ETSI TS 101 271 V1.2.1 (2013-08)

Technical Specification

Access, Terminals, Transmission and Multiplexing (ATTM); Access transmission systems on metallic access cables; Very High Speed digital subscriber line system (VDSL2) [Recommendation ITU-T G.993.2 modified]

Reference

RTS/ATTM-06012

Keywords

access, modem, transmission, VDSL2

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://ipr.etsi.org).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

The present document contains information on the European requirements for Very High Speed Digital Subscriber Line Systems (VDSL2). Unless specifically stated in the present document, the requirements are given in the Recommendation ITU-T G.993.2 [1] (Very high speed digital subscriber line transceivers 2).

1 Scope

The present document provides the necessary adaptions to Recommendation ITU-T G.993.2 [1] for European applications and other information relevant to the European environment.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

[1] Recommendation ITU-T G.993.2: "Very high speed digital subscriber line transceivers 2 (VDSL2)".

[2] ETSI TS 101 388 (V1.4.1): "Access Terminals Transmission and Multiplexing (ATTM); Access transmission systems on metallic access cables; Asymmetric Digital Subscriber Line (ADSL) - European specific requirements [ITU-T Recommendation G.992.1 modified]".

[3] Recommendation ITU-T G.227: "Conventional Telephone Signal".

[4] Recommendation ITU-T G.993.5: "Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers".

[5] Broadband Forum TR-114: "VDSL2 Performance Test Plan".

[6] Broadband Forum TR-115: "VDSL2 Functionality Test Plan".

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI ATTM TM6 Permanent Document TM6(97) 02, June 1998: "Cable reference models for simulating metallic access networks".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

crest factor (CF): peak to rms voltage ratio

design impedance (R_V): target input and output impedance of the VDSL2 modem

NOTE: This is set at 100 Ω in [1].

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

FTTCab: used to define when VDSL2 LT transceivers are located physically at a node (normally the Cabinet or PCP) in the periphery of the access network

FTTEx: used to define when VDSL2 LT transceivers are located physically at the serving Local Exchange

network side: central office in Recommendation ITU-T G.993.2 [1]

reference impedance (R_N): chosen impedance used for specifying transmission and reflection characteristics of cables and test loops

NOTE: ETSI has normalized this value at 135 Ω for a wide range of xDSL performance and conformance tests, including ADSL tests. This value is considered as being a reasonable average of characteristic impedances (Z_0) observed for a wide range of commonly used European distribution cables.

r.m.s: root mean square value

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

vectoring: coordinated transmission and/or coordinated reception of signals of multiple DSL transceivers using techniques to mitigate the adverse effects of crosstalk to improve performance

xDSL: generic term covering the family of all DSL technologies, e.g., SDSL, ADSL2, ADSL2plus, VDSL2

3.2 Symbols

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

f_T Test loop calibration frequency for setting the insertion loss of the loop
kbps kilo-bits per second

NOTE: 1 kbps = 1 000 bits per second.

Mbps Mega bits per second

NOTE: 1 Mbps = 1 000 kbps.

R_N Reference Impedance

NOTE: Used for specifying transmission and reflection characteristics of cables and test loops.

R_V VDSL2 source/load design impedance (purely resistive)
Z_0 Characteristic impedance of the test loop
Z_M Compromise reference impedance for the VDSL2 splitter (usually complex)

3.3 Abbreviations

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

ADSL Asymmetric Digital Subscriber Line
ADSL2 Asymmetric Digital Subscriber Line Transceivers 2
ADSL2plus Asymmetric Digital Subscriber Line Transceivers 2 with extended bandwidth
AM Amplitude Modulation
BER Bit Error Ratio
CF Crest Factor
CO Central Office
CP Customer Premises

DC	Direct Current
DN	Downstream
DRM	Digital Radio Mondiale
DSL	Digital Subscriber Line (or Loop)
FEC	Forward Error Correction
FEXT	Far End Cross Talk
FSAN	Full Services Access Network organization
FTTCab	Fibre To The Cabinet (see definitions)
FTTEx	Fibre To The Exchange (see definitions)
HAM interference	Amateur Radio interference
HD	High Density
HF	High Frequency
LAN	Local Area Network
LCL	Longitudinal Conversion Loss
LT	Line Termination

NOTE: VTU-O or VTU at the Central Office in Recommendation ITU-T G.993.2 [1].

LW	Long Wave
MD	Medium Density
MW	Medium Wave
NEXT	Near-end crosstalk
NT	Network Termination

NOTE: At the customer premise end of the line. VTU-R or VTU at the Remote End in Recommendation ITU-T G.993.2 [1].

PCP Primary Cross-connection Point

NOTE: Also known as the cabinet.

PDF	Probability Density Function
PE	Polyethylene
PEP	Psophometric Electrical Power
PRBS	Pseudo Random Bit Sequence
PSD	Power Spectral Density
PVC	Poly Vinyl Chloride
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Root Mean Square
RS	Red-Solomon
SDSL	Symmetric single pair high bitrate Digital Subscriber Line
SW	Short Wave
TBD	To Be Decided
UP	Upstream
UPBO	Upstream Power Back-Off
VDSL2	Very high speed Digital Subscriber Line Transceivers 2

NOTE: Specified in Recommendation ITU-T G.993.2 [1].

VTU-R VTU at the Remote site

4 Endorsement notice

All elements of the ITU Recommendation G.993.2 [1] apply. The European specific requirements are given in Recommendation ITU-T G.993.2 annex B [1].

5 Longitudinal Conversion Loss

Longitudinal conversion loss (LCL) is a measure of the degree of unwanted transversal signal produced at the input of the VDSL2 transceiver due to the presence of a longitudinal signal on the connecting leads. The LCL requirements, below and above 12 MHz, shall be identical to the requirements defined in clause 7.4. of Recommendation ITU-T G.993.2 [1].

6 Vectoring Requirements for the VTU-R

This clause defines the self-FEXT (far-end crosstalk) cancellation (vectoring) requirements for the VTU-R:

1) When deploying vectoring technology, it is essential that the VTU-R transceiver implements the requirements defined in Recommendation ITU-T G.993.5 [4].

2) VTU-R transceivers shall implement the vectoring requirements defined in Recommendation ITU-T G.993.5 [4].

7 Test Procedures

This clause provides a specification of the test set-up, the insertion path and the definition of signal and noise levels. The tests focus on the noise margin when VDSL2 signals under test are attenuated by standard test-loops and suffer interference from standard crosstalk noise or impulse noise. This noise margin indicates what increase of crosstalk noise or impulse noise level can be tolerated by the VDSL2 system under test before the bit error ratio exceeds the design target.

7.1 Test set-up definition

Figure 7.1 illustrates the functional description of the test set-up. It includes:

- A data source capable of generating a Pseudo Random Bit Sequence (PRBS) with a minimum length of 2^{15}-1 to the transmitter in the direction under test at the bitrate required. The transmitter in the opposite direction shall be fed with a similar PRBS signal, although there is no need to monitor the receiver output in this path.
- The test loops, as specified in clause 7.2.
- An adding element to add the common mode and differential mode impairment noise (a mix of random, impulsive and harmonic noise), as specified in clause 7.3.
- An impairment generator, as specified in clause 7.3, to generate both the differential mode and common mode impairment noise to be fed to the adding element.
- A high impedance and well balanced differential voltage probe (e.g. better than 60 dB across the whole VDSL2 bandwidth) connected with level detectors such as a spectrum analyzer or a true rms voltmeter.
- A high impedance and well balanced common mode voltage probe (e.g. better than 60 dB across the whole VDSL2 bandwidth) connected with level detectors such as a spectrum analyzer or a true rms voltmeter.

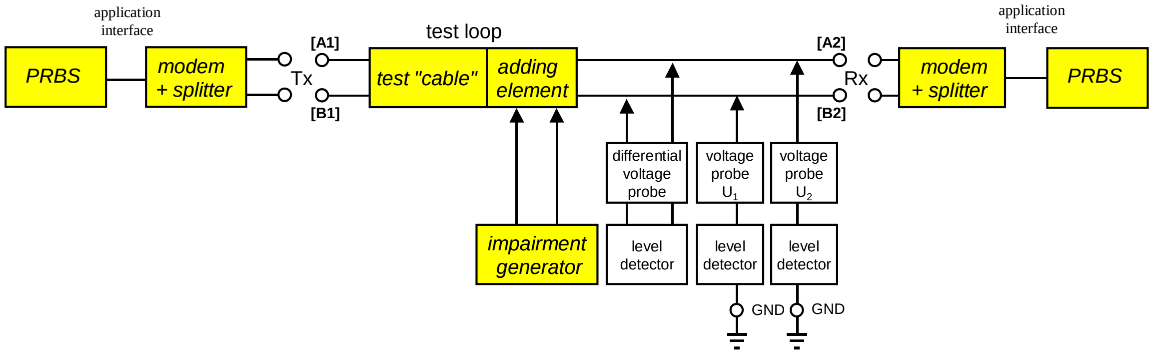


Figure 7.1: Functional description of the set-up of the performance tests

The two-port characteristics (transfer function, impedance) of the test-loop, as specified in clause 7.2, 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 7.1 shall 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 load the line.

The balance about earth, observed at both ports 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 VDSL2 transceivers under test. The impairment generator is switched off during this measurement.

Test Loop #0, as specified in clause 7.2, shall always be used for calibrating and verifying the correct settings of generators G1-G7, as specified in clause 7.3, during performance testing.

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 clause 7.3. The level that is specified in clause 7.3 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.

7.1.1 Signal and noise level definitions

The signal and noise levels are probed with a well balanced differential voltage probe (U_2-U_1). 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 7.1 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).

The common mode signal and noise levels are probed with a well balanced common mode voltage probe as the voltage between nodes A2, B2 and ground. Figure 7.1 shows the position of the two voltage probes when measuring the common mode signal. The common mode voltage is defined as $1/2(U_1+U_2)$.

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 the design impedance R_V or with VDSL2 transceivers under test.
Probing an rms-voltage Urms (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 Urms (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:
$P = 10 \times \log_{10} (U_{rms}{}^2/R_V \times 1\,000/\Delta f)$ (dBm/Hz)

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

7.2 Test loops

The purpose of the test loops shown in figure 7.2 is to stress VDSL2 transceivers under a wide range of different conditions that can be expected when deploying VDSL2 in real networks.

7.2.1 Functional description

The test loops in this clause are an artificial mixture of cable sections. A number of different loops have been used to represent a wide range of cable impedances, and to represent ripple in amplitude and phase characteristics of the test loop transfer function.

- The physical length of the individual loops is to be chosen such that the transmission characteristics of all loops are comparable. This is achieved by normalizing the *electrical* length of the loops (insertion loss at 300 kHz). The purpose of this is to stress the equaliser of the VDSL2 modem under test in a similar way over all loops, when testing at a specific bitrate.

The loops are defined as a combination of cable sections. Each section is defined by means of two-port cable models of the individual sections (see clause 8). Cable simulators as well as real cables can be used for these sections.

- Loop #0 is a symbolic name for a loop with zero (or near zero) length, to prove that the VDSL2 transceiver under test can handle the potentially high signal levels when two transceivers are directly interconnected.

- 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 relatively 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.

Test loops 1 to 4 in figure 7.2 have equal *electrical* length (insertion loss at 300 kHz), but differ in input impedance (see figure 7.3). It is these values for insertion loss and impedance that define an actual test loop set. This clause only defines the loop topology – the detailed loop lengths are out of scope for the present document.

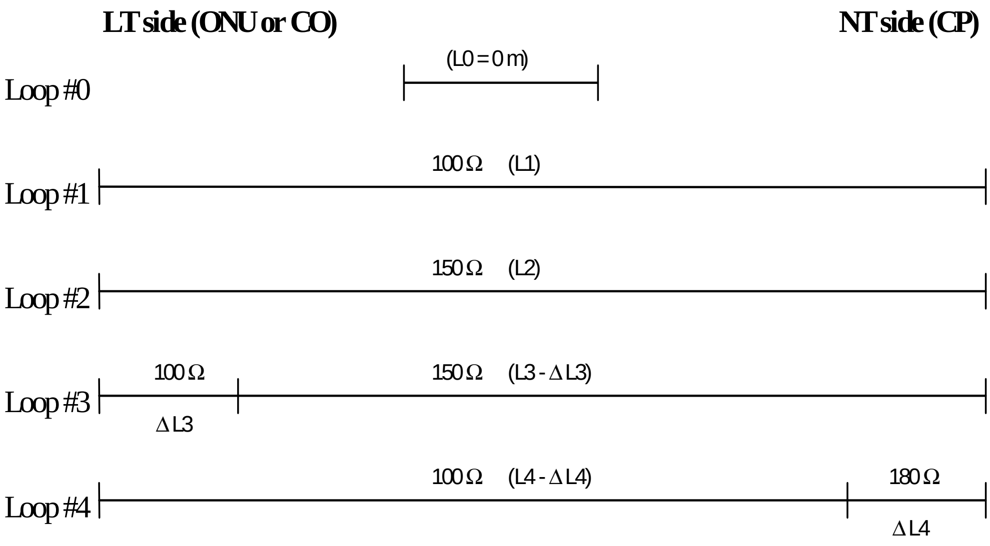


Figure 7.2: Test loop topology

The physical composition of the various test loops is defined in table 7.1.

Table 7.1: Test loop composition

Test loop	Distribution cable (L)	Extension cable (ΔL) LT or NT side	Extension length ΔL [m]
#0	-	-	-
#1	TP100	-	-
#2	TP150	-	-
#3	TP150	TP100x	70
#4	TP100	TP180x	70
NOTE: The labels "TPxxx" refer to the two-port cable models specified in clause 8.			

The variation of input impedance for the various test loops is shown in figure 7.3. Some typical transfer functions of loops #1 to #4 are illustrated in figure 7.4. 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 7.4. 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.

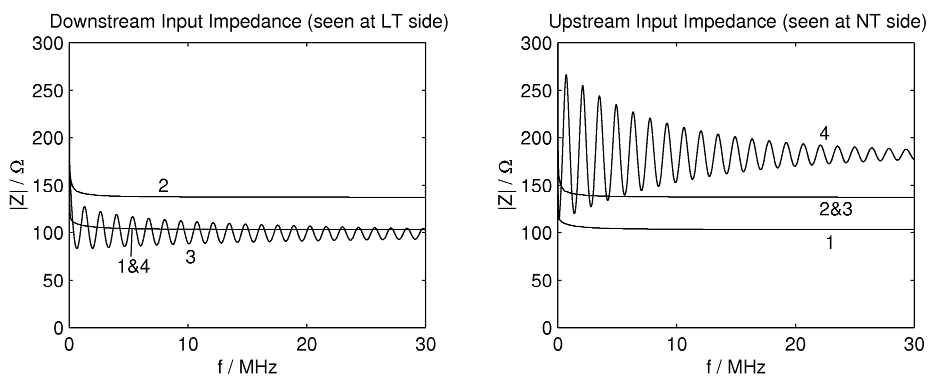


Figure 7.3: Calculated variation of input impedance at a normalized loop length of 5 000 m

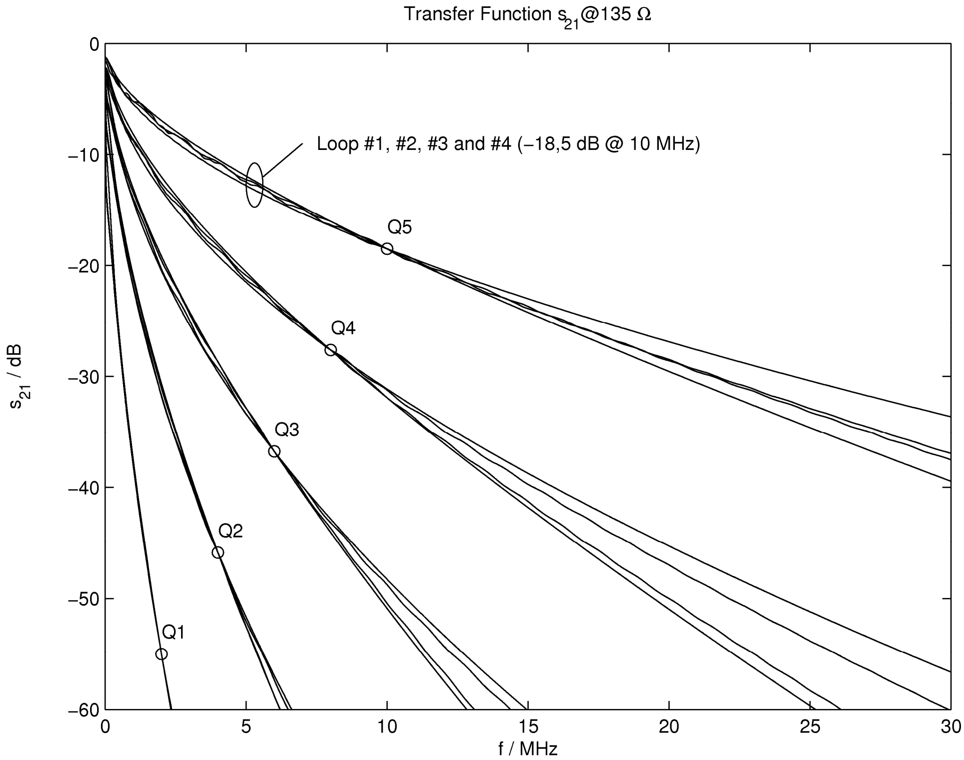


Figure 7.4: Typical transfer function (in R_N=135 Ω) of the test loops when normalized in electrical length

The sections of the loops are defined in clause 8 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 given in clause 8.

7.2.2 Test loop accuracy

The different cable sections are specified by two-port cable models that serve as a representation for real twisted-pair cables. Cable simulators as well as real cables can be used for these test loops. The associated models and line constants are specified in clause 8. The composition of the test-loops is specified in table 7.1.

The characteristics of each test loop, with cascaded sections, shall approximate the models within a specified accuracy. This accuracy specification does not hold for the individual sections:

- The magnitude of the test loop insertion loss shall approximate the insertion loss of the specified models within 3 % on a dB scale, between f_{0L} and the highest frequency of the VDSL2 system for each specific band plan as defined in table B.1 of Recommendation ITU-T G.993.2 [1].
- The magnitude of the test loop characteristic impedance shall approximate the characteristic impedance of the specified models within 7 % on a linear scale, between f_{0L} and the highest frequency of the VDSL2 system for each specific band plan as defined in table B.1 of Recommendation ITU-T G.993.2 [1].
- The group delay of the test loop shall approximate the group delay of the specified cascaded models within 3 % on a linear scale, between f_{0L} and the highest frequency of the VDSL2 system for each specific band plan as defined in table B.1 of Recommendation ITU-T G.993.2 [1].

- The total length of each loop is to be specified in terms of physical length. The *electrical* length (insertion loss at 300 kHz) is to be determined from simulation of VDSL2 performance over the test loops. If the implementation tolerances of a test loop cause the electrical length to be out of specification, then its physical length, L1 to L4 (see figure 7.2) shall be scaled accordingly to correct this error.

7.3 Impairment generators

The impairment generator produces the noise that is injected into the test set and includes the crosstalk noise, ingress noise and impulse noise.

The crosstalk noise power level varies with frequency, length of the test loop and transmit direction (upstream or downstream). Various crosstalk noise models are defined in the following clauses and they are applied, as appropriate, to a particular test scenario. The definition of the impairment noise for VDSL2 performance testing is very complex and for the purposes of the present document it has been broken down into smaller, more easily specified components. These components include equivalent disturbers and crosstalk coupling functions. These separate and uncorrelated components can be isolated and summed to form the impairment generator for the VDSL2 system under test. The detailed specifications of the components of the noise model(s) are given in the clauses below together with a brief explanation.

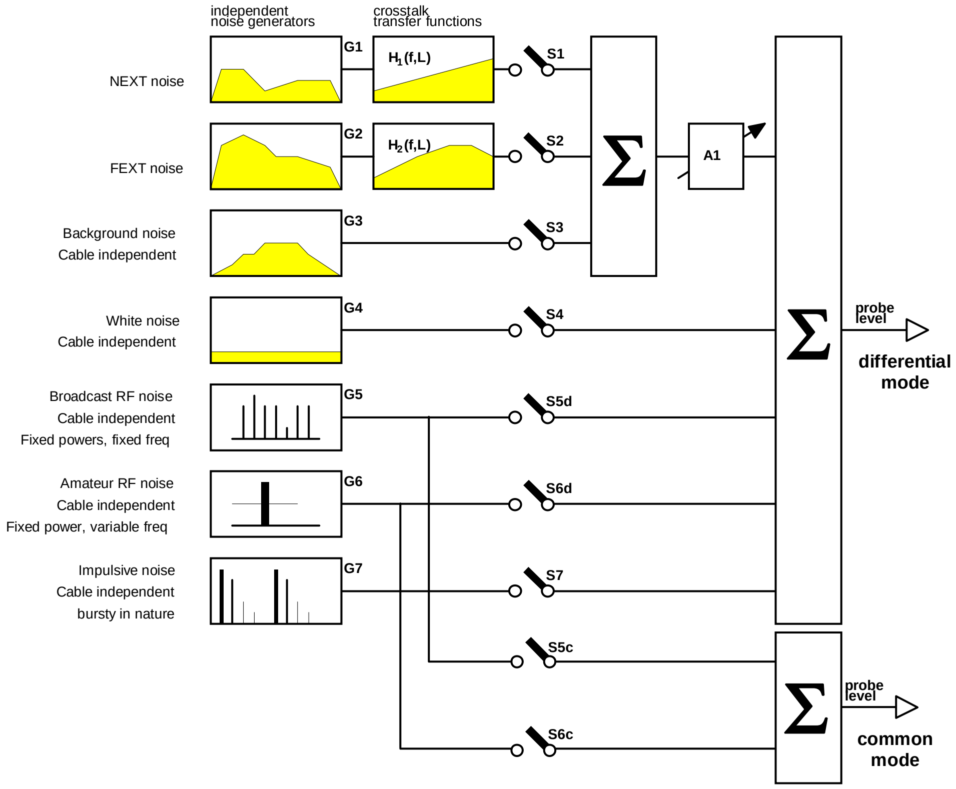
7.3.1 Functional description

Figure 7.5 defines a functional diagram of the composite impairment noise. It defines a functional description of the combined impairment noise, as it should appear at the test probes at the receiver input of the VDSL2 transceiver under test. Details of the measurement technique are defined in clause 7.1.

The functional diagram has the following elements:

- The seven impairment generators G1 to G7 generate noise as defined in clause 7.3.3. Their noise characteristics are independent of the test loops and bit-rates.
- The transfer function $H_1(f,L)$ models the length and frequency dependency of the NEXT impairment, as specified in clause 7.3.2. 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 clause 7.3.2. 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 provides the facility to increase the level of generators G1, G2 and G3. A value of **x** dB means a frequency independent increase of the level by **x** dB over the full VDSL2 band, from f_{0L} to the highest frequency of the VDSL2 system for each specific band plan as defined in table B.1 of Recommendation ITU-T G.993.2 [1]. 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 7.5. 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 7.5: Functional diagram of the composition of the impairment noise

This functional diagram will be used for impairment tests in downstream and upstream directions.

Each test has its own impairment specification that is described in clause 7.3.3 The overall impairment noise shall be characterized by the sum of the individual components as specified in the relevant clauses. 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.

7.3.2 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 7.5 when the *electrical* length of the test-loops are changed. The frequency and length dependency of these functions is in accordance with observations from real cables. The cable specification is based on the following constants, parameters and functions:

- Variable **f** identifies the frequency in Hz.
- 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 metres. This value is calculated from the cable models in clause 8 for a given insertion loss and test frequency.
- Constant $\mathbf{L_0}$ identifies a chosen reference length, which was set to 1 km.
- The function $\mathbf{s_T(f,L)}$ represents the frequency and length dependent amplitude of the transmission function of the actual test loops. This value equals $s_T = |s_{21}|$, where s_{21} is the transmission s-parameter of the loop normalized to the reference impedance $\mathbf{R_N}$=135 Ω as specified in clause 8.

- Constant $\mathbf{K_{xn}}$ identifies an empirically obtained number that scales the NEXT transfer function $H_1(f,L)$. The resulting transfer function represents a power summed crosstalk model ([i.1]) of the NEXT as it was observed in a test cable. Although several disturbers and wire pairs were used, this function $H_1(f,L)$ 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 ([i.1]) 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

7.3.3 Individual impairment generators

7.3.3.1 NEXT noise generator [G1]

The NEXT noise generator represents the equivalent disturbance of 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 clause 7.3.2 represents the contribution of all NEXT in the composite impairment noise of the test.

The PSD of the noise generator is a weighted sum of the self-crosstalk and alien crosstalk profiles as specified in clause 7.3.4.1:

- 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 "HD_Ex", "HD_CAB_27" etc.;
- "XS.LT.#" and "XS.NT.#" refer to the self crosstalk profiles defined in clause 7.3.4.2.1;
- "XA.LT.#" and "XA.NT.#" refer to the alien crosstalk profiles defined in clause 7.3.4.2.2;
- "♦" 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 modelled separately as transfer function $H_1(f,L)$ as specified in clause 7.3.2.

The noise from this generator shall be uncorrelated with all other noise sources in the impairment generator and uncorrelated with the VDSL2 system under test. The noise shall be random in nature with a near Gaussian amplitude distribution as specified in clause 7.3.4.3.

7.3.3.2 FEXT noise generator [G2]

The FEXT noise generator represents the equivalent disturbance of all the impairments that are identified as crosstalk noise from a predominantly Far End origin. The noise when filtered by the FEXT crosstalk coupling function of clause 7.3.2 represents the contribution of all FEXT in the composite impairment noise of the test.

The PSD of the noise generator is a weighted sum of the self-crosstalk and alien crosstalk profiles as specified in clause 7.3.4.1.

- 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 "HD_Ex", "HD_CAB_27","etc.;
- "XS.LT.#" and "XS.NT.#" refer to the self crosstalk profiles defined in clause 7.3.4.2.1;
- "XA.LT.#" and "XA.NT.#" refer to the alien crosstalk profiles defined in clause 7.3.4.2.2;
- "♦" 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 modelled separately as transfer function $H_2(f,L)$ as specified in clause 7.3.2.

The noise from this generator shall be uncorrelated with all other noise sources in the impairment generator and uncorrelated with the VDSL2 system under test. The noise shall be random in nature with a near Gaussian amplitude distribution as specified in clause 7.3.4.3.

7.3.3.3 Background noise generator [G3]

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

7.3.3.4 White noise generator [G4]

The white noise generator has a fixed value of -140 dBm/Hz 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 VDSL2 system under test. The noise shall be random in nature with a near Gaussian amplitude distribution as specified in clause 7.3.4.3.

7.3.3.5 Broadcast RF noise generator [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 cable. These interference sources have more temporal stability than the amateur/HAM interference because their carrier is not suppressed. Ingress causes differential mode as well as common mode interference.

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.

The ingress noise signal for differential mode impairment (or common mode impairment) shall be a superposition of random modulated carriers (AM). The total voltage *U(t)* of this signal is defined as:

$$U(t) = \sum_k U_k \times \cos(2\pi \bullet f_k \times t + \varphi_k) \times (1 + m \times \alpha_k(t))$$

The individual components of this ingress noise signal $U(t)$ are defined as follows:

U_k The voltage U_k of each individual carrier is specified in table 7.2 as power level P (dBm). Note that a spectrum analyser will detect levels that are slightly higher than the value specified in table 7.2 when their resolution bandwidth is set to 10 kHz or more since they will detect the modulation power as well.

f_k The frequency f_k of each individual carrier is specified in table 7.2. The values do not represent actual radio station broadcasts but they are chosen to cover the relevant frequency range of the VDSL2 modem under test. There is no harmonic relationship implied between the carriers.

φ_k The phase offset φ_k of each individual carrier shall have a random value that is uncorrelated with the phase offset of each other carrier in the ingress noise signal.

m The modulation depth m of each individually modulated carrier shall be 0,32 to create a modulation index of at least 80 % during the peak levels of the modulation signal $m \mathrm{x} \alpha_k(t)$ having a crest factor of 2,5.

$\alpha_k(t)$ The normalized modulation noise $\alpha_k(t)$ of each individually modulated carrier shall be random in nature with a near Gaussian distribution and an RMS value of $\alpha_{rms} = 1$ and a crest factor of 2,5 or more. There shall be no correlation between the modulation noise of each modulated carrier in the noise signal.

Δ_b The modulation width Δ_b of each modulated carrier shall be at least 2 x 5 kHz. This is equivalent to creating $\alpha_k(t)$ from white noise that has passed through a low-pass filter with a cut-off frequency at $1/2\Delta_b = 5$ kHz. This modulation width covers the full band used by AM broadcast stations.

The ingress noise generator may have two distinct outputs, one contributing to the differential mode impairment and the other contributing to the common mode impairment.

The RFI ingress is expected to vary depending on the network topology. The levels specified for generator G5 are given in table 7.2. Generator G5.#.A represents a strong RFI environment and generator G5.#.B represents a weaker RFI environment.

Table 7.2: Noise generator G5 carrier frequencies and average power

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

7.3.3.6 Amateur RF noise generator [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 Peak Envelope Power, 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 VDSL2 transmission.

This source of interference appears as a component of the noise entering the front-end of a VDSL2 receiver in the differential or transmission mode. It is very damaging to VDSL2 transmission because of:

- The adverse nature of the temporal characteristics of the single sideband suppressed carrier transmission.
- The close proximity of amateur radio transmitters to telephone network aerial cabling and home wiring.
- The high transmission powers, typically up to 400 W PEP (equivalent to +26 dBW).

7.3.3.6.1 Specification of Amateur RF noise generator

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 PEP at the VDSL2 receiver input in any internationally recognized amateur band (see table B.1). The modulating signal shall be speech weighted noise (Recommendation ITU-T G.227 [3]) 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 B.1. 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 7.3 anywhere in the internationally standardized amateur radio bands given in table B.1.

The RFI ingress is expected to vary depending on the network topology. The levels specified for generator G6 are given in table 7.3. Generator G6.#.A represents a strong RFI environment and generator G6.#.B represents a weaker RFI environment.

Table 7.3: 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

7.3.3.7 Impulse noise generator [G7]

A test with this noise generator is required to prove the implementation of the forward error correcting coder which is specified to give some protection from impulse noise. The impulse noise generator shall inject noise bursts onto the line with sufficient power to ensure effective erasure of the data for the duration of the burst.

Tests using this generator are to stress the FEC coder which is specified as an RS block code with interleaving. The noise bursts are not representative of realistic noise.

The generator has three parameters, the length of the "on" and "off" time periods and the amplitude:

T_1 This is the maximum duration of an isolated noise burst that the coder shall be able to correct.

T_2 This is the minimum duration that the coder needs to recover from the previous noise burst.

P_b This is the power level of the noise burst at which effective erasure of the data signal is to be expected (the bit error ratio during the burst shall be 0,5).

Noise immunity shall be demonstrated on short and long loops in the presence of other noises that model crosstalk and RF ingress. The parameter values are specified in table 7.4.

Table 7.4: Impulse noise parameters

Parameter	T_1 (s)	T_2 (s)	P_b (dBm)
	500 µs	1	tbd

7.3.4 Profile of the individual impairment generators

7.3.4.1 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 VDSL2 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.

7.3.4.2 Crosstalk Scenarios

Several scenarios have been identified to determine crosstalk profiles. These profiles 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 VDSL2 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 HD_EX model** is intended to represent a high penetration scenario**,** representing a medium or long term situation, where the VDSL2 system under test is located at the local exchange.
- **Type MD_EX model** is intended to represent a medium penetration scenario, representing a short to medium term situation**,** where the VDSL2 system under test is located at the local exchange.
- **Type HD_CAB27 model** is intended to represent a high penetration scenario, representing a medium or long term situation, in which the VDSL2 system under test is deployed from a street cabinet located at 27 dB (at 1 MHz) from the local exchange. This is equivalent to approximately 1,5 km of TP100.
- **Type MD_CAB27 model** is intended to represent a medium penetration scenario, representing a short to medium term situation, in which the VDSL2 system under test is deployed from a street cabinet located at 27 dB (at 1 MHz) from the local exchange. This is equivalent to approximately 1,5 km of TP100.
- **Type HD_CAB72 model** is intended to represent a high penetration scenario, representing a medium or long term situation, in which the VDSL2 system under test is deployed from a street cabinet located at 72 dB (at 1 MHz) from the local exchange. This is equivalent to approximately 4 km of TP100.
- **Type MD_CAB72 model** is intended to represent a medium penetration scenario, representing a short to medium term situation, in which the VDSL2 system under test is deployed from a street cabinet located at 72 dB (at 1 MHz) from the local exchange. This is equivalent to approximately 4 km of TP100.

7.3.4.2.1 Self crosstalk profiles

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 test the "#" is a placeholder for models "HD_EX", "HD_CAB27", etc.:

- 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 7.5.
- 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 7.5.
- The self-crosstalk power summation for the various deployment scenarios described above is given in table 7.5.
- All of the VDSL2 self disturbers in a particular deployment scenario are assumed to have the same signal template.

Table 7.5: Definition of self-crosstalk

HD	Exchange (EX)	Cabinet 27 (CAB27)	Cabinet 72 (CAB72)
XS.LT.#	VDSL2.LT.EX + 11,07 dB	VDSL2.LT.CAB27 + 10,67 dB	VDSL2.LT.CAB72 + 10,67 dB
XS.NT.#	VDSL2.NT.EX + 11,07 dB	VDSL2.NT.CAB27 + 10,67 dB	VDSL2.NT.CAB72 + 10,67 dB

MD	Exchange (EX)	Cabinet 27 (CAB27)	Cabinet 72 (CAB72)
XS.LT.#	VDSL2.LT.EX + 6,68 dB	VDSL2.LT.CAB27 + 7,06 dB	VDSL2.LT.CAB72 + 7,06 dB
XS.NT.#	VDSL2.NT.EX + 6,68 dB	VDSL2.NT.CAB27 + 7,06 dB	VDSL2.NT.CAB72 + 7,06 dB

7.3.4.2.2 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 for the deployment scenarios described in clause 7.3.4.2:

- The LT profiles 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 NT profiles 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 noise templates defined in tables 7.6 to 7.11 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).

7.3.4.2.2.1 HD VDSL2 noise templates

This clause defines the alien noise templates for VDSL2 systems deployed in a High Density (HD) scenario.

7.3.4.2.2.1.1 HD_EX

Table 7.6 defines the LT and NT noise templates for VDSL2 in a high density exchange (HD_EX) scenario.

Table 7.6: HD_EX Noise Template PSDs

Frequency [Hz]	LT PSD [dBm/Hz]
0,01	-21,8
5 000	-21,8
20 000	-22,6
35 000	-24,6
45 000	-26,6
55 000	-28,8
68 000	-30,3
137 000	-31,2
138 000	-28,7
139 000	-28,3
140 000	-27,1
180 000	-27,3
254 000	-27,4
255 000	-26,9
272 000	-26,9
273 000	-26,4
440 000	-26,5
1 104 000	-26,5
1 250 000	-30,6
1 295 000	-32,5
1 350 000	-33,9
1 622 000	-38,7
2 208 000	-40
3 001 500	-72
3 093 000	-77,2
3 185 000	-79,5
3 570 000	-85,3
3 750 000	-87
4 544 000	-97,4
7 224 000	-98,4
30 000 000	-98,4

Frequency [Hz]	NT PSD [dBm/Hz]
0,01	-21,8
5 000	-21,8
15 000	-22,2
23 000	-22,7
28 000	-22,6
49 000	-24,6
59 000	-25,1
68 000	-25,2
112 000	-25,3
119 000	-24,8
132 000	-24,8
136 000	-24,7
139 000	-25,7
140 000	-25,7
144 000	-26,4
152 000	-26,7
167 000	-26,8
273 000	-27
287 000	-32,2
297 000	-34,2
304 000	-35,2
340 000	-38,5
382 000	-43,6
439 000	-52
532 000	-66,4
642 000	-85,1
676 000	-85,1
758 000	-85,8
837 000	-86,1
1 030 000	-86,5
1 411 000	-86,5
1 630 000	-96,4
5 274 000	-98,4
30 000 000	-98,4

7.3.4.2.2.1.2 HD_CAB27

Table 7.7 defines the LT and NT noise templates for VDSL2 in a high density cabinet located close to the exchange (HD_CAB27).

Table 7.7: HD_CAB27 Noise Template Noise templates

Frequency [Hz]	LT PSD [dBm/Hz]
0,01	-29,6
5 000	-29,8
15 000	-31
60 000	-42,4
74 000	-43,9
136 000	-46
138 000	-43,7
139 000	-43,3
140 000	-42,1
254 000	-44,8
255 000	-44,4
272 000	-44,7
273 000	-44,2
597 000	-50,5
1 104 000	-58,2
1 250 000	-64,2
1 300 000	-67
1 622 000	-76,9
2 208 000	-84,4
3 002 000	-123,7
3 093 000	-129,6
3 492 000	-140
30 000 000	-140

Frequency [Hz]	NT PSD [dBm/Hz]
0,01	-23,6
7 000	-23,7
15 000	-24,1
24 000	-24,7
25 000	-24,7
28 000	-24,8
55 000	-28
70 000	-28,5
113 000	-28,5
119 000	-28
129 000	-28,1
136 000	-28
139 000	-29
140 000	-29
147 000	-29,9
162 000	-30,1
274 000	-30,3
284 000	-34,6
291 000	-36,4
301 000	-38
362 000	-44,2
510 000	-66
637 000	-87,7
676 000	-87,7
758 000	-88,8
917 000	-89,6
1 030 000	-89,8
1 411 000	-89,8
1 630 000	-99,7
5 274 000	-101,7
30 000 000	-101,7

7.3.4.2.2.1.3 HD_CAB72

Table 7.8 defines the LT and NT noise templates for VDSL2 deployed in a high density cabinet located far from the exchange (HD_CAB72).

Table 7.8: HD_CAB72 Noise Template PSDs

Frequency [Hz]	LT PSD [dBm/Hz]
0,01	-34,9
1 000	-35
22 000	-46,3
70 000	-60,2
138 000	-65,6
140 000	-61,9
272 000	-69,7
273 000	-68,6
662 000	-88
1 104 000	-105,6
1 250 000	-115,7
1 428 000	-140
30 000 000	-140

Frequency [Hz]	NT PSD [dBm/Hz]
0,01	-23,6
7 000	-23,7
16 000	-24,1
25 000	-24,8
27 000	-24,8
28 000	-24,7
54 000	-27,8
68 000	-28,3
129 000	-28,6
136 000	-28,3
138 000	-29,8
139 000	-29,9
140 000	-29,6
142 000	-29,9
175 000	-30,4
216 000	-30,5
274 000	-30,5
291 000	-47,5
292 000	-47,5
321 000	-52,5
322 000	-52,5
336 000	-72,6
355 000	-72,6
436 000	-77,8
597 000	-85,3
676 000	-87,7
834 000	-89,4
1 030 000	-89,8
1 411 000	-89,8
1 630 000	-99,7
5 274 000	-101,7
30 000 000	-101,7

7.3.4.2.2.2 MD VDSL2 noise templates

This clause defines the alien noise masks for VDSL2 deployment in a medium density (MD) scenario.

7.3.4.2.2.2.1 MD_EX

Table 7.9 defines the LT and NT noise templates for VDSL2 deployed in a medium density exchange (MD_EX) MD_EX scenario.

Table 7.9: MD_EX Noise Template PSDs

Frequency [Hz]	LT PSD [dBm/Hz]
0,01	-30,2
1 000	-30,2
6 500	-30,1
8 500	-30,1
15 000	-30,3
28 000	-31,4
59 000	-35
86 000	-35,6
137 000	-36,6
138 000	-35,5
139 000	-35,4
140 000	-34,8
183 000	-35,5
254 000	-35,8
255 000	-35
272 000	-35
273 000	-34,3
370 000	-34,6
1 104 000	-34,6
1 250 000	-38,6
1 300 000	-40,4
1 622 000	-46,4
2 208 000	-47,7
3 002 000	-79,7
3 093 000	-85,5
3 308 000	-90
3 750 000	-95
4 544 000	-105,3
7 255 000	-106,5
30 000 000	-106,5

Frequency [Hz]	NT PSD [dBm/Hz]
0,01	-30,2
1 000	-30,2
6 500	-30,1
8 500	-30,1
15 000	-30,3
22 000	-30,7
24 000	-30,7
25 000	-30,6
28 000	-30,7
56 000	-32,8
66 000	-33
109 000	-33,2
119 000	-32,6
131 000	-32,6
136 000	-32,5
138 000	-32,8
139 000	-33
140 000	-33
144 000	-33,4
165 000	-33,8
274 000	-34,2
284 000	-38
305 000	-41,5
385 000	-50
542 000	-74
650 000	-93,3
676 000	-93,3
759 000	-93,8
913 000	-94,4
1 030 000	-94,6
1 411 000	-94,6
1 630 000	-104,5
5 274 000	-106,5
30 000 000	-106,5

7.3.4.2.2.2.2 MD_CAB27

Table 7.10 defines the LT and NT noise templates for VDSL2 deployed in a medium density cabinet located close to the exchange (MD_CAB27).

Table 7.10: MD_CAB27 Noise Template PSDs

Frequency [Hz]	LT PSD [dBm/Hz]
0,01	-30,2
6 900	-30,3
15 000	-30,5
29 000	-32
45 000	-35,5
74 000	-47,4
86 000	-48
102 000	-47,5
137 000	-49,8
138 000	-48,2
139 000	-48
140 000	-47,2
254 000	-50,3
255 000	-49,3
272 000	-49,7
273 000	-49
560 000	-54,7
1 104 000	-63
1 250 000	-68,9
1 622 000	-81,2
2 208 000	-88,8
2 696 000	-113,1
2 830 000	-117,2
3 040 000	-118,2
30 000 000	-118,2

Frequency [Hz]	NT PSD [dBm/Hz]
0,01	-30,2
7 000	-30,2
15 000	-30,5
22 000	-31
24 000	-31
25 000	-30,9
28 000	-30,9
55 000	-33,3
69 000	-33,6
112 000	-33,7
119 000	-32,9
129 000	-33
136 000	-32,8
139 000	-33,3
140 000	-33,3
148 000	-33,9
168 000	-34,1
274 000	-34,3
283 000	-38,1
301 000	-42,4
362 000	-48,8
512 000	-71
644 000	-93,3
676 000	-93,3
759 000	-94
918 000	-94,5
1 030 000	-94,6
1 411 000	-94,6
1 630 000	-104,6
5 274 000	-106,5
30 000 000	-106,5

7.3.4.2.2.2.3 MD_CAB72

Table 7.11 defines the LT and NT noise templates for VDSL2 deployed in a medium density cabinet located far from the exchange (MD_CAB72).

Table 7.11: MD_CAB72 Noise Template PSDs

Frequency [Hz]	LT PSD [dBm/Hz]
0,01	-30,2
6 500	-30,3
15 000	-30,7
30 000	-32,4
55 000	-39,4
71 000	-50,4
79 000	-65
81 000	-65
89 000	-54,6
102 000	-50,1
110 000	-50,1
133 000	-55,1
157 000	-68,2
163 000	-68,7
177 000	-64,8
187 000	-63,3
193 000	-63,3
208 000	-65,3
234 000	-73
247 000	-73,6
272 000	-71,7
273 000	-71,1
336 000	-76,6
349 000	-76,5
682 000	-92,8
915 000	-101,8
1 157 000	-109,4
1 570 000	-118,2
30 000 000	-118,2

Frequency [Hz]	NT PSD [dBm/Hz]
0,01	-30,2
9 100	-30,2
16 000	-30,5
24 000	-31
26 000	-31
28 000	-30,8
55 000	-33,1
70 000	-33,4
129 000	-33,8
136 000	-33,4
138 000	-34,3
140 000	-33,7
142 000	-33,9
175 000	-34,3
216 000	-34,4
274 000	-34,4
291 000	-51,4
292 000	-51,4
321 000	-56,4
322 000	-56,4
338 000	-79,1
352 000	-79,1
516 000	-88,4
676 000	-93,3
838 000	-94,4
1 112 000	-94,6
1 411 000	-94,6
1 630 000	-104,5
5 274 000	-106,5
30 000 000	-106,5

7.3.4.3 Time domain profiles of generators G1-G4

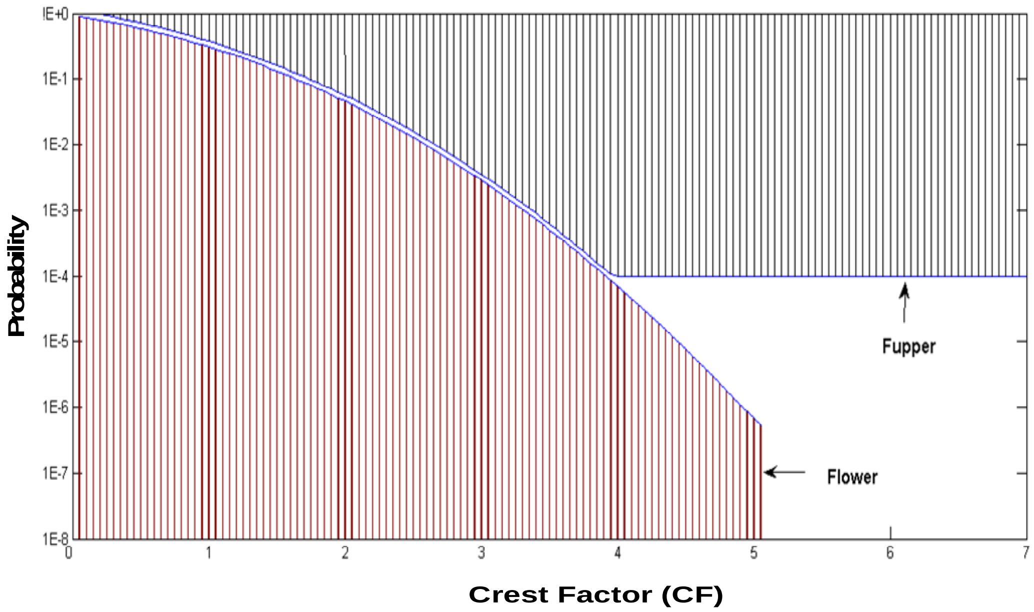
The noise, as specified in the frequency domain in clauses 7.3.1 to 7.3.4 shall be random in nature and near Gaussian distributed. This means that the amplitude distribution function of the combined impairment noise injected at the adding element (see figure 7.5) shall lie between the two boundaries illustrated in figure 7.6 and defined in table 7.12.

It is expected that noise generators will generate signals that are approximately Gaussian. Therefore, the upper bound of figure 7.6 is loose. The Probability Distribution Function (PDF) of signals generated by noise generators are expected to be well below the upper bound allowed by the PDF mask shown in figure 7.6.

The amplitude distribution function F(a) of noise voltage in time domain 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:

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

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).



NOTE: The non-shaded area is the allowed region. The boundaries of the mask are specified in table 7.12.

Figure 7.6: Mask for the amplitude distribution function

Table 7.12: Upper and lower boundaries of the amplitude distribution function of the noise

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

Parameter	Value
Crest Factor Gaussian Gap	CF = 5 ε = 0,1 A = 3,9

NOTE 1: Noise generated according to above specification is not suited to give reproducible results for margin verification relative to a reference BER lower than 10^{-7} or for systems using uncoded modulation (i.e. having no coding gain).

NOTE 2: There are indications that an even tighter specification may be required here to ensure this reproducibility. Therefore the need for an additional reduction of the upper limit and an additional requirement in the frequency domain is left for further study.

NOTE 3: Another characteristic that is for further study is the minimum duration time of repetitive pseudo-random noise.

The meaning of the parameters in table 7.12 is as follows:

- CF denotes the minimum crest factor of the noise. Crest factor is defined as the ratio between the absolute peak value and rms value ($CF = |u_{peak}| / u_{rms}$).
- ε denotes the Gaussian gap that indicates how closely the 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 practical repetition length.

7.3.5 Upstream Power Back-Off testing

Upstream power back-off (UPBO) is a method defined in [1] that is used to improve spectral compatibility between VDSL2 systems on loops of different lengths deployed in the same binder. Performance and functional requirements for UPBO testing are defined in the following Broadband Forum test specifications:

a) Broadband Forum TR-114: "VDSL2 Performance Test Plan" [5];

b) Broadband Forum TR-115: "VDSL2 Functionality Test Plan" [6].

8 Line Constants for Test Loop Set

This clause 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 [i.1] 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 8.1 and 8.2 shall be used (together with the equations) to calculate the values given in table 8.3 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, TP180x and PE 04

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

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

TP150 and TP100x

$$Z_{S0}(\omega) = \left(\frac{j\omega \times Z_{0\infty}}{c} + R_{ss00} \times \left(1 + K_l \times K_f \times \left(\chi \times \coth\left(4/3 \times \chi \right) - 3/4 \right) \right) \right) \times 1000 \qquad [\Omega/\text{km}]$$

$$Y_{p0}(\omega) = \left(\frac{j\omega}{Z_{0\infty} \times c} \times \left(1 + \frac{(K_c - 1)}{1 + \left(\omega / \omega_{C0} \right)^N} \right) + \frac{\tan(\phi)}{Z_{0\infty} \times c} \times \omega^M \right) \times 1000 \qquad [\text{S/km}]$$

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 8.1: Line constants for the TP100, TP180x and PE 04 cable sections in the test loops (per km)

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	174 877
NOTE: PE 04 Line constants for PE04 are given in [2].							

Table 8.2: Line constants for the TP150 and TP100x cable sections in the test loops (per metre)

	$Z_{0\infty}$	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	4 521 710	1
TP100x	97,4969	0,639405	0,177728	0,0189898	0,5	1,14	1	1	1	100 000	1
NOTE: Scaling constant $c_0 = 3 \times 10^8$ m/s and equals the velocity of light.											

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 8.3 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.

Insertion loss and return loss of a cable section, normalized to a chosen reference impedance R_N, can be calculated from the primary parameters $\{Z_s, Y_p\}$ per unit length (L0) by evaluating the two-port s-parameters, normalized to R_N as follows:

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

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

$$Y_p = L \times Y_{p0} \qquad Z_0 = \sqrt{Z_s / Y_p} \qquad \beta = imag(\gamma) \qquad L_s = imag(Z_s/\omega) \qquad C_p = imag(Y_p/\omega)$$

To calculate the two-port s-parameters:

$$\mathbf{S} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} = \frac{1}{\left(Z_0/R_v + R_v/Z_0 \right) \times \tanh(\gamma) + 2} \times \begin{bmatrix} \left(z_0/R_v - R_v/z_0 \right) \times \tanh(\gamma) & 2/\cosh(\gamma) \\ 2/\cosh(\gamma) & \left(z_0/r_v - R_v/Z_0 \right) \times \tanh(\gamma) \end{bmatrix}$$

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

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

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

$$\mathbf{S} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} = \frac{1}{1 - s_{22a} \times s_{11b}} \cdot \begin{bmatrix} s_{11a} - \Delta_{sa} \times s_{11b} & s_{12b} \times s_{12a} \\ s_{21a} \times s_{21b} & s_{22b} - \Delta_{sb} \times s_{22a} \end{bmatrix} \qquad \Delta_s = s_{\_1} \cdot s_{22} - s_{12} \cdot s_{21}$$

Table 8.3: Predicted parameters computed from the cable models

	Frequency (kHz)	Resistance (Ω/km) R_{sx}	Inductance (μH/km) L_{sx}	Capacitance (nF/km) C_{px}	Conductance (mS/km) G_{px}	Characteristic impedance (Ω) Z_0	Insertion loss (dB) @ 1km @ R_N = 135 Ω
TP100	1	179	694,972	55,501	0,0006	716,56	4,42
	10	179,16	694,564	55,398	0,0068	230,16	4,57
	100	192,93	688,471	55,316	0,0731	116,74	7,30
	1 000	438,33	640	55,251	0,7888	107,94	18,13
	10 000	1 376,49	591,529	55,200	8,5108	103,55	61,72
TP150	1	168,15	784,381	33,099	0,0040	899,29	4,21
	10	168,47	784,199	33,072	0,0401	290,62	4,26
	100	197,37	768,161	32,942	0,4011	158,71	5,77
	1 000	527,25	645,503	32,454	4,0107	141,61	18,66
	10 000	1 539,30	594,606	31,501	40,1067	137,43	72,59
TP100x	1	177,73	710,932	53,47	0,001	727,45	4,4
	10	178,15	710,611	53,47	0,0102	233,81	4,54
	100	212,24	685,002	53,47	0,1015	119,52	7,87
	1 000	482,66	568,898	53,47	1,0154	103,61	20,87
	10 000	1 306,43	527,442	53,47	10,1539	99,36	61,7
TP180x	1	41,16	999,814	37,456	0,0231	419,63	1,25
	10	41,59	997,166	34,128	0,1755	186,96	1,37
	100	62,28	969,667	31,549	1,3313	175,57	2,65
	1 000	186,92	920,407	29,551	10,0989	176,40	12,50
	10 000	590,76	911,210	28,003	76,6083	180,31	74,41
PE04	1	280,00	587,114	50	0	944,11	6,18
	10	280,11	586,736	50	0	299,88	6,38
	100	290,44	577,877	50	0	121,66	10,76
	1 000	566,57	490,494	50	0	99,87	24,92
	10 000	1 764,61	431,235	50	0	92,97	82,78

Annex A (informative): Cable Information

The following material gives supporting information regarding cable construction.

The cable sections in the test loops are representative of existing European metallic access cables, more details of which can be found in [i.1]. They represent the following cables :

Cable type TP100 (equivalent to BT_dwug in [i.1]).

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 [i.1]).

Multiple quads (4 wires or two pairs), 0,5 mm solid copper conductors. 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 [i.1]).

Four twisted pairs of 0,5 mm 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 [i.1]).

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.

Cable type PE 0,4 mm.

This additional cable model is 100 % artificial, not related to any particular cable being deployed in Europe. It has been designed to represent a legacy ADSL test loop below 1 MHz (see [2]), and extended up to 30 MHz by using an educated guess on how a cable could behave. As such, it does not stress VDSL2 modems in a way that is fundamentally different from the set of normative VDSL2 test loops. However, this cable model has been added purely for reasons of measurement convenience, to enable cable simulators dedicated to ADSL testing to offer meaningful characteristics up to VDSL2 frequencies.

The parameters for an artificial cable model simulating this cable type are included in clause 8.

Annex B (informative): External Systems in the frequency band 0 MHz to 30 MHz

This annex lists systems that operate within the VDSL2 bandwidth and therefore may impact the VDSL2 system in terms of RFI ingress or egress.

B.1 Amateur radio bands

Amateur radio bands are listed in table B.1.

Table B.1: Amateur radio bands

Start frequency [MHz]	Stop frequency [MHz]	Approximate Wavelength [m]
0,1357	0,1358	2 200
1,81	2,0	160
3,5	3,8	80
7,0	7,2	40
10,1	10,15	30
14,0	14,35	20
18,068	18,168	17
21,0	21,45	15
24,89	24,99	12
28,0	29,7	10

B.2 Other external radio systems

Frequency bands relating to other services are listed in table B.2.

Table B.2: Other external systems operating in the band 0 MHz to 30 MHz

Start frequency MHz	Stop frequency MHz	Application
2,173	2,191	GMDSS (Global Maritime Distress and Safety Service)
2,850	3,155	Aeronautical communications
3,400	3,500	Aeronautical communications
3,800	3,400	Aeronautical/ broadcasting
4,200	4,215	GMDSS
4,650	4,850	Aeronautical communications
5,450	5,730	Aeronautical communications
5,900	6,200	DRM radio
6,300	6,320	GMDSS
6,525	6,765	Aeronautical communications
7,200	7,450	DRM radio
8,405	8,420	GMDSS
8,815	9,040	Aeronautical communications
9,400	9,900	DRM radio
10,005	10,100	Aeronautical communications
11,175	11,400	Aeronautical communications
11,600	12,100	DRM radio
12,570	12,585	GMDSS
13,200	13,360	Aeronautical communications
13,570	13,870	DRM radio
15,010	15,100	Aeronautical communications
15,100	15,800	DRM radio
16,795	16,810	GMDSS
17,480	17,900	DRM radio

Start frequency MHz	Stop frequency MHz	Application
17,900	18,030	Aeronautical communications
26,965	27,405	CB radio

B.3 Citizens Band (CB) frequencies in Europe

The following frequencies shown in table B.3 are used for Citizens Band (CB) in the UK (referred to as the CB27/81 bandplan.

Table B.3: CB frequencies used in the UK

Frequency [MHz]	Channel Number	Frequency [MHz]	Channel Number
27,60125	1	27,80125	21
27,61125	2	27,81125	22
27,62125	3	27,82125	23
27,63125	4	27,83125	24
27,64125	5	27,84125	25
27,65125	6	27,85125	26
27,66125	7	27,86125	27
27,67125	8	27,87125	28
27,68125	9	27,88125	29
27,69125	10	27,89125	30
27,70125	11	27,90125	31
27,71125	12	27,91125	32
27,72125	13	27,92125	33
27,73125	14	27,93125	34
27,74125	15	27,94125	35
27,75125	16	27,95125	36
27,76125	17	27,96125	37
27,77125	18	27,97125	38
27,78125	19	27,98125	39
27,79125	20	27,99125	40

These channels apply to UK-only radios meeting MPT-1320 (marked CB 27/81) and MPT-1382 (marked PR 27/97, these may also feature the additional 40 CEPT channels).

In the UK the requirement to have a license has been dispensed with, but all permission for the public to use the UK-specific frequencies may be withdrawn in 2010, under plans to reassign the frequencies to the Community Audio Distribution System service.

The European Conference of Postal and Telecommunications Administrations (CEPT) has adopted the same channel allocations used in North America for CB radio in Europe. These are shown in table B.4.

Table B.4: CB frequencies adopted by CEPT for Europe

Frequency [MHz]	Channel Number	Frequency [MHz]	Channel Number
26,965	1	27,215	21
26,975	2	27,225	22
26,985	3	27,255	23
27,005	4	27,235	24
27,015	5	27,245	25
27,025	6	27,265	26
27,035	7	27,275	27
27,055	8	27,285	28
27,065	9	27,295	29
27,075	10	27,305	30
27,085	11	27,315	31
27,105	12	27,325	32
27,115	13	27,335	33
27,125	14	27,345	34
27,135	15	27,355	35
27,155	16	27,365	36
27,165	17	27,375	37
27,175	18	27,385	38
27,185	19	27,395	39
27,205	20	27,405	40

In Poland (and probably some other former Warsaw-pact countries) the channels are shifted 5 kHz down, so for example channel 30 is 27,300 MHz, many operators add a switch that can change between the "zeroes" (the Polish channel assignment), and the "fives" (the international assignment).

Annex C (informative): Change History

date	Version	Information about changes
June 2013	V1.2.1	1) Terms used in clause 5 integrated into clause 3 2) The following new clauses were defined: - 5 Longitudinal Conversion Loss - 6 Vectoring requirements for the VTU-R 3) The following clauses were renamed: - Normative Annexes ZA.1 and ZA.1 moved into main body of text (clause 7 and clause 8) - Informative Annexes ZA.3 and ZA.4 renamed into Annexes A and B, respectively 4) The following clause was modified: - 7.3.5 UPBO testing

History

Document history		
V1.1.1	January 2009	Publication
V1.2.1	August 2013	Publication