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PROTECTION OF CABLES AND OTHER ELEMENTS OF
OUTSIDE PLANT

**Multi-pair copper network cable supporting
shared multiple services such as POTS, ISDN
and xDSL**

Recommendation ITU-T L.19



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Multi-pair copper network cable supporting shared multiple services such as POTS, ISDN and xDSL

Summary

Recommendation ITU-T L.19 describes some general considerations on services and systems, such as ISDN and xDSL, to be supported by the access network. Some requirements for the digital local line characteristics are also given, as a factor contributing to the provision of good quality of service to the users. Furthermore, some issues for the use of multi-pair copper network cable supporting shared multiple services such as ISDN/xDSL are also described. This revision updates Recommendation ITU-T L.19 to include recent new or revised Recommendations for ADSL2 (ITU-T G.992.3, ITU-T G.992.4), ADSL2plus (ITU-T G.992.5) and VDSL (ITU-T G.993.1).

History

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FOREWORD

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Introduction

The local subscriber network has been providing the means for subscriber connection to the basic telephone service, without encountering any major transmission problems at voice frequencies (300 to 3400 Hz). With the evolution of transmission technologies, services and systems such as ISDN, HDSL, SHDSL, ADSL, ADSL2, ADSL2plus, VDSL and VDSL2 are being used into the existing copper line. And there is now a trend also to support multiple services of one or more providers on common cables and in other parts of the network. This is called "unbundling the network", i.e., more than one operator are sharing the network or are co-located in the same network. Providing the unbundling network makes crosstalk environment severer. Therefore, it is necessary to establish the quality of the subscriber loops for new services and systems such as ISDN, HDSL, SHDSL, ADSL, ADSL2, ADSL2plus, VDSL and VDSL2.

Recommendation ITU-T L.19

Multi-pair copper network cable supporting shared multiple services such as POTS, ISDN and xDSL

1 Scope

This Recommendation deals with the general considerations and the requirements of the digital local line characteristics, which are used between the line termination and the network termination, to provide ISDN and xDSL services. The field of home network is not addressed in this Recommendation. Moreover, this Recommendation describes the guidance for the use of multi-pair copper cable supporting shared multiple services such as ISDN/xDSL.

The values used in this Recommendation are based on a number of DSL technologies as they are known at the moment of publication of this Recommendation. However, the general principles are applicable to any type of DSL technology, generally referred to as xDSL.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.961] Recommendation ITU-T G.961 (1993), *Digital transmission system on metallic local lines for ISDN basic rate access*.
- [ITU-T G.991.1] Recommendation ITU-T G.991.1 (1998), *High bit rate digital subscriber line (HDSL) transceivers*.
- [ITU-T G.991.2] Recommendation ITU-T G.991.2 (2003), *Single-pair high-speed digital subscriber line (SHDSL) transceivers*.
- [ITU-T G.992.1] Recommendation ITU-T G.992.1 (1999), *Asymmetric digital subscriber line (ADSL) transceivers*.
- [ITU-T G.992.2] Recommendation ITU-T G.992.2 (1999), *Splitterless asymmetric digital subscriber line (ADSL) transceivers*.
- [ITU-T G.992.3] Recommendation ITU-T G.992.3 (2009), *Asymmetric digital subscriber line transceivers 2 (ADSL2)*.
- [ITU-T G.992.4] Recommendation ITU-T G.992.4 (2002), *Splitterless asymmetric digital subscriber line transceivers 2 (splitterless ADSL2)*.
- [ITU-T G.992.5] Recommendation ITU-T G.992.5 (2009), *Asymmetric digital subscriber line (ADSL) transceivers – Extended bandwidth ADSL2 (ADSL2plus)*.
- [ITU-T G.993.1] Recommendation ITU-T G.993.1 (2004), *Very high speed digital subscriber line transceivers (VDSL)*.
- [ITU-T G.993.2] Recommendation ITU-T G.993.2 (2006), *Very high speed digital subscriber line transceivers 2 (VDSL2)*.
- [ITU-T G.995.1] Recommendation ITU-T G.995.1 (2001), *Overview of digital subscriber line (DSL) Recommendations*.

- [ITU-T G.996.1] Recommendation ITU-T G.996.1 (2001), *Test procedures for digital subscriber line (DSL) transceivers*.
- [ITU-T G.996.2] Recommendation ITU-T G.996.2 (2009), *Single-ended line testing for digital subscriber lines (DSL)*.
- [ITU-T O.9] Recommendation ITU-T O.9 (1999), *Measuring arrangements to assess the degree of unbalance about earth*.
- [IEC 62255-x] IEC 62255-x (in force), *Multicore and symmetrical pair/quad cables for broadband digital communications (High bit rate digital access telecommunication networks) – Outside plant cables*.

3 Definitions

For the purpose of this Recommendation, the definitions given in [ITU-T G.961], G.991.x-series, G.992.x-series, [ITU-T G.995.1] and in [IEC 62255-x] apply.

4 Abbreviations

This Recommendation uses the following abbreviations:

ADSL	Asymmetric Digital Subscriber Line
BT	Bridged Tap
DLL	Digital Local Line
DSL	Digital Subscriber Line
ELFEXT	Equivalent Level Far-End crosstalk
FEXT	Far-End crosstalk
HDSL	High-speed Digital Subscriber Line
ISDN	Integrated Services Digital Network
LCL	Longitudinal Conversion Loss
LT	Line Termination
NEXT	Near-End crosstalk
NT	Network Termination
PSL	Power Sum Loss
SHDSL	Single-pair High-speed Digital Subscriber Line
UADSL	Universal Asymmetric Digital Subscriber Line
VDSL	Very high-speed Digital Subscriber Line
xDSL	Any of the various types of Digital Subscriber Line systems

5 Conventions

None.

6 General considerations

6.1 Objectives

Considering that the digital access section between the local exchange and the customer is a key element of the successful ISDN/xDSL services and systems, the following requirements for the network should be taken into account:

- the ability to operate on the existing two-wire unloaded lines, with open wires being excluded;
- the objective of achieving 100% cable fill for ISDN/xDSL services and systems without pair selection, cable rearrangements or the removal of bridged taps (BTs);
- the objective of being able to extend the new ISDN/xDSL services and systems to the majority of customers without the use of regenerators. In the remaining few cases special arrangements may be required;
- the coexistence, in the same cable unit, with most of the existing services such as telephony and voiceband data transmission;
- various national regulations concerning electro-magnetic compatibility (EMC);
- the provision of power feeding via the network under normal or restricted modes;
- the provision of the capability to support maintenance functions.

6.2 ISDN/xDSL technologies

The most important technologies, shown in Table 1, are:

- ISDN ITU-T G.961 basic access, which offers 160 kbit/s (2B + D) full duplex.
- HDSL ITU-T G.991.1, which offers 2 Mbit/s in each direction, but requires up to three copper pairs.
- SHDSL ITU-T G.991.2, which offers 2 Mbit/s in each direction over a single copper pair.
- ADSL ITU-T G.992.1, which offers up to 8 Mbit/s (in case of ITU-T G.992.2 ADSL, 1.5 Mbit/s) bandwidth in downstream for fast Internet access but not video applications.
- ADSL2 ITU-T G.992.3, which offers up to 8 Mbit/s (in case of ITU-T G.992.4 ADSL, 1.536 Mbit/s) bandwidth in downstream for fast Internet access but not video applications.
- ADSL2plus ITU-T G.992.5, which offers up to a minimum of 16 Mbit/s bandwidth in downstream for fast Internet access but not video applications.
- VDSL ITU-T G.993.1, which offers up to tens of Mbit/s bandwidth in downstream for fast Internet access but not video applications.
- VDSL2 ITU-T G.993.2, which offers up to 200 Mbit/s at a bidirectional net data rate (the sum of upstream and downstream rates).

The technologies considered in this clause were the most popular ones at the time of approval of this Recommendation. The list should be revised according to the development of new processes.

Table 1 – xDSL rates

xDSL "family"	Data rate (downstream)	References
ISDN	160 kbit/s	[ITU-T G.961]
ADSL (ADSL2)	up to 8 Mbit/s (or above)	[ITU-T G.992.1], [ITU-T G.992.2], [ITU-T G.992.3], [ITU-T G.992.4]
ADSL2plus	Min. 16 Mbit/s	[ITU-T G.992.5]
HDSL	2 Mbit/s	[ITU-T G.991.1]
SHDSL	up to 2 Mbit/s	[ITU-T G.991.2]
VDSL	tens of Mbit/s	[ITU-T G.993.1]
VDSL2	200 Mbit/s (downstream + upstream)	[ITU-T G.993.2]

6.3 ISDN/xDSL: Technical problems

Technical problems can occur with ISDN/xDSL-based services when more than one operator share pairs in the same cable.

The degree of interference between different applications, in the same cable, depends on the technology used and the physical characteristics of the cabling (separation between pairs, insulation used, etc.). High-powered technology such as ADSL creates the greatest interference problems.

There are five main technical challenges to use ISDN/xDSL services:

- the need to preserve the integrity of existing services: The interference created by xDSL loops can cause existing services (e.g., ISDN, HDSL on leased lines) to fail or to operate with significantly inferior performance;
- the need to modify line testing procedures: The presence of the ADSL modem in the local loop complicates line testing;
- a requirement to minimize interference between ISDN/xDSL transmission technologies;
- a need to maximize the use of local loops for broadband xDSL services;
- how best to select lines for xDSL use: Not all lines are suitable for ADSL. The most important factor preventing the use of ADSL is signal loss. This is dependent on distance, but the exact distance over which ADSL will operate also depends on the characteristics of the loop and the intended data rate. Other factors also affect performance (e.g., noise, crosstalk or radio-frequency interference, etc.).

6.4 Transmission medium

The transmission medium over which the digital transmission system is expected to operate is the access copper network which connects customers to the local exchange, or street cabinets, via local lines.

This network employs cables of copper pairs to provide services to customers.

A copper local line is expected to be able to simultaneously carry bidirectional digital transmission providing ISDN/xDSL rates between the line termination (LT) and the network termination (NT), as shown in Figure 1.

To simplify the provision of ISDN/xDSL, a digital transmission system must be capable of satisfactory operation over the majority of the copper local lines without special conditioning.

In the following, the term "Digital Local Line" is used to describe a copper local line that meets minimum ISDN/xDSL requirements.

7 Recommended DLL requirements for ISDN/xDSL

For the transmission technologies described in clause 6, appropriate reference values on digital local line requirements for ISDN/xDSL services are necessary to decide the subscriber line is suitable for the designated service. This clause describes minimal DLL requirements, physical and electrical characteristics, and operational requirements for ISDN/xDSL services in order to achieve 100% cable fill without any cable re-engineering against possible technical problems.

7.1 Minimum digital local line requirements for ISDN/xDSL

A digital local line for ISDN/xDSL should meet the following requirements:

- no loading coils;
- no open wires;
- no split pair:

A split pair is that where one wire becomes connected in a different pair at a splicing point and reversed back. This appears generally on the uncolour-coded cable.

When this is present, the performance of transmission in DSL services is dramatically degraded;

- no bridged taps:

When bridged taps (BTs) are present, the digital local line will experience the additional loss that depends on the signal frequency, velocity of propagation and the length of BTs. The presence of a bridge tap in the subscriber line will add losses to the signal transmitted.

A bridged tap is an un-terminated twisted pair section bridged across the line and connected at flexibility points or joints.

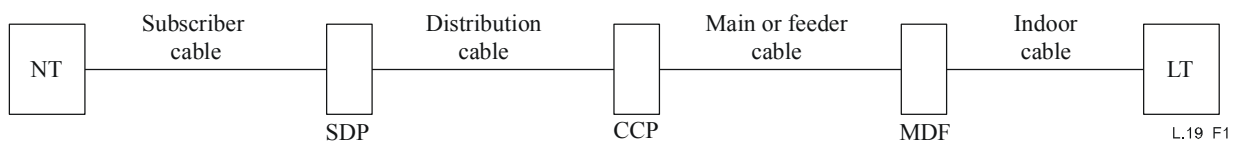
7.2 Digital local line physical characteristics

A DLL is constructed of one or more cable sections that are spliced or interconnected together.

The distribution or main cable is configured as follows:

- cascade of cable sections of different diameters and lengths;
- one or more bridged taps may exist at various points in feeder, distribution and subscriber cables.

A general description is shown in Figure 1 and typical examples of cable characteristics using digital local lines are given in Table 2.



Points of interconnection are:

CCP	Cross-Connection Point (or splice)
MDF	Main Distribution Frame
SDP	Subscriber Distribution Point

Figure 1 – Digital local line physical model

Table 2 – Typical cable characteristics

	Indoor cable	Main cable	Distribution cable	Subscriber cable
Conductor wire diameter [mm]	0.3 to 0.6	0.3 to 1.4	0.3 to 1.4	0.3 to 0.9
Structure	SQ or TP L or B	SQ or TP L or B	SQ or TP L or B	SQ, TP or UP
Maximum number of pairs	1200	2400/0.4 mm 4800/0.3 mm	600/0.4 mm	2 (aerial cable) 600 (indoor cable)
Mutual capacitance (nF/km at 800 Hz)	55 to 120	25 to 60	25 to 60	35 to 120
B Bundles (units)	TP Twisted Pairs			
L Layer	UP Untwisted Pairs			
SQ Star Quads				

7.3 Principal electrical and transmission characteristics for ISDN/xDSL services and systems

The principal electrical and transmission characteristics are described in [ITU-T G.961] for ISDN, G.991.x-series for HDSL/SHDSL, G.992.x-series for ADSL, and G.993.x-series for VDSL. The figures shown in Tables 3 to 5 are given as examples.

7.3.1 Insertion loss

Table 3 indicates example values for the maximum insertion loss acceptable for ISDN/xDSL services and systems. The example values are referenced to DSL Recommendations [ITU-T G.995.1]. The test frequency and maximum insertion loss cannot be defined only with a single value because xDSL uses band plan allocation where different portions of the spectrum are devoted to a particular transmission direction. Nevertheless, these values can be used when the service coverage is designed in the fields.

Table 3 – Example values for acceptable maximum insertion loss

xDSL family	Test frequencies [kHz]	Max. insertion loss [dB]
ISDN (American)	40	42
ISDN (European)	40	36
TCM-ISDN (Japanese)	160	50
HDSL	150	30
SHDSL	200	25
ADSL (1.5 Mbit/s, [ITU-T G.992.2])	300	60
ADSL (6 Mbit/s, [ITU-T G.992.1])	300	40

NOTE – For ADSL systems, only AWGN (arbitrary white Gaussian noise) –140 dBm/Hz is considered as noise environment. If any type of disturbance like bridge tap, crosstalk noise, etc., exists, the acceptable maximum insertion loss will be reduced accordingly.

Where high-frequency line test is not available, typical reach and acceptable DC resistance of DLL are useful references, together with insertion loss. Table 4 shows typical DC resistance [Ω /km] and line loss characteristics [dB/km] on copper pairs. Fundamentally, the values have been adopted

from [ITU-T G.996.1]. The typical reach for each service is shown in Table 5. VDSL or VDSL2 shall provide reliable operation on loops up to approximately 2 km or 2.5 km of 26 AWG (0.4 mm).

Table 4 – Typical DC resistance and line loss on copper pair

Diameter	DC resistance [Ω /km]	Insertion loss [dB/km]			
		40 kHz	150 kHz	200 kHz	300 kHz
0.4 mm	280	9.0	12.0	13.0	14.6
0.5 mm	179	6.2	8.5	9.5	11.0

Table 5 – Typical reach for ISDN/xDSL services

Services	Maximum DC resistance [Ω]	Typical reach [km]	
		0.4 mm	0.5 mm
ISDN (North American)	1300	4.6	6.7
ISDN (European)	1120	4.0	5.8
TCM-ISDN (Japanese)	810	2.7 (one pair) 4.7 (two pairs)	4.3 (one pair) 6.3 (two pairs)
HDSL	700	2.5	3.5
SHDSL	530	1.9	2.6
ADSL (1.5 Mbit/s – [ITU-T G.992.2])	1150	4.1	5.4
ADSL (6 Mbit/s – [ITU-T G.992.1])	760	2.7	3.6
ADSL2 (6 Mbit/s)	840	3.0	4.0
ADSL2plus (16 Mbit/s)	510	1.8	2.4
VDSL	560	2	3.1
VDSL2	700	2.5	3.9

7.3.2 Crosstalk

Crosstalk noise, in general, is due to finite coupling loss between pairs sharing the same cable, especially those pairs that are close to each other. Finite coupling between pairs causes an interference of the signal flowing on one DLL (disturbing DLL) to be coupled into an adjacent DLL (disturbed DLL). This interference is known as crosstalk noise. Near-end crosstalk (NEXT) and far-end crosstalk (FEXT) are the types of crosstalk.

NEXT is assumed to be the dominant type of crosstalk when the DSL system uses the same frequency band for signal transmission and reception.

For systems that use different frequency band for up and downstream like ADSL, FEXT will be the crosstalk to be considered. As FEXT criteria of copper cable, ELFEXT (equivalent level FEXT) is referred. The definition of ELFEXT is given in [IEC 62255-x].

Power sum crosstalk: Noise coupled into a disturbed digital local line from a number of digital local line disturbers as a function of frequency is known as power sum loss (PSL).

It is recommended that the PSL values of NEXT and ELFEXT on twisted pair cable for broadband digital transmission cable meet the values of [IEC 62255-x]. Example values of PSL are given in Table 6. For quad cable, its PSL values should be studied further.

Table 6 – Example values for minimum PSL on twisted pair cable

Frequency [kHz]	Minimum NEXT PSL [dB]	Minimum ELFEXT PSL [dB]
150	56	54
300	52	48
1000	44	38

NOTE – These values are defined in [IEC 62255-x].

7.3.3 Unbalance to earth

As the use of broadband access services increases, the egress (ingress) from (to) the transmission signal in the cable between xDSL systems and radio may cause mutual interference between the systems. This egress (ingress) level on the copper pair depends on the value of unbalance to earth. The digital local line will have finite unbalance to earth.

Unbalance to earth is described in terms of longitudinal conversion loss (LCL). The value of LCL for each service is defined in [ITU-T O.9]. Table 7 shows the minimum LCL for each service.

Table 7 – Minimum LCL requirements described in ITU-T Recommendations

Services	Frequency [kHz]	LCL	Impedance [Ω]	Reference
ISDN	80 8-800	44 dB 5 dB/decade decrease	150, 110	[ITU-T G.961]
ADSL ADSL2(plus)	25-1104	40 dB	100	[ITU-T G.992.1] (Note 1)
VDSL2	12000	38 dB	100	[ITU-T G.993.2] (Note 2)

NOTE 1 – This value is defined in clause A.4.3.1 of [ITU-T G.992.1] as LCL at U-C or U-R interface.
NOTE 2 – This value is defined in [ITU-T G.993.2] and LCL may be increased to a greater than value of 38 dB.

7.3.4 Impulse noise

The digital local line will have impulse noise resulting from other systems sharing the same cables as well as from other sources. The impulse noise, as an example, should be contained within the envelope given in Figure 2.

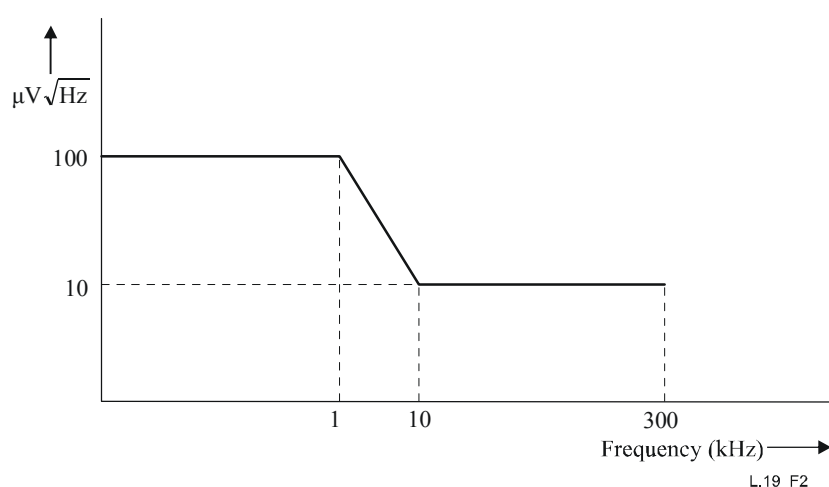


Figure 2 – Impulse noise

NOTE – For an ADSL system, the acceptable limits for impulse noise are under study.

7.4 Use of a multi-pair copper network cable supporting shared multiple services such as POTS, ISDN and xDSL

There is now a trend to support multiple services of one or more providers (unbundling) on a common multi-pair copper cable. The introduction of an optical transmission system from central office to remote location shortens the length of the digital local loop between LT and NT so that it can overcome distance limitations and provide faster speeds. Therefore, various systems that use an overall section or a sub-section of a copper line may exist on a multi-pair cable simultaneously. Typical digital local line configurations are shown in Figure 3.

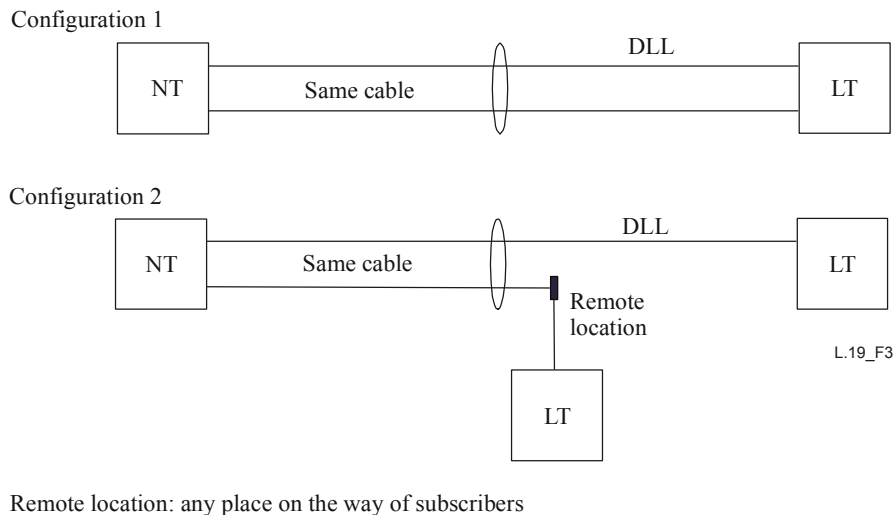


Figure 3 – Digital local line configuration in a multi-service environment

With these configurations, in order to maximize the use of the local line without pair selection, an appropriate installation guide for xDSL technology is required.

In the case of Configuration 1, where LTs are located at the same point and if insertion loss of the digital local line for each service meets the value defined in Table 3, any systems defined in this Recommendation (POTS, ISDN, xDSL) may use a multi-pair cable simultaneously. This is because each system has been designed considering possible crosstalk interference and acceptable disturbances due to the existing and the new systems.

For Configuration 2 of digital local line, where LTs are located at different positions (including remote locations in the network), systems that use an overlapped frequency region in the same direction (upstream or downstream) might experience serious crosstalk interference due to signal power difference along the line. Therefore, the common use of a loop between systems deployed as in Configuration 2 is not preferable. Whenever the application of Configuration 2 cannot be avoided, great care must be taken in order to maintain proper power balancing between differently located LTs.

Meanwhile, ADSL2plus and VDSL2 have a defined powerful mechanism like DPBO (downstream power back off) in order to guarantee the coexistence into the same binder of xDSL services deployed from different positions of LTs.

Appendix I

Bridge taps: Effect of the loss due to the length of a bridge tap

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

The effect of the loss due to the length of a bridge tap has been simulated for the systems given below.

I.1 Effect of BT loss in ISDN

For ISDN service, the loss in a transmission line with wires that have a gauge of 0.40 and 0.50 mm, or the ohmic resistance of 140.0 and 89.5 Ω /km respectively, in low frequency with an insulation of polyethylene (PE) and 0.40 mm (26 AWG) with a plastic insulation (135.1 Ω /km) and paper (135.2 Ω /km) is shown in Figure I.1. The simulated transmission line has a termination of 135 Ω resistive and the values of the losses are exclusively due to the presence of the bridge taps. The transmitted signal frequency test is 40 kHz, and Figure I.1 shows the losses according to the bridge taps length, for a propagation velocity whose value is a function of the signal frequency and cable characteristics of the transmission line.

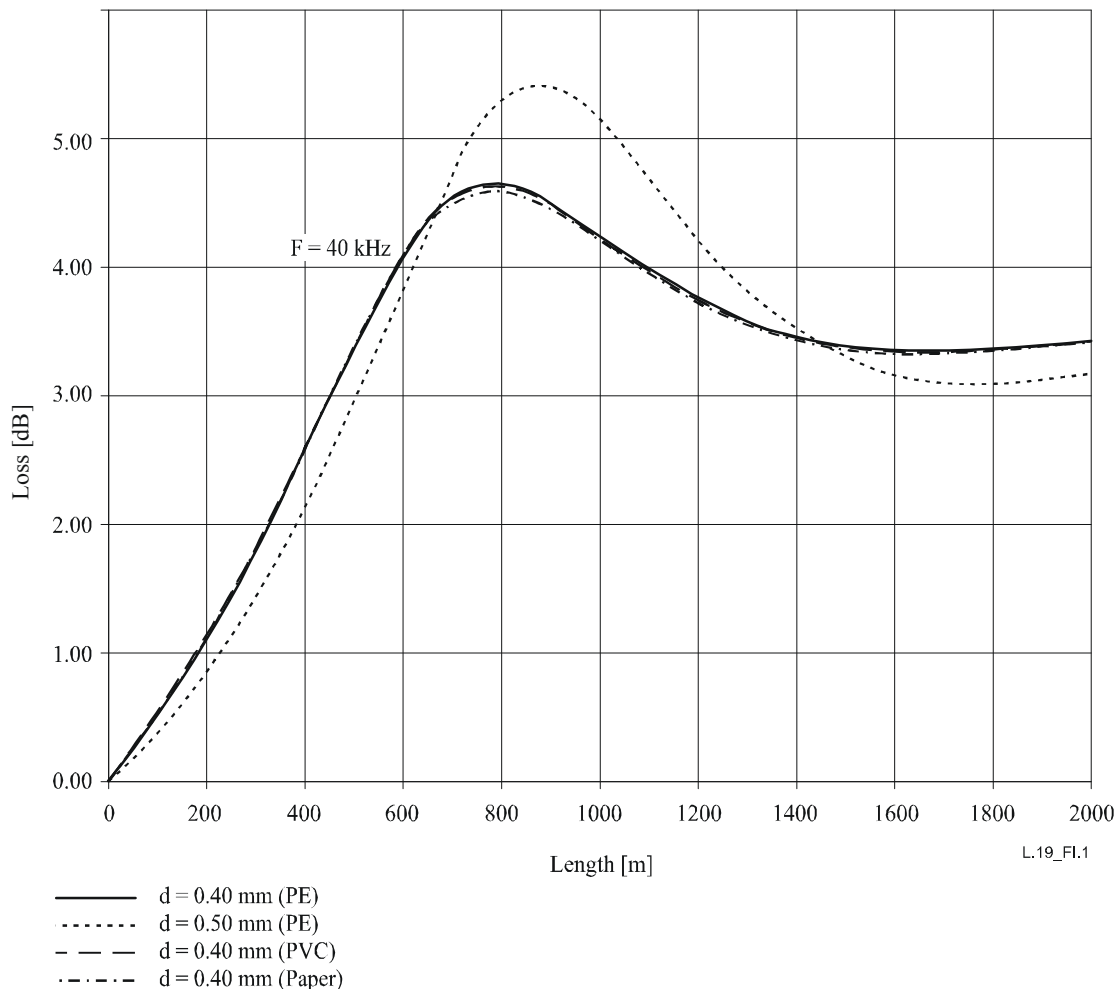


Figure I.1 – Loss due to BTs in an ISDN transmission line (40 kHz)

I.2 Effect of BT loss in HDSL systems

For an HDSL system, the loss in a transmission line with wires that have a gauge of 0.40 and 0.50 mm, or the ohmic resistance of 140.0 and 89.5 Ω/km respectively, in low frequency with an insulation of polyethylene (PE) and 0.40 mm (26 AWG) with a plastic insulation (135.1 Ω/km) and paper (135.2 Ω/km) is shown in Figure I.2. The simulated transmission line has a termination of 135 Ω resistive and the values of the losses are exclusively due to the presence of the bridge taps. The transmitted signal frequency test is 150 kHz, and Figure I.2 shows the losses according to the bridge taps length, for a propagation velocity whose value is a function of the signal frequency and cable characteristics of the transmission line.

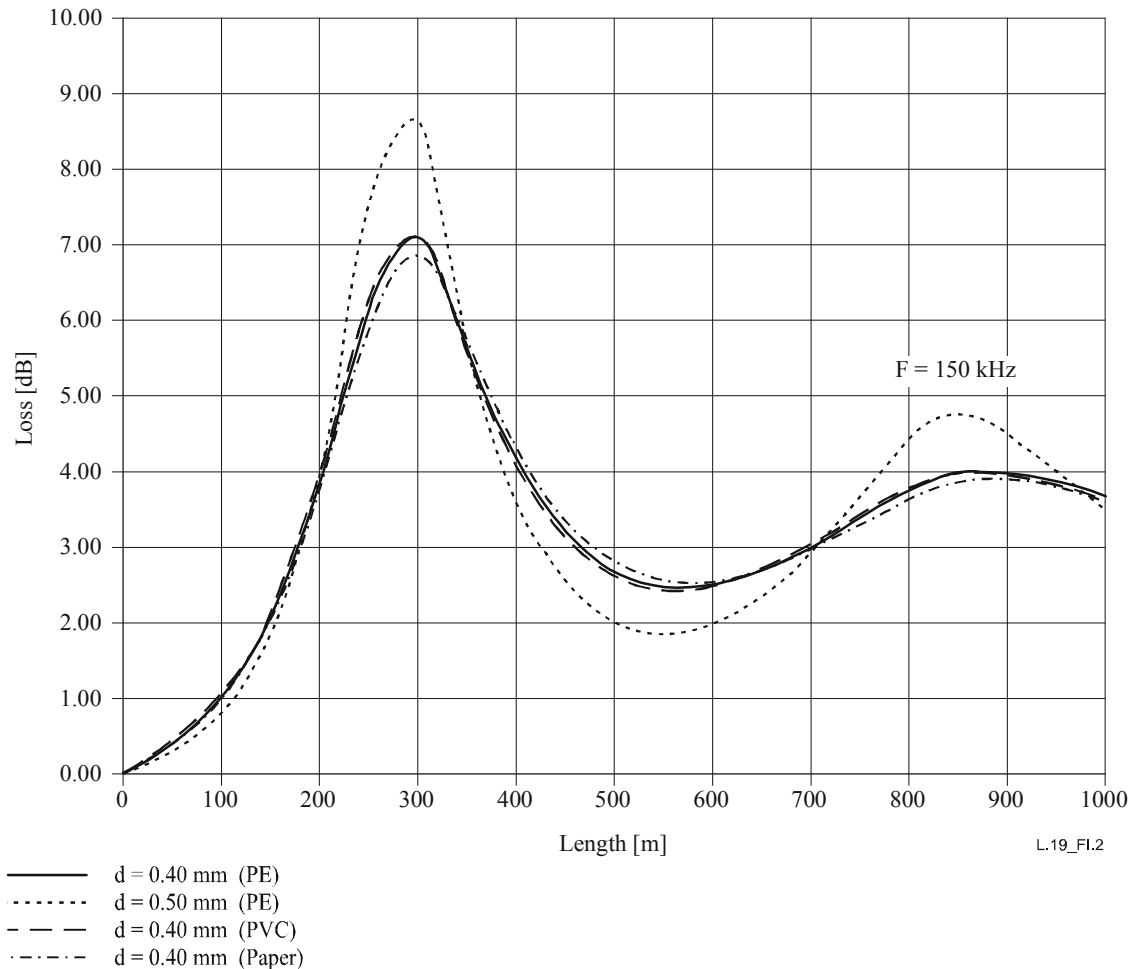


Figure I.2 – Loss due to BTs in an HDSL system (150 kHz)

I.3 Effect of BT loss in ADSL and UADSL

For ADSL and UADSL systems, the loss in a transmission line with wires that have a gauge of 0.40 and 0.50 mm, or the ohmic resistance of 140.0 and 89.5 Ω/km respectively, in low frequency with an insulation of polyethylene (PE) and 0.40 mm (26 AWG) with a plastic insulation (135.1 Ω/km) and paper (135.2 Ω/km) is shown in Figure I.3. The simulated transmission line has a termination of 100 Ω resistive and the values of the losses are exclusively due to the presence of the bridge taps. The transmitted signal frequency test is 300 kHz, and Figure I.3 shows the losses according to the bridge taps length, for a propagation velocity whose value is a function of the signal frequency and cable characteristics of the transmission line.

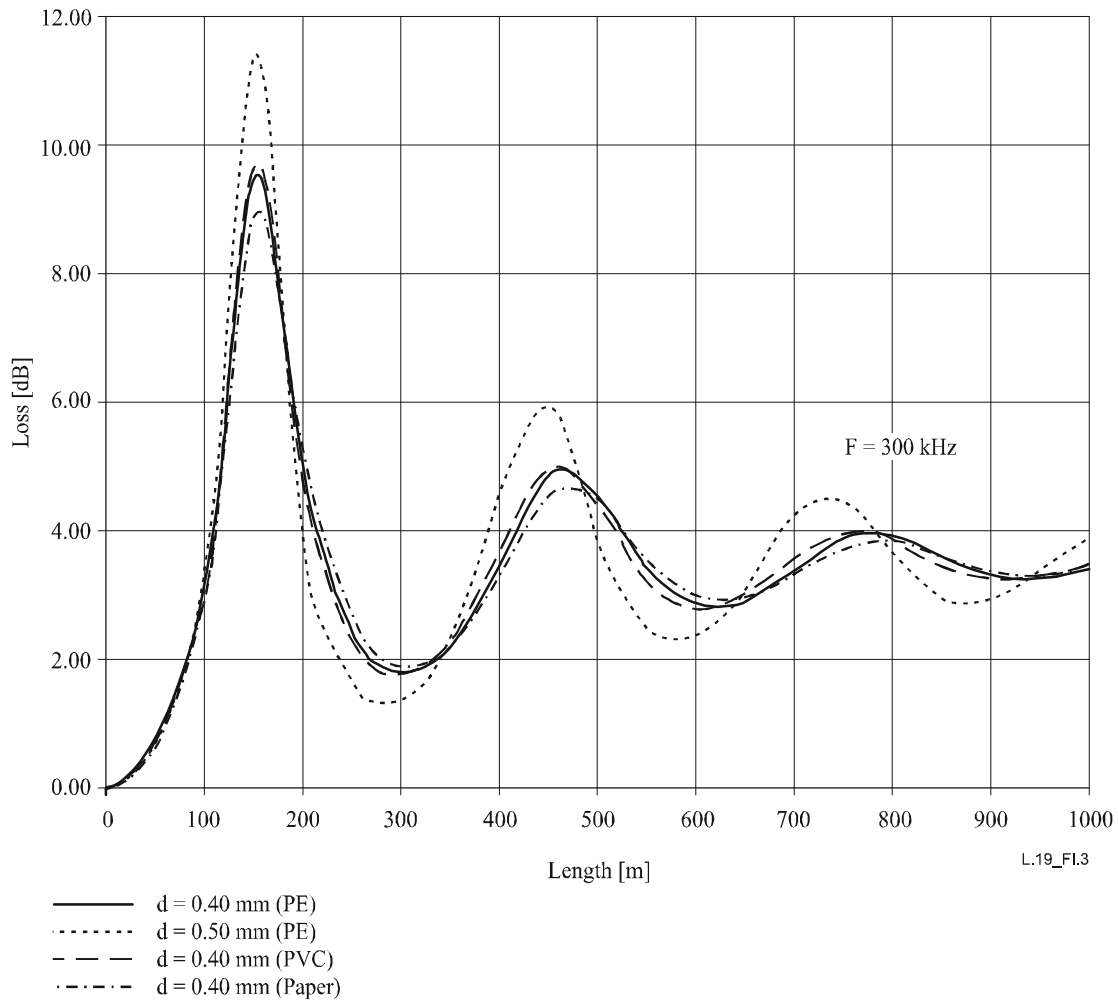


Figure I.3 – Loss due to BTs in ADSL and UADSL systems (300 kHz)

The transmission line impedance at the point of the bridge taps tends to zero for BT's lengths which are equal to the odd multiples of $\lambda/4$.

For very large bridge taps (bigger than 5λ), having the same characteristics of the transmission line wires, there is a plane attenuation of 3.52 dB (2/3 of the signal power).

The transfer function of the circuit does not depend on the position of the bridge taps when the transmission line is completely matched.

However, the losses will be different when there is no matching of the transmission lines or when there are gauge changes.

Appendix II

France Telecom experience

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

II.1 Mass deployment of ADSL: Loop qualification process

The mass deployment of ADSL may give rise to unacceptable costs due to operational issues like service provision and repair. The main issue is to determine if an existing loop is able to support ADSL or not. The process of responding to a customer's order for a given service is specific to every telecom operator and should not be considered herein.

II.2 Maximum reach of ADSL systems

The reach of ADSL for a given transmission data rate is determined by the signal-to-noise ratio at both ends of the copper line, which is strongly correlated to the following parameters: attenuation versus frequency, RF interferences, NEXT and FEXT.

In the field, noise measurements and software simulations would be enough to determine a maximum reach for a given service. This maximum reach can be calculated in terms of attenuation at 300 kHz. The total loss should be estimated by summing up the loss of the lengths of copper pair cables of different gauges.

The accuracy of this estimation depends on the reliability of the records of tests carried out on the plant, which should be checked previously.

II.3 Field quality tests of the copper pair

In order to reduce RF and impulse noise level, the copper pair has to be well balanced. For cost purposes, a network analyser is not appropriate. In most cases, automatic electrical test measurement is implemented in every central office.

First, AC and DC measurements are required in order to check that no hazardous voltage is present on the copper pair.

Second, electrical measurements, like resistance and capacitance, are very useful to verify whether the pair is or not sufficiently balanced:

- The resistance is measured between the two wires and between the two wires and the ground using a direct voltage limited to 150 volts.
- Capacitance between the two wires and the ground is measured using an alternate current. A few tens of hertz and signal processing is appropriate.

Laboratory tests should have been carried out to analyse the correlation between longitudinal unbalance and resistance and capacitance.

Resistance higher than 1 M Ω and capacitance unbalance (Delta C between wire A to earth and wire B to earth) less than 2% ensures that the cable is not damaged (moisture, etc.) and that the longitudinal unbalance does not cause interference.

Appendix III

India experience

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

Exploitation of the huge existing copper network for providing multiple services in addition to the POTS is assuming great importance. Various types of DSL and ISDN are typical examples. It is possible that more than just one service provider may need to share the same network. Attention should be paid to requirements for new copper networks that are being added, though these may not be in large scale.

The issue is to be studied from two angles, viz.,

- a) electrical requirements;
- b) installation and maintenance requirements.

Electrical requirements

The important parameters to be looked into are:

- Attenuation: This will mainly indicate the gauge of the conductor to be chosen or standardized. A 0.5-mm copper conductor is preferred, as this is already the largest gauge in use in the network. It is also proposed that a uniform gauge from the service provider to the subscriber terminal be attempted to enable grade of service and maintenance of the network. Further, the attenuation will depend on the length of the subscriber loop and, in order to provide high grade and reliable service, this needs to be limited to a maximum of about 4 km. The attenuation figures achieved in the present-day polyethylene insulated jelly-filled (PIJF) cable is in the range of 12 to 4.4 dB per km, measured at 150 kHz for gauge of conductors from 0.4 mm to 0.9 mm. Typically, for a 0.5-mm conductor, the value is 8.25 dB/km maximum. The attenuation increases with (frequency)^{1/2} and length. At 1 kHz it can be as high as 22 dB/km for a 0.5-mm gauge.
- Crosstalk: Crosstalk in the existing copper network mainly made of PIJF twisted pair can be high at high frequencies. This implies careful selection of the pairs for application other than plain voice service such as ISDN, ADSL, etc., for high-speed data transmission. However, the objective is to achieve 100% utilization without pair selection or cable rearrangements. Crosstalk manifests itself as interference downstream of the multi-pair cable. This would underline the importance of the system capability to tolerate interference, and requires further study in cooperation with ITU-T. The crosstalk achieved in the existing PIJF network is as follows:
 - NEXT: Better than 55 dB and ELFEXT 55 dB/km (RMS to be better than 67.8 dB/km all measured at 150 kHz).
- Impedance: The impedance parameter is one that is difficult to precisely define in the case of twisted pair cables. In practice it is a function of the frequency and can vary substantially from one pair to the other. However, the mismatch caused in practice may not seriously hamper the performance up to data rates of 2 Mbit/s. For higher bit rates, careful selection of the cable pair and good engineering is necessary.

Installation and maintenance requirements

Cable jointing and terminations are the most important considerations. Underground cables in general encounter joints about every 200 metres. As the outside plant is expected to support multiple types of services, its quality and reliability are required to be very high. It is a common experience that on many occasions a pair that reasonably gives a satisfactory performance for voice does not perform satisfactorily at high data rates. The heavy slowing down of data transfer and at

times a disconnection of the service itself is the result. The reason for this in most of the cases is the existence of twisted pair and screw-type joints.

The standardized method of jointing and terminating conductor is using insulation displacement connection (IDC) technology. Discrete IDC connectors and 20/25-pair modular connectors are used in the underground cable jointing. Similarly, IDC modules are used for termination of the cable in the MDF, cabinets and distribution point boxes. It is strongly recommended that in the network proposed to be used for high data rates application in addition to voice, all the twisted conductor joints and screw-type joints are replaced by IDC connectors.

Underground cables are generally laid at a depth of about one metre and it is a very expensive proposition having to attend to these cables frequently. The weak spot is the cable joint. Ingress of moisture can severely degrade the performance, particularly at high frequencies. The most commonly used type of joint closure makes use of thermo-shrinkable sleeves. This provides a watertight closure if installed with care. The disadvantage is that it requires a heat source that is generally a gas torch. Extreme care is required when used in manholes.

When an existing copper network is proposed for high bit-rate transmission, some of the network elements introduced earlier for improving voice performance like loading coils, or for providing flexibility like bridge taps, are required to be removed.

Proactive maintenance is assuming great importance, using remote and/or centralized network management systems (NMS). The periodic dressing of the outside plant terminations such as cabinets and DPs are very essential.

Appendix IV

Brazil experience

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

IV.1 Introduction

The majority of the access network used for telecommunication systems existing at the moment is still structured on copper networks. These copper networks were originally projected for the transmission of voice signals of the traditional telephone systems (POTS) and they are characterized by a narrow-band transmission line, losses and interference, which all limit the maximum reach without using a regenerator after few kilometres.

There are some factors of copper networks that need to be precisely compensated in the transmission of digital signal at higher speeds, even if they do not affect the voiceband. Besides the proper distance between the subscriber and the central office, the presence of bridge taps and gauge changes affect the transmission characteristics of cable.

The development of the large-scale integration of electronic components, as well as the improvement of digital signal processing techniques made possible new transmission techniques at high speed through symmetric copper pairs.

These new technologies allow to increase the application perspectives of the copper network. The optical and copper networks together are made feasible through a mixed architecture for the provision of services with a certain bandwidth. This is valid until the time when the fibre optics become cheaper. These techniques should be seen as the solution and/or the technology of transition that will make the existing services more economic and will incentivize the offer of new services, which would be offered only with the implementation of the optic network.

The metallic copper pairs network, used until now as a voice channel, will thereby be demanded as a broadband transmission line, serving as a means through which the signal will be transmitted at high bit rates. Therefore, the metallic copper pairs network shall be characterized and evaluated to support new services associated with these high bit rates.

IV.2 Local loop requirements

IV.2.1 DC link resistance

The maximum DC link resistance of metallic pairs in copper networks to be used in the HDSL systems must be of 700 Ω , for a wire with 0.40 mm diameter.

For ADSL systems, the maximum DC link resistance of metallic pairs in copper networks must tend to the limits shown in Table IV.1, for wires with 0.40 mm diameter and in function of its transport class (2M-1: 6 Mbit/s; 2M-2: 4 Mbit/s; 2M-3: 2 Mbit/s). The transport classes 2M-1, 2M-2 and 2M-3 are also classified according to the noise present in the transmission line. In the "A" noise model there is no HDB3 noise, while in the "B" noise model, the HDB3 noise is present.

Table IV.1 – Typical values of the maximum DC link resistance acceptable in ADSL systems

Transport class	DC link resistance [Ω]
2M-1 (A)	800
2M-1 (B)	490
2M-2 (A)	920
2M-2 (B)	590
2M-3 (A)	960
2M-3 (B)	685

Considering the typical DC link resistance of pairs with 0.40 mm diameter used in networks of 280 Ω /km with a polyethylene insulation, the typical reach is shown in Table IV.2.

Table IV.2 – Typical reach in HDSL and ADSL systems according to the maximum DC link resistance acceptable

Systems	Typical reach [km]
HDSL	2.50
ADSL – 2M-1 (A)	2.86
ADSL – 2M-1 (B)	1.75
ADSL – 2M-2 (A)	3.29
ADSL – 2M-2 (B)	2.11
ADSL – 2M-3 (A)	3.43
ADSL – 2M-3 (B)	2.45

The maximum DC link resistance of metallic pairs in copper networks in the ISDN basic access must be of 1300 Ω , for a wire with 0.40 mm diameter.

Considering the typical DC link resistance of pairs with 0.40 mm diameter used in Brazilian networks of 280 Ω /km with a polyethylene insulation, the typical reach will be approximately 4.65 km.

Table IV.3 shows the typical values for electric resistance of conductors, at 20° C, used in Brazilian networks, with polyethylene insulation for wires with 0.40 and 0.50 mm diameters and with PVC and paper insulation with 26 AWG (American wire gauge).

Table IV.3 – Typical values of electrical resistance to a pair of conductors

Frequency (kHz)	Resistance [Ω /km]			
	Polyethylene 0.40 mm	Polyethylene 0.50 mm	PVC 26 AWG	Paper 26 AWG
2.5	280.00	179.02	270.11	270.35
10	280.01	179.24	270.85	270.91
20	280.11	179.97	272.85	272.59
30	281.00	181.16	273.83	273.77
40	281.75	182.79	274.46	274.95
50	282.75	184.82	276.46	277.38
100	290.43	199.61	284.90	286.20

Table IV.3 – Typical values of electrical resistance to a pair of conductors

Resistance [Ω /km]				
Frequency (kHz)	Polyethylene 0.40 mm	Polyethylene 0.50 mm	PVC 26 AWG	Paper 26 AWG
150	302.07	218.72	296.64	298.94
200	316.39	239.13	312.31	315.97
300	349.17	279.17	347.30	353.76
500	417.43	350.24	425.61	437.60
700	481.18	410.91	499.69	515.79
1000	566.52	488.86	596.58	617.34

IV.2.2 Insertion loss

The maximum insertion loss acceptable for the HDSL systems is 30 dB at 150 kHz.

The maximum insertion loss acceptable for metallic pairs in a copper network to be used in the ADSL system, at 300 kHz, is shown in Table IV.4, depending on its transport class.

Table IV.4 – Maximum acceptable insertion loss in ADSL systems

Transport class	Maximum insertion loss [dB]
2M-1 (A)	41
2M-1 (B)	25
2M-2 (A)	47
2M-2 (B)	30
2M-3 (A)	49
2M-3 (B)	35

The maximum insertion loss acceptable for the ISDN basic access is 42 dB at 40 kHz.

At 40 kHz, which is the testing or reference frequency in ISDN basic access, the typical attenuation and reaches are shown in Table IV.5.

Table IV.5 – Insertion loss versus typical reach of metallic pairs for ISDN basic access

Diameter [mm]	Typical attenuation [dB/km]	Typical reach [km]
0.30	10.4	4.04
0.40	9.0	4.67
0.50	6.2	6.77
0.65	4.0	10.5
0.90	2.3	18.3

The typical reaches shown in Table IV.5 refer to a transmission line without bridge taps, gauge changes or any other connection system. The loss is only due to the media attenuation.

IV.2.3 Return loss

The return loss, related to the termination of 135 Ω , at 150 kHz, should be at least 16 dB for the ISDN systems.

The return loss in function of the frequency is supplied by the following publications:

- *Transmission and Multiplexing (TM), High Bit-rate Digital Subscriber Line (HDSL) transmission system on metallic local lines; HDSL core specification and applications for 2048 kbit/s based access digital sections including HDSL dual-duplex Carrierless Amplitude Phase Modulation (CAP) based system* (1995 technical report from ETSI);
- *ISDN Basic Access Digital Subscriber Lines* (Technical Reference TR-TSY-000393 from Bellcore);
- *Integrated Services Digital Network (ISDN) – Basic Interface for Use on Metallic Loops for Application at the Network Side of NT, Layer 1 Specification* (ANSI T1.601* – 1998).

IV.2.4 Bit error rate (BER)

The acceptable bit error rate (BER) in the HDSL, ADSL systems and in the ISDN basic access systems must be lower than or equal to 10^{-7} .

Impulsive noise and undesired electromagnetic coupling in a transmission line are the ones responsible for bit errors during data transmission.

IV.2.5 Unbalance

For HDSL systems, the unbalance on a testing metallic pair must be higher than 42.5 dB at 150 kHz, decreasing by 5 dB/decade with the increase of frequency.

For ADSL systems, the unbalance on a testing metallic pair must be higher than 40 dB at frequencies between 20 and 1100 kHz, while for ISDN basic access, the unbalance must be higher than 60 dB until 4 kHz and higher than 55 dB between 4 and 160 kHz.

IV.2.6 Near-end crosstalk (NEXT)

The near-end crosstalk (NEXT) loss for HDSL systems must attend the limits specified in Table IV.6, at 150 kHz, in function of the number of disturbers in a group of 50 pairs.

Table IV.6 – Acceptable near-end crosstalk loss

Number of disturbers	Minimum attenuation [dB]
1	63
10	60
49	54

The NEXT loss for ISDN basic access must attend the limits specified in Table IV.7 at 40 kHz, in function of the number of disturbers in a group of 50 pairs.

* T1 standards are maintained since November 2003 by ATIS.

Table IV.7 – Acceptable near-end crosstalk loss

Number of disturbers	Minimum attenuation [dB]
1	72
10	67
49	63

IV.2.7 Number of pairs with HDSL, ADSL and ISDN basic access in the same cable

The use of metallic pairs for HDSL, ADSL and for ISDN basic access in a cable or in a group within the cable is mainly determined by the conditions of the electromagnetic coupling to which these pairs are submitted, resistive and capacitive unbalance, external electromagnetic sources and noise, insulation, shielding, number of pairs in the same cable.

The electromagnetic coupling and the general noise are classified as random degradation factors and can therefore not be foreseen or classified as systematic factors. This comes from the difficulty in foreseeing or predicting the number of pairs inside the same cable for any xDSL system and ISDN basic access.

IV.2.8 Connection systems in metallic pairs

Any integrate part of connection systems in a copper network must not interfere in the network transmission characteristics for HDSL, ADSL and ISDN basic access signals.

The characteristic impedance of the connections in a copper network must not alter the characteristic impedance of the metallic pair, which would lead to the increase of the return loss due to reflections.

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