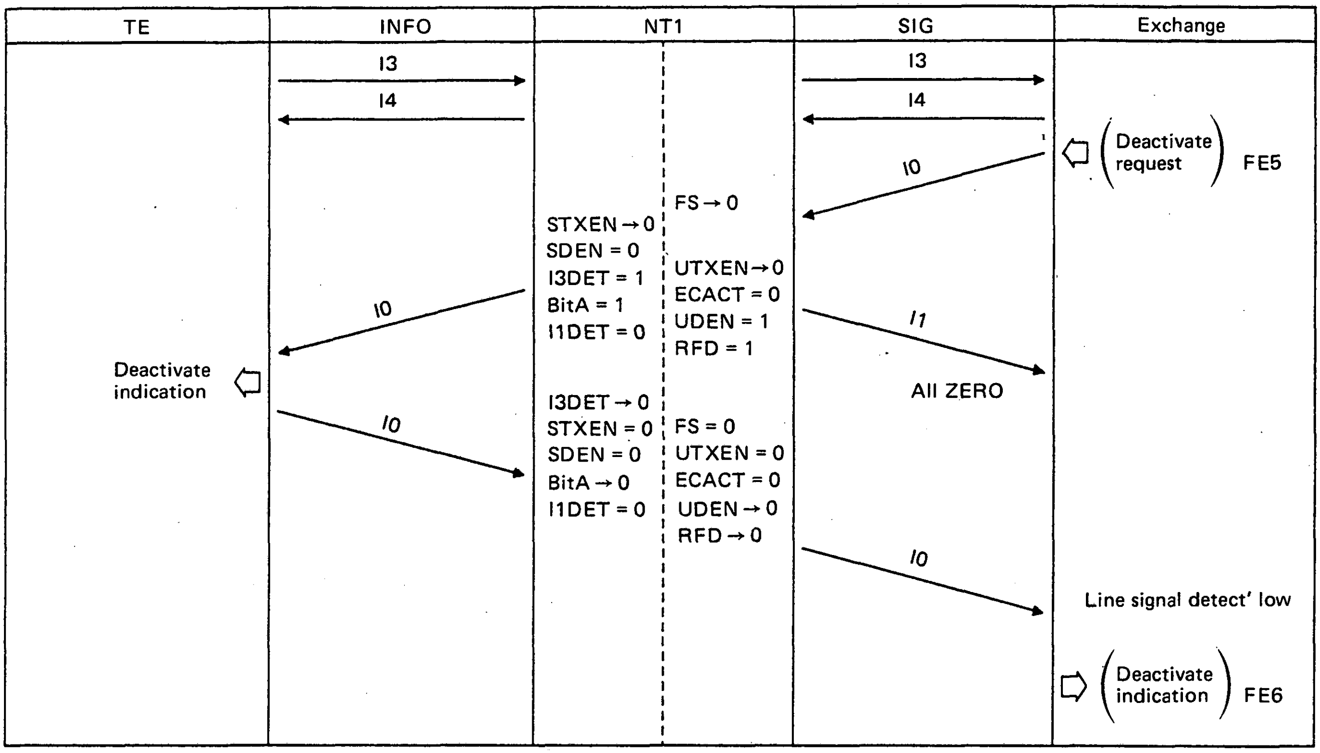


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FIGURE V-3/G.961 (Sheet 3 of 3)

Deactivation

V.10.4 *State transition table for NT1 as a function of INFOs, SIGs*

See Table V-1/G.961.

V.10.5 *State transition table for LT as a function of FEs, SIGs, and internal timers*

See Table V-2/G.961.

V.10.6 *Activation times*

Metallic pair cable transmission system.

Maximum activation time occurring immediately after a deactivation (without intervening loopback or powering action):

a) without regenerator: 100 ms;

b) with regenerator: 200 ms.

Maximum activation time occurring after the first powering of a line:

a) without regenerator: 250 ms;

b) with regenerator: 500 ms.

V.11 *Jitter*

Jitter tolerances are intended to ensure that the limits of Recommendation I.430 are supported by the jitter limits of the transmission system on local lines.

TABLE V-1/G.961

NT1 activation/deactivation state transition table

States		NT1 Deact.	NT2 Act. pendg.	NT3 Systm. act.	NT4 Wait data valid	NT5 Layer 1 act.
Events	SIG transmitted	I0	I1	I31	I3	I3
SIG received	I0 (Deact. req.)	–	–	I0 NT1	I0 NT1	I0 NT1
	I2 (Act. req.)	I2 NT3	I2 NT3	–	–	I2 NT3
	I4 (Dat. valid)	/	I2 NT3	/	I4 NT5	–
From TE	I0 (Deact. ind.)	–	I0 NT1	–	– NT3	I2 NT3
	I1 (Act. req.)	– NT2	–	/	/	/
	I3 (Act. ind.)	– NT2	–	– NT4	–	–

/ No change

– Impossible

TABLE V-2/G.961

LT activation/deactivation state transition table

States		LT1 Deact.	LT2 Wait for systm. act	LT3 Systm act.	LT4 Layer 1 act.	LT5 Loss of framg.	LT6 Wait for deact.
Events	SIG transmitted	I0	I2	I2	I4	(Note)	I0
SIG received	I0 (Deact. ind.)	–	–	FE7 –	FE7 –	–	FE6 LT1
	I1 (Act. req.)	FE2 TL2	–	/	/	/	–
	I31 (System activated)	/	FE3 LT3	–	Start TA LT3	/	–
	I3 (Layer 1 activated)	/	/	Stop TA FE4 LT4	–	/	–
Internal event	Loss of framing	/	/	Start TB LT5	Start TB LT5	/	–
	Frame recovery	/	/	/	/	Stop TB LT3	–
	Expiry of timer 2	–	–	–	–	–	FE6 LT1
	Expiry of timer A	–	–	Start T2 FE7 LT6	–	–	–
	Expiry of timer B	–	–	–	–	Start T2 FE7 LT6	–
Function element received	FE1	– LT2	/	/	/	/	– LT2
	FE5	–	Start T2 LT6	Start T2 LT6	Start T2 LT6	Start T2 LT6	–

– No change

/ Impossible

Note – The SIG transmitted by the LT when framing is lost will not change from that transmitted immediately prior to the loss (i.e. I2 or I4).

Meaning of symbols for Tables V-1/G.961 and V-2/G.961

States at NT

NT1	Deactivated
NT2	Activation pending
NT3	Transmission system activated
NT4	Wait for data valid
NT5	Layer 1 activated

States at LT

LT1	Deactivated
LT2	Waiting for transmission system activation
LT3	Transmission system activated
LT4	Layer 1 activated
LT5	Loss of framing
LT6	Waiting for deactivate indication
ST.T2	Start timer T2
STP.TA	Stop timer TA

Function element definitions are as in Recommendation G.960.

V.11.1 *NT1 input signal jitter tolerance*

For further study.

V.11.2 *NT1 output jitter limitations*

For further study.

V.11.3 *Test conditions for jitter measurements*

For further study.

V.12 *Transmitter output characteristics of NT1 and LT*

The following specifications apply with a load impedance of 140 ohms.

V.12.1 *Pulse amplitude*

The nominal peak amplitude of a transmitted signal pulse shall be 1.6 V, and the tolerance shall be ± 5%.

V.12.2 *Pulse shape*

The pulse shape shall be as shown in Figure V-4/G.961.

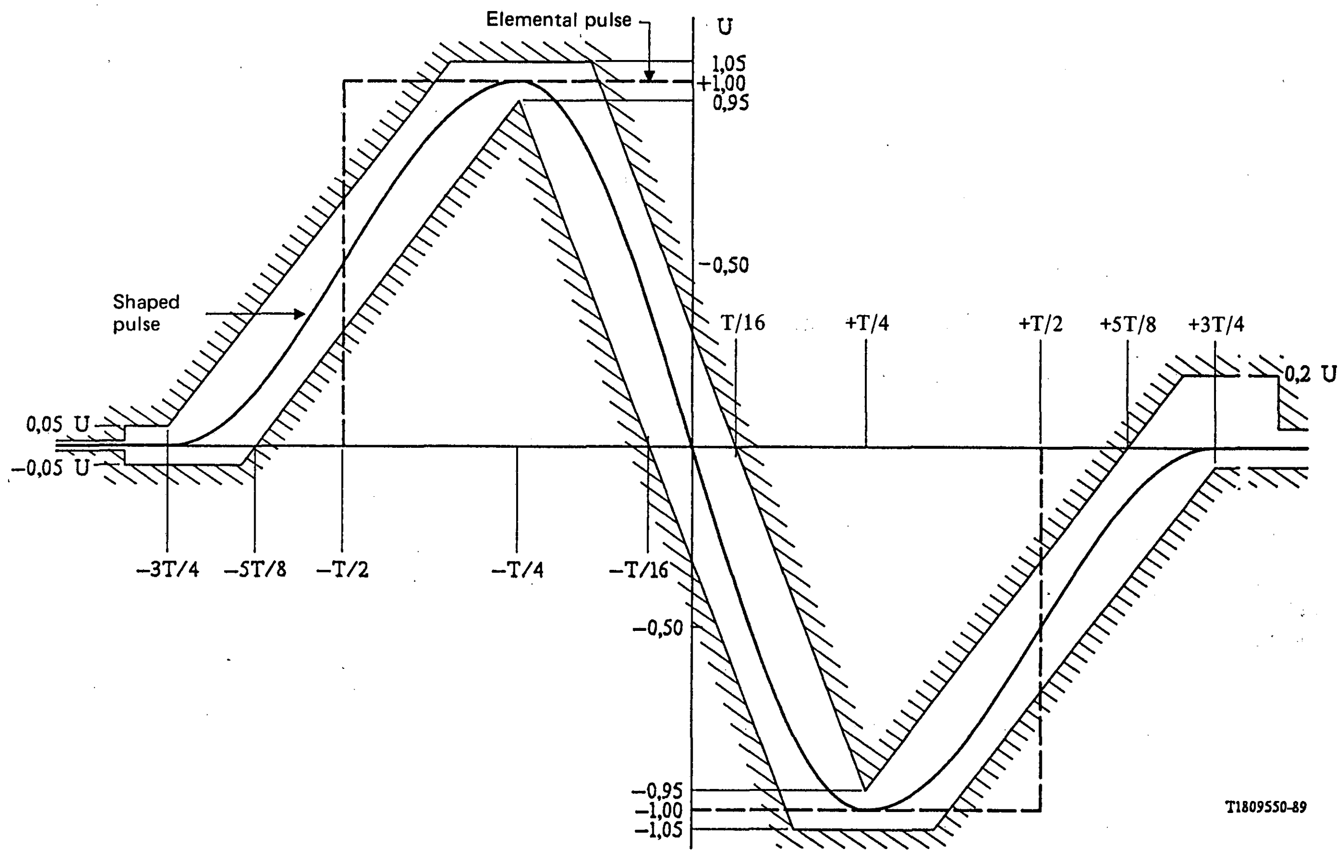


FIGURE V-4/G.961

Pulse shape

V.12.3 *Signal power*

The maximum total transmit power, averaged in any one second period, sent down to the line shall be +10 dBm.

V.12.4 *Power spectrum*

The upper bound of the power spectral density, averaged in any one second period in any 3 kHz band, shall be limited as shown in the template Figure V-5/G.961.

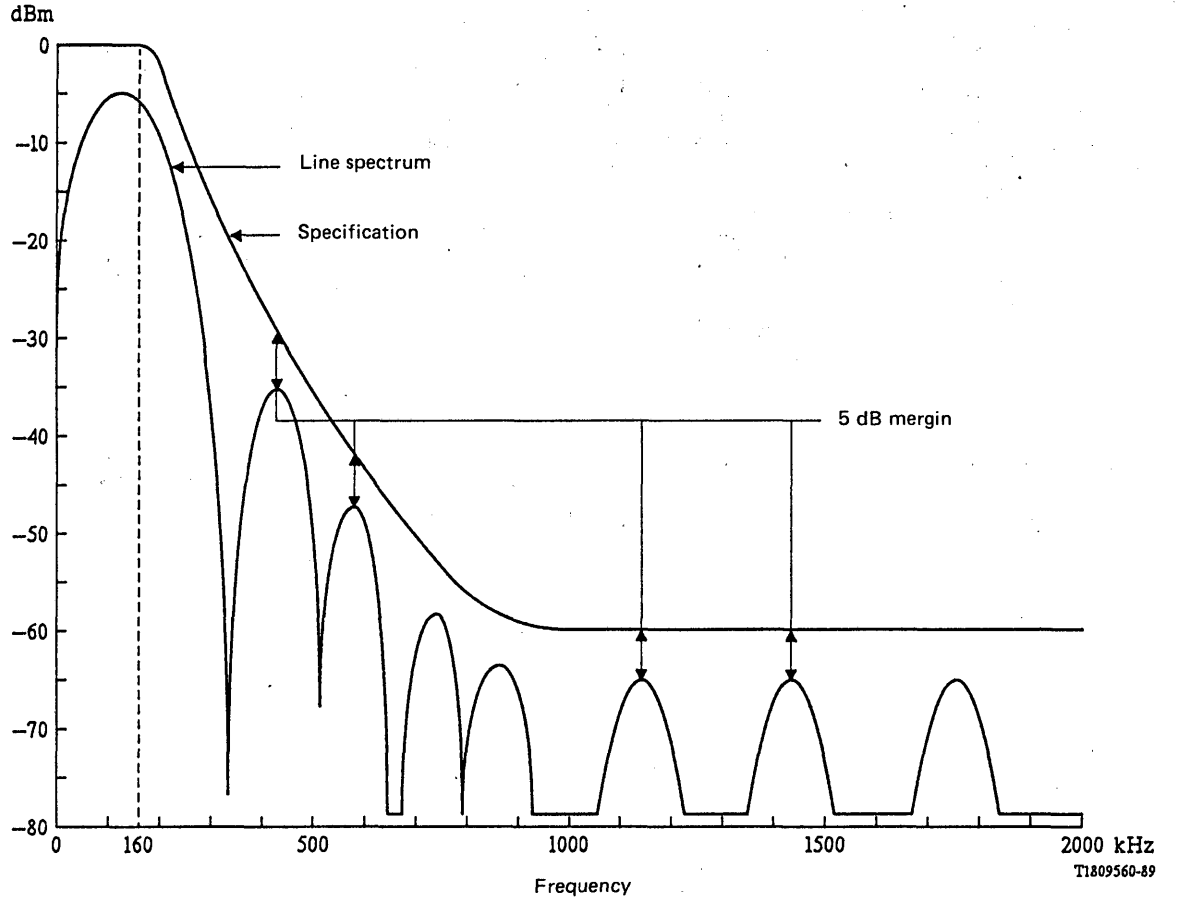


FIGURE V-5/G.961

Line signal power spectrum

V.12.5 *Transmitter signal nonlinearity*

This is a measure of the deviations from ideal pulse heights and the individual pulse nonlinearity. For further study.

V.13 *Transmitted/receiver termination*

V.13.1 *Impedance*

The nominal line driving impedance shall be 140 ohms.

V.13.2 *Return loss*

The return loss of the impedance (against 140 ohms) shall be greater than shown in the template Figure V-6/G.961.

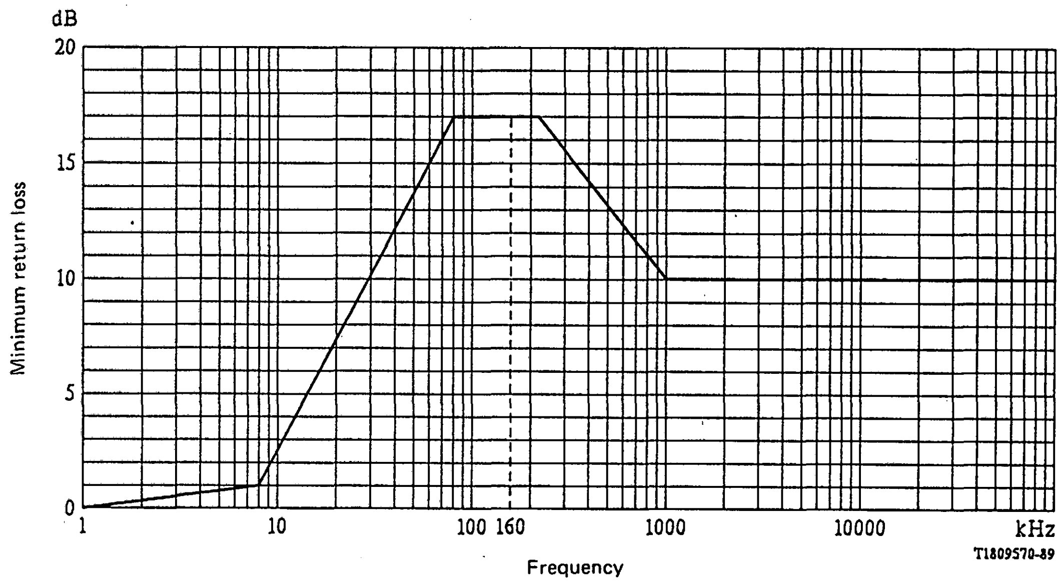


FIGURE V-6/G.961

Return loss

V.13.3 *Longitudinal conversion loss*

This is a measure of the immunity from longitudinal voltages. In the frequency band 100 Hz to 256 kHz, the conversion loss shall not be less than 46 dB. From 256 kHz to 4 MHz, the conversion loss shall not be less than [46 – 40 $\log_{10}$ (f/256)] dB (where f is frequency in kHz).

APPENDIX VI

(to Recommendation G.961)

Basic access transmission system using SU32 line code

VI.0 *General*

The SU32 standard will support the full duplex, transparent transmission of two 64 kbit/s B channels and one 16 kbit/s D channel over symmetric pair cables using echo cancelling techniques. In addition to transparent 2B + D transmission, 5.3 kbit/s capacity is provided for an Auxiliary channel supporting data CRC, control, supervisory and maintenance functions. The bit stream is encoded for transmision using a high performance ternary SU32 (substitutional 3B2T) conditional block code, filtered and transmitted to line at a baud rate of 108 kbauds. An orthogonal timing signal is superimposed on the line code for symbol sampling; which does not compromise either the line code efficiency or performance. A unique synchronisation word is used to achieve frame synchronisation. Fast and reliable activation is ensured by means of a binary handshake procedure, for separate training of canceller and equaliser.

VI.1 *Line code*

The binary data is encoded into a ternary form using the SU32 line code. This is based on the fixed and unconditional 3B2T line code and modified as follows. Each binary triplet is converted to a ternary duplet and is transmitted unless it is identical to the previously transmitted duplet. If current and previous duplets are identical, then the un-used code word "00" is transmitted in its place. The SU32 coding rule is shown in Table VI-1/G.961. In this Table, the left most bit is the first into the encoder and the left most symbol the first out of the encoder.

TABLE VI-1/G.961

SU32 coding (substitutional 3B2T)

Binary I/P	Ternary O/P	Binary I/P	Ternary O/P
000	− −	100	0−
001	−0	101	+ −
010	− +	110	+0
011	0+	111	+ +

Decoding

Decoding of the received signal is the inverse of the coding process.

Tolerance to line polarity inversion

The code is symmetric so that inversion of the ternary data results in an inversion of the decoded binary data. Thus polarity correction due to cable inversion can be applied either to scrambled or unscrambled binary data, or to ternary data. Both transmitted and received polarity correction is performed at the NT1.

VI.2 *Symbol rate*

The symbol rate is determined by the line code, the bit rate of the information stream and the frame structure. The symbol rate is 108 kbauds.

VI.2.1 *Clock tolerance*

VI.2.1.1 *NT1 free running clock accuracy*

The tolerance of the NT free running clock shall be ± 192 ppm.

VI.2.1.2 *Tolerance of the free running clock in the LT*

The free running clock in the LT will be phase locked to the exchange clock having a frequency tolerance of ± 50 ppm thus permitting operation with any equipment meeting Recommendation G.703.

VI.3 *Frame structure*

There are two states of operation of the transmission system, steady state and training state. The frame structure covered in this section is for the steady state (information transfer).

The B1, B2, D and CL channels map directly from binary bits through the scrambler into the ternary frame structure. The SU32 code table is designed to exclude certain uniquely identifiable code sequences, which are exploited for synchronisation purposes.

Multiframe: Multiframe word and location

The 12 ms multiframe is identified every 16th 3/4 ms frame by replacing the CRC data symbol (No. 79) with a ternary "0". In all other frames, this symbol is binary valued. This, combined with the frame synchronisation word preceding it, uniquely identifies the position of the start of the superframe.

Multiframe Format

A multiframe consists of sixteen 81-ternary-symbol 0.75 ms frames.

6 frames of 2B + D	Frame word	CRC_1	CL-channel$_1$
6 frames of 2B + D	Frame word	CRC_2	CL-channel$_2$
6 frames of 2B + D	Frame word	CRC_3	CL-channel$_3$
6 frames of 2B + D	Frame word	CRC_4	CL-channel$_4$
6 frames of 2B + D	Frame word	CRC_5	CL-channel$_5$
6 frames of 2B + D	Frame word	CRC_6	CL-channel$_6$
6 frames of 2B + D	Frame word	CRC_7	CL-channel$_7$
6 frames of 2B + D	Frame word	CRC_8	CL-channel$_8$
6 frames of 2B + D	Frame word	CRC_9	CL-channel$_1$
6 frames of 2B + D	Frame word	CRC_{10}	CL-channel$_2$
6 frames of 2B + D	Frame word	CRC_{11}	CL-channel$_3$
6 frames of 2B + D	Frame word	CRC_{12}	CL-channel$_4$
6 frames of 2B + D	Frame word	CRC_{13}	CL-channel$_5$
6 frames of 2B + D	Frame word	CRC_{14}	CL-channel$_6$
6 frames of 2B + D	Frame word	CRC_{15}	CL-channel$_7$
6 frames of 2B + D	Frame word	"0"	CL-channel$_8$

1 . . . . 72, 73 . . . 78 . . . 79 . . . 80 81

<-------------------- 750 μ sec transmission frame -------------------->

12 ms multiframe structure

Note – B1, B2, D and CL channel data is scrambled. CRC data and frame words are not scrambled.

VI.3.1 *Frame length*

There are 6 (2B + D) slots in each 3/4 ms 81 symbol frame.

VI.3.2 *Binary bit allocation in direction LT to NT*

The following binary bit ordering is applied before scrambling.

$B1_1$	$B1_2$	$B1_3$	$B1_4$	$B1_4$	$B1_5$	$B1_6$	$B1_7$	$B1_8$	$B2_1$	$B2_2$	$B2_3$	$B2_4$	$B2_5$	$B2_6$	$B2_7$	$B2_8$	D_1	D_2
$B1_1$	$B1_2$	$B1_3$	$B1_4$	$B1_4$	$B1_5$	$B1_6$	$B1_7$	$B1_8$	$B2_1$	$B2_2$	$B2_3$	$B2_4$	$B2_5$	$B2_6$	$B2_7$	$B2_8$	D_1	D_2
$B1_1$	$B1_2$	$B1_3$	$B1_4$	$B1_4$	$B1_5$	$B1_6$	$B1_7$	$B1_8$	$B2_1$	$B2_2$	$B2_3$	$B2_4$	$B2_5$	$B2_6$	$B2_7$	$B2_8$	D_1	D_2
$B1_1$	$B1_2$	$B1_3$	$B1_4$	$B1_4$	$B1_5$	$B1_6$	$B1_7$	$B1_8$	$B2_1$	$B2_2$	$B2_3$	$B2_4$	$B2_5$	$B2_6$	$B2_7$	$B2_8$	D_1	D_2
$B1_1$	$B1_2$	$B1_3$	$B1_4$	$B1_4$	$B1_5$	$B1_6$	$B1_7$	$B1_8$	$B2_1$	$B2_2$	$B2_3$	$B2_4$	$B2_5$	$B2_6$	$B2_7$	$B2_8$	D_1	D_2
$B1_1$	$B1_2$	$B1_3$	$B1_4$	$B1_4$	$B1_5$	$B1_6$	$B1_7$	$B1_8$	$B2_1$	$B2_2$	$B2_3$	$B2_4$	$B2_5$	$B2_6$	$B2_7$	$B2_8$	D_1	D_2
CL_1	CL_2	CL_3																

The binary data is scrambled as defined in § VI.9 and ternary encoded. It is then multiplexed into the following frame format.

T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}
T_{25}	T_{26}	T_{27}	T_{28}	T_{29}	T_{30}	T_{31}	T_{32}	T_{33}	T_{34}	T_{35}	T_{36}
T_{37}	T_{38}	T_{39}	T_{40}	T_{41}	T_{42}	T_{43}	T_{44}	T_{45}	T_{46}	T_{47}	T_{48}
T_{49}	T_{50}	T_{51}	T_{52}	T_{53}	T_{54}	T_{55}	T_{56}	T_{57}	T_{58}	T_{59}	T_{60}
T_{61}	T_{62}	T_{63}	T_{64}	T_{65}	T_{66}	T_{67}	T_{68}	T_{69}	T_{70}	T_{71}	T_{72}
0	0	0	0	0	0	CRC	T_{73}	T_{74}			

VI.3.3 *Binary bit allocation in direction NT1 to LT*

The frame structure and order of bits in the NT1 to LT direction is to identical that used in the LT to NT1 direction specified in § VI.3.2 above.

VI.4 *Frame word*

The frame word of six ternary zeros terminated by the binary CRC_{15} bit (as illustrated in the above Table) is used to define the 0.75 ms frame boundaries. Note that once every superframe a ternary zero is substituted for the binary CRC check bit. This frame word is unique and cannot be emulated by any 2B + D data pattern.

The frame word specified above is the same in both directions of transmission.

VI.5 *Frame alignment procedure*

The frame alignment function is specified in the Activation sequence. 2B + D transmission cannot commence unless frame alignment has been achieved. Initial frame alignment is considered to have been achieved when the cumulative total of correct versus incorrectly received 7-bit frame words exceeds 4. In steady state operation, this cumulative count is maintained but limited to a maximum of 64. Frame alignment loss is flagged if this cumulative total falls below two.

VI.6 *Multiframe*

The multiframe structure has been described in the frame structure, § VI.3 of this Appendix.

VI.7 *Frame offset between LT-NT1 and NT1-LT frames*

No specific phase requirements are necessary between frames in the LT-NT1 and NT1-LT directions.

VI.8 *CL channel*

An embedded protected operations channel (EPOC) of 4 kbit/s is partially allocated to supervisory and maintenance functions. Significant spare capacity and undefined bits remain for both future allocation of messages as well as specific national requirements.

This channel is protected by a 6-bit CRC check and compelled protocol which provides that all messages are repeated every 6 ms.

VI.8.1 *Bit rate*

Twenty-four bits per 6 ms multiframe (4 kbit/s) are allocated to an embedded protected operations channel (EPOC). This supports supervisory and maintenance functions between the network and the NT1 and includes spare capacity for user defined functions. Additionally a further 1.33 kbit/s is allocated to provide an error detecting CRC15 and 12 ms framing to the CL channel.

VI.8.2 *Structure*

Within each 12 frame, the operations channel sends two consecutive messages of 24 bits. Each 24 bit message comprises:

- 1 bit Ready for data/data valid (R).
- 5-bit Maintenance channel (M).
- 9-bit Supervisory channel (S).
- 3 Unassigned bits (500 bit/s subsidiary channel).
- 6-bit Cyclic redundancy check field (CRC).

The structure of the CL channel is as follows:

00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Subsid.			R	Maintenance (M)					Supervisory (S)									CRC						

← 6 ms →

VI.8.2.1 *Maintenance messages*

In the ET to NT1 direction 9 of the 32 possible command messages are allocated. An identical message is returned in the NT1 to ET direction as an acknowledgement.

ET to NT1 maintenance message codes						
No.	Message	5-bit code				
		M1	M2	M3	M4	M5
1	No loopback (null message)/remove loopback	1	1	1	1	1
2	Provide loopback B1 at NT1	1	1	0	1	1
3	Provide loopback B2 at NT1	1	0	1	1	1
4	Provide loopback B1 + B2 at NT1	1	0	0	1	1
5	Provide loopback B1 + B2 + D at NT1	1	0	0	0	1
6	Provide loopback B1 at regenerator	0	0	1	1	1
7	Provide loopback B2 at regenerator	0	1	0	1	1
8	Provide loopback B1 + B2 at regenerator	0	1	1	1	1
9	Provide loopback B1 + B2 + D loopback at regenerator	0	1	1	0	1

Supervisory sub-channel message formats

A 9-bit field is available in each direction of transmission to allow supervisory information to be provided. This contains an 8-bit data/address field and a one-bit flag used to indicate whether or not the 8-bit field contains valid data.

ET to NT1 supervisory message command codes		
No	Supervisory message and destination	S-interface
1	No supervisory information requested	1 1111 1111
2	ET AGC value	0 0000 0100
3	ET eye closure	0 0000 0101
4	ET eye height	0 0000 0110
5	ET CRC error count	0 0000 0111
6	NT1 AGC value	0 0001 0000
7	NT1 Eye closure	0 0001 0001
8	NT1 Eye height	0 0001 0010
9	NT1 CRC error count	0 0001 0011
11	Regenerator LT-side receiver AGC	0 0000 1000
12	Regenerator LT-side receiver Eye closure	0 0000 1001
13	Regenerator LT-side receiver Eye height	0 0000 1010
14	Regenerator LT-side receiver CRC count	0 0000 1011
15	Regenerator NT1-side receiver AGC	0 0000 1100
16	Regenerator NT1-side receiver Eye closure	0 0000 1101
17	Regenerator NT1-side receiver Eye height	0 0000 1110
18	Regenerator NT1-side CRC count	0 0000 1111

VI.8.3 *Protocols and procedures*

The maintenance channel is used to set loop backs from the LT. When a maintenance message has been received free from error and implemented, the same message is echoed back from the NT1 to the LT.

The supervisory channel is designed to be used as a compelled system, with a command sent by the LT end until the expected response is received. A delimiting idle message of nine ONEs is employed. All valid messages and responses set the first bit of the 9 supervisory bits to a ONE. An 8 bit word can therefore be securely passed across this channel. An example use of the supervision channel is for reporting eye closure information from the NT1 to the LT.

VI.8.4 *CL channel performance*

With a mean 144 kbit/s error rate of 1 in 1000, characterised by a mean error burst size of 10, the following performance will be achieved:

a) 99.8% of all messages will be conveyed within 6 ms.

b) No more than one message per hour shall be conveyed in more than 18 ms.

c) The mean erroneous error message rate is less than one per hour with a maximum time to correction of 18 ms.

VI.9 *Scrambling*

B1, B2, D and C channel binary data is scrambled as follows:

a) NT to LT scrambler polynomial

$$1 \oplus x^{-18} \oplus x^{-23} \text{ (where } \oplus \text{ denotes exclusive OR)}$$

b) LT to NT scrambler polynomial

$$1 \oplus x^{-5} \oplus x^{-23}$$

VI.10 *Activation/deactivation*

VI.10.1 *Signals used for activation*

Figure VI-1/G.961 illustrates the activation sequence initiated by the ET in terms of function elements (FE) and INFO's.

Figure VI-2/G.961 illustrates the activation sequence initiated by the user in terms of function elements (FE) and INFO's.

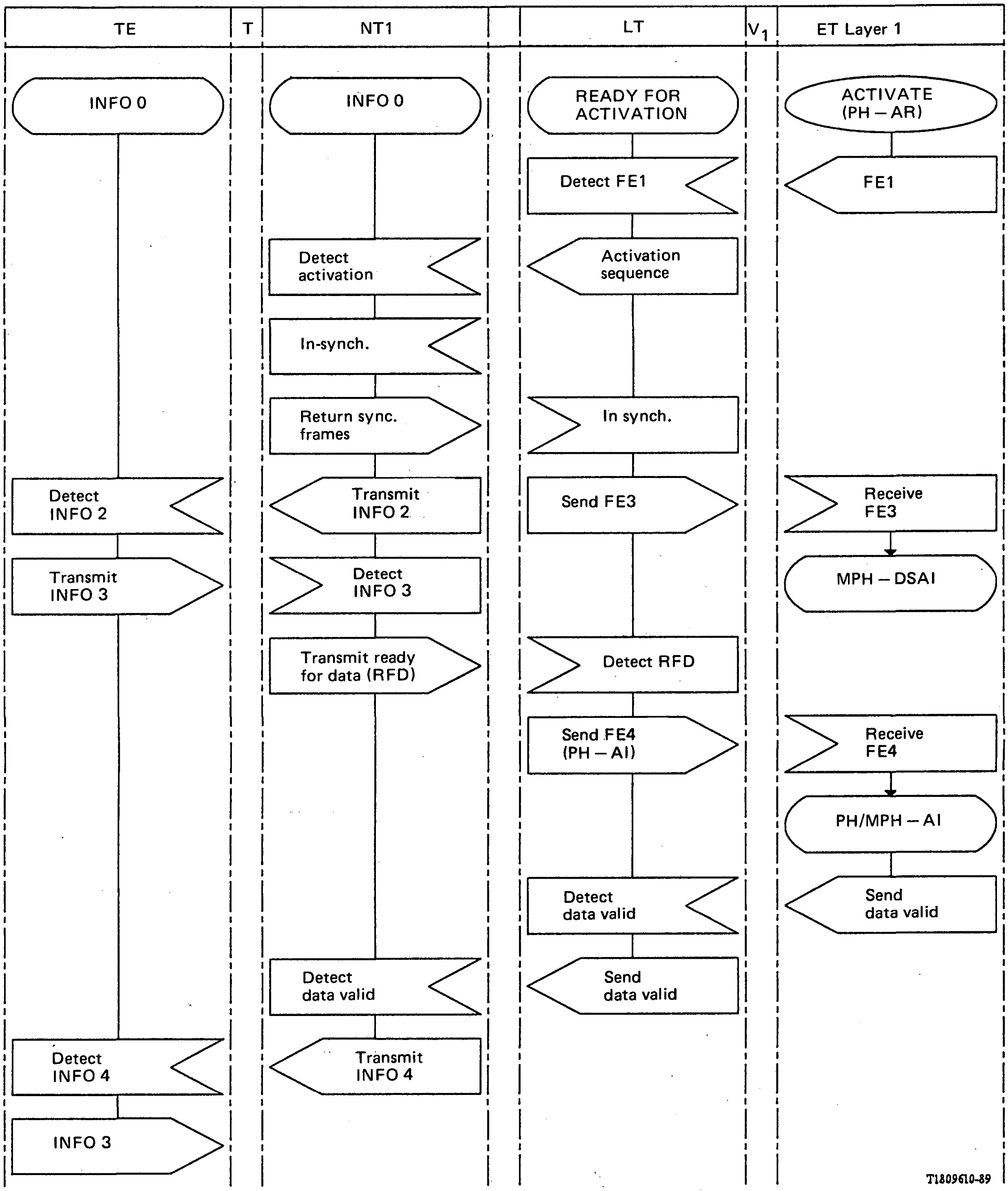


FIGURE VI-1/G.961

Activation from the network side

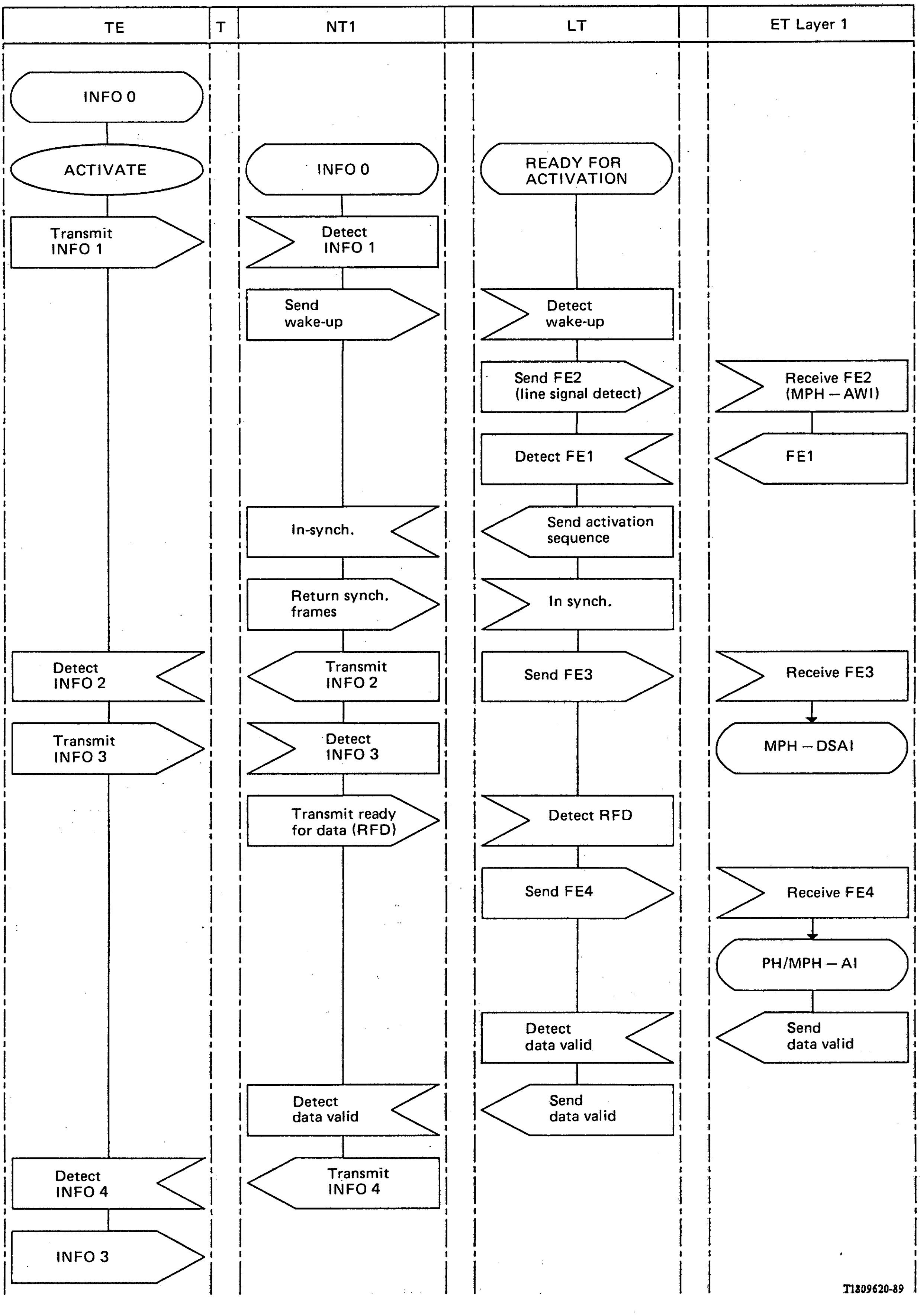


FIGURE VI-2/G.961

Activation from the user side

The definition of the function elements, LT states and NT states used in the activation Figures and the state transition tables in this Appendix is as follows.

Definition of FE's LT's and NT's	
	Function elements (FE)
FE1	Activation request for the interface from the ET.
FE2	Line signal detected on the digital section.
FE3	The digital section is activated (in synchronisation).
FE4	The user network at the T reference point is activated or a loopback is operated.
FE5	Deactivation request for the digital section.
FE6	The digital section and the interface at the T reference point has been de-activated.
FE7	Error indication. (Loss of synchronisation or no line signal detect).
	NT1 states
NT1	The NT1 is ready for activation.
NT2	The NT1 is executing the digital section training sequence.
NT3	The NT1 is in synchronisation with the LT and the LT to NT1 digital section is capable of error free data transmission.
NT4	Equivalent to state NT3 plus synchronisation of the interface at the T-reference point.
NT5	The 2B + D data channel through the digital section and across the T reference point is fully operational.
NT6	The NT1 has sent an activate request to the LT and is waiting for a response.
NT7	The NT1 is not active but is not ready for activation.
	LT states
LT1	The LT is ready for activation.
LT2	The LT is executing the digital section training sequence.
LT3	The digital section has been correctly activated and is synchronised in both directions.
LT4	Both the digital section and the interface at the T reference point are correctly activated and synchronised.
LT5	The 2B + D data channel through the digital section and across the T reference point is fully operational.
LT7	The LT has ceased transmission over the digital section and is waiting for all line signals to disappear.

The response of the digital section to the activation request FE1 from the ET or the activation request INFO 1 from the TE is to signal across the digital section by the transmission of a quarter baud rate (27 kHz) wake-up tone.

In the NT1 to LT direction, the duration of this wake up tone shall not be less than 32 complete cycles of the repetitive data pattern + - - +. The tone shall not exceed 10 ms in duration.

In the LT to NT1 direction, the duration of the wake-up tone shall not be less than 32 complete cycles of the repetitive data pattern + - - +. The tone shall not exceed 10 ms in duration.

VI.10.2 *Definition of internal timers*

The activation procedure shall nominally take 120 ms to the point where error free framed transmission can commence.

In the event of the activation procedure failing, or loss of synchronisation on either the interface at the T-Reference point or on the transmission system described herein, a timer is required in the NT to terminate operation. This timer shall not exceed 65 ms measured from the point of loss of synchronisation; or in the case of activation, measured from the time at which synchronisation should be achieved.

It is not essential to employ a timer for the identification of failure to activate or loss of synchronisation signalled to the LT. However, where there is no external control of the de-activation procedure applied to the two wire LT termination, a timer not exceeding 65 ms from the time of loss of synchronisation or as measured from the time at which activation should have been achieved should be employed.

VI.10.3 *Activation procedure*

Table VI-2/G.961 shows the training sequence signals that should be transmitted to line by the LT and NT1. At the LT, offsets are measured in baud periods from the end of the wake-up tone transmission. At the NT1, offsets are measured in baud periods from the detection of the end of the wake-up tone. For correct operation, it is necessary that the time from the LT completing the wake-up tone burst, to the NT1 detecting the end of wake-up tone is less than or equal to 32 bauds.

TABLE VI-2/G.961

Activation training sequence

Offset (bauds)	Duration (bauds)	LT timing signal	LT data	NT timing signal	NT data
0	64	OFF	None	OFF	None
64	512	ON	None	OFF	None
576	512	OFF	None	ON	None
1 088	512	ON	None	OFF	None
1 600	512	OFF	None	ON	None
2 112	4096	ON	PRBS	OFF	None
6 208	32	ON	None	OFF	None
6 240	4064	ON	None	OFF	PRBS
10 304	(405) (Note 1)	ON	Ternary (Note 1)	OFF	None
10 709 (Note 1)	(405) (Note 2)	ON	Ternary (Note 2)	OFF	Ternary (Note 2)

PRBS stand for a 511 bit pseudo-random binary sequence generated by the polynomial (1 $\oplus x^{-4} \oplus x^{-9}$).

Note 1 – The transmission of ternary data from the LT to the NT1 from this time onwards in continuous. The NT1 will not return ternary data until it has achieved synchronisation, the figure of 405 bauds and the subsequent offset to the next row is intended as a guide to the normal duration for this process.

Note 2 – Ternary transmission from NT1 to LT implies that error-free transmission and frame synchronisation have been achieved in the NT. Following the LT acquiring synchronisation, full duplex 2B + D transmission can commence.

The conditional step between the NT1 acquiring synchronisation and returning ternary data is included to provide a mechanism by which the optional alignment of LT to NT1 and NT1 to LT frame words can be achieved.

VI.10.4 *State transition table of the NT*

See Table VI-3/G.961.

TABLE VI-3/G.961

State transition table of the NT

	State	NT1 ready for act.	NT2 training	NT3 wait for T	NT4 wait for data valid	NT5 steady state	NT6 TE act.	NT7 pending deact.
	Signal transmitted to TE	I0	I0	I2	I2	I4	I0	
Events								
Source	Event							
LT	Activate indication [FE1]	NT2	–	–	–	–	NT2	–
NT1	In synch. [FE3]	/	NT3	–	–	–	/	–
TE	INFO 3	/	/	NT4	–	–	/	–
NT1	Data valid	/	/	/	NT5	–	/	–
TE	Activate indication INFO 1	NT6	/	/	/	/	/	–
NT1	Loss of synch. [FE3]	–	NT7	NT7	NT7	NT7	–	–
NT1	No line sig. detect on DS	–	–	–	–	–	–	NT1

– No change

/ Impossible

[] Remote source event

DS Digital system

VI.10.5 *State transition table of the LT*

See Table VI-4/G.961.

TABLE VI-4/G.961

State transition table of the LT

State	LT1 Ready for act.	LT2 Training	LT3 Dig. sect. active	LT4 T-ref in synch.	LT5 Steady state		LT7 Pending deact.
Signal transmitted to DS	Inactive	Training seq.	Steady state	Steady state	Steady state		Inactive
Events							
Source Event ET FE1 (activate reqst.)	LT2	/	/	/	/		–
LT DS in-synch.	/	FE3 LT3	–	–	–		/
LT FE2 No line activity LSD ⟶ False	/	–	–	–	–		LT1
NT1 [INFO 3] Ready for data	/	/	FE4 LT4	–	–		/
LT DS loss of synchronisation	/	FE7 LT7	FE7 LT7	FE7 LT7	FE7 LT7		–
ET FE5 deactivation request	/	FE7 LT7	FE7 LT7	FE7 LT7	FE7 LT7		–
ET Data valid	/	/	/	LT5	–		–

– No change

/ Impossible

[ ] Remote source event

LSD Line signal detect

VI.10.6 *Activation times*

The "cold start" and "warm start" times will be 120 ms ± 10 ms with all cable combinations permissible. This reliable and repeatable activation time is a result of the specific activation sequence specified in this SU32 standard.

VI.11 *Jitter*

Jitter performance must be sufficient for the purpose of providing the clock for interface at the T-reference point transmission function in accordance with Recommendation I.430.

The SU32 proposal features an orthogonal timing signal superimposed on the data. This leads to stable and low jitter digital phase locked loop timing circuitry being easily achieved.

VI.11.1 to V1.11.3

For further study.

VI.12 *Transmitter output characteristic of the NT or LT*

VI.12.1 *Pulse amplitude*

The nominal pulse amplitude shall be zero to peak 1.8 volts. The tolerance on this peak pulse amplitude shall be such that signal power and amplitude vs. frequency spectrum performance is as specified in § VI.12.

VI.12.2 *Pulse shape*

The pulse shape is determined by the pulse mask of Figure VI-3/G.961.

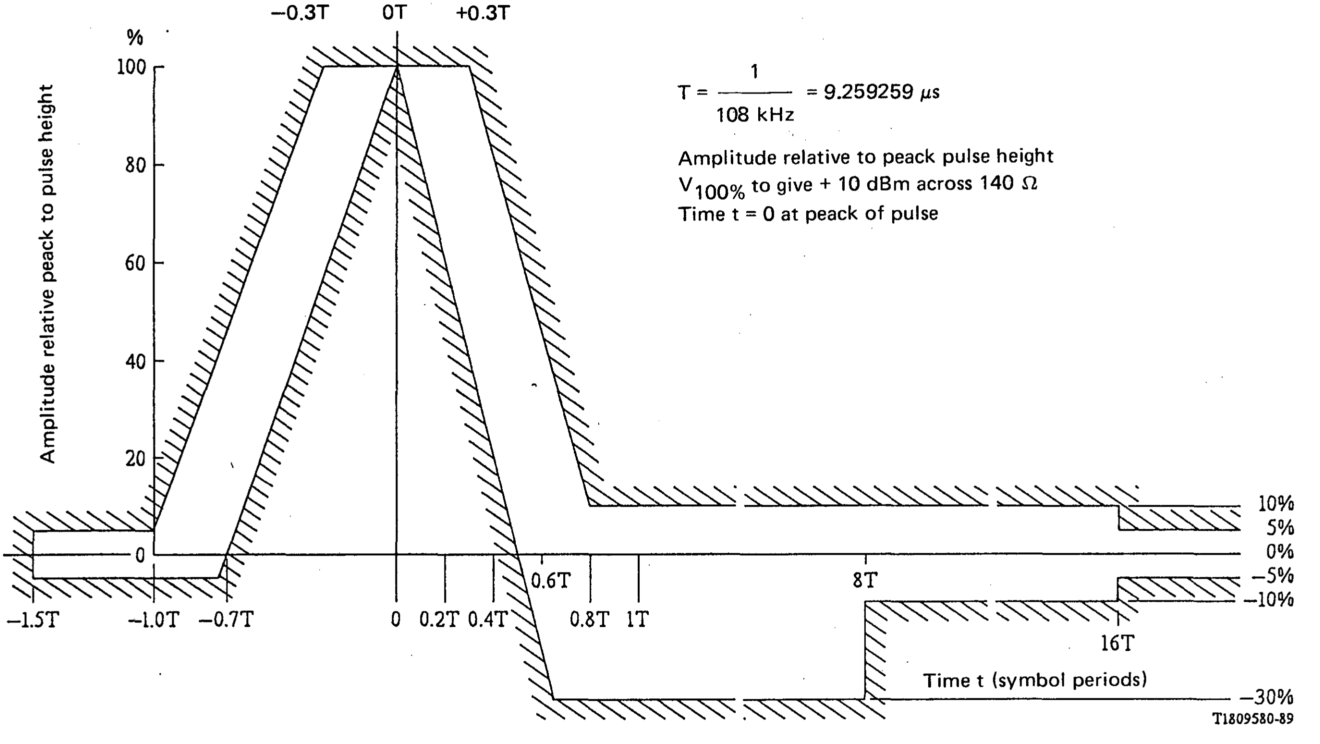


FIGURE VI-3/G.961

Single pulse mask – 108 kbauds transmitter pulse shaping

VI.12.4 *Power spectrum*

SU32 has a code spectrum modified by the conditional coding rule compared to random ternary signalling. The theoretical power spectrum when using SU32 having full width rectangular pulse shaping with transformer coupling is given in Figure VI-4/G.961.

Limits for the transmitted power spectral density are given in Figure VI-5/G.961.

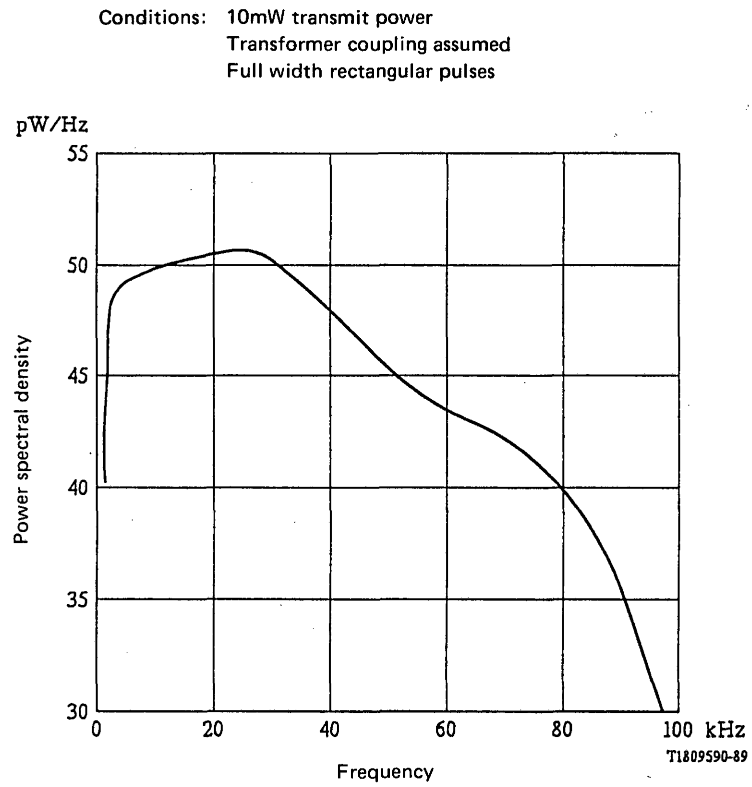


FIGURE VI-4/G.961

On line power spectral density of SU32 line code

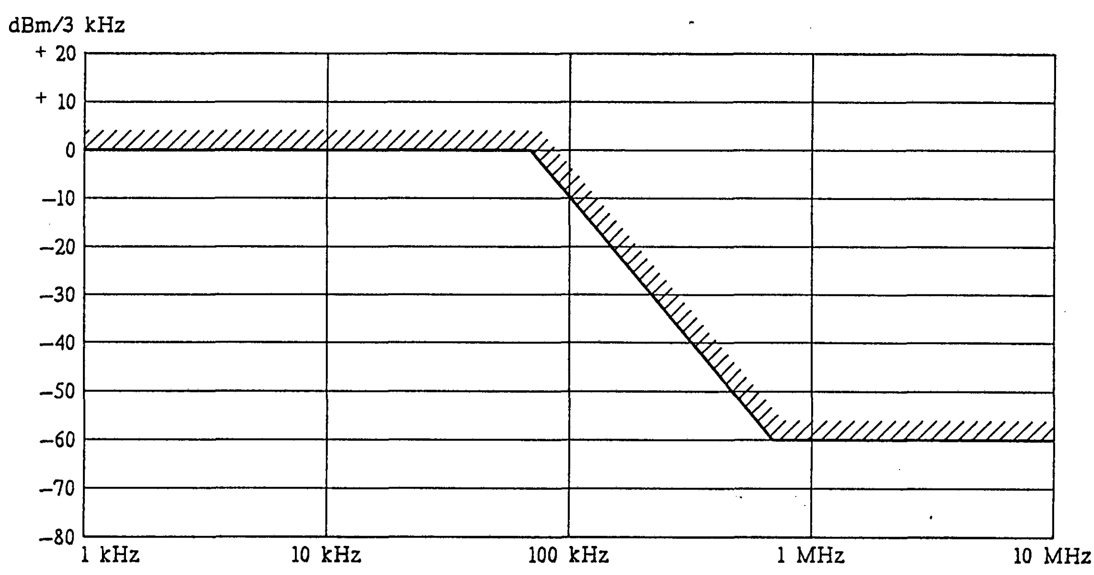


FIGURE VI-5/G.961

Transmitted power spectral density specification

Power levels

Signals sent to line must conform to the following criteria, under all operating conditions with 140 ohms resistive termination:

a) The maximum total transmit power, averaged in any 1 second period must not exceed +11 dBm.

b) The maximum transmit power average in any 1 second period in any 3 kHz band, below 100 kHz, must be less than 0 dBm. This limit extends down to DC (excluding power feed).

c) The nominal recommended transmit power will be +9.5 dBm with a tolerance of ± 1 dB.

VI.13 *Transmitter/receiver termination*

VI.13.1 *Impedance*

The nominal output/input impedance looking towards the NT shall be 140 ohms. The nominal output/input impedance looking towards the LT shall be 140 ohms.

VI.13.2 *Return loss*

For further study.

VI.13.3 *Longitudinal conversion loss*

The longitudinal conversion loss in the range 100 Hz to 1.6 times the symbol rate (fO) shall exceed 46 dB. For a frequency 10 MHz $> f >$ 1.6 f_0, the longitudinal loss shall exceed 46 $-$ 40 log $(f/1.6\, f_0)$ dB or 24 dB whichever is greater.

Supplement No. 15

ALMOST-DIFFERENTIAL QUASI-TERNARY CODE (ADQ CODE)

(Referred to in Recommendation G.911, this Supplement is to be found on page 673 of Fascicle III.3 of the Orange Book, Geneva, 1977)

Supplement No. 27

INTERFERENCE FROM EXTERNAL SOURCES

(Referred to in Recommendations G.221 and G.950; this Supplement is to be found on page 346 of Fascicle III.2 or on page 390 of Fascicle III.3 of the Red Book, Geneva, 1985.)

TEMPERATURE IN UNDERGROUND CONTAINERS FOR THE INSTALLATION OF REPEATERS

(Melbourne, 1988)

(see Recommendation G.950)

1 General

This Supplement consists of two parts: A and B.

Part A (source: Federal Republic of Germany) informs about the ground temperature taken from meteorological sources in most regions of the world, and shows the seasonal variations as a function of the depth (in the Federal Republic of Germany).

Part B (source: Italy) gives guidelines for the calculation of the ground temperature in the container, depending, *inter alia*, from the atmospheric temperature, the depth and the dissipation of the equipment in the container.

Both parts give additionally some general information which is useful as a guidance for planning.

2 Part A

2.1 *Definition*

In the following, climatic conditions are discussed which are relevant to small underground containers without any means for adjusting to specific temperature conditions. These containers are normally hermetically closed and need not be opened e.g., for preventive maintenance. They can be operated with or without gas pressure supervision or they may contain drying agents.

2.2 *Temperature in underground containers*

The temperature in underground containers depends on the temperature of the surrounding soil. Additionally, it is influenced by the power dissipation of the installed equipment.

The ground temperature at various depths is well known for most of the regions of the world [1]. Figure 1 shows the seasonal variation of the ground temperature as a function of the long term mean value of the ground temperature. Examples of the variation of the temperature with time for a period of 1 year is shown in Figure 2. The yearly minimum and maximum temperatures as a function of the depth are plotted in Figure 3. Figures 2 and 3 are examples only for a specific region in Germany (Federal Republic of) and for sandy soil.

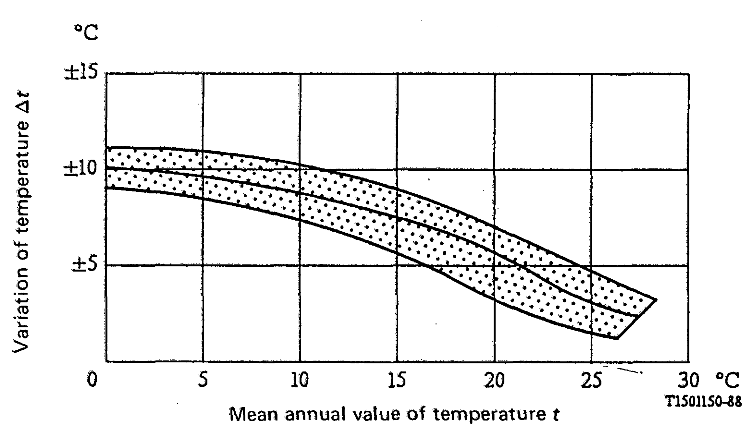


FIGURE 1

Relation between the long-term mean value of the ground temperature *t* and the annual variations to be expected at a depth of approximately 80 cm

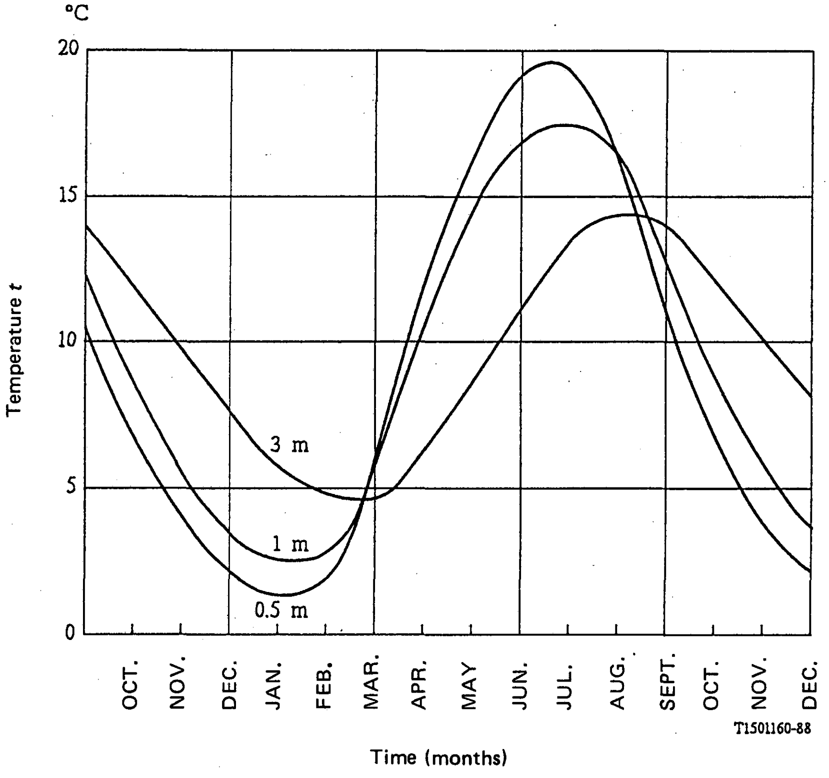
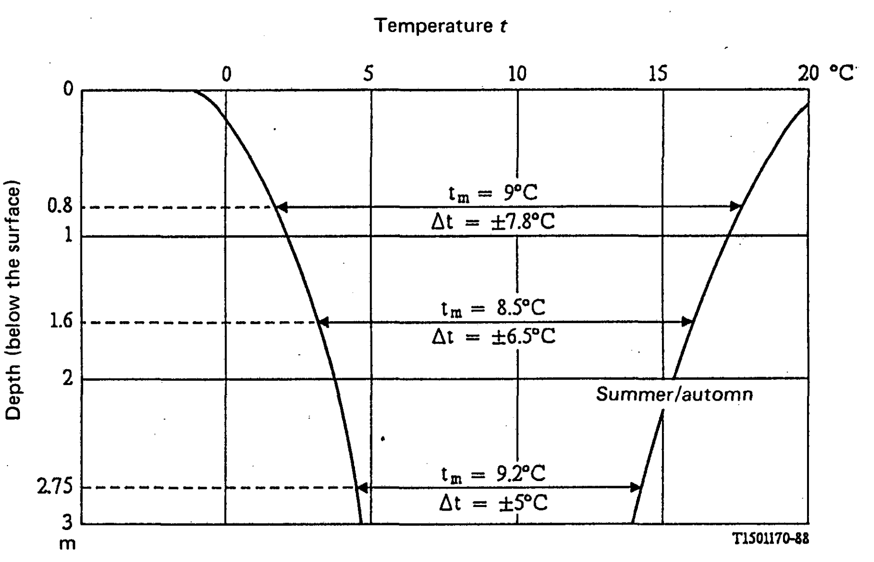


FIGURE 2

Temperature of the soil as a time function of the seasons for depths of 0.5 m, 1 m, and 3 m (long-term mean values, sandy soil in Germany (Federal Republic of))



t_m Annual mean value of the soil temperature

Δ_t Maximum annual tamperature variation in the ground referred to t_m

FIGURE 3

Annual maximum and minimum values of the soil temperature depending on the depth (long-term mean values, sandy soil in Germany (Federal Republic of))

The composition of the soil has a significant effect on the temperature and its variation with time. It should be noted that this variation occurs slowly, depending on the composition of the soil and on the depth.

The mean value of the temperature in the container is the same as that of the ground, if the possible increase caused by the heat generated by the power dissipation of the equipment is neglected. Variations of the air temperature cause variations of the temperature in the container, but with a time delay, and with an attenuation of the amplitude depending on the design of the container.

2.3 *Conclusion*

The temperature in small underground containers e.g., for the installation of remote power-fed repeaters depends on the geographical region, the composition of the soil, the depth of installation and the power dissipation of the installed equipment.

The humidity within the container is independent of external influences and can be controlled by suitable means, if necessary.

3 **Part B**

3.1 *Temperature in underground housing containing high dissipation equipment*

The temperature in the underground housing depends on the temperature of the surrounding soil, its composition and on the amount of power dissipated in the equipment.

3.1.1 The temperature in the soil at different depths can be directly measured at the site or can be calculated from seasonal mean temperature of the site (at ground level) taking into account thermal resistivity and diffusity of the soil.

Short term variations, like daily excursions, are rapidly damped and become negligible at a depth greater than 0.3 m so that only seasonal variation diffuses farther in the ground.

Of course such variations too are attenuated and delayed following the depth and the soil composition.

3.1.2 The heat generated by equipment dissipation in the housing is transferred via housing walls into surrounding soil thus disturbing the existing temperature field and determining a local gradient which decreases with the distance from housing walls.

In order to evaluate the maximum annual temperature in the housing it is advisable to define a mathematical model of the heat transmission and solve it for the conditions imposed by the site climate, the soil nature, the power consumption, etc.

The relevant calculation can be handled by computer making it possible to rapidly investigate the effect of the different parameters.

In critical condition, that is in soil of poor characteristics, advantage can be taken putting around the housing a backfilling material of good thermal conductivity. The effect of such an action can be previously verified by computer.

3.2 *Guidelines of the calculus*

The heat transmission from the atmosphere to the soil is described by the equation

$$T(y,t) = \mathrm{A} + \mathrm{B}\, \mathrm{e}^{-\gamma y} \sin (wt - \gamma y) \tag{1}$$

where

A	Mean value of the atmospheric temperature
B	Amplitude of the thermal oscillation at the ground surface
γ	Coefficient of diffusion
y	Depth

The temperature is a function of the time and depth only and the resulting field has horizontal isothermal surfaces.

The power dissipated in the housing determines a heat flux on the walls of the container and a two-dimensional thermal field in the soil.

The relevant equation is the

$$c\zeta \frac{\delta T}{\delta t} - k \left(\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2}\right) = F(x,y,t) \tag{2}$$

where

$F(x,y,t)$	takes into account the presence of thermal sources in the soil
C	Specific heat of the soil
ζ	Density of the soil
k	Thermal conductivity of the soil.

The problem can be further simplified neglecting the term $\frac{\delta T}{\delta t}$.

In fact the temperature in the soil is subjected to a slow variation and can be considered as steady in the short period.

Solve the equation

$$-k \left(\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2}\right) = F(x,y) \tag{3}$$

and introducing the "initial condition" of the (1) for the considered time, the temperature distribution in the soil can be plotted in a discrete number of points.

The centreline temperature in the housing is calculated from heat transfer relationships for natural convection on vertical walls: Nu = M. $(G\bar{r} \cdot Pr)^N$ where NU = Nusselt number; GR = Grashof number; Pr = Prandtl number; M, N are constants to be empirically determined.

An example of calculated thermal field is given in Figure 4 where the isothermal lines substitute the local temperature values plotted by computer.

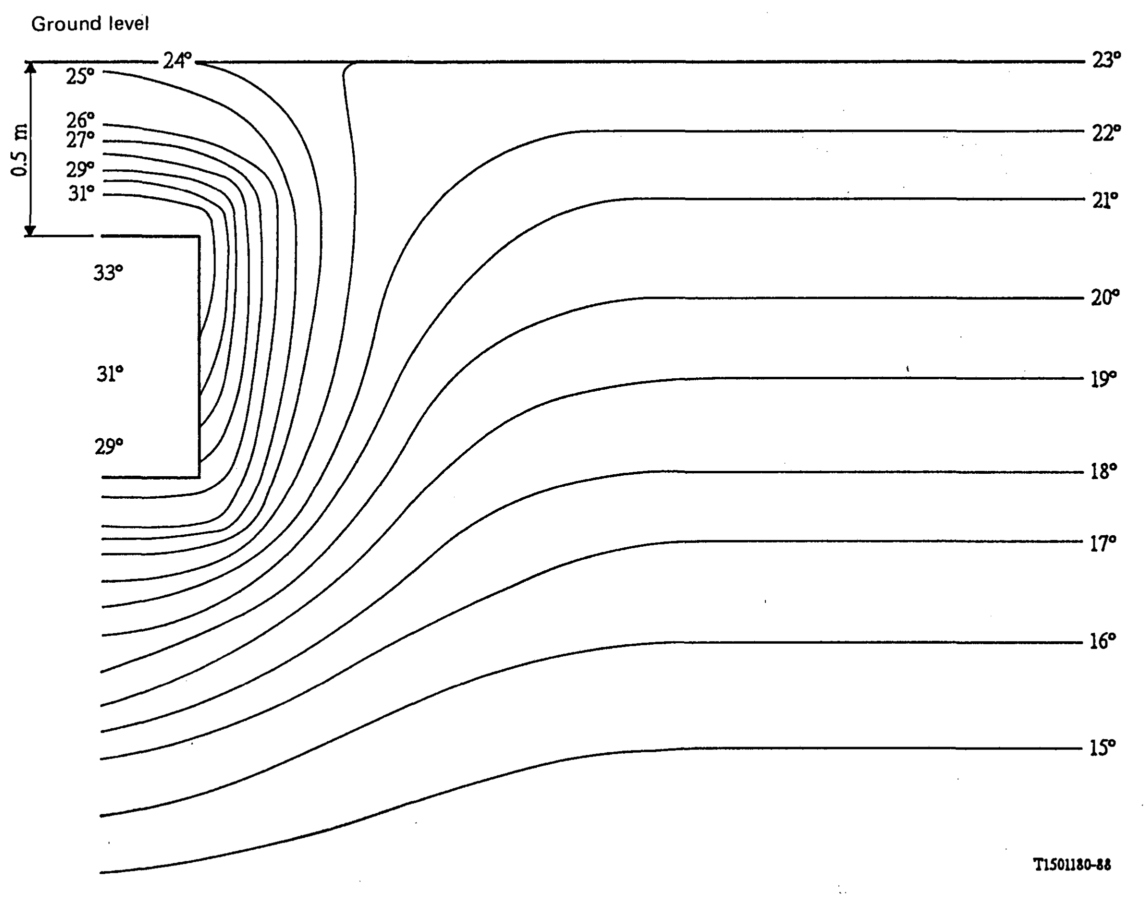


FIGURE 4

Example of calculated thermal field

3.3 *Conclusion*

The temperature in the underground housing depends on site climate, type of soil, depth, time of the year, equipment dissipation.

A mathematical analysis of the heat transmission makes it possible to evaluate the maximum temperature in the housing taking into account the effect of the parameters involved.

The use of selected backfilling material can be considered and the resulting effect evaluated.

HOUSING TYPE : CAI/24

Temperature at steady state (° C)

Housing dimensions (m) Ø 0.85 h 0.9

Dissipated power (watt)	100
Month	8
Mean temperature of the site (° C)	12.7
Amplitude of the thermal variation (° C)	11.7
Thermal conductivity of the soil (W m^{-1} K^{-1})	0.44
Density of the soil (kg · m^{-3})	1550
Specific heat of the soil (J kg^{-1} K^{-1})	1255
Thermal conductivity of the backfilling material (W m^{-1} K^{-1})	0.8
Depth of the backfilling material (m)	0.4
External radius of the backfilling material (m)	1.2

Reference

[1] JEN-HU-CHANG: Ground Temperature, *Blue Hill Meteorological Observatory, Harward University*, Vol. I, II – Hilton 86, Massachusetts, 1958.

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Supplement No. 35

GUIDELINES CONCERNING THE MEASUREMENT OF WANDER

(Contribution from United States of America, referred to in
Recommendations G.812 and G.824)

Wander measurement methodology

The purpose of this Supplement is to present one suitable method of verification of timing accuracy of clocks. Guidelines concerning the measurement of jitter are contained in Supplement No. 38 of the O-Series.

1 Output wander measurement

1.1 *Slave clock*

The measurement strategy is to be able to derive the values of the model parameters contained in the Annex to Recommendation G.812 for the slave clock under test.

Once these parameter values have been obtained compliance with the specifications contained in Recommendation G.812 may be verified.

To adequately characterize the performance of a slave clock a series of tests must be performed. In general, the test fall into the three categories of operation:

1) ideal operation;

2) stressed operation;

3) holdover operation.

1.1.1 *Test configuration*

The objective of the test procedure is to be able to estimate the parameters in the clock model described above for a given clock under test. The architecture for a clock testing arrangement is shown in Figure 1. The components and their interconnection are described next.

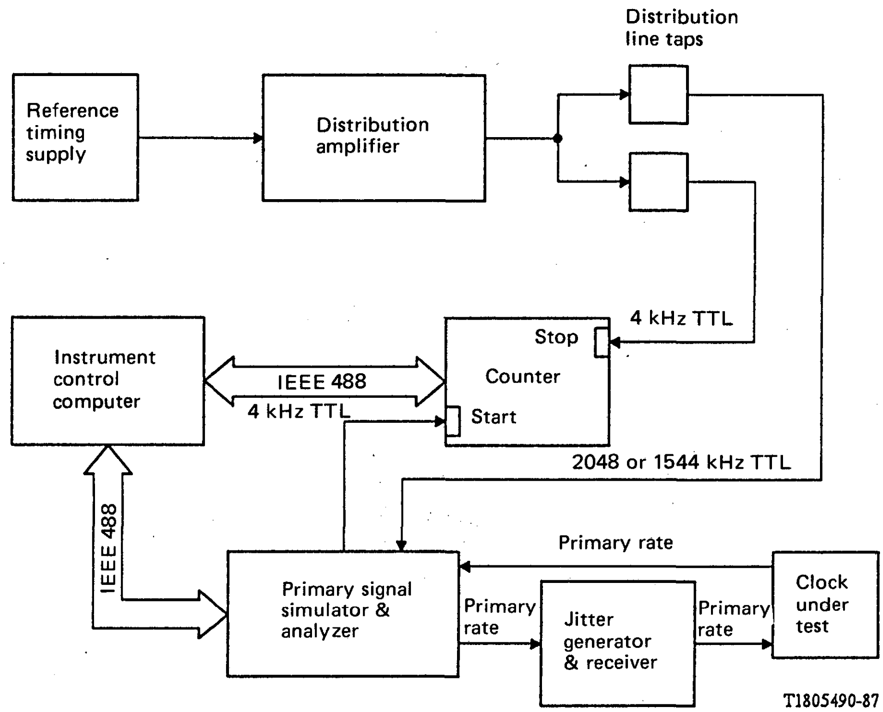


FIGURE 1

Test configuration

1.1.1.1 *Reference clock*

The test configuration is designed to provide the clock under test with a primary rate digital reference timed from a stable reference oscillator. In clock testing, it is the relative phase-time compared to the reference input that is critical[1]. Thus, the absolute accuracy of the reference input is not critical. What is important is that short-term instability of the reference oscillator be small to ensure low measurement noise and a low background tracking error in the control loop of the clock being tested.

[1] In holdover testing, the longer term stability and drift of the reference oscillator is important.

1.1.1.2 *Digital reference simulation*

The testing arrangement is designed to provide a primary rate digital reference with impairment to the clock to allow for stress testing of the clock. To accomplish this a primary rate digital signal simulator and analyzer is employed that has the capability to be externally synchronized. For the 1544 kHz primary rate digital signal[2)] a 1544 kHz timing signal is supplied to the simulator/analyzer to control outgoing transmit timing. The 1544 kHz signal is produced via a distribution amplifier and synthesizer line tap. This distribution arrangement allows one to develop multiple taps of timing signals synthesized from the 10 MHz input from the reference oscillator. Each line tap is a dedicated synthesizer producing the timing signal required. The jitter produced from these synthesizers should be less than 1000 ps rms.

The primary rate impairment simulator is programmed via an IEEE 488 control bus to produce the desired interruption events to stress the clock. The primary rate digital signal is next bridged through a jitter generator and receiver. The jitter generator is used to insert background jitter to the digital signal. It is important to simulate a realistic level of background jitter for several reasons. Primarily, when interruptions occur the background jitter can be a major source of phase build-out error as the synchronization unit attempts to bridge the interruption. Secondly, the jitter transfer characteristics of the clock can be evaluated.

The jitter generation unit is provided an external jitter modulation input. The jitter signal used is bandlimited white noise. A signal from a white noise source is filtered using a low pass single pole filter with 150 Hz 3 dB cutoff. The main reason for lowpass filtering the jitter is to avoid producing bit errors from high frequency alignment jitter. The jitter power should be set to reflect realistic jitter levels in the network. It is important that sinusoidal jitter be avoided as a test jitter input, as certain phase detection techniques are very insensitive to sinusoidal jitter.

1.1.1.3 *Output timing signal recovery*

To test a clock, reference input is provided from the output of the jitter generator. To recover the output timing signal from the clock, an outgoing primary rate signal is selected from the unit controlled by the clock under test. This digital signal is connected to the receive portion of the Primary Rate Signal Simulator and Analyzer. In this unit the receiver timing function is decoupled from the transmit timing used in the generator. The receiver extracts a 4 kHz frame timing signal from the input signal and provides this timing signal at an external port. This 4 kHz timing signal is phase coherent with the outgoing timing from the clock under test.

1.1.1.4 *Phase-time data collection*

A counter is used to observe the relative phase-time error of the output 4 kHz timing signal compared to a reference 4 kHz timing signal. The reference 4 kHz timing signal is derived from the distribution amplifier and synthesizer units. The synthesizer jitter in generating the 4 kHz reference signal is less than 1000 ps. By performing the phase comparison at 4 kHz the observation range of phase variation is 250 μs. If care is given to start a test near the centre of this range, there should not be a problem associated with cycle slipping for all tests except holdover testing. However, even this range can be extended by resolving cycle slips in the data collection software.

In reality, the measurement resolution is limited by the intrinsic jitter in the counter as well as trigger error. Experience has shown that the measurement resolution jitter can be maintained below 100 ps rms with reasonable care given to cabling and trigger levels. More importantly, the overall background jitter noise level can be checked prior to testing to ensure proper performance. For the components used in the particular system described, overall jitter levels of 1000 ps rms are typically attainable. This is more than adequate for measuring the levels of phase stability expected from clocks.

[2)] The following discussion is applicable in an analogous manner to the 2048 kHz primary rate digital signal.

1.1.1.5 *Data collection*

An instrument control computer should be used to automate the testing procedure and collect and analyze the phase-time data. The control computer is interfaced via an IEEE 488 bus to both the Counter and the Primary Rate Digital Signal Simulator and Analyzer.

A key function of the control computer is to gather phase-time data from the counter. The instrument controller obtains a phase-time sample from the counter every 10 seconds. The counter is programmed to average 4000 samples over a 3 second window and return the average to the controller. The resulting measurement bandwidth is 0.33 Hz. The phase-time data is processed in real-time to obtain running estimates of the Allan variance for 10, 100, 1000 and 10 000 second observation intervals. The program also calculates a running estimate of the frequency departure and the drift.

1.1.1.6 *Data analysis*

The objective of the data analysis is to estimate from the data the parameters associated with the clock model. From the Allan variance data, one can determine the presence of either the white noise PM or white noise FM components expected from the model. The frequency departure estimator is the y_{bias} term in the model, and the drift estimator D is the drift component in the model.

1.1.2 *Basic technique and procedure*

This paragraph contains the basic techniques and procedures for testing the three categories of slave clock operation. Appendix I provides examples of the application of these test using actual measurement data.

1.1.2.1 *Ideal operation*

The purpose of this testing is to obtain a baseline performance metric for a clock. The model predicts that clocks under ideal conditions should produce a white noise PM phase instability. This white noise PM should be small as it represents the best case performance of a clock (clearly less than 1 μs based on current MRTIE output requirements). It should be measured in the presence of realistic levels of jitter to assure acceptable jitter transfer.

In the standard test procedure described, the bandwidth of the measurement is 0.33 Hz. In some clock designs, there is significant noise between this 0.33 Hz cutoff and the 10 Hz cutoff associated with jitter. It is important to evaluate the jitter in this band. This could be accomplished by developing an additional measurement program to capture this fast wander data.

1.1.2.2 *Stressed operation*

This area of testing is critically important to adequately evaluate clocks. The difficulty in this testing is selection of the appropriate disruption events. For some clocks any event that appears as a severely errored second will produce a phase build-out event. In some clocks any outage or spurious noise spikes will perturb a counter in the phase detection producing a spurious phase hit which may or may not be phase built-out depending on its severity. On the other hand, clocks can be designed to observe the framing pulse position to extract phase. In such clocks, an interruption need not produce a phase build-out event unless there is an actual shift in the framing pulse position (for example a protection switch event).

It is proposed that one stress test which should be performed is to simulate an SES event with a short outage (100 ms) at a rate of 10 SES per day in the presence of background input jitter. Typically an outage of this magnitude will force a clock to attempt to phase build-out without switching references. An example of this stress test is given in the next section and should serve to clarify the concepts and the significance of the results.

Other stress inputs should also be considered in evaluating a clock.

- *Error bursts*: An error burst can be simulated in which the underlying timing waveform is not perturbed. Under this condition, it would be advantageous for a clock not to phase build-out. Such a test would gain in importance if it is determined that the majority of error burst events are actually pure data errors with no perturbation in timing.

– *Phase bit*: Phase hits are produced by protection activity, as well as from other clocks. Phase hits are interruption events that should either force a phase build-out event or inadvertently be followed by the clock. In either case they will degrade a clock's performance. This is an area for further study.

– *Restart events*: Restart events are a phenomena associated with certain clocks. A restart event is associated with a clock giving up its current state, and defaulting back to its initial conditions. The results are a transient event which can be significant. Restart events should not happen during normal clock operation, and thus should not likely be included in a general clock testing plan. However, it is important that the behaviour be better understood and controlled.

– *Frequently hit*: It is important that clocks do not follow references that exhibit large frequency hits. However the ability to detect frequency hits is closely tied to the selection of the tracking bandwidth of a given clock PLL. The solution to the problem will depend on the degree to which the bandwidth of various clocks in a network can be standardized.

1.1.2.3 *Holdover operation*

In holdover testing, the objective is to estimate the initial frequency offset (y_{bias}) and the Drift (D) of the clock model. The initial frequency offset is dependent on the accuracy of the frequency estimate obtained in the control loop, and the frequency settability of the local oscillator. It is important to test holdover from a reasonable stress condition prior to holdover to capture the control loops capability of obtaining an accurate frequency estimate.

In determining the drift estimate, one critical factor for quartz oscillators is that it typically takes observation intervals lasting over days to obtain a statistically significant drift estimator. This is a hard reality that cannot be avoided. In addition, attention must be placed on the temperature conditions maintained during the test. This is a subject for further study.

1.2 *Primary reference clock*

This section requires further study.

APPENDIX I

(to Supplement No. 35)

Example applications

This section presents the results of the application of some of the testing procedures for two clocks. It is important to point out that the two clocks tested have different internal architectures. The main result of the tests is that the model for clock performance was supported. This model can be summarized as follows:

1) For short observation intervals outside the tracking bandwidth of the PLL, the stability of the output timing signal is determined by the short-term stability of the local synchronizer time base.

2) In the absence of reference disruptions, the stability of the output timing signal behaves as a white noise PM process as the observation period is increased to be within the tracking bandwidth of the PLL.

3) In the presence of disruptions, the stability of the output timing signal behaves as a white noise FM process as the observation period is increased to be within the tracking bandwidth of the PLL.

4) In the presence of disruptions, the output timing signal may incur a systematic frequency offset with respect to the reference. This results from a bias in the phase build-out when reference is restored.

The specific test results are described below.

I.1 *Local clock evaluation*

The results described in this section are for actual performance data.

I.1.1 *Unstressed primary rate input tests*

The first test performed was to evaluate the timing signal output under ideal reference input conditions. The primary rate reference input is produced by the generator timed from the Caesium reference. The jitter outside the tracking bandwidth of the stratum 3 PLL is much less than 1 ns. Typically, 300 ps as measured by the counter.

For this test, the jitter test set was bypassed, and the primary rate from the primary rate simulator and analyzer was fed directly into the synchronizer. The test was run for 67 hours. The results are presented in Figure I-1. The square root of the Allan variance is plotted vs. observation time. The data points marked by triangles apply to this test.

The test results are consistent with the model. For observation times outside the tracking bandwidth of this PLL (less than 60 seconds), the Allan variance indicated a white FM noise resulting from the local quartz oscillator. As the observation time increases, the PLL tracks the reference and the noise process converges to white FM.

The magnitude of the white PM noise is 85 ns rms. One component of this noise is the rms time error of the oscillator in 60 seconds (the bandwidth of this PLL is 1/60 sec). In addition, there is a component resulting from the resolution of the phase detector. A phenomena that arises in digital loops is that the phase error can make excursions of at least one bit in either direction of the nominal setpoint. This effect is reduced when the input has jitter on the order of a phase detector bit.

I.1.2 *Stressed primary rate input test*

The purpose of this test is to emulate the behaviour of the synchronizer under stress conditions that arise in actual networks. For this test, a short outage event was produced under program control by the primary rate simulator and analyzer every 15 minutes. The outage events duration was randomized with a uniform distribution over the range of 10 to 100 ms.

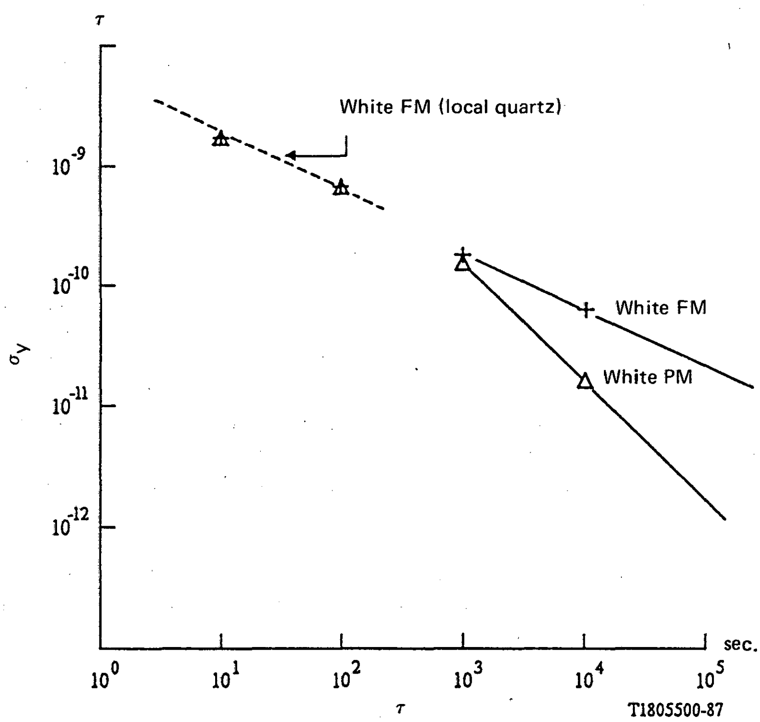
For this test, the jitter set was bypassed, and the primary rate signal from the primary rate simulator and analyzer was fed directly into the synchronizer. The test was run for 50 hours. The results are presented in Figure I-1. The square root of the Allan variance is plotted vs. observation time. The data points marked by plus signs apply to this test.

I.1.2.1 *Allan variance results*

The test results are consistent with the model. For observation times outside the tracking bandwidth of this PLL (less than 60 seconds), the Allan variance indicates a white FM noise resulting from the local quartz oscillator. As the observation time increases, the PLL is experiencing a disruption every 900 seconds. The residual phase build-out error accumulates and produces a random walk in phase (white noise FM). The build-out error per disruption is calculated as 180 ns rms.

I.1.2.2 *Systematic frequency offset*

The stress test data shows a statistically significant frequency offset. The frequency offset over the 50 hour test was 3×10^{-11}. Given the white FM noise, the rms error is 1.5×10^{-11}. These numbers reflect a bias error in the phase build-out in the range of 15 to 45 ns. Such bias errors in clocks result in frequency offsets. The implications of this is that to some extent all clocks in a network operate plesiochronously. Given a worse case level of disruption of ten per day the resulting frequency offset is of the order of parts in 10^{12}.



Δ Undisturbed clean DS1, observation time 240,100 sec
$\bar{Y}$ = 7E-13 white PM 148 ns/τ, $\tau > 10^3$, 85 ns daily r.m.s., prediction error

+ Clean 1544 kbit/s 1 outage/15 minutes observation time 180,000 sec
$\hat{Y}$ = 3E–11 (1 σ = 1.5 E–11) white FM 6E–9/$\sqrt{\tau}$, $\tau > 10^3$, 1.76 μs daily r.m.s. (180 ns RMS/disruption) prediction error

f_3 dB = 1/60 sec

Measurement interval τ_0 = 10 sec. Measurement bandwidth = 0.33 Hz.

FIGURE I-1

Example of local node clock

I.1.2.3 *Significance of stress test results*

To obtain a meaningful interpretation of the stress test results one must consider the disruption level. In this test the disruption level was 100 disruptions per day. This is an order of magnitude greater than what can be expected on actual primary rate links. In this particular PLL the build-out error process is independent from one event to the next. This can be proven by testing at several disruption levels. The results indicated a rms error of 180 ns per disruptions. Given 10 disruptions per day the resulting daily rms error is 570 ns.

I.2 *Transit clock evaluation*

The results described in this section are for actual performance data.

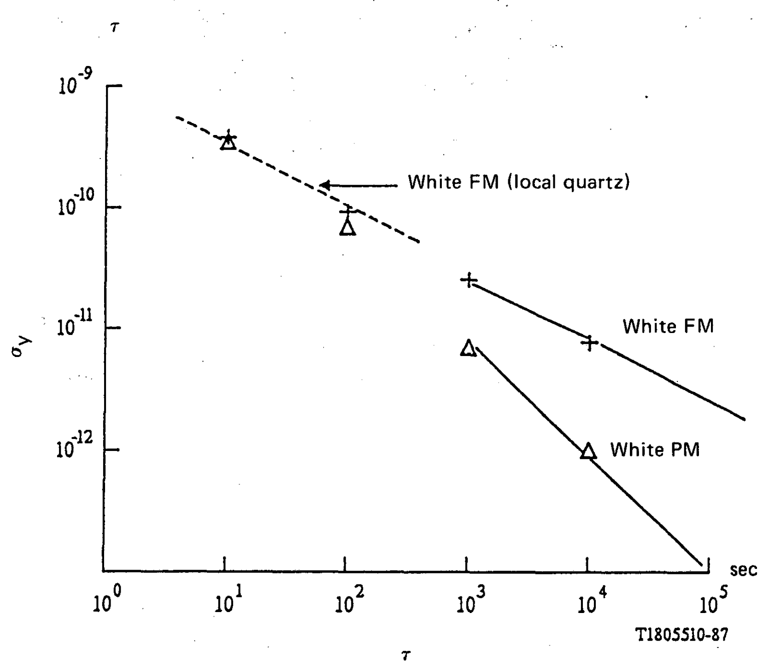
I.2.1 *Unstressed primary rate input test*

The first test performed was to evaluate the timing signal output under ideal reference input conditions. The primary rate reference input is produced by the primary rate simulator and analyzer timed from the Caesium reference. The jitter outside the tracking bandwidth of the stratum 3 PLL is much less than 1 ns. Typically, 300 ps as measured by the counter.

For this test, the jitter test set was included. The jitter test set was given an external jitter modulation input. The jitter signal was band limited white noise. A single pole filter was employed with a 150 Hz 3 dB cutoff. The jitter was low passed filter to avoid producing framing errors resulting from high frequency alignment jitter. The external signal was adjusted to achieve a peak-to-peak jitter level of 1.5 µs. The test was run for 23 hours. The results are presented in Figure I-2. The square root of the Allan variance is plotted vs. observation time. The data points marked by triangles apply to this test.

The test results are consistent with the model. For observation times outside the tracking bandwidth of this PLL (less than 450 seconds), the Allan variance indicated a white FM noise resulting from the local quartz oscillator. As the observation time increases, the PLL tracks the reference and the noise process converges to white PM.

The magnitude of the white PM noise is 6 ns rms. This is an exceptionally good number and results from the tight time constant for the loop (450 seconds). In this case the input jitter prevents the edge jumping effects.



Δ Undisturbed DS1[a]. Input observation time 83,000 sec

$\overline{Y}$ = +6E–13 white PM 1E–8/τ, $\tau > 10^3$, 6 ns daily r.m.s. prediction error

+ 1544 kbit/s[a] 1 outage/30 minutes. Observation time 253,800 sec

$\overline{Y}$ = +6E–13. White FM 8E–10/$\sqrt{\tau}$, $\tau > 10^3$, 235 nsec daily r.m.s. prediction error

f_3 dB = 1/450 sec

[a] 1.5 µ sec p-p. Jitter BW = 150 Hz.

Measurement interval τ_0 = 10 sec. Measurement bandwidth = 0.33 Hz.

FIGURE I-2

Example of transit node clock

I.2.2 *Stressed primary rate input test*

The purpose of this test is to emulate the behaviour of the synchronizer under stress conditions that arise in actual networks. For this test, a short outage event was produced under program control by the primary rate simulator and analyzer every 30 minutes. The outage events duration was randomized with a uniform distribution over the range of 10 to 100 ms.

For this test, the jitter test set was included. The jitter test set was given an external jitter modulation input. The jitter signal was bandlimited white noise. A single pole filter was employed with a 150 Hz 3 dB cutoff. The jitter was low passed filter to avoid producing framing errors resulting from high frequency alignment jitter. The external signal was adjusted to achieve a peak-to-peak jitter level of 1.5 µs. The test was run for 70 hours. The results are presented in Figure I-2. The square root of the Allan variance is plotted vs. observation time. The data points marked by plus signs apply to this test.

I.2.2.1 *Allan variance results*

The test results are consistent with the model. For observation times outside the tracking bandwidth of this PLL (less than 450 seconds), the Allan variance indicated a white FM noise resulting from the local quartz oscillator. As the observation time increases, the PLL is experiencing a disruption every 1800 seconds. The residual phase build-out error accumulates and produces a random walk in phase (white noise FM). The build-out error per disruption is calculated at 34 ns rms. A contributor to this error is the input primary rate jitter. The algorithm averages the input to improve the estimate of the phase error to build-out.

I.2.2.2 *Systematic frequency offset*

The stress test data shows a statistically insignificant frequency offset. The frequency offset over the 70 hour test was 6×10^{-13}. Given the white FM noise, the rms error is 1.5×10^{-12}. Given this uncertainty, there is no indication of a bias in the data. In the worse case the bias should not be more than the uncertainty level of 1.5×10^{-12}.

I.2.2.3 *Significance of stress test results*

To obtain a meaningful interpretation of the stress test results one must consider the disruption level. In this test the disruption level was 48 disruptions per day. This is five times greater than what can be expected on actual primary rate links. In this particular PLL the build-out error process should be independent from one event to the next based on a knowledge of the PLL design. This can be proven by testing at several disruption levels. The results indicated an rms error of 34 ns per disruption. Given 10 disruptions per day, the resulting daily rms error is 100 ns.

I.3 *Allan variance confidence limits*

Sample variances (like sample Allan variances) are distributed as chi-square. Based on J. Barnes work described in [1], the confidence interval for the Allan variance can be determined assuming a given noise process. In calculating the sample Allan variances a complete overlap of lag intervals was used. This is the most efficient use of data. However, it is incorrect to assume independence in overlapping samples when calculating confidence intervals. This is described in complete detail in [1]. For brevity, the methods for calculating the confidence interval described in reference [1] were employed.

The 90% confidence factors for white PM noise are bounded within 0.9 and 1.1 for all lag times up to 10,000 assuming an observation period of a day. For white FM noise over a day observation interval the confidence factors were as follows. For 1000 second lag interval the lower bound is 0.9, and the upper bound is 1.2. At 10 000 the confidence factors are 0.75 and 1.5.

As an example of what these factors mean consider the white FM noise component in Figure I-2 (plus sign tagged data). For the 10 000 second lag, the square root of the sample variance is 8×10^{-12}. The 90% confidence interval for the true variance is bounded by the confidence factors multiplied by the sample variance. This leads to the square root of the Allan variance being bounded between 6.9×10^{-12} and 9.8×10^{-12} with a 90% confidence level.

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Supplement No. 36

JITTER AND WANDER ACCUMULATION IN DIGITAL NETWORKS

(Referred to in Recommendation G.824)

The present Supplement describes a model which has been used to compute jitter/wander accumulation in digital networks arising from cascaded digital regenerators and asynchronous digital multiplexes. This model does not include other sources of wander generation; e.g., environmental, disruptions in synchronization reference distribution, etc.

1 Jitter and wander accumulation – Digital regenerator component

The most widely used model of regenerator jitter/wander accumulation, attributed to Chapman [1], treats the regenerator as linear, shift-invariant system. In order to compute the accumulated jitter/wander after N cascaded regenerators, intrinsic regenerator jitter/wander is categorized in terms of "random" and "systematic" components. Chamzas model of regenerator jitter/wander accumulation [2] addresses how stochastic variations in regenerator retiming circuits affect jitter/wander accumulation. The results of this study demonstrate that use of the appropriate *mean* jitter/wander transfer characteristic in the identical regenerator accumulation model, summarized above, provides a very good estimate to jitter/wander accumulation computed assuming a stochastic variation of retiming circuits.

Using Chapman's model for a chain of N *identical* regenerators, defining $H_1(j\omega)$ as the jitter/wander transfer characteristic for one regenerator, and redefining the random and systematic components as completely uncorrelated and correlated components, respectively,

– the power spectral density of the random jitter/wander component is:

$$\Phi_N^R(\omega) = \Phi_{i1}^R |H_1(j\omega)|^2 \frac{1 - |H_1(j\omega)|^{2N}}{1 - |H_1(j\omega)|^2} \tag{1}$$

where Φ_{i1}^R is the constant, internally generated, random (pattern independent plus uncorrelated pattern dependent) jitter/wander power spectral density for one regenerator.

– the power spectral density of the systematic jitter/wander component is:

$$\Phi_N^S(\omega) = \Phi_{i1}^S |H_1(j\omega)|^2 \frac{|1 - H_1(j\omega)^N|^2}{|1 - H_1(j\omega)|^2} \tag{2}$$

where Φ_{i1}^S is the constant, internally generated, systematic (correlated pattern dependent) jitter/wander power spectral density for one regenerator. Φ_{i1}^R and Φ_{i1}^S can be estimated from practical measurements based upon the regenerator's jitter/wander response to short and long word lengths from a pattern generator, and correlation studies.

When there is no peaking in the regenerator jitter/wander transfer characteristic, the systematic jitter/wander accumulates much more rapidly than the random jitter/wander [1], [4], [5]; as a result, random jitter/wander accumulation is often ignored. However, for a large number of regenerators with peaking in the jitter/wander transfer characteristic, the total jitter/wander accumulation can be dominated by the random component.

2 Jitter and wander accumulation – Asynchronous digital multiplex component

With Gaussian input jitter/wander, having an rms amplitude of σ, and double-sided power spectral density $\theta_{in}(f)$, the unfiltered multiplex intrinsic jitter/wander is given by [6].

$$\Phi_{out}(f) = sinc^2 f\, rep\, \Phi_{in}(f) + \sum_{n=1}^{x} \frac{p^2}{(2\pi n)^2}\left[\delta(f - n) + \delta(f + n)\right]$$
$$+ \sum_{n=1}^{x} \frac{sinc^2 f}{(2\pi n)^2}\left[rep\, Z_n(f - np) + rep\, Z_n(f + np)\right] \qquad (3)$$

where $rep\, X(f) = \sum_{k=x}^{x} X(f - k)$

$$Z_n(f) = e^{-2\pi n\sigma}\left[\delta(f) + \sum_{k=1}^{x}\left[\frac{2\pi n}{k!}\right]^{2k} \underbrace{\Phi_{in}(f) * \ldots * \Phi_{in}(f)}_{k\ terms}\right]$$

p Multiplexer stuffing ratio

f jitter/wander frequency normalized by the multiplexer maximum suffising frequency

3 Method of combination

Assuming that the jitter/wander accumulation from each component part can be modeled by filtered Gaussian randam variables, the power spectrum and rms amplitude after each component part[1)] is computed as the accumulation due to the preceding parts according to the following rules [3]:

i) The jitter/wander spectrum at the output of a chain of regenerators is the power sum of the jitter/wander generated by the regenerators (equations [1] and [2]) and any jitter/wander at the input of the chain, appropriately filtered by the equivalent jitter/wander transfer characteristic. Thus, for input jitter/wander, $\theta_{in}(\omega)$, the output jitter/wander, $\theta_{out}(\omega)$, is given by

$$\Phi_{out}(\omega) = \Phi_{i1}^{R}\, |H_1(j\omega)|^2 \frac{1 - |H_1(j\omega)|^{2y}}{1 - |H_1(j\omega)|^2} +$$
$$+ \Phi_{i1}^{S}\, |H_1(j\omega)|^2 \frac{|1 - H_1(j\omega)^N|^2}{|1 - H_1(j\omega)|^2} + \Phi_{in}(\omega)\, |H_1(j\omega)^N|^2 \qquad (4)$$

ii) The jitter/wander spectrum at the output of a demultiplexer is the power sum of the unfiltered intrinsic multiplex jitter/wander and the accumulated higher rate input jitter/wander, attenuated by the desynchronizer jitter/wander transfer characteristic. Thus, if $\theta_{in,1}(\omega)$ is the unfiltered intrinsic multiplex jitter/wander and $\theta_{in,2}(\omega)$ is the accumulated higher rate input jitter/wander, the output jitter/wander, $\theta_{out}(\omega)$ is given by

$$\Phi_{out}(\omega) = \left\{\Phi_{in,1}(\omega) + \frac{\Phi_{in,2}(\omega)}{r^2}\right\} |G(j\omega)|^2 \qquad (5)$$

where r is the ratio of the multiplexer output frequency to tributary frequency, and $G(j\omega)$ represents the desynchronizer jitter/wander transfer characteristic.

1) The following equations are valid for both single- and double-sided power spectra and corresponding transfer characteristics.

4 Definition of peak-to-peak jitter/wander amplitude

The probability that the jitter/wander exceeds a particular threshold amplitude $|x|$ n times in the time interval $(t,\ t + \Delta t)$ may be described by a Poisson density function [3].

$$Pr\left\{n(\pm x) \text{ crossings in } (t, t+\Delta t)\right\} = \frac{\{\overline{N(x)}\Delta t\}^n}{n!} e^{-\overline{N(x)}\Delta t} \tag{6}$$

where $\overline{N(x)}$ is the average number of times/second that the threshold $|x|$ is exceeded.

For Gaussian jitter/wander, with double-sided power spectral density $\theta(\omega)$, $\overline{N(x)}$ is given by [7]

$$\overline{N(x)} = N_0\ e^{-x^2 \Omega \sigma 2}$$

$$\text{where} \qquad \sigma^2 = \frac{1}{2\pi} \int_{-\infty}^{\infty} \Phi(\omega) d\omega \tag{7}$$

$$N_0 = \frac{1}{\pi} \left\{ \frac{\int_{-\infty}^{\infty} \omega^2 \Phi(\omega) d\omega}{2\pi\sigma^2} \right\}^{1/2}$$

The probability that the jitter/wander doesn't exceed the threshold during the time interval $(t,\ t + \Delta t)$ is

$$1 - P_0 = e^{-\overline{N(x)}\Delta t} \tag{8}$$

Solving for the threshold,

$$|x| = \left\{ 2\sigma^2 \ln \left[N_0 \frac{\Delta t}{\ln\left(\frac{1}{1 - P_\sigma}\right)} \right] \right\}^{1/2} \tag{9}$$

If we assume that each time the threshold is crossed, an undesirable event (impairment) may result, the mean time between impairments, MTBI, may be taken as

$$MTBI = \frac{1}{\overline{N(x)}} \tag{10}$$

Thus, equation (9) may be expressed as

$$|x| = \left\{ 2\sigma^2 \ln(N_0\ MTBI) \right\}^{1/2} \tag{11}$$

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