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Technical Specification

Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

The present document is currently intended to be a three part specification as follows:

Part 1: "Functional requirements";

Part 2: "Transceiver specification";

Part 3: "Interoperability specification".

The present document includes clarification of the noise models, power spectral density masks and evaluation data rates.

1 Scope

The present document specifies requirements for transceivers providing very high bit-rate digital transmission on metallic, unshielded, access network wire pairs. The technology is referred to as Very high speed Digital Subscriber Line (VDSL).

The present document is part 1 of the specification for VDSL and is applicable to metallic access transmission systems designed to provide multi-megabit/s digital access over part of the existing, unshielded, metallic access network. It is concerned with the key functional and electrical requirements for VDSL. It is linecode independent and is intended to set the boundary requirements that all compliant VDSL transceivers shall meet. Part 2 is concerned with requirements on linecode and duplexing method that enable the requirements of part 1 to be met. Part 3 is a full interoperability specification for VDSL designed to ensure that VDSL transceivers from different manufacturers inter-operate.

The definition of physical interfaces is outside the scope of this specification. If an appropriate interface for a specific application exists it may be included to describe how these requirements map to it. The VDSL transmission system, in its most basic form, consists of an application independent core and an application specific block.

The core is purely a transparent STM bit-pump or ATM cell-pump which transports information from one end of the metallic access link to the other. The digital data is mapped into a core frame that is defined logically and not physically. The core frame is therefore considered to be the interface between the application specific part and the application independent part of the VDSL system. The application specific part may be subdivided into (at least) two smaller parts: mapping and interface.

The scope of the present document is shown graphically in figure 1 and figure 2, where the Network Termination (NT) and Line Termination (LT) are considered separately.

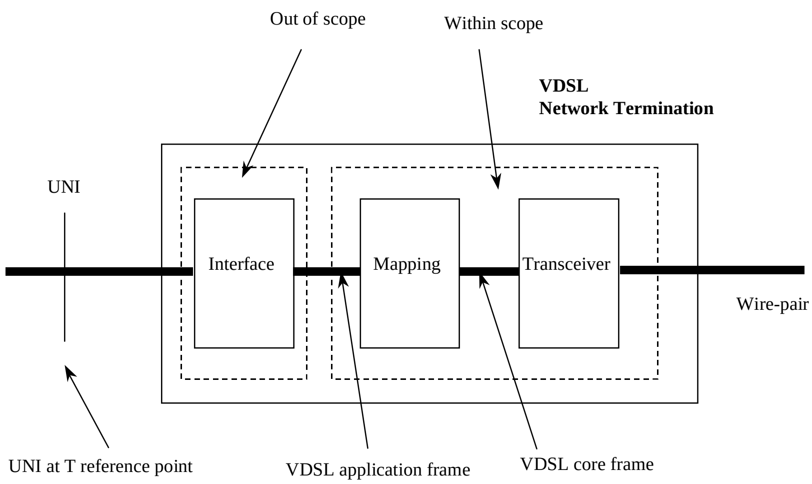


Figure 1: NT reference model scope

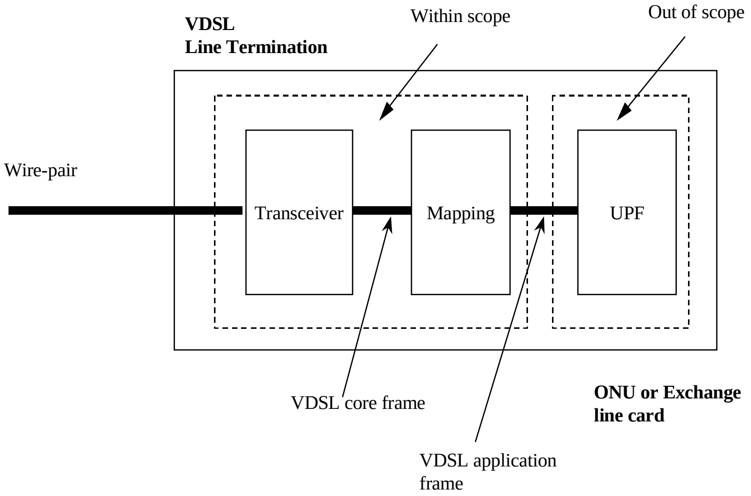


Figure 2: LT reference model scope

2 References

The following documents contain provisions that through reference in this text constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, subsequent revisions do apply.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] ANSI T1.413 Issue 2 (1998): "Asymmetric Digital Subscriber Line (ADSL)".

[2] EN 55022 (1998): "Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement".

[3] EN 61000-4-6 (1996): "Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields".

[4] TS 102 080 (V1.3): "Transmission and Multiplexing (TM); Integrated Services Digital Network (ISDN) basic rate access; Digital transmission system on metallic local lines".

[5] ETS 300 001: "Attachments to the Public Switched Telephone Network (PSTN); General technical requirements for equipment connected to an analogue subscriber interface in the PSTN".

[6] TBR 021: "Terminal Equipment (TE); Attachment requirements for pan-European approval for connection to the analogue Public Switched Telephone Networks (PSTNs) of TE (excluding TE supporting the voice telephony service) in which network addressing, if provided, is by means of Dual Tone Multi Frequency (DTMF) signalling".

[7] ETS 300 019-1: "Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 1: Classification of environmental conditions".

[8] ETS 300 019-1-3: "Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 1-3: Classification of environmental conditions; Stationary use at weather protected locations".

[9] ETS 300 019-2: "Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2: Specification of environmental tests".

[10] ITU-T Recommendation G.703 (1991): "Physical/electrical characteristics of hierarchical digital interfaces".

[11] ITU-T Recommendation G.704 (1995): "Synchronous frame structures used at 1 544, 6 312, 2 048, 8 488 and 44 736 kbit/s hierarchical levels".

[12] ITU-T Recommendation G.117 (1996): "Transmission aspects of unbalance about earth".

[13] ITU-T Recommendation G.227 (1968): "Conventional telephone signal".

[14] CCITT Recommendation O.9 (1988): "Measuring arrangements to assess the degree of unbalance about earth".

[15] ITU-T Recommendation Q.552 (1996): "Transmission characteristics at 2-wire analogue interfaces of digital exchanges".

[16] RFC 1483 (1993): "Multiprotocol Encapsulation over ATM Adaptation Layer 5, Juha Heinanen".

[17] 89/336/EEC (1989): "Guidelines on the application of council directive on the approximation of the laws of the Member States relating to electromagnetic compatibility".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following definitions apply:

clear channel: transparent bit or byte pipe.

crest factor: peak to RMS voltage ratio.

FTTCab: used to define when VDSL LT transceivers located physically at a node (normally the Cabinet or PCP) in the periphery of the access network.

FTTEx: used to define when VDSL LT transceivers located physically at the serving Local Exchange.

Downstream: transmission in the direction of LT towards NT (network to customer premise).

Upstream: transmission in the direction of NT towards LT (customer premise to network).

Payload bit rate: total data rate that is available to user data in any one direction.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

f_H	Upper frequency limit of the VDSL operating band
f_I	Upper frequency limit of the passband for existing narrow-band transmission systems
$f_{L'}$	Lower frequency -3 dB point of the VDSL signal
f_L	Lower frequency limit of the VDSL operating band
f_T	Test loop calibration frequency for setting the insertion loss of the loop
kbit/s	kilo-bit per second
kbps	kilo bits per second (1 kbps = 1 000 bits per second = 1 kbit/s)
Mbps	Mega bits per second (1 Mbps = 1 000 kbps = 1 000 kbit/s)
R_V	VDSL source/load design impedance (purely resistive)
Z_0	Characteristic impedance of the test loop
Z_M	Compromise reference impedance for the VDSL splitter (usually complex)

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

2B1Q	Baseband linecode for ISDN-BA (4-PAM)
4B3T	Alternative ISDN-BA baseband linecode with wider frequency spectrum than 2B1Q
ADSL	Asymmetric DSL (1,5-8 Mbps downstream, and up to 640 kbps upstream simultaneously over a single wire-pair carrying analogue POTS or ISDN).
AM	Amplitude Modulation
AMI	Alternate Mark Inversion
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
CF	Crest Factor
CRC	Cyclic Redundancy Check
DC	Direct Current
DSL	Digital Subscriber Line (or Loop)
EM	Element Manager
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
EOC	Embedded Operations Channel
FEC	Forward Error Correction
FEXT	Far-End crosstalk
FSAN	Full Services Access Network
FTTCab	Fibre To The Cabinet (see definitions)
FTTEx	Fibre To The Exchange (see definitions)
Gx	FSAN Group of partners
HAPI	Hypothetical Application Independent Interface
HDB3	Linecode for ISDN-PRA, Digital Private or Trunk circuits (similar to AMI)
HDSL	High bit-rate Digital Subscriber Line (1, 2 or 3 wire-pairs presenting ITU-T Recommendations G.703 [10] and G.704 [11] 2 Mbps symmetric data rates or 2 wire-pairs carrying T1 to a DS1 interface).
IETF	Internet Engineering Task Force
IL	Insertion Loss
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISDN-BA	ISDN Basic-rate Access (2B+D)
ISDN-PRA	ISDN Primary Rate Access
LCL	Longitudinal Conversion Loss
LCTL	Longitudinal Conversion Transfer Loss
LT	Line Termination
NEXT	Near-end crosstalk
NT	Network Termination (at the customer premise end of the line)
OAM	Operations, Administration and Maintenance
O&M	Operations and Management
ONU	Optical Network Unit
PAM	Pulse Amplitude Modulation
PCP	Primary Cross-connect Point
PDH	Plesiochronous Digital Hierarchy
PE	Poly-Ethylene
PEP	Peak Envelope Power
PLOAM	Physical Layer Operations, Administration and Maintenance
PMD	Physical Media Dependent
PMS	Physical Media Specific
PMS-TC	Physical Media Specific-Transmission Convergence
POTS	Plain Old Telephony Service
PPP	Point-to-Point Protocol
PRC	Payload Rate Change
PSD	Power Spectral Density (usually quoted in dBm/Hz, and in the present document is restricted to single sided PSDs).
PVC	Poly Vinyl Chloride

RF	Radio Frequency
RFC	Request for comment (stable specification from IETF)
RFI	Radio Frequency Interference
RMS	Root Mean Square
SDH	Synchronous Digital Hierarchy
SNR	Signal to Noise Ratio
STM	Synchronous Transfer Mode
SW	Short Wave
TBD	To Be Decided
TC	Transmission Convergence
TE	Terminal Equipment
Telco	Telecommunications Network Operator
TELE	Telephone port for the VDSL splitter
TMN	Telecommunication Management Network
TPS	Transmission Protocol Specific
TPS-TC	Transmission Protocol Specific-Transmission Convergence
TS	(ETSI) Technical Specification
UNI	User Network Interface
VDSL	Very high speed Digital Subscriber Line
xDSL	Generic term covering the family of all DSL technologies, e.g. DSL, HDSL, ADSL, VDSL

4 Reference configuration and description

4.1 General

Figures 3 and 4 show the reference model used for VDSL. It is essentially a Fibre to the Node architecture with an Optical Network Unit (ONU) sited in the existing metallic access network (or at the serving Local Exchange or Central Office). Existing unscreened twisted metallic access wire-pairs are used to convey the signals to and from the customer's premises. This architectural model covers both short- and long-range options for the VDSL.

The model provides two or four data channels with bit rate under the control of the network operator, consisting of one or two downstream and one or two upstream channels. A single channel in each direction can be of high latency/low BER or lower latency/higher BER. Dual channels in each direction provide one channel of each type. The dual latency configuration is thought to be the minimum that is capable of supporting a sufficient full service set, although there are organizations supporting both the single latency model with programmable latency, and others requesting more than two channels/latencies. The model assumes that Forward Error Correction (FEC) will be needed for part of the payload and that deep interleaving will be required to provide adequate protection against impulse noise for transport of digitally encoded motion picture signals. The VDSL transceiver shall also be required to transport delay sensitive services (e.g. POTS/Video conferencing). The model introduces service-split functional blocks to accommodate shared use of the physical transmission media for VDSL and either POTS or ISDN-BA. The rationale behind this is that network operators are then free to evolve their networks in one of two ways: complete change out or overlay. An active Network Termination (NT) provides termination of the point-to-point VDSL transmission system and presents a standardized set of User Network Interfaces (UNIs) at the customer's premises. The NT provides the network operator with the ability to test the network up to the UNI at the customer's premises in the event of a fault condition or via nighttime routining. The home wiring transmission system is currently outside the scope of the present document.

It is envisaged that VDSL will find applications in the transport of various protocols. For each application different functional requirements must be developed for the Transport Protocol Specific - Transmission Convergence Layer (TPS-TC). This specification covers the functional requirements for the transport of ATM and STM (SDH). However the VDSL core transceiver shall be capable of supporting future additional applications, for example packet modes. VDSL transceivers shall be required to transport ATM cells to and from broadband customer premise equipment. This is a prime Telco requirement for Full Services Access Networks (see bibliography, [I-1] and [I-2]). The VDSL ATM TC functions shall adopt the same methods as described in ANSI T1.413 [1] and shall only deviate, where there are good reasons for an alternative solution.

Furthermore, VDSL transceivers shall be required to transport SDH containers and associated network timing reference(s). This would appear to be an essential functional requirement for STM (SDH) transport. It is not a requirement that SDH and ATM are transported simultaneously.

Any existing narrowband services shall not be affected by failure of power to the broadband NT. This may imply that the splitter filter is of a passive nature not requiring external power in order to provide frequency separation of the VDSL and existing narrowband signals. Further requirements concerning the splitter filter are found in clause 12.

POTS shall continue to be powered from the existing exchange node and a DC path is required from the local exchange to the customer telephone. Similarly a DC path is required for ISDN-BA in order to provide remote power feeding to the ISDN-BA NT (and that emergency power can be provided by the local exchange for one ISDN terminal to function for lifeline service).

POTS and ISDN-BA cannot exist simultaneously on the same pair at present. Network Operators may provide one or the other but not both over a single wire-pair. Network Operators may choose to provide VDSL on access lines without any narrowband services.

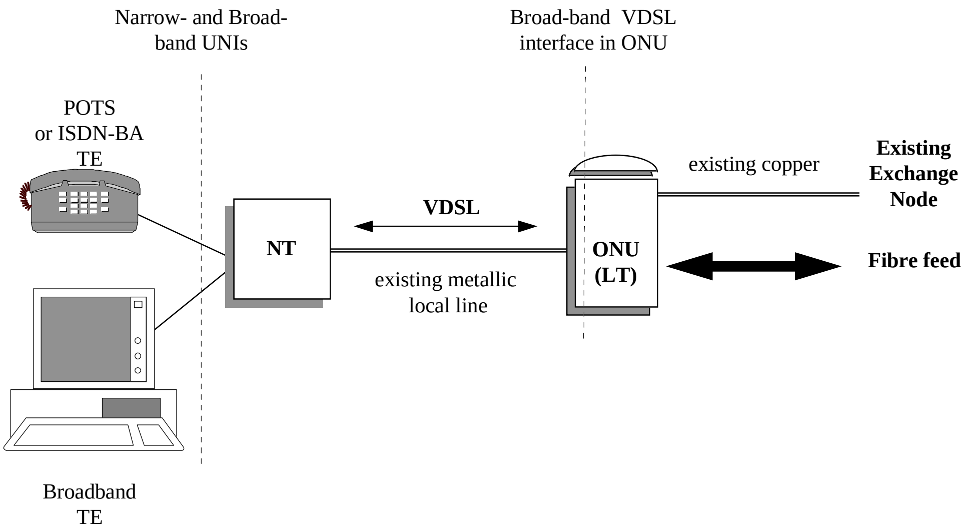
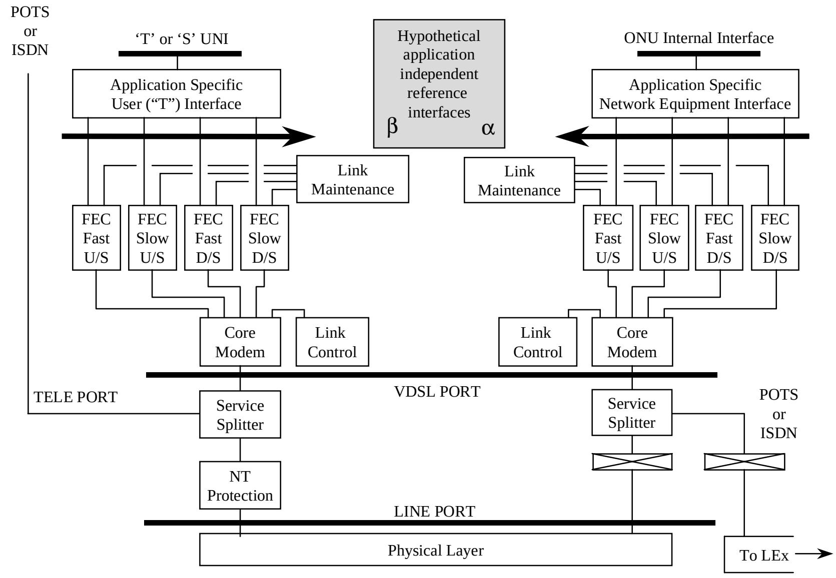


Figure 3: General reference model

Figure 4 shows the VDSL reference model and the various logical and physical interfaces between a VDSL transceiver at the NT and the LT ends of the access link. The reference points α and β of the HAPI are also shown. The HAPI is only required for performance evaluation purposes and may not be embodied in every VDSL transceiver. For convenience, dual latency paths are shown in both the up- and downstream directions (see notes in figure 4).

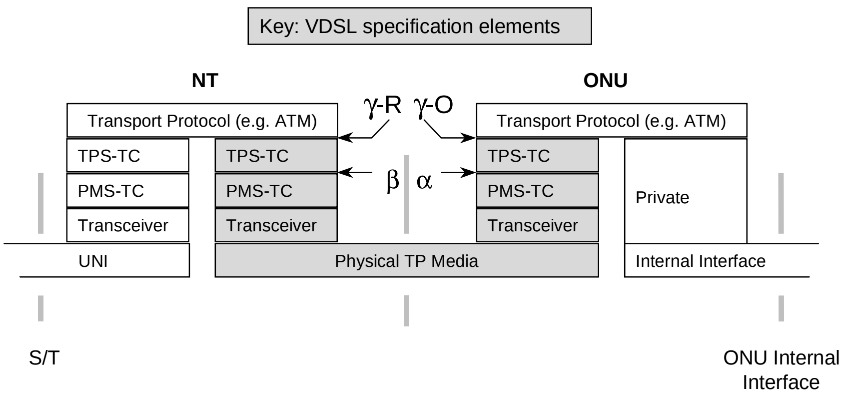
A VDSL transceiver is not required to implement the ONU internal interface or the broadband UNI. However, this is not precluded by the present document. Link maintenance is required to enable Operations, Administration and Maintenance (OAM) information flows between the LT and NT transceivers. Figure 5 shows the VDSL application reference model and the functional elements covered by the present document.



NOTE 1: It is not compulsory to implement both the fast and slow channels. Single channels with programmable latency are equally acceptable.

NOTE 2: The full definition of TPS-TC interfaces (γ-R and γ-O) are outside the scope of the present document. However key functional requirements are listed with reference to the particular application under consideration (see clause 13).

Figure 4: VDSL reference model



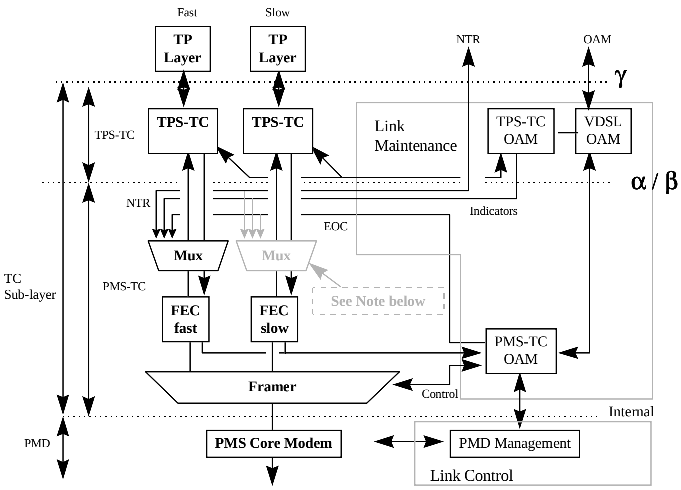
TPS-TC Transport Protocol Specific Transmission Convergence Layer
PMS-TC Physical Media Specific Transmission Convergence Layer

Figure 5: VDSL application reference model

4.2 Functional decomposition

4.2.1 The α and β interfaces

The Hypothetical Application Independent Interface (HAPI) is embodied in the α and β interfaces which apply to the LT and NT ends of the VDSL link respectively. Further requirements relating to the HAPI are given in clause 13.



NOTE 1: It is not compulsory to implement both the fast and slow channels. Single channels with programmable latency are equally acceptable.

NOTE 2: The EOC may be in the fast or slow channel or potentially in a separate TC sub-layer. The actual implementation of the EOC channel is modulation dependent and shall be described in part 2.

Figure 6: Generic VDSL functional reference model

Figure 6 above shows the generic functional reference model which indicates the disposition of major functions partitioned by the α and β interfaces. These interfaces define the separation between the application dependent Transport Protocol Specific (TPS) part and the application independent Physical Media Specific (PMS) core transceiver parts of the VDSL transmission system.

The TPS part includes transport protocol layer functions outside the scope of this specification, and transport protocol specific transmission convergence layer functions (TPS-TC).

The application independent part contains Physical Media Specific transmission convergence layer functions (PMS-TC), and transceiver (PMD) functions.

By convention the PMS-TC, TPS-TC, and transceiver layers are assumed to include applicable OAM functions. The overall VDSL link maintenance functions are associated with the application dependent part. Figure 7 shows the VDSL reference points and the scope of the OAM.

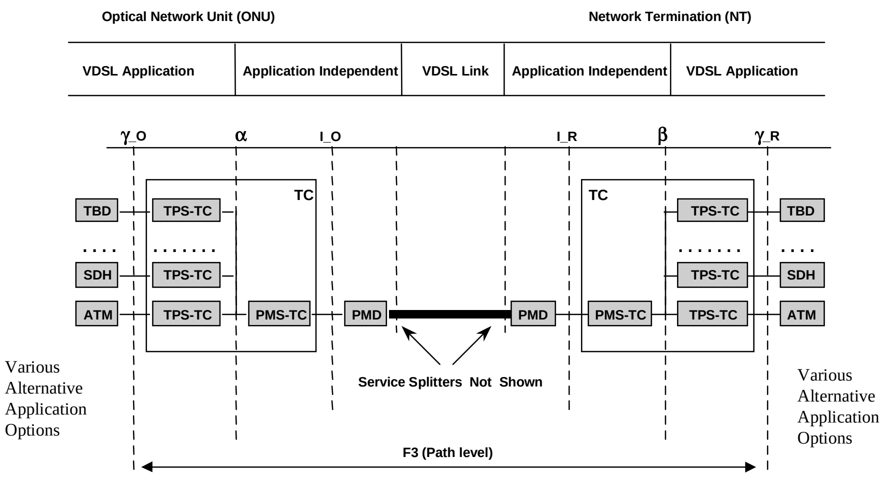


Figure 7: VDSL reference points and OAM scope

4.2.2 Elemental information flows across the α and β interfaces

Five elemental information flows across the α and β interfaces are identified:

- data flow;
- synchronization flow;
- link control flow;
- link performance and path characterization flow;
- VDSL TPS-TC performance information flow.

4.2.2.1 Data flow

The data flow shall be supported by one or two data pipes with different error protection properties and therefore different latency characteristics; it shall be byte oriented and the data shall be treated as unstructured by the application independent part.

4.2.2.2 Synchronization flow

This flow provides the means through which synchronization between the PMD level and the TC level is performed. The different considered items are:

- data (bit synchronization or byte synchronization or other synchronization flows);
- performance and path characterization primitives;
- control and performance parameters (asynchronous);
- network timing reference.

With the exception of control and performance parameter passing synchronization flows are based on a fixed timing regime. Synchronization of control and performance parameter passing is implied by a message transfer protocol.

4.2.2.3 Link Control Flow

The Link Control flow comprises all the relevant control, configuration and status messages for VDSL link. A non-exhaustive list of Control Primitives is (common to both the α and β interfaces):

- activation;
- deactivation;
- alarms and anomalies (e.g. dying gasp);
- link status;
- synchronization status.

Control parameters may include the requested data rate, link status parameters and specific bandwidth allocation parameter (at the α interface).

4.2.2.4 Link Performance and Path Characterization flow

The Link Performance and Path Characterization flow provides all the relevant performance and physical characteristics of the VDSL link.

Performance Primitives typically report defects and errors (e.g. Loss of Signal, Loss of Frame, FEC anomalies etc.) and Performance Parameters include counts of errored blocks, CRC and FEC anomalies.

Typical Path Characterization Parameters are the line attenuation, the Signal to Noise Ratio (SNR) and the Return Loss.

4.2.2.5 VDSL TPS-TC performance information flow

The application independent part shall provide means for transporting indication of remote anomalies detected in the TPS-TC (such as loss of cell delineation in the case of ATM), not relying on the correct operation of the remote TPS TC sub-layer.

5 Operations and Maintenance

5.1 VDSL Link Control

VDSL transceivers shall be capable of sending and receiving pre-defined messages intended for operation and maintenance of the VDSL transmission link. Successful reception of a message shall always be acknowledged by the receiving transceiver. The sending transceiver shall continue to repeat the message until it is successfully acknowledged by the receiving transceiver. The full definition of the protocol is outside the scope of the present document.

5.2 Embedded Operations Channel

The application independent part shall provide a full duplex Embedded Operations Channel (EOC) capable of supporting OAM flows. Operations and Maintenance (OAM) functions relating to the PMD and PMS-TC. Loop-back functionality shall be supported at the TPS-TC layer.

The EOC shall support the transport of indicator states to support the status and performance monitoring of the VDSL PMD layer. It shall provide a control channel to allow management of link characteristics (e.g. transport rates, latency, low-power mode, spectrum utilization etc.).

The payload data rate of the EOC shall not be less than 24 kbps and not more than 64 kbps. It shall be able to operate in a clear channel mode, which is a duplex, transparent bit or byte pipe.

6 ElectroMagnetic Compatibility

The system shall meet the European Union directive on ElectroMagnetic Compatibility (EMC) 89/336/EEC [17] as described in EN 55022 [2] and EN 61000-4-6 [3].

7 Climatic requirements

As VDSL may be deployed in the FTTCab model, it is necessary to specify the classes of climatic conditions in ETS 300 019-1 [7] and ETS 300 019-2 [9] that are applicable. ETS 300 019 consists of two main parts:

- Equipment Engineering; Environmental conditions and environmental tests for telecommunication equipment; Part 1: Classification of environmental conditions [7].
- Equipment Engineering; Environmental conditions and environmental tests for telecommunication equipment; Part 2: Specification of environmental tests [9].

For classification of environmental conditions, ETS 300 019-1-3 [8] contains five sub-classes, three of which are relevant to VDSL. These are:

3.1 Temperature controlled locations;

3.2 Partly temperature controlled locations;

3.3 Non-temperature controlled locations.

The requirements of the appropriate parts of ETS 300 019 relating to the design environment shall be met by VDSL transceivers.

8 Transceiver specific requirements

The transceiver related functional requirements detailed in this clause are independent of the application or service carried by the VDSL transceiver.

8.1 Classes of operation

Two classes of functional operation are defined for VDSL systems. A compliant VDSL transceiver shall be capable of meeting the requirements of either or both classes.

Class I VDSL transceivers that offer asymmetric data rates (i.e. much higher downstream than upstream data rate).

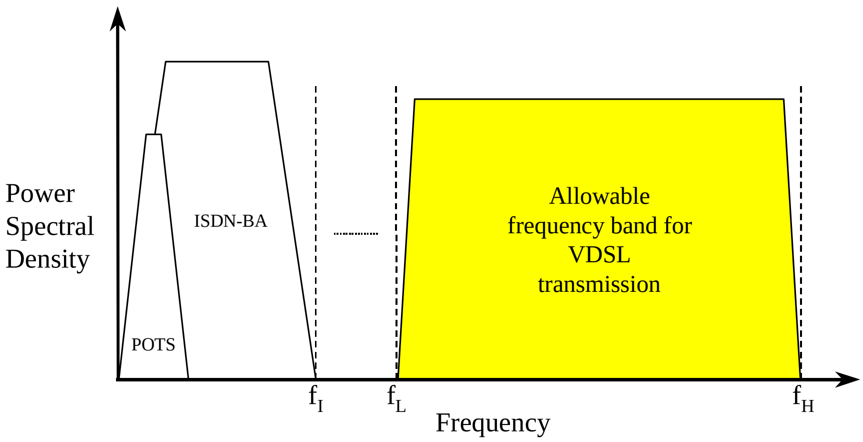
Class II VDSL transceivers that offer symmetric data rates (i.e. equal upstream and downstream data rates).

When claiming conformance to the requirements of clause 9 of the present document, the vendor shall quote whether the VDSL transceiver is compliant to class I or class II operation or both.

8.2 Frequency plan

VDSL systems may operate within the bounds of the frequency band f_L to f_H as shown in figure 8. VDSL signals shall be confined within these bands to power levels appropriate to ensure spectral compatibility with existing heritage xDSL metallic access systems such as ISDN-BA, HDSL and ADSL, and to prevent unnecessary radiated emissions. Compatibility with existing narrowband services will set limits on the upper passband limit, f_I. This is defined in subclause 11.2. There are two alternate deployment scenarios that affect the frequency plan. The LT transceiver may be placed either in the Central Office Exchange (FTTEx) or at a street location (FTTCab). The frequency plan changes depending on the crosstalk environment and the presence of narrowband services.

The generic boundary values for the VDSL transmission band are f_L = 300 kHz and f_H = 30 MHz. The power spectral density upper limits attributed to the VDSL transceiver are specified further in subclause 8.3.5 where absolute "brick-wall" limits are defined.



NOTE 1: Optimization of the lower frequency limit for VDSL (f_L) is very complex because of the need to ensure spectral compatibility with other xDSL transmission systems operating in the same cable plant (i.e. within the same multi-pair wire grouping).

NOTE 2: The operation of VDSL below the lower frequency limit (f_L) is not precluded, e.g. on new lines where existing narrowband services may not be present. The issue of VDSL transmit energy polluting parts of the spectrum occupied by other xDSL systems (e.g. ADSL) may preclude the use of certain parts of the spectrum, especially in the VDSL upstream direction of transmission. For example, there may be situations where it is possible to use the lower frequencies especially if ADSL systems are not present in the same binder. However, in some circumstances where ADSL is present it may be prudent to place the start of the VDSL band above 1,1 MHz.

NOTE 3: National regulations may preclude the use of certain frequency ranges.

Figure 8: Generic frequency plan for VDSL

8.3 Transceiver interface

For compliance with the requirements of this clause the following interfaces are defined. These ports are shown in figure 17.

TELE port: The physical interface to POTS or ISDN-BA at the service splitter.

VDSL port: This port may be internal to the VDSL equipment where part(s) of the splitter are incorporated into ONU linecards or NTs. Physical access may or may not be available for test purposes.

LINE port: The physical interface to the wire-line.

8.3.1 Impedance

A reference source/load impedance of R_V = 135 Ω (i.e. purely resistive, 135 + j0 Ω) over the complete VDSL frequency band shall be used for the design of both the LT and NT transceivers when matching to the metallic access wire-pair. This enables a compromise high-frequency impedance match to the various unshielded cable types encountered in European metallic access networks.

NOTE: The optional use of a more optimum impedance for specific countries or regions is not precluded.

8.3.2 Return loss

The minimum return loss requirement is defined to limit signal power uncertainties due to the tolerance of the line interface impedance.

NOTE 1: The return loss $1/\Gamma = (Z + RV)/(Z - R_V)$ is an alternative way to specify an impedance (Z) normalized to the chosen design impedance. This makes impedance tolerance and minimum return loss similar quantities. Its definition is independent of the characteristic impedance Z_0 of the cable because VDSL can handle a wide range of cable types having significantly different Z_0 values.

The return loss of the VDSL transceiver, including the high pass part of the splitter (i.e. measured at the LINE port) shall be greater than or equal to 18 dB across the VDSL frequency band when measured against a reference impedance of R_V.

NOTE 2: The value of 18 dB specifies the more general case when an external POTS/ISDN splitter is involved and refers to the splitter output port (LINE port). Where a splitter is not used, the VDSL transceiver return loss may be as low as 12 dB. Where the splitter is an integral part of the VDSL transceiver, the return loss of the transceiver may be as low as 12 dB.

The splitter output port return loss requirements shall be met for the full range of possible values of both the input port (VDSL port) termination and POTS/ISDN port (TELE port) termination.

8.3.3 Balance about earth

The equipment balance should be better than the anticipated cable balance in order to minimize the unwanted emissions and susceptibility to external RFI. The typical worst case balance for an aerial dropwire has been observed to be in the range 30 dB to 35 dB, therefore the VDSL equipment should be significantly better than this.

The transmitter source balance about earth shall be evaluated according to the LCTL method CCITT Recommendation O.9 [14] and ITU-T Recommendation G.117 [12].

All exposed ports carrying a VDSL signal shall exhibit a balance of greater than 55 dB below f_L, and then falling at 6 dB/octave until intercepting 43 dB which shall be sustained until 30 MHz. This shall be measured at any exposed port carrying a VDSL signal.

NOTE: A VDSL transceiver, when connected to poorly balanced aerial telephony wire-pairs, could emit levels of unwanted RF emissions which may, in some circumstances, cause interference to existing licensed users of the HF radio spectrum (e.g. SW listeners). The present document currently covers the requirements for VDSL transceivers operating over wire-pairs in normal operation (i.e. non-fault) where the balance of the wire-pair exceeds 30 dB.

8.3.4 Wideband launch power

For compliance with the requirements detailed in this subclause the VDSL transceiver shall be terminated in the design impedance (R_V) and be configured to transmit pseudo-random data with any repetitive framing patterns enabled. Power shall be measured across the termination resistance of R_V.

The average wideband power of the transmitted VDSL signal measured over the frequency range 10 kHz to 30 MHz shall be no greater than +11,5 dBm when terminated with an impedance of R_V. This shall be measured at the LINE port. There shall be no energy inserted into the TELE port during this test.

8.3.5 Power spectral density

A VDSL transceiver shall have the capability of operating according to the requirements of all transmitter PSD masks described in this subclause. These masks shall be measured at the LINE port when it is terminated by impedance R_V. These masks shall apply equally to class I and class II compliant transceivers.

For the purposes of compliance with this requirement, a measurement resolution bandwidth of 10 kHz (in line with standard EMC practice) shall be used.

The location of the LT transceiver (FTTCab or FTTEx) effects the allowable crosstalk and therefore the PSD masks for both the LT and the NT.

- Where the LT is situated in a street cabinet (FTTCab scenario) two groups of PSD masks are defined. The PSD masks for the LT and NT are identical in this case. All groups contain two masks, mask M1 with notches (see subclause 8.3.5.1) and mask M2 without notches (see subclause 8.3.5.2). The symbolic names of the masks are shown in table 1 and their boundary values detailed in table 2.
- In the case where the LT is situated in the central office exchange (FTTEx scenario) five groups of PSD masks are defined for the LT and two for the NT. All groups contain two masks, mask M1 with notches (see subclause 8.3.5.1) and mask M2 without notches (see subclause 8.3.5.2). The symbolic names of the masks are shown in table 1 and their boundary values detailed in tables 3 and 4.
- At frequencies below 1 104 kHz masks M1 and M2 are identical. At higher frequencies the PSD for mask M2 is boosted as shown in tables 2,3 and 4 (Pcab.#.M2, Pex.#.LT.M2, Pex.#.NT.M2).

The following tables shall be used as upper bounds for the PSD when joining the points using straight lines on a graph with a logarithmic frequency scale (Hz) and a linear power density scale (dBm/Hz). The different PSD masks are illustrated in annex D.

Table 1: Overview of all PSDs
The symbolic names refer to the detailed specifications in tables 2, 3 and 4

Scenario	No baseband on same wire pair			Baseband on same wire pair	
FTTCab.LT	Pcab.D.M1 Pcab.D.M2			Pcab.P.M1 Pcab.P.M2	
FTTCab.NT	Pcab.D.M1 Pcab.D.M2			Pcab.P.M1 Pcab.P.M2	
FTTEx.LT	Pex.D1.LT.M1 Pex.D1.LT.M2	Pex.D2.LT.M1 Pex.D2.LT.M2	Pex.D3.LT.M1 Pex.D3.LT.M2	Pex.P1.LT.M1 Pex.P1.LT.M2	Pex.P2.LT.M1 Pex.P2.LT.M2
FTTEx.NT	Pex.D.NT.M1 Pex.D.NT.M2			Pex.P.NT.M1 Pex.P.NT.M2	

Table 2: Specification of all PSD masks for the FTTCab scenario

Frequency (kHz)	PSD line start point (dBm/Hz)	Frequency (kHz)	PSD line end point (dBm/Hz)	Slope
Pcab.#.M2	**FTTCab (LT/NT) Boosted.**			
1 104	-60	1 349	-51,3	30 dB/octave
1 349	-51,3	10 000	-60	-10 dB/decade
10 000	-60	30 000	-60	Flat
30 000	-60	30 000	-120	Brick wall
Pcab.D.M1	**FTTCab (LT/NT) No baseband services.**			
0	-90	552	-90	Flat
552	-90	1 104	-60	30 dB/octave
1 104	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
Pcab.P.M1	**FTTCab (LT/NT) With baseband services.**			
0	-110	225	-110	Flat
225	-110	225	-90	Brick wall
225	-90	552	-90	Flat
552	-90	1 104	-60	30 dB/octave
1 104	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
NOTE 1: The PSD mask for Pcab.D.M2 is identical to Pcab.D.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pcab.#.M2. NOTE 2: The PSD mask for Pcab.P.M2 is identical to Pcab.P.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pcab.#.M2.				

Table 3: Specification of all PSD masks for the LT in the FTTEx scenario

Frequency (kHz)	PSD line start point (dBm/Hz)	Frequency (kHz)	PSD line end point (dBm/Hz)	Slope
Pex.#.LT.M2	**FTTEx (LT) Boosted.**			
1 104	-39,5	1 394	-51,44	-36 dB/octave
1 394	-51,44	10 000	-60	-10 dB/decade
10 000	-60	30 000	-60	Flat
30 000	-60	30 000	-120	Brick wall
Pex.D1.LT.M1	**FTTEx (LT) No baseband services present in the bundle.**			
0	-39,5	1 104	-39,5	Flat
1 104	-39,5	1 677	-60	-36 dB/octave
1 677	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
Pex.D2.LT.M1	**FTTEx (LT) No baseband service on same pair. Baseband services and ADSL over POTS present in the bundle.**			
0	-60	108	-60	Flat
108	-60	138	-39,5	48 dB/octave
138	-39,5	1 104	-39,5	Flat
1 104	-39,5	1 677	-60	-36 dB/octave
1 677	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
Pex.D3.LT.M1	**FTTEx (LT) No baseband services on same pair. Baseband services and ADSL over ISDN present in the bundle.**			
0	-60	217	-60	Flat
217	-60	276	-39,5	48 dB/octave
276	-39,5	1 104	-39,5	Flat
1 104	-39,5	1 677	-60	-36 dB/octave
1 677	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
Pex.P1.LT.M1	**FTTEx (LT) Baseband services on same pair. ADSL over ISDN present in the bundle.**			
0	-90	138	-90	Flat
138	-90	138	-60	Brick wall
138	-60	217	-60	Flat
217	-60	276	-39,5	48 dB/octave
276	-39,5	1 104	-39,5	Flat
1 104	-39,5	1 677	-60	-36 dB/octave
1 677	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
Pex.P2.LT.M1	**FTTEx (LT) Baseband services on same pair. ADSL over POTS present in the bundle.**			
0	-90	138	-90	Flat
138	-90	138	-39,5	Brick wall
138	-39,5	1 104	-39,5	Flat
1 104	-39,5	1 677	-60	-36 dB/octave
1 677	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
NOTE 1: The PSD mask for Pex.D1.LT.M2 is identical to Pex.D1.LT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.LT.M2. NOTE 2: The PSD mask for Pex.D2.LT.M2 is identical to Pex.D2.LT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.LT.M2. NOTE 3: The PSD mask for Pex.D3.LT.M2 is identical to Pex.D3.LT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.LT.M2. NOTE 4: The PSD mask for Pex.P1.LT.M2 is identical to Pex.P1.LT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.LT.M2. NOTE 5: The PSD mask for Pex.P2.LT.M2 is identical to Pex.P2.LT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.LT.M2.				

Table 4: Specification of all PSD masks for the NT in the FTTEx scenario

Frequency (kHz)	PSD line start point (dBm/Hz)	Frequency (kHz)	PSD line end point (dBm/Hz)	Slope
Pex.#.NT.M2	**FTTEx (NT) Boosted.**			
1 104	-60	1 349	-51,3	30 dB/octave
1 349	-51,3	10 000	-60	-10 dB/decade
10 000	-60	30 000	-60	Flat
30 000	-60	30 000	-120	Brick wall
Pex.D.NT.M1	**FTTEx (NT) No baseband services.**			
0	-39,5	138	-39,5	Flat
138	-39,5	307	-90	-48 dB/octave
307	-90	552	-90	Flat
552	-90	1 104	-60	30 dB/octave
1 104	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
Pex.P.NT.M1	**FTTEx (NT) With baseband services.**			
0	-90	552	-90	Flat
552	-90	1 104	-60	30 dB/octave
1 104	-60	10 000	-60	Flat
10 000	-60	30 000	-120	-38 dB/octave
NOTE 1: The PSD mask for Pex.D.NT.M2 is identical to Pex.D.NT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.NT.M2. NOTE 2: The PSD mask for Pex.P.NT.M2 is identical to Pex.P.NT.M1 at all frequencies below 1 104 MHz. Above this frequency the PSD mask is identical to Pex.#.NT.M2.				

8.3.5.1 Mask M1 (notched)

Notching is implemented in the internationally standardized amateur radio bands (see table 10) to limit the transmitted PSD within these designated bands. The notching is provided to reduce the effect of unwanted radiated emissions from VDSL causing undue interference to existing licensed users of that part of the spectrum.

Class I and II operation shall be possible within the power density constraints imposed by Mask M1. A VDSL transceiver conforming to the requirements of Mask M1 shall be able to reduce the PSD simultaneously to below -80 dBm/Hz in one or more of the internationally standardized Amateur Radio bands listed in table 10.

It is desirable to implement programmability of the notch frequencies to cater for national and regional variations.

8.3.5.2 Mask M2 (unnotched)

Class I and class II operation shall be possible within the power density constraints imposed by Mask M2.

Mask M2 may be used when EMI effects are weak and therefore notching of the amateur radio bands is not required.

8.3.6 A-B leg (tip-ring) reversal

All requirements in the present document shall be unaffected by reversal of the A and B leg (or tip and ring) connections.

8.4 Transmitter power back off

In order to prevent unwanted detrimental interactions between VDSL transceivers operating on the same multi-pair cable the ability to lower the transmitter power spectral density shall be provided.

The VDSL transmitter shall have an ability to reduce its transmit PSD whenever the required SNR margin at the corresponding receiver is exceeded significantly when the transmitter operates at its maximum PSD. The adjustment is attenuation to reduce the transmit spectrum below the maximum allowed. The minimum attenuation allowed is zero, i.e. if the system cannot obtain the specified SNR margin at a receiver then the corresponding transmitter will transmit at its maximum allowed power spectral density.

8.4.1 Upstream back off

Power back off shall be provided in the upstream direction, NT → LT, so that crosstalk from systems on short lines does not unduly compromise service on long lines. The back-off method shall be described in Part 2. The NT shall perform power back off autonomously; however, the management system shall provide the facility to change the back off parameters.

8.4.2 Downstream back off

Power back off shall be provided in the downstream direction, LT → NT, to reduce the risk of interference with other xDSL systems running through the cabinet or node containing the VDSL system.

8.5 Transceiver latency

There are currently two options defined. These are known as single latency mode and dual latency mode (see subclauses 8.5.2 and 8.5.3). It is not intended that both options be implemented within the same transceiver.

8.5.1 Trade-off between channel latency and impulse noise immunity

VDSL systems shall provide protection against disturbance from impulse noise. Furthermore they shall provide at least two levels of protection. The level of protection shall be set and controlled via the Network Management Element Manager. The lowest level of protection is required to support latency sensitive services such as voice, while the highest level is required to support burst error sensitive services such as entertainment video.

NOTE: Some network operators require more than two levels of protection.

A "low-latency" VDSL channel shall exhibit no greater than 1 ms delay (average of upstream and downstream) between the α and β interfaces. A "high-latency" VDSL channel shall have a programmable delay between the α to β interfaces. The maximum delay of 20 ms being capable of sustaining error free performance when the path is subject to a noise burst of up to 500 µs (see subclause 9.3.2.7). Optionally, it is permitted to operate with a maximum delay of up to 10 ms when subject to a noise burst of duration up to 250 µs.

8.5.2 Single latency mode

In a "single-latency" configuration, all the VDSL system data payload capacity is dedicated to one channel.

A "single-latency" VDSL system shall provide programmable burst error protection. The level of protection shall be chosen by setting the latency in the range from 1 ms to 20 ms in approximately 1 ms increments. Additional intermediate levels of protection may be provided. Configuration of the burst error correction behaviour shall be provisioned via the Network Management Element Manager.

8.5.3 Dual latency mode

In a dual-latency configuration the VDSL system data payload capacity is divided between two channels - the "fast-channel" and "slow-channel".

A "dual-latency" VDSL system shall provide "low-latency" on the "fast-channel" and "high-latency" on the "slow-channel" concurrently. The configuration of the burst-error correction behaviour of both channels may be programmable via the Network Management Element Manager (in particular to provide various trade-offs between latency and burst error performance for the slow-channel).

The allocation of capacity between the "fast-channel" and "slow-channel" shall be configured at start-up via the Network Management Element Manager.

8.5.4 Measuring latency

Implementations shall provide the means to verify delay between the α to β interfaces for the purposes of laboratory design qualification testing, although this may require additional external hardware and software not required for normal use.

8.6 Remote powering

Remote powering (via. the wire-line) of the broadband VDSL transceiver located in the NT is not required. Existing narrowband services carried in the baseband shall not be affected by removal of local power to the broadband NT.

8.7 Power-down mode

A low power and/or power down mode shall be provided when the transceiver is not in use (see subclause 10.1).

8.8 Repeatered operation

Repeatered operation for VDSL transceivers is not required.

8.9 Payload bit-rates

The payload rates shown in table 5 shall be provided to ensure that the transmission performance requirements of the present document can be met. The line rate is left to the vendor, but it shall be sufficient to carry the additional overhead necessary to ensure that the transmission performance requirements can be met. The overhead will include components necessary for Forward Error Correction, maintenance channel, synchronization, etc.

Selection of the payload bit rate shall be performed according to one of the following two methods:

1) the network operator performs selection at installation. The bit rate shall be fixed for the duration of service provision to the customer and would normally be governed by the Element Manager or TMN;

2) selection is performed at installation as in method 1. However, the selected payload can be changed via a Payload Rate Change (PRC) procedure under the responsibility of an Operations and Management (O&M) entity under the control of the Network Operator. The purpose of this O&M is to guarantee that the PRC procedure will never induce network instability or increase spectral incompatibility between VDSL and other services.

NOTE 1: Customer control, or autonomous/dynamic rate adaptation, of the VDSL line rate is specifically excluded for reasons of increased likelihood of spectral incompatibility between different VDSL and other heritage xDSL systems operating in the same multi-pair cable.

Table 5: Payload bit-rates

Class (code) of operation	Downstream (kbps)	Upstream (kbps)
Class I (A4)	362 x 64 = 23 168	64 x 64 = 4 096
Class I (A3)	226 x 64 = 14 464	48 x 64 = 3 072
Class I (A2)	134 x 64 = 8 576	32 x 64 = 2 048
Class I (A1)	100 x 64 = 6 400	32 x 64 = 2 048
Class II (S5)	442 x 64 = 28 288	442 x 64 = 28 288
Class II (S4)	362 x 64 = 23 168	362 x 64 = 23 168
Class II (S3)	226 x 64 = 14 464	226 x 64 = 14 464
Class II (S2)	134 x 64 = 8 576	134 x 64 = 8 576
Class II (S1)	100 x 64 = 6 400	100 x 64 = 6 400

NOTE 2: Optionally, other payload data rates may be provided to enhance the granularity of operation. However, transmission performance at these payload rates remains undefined by the present document.

9 Transmission performance

The performance requirements given in this clause shall be met by a VDSL transceiver operating in the specific payload mode outlined by the operation codes given in table 5.

9.1 Test procedure

The purpose of this subclause is to provide an unambiguous specification of the test set-up, the insertion path and the way in which signal and noise levels are defined. The tests are focused on the noise margin, with respect to the crosstalk noise or impulse noise levels when VDSL signals are attenuated by standard test-loops and interfered with standard crosstalk noise or impulse noise. This noise margin indicates what increase of crosstalk noise or impulse noise level is allowed under (country-specific) operational conditions to ensure sufficient transmission quality.

NOTE: The interpretation of noise margin, and the development of deployment rules based on minimum margin requirements under operational conditions, are not the responsibility of transceiver manufacturers. Nevertheless, it is recommended that manufacturers provide Network Operators with models that enable them to perform reliable predictions on transceiver behaviour under deviant insertion loss or crosstalk conditions. Different linecodes or duplexing techniques may behave differently.

9.1.1 Test set-up definition

Figure 9 illustrates the functional description of the test set-up. It includes:

- the test loops, as specified in subclause 9.2;
- an adding element to add the impairment noise (a mix of random, impulsive and harmonic noise), as specified in subclause 9.3;
- a high impedance, and well balanced (e.g. better than 60 dB across the whole VDSL band) differential voltage probe connected with level detectors such as a spectrum analyzer or a true rms voltmeter.

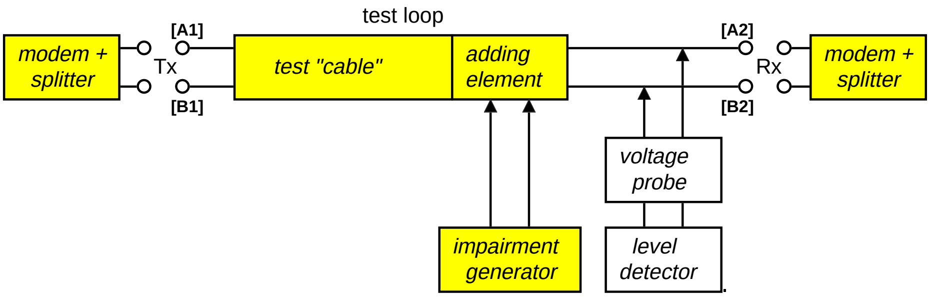


Figure 9: Functional description of the set-up of the performance tests

Test Loop #0 shall always be used for calibrating and verifying the correct settings of generators G1-G7 when performing performance tests.

The two-port characteristics (transfer function, impedance) of the test-loop, as specified in subclause 9.2, is defined between port Tx (node pairs A1, B1) and port Rx (node pair A2, B2). The consequence is that the two-port characteristics of the test "cable" in figure 9 should be properly adjusted to take full account of non-zero insertion loss and non-infinite shunt impedance of the adding element and impairment generator. This is to ensure that the insertion of the generated impairment signals does not appreciably loads the line.

The balance about earth, observed at port Tx at port Rx and at the tips of the voltage probe shall exhibit a value that is 10 dB greater than the transceiver under test. This is to ensure that the impairment generator and monitor function does not appreciably deteriorate the balance about earth of the transceiver under test.

The signal flow through the test set-up is from port Tx to port Rx, which means that measuring upstream and downstream performance requires an interchange of transceiver position and test "cable" ends.

The received signal level at port Rx is the level, measured between node A2 and B2, when port Tx as well as port Rx are terminated with the VDSL transceivers under test. The impairment generator is switched off during this measurement.

The transmitted signal level at port Tx is the level, measured between node A1 and B1, under the same conditions.

The impairment noise shall be a mix of random, impulsive and harmonic noise, as defined in subclause 9.3. The level that is specified in subclause 9.3 is the level at port Rx, measured between node A2 and B2, while port Tx as well as port Rx are terminated with the design impedance RV. These impedances shall be passive when the transceiver impedance in the switched-off mode is different from this value.

9.1.2 Signal and noise level definitions

The signal and noise levels are probed with a well balanced differential voltage probe, and the differential impedance between the tips of that probe shall be higher than the shunt impedance of 100 kΩ in parallel with 10 pF. Figure 9 shows the probe position when measuring the Rx signal level at the LT or NT receiver. Measuring the Tx signal level requires the connection of the tips to node pair (A1, B1).

NOTE: The various levels (or spectral masks) of signal and noise that are specified in the present document are defined at the Tx or Rx side of this set-up. The various levels are defined while the set-up is terminated, as described above, with design impedance RV or with VDSL transceivers under test.

Probing an rms-voltage U_{rms} (V) in this set-up, over the full signal band, means a power level of P (dBm) that equals:

- $P = 10 \times \log_{10} (U_{rms}^2 / R_V \times 1\,000)$ dBm.

Probing an rms-voltage U_{rms} (V) in this set-up, within a small frequency band of Δf (in Hertz), means an average spectral density level of P (dBm/Hz) within that filtered band that equals:

- $P = 10 \times \log_{10} (U_{rms}^2 / RV \times 1\,000 / \Delta f)$ (dBm/Hz).

The bandwidth Δf identifies the noise bandwidth of the filter, and not the -3dB bandwidth.

9.2 Test loops

The purpose of the test loops shown in figure 10 is to stress VDSL transceivers in various ways; in particular to test the VDSL performance under quasi-realistic circumstances.

9.2.1 Functional description

Loop #0 is a symbolic name for a loop with zero (or near zero) length, to prove that the VDSL transceiver can handle the potentially high signal levels when two transceivers are directly interconnected.

All other test loops in figure 10 have equal electrical length (insertion loss at a specified test frequency), but differ in input impedance (see figure 11). It is these values for insertion loss and impedance that define an actual test loop set. The loops are not defined in terms of a specific physical length.

The impedances of Loop #1 and #2 are nearly constant over a wide frequency interval. These two loops represent uniform distribution cables, one having a relatively low characteristic impedance and another having a relative high impedance (low capacitance per unit length). These impedance values are chosen to be the lowest and highest values of distribution cables that are commonly used in Europe.

The impedances of Loop #3 and #4 follow frequency curves that are oscillating in nature. This represents the mismatch effects in distribution cables caused by a short extent with a cable that differs significantly in characteristic impedance. Loop #3 represents this at the LT side to stress downstream signals. Loop #4 does the same at the NT side to stress upstream signals.

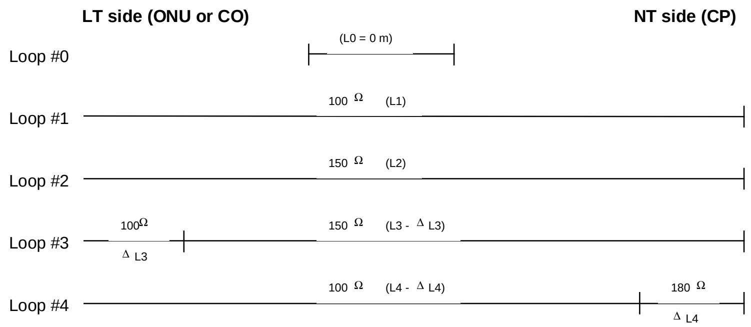


Figure 10: Test loop topology

The variation of input impedance for the various test loops is shown in figure 11. Some typical transfer functions of loops #1 to #4 are illustrated in figure 12. The test loops in this example are normalized in electrical length (or insertion loss) at an arbitrary chosen frequency. Five examples denoted by Q1 to Q5 are shown in figure 12. Loop-set Q1 has an insertion loss of 55 dB at 2 MHz and loop-set Q5 has an insertion loss of 18,5 dB at 10 MHz. The physical length of loop-set Q1 is in the range of 1 990 m to 2 100 m and for loop-set Q5 is in the range of 250 m to 300 m. The plot demonstrates the similarity of the transfer function of all the different loops when they are normalized.

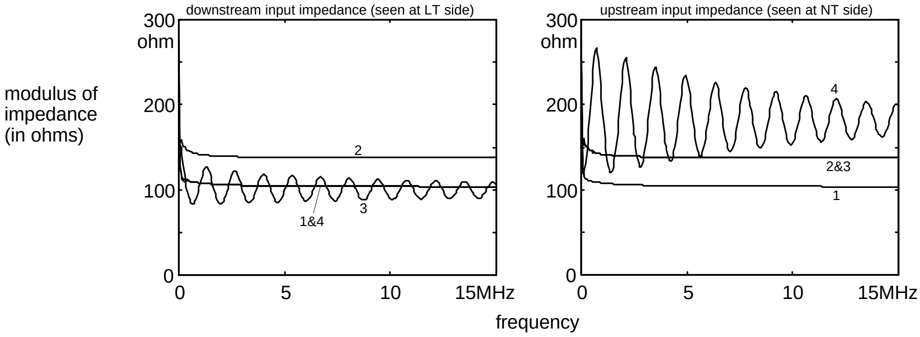


Figure 11: Calculated variation of input impedance, at a normalized loop length of 1 500 m

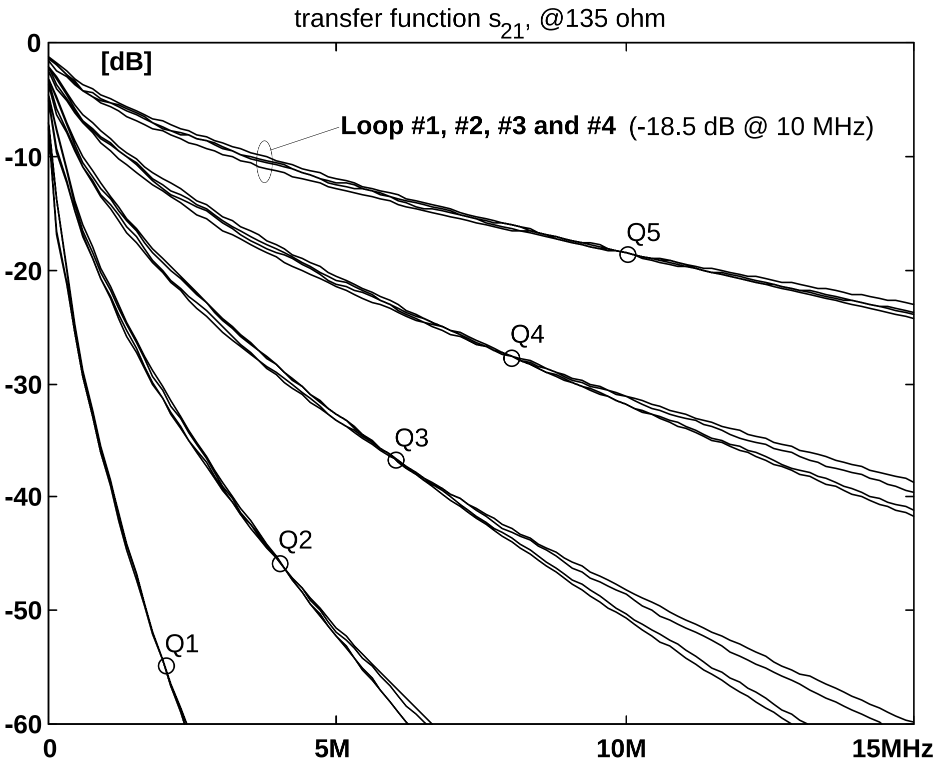


Figure 12: Typical transfer function (in 135 Ω) of the test loops when normalized in electrical length

The sections of the loops are defined in subclause 9.2.2 by means of two-port cable models of the individual sections. Cable simulators as well as real cables can be used for these sections. To minimize the electrical differences between test loop configurations, their length is specified as *electrical* lengths instead of the physical length of the sections in cascade (meaningful only when real cables are used). The electrical length is equivalent to the insertion loss of the loop at a given test frequency and termination impedance.

The relationship between electrical length (insertion loss) and total physical length (when real cables are used) can be calculated from the two-port models. Examples are shown in annex A.

9.2.2 Loop topology requirements

The different cable sections are specified by reference models that serve as a template for real twisted-pair cables. The composition of the test-loops is specified in table 6. The associated models and line constants are specified in annex A. Cable simulators as well as real cables can be used for these test loops. In the case that real cables are used, their estimated physical lengths are summarized in annex A.

The magnitude of the test-loop insertion loss shall approximate the insertion loss of the specified models within 3 % on a decibel scale, between 0,1 × f_T and 3 × f_T.

The magnitude of the test-loop characteristic impedance shall approximate the characteristic impedance of the specified models within 7 % on a linear scale, between 0,1 × f_T and 3 x f_T.

Table 6: Test-loop composition

Test loop	Distribution cable (L)	Extension cable (ΔL) LT or NT side	Extension length ΔL
#0	-	-	-
#1	TP100	-	-
#2	TP150	-	-
#3	TP150	TP100x	70 m
#4	TP100	TP180x	70 m

NOTE: The labels "TPxxx" refer to the two-port cable models specified in annex A.

9.2.3 Electrical length requirements (insertion loss)

For each VDSL payload bit-rate, the electrical length of the individual test loop is defined in terms of the insertion loss in circuit resistance of R_V, at a test frequency (f_T). This frequency is chosen to be a typical high-band frequency that is used for transporting that payload bit-rate. The insertion loss is chosen as a typical maximum value that can be handled correctly by the VDSL transceiver. The higher the payload bit-rate, the lower the insertion loss is that can be handled in practice. This is because the crosstalk in real cables increases with the frequency. Tables 7 and 8 specifies these insertion loss values for the different VDSL payload bit-rates at a given test frequency.

Table 7: Test loop insertion loss as a function of payload rate, noise model and test frequency using PSD Mask M1 (notches not taken into account)

Payload Rate	Noise model A		Noise model B		Noise model C		Noise model D		Noise model E		Noise model F	
	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB
S1	4	50,8	4	50,8	4	33,8	3,5	45,5	3,5	49	3,5	33,3
S2	5	50,9	5	50,9	5	36	4,5	48,1	4,5	50,1	4,5	36,1
S3	6,5	36,6	6,5	36,6	6,5	26,8	6	32,7	6	37,4	6	30,4
S4												
S5												
A1	2,5	46,7	2,5	49,6	2,5	26,3						
A2	3	48,3	3	51,5	3	27,4						
A3	4,5	50,1	4,5	52,1	4,5	32,1						
A4	5	36	5	38,2	5	21,2						

NOTE 1: See subclause 9.3.4 for the definition of the noise models.
NOTE 2: The insertion loss values have been calculated based on an assumed set of parameters for the VDSL transceiver. These parameters are to be defined in Part 2. The insertion loss values are for further study.
NOTE 3: The notches defined for mask M1 (see subclause 8.3.5.1) were not taken into account when calculating the insertion losses for the different payload rates.
NOTE 4: Noise models A, B and C are used for evaluating performance in the FTTCab scenario.
NOTE 5: Noise models D, E and F are used for evaluating performance in the FTTEx scenario.
NOTE 6: Symmetrical rates S4 and S5 have insufficient reach using mask M1 to be viable and so are left empty.
NOTE 7: Asymmetrical rates have not been evaluated in the FTTEx scenario because ADSL is a more appropriate solution.

Table 8: Test loop insertion loss as a function of payload rate, noise model and test frequency using PSD Mask M2

	Noise model A		Noise model B		Noise model C		Noise model D		Noise model E		Noise model F	
Payload Rate	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB	fT MHz	IL dB
S1	4	54,5	4	54,5	4	37,6	3,5	47,3	3,5	50,8	3,5	33,3
S2	5	53	5	53	5	40,3	4,5	50,1	4,5	52,1	4,5	36,1
S3	6,5	39	6,5	39	6,5	31,7	6	35	6	39,7	6	30,4
S4	8	16,4	8	16,4	8	16,4	8	21,8	8	21,8	8	19,1
S5	10	15,4	10	15,4	10	15,4	10	18,5	10	18,5	10	18,5
A1	2,5	49,6	2,5	52,6	2,5	29,2						
A2	3	51,5	3	54,7	3	30,6						
A3	4,5	52,1	4,5	54,1	4,5	36,1						
A4	6	44,4	6	46,7	6	28						

NOTE 1: See subclause 9.3.4 for the definition of the noise models.
NOTE 2: The insertion loss values have been calculated based on an assumed set of parameters for the VDSL transceiver. These parameters are to be defined in part 2. The insertion loss values are for further study.
NOTE 3: Noise models A, B and C are used for evaluating performance in the FTTCab scenario.
NOTE 4: Noise models D, E and F are used for evaluating performance in the FTTEx scenario.
NOTE 5: Asymmetrical rates have not been evaluated in the FTTEx case because ADSL is a more appropriate solution.

9.3 Impairment generators

The impairment noise for VDSL performance tests is very complex and for the purposes of the present document it has been broken down into smaller, more easily specified components. The separate and uncorrelated impairment "generators" may therefore be isolated and summed to form the impairment generator for VDSL. The detailed specifications for the components of the noise model(s) are given in this subclause, together with a brief explanation.

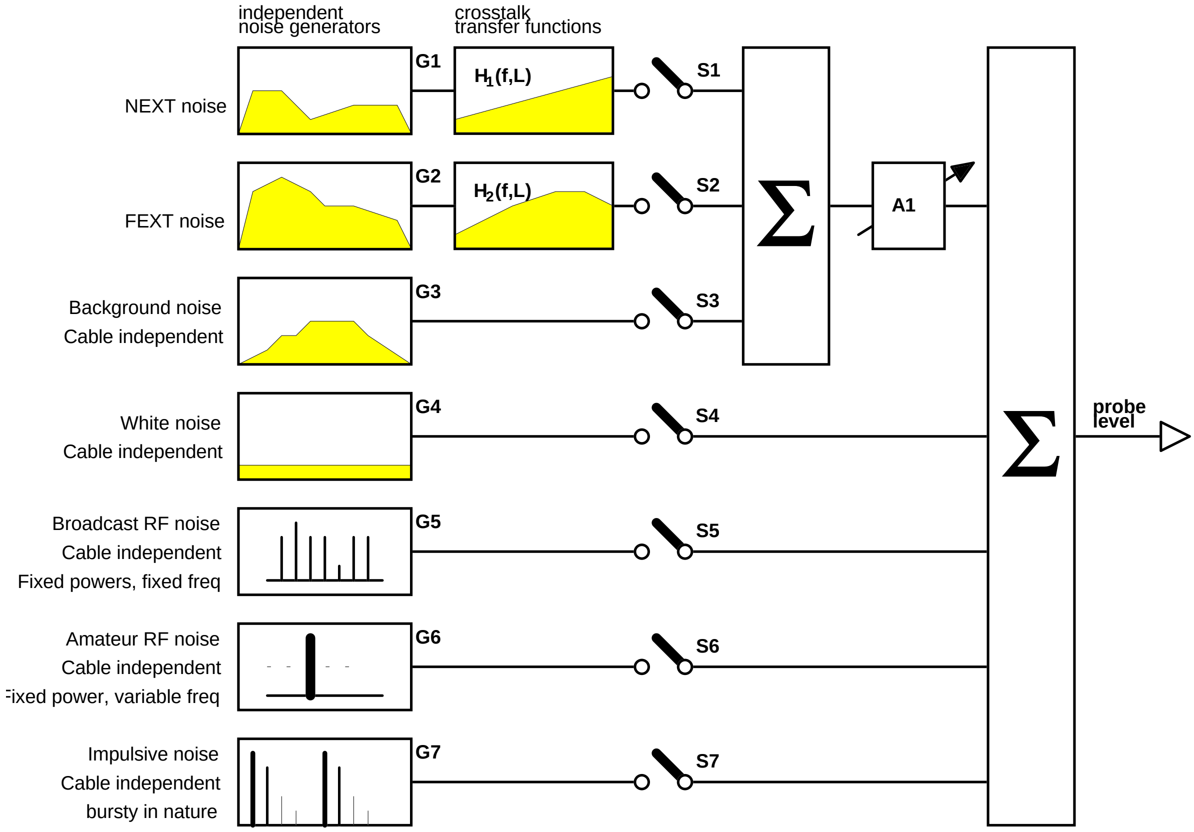
9.3.1 Functional description

Figure 13 defines a functional diagram of the composite impairment noise. It defines a functional description of the combined impairment noise, as it should be probed at the receiver input of a VDSL transceiver under test. This probing is defined in subclause 9.1.2.

The functional diagram has the following elements:

- the seven impairment "generators" G1 to G7 generate noise as defined in subclause 9.3.3. Their noise characteristics are independent from the test-loops and bit-rates;
- the transfer function $H_L(f_L')$ models the length and frequency dependency of the NEXT impairment, as specified in subclause 9.3.2. The transfer function is independent of the loop-set number, but changes with the electrical length of the test loop. Its transfer function changes with the frequency *f*, roughly according to $f^{0,75}$;
- the transfer function $H_2(f_L')$ models the length and frequency dependency of the FEXT impairment, as specified in subclause 9.3.2. Its transfer function is independent of the loop-set number, but changes with the electrical length of the test loop. Its transfer function changes with the frequency *f*, roughly according to *f* times the cable transfer function;
- switches S1-S7 determine whether or not a specific impairment generator contributes to the total impairment during a test;
- amplifier A1 models the property to increase the level of some generators simultaneously to perform the noise margin tests as defined in subclause 9.4.2. A value of x dB means a frequency independent increase of the level by x dB over the full VDSL band, from 0 Hz to f_H (see subclause 8.2). Unless otherwise specified, its gain is fixed at 0 dB.

In a practical implementation of the test set-up, there is no need to give access to any of the internal signals of the diagram in figure 13. These function blocks may be incorporated with the test-loop and the adding element as one integrated construction.



NOTE: Generator G7 is the only one that is symbolically shown in the time domain.

Figure 13: Functional diagram of the composition of the impairment noise

This functional diagram will be used for impairment tests in downstream and upstream directions. Several deployment scenarios have been identified that can be applied to VDSL testing. These scenarios are representative of the impairments that can be found in metallic access networks.

Each scenario (noise model) results in a length dependent PSD description of noise. Each noise model is sub-divided into two parts, one that is injected at the LT side and one that is injected at the NT side of the VDSL transceiver link under test. Some of the seven individual impairment "generators" G1 to G7 are used in more than one noise model with different values.

Type "A" models (Cabinet) are intended to represent a ***mixed scenario including full ADSL*** where the VDSL system under test is placed in a distribution cable (up to tens of wire pairs) that is filled with many other (potentially incompatible) transmission systems. The LT is located in a street cabinet (FTTCab) and the cable from the exchange to the cabinet attenuates the downstream PSDs of the disturbers.

Type "B" models (Cabinet) are intended to represent a ***mixed scenario including DSL-lite*** where the VDSL system under test is placed in a distribution cable (up to tens of wire pairs) that is filled with many other (potentially incompatible) transmission systems. The LT is located in a street cabinet (FTTCab) and the cable from the exchange to the cabinet attenuates the downstream PSDs of the disturbers.

Type "C" models (Cabinet) are intended to represent a ***legacy scenario*** that accounts for systems such as ISDN-PRA (HDB3) in addition to the scenario of type "A" models.

Type "D" models (Exchange) are intended to represent a ***high penetration scenario*** where the VDSL system under test is placed in a distribution cable (up to hundreds of wire pairs) that is filled with many other (potentially incompatible) transmission systems and the LT is located in the exchange (FTTEx).

Type "E" models (Exchange) are intended to represent a ***medium penetration scenario*** where the VDSL system under test is placed in a distribution cable (up to tens of wire pairs) that is filled with many other (potentially incompatible) transmission systems and the LT is located in the exchange (FTTEx).

Type "F" models (Exchange) are intended to represent a ***legacy scenario*** that accounts for systems such as ISDN-PRA (HDB3) in addition to the medium penetration scenario of type "E" models with the LT located in the exchange (FTTEx).

Each test has its own impairment specification that is described in subclause 9.4. The overall impairment noise shall be characterized by the sum of the individual components as specified in the relevant subclauses. The combined impairment noise is applied to the receiver under test at either the LT (for upstream) or NT (for downstream) end of the test loop.

9.3.2 Cable crosstalk models

The purpose of the cable crosstalk models is to model both the length and frequency dependence of crosstalk measured in real cables. These crosstalk transfer functions adjust the level of the noise generators in figure 13 when the test-loops are changed. The frequency and length dependency of these functions is in accordance with observations from real cables. The specification is based on the following constants, parameters and functions:

- variable **f** identifies the frequency in Hertz;
- constant $\mathbf{f_0}$ identifies a chosen reference frequency, which was set to 1 MHz;
- variable **L** identifies the physical length of the actual test loop in meters. This value is calculated from the cable models in annex A for a given insertion loss and test frequency. Tables A.4 and A.5 in annex A summarize the calculated values for each combination of payload bit-rate, noise model and test loop;
- constant $\mathbf{L_0}$ identifies a chosen reference length, which was set to 1 km;
- transfer function $\mathbf{s_T (f_L')}$ represents the frequency and length dependent amplitude of the transfer function of the actual test loops. This value equals $s_T = |s_{21}|$, where s_{21} is the transmission parameter of the loop normalized to R_V as specified in annex A;
- constant $\mathbf{K_{xn}}$ identifies an empirically obtained number that scales the NEXT transfer function $H_L (f_L')$. The resulting transfer function represents a power summed crosstalk model (see Bibliography [I-3]) of the NEXT as it was observed in a test cable. Although several disturbers and wire pairs were used, this function $H_L (f_{L'})$ is scaled down as if it originates from a single disturber in a single wire pair;
- constant $\mathbf{K_{xf}}$ identifies an empirically obtained number that scales the FEXT transfer function $H_2 (f_{L'})$. The resulting transfer function represents a power summed crosstalk model (see Bibliography [I-3]) of the FEXT as it was observed in a test cable. Although several disturbers and wire pairs were used, this function $H_2 (f_{L'})$ is scaled down as if it originates from a single disturber in a single wire pair.

The transfer function equations below shall be used as crosstalk transfer functions in the impairment generator:

$$H_1(f, L) = K_{xn} \times (f/f_0)^{0,75} \times \sqrt{1 - |s_T (f, L)|^4}$$

$$H_2(f, L) = K_{xf} \times (f/f_0) \times \sqrt{(L/L_0)} \times |s_T(f, L)|$$

Where:

$K_{xn} = 10^{(-50/20)} \approx 0{,}0032$, $f_0 = 1$ MHz

$K_{xf} = 10^{(-45/20)} \approx 0{,}0056$, $L_0 = 1$ km

$S_T(f, L) = |s_{21}|$ = test loop transfer function

NOTE: There are not enough measurements available to be sure that these are reasonable values to represent the "average" European cables. The few values that are available for European cables sometimes demonstrate significant differences from the above values.

9.3.3 Individual impairment generators

9.3.3.1 NEXT noise generator [G1]

The NEXT noise generator represents all impairments that are identified as crosstalk noise from a predominantly Near End origin. The noise when filtered by the NEXT crosstalk coupling function of subclause 9.3.2 represents the contribution of all NEXT in the composite impairment noise of the test.

The PSD of the noise generator is a combination of the self-crosstalk and alien crosstalk profiles as specified in subclause 9.3.4.1. These profiles shall be met for all frequencies between 0 Hz and f_H as specified in subclause 8.2. The PSD shall be measured using a measurement bandwidth of less than 10 kHz.

G1.UP.# = (XS.LT.# ♦ XA.LT.#)

G1.DN.# = (XS.NT.# ♦ XA.NT.#)

The symbols in the above expressions are defined below:

- "#" is a placeholder for noise model "A", "B" … "F";
- "XS.LT.#" and "XS.NT.#" refer to the self crosstalk profiles defined in subclause 9.3.4.1;
- "XA.LT.#" and "XA.NT.#" refer to the alien crosstalk profiles defined in subclause 9.3.4.1;
- "♦" refers to the FSAN crosstalk sum of two PSDs which is defined as $P_X = (P_{XS}^{Kn} + P_{XA}^{Kn})^{1/Kn}$ where P is the PSD in W/Hz and Kn = 1/0,6.

The PSD of this generator is independent of the cable because this is modeled separately as transfer function H_L ($f_{L'}$) as specified in subclause 9.3.2.

The noise from this generator shall be uncorrelated with all other noise sources in the impairment generator and uncorrelated with the VDSL system under test. The noise shall be random in nature with a near Gaussian amplitude distribution as specified in subclause 9.3.4.2.

9.3.3.2 FEXT noise generator [G2]

The FEXT noise generator represents all impairments that are identified as crosstalk noise from a predominantly Far End origin. The noise when filtered by the FEXT crosstalk coupling function of subclause 9.3.2 represents the contribution of all FEXT in the composite impairment noise of the test.

The PSD of the noise generator is a combination of the self-crosstalk and alien crosstalk profiles as specified in subclause 9.3.4.1. These profiles shall be met for all frequencies between 0 Hz and f_H as specified in subclause 8.2. The PSD shall be measured using a measurement bandwidth of less than 10 kHz.

G2.UP.# = (XS.NT.# ♦ XA.NT.#)

G2.DN.# = (XS.LT.# ♦ XA.LT.#)

The symbols in the above expressions are defined below:

- "#" is a placeholder for noise model "A", "B" … "F";
- "XS.LT.#" and "XS.NT.#" refer to the self crosstalk profiles defined in subclause 9.3.4.1;
- "XA.LT.#" and "XA.NT.#" refer to the alien crosstalk profiles defined in subclause 9.3.4.1;
- "♦" refers to the FSAN crosstalk sum of two PSDs which is defined as $P_X = (P_{XS}^{Kn} + P_{XA}^{Kn})^{1/Kn}$ where P is the PSD in W/Hz and Kn = 1/0,6.

The PSD of this generator is independent of the cable because this is modeled separately as transfer function H_2 ($f_{L'}$) as specified in subclause 9.3.2.

The noise from this generator shall be uncorrelated with all other noise sources in the impairment generator and uncorrelated with the VDSL system under test. The noise shall be random in nature with a near Gaussian amplitude distribution as specified in subclause 9.3.4.2.

9.3.3.3 Background noise generator [G3]

The background noise generator G3 is inactive and currently is set to zero.

9.3.3.4 White noise generator [G4]

The white noise generator has a fixed value of -140 dBm/Hz into 135 Ω and is frequency independent.

The noise from this generator shall be uncorrelated with all other noise sources in the impairment generator and uncorrelated with the VDSL system under test. The noise shall be random in nature with a near Gaussian amplitude distribution as specified in subclause 9.3.4.2.

9.3.3.5 Broadcast RF noise models [G5]

The broadcast RF noise generator represents the discrete tone-line interference caused by amplitude modulated broadcast transmissions in the SW, MW and LW bands which ingress into the differential or transmission mode of the wire-pair. These interference sources have more temporal stability than the amateur/ham interference because their carrier is not suppressed. The modulation index (MI) is usually up to 80%. These signals are detectable using a spectrum analyzer and result in line spectra of varying amplitude in the VDSL band. Maximum observable power levels of up to -40 dBm can occur on telephone lines in the distant vicinity of broadcast AM transmitters. The closest ten transmitters to the victim wire-pair typically dominate the noise.

Several noise models are specified in this subclause. The average minimum power of each carrier frequency is specified in table 9 for each model.

This broadcast RF noise model is comprised of ten broadcast interferers that are applied simultaneously to the receiver under test. Noise generator G5.UP.x shall be applied to the receiver under test at the LT side of the test-loops, when performing the upstream tests. Noise generator G5.DN.x shall be applied to the receiver under test at the NT side of the test-loops, when performing the downstream tests.

A fixed frequency carrier shall model each interfering source. The carrier shall be 80 % AM modulated with a flat (±3 dB) Gaussian white noise source that is band limited to 0 kHz to 5 kHz. The average minimum power of the modulated signal shall be no lower than that specified in table 9, column [G5.UP.A]. The measurement bandwidth shall be less than 10 kHz.

The two models represent strong [G5.xx.A] coupling (where there is a significant length of overhead cable) or weak [G5.xx.B] coupling (where the cable is mainly buried).

Table 9: Noise generator G5 carrier frequencies and average minimum powers

Frequency (kHz)	Power (dBm)	Power (dBm)	Power (dBm)	Power (dBm)
	[G5.UP.A]	[G5.DN.A]	[G5.UP.B]	[G5.DN.B]
99	-70	-60	-80	-70
207	-70	-60	-80	-70
711	-70	-60	-80	-70
801	-70	-60	-80	-70
909	-70	-60	-80	-70
981	-50	-40	-60	-50
1 458	-50	-40	-60	-50
6 050	-50	-40	-60	-50
7 350	-50	-40	-60	-50
9 650	-50	-40	-60	-50

9.3.3.6 Amateur RF noise models [G6]

The Amateur RF noise generator represents a large (almost impulse like) RF interference that has radically changing temporal characteristics due to the single-sideband suppressed nature of the amateur radio transmission. The interference exhibits severe temporal variations, can be high in amplitude (up to 0 dBm PEP), can occur anywhere within the internationally standardized HF amateur bands and at any time of day or night. Overhead wiring is especially susceptible to RF ingress of this nature. Coupling into twisted telephone wires is usually via the common mode and then into the differential mode.

This high-level interferer is designed to simulate the worst-case interference from Short Wave amateur radio transmissions coupling from nearby amateur radio transmissions into the differential or transmission mode of the unscreened twisted wire pair of the metallic access network which is being used for VDSL transmission.

This source of interference appears as a component of the noise entering the front-end of a VDSL receiver in the differential or transmission mode. It is very damaging to VDSL transmission because of:

a) the adverse nature of the temporal characteristics of the single sideband suppressed carrier transmission;

b) the close proximity of amateur radio transmitters to telephone network aerial cabling and home wiring;

c) the high transmission powers, typically up to 400 W PEP (+26 dBW).

9.3.3.6.1 Specification of all Amateur RF noise models

In order to simulate this amateur radio interference, a carrier is amplitude modulated with speech or Morse like properties. The interfering noise shall be injected in the differential mode and set to 0 dBm Peak Envelope Power (PEP) at the VDSL receiver input in any internationally recognized amateur band (see table 10). The modulating signal shall be speech weighted noise (ITU-T Recommendation G.227 [13]) and shall be interrupted such that within each 15 s period it spends 5 s on and 10 s off to simulate speech activity. The resultant baseband signal shall be further interrupted such that within each period of 200 ms it spends 50 ms on and 150 ms off which corresponds to the syllabic rate. The resultant signal shall then be band-limited to 4 kHz with a 6 dB/octave pre-emphasis in-band. The carrier frequency should change by at least 50 kHz every 120 s. The amateur interferer can appear anywhere in the chosen amateur frequency bands listed in table 10.

This noise source shall be applied to the receiver under test at the LT side of the test-loops, when performing the upstream tests [G6.UP.x]. This noise source shall be applied to the receiver under test at the NT side of the test-loops, when performing the downstream tests [G6.DN.x].

The level of this noise model shall be no lower than that given in table 11 anywhere in the internationally standardized amateur radio bands given in table 10.

Table 10: International HF amateur radio bands

Band start (kHz)	Band stop (kHz)
1 810	2 000
3 500	3 800
7 000	7 100
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 100

Table 11: Amateur RF noise power (PEP) levels

Model	G6.UP.A	G6.DN.A	G6.UP.B	G6.DN.B
Power (dBm)	-10	0	-30	-20

9.3.3.7 Impulse noise model [G7]

A test with this noise model is required to prove the burst noise immunity of the VDSL transceiver. This immunity shall be demonstrated on short and long loops with impairment noise injected to model crosstalk and RFI. Further test details are given in subclause 8.5.1.

The noise shall consist of burst of Additive White Gaussian Noise injected onto the line with sufficient power to ensure effective erasure of the data for the period of the burst, i.e. the bit error ratio during the burst should be approximately 0,5. The noise burst shall be applied regularly at a repetition rate of at least 1 Hz.

9.3.4 Profile of the individual impairment generators

9.3.4.1 Frequency domain profiles of generators G1 and G2

Crosstalk noise represents all impairments that originate from systems connected to adjacent wire pairs that are coupled to the wires of the VDSL system under test. The noise spectrum varies with the electrical length of the test loop.

Noise generators G1 and G2 represent the equivalent of many disturbers in a real scenario with all disturbers co-located at the ends of the test loops. This approach simplifies the definition of crosstalk noise and isolates the NEXT and FEXT coupling functions of the cable from the PSD of the generators.

9.3.4.1.1 Self crosstalk profiles

The noise profile of self-crosstalk is implementation specific to the VDSL system under test. The transceiver manufacturer shall determine the signal spectrum of the VDSL system under test (VDSL.LT.# or VDSL.NT.#) over the full VDSL band as observed at the Tx port of the test set-up described in subclause 9.1. The measurement bandwidth shall be 10 kHz.

Separate spectral profiles are used to describe the self-crosstalk at the LT end and at the NT end of the test loop. In the following text the "#" is a placeholder for models "A" to "F".

- The profiles XS.LT.# describe the self crosstalk portion of an equivalent disturber co-located at the LT end of the test loop. When testing the upstream this profile is applied to generator G1. When testing the downstream this profile is applied to generator G2. The self-crosstalk profile is specified in table 12.

- The profiles XS.NT.# describe the self-crosstalk portion of an equivalent disturber co-located at the NT end of the test loop. When testing the upstream this profile is applied to generator G2. When testing the downstream this profile is applied to generator G1. The self-crosstalk profile is specified in table 12.

Table 12: Definition of self-crosstalk

Cabinet	Model A	Model B	Model C
XS.LT.#	VDSL.LT.A + 8 dB	VDSL.LT.B + 8 dB	VDSL.LT.C + 8 dB
XS.NT.#	VDSL.NT.A + 8 dB	VDSL.NT.B + 8 dB	VDSL.NT.C + 8 dB

Exchange	Model D	Model E	Model F
XS.LT.#	VDSL.LT.D + 8 dB	VDSL.LT.E + 8 dB	VDSL.LT.F + 8 dB
XS.NT.#	VDSL.NT.D + 8 dB	VDSL.NT.E + 8 dB	VDSL.NT.F + 8 dB

NOTE 1: The addition of 8 dB simulates the power generated by the sum of 20 similar VDSL systems operating in a multi-pair cable.

NOTE 2: The VDSL self-crosstalk is assumed to be generated by transceivers with the same PSD as the transceiver under test. Further study is required in cases where this is not valid.

9.3.4.1.2 Alien crosstalk profiles

Separate spectral profiles are used to describe the alien crosstalk at the LT end and at the NT end of the test loop. In the following text the "#" is a placeholder for models "A" to "F".

- The profiles XA.LT.# describe the alien crosstalk portion of an equivalent disturber co-located at the LT end of the test loop. When testing the upstream this profile is applied to generator G1. When testing the downstream this profile is applied to generator G2. The alien crosstalk profiles are specified in table 13.
- The profiles XA.NT.# describe the alien crosstalk portion of an equivalent disturber co-located at the NT end of the test loop. When testing the upstream this profile is applied to generator G2. When testing the downstream this profile is applied to generator G1. The alien crosstalk profiles are specified in table 14.

The PSD profiles in tables 13 and 14 should be drawn using straight lines between the points specified on a graph with a logarithmic frequency scale (Hz) and a linear power density scale (dBm/Hz). The power level is defined into a resistive load impedance (RV) of 135 Ω.

Table 13: PSD profile of alien noise spectra at the LT

VDSL from the Cabinet

XA.LT.A (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,2
75	-30,6
100	-34,2
292	-35,3
400	-43,7
1 104	-52,6
2 500	-99,6
3 637	-111,3
30 000	-111,5

VDSL from the Cabinet

XA.LT.B (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,2
75	-30,7
100	-34,4
135	-35,3
139	-35,1
292	-35,3
400	-43,7
552	-46,7
956	-74,5
1 800	-83,3
2 000	-93,1
3 637	-111,3
30 000	-111,5

VDSL from the Cabinet

XA.LT.C (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,2
75	-30,6
100	-34,2
292	-35,3
400	-43,6
500	-45,4
900	-46,5
1 024	-46,9
1 400	-50,7
1 800	-60,6
16 500	-103,1
30 000	-109,8

VDSL from the Exchange

XA.LT.D (kHz)	PSD (dBm/Hz)
4	-18,2
50	-18,2
75	-25,1
117	-26,6
138	-25,4
290	-25,4
330	-25,8
1 104	-26
2 500	-66
4 530	-96
30 000	-96,4

VDSL from the Exchange

XA.LT.E (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,2
77	-30,9
117	-35
140	-30,2
292	-30,3
330	-30,6
550	-30,6
600	-32,5
700	-33,4
1 104	-33,5
4 530	-100,7
30 000	-101,1

VDSL from the Exchange

XA.LT.F (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,2
74	-30,3
117	-35
140	-30,2
292	-30,3
330	-30,6
550	-30,6
600	-32,5
700	-33,4
1 104	-33,5
2 100	-64,6
2 450	-63,6
16 500	-99,1
30 000	-101

Table 14: PSD profile of alien noise spectra at the NT

VDSL from the Cabinet

XA.NT.A (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,1
75	-29,3
100	-30,8
138	-31
150	-34,2
166	-35,3
292	-35,4
400	-46,3
900	-74,5
1 104	-79,6
1 400	-82
2 500	-99,8
3 200	-103,5
4 545	-103,9
30 000	-103,9

VDSL from the Cabinet

XA.NT.B (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,1
75	-29,3
100	-30,8
138	-31
150	-34,2
166	-35,3
292	-35,4
400	-46,3
900	-74,5
1 104	-79,6
1 400	-82
2 500	-99,8
3 200	-103,5
4 545	-103,9
30 000	-103,9

VDSL from the Cabinet

XA.NT.C (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22,1
75	-29,3
100	-30,8
138	-31
150	-34,2
166	-35,3
292	-35,4
400	-46
500	-49,1
900	-47,1
1 024	-47,3
1 400	-50,7
1 800	-60,6
16 500	-101,7
30 000	-103,7

VDSL from the Exchange

XA.NT.D (kHz)	PSD (dBm/Hz)
4	-18,2
50	-18,1
75	-24,2
275	-25,4
400	-40,6
600	-54,3
1 000	-71,6
2 750	-95,7
30 000	-96,4

VDSL from the Exchange

XA.NT.E (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22
71	-27,8
145	-30
175	-31
274	-31
400	-46,5
600	-60,3
1 000	-77,1
1 400	-82,2
2 800	-100,3
30 000	-101,1

VDSL from the Exchange

XA.NT.F (kHz)	PSD (dBm/Hz)
4	-22,2
50	-22
71	-27,8
145	-30
175	-31
274	-31
450	-47,5
900	-45,3
1 200	-46,7
1 500	-50,4
1 780	-58,3
16 500	-99,1
30 000	-101

9.3.4.2 Time domain profiles of generators G1 to G4

The noise as specified in the frequency domain in subclauses 9.3.3.1 to 9.3.3.4 shall be random in nature and near Gaussian distributed. This means that the amplitude distribution function of the combined impairment noise injected at the adding element (see figure 9) shall lie between the two boundaries as illustrated in figure 14 and defined in table 15.

The amplitude distribution function F(a) of noise u(t) is the fraction of the time that the absolute value of u(t) exceeds the value "a". From this definition, it can be concluded that F(0) = 1 and that F(a) monotonically decreases up to the point where "a" equals the peak value of the signal. From there on, F(a) vanishes:

$$F(a) = 0 \text{, for } a \geq \left| u_{peak} \right|$$

The boundaries on the amplitude distribution ensure that the noise is characterized by peak values that are occasionally significantly higher than the rms-value of that noise (up to 5 times the rms-value).

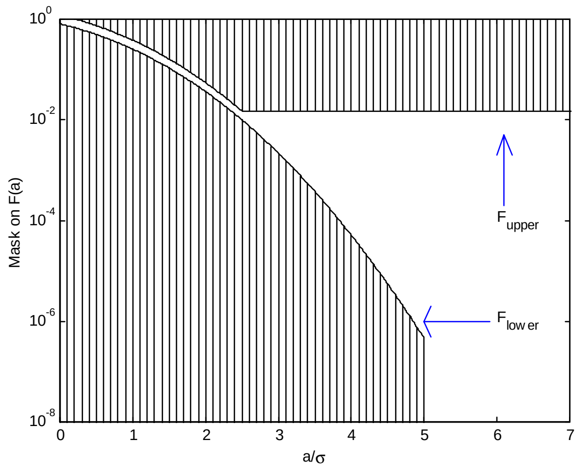


Figure 14: Mask for the Amplitude Distribution Function: the non-shaded area is the allowed region. The boundaries of the mask are specified in table 15

Table 15: Upper and lower boundaries of the amplitude distribution function of the noise

Boundary (σ = rms value of noise)	interval
$F_{lower}(a) = (1 - \varepsilon) \cdot \{1 - erf((a/\sigma)/\sqrt{2})\}$ $F_{lower}(a) = 0$	$0 \le a/\sigma < CF$ $CF \le a/\sigma < \infty$
$F_{upper}(a) = (1 + \varepsilon) \cdot \{1 - erf((a/\sigma)/\sqrt{2})\}$ $F_{upper}(a) = (1 + \varepsilon) \cdot \{1 - erf(A/\sqrt{2})\}$	$0 \le a/\sigma < A$ $A \le a/\sigma < \infty$

parameter	value
crest factor Gaussian gap	CF = 5 ε = 0,1 A = CF/2 = 2,5

The meaning of the parameters in table 15 is as follows:

- CF denotes the minimum crest factor of the noise, that characterizes the ratio between the absolute peak value and rms value ($CF= |u_{peak}| / u_{rms}$);
- ε denotes the Gaussian gap that indicates how 'close' near Gaussian noise approximates true Gaussian noise;
- a denotes the point beyond which the upper limit is alleviated to allow the use of noise signals of practicable repetition length.

9.4 Transmission Performance tests

9.4.1 Bit error ratio requirements

The VDSL system shall operate with a noise margin of at least +6 dB and a long-term bit error ratio of < 1 in 10^7 when operated over any of the test loops with the noise models and test conditions as specified in this subclause.

The measurement period shall be at least 30 minutes and the amateur radio interferer (see subclause 9.3.3.6) shall visit each amateur band at least twice (at different frequencies within the band) during the test period.

A long-term performance test shall be performed for a period of not less than 24 hours to ensure long-term temporal stability (see subclauses 9.4.4 and 9.4.5).

9.4.2 Measuring noise margin

Before start-up of the VDSL transceiver under test the level and shape of the crosstalk noise or impulse noise is adjusted so that the level observed at port Rx (figure 9) meets the impairment level specification in subclause 9.3. This relative level is referred to as 0 dB. The transceiver link is subsequently activated, and the bit error ratio of the link is monitored.

By adjusting the gain of amplifier A1 in figure 13 the crosstalk noise level of the impairment generators is then increased (equally over the full VDSL frequency band) until the bit error ratio is approximately 10^{-7}. This BER will be achieved at an increase of noise of x dB, with a small uncertainty of Δx dB. The value x is defined as the noise margin with respect to a standard noise model and may (optionally) be used to indicate the sensitivity of the system under test to changes in BER.

NOTE: It is expected that the noise level that brings the BER to 10^{-7} is very close to the level associated with a BER of 10^{-5} (usually within a fraction of a dB for a coded system). In order to speed up the iterative search for noise margins, it is a practical approach to start the margin search for a BER of 10^{-5}, and then search for the noise level associated with a BER of 10^{-7}. The BER requirements of 10^{-7} in subclause 9.4.1 remains valid in order to pass the transmission performance test.

The noise margins shall be measured for upstream as well as downstream transmission under test loops #1, #2, #3, and #4.

9.4.3 Generator sets for different test scenarios

Several VDSL performance tests shall be carried out to prove adequate upstream and downstream performance. The tests are split into two scenarios, FTTCab and FTTEx. Not all RF noise models apply in each case. Figure 15 shows the upstream tests, a similar figure can be drawn for the downstream tests.

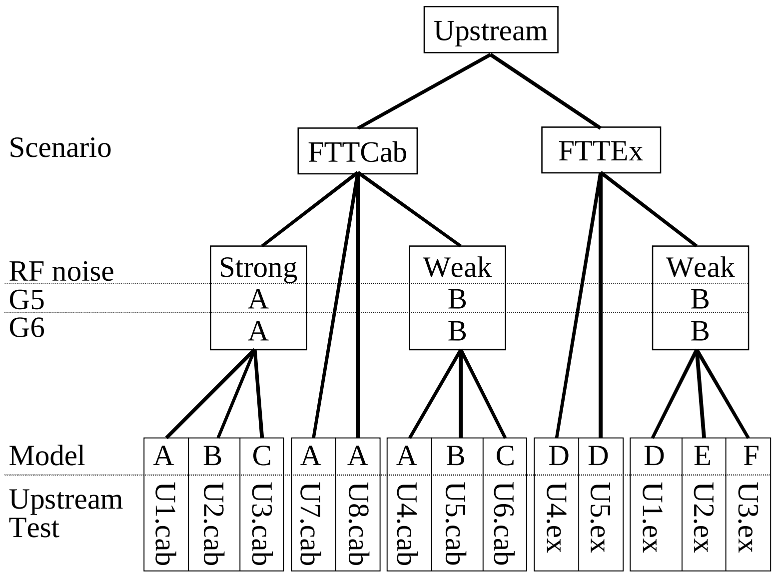


Figure 15: Upstream test scenarios and conditions

NOTE: The attenuation of the downstream ADSL generator contributions in the FTTEx generator models A, B and C is equivalent to a 1 km length of cable of type A as defined in annex A.

9.4.4 Upstream tests

Several VDSL performance tests shall be carried out to prove adequate upstream performance. Each symbolic name in this table refers to a specified noise model as defined in subclause 9.3. The injection of the impairment noise shall be at the LT side of the test-loop.

Transceivers operating in a FTTCab scenario shall pass all upstream test U1.cab to U8.cab in the table below for each relevant payload bit-rate (see tables 7 and 8) and PSD (see tables 1 to 4). The appropriate test loop attenuation (see tables 7 and 8) and associated combined impairment (as described in subclause 9.3) shall be used for each test.

Table 16: Composition of noise models in the upstream tests for the FTTCab scenario

Test	Scenario	Loops	G1	G2	G3	G4	G5	G6	G7	Comments
U1.cab	FTTCab	0-4	G1.UP.A	G2.UP.A		G4	G5.UP.A	G6.UP.A		
U2.cab	FTTCab	0-4	G1.UP.B	G2.UP.B		G4	G5.UP.A	G6.UP.A		
U3.cab	FTTCab	0-4	G1.UP.C	G2.UP.C		G4	G5.UP.A	G6.UP.A		
U4.cab	FTTCab	0-4	G1.UP.A	G2.UP.A		G4	G5.UP.B	G6.UP.B		
U5.cab	FTTCab	0-4	G1.UP.B	G2.UP.B		G4	G5.UP.B	G6.UP.B		
U6.cab	FTTCab	0-4	G1.UP.C	G2.UP.C		G4	G5.UP.B	G6.UP.B		
U7.cab	FTTCab	4	G1.UP.A	G2.UP.A		G4			G7	
U8.cab	FTTCab	0 & 1	G1.UP.A	G2.UP.A		G4				24 hours
NOTE 1: Test U7.cab is a broadband impulse noise test. NOTE 2: Test U8.cab is a long-term stability test with representative noise models.										

Transceivers operating in a FTTEx scenario shall pass all upstream test U1.ex to U5.ex in the table below for each relevant payload bit rate (see tables 7 and 8) and PSD (see tables 1 to 4). The appropriate test loop attenuation (see tables 7 and 8) and associated combined impairment (as described in subclause 9.3) shall be used for each test.

Table 17: Composition of noise models in the upstream tests for the FTTEx scenario

Test	Scenario	Loops	G1	G2	G3	G4	G5	G6	G7	Comments
U1.ex	FTTEx	0-4	G1.UP.D	G2.UP.D		G4	G5.UP.B	G6.UP.B		
U2.ex	FTTEx	0-4	G1.UP.E	G2.UP.E		G4	G5.UP.B	G6.UP.B		
U3.ex	FTTEx	0-4	G1.UP.F	G2.UP.F		G4	G5.UP.B	G6.UP.B		
U4.ex	FTTEx	4	G1.UP.D	G2.UP.D		G4			G7	
U5.ex	FTTEx	0 & 1	G1.UP.D	G2.UP.D		G4				24 hours
NOTE 1: Test U4.ex is a broadband impulse noise test. NOTE 2: Test U5.ex is a long-term stability test with representative noise models.										

9.4.5 Downstream tests

Several VDSL performance tests shall be carried out to prove adequate downstream performance. Each symbolic name in this table refers to a specified noise model as defined in subclause 9.3. The injection of the impairment noise shall be at the NT side of the test loop.

Transceivers operating in a FTTCab scenario shall pass all downstream test D1.cab to D8.cab in the table below for each relevant payload bit-rate (see tables 7 and 8) and PSD (see tables 1 to 4). The appropriate test loop attenuation (see tables 7 and 8) and associated combined impairment (as described in subclause 9.3) shall be used for each test.

Table 18: Composition of noise models in the downstream tests for the FTTCab scenario

Test set	Scenario	Loops	G1	G2	G3	G4	G5	G6	G7	Comments
D1.cab	FTTCab	0-4	G1.DN.A	G2.DN.A		G4	G5.DN.A	G6.DN.A		
D2.cab	FTTCab	0-4	G1.DN.B	G2.DN.B		G4	G5.DN.A	G6.DN.A		
D3.cab	FTTCab	0-4	G1.DN.C	G2.DN.C		G4	G5.DN.A	G6.DN.A		
D4.cab	FTTCab	0-4	G1.DN.A	G2.DN.A		G4	G5.DN.B	G6.DN.B		
D5.cab	FTTCab	0-4	G1.DN.B	G2.DN.B		G4	G5.DN.B	G6.DN.B		
D6.cab	FTTCab	0-4	G1.DN.C	G2.DN.C		G4	G5.DN.B	G6.DN.B		
D7.cab	FTTCab	4	G1.DN.A	G2.DN.A		G4			G7	
D8.cab	FTTCab	0 & 1	G1.DN.A	G2.DN.A		G4				24 hours
NOTE 1: Test D7.cab is a broadband impulse noise test. NOTE 2: Test D8.cab is a long-term stability test with representative noise models.										

Transceivers operating in a FTTEx scenario shall pass all downstream tests D1.ex to D5.ex in the table below for each relevant payload bit-rate (see tables 7 and 8) and PSD (see tables 1 to 4). The appropriate test loop attenuation (see tables 7 and 8) and associated combined impairment (as described in subclause 9.3) shall be used for each test.

Table 19: Composition of noise models in the downstream tests for the FTTEx scenario

Test set	Scenario	Loops	G1	G2	G3	G4	G5	G6	G7	Comments
D1.ex	FTTEx	0-4	G1.DN.D	G2.DN.D		G4	G5.DN.B	G6.DN.B		
D2.ex	FTTEx	0-4	G1.DN.E	G2.DN.E		G4	G5.DN.B	G6.DN.B		
D3.ex	FTTEx	0-4	G1.DN.F	G2.DN.F		G4	G5.DN.B	G6.DN.B		
D4.ex	FTTEx	4	G1.DN.D	G2.DN.D		G4			G7	
D5.ex	FTTEx	0 & 1	G1.DN.D	G2.DN.D		G4				24 hours
NOTE 1: Test D4.ex is the broadband impulse noise test. NOTE 2: Test D5.ex is a long-term stability test with representative noise models.										

9.5 Micro interruptions

A micro interruption is a temporary line interruption due to external mechanical action on the copper wires constituting the transmission path, for example, at a cable splice. Splices can be hand-made wire-to-wire junctions, and during cable life oxidation phenomena and mechanical vibrations can induce micro interruptions at these critical points.

The effect of a micro interruption on the transmission system can be a failure of the digital transmission link, together with a failure of the power feeding (if provided) for the duration of the micro interruption.

The objective is that in the presence of a micro interruption of specified maximum length the VDSL transceiver should not reset, and the system should automatically reactivate (see subclause 10.1).

The transceiver shall not be reset by a micro interruption event of duration t = 10 ms which shall occur at an event frequency of 0,2 Hz.

10 Core

This clause details the functional requirements of the VDSL transceiver core.

10.1 Activation/deactivation

Activation and deactivation may be commanded by network management or result from autonomous actions caused by transmission anomalies. Additionally, where call-state information is available, activation may be linked to broadband call-state transitions. Such linkage is not applicable to SDH applications, and is not currently supported by ATM level standards. Methods may however be developed to enable the transmission performance advantages for VDSL to be exploited by ATM applications.

10.1.1 Activation/deactivation definitions

On first installation or service change, the start-up of a VDSL transceiver might be subject to an installation procedure under control of the network operator in order to check the spectral compatibility of the transceiver. Such tests are operator specific and designed to minimize disruption of existing services.

One purpose of the installation procedure is to check that the transceiver pair is correctly connected, correctly configured, and that the line is good.

NOTE 1: The "line is good" means that the channel characteristics are within the service provider's limits and are likely to support a viable service. The most important channel characteristic is the attenuation as any noise level observed during the tests is likely to increase with time as more systems are installed on adjacent pairs. The attenuation limits for service viability will differ for each service provider so they cannot be pre-programmed during transceiver manufacture.

Following a successful first installation, the activation procedures shall start. Four mandatory activation procedures shall exist.

NOTE 2: Further evolution of the state diagram is anticipated in part 2.

The mandatory procedures are defined below and shown in figure 16.

Cold-Start: Cold-Start applies when power is first applied to the transceiver after intrusive maintenance or if there have been significant changes in line characteristics (e.g. due to thermal effects). Intrusive maintenance will also apply to the service level when transmission rates and other transmission parameters (e.g. margin, spectral masks, class of service, etc.) are altered. Failure to achieve steady state after T1 seconds constitutes a fault condition.

Warm-Start: This start applies when both transceivers start from the Power-Down state. Power-Down is reached when a transceiver had its AC removed on purpose via the Power-Down procedure, forced typically by the customer. Warm-start applies only if there have been little or no changes in line characteristics. This procedure applies also, when there is an accidental AC removal or failure at the customer, provided the transceiver could store all necessary data and parameters to avoid the Cold-Start.

Resume-on-Error: The start-up process that applies to transceivers which lose synchronization during transmission, e.g. due to a large impulse hit or an interruption longer than the specified micro-interruption (see subclause 9.5). This applies only if there have been no changes in line characteristics, and when the clock-frequencies recovery circuits can still predict the sample timing. The event that leads to loss of synchronization shall be longer than a micro-interruption but limited to a TBD maximum value, related to the loss of frequency locking.

Warm-Resume: The start-up process that applies to transceivers that having reached synchronization have subsequently responded to a deactivation request. Warm-resume is the usual method of activating the VDSL transmission system on receipt of a first incoming or outgoing broadband call request.

Warm-Resume can only be initiated after a deactivation procedure, towards the Power-Saving state, which keeps both LT and NT VDSL transceivers in a power-saving sleeping mode.

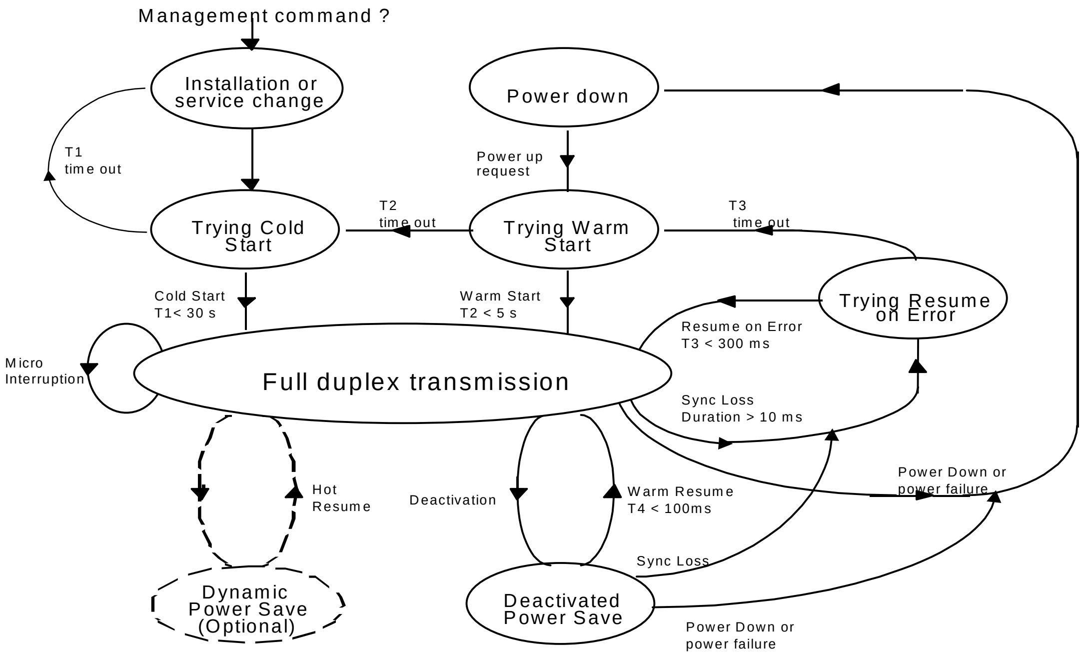


Figure 16: State and timing diagram

Steady State transmission: To achieve Steady State transmission all start-up processes should have been completed. This means full clock and frame synchronization have been achieved and DSP filter adaptations have been performed.

Dynamic Power Save State (optional): The Dynamic Power Save State is intended to reduce the overall power consumption of the VDSL LT transceiver, and to reduce the crosstalk level and RFI radiation of the VDSL system. It could be used when ATM or some other application links are active, but are not consuming the full bandwidth of the VDSL transmission. It alternates with the Steady State transmission. No loss of application data shall be tolerated when the VDSL transceiver moves back and forth between Steady State and Dynamic Power Save State. This state implies the use of the Hot-Resume process.

Hot-Resume (optional): The implied immediate power-ON, to resume transmission, whenever the VDSL transceiver alternates between Steady State and the optional Dynamic Power Save State.

Power-Down procedure: The process by which a pair of fully operational transceivers go to the Power-Down state. It is a guided procedure used e.g. when the customer wants to turn off the transceiver AC power, or when the LT can not go to the Power-Saving deactivation. The VDSL transceivers may store transmission related data, such as equalizer states, line characteristics, and service related parameters to be able to use the Normal-Start procedure later.

Deactivation: This is a process that places the VDSL transceiver into a power-saving state to save ONU power and reduce unwanted RF emissions. Included in this process is the confirmation towards UNI and the network side that the VDSL transmission is terminated. The Deactivation assumes the termination of all broadband traffic.

Power-Down state: The full removal of power at the NT or LT, or the state at the LT when the Power-Saving deactivated state can not used and VDSL transmission shall be halted, e.g. for maintenance (hardware and/or software).

Deactivated Power-Saving state: This state is required to permit the digital transmission system to be placed in a low power consumption mode when no calls are in progress. The NT and LT consume less power but are capable of detecting a wake up signal from the network side and/or from the UNI, and execute a Warm-Resume. When enabled by the Network Management System, this state may be entered automatically after a programmable time after the last broadband call. During the deactivated Power-Saving state the transceivers could continue some (modulation dependent) form of synchronization on some of the following levels: clock-sync, frame-sync, equalizer checking and trimming, etc.

Delay to service start-up: The time from when Activation is requested or power is applied until the broadband dial tone is issued towards the UNI. The VDSL system shall have achieved Steady State transmission before the broadband dial tone (or equivalent) is issued.

10.1.2 Timing requirements

Delay to service start-up during Cold-Start conditions:	T1 maximum 30 s, typically 15 s.
Delay to service start-up during Normal-Start conditions:	T2 maximum 5 s, typically 2 s.
Delay to recovery of service by a successful Resume-on-Error:	T3 < 100 ms.
Delay to service start-up during Warm-Resume conditions:	T4 < 300 ms.

11 Spectral compatibility

Ensuring spectral compatibility with existing and future DSL transmission systems is of paramount importance to Network Operators. The following requirements are separated into those which apply to adjacent wire-pairs, and the same wire-pair, which may be used as transmission bearers for other forms of service (e.g. POTS, ISDN-BA, etc.).

NOTE: The operation of VDSL below the lower frequency limit ($\mathbf{f_L}$) is not excluded, e.g. on new lines where existing narrowband services may not be present. The issue of VDSL transmit energy polluting parts of the spectrum occupied by other xDSL systems (e.g. ADSL) may preclude the use of lower frequencies, especially in the upstream direction of transmission.

11.1 Adjacent wire-pairs

VDSL systems shall be required to operate with a number of different DSL systems operating on adjacent wire-pairs in a multi-pair cable. Each of the other systems will generate crosstalk which will appear, to a lesser or greater extent, as unwanted noise at the front-end of a VDSL receiver.

Class I and Class II VDSL systems shall be able to operate on different wire-pairs within a multi-pair cable. No special arrangements shall be required for pair selection.

All forms of VDSL are required to co-exist with an installed base of heritage xDSL systems (e.g. other VDSL, HDSL, ADSL, ISDN-BA, ISDN-PRA, etc.) operating in the same multi-pair cable.

11.2 Same wire-pair

VDSL is required to co-exist with some existing narrowband services that may be carried on the same wire-pair. This is to ensure that the VDSL system can provide a broadband overlay capability. In particular, VDSL shall be required to operate at frequencies above POTS as described in ETS 300 001 [5], TBR 021 [6], and both 2B1Q and 4B3T forms of ISDN-BA in Europe according to TS 102 080 [4].

The splitter filter characteristics are defined in clause 12.

Frequency separation shall be used to separate the VDSL signals from the existing narrowband signals.

11.3 Symmetric versus asymmetric VDSL

Co-existence of asymmetric and symmetric VDSL systems in the same multi-pair cable shall be possible. However, there is an unavoidable performance penalty that shall be managed by the Network Operator via appropriate planning rules for deployment. No special arrangements shall be required for pair selection.

12 Splitter filter requirements

A splitter filter is required at both ends of the line that carries VDSL signals if existing narrowband services are to remain unaffected by the presence of higher frequency VDSL signals on the same wire-pair. The structure of the splitter filter port is given in figure 17. The VDSL port connects to the VDSL transceiver. The TELE port connects to the existing POTS NT or ISDN-BA NT. The TELE-LINE function is that of a low-pass filter, whereas the VDSL-LINE port function is high-pass. Exceptional isolation is required between TELE and VDSL ports to prevent undesirable interaction between VDSL and any existing narrowband services.

Designs shall take into careful account the relevant national specifications. In the absence of national specifications the narrowband requirements of ETS 300 001 [5] and TBR 021 [6] shall be met for POTS and TS 102 080 [4] for ISDN-BA.

The splitter filter requirements given at present in this clause are based on key requirements of the low pass filter indicated by several network operators. Those requirements shall guarantee the proper operation of POTS and ISDN on lines that carry VDSL signals, however, there may be some space for an optimization.

The requirements of the high pass filter are more dependent on the VDSL splitter structure than those of the low pass filter. The high pass filter will probably be included in the NT or LT respectively, where the low pass filter may be combined with an all pass function for the VDSL branch.

After more simulations and measurements have been done on topics like mismatching (for example due to the additional line between splitter and exchange in FTTCab scenarios), co-existence and transmission performance (for POTS, ISDN and VDSL) further refinements of the splitter filter requirements are expected to be made.

The splitter shall meet the requirements of this clause with all VDSL transceiver impedances that are tolerated by the return loss specification in subclause 8.3.2.

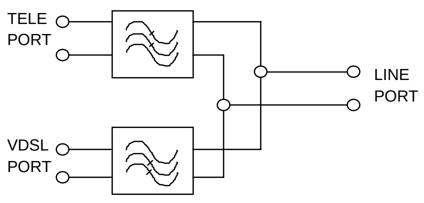


Figure 17: Structure of the VDSL splitter filter

The reference impedances associated with the TELE and VDSL ports are as follows:

TELE port: $\mathbf{Z_M}$ for POTS and 135 Ω for 2B1Q-based ISDN-BA according to TS 102 080 [4], annex A and 150 Ω for 4B3T-based ISDN-BA according to TS 102 080 [4], annex B;

VDSL port: $\mathbf{R_V}$.

NOTE: $\mathbf{Z_M}$ is country specific - see annex C for more detailed specification.

The key requirements for the VDSL splitter filter are shown in table 20.

Table 20: Key VDSL splitter filter electrical requirements

Ref.	Requirement
S1	f_l shall be set to 120 kHz.
S2	TELE port to LINE port insertion loss into Z_M should be < 0,5 dB from 200 Hz to 4 kHz, the insertion loss variation (ripple) over this frequency band should be < 0,2 dB.
S3	For countries requiring the use of SPM or tax tones, the TELE port to LINE port insertion loss into 200 Ω should be < 1 dB at 16kHz ± 1kHz, and into 200 Ω should be < 1 dB at 12 kHz ± 1kHz. The insertion loss variation (ripple) over these frequency bands should be < 0,2 dB.
S4	TELE port and LINE port return loss against Z_M when the other port is terminated in Z_M should be better than 18 dB, from 200 Hz to 4 kHz.
S5	TELE port to LINE port insertion loss into 135 Ω and into 150 Ω should be < 0,5 dB from 100 Hz to f_l the insertion loss variation (ripple) over this frequency band shall be < 0,05 dB (c.f. a group delay of < 7 µS).
S6	TELE port and LINE port return loss against 135 Ω and 150 Ω when the other port is terminated in 135 Ω and 150 Ω respectively should be better than 18 dB, over the band 0 to f_l.
S7	LINE port to VDSL port insertion loss in R_V of less than 0,6 dB from f_L to f_H.
S8	LINE port and VDSL port return loss to R_V shall both meet the requirements in subclause 8.3.2.
NOTE:	Both ports shall be better than 18 dB from f_L to f_H.
S9	TELE port to VDSL port isolation should be > 70 dB over the bands 200 Hz to f_l and from f_L to f_H, with some relaxation permissible in the transition band.
S10	The common-mode isolation between TELE and LINE when terminated in a 50 Ω common mode circuit from f_L to f_H shall be > 35 dB.
S11	The LCL at the LINE port from 300 Hz to f_H when measured with 50 Ω common mode source and R_V differential mode load shall be > 40 dB. Additional requirements at some frequencies are listed in subclause 8.3.3.
S12	TELE port to LINE port DC resistance shall be < 25 Ω.

The requirements of table 20 shall be met when the port, which is not in use for the test of a specific requirement, is terminated:

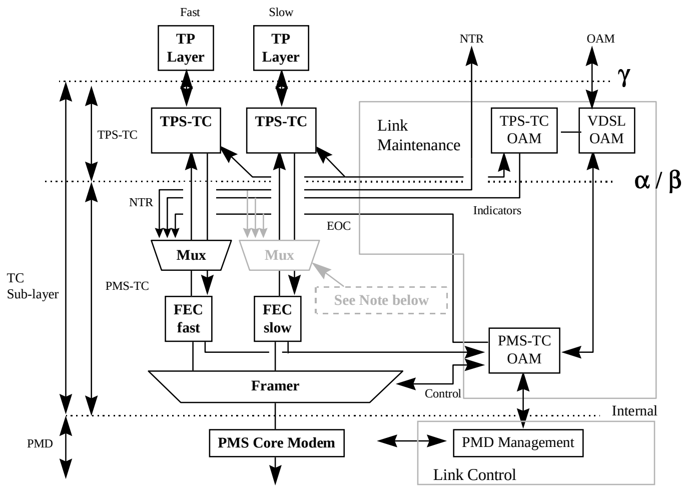
- with the appropriate matching impedance outlined in this subclause;
- with a mismatched impedance due to reasonable fault conditions at this port (e.g. line break, typical resistive load, ringer load, A or B wire to earth, etc.).

13 Application specific requirements

This clause specifies additional application specific functional requirements where they differ from the application independent functional requirements detailed elsewhere in the present document.

13.1 ATM transport mode

Figure 18 shows the VDSL functional reference model as applied to the ATM application.



NOTE 1: It is not compulsory to implement both the fast and slow channels. Single channels with programmable latency are equally acceptable.

NOTE 2: The EOC may be in the fast or slow channel or potentially in a separate TC sub-layer.

Figure 18: VDSL functional reference model applied to ATM

13.1.1 Latency

Two different latency paths for the transport of ATM cells may be optionally simultaneously provided in VDSL transceiver implementations (also known as dual latency). The "slow" path is associated with Forward Error Correction and Data Interleaving that provides for lower BER at the expense of higher throughput delay or latency. ATM applications requiring this facility would normally be delay insensitive requiring very low BER. The transport of an ATM cell through the "fast" path would naturally incur the minimum of delay but at the expense of a worse (higher) BER.

VDSL transceivers shall implement appropriate FEC and data interleaving to meet the performance requirements as detailed in clause 9. Details of the latency requirements may be found in clause 8.

The facility for dual latency for ATM applications is optional.

13.1.2 OAM requirements

The ATM TPS-TC shall implement loop-back test facilities by PLOAM cells, and the EOC shall provide a control channel to allow loop backs to be applied by the TPS-TC. Responses to other OAM cells may be specified later.

13.2 SDH transport mode at sub STM-1 rates

Figure 19 shows the VDSL functional reference model as applied to the SDH application.

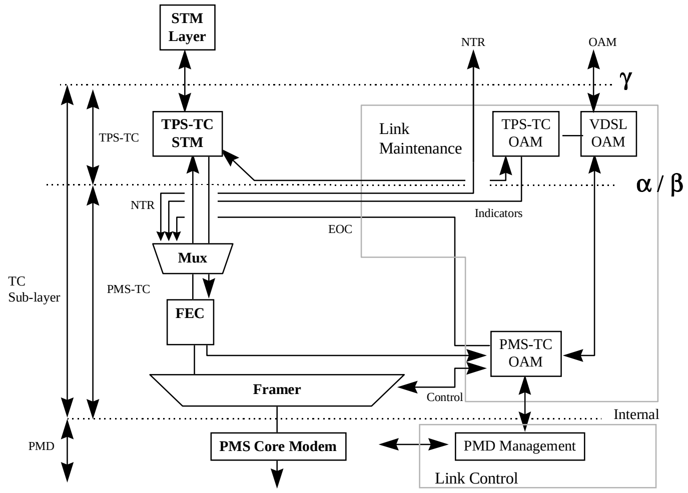


Figure 19: VDSL functional reference model applied to SDH

13.2.1 Dual Latency

Dual latency is not applicable to the SDH application. The latency may need to be programmable to suit the line characteristics. The limits need to be defined.

13.2.2 OAM requirements

The SDH TPS-TC shall implement loop-back functionality, and the EOC shall provide a control channel to allow loop backs to be applied by the TPS-TC.

13.3 Additional applications

Additional applications for VDSL are foreseen. The following list is provisional and all of these applications are for further study.

It is possible that a mixture of services may be supported simultaneously.

13.3.1 Multiple PDH

A number of ITU-T Recommendation G.703 [10] physical interfaces (T reference point) may provide ISDN-PRA (full or partially filled) or private network services. The VDSL link may also implement a native multiplexing scheme that provides section level performance monitoring and management capabilities equivalent to SDH.

13.3.2 Narrowband in-band

The VDSL link carries a number of N-ISDN channels with low latency over the VDSL link at the same time as broadband traffic. These may be presented to the customer on N-ISDN S/T interfaces or as analog POTS ports.

13.3.3 IP transport

IP packets will be transported by a variety of means. The IP/PPP/ATM method as developed by the ADSL Forum and IETF is particularly applicable to heritage data services. IP encapsulation on ATM is defined by RFC 1483 [16]. Native IP transport may be supported by well known frame encapsulation methods for PDH channels which may be provided by VDSL, or by a new packet mode TC layer.

13.3.4 Campus access reference models

Both the existing and the additional applications listed here may be useful in campus applications where the existing reference model is not appropriate. These campus applications may benefit from allowing dynamic rate adaptation.

Annex A (normative): Line constants for the test loop-set

Annex A details the typical line constants for the cable sections in the test loops. The cable types used to create this annex are representative of existing European metallic access networks. See Bibliography, [I-3] for an overview of country specific line constants.

The primary cable parameters vary with frequency. Their typical values shall be calculated at any frequency (up to 30 MHz) by using the empirical models shown below. The line constants given in tables A.1 and A.2 shall be used (together with the equations) to calculate the values given in figure 12 and determine the transmission characteristics of the test loops contained in the main body of the present document.

NOTE 1: Conductance becomes significant at high frequencies and should not be ignored.

NOTE 2: Both models are equally valid from DC to 30 MHz when using the appropriate parameter sets and values.

The formal models for the cable parameters in the test loops are shown below:

TP100 and TP180x

$$Z_{s0}(f) = \left[\sqrt[4]{R_{0C}{}^4 + a_c \times f^2} + j \times 2\pi \times f \times \left(\frac{L_0 + L_\infty \times \left(f/f_m \right)^{Nb}}{1 + \left(f/f_m \right)^{Nb}} \right) \right] \times \frac{1}{1000} \quad [\Omega/\text{m}]$$

$$Y_{p0}(f) = \left[(g_0 \times f^{N_{ge}}) + j \times 2\pi \times f \times \left(C_\infty + C_0 / f^{N_{ce}} \right) \right] \times \frac{1}{1000} \quad [\text{S/m}]$$

TP150 and TP100x

$$Z_{S0}(\omega) = \frac{j\omega \times Z_{0\infty}}{c} + R_{ss00} \times \left(1 + K_l \times K_f \times \left(\chi \times \coth\left(4/3 \times \chi \right) - 3/4 \right) \right) \quad [\Omega/\text{m}]$$

$$Y_{p0}(\omega) = \frac{j\omega}{Z_{0\infty} \times c} \times \left(1 + \frac{(K_c - 1)}{1 + \left(\omega / \omega_{C0} \right)^N} \right) + \frac{\tan(\phi)}{Z_{0\infty} \times c} \times \omega^M \quad [\text{S/m}]$$

where:

$$\chi = \chi(\omega) = (1 + j) \times \sqrt{\frac{\omega}{2\pi} \times \frac{\mu_0}{R_{SS00}} \times \frac{1}{K_n \times K_f}}$$

$$\omega_{C0} = 2\pi \times f_{C0}$$

$$\mu_0 = 4\pi \times 10^{-7}$$

Table A.1: Line constants for the TP100 and TP180x cable sections in the test loops

Wire Type	Roc Nb	ac g0	Ros Nge	As Co	Lo C∞	L∞ Nce	fm
TP100	179 1,2	$35,89 \times 10^{-3}$ $0,5 \times 10^{-9}$	0 1,033	0 1×10^{-9}	$0,695 \times 10^{-3}$ 55×10^{-9}	585×10^{-6} 0,1	1×10^{6}
TP180x	41,16 1,1952665	$1,2179771 \times 10^{-3}$ 53×10^{-9}	0 0,88	0 $31,778569 \times 10^{-9}$	1×10^{-3} $22,681213 \times 10^{-9}$	$910,505 \times 10^{-6}$ 0,110866740	174877

Table A.2: Line constants for the TP150 and TP100x cable sections in the test loops Scaling constant $c_0 = 3 \times 10^8$ m/s and equals the velocity of light

	$Z_{0\infty}$	c/c_0	R_{ss00}	$2\pi\cdot\tan(\phi)$	K_f	K_l	K_n	K_c	N	f_{c0}	M
TP150	136,651	0,79766	0,168145	0,13115	0,72	1,2	1	1,08258	0,7	4521710	1
TP100x	97,4969	0,639405	0,177728	0,0189898	0,5	1,14	1	1	1	100000	1

The transmission and reflection (or insertion loss and return loss) of the test loops shall be calculated from the primary cable parameters using the formulae below. Table A.3 may be used to verify the results of the calculations based on typical values for a 1 km length.

The test loops can be built using a combination of real cables and cable simulators. Tables A.4 and A.5 summarize the estimated length of real cables if they are used. Their actual lengths may deviate from this because real test loops have to meet the electrical length requirements (based on insertion loss) instead of physical length requirements.

The insertion loss and return loss at RV = 135 Ω for an arbitrary length "L" can be calculated from $\{Z_{s0}, Y_{p0}\}$ by evaluating the two-port s-parameters normalized to RV using the formulae shown below.

To calculate the primary $\{Z_{s0}, Y_{p0}\}$ and secondary $\{\gamma, Z_0\}$ parameters:

$$Z_s = L \cdot Z_{s0} \qquad \gamma = \sqrt{Z_s \cdot Y_p} \qquad \alpha = real(\gamma) \qquad R_s = real(Z_s) \qquad G_p = real(Y_p)$$

$$Y_s = L \cdot Y_{s0} \qquad Z_0 = \sqrt{Z_s / Y_p} \qquad \beta = imag(\gamma) \qquad L_s = imag(Z_s / \omega) \qquad C_p = imag(Y_p / \omega)$$

To calculate the two-port s-parameters:

$$\mathbf{s} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \frac{1}{(Z_0 / R_V + R_V / Z_0) * \tanh(\gamma) + 2} \; x \begin{bmatrix} (Z_0 / R_V - R_V / Z_0) * \tanh(\gamma) & 2 / \cosh(\gamma) \\ 2 / \cosh(\gamma) & (Z_0 / R_V - R_V / Z_0) * \tanh(\gamma) \end{bmatrix}$$

Transmission @ RV: s_{21} and s_{12} — Insertion loss @ RV: $1/s_{21}$ and $1/s_{12}$

Reflection @ RV: s_{11} and s_{22} — Return loss @ RV: $1/s_{11}$ and $1/s_{22}$

To calculate the two-port s-parameters of a cascaded cable of two sections "a" and "b":

$$\mathbf{s} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \frac{1}{1 - S_{22a} * S_{11b}} * \begin{bmatrix} S_{11a} - \Delta_{sa} * S_{11b} & S_{12b} * S_{12a} \\ S_{21a} * S_{21b} & S_{22b} - \Delta_{sb} * S_{22a} \end{bmatrix} \qquad \Delta_S = S_{11} * S_{22} - S_{12} * S_{21}$$

Table A.3: Predicted parameters computed from the cable models

	Frequency (kHz)	Resistance (Ω/km) R_{sx}	Inductance (μH/km) L_{sx}	Capacitance (pF/km) C_{px}	Conductance (mS/km) G_{px}	Insertion loss (dB) @ 1km @ 135Ω	Characteristic impedance (Ω) Z_0
TP100	1	179	694,972	55,501	0,0006	4,42	716,56
	10	179,16	694,564	55,398	0,0068	4,57	230,16
	100	192,93	688,471	55,316	0,0731	7,30	116,74
	1 000	438,33	640	55,251	0,7888	18,13	107,94
	10 000	1376,49	591,529	55,200	8,5108	61,72	103,55
TP150	1	168,15	784,381	33,099	0,0040	4,21	899,29
	10	168,47	784,199	33,072	0,0401	4,26	290,62
	100	197,37	768,161	32,942	0,4011	5,77	158,71
	1 000	527,25	645,503	32,454	4,0107	18,66	141,61
	10 000	1539,30	594,606	31,501	40,1067	72,59	137,43
TP100x	1	177,73	710,932	53,47	0,001	4,4	727,45
	10	178,15	710,611	53,47	0,0102	4,54	233,81
	100	212,24	685,002	53,47	0,1015	7,87	119,52
	1 000	482,66	568,898	53,47	1,0154	20,87	103,61
	10 000	1306,43	527,442	53,47	10,1539	61,7	99,36
TP180x	1	41,16	999,814	37,456	0,0231	1,25	419,63
	10	41,59	997,166	34,128	0,1755	1,37	186,96
	100	62,28	969,667	31,549	1,3313	2,65	175,57
	1 000	186,92	920,407	29,551	10,0989	12,50	176,40
	10 000	590,76	911,210	28,003	76,6083	74,41	180,31

Table A.4: Predicted physical length computed from the cable models for the electrical length requirements of table 7 (PSD mask M1, notches not taken into account)

Payload Rate	Noise model A (m)	Noise model B (m)	Noise model C (m)	Noise model D (m)	Noise model E (m)	Noise model F (m)
S1 - Loop #1	1 344	1 344	893	1 292	1 392	945
Loop #2	1 242	1 242	826	1 204	1 297	881
Loop #3	1 242	1 242	827	1 199	1 291	876
Loop #4	1 342	1 342	891	1 284	1 384	937
S2 - Loop #1	1 195	1 195	844	1 195	1 245	896
Loop #2	1 087	1 087	769	1 095	1 141	822
Loop #3	1 087	1 087	769	1 093	1 139	820
Loop #4	1 184	1 184	833	1 190	1 240	891
S3 - Loop #1	746	746	546	695	796	646
Loop #2	664	664	486	624	714	580
Loop #3	668	668	491	625	714	581
Loop #4	732	732	531	685	785	636
S4 - Loop #1						
Loop #2						
Loop #3						
Loop #4						
S5 - Loop #1						
Loop #2						
Loop #3						
Loop #4						
A1 - Loop #1	1 588	1 687	892			
Loop #2	1 505	1 598	847			
Loop #3	1 500	1 594	843			
Loop #4	1 590	1 689	894			
A2 - Loop #1	1 490	1 589	844			
Loop #2	1 400	1 493	794			
Loop #3	1 395	1 488	789			
Loop #4	1 493	1 592	846			
A3 - Loop #1	1 245	1 294	796			
Loop #2	1 141	1 186	731			
Loop #3	1 139	1 184	729			
Loop #4	1 240	1 290	791			
A4 - Loop #1	844	896	496			
Loop #2	769	816	453			
Loop #3	769	816	453			
Loop #4	833	885	485			

Table A.5: Predicted physical length computed from the cable models for the electrical length requirements of table 8 using PSD mask M2

Payload Rate	Noise model A (m)	Noise model B (m)	Noise model C (m)	Noise model D (m)	Noise model E (m)	Noise model F (m)
S1 - Loop #1	1 442	1 442	994	1 344	1 444	945
Loop #2	1 332	1 332	919	1 252	1 345	881
Loop #3	1 333	1 333	920	1 246	1 339	876
Loop #4	1 440	1 440	992	1 336	1 435	937
S2 - Loop #1	1 245	1 245	946	1 245	1 294	896
Loop #2	1 132	1 132	861	1 141	1 186	822
Loop #3	1 132	1132	861	1 139	1 184	820
Loop #4	1 233	1 233	934	1 240	1 290	891
S3 - Loop #1	795	795	646	745	845	646
Loop #2	708	708	575	668	758	580
Loop #3	712	712	580	668	758	581
Loop #4	781	781	632	734	834	636
S4 - Loop #1	298	298	298	397	397	347
Loop #2	261	261	261	347	347	304
Loop #3	268	268	268	354	354	311
Loop #4	281	281	281	380	380	330
S5 - Loop #1	248	248	248	298	298	298
Loop #2	212	212	212	255	255	255
Loop #3	219	219	219	262	262	262
Loop #4	229	229	229	280	280	280
A1 - Loop #1	1 687	1 789	991			
Loop #2	1 598	1 695	941			
Loop #3	1 594	1 690	936			
Loop #4	1 689	1 791	993			
A2 - Loop #1	1 589	1 688	943			
Loop #2	1 493	1 585	887			
Loop #3	1 488	1 580	882			
Loop #4	1 592	1 691	945			
A3 - Loop #1	1 294	1 344	896			
Loop #2	1 186	1 232	822			
Loop #3	1 184	1 230	820			
Loop #4	1 290	1 340	891			
A4 - Loop #1	945	995	595			
Loop #2	847	891	534			
Loop #3	848	892	535			
Loop #4	935	984	584			

Annex B (informative): Cable information

The following material though not specifically referenced in the body of the present document, gives supporting information regarding cable construction.

The cable sections in the test loops are representative of existing European metallic access cables. They represent the following cables (they are described in more detail in Bibliography [I-3]).

Cable type TP100 (equivalent to BT_dwug in Bibliography [I-3]):

This is a multi-pair cable with 0,5 mm solid copper conductors with polyethylene insulation. It is predominantly used for underground distribution.

Cable type TP150 (equivalent to KPN_L1 distribution cable in Bibliography [I-3]):

Multiple quads (4 wires or two pairs), 0,5mm solid copper conductors with paper insulation. The cables are constructed in concentric layers, and each layer consists of a number of twisted quads. A shield of lead (connected to earth) provides mechanical protection for the bundle of quads. It is predominantly used for underground distribution.

This class covers cables containing up to 900 pairs (450 quads) in the same bundle. They are organized as 450 quads in 11 concentric layers (no binder groups). A 50 quad version has been used as a template for the models.

Cable type TP100x (equivalent to KPN_R2 indoor cable in Bibliography [I-3]):

Four twisted pairs of 0,5mm solid copper conductors shielded by a foil. It is suitable for use as Category 5 LAN cabling. It is used in Dutch local exchanges as indoor cable to connect from xDSL equipment to distribution cables (Polyethylene insulated).

Cable type TP180x (equivalent to BT_dw8 in Bibliography [I-3]):

Single pair dropwire consisting of a flat twin (i.e. untwisted) with 1,14 mm cadmium copper conductors with PVC insulation. This cable has no steel strengthening member.

Annex C (informative): Telephony matching impedance

The European harmonized matching impedance, Z_M, for non-voice terminals (e.g. voice-band transceivers), is given in figure C.1 below. This compromise impedance is detailed more fully in ITU-T Recommendation Q.552 [15].

Different three-element compromise impedances are used for voice terminal operation in different countries. The subclauses below detail the reference impedances and any other country specific parameters. Component values are ± 0,1 % unless otherwise stated.

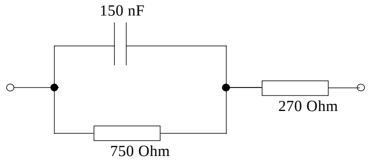


Figure C.1: Z_M compromise reference impedance (European harmonized - non voice terminals)

Unless otherwise required this voice-band matching impedance should be used for the design of the VDSL service splitter filter at voice-band frequencies. Where country specific requirements for the telephony matching impedance differ, they are described within the remainder of annex C.

NOTE: The harmonized matching impedance described above has been advocated in France (by France Telecom) and Spain (by Telefonica) for POTS matching.

C.1 Germany

For POTS operation in Germany, the following compromise matching impedance should be used when meeting the splitter requirements.

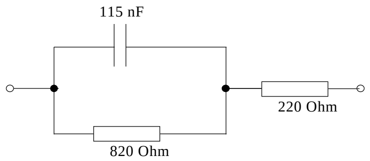


Figure C.2: Z_M compromise reference impedance used by Deutsche Telekom AG (voice terminals)

C.2 United Kingdom

For POTS operation in the UK, the following compromise matching impedance should be used when meeting the splitter requirements.

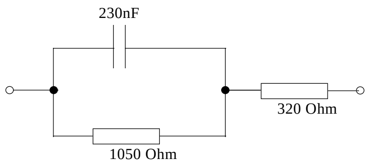


Figure C.3: Z_M compromise reference impedance used by British Telecommunications plc (voice terminals)

Annex D (informative): Illustrative graphs of PSD masks

The graphs shown below may be used to illustrate the PSD masks given in subclause 8.3.5.

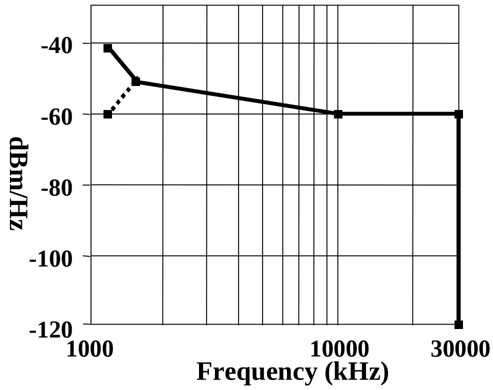


Figure D.1: Pcab.#.M2, Pex.#.LT.M2 and Pex.#.NT.M2

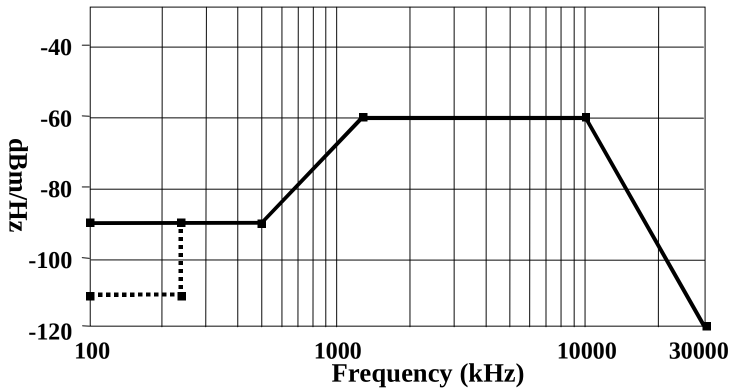


Figure D.2: FTTCab scenarios Pcab.D.M1 and Pcab.P.M1

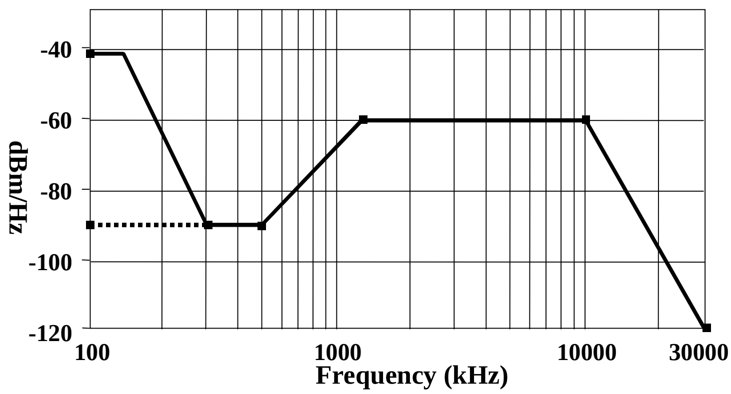


Figure D.3: FTTEx scenarios Pex.D.NT.M1 and Pex.P.NT.M1

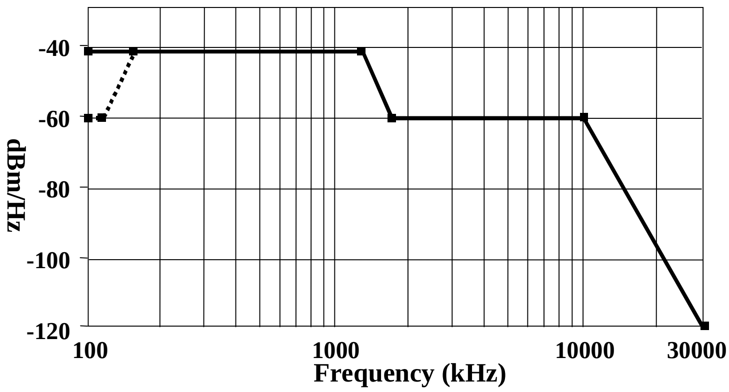


Figure D.4: FTTEx scenario Pex.D1.LT.M1 and Pex.D2.LT.M1

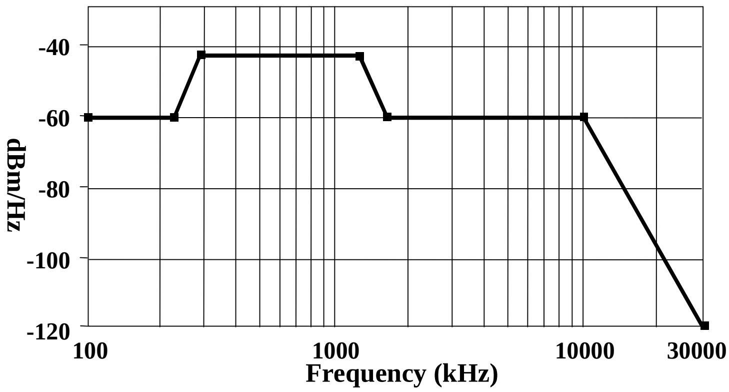


Figure D.5: FTTEx scenario Pex.D3.LT.M1

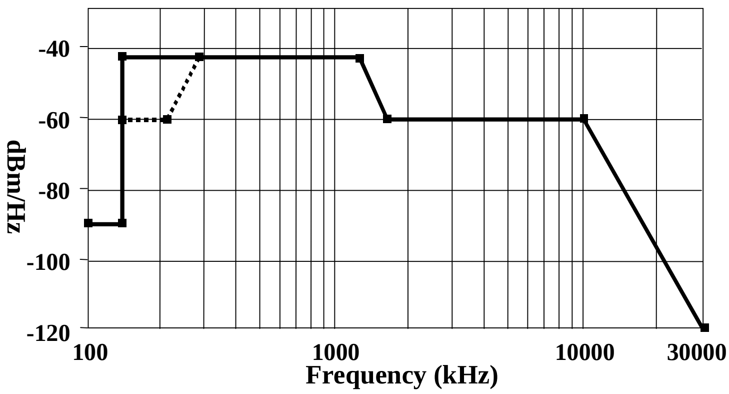


Figure D.6: FTTEx scenario Pex.P1.LT.M1 and Pex.P2.LT.M1

Bibliography

The following documents have been used in the preparation of the present document:

[I-1] "VDSL Copper Transport System, Gx telco group concerned with requirements for VDSL technology for Full Services Access Networks", IEEE VIII International Workshop on Optical/Hybrid Access Networks, Atlanta USA, 4 March 1997.

[I-2] "Specification for Full Services Access Networks (1997)", Gx/FSAN group of Network Operators and Manufacturers.

[I-3] "Cable reference models for simulating metallic access networks", R.F.M. van den Brink, ETSI TM6 Permanent document TM6 (97) 02 revision 3, Luleå, Sweden, June 1998.

History

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