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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Access networks

Very high speed digital subscriber line transceivers

ITU-T Recommendation G.993.1

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ITU-T Recommendation G.993.1

Very high speed digital subscriber line transceivers

Summary

G.993.1 VDSL (Very high speed Digital Subscriber Line) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 includes worldwide frequency plans that allow asymmetric and symmetric services in the same group of twisted pairs (known as a binder). G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power transmission levels have been designed to minimize potential egress interference into other transmission systems. As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

Source

ITU-T Recommendation G.993.1 was approved on 13 June 2004 by ITU-T Study Group 15 (2001-2004) under the ITU-T Recommendation A.8 procedure.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g. interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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ITU-T Recommendation G.993.1

Very high speed digital subscriber line transceivers

1 Scope

G.993.1 VDSL (Very high speed Digital Subscriber Line) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS services. While POTS uses approximately the lower 4 kHz and ADSL/HDSL use approximately 1 MHz of the copper wire spectrum, G.993.1 uses up to 12 MHz of the spectrum. G.993.1 can be deployed from central offices or from Fibre-fed cabinets located near the customer premises.

G.993.1 includes worldwide frequency plans that allow asymmetric and symmetric services in the same group of wire pairs (known as a binder). This is accomplished by designating frequency bands for the transmission of upstream and downstream signals.

G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power levels have been designed to minimize potential egress interference into other transmission systems.

As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

It has been agreed in the ITU-T to develop a subsequent VDSL2 Recommendation that specifies only DMT modulation, and that is based on this Recommendation (VDSL) and on ITU-T Rec. G.992.3 (ADSL2).

2 References

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

– ITU-T Recommendation G.117 (1996), *Transmission aspects of unbalance about earth*.

– ITU-T Recommendation G.227 (1988), *Conventional telephone signal*.

– ITU-T Recommendation G.994.1 (2003), *Handshake procedures for digital subscriber line (DSL) transceivers*.

– ITU-T Recommendation G.996.1 (2001), *Test procedures for digital subscriber line (DSL) transceivers*.

– ITU-T Recommendation G.997.1 (2003), *Physical layer management for digital subscriber line (DSL) transceivers*.

– ITU-T Recommendation I.432.1 (1999), *B-ISDN user-network interface – Physical layer specification: General characteristics*.

– ITU-T Recommendation O.9 (1999), *Measuring arrangements to assess the degree of unbalance about earth*.

– ISO/IEC 3309:1993, *Information technology – Telecommunications and information exchange between systems – High-level data link control (HDLC) procedures – Frame structure*.

3 Definitions

This Recommendation defines the following terms:

3.1 bit error ratio: The ratio of the number of bits in error to the number of bits sent over a period of time.

3.2 channel: A connection conveying signals between two blocks (the conveyed signals represent information). Channels also convey signals between a block and the environment. Channels may be unidirectional or bidirectional.

3.3 connection: An association of transmission channels or circuits, switching and other functional units set up to provide a means for a transfer of user, control and management information between two or more end points (blocks) in a telecommunication network.

3.4 downstream: Information flow whose direction is from an End-Service Provider System to an End-Service Consumer System.

3.5 electrical length: An estimate of the loop attenuation, assuming that all the sections of cable obey a √f attenuation characteristic. Specifically, the electrical length is the attenuation, in dB at 1 MHz, of an equivalent hypothetical loop with a perfect √f attenuation characteristic.

NOTE – The attenuation caused by bridged taps does not follow a √f characteristic, and thus the effects of bridged taps may not be accurately represented in the estimate.

3.6 interface: A point of demarcation between two blocks through which information flows from one block to the other. See logical- and physical-interface definitions for further details. An interface may be a physical interface or a logical interface.

3.7 layer/sublayer: A collection of objects of the same hierarchical rank.

3.8 logical information flow path: A sequence of information transfers from an initial information source object to a terminal information destination object, either directly or through intermediate objects. Different physical information flow paths may be associated with a logical information flow path segment or with the entire path, in different implementations.

3.9 logical (functional) interface: An interface where the semantic, syntactic, and symbolic attributes of information flows are defined. Logical interfaces do not define the physical properties of signals used to represent the information. A logical interface can be an internal or external interface. It is defined by a set of information flows and associated protocol stacks.

3.10 management plane (MP): A plane that contains management information.

3.11 management information: Information exchanged by Management Plane objects; it may content information or control information.

3.12 network: A collection of interconnected elements that provide connection services to users.

3.13 network control function: The network control function is responsible for the error-free receipt and transmission of content flow information to and from the server.

3.14 network termination (NT): The element of the Access Network performing the connection between the infrastructures owned by the Access Network operator and the Service-Consumer System (ownership decoupling). The NT can be passive or active, transparent or not.

3.15 noise margin: The maximum amount by which the reference noise level can be increased during a BER test without causing the modem to fail the BER requirement.

3.16 physical interface: An interface where the physical characteristics of signals used to represent information and the physical characteristics of channels used to carry the signals are defined. A physical interface is an external interface. It is fully defined by its physical and electrical characteristics. Logical information flows map to signal flows that pass through physical interfaces.

3.17 plane: A category that identifies a collection of related objects, e.g., objects that execute similar or complementary functions, or peer objects that interact to use or to provide services in a class that reflects authority, capability, or time period. Management-plane service objects, for example, may authorize ISP-clients' access to certain control-plane service objects that in turn may allow the clients to use services provided by certain user-plane objects.

3.18 primitives: Basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicators from the far end. Performance primitives are categorized as events, anomalies, and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators.

3.19 reference point: A set of interfaces between any two related blocks through which information flows from one block to the other. A reference point comprises one or more logical (non-physical) information-transfer interfaces, *and* one or more physical signal-transfer interfaces.

3.20 SNR margin: The modem's estimate of the maximum amount by which the receiver noise (internal and external) could be increased without causing the modem BER to fail the BER requirement.

3.21 symbol: A bit or a defined sequence of bits.

3.22 system: A collection of interacting objects that serves a useful purpose; typically, a primary subdivision of an object of any size or composition (including domains).

3.23 upstream: Information flow whose direction is from an End-Service Customer System to an End-Service Provider System.

3.24 user: A service-consuming object or system (block).

3.25 user plane (UP): A classification for objects whose principal function is to provide transfer of end-user information: user information may be user-to-user content (e.g., a movie), or private user-to-user data.

4 Abbreviations

This Recommendation uses the following abbreviations:

ATM	Asynchronous Transfer Mode
DS	Downstream
DSL	Digital Subscriber Line
EIO	External Interface Adapter
eoc	Embedded Operations Channel (between the VTU-O and VTU-R)
FDD	Frequency Division Duplexing
FEC	Forward Error Correction
HEC	Header Error Control
ISDN	Integrated Services Digital Network
LCD	Loss of Cell Delineation
LSB	Least Significant Bit

LT	Line Termination
MIB	Management Information Base
MSB	Most Significant Bit
NMA	Network Management Agent
NT	Network Termination
NTR	Network Timing Reference
OAM	Operations, Administration and Maintenance
OC	Overhead Channel
ONU	Optical Network Unit
PHY	Physical Layer
PMD	Physical Media Dependent
PMS	Physical Media Specific
PMS-TC	Physical Media Specific-Transmission Convergence
PSD	Power Spectral Density
PTM	Packet Transfer Mode
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency
SNR	Signal-to-Noise Ratio
STP	Set of Transmission Parameters
TBD	To Be Determined
TC	Transmission Convergence
TCM	Time Compression Multiplex
TPS	Transmission Protocol Specific
TPS-TC	Transport Protocol Specific-Transmission Convergence
Tx	Transmitter
UPBO	Upstream Power Back-off
US	Upstream
VDSL	Very high speed Digital Subscriber Line
VME_O	VTU-O Management Entity
VME_R	VTU-R Management Entity
VTU	VDSL Transceiver Unit
VTU-O	VTU at the ONU
VTU-R	VTU at the Remote site
VTU-x	Any one of VTU-O or VTU-R
xDSL	Generic term covering the family of all DSL technologies, e.g., DSL, HDSL, ADSL, VDSL

5 Reference models

5.1 General reference models

Figure 5-1 shows the reference configuration used for G.993.1. 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). The first architectural model covers Fibre-to-the-cabinet (FTTCab) type of deployment; the second one is Fibre-to-the-exchange (FTTEx) type of deployment. Existing unscreened twisted metallic access wire-pairs are used to convey the signals to and from the customer's premises.

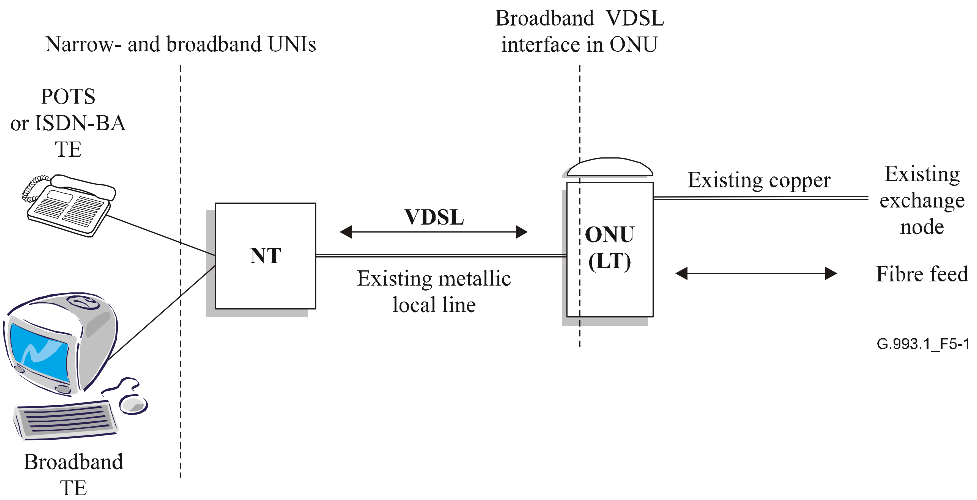


Figure 5-1/G.993.1 – General reference model

The reference configuration provides two or four data paths with bit rate under the control of the network operator, consisting of one or two downstream and one or two upstream data paths. A single path in each direction can be of high latency (with lower BER expected) or lower latency (with higher BER expected). Dual paths in each direction provide one path 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 paths/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.

The model introduces service-splitter 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 routing. The home wiring transmission system is outside the scope of this Recommendation.

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 PTM. However, the G.993.1 core transceiver shall be capable of supporting future additional applications. VDSL service should non-invasively coexist with the narrow-band services on the same pair. Failure of power to the broadband NT or failure of the VDSL service shall not affect any existing narrow-band services. 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 narrow-band signals.

POTS, if present, 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 in the event of loss of power at the subscriber premises).

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 narrow-band services.

The broadband NT is not required to be powered remotely.

Repeatered operation is not a requirement for G.993.1.

5.2 Functional reference model

One of the TPS-TC in Figure 5-2 may be assigned for management purposes and is called Overhead Channel TC (OC-TC).

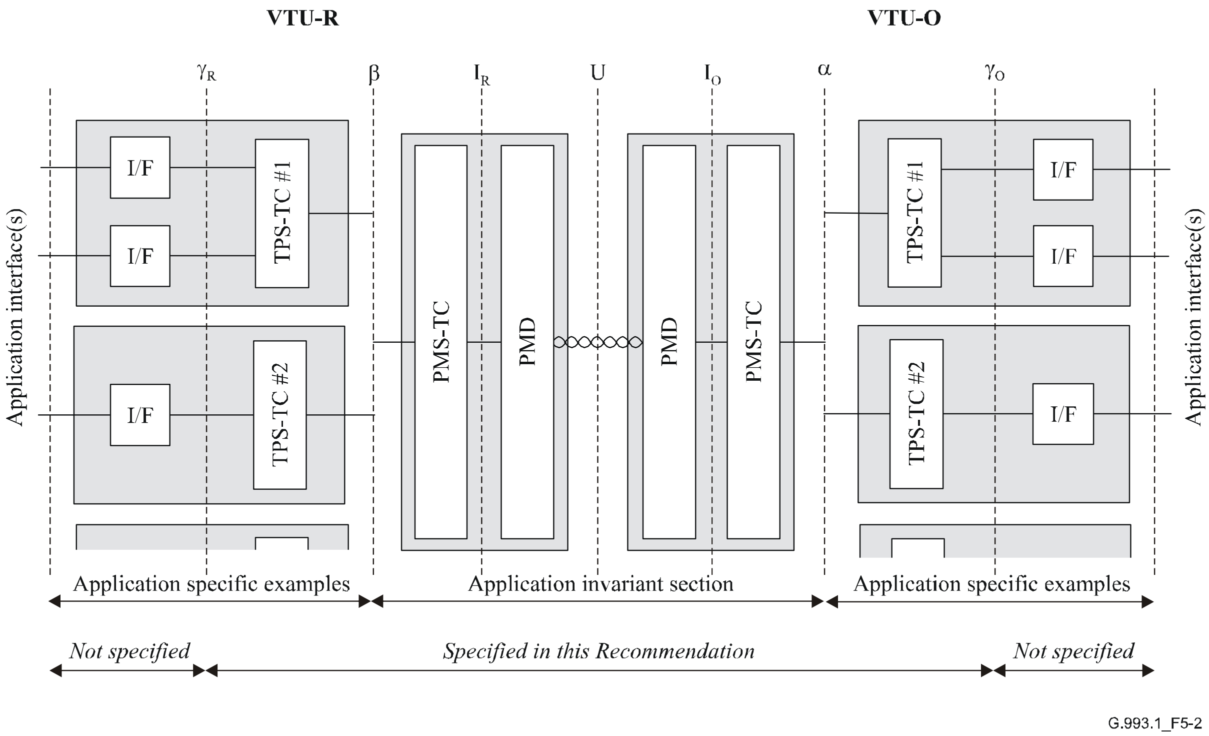


Figure 5-2/G.993.1 – VTU-x functional reference model

5.3 Protocol reference model

Figure 5-3 shows the G.993.1 protocol reference model.

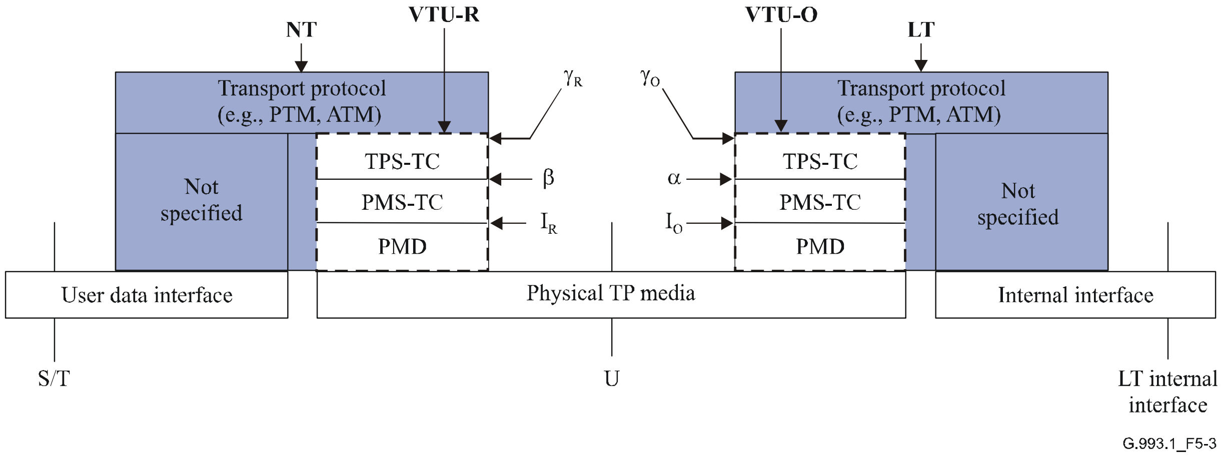


Figure 5-3/G.993.1 – VTU-x protocol reference model

6 Transmission medium interface characteristics

This clause specifies the interface between the transceiver and the transmission medium (U-O2 and U-R2 reference points – see Figure 8 *bis*/G.995.1/Amd.1 named G.993.1 System Reference Model). For the purposes of this Recommendation, the U-O2/U-R2 and U interfaces are spectrally equivalent.

6.1 Duplexing method

G.993.1 transceivers shall use Frequency Division Duplexing (FDD) in separating upstream and downstream transmission.

G.993.1 systems use a four-band plan that starts at 138 kHz and extends up to 12 MHz. The four frequency bands denoted as DS1, US1, DS2, and US2, for the first downstream band, the first upstream band, the second downstream band, and the second upstream band, respectively, as shown in Figure 6-1, shall be allocated according to the band separating frequencies f_1, f_2, f_3, f_4 and f_5.

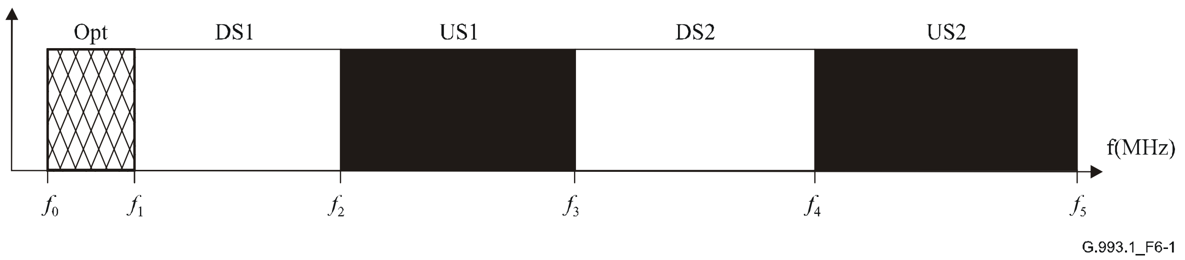


Figure 6-1/G.993.1 – G.993.1 band allocation

The use of the band between 25 kHz (f_0) and 138 kHz (f_1) shall be negotiated using G.994.1. The G.994.1 handshake mechanism indicates and selects (see 12.1 and 12.2) one of the following:

- If the band is to be used for upstream, bit "OptUp".
- If the band is to be used for downstream, bit "OptDn".

See Annexes A, B and C for the specifics of f_0, f_1, f_2, f_3, f_4 and f_5 for the Bandplans.

6.2 Power Spectral Density (PSD)

6.2.1 Transmit bands

See Annexes D, E and F.

6.2.2 Stop bands

The Power Spectral Density (PSD) mask inside the stop bands shall be as defined in Figure 6-2. The narrow-band PSD mask applies between band separating frequencies *ftr*1 and *ftr*2. The wideband power limit applies in that part of the receive band lying between the transition bands.

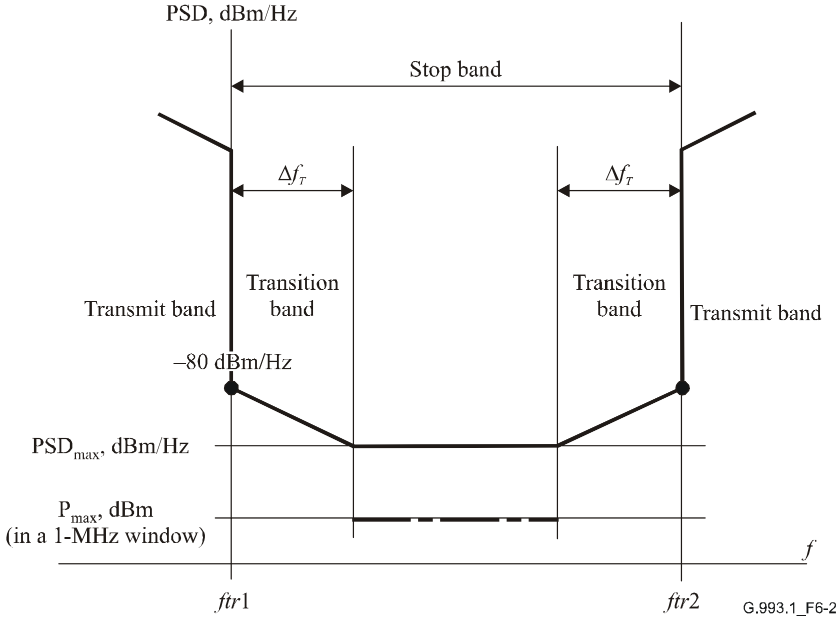


Figure 6-2/G.993.1 – Stop-band PSD mask

The width of the transition bands Δf_T shall be independent of frequency and shall not exceed 175 kHz. Transition bands and values of stop-band PSD below 276 kHz are subject to regional regulations. For some regions, the relevant PSD specifications may be found in Annexes D, E and F.

The corresponding PSD mask values inside the stop-bands shall be as listed in Table 6-1. The values between the points listed in Table 6-1 shall be found using linear interpolation over a linear scale of frequency.

Table 6-1/G.993.1 – Stop-band PSD mask

Frequency [MHz]	Maximum PSD [PSD_{max}, dBm/Hz]	Maximum power in a 1-MHz sliding window [P_{max}, dBm]
<0.276	Subject to regional regulations	–
0.276-4.0	–100	–
4.0-5.0	–100	–50
5.0-30.0	–100	–52
≥30.0	–120	–
Transition frequency	–80	–

The stop-band transmit PSD shall comply with *both* the maximum PSD limitations, using a measurement resolution bandwidth of 10 kHz and the maximum power in a 1-MHz sliding window limitations presented in Table 6-1. The power in a 1-MHz sliding window is measured in a 1-MHz bandwidth starting at frequency $\boldsymbol{ftr1} + \boldsymbol{\Delta f_T}$ of the corresponding transmit signal band and finishing at the next transition frequency $\boldsymbol{ftr2} - \boldsymbol{\Delta f_T}$, as defined in Figure 6-2. If the value of the stop band minus $2\boldsymbol{\Delta f_T}$, $(\boldsymbol{ftr2} - \boldsymbol{ftr1} - 2\boldsymbol{\Delta f_T})$, is narrower than 1 MHz, the bandwidth of the measurement device should be set to $\boldsymbol{\Delta f_M}$, with $\boldsymbol{\Delta f_M}$ equal to or less than the value of the stop band minus $2\boldsymbol{\Delta f_T}$ $(\boldsymbol{\Delta f_M} \leq \boldsymbol{ftr2} - \boldsymbol{ftr1} - 2\boldsymbol{\Delta f_T})$, and the measured result should be recalculated to the 1-MHz sliding window as:

$$P_{\max} = P - 10\log(\Delta f_M)$$

where $\boldsymbol{P}$ is the measured result in dBm, $\boldsymbol{\Delta f_M}$ is the bandwidth used for the measurement in MHz.

6.2.3 PSD reduction function in the frequency region below 1.104 MHz

The implementation of the PSD reduction function in the frequency region below 1.104 MHz is mandatory, and the operator determines whether the function is used or not. The exact PSD reduction function for some regions are presented in Annexes D, E and F.

The use of the PSD reduction function shall be selected through G.994.1 (see 12.1 and 12.2).

6.2.4 Egress control

G.993.1 equipment shall be able to reduce the PSD below –80 dBm/Hz in one or more of the standardized amateur radio bands simultaneously. –80 dBm/Hz is applied to maximum PSD. The bands to be notched are defined in Table 6-2, which includes the amateur radio frequencies for all regions (Regions 1, 2 and 3; see Figure II.1) described in Table II.1.

Table 6-2/G.993.1 – Transmit notch bands

Band start [kHz]	Band stop [kHz]
1 800	2 000
3 500	4 000
7 000	7 300
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 700

6.3 Upstream Power Back-Off (UPBO)

6.3.1 Power back-off mechanism

Upstream Power Back-Off (UPBO) shall be applied to provide spectral compatibility between loops of different lengths deployed in the same binder. Only one UPBO mode shall be supported as described below.

- It shall be possible for the network management system to set the limiting transmit PSD mask, PSD_0, for the VTU-R to one of the standard transmit PSD masks defined in 6.2.1.

- The VTU-R shall perform UPBO as described in 6.3.2 autonomously, i.e., without sending any significant information to the VTU-O until the UPBO is applied.
- After UPBO has been applied, the VTU-O shall be capable of adjusting the transmit PSD selected by the VTU-R; the adjusted transmit PSD shall be subject to the limitations given in 6.3.2.
- To enable the VTU-R to initiate a connection with the VTU-O, which will occur before UPBO has been applied, the VTU-R shall be allowed to cause more degradation to other loops than expected when using the mode described in 6.3.2.

6.3.2 Power back-off mask

The VTU-R shall explicitly estimate the electrical length of its line, kl_0, and use this value to calculate the transmit PSD mask $TxPSD(kl_0, f)$. The VTU-R shall then adapt its transmit signal to conform strictly to the mask $TxPSD(kl_0, f)$ while remaining below the PSD_0 limit set by the management system as described above. Given:

$$TxPSD(kl_0, f) = PSDREF(f) + \left(LOSS(kl_0, f)\,\text{in dB}\right)$$

$$LOSS = kl_0\sqrt{f}\ \text{in dB}$$

The *LOSS* function is an approximation of the loop attenuation (loss).

PSDREF(f) is a function of frequency but is independent of length and type of loop. *PSDREF(f)* is of the form $-a\text{-}b\sqrt{f}$. The values of *a* and *b* for PSD_REF depend on the geographic region and for some regions are presented in Annexes D, E and F.

If the estimated value of kl_0 is smaller than 1.8, the modem shall be allowed to perform power back-off as if kl_0 was equal to 1.8.

The estimate of the electrical length should be sufficiently accurate to avoid spectrum management problems and additional performance loss.

NOTE 1 – A possible estimation of kl_0 is as $min[loss(f)/\sqrt{f}]$. The minimum is taken over the usable VDSL frequency band above 1 MHz. The function *loss* is the insertion loss in dB of the loop at frequency *f*. This definition is abstract, implying an infinitely fine grid of frequencies. Elsewhere, practical measurements will be specified with a finite frequency grid.

NOTE 2 – To meet network-specific requirements, network management may set parameters *a* and *b* in *PSDREF(f)* and also provide a means to override the modem's autonomous estimate of kl_0.

6.4 Termination impedance

A termination impedance of R_V, purely resistive, shall be used over the entire VDSL frequency band for both the LT and NT transceivers when matching to the metallic access wire-pair (either source or load). In particular, it shall be used as a termination for the transmit PSD and power definition and verification.

This termination impedance approximates (and is based upon) the insertion-point impedance of the VDSL test loop. It enables a compromise high-frequency impedance match to the various types of unshielded cable in metallic access networks.

The value of R_V is regionally specific. For some regions the value of R_V is presented in Annexes D, E and F.

6.5 Return loss

The return loss requirement is defined to limit signal power uncertainties due to the tolerance of the line interface impedance. The return loss specifies the amount of reflected differential signal upon a reference impedance R_V:

$$RL = 20\log_{10}\left|\frac{Z + R_V}{Z - R_V}\right|, \text{ [dB]}$$

where Z is the internal impedance of the VTU.

The in-band return loss value of the VDSL transceiver shall be greater than or equal to 12 dB. The out-of-band return loss value shall be greater than or equal to 3 dB. In-band and out-of-band frequencies for each transmit direction are defined by the frequency plan as shown in 6.1. The value of 12 dB assumes a flat transmit PSD is applied over the entire in-band region. Requirements may be relaxed in the frequency ranges of reduced PSD values.

The return loss shall be measured on a resistive test load of R_V while the tested implementation of the VDSL transceiver is powered.

If a service splitter is used, the return-loss requirements shall be met for the full range of possible values of the POTS/ISDN port termination.

6.6 Output signal balance

Output Signal Balance (OSB) is a measure of unwanted longitudinal signals at the output of the transceiver. The longitudinal output voltage (V_{cm}) to the differential output voltage (V_{diff}) ratio shall be measured while the VTU transmitter is active in accordance with ITU-T Recs G.117 and O.9.

$$OSB = 20\log_{10}\left|\frac{V_{diff}}{V_{cm}}\right|, \text{ [dB]}$$

The OSB of the VDSL transceiver shall be equal to or greater than 35 dB in the entire VDSL band. The termination impedance of the transceiver for OSB measurement shall be R_V.

NOTE – 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 drop-wire has been observed to be in the range of 30-35 dB; therefore, the balance of the VDSL equipment should be equal or better.

7 TPS-TC sublayer general functional characteristics

The physical layer shall be able to transport at least one of ATM or PTM signals. See Annexes G and H for the specifics of these TPS-TC applications.

7.1 α/β interface specification

The α and β reference points define corresponding interfaces between the TPS-TC and PMS-TC at the VTU-O and VTU-R sides, respectively. Both interfaces are hypothetical, application-independent, identical. The interfaces comprise the following flows of signals between the TPS-TC and the PMS-TC sublayers:

- data flow;
- synchronization flow.

NOTE – If dual latency is applied, the interface comprises two identical Data and Synchronization flows: one for the Fast and one for the Slow channel, respectively. Each flow is between the corresponding TPS-TC and PMS-TC sublayer.

7.1.1 Data flow

Data flow comprise two generic *octet-oriented* streams with the rates defined by the physical net capabilities:

- transmit data stream: Tx;
- receive data stream: Rx.

The Data flow signals description is presented in Table 7-1.

If data streams are *serial* by implementation, the MSB of each octet shall be sent first. The Tx, Rx data rate values are set during the system configuration.

Table 7-1/G.993.1 – TPS-TC: α/β interface data and synchronization flows signal summary

Signal(s)	Description	Direction	Notes
Data signals			
Tx	Transmit data	TPS-TC → PMS-TC	
Rx	Receive data	TPS-TC ← PMS-TC	
Synchronization signals			
Clk_t	Transmit bit timing	TPS-TC ← PMS-TC	Optional
Clk_r	Receive bit timing		
Osync_t	Transmit octet timing		
Osync_r	Receive octet timing		

7.1.2 Synchronization flow

This flow provides synchronization between the TPS-TC sublayer and PMS-TC sublayer. The Synchronization flow comprises up to four synchronization signals presented in Table 7-2:

- transmit and receive data flow bit-synchronization (Clk_t, Clk_r);
- transmit and receive data flow octet-synchronization ($Osync_t$, $Osync_r$).

All synchronization signals are asserted by PMS-TC and directed towards TPS-TC. The signals $Osync_t$, $Osync_r$ are mandatory; other signals are *optional*.

The Clk_t and the Clk_r rates are matched with the Tx and the Rx data rates, respectively.

7.2 OC TPS-TC application interface (γ_O, γ_R) description

This clause specifies a VDSL Operations Channel Transport Protocol Specific Transmission Convergence sublayer (OC-TC), which describes the transmission of the Embedded Operations Channel (eoc) over a VDSL link between the VDSL Management Entities (VME) at the opposite sides of the link (see Figure 10-2). The OC-TC is specified at both the γ_O and γ_R reference points of the VTU-O and VTU-R sites, respectively. Both γ interfaces are functional, identical and contain the following flows of signals:

- data flow;
- synchronization flow.

7.2.1 Data flow

The eoc data flow includes two contra-directional streams of 2-octet blocks each (eoc_tx, eoc_rx) with independent rates flowing between the eoc application layer (VME) and TPS-TC OC block (OC-TC). The bit rates of both streams shall not exceed the predefined upper limit of the OC channel aggregate transport capability. The data flow signal description is presented in Table 7-1.

If data streams are *serial* by implementation, the MSB of each octet shall be sent first.

7.2.2 Synchronization flow

This flow provides synchronization between the eoc application layer (VME) and the OC-TC (see 10.3.1). The flow includes the following synchronization signals, presented in Table 7-2:

- transmit and receive timing signals (eoc_tx_clk, eoc_rx_clk): both asserted by the eoc processor;
- transmit enable flag (tx_enbl): asserted by OC-TC and allows to transmit the next 2-octet block;
- receive enable flag (rx_enbl): asserted by OC-TC and indicates that the next 2-octet block is allocated in the OC-TC receive buffer.

Table 7-2/G.993.1 – OC-TC: γ interface data and synchronization flow summary

Signal	Description	Direction	Notes
Data flow			
eoc_tx	Transmit eoc data	VME → OC-TC	Two-octet block
eoc_rx	Receive eoc data	VME ← OC-TC	
Synchronization flow			
eoc_tx_clk	Transmit clock	VME → OC-TC	
eoc_rx_clk	Receive clock	VME → OC-TC	
tx_enbl	Transmit enable flag	VME ← OC-TC	
rx_enbl	Receive enable flag	VME ← OC-TC	

NOTE – The main buffering required to implement the eoc communication protocol should be provided by the VME; only a minimum buffering for eoc is supposed in OC-TC.

8 PMS-TC sublayer

The PMS-TC sublayer provides transmission medium specific TC functions, such as framing, Forward Error Correction (FEC), and interleaving.

8.1 PMS-TC functional model

All data bytes shall be transmitted MSB first. All serial processing (e.g., scrambling, CRC calculation) shall however be performed LSB first, with the outside world MSB considered as the VDSL LSB. As a result, the first incoming bit (outside world MSB) shall be the first bit processed inside VDSL (VDSL LSB). The PMS-TC functional diagram is presented in Figure 8-1.

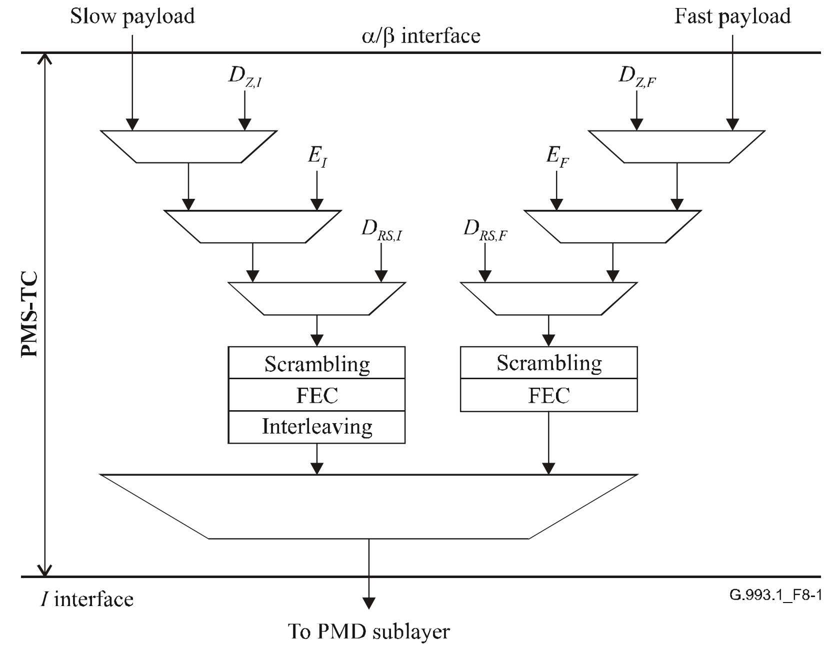


Figure 8-1/G.993.1 – Diagram of PMS-TC sublayer

8.2 Scrambler

A scrambler shall be used to reduce the likelihood that a long sequence of zeros will be transmitted over the channel. The scrambler shall be self-synchronizing such that descrambling can occur without requiring a particular alignment with the scrambled sequence. The scrambler shall be represented by the equation below, where *m(n)* is a message bit sample at sample time *n* and the output of the scrambler *x(n)* shall be given by:

$$x(n) = m(n) + x(n-18) + x(n-23)$$

All arithmetic shall be modulo 2. As long as the scrambler is initialized with values other than zero, an "all zeros" sequence for *m(n)* will result in a pseudo-random sequence of length $2^{23} - 1$.

8.3 Forward error correction

A standard byte-oriented Reed-Solomon code shall be used to provide protection against random and burst errors.

A Reed-Solomon code word contains $N = K + R$ bytes, comprised of R redundant check bytes c_0, c_1, ..., c_{R-2}, c_{R-1} appended to K message bytes m_0, m_1, ..., m_{K-2}, m_{K-1}. The check bytes shall be computed from the message bytes using the equation

$$C(D) = M(D)D^R \bmod G(D)$$

where:

$M(D)$ = $m_0 D^{K-1} \oplus m_1 D^{K-2} \oplus \ldots \oplus m_{K-2} D \oplus m_{K-1}$ is the message polynomial

$C(D)$ = $c_0 D^{R-1} \oplus c_1 D^{R-2} \oplus \ldots \oplus c_{R-2} D \oplus c_{R-1}$ is the check polynomial

$G(D)$ = $\prod (D \oplus \alpha^i)$ is the generator polynomial of the Reed-Solomon code, where the index of the product runs from i = 0 to $R - 1$.

This means that $C(D)$ is the remainder obtained from dividing $M(D)D^R$ by $G(D)$. The arithmetic shall be performed in the Galois Field GF(256), where α is a primitive element that satisfies the primitive binary polynomial $x^8 \oplus x^4 \oplus x^3 \oplus x^2 \oplus 1$. A data byte ($d_7, d_6, \ldots, d_1, d_0$) is identified with the Galois Field element $d_7\alpha^7 \oplus d_6\alpha^6 \oplus \ldots \oplus d_1\alpha \oplus d_0$.

Both K and R shall be programmable parameters. Redundancy values of $R = 0, 2, 4, 6, 8 \ldots 16$ shall be supported. The following codeword parameters specified as (N,K) shall be supported: (144,128) and (240,224). Other values for N and K are optional. However, N shall be less than or equal to 255.

8.4 Interleaving

8.4.1 General

Interleaving shall be used to protect the data against bursts of errors by spreading the errors over a number of Reed-Solomon codewords. The interleave depth shall be programmable with a maximum interleave depth of 64 codewords when the number of octets per codeword (N) equals 255. For smaller values of N the interleave depth can grow nearly proportionately.

It shall be possible to adjust the interleave depth via the management system to meet latency requirements. The latency of the slow path is a function of the data rate and burst error correction capability. For data rates greater than or equal to 13 Mbit/s, the latency between the α and β interfaces shall not exceed 10 ms when the interleaver depth is set to the maximum. At lower data rates there is a trade-off between higher latency and decreased burst error correction ability. At any data rate, the minimum latency occurs when the interleaver is turned off.

When the interleaver is on, the codewords shall be interleaved before transmission to increase the immunity of RS codewords to bursts of errors. The convolutional interleaver is defined by two parameters: the interleaver block length, I, and the interleaving depth, D. The block length I shall divide the RS codeword length N (i.e., N shall be an integer multiple of I). The convolutional interleaver uses a memory in which a block of I octets is written while an (interleaved) block of I octets is read. Details of the implementation are given in 8.4.2.

The same size interleaving memory (see Table 8-1) is needed for interleaving at the transmitter and de-interleaving at the receiver.

The convolutional interleaving introduces an absolute read-to-write delay, Δ_J, that increments linearly with the octet index within a block of I octets:

$$\Delta_j = (D-1) \times j$$

where $j = 0, 1, 2, \ldots, I-1$.

8.4.2 Triangular implementation

To decrease the implementation complexity, the delay increment $(D-1)$ shall be chosen as a multiple of the interleaver block length (I), i.e.: $D-1 = M \times I$. The $(D-1)$ to I ratio is the interleaving depth parameter (M). The characteristics of convolutional interleaving are shown in Table 8-1. The parameters t and q depend on the characteristics of the RS code and are defined as:

– t = number of bytes that can be corrected by RS codewords = half the number of redundancy bytes = $R/2$;

– q = length of RS codeword divided by the length of an interleaver block = N/I.

Table 8-1/G.993.1 – Characteristics of convolutional interleaving

Parameter	Value
Interleaver block length (I)	I bytes (equal to or divisor of N)
Interleaving Depth (D)	$M \times I + 1$
(De)interleaver memory size	$M \times I \times (I - 1)/2$ bytes
Correction capability	$\lfloor t/q \rfloor \times (M \times I + 1)$ bytes
End-to-end delay	$M \times I \times (I - 1)$ bytes

The example in Figure 8-2 shows $I = 7$. I parallel branches (numbered $0...I - 1$) are implemented with a delay increment of M octets per branch. Each branch shall be a FIFO shift register (delay line) with length $0 \times M$ ...$(I - 1) \times M$ bytes. The deinterleaver is similar to the interleaver, but the branch indices are reversed so that the largest interleaver delay corresponds to the smallest deinterleaver delay. Deinterleaver synchronization shall be achieved by routing the first byte of an interleaved block of I bytes into branch 0.

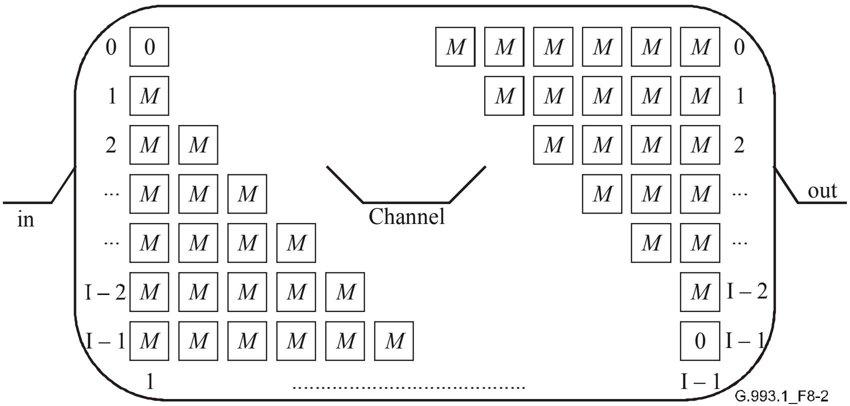


Figure 8-2/G.993.1 – Implementation example with $D - 1 = M \times I$ and $I = 7$

Table 8-2/G.993.1 – Example of interleaver parameters with RS(144,128)

Rate [kbit/s]	Interleaver parameters	Interleaver depth	(De)interleaver memory size	Erasure correction	End-to-end delay
50 × 1024	I = 72 M = 13	937 blocks of 72 bytes	33 228 bytes	3 748 bytes 520 µs	9.23 ms
24 × 1024	I = 36 M = 24	865 blocks of 36 bytes	15 120 bytes	1 730 bytes 500 µs	8.75 ms
12 × 1024	I = 36 M = 12	433 blocks of 36 bytes	7 560 bytes	866 bytes 501 µs	8.75 ms
6 × 1024	I = 18 M = 24	433 blocks of 18 bytes	3 672 bytes	433 bytes 501 µs	8.5 ms
4 × 1024	I = 18 M = 16	289 blocks of 18 bytes	2 448 bytes	289 bytes 501 µs	8.5 ms
2 × 1024	I = 18 M = 8	145 blocks of 18 bytes	1 224 bytes	145 bytes 503 µs	8.5 ms

The following interleaver parameters shall be supported:

– For (N,K) = (144,128) the following values for M and I shall be supported:

  I = 36 and M between 2 and 52.

– For (N,K) = (240,224) the following values for M and I shall be supported:

  I = 30 and M between 2 and 62.

8.5 Framing

8.5.1 Frame description

A *frame* is a set of bytes carried by one DMT symbol. The frame frequency depends on the total length of the cyclic extension (see 9.2.2). A frame shall be composed of two sources: the "fast" buffer and the "interleaved" (or "slow") buffer. The index i refers to parameters related to the fast or interleaved buffers ($i \in \{F, I\}$). The inclusion of the fast buffer shall be optional. When the fast buffer is not included, the interleaved buffer shall have the capability to carry non-interleaved data by setting the interleaver depth to zero.

Both fast and interleaved buffer shall contain an integer number of RS-encoded bytes. Neither the fast nor the interleaved buffer is required to carry an integer number of RS codewords. To reduce the end-to-end delay, it is recommended that the fast buffer (or the interleaved buffer when the interleaver depth is zero) carries at least one RS codeword. The framing parameters shall be exchanged between the VTU-O and VTU-R during initialization.

The framing rules described in this clause are represented in Figure 8-3.

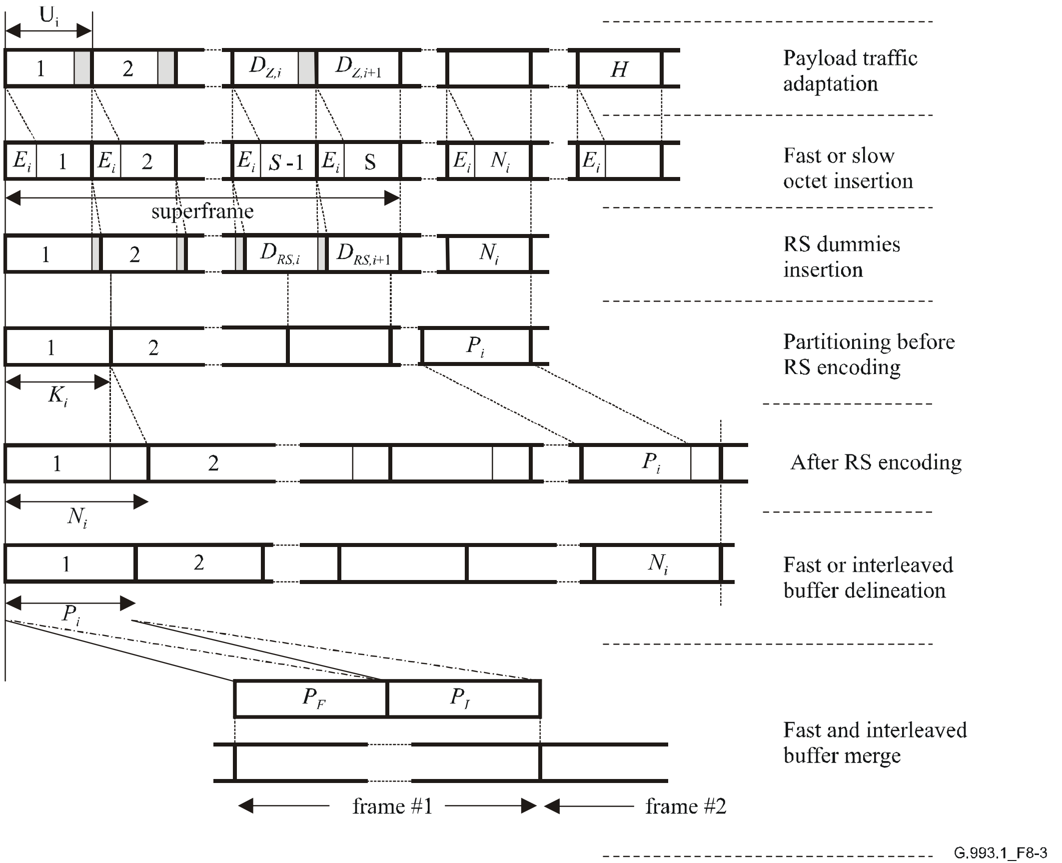


Figure 8-3/G.993.1 – Framing description

8.5.2 Payload adaptation

The α/β interface provides bytes at a rate multiple of 64 kbit/s. In order to map an integer number of bytes into a frame, the TPS-TC byte flow shall be stuffed with the appropriate number of dummies.

For an $n_i \times 64$ kbit/s rate, we have on average $n_i \times 8000/f_s$ bytes per frame, with f_s the symbol frequency. This number will not be integer for a general value of f_s. Since the cyclic extension $L_{CP} + L_{CS} - \beta$ is a multiple of 2^{n+1} however, (see 9.2.2), we always have an integer number of bytes every $H = 138$ frames. If we define k as:

$$k = \frac{8\ kbytes \times H}{f_s}$$

we can transport $n_i \times k$ TPS-TC payload bytes in H frames. In order to transport an integer number of bytes per frame, we have to insert an appropriate number of dummy bytes. Every frame will contain a total of U_i bytes (TPS-TC bytes + dummy bytes), with:

$$U_i = \left\lceil \frac{n_i \times k}{H} \right\rceil$$

The number of dummy bytes $D_{Z,i}$ to be inserted every H packets shall therefore be:

$$D_{Z,i} = \left\lceil \frac{n_i \times k}{H} \right\rceil \times H - (n_i \times k)$$

These dummy bytes shall be inserted in the last position of the first $D_{Z,i}$ packets of U_i bytes in a sequence of H packets. The value of the $D_{Z,i}$ dummies shall be 0x3A.

8.5.3 RS encoding

After payload adaptation, E_i overhead bytes (see 8.5.5) shall be added to the head-end of each packet of U_i bytes (see Figure 8-3). These bytes are called fast and slow bytes for the fast and slow channel respectively. Next, a sequence of N_i packets of (E_i + U_i) bytes shall be RS-encoded. In order to achieve an integer number of RS-codewords per N_i packets, RS-dummy bytes may have to be inserted. The RS-codeword length is equal to the parameter N_i.

The number of RS-encoded bytes, B_i, per N_i packets is given by:

$$B_i = \left[N_i \times (E_i + U_i) + D_{RS,i}\right] \times \frac{N_i}{K_i}$$

In the above equation, the parameter N_i denotes both the number of packets of (E_i + U_i) bytes and also the length of a RS-codeword (in bytes). The parameter K_i is the number of information bytes in an RS-codeword.

The number of RS dummy bytes, $D_{RS,i}$, inserted to carry an integer number of RS-codewords in every N_i frames is given by

$$D_{RS,i} = \left\lceil \frac{N_i \times (E_i + U_i)}{K_i} \right\rceil \times K_i - N_i \times (E_i + U_i)$$

Each one of the $D_{RS,i}$ dummies shall be inserted at the tail-end of the first $D_{RS,i}$ packets of (E_i + U_i) bytes in a sequence of N_i packets (see Figure 8-3). The value of the $D_{RS,i}$ bytes shall be 0xD3.

After RS-dummy insertion, the number of RS-encoded bytes per frame carried in either the fast or interleaved buffer is given by:

$$P_i = \frac{B_i}{N_i} = \frac{N_i \times (E_i + U_i) + D_{RS,i}}{K_i} = \left\lceil \frac{N_i \times (E_i + U_i)}{K_i} \right\rceil$$

NOTE – The parameter $B_i = P_i N_i$ represents both the number of bytes in N_i frames (with P_i bytes per frame) and also the number of bytes in P_i codewords (with N_i bytes per codeword). See Figure 8-3.

8.5.4 Definition of superframe

A superframe shall be composed of 10 packets of $U_i + E_i$ bytes.

8.5.5 Contents of fast and slow bytes

Each of the packets in a superframe shall transport E_i overhead bytes, called fast or slow bytes, depending on the channel. The content of these bytes is summarized in Table 8-3. If the fast buffer is empty, the F-EOC bytes shall be transported in the S-EOC bytes. Otherwise, the S-EOC bytes shall be replaced with payload bytes.

There shall be V VOC bytes per packet. They shall always be transported in the slow channel. A setting of $V = 1$ shall be supported, other values for V should be allowed as optional. The value of V shall be exchanged during initialization (see 12.4.6.2.1.1).

If the fast path is active, the NTR byte in the slow channel shall be replaced with a dummy byte. Similarly for the IB bytes.

The fast and slow dummy bytes shall have the value 0xFF.

Table 8-3/G.993.1 – Contents of fast and slow bytes

Packet	Fast bytes		Slow bytes		
	First byte	Other bytes (if any)	First byte	2nd up to (V + 1)st byte	Other bytes (if any)
1	F-CRC	F-EOC	S-CRC	VOC	S-EOC/payload
2	Synch byte	F-EOC	Synch byte	VOC	S-EOC/payload
3-5	IB	F-EOC	IB/dummy	VOC	S-EOC/payload
6	NTR	F-EOC	NTR/dummy	VOC	S-EOC/payload
7-10	Dummy	F-EOC	Dummy	VOC	S-EOC/payload

8.5.5.1 Cyclic Redundancy Check (CRC)

Two cyclic redundancy checks (CRC) – one for the fast buffer and one for the interleaved buffer – shall be generated for each superframe and shall be transmitted in the first packet of the following superframe (see Table 8-3). The CRC byte for the first superframe shall be set to zero.

Eight bits per buffer type (fast or interleaved) and per superframe shall be allocated to the CRC check bits. These bits shall be computed from the k message bits using the equation:

$$crc(D) = M(D)\, D^8 \text{ modulo } G(D)$$

where:

$M(D) = m_0 D^{k-1} + m_1 D^{k-2} + \ldots + m_{k-2} D + m_{k-1}$ is the message polynomial

$G(D) = D^8 + D^4 + D^3 + D^2 + 1$ is the generating polynomial

$crc(D) = c_0 D^7 + c_1 D^6 + \ldots + c_6 D + c_7$ is the check polynomial

D is the delay *operator*.

That is, crc(D) shall be the remainder when $M(D)D^8$ is divided by $G(D)$.

The bits covered by the crc shall include:

– fast buffer: all bits of the fast buffer before RS encoding, except the crc;

– interleaved buffer: all bits of the interleaved buffer before RS encoding, except the crc.

Each byte shall be clocked into the CRC least significant bit first.

8.5.5.2 Synchronization byte

The synchronization byte has the value 0x3C. This synchronization byte shall be used to monitor the frame synchronization.

8.5.5.3 Indicator Bits (IB)

The indicator bits are used to transmit far-end defects and anomalies. The description of the content of the three indicator bytes shall be as summarized in Table 8-4. If the fast channel is active, the indicator bytes shall be transmitted in this channel and the indicator bytes in the slow channel shall be replaced by dummies (having value 0xFF, see 8.5.5).

Table 8-4/G.993.1 – Content of indicator bits

Byte #	Bit #	Definition
1	b0-b7	Reserved for future use
2	b0	Febe-s
	b1	Ffec-s
	b2	Febe-f
	b3	Ffec-f
	b4	Flos
	b5	Rdi
	b6	Fpo
	b7	Flpr
3	b0	LoM (Loss of Margin)
	b1	Fhec-s (used for ATM only, shall be set to 0 for PTM)
	b2	Fhec-f (used for ATM only, shall be set to 0 for PTM)
	b3	Fncd-s/Focd-s (used for ATM only, shall be set to 0 for PTM)
	b4	Fncd-f/Focd-f (used for ATM only, shall be set to 0 for PTM)
	b5-b7	Reserved for future use

The active state of a bit shall be high (value 1). Bits that are reserved for future use shall be set to low (value 0).

The definition of the anomalies and defects linked to each of the indicator bits can be found in 10.5.4. The LoM-bit shall signal a loss of margin at the far end. It shall become high once loss of margin is detected and shall remain high as long as this condition exists.

8.5.5.4 Network Timing Reference (NTR)

Isochronous services require the same timing reference at transmit and receive sides in higher layers of the protocol stack. To support the transmission of this timing signal, the VDSL system shall transport an 8-kHz timing marker.

For applications that require NTR, NTR shall be transported in the following way:

The VTU-O shall derive a local 8-kHz timing reference (LTR), by dividing its sample clock with the appropriate number. For a VDSL system using $N_{sc} = 2^{n+8}$ tones, the sampling frequency could for instance be 2 $N_{sc}\ \Delta f$ and the dividing factor would then be $69 \times 2^{n+2}$.

The VTU-O shall estimate the change in phase offset between the NTR and the LTR from the previous superframe to the present. This value shall be expressed in cycles of a clock running at frequency 2 N_{sc} Δf and shall be transported in the NTR overhead byte (see Table 8-3) as a 2's-complement number.

A positive value of the change in phase offset shall indicate that the LTR has a higher frequency than the NTR. A negative value of the change in phase offset shall indicate that the LTR has a lower frequency than the NTR.

The LTR, being proportional to Δf, has a maximum frequency variation of 50 ppm (see 9.2.1.1). The NTR has a maximum variation of 32 ppm. The maximum difference is therefore 82 ppm. This would result in a maximal phase offset of 0.205 µs per superframe. This corresponds to about $0.45.2^n$ samples. For the largest value of n (n = 4), this corresponds to somewhat more than 7 samples (in the positive or negative direction). One byte of information should therefore be sufficient.

8.5.6 Convergence of fast and interleaved buffer

Data from the interleaved and (optional) fast buffer shall be combined so that in each frame there shall first be a segment of fast data followed by a segment of interleaved data. Figure 8-4 illustrates this process.

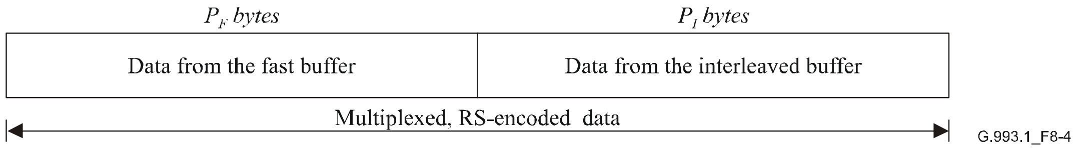


Figure 8-4/G.993.1 – Convergence of the fast and interleaved data into one frame

The total number of RS-encoded bytes per frame, P_{total}, is given by:

$$P_{total} = P_I + P_F$$

where P_I and P_F are the number of RS-encoded bytes from the interleaved and fast paths.

9 PMD sublayer

9.1 PMD functional model

The functional model of the PMD sublayer is presented in Figure 9-1.

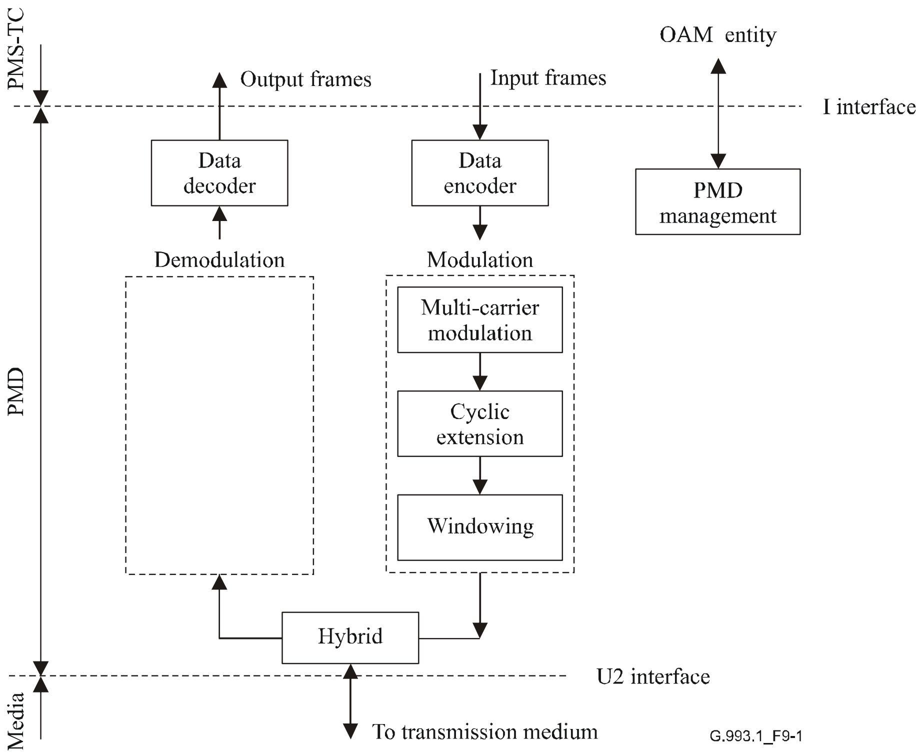


Figure 9-1/G.993.1 – Functional diagram of PMD sublayer

In the transmit direction, the PMD layer shall receive input frames from the PMS-TC sublayer. A frame shall contain exactly the number of bytes that will be modulated onto one DMT symbol. This shall be an integer number. Each carrier shall have a number of bits assigned to it during initialization. The bits that are to be modulated on a carrier shall be encoded into constellation points according to the rules given in 9.2.5. After encoding, the carriers shall be modulated and summed using an IDFT. The resulting digital signal shall be cyclically extended and windowed before being sent towards the transmission medium over the U interface.

In the receive direction, the modem shall receive the signal over the U interface and perform the required actions to recover the transmitted signal. The data obtained from the demodulator shall be sent to the data decoder that will extract the output data frames. These data frames shall be sent to the PMS-TC layer over the I interface.

The management block is responsible for all OAM functions relating to the PMD layer.

9.2 PMD functional characteristics

9.2.1 Multi-carrier modulation

The modulation shall use a maximum number of sub-carriers equal to $N_{SC} = 2^{n+8}$, where n can take the values 0, 1, 2, 3, 4. Disjoint subsets of the N_{SC} sub-carriers shall be defined for use in the downstream and upstream directions. These subsets are determined by the frequency plan (see 6.1). The exact subsets of sub-carriers used to modulate data in each direction shall be determined during initialization and shall be based on management system settings and the signal-to-noise ratios (SNRs) of the sub-channels. In many cases the number of sub-carriers used in a direction will be less than the maximum number allowed by the partitioning.

9.2.1.1 Tone spacing

The frequency spacing, Δf, between the sub-carriers shall be 4.3125 kHz, with a tolerance of 50 ppm. The sub-carriers shall be centred at frequencies $f = k\ \Delta f$. The tone index k can take the values $k = 0, 1, 2, \ldots, N_{SC} - 1$.

9.2.1.2 Data sub-carriers

Transmission may take place on up to $N_{SC} - 1$ sub-carriers, since DC is not used. The actual number of sub-carriers used may be lower than this maximum number. The lower limit depends on the presence of amateur radio-frequency bands and the required notching in these bands, the POTS or ISDN splitter, PSD masks, implementation-specific filters and the services to be provided.

9.2.1.3 Modulation by the Inverse Discrete Fourier Transform (IDFT)

The encoder shall generate N_{SC} complex values Z_i ($i = 0, \ldots, N_{SC} - 1$), including the zero at DC because the sub-carrier centred at DC shall not be used for data transmission. To generate real time-domain values x_k using a complex-to-real IDFT, the set of frequency-domain values Z_i shall be augmented to generate a new vector Z_i' of size $N = 2N_{SC}$. The vector Z_i' shall be Hermitian. That is:

$$Z'_i = Z_i,\ i = 0, \ldots, N_{sc} - 1$$

$$Z'_i = conj\ (Z_{2N_{sc} - i}),\ i = N_{sc}, \ldots, 2N_{sc} - 1$$

The Nyquist frequency shall not be modulated, therefore, $Z_i' = 0$ for $i = N_{SC}$.

The vector Z_i' shall be transformed to the time domain by an inverse discrete Fourier transform (IDFT). The modulating transform defines the relationship between the $2N_{SC}$ real time-domain values x_k and the $2N_{SC}$ complex numbers Z_i':

$$x_k = \sum_{i=0}^{2N_{sc}-1} Z_i' e^{j\frac{2\pi ki}{2N_{sc}}}, \quad k = 0, \ldots, 2N_{SC} - 1$$

9.2.2 Cyclic extension

The last L_{CP} samples of the IDFT output x_k shall be prepended to the $2N_{SC}$ time-domain samples x_k as the cyclic prefix. The first L_{CS} samples of x_k shall be appended to the block of time-domain samples as the cyclic suffix.

The first β samples of the prefix and last β samples of the suffix shall be used for shaping the envelope of the transmitted signal. The maximal value of β shall be 16×2^n, but not more than 255. The windowed parts of consecutive symbols shall overlap (β samples). Figure 9-2 summarizes all the operations that have to be performed and illustrates the relationship between the various parameters.

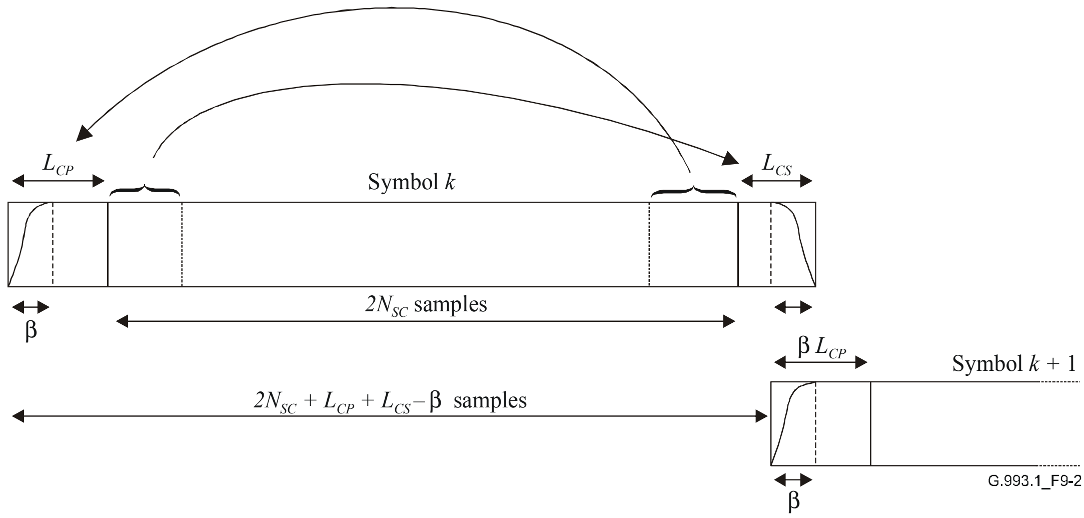


Figure 9-2/G.993.1 – Cyclic extensions, windowing and overlap of DMT symbols

The total cyclic extension is defined as $L_{CE} = L_{CP} + L_{CS} - \beta$. The values L_{CP}, L_{CS} and β shall be chosen in order to satisfy the equation $(L_{CP} + L_{CS} - \beta) = m \times 2^{n+1}$, where m shall be an integer value. L_{CP}, L_{CS} and β shall be chosen such that $L_{CP} + L_{CS} - \beta$ can at least take the value 40×2^n. Other values should be allowed as optional.

In all cases, the following relations shall hold: $\beta < L_{CP}$ and $\beta < L_{CS}$.

In synchronous mode of operation (see 9.2.3.4), the size of the non-windowed part of the suffix shall be the same for all modem pairs in a binder group and its duration shall be equal to the propagation delay (one way) of the longest line in the binder. In synchronous operation, VTU-Os and VTU-Rs operating in the same binder shall have a common frame clock. All transceivers shall start transmission of DMT frames at the same time.

Table 9-1 lists the number of samples in the cyclic extension as a function of the maximum number of sub-carriers, for the case $L_{CE} = 40 \times 2^n$. In selecting these values, each DMT symbol has a duration of 250 μs, irrespective of the sampling rate. This results in a 4-kHz symbol rate.

Table 9-1/G.993.1 – Selection of cyclic extension as function of the number of sub-carriers to achieve a 4-kHz symbol rate

Cyclic extension (samples)	Maximum of sub-carriers N_{SC}
40	256
80	512
160	1024
320	2048
640	4096

For a given choice of the cyclic extensions and windowing length β, the symbols will be transmitted at a symbol rate equal to:

$$f_s = \frac{2N_{SC} \times \Delta f}{2N_{SC} + L_{CP} + L_{CS} - \beta}$$

9.2.3 Synchronization

9.2.3.1 Pilot tones

Use of dedicated pilot tones shall be optional. During initialization, the VTU-R shall select a sub-channel to use for timing recovery. The VTU-R may require a dedicated pilot tone on which data shall not be transmitted, or it may be capable of performing timing recovery using sub-channels that support data. If the VTU-R requires a dedicated pilot tone, it shall indicate its choice of pilot tone to the VTU-O during initialization (see 12.4.6.3.1.4). The VTU-O shall then transmit the 4QAM value of 00 on that tone during every symbol.

9.2.3.2 Loop timing

The VTU-R shall loop time its local sampling clock to the pilot selected during initialization.

9.2.3.3 Timing advance

The VTU-R shall be capable of implementing a timing offset called Timing Advance (TA) in the transmission of DMT symbols. The TA forces the VTU-O/VTU-R pair to start transmissions of frames in opposite directions simultaneously (i.e., the frames in downstream and upstream transmission direction start at the same (absolute) time). The timing advance shall be equal to the propagation delay from the VTU-O to the VTU-R. It shall be calculated during initialization. The TA is subtracted from the received symbol start time, and the result shall be used as the VTU-R's individual symbol start time so that both the VTU-O and VTU-R transmitters start transmitting each DMT frame at the same time. This is illustrated in Figure 9-3.

NOTE – The timing advance should apply at the U2 interface to obtain the desired orthogonality between transmit and receive signals.

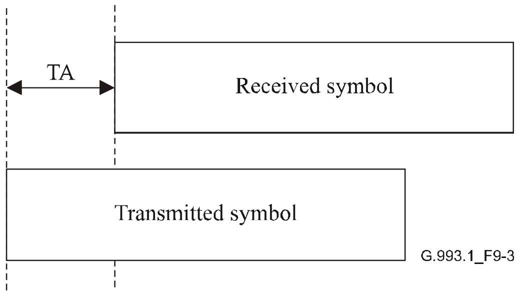


Figure 9-3/G.993.1 – Illustration of Timing Advance (TA)

9.2.3.4 Synchronous mode (optional)

In synchronous mode, all VTU-O transceivers in the same cable binder shall transmit with respect to a common symbol clock, and thus start the transmission of DMT symbols at the same time. The symbol clock, which may be derived from a reference clock, shall be phase synchronous at all VTU-Os in a shared cable with a 1 µs maximum phase error tolerance. The VTU-R shall extract the symbol clock from the received data. Timing advance (see 9.2.3.3) shall be used to correct the VTU-R symbol timing to synchronize VTU-O and VTU-R transmissions.

In synchronous mode, near-end crosstalk (NEXT) due to other (synchronized) VDSL systems will be orthogonal to the desired useful signal and hence not interfere with the useful received signal.

9.2.4 Power back-off in the upstream direction

To mitigate the effects of FEXT from short lines into long lines in distributed cable topologies, upstream power back-off shall be applied. Transceivers shall be capable of performing frequency-dependent power back-off.

The mechanism for power back-off shall comply with the procedure specified in 6.3. This shall be implemented as described below.

The PBO method is defined by a reference PSD (PSD_REF) at the VTU-O. This reference PSD shall be input via the management interface and shall be transmitted from the VTU-O to the VTU-R (see 12.4.4.2.1.1).

The VTU-R shall estimate the insertion losses of the upstream bands based on the received downstream signals. From this, the shape of the LOSS function (or, equivalently, the electrical length) as defined in 6.3.2 shall be derived. The VTU-R shall then compute the transmit PSD by dividing the reference PSD in the upstream bands by the estimated LOSS function. Next, the VTU-R shall take a tone-by-tone minimum of this computed PSD and the maximum allowed transmit PSD in the upstream direction. The result shall be used as the initial upstream transmit PSD. The PSD received by the VTU-O should approximate the reference PSD. Upon receiving signals from the VTU-R, the VTU-O shall compare the actual received PSD to the reference PSD. If necessary, it shall instruct the VTU-R to fine-tune its PSD (under the requirements of 6.3.2).

The VTU-O shall also have the capability to directly impose a maximum allowed transmit PSD at the VTU-R. This maximum transmit PSD shall also be input via the management interface and shall be transmitted from VTU-O to VTU-R in the early stages of the initialization. The VTU-O shall allow the operator to select one of these two methods. If the PBO is defined as a maximum transmit PSD at the VTU-R, the VTU-R shall adjust its transmit PSD such that it does not exceed the maximum allowed transmit PSD. The restrictions specified in 6.3.2 shall also apply in this case (i.e., the VTU-O shall not impose a transmit PSD mask that violates the mask specified there).

9.2.5 Constellation encoder

An algorithmic constellation encoder shall be used to construct sub-channel QAM constellations with a minimum number of bits equal to 1. The maximum number of bits that shall be supported is negotiated during initialization. The maximum number in the downstream direction shall be B_{max_d}; the maximum number in the upstream direction shall be as B_{max_u}. The values of B_{max_d} and B_{max_u} shall be exchanged during initialization (see 12.4.6.2.1.1 and 12.4.6.3.1.1) and shall be constrained by:

$$8 \le B_{\max\_d} \le 15$$

and:

$$8 \le B_{\max\_u} \le 15$$

For a given sub-channel, the encoder shall select an odd-integer point (X,Y) from the square-grid constellation based on the b bits $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$. For convenience of description, these b bits shall be identified with an integer label whose binary representation is $(v_{b-1}, v_{b-2}, ..., v_1, v_0)$. For example, for $b = 2$, the four constellation points shall be labelled 0, 1, 2, and 3 corresponding to (v_1,v_0) = (0,0), (0,1), (1,0), and (1,1), respectively.

9.2.5.1 Even values of *b*

For even values of b, the integer values X and Y of the constellation point (X,Y) shall be determined from the b bits $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$ as follows. X and Y shall be the odd integers with twos-complement binary representations $(v_{b-1}, v_{b-3}, ..., v_1, 1)$ and $(v_{b-2}, v_{b-4}, ..., v_0, 1)$, respectively. These values require appropriate scaling such that, at the output of the constellation mapper, all constellations regardless of size represent the same RMS energy as a subcarrier transmitted at a level equal to the PSD template. The most significant bits (MSBs), v_{b-1} and v_{b-2}, shall be the sign bits for X and Y, respectively. Figure 9-4 shows example constellations for $b = 2$ and $b = 4$.

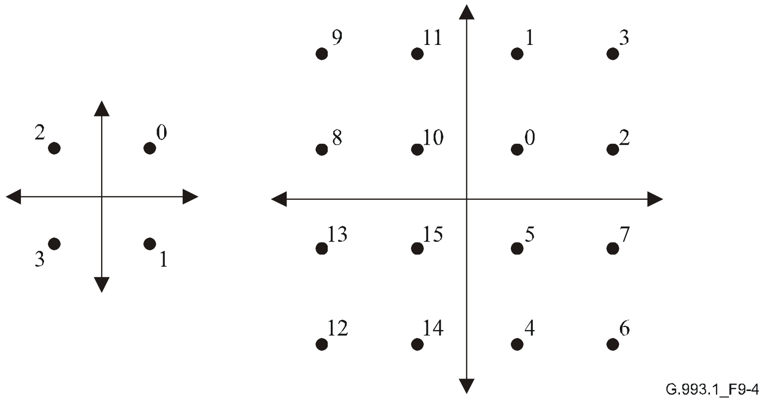


Figure 9-4/G.993.1 – Constellation labels for *b* = 2 and *b* = 4

The 4-bit constellation shall be obtained from the 2-bit constellation by replacing each label *n* by the 2 × 2 block of labels:

$4n + 1$	$4n + 3$
$4n$	$4n + 2$

The same procedure shall be used to construct the larger even-bit constellations recursively. The constellations obtained for even values of *b* are square in shape.

9.2.5.2 Odd values of *b*, *b* = 1 or *b* = 3

Figure 9-5 shows the constellations for the cases *b* = 1 and *b* = 3.

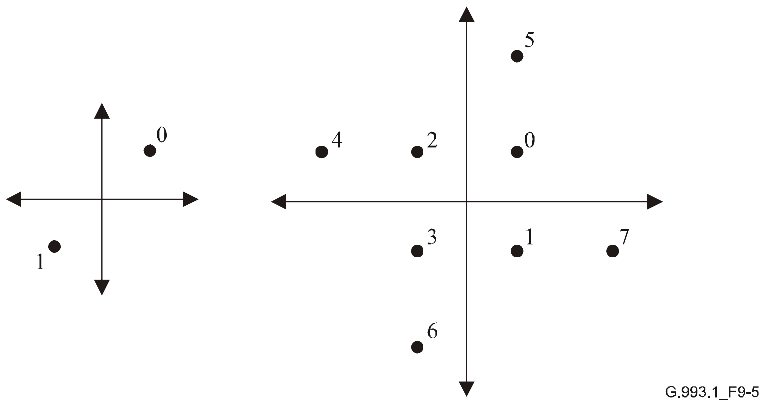


Figure 9-5/G.993.1 – Constellation labels for *b* = 1 and *b* = 3

9.2.5.3 Odd values of *b*, *b* > 3

If *b* is odd and greater than 3, the 2 MSBs of *X* and the 2 MSBs of *Y* shall be determined by the 5 MSBs of the *b* bits. Let $c = (b + 1)/2$, then *X* and *Y* shall have the twos-complement binary representations $(X_c, X_{c-1}, v_{b-4}, v_{b-6}, \ldots, v_3, v_1, 1)$ and $(Y_c, Y_{c-1}, v_{b-5}, v_{b-7}, v_{b-9}, \ldots, v_2, v_0, 1)$, where X_c and Y_c are the sign bits of *X* and *Y*, respectively. These values require appropriate scaling such that, at the output of the constellation mapper, all constellations regardless of size represent the same RMS energy as a subcarrier transmitted at a level equal to the PSD template. The relationship between X_c, X_{c-1}, Y_c, Y_{c-1}, and $v_{b-1}, v_{b-2}, \ldots, v_{b-5}$ shall be as shown in Table 9-2.

Table 9-2/G.993.1 – Determining the top two bits of *X* and *Y*

$v_{b-1}, v_{b-2}, \ldots, v_{b-5}$	X_c, X_{c-1}	Y_c, Y_{c-1}
0 0 0 0 0	0 0	0 0
0 0 0 0 1	0 0	0 0
0 0 0 1 0	0 0	0 0
0 0 0 1 1	0 0	0 0
0 0 1 0 0	0 0	1 1
0 0 1 0 1	0 0	1 1
0 0 1 1 0	0 0	1 1
0 0 1 1 1	0 0	1 1
0 1 0 0 0	1 1	0 0
0 1 0 0 1	1 1	0 0
0 1 0 1 0	1 1	0 0
0 1 0 1 1	1 1	0 0
0 1 1 0 0	1 1	1 1
0 1 1 0 1	1 1	1 1
0 1 1 1 0	1 1	1 1
0 1 1 1 1	1 1	1 1
1 0 0 0 0	0 1	0 0
1 0 0 0 1	0 1	0 0
1 0 0 1 0	1 0	0 0
1 0 0 1 1	1 0	0 0
1 0 1 0 0	0 0	0 1
1 0 1 0 1	0 0	1 0
1 0 1 1 0	0 0	0 1
1 0 1 1 1	0 0	1 0
1 1 0 0 0	1 1	0 1
1 1 0 0 1	1 1	1 0
1 1 0 1 0	1 1	0 1
1 1 0 1 1	1 1	1 0
1 1 1 0 0	0 1	1 1
1 1 1 0 1	0 1	1 1
1 1 1 1 0	1 0	1 1
1 1 1 1 1	1 0	1 1

Figure 9-6 shows the constellation for the case $b = 5$.

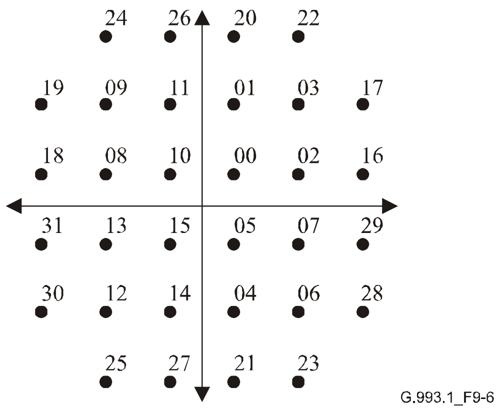


Figure 9-6/G.993.1 – Constellation labels for *b* = 5

The 7-bit constellation shall be obtained from the 5-bit constellation by replacing each label n by the 2 × 2 block of labels:

$4n + 1$	$4n + 3$
$4n$	$4n + 2$

The same procedure shall then be used to construct the larger odd-bit constellations recursively.

9.2.6 Gain scaling

A gain adjuster g_i shall be used to achieve a frequency-variable transmit power spectral density (PSD). It shall consist of a fine gain adjustment with a range from approximately 0.75 to 1.33 (that is, ±2.5 dB), which may be used to equalize the expected error rates for all the sub-channels. Each point (X_i, Y_i), or complex number $Z_i = X_i + jY_i$, output from the encoder is multiplied by g_i: $Z_i' = g_i Z_i$.

9.2.7 Tone ordering

Because the DMT symbol has a high peak to average power ratio (PAR), peak values in the signal may be clipped by the D/A-converter. To a first approximation, this leads to an additive noise that is comparable with impulse noise (with an amplitude equal to the clipped portion, but with opposite sign). This noise will be almost white over all the tones. It is likely that the tones with the densest constellations (i.e., the tones with the largest SNR) will be more affected when this noise is present. Thus, the occurrence of an error is more likely on these tones due to the smaller distance between the constellation points.

If the dual latency option is supported, bits in the slow buffer shall be assigned to tones with the highest SNRs. With this scheme, occasional errors on these tones due to clipping can be corrected by the combination of interleaving and RS coding. The bits on tones with smaller constellations are less likely to be in error due to clipping noise and shall therefore support bits from the fast buffer.

The "tone-ordered" encoding shall first assign all the bits from the fast buffer to the tones with the smallest number of bits assigned to them, and then assign all the bits from the interleaved buffer to the remaining tones. All tones shall be encoded with the number of bits assigned to them. Therefore, a single tone may support a mixture of bits from the fast and slow buffers.

The ordered bit table b_i' shall be based on the original bit table b_i as follows:

For $k = 0$ to B_{max}

– From the bit table, find the set of all i with the number of bits per tone $b_i = k$;

– Assign b_i to the ordered bit allocation table in ascending order of i.

A complementary de-ordering procedure shall be performed by the receiver at the other end of the line. It is not necessary to transmit the results of the ordering procedure to the receiver because all the information required to perform the de-ordering already exists at the receiver.

If only one single-latency channel is supported, bits shall be assigned to tones starting from the lowest available frequency based on the original bit table b_i.

Figure 9-7 illustrates how the bits shall be extracted from the fast and interleaved data buffer when tone-ordering is applied. In this example, both fast and interleaved buffer are one byte long. Following the above rule, the first bits shall be taken from the fast buffer, starting from the LSB and shall be placed on the tones with the lowest number of bits assigned to it. The fourth tone to be loaded (carrying b_3' bits) shall take bits from both the fast and the slow buffer.

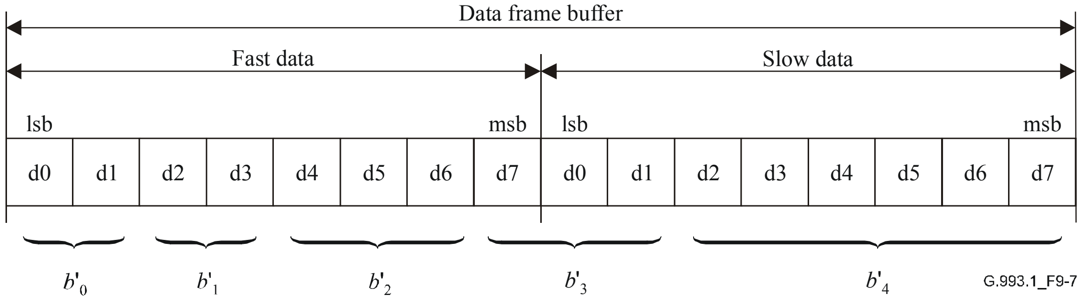


Figure 9-7/G.993.1 – Bit extraction after tone ordering

10 Management

10.1 OAM functional model

The OAM functional model of a VDSL link, as shown in Figure 10-1, contains OAM entities intended to manage the following transmission entities:

- *VDSL Line entity*: the physical transport vehicle provided by PMD and PMS-TC transmission sublayers.
- *VDSL Path entity*: the applicable transport protocol path, provided by TPS-TC sublayer. A path could be either for a single application (single latency, single transport protocol) or multiple, including optionally different transport protocols over single and dual latency.
- *VDSL System entity*: the user-application path, provided by the layers higher than TC. This path also provides the high level OAM functionality between the VTU-O and the VTU-R.

The structure of OAM entities at both the VTU-O and VTU-R is identical. The data exchange between the management processes of the peer OAM entities at the VTU-O and VTU-R is established over three OAM-dedicated communication channels.

Management process also assumes an exchange of management information inside the VTU between the OAM entities and the Network Management Agent (NMA). Such exchange is accomplished:

- via γ interface: between the NMA and the TPS-TC;
- via α(β) interface: between the NMA and PMS-TC/PMD.

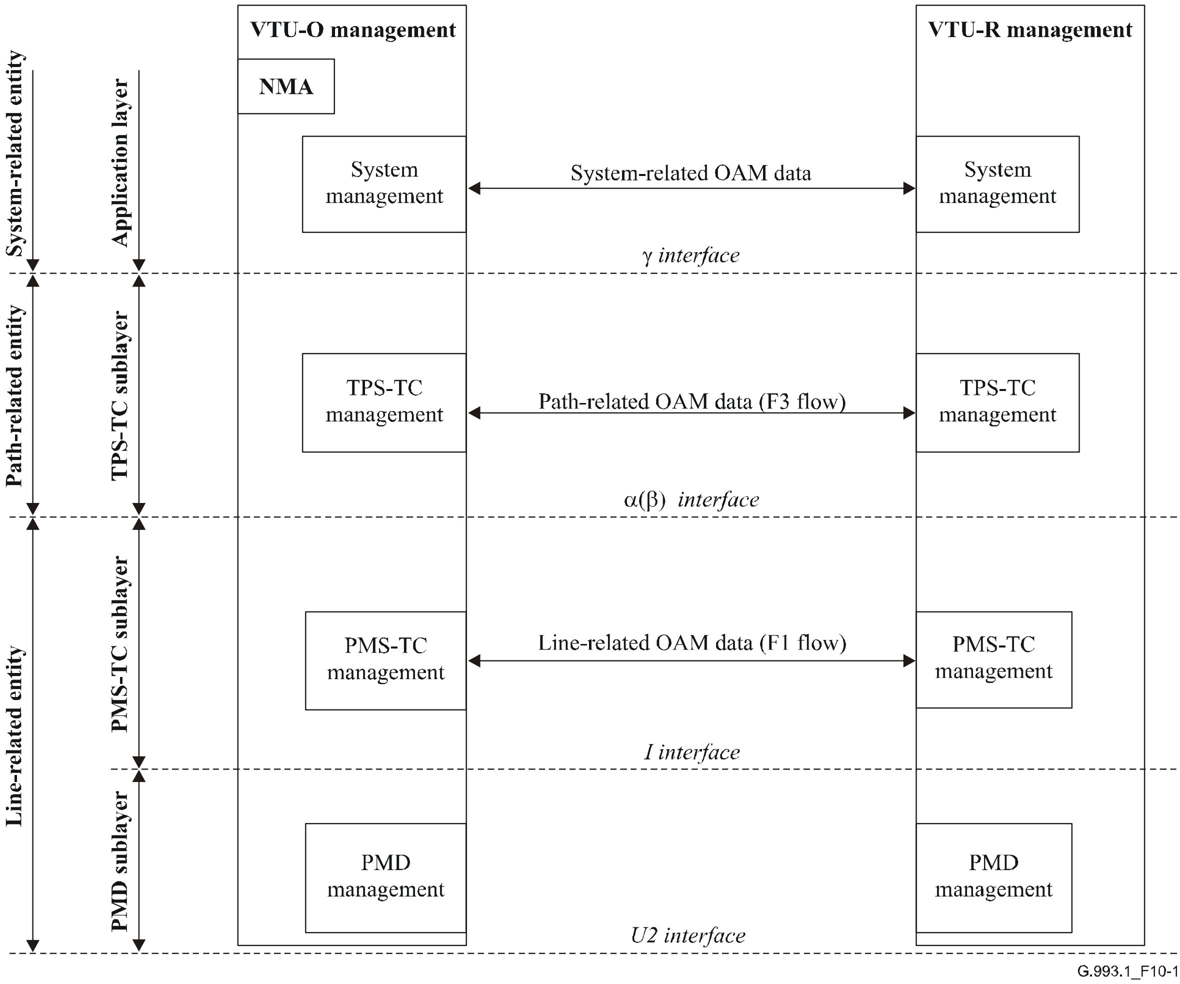


Figure 10-1/G.993.1 – OAM functional model

The OAM flows across both interfaces are bidirectional. They convey, respectively, path-related and line-related primitives and parameters, configuration set-ups, and maintenance commands and acknowledgments of the certain levels.

NOTE – The OAM flow rate should meet requirements for performance calculation and enable the required system management response time.

10.2 OAM communication channels

The following three OAM dedicated communication channels shall be arranged to provide OAM data transfer between the VTU-O and VTU-R:

- Indicator Bits (IB) channel;
- embedded operations channel (eoc);
- VDSL Overhead Control (VOC) Channel.

The three OAM channels shall provide transport of the following OAM data:

- primitives (anomalies, defects, failures) from all the transmission entities;
- parameters (performance and testing);
- configuration set-up;
- maintenance signals.

The interface between a certain OAM channel and the corresponding OAM entity is functional. It is defined by a specific communication protocol and a list of transferred information, including a part for proprietary use. Each OAM channel has specific characteristics and is intended to bear a specific type of OAM data. Partitioning of the OAM data between different OAM channels is described in 10.2.4.

10.2.1 Indicator bits

The IB transport is supported by the PMS-TC sublayer. The IB are used to arrange communication channels between the peer OAM entities intended to transfer the far-end time-sensitive primitives, which require immediate action at the opposite side. The IB channel shall work in unidirectional mode, i.e., independently in both the upstream and downstream directions. The main data to be sent over IB is information on defects/failures, where timing is critical. The IB may also transfer other line-related and path-related primitives. The list of minimum required IB is specified in 10.5.4.

10.2.2 VDSL embedded operations channel (eoc)

The eoc is supported at the system (application) layer. The eoc is a clear channel to exchange the VDSL system management data and to control traffic between the VTU-O and VTU-R. The exchanged data includes system-related primitives, performance parameters, test parameters, configuration and maintenance.

The eoc, except some special cases, works in bidirectional mode using an echoing protocol. Both transmission directions are required to provide communication for the eoc. The clear eoc channel interface is equal for both the VTU-O and VTU-R. The eoc is specified in 10.3.

10.2.3 VDSL overhead control (VOC) channel

The VOC channel is supported by the TPS-TC sublayer and is intended mainly to transfer VDSL link activation and configuration message between the VTU-O and VTU-R. The VOC channel may also transfer line-related and path-related primitives.

The VOC channel works in a bidirectional mode using an echoing protocol and, hence, both transmission directions are required to provide communication for the VOC. The VOC is specified in 10.6.

10.2.4 Partitioning of OAM data

The OAM data at both the VTU-O and VTU-R, after being collected from different entities, is stored in the corresponding part of MIB and then could be transferred to the far-end over the corresponding OAM channel. Partitioning of the OAM data between different OAM communication channels is summarized in Table 10-1.

Table 10-1/G.993.1 – OAM data partitioning

OAM data	Transferred to the far-end by:	Notes
Primitives		
Line-related, time-sensitive	IB	PMD and PMS-TC defects
Path-related, time-sensitive		TPS defects/failures (Note 1), separately for each TPS-TC
Line-related, time-insensitive	IB or VOC	PMD and PMS-TC anomalies
Path-related, time-insensitive	IB or eoc (Note 1)	TPS anomalies, separately for each TPS-TC
System-related primitives	IB or eoc (Note 2)	

Table 10-1/G.993.1 – OAM data partitioning

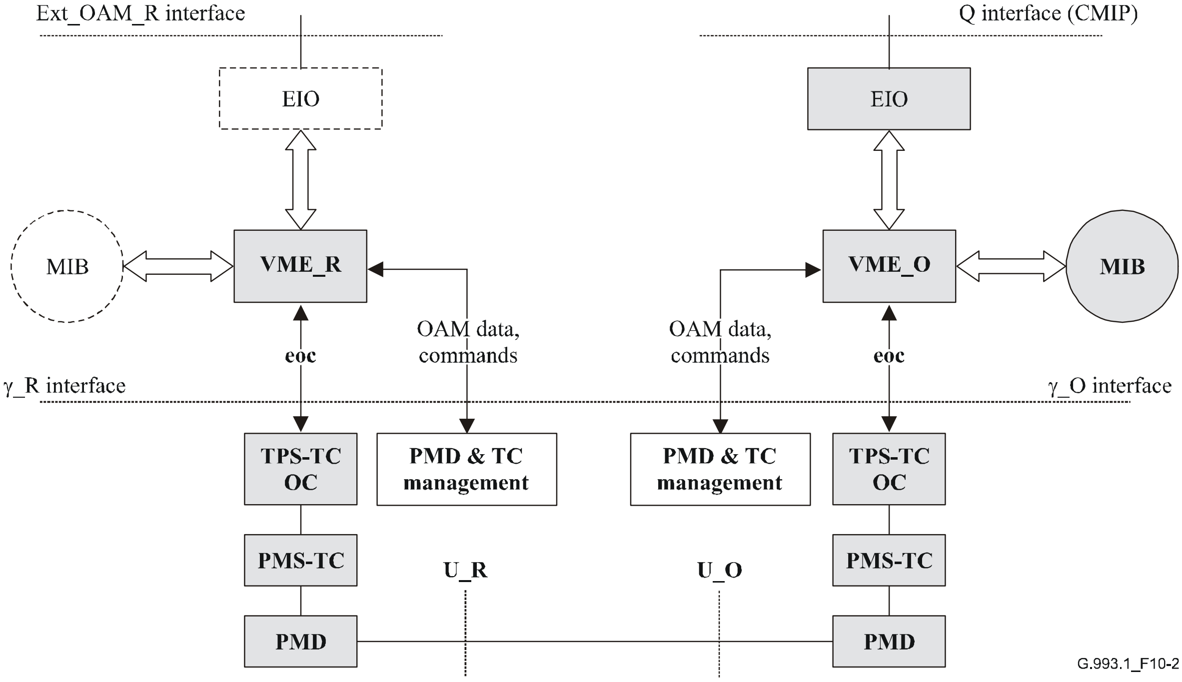
OAM data	Transferred to the far-end by:	Notes
Parameters		
Line-related, performance	None	Calculated from retrieved line-related and path-related primitives
Path-related, performance		
Path-related, testing	eoc	For some TPS-TC
Line-related, testing		ATT, SNR margin and other local measurements
Self-test		For some VTU blocks or completely
VTU identification		Vendor ID, revision number, serial number
Service modules parameters		Proprietary (Service modules performance, test or other parameters)
Configuration		
Line-related parameters	VOC or eoc	Frame structure, interleaving depth, etc.
Path-related parameters	eoc	With respect to the applied TPS-TC
System-related parameters	eoc	Proprietary, respective to the applied service modules
Maintenance		
VTU state control	eoc	Hold the state, return to normal state
Self-test activation		A complete VTU self-test and self sub-tests on specific VTU blocks
Loopback activation		At TPS-TC and application layers
Performance monitoring supervision		Request for FEC corruption test, notify FEC corruption test
NOTE 1 – The IB are necessary to monitor the primitives which destroy the path (for instance, ATM cell delineation loss). The anomalies in a certain active path are monitored by the corresponding TPS-TC management function and delivered to the other side by the standard means of the applicable transport protocol (TP), IB or VOC. NOTE 2 – eoc is preferable for system-related primitives.		

10.3 Embedded operations channel (eoc) functions and description

Embedded Operations Channel (eoc) is intended to exchange the system management data and control traffic between the VTU-O and VTU-R. The exchanged data includes system-related primitives, performance parameters, test parameters, configuration and maintenance commands. The specified eoc can provide both "internal" management functions to support the VDSL transceiver and to be used as a clear management channel between the VTU-O and VTU-R.

10.3.1 eoc functional model

The eoc functional model is presented in Figure 10-2. The eoc traffic between the VTU-O and VTU-R may include either internal eoc traffic (originated in the VTU-O) or external eoc traffic, delivered through the external Q interface. The VTU-O Management Entity (VME_O) multiplexes the internal and the external traffics into an eoc information stream. The latest is formatted and presented at the γ_O interface to be sent transparently over the VDSL link to the VTU-R Management Entity (VME_R).



EIO External interface adapter
MIB Management information base
VME VDSL management entity

Figure 10-2/G.993.1 – eoc functional model

The Management Information Base (MIB) contains all the management information related to the VDSL link. It may be implemented either as a part of the VTU-O or as a common part to be shared between several VTU-Os. In the first case, the Network Management Agent (located outside of the VTU-O) accesses the MIB via the Q interface and should be supported by the VME_O. If the MIB belongs to the common part of the ONU, VME_O accesses MIB (if necessary) via the Q interface. At the VTU_R, the MIB and external interface support are optional.

10.3.1.1 VME functionality

VME (both the VME_O and VME_R) shall provide at least the following management functions over the VDSL link:

- performance management;
- configuration management;
- fault management.
- support of the external interface (Q-interface) and MIB interface (only mandatory for the VME_O).

  NOTE 1 – This part of VME functionality is beyond the scope of this Recommendation.

The VME provides management functions at the remote end via eoc including:

- support of VDSL link (maintenance and fault management);
- performance monitoring (in addition or instead available indicator bits/VOC), including precision measurements for QoS confirmation;
- configuration management of TPS-TC and, optionally, of PMS-TC;
- user interface related functions.

NOTE 2 – This part of VME functionality is beyond the scope of this Recommendation.

The VME shall also provide the following eoc-related functionality:

- support of the eoc protocol at the γ interface;
- multiplexing/de-multiplexing of the internal and external eoc traffic.

10.3.2 eoc protocol and messages

The same eoc protocol format shall be used on the γ interface at both sides of the link. The eoc protocol format shall implement HDLC protocol as it is defined in ITU-T Rec. G.997.1. The use of the information payload of the HDLC frame is defined in the following clauses.

The VME shall multiplex internal eoc and external messages received via the Q interface, and combine them into a standard HDLC frame. To be transported over the VDSL links, external messages shall get the HDLC address field value of "0xFF" as it is defined in ITU-T Rec. G.997.1. The internal eoc messages may have an HDLC address field with a value of "0x11".

10.3.2.1 External message format

The information payload of the HDLC frame carrying an external message shall not exceed 510 octets. The encapsulation method and the contents of external messages are beyond the scope of this Recommendation.

10.3.2.2 Internal message format

The information payload of the HDLC frame carrying an internal message (further denoted as "eoc message") shall contain at least 2 octets sent from the VME_O to the VME_R and vice versa.

10.3.2.3 eoc organization and message types

The eoc allows the VTU-O (acting as a master) to invoke certain management functions at the VTU-R by sending eoc command messages. The VTU-R (acting as a slave) shall acknowledge a command message it has received correctly by sending a response eoc message (echo) and performing the requested function. The echo shall be a copy of the corresponding command message. In exception to this, autonomous messages may be sent from the VTU-R independently (as soon as the appropriate data is available) but not in response to a VTU-O message.

There are three types of eoc messages specified:

– *bidirectional messages (d/u)*: these are originated by the VTU-O, and echoed by the VTU-R to indicate a correct reception of each message;

– *downstream messages (d)*: these are originated by the VTU-O and not echoed, but always acknowledged by a different message from the VTU-R;

– *upstream messages (u)*: these are originated by the VTU-R and may be in response to a downstream message or autonomous.

NOTE – Acting as a master, the VTU-O usually determines the rate of the eoc communication, as the VTU-R responds by only one echo message following receipt of each eoc command message.

10.3.2.3.1 eoc message structure

The 16 bits of an eoc message are partitioned among six fields, which are summarized in Table 10-2 and defined in the following subclauses. The first 13 MSB of the transmitted 2-octet eoc data shall be used for the eoc message starting from bit #1. The last three LSB shall be reserved.

Table 10-2/G.993.1 – eoc message fields

Field #	Bit #	Description	Notes
1	1-2	ADDRESS field	Can address up to 4 locations
2	3	DATA (0) or OPCODE (1) field	Data used for both read and write
3	4	PARITY field Odd (1) or Even (0)	Byte order indication for multi-byte transmission
4	5	MESSAGE/RESPONSE field Message/Response (1) or Autonomous message (0)	Currently, autonomous messages are defined for the VTU-R only.
5	6-13	INFORMATION field	One out of 58 OPCODEs or 8 bits of data
6	14-16	Reserved	For future use

10.3.2.3.1.1 Address field (# 1)

The two bits of the address field can address up to four locations. Only two locations are presently defined:

11: VTU-O address;

00: VTU-R address;

01, 10: Reserved for future applications; presently invalid.

The VTU-O shall address messages to the VTU-R by setting the ADDRESS field equal to the VTU-R address (00). When responding to a message received from the VTU-O, the VTU-R shall keep the ADDRESS field equal to the VTU-R address (00). The VTU-R shall set the ADDRESS field equal to the VTU-O address (11) only when sending an autonomous message to the VTU-O.

10.3.2.3.1.2 Data or OPCODE field (# 2)

A "0" in this field indicates that the information field of the eoc message contains a data byte; a "1" indicates that it contains an OPCODE.

10.3.2.3.1.3 Parity field (# 3)

This bit helps to speed up the multi-byte reads and writes of data by eliminating the intermediate messages to indicate to the far end that the previous byte was successfully received.

For the first byte of the sent read/write data, this bit shall be set to "1" to indicate an "odd" byte. For the next byte, it shall be set to "0" to indicate an "even" byte and so on, alternately.

The PARITY field shall always be set to "1" if the information field carries an OPCODE different from the "Next Byte" OPCODE. If a "Next Byte" OPCODE is applied, the PARITY field is toggled for multi-byte data transfer.

10.3.2.3.1.4 Message/response field (# 4)

A "1" in this field designates that the current eoc message is an eoc command message or an eoc response message (echo); a "0" designates that it is an autonomous message.

NOTE – For the VTU-O, this field shall always be set to "1". For the VTU-R, this field shall also be set to "1" except for the autonomous messages.

10.3.2.3.1.5 Information field (# 5)

Up to 58 different 8-bit OPCODEs or an 8-bit data may be encoded in the information field.

The OPCODE set is restricted to codes that provide a minimum Hamming distance of 2 between all OPCODEs, and a minimum distance of 3 between certain critical codes and all other codes.

10.3.2.3.2 eoc message set

All the eoc messages and their OPCODEs are summarized in Table 10-3.

Table 10-3/G.993.1 – The eoc message set list

OPCODE (HEX)	OPCODE meaning	Direction	Abbreviation and notes
01	Hold state	d/u	HOLD
F0	Return-To-Normal	d/u	RTN
02	Perform "self test"	d/u	SLFTST
04	Unable-to-comply	u	UTC
07	Request for corrupted CRC/FEC	d/u	REQCOR (latching)
08	Request end of corrupted CRC/FEC	d/u	REQEND
0B	Notify corrupted CRC/FEC	d/u	NOTCOR (latching)
0D	Notify end of corrupted CRC/FEC	d/u	NOTEND
0E	End of data	d/u	EOD
10	Next byte	d	NEXT
13	Request test parameters update	d/u	REQTPU
14	Error	d/u	ERR
20, 23, 25, 26, 29, 2A, 2C, 2F, 31, 32, 34, 37, 38, 3B, 3D, 3E	Write data register with numbers from 0x0 to 0xF, respectively, as specified in Table 10-4	d/u	WRITE
40, 43, 45, 46, 49, 4A, 4C, 4F, 51, 52, 54, 57, 58, 5B, 5D, 5E	Read data register with numbers from 0x0 to 0xF, respectively, as specified in Table 10-4	d/u	READ
19, 1A, 1C, 1F	Vendor proprietary protocols	d/u	Four OPCODEs are reserved for vendor proprietary use.
15, 16, 80, 83, 85, 86, 89, 8A, 8C, 8F	Undefined codes		These codes are reserved for future use and shall not be used for any purpose.
NOTE – The given OPCODE values guarantee a minimum Hamming distance of 2 between all OPCODEs (by requiring odd parity for all but two critical codes), and Hamming distance of 3 between the "Return to Normal" (or "idle") code and all other codes.			

The VTU-O shall send command messages to perform certain functions at the VTU-R. Some of these functions require the VTU-R to activate changes in the circuitry (e.g., to send corrupted CRC/FEC bits). Other functions are to read from and to write into the MIB data registers at the VTU-R. These functions are used by the VTU-O to read the VTU-R status or performance parameters, or for limited maintenance extensions to the service modules.

Some of eoc commands are "latching", meaning that a subsequent eoc command shall be required to release the VTU-R from that state. Thus, multiple VDSL eoc-initiated functions can be in effect simultaneously. To maintain the latched state, the command "Hold State" shall be sent.

A command, "Return-To-Normal" is used to unlatch all latched states. This command is also used to bring the VDSL system to the Idle state, when no eoc command is active in the VTU-R.

10.3.2.3.3 Bidirectional eoc messages

Each bidirectional message sent by the VTU-O shall be echoed by the VTU-R if received correctly. The following messages are specified as bidirectional (with their abbreviated names and hex OPCODEs in parentheses):

– *Hold State (HOLD, 01)*: This message tells the VME-R to maintain the VTU-R eoc processor and any active VDSL eoc-controlled operations (such as latching commands) in their present state;

– *Return to Normal (Idle Code) (RTN, F0)*: This message releases all outstanding *eoc*-controlled operations (latched conditions) at the VTU-R and returns the VDSL *eoc* processor to its initial state;

– *Request Corrupt CRC/FEC (REQCOR, 07)*: This message requests the VTU-R to send corrupt CRC/FECs to the VTU-O until cancelled by the "Request End of Corrupt FEC" or "Return-To-Normal" message. In order to allow multiple VDSL eoc-initiated actions to be in effect simultaneously, the "Request corrupt FEC" command shall be latching;

– *Request End of Corrupt CRC/FEC (REQEND, 08)*: This message requests the VTU-R to stop sending corrupt CRC/FECs toward the VTU-O;

– *Notify Corrupted CRC/FEC (NOTCOR, 0B)*: This message notifies the VTU-R that intentionally corrupted CRC/FECs will be sent from the VTU-O until cancellation is indicated by "Notify End of Corrupted CRC/FEC" and "Return-To-Normal";

– *Notify End of Corrupted CRC/FEC (NOTEND, 0D)*: This message notifies the VTU-R that the VTU-O has stopped sending corrupted CRC/FECs;

– *Perform Self-Test (SLFTST, 02)*: This message requests the VTU-R to perform a self-test. The result of the self-test shall be stored in a register at the VTU-R. After the VTU-R self-test, the VTU-O reads the test results from the VTU-R register;

– *Receive/Write Data (Register #) (WRITE, see 10.3.2.5.3.2)*: This message directs the VTU-R to enter the Data Write Protocol state, receive data, and write it in the register specified by the OPCODE;

– *Read/Send Data (Register #) (READ, see 10.3.2.5.3.1)*: This message directs the VTU-R to enter the Data Read Protocol state, read data from the register specified by the OPCODE, and transmit it to the VTU-O;

– *End of Data (EOD, 0E)*: This message is sent by the VTU-O after it has sent all bytes of data to the VTU-R. The message is sent by the VTU-R in either of the following cases:
  - in response to a "Next Byte" message from the VTU-O that is received after all bytes have been read from the currently addressed VTU-R register;
  - in response to a message from the VTU-O that contains a data byte after all bytes have been written to the currently addressed VTU-R register;

– *Vendor Proprietary OPCODEs (VPC, 19, 1A, 1C, 1F)*: Four OPCODEs have been reserved for vendor-proprietary use. The VTU-O shall read the Vendor ID code register of the VTU-R to ensure compatibility between the VTUs before using proprietary OPCODEs;

– *Request Test Parameters Update (REQTPU, 13)*: This message requests the VTU-R to update the test parameters set as defined in 10.4.2. Test parameters supported by the VTU-R shall be updated within 10 s after the request is received. Updated test parameters may be read by the VTU-O thereafter;

– *Error (ERR, 14)*: This message requests the opposite side to repeat the last message. The message is sent as a response on a non-correctable error detected in the received HDLC frame.

10.3.2.3.4 Downstream messages

One message is specified that may be sent only by the VTU-O:

– *next byte (NEXT, 10)*: This message is sent repeatedly by the VTU-O (toggling bit four for multi-byte data until all data has been sent) while it is in Data Read protocol state. As a reply to this message, either the requested byte of the VTU-R data is sent, with bit four toggled for multi-byte data or the *End-of-Data* message is sent.

10.3.2.3.5 Upstream messages

The messages that may be sent only by the VTU-R are:

– *Unable-to-Comply (UTC) (UTC, 04), acknowledgment*: The VTU-R shall send this message when it receives a command or *eoc* message that it cannot perform for any of the following reasons:
  - it does not recognize the command;
  - it cannot implement the command;
  - the command is unexpected for the current state of the *eoc* protocol;

– *autonomous messages*. All autonomous messages have bit 5 set to "0" and bit 3 set to "1" to indicate that the message contains an OPCODE. The information field shall contain the OPCODE of the corresponding message (see Table 10-3).

10.3.2.4 VTU-R data registers

The VTU-R data registers shall be defined as:

– *VTU-R Vendor ID code (4 bytes)*: The format of the VTU-R Vendor ID code is undefined;

– *VTU-R Revision number (2 bytes)*: The format of the VTU-R Revision Number is vendor-discretionary;

– *VTU-R Serial number (32 bytes)*: The format of the VTU-R serial number is vendor-discretionary;

– *Self-Test Results*: The most significant byte of the Self-Test Results shall be 0x00 if the self-test passed, and 0x01 if it failed (the meaning of "failure" is vendor-discretionary); other values are reserved for future use. The length and syntax of the remainder shall be vendor-discretionary;

– *Performance (16 bytes)*: Contains the downstream attainable line rate as well as the VTU-R corrected and uncorrected error counts. Used to retrieve data for computation of various error performance parameters. Bytes 0x00-0x03 indicate the attainable downstream data rate in 1-kbit/s steps. Bytes 0x04-0x05 indicate the number of corrected error octets in the slow channel. Bytes 0x06-0x07 indicate the number of corrected error octets in the fast channel. Bytes 0x08-0x09 indicate the number of uncorrected error octets in the slow channel. Bytes 0x0A-0x0B indicate the number of uncorrected error octets in the fast channel. Bytes 0x0C-0x0F are reserved and shall be set to 0xFF.

– *Loop attenuation (Minimum 1 byte)*: The loop attenuation format shall be as defined in 10.5.6;

– *SNR Margin (Minimum 1 byte)*: The SNR margin format shall be as defined in 10.5.6;

– *VTU-R configuration (64 bytes)*: The VTU-R configuration registers contain the relevant data for PMD, PMS-TC, and TPS-TC configuration. This data is established during the link initialization via the VOC.

Table 10-4 summarizes the VTU-R data registers and their applications including the format and detailed contents of VTU-R registers.

Table 10-4/G.993.1 – VTU-R data registers

REG # (HEX)	Use	Length	Description
0	Read	4 bytes	VTU-R vendor ID
1	Read	2 bytes	VTU-R revision number
2	Read	32 bytes	VTU-R serial number
3	Read	Vendor-discretionary	Self-test results
4	Read	16 bytes	Performance
5	Read/Write	Vendor-discretionary	Vendor-discretionary
6	Read/Write	Minimum of one byte; additional bytes are Vendor-discretionary	Loop attenuation
7	Read	Minimum of one byte; additional bytes are vendor-discretionary	SNR margin
8	Read	64 bytes	VTU-R configuration
9-F	Read	Reserved	For future use

All VTU-R registers shall be read MSB first. The VTU-R shall respond UTC if requested to write into the Read register.

10.3.2.5 eoc protocol states

10.3.2.5.1 Message/echo-response protocol state (idle state)

To initiate an action at the VTU-R, the VTU-O shall begin sending eoc messages with the Data/OPCODE set to "1" and with the appropriate message OPCODE in the information field. The VTU-R shall initiate the action only when an error-free and properly addressed eoc messages has been received. The VTU-R shall respond to all the received messages by an echo of the received message. If either the VTU-R or VTU-O detects a non-correctable error in the received HDLC frame, it shall send the *Error* message. The combination of the VTU-O sending a message and the VTU-R echoing the message back comprises the message/echo-response protocol state.

If the eoc message is one of the latching commands, the VTU-R shall maintain the commanded condition until the VTU-O issues the appropriate command to end the specific latched condition or until the VTU-O issues the "*Return-to-Normal*" command.

NOTE – The time it takes to complete an eoc message transmission under both error and error-free conditions depends on the vendor's implementation.

10.3.2.5.2 Message/unable-to-comply response protocol state (UTC state)

When the VTU-R does not support the function requested by a message that it has properly received, it shall respond with the UTC message with its own address and switch to the UTC state. The reception by the VTU-O of a properly addressed UTC message constitutes notification to the VTU-O that the VTU-R does not support the requested function.

10.3.2.5.3 Message/data-response protocol state

The VTU-O may either write data into, or read data from, the VTU-R MIB.

10.3.2.5.3.1 Data read protocol

To read data from the VTU-R, the VTU-O shall send a *Send Data* OPCODE message to the VTU-R which specifies the register to be read. After receiving the acknowledgment, the VTU-O shall request the first byte to be sent from the VTU-R by sending *Next Byte* message with bit 4 set to "1", indicating a request for an *odd* byte. The VTU-R shall respond to this *Next Byte* message by sending the first byte of the requested data in the information field of an eoc message with bit 4 set to "1" to indicate *odd byte* and with bit 3 set to "0" to indicate the eoc data message. If there are more data to be read, the VTU-O shall request the second byte of data by sending *Next Byte* messages with bit 4 set to "0" ("even byte"). The VTU-R responds to the message by sending eoc message containing the second byte of the register with bit 4 set to *even byte*. The process continues for the third and all subsequent bytes with the value of bit 4 toggling from *odd byte* to *even byte* or vice versa, on each succeeding byte. Each time bit 4 is toggled, the VTU-R responds by sending the next data octet. The process ends only when all the requested data in the register has been read.

To continue reading data, once the VTU-R is in the *Data Read odd* or *even state*, the only message that the VTU-O is allowed to send is *Next Byte* with bit 4 toggling. To end the data-read mode abnormally, the VTU-O sends either *Hold State* or *Return to Normal*, depending on whether any latched states are to be retained. If the VTU-R receives any other message while it is in *Data Read odd* or *even state*, it shall go into the *UTC state*.

If, after all bytes have been read from the VTU-R register, the VTU-O continues to send the *Next Byte* message with bit 4 toggled, then the VTU-R shall send an *End-of-Data* message.

For the VTU-O, the *data-read mode* ends either after the VTU-O receives the last requested data byte, or after the VTU-O receives the *End-of-Data* message. The VTU-O shall then switch both itself and the VTU-R into the *Idle State* (by sending a *Hold State* or a *Return-to-Normal* message), and the VTU-R shall release the register and leave the *Data Read state* after receiving either *Hold State* or *Return-to-Normal* message.

10.3.2.5.3.2 Data write protocol

To write data into the VTU-R MIB, the VTU-O shall send a *Write Data* OPCODE message to the VTU-R that specifies the register to be written. When the VTU-R acknowledges (echoing), the VTU-O sends the first byte of data. The VTU-R shall acknowledge the receipt of the byte with an echo of the message. After the VTU-O receives the echo response, it shall send the next byte of data. Each time the VTU-O receives echo response, it shall switch to sending the next byte of data. It shall also toggle the "odd/even" bit accordingly. (*Next Byte* messages are not used in the *Data-Write mode*). The VTU-O shall end the write mode with the *End-of-Data* message indicating to the VTU-R to release the register and return to the Idle State.

To continue writing data once the VTU-R is in the *Data Write odd or even state*, the only message that the VTU-O is allowed to send is the *Data Byte* message with bit 3 set to "0" and with bit 4 toggling. To end the *Data Write state* abnormally, the VTU-O may switch to the *End-of-Data* message. If the VTU-R receives any other message while it is in *Data Write state*, it shall go into the *UTC state*.

If, after all bytes have been written to the VTU-R register, the VTU-O continues to send the data, then the VTU-R shall send an *End-of-Data* message.

10.4 Fault and performance monitoring

The general process of fault and performance monitoring is based on performance primitives, as shown in Figure 10-3, and expressed by applicable performance parameters.

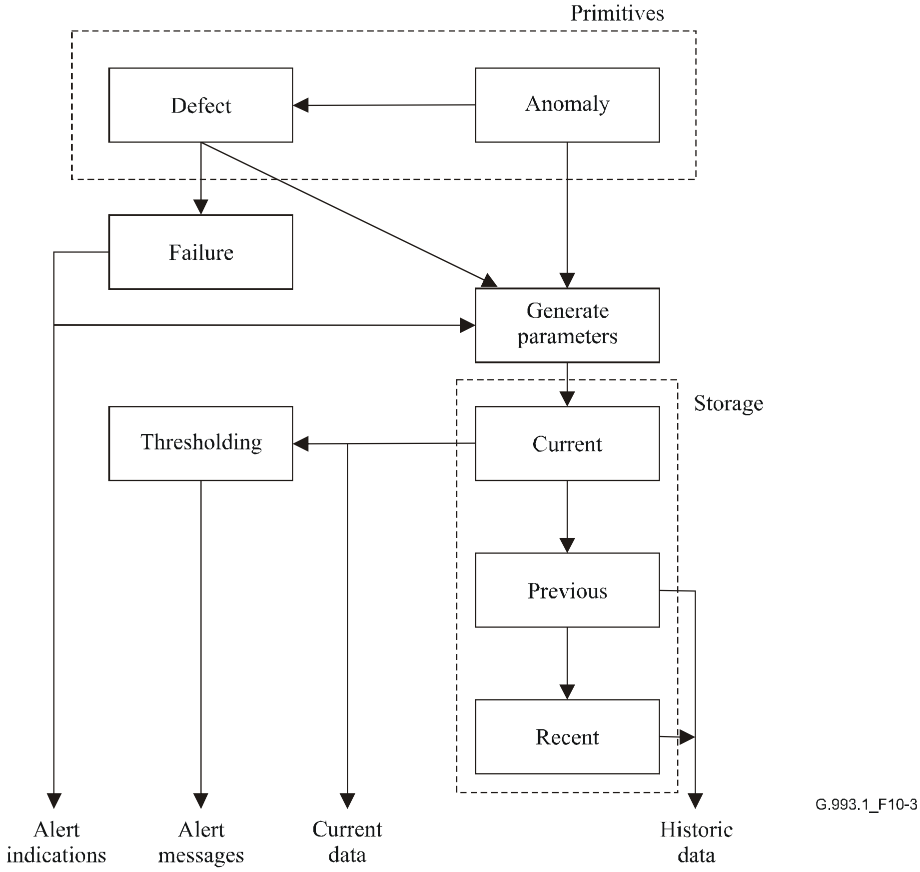


Figure 10-3/G.993.1 – Performance monitoring process

The following definitions are applicable:

- Primitives: Primitives are basic measures of performance. Performance primitives are categorized as anomalies and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators.
- Near-end primitives are usually detected by monitoring the local signal protocols and frame formats.
- Far-end primitives are detected by reading fields in the overhead that are defined to report the nature and number of basic error events or other performance-related occurrences detected at the far-end.
- Anomalies: An anomaly is a discrepancy between the actual and desired characteristics of an item. The desired characteristic may be expressed in the form of a specification. An anomaly may or may not affect the ability of an item to perform a required function.
- Defects: A defect is a limited interruption in the ability to perform a required function. It may or may not lead to maintenance action depending on the result of additional analysis. Successive anomalies causing a decrease in the ability of an item to perform a required function are considered as a defect.
- Failures: A failure is the termination of an item's ability to perform a required function. At a network element, both local and remote failures can be observed. Local failures include

near-end signal failures. Remote failures are those that occur and are recognized elsewhere, and are reported within the transmission signal.

- Parameters: These parameters are counts of the various impairment events detected during the accumulation period. Performance parameters are directly derived from the corresponding performance primitives.
- Thresholding: All performance parameters (e.g., errored seconds) have associated thresholds, which may be set, read, or changed by the Network Management System (NMS) that is doing performance monitoring. A threshold crossing for performance parameters may be autonomously reported to the NMS by the VTU-O.

Figure 10-4 describes graphically the near-end and far-end performance monitoring concepts applied to a VDSL link.

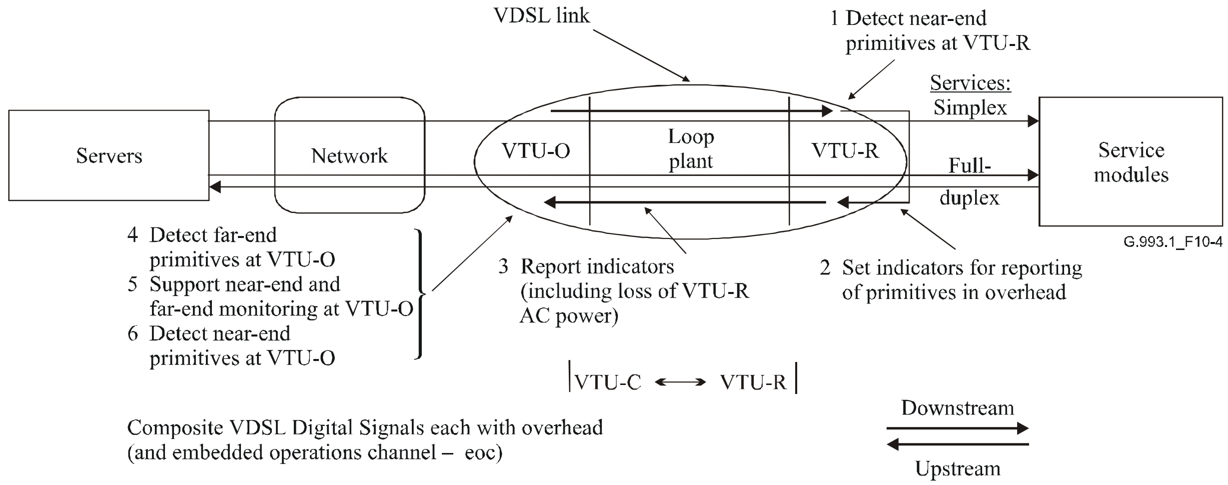


Figure 10-4/G.993.1 – In-service surveillance of the VDSL link shown from the VTU-O's standpoint

10.5 OAM parameters and primitives

10.5.1 Line-related primitives

Any of the detected line-related primitives is represented by a corresponding indicator at the OAM interface of α(β) reference point. The indicator shall be coded "0" to indicate that no anomaly, defect or failure has been registered since the previous transmission period and shall be coded "1" to indicate that at least one anomaly, defect or failure has been registered since the previous transmission period.

All the near-end anomalies, defects and failures should be represented at both the VTU-O and VTU-R. The representation of far-end anomalies, defects and failures at the VTU-R is *optional*. The representation of far-end anomalies at the VTU-O is mandatory.

10.5.1.1 Near-end anomalies

- *Forward Error Correction – Fast data (fec-f)* anomaly occurs when errored octets corrected by the FEC have been detected in the received block of fast data.
- *Forward Error Correction – Slow data (fec-s)* anomaly occurs when errored octets corrected by the FEC have been detected in the received block of slow data.
- *Block Error – Fast data (be-f)* anomaly occurs when non-corrected errors have been detected in the received block of fast data.

– *Block Error – Slow data (be-s)* anomaly occurs when non-corrected errors have been detected in the received block of slow data.

10.5.1.2 Far-end anomalies

– *Far-end Forward Error Correction – Fast data (ffec-f)* anomaly occurs when a *fec-f* anomaly detected at the far end is reported. A *ffec-f* anomaly terminates when the received report on *fec-f* anomaly is set to "0".

– *Far-end Forward Error Correction – Slow data (ffec-s)* anomaly occurs when a *fec*-s anomaly detected at the far end is reported. A *ffec-s* anomaly terminates when the received report on *fec-s* anomaly is set to "0".

– *Far-end Block Error – Fast data (febe-f)* anomaly occurs when a *be-f* anomaly detected at the far end is reported. A *febe-f* anomaly terminates when the received report on *febe-f* indicator is set to "0".

– *Far-end Block Error – Slow data (febe-s)* anomaly occurs when a *be-s* anomaly detected at the far end is reported. A *febe-s* anomaly terminates when the received report on *febe-s* indicator is set to "0".

10.5.1.3 Near-end defects

– *Loss-of-Signal (los)* A reference power is established by averaging the VDSL power over a 0.1 s period and over a subset of carriers after the start of steady state transmission and a threshold shall be set 6 dB below this. A los defect occurs when the level of the received VDSL power averaged over a 0.1-s period and over the same subset of carriers is lower than the threshold, and terminates when this level, measured in the same way, is at or above the threshold. The subset of carriers is implementation dependent.

– *Severely Errored Frame (sef)* defect is managed in accordance with the transmission frame delineation state diagram. A *sef* defect occurs with a transition out of synchronization (*SYNC*) state of the frame delineation state machine and terminates with a transition into the *SYNC* state.

10.5.1.4 Far-end defects

– *Far-end Loss Of Signal (flos)* defect occurs when a *los* defect detected at the far end is reported in four or more out of six contiguously received far-end *los* indicator reports. A *flos* defect terminates when less than two far-end *los* indicators are reported out of six contiguously received reports.

– *Far-end Remote Defect Indication (frdi)* defect occurs when a *sef* defect detected at the far end is reported. A remote defect indication (*rdi)* defect terminates when the received report on *sef* is set to "0".

10.5.1.5 Near-end failures

– *Loss of Signal (LOS)* failure is declared after TS1 = 2.5 ± 0.5 s of contiguous *los* defect, or, if *los* defect is present when the criteria of *LOF* failure declaration have been met. A *LOS* failure is cleared after TS2 = 10 ± 0.5 s of no *los* defect.

– *Loss of Frame (LOF)* failure is declared after TF1 = 2.5 ± 0.5 s of contiguous *sef* defect, except when a *los* defect or failure is present. A *LOF* failure is cleared when *LOS* failure is declared, or after TF2 = 10 ± 0.5 s of no *sef* defect.

10.5.1.6 Far-end failures

– *Far-end Loss of Signal (FLOS)* failure is declared after TS1 = 2.5 ± 0.5 s of contiguous *flos* defect is reported, or, if *flos* defect is reported when the criteria for *LOF* failure declaration have been met. A *FLOS* failure is cleared after TS2 = 10 ± 0.5 s of no *flos* defect.

– *Far-end Remote Failure Indication (FRFI)* failure is declared after TR1 = 2.5 ± 0.5 s of contiguous *rdi* defect, except when *flos* defect or *FLOS* failure is present. A *FRFI* is cleared when *FLOS* failure is declared, or after TR2 = 10 ± 0.5 s of no *rdi* defect.

10.5.2 Path-related primitives

All path-related primitives are defined separately for each dedicated path, terminated by the corresponding TPS-TC block. The anomalies, defects and failures are different for different protocols (ATM, PTM, etc.). For each protocol they should be represented by standard OAM indicators specified for that protocol. The indicators should be represented at the OAM interface of γ – O (γ – R) reference points. The indicators should be coded "0" if no primitive has been registered during the monitoring period and shall be coded "1" to indicate that at least the primitive has been registered once during the monitoring period.

All the near-end primitives should be represented at both the VTU-O and VTU-R. The representation of far-end primitives at the VTU-O is mandatory. The representation of far-end primitives at the VTU-R is optional.

10.5.2.1 Anomalies, defects and failures for ATM transport

The set of anomalies, defects and failures for the ATM transport shall comply with ITU-T Rec. I.432.1. The ATM transport anomalies, defects and failures shall be supported by the ATM-TC. If both the Fast and Slow ATM transport are established, the two corresponding ATM-TC channels shall be represented by two equal and independent sets of anomalies, defects and failures.

10.5.2.1.1 Near-end anomalies

– *No Cell Delineation (ncd)* anomaly occurs immediately after ATM-TC start-up when ATM data are allocated to the buffer and as long as the cell delineation process operating on these data is in the HUNT or PRESYNC state (see G.4.3.3), as defined in ITU-T Rec. I.432.1. The *ncd* anomaly is optional. If *ncd* is not supported, the *ocd* anomaly shall be used instead.

– *Out of Cell Delineation (ocd)* anomaly occurs when ATM data is allocated to the buffer and the cell delineation process operating on these data transitions from SYNC to HUNT state, as defined in ITU-T Rec. I.432.1. An *ocd* anomaly terminates when the cell delineation process transitions from PRESYNC to SYNC state or when the *lcd* defect is entered.

– *Header Error Check (hec)* anomaly occurs when an ATM cell header error check fails.

10.5.2.1.2 Far-end anomalies

– *Far-end No Cell Delineation (fncd)* anomaly occurs when either a *ncd* or an *ocd* anomaly is detected at the far end and reported by a *fncd* indicator. An *fncd* anomaly always occurs immediately after VTU start-up. An *fncd* anomaly terminates when the received *fncd* indicator is coded "0".

– *Far-end Out of Cell Delineation (focd)* anomaly occurs when an *ocd* anomaly is detected at the far end and reported by a *focd* indicator and no *fncd* anomaly is present. A *focd* anomaly terminates if the received *focd* indicator is coded "0". Indication of *focd* is optional.

– *Far-end Header Error Check (fhec)* anomaly occurs when *hec* anomaly is detected at the far end and reported by an *fhec* indicator. The *fhec* anomaly terminates when a received *fhec* indicator is set to "0". Indication of *fhec* is optional.

NOTE – Both the *focd* and *fhec* anomaly indication are optional, as neither is required by ITU-T Rec. I.432.1.

10.5.2.1.3 Near-end defects

– *Loss of Cell Delineation (lcd)* defect occurs when at least one *ocd* anomaly is present in each of 4 consecutive superframes and no *sef* defect is present. An *lcd* defect terminates when no *ocd* anomaly is present in 4 consecutive superframes.

10.5.2.1.4 Far-end defects

– *Far-end Loss of Cell Delineation (flcd)* defect occurs when a *lcd* defect is detected at the far end. An *flcd* defect occurs when a *focd* anomaly is present or a *fncd* anomaly is present in each of 4 consecutive superframes and no *rdi* defect is present. A *flcd* defect terminates if neither *focd* nor *fncd* anomaly is present in 4 consecutive superframes.

10.5.2.1.5 Near-end failures

– *No Cell Delineation (NCD)* failure is declared when a *ncd* anomaly persists for more than 2.5 ± 0.5 s after the start of steady-state transmission. An *NCD* failure terminates when no *ncd* anomaly is present for more than 10 ± 0.5 s.

– *Loss of Cell Delineation (LCD)* failure is declared when a *lcd* defect persists for more than 2.5 ± 0.5 s. A *LCD* failure terminates when no *lcd* defect is present for more than 10 ± 0.5 s.

10.5.2.1.6 Far-end failures

– *Far-end No Cell Delineation (FNCD)* failure is declared when a *fncd* anomaly has persisted for more than 2.5 ± 0.5 s. A *FNCD* failure terminates when no *fncd* anomaly is present for more than 10 ± 0.5 s.

– *Far-end Loss of Cell Delineation (FLCD)* failure is declared when a *flcd* defect has persisted for more than 2.5 ± 0.5 s. A *FLCD* failure terminates when no *flcd* anomaly is present for more than 10 ± 0.5 s.

10.5.2.2 Anomalies, defects and failures of STM transport

For further study.

10.5.2.3 Anomalies, defects and failures for PTM transport

The PTM transport anomalies, defects and failures shall be supported by the PTM-TC. If both the Fast and Slow PTM channels are established, the two corresponding PTM-TC shall be represented by two equal and independent sets of anomalies, defects and failures.

10.5.2.3.1 Near-end anomalies

– *Packet Error (per)* anomaly occurs when packet error is indicated by an FCS count.

10.5.2.3.2 Far-end anomalies

– *Far-end Packet Error* (*fper*) is declared when *per* anomaly is detected at the far end and reported by an *fper* indicator. The anomaly terminates when the received *fper* indicator is coded "0".

10.5.2.3.3 Near-end defects

– *Packet Error (PER)* defect occurs if packet error anomaly persists for more than TD4_1 s. The *PER* defect terminates when no *per* anomaly is present in more than TD4_2 s.

  NOTE – The values of TD4 are TBD.

10.5.2.3.4 Far-end defects

– *Far-end Packet Error (FPER)* defect is declared when *PER* defect is detected at the far end reported by an *FPER* indicator. The *FPER* defect terminates when the received *FPER* indicator is coded "0".

10.5.3 Power-related primitives

Power-related primitives shall be represented by the corresponding indicators. The indicators shall be coded "0" if no power primitive has been registered during the monitoring period and shall be coded "1" to indicate that a power primitive has been registered during the monitoring period.

The near-end primitives shall be represented at both the VTU-O and VTU-R. The far-end primitives shall be represented at the VTU-O.

10.5.3.1 Near-end primitives

– *Loss of Power (lpr)* primitive occurs when the VTU power supply (mains) voltage drops below the manufacturer-determined level required for proper VTU operation. An *lpr* primitive terminates when the power level exceeds the manufacturer-determined minimum power level.

– *Loss of Power (LPR)* failure is declared after TP1 = 2.5 ± 0.5 s of contiguous *lpr* primitive presence. A *LPR* failure is cleared after TP2 = 10 ± 0.5 s of no *lpr* primitive presence.

– *Power Off (PRO)* failure is declared when the VTU power switch is turned off by the operator. A *PRO* failure is cleared after the power switch is turned on. The PRO indicator is optional.

10.5.3.2 Far-end primitives

– *Far-end Loss of Power (flpr)* primitive occurs when a *lpr* primitive is detected at the VTU-R and reported.

– *Far-end Loss of Power (FLPR)* failure is declared after the occurrence of a *flpr* primitive followed by TP1 = 2.5 ± 0.5 s of contiguous near-end *los* defect. A *FLPR* failure is cleared after TP2 = 10 ± 0.5 s of no near-end *los* defect.

– *Far-end Power-off (FPO)* failure occurs when a *PRO* failure detected at the VTU-R is reported. A *FPO* failure terminates after TP2 s during which no *PRO* indicator is received and no near-end *los* defect is present. The FPO indicator is optional.

10.5.4 A minimum set of far-end indicators

Far-end indicators exchange the far-end primitives between the VTU-O and the VTU-R. A minimum set of required far-end indicators is presented in Table 10-5.

Table 10-5/G.993.1 – A minimum set of far-end indicators

Indicator	Description	Note
Line-related		
febe_s	Reports non-corrected errors in the received Slow data block at the far end	
febe_f	Reports non-corrected errors in the received Fast data block at the far end	
ffec_s	Reports corrected errors in the received Slow data block at the far end	
ffec_f	Reports corrected errors in the received Fast data block at the far end	
flos	Reports a loss of received signal energy at the far end	Applicable in the power-saving state
rdi	Reports severe frame errors at the far end	

Table 10-5/G.993.1 – A minimum set of far-end indicators

Indicator	Description	Note
Power-related (System-related)		
flpr	Reports the drop of supply voltage below the predefined level at the far end	Applicable in the power-saving state
FPO	Reports that the power switch was turned off at the far end	Optional. Applicable in the power-saving state
ATM-path-related		
fncd	Reports on a loss of cell delineation anomaly at the far end	
fhec	Reports on hec errors at the far end	Optional
PTM-path-related		
FPER	Reports on a persisting and significant packet errors at the far end	
PLOS	Reports on a persisting and significant packet loss at the far end	
Other-path-related		
TBD		

All indicators shall be sent periodically, when the system is in a *Steady-State Transmission state*, to update the information on far-end primitives. Indicators of *far-end loss of signal (flos)* and the *far-end power-related primitives (flpr, FPO)* shall also be transmitted when the system is in *Deactivated Power Saving (IDLE) state*. The transfer mechanism of the indicators is specified in 8.5.5.

10.5.5 Performance parameters

The defined set of performance parameters shall describe both line-related and path-related parameters at the VTU-O and VTU-R.

10.5.5.1 Line-related performance parameters

The VDSL line-related performance parameters shall be calculated using the related anomalies as presented in 10.5.1.

10.5.5.2 Path-related performance parameters

The path-related performance parameters shall be calculated specifically for each applied service transport protocol separately, in accordance with the corresponding definition for that transport protocol. If the same transport protocol is used for both the fast and the slow paths, separate performance parameters for each should be calculated.

10.5.5.2.1 ATM data path-related performance parameters

The following near-end performance parameters shall be provided at the VTU-O and VTU-R:

– *HEC_violation_count*: The *HEC_violation_count* performance parameter is a count of the number of occurrences of *hec* anomaly;

– *HEC_total_cell_count*: The *HEC_total_cell_count* performance parameter is a count of the total number of cells passed through the cell delineation process operating on the fast data when in the SYNC state;

– *User_total_cell_count*: The *User_total_cell_*count performance parameter is a count of the total number of cells in the fast data path delivered at the γ-O (for the VTU-O) or γ-R (for the VTU-R) interface.

10.5.5.2.2 STM data path-related performance parameters

10.5.5.2.3 PTM data path-related performance parameters

NOTE – Performance parameters for other path types will be added as the relevant path type is specified in 9.1.1.

10.5.6 Testing parameters

The near-end testing parameters shall be provided at both the VTU-O and VTU-R; the far-end testing parameters shall be provided at the VTU-O only.

10.5.6.1 Near-end test parameters

The following near-end test parameters shall be provided at the VTU-O and the VTU-R:

– *Loop Attenuation (ATN)* is the difference in dB between the power received at the near end and that transmitted from the far end. The ATN shall be reported for each of the used (receive direction) carriers in the range from 0 to 63.5 dB, with 0.5-dB steps.

– *Signal-to-Noise Ratio margin (SNR_M)* expresses the modem's estimation of the maximum amount by which the receiver noise (internal and external) could be increased without causing the modem to fail the BER requirement (see 14.3). The *SNR_M* shall be reported for each of the used (receive direction) carriers in the range from –31.75 dB to +31.75 dB, with 0.25-dB steps.

10.5.6.2 Far-end test parameters

The following far-end test parameters shall be provided at the VTU-O:

– *Far-end Loop Attenuation (FATN)*: The far-end attenuation is measured at the VTU-R and reported back to the VTU-O. The *FATN* shall be reported in the range from 0 dB to 63.75 dB, with 0.25-dB steps. Byte number 0x00 of VTU-R data register 0x06 shall contain the average *FATN* of all of the used downstream carriers. Optionally, the *FATN* per downstream band may be provided in byte numbers 0x01 thru 0xFF.

– *Far-end Signal-to-Noise Ratio margin (FSNR_M)*: The far-end signal-to-noise ratio margin is measured at the VTU-R and reported back to the VTU-O. The *FSNR_M* shall be reported in the range from –31.75 dB to +31.75 dB, with 0.25-dB steps. Byte number 0x00 of VTU-R data register 0x07 shall contain the average *FSNR_M* of all of the used downstream carriers. Optionally, the *FSNR_M* per downstream band may be provided in byte numbers 0x01 thru 0xFF.

NOTE – The *ATN* and *SNR_M* testing parameters should be updated and provided "on-demand" at any time following the initialization of the system. There is no requirement to continuously monitor them.

10.6 VDSL Overhead Channel (VOC)

10.6.1 VOC bandwidth

A VDSL overhead control channel shall be included to support overhead functions. The raw VOC channel rate shall be $8 f_s V$ kbit/s with f_s the DMT symbol rate in kHz (see 9.2.2) and V is the number of bytes per frame that is reserved for VOC transport (see Table 8-3). The mechanism used to support the VOC channel is described in detail in 10.6.2.

10.6.2 VOC protocol

All VOC messages shall be transmitted five consecutive times to improve the probability of proper reception and decoding. A transceiver unit shall only act on a VOC message if it has received three identical messages in a time period spanning five of that particular message. When an unrecognizable command is received (no three identical in a sequence of five), no action shall be taken.

Between two consecutive messages (i.e., a repetition of five), at least 20 idle bytes shall be transmitted. The idle bytes shall have the value 0x00.

10.6.3 High-level on-line adaptation

10.6.3.1 Bit swapping

Bit swapping enables a VDSL system to change the number of bits assigned to a sub-channel, or change the transmit energy of a sub-carrier without interrupting the data flow.

Either VTU may initiate a bit swap. The swapping procedures in the upstream and downstream directions shall be independent and may take place during the same set of superframes. The "receiver" is defined as the modem that initiates the bit swap. It shall transmit the bit-swap request message and receive the bit-swap acknowledge message. The "transmitter" receives the bit-swap request and shall transmit the bit-swap acknowledge.

There shall be a maximum of one outstanding bit-swap request at any time in downstream. There shall be a maximum of one outstanding bit-swap request at any time in upstream.

Bit swap is a mandatory feature.

10.6.3.2 Bit-swap channel

Bit swaps shall be conducted using the VOC channel, using the protocol described in 10.6.2. Consequently, all bit-swap messages shall be repeated five consecutive times over the VOC channel.

10.6.3.3 Bit-swap coordination

Bit swapping shall be conducted using synchronized counters at the VTU-O and VTU-R. The counters shall increment by one after each bit-swap frame interval. A bit-swap frame interval is defined as the duration of 16 DMT symbols. The counters shall be started and incremented as follows:

– The VTU-O and VTU-R transmitters shall start their counters immediately after transitioning from initialization to steady-state operation. The value of the counter for the first superframe shall be zero;
– Each transmitter shall increment its counter after transmitting each bit-swap frame;
– Correspondingly, each receiver shall start its counter immediately after transitioning from initialization to steady state, and shall then increment it after receiving each bit-swap frame.

Any form of restart that requires a transition from initialization to steady-state shall reset the counters.

Counting of bit-swap frames shall be performed modulo 256.

10.6.3.4 Bit-swap request

Upon detecting SNR degradation in one or more sub-channels, the receiver shall initiate a bit swap by sending a bit-swap request back to the transmitter via the VOC channel. It shall be up to the receiver to determine what is considered to be a degradation. This request tells the transmitter which sub-channels are to be modified. The bit-swap request message shall contain the following:

– a VOC message header consisting of eight binary ones to indicate the ensuing bit-swap request;
– four message fields, each of which shall consist of an eight-bit command followed by a related 12-bit sub-channel index. Valid eight-bit commands for the bit-swap message shall

be as shown in Table 10-6. The 12-bit sub-channel index is counted from low to high frequencies with the lowest frequency sub-carrier assigned the number zero.

Table 10-6/G.993.1 – Bit-swap request commands

Value	Interpretation
00000000	Do nothing
00000001	Increase the allocated number of bits by one
00000010	Decrease the allocated number of bits by one
00000011	Change the transmitted power by the factor +1 dB
00000100	Change the transmitted power by the factor +2 dB
00000101	Change the transmitted power by the factor +3 dB
00000110	Change the transmitted power by the factor –1 dB
00000111	Change the transmitted power by the factor –2 dB
00001xxx	Reserved for vendor-specific commands

For a g_i update with Δ dB, the new value of g_i shall be calculated as:

$$g_i' = 1/512 \times round(512\ g_i\ 10^{\Delta 20})$$

The bit-swap request message (that is, the header plus the four message fields, a total of 11 bytes) is transmitted five consecutive times.

10.6.3.5 Bit-swap acknowledge

After a VTU (the transmitter) has received three identical bit swap request messages within the span of five message-times, the transmitter shall act on the request. Within 400 ms of receiving the bit swap request, the transmitter shall first send a bit-swap acknowledge, which shall contain the following:

- a VOC message header containing eight binary ones, indicating receipt of the request message;
- one message field that consists of eight binary ones followed by the eight-bit bit-swap frame counter number, which indicates after how many bit-swap frame intervals should the bit swap occur. This number shall be at least 200 greater than that of the value of the counter when the bit-swap request was received. This corresponds to a minimum wait time of 800 ms.

Specifically, the new bit or transmit energy table(s), or both, shall take effect starting from the first symbol of the VDSL bit-swap frame specified by the bit-swap frame counter number. In other words, if the bit-swap frame counter number contained in the bit-swap acknowledge message is *n*, then the new table(s) shall take effect starting from the first applicable symbol of the *n*th bit-swap frame.

When the transmitter correctly receives the message, but is unable to perform the requested action, it shall transmit an Unable-To-Comply message (UTC). This message shall consist of a single byte with value 0xF0 (repeated five times as described in 10.6.2).

10.6.3.6 Bit swap – Receiver

The receiver shall start a timeout of 500 ms from the moment it sends the bit-swap request. When no acknowledgement has been received in this timeout interval, the receiver can retransmit the request. After a number of unsuccessful retries, the modem can take vendor discretionary actions to accomplish bit swap.

The receiver shall act on a bit-swap request when it has received three identical bit-swap acknowledge messages within the span of five message-times. The receiver shall then wait until the bit-swap frame counter equals the value specified in the bit-swap acknowledge. Then, beginning with the first symbol in the next bit-swap frame, the receiver shall:

- change the bit assignment of the appropriate sub-channels and, if necessary, perform tone re-ordering based on the new sub-channel bit assignment;
- update applicable receiver parameters of the appropriate sub-channels to account for any changes in their transmitted energy.

10.6.3.7 Bit swap – Transmitter

After the bit-swap acknowledge has been transmitted, the transmitter shall wait until the bit-swap frame counter equals the value specified in the bit-swap acknowledge. Then, beginning with the first symbol in the next bit-swap frame, the transmitter shall:

– change the bit assignment of the appropriate sub-channels and, if necessary, perform tone re-ordering based on the new sub-channel bit assignment;

– change the transmitter energy in the appropriate sub-channels by the desired factors.

10.6.3.8 Express swapping

Express swapping enables a VDSL system to change the number of bits assigned to a sub-channel, or change the transmit energy of a sub-carrier *without* any hand-shaking acknowledgements. Express swapping is an option. It is introduced to augment the performance of bit swapping.

Express swapping:

– increases the execution speed for a swap significantly;

– requires the use of a more sophisticated receiver for the monitoring of the received signal to determine if an express-swap request was executed correctly.

10.6.3.9 Express swap request

Upon detecting changes in the sub-channels' SNR, the receiver shall initiate an express swap by sending an express-swap request back to the transmitter via the VOC channel.

An express-swap command shall be sent only *once* and allows alteration of the bit distribution (or gain distribution) on *n* tones through the transmission of a command as shown in Table 10-7.

Table 10-7/G.993.1 – Express swap request command

VOC message headers	VOC message field total length including message header (bytes)	Interpretation
11110010	$2.5n + 5$ for n even $2.5n + 4.5$ for n odd	Implement express bit-swap request for a total of n tones on the *next* bit-swap frame
11110011	$2.5n + 5$ for n even $2.5n + 4.5$ for n odd	Implement express bit-swap request for a total of n tones on the *next-to-next* bit-swap frame

An express-swap request command shall contain the following:

– a VOC message header consisting of either the pattern 11110010 or 11110011 to indicate the ensuing express-swap request. The header pattern 11110010 means the express swap should be executed in the next bit-swap frame while the pattern 11110011 means the express swap should be implemented in the next-to-next bit-swap frame;

– a 12-bit message field to indicate the total number of tones (*n)* whose bit or gain distributions (or both) need to be updated;

– *n* message fields, each of which shall be 20 bits long. The first 12 bits indicate the sub-channel index. In the next 8 bits, the upper nibble of 4 bits shall encode the new absolute number of bits, which is a number between 0 and a maximum of 15, according to 0000 for no bits, 0010 for 2 bits, up to 1111 for 15 bits. The lower nibble of 4 bits, with the most significant bit as the sign bit, shall encode the relative gain by a 2's complement 4-bit quantity between –4 and +3.5 dB (with 0.5-dB increments);
– 4 dummy bits if *n* is even;
– an internal 16-bit CRC protection for error detection.

Table 10-8/G.993.1 – Express swap request command

Message header	ES control	1st tone index	1st tone total bits/gain	..	nth tone index	nth tone total bits/gain	Dummy bits	CRC
1111001x (1 byte)	Tone count (12 bits)	Tone number (12 bits)	# of bits/gain (1 byte)		tone number (12 bits)	# of bits/gain (1 byte)	0 to *n* odd 4 to *n* even	16 bits

There is no Express-Swap Acknowledge command. The receiver that initiates an express swap shall be responsible for monitoring the returned DMT signal to determine if the command has been implemented by the transmitter. If the swap has not been detected on the correct superframe, then the receiver assumes the request is not implemented by the transmitter. The express-swap initiating DMT receiver may then choose to repeat the express-swap command, to send another VOC command, or to retrain.

The CRC at the end of the command shall follow the same byte CRC protocol as used in initialization for confirmation of correct receipt of message fields. The polynomial used is $g(Z) = Z^{16} + Z^{12} + Z^{15} + 1$ where Z is an advance of one bit period. The CRC shall be calculated over all bits in the express-swap request command.

11 Performance requirements

11.1 Error performance requirements

The G.993.1 system shall operate with a noise margin of at least +6 dB and a long-term bit error ratio of <1 in 10^{7}·

11.2 Latency requirements

The latency of fast channel averaged over upstream and downstream shall be no greater than 1 ms, measured between the α and β-interfaces.

11.3 Impulse noise immunity requirements

G.993.1 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 NMS as specified in 10.4.

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.

In a high latency VDSL channel, at the maximum delay of 20 ms, the bit error probability specified in 11.1 should not be exceeded when the path is subject to a noise burst of up to 500 µs.

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.

12 Initialization

12.1 Handshake – VTU-O

The detailed procedures for handshake at the VTU-O are defined in ITU-T Rec. G.994.1. A VTU-O, after power-up, loss of signal or recovery from errors during the initialization procedure, shall enter the initial G.994.1 state C-SILENT1. The VTU-O may transition to C-TONES under instruction of the network operator. The VTU-O may transition to the Initialization Reset Procedure under instruction from the network. From either state, operation shall proceed according to the procedures defined in ITU-T Rec. G.994.1.

If G.994.1 procedures select ITU-T Rec. G.993.1 as the mode of operation, the VTU-O shall transition to G.993.1 at the conclusion of G.994.1 operation. If G.994.1 procedures select Annex I/G.993.1 as the mode of operation, the VTU-O shall transition to Annex I/G.993.1 at the conclusion of G.994.1 operation.

12.1.1 CL messages

A VTU-O wishing to indicate G.993.1 capabilities in a G.994.1 CL message shall do so by setting to ONE the SPar(1) G.993.1 bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to the "G.993.1" Level 1 bit are defined in Tables 12-1 and 12-2, respectively. For each G.993.1 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

Table 12-1/G.993.1 – VTU-O CL message NPar(2) bit definitions

G.994.1 NPar(2) bit	Definition
OptUp	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O and VTU-R shall be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	If set to ONE, signifies that the VTU-O can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-O can be configured for ATM cell transport. (Annex G)
EOC-Clear	If set to ONE, signifies that the VTU-O supports transmission and reception of G.997.1 OAM frames.

At least one of the PTM and ATM bits shall be set to ONE in a CL message.

Table 12-2/G.993.1 – VTU-O CL message SPar(2) bit definitions

G.994.1 SPar(2) bit	Definition
Used bands in upstream	The use of this bit is optional. If set to ONE, indicates the used upstream bands. The optional band between 25 kHz to 138 kHz shall not be included.
Used bands in downstream	The use of this bit is optional. If set to ONE, indicates the used downstream bands. The optional band between 25 kHz to 138 kHz shall not be included.
IDFT/DFT size	Always set to ONE in a CL message. Indicates the maximum IDFT/DFT size that VTU-O can support. The value shall be present in the corresponding NPar(3) field.
Initial length of CE	If set to ZERO, it signifies that the VTU-O can support only the mandatory cyclic extension length of 40 2^n for a number of tones equal to 256 2^n. If set to ONE in a CL message, it indicates the initial sample length of the cyclic extension that VTU-O can support. It also signifies that the VTU-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems supports only the mandatory value, then this value shall be used.
RFI bands	The use of this bit is optional. If set to ONE, indicates that the start and stop frequencies of the RFI bands will be transmitted.

12.1.2 MS messages

A VTU-O selecting G.993.1 mode of operation in a G.994.1 MS message shall do so by setting to ONE the SPar(1) G.993.1 bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to this bit are defined in Tables 12-3 and 12-4, respectively. For each SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

Table 12-3/G.993.1 – VTU-O MS message NPar(2) bit definitions

NPar(2) bit	Definition
OptUp	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for upstream (VTU-R → VTU-O) transmission.
OptDn	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O and VTU-R shall be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

If both bits "OptUp" and "OptDn" are enabled in the CL and CLR message, one and only one of the bits shall be set to ONE in an MS message sent from the VTU-O, and the use of the band between 25 kHz and 138 kHz is at the VTU-O's discretion. If the VTU-O and VTU-R have no common usage of the optional band, both bits shall be set to ZERO in an MS message sent from the VTU-O.

One and only one of the PTM and ATM bits shall be set to ONE in an MS message sent from the VTU-O. If both bits are enabled in the CL and CLR message, the PTM or ATM selection is at the VTU-O's discretion.

Table 12-4/G.993.1 – VTU-O MS message SPar(2) bit definitions

SPar(2) bit	Definition
Used bands in upstream	Always set to ZERO in an MS message.
Used bands in downstream	Always set to ZERO in an MS message.
IDFT/DFT size	Always set to ONE in an MS message. Indicates the maximum IDFT/DFT size that both the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	Set to ZERO if and only if this bit was set to ZERO in the last previous CL message or the last previous CLR message, or both. It signifies that both VTU-O and VTU-R shall use only the mandatory cyclic extension length. Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both VTU-O and VTU-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to ZERO in an MS message.

12.2 Handshake – VTU-R

The detailed procedures for handshake at the VTU-R are defined in ITU-T Rec. G.994.1. After power-up, loss of signal, or recovery from erros during the initialization procedure, a VTU-R shall enter the initial G.994.1 state R-SILENT0. Upon command from the host controller, the VTU-R shall initiate handshaking by transitioning from the R-SILENT0 state to the G.994.1 R-TONES-REQ state. Operation shall then proceed according to the procedures defined in ITU-T Rec. G.994.1.

If G.994.1 procedures select G.993.1 as the mode of operation, the VTU-R shall transition to G.993.1 at the conclusion of G.994.1 operation. If G.994.1 procedures select Annex I/G.993.1 as the mode of operation, the VTU-R shall transition to Annex I/G.993.1 at the conclusion of G.994.1 operation.

12.2.1 CLR messages

A VTU-R wishing to indicate G.993.1 capabilities in a G.994.1 CLR message shall do so by setting to ONE the G.993.1 SPar(1) bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to the G.993.1 SPar(1) bit are defined in Tables 12-5 and 12-6, respectively. For each Level 2 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

Table 12-5/G.993.1 – VTU-R CLR message NPar(2) bit definitions

NPar(2) bit	Definition
OptUp	If set to ONE, signifies that the VTU-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the downstream (VTU-O → VTU-R) transmission.
PSDRed	Shall be set to ONE.
PTM	If set to ONE, signifies that the VTU-R can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-R can be configured for ATM cell transport.
EOC-Clear	If set to ONE, signifies that the VTU-R supports transmission and reception of G.997.1 OAM frames.

At least one of the PTM and ATM bits shall be set to ONE in a CLR message.

Table 12-6/G.993.1 – VTU-R CLR message SPar(2) bit definitions

SPar(2) bit	Definition
Used bands in upstream	Always set to ZERO in a CLR message.
Used bands in downstream	Always set to ZERO in a CLR message.
IDFT/DFT size	Always set to ONE in a CLR message. Indicates the maximum IDFT/DFT size that VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	If set to ZERO, it signifies that the VTU-R can support only the mandatory cyclic extension length of 40 2^n for a number of tones equal to 256 2^n. If set to ONE in a CLR message, it indicates the initial sample length of the cyclic extension that VTU-R can support. It also signifies that the VTU-R can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems supports only the mandatory value, then this value shall be used.
RFI bands	Always set to 0 in a CLR message.

12.2.2 MS messages

A VTU-R selecting G.993.1 mode of operation in a G.994.1 MS message shall do so by setting to ONE the G.993.1 SPar(1) bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to this bit are defined in Tables 12-7 and 12-8, respectively. For each G.993.1 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

Table 12-7/G.993.1 – VTU-R MS message NPar(2) bit definitions

NPar(2) bit	Definition
OptUp	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for upstream (VTU-R → VTU-O) transmission.
OptDn	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE in a CL message, it shall be set to ONE in an MS message and signifies that the VTU-O and VTU-R shall be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

If both bits "OptUp" and "OptDn" are enabled in the CL and CLR message, one and only one of the bits shall be set to ONE in an MS message sent from the VTU-R, and the use of the band between 25 kHz and 138 kHz shall be at the VTU-R's discretion. If the VTU-O and VTU-R have no common usage of the optional band, both bits shall be set to ZERO in an MS message sent from the VTU-R.

One and only one of the PTM and ATM bits shall be set to ONE in an MS message sent from the VTU-R. If both bits are enabled in the CL and CLR message, the PTM or ATM selection shall be at the VTU-R's discretion.

Table 12-8/G.993.1 – VTU-R MS message SPar(2) bit definitions

SPar(2) bit	Definition
Used bands in upstream	Always set to ZERO in an MS message.
Used bands in downstream	Always set to ZERO in an MS message.
IDFT/DFT size	Always set to ONE in an MS message. Indicates the maximum IDFT/DFT size that both the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	Set to ZERO if and only if this bit was set to ZERO in the last previous CL message or the last previous CLR message, or both. It signifies that both VTU-O and VTU-R shall use only the mandatory cyclic extension length. Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both VTU-O and VTU-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to ZERO in an MS message.

12.2.3 MP messages

A VTU-R proposing G.993.1 mode of operation in a G.994.1 MP message shall do so by setting to ONE the G.993.1 SPar(1) bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to this bit are defined in Tables 12-9 and 12-10, respectively. For each Level 2 SPar(2) bit set to 1_b, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

Table 12-9/G.993.1 – VTU-R MP message NPar(2) bit definitions

NPar(2) bit	Definition
OptUp	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE signifies to propose to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

One and only one of the PTM and ATM bits shall be set to ONE in an MP message sent from the VTU-R.

Table 12-10/G.993.1 – VTU-R MP message SPar(2) bit definitions

SPar(2) bit	Definition
Used bands in upstream	Always set to ZERO in an MP message.
Used bands in downstream	Always set to ZERO in an MP message.
IDFT/DFT size	Always set to ONE in an MP message. Indicates the maximum IDFT/DFT size that both the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	Set to ZERO if and only if this bit was set to ZERO in the last previous CL message or the last previous CLR message, or both. It signifies that both VTU-O and VTU-R shall use only the mandatory cyclic extension length. Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both VTU-O and VTU-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to ZERO in an MP message.

12.3 Link state and timing diagram

12.3.1 Overview

The VDSL link state and timing diagram is described in Figure 12-1. The diagram includes five states (rounded blocks), four procedures of link activation (rectangular blocks) and two types of link deactivation.

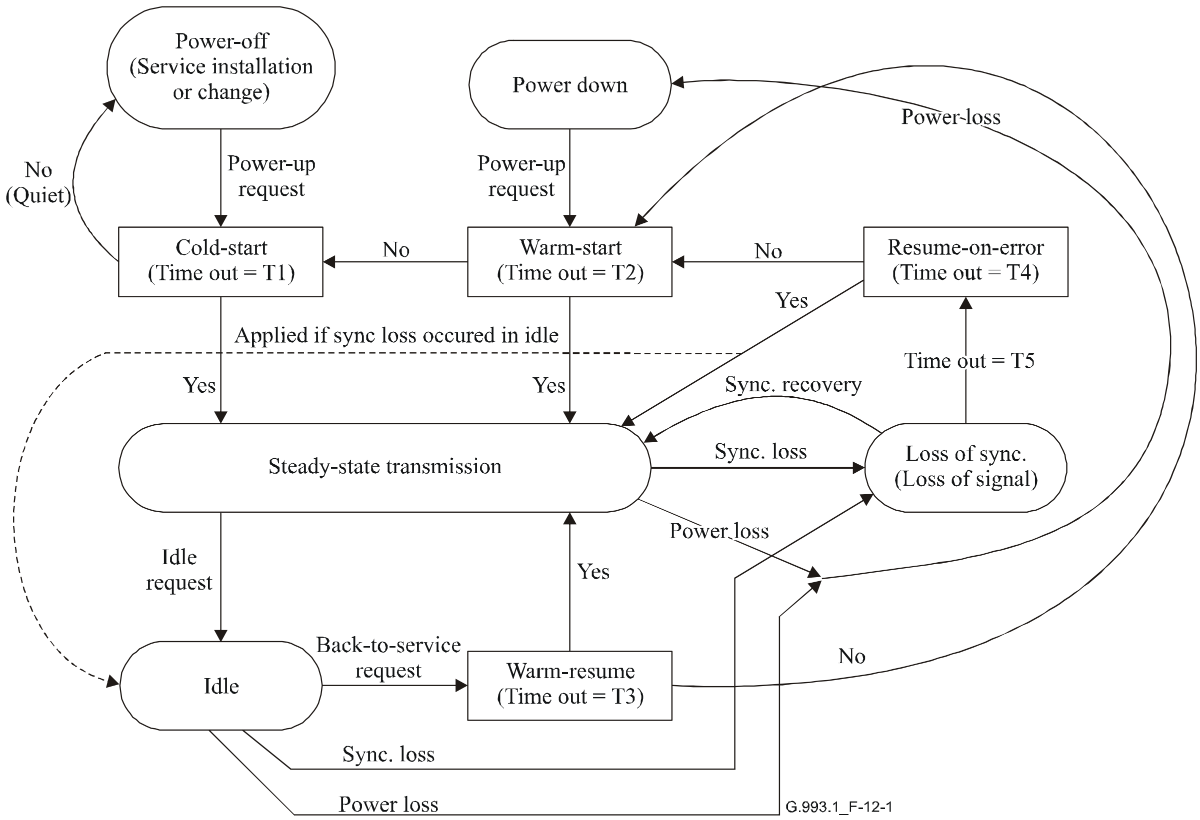


Figure 12-1/G.993.1 – VDSL link state and timing diagram

12.3.1.1 States

The link State and Timing diagram shall contain the following five states:

1) *Power-off* is the initial state intended for service installation and modification prior to the first power-up process.

2) *Steady-State Transmission* is a state achieved after the link activation process is completed. In this state, the link shall transport user information with standard performance characteristics.

3) *Loss of Sync (Loss of Signal)* is a state achieved if transmission frame synchronization loss occurs (also as a result of signal energy loss or symbol timing loss). During this state the link is interrupted. The link shall return from this state back to *Steady-State Transmission* if frame synchronization is recovered in a short period of time (T5). Otherwise, the link shall be moved to perform the *Resume-on-Error* activation procedure.

4) *Power Down* is a state achieved after a guided power removal, power failure or *QUIET* deactivation at either the VTU-O or VTU-R. During this state the link is terminated. The link shall be moved from this state into the *Warm-Start* procedure by applying a Power-up request.

5) *Idle* state generates low crosstalk and reduced power consumption for the link when no broadband calls are in progress. After the VTU-O or VTU-R detects a broadband call wake-up signal (Back-to-Service request) from the network or from the CPE, respectively, a *Warm-Resume* procedure is executed.

NOTE – If the link connection is maintained during the *Idle* state, at least data frame synchronization, VOC transparency and Sync. Loss event monitoring should be provided. The user data channels and eoc transparency are optional. If the link connection is not maintained during the *Idle* state, the Sync. Loss event in the *Idle* state is not monitored.

12.3.1.2 Activation procedures

Either the VTU-R or the VTU-O shall be able to initiate the activation process. The activation process may be started by a power-up request, or after link interruption/deactivation. A successfully completed activation process makes the link ready for steady-state data communication.

12.3.1.3 Cold start

Cold-Start shall be applied after the first power-up or after an unsuccessful *Warm-Start* activation. If finished unsuccessfully, some changes in the installed service shall be made to simplify the link establishment.

NOTE – Unsuccessful *Cold-Start* activation usually occurs when the activated link environment (attenuation, noise etc.) cannot provide the desired service.

12.3.1.4 Warm start

Warm-Start shall be applied after an unsuccessful *Resume-on-Error* activation, or an unsuccessful *Warm-Resume* activation, or after either Power-down/Power failure or a link deactivation (*QUIET*) event. If *Warm-Start* fails, the *Cold-Start* activation is applied.

NOTE – Unsuccessful *Warm-Start* activation usually occurs after significant change of line characteristic (for example a connection to a new line with unknown parameters).

12.3.1.5 Resume on error

Resume-on-Error shall be applied after a link interruption due to loss of synchronization, which was not self-recovered during the defined time-out (T5). If *Resume-on-Error* fails, the *Warm-Start* activation is applied.

NOTE – Unsuccessful *Resume-on-Error* activation is usually due to a temporary change of noise conditions in the loop or due to modification of the transmission parameters.

12.3.1.6 Warm resume

Warm-Resume shall be applied on receipt of a broadband call wake-up signal (Back-to-Service request command) if the link resides in the *Idle* mode. If *Warm-Resume* fails, the *Warm-Start* activation is applied.

NOTE 1 – Unsuccessful *Warm-Resume* activation is usually due to a temporary change of noise conditions in the loop.

NOTE 2 – Back-to-Service request command may be applied at both the VTU-O and the VTU-R.

12.3.2 Activation process

Any of the defined activation processes conceptually includes the following steps:

1) Upstream and Downstream PMD sub-layer synchronization;
2) Upstream and Downstream PMS-TC sub-layer synchronization;
3) Open the steady-state data communication between the VTU-O and VTU-R (TPS-TC sublayer activation).

12.3.3 Deactivation procedure

The deactivation process may be initiated at either the VTU-O or VTU-R by special control signals. Both the VTU-O and VTU-R should support the following two types of link deactivation:

1) *QUIET* shall terminate the link. *QUIET* shall be applied if power failure occurs, or if a transceiver restart is desired, or as a part of the power-down process. *QUIET* may be initiated while the link resides in any state or during any activation process. In any case, except the Cold-Start, after *QUIET* deactivation the link shall be moved into the Power-Down state. *QUIET* deactivation during the Cold-Start move the link into the initial (Power-off) state.
2) *Idle Request* shall move the link into the *Idle* state. *Idle Request* may be applied on receipt of a broadband call release while the link resides in *Steady-State Transmission* state only.

NOTE – The *Warm-Resume* activation procedure is applied to return the link from the *Idle* state to a *Steady-State Transmission* state.

12.3.4 Delay to service

Delay to service is defined by the activation time, which equals the time interval from the beginning of the activation process until the link reaches the steady-state communication. The activation time shall not exceed the value of the time constants T1-T5, listed in Table 12-11.

Table 12-11/G.993.1 – Activation time constants

Process	Time constant	Maximum value [ms]
Cold-Start activation	T1	10000
Warm-Start activation	T2	5000
Warm-Resume activation	T3	100
Resume-on-Error activation	T4	300
Sync. Loss recovery	T5	200

12.4 Link activation/deactivation method

12.4.1 Overview

Initialization of a VTU-O/VTU-R pair includes a variety of tasks. The set of tasks consist of:

– Definition of a common mode of operation;
– Synchronization (sample clock alignment and symbol alignment);
– Transfer of frequency band allocation and PSD mask information from the VTU-O to the VTU-R;
– Channel identification;
– Noise identification;
– Calculation of bit loading and energy tables;
– Exchange of parameters (RS settings, interleaver parameters, VOC settings, bit loading and energy tables, ...).

Information such as the PSD mask, frequency band allocation, location of HAM & RFI bands, and bit-rate symmetry ratio is initially available at the VTU-O side. The initial value of the cyclic extension shall be exchanged during G.994.1 handshake, while timing advance (see 9.2.2 and 9.2.3.3) shall be set to the default value corresponding to a loop with a length of 1.5 km.

NOTE – Alternatively, a non-default value of the timing advance could be negotiated during G.994.1 handshake. This would allow communication on even longer loops (which may become feasible by using the optional frequency band for upstream transmission).

The timeline in Figure 12-2 provides an overview of the initialization protocol. Following the initial G.994.1 handshake procedure, a full duplex link between the VTU-O and the VTU-R is established. During the training phase, timing advance and upstream power back-off shall be refined. During the channel analysis and exchange state, the two modems shall measure the characteristics of the channel and agree on a contract that thoroughly defines the communication link.

VTU-O

Activation: G.994.1 handshake procedures (see 12.4.3)	Training (see 12.4.4)	Channel analysis and exchange (see 12.4.6)

VTU-R

Activation: G.994.1 handshake procedures (see 12.4.3)	Training (see 12.4.4)	Channel analysis and exchange (see 12.4.6)

Figure 12-2/G.993.1 – Overview of initialization

The transition between states or various operations shall be made following completion of the current state or the specific task rather than at fixed times.

During initialization (but not in the initial G.994.1 handshake phase), a SOC message channel shall exist in order to exchange information.

12.4.2 SOC protocol

12.4.2.1 Message format

The SOC shall use HDLC-like format with byte stuffing to delineate the messages as specified in ITU-T Rec. G.994.1. A reliable transmission shall be insured by using either an automatic repeat (AR) mode or a repeat request (RQ) mode. The maximum size of an HDLC frame shall be 1026 bytes (this also defines the maximum size of a SOC message segment). This is the size of the payload before octet stuffing and addition of any flags.

In the AR mode, the message encapsulated in the HDLC frame shall be automatically repeated. At least four idle flags (0x7E) shall be inserted between successive frames.

In the RQ mode, the messages encapsulated in HDLC frame shall be sent once. However, the VTU expecting the message shall have the possibility to request the remote side to repeat it by sending a REPEAT_REQUEST message. This operation is necessary when the expected message has a wrong Check Sequence or when a timeout has expired. After two unsuccessful REPEAT_REQUEST, the initialization shall be aborted. This means the initiating side will restart the G.994.1 handshake after a silent period. After a number of unsuccessful attempts, the modems shall stop all attempts. The number of attempts that is made before a final abort of the initialization shall be chosen by the initiating modem.

A SOC message shall contain an integer number of octets (8 bits per octet). The octets shall be sent least significant bit first. A message is subdivided in fields. A field can contain more than one byte. In this case, the field shall be split in bytes with the byte containing the most significant bits sent first. For example a field of 16 bits made of the bits $m_{15}, \dots, m_0$ shall be segmented in a first byte $B_0 = m_{15} \dots m_8$ and a second byte $B_1 = m_7 \dots m_0$. Some fields can be merged together to form a logical entity called a macro-field, such as "PSD descriptor", "Band descriptor".

The structure of an HDLC frame is illustrated in Figure 12-3.

Meaning	**Value** (← 1 *byte* →)
Flag	0x7E
Address Field	Address
Control Field	Control
Information Payload	Payload bytes
Check Sequence	FCS
Check Sequence	FCS
Flag	0x7E

Figure 12-3/G.993.1 – Structure of an HDLC frame

12.4.2.2 O/R-IDLE

When the VTU-O is in the idle state (i.e., it has no SOC message to send), it shall send O-IDLE. The VTU-R shall send R-IDLE when in the idle state.

O-IDLE and R-IDLE correspond to the idle state of the HDLC protocol: 0x7E. This octet shall be transmitted repeatedly (i.e., there is no HDLC framing).

12.4.2.3 O/R-REPEAT_REQUEST

This message shall request the remote side to repeat the last unacknowledged message.

NOTE – Due to the structure of the initialization sequence, all messages are acknowledged either by another message or by a symbol type transition. The information payload of the message shall consist of one octet: 0x55.

In AR mode, REPEAT_REQUEST messages shall be ignored.

When messages are segmented, the REPEAT_REQUEST message shall be able to ask for the retransmission of a particular segment of a message (see 12.4.2.6).

12.4.2.4 Message codes

The information payload of every SOC message shall start with a field (with a length of one byte) containing a unique code to identify the message and to allow fast and easy recognition of each SOC message. The message codes of all the messages sent during the initialization sequence are shown in Table 12-12 in hexadecimal notation. They are numbered in the order in which they appear. The messages originating at the VTU-O have the MSB equal to zero, the messages originating at VTU-R have MSB equal to one. Some one-byte messages have special codes.

Table 12-12/G.993.1 – Message codes for the SOC messages

SOC message	Message code
O/R-REPEAT_REQUEST	0x55 (Note)
R-ACK	0x00 (Note)
R-NACK	0xFF (Note)
O/R-ACK-SEG	0x0F (Note)
O-SIGNATURE	0x01
O-UPDATEn	0x02
O-MSG1	0x03
O-MSG2	0x04

Table 12-12/G.993.1 – Message codes for the SOC messages

SOC message	Message code
O-CONTRACTn	0x05
O-B&G	0x06
R-MSG1	0x81
R-MSG2	0x82
R-CONTRACT1	0x83
R-MARGINn	0x84
R-B&G	0x85
NOTE – This is the entire payload of the message.	

12.4.2.5 Message fields

Typically, the information in a SOC message will be subdivided in a number of fields. The fields in every message will be given in detail below. It is possible that future versions will add extra fields to the ones already defined.

For reasons of backward compatibility, fields that are added in the future shall be appended to the currently defined fields.

For future safety, the current implementation shall ignore any extra fields following the currently defined fields in a message.

12.4.2.6 Segmentation of messages

Some messages could potentially be large, and even larger than the maximal allowed frame size of an HDLC frame (1026 octets). It shall therefore be possible to segment messages before transmission. In order to do this, all messages transmitted during initialization shall receive a number that counts the message. This number shall be stored in one byte and will wrap around in case of overflow. The value 0 shall not be used because it has a special meaning (see later). This means that 255 shall be followed by 1.

This "message index" shall be transmitted in the Address Field of the HDLC frame (see Figure 12-3). The message index allows to track lost messages and to request the retransmission of a particular message. The index shall initially be set to one and shall be incremented with one after the transmission of a message. The index shall not be incremented in case of a REPEAT-REQUEST. The counting of messages shall start when the transmission starts using RQ mode instead of automatic repeat (AR) mode.

A segmentation index (1 byte) shall be included in the Control Field of the HDLC frame. The four MSBs of this field shall indicate the number of segments that make up the total message. The four LSBs shall indicate the index of the current segment. For instance a value 0x93 indicates the third segment of a total of nine. In case the message is not segmented, the value of the field shall be 0x11.

The REPEAT-REQUEST message will behave differently from the other messages. The message index counter shall not be increased when a REPEAT-REQUEST message is sent. Also, the meaning of the message index and the segmentation index is different in this case.

The message index of the REPEAT-REQUEST message shall contain the message index of the message that should be retransmitted. The default value 0 indicates that the last unacknowledged message should be sent (this is why 0 shall never be used as message index for any other message). If this message contains several segments, only the last segment shall be retransmitted.

Likewise, the control field shall contain the segment that should be retransmitted. The Information payload of the REPEAT-REQUEST message shall still consist of one byte, containing the value 0x55.

In the initialization procedure, a transmitter should never send two consecutive messages without acknowledgement of the first message. It will always first receive some message from the other side before transmitting again. Therefore, an acknowledgement shall be sent for all but the last segment. Typically, the last segment signals the end of the message and it will therefore be acknowledged by the reply to this message. The ACK-SEG-message (see Table 12-12) shall be used to acknowledge the reception of the other segments. The ACK-SEG-message shall have its own message and segment index, which shall not refer to the segmented message that is being sent.

Once acknowledged, messages (or segments) are not expected to be retransmitted again. Also, a REPEAT-REQUEST that contains a number that is higher than the most recent value of the counter shall be ignored.

In AR mode, segmentation shall be done in the same way, but there will be no acknowledgements (ACK-SEG) between different segments of the same message. Segments shall be sent in order.

12.4.3 G.994.1 handshake procedure

The following parameters shall be transmitted with G.994.1:

– The size of the IDFT/DFT, N.

  NOTE – The size of the (I)FFT is twice the number of tones NSC.

– The initial length of the cyclic extension: $CE = L_{CS} + L_{CP} - \beta$.

– Flags indicating the use of the optional band, 25 ~ 138 kHz.

After the G.994.1 handshake phase, the VTU-O shall initiate the start of the training state.

12.4.4 Training state

Figure 12-4 gives an overview of the sequence of SOC messages and symbol types that are transmitted by VTU-O and VTU-R during the training phase.

12.4.4.1 Sequence of messages and symbols during training state

The sequence of message is illustrated in Figure 12-4.

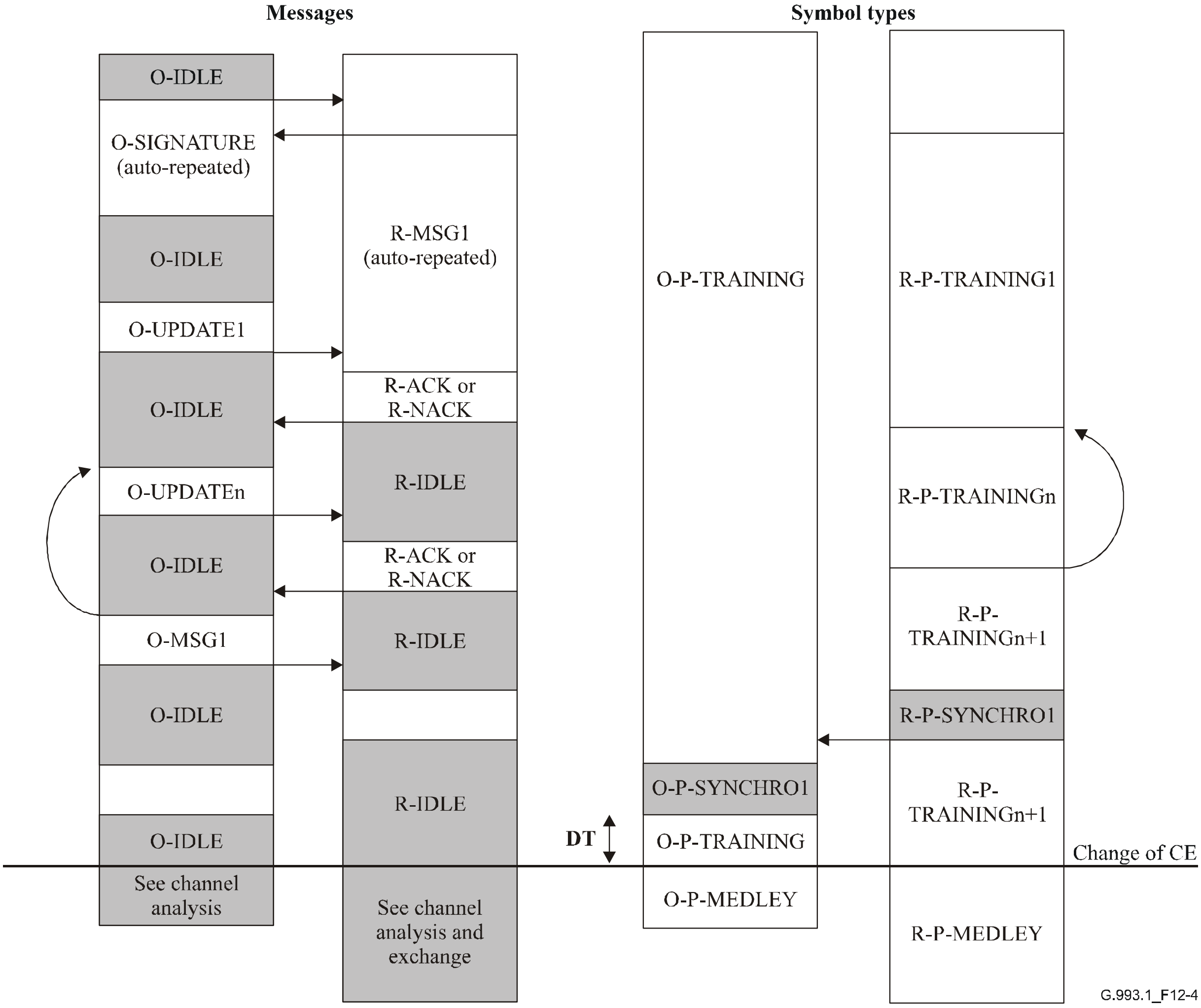


Figure 12-4/G.993.1 – Timeline of training phase

The VTU-O shall initiate the start of the training phase by transmitting the symbol O-P-TRAINING. The message O-SIGNATURE shall be sent in parallel over the SOC channel (automatically repeated). Optionally, the message O-IDLE could be sent prior to transmission of O-SIGNATURE. This can for instance be useful for training the VTU-O echo canceller (see 12.4.5). During this first phase, the modems will synchronize.

Once the VTU-R is synchronized and has successfully decoded O-SIGNATURE, it shall transmit the symbol R-P-TRAINING. The SOC channel shall transmit the message R-MSG1. The VTU-O shall keep transmitting the O-P-TRAINING symbol and the O-SIGNATURE message. Optionally, it can switch to sending the O-IDLE messages, since the information in O-SIGNATURE has been already decoded correctly. During this phase, the VTU-O shall optimize timing advance and measure the received PSD at the VTU-O side. From then on, the VTU-O shall be able to initiate the next phase by transmitting the SOC message O-UPDATE1.

During this last phase, the transmit PSD of the VTU-R shall be tuned in an iterative procedure (if needed). The VTU-O shall send a change request over the SOC channel by transmitting the message O-UPDATEn. The VTU-R shall respond to each message by replying with a R-ACKn or R-NACKn SOC message. If R-ACK is transmitted, the VTU-R shall update the symbol R-P-TRAININGn to R-P-TRAININGn+1 five symbols after sending R-ACK.

If R-NACK is transmitted, the VTU-O can continue the iterative process by sending O-UPDATEn+1, it can end the iterative process by sending O-MSG1 or it can abort the initialization.

This last phase shall be terminated by the VTU-O by sending the SOC message O-MSG1. Upon detection of O-MSG1, the VTU-R shall transmit the symbol R-P-SYNCHRO1. The VTU-O shall reply with O-P-SYNCHRO1. Both sides shall simultaneously update the *CE*, reset the quadrant scramblers and enter the next state (channel analysis and exchange) *DT* s after the last symbol of O-P-SYNCHRO1 has been sent. *DT* shall correspond to 15 DMT symbols (using the initial value for the cyclic extension).

NOTE 1 – If both VTU-O and VTU-R have agreed during G.994.1 handshake to use only the mandatory *CE* length, the *CE* length shall not be changed during the transition (and hence remain equal to the mandatory value; see 9.2.2).

NOTE 2 – If only the mandatory *CE* length is supported, the transitions in upstream and downstream need in principle not be simultaneous.

12.4.4.2 Messages and symbols transmitted by VTU-O during the training state

12.4.4.2.1 SOC messages

During the training state, the VTU-O will send the SOC messages O-SIGNATURE, O-UPDATEn and O-MSG1, as well as the idle message O-IDLE.

The way these messages are modulated on the transmit symbol is described in 12.4.4.2.2. The sequence in which the messages are sent is illustrated in Figure 12-4 and explained in more detail in 12.4.4.1.

12.4.4.2.1.1 O-SIGNATURE

This message shall contain the following nine fields:

- message descriptor;
- the bands used in downstream direction;
- the bands used in upstream direction;
- RFI bands;
- transmit PSD in downstream direction;
- whether PBO is performed using a maximum receive PSD or using an upstream PSD mask;
- the maximal transmit PSD in upstream direction;
- the reference PSD (see 9.2.4);
- the overall length of the window at the transmitter (β, see 9.2.2).

The content of O-SIGNATURE is summarized in Table 12-13.

O-SIGNATURE shall be automatically repeated (AR mode).

Table 12-13/G.993.1 – Description of message O-SIGNATURE

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Used band in downstream	Bands descriptor (see Table 12-14)
Used band in upstream	Bands descriptor
RFI bands	Band descriptor
Transmit PSD in downstream	PSD descriptor (see Table 12-15)
Receive or transmit PSD mask selector for PBO	1 byte
Maximal transmit PSD in upstream	PSD descriptor
Reference PSD	PSD descriptor
Length of the transmit window, β	1 byte

Every SOC message shall start with a field that contains a unique code describing that message. This allows fast and easy recognition of SOC messages. See Table 12-12 for the complete list of codes.

Fields two through four contain a "bands descriptor". The first octet of these fields shall contain the number of bands being described. After the first octet, groups of 3 consecutive octets shall describe each band. The first 12 bits (0-11) shall contain the index of the tone at the lower edge of the band. The last 12 bits (12-23) shall contain the index of the tone at the upper edge of the band. The starting and ending tones shall be included in the band. For example, a field value 0x400200 means that all tones from 0x200 = 512 to 0x400 = 1024 are used, including tones 512 and 1024.

The structure of a bands descriptor is shown in Table 12-14.

Table 12-14/G.993.1 – Bands descriptor

Octet	Content of field
1	Number of bands to be described
2-4	Bits 0-11: Start tone index of band 1 Bits 12-23: Ending tone index of band 1
5-7 (if applicable)	Bits 0-11: Start tone index of band 2 Bits 12-23: Ending tone index of band 2
etc.	etc.

Fields five, seven and eight contain a "PSD descriptor". The first octet of this field shall contain the number of tones being specified. After the first octet, groups of 3 consecutive octets shall describe the PSD at a certain tone index. The first 12 bits (0-11) shall contain the index of the tone being described. The last 12 bits (12-23) shall contain the PSD level. The PSD level shall be an integer multiple of 0.5 dB with an offset of –140 dBm/Hz. For example, a field value of 0x0A0400 means a PSD of 0x0A0 × 0.5 – 140 = –60 dBm/Hz on tone index 0x400 = 1024. The PSD level of intermediate unspecified tones shall be obtained using a linear interpolation between the given PSD points (in dBm/Hz) with the frequency axis on a linear scale. The PSD descriptor is described in Table 12-15. The PSD descriptor shall contain the PSD template.

Table 12-15/G.993.1 – PSD descriptor

Octet	Content of field
1	Number of tones being described
2-4	Bits 0-11: Index of first tone being described Bits 12-23: PSD level in steps of 0.5 dB with an offset of –140 dBm/Hz
5-7 (if applicable)	Bits 0-11: Index of second tone being described Bits 12-23: PSD level in steps of 0.5 dB with an offset of –140 dBm/Hz
etc.	etc.

The sixth field of O-SIGNATURE shall be a flag indicating whether the transmit PSD at the VTU-R should be calculated from the maximal receive PSD (field eight) or not. If this field has the value 0xFF, the upstream transmit PSD shall be calculated using the reference PSD given in field eight (see 9.2.4). If this field has the value 0x00, the transmit PSD at the VTU-R shall be determined from the maximal upstream PSD only (field seven). The last field in the O-SIGNATURE message shall contain the length of the transmit window, counted in samples at the sampling rate corresponding to the negotiated value of N. This sampling rate is given by $2N_{SC}\ \Delta f = N\ \Delta f$ (i.e., 2 times the Nyquist frequency of an N_{SC}-tone multi-carrier signal).

12.4.4.2.1.2 O-UPDATEn

This message shall be used to instruct the VTU-R to tune its transmit PSD to optimize the power back-off and allows the VTU-O to optimize the timing advance. O-UPDATEn shall be repeated only at the request of the VTU-R (see R-ACKn (12.4.4.3.1.2), R-NACKn (12.4.4.3.1.3)). The structure of O-UPDATEn is shown in Table 12-16.

Table 12-16/G.993.1 – Description of message O-UPDATEn

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Gain update	Update descriptor (see Table 12-17)
Timing advance correction	2 bytes

This message shall contain a macro-field, called "Update descriptor". The first byte shall contain the number of tones specified in this field. After the first octet, groups of 3 consecutive octets shall describe the gain to be applied at a given frequency. The first 12 bits shall contain the gain level, the next 12 bits the tone index. The gain level is the amplification applied on one tone. It shall be specified in 2's complement format in steps of 0.25 dB. For example, a field value of 0x030400 means a PSD amplification of 0x030 × 0.25 = 12 dB on the tone index 0x400 = 1024. The gain on unspecified tones shall be derived by linear interpolation between tones specified using a dB gain scale and a linear frequency scale.

The update descriptor is shown in Table 12-17.

Table 12-17/G.993.1 – Update descriptor

Octet	Content of field
1	Number of tones to be described
2-4	Bits 0-11: Index of first tone being described Bits 12-23: Gain level adjustment in 2's complement in steps of 0.25 dB
5-7 (if applicable)	Bits 0-11: Index of second tone being described Bits 12-23: Gain level adjustment in 2's complement in steps of 0.25 dB
etc.	etc.

The last field of O-UPDATEn shall define the timing advance correction in samples at the sampling rate corresponding to the negotiated value of *N* ($2N_{SC}\ \Delta f$; see 12.4.4.2.1.1). The value shall be encoded in a 16-bit field using 2's complement format. Positive values shall indicate that the transmitted symbol will be advanced more with respect to the received symbol (see Figure 9-3).

12.4.4.2.1.3 O-MSG1

This message shall contain the final length of the *CE* expressed in samples at the sampling frequency corresponding to the negotiated value of *N*. The message is described in Table 12-18. O-MSG1 shall be sent only once and shall only be repeated if the VTU-R sends a repeat request.

The final *CE* length shall be applied from the beginning of channel analysis phase.

Table 12-18/G.993.1 – Description of message O-MSG1

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Final length of *CE*	2 bytes

12.4.4.2.2 Symbol types transmitted by VTU-O

During the entire training phase, the VTU-O shall transmit the symbol O-P-TRAINING. To signal the end of the training phase, O-P-SYNCHRO1 shall be transmitted.

12.4.4.2.2.1 O-P-TRAINING

O-P-TRAINING is a wideband signal that allows the VTU-R to synchronize and to measure the attenuation over the channel. It shall be made of all the allowed downstream tones modulated in 4QAM, using the constellation encoder described in 9.2.5. The symbol length is $N+CE$ samples. *N* and *CE* shall be as specified during the initial G.994.1 protocol. Windowing shall be applied at the transmitter and the overall window length shall be equal to β. The transmit PSD is defined by the network management. O-P-TRAINING shall carry one byte of information per DMT symbol. The information mapping is summarized in Table 12-19.

Table 12-19/G.993.1 – O-P-TRAINING bit mapping

Tone index	Constellation point
Even	00
1, 11, 21, …, $10n + 1$, …	SOC message bits 0 & 1
3, 13, 23, …, $10n + 3$, …	SOC message bits 2 & 3
5, 15, 25, …, $10n + 5$, …	SOC message bits 4 & 5
7, 17, 27, …, $10n + 7$, …	SOC message bits 6 & 7
9, 19, 29, …, $10n + 9$, …	00

The selected constellation points shall be pseudo-randomly rotated by 0, π/2, π or 3 π/2 depending on the value of a 2-bit pseudo-random number. The DC component shall not be rotated. The rotation is equivalent to the following transformation of the (X,Y) coordinates, where X and Y are the coordinates before scrambling:

Table 12-20/G.993.1 – Pseudo-random transformation

d_{2n}, d_{2n+1}	Angle of rotation	Final coordinates
0 0	0	(X,Y)
0 1	π/2	$(-Y,X)$
1 1	π	$(-X,-Y)$
1 0	3π/2	$(Y,-X)$

The 2-bit pseudo-random number shall be the output of a pseudo-random bit generator defined by the following equation:

$$d_n = d_{n-9} \oplus d_{n-11}$$

Two bits of the scrambler shall be mapped onto each tone, including DC. The two bits corresponding to DC shall be overwritten with 00. The bit generator is illustrated in Figure 12-5.

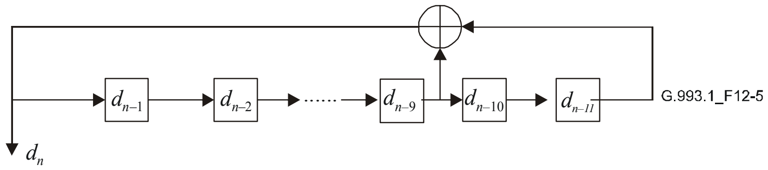


Figure 12-5/G.993.1 – Bit generator

For a VDSL system that uses N tones, $2N$ bits shall be generated by the scrambler every DMT-symbol (b_0 b_1 b_2 ... b_{2N-2} b_{2N-1}). These $2N$ bits shall be generated in every transmission direction. The first two bits (b_0 b_1) shall correspond to tone 0, the next two bits (b_2 b_3) to tone 1, …. In general, bits (b_{2j} b_{2j+1}) shall correspond to tone j. Tones that are not used for transmission will not effectively use the bits, but it is still required to generate $2N$ bits.

Initially, all the registers of the bit generator shall be set to one. During the training phase, the scrambler shall be reset at the start of every symbol (meaning that all registers are reset to one) and therefore the same $2N$ bits will be used every symbol. This means that each tone always has the same two bits assigned to it for successive DMT symbols.

In the channel analysis state (see 12.4.6), the scrambler shall not be reset, but keeps running from one symbol to the next. It is required that the sequence be random in time for one single tone. This means that there should be no correlation between the two bits that are mapped on tone j during symbol m and the two bits that are mapped on the same tone during symbol $m+1$. In order to guarantee this[1] for all allowed values of N, a number of output bits from the quadrant scrambler shall be skipped when going from symbol m to symbol $m+1$. The number of skipped bits shall be equal to 4.

In practice this means that the quadrant scrambler generates $2N$ bits which are allocated to symbol m. The next four bits generated by the quadrant scrambler are not used. The next $2N$ bits from the quadrant scrambler are then allocated to symbol $m+1$.

12.4.4.2.2.2 O-P-SYNCHRO1

O-P-SYNCHRO1 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the channel analysis and exchange state. It shall use all the allowed downstream tones modulated in 4QAM. The symbol length shall be $N+CE$ samples. N and CE shall be set to the values specified in ITU-T Rec. G.994.1. Windowing shall be applied at the transmitter and the overall window length β shall be set to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD mask is defined by the network management. The overall duration of O-P-SYNCHRO1 shall be 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the 5 first and the 5 last DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by 0, $\pi/2$, π or $3\pi/2$ depending on the 2-bit random number provided by the pseudo-random bit generator defined in 12.4.4.2.2.1.

The scrambler shall be reset every symbol.

(See Notes in 12.4.4.1.)

12.4.4.3 Messages and symbols transmitted by VTU-R during training state

12.4.4.3.1 SOC messages

During the training state, the VTU-R will send the SOC messages R-MSG1, R-ACKn and R-NACKn as well as the idle message R-IDLE. The way these messages are modulated on the transmit symbol is described in 12.4.4.3.2.

12.4.4.3.1.1 R-MSG1

This message shall contain the description of the transmit PSD of the VTU-R. This PSD shall be encoded in one macro-field "PSD descriptor" as described in Table 12-15. The PSD level on unspecified tones shall be obtained by using a linear interpolation between the PSD in dBm/Hz, using a linear frequency scale.

The initial estimate for the transmit PSD shall be obtained differently depending on the value of the selector byte in O-SIGNATURE. If this byte indicates that the modem should use the reference PSD, it shall be computed by dividing the reference PSD by the estimate of the upstream channel insertion loss. The transmit PSD shall however always be bounded by the upstream PSD mask. Otherwise, the transmit PSD shall just be the upstream PSD mask transferred from the VTU-O to the VTU-R in O-SIGNATURE.

R-MSG1 shall also indicate whether the optional echo canceller state should be entered or bypassed.

R-MSG1 shall be repeated automatically. The transmission shall be stopped after detection of O-UPDATE1.

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[1] An alternative solution would be to make the scrambler adaptive, depending on the (I)FFT size. This approach is currently being investigated in ITU-T Rec. G.992.1.

Table 12-21/G.993.1 – Description of R-MSG1

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Transmit PSD in upstream	PSD descriptor (see Table 12-15)
Echo canceller training flag	1 byte (0x00: No echo canceller training; 0xFF: Echo canceller training required)

12.4.4.3.1.2 R-ACKn

This message is an acknowledgement of the O-UPDATEn message. It shall be sent only once, unless the VTU-O asks for a retransmission. The message shall contain the byte 0x00. Five symbols after sending this message, the VTU-R shall change its symbol type from R-P-TRAININGn to R-P-TRAININGn+1. On reception of this message, the VTU-O could decide to ask for a new update by sending O-UPDATEn+1 or to end the iterative VTU-R PSD optimization by sending O-MSG1.

If the VTU-R receives a REPEAT_REQUEST for this message, it shall take the following actions to repeat the message:

– Return to the symbol type R-P-TRAININGn;
– Send back R-ACKn;
– Return to the symbol type R-P-TRAININGn+1.

12.4.4.3.1.3 R-NACKn

This message shall be sent when the VTU-R is unable to apply the update encoded in O-UPDATEn. It shall be sent only once, unless the VTU-O asks for a retransmission. The message shall contain one byte 0xFF. Upon reception of this message, the VTU-O can decide to continue the initialization by sending either O-UPDATEn or O-MSG1 or to abort the initialization.

12.4.4.3.2 Symbol types transmitted by the VTU-R

During the training phase, the VTU-R shall transmit the various R-P-TRAININGn symbols. These will differ in their PSD level and in the timing advance that is applied to the symbols. To trigger the transition from training phase to channel analysis and exchange (in the upstream direction), the signal R-P-SYNCHRO1 shall be transmitted.

12.4.4.3.2.1 R-P-TRAININGn

R-P-TRAININGn is a wideband signal that allows the VTU-O to optimize the VTU-R timing advance (TA) and the VTU-R transmit PSD in order to be compliant with the power back-off requirement. R-P-TRAINING shall be made of all the allowed upstream tones modulated in 4QAM. The symbol length shall be $N+CE$ samples. N and CE shall have the values specified during the initial G.994.1 protocol. Windowing shall be applied at the transmitter with the window length β as specified in O-SIGNATURE. The PSD mask shall be chosen to be compliant with the power back-off requirement defined in O-SIGNATURE (see 12.4.4.2.1.1).

Afterward, the PSD mask shall be updated on the basis of the instructions transmitted by the VTU-O by means of O-UPDATEn. R-P-TRAININGn will essentially be identical to R-P-TRAINING1, apart from the PSD level and timing advance.

Timing advance shall be applied. At the first iteration (R-P-TRAINING1), the timing advance shall be set to a value corresponding to the default loop length (1.5 km or 7.5 µs). Afterward, the timing advance shall be updated on the basis of the instruction transmitted by the VTU-O by means of

O-UPDATEn. R-P-TRAINING shall carry one byte of information per DMT symbol. The information mapping is summarized in Table 12-22.

Table 12-22/G.993.1 – R-P-TRAINING bit mapping

Tone index	Constellation point
Even	00
1, 11, 21, …, 10*n* + 1, …	SOC message bits 0 & 1
3, 13, 23, …, 10*n* + 3, …	SOC message bits 2 & 3
5, 15, 25, ..., 10*n* + 5, …	SOC message bits 4 & 5
7, 17, 27, …, 10*n* + 7, …	SOC message bits 6 & 7
9, 19, 29, …, 10*n* + 9, …	00

The point 00 corresponds to a point in the first quadrant, in accordance with a 4QAM constellation.

The selected constellation points shall be pseudo-randomly rotated by 0, π/2, π or 3π/2 depending on the value of a 2-bit pseudo-random number provided by the pseudo-random generator described in 12.4.4.2.2.1. The DC component shall not be rotated. The scrambler shall be reset at the start of every symbol.

12.4.4.3.2.2 R-P-SYNCHRO1

R-P-SYNCHRO1 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the channel analysis and exchange state. It shall use all of the allowed upstream tones modulated in 4QAM. The symbol length shall be $N+CE$ samples. N and CE shall have the values specified during the initial G.994.1 protocol. Windowing shall be applied at the transmitter and the overall window length β shall be set to the value specified in O-SIGNATURE. The transmit PSD mask shall meet the power back-off requirements. The timing advance shall be applied and shall correspond to the loop length (the final value shall be determined by the VTU-O). The overall duration of R-P-SYNCHRO1 shall be 15 DMT symbols. Value 11 shall be mapped on all the allowed upstream tones for the 5 first DMT symbols and the 5 last DMT symbols. Value 00 shall be mapped on all the allowed upstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on the 2-bit random number generated by a pseudo-random bit generator defined in 12.4.4.2.2.1.

The scrambler shall be reset at the start of every symbol.

(See Notes in 12.4.4.1.)

12.4.5 Echo canceller training state (optional)

The echo canceller state is optional in the sense that it will be skipped when modems do not need to train an echo canceller. Any modem that requires this state shall be able to demand that it is included in the initialization sequence.

Some modems may use an (analog) echo canceller that will have to be trained at some point during the initialization sequence. During the training of an echo canceller, the other side shall be completely quiet.

Such a silent period exists for the VTU-O at the beginning of the training state. Here, the VTU-R will be quiet until it has decoded O-SIGNATURE correctly. This period could be used by the VTU-O to train its echo canceller. It could even make the available period longer by delaying the transmission of O-SIGNATURE and sending IDLE messages instead (see Figure 12-4).

The VTU-R does not have a convenient echo canceller training state however. Therefore, the modems can follow two different paths after the PSD training. It shall be signalled in R-MSG1 whether an echo canceller training state is required for the VTU-R. If so, both modems shall go to the echo canceller training state at the end of the PSD training state.

In the echo canceller training state, the VTU-O shall go completely silent after transmission of O-MSG1 and shall perform no operations, other than listening to the signal on the line. After reception of O-MSG1, the VTU-R shall keep transmitting the same signal as during the last phase of the training state.

In this state, the VTU-R shall train its echo canceller with a proprietary algorithm. After completion of this task, the VTU-R shall go completely silent. This transition (no power on the line) shall be detected by the VTU-O, which shall react by returning to the beginning of the training state (synchronization).

NOTE – The situation is now identical to that at the beginning of initialization: the VTU-R is quiet and the VTU-O starts the communication.

After performing an echo canceller training, the content of R-MSG1 shall be changed such that at the second pass through the PSD training state, the sequence will continue with the channel analysis state and not perform another echo canceller training. At the second pass, the VTU-R already knows its correct transmit PSD, so the training phase will automatically be shortened. There is no need to explicitly bypass any stages.

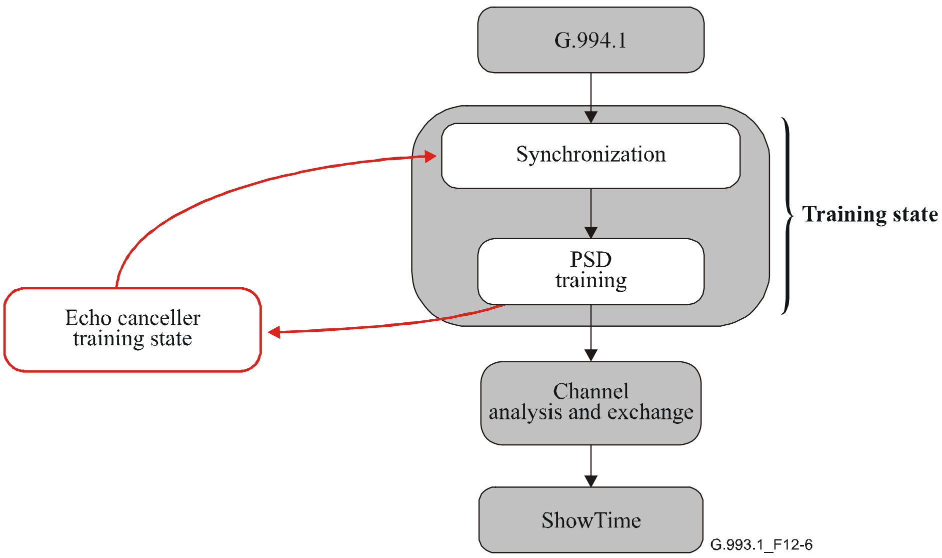


Figure 12-6/G.993.1 – Position of (optional) echo canceller training state in the initialization procedure

12.4.6 Channel analysis and exchange

Figure 12-7 gives an overview of the sequence of SOC messages and symbol types during the channel analysis and exchange state.

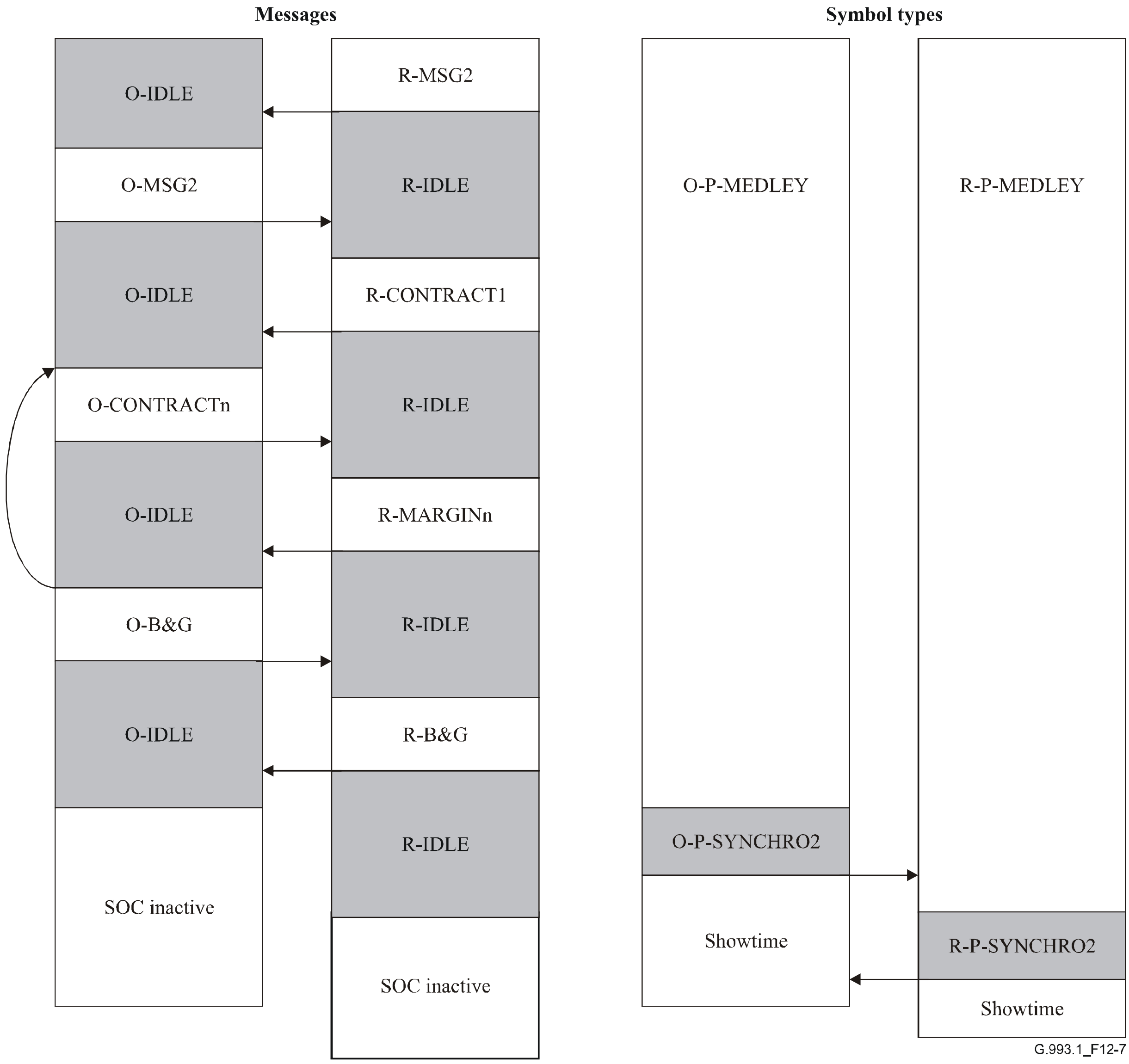


Figure 12-7/G.993.1 – Timeline of the channel analysis and exchange phase

12.4.6.1 Sequence of messages and symbols during channel analysis and exchange state

The sequence of SOC messages and symbols is depicted in Figure 12-7. Upon entering the channel analysis and exchange state, the VTU-R shall transmit symbol type R-P-MEDLEY, while the VTU-O shall send O-P-MEDLEY. The VTU-R shall send the message R-MSG2 over the SOC channel to transfer information about its bit allocation capabilities and several other features. After receiving this message, the VTU-O shall do the same by sending the SOC message O-MSG2, containing the capabilities of the VTU-O.

After receiving O-MSG2, the VTU-R shall send the SOC message R-CONTRACT1, which contains the proposed contract in downstream.

Following this, the VTU-O and VTU-R shall enter an iterative procedure to agree on a contract for the transmission in upstream and downstream. At the *n*th iteration, the VTU-O shall send O-CONTRACTn. The VTU-R shall reply with R-MARGINn.

To end the contract negotiations, the VTU-O shall transmit the message O-B&G. After receiving this message, the VTU-R shall send the message R-B&G. After receiving R-B&G, the VTU-O shall initiate the transition to ShowTime by sending the symbol O-P-SYNCHRO2, which allows a simultaneous transition at both sides in the downstream direction. The VTU-R shall reply by sending the message R-P-SYNCHRO2, which allows a simultaneous transition in the upstream direction.

12.4.6.2 Messages and symbols transmitted by VTU-O

12.4.6.2.1 SOC messages

During the channel analysis and exchange phase, the VTU-O will send the SOC messages O-MSG2, O-CONTRACTn and O-B&G as well as the idle message O-IDLE.

The way these messages are modulated on the transmit symbol is described in 12.4.6.2.2. The sequence in which the messages are sent is illustrated in Figure 12-7 and explained in more detail in 12.4.6.1.

During this state, all messages shall be sent in RQ-mode (see 12.4.2.1).

12.4.6.2.1.1 O-MSG2

This message contains information about the capability of VTU-O for contract negotiation. The content of O-MSG2 shall be as shown in Table 12-23.

Table 12-23/G.993.1 – Description of O-MSG2

Field content	Field or macro-field type	Remark
Message descriptor	1 byte	See Table 12-12.
Minimal SNR margin	1 byte	In units of 0.5 dB
Maximal constellation size in downstream (B_{max_d})	1 byte	Maximum number of bits per tone
RS setting supported by VTU-O	1 byte	0x00: Only mandatory settings 0xFF: All settings
Interleaver settings supported by the VTU-O	1 byte	0x00: Only mandatory settings 0xFF: All settings 0xNN NN = Number of additional (i.e., non-mandatory) settings in hexadecimal (NN ≠ 0x00 and NN ≠ 0xFF)
Detailed interleaver setting description	0 byte if NN = 0x00 or NN = 0xFF, 4xNN otherwise	Interleaver descriptor (see Table 12-24)
Maximal power in downstream	1 byte (unsigned)	In units of 0.25 dBm
Maximum interleaver delay	1 byte	In ms by steps of 0.5 ms (Note 1)
Maximum number of EOC bytes per frame in downstream	1 byte	Number of EOC bytes per frame
Maximum number of VOC bytes per frame in downstream	1 byte	Number of VOC bytes per frame

Table 12-23/G.993.1 – Description of O-MSG2

Field content	Field or macro-field type	Remark
Support of express bit swapping	1 byte	0x00: Not supported 0xFF: Supported
j_{max}	1 byte	Maximum value of j_{max} supported by the VTU-O (Note 2)
NOTE 1 – This field can be set to 0 in order to emulate the fast channel. This field is used for the creation of R-CONTRACT1 even if dual latency is used at the end. NOTE 2 – Specification of $j_{max} = k$ means that all values 0,1, …, k are supported.		

j_{max} is defined in 12.4.6.2.1.3.

The structure of the interleaver descriptor shall be as given in Table 12-24. *I*, *q* and *M* are the interleaver parameters (see 8.4.2).

Table 12-24/G.993.1 – Interleaver descriptor

Field	Field or macro-field type
I	1 byte
q	1 byte
M_{min}	1 byte
M_{max}	1 byte
NOTE – The four fields are repeated for each interleaver setting.	

12.4.6.2.1.2 O-CONTRACTn

This message shall contain a proposal of an upstream and downstream contract and the EOC and VOC capacity, based on the EOC and VOC capabilities of both modems (exchanged during O-MSG1 and R-MSG1). The downstream contract shall be based on the information carried by R-CONTRACT1. Ideally, the downstream contract is the same as the one proposed in R-CONTRACT1. Table 12-25 describes O-CONTRACTn.

Table 12-25/G.993.1 – Description of O-CONTRACTn

Field	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Downstream contract	Contract descriptor (see Table 12-26)
Upstream contract	Contract descriptor
EOC capacity (number of EOC bytes per frame)	1 byte
VOC capacity (value of V; see 8.5.5)	1 byte

Both upstream and downstream contracts shall be encoded in a macro-field called "Contract descriptor". This macro-field contains all the necessary data for the setting of the framing. The contract descriptor shall be as described in Table 12-26. It shall specify the rates in upstream and downstream and the encoder settings.

Table 12-26/G.993.1 – Contract descriptor

Field	Field or macro-field type	Remark
Rate in fast channel	2 bytes	In multiples of 64 kbit/s
RS setting in fast channel	2 bytes	B15 → B8: RS overhead B7 → B0: RS codeword length
Rate in slow channel	2 bytes	In multiples of 64 kbit/s
RS setting in slow channel	2 bytes	B15 → B8: RS overhead B7 → B0: RS codeword length
Interleaver setting	2 bytes	B15 → B8: *M* (Note) B7 → B0: *I*
NOTE – *I* must be a divider of the RS codeword length (in the slow channel).		

12.4.6.2.1.3 O-B&G

O-B&G shall signal the end of the contract negotiation and shall be used to transmit to the VTU-R the bits and the gains information that are to be used in the upstream direction. b_i shall indicate the number of bits to be coded by the VTU-R onto the carrier i; g_i shall indicate the scale factor, relative to the gain that was used for that carrier during the transmission of R-P-MEDLEY, that shall be applied onto the carrier i.

The b_is and g_is shall only be defined for those tones that are used during the transmission of R-P-MEDLEY (i.e., the upstream tones indicated in O-SIGNATURE). Because no bits or energy will be transmitted at the other frequencies (at least in the upstream direction), the corresponding b_is and g_is shall all be presumed to be equal to zero and shall not be transmitted.

The b_is and g_is shall be transmitted in ascending order (i.e., from lowest to highest tone). In case all b_is above a certain tone are zero, the remaining zero values do not have to be transmitted. The VTU-R shall assume that any missing b_is and g_is after the last received value correspond to tones that carry no bits.

Each b_i shall be represented as an unsigned 4-bit integer. Valid b_is shall lie in the range of zero to B_{max_u}, the maximum number of bits that the VTU-R is prepared to modulate onto any subcarrier.

Each g_i shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 001.010000000_2 would instruct the VTU-R to scale the constellation for carrier i, by a gain of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during R-P-MEDLEY.

The whole spectrum shall be split up into groups of adjacent tones such that the number of bits allocated to the carriers of a group is constant. The length of all the groups of carriers need not be constant but it cannot exceed 255 carriers. The scale factor g_i for each carrier within a group is defined by a polynomial interpolation. This polynomial is specified by means of the values taken on at (j_{max} + 1) defined tones, where j_{max} is the order of the polynomial. The (j_{max} + 1) tones are chosen to be (almost) equidistant (see below). In the case of a group of carriers [x_n,x_{n+1}], where x_n and x_{n+1} are the carrier indexes of the lowest and the highest tones respectively of the n-th group of carriers, the (j_{max} + 1) positions X_{nj} of the tones that will be used in the interpolation are defined as:

$$X_{nj} = x_n + \left\lfloor \frac{j(x_{n+1} - x_n)}{j_{max}} \right\rfloor \text{ for } j = 0 \ldots j_{max}$$

j_{max} shall be chosen by the VTU-O based on the values supported by the VTU-R as specified in R-MSG2.

The O-B&G message is defined in Table 12-27.

Table 12-27/G.993.1 – Description of message O-B&G

Field content	Field or macro-field type
Message descriptor	Message code (See Table 12-12.)
j_{max}	1 byte
b_is and g_i information	B&G descriptor (See Tables 12-28 to 12-30.)

Table 12-28/G.993.1 – B&G descriptor $j_{max} = 0$

Byte	Content of field
$2n + 1 \rightarrow 2n + 2$	Specification of tone $n + 1$ for $n = 0$ to $N_{SC} - 2$ (Note) Bits 0-3: Number of bits b_n Bits 4-15: Scale gain g_n
NOTE – If tone n is not used in the upstream direction, specification is not transmitted.	

Table 12-29/G.993.1 – B&G descriptor $j_{max} > 0$ and odd

Byte	Content of field
$1 \rightarrow 2$	N_{gr} (Number of groups of tones)
$3 + n \times (1.5\,j_{max} + 3.5)$ $\rightarrow 3 + (n + 1) \times (1.5\,j_{max} + 3.5) - 1$	Specification of tones in group $n + 1$ for $n = 0$ to $N_{gr} - 1$ Bits 0-3: Number of bits Bits 4-15: Number of carriers of group $n + 1$ Bits $16 + 12\,j \rightarrow 27 + 12\,j$: $g_{X_{nj}}$ for tones $X_{nj}\,j = 0$ to j_{max}

Table 12-30/G.993.1 – B&G descriptor $j_{max} > 0$ and even

Byte	Content of field
$1 \rightarrow 2$	N_{gr} (Number of group of tones)
$3 + n \times (1.5\,j_{max} + 3)$ $\rightarrow 3 + (n + 1) \times (1.5\,j_{max} + 3) - 1$	Specification of tones in group $n + 1$ for $n = 0$ to $N_{gr} - 1$ Bits 0-3: Number of bits Bits 4-11: Number of carriers of group $n + 1$ Bits $12 + 12\,j \rightarrow 23 + 12\,j$: $g_{X_{nj}}$ for tones $X_{nj} = 0$ to j_{max}

12.4.6.2.2 Symbol types transmitted by VTU-O

12.4.6.2.2.1 O-P-MEDLEY

O-P-MEDLEY is a wideband signal used for estimation at the VTU-R of the downstream SNR. O-P-MEDLEY shall be made of all the allowed downstream tones modulated in 4QAM. The symbol length shall be N+CE samples. N shall be set to the value specified in ITU-T Rec. G.994.1 and CE shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). The change in CE shall be made after transmission of O-P-SYNCHRO2. Any change in CE shall be made at the beginning of the DMT symbol (i.e., by changing the number of samples in L_{CP}; see 9.2.2). Windowing shall be applied at the transmitter and the overall window length β shall be equal to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD mask is defined by the network management.

O-P-MEDLEY shall carry 2 bytes of information (b_{15} b_{14} ... b_0) per DMT symbol. The mapping shall be as described in Table 12-31.

Table 12-31/G.993.1 – O-P-MEDLEY bit mapping

Tone index	Constellation point
5, 10, 15, ..., 5*n*, ...	00
1, 11, 21, ..., 10*n* + 1, ...	SOC message bits 0 & 1
2, 12, 22, ..., 10*n* + 2, ...	SOC message bits 2 & 3
3, 13, 23, ..., 10*n* + 3, ...	SOC message bits 4 & 5
4, 14, 24, ..., 10*n* + 4, ...	SOC message bits 6 & 7
6, 16, 26, ..., 10*n* + 6, ...	SOC message bits 8 & 9
7, 17, 27, ..., 10*n* + 7, ...	SOC message bits 10 & 11
8, 18, 28, ..., 10*n* + 8, ...	SOC message bits 12 & 13
9, 19, 29, ..., 10*n* + 9, ...	SOC message bits 14 & 15

The selected constellation points shall be pseudo-randomly rotated by 0, π/2, π or 3π/2 depending on the value of a 2-bit random number provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. Two bits shall be mapped onto each tone including DC. The pseudo-random bit sequence shall continue from one symbol to the next one. The scrambler shall be reset only when the VTU-O enters the channel analysis and exchange state.

NOTE – Between any two consecutive DMT symbols, a number of bits of the random bit generator shall be skipped, as discussed in 12.4.4.2.2.1.

12.4.6.2.2.2 O-P-SYNCHRO2

O-P-SYNCHRO2 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the ShowTime state (in the downstream direction). It uses all the allowed downstream tones modulated in 4QAM. The symbol length shall be *N*+*CE* samples. *N* shall be set to the value specified in ITU-T Rec. G.994.1 and *CE* shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). Windowing shall be applied at the transmitter and the overall window length β shall be set to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD mask is defined by the network management. The overall duration of O-P-SYNCHRO2 shall be 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the 5 first and the 5 last DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. The pseudo-random bit sequence shall continue from symbol to the next one.

The scrambler shall be running free during the transmission of this O-P-SYNCHRO2.

In the downstream direction, the quadrant scrambler shall be disabled after the transmission of O-P-SYNCHRO2.

12.4.6.3 Messages and symbols transmitted by VTU-R

12.4.6.3.1 SOC messages

During the channel analysis and exchange phase, the VTU-R will send the SOC messages R-MSG2, R-CONTRACTn, R-MARGINn and R-B&G as well as the idle message R-IDLE. The way these messages are modulated on the transmit symbol is described in 12.4.6.3.2.

12.4.6.3.1.1 R-MSG2

This message contains information about the capabilities of the VTU-R for bit allocation. The content of R-MSG2 shall be as specified in Table 12-32.

Table 12-32/G.993.1 – Description of R-MSG2

Field	Field or macro-field type	Remark
Message descriptor	1 byte	See Table 12-12.
Maximal constellation size in upstream (B_{max_u})	1 byte	Maximum number of bits per tone
RS setting supported by VTU-R	1 byte	0: Only mandatory settings 1: All settings
Interleaver settings supported by the VTU-R	1 byte	0x00: Only mandatory settings 0xFF: All settings 0xNN NN = Number of additional (i.e., non-mandatory) settings in hexadecimal (NN ≠ 0x00 and NN ≠ 0xFF)
Detailed interleaver setting description	0 byte if NN = 0x00 or NN = 0xFF; 4xNN otherwise	Interleaver descriptor (See Table 12-24.)
Maximal power transmitted	1 byte (unsigned)	In dBm by steps of 0.25 dBm
Maximal interleaver memory	3 bytes	In bytes (Note 1)
Maximum number of EOC bytes per frame in upstream	1 byte	Number of EOC bytes per frame
Maximum number of VOC bytes per frame in upstream	1 byte	Number of VOC bytes per frame
Support of express bit swapping	1 byte	0x00: Not supported 0xFF: Supported
j_{max}	1 byte	Specify maximum value of j_{max} supported by the VTU-R (Note 2)
NOTE 1 – The interleaver memory is computed as $M \times I \times (I - 1)$. NOTE 2 – Specification of $j_{max} = k$ means that all values from 0, 1, ..., k are supported.		

12.4.6.3.1.2 R-CONTRACT1

This message shall contain the proposed downstream contract based on the maximal number of bits in the slow channel based upon the restrictions specified in O-MSG2 (i.e., as if only the slow channel will be used). The contract shall be encoded in a "Contract descriptor" macro-field (see Table 12-26) with all fields related to the fast channel set to 0x00.

12.4.6.3.1.3 R-MARGINn

This message shall contain the SNR margin (i.e., the minimal SNR margin over all tones) computed by the VTU-R for the downstream contract proposed in O-CONTRACTn. Upon reception of R-MARGINn, the VTU-O can decide to choose this contract by sending O-B&G or to propose a new contract by sending O-CONTRACTn. The fields of R-MARGINn are described in Table 12-33.

Table 12-33/G.993.1 – Description of R-MARGINn

Field	Field or macro-field type	Remark
Message descriptor	1 byte	See Table 12-12.
SNR margin	1 byte	In dB by steps of 0.5 dB

12.4.6.3.1.4 R-B&G

R-B&G shall be used to transmit to the VTU-O the bits and the gains information that are to be used in the downstream direction. b_i indicates the number of bits to be coded by the VTU-O onto the carrier i; g_i shall indicate the scale factor, relative to the gain that was used for that carrier during the transmission of O-P-MEDLEY, that shall be applied onto the carrier i.

The b_is and g_is shall only be defined for those tones that are used during the transmission of O-P-MEDLEY (i.e., the downstream tones indicated in O-SIGNATURE). Because no bits or energy will be transmitted at the other frequencies (at least in the downstream direction), the corresponding b_is and g_is shall all be presumed to be set to zero and shall not be transmitted.

The b_is and g_is shall be transmitted in ascending order (i.e., from lowest to highest tone). In case all b_is above a certain tone are zero, the remaining zero values do not have to be transmitted. The VTU-O shall assume that any missing b_is and g_is after the last received value correspond to tones that carry no bits.

Each b_i shall be represented as an unsigned 4-bit integer, with valid b_is lying in the range of zero to $B_{\max\_d}$, the maximum number of bits that the VTU-O is prepare to modulate onto any subcarrier.

Each g_i shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 001.010000000_2 would instruct the VTU-O to scale the constellation for carrier i, by a gain of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during O-P-MEDLEY.

If use of a dedicated pilot tone, k, is required, the VTU-R shall indicate this requirement to the VTU-O by sending the value "2" in the position of b_k in the bit table in R-B&G. In the gain table, it shall transmit a value of zero for the gain scaling of tone k. Receipt by the VTU-O of "2" in a bit table entry and zero in the corresponding gain scaling table entry indicates that this tone has been selected as a dedicated pilot and that it should be loaded with the 4QAM constellation point 00 during every symbol.

The whole spectrum shall be split up into groups of adjacent tones such that the number of bits allocated to the carriers of a group is constant. The length of all the groups of carriers need not be constant but it cannot exceed 255 carriers. The scale factor for each carrier within a group shall be defined by a polynomial interpolation. This polynomial shall be specified by means of the values taken on at ($j_{\max}$ + 1) defined tones, where $j_{\max}$ is the order of the polynomial. The ($j_{\max}$ + 1) tones are chosen to be (almost) equidistant (see below). In the case of a group of carriers $[x_n, x_{n+1}]$, where x_n and x_{n+1} are the carrier indexes of the lowest and the highest tones respectively of the nth group of carriers, the ($j_{\max}$ + 1) X_{nj} positions are defined as:

$$X_{nj} = x_n + \left\lfloor \frac{j(x_{n+1} - x_n)}{j_{\max}} \right\rfloor \text{ for } j = 0 \ldots j_{\max}$$

$j_{\max}$ shall be chosen by the VTU-R based on the values supported by the VTU-O as specified in O-MSG2.

Table 12-34/G.993.1 – Description of message R-B&G

Field content	Field or macro-field type
Message descriptor	Message code (See Table 12-12.)
j_{max}	1 byte
b_i's and g_i's information	B&G descriptor (See Tables 12-28 to 12-30.)

12.4.6.3.2 Symbol types transmitted by VTU-R

12.4.6.3.2.1 R-P-MEDLEY

R-P-MEDLEY is a wideband signal used for estimation at the VTU-O of the upstream SNR. It is made of all the allowed upstream tones modulated in 4QAM. The symbol length shall be $N+CE$ samples. N shall be set to the value specified in ITU-T Rec. G.994.1 and CE shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). Any change in CE shall be made at the beginning of the DMT symbol (i.e., by changing the number of samples in L_{CP}; see 9.2.2). Windowing shall be applied at the transmitter and the overall window length β shall be as specified in O-SIGNATURE (see 12.4.4.2.1.1). The transmit PSD mask shall meet the power back-off requirements. The timing advance shall be applied and shall correspond to the loop length as estimated by the VTU-O. R-P-MEDLEY shall carry two bytes of information (b_{15} b_{14} ... b_8) and (b_7 b_6 ... b_0) per DMT symbol. These shall be mapped as described in Table 12-35.

Table 12-35/G.993.1 – R-P-MEDLEY bit mapping

Tone index	Constellation point
5, 10, 15, ..., 5n, ...	00
1, 11, 21, ..., 10n + 1, ...	SOC message bits 0 & 1
2, 12, 22, ..., 10n + 2, ...	SOC message bits 2 & 3
3, 13, 23, ..., 10n + 3, ...	SOC message bits 4 & 5
4, 14, 24, ..., 10n + 4, ...	SOC message bits 6 & 7
6, 16, 26, ..., 10n + 6, ...	SOC message bits 8 & 9
7, 17, 27, ..., 10n + 7, ...	SOC message bits 10 & 11
8, 18, 28, ..., 10n + 8, ...	SOC message bits 12 & 13
9, 19, 29, ..., 10n + 9, ...	SOC message bits 14 & 15

The selected constellation points shall be pseudo-randomly rotated by 0, π/2, π or 3π/2 depending on the value of a 2-bit random number, provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. Two bits shall be mapped onto each tone including DC. The pseudo-random bit sequence shall continue from one symbol to the next one.

NOTE – Between any two consecutive DMT symbols, a number of output bits of the random bit generator shall be skipped, as discussed in 12.4.4.2.2.1.

12.4.6.3.2.2 R-P-SYNCHRO2

R-P-SYNCHRO2 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the ShowTime state (in the upstream direction). It uses all the allowed upstream tones modulated in 4QAM. The symbol length shall be $N+CE$ samples. N shall be set to the value specified in ITU-T Rec. G.994.1 and CE shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). Windowing shall be applied at the transmitter and the overall window length β shall be set to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD shall conform with the UPBO requirements. The overall duration of R-P-SYNCHRO2 shall be 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the 5 first and the 5 last

DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by 0, $\pi/2$, π, $3\pi/2$ depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. The pseudo-random bit sequence shall continue from symbol to the next one.

The scrambler shall be running free during the transmission of this R-P-SYNCHRO2.

In the upstream direction, the quadrant scrambler shall be disabled after the transmission of R-P-SYNCHRO2.

13 Electrical requirements

13.1 Service splitters

13.1.1 General

A service splitter (splitter filter) is required at both ends of the line that carries VDSL signals if existing narrow-band services are to remain unaffected by the presence of VDSL signals on the same wire-pair. The structure of the splitter filter is given in Figure 13-1. 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 the used narrow-band service.

The splitter filter requirements are intended to guarantee the proper operation of POTS and ISDN-BA on lines that carry VDSL signals. The requirements of the high-pass filter are more dependent on the VDSL transceiver structure and may be partially combined with an all pass function of the VDSL branch.

NOTE – Splitter implementations may be subject to additional administration-imposed requirements, beyond those contained herein.

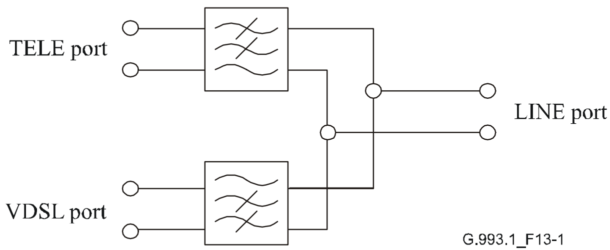


Figure 13-1/G.993.1 – Structure of the VDSL splitter filter

The splitter shall meet the requirements with all VDSL transceiver impedance values that are tolerated by its return loss specification. The reference impedance values associated with the TELE and VDSL ports are as follows:

- TELE port: Z_M
- VDSL port: R_V

The particular values of Z_M and R_V are regionally specific and specified in Annexes D, E and F.

The basic electrical requirements for the splitter are listed in Table 13-1. The values of the parameters, as well as other specific requirements, are regionally specific and described in regional specific annexes (e.g., Annexes D, E and F).

Table 13-1/G.993.1 – Basic VDSL splitter filter electrical requirements

#	Requirement
1	TELE port to LINE port insertion loss into Z_M, and the insertion loss variation (ripple)
2	TELE port and LINE port return loss against Z_M, and return loss variation (ripple) when the other port is terminated in Z_M
3	LINE port to VDSL port insertion loss into R_V, and the insertion loss variation (ripple)
4	LINE port and VDSL port return loss against R_V, and return loss variation (ripple) when the other port is terminated in R_V
5	TELE port to VDSL port isolation
6	The common-mode isolation between TELE and LINE ports
7	TELE port to LINE port DC resistance

The requirements of Table 13-1 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;
- with a mismatched impedance due to reasonable fault conditions at this port (e.g., line break, typical resistive load, ringer load, etc.).

14 Testing methodology

14.1 VDSL test loop types

Test loops characterized twisted pairs used for VDSL deployment and shall be used for testing and competitive evaluations of VDSL modems. Test loops (VDSL0 – VDSL1) presented in Figure 14-1 characterize the most generic case. Loop VDSL0 is a symbolic name for a loop with near zero length to prove that the VDSL transceiver can handle the potentially high signal levels when two transceivers are directly interconnected. Loop VDSL1 is useful for a generic range test. The values of X and Y vary for different bit rates of the system under test. Other types of test loop, which are specific for different regions, are described in Annexes D, E, and F.

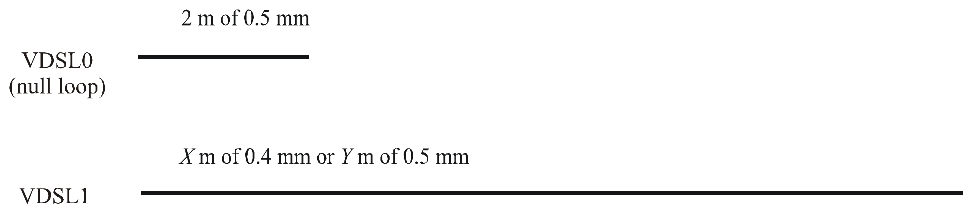


Figure 14-1/G.993.1 – Generic VDSL test loops

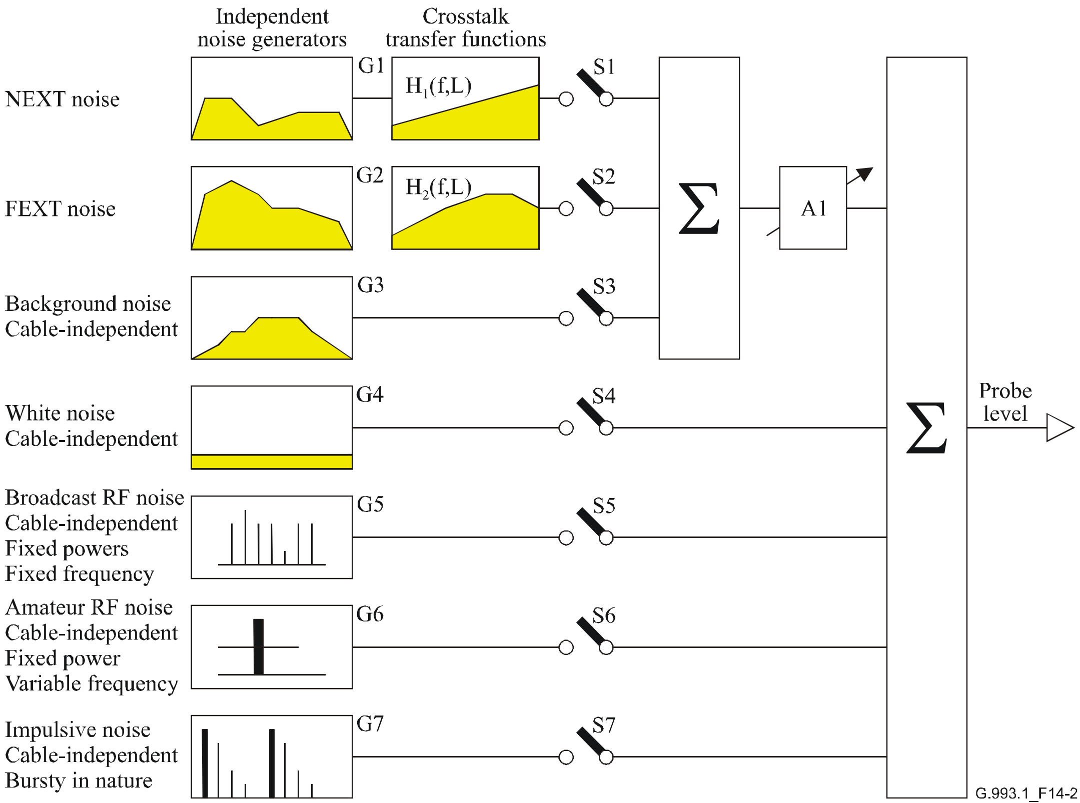
NOTE – The parameter values for loop types with wire gauge 0.4 mm and 0.5 mm are region-specific. For comparative analysis the loops types TP1 (0.4 mm) and TP2 (0.5 mm) as specified in ITU-T Rec. G.996.1 may be used.

14.2 Impairment generators

Figure 14-2 defines a functional diagram of the composition of the impairment noise. It defines a functional description of the combined impairment noise, as it shall be probed at the receiver input of a VDSL transceiver under test.

The functional diagram has the following elements:

- The seven impairment "generators" G1 to G7 simulate the noise in the loop. Their noise characteristics are independent of the test loops and bit rates.
- 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. 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 12 MHz. Unless otherwise specified, its gain is fixed at 0 dB.
- The square of the magnitude of the transfer functions, $|H_1(f,L)|^2$ and $|H_2(f,L)|^2$, for NEXT and FEXT simulation, respectively, are defined in 14.2.1.



NOTE – Generator G7 is the only one that is symbolically shown in the time domain. Others are shown in the frequency domain.

Figure 14-2/G.993.1 – Functional diagram of the composition of the impairment noise

The same functional diagram shall be used for impairment tests in downstream and upstream directions. Each test has its own impairment specification. The overall impairment noise shall be characterized by the sum of the individual components as specified in the relevant subclauses.

Several deployment scenarios can be applied to VDSL testing. These scenarios are representative of the impairments that can be found in metallic access networks.

14.2.1 Crosstalk noise

The crosstalk noise impairments are reflected by generators G1-G3. Their noise characteristics are independent from the test loops and bit rates.

Near-end crosstalk or NEXT shall be a Gaussian signal with the square of the magnitude of its transfer function defined as:

$$|H_1(f,L)|^2 = K_{\text{NEXT}}(1/49)^{0.6} f^{1.5}[1-|H(f,L)|^4]$$

Similarly, the square of the magnitude of the transfer function of far-end crosstalk or FEXT is defined as:

$$|H_2(f,L)|^2 = |H(f,L)|^2 K_{\text{FEXT}}(1/49)^{0.6} Lf^2$$

where:

$|H(f,L)|$ is the magnitude of loop insertion gain transfer function

K_{NEXT} and K_{FEXT} are crosstalk coupling coefficients, $K_{\text{NEXT}} = 8.818 \times 10^{-14}$, and $K_{\text{FEXT}} = 7.999 \times 10^{-20}$

L is loop length in feet

f is frequency in hertz.

The factor $(1/49)^{0.6}$ accounts for the fact that the alien and self-noise transmit PSDs have already been scaled up to account for the effective number of disturbers of each type.

14.2.1.1 Crosstalk noise model definition

The two main deployment scenarios, Fibre-To-The-Exchange (FTTEx) and Fibre-To-The-Cabinet (FTTCab), are considered for noise model definition. Each scenario results in a length-dependent PSD of noise, reflecting the distance between the exchange and the cabinet ($L1$) and also distances $L2$ and $L3$ as described in Figure 14-3. The crosstalk to be emulated by G1 and G2 comprise of "self-crosstalk" and "alien crosstalk". The self-crosstalk is caused by the VDSL systems, and the alien-crosstalk is due to other systems. The PSD mask of the generator G1 and G2 for alien crosstalk shall both be attenuated in the FTTCab scenario by the value that reflects the attenuation of the corresponding signals while propagating from the exchange to the cabinet. For performance evaluation purposes, length $L1$ shall be set to 1000 m, length $L2$ shall be set equal to the length of the applicable test loop, and length $L3$ shall be set to 0 m.

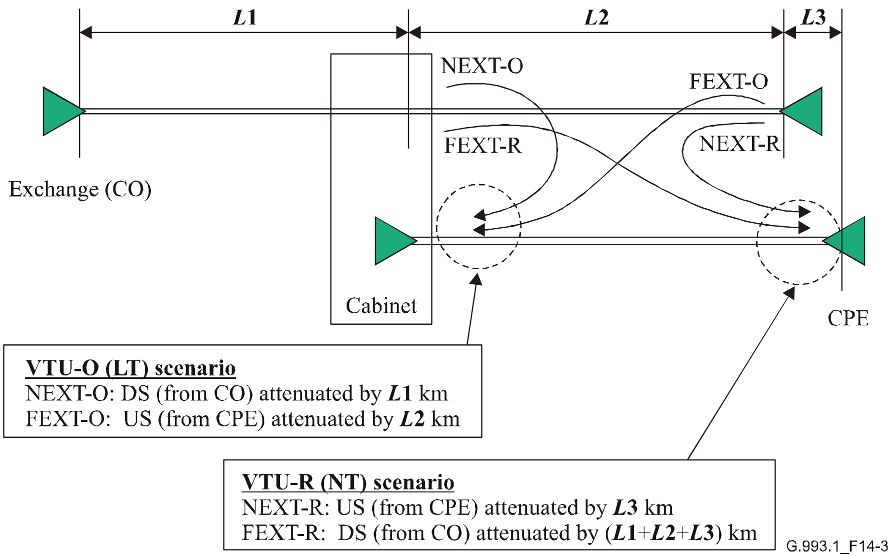


Figure 14-3/G.993.1 – Alien crosstalk noise model definition for different scenarios

The model for self-crosstalk noise in all cases shall include 20 VDSL disturbers. The model for alien crosstalk noise depends on the type and the expected amount of other (alien) DSL operating over the same binder and is regionally specific.

14.2.1.2 NEXT noise generator [G1]

The NEXT noise generator represents all impairments that are identified as crosstalk noise from a predominantly Near-end origin. The [G1] noise when filtered by the NEXT crosstalk coupling function $H_1(f,L)$ 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 14.2.1.4. These profiles shall be met for all frequencies of the VDSL range. For verification purposes 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 12.2.1.4.
– "XA.LT.#" and "XA.NT.#" refer to the alien-crosstalk profiles defined in 12.2.1.4.
– "♦" defines the crosstalk sum of two PSDs as P_{XS} ♦ $P_{XA} = (P_{XS}^{1/0.6} + P_{XA}^{1/0.6})^{0.6}$ where P is the PSD in W/Hz.

The PSD of G1 is independent of the cable NEXT coupling. The magnitude response of the NEXT coupling function $H_1(f,L)$ is specified in 14.2.1.

The noise from this generator shall be non-correlated with all other noise sources in the impairment generator and non-correlated with the VDSL system under test. The noise shall be random in nature with a near-Gaussian amplitude distribution as specified in 14.2.6.

14.2.1.3 FEXT noise generator [G2]

The FEXT noise generator represents all impairments that are identified as crosstalk noise from a predominantly Far-end origin. The [G2] noise when filtered by the FEXT crosstalk coupling function $H_2(f,L)$ 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 14.2.1.4. These profiles shall be met for all frequencies in the VDSL range. 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 12.2.1.4.
– "XA.LT.#" and "XA.NT.#" refer to the alien-crosstalk profiles defined in 12.2.1.4.
– "♦" defines the crosstalk sum of two PSDs as P_{XS} ♦ $P_{XA} = (P_{XS}^{1/0.6} + P_{XA}^{1/0.6})^{0.6}$ where P is the PSD in W/Hz.

The PSD of G2 shall be independent of the cable FEXT coupling. The magnitude response of FEXT coupling function $H_2(f,L)$ is specified in 14.2.1.

The noise from this generator shall be non-correlated with all other noise sources in the impairment generator and non-correlated with the VDSL system under test. The noise shall be random in nature with a near-Gaussian amplitude distribution as specified in 14.2.6.

14.2.1.4 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. 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.

14.2.1.4.1 Self-crosstalk profiles

The noise profile of self-crosstalk is implementation-specific to the VDSL system under test. The transceiver manufacturers shall determine the VDSL transmit signal spectrum of the VDSL system under test at both LT and NT (VDSL.LT.# or VDSL.NT.#) over the full VDSL band as observed at the Tx port of the test set-up described in 14.3.1. The resolution bandwidth for measurement shall be 10 kHz, but regional requirements may apply.

Separate spectral profiles shall be 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 shall be applied to generator G1. When testing the downstream, this profile is applied to generator G2. The self-crosstalk profile is specified in Table 14-1.
- 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 14-1.

Table 14-1/G.993.1 – 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 approximates the power generated by the sum of 20 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 template/mask as the transceiver under test, but not necessarily with the same transmit PSD.

14.2.1.4.2 Alien-crosstalk profiles

Alien crosstalk models A-F are regional-specific and described in Annexes E, D and F. Separate spectral profiles shall be 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 shall be applied to generator G1. When testing the downstream, this profile shall be applied to generator G2. The alien-crosstalk profiles are specified in Annexes D, E and F.

- 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 shall be applied to generator G2. When testing the downstream, this profile is applied to generator G1. The alien-crosstalk profiles are specified in Annexes D, E and F.

14.2.2 Background noise generator [G3]

The background noise generator G3 shall generate coloured noise. For the tests specified in this Recommendation, G3 shall be inactive and shall be set to zero.

14.2.3 Additive white Gaussian noise generator [G4]

The Additive White Gaussian Noise (AWGN) generator G4 shall have a flat PSD of –140 dBm/Hz in the whole VDSL frequency band, as specified in 6.1.

14.2.4 Radio 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 differential or transmission mode of the wire-pair. These interference sources have more temporal stability than the amateur/ham interference (noise generator [G6]) because their carrier is not suppressed. The modulation index (MI) and the carrier frequencies of broadcast transmitters are regionally-specific. Each simulated RFI threat may include several simulated AM broadcast stations in the SW, MW and LW band. For some regions the requirements are specified in Annexes D, E and F.

14.2.5 Amateur radio noise generator [G6]

The amateur radio noise generator represents a large (almost impulse-like) RF interference that has changing temporal characteristics due to the single-sideband suppressed nature of the amateur radio transmission. The interference exhibits severe temporal variations, and can be high in amplitude, and can occur anywhere within the regionally 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. The amateur radio noise bands are specified in Table 14-2. The modulating base-band signal shall be speech-weighted noise as specified in ITU-T Rec. G.227. Some regional-specific amateur bands, the amateur noise power to be applied are specified in Annexes D, E and F.

Table 14-2/G.993.1 – Amateur radio noise bands

Band start [kHz]	Band stop [kHz]
1 800	2 000
3 500	4 000
7 000	7 300
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 700

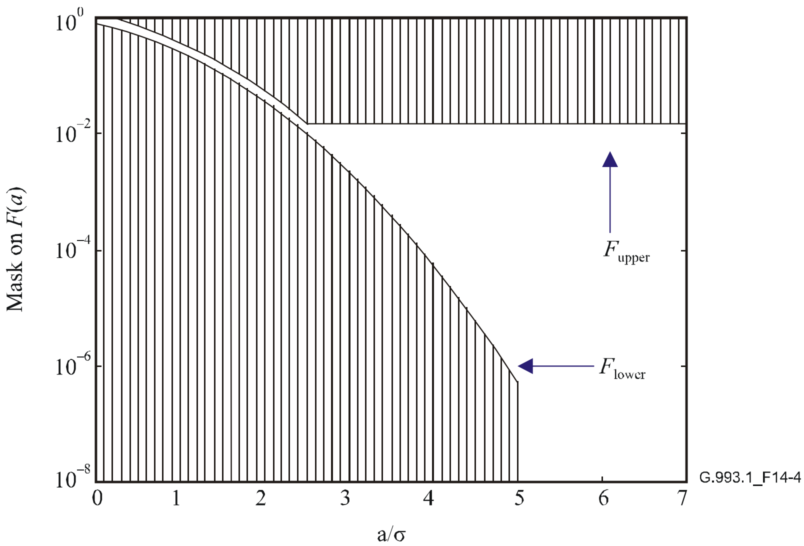
14.2.6 Impulse noise model [G7]

The impulse noise generator is required to prove the burst noise immunity of the VDSL transceiver. The noise shall consist of bursts of additive white Gaussian noise (AWGN) 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 shall be approximately 0.5 (assuming FEC is not applied). The noise burst shall be applied regularly at a repetition rate of at least 1 Hz.

The duration of the burst is variable; at least values of 10, 50, 100, 250, and 500 µs shall be supported. The AWGN shall be generated with crest-factor of 5 and flat PSD up to 12 MHz, and further continuously declined with a roll-off equal to or steeper than 12 dB per octave. The PSD of the AWGN shall be variable in the range from –70 dBm/Hz to –140 dBm/Hz.

14.2.7 Time domain profiles of generators [G1] to [G4]

The noise as specified in the frequency domain shall be random in nature and near-Gaussian distributed, which means that the amplitude distribution function of the combined impairment noise injected at the adding element shall lie between the two boundaries as illustrated in Figure 14-4 and defined in Table 14-3.



NOTE The non-shaded area is the allowed region.

Figure 14-4/G.993.1 – Mask for the amplitude distribution function

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 $F(a)$ shall decrease up to the point where "a" equals the peak value of the signal. From there on, $F(a)$ shall vanish:

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

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).

Table 14-3/G.993.1 – Upper and lower boundaries of the amplitude distribution function of the noise

Boundary (σ = rms value of noise)	**Interval**	**Parameter**	**Value**
$F_{lower}(a) = (1-\varepsilon)\times\{1-\mathrm{erf}((a/\sigma)/\sqrt{2})\}$	$0 \le a/\sigma < CF$	crest factor	CF = 5
$F_{lower}(a) = 0$	$CF \le a/\sigma < \infty$	Gaussian gap	ε = 0.1
$F_{upper}(a) = (1+\varepsilon)\times\{1-\mathrm{erf}((a/\sigma)/\sqrt{2})\}$	$0 \le a/\sigma < A$		A = CF/2 = 2.5
$F_{upper}(a) = (1+\varepsilon)\times\{1-\mathrm{erf}(A/\sqrt{2})\}$	$A \le a/\sigma < \infty$	Gaussian gap	ε = 0.1

The meaning of the parameters in Table 14-3 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 practical repetition length.

14.3 Transmission performance tests

VDSL systems shall be tested to verify BER ≤ 10^{-7} and a minimum noise margin of 6 dB using the test set-up specified in 14.3.1 and test procedures specified in 14.3.2. This noise margin indicates the amount of increase of crosstalk noise or impulse noise level that the system can tolerate under operational conditions while still ensuring required transmission quality.

14.3.1 Test setup

Figure 14-5 illustrates the functional description of the test set-up. It shall include:

– the relevant test loop, as specified in 14.1 or Annexes D, E, F;

– the impairment noise generator, as specified in 14.2;

– an Adding Element to add the relevant impairment noise to the test loop;

– a high impedance, and well balanced (e.g., better than 60 dB balance across the whole VDSL band) differential voltage probe connected with level detectors such as a spectrum analyser or a true RMS volt-meter.

NOTE – Test Loop VDSL0 may be used for calibrating and verifying the correct settings of impairment noise generators when performing performance tests.

The transfer function and impedance of the test-loop between port Tx (node pairs A1, B1) and port Rx (node pair A2, B2) 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 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 do not appreciably deteriorate the balance about earth of the transceiver under test.

The signal flow through the test set-up shall be from port Tx to port Rx. Measuring upstream and downstream performance requires an interchange of transceiver position and test loop end.

The received signal level at port Rx shall be 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 shall be switched off during this measurement. The transmitted signal level at port Tx shall be measured between node A1 and B1, under the same conditions.

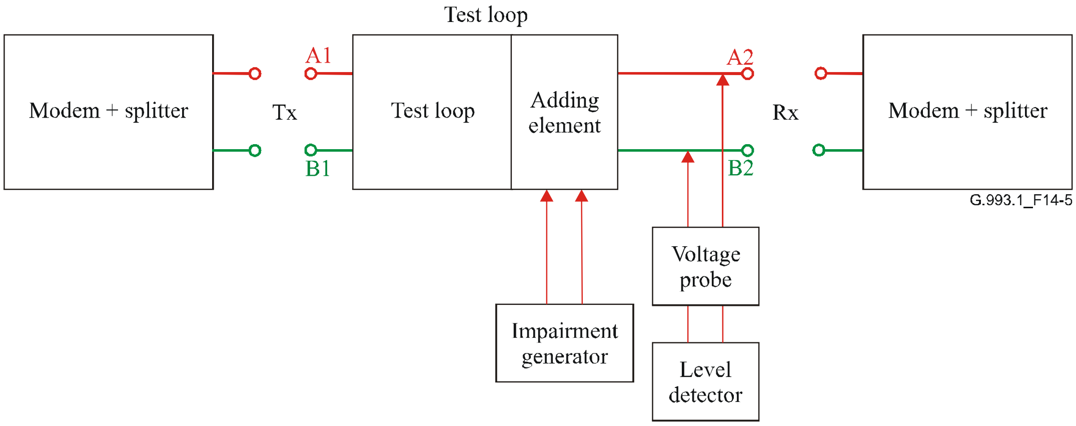


Figure 14-5/G.993.1 – Functional description of the set-up of the performance tests

The impairment noise generator shall be as defined in 14.2. The level of inserted impairment noise shall be measured at port Rx, between node A2 and B2, while port Tx as well as port Rx are terminated with the Termination impedance R_V. The signal and the impairment noise levels shall be probed with a well-balanced differential voltage probe. The differential impedance between the tips of the probe shall be higher than the shunt impedance of 100 kΩ in parallel with 10 pF. Figure 14-5 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 various levels of signals and impairment noise specified in this Recommendation are defined at the Tx or Rx side of this set-up. For all power measurements, probing an RMS-voltage of U_{RMS} [V] at the test point terminated by the resistive impedance of R_V means the power level of P [dBm] over the full band equals:

$$P = 10\log_{10}\left(\frac{U_{RMS}^2}{R_v}\cdot 1000\right), \text{ in dBm}$$

Probing an RMS-voltage U_{RMS} [V] in this set-up within a small frequency band of f [Hz] means an average power spectral density level of PSD [dBm/Hz] within that filtered band that equals:

$$PSD = 10\log_{10}\left(\frac{U_{RMS}^2}{R_v}\cdot\frac{1000}{\Delta f}\right), \text{ in dBm/Hz}$$

The bandwidth f shall identify the noise bandwidth of the filter, but not the 3 dB bandwidth. The value of f shall be 10 kHz, but regional requirements may apply.

14.3.2 Measuring noise margin

Before start-up of the VDSL transceiver under test, the level and shape of the crosstalk noise or impulse noise are adjusted so that the level observed at port Rx in Figure 14-5 meets the impairment level specification. 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 14-2, 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 x 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 requirement of 10^{-7} remains valid in order to pass the transmission performance test.

The noise margins shall be measured for upstream as well as downstream transmission under all relevant test loops and noise generator settings.

14.3.3 Noise generator sets for different test scenarios

The set of noise generators valid for VDSL performance tests to be carried out to prove adequate upstream and downstream performance is regionally specific. For some regions the set of noise generators is specified in Annexes D, E and F.

Annex A

Bandplan A

Table A.1 defines the frequencies and usage of Bandplan A as illustrated in Figure A.1.

NOTE – Bandplan A is formerly called Plan 998.

Table A.1/G.993.1 – Bandplan A

	[MHz]	Direction
f_0-f_1	0.025-0.138	Usage and Directional are optional
f_1-f_2	0.138-3.75	Downstream
f_2-f_3	3.75-5.2	Upstream
f_3-f_4	5.2-8.5	Downstream
f_4-f_5	8.5-12	Upstream

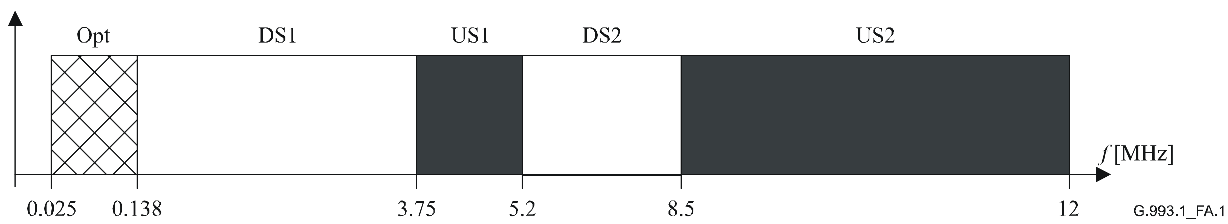


Figure A.1/G.993.1 – Bandplan A

Annex B

Bandplan B

Table B.1 defines the frequencies and usage of Bandplan B as illustrated in Figure B.1.

NOTE – Bandplan B is formerly called Plan 997.

Table B.1/G.993.1 – Bandplan B

	[MHz]	Direction
f_0-f_1	0.025-0.138	Usage and Directional are optional
f_1-f_2	0.138-3.0	Downstream
f_2-f_3	3.0-5.1	Upstream
f_3-f_4	5.1-7.05	Downstream
f_4-f_5	7.05-12	Upstream

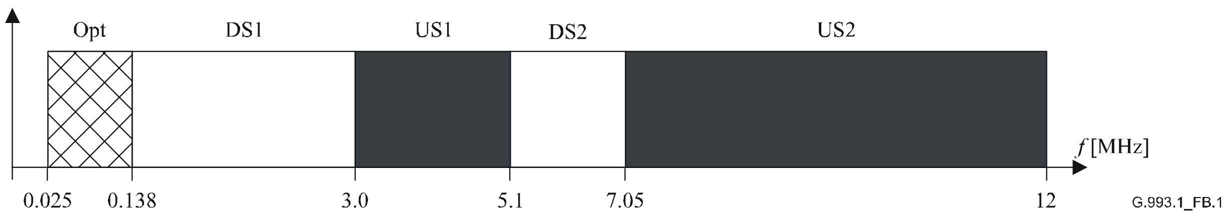


Figure B.1/G.993.1 – Bandplan B

Annex C

Bandplan C

NOTE – This annex is intended for use in Sweden only.

Table C.1 defines the frequencies and usage of Bandplan C as illustrated in Figure C.1.

F_x is a variable frequency.

Table C.1/G.993.1 – Bandplan C

	[MHz]	Direction
f_0-f_1	0.025-0.138	Usage and Directional are optional
f_1-f_2	0.138-2.5	Downstream
f_2-f_3	2.5-3.75	Upstream
f_3-f_4	3.75-F_x	Downstream
f_4-f_5	F_x-12	Upstream

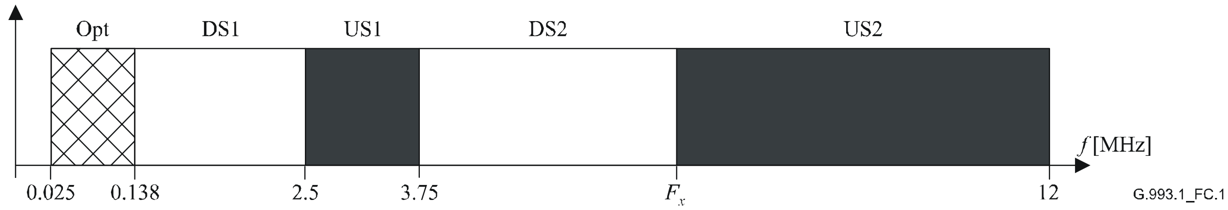


Figure C.1/G.993.1 – Bandplan C

Annex D

Requirements for Region A (North America)

D.1 Physical interface

D.1.1 Bandplan

Bandplan A as specified in Annex A shall be used.

D.1.2 Wideband transmit power

As specified in [American National Standard Institute (ANSI)].

D.1.3 PSD of the transmit signal

As specified in [ANSI].

D.1.4 Termination impedance

As specified in [ANSI].

D.1.5 Reference PSD

The values of PSD_REF for noise environments as specified in 6.3.1 and transmit signal PSDs as specified in 6.3.1 shall be as defined in [ANSI].

D.2 Testing methodology

D.2.1 Noise models

D.2.1.1 Alien crosstalk noise models

As specified in [ANSI].

D.2.1.2 RFI noise generators models

As specified in [ANSI].

D.2.2 Test loops

As specified in [ANSI].

D.2.3 Service splitters and electrical characteristics

As specified in [ANSI].

Annex E

Requirements for Region B (Europe)

E.1 Physical interface

E.1.1 Bandplan

Bandplan A as specified in Annex A or Bandplan B as specified in Annex B may be used with restrictions specified in [ETSI].

E.1.2 Wideband transmit power

As specified in [ETSI].

E.1.3 PSD of the transmit signal

As specified in [ETSI].

E.1.4 Termination impedance

As specified in [ETSI].

E.1.5 Reference PSD

The values of PSD_REF for noise environments as specified in 6.3.1 and transmit signal PSDs as specified in 6.3.1 shall be as defined in [ETSI].

E.2 Testing methodology

E.2.1 Noise models

E.2.1.1 Alien crosstalk noise models

As specified in [ETSI].

E.2.1.2 RFI noise generators models

As specified in [ETSI].

E.2.2 Test loops

As specified in [ETSI].

E.2.3 Service splitters and electrical characteristics

As specified in [ETSI].

Annex F

Regional requirements for environment coexisting with TCM-ISDN DSL as defined in Appendix III/G.961

F.1 Bandplan and PSD masks

F.1.1 Bandplan

The bandplan shall be compliant to Bandplan A specified in Annex A. Subsets composed of at least one downstream band and one upstream band among DS1, US1, DS2 and US2 may be implemented.

F.1.2 Transmit signal PSD masks

F.1.2.1 VDSL system operating in the frequency region above POTS band

The frequencies above 138 kHz are used for VDSL. The use of the optional band between 25 kHz and 138 kHz is specified in Table F.2.

A nominal PSD of –60 dBm/Hz applies across the whole transmit-band frequency range. The PSD mask defines the transmit power spectral density limitation, and is defined as 3.5 dB above the nominal PSD in dBm/Hz. The PSD requirements are specified in Table F.1 for VTU-O transmitter (downstream) and Table F.2 for VTU-R transmitter (upstream), and shall be measured at the U interface point defined in Figure 5-2, where the U interface point corresponds to LINE port defined in Figure F.1.

NOTE 1 – This annex specifies a full flat transmit signal PSD of –60 dBm/Hz as a widely common PSD.

NOTE 2 – The stop-band PSD requirements specified in this annex are compliant to those in 6.2.2. The requirements are also applied to the out-of-bands below 0.138 MHz and above 12 MHz in this annex, excepting that the transition band of 0.018 MHz (= 0.138 MHz – 0.12 MHz) is adopted at the band separating frequency of 0.138 MHz.

Table F.1/G.993.1 – VTU-O transmit PSD requirements (VDSL above POTS band)

Band attribute	Frequency band f [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	–120	–	8.4
	$0.12 \le f \le 0.138$	$-60 + (50/0.018) \times (f - 0.138)$	–	
DS1	$0.138 < f < 3.75$	–60 + 3.5 (= –56.5)	–	
	$3.75 \le f \le 3.925$	$-80 - (20/0.175) \times (f - 3.75)$	–	
	$3.925 < f < 5.025$	–100	–50	
	$5.025 \le f \le 5.2$	$-80 + (20/0.175) \times (f - 5.2)$	–	
DS2	$5.2 < f < 8.5$	–60 + 3.5 (= –56.5)	–	
	$8.5 \le f \le 8.675$	$-80 - (20/0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	–100	–52	
	$30 \le f < \infty$	–120	–	–

Table F.1/G.993.1 – VTU-O transmit PSD requirements (VDSL above POTS band)

NOTE 1 – All PSD and power measurements are in 100 Ω. NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth. NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth. NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2, excepting transition band below 138 kHz.

Table F.2/G.993.1 – VTU-R transmit PSD requirements (VDSL above POTS and ISDN bands)

Band attribute	Frequency band *f* [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	–120	–	7.0
	$0.12 \le f < 0.225$	–110	–	
	$0.225 \le f < 3.575$	–100	–	
	$3.575 \le f \le 3.75$	$-80 + (20/0.175) \times (f - 3.75)$	–	
US1	$3.75 < f < 5.2$	$-60 + 3.5$ (= –56.5)	–	
	$5.2 \le f \le 5.375$	$-80 - (20/0.175) \times (f - 5.2)$	–	
	$5.375 < f < 8.325$	–100	–52	
	$8.325 \le f \le 8.5$	$-80 + (20/0.175) \times (f - 8.5)$	–	
US2	$8.5 < f < 12$	$-60 + 3.5$ (= –56.5)	–	
	$12 = f \le 12.175$	$-80 - (20/0.175) \times (f - 12)$	–	
	$12.175 < f < 30$	–100	–52	
	$30 \le f < \infty$	–120	–	–

NOTE 1 – All PSD and power measurements are in 100 Ω.

NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.

NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.

NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2.

F.1.2.2 VDSL system operating in the frequency region above TCM-ISDN DSL band

The frequencies above 640 kHz are used for VDSL. The frequencies below 320 kHz are used for TCM-ISDN DSL, and the band between 320 kHz and 640 kHz are used for guardband.

The nominal PSD of –60 dBm/Hz applies across the whole transmit-band frequency range. The PSD mask defines the transmit power limitation, and is defined as 3.5 dB above the nominal PSD in dBm/Hz. The PSD requirements are specified in Table F.3 for VTU-O transmitter (downstream) and Table F.2 for VTU-R transmitter (upstream), and shall be measured at the U interface point defined in Figure 5-2, where the U interface point corresponds to LINE port defined in Figure F.1.

NOTE – The stop-band PSD requirements specified in this annex are compliant to those in 6.2.2. The requirements are also applied to the out-of bands below 0.64 MHz and above 12 MHz in this annex.

Table F.3/G.993.1 – VTU-O transmit PSD requirements (VDSL above TCM-ISDN DSL band)

Band attribute	Frequency band f [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	–120	–	8.1
	$0.12 \le f < 0.225$	–110	–	
	$0.225 \le f < 0.465$	–100	–	
	$0.465 \le f \le 0.640$	$-60 + (40/0.175) \times (f - 0.64)$	–	
DS1	$0.640 < f < 3.75$	–60 + 3.5 (= –56.5)	–	
	$3.75 \le f \le 3.925$	$-80 - (20/0.175) \times (f - 3.75)$	–	
	$3.925 < f < 5.025$	–100	–50	
	$5.025 \le f \le 5.2$	$-80 + (20/0.175) \times (f - 5.2)$	–	
DS2	$5.2 < f < 8.5$	–60 + 3.5 (= –56.5)	–	
	$8.5 \le f \le 8.675$	$-80 - (20/0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	–100	–52	
	$30 \le f < \infty$	–120	–	–

NOTE 1 – All PSD and power measurements are in 100 Ω.

NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.

NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.

NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2.

F.1.2.3 VDSL system with PSD reduction function in the frequency region below 1.104 MHz

The PSD reduction requirements are specified in Table F.4 for VTU-O transmitter (downstream), and shall be measured at the U interface point defined in Figure 5-2, where the U interface point corresponds to LINE port defined in Figure F.1.

NOTE – The stop-band PSD requirements specified in 6.2.2 are applied to PSD reduction function below 1.104 MHz in this annex.

Table F.4/G.993.1 – VTU-O transmit PSD requirements (VDSL with PSD reduction function below 1.104 MHz)

Band attribute	Frequency band f [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	–120	–	7.8
	$0.12 \leq f < 0.225$	–110	–	
	$0.225 \leq f < 0.850$	–100	–	
	$0.850 \leq f \leq 1.104$	$-60 + (40/0.254) \times (f - 1.104)$	–	
DS1	$1.104 < f < 3.75$	$-60 + 3.5$ (= –56.5)	–	
	$3.75 \leq f \leq 3.925$	$-80 - (20/0.175) \times (f - 3.75)$	–	
	$3.925 < f < 5.025$	–100	–50	
	$5.025 \leq f \leq 5.2$	$-80 + (20/0.175) \times (f - 5.2)$	–	
DS2	$5.2 < f < 8.5$	$-60 + 3.5$ (= –56.5)	–	
	$8.5 \leq f \leq 8.675$	$-80 - (20/0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	–100	–52	
	$30 \leq f < \infty$	–120	–	–

NOTE 1 – All PSD and power measurements are in 100 Ω.

NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.

NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.

NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2. The stop-band PSD requirements are also applied for the transition band below 1.104 MHz.

F.1.2.4 Transmit notches

As defined in 6.2.4, the maximum PSD within the amateur radio bands shall be able to be reduced below –80 dBm/Hz. In order to reduce egression to amateur radio receivers located in Region 3 that receive amateur radio frequencies from Regions 1, 2, and 3 (see Figure II.1), the bands to be notched are defined in Table 6-2.

F.1.2.5 Upstream power back-off (UPBO) PSD masks

As defined in 6.3.2, the VTU-R shall explicitly estimate the electrical length of its line, kl_0, and use this value to calculate the transmit PSD mask $TxPSD(kl_0, f)$. The VTU-R shall then adapt its transmit signal to conform to the mask $TxPSD(kl_0, f)$ given below. $TxPSD(kl_0, f)$ given below is maximum PSD limitation, and is defined as 3.5 dB above the nominal PSD.

$$TxPSD(kl_0, f) = \min\left[\left\{PSDREF(f) + k\,l_0\sqrt{f}\right\},\ PSD_0(f)\right]\ \text{[dBm/Hz]}$$

where $PSD_0(f)$ is the VTU-R transmit mask in dBm/Hz defined in Table F.2, and $k\,l_0\sqrt{f}$ is an approximation of the loop attenuation in dB. Assuming electrical length kl_0 to be $k \times l_0$, l_0 and k represent physical loop length and attenuation coefficient, respectively.

The reference PSD, $PSDREF(f)$, is a function of frequency but is independent of loop length, type of cable, and noise models. $PSDREF(f)$ shall be as given below.

$$PSDREF(f) = \begin{pmatrix} \text{Band US1}: -56.5 - 10.20\times10^{-3}\sqrt{f}: & 3.75\times10^{6} < f < 5.2\times10^{6} \\ \text{Band US2}: -56.5 - 6.419\times10^{-3}\sqrt{f}: & 8.5\times10^{6} < f < 12\times10^{6} \end{pmatrix} \text{[dBm/Hz]}$$

where f in Hz.

The values of k, k_1 and k_2, which are used to define the above values of 10.20×10^{-3} ($= k_1 l_{ref1}$) and 6.419×10^{-3} ($= k_2 l_{ref2}$) in $PSDREF(f)$ are calculated at the centre frequencies of Band US1 and Band US2, 4.475×10^{6} Hz and 10.25×10^{6} Hz respectively, by assuming 0.4-mm PE cable defined in F.3.1 (also see Table F.6), and are given below. $PSDREF(f)$ also assumes l_{ref1} = 375 m and l_{ref2} = 225 m.

$$k = \begin{pmatrix} \text{Band US1}: k_2 = 2.719\times10^{-5}: & 3.75\times10^{6} < f < 5.2\times10^{6} \\ \text{Band US2}: k_2 = 2.853\times10^{-5}: & 8.5\times10^{6} < f < 12\times10^{6} \end{pmatrix} \text{[dB/(m}\sqrt{\text{Hz}}\text{)]}$$

where f *in* Hz, and l_{ref1}, l_{ref2} in m.

The VTU-R transmit PSD with power back-off, $TxPSD(kl_0, f)$, shall be measured with a 10-kHz resolution bandwidth, and with using 0.4-mm PE cable defined in F.3.1 (abbreviated by TP), where the loop lengths l_0 are parameters to check the conformance of $TxPSD(kl_0, f)$. The equation below gives the VTU-R transmit PSD mask with power back-off for a test loop length of l_0 m for conformance purpose.

$$TxPSD(kl_0, f) = \begin{Bmatrix} \min\left[-56.5 + k_1(l_0 - l_{ref1})\sqrt{f}, -56.5\right]: 3.75\times10^{6} < f < 5.2\times10^{6} \\ \min\left[-56.5 + k_2(l_0 - l_{ref2})\sqrt{f}, -56.5\right]: 8.5\times10^{6} < f < 12\times10^{6} \end{Bmatrix} \text{[dBm/Hz]}$$

where f in Hz, l_0 in m, and $k_1 = 2.719\times10^{-5}$, $k_2 = 2.853\times10^{-5}$, $l_{ref1} = 375$ m, $l_{ref2} = 225$ m.

F.2 Service splitter

F.2.1 Introduction

Requirements for a POTS splitter appropriate to Japan are specified in F.2.2. A VDSL using the frequencies from 138 kHz up to 12 MHz enables coexistent operation with POTS on the same wire-pair by using the POTS splitter.

Requirements for an ISDN splitter appropriate to Japan are specified in F.2.3. A VDSL using the frequencies from 640 kHz up to 12 MHz enables coexistent operation with either TCM-ISDN DSL or POTS on the same wire-pair by using the ISDN splitter.

F.2.2 POTS splitter

F.2.2.1 General definition

Requirements for a POTS splitter appropriate to Japan for use with ADSL (ITU-T Recs G. 992.1 and G.992.3) using the frequencies from 25 kHz up to 1.104 MHz are specified in clause E.4/G.992.3, where the splitter installed at the VTU-R-side end is called remote POTS splitter, and the splitter installed at the VTU-O-side end is called CO POTS splitter.

Requirements for a POTS splitter appropriate to Japan for use with a VDSL using the frequencies from 138 kHz up to 12 MHz are specified below. The POTS splitter consists of a low-pass filter (LPF) function, and the function may be implemented either internally to VTU-x modem or externally, where x = R or O. In each case, all requirements specified below shall be met. A high pass-filter function (HPF) is part of the VTU-R and VTU-O, and specific requirements are not defined as in the case of ADSL related ITU-T Recommendations.

F.2.2.2 Requirements

The POTS splitter designed for use with the VDSL shall be compliant to the requirements specified in clause E.4/G.992.3 for the frequencies from DC to 1.104 MHz. Besides, the POTS splitter shall be also compliant to the requirements for the frequencies from 1.104 MHz to 12 MHz as specified below.

1) The attenuation of LPF of the POTS splitter (i.e., the difference in attenuation measured with and without inserting LPF) shall be greater than 55 dB for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figures E.26/G.992.3 and E.27/G.992.3, where proper values of C and L (e.g., C ≥ 0.2 µF and L ≥ 5 mH) should be set for the test frequency band.
2) The insertion loss caused by loading LPF of the POTS splitter shall be less than 1.5 dB for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figures E.28/G.992.3 and E.29/G.992.3, where proper values of C and L (e.g., C ≥ 0.2 µF and L ≥ 5 mH) should be set for the test frequency band.
3) The return loss caused by loading LPF of the POTS splitter shall be greater than 12 dB against the reference impedance of 100 Ω for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figure E.30/G.992.3.
4) The longitudinal balance of the POTS splitter shall be greater than 40 dB for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figures E.31/G.992.3 and E.32/G.992.3, where proper values of C and L (e.g., C ≥ 0.2 µF and L ≥ 5 mH) should be set for the test frequency band.

F.2.3 ISDN splitter

The requirements for the ISDN splitter for use with a VDSL using the frequencies from 640 kHz up to 12 MHz is specified in this clause, where ISDN is TCM-ISDN DSL. Electrical characteristics of the ISDN splitter specified in this clause shall support both TCM-ISDN DSL and POTS as a coexistent service line with the VDSL.

F.2.3.1 Splitter LPF and HPF functions

The requirements for the ISDN splitters, one installed at the VTU-R-side end and the other installed at the VTU-O-side end, are specified. The requirements are the same for the splitters at both side ends. The splitter functions consist of a low-pass filter (LPF) function and a high-pass filter (HPF) function. Each function may be implemented either internally to VTU-x modem or externally, where x = R or O. Possible cases for internal or external implementation are shown in Figure F.1. In each case, all requirements specified shall be met.

In Figure F.1, R_V represents a terminal impedance of the transceiver function in VTU-x modem, and defined in F.2.3.2.3 for use in test. Each port of the splitter consists of two terminals, L1 and L2. LINE port is to be connected to the line (2-wire pair). TELE port is to be connected to NT (Network Termination function) or LT (Line termination function) of ISDN or POTS. VDSL(HPF) port is to be connected to VTU-x modem with HPF function of the splitter. VDSL(R_V) port is to be connected to VTU-x modem without LPF and HPF functions of the splitter.

C_{OPT} in Type $J1_{opt}$ shown in Figure F.1 b) is a DC blocking capacitance of 0.12 µF to protect ISDN or POTS against DC faults at 2-wire pair between the external LPF splitter and VTU-x modem. Equipping C_{OPT} with the external LPF splitter is optional.

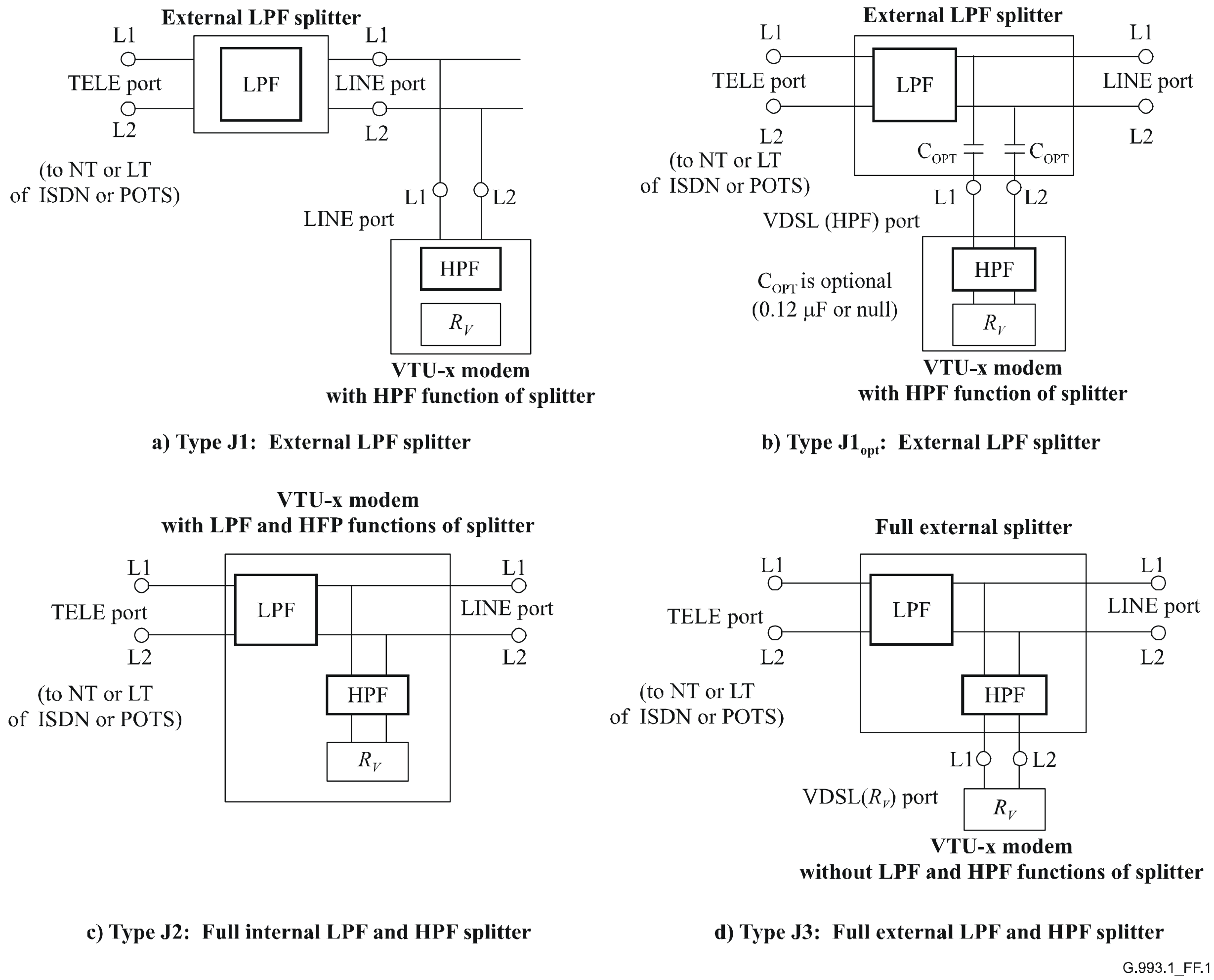


Figure F.1/G.993.1 – ISDN splitter LPF and HPF function location

F.2.3.2 General definition

F.2.3.2.1 Test frequency band

Three bands of frequencies are used for test.

- Voiceband frequencies: DC and 0.2 kHz to 4.0 kHz (0.2 kHz $\le f \le$ 4.0 kHz)
- ISDN band frequencies: DC and 4.0 kHz to 320 kHz (4.0 kHz $< f \le$ 320 kHz)
- VDSL band frequencies: 640 kHz to 12 MHz (640 kHz $\le f \le$ 12 MHz)

The frequencies between 320 kHz to 640 kHz (320 kHz $< f <$ 640 kHz) constitute the guardband. The specific requirements in the guardband are not defined, and test is not performed for the guardband. It is, however, expected that LPF and HPF should behave well in the guardband.

F.2.3.2.2 Single-ended test

Single-ended test is performed for each side splitter, VTU-R-side end or VTU-O-side end. The requirements specified in F.2.3 are for a single-end splitter.

F.2.3.2.3 R_V definition used in test

R_V is defined as a terminal impedance of the transceiver function in VTU-x modem to facilitate test of the splitter independently of actual VTU-x modem implementation.

R_V for voice and ISDN band test shall be ZHP as defined in Figure F.2. R_V of an open impedance is also used for voice and ISDN band test to simulate the case that VTU-x modem is not connected to the line and only either POTS or ISDN NT/LT is connected to the line through the splitter.

R_V for VDSL band test shall be pure resistive 100 Ω.

NOTE – R_V also represents the maximum permissible input capacitance of the transceiver function in VTU-x modem. The requirements are specified in F.2.3.6.

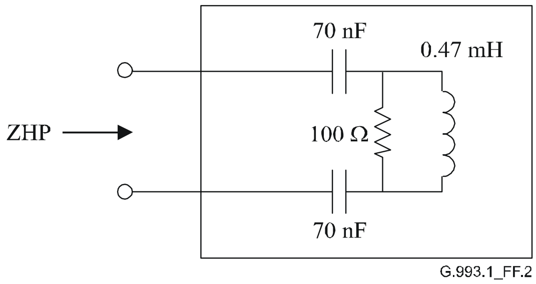


Figure F.2/G.993.1 – ZHP definition as R_V for voice and ISDN band test

F.2.3.3 Signal requirement

F.2.3.3.1 DC signal requirement

The splitter shall ensure normal operation of DC voltage and current superimposed on the line from the central office (CO) side for remote power feeding and maintenance test purposes. The splitter shall also ensure normal operation of a POTS ringing signal.

F.2.3.3.1.1 DC voltage

The splitter shall ensure normal operation of the L1-to-L2 DC voltage, defined below, imposed at TELE and LINE ports of the splitter. The requirements shall be also taken into account at VDSL(HPF) and VDSL(R_V) ports to protect against an accidental line connection.

POTS: 0 V to (±53 V);

ISDN: 0 V to (±63V);

Maintenance test: ±120 V (10 s Max).

F.2.3.3.1.2 DC current

The splitter shall ensure normal operation of the L1-to-L2 DC current, defined below, applied at TELE and LINE ports of the splitter. The requirements shall be also taken into account at VDSL(HPF) and VDSL(R_V) ports to protect against an accidental line connection.

POTS: 0 mA to 130 mA

ISDN: 0 mA to (39 mA ± 3.9 mA)

F.2.3.3.1.3 POTS ringing signal

The splitter shall ensure normal operation of a POTS ringing signal, defined below, impressed at TELE and LINE ports of the splitter. The requirements shall be also taken into account at VDSL(HPF) and VDSL(R_V) ports to protect against an accidental line connection.

Ringing frequency: 15 Hz to 20 Hz

Ringing AC (superimposed on DC): 83 V_{rms} Max

DC: 53 V Max

F.2.3.3.2 AC signal requirement

The splitter shall ensure normal operation of service line signals defined below.

F.2.3.3.2.1 POTS signal

Frequency: 0.2 kHz to 4.0 kHz

Level: +3 dBm Max (600 Ω)

Howler signal: +36 dBm (600 Ω) at 400 Hz

F.2.3.3.2.2 ISDN signal

Line baud rate: 320 kBaud

Line code: AMI (Alternate Mark Inversion)

Pulse shape: 6 V_{op} (+20% and –10%) (110 Ω)

50% (±10%) duty rectangular pulse with 2nd order LPF at f_c = 640 kHz

F.2.3.3.2.3 VDSL signal

Frequency: 640 kHz to 12 MHz

Level: +20 dBm Max (100 Ω)

NOTE – The signal level of +20 dBm Max is referred to a regulation in Japan, and is not correspondent to the VDSL PSD specifications defined in F.1.

F.2.3.4 Resistibility requirement to overvoltages and overcurrents

The VTU-O-side splitter, which is installed in customer premises, shall be compliant to the requirements and test procedures specified in ITU-T Rec. K.21. The VTU-O-side splitter, which is installed in customer premises or may be installed in a CO, shall be compliant to the requirements and test procedures specified in both ITU-T Recs K.20 and K.21.

Any terminal connecting to ground as a protective means to overvoltages and overcurrents, e.g., a frame ground (FG) or a lightning ground (LG), shall not be equipped with the external splitters shown in Types J1, $J1_{opt}$ and J3 in Figure F.1. The external splitter shall be resistive to overvoltages and overcurrents without being connected to any grounds.

F.2.3.5 Splitter DC requirement

F.2.3.5.1 DC resistance requirement

The L1-to-L2 DC resistance between L1 and L2 terminals of LPF part of the splitter, at LINE port with TELE port shorted and vice versa, shall be less than or equal to 10 Ω.

F.2.3.5.2 DC isolation resistance requirement

F.2.3.5.2.1 Differential mode DC isolation resistance

The L1-to-L2 DC isolation resistance between L1 and L2 terminals of LPF part of the splitter, at any one port with the other ports opened if they exist, shall be greater than 10 MΩ.

The L1-to-L2 DC isolation resistance between L1 and L2 terminals of HPF part of the splitter, at any one port with the other ports opened and shorted if they exist, shall be greater than 10 MΩ.

F.2.3.5.2.2 Common mode DC isolation resistance

The DC isolation resistance between any L1 or L2 terminal and the exterior housing of the external splitter with all ports opened shall be greater than or equal to 10 MΩ for the external splitters shown in Types J1, $J1_{opt}$ and J3 in Figure F.1.

NOTE – Equipping FG or LG terminal with the external splitter is not permitted.

The isolation resistance between any L1 or L2 terminal and ground with all ports opened shall be greater than or equal to 10 MΩ for the VTU-x modems shown in Types J1, $J1_{opt}$, J2, and J3 in Figure F.1, where ground may be FG or LG terminal of the modem if it exists, or AC or DC main terminal of the modem.

F.2.3.6 Splitter capacitance requirement

F.2.3.6.1 Differential mode capacitance

Maximum permissible input capacitances for R_V, LPF and HPF parts shown in Figure F.1 are specified individually so as to depend on the types of the splitters shown in Figure F.1. The input capacitance for each part shall be as follows: LPF and HPF are two port networks, and the input capacitance is defined as the capacitance between L1 and L2 terminals at any one port with the other port opened. R_V represents the maximum permissible input capacitance of the transceiver function in VTU-x modem. The C_{OPT} of 0.12 μF in Type $J1_{opt}$ in Figure F.1 is excluded in the following specific values:

- LPF part: 50 nF Max (DC to 30 Hz);
- HPF part: 40 nF Max (DC to 30 Hz);
- R_V part: 35 nF Max (DC to 30 Hz).

Maximum permissible input capacitances for each type shown in Figure F.1 are described in the following clauses.

F.2.3.6.1.1 Type J1

– External LPF splitter:

The L1-to-L2 capacitance between L1 and L2 terminals, at LINE port with TELE port opened and vice versa, shall be less than or equal to 50 nF which corresponds to LPF part of 50 nF.

– VTU-x modem with HPF function of the splitter:

The L1-to-L2 capacitance between L1 and L2 terminals at LINE port shall be less than or equal to 75 nF which is the sum of the HPF part of 40 nF and R_V part of 35 nF.

F.2.3.6.1.2 Type $J1_{opt}$

– External LPF splitter:

The L1-to-L2 capacitance between L1 and L2 terminals with VDSL(HPF) port opened, at LINE port with TELE port opened and vice versa, shall be less than or equal to 50 nF which corresponds to LPF part of 50 nF.

– VTU-x modem with HPF function of the splitter:

The L1-to-L2 capacitance between L1 and L2 terminals at VDSL(HPF) port shall be less than or equal to 75 nF which is the sum of the HPF part of 40 nF and R_V part of 35 nF.

NOTE – The input capacitance becomes 33 nF (= 75//(120/2) nF), when including the C_{OPT} of 0.12 μF.

F.2.3.6.1.3 Type J2

– VTU-x modem with LPF and HPF functions of the splitter:

The L1-to-L2 capacitance between L1 and L2 terminals, at LINE port with TELE port opened and vice versa, shall be less than or equal to 125 nF which is the sum of LPF part of 50 nF and HPF part of 40 nF and R_V part of 35 nF.

F.2.3.6.1.4 Type J3

– Full external LPF and HPF splitter:

  The L1-to-L2 capacitance between L1 and L2 terminals, at any one port with the other ports opened, shall be less than or equal to 90 nF which is the sum of LPF part of 50 nF and HPF part of 40 nF.

– VTU-x modem without LPF and HPF functions of the splitter:

  The L1-to-L2 capacitance between L1 and L2 terminals at VDSL(R_V) port shall be less than or equal to 35 nF which correspond to R_V part of 35 nF.

F.2.3.6.2 Common mode capacitance

The capacitance between any L1 or L2 terminal and the exterior housing of the external splitter with all ports opened shall be less than or equal to 1.0 nF for the external splitters shown in Types J1, $J1_{opt}$ and J3 in Figure F.1.

NOTE – Equipping FG or LG terminal with the external splitter is not permitted.

The capacitance between any L1 or L2 terminal and ground with all ports opened shall be less than or equal to 1.0 nF for the VTU-x modems shown in Types J1, $J1_{opt}$, J2, and J3 in Figure F.1, where ground may be FG or LG terminal of the modem if it exists, or AC or DC main terminal of the modem.

F.2.3.7 Splitter AC characteristics requirement

The requirements for AC characteristics of LPF and HPF parts of the splitter are specified in this clause. LPF and HPF are normally connected to the same wire-pair end, and this causes the mutual effect described below.

LPF signal path characteristics are affected by HPF behaving as a load, where voice and ISDN signals pass through LPF. This degradation by HPF is called HPF loading effect hereafter. Vice versa, HPF signal path characteristics are affected by LPF behaving as a load, where VDSL signal passes through HPF. This degradation by LPF is called LPF loading effect hereafter.

Therefore, the requirements for LPF signal path characteristics shall be met with and without HPF loading and vice versa, the requirement for HPF signal path characteristics shall be met with and without LPF loading.

The associate test methods for splitter AC characteristics are specified in F.2.3.8.

F.2.3.7.1 Requirement for LPF signal path characteristics and LPF loading effect

The requirements for AC characteristics of LPF part of the splitter are specified in this clause. The requirements are specified in terms of LPF signal path characteristics and LPF loading effect. As for LPF loading effect on VDSL signal path, discrete LPF loading effect without connecting HPF is specified in this clause. LPF loading effect on VDSL signal path with connecting HPF is specified in F.2.3.7.2.

F.2.3.7.1.1 LPF insertion loss requirement

The insertion loss of LPF part of the splitter, which is denoted below as LS(f) dB at f kHz, shall be as follows.

1) Voiceband (LPF signal path characteristics with and without HPF loading)

   f = 1.0 kHz: –1.0 dB ≤ LS(1 kHz) ≤ +1.0 dB

   0.2 kHz ≤ f ≤ 3.4 kHz: –1.0 dB ≤ {LS(f) – LS(1 kHz)} ≤ +1.0 dB

   3.4 kHz < f ≤ 4.0 kHz: –1.5 dB ≤ {LS(f) – LS(1 kHz)} ≤ +1.5 dB

   NOTE 1 – {LS(f) – LS(1 kHz)} denotes the insertion loss variation in dB at f kHz from that at 1 kHz.

2) ISDN band (LPF signal path characteristics with and without HPF loading)

4.0 kHz < f ≤ 160 kHz: LS(f) ≤ 1.0 dB

160 kHz < f ≤ 320 kHz: LS(f) ≤ {1.0+3.01 × Log_2 (f/160)} dB (where f in kHz)

3) Guardband

320 kHz < f < 640 kHz: Not specified

NOTE 2 – The suggested requirements in the guardband is 42.14 × Log_2 (f/320) dB ≤ LS(f) (where f in kHz), in order to suppress the TCM-ISDN transmit signal alias leakage, especially at the frequency of 480 kHz, into the VDSL receiver.

4) VDSL band (LPF signal path characteristics with HPF loading)

640 kHz ≤ f < 932 kHz: 42.14 × Log_2 (f/320) dB ≤ LS(f) (where f in kHz)

932 kHz ≤ f ≤ 6.0 MHz: 65.0 dB ≤ LS(f)

6.0 MHz < f ≤ 12 MHz: 55.0 dB ≤ LS(f)

F.2.3.7.1.2 LPF absolute group delay requirement

The absolute group delay of LPF part of the splitter, which is denoted below as GD(f) µs at f kHz, shall be as follows.

1) Voiceband (LPF signal path characteristics with and without HPF loading)

Min [GD(f) {0.2 kHz ≤ f ≤ 4.0 kHz}] ≤ 150 µs

0.2 kHz ≤ f < 0.6 kHz: GD(f) – GD(f_x) ≤ 250 µs

0.6 kHz ≤ f ≤ 3.2 kHz: GD(f) – GD(f_x) ≤ 200 µs

3.2 kHz < f ≤ 4.0 kHz: GD(f) – GD(f_x) ≤ 250 µs

NOTE – Min[GD(f) {0.2 kHz ≤ f ≤ 4.0 kHz}] denotes minimum absolute group delay for the frequencies from 0.2 kHz to 4.0 kHz, and the frequency of f_x kHz is defined as the frequency which appears the minimum absolute group delay. GD(f) – GD(f_x) denotes the increase in µs at f kHz from the minimum absolute group delay at f_x kHz.

2) ISDN band (LPF signal path characteristics with and without HPF loading)

4.0 kHz < f ≤ 160 kHz: GD(f) ≤ 3.125 µs

160 kHz < f ≤ 320 kHz: GD(f) ≤ 3.125 × {1.0 + 2.0 × Log2 (f/160)} µs (where f in kHz)

3) Guardband

320 kHz < f < 640 kHz: Not specified

4) VDSL band

640 kHz ≤ f ≤ 12 MHz: Not specified

(specified as HPF signal path characteristics with and without LPF loading)

F.2.3.7.1.3 LPF return loss requirement

The return loss of LPF part of the splitter, which is denoted below as RL(f) dB at f kHz, shall be as follows. The definition of RL(f) in terms of complex impedances is given below.

$$RL(f) = -20 \times Log_{10}[Abs[\{Zref(jf) - Zin(jf)\}/\{Zin(jf) + Zref(jf)\}]]\ dB$$

where Zin(jf) is measurements of a complex input impedance and Zref(jf) is the complex reference impedance and Zref(jf) is test band dependent.

1) Voiceband (LPF signal path characteristics with and without HPF loading)

0.2 kHz ≤ f ≤ 1.5 kHz: 11.0 dB ≤ RL(f)

1.5 kHz < f ≤ 2.0 kHz: 10.0 dB ≤ RL(f)

2.0 kHz < f ≤ 3.4 kHz: 9.0 dB ≤ RL(f)

3.4 kHz < f ≤ 4.0 kHz: Not specified

2) ISDN band (LPF signal path characteristics with and without HPF loading)

4.0 kHz < f < 10 kHz: $\{15.0 - 6.02 \times \text{Log}_2 (10/f)\}$ dB ≤ RL(f) (where f in kHz)

10 kHz ≤ f ≤ 160 kHz: 15.0 dB ≤ RL(f)

160 kHz < f ≤ 220 kHz: $\{15.0 - 6.02 \times \text{Log}_2 (f/160)\}$ dB ≤ RL(f) (where f in kHz)

220 kHz < f ≤ 320 kHz: Not specified

3) Guardband

320 kHz < f < 640 kHz: Not specified

4) VDSL band (LPF loading effect on HPF signal path characteristics)

640 kHz ≤ f < 1.28 MHz: $\{12.0 - 6.02 \times \text{Log}_2 (1280/f)\}$ ≤ RL(f) (where f in kHz)

1.28 MHz ≤ f ≤ 12 MHz: 12.0 dB ≤ RL(f)

F.2.3.7.1.4 LPF longitudinal balance requirement

The longitudinal balance of LPF part of the splitter, which is denoted below as LB(f) dB at f kHz, shall be as follows. The definition of LB(f) is given below.

$$LB(f) = -20 \times \text{Log}_{10} \{Vm(f)/Vt(f)\} \text{ dB}$$

where Vt(f) is a voltage imposed in common mode from a constant voltage source and in Vemf (electromotive force) which is an output voltage with an open load. Vm(f) is voltage measurements in differential mode which is converted from common mode to differential mode.

1) Voiceband (LPF signal path characteristics with and without HPF loading)

0.2 kHz ≤ f ≤ 3.4 kHz: 58.0 dB ≤ LB(f)

3.4 kHz < f ≤ 4.0 kHz: Not specified

2) ISDN band (LPF signal path characteristics with and without HPF loading)

50 Hz ≤ f < 150 kHz: 60.0 dB ≤ LB(f)

150 kHz ≤ f ≤ 250 kHz: 63.0 dB ≤ LB(f)

250 kHz < f ≤ 320 kHz: $\{63.0 - 6.02 \times \text{Log}_2 (f/250)\}$ dB ≤ LB(f)

3) Guardband

320 kHz < f < 640 kHz: Not specified

4) VDSL band (LPF loading effect on HPF signal path characteristics)

640 kHz ≤ f ≤ 12 MHz: 46.0 dB ≤ LB(f)

F.2.3.7.2 Requirement for HPF signal path characteristics and HPF loading effect

The requirements for AC characteristics of HPF part of the splitter are specified in this clause. The requirements are specified in terms of HPF signal path characteristics and HPF loading effect. As for HPF loading effect on voice and ISDN signal paths, discrete HPF loading effect without connecting LPF is specified in this clause. HPF loading effect on voice and ISDN signal paths with connecting LPF is specified in F.2.3.7.1.

F.2.3.7.2.1 HPF insertion loss requirement

The insertion loss of HPF part of the splitter, which is denoted below as LS(f) dB at f kHz, shall be as follows.

1) Voiceband (HPF signal path characteristics with LPF loading)

   0.2 kHz ≤ f ≤ 4.0 kHz: 50.0 dB ≤ LS(f)

2) ISDN band (HPF signal path characteristics with LPF loading)

   4.0 kHz < f < 20 kHz: 50.0 dB ≤ LS(f)

   20 kHz ≤ f ≤ 200 kHz: 60.6 dB ≤ LS(f)

   200 kHz < f ≤ 320 kHz: $36.1 \times \text{Log}_2 (640/f)$ dB ≤ LS(f) (where f in kHz)

3) Guardband

   320 kHz < f < 640 kHz: Not specified

   NOTE – The suggested requirements in the guardband is $36.1 \times \text{Log}_2 (640/f)$ dB ≤ LS(f) (where f in kHz), in order to suppress the TCM-ISDN transmit signal alias leakage, especially at the frequency of 480 kHz, into the VDSL receiver.

4) VDSL band (HPF signal path characteristics with and without LPF loading)

   640 kHz ≤ f < 1.28 MHz LS(f) ≤ $4.5 - 3.01 \times \text{Log}_2 (f/640)$ dB (where f in kHz)

   1.28 MHz ≤ f ≤ 12 MHz LS(f) ≤ 1.5 dB

F.2.3.7.2.2 HPF absolute group delay requirement

The absolute group delay of HPF part of the splitter, which is denoted below as GD(f) µs at f kHz, shall be as follows.

1) Voiceband

   0.2 kHz ≤ f ≤ 4.0 kHz: Not specified

   (specified as LPF signal path characteristics with and without HPF loading)

2) ISDN band

   4.0 kHz < f ≤ 320 kHz: Not specified

   (specified as LPF signal path characteristics with and without HPF loading)

3) Guardband

   320 kHz < f < 640 kHz: Not specified

4) VDSL band (HPF signal path characteristics with and without LPF loading)

   640 kHz ≤ f < 1.28 MHz: GD(f) ≤ $1.0 \times \{3.0 - 2.01 \times \text{Log}_2 (f/640)\}$ µs (where f in kHz)

   1.28 MHz ≤ f ≤ 12 MHz: GD(f) ≤ 1.0 µs

F.2.3.7.2.3 HPF return loss requirement

The return loss of HPF part of the splitter, which is denoted below as RL(f) dB at f kHz, shall be as follows. The definition of RL(f) in terms of complex impedances is given below.

$$RL(f) = -20 \times \text{Log}_{10}[\text{Abs}[\{Zref(jf) - Zin(jf)\}/\{(Zin(jf)+Zref(jf))]\ \text{dB}$$

where Zin(jf) is measurements of a complex input impedance and Zref(jf) is the complex reference impedance.

1) Voiceband (HPF loading effect on LPF signal path characteristics)

0.2 kHz ≤ f ≤ 1.5 kHz: 11.0 dB ≤ RL(f)

1.5 kHz < f ≤ 2.0 kHz: 10.0 dB ≤ RL(f)

2.0 kHz < f ≤ 3.4 kHz: 9.0 dB ≤ RL(f)

3.4 kHz < f ≤ 4.0 kHz: Not specified

2) ISDN band (HPF loading effect on LPF signal path characteristics)

4.0 kHz < f < 10 kHz: {15.0 – 6.02 × Log_2 (10/f)} dB ≤ RL(f) (where f in kHz)

10 kHz ≤ f ≤ 160 kHz: 15.0 dB ≤ RL(f)

160 kHz < f ≤ 220 kHz: {15.0 – 6.02 × Log_2 (f/160)} dB ≤ RL(f) (where f in kHz)

220 kHz < f ≤ 320 kHz: Not specified

3) Guardband

320 kHz < f < 640 kHz: Not specified

4) VDSL band (HPF signal path characteristics with and without LPF loading)

640 kHz ≤ f < 1.28 MHz: {12.0 – 6.02 × Log_2 (1280/f)} ≤ RL(f) (where f in kHz)

1.28 MHz ≤ f ≤ 12 MHz: 12.0 dB ≤ RL(f)

F.2.3.7.2.4 HPF longitudinal balance requirement

The longitudinal balance of HPF part of the splitter, which is denoted below as LB(f) dB at f kHz, shall be as follows. The definition of LB(f) is given below.

$$LB(f) = -20 \times Log_{10} \{Vm(f)/Vt(f)\} \text{ dB}$$

where Vt(f) is a voltage imposed in common mode from a constant voltage source and in Vemf (electromotive force) which is an output voltage with an open load. Vm(f) is voltage measurements in differential mode which is converted from common mode to differential mode.

1) Voiceband (HPF loading effect on LPF signal path characteristics)

0.2 kHz ≤ f ≤ 3.4 kHz: 64.0 dB ≤ LB(f)

3.4 kHz < f ≤ 4.0 kHz: Not specified

2) ISDN band (HPF loading effect on LPF signal path characteristics)

50 Hz ≤ f < 150 kHz: 66.0 dB ≤ LB(f)

150 kHz ≤ f ≤ 250 kHz: 69.0 dB ≤ LB(f)

250 kHz < f ≤ 320 kHz: {69.0 – 6.02 × Log_2 (f/250)} dB ≤ LB(f)

3) Guardband

320 kHz < f < 640 kHz: Not specified

4) DSL band (HPF signal path characteristics with and without LPF loading)

640 kHz ≤ f ≤ 12 MHz: 40.0 dB ≤ LB(f)

F.2.3.8 AC characteristics test method

The test set-up configurations and the test conditions regarding splitter AC characteristics are specified in this clause. The test set-up configurations shown in this clause enable to test LPF and HPF parts of the splitter independently of the types of the splitters shown in Figure F.1.

The test methods for LPF signal path characteristics with and without HPF loading and discrete LPF loading effect without connecting HPF are specified in F.2.3.8.1.

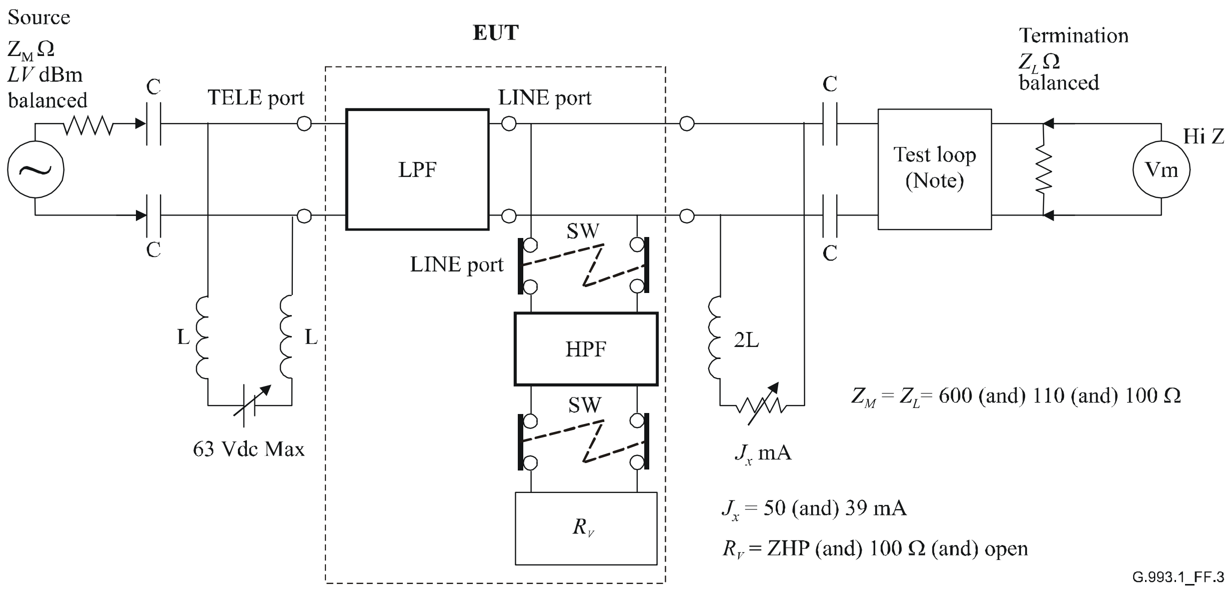
The test methods for HPF signal path characteristics with and without LPF and discrete HPF loading effect without connecting LPF are specified in F.2.3.8.2.

F.2.3.8.1 Test method for LPF signal path characteristics and LPF loading effect

The test set-up configurations and the test conditions regarding splitter AC characteristics for LPF part of the splitter are specified in this clause. The requirements which shall be met in test below are specified in F.2.3.7.1

F.2.3.8.1.1 LPF insertion loss and absolute group delay test

The test set-up is shown in Figure F.3. The insertion loss and group delay from the source of Z_M Ω to the termination of Z_L Ω shall be measured, with and without inserting the equipment under test (EUT), with a level of LV dBm under the all conditions of HPF loading. The test loop in the figure is used only for voiceband test and defined in Figure F.4. Null loop is applied for ISDN and VDSL band test.



NOTE – Test loop is used only for voice band test. Null loop is applied for ISDN and VDSL band test.

Figure F.3/G.993.1 – Test set-up for LPF insertion loss and absolute group delay

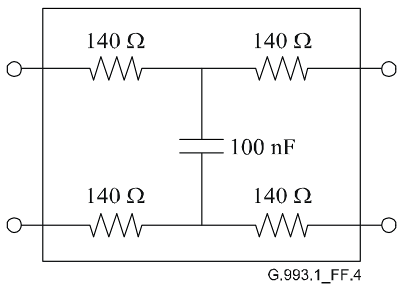


Figure F.4/G.993.1 – Voiceband test loop (approx. 2 km)

All possible conditions are defined as for HPF loading although the conditions of HPF loading are dependent on the types of the splitters shown in Figure F.1. Thus, the conditions defined below may include inapplicable cases which are unable to test for a certain type of actual implementation. Even in those types, LPF as part of the splitter shall meet all requirements under the all conditions defined below.

A DC bias current of J_x mA to LPF part of the splitter shall be applied during the test. The C and L in Figure F.3 are for superimposing the DC bias current of J_x mA. Proper values of the C and L should be set for testing each band.

LV dBm, Z_M Ω, Z_L Ω, J_x mA, and the conditions of HPF loading are test band dependent and shall be as follows:

1) Voiceband (0.2 kHz ≤ *f* ≤ 4.0 kHz)

   LV = 0 dBm

   $Z_M = Z_L = 600$ Ω

   $J_x = 50$ mA (e.g., C ≥ 20 µF and L ≥ 15 H)

   a1) Connecting HPF terminated with R_V = ZHP (defined in Figure F.2) to the line

   a2) Connecting HPF terminated with R_V = open to the line

   b) Unconnecting HPF terminated with R_V to the line

2) ISDN band (4.0 kHz < *f* ≤ 320 kHz)

   LV = +15 dBm

   $Z_M = Z_L = 110$ Ω

   $J_x = 39$ mA (e.g., C ≥ 10 µF and L ≥ 0.5 H)

   a1) Connecting HPF terminated with R_V = ZHP (defined in Figure F.2) to the line

   a2) Connecting HPF terminated with R_V = open to the line

   b) Unconnecting HPF terminated with R_V to the line

3) Guardband (320 kHz < *f* < 640 kHz)

   Not specified

4) VDSL band (640 kHz ≤ *f* ≤ 12 MHz): only for insertion loss, not applied for group delay.

   LV = +15 dBm

   $Z_M = Z_L = 100$ Ω

   $J_x = 39$ mA (e.g., $C \geq 0.2$ µF and $L \geq 5$ mH)

   Connecting HPF terminated with R_V = 100 Ω to the line

F.2.3.8.1.2 LPF return loss test

The test set-up is shown in Figure F.5. The return loss is measured in terms of a complex input impedance of Zin(*jf*). Zin(*jf*) shall be measured with inserting EUT and terminating the opposite side by the complex reference impedance of Zref(*jf*). Note that the port where Zin(*jf*) is measured is opposite each other for voice and ISDN bands. As for VDSL band test, an effect on VDSL signal path is evaluated as discrete LPF loading effect without connecting HPF.

A DC bias current is not necessarily required to apply during the test.

Zref(jf) and the conditions of HPF and LPF loading are test band dependent, and shall be as follows:

1) Voiceband (0.2 kHz ≤ f ≤ 4.0 kHz)

Zref(jf) = ZNLr for testing VTU-R-side splitter and ZNLc for testing VTU-O-side splitter

where ZNLr = 150 Ω +{(830 Ω + 1 μF) // 72 nF}

ZNLc = 150 Ω + (830 Ω // 72 nF)

(+: series connection //: parallel connection)

NOTE – The definition of ZNLr and ZNLc is as per E.4/G.992.3.

a1) Connecting HPF terminated with R_V = ZHP (defined in Figure F.2) to the line

a2) Connecting HPF terminated with R_V = open to the line

b) Unconnecting HPF terminated with R_V to the line

2) ISDN band (4.0 kHz < f ≤ 320 kHz)

Zref(jf) = pure resistive 110 Ω

a1) Connecting HPF terminated with R_V = ZHP (defined in Figure F.2) to the line

a2) Connecting HPF terminated with R_V = open to the line

b) Unconnecting HPF terminated with R_V to the line

3) Guardband (320 kHz < f < 640 kHz)

Not specified

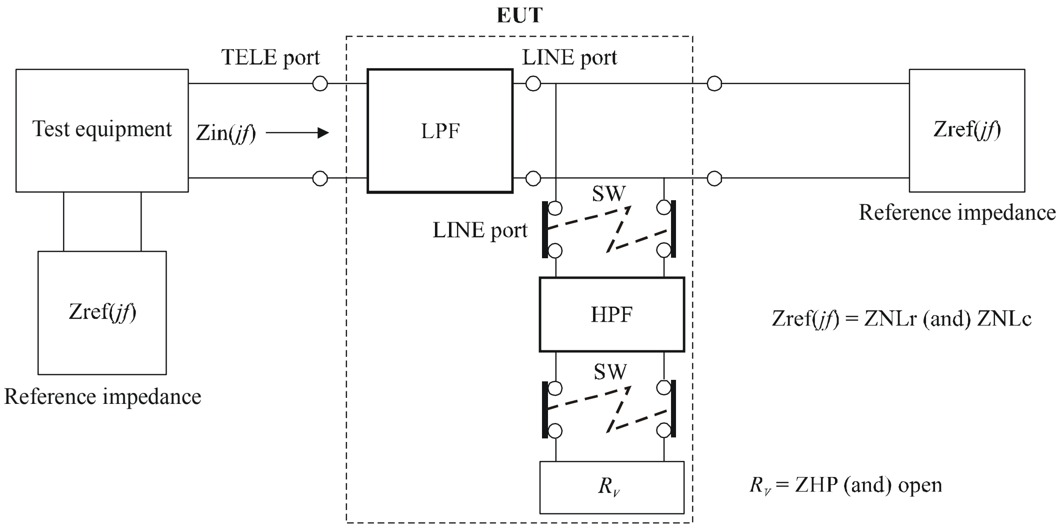
4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

Zref(jf) = pure resistive 100 Ω

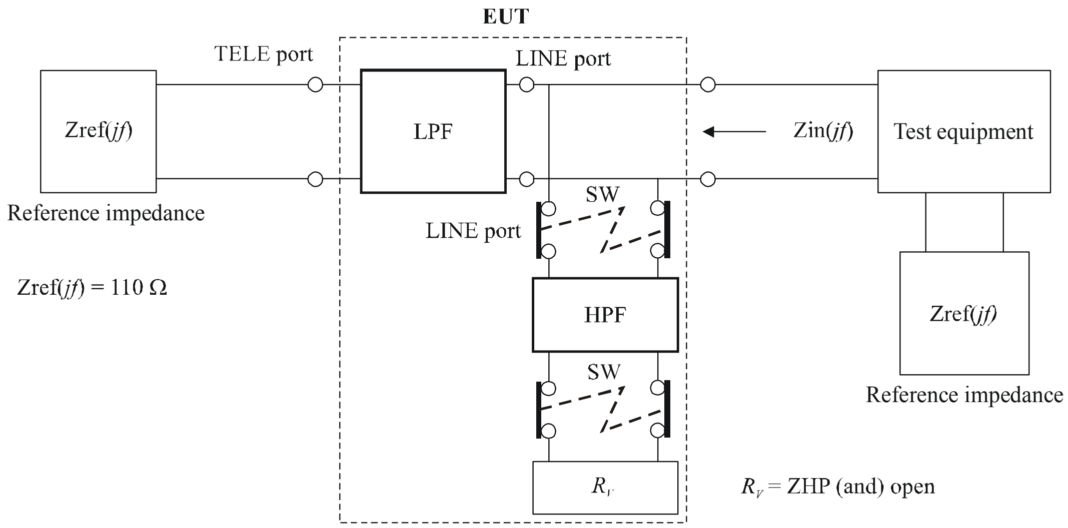
a1) Connecting LPF only in parallel to the line and terminating with Z_M = 600 Ω

a2) Connecting LPF only in parallel to the line and terminating with Z_M = 110 Ω

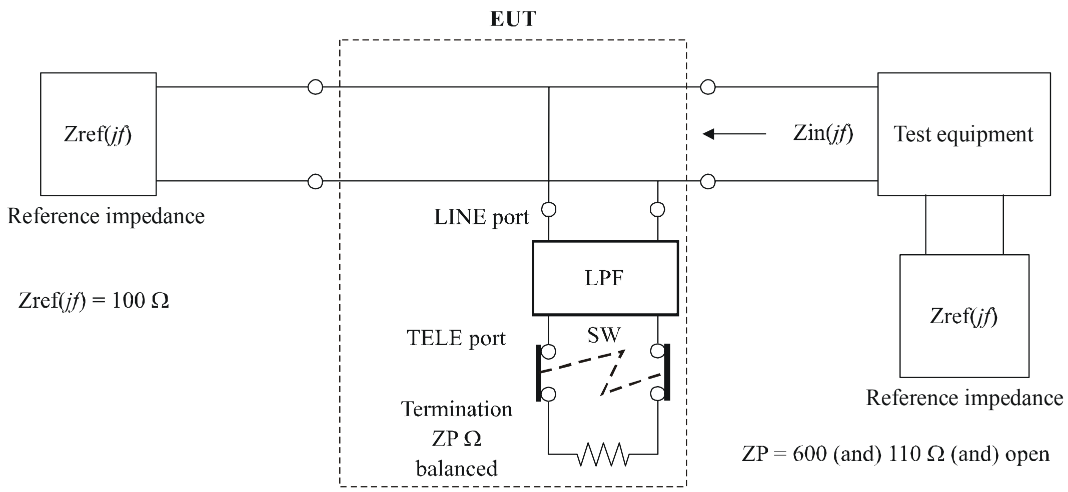
a3) Connecting LPF only in parallel to the line and terminating with Z_M = open



a) Voice band test set-up



b) ISDN band test set-up



c) VDSL band test set-up

Figure F.5/G.993.1 – Test set-up for LPF return loss

F.2.3.8.1.3 F longitudinal balance test

The longitudinal balance shall be measured under the all conditions of HPF loading by using the test set-up shown in Figure F.6. As for VDSL band test, an effect on VDSL signal path is evaluated as discrete LPF loading effect without connecting HPF.

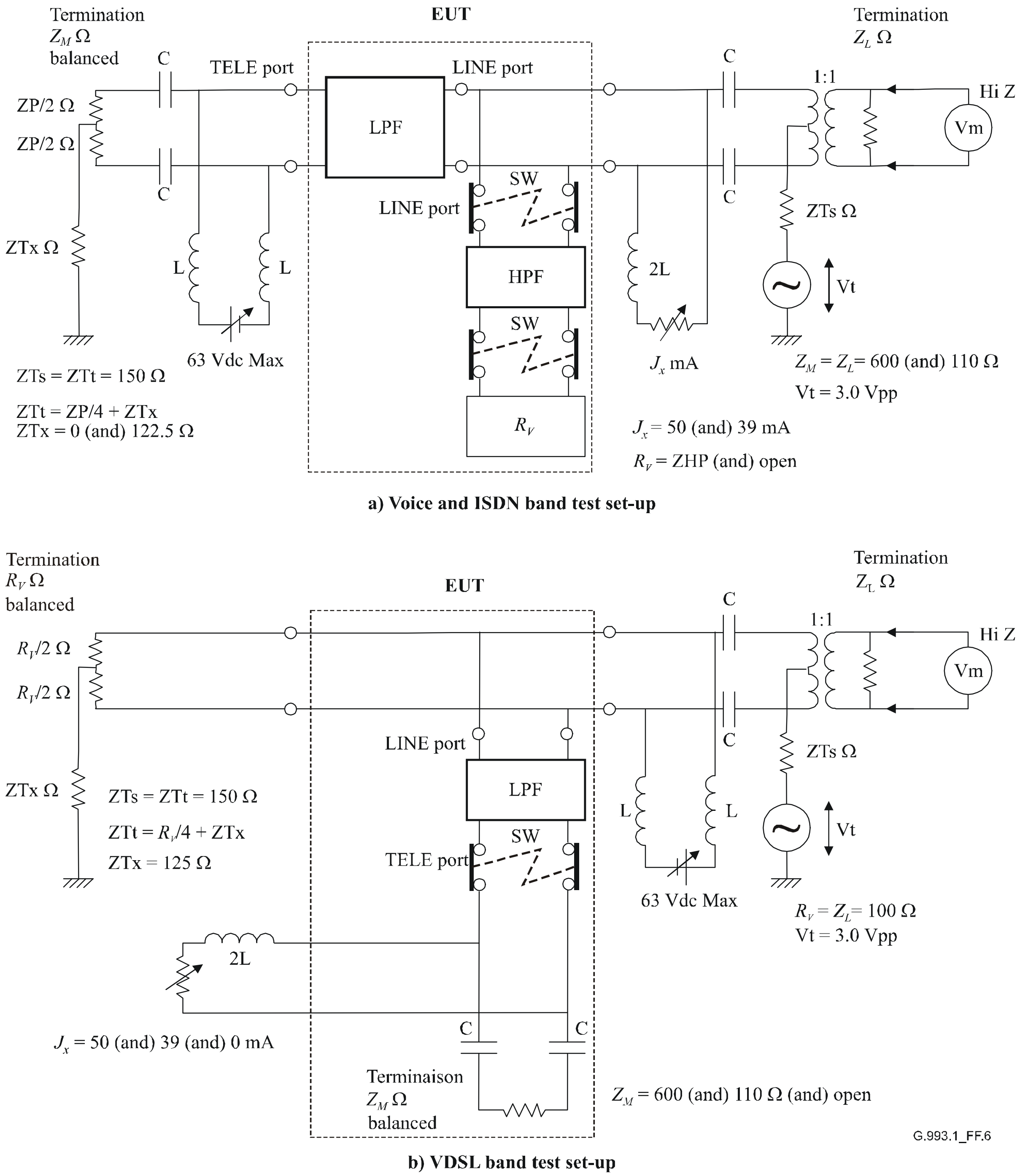


Figure F.6/G.993.1 – Test set-up for LPF longitudinal balance

The source impedance of ZTs Ω and the terminal impedance of ZTt Ω in common mode are compliant to the requirement specified in ITU-T Rec. K.43, and shall be 150 Ω, where ZTs = ZTt (= Z_M/4 + ZTx).

The electromotive force Vt(f) of the constant voltage source shall be 3.0 Vpp (emf), and this level in Vemf corresponds to the level in dBm of +7.5 dBm for the signal generator with the source of 50 Ω and the termination of 50 Ω.

A DC bias current of J_x mA to LPF part of the splitter shall be applied during the test. Proper values of the C and L in the figure should be set for testing each band.

Z_M Ω, Z_L Ω, ZTx Ω, J_x mA, and the conditions of HPF and LPF loading are test band dependent, and shall be as follows.

1) Voiceband (0.2 kHz ≤ f ≤ 4.0 kHz)

Vt(f) = 3.0 Vpp (emf)

$Z_M = Z_L = 600$ Ω

ZTx = 0 Ω

J_x = 50 mA (e.g., C ≥ 20 µF and L ≥ 15 H)

a1) Connecting HPF terminated with R_V = ZHP (defined in Figure F.2) to the line

a2) Connecting HPF terminated with R_V = open to the line

b) Unconnecting HPF terminated with R_V to the line

2) ISDN band (4.0 kHz < f ≤ 320 kHz)

Vt(f) = 3.0 Vpp (emf)

$Z_M = Z_L = 110$ Ω

ZTx = 122.5 Ω

J_x = 39 mA (e.g., C ≥ 10 µF and L ≥ 0.5 H)

a1) Connecting HPF terminated with R_V = ZHP (defined in Figure F.2) to the line

a2) Connecting HPF terminated with R_V = open to the line

b) Unconnecting HPF terminated with R_V to the line

3) Guardband (320 kHz < f < 640 kHz)

Not specified

4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

Vt(f) = 3.0 Vpp (emf)

$R_V = Z_L = 100$ Ω

ZTx = 125 Ω

a1) Connecting LPF only in parallel to the line and terminating with Z_M = 600 Ω

J_x = 50 mA (e.g., C ≥ 0.2 µF and L ≥ 5 mH)

a2) Connecting LPF only in parallel to the line and terminating with Z_M = 110 Ω

J_x = 39 mA (e.g., C ≥ 0.2 µF and L ≥ 5 mH)

a3) Connecting LPF only in parallel to the line and terminating with Z_M = open

No DC bias current

F.2.3.8.2 Test method for HPF signal path characteristics and HPF loading effect

The test set-up configurations and the test conditions regarding splitter AC characteristics for HPF part of the splitter are specified in this clause. The requirements which shall be met in test below are specified in F.2.3.7.2.

F.2.3.8.2.1 HPF insertion loss and absolute group delay test

The test set-up is shown in Figure F.7. The insertion loss and group delay from the source of R_V Ω to the termination of Z_L Ω shall be measured, with and without inserting EUT, with a level of LV dBm under the all conditions of LPF loading.

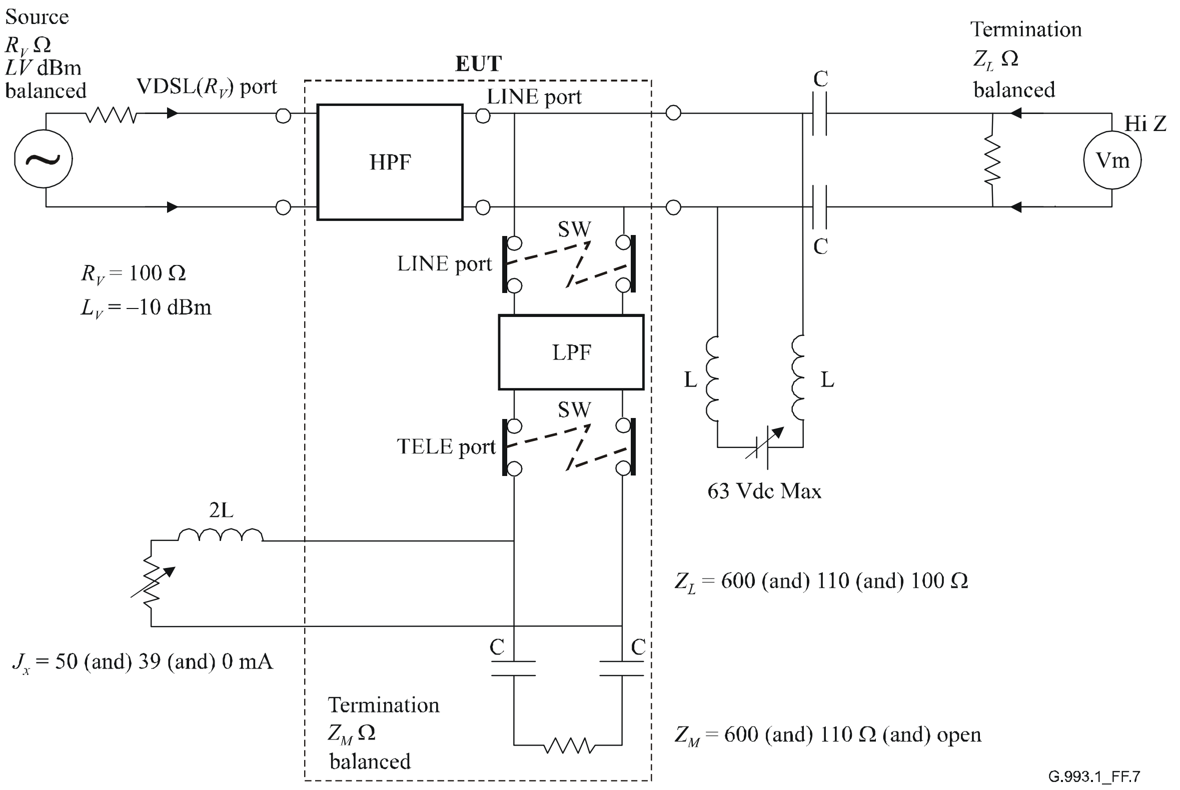


Figure F.7/G.993.1 – Test set-up for HPF insertion loss and absolute group delay

All possible conditions are defined as for LPF loading although the conditions of LPF loading are dependent on the types of the splitters shown in Figure F.1. Thus, the conditions defined below may include inapplicable cases which are unable to test for a certain type of actual implementation. Even in those types, HPF as part of the splitter shall meet all requirements under the conditions defined below.

A DC bias current of J_x mA to LPF part of the splitter shall be applied during the test in all available cases. Proper values of the C and L should be set for testing each band.

LV dBm, R_V Ω, Z_L Ω, J_x mA and the conditions of LPF loading shall be as follows, where the Z_L Ω, J_x mA and conditions of LPF loading are test band dependent.

1) Voiceband (0.2 kHz ≤ f ≤ 4.0 kHz): only for insertion loss, not applied for group delay.

   LV = –10 dBm

   R_V = 100 Ω

   Z_L = 600 Ω

   Connecting LPF terminated with Z_M = 600 Ω to the line

   J_x = 50 mA (e.g., C ≥ 20 µF and L ≥ 15 H)

2) ISDN band (4.0 kHz < f ≤ 320 kHz) : only for insertion loss, not applied for group delay.

$LV = -10$ dBm

$R_V = 100\ \Omega$

$Z_L = 110\ \Omega$

Connecting LPF terminated with $Z_M = 110\ \Omega$ to the line

$J_x = 39$ mA (e.g., C ≥ 10 µF and L ≥ 0.5 H)

3) Guardband (320 kHz < f < 640 kHz)

Not specified

4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

$LV = -10$ dBm

$R_V = Z_L = 100\ \Omega$

a1) Connecting LPF terminated with $Z_M = 600\ \Omega$ to the line

$J_x = 50$ mA (e.g., C ≥ 0.2 µF and L ≥ 5 mH)

a2) Connecting LPF terminated with $Z_M = 110\ \Omega$ to the line

$J_x = 39$ mA (e.g., C ≥ 0.2 µF and L ≥ 5 mH)

a3) Connecting LPF terminated with Z_M = open to the line

No DC bias current

b) Unconnecting LPF terminated with Z_M to the line

No DC bias current

F.2.3.8.2.2 HPF return loss test

The test set-up is shown in Figure F.8. The return loss is measured in terms of a complex input impedance of Zin(*jf*). Zin(*jf*) shall be measured with inserting EUT and terminating the opposite side by the complex reference impedance of Zref(*jf*). As for voice and ISDN band test, effects on voice and ISDN signal paths are evaluated as discrete HPF loading effect without connecting LPF.

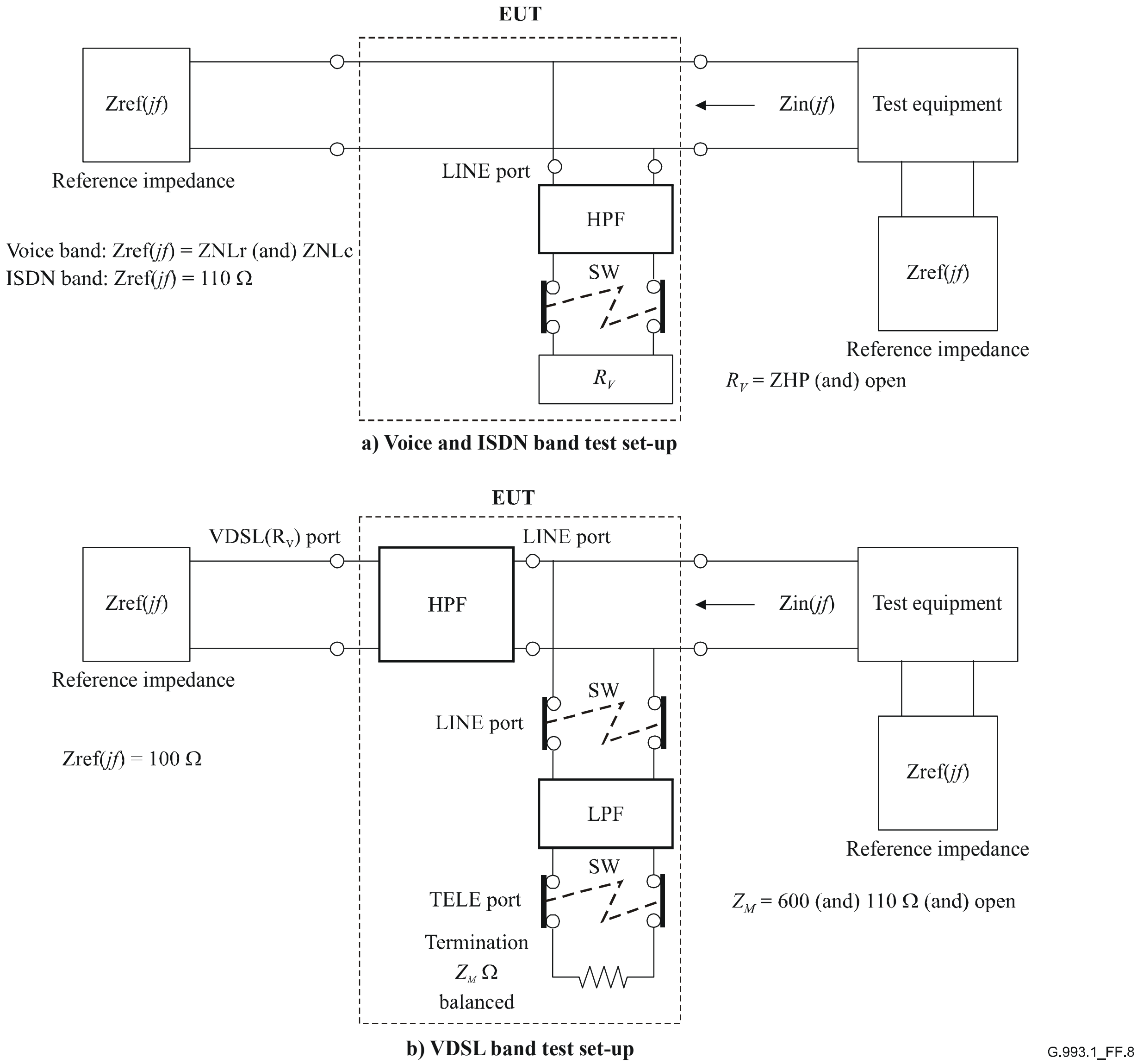


Figure F.8/G.993.1 – Test set-up for HPF return loss

A DC bias current is not necessarily required to apply during the test.

Zref(*jf*) and the conditions of LPF and HPF loading are test band dependent, and shall be as follows.

1) Voiceband (0.2 kHz ≤ *f* ≤ 4.0 kHz)

Zref(*jf*) = ZNLr for testing VTU-R-side splitter and ZNLc for testing VTU-O-side splitter

where ZNLr = 150 Ω +{(830 Ω + 1 µF) // 72 nF}

ZNLc = 150 Ω + (830 Ω // 72 nF)

(+: series connection //: parallel connection)

NOTE – The definition of ZNLr and ZNLc is as per E.4/G.992.3.

a1) Connecting HPF only in parallel to the line and terminating with R_V = ZHP (defined in Figure F.2)

a2) Connecting HPF only in parallel to the line and terminating with R_V = open

2) ISDN band (4.0 kHz < f ≤ 320 kHz)

Zref(jf) = pure resistive 110 Ω

a1) Connecting HPF only in parallel to the line and terminating with R_V = ZHP (defined in Figure F.2)

a2) Connecting HPF only in parallel to the line and terminating with R_V = open

3) Guardband (320 kHz < f < 640 kHz)

Not specified

4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

Zref(jf) = pure resistive 100 Ω

a1) Connecting LPF terminated with Z_M = 600 Ω to the line

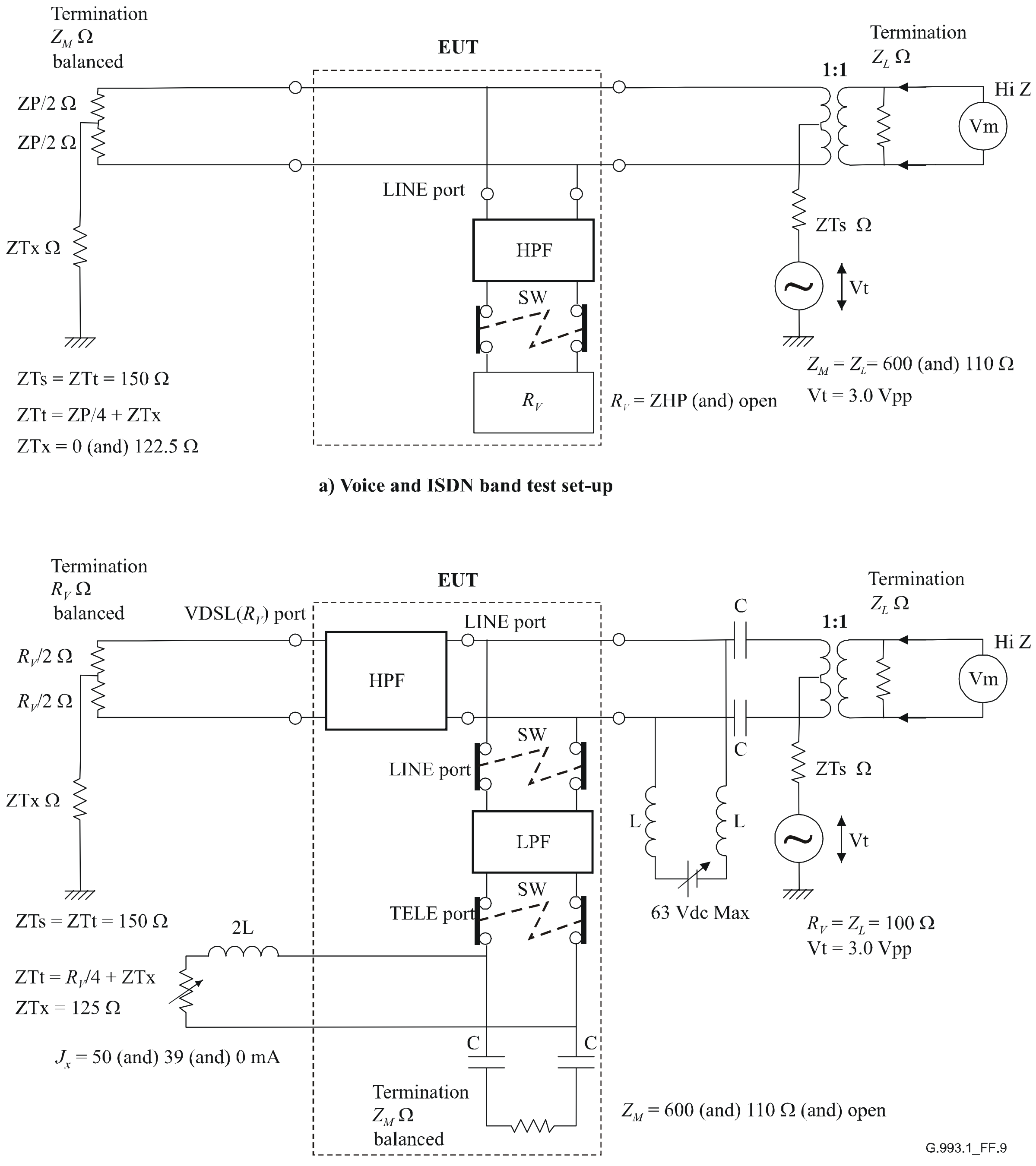
a2) Connecting LPF terminated with Z_M = 110 Ω to the line

a3) Connecting LPF terminated with Z_M = open to the line

b) Unconnecting LPF terminated with Z_M to the line

F.2.3.8.2.3 HPF longitudinal balance test

The longitudinal balance shall be measured under the all conditions of LPF loading by using the test set-up shown in Figure F.9. As for voice and ISDN band test, effects on voice and ISDN signal paths are evaluated as discrete HPF loading effect without connecting LPF.



a) Voice and ISDN band test set-up

b) VDSL band test set-up

Figure F.9/G.993.1 – Test set-up for HPF longitudinal balance

The source impedance of ZTs Ω and the terminal impedance of ZTt Ω in common mode comply with the requirement specified in ITU-T Rec. K.43, and shall be 150 Ω, where ZTs = ZTt (= R_V/4 + ZTx).

The electromotive force Vt(*f*) of the constant voltage source shall be 3.0 Vpp (emf), and this level in Vemf corresponds to the level in dBm of +7.5 dBm for the signal generator with the source of 50 Ω and the termination of 50 Ω.

A DC bias current of J_x mA to LPF part of the splitter shall be applied during the test in all available cases. Proper values of the C and L should be set for testing each band.

Z_M Ω, Z_L Ω, ZTx Ω, J_x mA and the conditions of LPF and HPF loading are test band dependent, and shall be as follows:

1) Voiceband (0.2 kHz ≤ f ≤ 4.0 kHz)

   Vt(f) = 3.0 Vpp (emf)

   $Z_M = Z_L = 600$ Ω

   ZTx = 0 Ω

   a1) Connecting HPF only in parallel to the line and terminating with R_V = ZHP (defined in Figure F.2)

   No DC bias current

   a2) Connecting HPF only in parallel to the line and terminating with R_V = open

   No DC bias current

2) ISDN band (4.0 kHz < f ≤ 320 kHz)

   Vt(f) = 3.0 Vpp (emf)

   $Z_M = Z_L = 110$ Ω

   ZTx = 122.5 Ω

   a1) Connecting HPF only in parallel to the line and terminating with R_V = ZHP (defined in Figure F.2)

   No DC bias current

   a2) Connecting HPF only in parallel to the line and terminating with R_V = open

   No DC bias current

3) Guardband (320 kHz < f < 640 kHz)

   Not specified

4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

   Vt(f) = 3.0 Vpp (emf)

   $R_V = Z_L = 100$ Ω

   ZTx = 125 Ω

   a1) Connecting LPF terminated with Z_M = 600 Ω to the line

   J_x = 50 mA (e.g., C ≥ 0.2 μF and L ≥ 5 mH)

   a2) Connecting LPF terminated with Z_M = 110 Ω to the line

   J_x = 39 mA (e.g., C ≥ 0.2 μF and L ≥ 5 mH)

   a3) Connecting LPF terminated with Z_M = open to the line

   No DC bias current

   b) Unconnecting LPF terminated with Z_M to the line

   No DC bias current

F.3 Test loops and crosstalk disturbers

F.3.1 Test loops

F.3.1.1 Loop configurations

The test loops specified in Figure F.10 shall be used to test the transmission performance of VDSL.

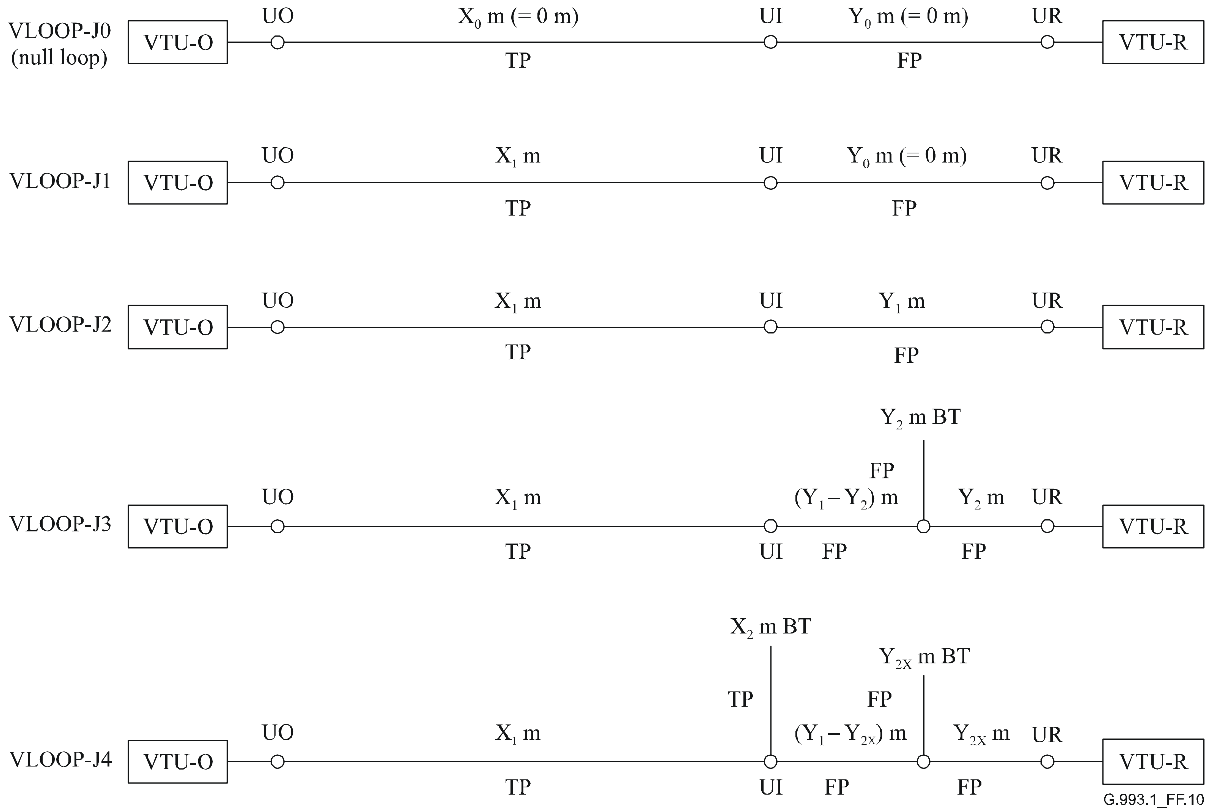


Figure F.10/G.993.1 – VDSL test loops for environment co-existing with TCM-ISDN DSL

1) Two kinds of wire pairs abbreviated by TP and FP in Figure F.10 are as follows:

   TP: 0.4 mm PE cable – Polyethylene insulated and quad configuration multi-pair cable

   FP: 0.5 mm PVC FP – Polyvinyl chloride insulated and flat untwisted single pair

2) The nominal values of X_j (j = 0 to 2) and Y_j (j = 0 to 2) marked in Figure F.10 as adjustable-length sections are as follows. The lengths of TP range from 0 to 1500 m and the lengths of FP are 0 m and 50 m. A bridged tap (BT) is an unterminated open-ended and branched section.

   X_0 = 0 m

   X_1 = 300, 500, 1000, 1200, 1500 m

   X_2 = 25, 50 m

   Y_0 = 0 m

   Y_1 = 50 m

   Y_2 = 5 to 50 m at every 5-m step

   Y_{2DS}: The most significant length for downstream transmission performance

   Y_{2US}: The most significant length for upstream transmission performance

   Y_{2X} = Y_{2DS} for downstream performance test and Y_{2US} for upstream performance test

F.3.1.2 Primary line constants

The primary line constants are *R*, *L*, *C*, and *G*. The equations below give the values of *R* in ohm/m, *L* in *H*/m, *G* in mho/m, *C* in *F*/m, and *f* (frequency) in Hz. The coefficient values are shown in Table F.5.

$$R = 2(Ri + Rn + Rns) \quad \text{[ohm/m]}$$

$$L = 2(La + Li + Ln + Lns) \quad \text{[H/m]}$$

$$C = C_i + \frac{C_{0a}}{(f+1)^{ce}} \quad \text{[F/m]}$$

$$G = 2\pi f^{ge} C \tan\delta \quad \text{[mho/m]}$$

$$Ri = \frac{1}{\pi r_i^2 \sigma_i} \mathrm{Re}\left[\frac{\lambda}{2}\frac{J_0(\lambda)}{J_1(\lambda)}\right] \text{: skin effect}$$

$$Rn = \frac{1}{\pi d_i^2 \sigma_i} \mathrm{Re}\left[-\lambda \frac{J_1(\lambda)}{J_0(\lambda)}\right] \text{: intra-pair eddy current effect}$$

$$Rns = \frac{1}{\pi d_i^2 \sigma_i} 4\,\mathrm{Re}\left[-\lambda \frac{J_1(\lambda)}{J_0(\lambda)}\right] \text{: intra-quad eddy current effect (in case of 0.4 mm PE)}$$

$Rns = 0$: intra-quad eddy current effect (in case of 0.5 mm PVC FP)

$$La = \frac{\mu_0}{2\pi} \ln\left(\frac{d_i}{r_i}\right) \text{: external inductance}$$

$$Li = \frac{\mu_i}{2\pi} \mathrm{Re}\left[-\frac{1}{\lambda}\frac{J_0(\lambda)}{J_1(\lambda)}\right] \text{: skin effect}$$

$$Ln = -\frac{\mu_0}{2\pi}\left(\frac{r_i}{d_i}\right)^2 \mathrm{Re}\left[-\frac{J_2(\lambda)}{J_0(\lambda)}\right] \text{: intra-pair eddy current effect}$$

$$Lns = -\frac{\mu_0}{2\pi}\left(\frac{r_i}{d_i}\right)^2 4\,\mathrm{Re}\left[-\frac{J_2(\lambda)}{J_0(\lambda)}\right] \text{: intra-quad eddy current effect (in case of 0.4 mm PE)}$$

$Lns = 0$: intra-quad eddy current effect (in case of 0.5 mm PVC FP)

where:

J_0, J_1, J_2 zero-, first-, and second-order Bessel functions

Re[ ] real part in [ ]

$$\lambda \equiv (1+j)\frac{r_i}{\delta_i}$$

r_i: radius of conductor [m]

$$\delta_i = \sqrt{\frac{2}{\omega\sigma_i\mu_i}} \text{: skin depth [m]}$$

σ_i: conductivity of copper (conductor) [mho/m]

μ_0: permeability of vacuum [H/m]

μ_i: permeability of copper (conductor) [H/m]: $= \mu_r \mu_0$

μ_r: relative permeability of copper (conductor)

ω: angular frequency [rad/s]

d_i: distance between wire (conductor) centres of a pair [m]

$d_i = 2\sqrt{2}(r_i + CO_i)$: in case of 0.4 mm PE

$d_i = 2(r_i + CO_i)$: in case of 0.5 mm PVC FP

CO_i: thickness of insulator for wire (conductor) [m]

Table F.5/G.993.1 – Coefficient values

Item	TP (0.4 mm PE)	FP (0.5mm PVC FP)
r_i [m]	0.2×10^{-3}	0.25×10^{-3}
CO_i [m]	0.13×10^{-3}	0.78×10^{-3}
C_i [F/m]	50×10^{-12}	20×10^{-12}
C_{oa} [F/m]	0	20×10^{-12}
ce	0	0.095
$\tan\delta$	5.0×10^{-4}	1.9×10^{-1}
ge	1.16	0.895
σ_i [mho/m]	5.8×10^{7}	5.8×10^{7}
μ_0 [H/m]	$4\pi \times 10^{-7}$	$4\pi \times 10^{-7}$
μ_r	1	1

F.3.1.3 Line transfer function and test loop characteristics

The line transfer function (of voltage) based on the propagation constant is given below. The transfer function below assumes no impedance mismatch and perfect terminations by characteristic impedances at both ends, and is a simplified approximation.

$$H(f) = e^{\gamma_{TP} X} e^{\gamma_{FP} Y}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \text{ : propagation constant}$$

X, Y: line distance [m]

The test loop characteristics for reference are presented in Tables F.6, F.7, and F.8 as results of calculation using the above line transfer function and coefficient values.

NOTE – The insertion loss with a source impedance of 100 Ω and a terminal impedance of 100 Ω should be calculated by using the loop ABCD parameters, and the result is loop length and composition dependent.

Table F.6/G.993.1 – Test loop image attenuation in dB for reference

Loop type	Loop length	Frequency [MHz]									
		f_1	f_{1j}		f_2		f_3		f_4		f_5
		0.138	0.640	2.195	3.75	4.475	5.20	6.85	8.50	10.25	12.00
TP	300 m	3.27 dB	6.13	11.8	15.7	17.3	18.7	21.8	24.6	27.4	30.0
FP	50 m	0.27 dB	0.57	1.22	1.74	1.96	2.18	2.65	3.09	3.54	3.98

Table F.7/G.993.1 – Test loop group delay in µs (micro-second) for reference

Loop type	Loop length	Frequency [MHz]									
		f_1	f_{1j}		f_2		f_3		f_4		f_5
		0.138	0.640	2.195	3.75	4.475	5.20	6.85	8.50	10.25	12.00
TP	300 m	1.73 µs	1.63	1.58	1.57	1.57	1.57	1.56	1.56	1.56	1.56
FP	50 m	.24 µs	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22

Table F.8/G.993.1 – Test loop characteristic impedance in Ω (ohm) for reference

Loop type	Frequency [MHz]									
	f_1	f_{1j}		f_2		f_3		f_4		f_5
	0.138	0.640	2.195	3.75	4.475	5.20	6.85	8.50	10.25	12.00
TP	125 Ω	114	109	107	107	107	107	107	107	107
FP	191 Ω	188	187	187	187	187	187	187	187	188

F.3.2 Crosstalk disturbers

F.3.2.1 Disturber types

Crosstalk margin measurements are performed with several types of disturbers, VDSL (ITU-T Rec. G.993.1) self, TCM-ISDN DSL (Appendix III/G.961), ADSL (Annex C/G.992.1 DBM), and PNT (ITU-T Rec. G.989.1).

Two kinds of noise models are defined as follows. Noise A and Noise B_j (j = 1 to 4).

1) Noise A only or Noise A + each Noise B_j (j = 1 or 2 or 3 or 4) shall be injected at each UI or UO port defined in Figure F.10, and the test should be performed several (3 to 4) times.
   - A combination Noise B_j and Noise B_k (j<>k) is not used for performance test. Also, simultaneous injection at both UI and UO ports is not used.
   - Noise A = –140 dBm/Hz AWGN (Additive White Gaussian Noise)
   - Noise B_1 = 9 VDSL self NEXT and FEXT (see F.3.2.2 for the disturber PSD)
   - Noise B_2 = 9 ADSL NEXT and FEXT (see ITU-T Rec. G.996.1 for the disturber PSD)
   - Noise B_3 = 9 PNT NEXT (see F.3.2.2 and ITU-T Rec. G.989.1 for the disturber PSD)
   - Noise B_4 = 9 TCM-ISDN DSL alternate NEXT and FEXT (see ITU-T Rec. G.996.1 for the disturber PSD)

   NOTE 1 – PNT NEXT and FEXT appear alternately in the same frequency band, and are not cyclostationary. This annex adopts only NEXT injection for VDSL test purposes as significant crosstalk.

   NOTE 2 – TCM-ISDN DSL NEXT and FEXT appear alternately in the same frequency band, and are cyclostationary. This annex adopts cyclostationary crosstalk injection of NEXT and FEXT for VDSL test purposes as defined in ITU-T Rec. G.996.1 for ADSL test purposes.

   NOTE 3 – VDSL and ADSL NEXT injection is for testing input signal dynamic range of a VDSL receiver.

2) Only intra-quad condition is defined for Noise B.

The XT PSL (crosstalk power sum loss) values for 9 disturbers with 1% worst case are defined below. This is the reason why the PE insulated cable adopts a unit binding five quads (= ten pairs), so the maximum number of disturbers within a unit is nine.

NPSL9 (NEXT PSL) = 49.5 dB at $f_{NEXT} = 160 \times 10^3$ Hz

FPSL9 (FEXT PSL) = 51.5 dB at $f_{FEXT} = 160 \times 10^3$ Hz and $d_{FEXT} = 1 \times 10^3$ m

3) Only the TP (X_1) section in Figure F.10 shall be considered as crosstalk coupling path. That is the TP (X_2) section (BT) shall not be incorporated in the simulated FEXT disturber PSD as part of FEXT coupling path. As for the FP section in Figure F.10, no crosstalk is considered since the FP is a single pair.

F.3.2.2 Power spectral density of disturbers

The single-sided power spectral density (PSD) functions in watts/Hz for TCM-ISDN DSL and ADSL disturbers are defined in ITU-T Rec. G.996.1. Those for VDSL disturbers are shown in F.3.2.2.1 which are compliant to the PSD requirements specified in F.1. PNT PSD is defined in ITU-T Rec. G.989.1, and is reproduced in F.3.2.2.2.

F.3.2.2.1 VDSL disturber PSD

Two kinds of VDSL disturber PSD are defined. One is for a VDSL that enables coexistent operation with POTS on the same wire-pair by using the frequencies above 0.138 MHz (= f_1). The other is for a VDSL that enables coexistent operation with TCM-ISDN DSL on the same wire-pair by using the frequencies above 0.64 MHz (= f_{1J}). Both of them are abbreviated VDSL-x, where x = P (POTS) and x = I (ISDN). The VDSL-I downstream disturber PSD is different from the VDSL-P downstream disturber PSD, so they are abbreviated VDSL-I-DS and VDSL-P-DS. Meanwhile, the upstream disturber PSD of VDSL-I are the same as that of VDSL-P, so both are abbreviated VDSL-US.

The single-sided PSD of VDSL-P and VDSL-I downstream disturbers in watts/Hz are expressed as follows. Also, the single-sided PSD of VDSL upstream disturber in watts/Hz is expressed as follows.

$$PSD_{VDSL-P-DS}(f) = 10^{\frac{KDS-P(f)}{10}-3} \text{ watts/Hz}$$

$$PSD_{VDSL-1-DS}(f) = 10^{\frac{KDS-I(f)}{10}-3} \text{ watts/Hz}$$

$$PSD_{VDSL-US}(f) = 10^{\frac{KUS-I(f)}{10}-3} \text{ watts/Hz}$$

where:

$f_1 =$ 0.138×10^6 Hz

$f_{1J} =$ 0.64×10^6 Hz

$f_2 =$ 3.75×10^6 Hz

$f_3 =$ 5.2×10^6 Hz

$f_4 =$ 8.5×10^6 Hz

$f_5 =$ 12×10^6 Hz

$\Delta f_T =$ 0.175×10^6 Hz: transition band at f_{1j}, f_2, f_3, f_4, and f_5

$\Delta f_{TX} =$ 0.018×10^6 Hz: transition band at f_1

$$
\text{KDS-P}(f)\begin{cases}
-120 & \text{dBm/Hz} & 0\ \text{Hz} < f < 0.12\times10^{6}\ \text{Hz} \\
-60+(50/\Delta f_{TX})\times(f-f_1) & \text{dBm/Hz} & f_1-\Delta f_{TX} \le f \le f_1 \\
-60 & \text{dBm/Hz} & f_1 < f < f_2 \\
-80-(20/\Delta f_T)\times(f-f_2) & \text{dBm/Hz} & f_2 \le f \le f_2+\Delta f_T \\
-100 & \text{dBm/Hz} & f_2+\Delta f_T < f < f_3-\Delta f_T \\
-80+(20/\Delta f_T)\times(f-f_3) & \text{dBm/Hz} & f_3-\Delta f_T \le f \le f_3 \\
-60 & \text{dBm/Hz} & f_3 < f < f_4 \\
-80-(20/\Delta f_T)\times(f-f_4) & \text{dBm/Hz} & f_4 \le f \le f_4+\Delta f_T \\
-100 & \text{dBm/Hz} & f_4+\Delta f_T < f < 30\times10^{6}\ \text{Hz} \\
-120 & \text{dBm/Hz} & 30\times10^{6}\ \text{Hz} \le f < \infty
\end{cases}
$$

$$
\text{KDS-I}(f)\begin{cases}
-120 & \text{dBm/Hz} & 0\ \text{Hz} < f < 0.12\times10^{6}\ \text{Hz} \\
-110 & \text{dBm/Hz} & 0.12\times10^{6}\ \text{Hz} \le f < 0.225\times10^{6}\ \text{Hz} \\
-100 & \text{dBm/Hz} & 0.225\times10^{6}\ \text{Hz} \le f < f_{1j}-\Delta f_T \\
-60+(40/\Delta f_T)\times(f-f_{1J}) & \text{dBm/Hz} & f_{1J}-\Delta f_T \le f \le f_{1J} \\
-60 & \text{dBm/Hz} & f_{1J} < f < f_2 \\
-80-(20/\Delta f_T)\times(f-f_2) & \text{dBm/Hz} & f_2 \le f \le f_2+\Delta f_T \\
-100 & \text{dBm/Hz} & f_2+\Delta f_T < f < f_3-\Delta f_T \\
-80+(20/\Delta f_T)\times(f-f_3) & \text{dBm/Hz} & f_3-\Delta f_T \le f \le f_3 \\
-60 & \text{dBm/Hz} & f_3 < f < f_4 \\
-80-(20/\Delta f_T)\times(f-f_4) & \text{dBm/Hz} & f_4 \le f \le f_4+\Delta f_T \\
-100 & \text{dBm/Hz} & f_4+\Delta f_T < f < 30\times10^{6}\ \text{Hz} \\
-120 & \text{dBm/Hz} & 30\times10^{6}\ \text{Hz} \le f < \infty
\end{cases}
$$

$$
\text{KUS}(f)\begin{cases}
-120 & \text{dBm/Hz} & 0\ \text{Hz} < f < 0.12\times10^{6}\ \text{Hz} \\
-110 & \text{dBm/Hz} & 0.12\times10^{6}\ \text{Hz} \le f < 0.225\times10^{6}\ \text{Hz} \\
-100 & \text{dBm/Hz} & 0.225\times10^{6}\ \text{Hz} \le f < f_2-\Delta f_T \\
-80+(20/\Delta f_T)\times(f-f_2) & \text{dBm/Hz} & f_2-\Delta f_T \le f \le f_2 \\
-60 & \text{dBm/Hz} & f_2 < f < f_3 \\
-80-(20/\Delta f_T)\times(f-f_3) & \text{dBm/Hz} & f_3 \le f \le f_3+\Delta f_T \\
-100 & \text{dBm/Hz} & f_3+\Delta f_T < f < f_4-\Delta f_T \\
-80+(20/\Delta f_T)\times(f-f_4) & \text{dBm/Hz} & f_4-\Delta f_T \le f \le f_4 \\
-60 & \text{dBm/Hz} & f_4 < f < f_5 \\
-80-(20/\Delta f_T)\times(f-f_5) & \text{dBm/Hz} & f_5 \le f \le f_5+\Delta f_T \\
-100 & \text{dBm/Hz} & f_5+\Delta f_T < f < 30\times10^{6}\ \text{Hz} \\
-120 & \text{dBm/Hz} & 30\times10^{6}\ \text{Hz} \le f < \infty
\end{cases}
$$

The VDSL disturber $PSD_{VDSL\text{-}P\text{-}DS}(f)$ and $PSD_{VDSL\text{-}US}(f)$ in dBm/Hz are presented in Figure F.11. VDSL disturber $PSD_{VDSL\text{-}I\text{-}DS}(f)$ and $PSD_{VDSL\text{-}US}(f)$ in dBm/Hz are presented in Figure F.12. In Figures F.11 and F.12, a solid line shows the downstream $PSD_{VDSL\text{-}x\text{-}DS}(f)$, and a dotted line shows the upstream $PSD_{VDSL\text{-}US}(f)$.

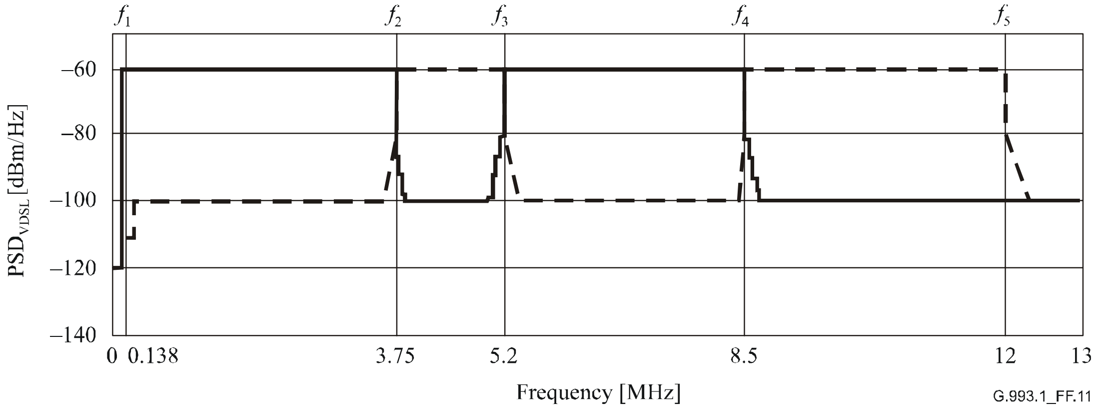


Figure F.11/G.993.1 – VDSL-P downstream and upstream disturber PSD

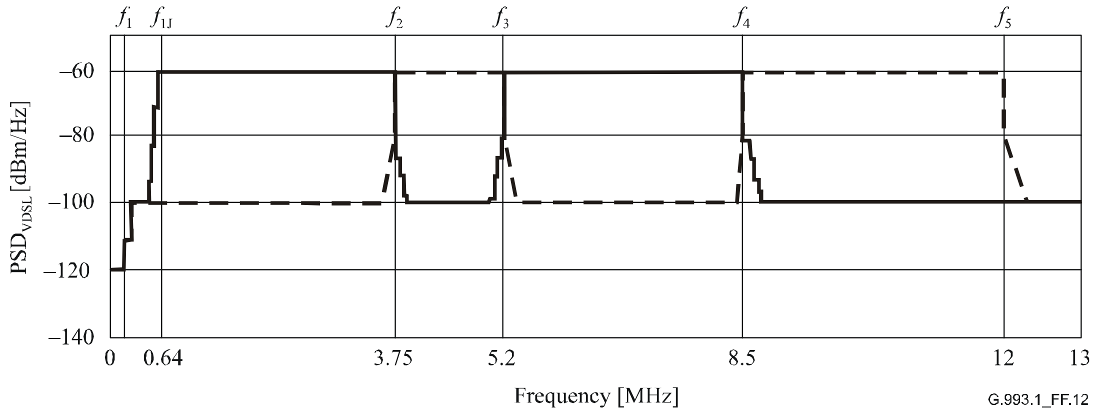


Figure F.12/G.993.1 – VDSL-I downstream and upstream disturber PSD

F.3.2.2.2 PNT disturber PSD

The single-sided PSD of PNT disturbers in watts/Hz, abbreviated by $PSD_{PNT}(f)$, is expressed as follows:

$$PSD_{PNT}(f) = 10^{\frac{KPNT(f)}{10} - 3} \quad \text{watts/Hz}$$

where:

$$\text{KPNT}(f) = \begin{cases} -140 & \text{dBm/Hz} & 0.015\times10^6\,\text{Hz} < f \le 1.7\times10^6\,\text{Hz} \\ -140 + (50.0/1.8)\times(f/10^6 - 1.7) & \text{dBm/Hz} & 1.7\times10^6\,\text{Hz} < f \le 3.5\times10^6\,\text{Hz} \\ -90 + 17.0\times(f/10^6 - 3.5) & \text{dBm/Hz} & 3.5\times10^6\,\text{Hz} < f \le 4.0\times10^6\,\text{Hz} \\ -71.5 & \text{dBm/Hz} & 4.0\times10^6\,\text{Hz} < f < 7.0\times10^6\,\text{Hz} \\ -81.5 & \text{dBm/Hz} & 7.0\times10^6\,\text{Hz} \le f \le 7.3\times10^6\,\text{Hz} \\ -71.5 & \text{dBm/Hz} & 7.3\times10^6\,\text{Hz} < f < 10.0\times10^6\,\text{Hz} \\ -81.5 - (43.5/3.0)\times(f/10^6 - 10.0) & \text{dBm/Hz} & 10.0\times10^6\,\text{Hz} \le f < 13.0\times10^6\,\text{Hz} \\ -125 & \text{dBm/Hz} & 13.0\times10^6\,\text{Hz} \le f < 25.0\times10^6\,\text{Hz} \\ -140 & \text{dBm/Hz} & 25.0\times10^6\,\text{Hz} \le f < 30.0\times10^6\,\text{Hz} \end{cases}$$

The PNT disturber $PSD_{PNT}(f)$ in dBm/Hz is presented in Figure F.13.

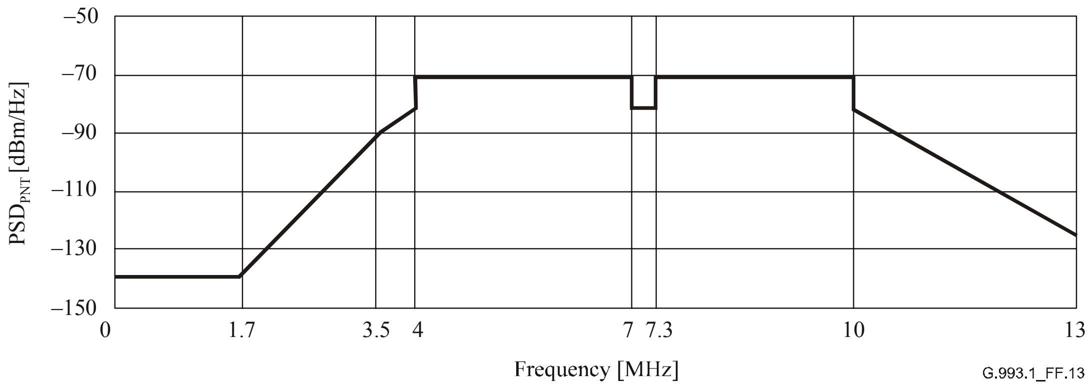


Figure F.13/G.993.1 – PNT (Phoneline Networking Transceiver) disturber PSD

F.3.2.3 Power spectral density of crosstalk

XT (crosstalk) PSD for each xDSL disturber is given by multiplying the xDSL disturber PSD and the XT power coupling function. The XT power coupling functions XT(*f*) are given below for cases of NEXT and FEXT.

$$XT_{NEXT}(f) = \left(\frac{Z_{disturbed}}{Z_{disturber}}\right) 10^{-\frac{NPSL9}{10}} \left(\frac{f}{f_{NEXT}}\right)^{\frac{3}{2}}$$

$$XT_{FEXT}(f) = \left(\frac{Z_{disturbed}}{Z_{disturber}}\right) \left| e^{-2\gamma_{TP}X_1} \right| 10^{-\frac{FPSL9}{10}} \left(\frac{f}{f_{FEXT}}\right)^{2} \left(\frac{X_1}{d_{FEXT}}\right)$$

where:

f: frequency in Hz

NPSL9 = 49.5 dB at $f_{NEXT} = 160 \times 10^3$ Hz

FPSL9 = 51.5 dB at $f_{FEXT} = 160 \times 10^3$ Hz

X_1: crosstalk coupling path length in m

$d_{FEXT} = 1 \times 10^3$ m

$\exp(\gamma_{TP}X_1)$: line transfer function of TP with the length of X_1 m

$Z_{disturbed}$: termination impedance of disturbed VDSL (= 100 Ω)

$Z_{disturber}$: termination impedance of disturbing xDSL

100 Ω: for VDSL, ADSL, and PNT

110 Ω: for TCM-ISDN

NOTE 1 – The NEXT power coupling function of $XT_{NEXT}(f)$ is a function of a coupling path length, to be exact, as expressed below. However, this annex does not adopt the equation so as to reduce test parameters.

$$XT_{NEXT}(f) = \left(\frac{Z_{disturbed}}{Z_{disturber}}\right) 10^{-\frac{NPSL9}{10}} \left(\frac{f}{f_{NEXT}}\right)^{\frac{3}{2}} \left(1 - \left| e^{-4\gamma_{TP}X_1} \right|\right)$$

NOTE 2 – This annex assumes FEXT coupling to be equal level coupling, i.e., a line length of a disturbed xDSL is the same as that of a disturbing xDSL, so as to reduce test parameters.

F.3.2.3.1 VDSL XTPSD

The single-sided XTPSD of VDSL downstream NEXT and FEXT are given below.

$$XTPSD_{VDSL\text{-}x\text{-}DS\text{-}NEXT}(f) = PSD_{VDSL\text{-}x\text{-}DS}(f)\ XT_{NEXT}(f) \quad \text{watts/Hz}$$

$$XTPSD_{VDSL\text{-}x\text{-}DS\text{-}FEXT}(f) = PSD_{VDSL\text{-}x\text{-}DS}(f)\ XT_{FEXT}(f) \quad \text{watts/Hz}$$

where x = P or I.

The single-sided XTPSD of VDSL upstream NEXT and FEXT are given below.

$$XTPSD_{VDSL\text{-}US\text{-}NEXT}(f) = PSD_{VDSL\text{-}US}(f)\ XT_{NEXT}(f) \quad \text{watts/Hz}$$

$$XTPSD_{VDSL\text{-}US\text{-}FEXT}(f) = PSD_{VDSL\text{-}US}(f)\ XT_{FEXT}(f) \quad \text{watts/Hz}$$

NOTE – The VDSL upstream disturber signal PSD ($PSD_{VDSL\text{-}US}(f)$) transmitted at UR port to the line attenuates at UI port as passing through the FP section with the length of Y_1 m. Thus, XTPSD is expressed as follows, to be exact. However, this annex does not adopt the equations below so as to reduce test parameters, since the simulated XTPSDs for injection at UI and UO ports become dependent on the length of Y_1 if below are adopted.

$$XTPSD_{VDSL\text{-}US\text{-}NEXT}(f) = PSD_{VDSL\text{-}US}(f)\ |\exp(-4\gamma_{FP}\ Y_1)|\ XT_{NEXT}(f) \quad \text{watts/Hz}$$

$$XTPSD_{VDSL\text{-}US\text{-}FEXT}(f) = PSD_{VDSL\text{-}US}(f)\ |\exp(-2\gamma_{FP}\ Y_1)|\ XT_{FEXT}(f) \quad \text{watts/Hz}$$

The single-sided XTPSD of VDSL self for injection at each UI or UO port is given below, where UI port is the VTU-R side and UO port is the VTU-O side as defined in Figure F.10.

$$XTPSD_{VDSL\text{-}x\text{-}UI}(f) = XTPSD_{VDSL\text{-}US\text{-}NEXT}(f) + XTPSD_{VDSL\text{-}x\text{-}DS\text{-}FEXT}(f) \quad \text{watts/Hz}$$

$$XTPSD_{VDSL\text{-}x\text{-}UO}(f) = XTPSD_{VDSL\text{-}x\text{-}DS\text{-}NEXT}(f) + XTPSD_{VDSL\text{-}US\text{-}FEXT}(f) \quad \text{watts/Hz}$$

The calculation results of VDSL-I XTPSD are shown in Figure F.14 for the cases of the TP lengths (X_1) of 300 m and 500 m with the FP length of 0 m, where a solid line shows $XTPSD_{VDSL\text{-}I\text{-}UI}(f)$ and $XTPSD_{VDSL\text{-}I\text{-}UO}(f)$ in dBm/Hz, and a dotted line shows received signal PSD at UR (= UI in this case) and UO ports, $PSD_{VDSL\text{-}I\text{-}DS}(f) \times |\exp(-2\gamma_{TP}\ X_1)|$ and $PSD_{VDSL\text{-}US}(f) \times |\exp(-2\gamma_{TP}\ X_1)|$ in dBm/Hz, for reference.

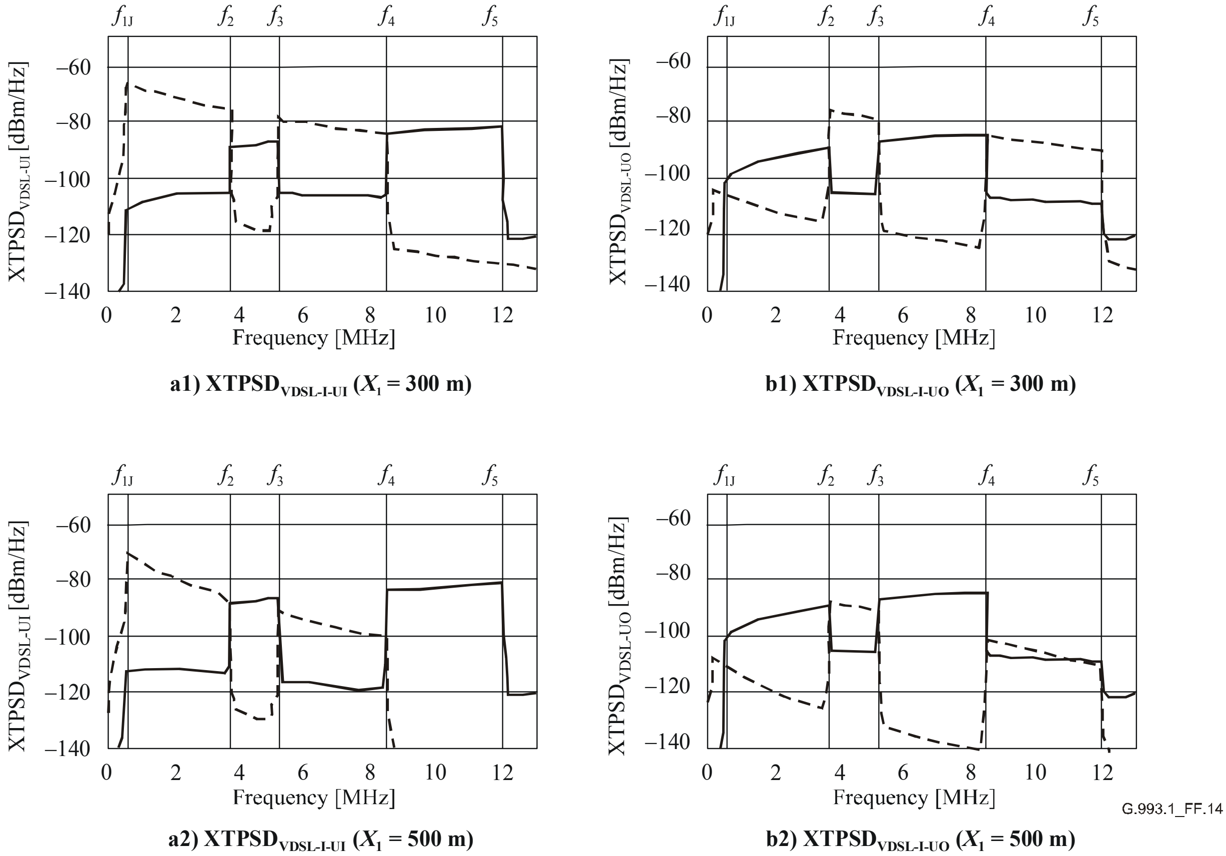


Figure F.14/G.993.1 – 9-disturber VDSL-I NEXT and FEXT PSD for injection at UI and UO ports

F.3.2.3.2 PNT XTPSD

The single-sided XTPSD of PNT for injection at each UI or UO port is given below, where the upstream disturber signal attenuation through the FP section is ignored as mentioned above.

$$XTPSD_{PNT}(f) = PSD_{PNT}(f)\, XT_{NEXT}(f) \quad \text{watts/Hz}$$

The calculation result of PNT XTPSD is shown in Figure F.15, where a solid line shows $XTPSD_{PNT}(f)$ in dBm/Hz and a dotted line shows transmit signal PSD, $PSD_{PNT}(f)$, in dBm/Hz for reference.

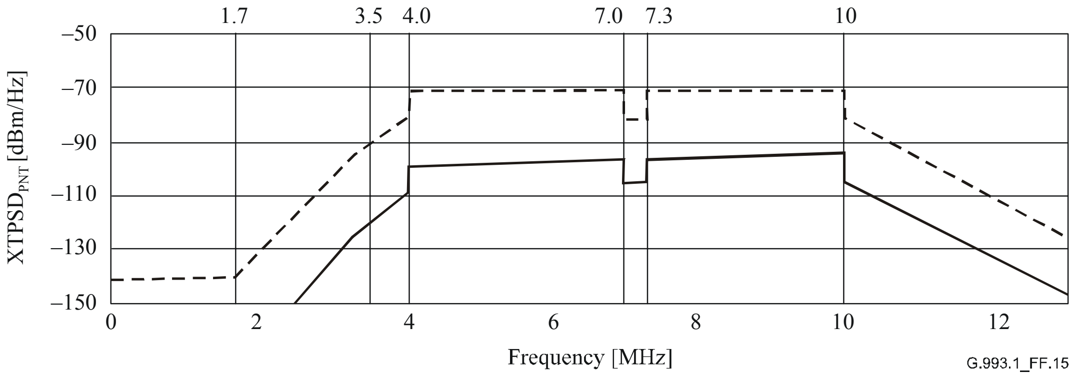


Figure F.15/G.993.1 – 9-disturber PNT NEXT PSD for injection at UI and UO ports

F.3.2.4 Power of crosstalk

A disturber crosstalk power in watts to be injected into a disturbed xDSL receiver is calculated by integration of power spectral density of crosstalk, XTPSD(*f*), over frequencies. The numerical integration results in dBm over the frequency range from 0 Hz to 30 MHz are presented in Table F.9 for reference.

NOTE 1 – ADSL disturber crosstalk power for non-overlapped spectrum defined in Annex A/G.992.1 is given in Table F.9.

NOTE 2 – NEXT and FEXT power of TCM-ISDN DSL disturber in Table F.9 is given by assuming the transmit signal of TCM-ISDN DSL to be continuous. Cyclostationary NEXT and FEXT injection timing is shown in Figure F.16, which is reproduced from ITU-T Rec. G.996.1.

Table F.9/G.993.1 – Crosstalk power in dBm to be injected into disturbed xDSL receiver

Disturber	Injection port	Crosstalk power [dBm]							
		Abbreviation	Item	X_1 (TP length) with Y_0 = 0 m (FP length)					
				100 m	200 m	300 m	500 m	1000 m	1500 m
VDSL-P	UI	XTPSD$_{\text{VDSL-P-UI}}$	XTPSD$_{\text{VDSL-P-US-NEXT}}$	–16.4	←	←	←	←	←
			XTPSD$_{\text{VDSL- P-DS-FEXT}}$	–30.1	–33.7	–37.9	–45.6	–58.7	–67.7
			(power sum)	–16.3	–16.4	–16.4	–16.4	–16.4	–16.4
	UO	XTPSD$_{\text{VDSL-P-UO}}$	XTPSD$_{\text{VDSL-P-DS-NEXT}}$	–19.1	←	←	←	←	←
			XTPSD$_{\text{VDSL-P-US-FEXT}}$	–28.4	–33.8	–40.0	–51.6	–77.9	–102.6
			(power sum)	–18.6	–18.9	–19.0	–19.1	–19.1	–19.1
VDSL-I	UI	XTPSD$_{\text{VDSL-I-UI}}$	XTPSD$_{\text{VDSL-I-US-NEXT}}$	–16.4	←	←	←	←	←
			XTPSD$_{\text{VDSL-I-DS-FEXT}}$	–30.1	–33.7	–38.0	–45.8	–60.5	–72.4
			(power sum)	–16.3	–16.4	–16.4	–16.4	–16.4	–16.4
	UO	XTPSD$_{\text{VDSL-I-UI}}$	XTPSD$_{\text{VDSL-I-DS-NEXT}}$	–19.1	←	←	←	←	←
			XTPSD$_{\text{VDSL-I-US-FEXT}}$	–28.4	–33.8	–40.0	–51.6	–77.9	–102.6
			(power sum)	–18.6	–18.9	–19.0	–19.1	–19.1	–19.1
ADSL	UI	XTPSD$_{\text{ADSL-UI}}$	XTPSD$_{\text{ADSL-US-NEXT}}$	–43.1	←	←	←	←	←
			XTPSD$_{\text{ADSL-DS-FEXT}}$	–33.4	–32.6	–33.1	–35.1	–41.9	–48.9
			(power sum)	–33.0	–32.3	–32.6	–34.4	–39.5	–42.1
	UO	XTPSD$_{\text{ADSL-UO}}$	XTPSD$_{\text{ADSL-DS-NEXT}}$	–24.5	←	←	←	←	←
			XTPSD$_{\text{ADSL-US-FEXT}}$	–57.3	–55.3	–54.6	–54.4	–56.4	–59.6
			(power sum)	–22.5	–22.5	–22.5	–22.5	–22.5	–22.5
PNT	UI and UO	XTPSD$_{\text{PNT}}$	XTPSD$_{\text{PNT-NEXT}}$	–28.7	←	←	←	←	←
TCM-ISDN DSL	UI and UO	XTPSD$_{\text{TCM-ISDN}}$	XTPSD$_{\text{TCM-ISDN-NEXT}}$	–29.6	←	←	←	←	←
			XTPSD$_{\text{TCM-ISDN-FEXT}}$	–41.8	–40.4	–40.1	–40.8	–44.5	–49.0

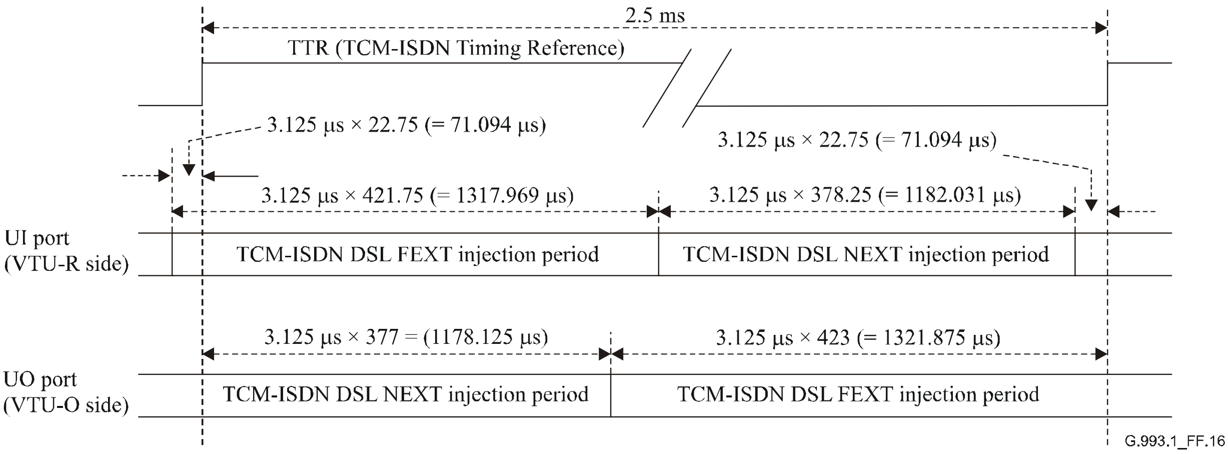


Figure F.16/G.993.1 – TCM-ISDN DSL alternate NEXT and FEXT injection timing

Annex G

ATM-TC

G.1 Scope

This annex specifies a VDSL ATM Transport Protocol Specific Transmission Convergence sublayer (ATM-TC), which describes the ATM-based service transmission over a VDSL link. This annex defines a minimum set of requirements to deliver an ATM service from the ONU to the remote customer premises. It is based on ITU-T Rec. I.432.1. The ATM-TC specification is applicable at both the VTU-O and the VTU-R sides.

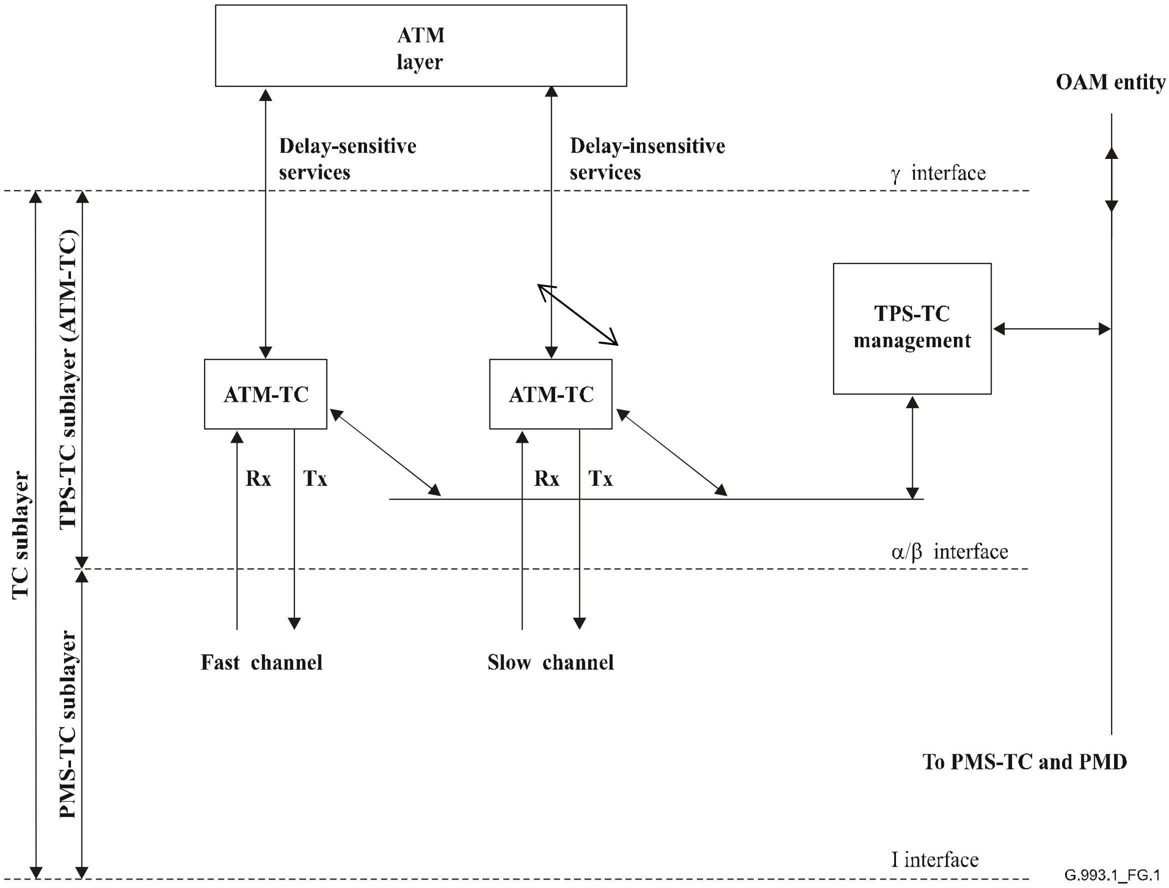
G.2 Reference model for ATM transport

The TPS-TC sublayer for the ATM transport reference model is presented in Figure G.1. The model defines the TPS-TC sublayer located between the α/β and γ_O/γ_R reference points.

The TPS-TC sublayer for ATM transport consists of two identical ATM TPS-TC blocks, intended to support ATM transmission over the Fast *(Delay-sensitive* applications) and the Slow *(Delay-insensitive* applications) channels. Among the two ATM channels (Fast, Slow) only the Slow channel is mandatory. The system provides Dual latency if both the Fast and the Slow channels are implemented; the system provides Single latency if only the Slow channel is implemented.

The TPS-TC OAM block provides all necessary OAM functions to support both ATM TPS-TC blocks.

The interface of both ATM TPS-TC at the γ reference point meets the requirements for ATM Layer interfacing (see G.4.1). Both the Fast and the Slow ATM TPS-TC have an application-independent format at the α/β interface (see G.4.4).



NOTE – At VTU-O: Tx = Downstream, Rx = Upstream. At VTU-R: Tx = Upstream, Rx = Downstream

Figure G.1/G.993.1 – ATM-TC reference model

Network Timing Reference (NTR) is an 8-kHz network timing marker, which should be transported to the customer unit via the access network for some specific services. NTR is sent to the VTU-O TC across the γ_O interface and then transported to VTU-R. NTR is recovered in the PMS_TC of the VTU-R and delivered to the customer unit across the γ_R interface. The method of transporting the NTR has not yet been determined.

G.3 Transport of ATM data

To transport the ATM data both the upstream and the downstream channels shall be set independently from each other to any of the eligible bit rates up to the maximum aggregate channel capacity, determined by the physical net data rate (PMS-TC sublayer). The last is set during the system configuration.

The channelization of different user payloads into either the Fast or the Slow channel is embedded within the ATM data stream by using different Virtual Paths and/or Virtual Channels. To meet the basic requirements for ATM data transport, a G.993.1 system shall support ATM data transport at least in a single latency mode (one downstream channel and one upstream channel).

The need for a single or a dual latency channel for ATM transport depends on the type of service (application). One of the three possible "latency classes" may be used:

- Latency Class 1: single latency both upstream and downstream (not necessarily the same for each direction of transmission) – *mandatory*.
- Latency Class 2: dual latency downstream, single latency upstream – *optional*.

• Latency Class 3: dual latency both upstream and downstream – *optional*.

NOTE – For single latency applications, the Slow channel may be used to implement the Fast channel as well by changing its interleaving depth. Particularly, the interleaver may be disabled in the Slow channel by setting the interleaver depth to 0.

G.4 ATM Transport Protocol Specific TC (ATM_TC)

G.4.1 Application interface description (γ reference point)

The γ reference point defines both the γ_O and γ_R interfaces at the VTU-O and VTU-R sites respectively, as shown in Figure G.1. Both γ interfaces are hypothetical and identical. The interfaces are defined by the following flows of signals between the ATM layer and the ATM-TC sublayer:

• data flow;

• synchronization flow;

• control flow;

• OAM flow.

NOTE 1 – If the dual latency is applied, the γ interface comprises two identical Data flows, Synchronization flows and Control flows – each between the corresponding ATM TPS-TC and ATM layer.

NOTE 2 – For a dual latency implementation ATM cell de-multiplexing to (multiplexing from) the appropriate ATM-TPS TC (i.e., Fast and Slow channel) could be performed at the ATM layer based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header.

G.4.1.1 Data flow

The Data flow consists of two streams of 53 octet ATM cells each (Tx_ATM, Rx_ATM) with independent rates flowing in opposite directions. Rate values are arbitrary under a predefined upper limit of aggregate channel capacity determined by the data rate at the corresponding α (or β) interface. The Data flow signal description is presented in Table G.1.

Table G.1/G.993.1 – ATM-TC: γ interface data, synchronization and control flows signal summary

Flow	Signal	Description	Direction	Notes
		Transmit signals		
Data	*Tx_ATM*	Transmit cell	ATM → ATM-TC	
Sync	*Tx_Clk*	Transmit timing	ATM → ATM-TC	
Sync	*TxSOC*	Start of the transmit cell	ATM → ATM-TC	
Sync	*TxClAv*	TPS-TC is ready to get a cell	ATM ← ATM-TC	
Control	*Enbl_Tx*	TPS-TC polling for an incoming cell	ATM → ATM-TC	
NTR	*TxRef*	8-kHz NTR	VTU-O → ATM-TC	VI_O only
		Receive signals		
Data	*Rx_ATM*	Receive cell	ATM ← ATM-TC	
Sync	*Rx_Clk*	Receive timing	ATM → ATM-TC	
Sync	*RxSOC*	Start of the receive cell	ATM ← ATM-TC	
Sync	*RxClAv*	TPS-TC is ready to transmit a cell	ATM ← ATM-TC	
Control	*Enb_Rx*	TPS-TC polling for the outgoing cell	ATM → ATM-TC	
NTR	*RxRef*	8-kHz NTR	VTU-R ← ATM-TC	VI-R only

The ATM cell format is identical in both transmit and receive directions: 52 out of the 53 octets carry ATM layer data (user data). Octet number 5 is undefined (intended for HEC insertion in the TC sublayer).

NOTE 1 – If data streams are *serial* by implementation, the MSB of each octet is sent first.

NOTE 2 – The Data flow signals are amenable to UTOPIA interface implementation [ATMF].

G.4.1.2 Synchronization flow

This flow provides synchronization between the ATM layer and the ATM-TC sublayer and includes both ATM data synchronization signals and the Network Timing reference signal.

The Synchronization flow comprises the following signals, presented in Table G.1:

- Transmit and receive timing signals (Tx_Clk, Rx_Clk); both asserted by ATM layer;
- Start-of-Cell marker (TxSOC, RxSOC): bidirectional signal, intended to identify the beginning of the transported cell in the corresponding direction;
- Transmit Cell Available flag (TxClAv), asserted by ATM TPS-TC: indicates that ATM TPS-TC is ready to get a transmitted cell from the ATM layer;
- Receive Cell Available flag (RxClAv), asserted by ATM TPS-TC: indicates that TPS-TC contains a valid cell and is ready to transmit it towards ATM layer;
- Transmit Timing Reference (TxRef), applied at the VTU-O only: an 8-kHz NTR signal incoming from the network;
- Receive Timing Reference (RxRef): an 8-kHz NTR signal, recovered from the received VDSL signal at the VTU-R.

NOTE 1 – The Tx_Clk and the Rx_Clk rates are matched with the Tx_ATM and the Rx_ATM data rates respectively.

NOTE 2 – Network Timing Reference signals have opposite directions at the VTU-O and the VTU-R.

NOTE 3 – The Synchronization flow signals are amenable to UTOPIA interface implementation [Appendix I].

G.4.1.3 Control flow

Two control signals are used to provide multiple ATM TPS-TC connection. Both are asserted by the ATM layer:

- Transmit Enable signal (Enbl_Tx): indicates to the ATM TPS-TC that the next transmitted Tx_ATM cell is valid;
- Receive Enable signal (Enbl_Rx): allows the ATM TPS-TC to transmit a Rx_ATM cell towards the ATM layer.

NOTE – The Control flow signals are amenable to UTOPIA interface implementation [Appendix I].

G.4.1.4 OAM flow

The OAM flow across the γ interface exchanges OAM information between the OAM entity and its ATM related TPS-TC management functions. OAM flow is bidirectional.

G.4.2 ATM TPS-TC functionality

The following ATM TPS-TC functionality should be applied both to the downstream and upstream transmission directions.

G.4.3 Cell rate decoupling

Cell rate decoupling should be implemented by Idle cells insertion in the transmit direction and Idle cells deletion in the receive direction (at the remote ATM TPS-TC), as specified in ITU-T Rec. I.432.1. A standard cell header, also specified in ITU-T Rec. I.432.1, identifies idle cells.

G.4.3.1 HEC generation/verification

The HEC byte shall be generated as described in ITU-T Rec. I.432.1, including the recommended modulo-2 addition (XOR) of the pattern 01010101_2 to the HEC bits. The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with ITU-T Rec. I.432.1.

The HEC sequence shall be capable of multiple-bit error detection, as defined in ITU-T Rec. I.432.1. The single bit error correction of the cell header shall not be performed.

G.4.3.2 Cell payload randomization and de-randomization

Randomization of the transmit ATM cell payload avoids continuous non-variable bit patterns in the ATM cell stream and so improves the efficiency of the cell delineation algorithm.

The ATM cell randomizer uses a self-synchronizing scrambler polynomial $x^{43}+1$ and randomization procedures as defined in ITU-T Rec. I.432.1 for STM-based transmission shall be implemented. The corresponding de-randomization process should be implemented at the remote ATM TPS-TC.

G.4.3.3 Cell delineation

The cell delineation function permits the identification of the cell boundaries in the payload. It is based on a coding law using the Header Error Control (HEC) field in the cell header.

The cell delineation algorithm should be as described in ITU-T Rec. I.432.1. It includes the following states and state transitions, presented in Figure G.2:

- "Sync" to "Hunt" state transition when HEC coding law is violated α = 5 times consecutively.
- "Presync" to "Sync" state transition when HEC coding law is confirmed δ = 7 times consecutively.

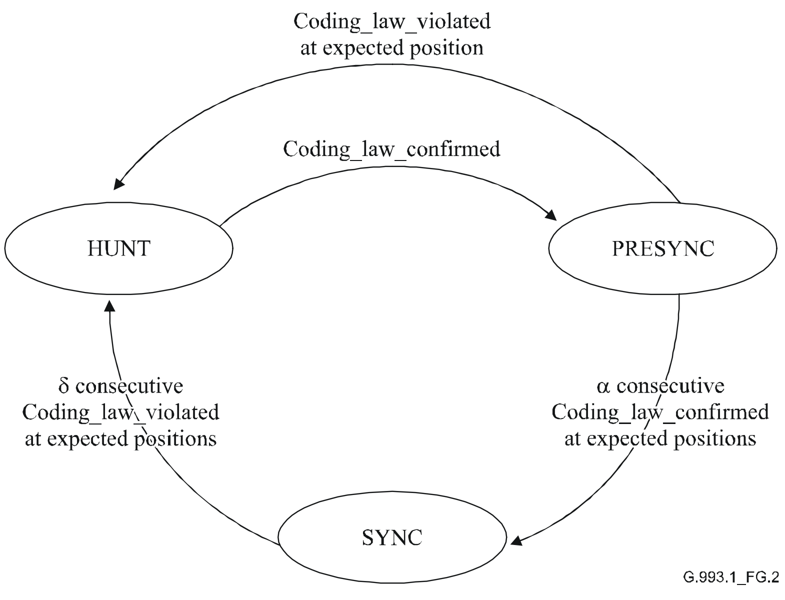


Figure G.2/G.993.1 – ATM cell delineation state machine

G.4.4 α(β) interface

The **α** and **β** reference points define interfaces between the ATM-TC and PMS-TC at the VTU-O and VTU-R respectively. Both interfaces are functional, application independent, and should comply with the generic definition for all TPS-TC as specified in clause 7.

Annex H

PTM-TC

H.1 Packetized data transport

H.1.1 Functional model

The functional model of packetized data transport is presented in Figure H.1. In the transmit direction, the *PTM entity* obtains data packets to be transported over VDSL from the application interface. The PTM entity processes each packet and applies it (depending on the latency requirements) to the γ interface of the either Fast or Slow VDSL path intended for packetized data transport. The corresponding TPS-TC (PTM-TC) receives the packet from the γ interface, encapsulates it into a special frame (PTM-TC frame) and maps into the PMS-TC frame (transmission frame) for transmission over the VDSL link.

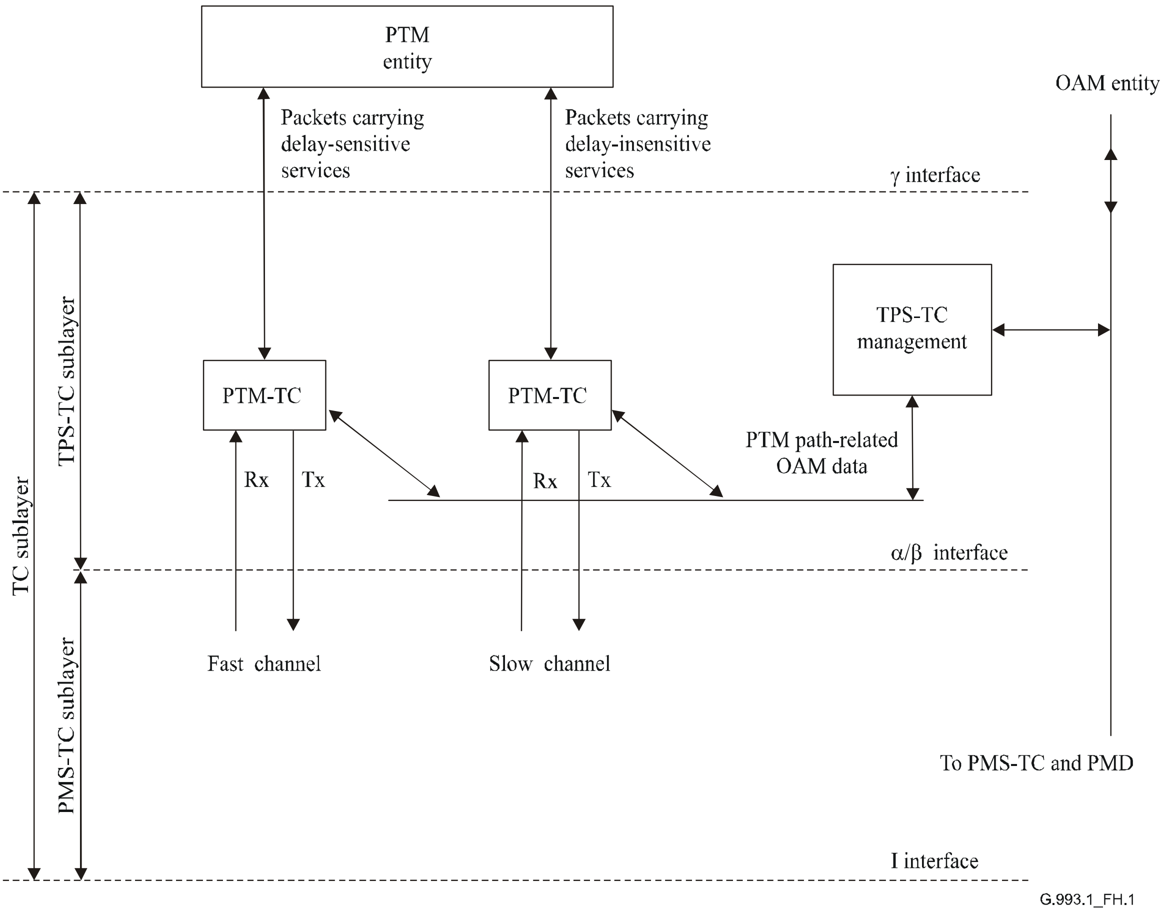


Figure H.1/G.993.1 – Functional model of PTM transport

In the receive direction, the PTM-TC frame extracted from the received PMS-TC frame is directed into the PTM-TC. The PTM-TC recovers the transported packet and delivers it to the PTM entity via the γ interface.

The PTM path-related OAM data, including information on errored packets, shall be presented to the TPS-TC management entity providing all necessary OAM functions to support both PTM-TC.

The γ interfaces of both PTM-TC are identical and described in H.3.1. The α/β interfaces are application independent and thus has the same format as for other TPS-TC (see H.3.1.5).

H.2 Transport of PTM data

The bit rate of PTM data transport in the upstream and downstream directions may be set independently of each other to any eligible value which is less than the assigned maximum bit rate in the corresponding direction. Both the upstream and downstream maximum bit rates for PTM transport are set during the system configuration.

The PTM transport could be arranged using either Slow channel or Fast channel or both. The PTM-TC supporting either channel has the same characteristics. The mandatory configuration for packet transport shall include one PTM-TC (either Fast or Slow). The second PTM-TC is optional.

If PTM is the only transport established over the VDSL link, usage of Slow channel is the mandatory configuration for single latency in accordance with the generic TPS-TC sublayer architecture. The required latency should be obtained by adjustment of the interleaving depth.

The PTM-TC shall provide full transparent data transfer between γ_O and γ_R interfaces (except non-correctable errors in the PMD sublayer due to the noise in the loop). The PTM-TC shall provide packet integrity over either Fast or Slow channel.

H.3 Interface description

H.3.1 γ interface

The $\boldsymbol{\gamma_O}$ and $\boldsymbol{\gamma_R}$ reference points define interfaces between the PTM entity and PTM-TC at the VTU-O and VTU-R respectively as shown in Figure H.1. Both interfaces are identical, functional, and independent of the contents of the transported packets. The interfaces are defined by the following flows of signals between the PTM entity and the PTM-TC sublayer:

- data flow;
- synchronization flow;
- control flow;
- OAM flow.

H.3.1.1 Data flow

The data flow shall consist of two contra-directional octet-based streams of packets: transmit packets (***Tx_PTM***) and receive packets (***Rx_PTM***). The packet transported in either direction over the γ interface may be of variable length. Bits within an octet are labeled a_1 through a_8, with a_1 being the LSB and a_8 being the MSB. If either of data streams is transmitted serially, the first octet of the packet shall be transmitted first and bit a_1 of each octet shall be transmitted first as shown in Figure H.3. The Data Flow signal description is presented in Table H.1.

Table H.1/G.993.1 – PTM-TC: γ interface data, synchronization and control flows signal summary

Flow	Signal	Description	Direction
Transmit signals			
Data	*Tx_PTM*	Transmit data	PTM → PTM-TC
Control	*Tx_Enbl*	Asserted by the PTM-TC; indicates PTM may push data to the PTM-TC	PTM ← PTM-TC
Control	*TX_Err*	Errored transmit packet (request to abort)	PTM → PTM-TC

Table H.1/G.993.1 – PTM-TC: γ interface data, synchronization and control flows signal summary

Flow	Signal	Description	Direction
Sync	*Tx_Avbl*	Asserted by the PTM entity if data is available for transmission	PTM → PTM-TC
Sync	*Tx_Clk*	Clock signal asserted by the PTM entity	PTM → PTM-TC
Sync	*Tx_SoP*	Start of the transmit Packet	PTM → PTM-TC
Sync	*Tx_EoP*	End of the transmit Packet	PTM → PTM-TC
Receive signals			
Data	*Rx_PTM*	Receive data	PTM ← PTM-TC
Control	*Rx_Enbl*	Asserted by the PTM-TC; indicates PTM may pull data from the PTM-TC	PTM ← PTM-TC
Control	*RX_Err*	Received error signals including FCS error, Invalid Frame, and OK	PTM ← PTM-TC
Sync	*Rx_Clk*	Clock signal asserted by the PTM entity	PTM → PTM-TC
Sync	*Rx_SoP*	Start of the receive Packet	PTM ← PTM-TC
Sync	*Rx_EoP*	End of the receive Packet	PTM ← PTM-TC

H.3.1.2 Synchronization flow

This flow provides synchronization between the PTM entity and the PTM-TC sublayer and contains the necessary timing to provide packet integrity during the transport. The synchronization flow shall consist of the following signals presented in Table H.1:

- Transmit and receive timing signals (Tx_Clk, Rx_Clk): both asserted by PTM entity.
- Start of Packet signals (Tx_SoP, Rx_SoP): asserted by PTM entity and by PTM-TC respectively and intended to identify the beginning of the transported packet in the corresponding direction of transmission.
- End of Packet signals (Tx_EoP, Rx_EoP): asserted by PTM entity and by PTM-TC respectively and intended to identify the end of the transported packet in the corresponding direction of transmission.
- Transmit Packet Available signals (Tx_Avbl): asserted by PTM entity to indicate that data for transmission in the corresponding direction is ready.

H.3.1.3 Control flow

Control signals are used to improve robustness of data transport between the PTM-entity and PTM-TC and are presented in Table H.1.

- Enable signals (Tx_Enbl, Rx_Enbl): asserted by PTM-TC and indicates that data may be respectively sent from PTM entity to PTM-TC or pulled from PTM-TC to PTM entity.
- Transmit error message (Tx_Err): asserted by the PTM entity and indicates that the packet or a part of the packet already transported from PTM entity to PTM-TC is errored or undesirable for transmission (abort of transmitted packet).
- Receive error message (Rx_Err): shall be asserted by the PTM-TC to indicate that an errored packet is transported from PTM-TC to PTM entity.

Handling of packet errors is described in H.4.2.

H.3.1.4 OAM flow

The OAM Flow across the γ interface exchanges OAM information between the OAM entity and its PTM related TPS-TC management functions. OAM flow is bidirectional.

H.3.1.5 α(β) interface

The α and β reference points define interfaces between the PTM-TC and PMS-TC at the VTU-O and VTU-R respectively. Both interfaces are functional, application independent, and should comply with the generic definition for all TPS-TC as specified in clause 7.

H.4 PTM TPS-TC functionality

The following PTM TPS-TC functionality should be applied both to the downstream and upstream transmission directions.

H.4.1 Packet encapsulation

For packet encapsulation, an HDLC-type mechanism shall be used with detailed characteristics as specified in the following subclauses.

H.4.1.1 Frame structure

The PTM-TC frame format shall be as shown in Figure H.2. The opening and closing Flag Sequences shall be set to $7E_{16}$. They identify the start and the end of the frame. Only one Flag Sequence is required between two consecutive frames.

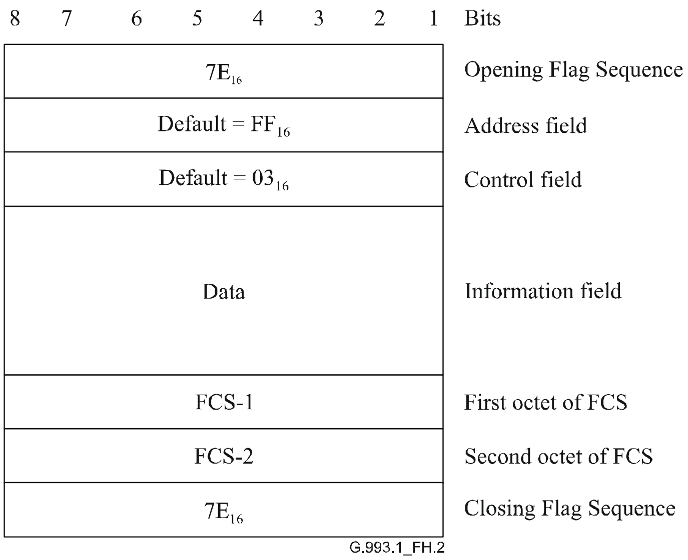


Figure H.2/G.993.1 – PTM-TC frame format

The Address and Control octets are intended for auxiliary information. They shall be set to their default values of hexadecimal FF_{16} and 03_{16} respectively if not used.

NOTE 1 – The address and Control fields may be used for different auxiliary OAM functions.

The Information field shall be filled with the transported data packet. Prior to encapsulation the octets of the data packet shall be numbered sequentially. Octets shall be transmitted in ascending numerical order.

The Frame Check Sequence (FCS) octets are used for packet level error monitoring, and shall be set as described in H.4.3.

After encapsulation, bits within an octet are labeled b_1 through b_8, as defined in Figure H.3. If the α(β) interface is serial by implementation, bit b_8 of each octet shall be transmitted first.

NOTE 2 – In keeping with existing labelling convention for the α/β interface, bit b_8 (MSB) is transmitted first. The PTM-TC functionality defines a correspondence between a_1 and b_8, a_2 and b_7, etc., in order to conform to the HDLC convention of transmitting bit a_1 first.

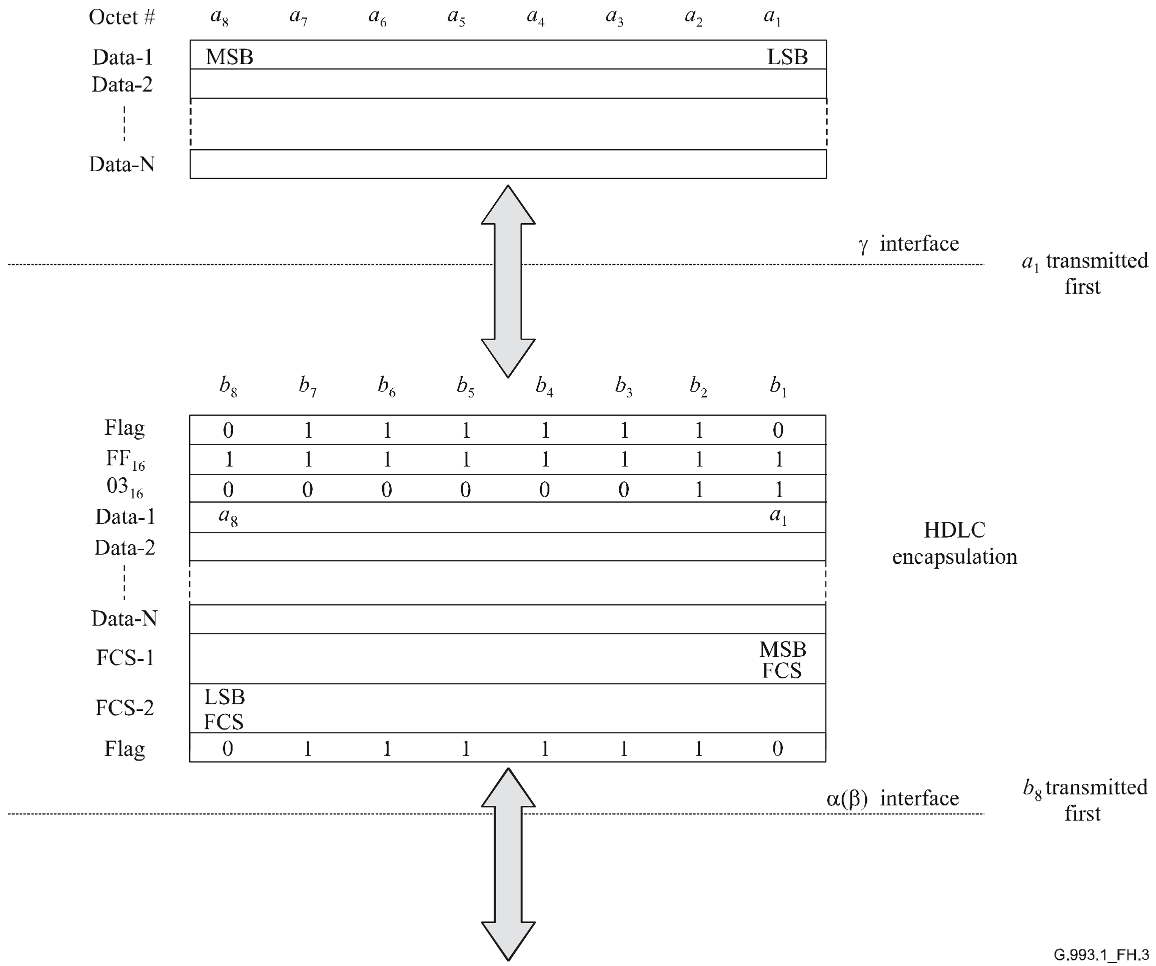


Figure H.3/G.993.1 – PTM-TC data flow

H.4.1.2 Octet transparency

To prevent failures due to false frame synchronization, any octet inside the PTM-TC frame that is equal to hexadecimal $7E_{16}$ (the Flag Sequence) or hexadecimal $7D_{16}$ (the Control Escape) shall be escaped as described below.

After FCS computation, the transmitter examines the entire frame between the opening and the closing Flag Sequences. Any data octets which are equal to the Flag Sequence or the Control Escape shall be replaced by a two-octet sequence consisting of the Control Escape octet followed by the original octet exclusive-OR'ed with hexadecimal 20_{16}. In summary, the following substitutions shall be made:

- any data octet of $7E_{16}$ – encoded as two octets $7D_{16}$, $5E_{16}$.
- any data octet of $7D_{16}$ – encoded as two octets $7D_{16}$, $5D_{16}$.

On reception, prior to FCS computation, each Control Escape octet shall be removed, and the following octet shall be exclusive-OR'ed with hexadecimal 20_{16} (unless the following octet is $7E_{16}$, which is the flag, and indicates the end of frame, and therefore an abort has occurred). In summary, the following substitutions are made:

- any sequence of $7D_{16}$, $5E_{16}$ – replaced by the data octet $7E_{16}$.
- any sequence of $7D_{16}$, $5D_{16}$ – replaced by the data octet $7D_{16}$.
- a sequence of $7D_{16}$, $7E_{16}$ aborts the frame.

NOTE – Since octet stuffing is used, the PTM-TC frame is guaranteed to have an integer number of octets.

H.4.1.3 Frame check sequence

The FCS shall be calculated over all bits of the address, control, and information fields of the PTM-TC frame as defined in ISO/IEC 3309, i.e., it shall be the one's complement of the sum (modulo 2) of:

- the remainder of $x^k(x^{15} + x^{14} + x^{13} + x^{12} + x^{11} + x^{10} + x^9 + x^8 + x^7 + x^6 + x^5 + x^4 + x^3 + x^2 + x + 1)$ divided (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$, where k is the number of bits in the frame existing between, but not including, the last bit of the opening flag and the first bit of the FCS, excluding octets inserted for transparency (H.4.1.2); and
- the remainder of the division (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$, of the product of x^{16} by the content of the frame existing between, but not including, the last bit of the opening flag and the first bit of the FCS, excluding octets inserted for transparency.

The FCS is 16 bits (2 octets) in length and occupies fields FCS-1, FCS-2 of the PTM-TC frame. The FCS shall be mapped into the frame so that bit a_1 (b_8) of FCS-1 shall be the MSB of the calculated FCS, and bit a_8 (b_1) of the FCS-2 shall be the LSB of the calculated FCS (Figure H.3).

The register used to calculate the FCS at the transmitter shall be initialized to the value $FFFF_{16}$.

NOTE – As a typical implementation at the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all binary ONEs and is then modified by division by the generator polynomial, as described above, on the information field. The one's complement of the resulting remainder is transmitted as the 16-bit FCS. As a typical implementation at the receiver, the initial content of the register of the device computing the remainder of the division is preset to all binary ONEs. The final remainder, after multiplication by x^{16} and then division (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$ of the serial incoming protected bits after removal of the transparency octets and the FCS, will be 0001110100001111_2 (x^{15} through x^0, respectively) in the absence of transmission errors.

H.4.2 Packet error monitoring

Packet error monitoring includes detection of invalid and errored frames at the receive side.

H.4.2.1 Invalid frames

The following conditions result in an invalid frame:

- Frames which are less than 5 octets in between flags not including transparency octets (Flag Sequence and Control Escape). These frames shall be discarded.
- Frames which contain a Control Escape octet followed immediately by a Flag (i.e., $7D_{16}$ followed by $7E_{16}$). These frames shall be passed across the γ interface to the PTM entity.
- Frames which contain control escape sequences other than $7D_{16}$, $5E_{16}$ and $7D_{16}$, $5D_{16}$. These frames shall be passed across the γ interface to the PTM entity.

All invalid frames shall not be counted as FCS errors. The receiver shall immediately start looking for the opening flag of a subsequent frame upon detection of an invalid frame. A corresponding receive error message (Rx_Err – see H.3.1.2) shall be sent across the γ interface to the PTM entity.

H.4.2.2 Errored frames

A received frame shall be qualified as an errored frame (FCS-errored) if the CRC calculation result for this frame is different from the one described in H.4.1.3. Errored frames shall be passed across the γ interface. A corresponding receive error message (Rx_Err – see H.3.1.2) shall be sent across the γ interface to the PTM entity.

H.4.3 Data rate decoupling

Data rate decoupling is accomplished by filling the time gaps between transmitted PTM-TC frames with additional Flag Sequences ($7E_{16}$). Additional Flag Sequences shall be inserted at the transmit side between the closing Flag Sequence of the last transmitted PTM-TC frame and the subsequent opening Flag Sequence of the next PTM-TC frame, and discarded at the receive side respectively.

H.4.3.1 Frame delineation

The PTM-TC frames should be delineated by detecting of Flag Sequences. The incoming stream is examined on an octet-by-octet basis for the value of hexadecimal $7E_{16}$. Two (or more) consecutive Flag Sequences constitute an empty frame (frames), which shall be discarded, and not counted as a FCS error.

Annex I

Specifics of implementation in systems using QAM modulation

For systems that implement this annex, all of this Recommendation is implemented with the following exceptions:

- I.1 replaces clause 8;
- I.2 replaces clause 9;
- I.3.1 redefines some terms in 10.5.1 and 10.5.2;
- I.3.2 replaces 10.6;
- I.3.3 redefines some terms in 7.2;
- I.3.4 redefines some terms in 10.3.2.4;
- I.4.1 replaces 12.3;
- I.4.2 and I.4.3 replaces 12.4;
- I.4.4 replaces 12.1 and 12.2;
- I.5 is an informative clause that presents supplemental information.

I.1 Physical Media Specific TC (PMS-TC) sublayer

I.1.1 Functional model

The PMS-TC sublayer functional model for both VTU-O and VTU-R is presented in Figure I.1. The PMS-TC sublayer includes functional blocks for randomization (Scrambler), forward error correction (FEC), interleaving, transmission frame encapsulation (MUX), and management. Both the Fast and the Slow channel have an application-independent format at the α(β) interface. The transmission frame (see I.1.2, I.1.2.2) is multiplexed from the Slow data, Fast data, and a header. The header carries the NTR marker, Indicator Bits (IB), special flags for link activation, and a Syncword for frame alignment. The PMS-TC management provides all OAM primitives and parameters related to the PMS-TC.

Transmit data of both the Fast and Slow channels incoming via the α(β) interface is randomized, protected by FEC, and multiplexed into the transmission frame. Slow channel protection includes interleaving. The PMS-TC provides a dual latency mode if both the Fast and Slow channels are implemented. It provides a single latency mode if only the Slow channel is implemented. The latency mode can be different in different transmission directions. The transport class of the transmission frame (see I.1.2.3) determines the latency mode and transport capability of both channels at the I_O (I_R) reference point. It shall be set during the system configuration.

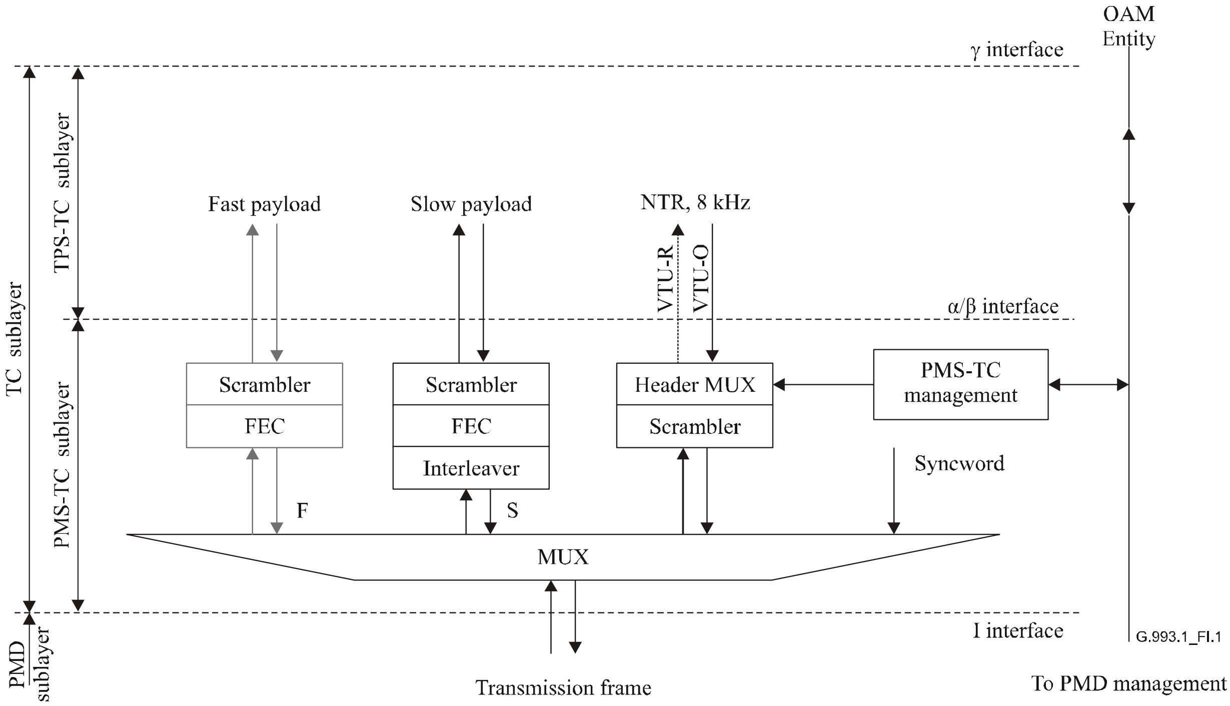


Figure I.1/G.993.1 – PMS-TC functional model

I.1.2 Transmission frame

I.1.2.1 Frame format

The same format of the transmission frame, as shown in Figure I.2, shall be applied in both the upstream and downstream directions. The frame shall contain 405 octets: a 5-octet header and a 400-octet payload. The frame payload shall include two equal fields for the Fast channel (*F* octets each) and two equal fields for the Slow channel (*S* octets each). Slow and Fast fields shall alternate, as shown in Figure I.2.

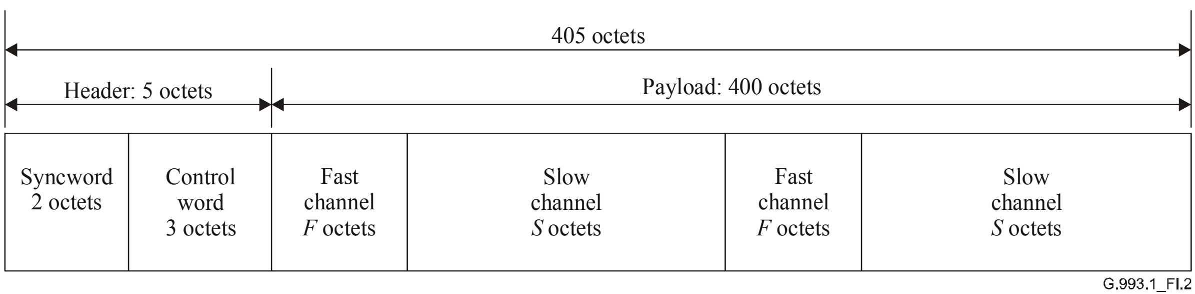


Figure I.2/G.993.1 – Transmission frame format

Each Fast channel field transports one Reed-Solomon (RS) codeword with no interleaving (Fast codeword). Each Slow channel field transports one RS codeword (Slow codeword), which shall pass through an interleaver (see I.1.2.8) before transmission onto the line. Both F and S values shall be even, and shall comply with the applied transport class (Table I.5). Fast channel is optional. If not used, $F = 0$.

All frame octets are transmitted with MSB first. The MSB of the first transmitted frame octet corresponds to the beginning of the frame.

NOTE – The appropriate transport class should be specified during the system configuration prior to steady state transmission.

I.1.2.1.1 Fast codeword

The structure of the Fast codeword shall be as shown in Figure I.3. The codeword shall consist of a Fast Payload field of *PF* octets and Fast FEC field of *RF* octets. The length of the Fast codeword may be 0-180 octets. The value of *RF* octets may be 0, 2, 4 or 16 octets. Non-zero values of *PF* and *RF* are optional; the valid non-zero values for class 2 frame (dual latency) are presented in Table I.5. The first octet of the Fast codeword in Figure I.3 shall correspond to the first octet of the Fast Payload shown in Figure I.2.

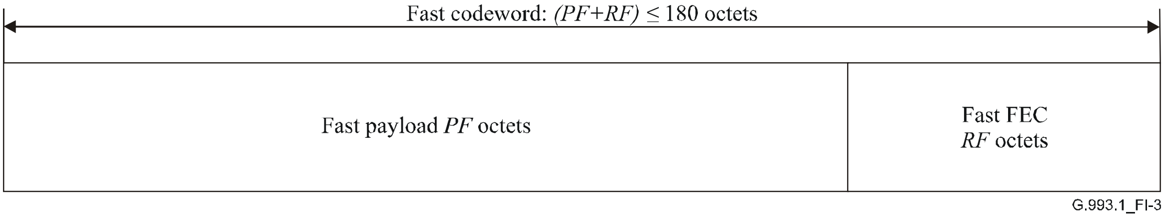


Figure I.3/G.993.1 – Fast codeword

NOTE 1 – The value $RF = 0$ provides uncoded data transmission over the Fast channel.

NOTE 2 – For an uncoded implementation of the Fast channel, the standard method of verification of the error monitoring procedure described in I.1.2.7 is not applicable. The verification method in this case is left to be done by means of the relevant TPS-TC or by means of the application.

I.1.2.1.2 Slow codeword

The structure of a Slow codeword (prior to interleaving) shall be as shown in Figure I.4. The codeword shall consist of a 3-octet Operations Channel (OC) field, a Slow Payload field of *PS* octets, and a Slow FEC field of 16 octets. The length of the Slow codeword may be 20-200 octets. For a class-1 frame (single latency), $S = 200$. The valid values of S for class 2 frame (dual latency) may be derived from Table I.5. The first octet of the Slow codeword in Figure I.4 shall correspond to the first octet of the OC shown in Figure I.5.

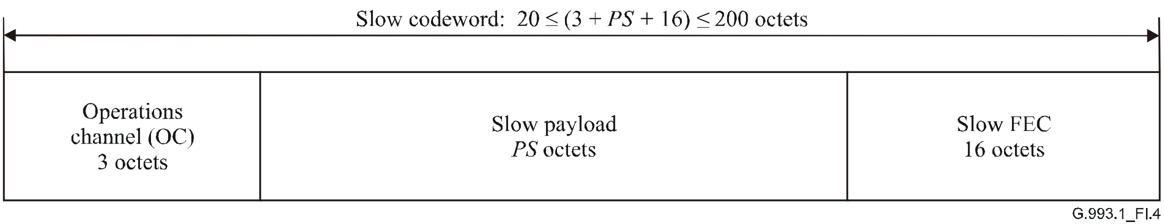


Figure I.4/G.993.1 – Slow codeword

The structure of the OC field shall be as shown in Figure I.5. The first OC octet shall be reserved for OC OPCODE, the second and third shall be for OC data.

NOTE – The OC is shared between the embedded operations channel (eoc) and the VDSL Overhead Control (VOC) channel as described in I.3.3.

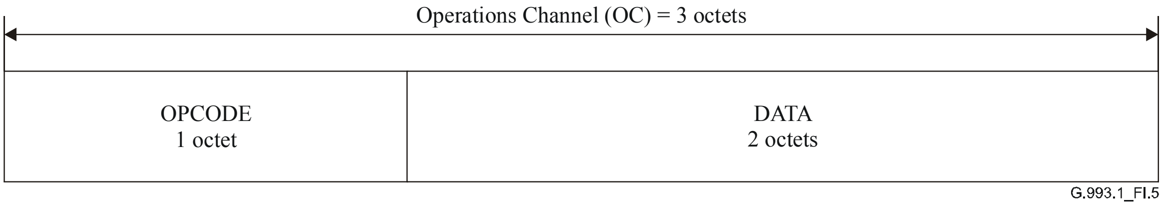


Figure I.5/G.993.1 – Operations channel field

I.1.2.2 Frame header

The transmission frame header includes a 2-octet Syncword and a 3-octet Control field. The Syncword contains frame alignment information. The Control field conveys management and auxiliary information as described in Tables I.2 to I.4, including four bits reserved for proprietary use. A 4-bit cyclic redundancy check (CRC) incorporated into the Control field allows error detection in the received data. The header is described in Table I.1. In all the following descriptions, bit #7 of any octet is MSB. Bit #7 of octet #0 shall be transmitted first.

Table I.1/G.993.1 – Allocation of octets in frame header

Octet	Name	Description	Value
0	Sync 1	Syncword, octet 1	0xF6
1	Sync 2	Syncword, octet 2	0x28
2	Control 1	Control and Management information, octet 1	Variable
3	Control 2	Control and Management information, octet 2	
4	Control 3	Control and Management information, octet 3	

NOTE – Here and further, "0x" is used as a placeholder for "hexadecimal".

I.1.2.2.1 Syncword octets

The same Syncword shall be used in both transmission directions. The Syncword shall consist of two octets with the values: Sync 1 = 0xF6, Sync 2 = 0x28.

I.1.2.2.2 Control 1 octet

The Control 1 octet shall contain the *NTR*-bit, the *o/r_trig* and *o/r_flag* bits, used for the link activation support, and the first five indicator bits (IB-1 through IB-5) intended for far-end monitoring, as described in Table I.2. All IB shall be coded "0" for normal operation and "1" for abnormal operation (defect or failure condition).

Table I.2/G.993.1 – Control 1 octet

Bit	Name	Description	Value	Note
7	*trig*	"*o_trig*" signal in downstream direction "*r_trig*" signal in upstream direction	"0" for normal state "1" for the active state	See I.4
6	*flag*	"*o_flag*" signal in downstream direction "*r_flag*" signal in upstream direction		
5	IB-1 (*fp_1*)	Far-end TPS_TC #1 defect/failure	"0" for normal state "1" for the TPS-TC failure	
4	IB-2 (*fp_2*)	Far-end TPS_TC #2 defect/failure		
3	IB-3 (*fp_3*)	Far-end TPS_TC #3 defect/failure		
2	IB-4 (*fp_4*)	Far-end TPS_TC #4 defect/failure		
1	IB-5 (Reserved)	For additional defects/failures	"0" for normal state "1" for the failure state	
0	*NTR*	NTR marker	"1" if NTR marker is transmitted, "0" otherwise	See I.1.2.4

Far-end path indicators (*fp*) shall be used for path-related primitives of possible paths numbered from #1 to #4. Additional paths can be indicated using bit 1 of the Control 1 octet and bits 1, 2 of the Control 2 octet. The definition of the *fp* shall coincide with the definition of the corresponding path-related primitive. If only one type of service is applied, the *fp_1* shall be used to indicate the failure of the Slow channel TPS-TC, and the *fp_2* shall be used to indicate the failure of the Fast channel TPS-TC.

For the ATM path, *fp* shall indicate the *Far-end Loss of Cell Delineation* (*flcd)* defect, as it is defined in 10.5.2.1.

For the PTM-TC, *fp* shall indicate the *FPER* defect, as it is defined in 10.5.2.3.

As an example, if ATM is the only service, the *fp_1* shall be used to indicate the *flcd* defect for the Slow ATM-TC, and the *fp_2* shall be used to indicate the *flcd* defect for the Fast ATM-TC, if applicable.

I.1.2.2.3 Control 2 octet

The Control 2 octet shall contain the first and second CRC bits, and the IB bits IB-6 through IB-11, as presented in Table I.3. All IB shall be coded "0" for normal operation and "1" for abnormal operation (defect or failure condition). The *CRC_1* and *CRC_2* bits shall be assigned as described in I.1.2.2.5.

Table I.3/G.993.1 – Control 2 octet

Bit	Name	Description	Value	Note
7	*CRC_1*	Frame header CRC check	First bit	See I.1.2.2.5
6	IB-6 (Reserved)	IB for future applications	"0" for normal state "1" for the failure state	

Table I.3/G.993.1 – Control 2 octet

Bit	Name	Description	Value	Note
5	IB-7 (*flos_cr1*)	Far-end loss of energy – Carrier 1	"0" for normal state "1" for the loss state	PMD, PMS-TC primitives: see I.3.1 and 10.5
4	IB-8 (*flos_cr2*)	Far-end loss of energy – Carrier 2		
3	IB-9 (*rdi*)	Far-end severely errored frame defect	"0" for normal state "1" for the failure state	
2	IB-10 (Reserved)	IB for future applications	"0" for normal state "1" for the failure state	
1	IB-11 (Reserved)	IB for future applications	"0" for normal state "1" for the failure state	
0	*CRC_2*	Frame header CRC check	Second bit	See I.1.2.2.5

I.1.2.2.4 Control 3 octet

The Control 3 octet shall contain the third and the fourth *CRC* bits, two IB bits (IB-12, IB-13), and four bits for proprietary use, as presented in Table I.4. All IB shall be coded "0" for normal operation, and "1" for abnormal operation (defect or failure condition). The *CRC_3* and *CRC_4* bits shall be assigned as described in I.1.2.2.5.

Table I.4/G.993.1 – Control 3 octet

Bit	Name	Description	Value	Note
7	*CRC_3*	Frame header CRC check	Third bit	See I.1.2.2.5
6	IB-12 (*FPO*)	Far-end power-off failure	"0" for normal state "1" for the power failure state	Power related primitives: see I.3.1 and 10.5.3.
5	IB-13 (*flpr*)	Far-end loss-of-power defect ("dying gasp")		
4-1	Reserved	For proprietary applications	"0" for normal state "1" for the failure state	
0	*CRC_4*	Frame header CRC check	Fourth bit	See I.1.2.2.5

I.1.2.2.5 CRC-bits

The *CRC* bits *CRC_1* ÷ *CRC_4* are computed by multiplying the polynomial

$$m_0 D^{23} + m_1 D^{22} + \ldots + m_{23} \text{ by } D^4$$

dividing by $D^4 + D + 1$, and taking the remainder.

The polynomial coefficient m_0 shall be the MSB of the first Control 1 octet, m_{23} shall be the LSB of Control 3 octet, and m_8, m_{15}, m_{16}, m_{23}, = 0. The *CRC_1* shall be the MSB of the remainder; the *CRC_4* shall be the LSB of the remainder.

I.1.2.3 Frame transport classes

The transmission frame transport class defines the number of *S*, *F*, and *RF* octets in the transmission frame. The mandatory class 1 provides single latency transport. The optional class 2 provides dual latency transport.

A class 1 frame shall include two Slow codewords of 200 octets each. A class 2 frame shall include both Slow and Fast codewords. The format of class 2 frame is defined by the values of *F* and *RF*, and denoted as [*F/RF*], where *RF* can be 0, 2, 4 or 16, and *F* is even between 2 and 180. In the same manner, class 1 frame is denoted as [0/0].

NOTE 1 – A class 2 frame denoted [12/8], for example, defines a frame that contains a Fast codeword with 4 Fast Payload octets, 8 Fast FEC octets and a Slow codeword with 200 – 12 = 188 octets (three OC octets, 169 Slow Payload octets and 16 Slow FEC octets, Figure I.4).

NOTE 2 – The possible settings of *F* are limited to those which result in relevant settings of $S = 200 - F$ for the selected configuration of the interleaver (value *S*/*I*), as specified in I.1.2.8.

The frame definition of class 1 and class 2 is summarized in Table I.5. The calculation of the aggregate transport capability of the frame of the particular class is presented in I.5.2.

Table I.5/G.993.1 – Frame transport classes

Class	Slow Data *S*, octets	Fast Data *F*, octets	Fast Redundancy *RF*, octets	Symbol	Mode	Notes
1	200	0	0	[0/0]	Single latency	Mandatory
2	200 – *F*	*F* = 2 – 180	*RF* = 0, 2, 4, 16	[*F*/*RF*]	Dual latency	Optional

I.1.2.4 NTR transport and NTR marker generation

An 8-kHz NTR is conveyed from the VTU-O to VTU-R by synchronizing the downstream transmission frame boundaries with NTR and transmitting an NTR marker in the frame header, as described in I.1.2.2. The NTR is reconstructed at the VTU-R using the received NTR marker.

An NTR marker for the transmission profile with a bit rate of $N \times 33.75$ kbit/s shall be generated every $768/Q$ NTR periods (i.e., every $96/Q$ ms the NTR marker will transition from low to high level), where Q is the greatest common divisor of 768 and N.

NOTE – As follows from the definition above, the NTR marker will be set to 1 every N/Q transmission frames. For example, assume $N = 96$ ($TR = 3.24$ Mbit/s). Then $Q = \gcd(768,96) = 96$, and $96/Q = 1$. Accordingly, the NTR marker bit will be set to 1 every 1 ms. The number of transmission frames between two adjacent NTR markers equals 1, and the number of NTR periods between two adjacent NTR markers equals 8.

I.1.2.5 Frame delineation algorithm

The delineation algorithm for the transmission frame shall be left to the discretion of the implementers. The recommended algorithm is based on Syncword detection at the expected locations (i.e., on Sync_Events as described in I.5.3).

I.1.2.6 Randomization and de-randomization

Randomization shall be performed in both transmission directions by the same randomization algorithm prior to RS encoding. Data de-randomization shall be performed after RS decoding. Randomization/de-randomization shall be performed on the frame header, except for Sync1 and Sync2 octets, and on the frame payload, except for the RS redundancy octets. The header, Fast codewords and Slow codewords transmitted in the same direction shall be randomized separately by the same randomization algorithm.

The randomization algorithm in both the VTU-O and VTU-R shall be:

$$D_{out}^{n} = D_{in}^{n} \oplus D_{out}^{n-18} \oplus D_{out}^{n-23}$$

The de-randomization algorithm shall reconstruct the randomized data. The block diagram of the randomizer is presented in Figure I.6.

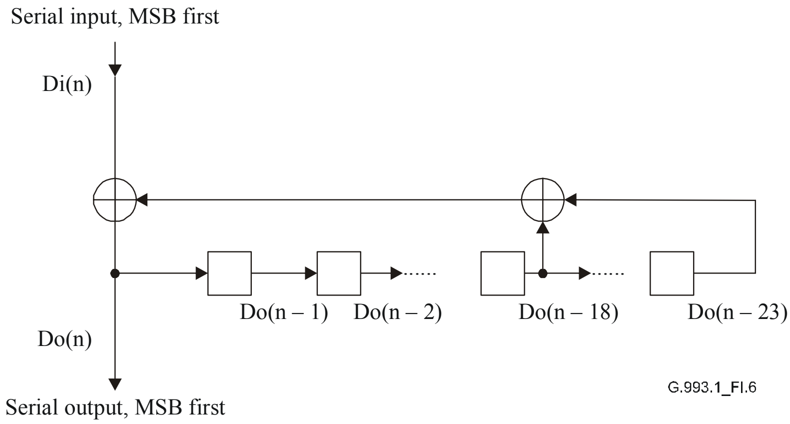


Figure I.6/G.993.1 – Randomizer

NOTE – Both the randomizer and de-randomizer are self-synchronizing.

I.1.2.7 Forward error correction

Reed-Solomon (RS) coding shall be used for forward error correction (FEC). The applied code RS(N,K) is expressed by the total codeword length in octets (N) and the number of data octets (K). The difference ($N – K$) is the number of FEC octets (redundancy octets).

NOTE 1 – The error correcting power of the RS code is related to the number of FEC octets ($N – K$). The number of corrected octets t per codeword equals $\lfloor(N – K)/2\rfloor$, where $\lfloor X \rfloor$ denotes truncating X to the lower integer.

NOTE 2 – The actual values of N and K in RS(N,K) are ($OC + PS + 16$, $OC + PS$) for the Slow codeword and to ($PF + RF$, PF) for the Fast codeword (see Figures I.3 and I.4, respectively).

The RS codes applied for downstream and upstream shall use the generator polynomial:

$$g(x) = \prod_{i=0}^{N-K-1}(x + \mu^i)$$

where μ is a root of the binary primitive polynomial:

$$x^8 + x^4 + x^3 + x^2 + 1$$

A data octet shall be identified within the Galois Field (256) of 256 elements as:

$$(d_7 d_6 d_5 d_4 d_3 d_2 d_1 d_0) \sum_{n=0}^{7} d_n \mu^n \Leftrightarrow \mu^p \quad (\mu = 02\text{hex})$$

with a one-to-one mapping of octet values (d_0 remains the LSB, d_7 remains the MSB; the MSB shall be transmitted first).

An RS(N,K) codeword shall be a function of the K data octets as:

$$\left[x^{N-K}\left(\sum_{i=0}^{K-1}\mu^{p(i)}x^i\right)\right] + \left[x^{N-K}\left(\sum_{i=0}^{K-1}\mu^{p(i)}x^i\right)\right] MODg(x)$$

where the K most significant octets (coefficients of x^n, $n = N – K..N – 1$) correspond to the K input data octets, and the $N – K$ least significant octets (coefficients of x^n, $n = 0..N – K – 1$) correspond to the $N – K$ output FEC octets.

The RS(N,K) encoding/decoding shall be implemented as a shortened RS(255,255 – N + K) code. At the encoder side, (255 – N) octets, all set to 0, shall be appended before the K data octets at the input of the RS(255,255 – N + K) encoder. These appended octets shall be discarded after the encoding procedure.

It shall be possible to introduce intentional corruption into RS codeword for error monitoring verification purposes. A corruption shall be introduced upon the appropriate request from the management system (see 10) into a single octet of the FEC redundancy field of either the Slow or the Fast channel.

I.1.2.8 Interleaving

Slow codewords of the transmission frame shall be interleaved before transmission by a convolutional interleaver. The latter is defined by the following parameters:

S: Incoming codeword length defined by the transmission frame format, Table I.5;

I: Interleaver block length, octets;

D: Interleaving depth, octets;

M: Interleaving depth index.

The interleaver shall function as follows. The incoming codeword of S octets shall be divided into blocks of I octets. The nominal block length I shall be $S/8$. Optionally, it may equal to $S/16$, $S/4$ or $S/2$. The particular value of I is set during the initialization as specified in I.3.2.1.1.8. The octets within the interleaver blocks shall be numbered from $j = 0$ to $j = I - 1$. Each octet j of any block shall be delayed at the interleaver output by $(D - 1) \times j$ octets, where $j = 0, 1, 2, \ldots (I - 1)$ is the octet number within the block and D is the interleaving depth. For example, the first octet of any block shall not be delayed. The third octet of any block shall be delayed by $2 \times (D - 1)$ octets, and so on. The value of $(D - 1)$ shall be a multiple of the interleaver block length I:

$$D = M \times I + 1$$

where M is an integer. The value of M shall be programmable to any integer in the range of 0 to 64. The actual values of I and M should be set prior to the link initialization.

The main characteristics of the interleaver and an example of interleaver and de-interleaver implementation are presented in I.5.4.

The value $D - 1$ characterizes the number of octets separating any two sequential octets of the same RS codeword after interleaving. It should be chosen in accordance with the required impulse noise protection and latency requirements. Setting $M = 0$ cancels interleaving.

NOTE – The specified range of values for M allows erasure correction capability up to 500 μs for all transmission data rates below 26 Mbit/s as shown in I.5.4.

I.2 Physical medium-dependent (PMD) sublayer

I.2.1 PMD functional model

The PMD sublayer functional model is presented in Figure I.7. The model defines VDSL transceiver functionality between the I_O (I_R) and U_2_O (U_2_R) reference points, respectively.

In the transmit direction, the input frame (see I.1.2) coming from the PMS-TC via the I-interface is split into two streams. Each stream is encoded, modulated, and sent onto the transmission line via the U_2-interface. Each stream is transmitted in one of the frequency bands specified in 6.1, separated by the band-pass filter. The signal transmitted in a particular band is called a carrier.

Four possible carriers: 1D (carrier 1, downstream), 2D (carrier 2, downstream), 1U (carrier 1, upstream), and 2U (carrier 2, upstream) can be used; up to two carriers can be transmitted in the same direction. If the first carrier can transmit all the input data, the usage of the second carrier is optional. In that case, both the splitter and multiplexer are bypassed.

NOTE – The name of the carrier is not associated with any particular frequency band. If the optional frequency band or any later specified additional band is used, the name of the carrier using this band will be one of those already defined.

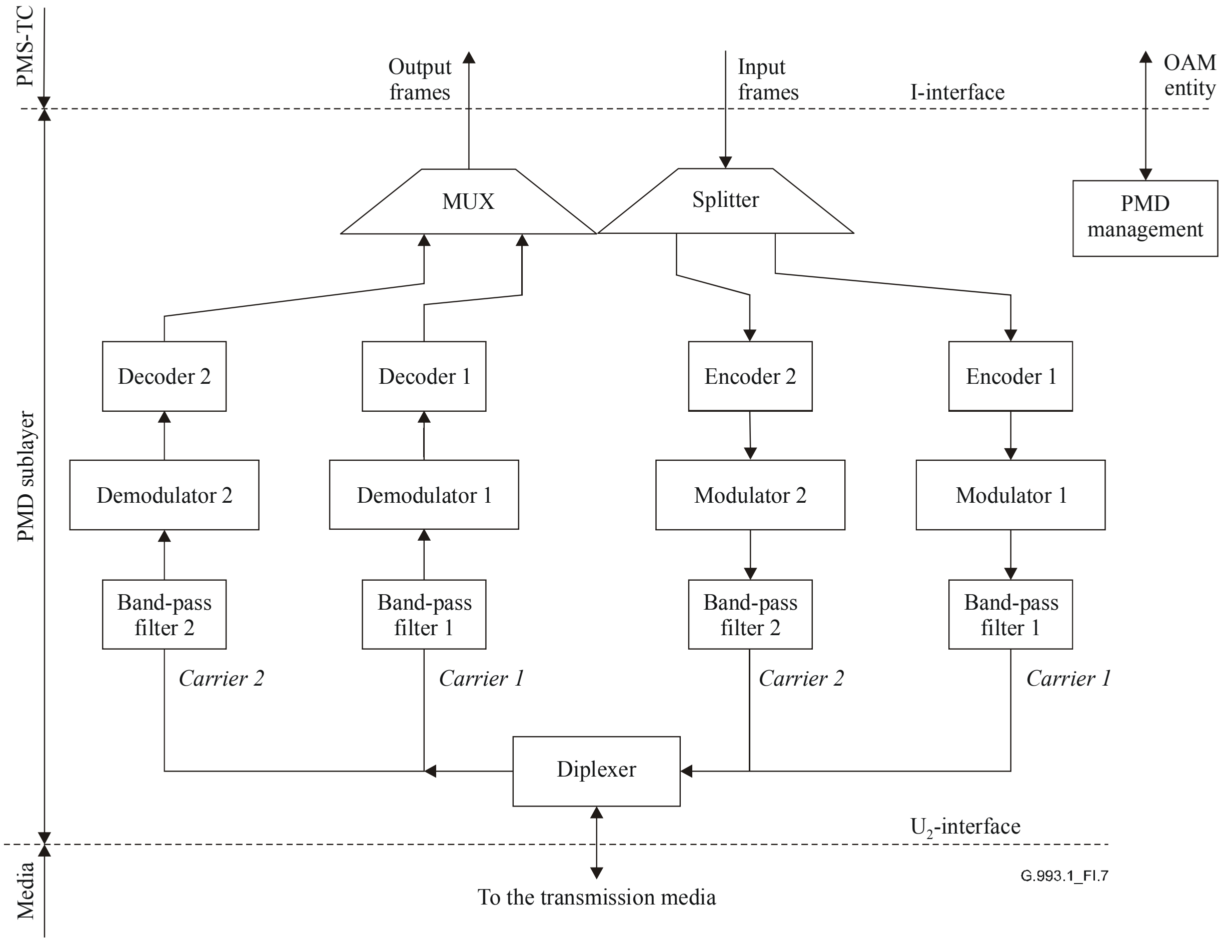


Figure I.7/G.993.1 – VTU PMD sublayer functional model

The band-pass filters restrict the transmit out-of-band power to prevent crosstalk between the upstream and downstream carriers. The diplexer provides additional decoupling between transmit and receive signals.

In the receive direction, the carriers received in both bands are demodulated, decoded and multiplexed into the output frame, which has the same structure as the input frame. The output frame is sent to the PMS-TC via the I-interface.

The PMD management block is responsible for all the OAM functions corresponding with PMD. The exchange of management information between the PMD management block and the OAM entity is accomplished via the I-interface.

I.2.2 Transmitter functionality

I.2.2.1 Splitting

The same splitting procedure shall be used in both the upstream and downstream directions. The splitter shall originate a PMD-frame for both transmitted carriers to compensate for the difference in propagation delay between the two carriers at the receive side. The PMD-frame format shall consist of 405 octets: a 2-octet Syncword for frame alignment followed by a 403-octet data field. The PMD-frame Syncword shall be the same as specified in I.1.2.2.1 for the transmission frame (contains Sync1, Sync2 octets).

The PMD-frame structure and splitting procedure of the input frame are described in Figure I.8. The splitter maps the input frame into two PMD-frames with data rate ratio of *N1/N2*, where *N1*, *N2* are integers. The splitting cycle shall start from the frame alignment octet Sync1 of any input frame (input frame #1 in Figure I.8). The Sync1 octet and the following Sync2 octet from input frame #1 shall be sent into both carrier 1 and carrier 2 to arrange their own Syncwords. Further, the *N1* octets of input frame #1 following Sync2 octet shall be mapped into carrier 1, and the *N2* following octets of the input frame #1 shall be mapped into carrier 2. A repetition of this process over subsequent input frames forms the information field of the PMD frame. An inverted Syncword shall be inserted into each PMD frame after every 403 data octets inserted into its information field. If fewer than *N1* or *N2* octet positions remain at the end of a given PMD frame, the next group of *N1* or *N2* octets, respectively, shall be split in the corresponding PMD frame by an inverted Syncword, as shown in Figure I.8.

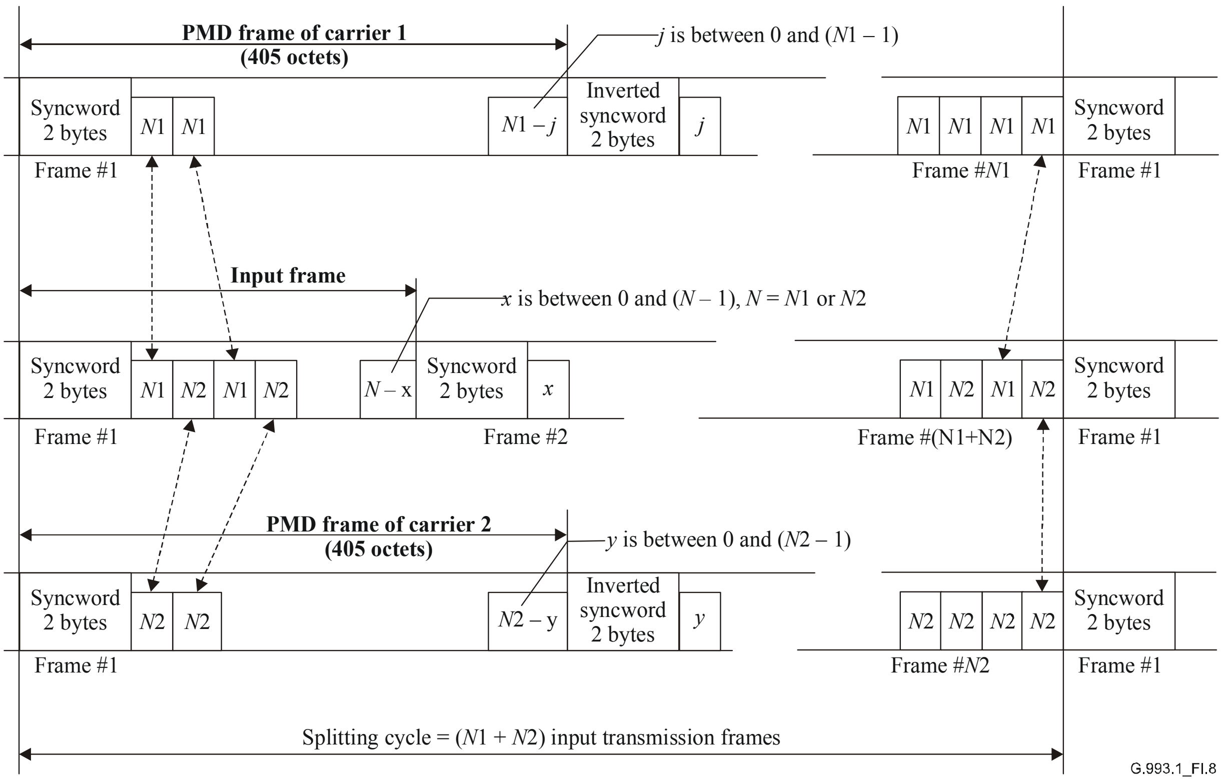


Figure I.8/G.993.1 – PMD-frame format

The splitting process is cyclic. A cycle contains (*N1* + *N2*) input frames. During the splitting cycle exactly *N1* frames are mapped into carrier 1 and exactly *N2* frames are mapped into carrier 2.

NOTE – For the given bit rates DR1 and DR2 of carrier 1 and carrier 2, respectively, with a greatest common divisor g = gcd (DR1, DR2), the values of *N1*, *N2* will be: *N1* = DR1/g, *N2* = DR2/g.

The time difference between the beginnings of the splitting cycles of the PMD frames transmitted by carrier 1 and carrier 2, measured at the output of the transceiver, shall be less than $max\{40\times abs(T1 - T2) + 5, 20\}$ µs, where $T1 = 1/SR_1$, $T2 = 1/SR_2$, SR_1, SR_2 are symbol rates of carrier 1 and carrier 2, respectively. The timing difference should be measured with respect to the start of the first bit of the PMD frame starting the splitting cycle for each carrier.

I.2.2.2 Timing

Transmitters of both carriers in the VTU-O shall use a transmit clock derived from the network clock (e.g., SONET clock, SDH clock, PON clock) to allow end-to-end network synchronization. If the network clock is not available, the VTU-O shall use a locally generated master clock with a maximum tolerance of ±50 ppm.

Transmitters of both carriers in the VTU-R shall use a transmit clock derived from the received data clock of either the first or the second downstream carrier (loop timing). If the received data clock is lost during steady-state transmission, the VTU-R shall use a locally generated clock with a maximum tolerance of ±50 ppm to perform the link activation.

I.2.2.3 Coding and modulation

The transmission capability and timing between the VTU-O and the VTU-R in both transmission directions shall be provided by using Quadrature Amplitude Modulation (QAM). The coding and modulation functionality of the transceiver is described in Figure I.9. The input data stream shall be encoded into two symbol streams I_n and Q_n, where n designates the nth symbol period. The symbol streams I_n and Q_n shall be modulated and sent into the transmission media via the band-pass filter.

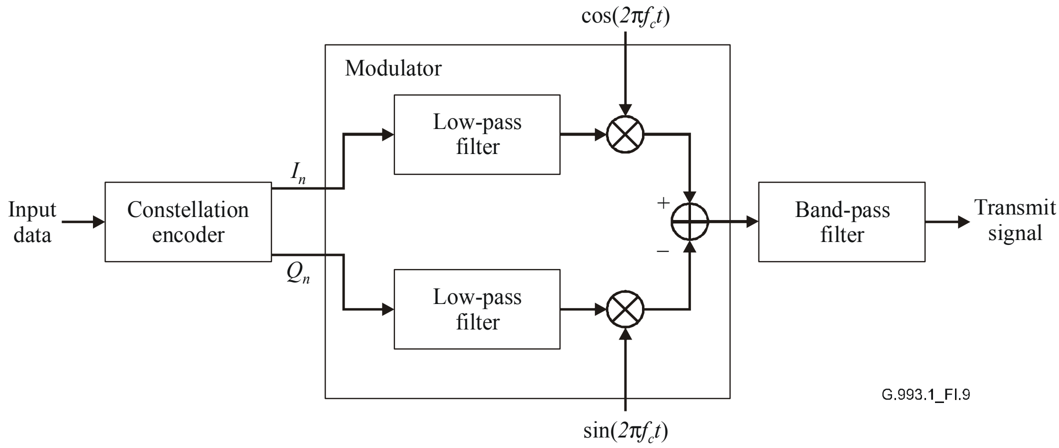


Figure I.9/G.993.1 – Block diagram of a SCM transmitter

I.2.2.3.1 Constellation encoder

The encoding procedure shall treat the input data as a serial stream of bits with the most significant bit first. For a given constellation of size 2^M, a group of M consecutive bits $\{b_1, b_2, \ldots b_M\}$ of the input data shall be encoded into one symbol, and consecutive groups of M bits are encoded into consecutive symbols as illustrated in Figure I.10. Differential quadrant encoding shall be used. For $M = 1$, every input bit shall be encoded as specified in the upper part of Table I.6. The two possible values of $\{b_1\}$ represent the transition of the symbol between first and third quadrants. For $M > 1$, the first two bits $\{b_1,b_2\}$ shall be encoded as described in Table I.6. The four values of $\{b_1,b_2\}$ represent the quadrant transition of the symbols, Figure I.11. The remaining $(M – 2)$ bits shall be encoded in accordance with the relevant constellation diagrams.

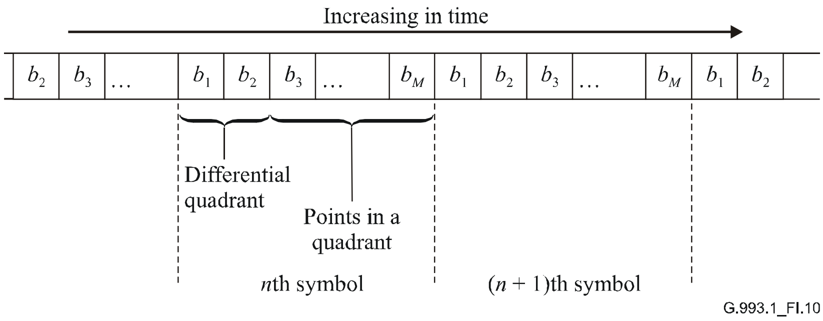


Figure I.10/G.993.1 – Bit to symbol mapping

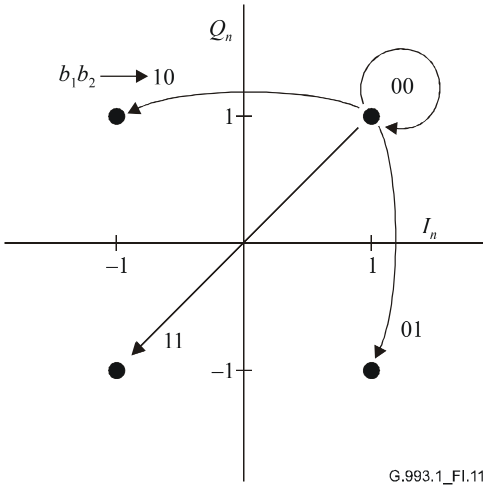


Figure I.11/G.993.1 – 4-point constellation with differential bit encoding

Table I.6/G.993.1 – Differential encoding of b_1 and $\{b_1b_2\}$

$\{b_1\}$, or $\{b_1\ b_2\}$	Previous quadrant number	Sign of previous symbol I_{n-1} Q_{n-1}	Current quadrant number	Sign of current symbol I_n Q_n
$M = 1$ (QAM-2)				
0	1st	+ +	1st	+ +
0	3rd	– –	3rd	– –
1	1st	+ +	3rd	– –
1	3rd	– –	1st	+ +
$M > 1$ (QAM-4 and higher)				
00	1st	+ +	1st	+ +
00	2nd	– +	2nd	– +
00	3rd	– –	3rd	– –
00	4th	+ –	4th	+ –
01	1st	+ +	4th	+ –
01	2nd	– +	1st	+ +
01	3rd	– –	2nd	– +

Table I.6/G.993.1 – Differential encoding of b_1 and $\{b_1b_2\}$

$\{b_1\}$, or $\{b_1\ b_2\}$	Previous quadrant number	Sign of previous symbol I_{n-1} Q_{n-1}	Current quadrant number	Sign of current symbol I_n Q_n
01	4th	+ –	3rd	– –
10	1st	+ +	2nd	– +
10	2nd	– +	3rd	– –
10	3rd	– –	4th	+ –
10	4th	+ –	1st	+ +
11	1st	+ +	3rd	– –
11	2nd	– +	4th	+ –
11	3rd	– –	1st	+ +
11	4th	+ –	2nd	– +

For a constellation diagram of 8 points, the encoding shall be as specified in Figure I.12.

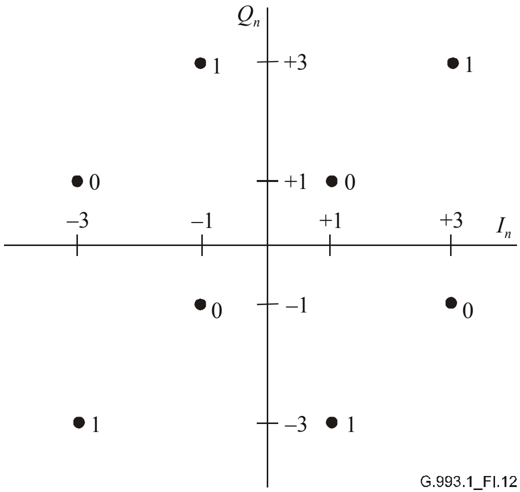


Figure I.12/G.993.1 – 8-point constellation and bit mapping

For constellation diagrams of 2^M points with even values of M between 4 and 12 (square constellations), the binary values of in-phase I_n and quadrature Q_n coordinates for the $M - 2$ bit group $\{b_3 \ldots b_{M-2}\}$ in the first quadrant shall be as specified in Table I.7.

Table I.7/G.993.1 – First quadrant encoding for even values of *M*

I_n (binary) = $[X_1\ X_2\ \ldots\ X_{M/2-1}\ 1]$	Q_n (binary) = $[Y_1\ Y_2\ \ldots Y_{M/2-1}\ 1]$
$X_1 = b_3$	$Y_1 = b_{M/2+2}$
$X_2 = X_1 + b_4$	$Y_2 = Y_1 + b_{M/2+3}$
$X_3 = X_2 + b_5$	$Y_3 = Y_2 + b_{M/2+4}$
…	…
$X_{M/2-1} = X_{M/2-2} + b_{M/2+1}$	$Y_{M/2-1} = Y_{M/2-2} + b_M$

NOTE – The following example clarifies usage of Table I.7. For QAM-64 (M = 6), and a group with the four last bits $\{b_3b_4b_5b_6\}$ = 0001, we get $X_1 = X_2 = 0$, $Y_1 = 0$, $Y_2 = 1$, and $I_n = 001$, $Q_n = 011$. Using decimal values we find that the constellation point with $I_n = 1$ and $Q_n = 3$ to be coded 0001.

For verification purposes, the first quadrant of the QAM-64 constellation diagram is presented in Figure I.14.

For constellation diagrams of 2^M points with odd values of M between 5 and 11 (cross-shaped constellations) the encoding in the first quadrant shall be as follows. First, the quadrant shall be divided into 8 sections, as shown in Figure I.13, and each section shall be coded by a 3-bit section code using bits $b_3b_4b_5$.

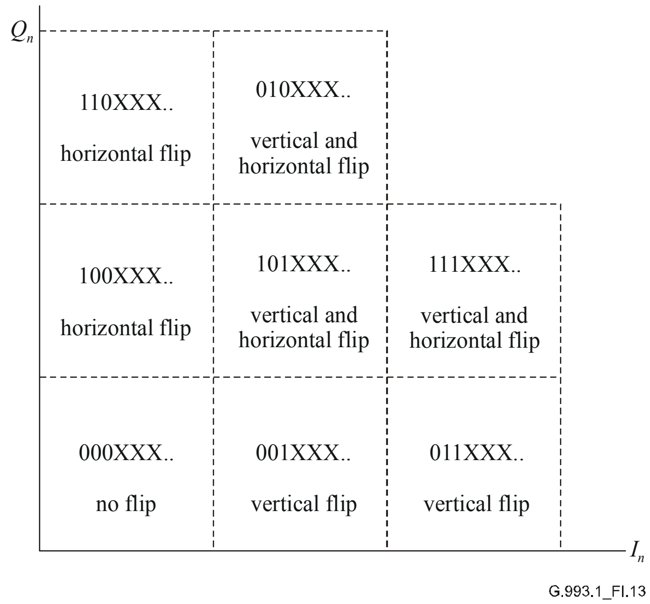


Figure I.13/G.993.1 – Mapping sections for constellations with odd values of M > 5

The rest of the bits (applicable for M > 5 and those bits denoted "XXX" in Figure I.13) shall be mapped inside each section as specified in Table I.18. Further, the coded sections shall be flipped horizontally, vertically, or both, as shown in Figure I.13. For verification purposes, the first quadrant of QAM-128 constellation (M = 7) is presented in Figure I.15.

Table I.8/G.993.1 – First quadrant encoding for odd values of M > 5

$I_{n\text{-}sec}$ (binary) = $[X_1\ X_2\ \ldots\ X_{(M-5)/2}\ 1]$	$Q_{n\text{-}sec}$ (binary) = $[Y_1\ Y_2\ \ldots Y_{(M-5)/2}\ 1]$
$X_1 = b_6$	$Y_1 = b_{(M-5)/2+6}$
$X_2 = X_1 + b_7$	$Y_2 = Y_1 + b_{(M-5)/2+7}$
…	…
$X_{(M-5)/2} = X_{(M-5)/2-1} + b_{(M-5)/2+5}$	$Y_{(M-5)/2} = Y_{(M-5)/2-1} + b_M$

For all constellations with sizes more than 8 ($M \geq 4$) the second, third and fourth quadrant mappings shall be derived from the mappings in the first quadrant by rotating the quadrant counter-clockwise by 90 degrees, 180 degrees, and 270 degrees, respectively.

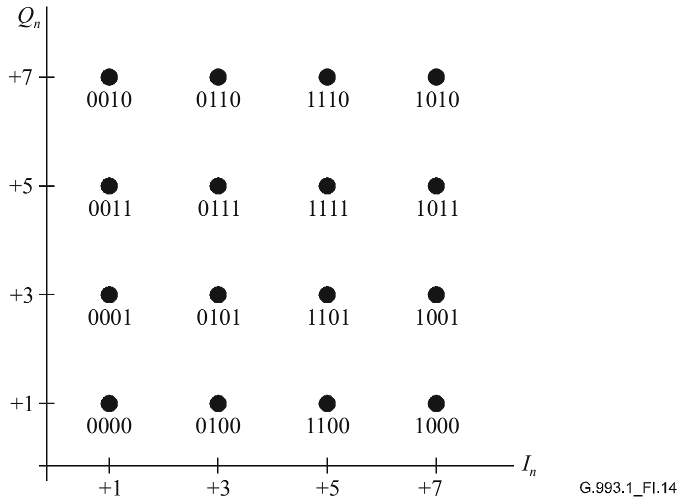


Figure I.14/G.993.1 – 64-point constellation and bit mapping (first quadrant)

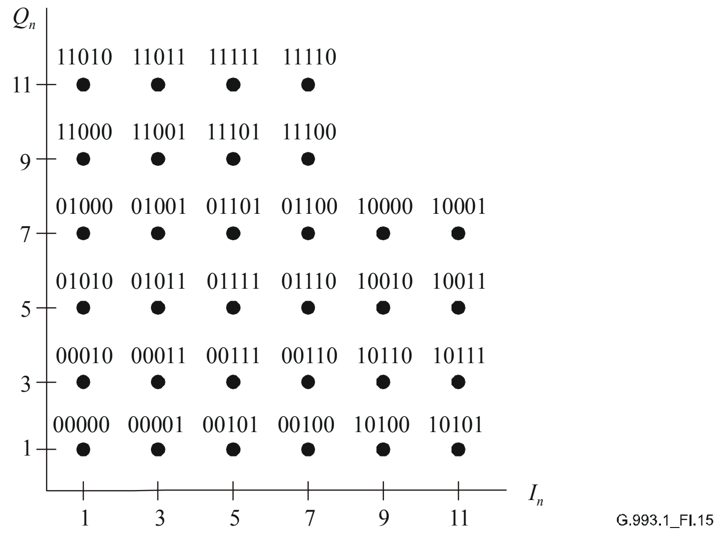


Figure I.15/G.993.1 – 128-point constellation and bit mapping (first quadrant)

I.2.2.3.2 Modulator

The two encoded streams, I_n and Q_n, shall be sent to identical low-pass shaping filters (see Figure I.9). The output of the filter for the in-phase path is heterodyned with a cosine carrier signal. The output of the filter for the quadrature path is heterodyned with a sine carrier signal of the same frequency. The outputs of the in-phase path and the inverted quadrature path shall be summed to form a modulated signal.

The amplitudes of the I_n and Q_n components in the transmitted constellations shall maintain the relative values of 1, 3, 5, 7, 9, 11, 13, 15, … as used in the constellation diagrams derived from Tables I.7 and I.8 with a tolerance of ±0.06 relative to these values.

I.2.2.3.2.1 Symbol rates and carrier frequencies

All available values of symbol rates (SR) for both carriers in both downstream and upstream directions shall be multiples of the Basic Symbol Rate (BSR):

$$SR = s \times BSR$$

where s is an integer, BSR = 33.75 kBaud. The carrier signal frequencies f_C shall be an integer multiple of $BSR/2$:

$$f_C = 0.5 \times BSR \times k \text{ [kHz]}$$

where k is an integer. The resulting f_C shifting granularity is equal to 16.875 kHz.

The value of SR/f_C shall be an exact ratio of two integers under all possible frequency tolerances.

NOTE – The total bit rate (TR) provided in a particular direction is determined by symbol rates SR_1, SR_2 and constellation sizes C_1, C_2 of the first and the second carriers:

$$TR = SR_1 \times \log_2 C_1 + SR_2 \times \log_2 C_2$$

For the given symbol rates, the bit rate can be adjusted with the minimum granularity of $min\{SR_1, SR_2\}$. For the given constellation sizes, the bit rate can be adjusted with the minimum granularity of $33.75 \times min\{C_1, C_2\}$ kbit/s.

I.2.2.3.2.2 Spectral shaping filters

The low-pass filters (see Figure I.9) of both carriers shall have the transfer function with a nominal value following the square-root raised-cosine approximation of the frequency response:

$$|G_{nom}(f)| = \begin{cases} 1 & , |f| \le f_1 \\ \cos\left(\frac{\pi T}{2\alpha}\left[|f| - f_1\right]\right) & , f_1 \le |f| \le f_2 \\ 0 & , elsewhere \end{cases}, \quad f_1 = \frac{1-\alpha}{2T}, \quad f_2 = \frac{1+\alpha}{2T}$$

where T is the symbol period used for the particular carrier, and α is the excess bandwidth. The excess bandwidth of both low-pass filters shall be identical and in the range of α = 0.10 to 0.20. The default value of the excess bandwidth shall be 0.2. The actual value of the excess bandwidth shall be communicated between the transceivers at both sides of the link over VOC as specified in I.3.1.2.

The accuracy of implementation of the transfer function $|G(f)|$ and the group delay distortion D of the shaping filters shall be as defined in Table I.9. The lower and upper limits of the attenuation are defined as a function of the normalized frequency $x = \frac{f - f_C}{SR/2}$.

Table I.9/G.993.1 – Shaping filter transfer function and group delay distortion templates

Normalized frequency	G_{min} [dB]	G_{max} [dB]	$D(x) - D_{min}$ [s]
≤–1.4	N/A	<–40	N/A
–1.3		<–30	
–1.2		<–20	
1.15	G_{nom} – 4.5	G_{nom} + 4.0	<8T
–1.1	G_{nom} – 3.5	G_{nom} + 2.5	<5T
–1.05	G_{nom} – 3.0	G_{nom} + 2.0	<4.5T

Table I.9/G.993.1 – Shaping filter transfer function and group delay distortion templates

Normalized frequency	G_{min} [dB]	G_{max} [dB]	$D(x) - D_{min}$ [s]
–1.0	$G_{nom} - 1.0$	$G_{nom} + 1.0$	<4T
–0.95			<3T
–0.9			
–0.8			
0			
0.8			
0.9			
0.95			
1.0			<4T
1.05	$G_{nom} - 3.0$	$G_{nom} + 2.0$	<4.5T
1.1	$G_{nom} - 3.5$	$G_{nom} + 2.5$	<5T
1.15	$G_{nom} - 4.5$	$G_{nom} + 4.0$	<8T
1.2	N/A	<–20	N/A
1.3		<–30	
≥1.4		<–40	

NOTE – D_{min} is the minimum group delay within the in-band part of the spectrum: $D_{min} = \min D(x)$ for $|x| \le 1.2$.

I.2.3 Receiver functionality

The receiver demodulates and decodes the incoming signal of both carriers received from the transmission medium, and multiplexes them into an output frame as shown in Figure I.7. At the VTU-R side, receiver functionality also includes recovering the symbol timing.

The demodulation and decoding processes shall be matched with the modulation and encoding processes, respectively, as described in I.2.2.3.

The multiplexing procedure combines the received PMD frames of carrier 1 and carrier 2 into the original transmission frame (see I.1.2), and reconstructs the original frame alignment octets Sync1 and Sync2. The multiplexing procedure shall match the splitting procedure as specified in I.2.2.1.

The receiver shall tolerate delay difference from the transmitter plus the delay difference introduced by the loop.

NOTE – In most of the practical cases the delay difference introduced by the loop is less than 1 µs.

I.2.4 Transmission profile

The transmission profile is a set of transmission parameters (STP) that define the main characteristics of the VDSL link, such as transport capacity, spectral allocation, and transmit PSD. The STP includes symbol rates, constellations, carrier frequencies and some other parameters of both carriers. The full description of STP is presented in I.4.2.1.

The transceiver shall be capable of providing the following two modes of operation:

– manual mode, when the particular STP for the given loop and type of service is configured by the network operator;

– automatic mode, when the particular STP for the given loop and type of service is automatically selected by the transceiver during the initialization procedure.

In both modes the VTU-O originates the STP to be used and transports it to the VTU-R using VOC as described in I.3.1.2. The VTU-R accepts the STP if the parameter values are from the range specified in I.3.1.2 and sets the profile required by the VTU-O. The particular algorithm of STP selection to be used in automatic mode is left to the discretion of the VTU-O implementers. No specific limitations apply.

I.3 Operations and maintenance

I.3.1 QAM-specific OAM primitives

I.3.1.1 Line-related OAM primitives

I.3.1.1.1 Near-end defects

Loss-of-Carrier (los_cr) defect occurs when the received carrier signal power, averaged over a 0.5-s period, is lower than the set threshold. It terminates when this power, measured in the same way, is at or above the threshold.

Loss-of-Signal (los) defect occurs when *los_cr* defect occurs in any of the carriers specified by the applied transmission profile, and terminates when *los_cr* is cleared in both carriers.

I.3.1.1.2 Far-end defects

Far-end Loss-of-Carrier (flos_cr) defect occurs when a *los_cr* defect is reported in four or more out of six contiguously received far-end indicator reports. The *flos_cr* is terminated when less than two far-end *los_cr* indicators are reported out of six contiguously received far-end indicator reports.

Far-end Loss-of-Signal (flos) defect occurs when *flos_cr* defect is reported for any carrier specified by the applied transmission profile, and terminates when *flos_cr* is cleared in both carriers.

I.3.1.1.3 Near-end and far-end failures

The default values of TR1, TR2, TS1, TS2, TF1, and TF2 are 0.5 s.

I.3.1.2 ATM path-related OAM primitives

I.3.1.2.1 Near-end defects

Loss of Cell Delineation (lcd) defect occurs when *ocd* anomaly persists for more than 50 ms; the *lcd* terminates when no *ocd* anomaly is present during at least 50 ms.

I.3.1.2.2 Far-end defects

Far-end Loss of Cell Delineation (flcd) defect occurs when *focd* anomaly is present or *fncd* anomaly persists for more than 50 ms, and no *rdi* defect is present. A *flcd* defect terminates if neither *focd* nor *fncd* anomaly is present in more than 50 ms.

I.3.1.3 PTM path-related OAM primitives

I.3.1.3.1 Near-end defects

Packet Error (PER) defect occurs if packet error anomaly persists for more than 0.5 s. The *PER* defect terminates when no *per* anomaly is present in more than 0.5 s.

I.3.1.4 Power-related OAM primitives

I.3.1.4.1 Near-end and far-end primitives

The default values of TP1, TP2 are 2.5 s and 5 s, respectively.

I.3.1.4.2 A set of far-end indicators

The transfer mechanism of the far-end indicators listed in Table 10-5 is specified in I.1.2.2.

I.3.2 VDSL overhead channel

I.3.2.1 VOC functions and description

A VDSL Overhead Control (VOC) is defined to support the link activation. Additionally, it can provide maintenance and performance monitoring of the link, and modification of the transmission parameters. Communication over VOC is always initiated by the VTU-O; the VTU-R replies to the VTU-O upon successful reception of a message.

I.3.2.1.1 VOC messages

A VOC message contains an OPCODE octet followed by two DATA octets. The OPCODE value determines the content and type of the message. The following three types of VOC messages are specified:

– COMMAND-type message: The message is sent from the VTU-O to convey information to the VTU-R (WRITE command) or to request information from the VTU-R (READ command).

– ECHO-type message: The message is a reply from the VTU-R to acknowledge receipt of a COMMAND-type message.

– STATUS-type message: This message could be an IDLE message, an EOC message, or an Unable-To-Comply (UTC) message. The IDLE message shall be sent from both the VTU-O and VTU-R when no activity is going over the VOC and *eoc*. The EOC message shall be sent to transfer *eoc* messages. The UTC message shall be sent by the VTU-R as a reply to a COMMAND-type message to indicate the VTU-R's inability to comply with the received command (WRITE or READ).

I.3.2.1.1.1 VOC message transport

The VOC messages shall be carried through the VDSL link by the 3-octet OC field of the transmission frame (see I.1.2 and I.3.3).

I.3.2.1.1.2 VOC handshake

A special handshake procedure for COMMAND-type messages shall be used to obtain reliable VOC message transport between the VTU-O and VTU-R. The VOC handshake shall start from at least four IDLE VOC messages and use the following algorithm: At the start of the VOC handshake, both the VTU-O and VTU-R transmit the IDLE message. When a particular command is to be sent, the VTU-O begins and continues transmitting the corresponding COMMAND-type message. The VTU-R shall accept and latch the transmitted COMMAND-type message after it has received identical messages in three transmission frame samples in a row. The VTU-R shall then respond by beginning and continuing to transmit an ECHO-type message corresponding to the accepted COMMAND-type message. If the VTU-R is unable to comply with the received message, it shall transmit a UTC message instead of echoing the COMMAND-type message.

NOTE – At either receiver under-sampling of received frames may occur (i.e., not every received frame need be sampled during the VOC handshake).

After the VTU-O receives correct and identical ECHO-type responses or UTC messages in three frame samples in a row, it shall respond to the VTU-R by beginning and continuing to transmit the IDLE message. When the VTU-R receives an IDLE message, it shall stop transmission of the ECHO or the UTC message, and instead start transmission of IDLE messages at least four times consecutively.

The VTU-O shall continue to send the COMMAND-type message until it detects the correct ECHO or UTC message three samples in a row. Similarly, the VTU-R shall continue to send the echoed message until it receives the IDLE message from the VTU-O. The total VOC handshake time at both the VTU-O and VTU-R shall be limited to 0.9 s.

The VOC handshake process is considered complete when both the VTU-O and VTU-R have resumed transmitting the IDLE message.

An example of the VOC handshake process, under the assumptions that the VTU-R complies with the transmitted VOC command, is illustrated in Figure I.16. The solid arrows indicate the COMMAND-type message sent by the VTU-O, the dashed arrows indicate the VTU-R ECHO, and the dotted arrows indicate IDLE messages sent by both the VTU-O and the VTU-R. Each message is sent during a time corresponding to the number of transmission frames (prior to interleaving – see I.1.2.8) for which the OC field contains the indicated message. Because of interleaving and VOC handshake, there may be a considerable delay in VOC message transitions.

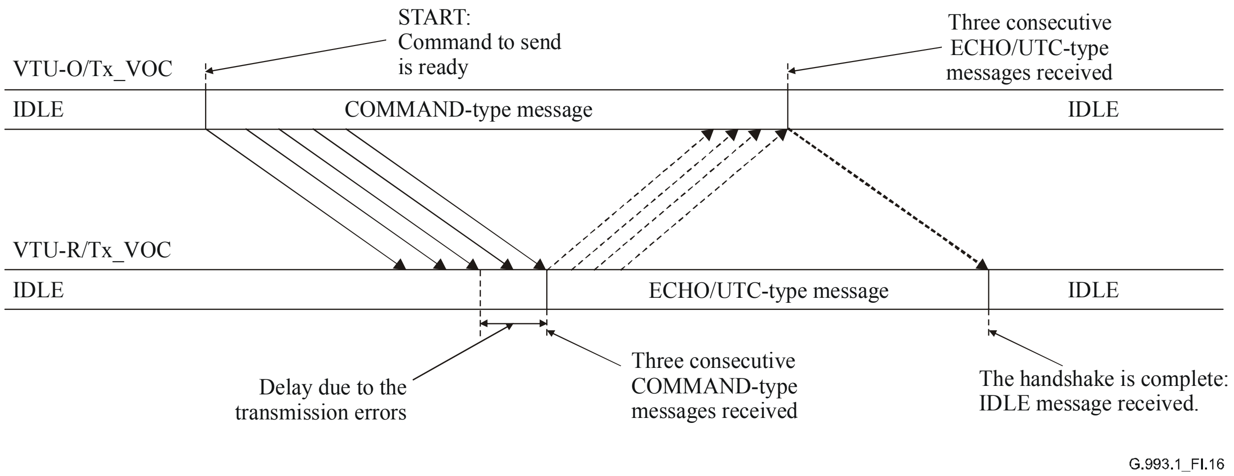


Figure I.16/G.993.1 – Example of VOC handshake for a successfully communicated command

I.3.2.1.1.3 VOC handshake flow charts

The VOC handshake process at the VTU-O shall meet the flow chart presented in Figure I.17; at the VTU-R it shall meet the flow chart presented in Figure I.18.

NOTE 1 – The following notation is used in both Figures I.17 and I.18:

- Rx_VOC, Tx_VOC: the received and transmitted VOC message, respectively;
- Echo_Count: the count of sampled ECHO/UTC messages (at the VTU-O);
- Msg_Count: the count of sampled COMMAND-type messages (at the VTU-R).

NOTE 2 – The "Correct Echo" in Figure I.17 is an ECHO-type message, which corresponds to the sent COMMAND-type message, or a UTC message.

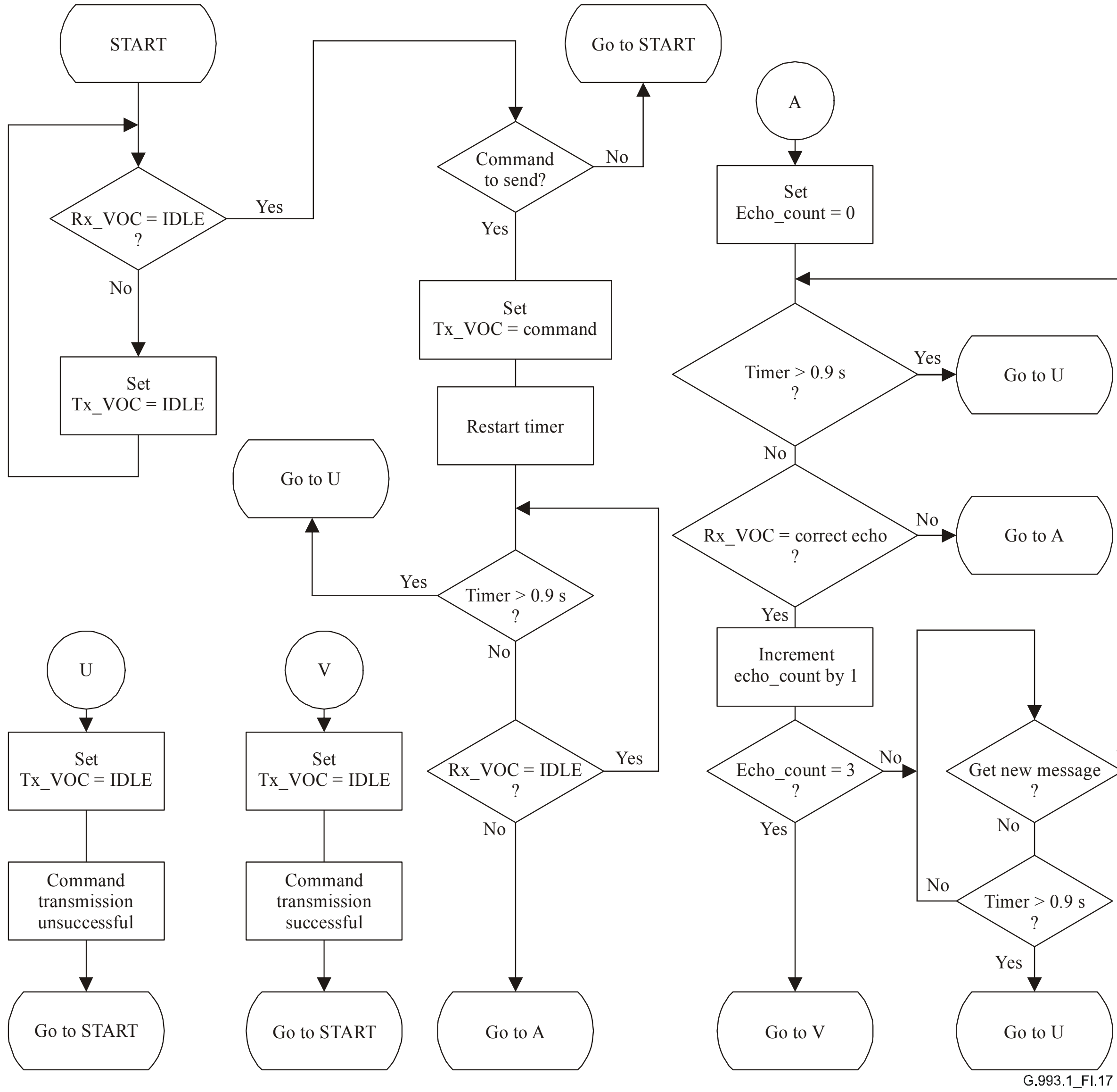


Figure I.17/G.993.1 – VTU-O VOC handshaking flow chart

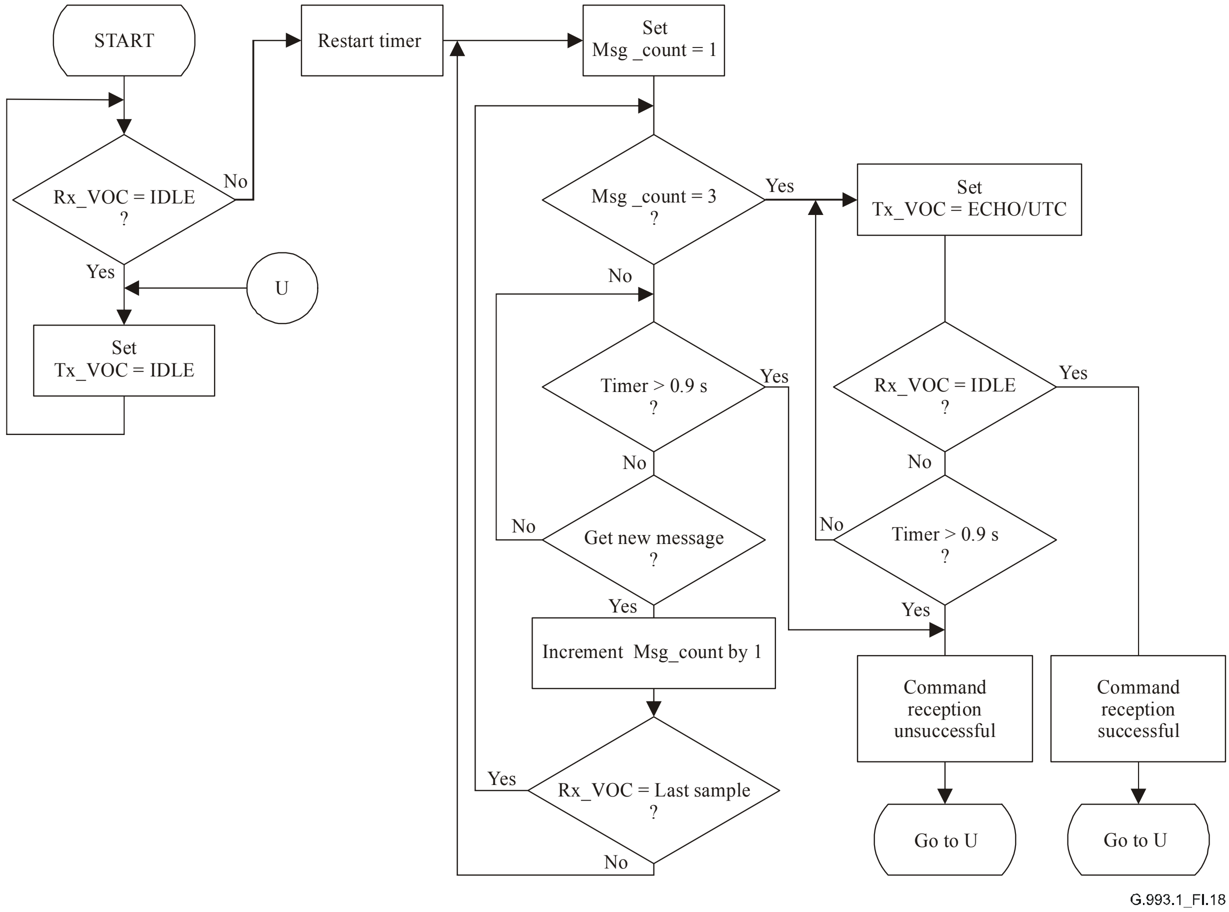


Figure I.18/G.993.1 – VTU-R VOC handshaking flow chart

I.3.2.1.1.4 Multiple words communication

A standard VOC message carries two octets of data. In some cases this is not sufficient. The number of data octets carried by VOC messages can be extended by using NEXT_WORD commands as described below. There are two types of multiple word messages:

– WRITE-type, to send information from the VTU-O to the VTU-R;

– READ-type, to retrieve information from the VTU-R to the VTU-O.

A multiple word message consists of a VOC header, which is a standard VOC message, followed by multiple NEXT_WORD messages that include the data. The format of READ-type and WRITE-type messages is described in Table I.15.

I.3.2.1.1.5 VOC message set

The VOC message set contains five groups of messages:

– STATUS messages;

– Performance monitoring messages;

– Configuration messages;

– Control messages;

– Trigger messages.

The status of the message may be mandatory (**M**) or optional (**O**).

Any ECHO-type message shall use the same OPCODE value as the COMMAND-type message it echoes. The DATA field of an ECHO-type message shall contain either the same data as that sent in a COMMAND-type "WRITE" message, or the data requested by a COMMAND-type "READ" message.

I.3.2.1.1.6 Status messages

The VOC shall support at least the set of STATUS messages presented in Table I.10.

Table I.10/G.993.1 – STATUS-type VOC messages

Name	Type	OPCODE	DATA field	Description	Status
IDLE	STATUS	0xFF	0x0000	An IDLE message. Sent by both VTU-O and VTU-R when VOC is inactive	M
EOC	STATUS	0xFC	*eoc* message	Sent by both VTU-O and VTU-R when OC is used for *eoc* transport (VOC inactive)	M
UTC	STATUS	0xF0	Same as the COMMAND message being UTC'ed	An Unable-To-Comply message. Sent by the VTU-R when the received command cannot be executed for any reason	M

The UTC message from the VTU-R is a valid response to a COMMAND-type message only if support for the requested command by the VTU-R is optional.

I.3.2.1.1.7 Performance monitoring messages

Performance monitoring messages are intended to deliver far-end line-related primitives, detected in PMD and PMS-TC sublayers, and other performance parameters obtained by the VTU-R. The OPCODES from 0x90 to 0x9F shall be reserved for proprietary use. The VOC shall support at least the set of Performance monitoring messages presented in Table I.11.

Table I.11/G.993.1 – Performance monitoring VOC messages

Name	Type	OPCODE	DATA field	Description	Status
	Generic				
VTUR_INFO	COMMAND (READ) and ECHO	0x1F	COMMAND: 0x0000 ECHO: First two octets of the VTU-R INFO data (Note 3)	Requests the VTU-R to send INFO to the VTU-O	M
VTUO_INFO	COMMAND (WRITE) and ECHO	0x1E	COMMAND and ECHO: First two octets of the VTU-O INFO data (Note 3)	Reports the VTU-O INFO to the VTU-R	M

Table I.11/G.993.1 – Performance monitoring VOC messages

Name	Type	OPCODE	DATA field	Description	Status
Line related: PMD					
SNR_REQ	COMMAND (READ) and ECHO	0x01	COMMAND: 2 MSB = DS carrier code, the rest = 0. ECHO: 2 MSB = DS carrier code, 8 LSB = SNR in dB, the rest = 0. LSB weight = 1/4 dB	Requests the VTU-R to send the SNR pertaining to the specified DS carrier in dB	M
SNR_REP	COMMAND (WRITE) and ECHO	0x02	COMMAND and ECHO: 2 MSB = US carrier code, 8 LSB = SNR in dB, the rest = 0. LSB weight = 1/4 dB	Sent by the VTU-O to indicate the SNR pertaining to the specified US carrier in dB	O
ATT_REQ	COMMAND (READ) and ECHO	0x03	COMMAND: 2 MSB = DS carrier code, the rest = 0. ECHO: 2 MSB = DS carrier code; 9 LSB = attenuation in dB, the rest = 0. LSB weight = 1/4 dB	Requests the VTU-R to send attenuation in dB pertaining to the specified DS carrier	M
ATT_REP	COMMAND (WRITE) and ECHO	0x04	COMMAND and ECHO: 2 MSB = US carrier code, 9 LSB = attenuation in dB, the rest = 0. LSB weight = 1/4 dB	Sent by the VTU-O to indicate attenuation in dB pertaining to the specified US carrier in dB	O
Reserved	COMMAND and ECHO	0x05-0x0F			O
Line related: PMS-TC					
FECS_REQ	COMMAND (READ) and ECHO	0x10	COMMAND: 0x0000 ECHO: VTU-R *fec-s* data as a 16-bit number of errored octets (Note 1)	Requests the VTU-R to send number of errored octets corrected by FEC in the Slow channel since the last FECS_REQ command	M
FECS_REP	COMMAND (WRITE) and ECHO	0x11	COMMAND and ECHO: VTU-O *fec-s* data as a 16-bit number of errored octets (Note 1)	Reports the number of errored octets corrected by FEC in the VTU-O Slow channel since the last FECS_REP command	O

Table I.11/G.993.1 – Performance monitoring VOC messages

Name	Type	OPCODE	DATA field	Description	Status
FECF_REQ	COMMAND (READ) and ECHO	0x12	COMMAND: 0x0000 ECHO: VTU-R *fec-f* data as a 16-bit number of errored octets (Note 1)	Requests the VTU-R to send the number of errored octets corrected by FEC in the Fast channel since the last FECF_REQ command	O (Note 2)
FECF_REP	COMMAND (WRITE) and ECHO	0x13	COMMAND and ECHO: VTU-O *fec-f* data as a 16-bit number of errored octets (Note 1)	Reports the number of errored octets corrected by FEC in the VTU-O Fast channel since the last FECF_REP command	O
ERRS_REQ	COMMAND (READ) and ECHO	0x14	COMMAND: 0x0000 ECHO: VTU-R *err-s* data as a 16-bit number of errored codewords (Note 1)	Requests the VTU-R to send the number of codewords uncorrectable by FEC in the Slow channel since the last ERRS_REQ command	M
ERRS_REP	COMMAND (WRITE) and ECHO	0x15	COMMAND and ECHO: VTU-O *err-s* data as a 16-bit number of errored codewords (Note 1)	Reports the number of codewords uncorrectable by FEC in the VTU-O Slow channel since the last ERRS_REP command	O
ERRF_REQ	COMMAND (READ) and ECHO	0x16	COMMAND: 0x0000 ECHO: VTU-R *err-f* data as a 16-bit number of errored codewords (Note 1)	Requests the VTU-R to send the number of codewords uncorrectable by FEC in the Fast channel since the last ERRF_REQ command	O (Note 2)
ERRF_REP	COMMAND (WRITE) and ECHO	0x17	COMMAND and ECHO: VTU-O *err-f* data as 16-bit number of errored codewords (Note 1)	Reports the number of codewords uncorrectable by FEC in the VTU-O Fast channel since the last ERRF_REP command	O
Reserved	COMMAND and ECHO	0x18-0x1D			O
Proprietary use					
Reserved	COMMAND and ECHO	0x90-0x9F			O

Table I.11/G.993.1 – Performance monitoring VOC messages

NOTE 1 – The error count saturates at 65 535. NOTE 2 – Message shall be mandatory if Fast channel is supported. NOTE 3 – The VTUR_INFO and VTUO_INFO data fields shall consist of the following 12 octets of data, in the order listed: – Vendor ID (4 octets); – Revision Number (2 octets); – Spectral Plan Support and Band Support (2 octets); – TPS-TC configuration (2 octets); – BSR support and auxiliary functions (2 octets). The data fields of VTUR_INFO/VTUO_INFO shall be communicated using the NEXT_WORD commands. The format of the VTUR_INFO and VTUO_INFO shall be identical; the format of all octets shall be as specified in Tables I.16 and I.18.

The 2-bit code for identification of the US and DS carrier in Table I.11 shall be as follows:

00 – Carrier 1D;

01 – Carrier 2D;

10 – Carrier 1U;

11 – Carrier 2U.

In commands relating to both carriers of the same transmission direction, the LSB shall be set to 0 at the transmit side and omitted at the receive side.

I.3.2.1.1.8 Configuration messages

Configuration VOC messages are intended to reconfigure the VDSL link by modifying its transmission parameters as described in I.4.2.2. Two types of messages are defined for link configuration: Parameter setting messages and Trigger messages. The Parameter setting messages (Table I.13) deliver the configured parameter value from the VTU-O to the VTU-R Activation database (see I.4.3). The Trigger messages (Table I.14) execute the changing of link transmission parameters to a new setting.

I.3.2.1.1.8.1 Parameter setting messages

VDSL link configuration is performed by modification of its Set of Transmission Parameters (STP), as described in I.4.2.1, Table I.22. The Parameter setting messages include the targeted upstream or downstream carrier code, the targeted STP code, and the applied parameter value. The VOC shall support at least the Parameter setting messages presented in Table I.13.

All Parameter setting messages are of COMMAND WRITE type; the COMMAND and the ECHO DATA fields shall be equal and contain the parameter value of the particular STP to be set at the VTU-R. The DATA field format of the Parameter setting messages shall be as presented in Table I.12.

Table I.12/G.993.1 – DATA field format for parameter setting and read-back messages

<table>
<tr><th>D15</th><th>D14</th><th>D13</th><th>D12</th><th>D11-D0</th></tr>
<tr><td colspan="2" rowspan="2">STP code</td><td>US or DS</td><td>Carrier 1 or 2</td><td rowspan="2">Parameter value</td></tr>
<tr><td colspan="2">Carrier code (Notes 2, 3)</td></tr>
</table>

The following 2-bit combinations shall be used for STP code in Table I.12:

00 – for I_STP;

01 – for WS_STP;

10 – for CR_STP;

11 – setting recommended for CR_STP (valid for read-back messages only).

The same 2-bit combinations as presented in I.3.2.1.1.7 shall be used in Table I.12 for coding of the DS and US carriers (Carrier code).

In VOC commands relating to both carriers of the same transmission direction (i.e., INTERLV, FRAME) bit D12 shall be set to 0 at the transmit side and omitted at the receive side.

For any Parameter setting message a complementary readback message of COMMAND READ type may be used for verifying the value of the configured parameter. In addition, the readback message may be used for reading the particular parameter value recommended for CR_STP. A readback message, if used, shall be built in accordance with the following rules:

– The OPCODE of a readback message equals the OPCODE of the corresponding Parameter setting message increased by 0x20 (in the range of OPCODEs from 0x40 to 0x5F);
– The DATA field of a readback message differs from the corresponding Parameter setting message by the parameter value (bits D0-D11) only. The latter is set to zero for the COMMAND, and equals the actual parameter value setting at the VTU-R for the ECHO.

Table I.13/G.993.1 – Parameter setting messages

Name	Type	OPCODE	Parameter value	Description	Status
EXCBAND	COMMAND (WRITE) and ECHO	0x29	10 MSB = 0, 2 LSB = extra excess bandwidth above 0.1. The LSB weight = 1/30 (Note 1).	Selects the VTU-R excess bandwidth for both transmission directions	O
INTERLV	COMMAND (WRITE) and ECHO	0x21	2 MSB = log2(S/I) for S/I < 16. For S/I = 16, 3 MSB =1. 8 LSB = M, the rest = 0. M = 0 or 3 MSB = 0 disables the interleaver	Selects the VTU-R interleaving depth for the specified direction and STP	M
FRAME	COMMAND (WRITE) and ECHO	0x22	8 MSB = *F*, 4 LSB = *RF*/2 (Note 2)	Selects the VTU-R frame format for the specified direction and STP	M
PSDMASK	COMMAND (WRITE) and ECHO	0x23	12-bit PSD mask code (Note 3)	Selects the VTU-R transmit PSD mask for the specified STP	M
PSDLEVEL	COMMAND (WRITE) and ECHO	0x24	4 MSB = 0, 8 LSB = PSD[dBm/Hz] +100, LSB weight = 1/4 dBm/Hz	Selects the VTU-R transmit PSD level for the specified US carrier and STP	M

Table I.13/G.993.1 – Parameter setting messages

Name	Type	OPCODE	Parameter value	Description	Status
PSDLEVEL_REP	COMMAND (WRITE) and ECHO	0x25	4 MSB = 0, 8 LSB = PSD[dBm/Hz] +100, LSB weight = 1/4 dBm/Hz	Reports the VTU-O transmit PSD level for the specified DS carrier and STP	O
SMBLRATE	COMMAND (WRITE) and ECHO	0x26	2 MSB = 0, 10 LSB = symbol rate profile *s* (Note 4)	Selects the VTU-R symbol rate profile for the specified carrier and STP	M
CONSTEL	COMMAND (WRITE) and ECHO	0x27	8 MSB = 0, 4 LSB = $\log_2$(constellation size)	Selects the VTU-R constellation size for the specified carrier and STP	M
CENFREQN	COMMAND (WRITE) and ECHO	0x28	1 MSB = 0, 11 LSB = centre frequency profile *k* (Note 5)	Selects the VTU-R centre frequency profile for the specified carrier and STP	M
PSD_REF	COMMAND (WRITE) and ECHO	0x30	*First field*: 4 MSB = 0, 8 LSB = a[dBm/Hz] + 100, LSB weight = 1/4 dBm/Hz *Second field*: 3 MSB = 0, 10 LSB = b[dBm/Hz] + 50, LSB weight = 1/20 dBm/Hz	Selects the value of PSD_REF for the specified US carrier (Note 6)	M
PSD_REFS	COMMAND (WRITE)	0x31	4 MSB = 0, 8 LSB = PSD_REFS[dBm/Hz] + 120, LSB weight = 1/4 dBm/Hz	Selects the value of the start-up PSD_REF (I.4.3.5)	M
Reserved	COMMAND and ECHO	0x20, 0x32-0x3F	Note 7		O

Table I.13/G.993.1 – Parameter setting messages

NOTE 1 – As an example, the EXBAND value of 0x2 results in the excess bandwidth of 0.1 + 2/30 = 0.167 (16.7%).
NOTE 2 – The frame format shall be defined by the total number of octets ($F \leq 180$) and the number of redundancy octets ($RF \leq 16$) in the Fast codeword. Valid non-zero values for *F* and *RF* shall be as defined in I.1.2.3.
NOTE 3 – The PSD mask code bears the PSD mask specification which is regionally specific. For some regions PSD mask codes could be found in [ETSI] and [ANSI] and in Annex F. The setting for bandwidth of the amateur radio notches shall comply with the specification in 6.2.4.
NOTE 4 – The symbol rate profile is calculated as $s = SR/BSR$, where *SR* is the required symbol rate in kBaud, *BSR* = 33.75 kBaud, as defined in I.2.2.3.2.1, unless the VTU_INFO command informs on a different setting.
NOTE 5 – The centre frequency profile is calculated as $K = 0.5x\, f_C/BSR$, where f_C is the required centre frequency in kHz, *BSR* = 33.75 kBaud (see I.2.2.3.2.1).
NOTE 6 – The command requires two VOC fields and communicated using Next Word commands.
NOTE 7 – The OPCODE 0x20 is reserved for the regionally specific PROFILE message (see [ETSI]).

I.3.2.1.1.9 Trigger messages

All Trigger messages are of the COMMAND (WRITE) type. Both the COMMAND field and the ECHO DATA field contents shall be equal to 0xAAAA. The VOC shall support at least the Trigger messages presented in Table I.14.

Table I.14/G.993.1 – Trigger messages

Name	Type	OPCODE	Description	Status
CHANGE	COMMAND (WRITE) and ECHO	0xA0	Requests the VTU-R to be ready to change the CR_ STP to a new parameter setting upon execution of a trigger procedure (I.4.3.6).	M
IDLEREQ	COMMAND (WRITE) and ECHO	0xA1	Requests the VTU-R to be ready to change the CR_ STP to I_STP upon execution of a trigger procedure (I.4.3.6).	M
BTSERV	COMMAND (WRITE) and ECHO	0xA2	Requests the VTU-R to be ready to change the CR_ STP to WR_STP upon execution of a trigger procedure (I.4.3.6).	M

I.3.2.1.1.10 Control messages

Control messages are intended for system maintenance in some special cases and allow the management system to override some routine processes. The VOC shall support at least the Control messages presented in Table I.15.

Table I.15/G.993.1 – Control messages

Name	Type	OPCODE	DATA field	Description	Status
USPB_RESET	COMMAND (WRITE) and ECHO	0xE0	COMMAND and ECHO: 2 MSB = US carrier code, the rest = 0	Requests the VTU-R to renew US power back-off process for the specified US carrier	M
THRPUT	COMMAND (WRITE) and ECHO	0xE1	COMMAND and ECHO: 8 MSB = data throughput, 8 LSB = *eoc* throughput (0x00 = set, 0xFF = reset)	Sets or resets data throughput and *eoc* throughput at the VTU-R	M
THRPUT_REQ	COMMAND (READ) and ECHO	0xE2	COMMAND: 0x0000 ECHO: 8 MSB = data throughput, 8 LSB = *eoc* throughput (0x00 = set, 0xFF = reset)	Requests the VTU-R to send the status of data throughput and *eoc* throughput at the VTU-R	O
NEXT_WORD_W	COMMAND (WRITE) and ECHO	0xE3	COMMAND and ECHO: next two octets of data	Conveys the next two octets of data specified by the last WRITE-type command other than NEXT_WORD_W	M
NEXT_WORD_R	COMMAND (READ) and ECHO	0xE4	COMMAND: 0x0000 ECHO: next two octets of data	Requests the VTU-R to send the next two octets of data specified by the last READ-type command other than NEXT_WORD_R	M
TX_FILTER_REP	COMMAND (WRITE) and ECHO	0xE5	COMMAND and ECHO: 4 MSB = STP code and carrier code (Table I.12), 8 LSB = the first octet of the VTU-O Transmit filter register to be sent to the VTU-R (Note 1), the rest = 0	Reports parameters of the VTU-O transmit filter specified in the Transmit filter register (see I.3.4.3). This command shall precede any change in parameters of the Transmit filter (i.e., sent before the changes take effect).	M

Table I.15/G.993.1 – Control messages

Name	Type	OPCODE	DATA field	Description	Status
TX_FILTER_REQ	COMMAND (READ) and ECHO	0xE6	COMMAND: 4 MSB = STP code and carrier code (Table I.12), the rest = 0. ECHO: 8 MSB = 8 MSB of the COMMAND, 8 LSB = the first octet of the VTU-R Transmit filter register to be sent to the VTU-O (Note 1)	Requests the parameters of the VTU-R transmit filter specified in the Transmit filter register (see I.3.4.3)	M
QUIET	COMMAND (WRITE) and ECHO	0xE7	COMMAND and ECHO: D10 = mode of the non-silenced transceiver, D9 = 1 reports silenced VTU-O, D8 = 1 requests silenced VTU-R, 4 LSB = maximum quiet period in s up to 10, the rest = 0 (Note 2)	Requests the VTU-R to silence its transmitter and reports whether the VTU-O transmitter will be silenced. Either transmitter shall be silenced for up to the specified time period immediately after completion of the VOC handshake. Following the silent period, both modems enter *Cold-Start* activation. A modem that has not been silenced can request to end the quiet period early by transmitting a QUIET signal followed by DF_STP (Note 3)	M

Table I.15/G.993.1 – Control messages

Name	Type	OPCODE	DATA field	Description	Status
COPY_STP	COMMAND (WRITE) and ECHO	0xE8	COMMAND and ECHO: 8 MSB = source STP, 8 LSB = destination STP. STP encoding: 0x00 – CR_STP; 0x01 – DF_STP; 0x02 – WS_STP; 0x03 – WR_STP; 0x04 – RE_STP; 0x05 – I_STP; 0xFF – all STP (except DF_STP)	Requests the VTU-R to copy parameter values of an indicated source STP to an indicated destination STP (DF_STP is allowed only in the source field; see I.4.2.2.1)	M
Reserved	COMMAND and ECHO	0xE9-0xEF			O

NOTE 1 – The TX_FILTER command communicates parameters of the VTU transmit filter corresponding to the defined STP and the selected carrier. It is assumed that prior to the VOC communication, the filter parameters are loaded into the Transmit filter register using the format specified in I.3.4.3. The filter parameters are sent to or retrieved from the other side by NEXT_WORD commands. The first octet of the Transmit filter register includes the number of octets to send/retrieve.

NOTE 2 – Bits D9 and D8 of the data field specify that either or both modems shall silence their transmitters for the quiet period specified by bits D3-D0. If both modems are silenced, the quiet period lasts the specified time, after which both modems initiate *Cold-Start* activation (begin transmitting DF_STP). If only one modem is silenced, the non-silenced modem shall continue to transmit the same signal as before this command if D10 = 0, or may transmit any other signal that complies with PSD mask M1, excluding the QUIET signal (see I.4.3.4), if D10 = 1.

NOTE 3 – The non-silenced modem can request early termination of the quiet period at any time by transmitting the QUIET signal for at least 100 ms followed by DF_STP, thereby initiating *Cold-Start* activation. The silenced modem may either remain quiet up to the end of the specified time period, or can (but is not required to) terminate the quiet period early if it detects the DF_STP signal.

Transmission of the NEXT_WORD_R/NEXT_WORD_W command always refers to the last VOC OPCODE other than NEXT_WORD_W/R, IDLE, and EOC that was successfully communicated over the VOC. If the last successfully communicated VOC command was a READ-type, subsequent NEXT_WORD_R commands will read the next two octets of data from the VTU-R corresponding to that READ-type command. If the last successfully communicated VOC command was a WRITE-type, subsequent NEXT_WORD_W commands will write the next two octets of data into the VTU-R corresponding to that WRITE-type command. NEXT_WORD_R or NEXT_WORD_W transmissions, which attempt to read or write beyond the data field length defined for the preceding OPCODE, shall be echoed with UTC by the VTU-R. Reception by the VTU-R of a command other than NEXT_WORD_R, NEXT_WORD_W, or IDLE shall terminate processing of the previous OPCODE. Reception of a single NEXT_WORD_R or a single NEXT_WORD_W command that does not correspond with the preceding command (either NEXT_WORD_R after a WRITE-type command or NEXT_WORD_W after a READ-type command) shall be echoed with a UTC.

I.3.3 Operations Channel TPS-TC (OC-TC) functionality

I.3.3.1 Multiplexing of VOC and eoc

The VOC and *eoc* multiplexing/de-multiplexing is based on the OC channel OPCODE value (see I.1.2.1) that distinguishes the OC DATA field contents. The VOC shall get priority in the multiplexing process: if both VOC and *eoc* messages are ready to be sent, the VOC message shall be sent first.

When no VOC message is to be sent in the given Slow codeword, the OC OPCODE octet of this codeword shall be set either to 0xFF or to 0xFC ("IDLE" message OPCODE or "EOC" message opcode, I.3.2.1.1.5). In the case OPCODE=0xFF, 0x0000 shall be inserted into the OC DATA field. In the case OPCODE=0xFC, the next 2 octets of *eoc* message shall be inserted into the OC DATA field. When a non-IDLE VOC message is to be sent, the *eoc* transparency shall be interrupted, and the corresponding VOC OPCODE (see I.3.2.1.1.4) shall be set to transmit a VOC message. When the VOC message transmission is completed, the OPCODE value shall be set to IDLE. After the specified number of IDLE messages is sent (see I.3.2.1.1.1), *eoc* transport over the OC may be resumed.

I.3.3.2 De-multiplexing

If the received OC OPCODE equals 0xFC, the contents of the OC DATA field shall be output via the corresponding γ-interface. If the received OC OPCODE is equal to any value other than 0xFF or 0xFC, the received OC DATA field shall be directed to the VOC processor as a possible valid VOC OPCODE (see I.3.2.1.1.5).

NOTE – The value of OC OPCODE 0xFC indicates that the received OC DATA octets may contain an *eoc* message. The *eoc* processor will distinguish a valid *eoc* message as described in 10.3.2.

I.3.4 VTU-R registers

I.3.4.1 VTU-R configuration register

The VTU-R configuration register is intended for storing the VTU-R configuration data, either default or delivered from the VTU-O via VOC. The register consists of 64 bytes and shall include the data as specified in Table I.16:

Table I.16/G.993.1 – VTU-R configuration register (Register 0x8)

Byte number, HEX	Parameter description	Format
	Line-related	
0x00-0x01	Reserved for use by the ITU-T	For PROFILE code [ETSI] default 0xFF
0x02-0x03	Transmit PSD mask	See Table I.13, PSD_MASK
0x04-0x05	Frame setup	See Table I.13, FRAME
0x06-0x07	Symbol rate, Carrier US1	See Table I.13, SMBLRATE
0x08-0x09	Symbol rate, Carrier US2	See Table I.13, SMBLRATE
0x0A-0x0B	Symbol rate, Carrier DS1	See Table I.13, SMBLRATE
0x0C-0x0D	Symbol rate, Carrier DS2	See Table I.13, SMBLRATE
0x0E-0x0F	Constellation, Carrier US1	See Table I.13, CONSTEL
0x10-0x11	Constellation, Carrier US2	See Table I.13, CONSTEL
0x12-0x13	Constellation, Carrier DS1	See Table I.13, CONSTEL
0x14-0x15	Constellation, Carrier DS2	See Table I.13, CONSTEL
0x16-0x17	Centre frequency, Carrier US1	See Table I.13, CENFREQN

Table I.16/G.993.1 – VTU-R configuration register (Register 0x8)

Byte number, HEX	Parameter description	Format
0x18-0x19	Centre frequency, Carrier US2	See Table I.13, CENFREQN
0x1A-0x1B	Centre frequency, Carrier DS1	See Table I.13, CENFREQN
0x1C-0x1D	Centre frequency, Carrier DS2	See Table I.13, CENFREQN
0x1E-0x1F	Excess bandwidth, US Carriers	See Table I.13, EXCBAND
0x30-0x31	Excess bandwidth, DS Carriers	See Table I.13, EXCBAND
0x32-0x33	PSD_REF, Carrier US1, value a	See Table I.13, PSD_REF
0x34-0x35	PSD_REF, Carrier US1, value b	See Table I.13, PSD_REF
0x36-0x37	PSD_REF, Carrier US2, value a	See Table I.13, PSD_REF
0x38-0x39	PSD_REF, Carrier US2, value b	See Table I.13, PSD_REF
0x3A-0x3B	Startup PSD_REF	See Table I.13, PSD_REFS
0x3C-0x3F	Reserved	0xFF
0x40-0x41	Interleaver set-up	See Table I.13, INTERLV
0x42-0x43	Spectral plan support and band support	See Note 1
0x44-0x45	Transmit PSD level, carrier US1	See Table I.13, PSDLEVEL
0x46-0x47	Transmit PSD level, carrier US2	See Table I.13, PSDLEVEL
0x48-0x49	Transmit PSD level, carrier DS1	See Table I.13, PSDLEVEL
0x4A-0x4B	Transmit PSD level, carrier DS2	See Table I.13, PSDLEVEL
0x4C-0x4D	BSR support and auxiliary functions	See Note 2
0x4E-0x4F	Reserved	
	Path-related	
0x20-0x21	TPS-TC configuration	See Note 3, Note 4
0x22-0x23	ATM-TC configuration	Reserved, default 0xFF
0x24-0x25	STM-TC configuration	Reserved, default 0xFF
0x26-0x27	PTM-TC configuration	Reserved, default 0xFF
0x28-0x2F	Reserved	0xFF

NOTE 1 – The spectral plan code format shall be as defined in Table I.17, and the band support code format shall be as defined in Table I.18. In Table I.17 a value of 1 indicates support for the spectral plan as specified in 6.1, including regionally-specific band plans (Annexes A-C) and ETSI applications defined in [ETSI]. Value of 0 indicates no support. In Table I.18 a value of 1 indicates support of the particular band, and a value of 0 indicates no support.

NOTE 2 – The format of byte 0x4C shall be: D0-D3 set to 0; D4-D5 BSR support; D6, D7 reserved. The following coding shall be used for D4D5:

00 Supports BSR = 67.5 kBaud only (legacy value)

01 Supports BSR = 33.75 kBaud only (nominal value)

10, 11 Reserved.

Byte 0x4D is reserved for auxiliary functions. All reserved bits shall be set to 1.

Table I.16/G.993.1 – VTU-R configuration register (Register 0x8)

NOTE 3 – Use the following bits of 0x20: D0, D1 for ATM-TC; D3, D4 for STM-TC, D5, D6 for PTM-TC. Use the following coding: 00 Not installed 11 Installed and activated 10 Installed and disabled 01 N/A NOTE 4 – The format of byte 0x21 shall be: D0-D3 TPS-TC defect indicators $fp_1 – fp_4$, respectively, the rest of the bits is reserved and shall be set to 1. The definition and coding of *fp* shall be as specified in I.1.2.2.2.

Table I.17/G.993.1 – Spectral plan support code (byte 0x42)

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	Annex C	ETSI FTTCab B	ETSI FTTCab A	Annex B	Annex A

Table I.18/G.993.1 – Band support code (byte 0x43)

D7	D6	D5	D4	D3	D2	D1	D0
0	0	US2	DS2	US1	DS1	25-138, DS	25-138, US

I.3.4.2 VTU-R performance registers

Performance registers are intended to store the VTU-R performance-related and loop-related information. The registers shall include data as specified in Table I.19:

Table I.19/G.993.1 – VTU-R performance registers

Byte number, HEX	Parameter description	Format
Register 0x3:	**Self-test results**	
0x00-0x0F	Reserved	0xFF
Register 0x4:	**Performance**	
0x00-0x01	Corrected error octets, Slow channel	See Table I.11, FECS
0x02-0x03	Corrected error octets, Fast channel	See Table I.11, FECF
0x04-0x05	Uncorrected error octets, Slow channel	See Table I.11, ERRS
0x06-0x07	Uncorrected error octets, Fast channel	See Table I.11, ERRF
0x08-0x0A	Reserved	0xFF
Register 0x6:	**Loop attenuation**	
0x00	Carrier DS1	See I.3.1, (Note 1)
0x01	Carrier DS2	
0x02	Carrier US1	
0x03	Carrier US2	

Table I.19/G.993.1 – VTU-R performance registers

Byte number, HEX	Parameter description	Format
0x04	Electrical length, US	Note 2
0x05	Electrical length, DS	
0x06-0x0F	Reserved	
Register 0x7:	**SNR margin**	
0x00	SNR-M, Carrier DS1	See 10.5
0x01	SNR-M, Carrier DS2	
NOTE 1 – The value of attenuation for carriers US1 and US2 shall be set to 0x00 if no relevant data from the VTU-O is available. NOTE 2 – The values of electrical length should be calculated using carrier attenuation data and set to 0x00 if no relevant data is available.		

I.3.4.3 VTU transmit filter register

The Transmit filter register at both the VTU-O and VTU-R shall include the data as specified in Table I.20. The data relates only to the part of the filter operating at symbol rate.

Table I.20/G.993.1 – Transmit filter register

Byte number, HEX	Parameter description	Format
0x00	Length of the register, L octets	0x01-0xFF, Note 1
0x01	Number of zeros, NZ (NZ × 4 octets)	Notes 2, 3
0x02-0x03	First zero, real part	
0x04-0x05	First zero, imaginary part	
0x06-0x07	Second zero, real part	
0x08-0x09	Second zero, imaginary part	
…		
0x(4 × NZ – 2)-0x(4 × NZ – 1)	NZ-zero, real part	
0x(4 × NZ)-0x(4 × NZ + 1)	NZ-zero, imaginary part	
0x(4 × NZ + 2)-0x(4 × NZ + 3)	First pole, real part	
0x(4 × NZ + 4)-0x(4 × NZ + 5)	First pole, imaginary part	
…		
0x(4 × (NZ + NP) – 2)-0x(4 × (NZ + NP) – 1)	NP-pole, real part	
0x(4 × (NZ + NP))-0x(4 × (NZ + NP) + 1)	NP-pole, imaginary part	
NOTE 1 – The length of the register L equals the total number of octets specifying NZ zeros and NP poles of the transmit filter: L = 4 × (NZ + NP). NOTE 2 – Both poles and zeros shall be listed in ascending order. NOTE 3 – The real and imaginary parts of the poles and zeros shall be represented by 16 bits each, 2's complement representation, where 214 corresponds to 1.		

If parameters of the transmit filter are not available, the value of *L* shall be set to 0.

I.4 Link activation and de-activation

The link activation/deactivation process is intended to establish/terminate a VDSL link with required transmission parameters between physically connected and powered VTU-O and VTU-R. The process also allows modification of the transmission parameters of the VDSL link. The VTU activation procedure commences with the handshake procedures described in ITU-T Rec. G.994.1. The Annex I NPar(2) and SPar(2) G.994.1 Handshake bit definitions are specified in I.4.4. If G.994.1 procedures select this annex as the mode of operation, the VTU shall transition to Annex I/G.993.1 operation at the conclusion of G.994.1 operation.

I.4.1 VDSL link state and timing diagram

The VDSL link state and timing diagram is described in Figure I.19. The diagram includes five states (rounded blocks), four procedures of link activation (rectangular blocks), and two procedures of link deactivation.

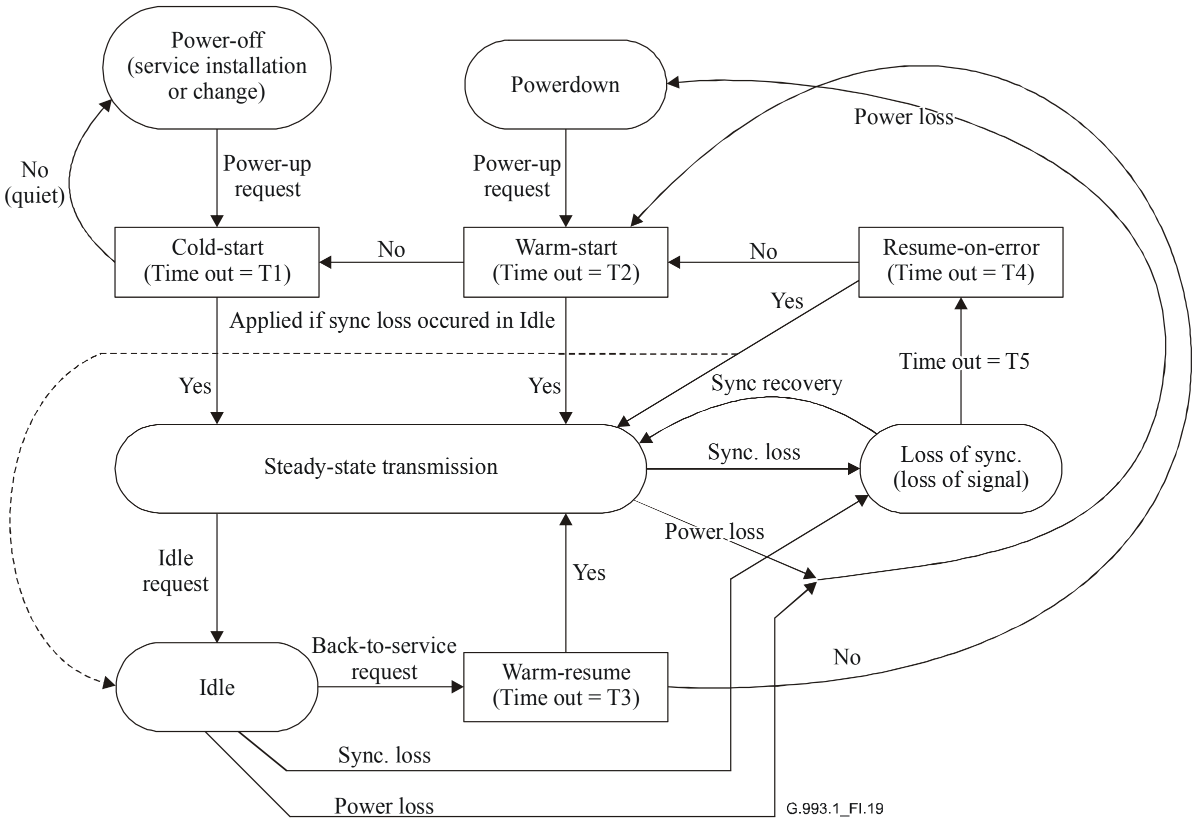


Figure I.19/G.993.1 – VDSL link state and timing diagram

I.4.1.1 States

The link State and Timing diagram shall contain the following five states:

– *Power-off* is the initial state intended for service installation and modification prior to the first power-up process.

– *Steady-State Transmission* is a state achieved after the link activation process is completed. In this state, the link shall transport user information with standard performance characteristics.

– *Loss of Sync (Loss of Signal)* is a state achieved if transmission frame synchronization loss occurs (also as a result of signal energy loss or symbol timing loss). During this state the link is interrupted. The link shall return from this state back to *Steady-State Transmission* if frame synchronization is recovered in a short period of time (T5). Otherwise, the link shall be moved to perform the *Resume-on-Error* activation procedure.

– *Power-Down* is a state achieved after a guided power removal, power failure or *QUIET* deactivation at either the VTU-O or VTU-R. During this state the link is terminated. The link shall be moved from this state into the *Warm-Start* procedure by applying a Power-up request.
– *Idle* state generates low crosstalk and reduced power consumption for the link when no broadband calls are in progress. After the VTU-O or VTU-R detects a broadband call wake-up signal (Back-to-Service request command) from the network or from the CPE, respectively, a *Warm-Resume* procedure is executed. Support of *Idle* state is optional.

If the VDSL link is maintained during the *Idle* state, at least data frame synchronization, VOC transparency and Sync. Loss event monitoring should be provided. The user data and eoc transport are optional.

I.4.1.2 Activation

Either the VTU-R or the VTU-O is capable to activate the link. A successfully completed activation brings the link into steady-state transmission. The following four types of link activation (Figure I.19) correspond to the four activation procedures:

– *Cold-Start*: shall be applied after the first power-up or after an unsuccessful *Warm-Start* activation. If finished unsuccessfully, some changes in the installed service shall be made to simplify the link establishment.

NOTE 1 – Unsuccessful *Cold-Start* activation usually occurs when the activated link environment (loop attenuation, noise, etc.) is too poor to provide the desired service.

– *Warm-Start*: shall be applied after an unsuccessful *Resume-on-Error* activation, or after an unsuccessful *Warm-Resume* activation, or after either Power-down/Power failure, or after link deactivation (*QUIET*) event. If *Warm-Start* fails, the *Cold-Start* activation is applied.

NOTE 2 – Unsuccessful *Warm-Start* activation usually occurs after significant change of line characteristic (for example, a connection to a new line with unknown parameters).

– *Resume-on-Error* shall be applied after a link interruption due to loss of synchronization, which was not self-recovered during the specified time-out (T5). If *Resume-on-Error* fails, the *Warm-Start* activation is applied.

NOTE 3 – Unsuccessful *Resume-on-Error* activation is usually due to a temporary change of noise conditions in the loop or due to modification of the transmission parameters.

– *Warm-Resume* shall be applied on receipt of a broadband call wake-up signal (Back-to-Service request command) if the link resides in the *Idle* state. If *Warm-Resume* fails, the *Warm-Start* activation is applied.

NOTE 4 – Unsuccessful *Warm-Resume* activation is usually due to a temporary change of noise conditions in the loop.

I.4.1.3 Deactivation

The deactivation process may be initiated at either the VTU-O or VTU-R by special control signals. Both the VTU-O and VTU-R should support two types of link deactivation.

– *QUIET* shall terminate the link. *QUIET* shall be applied if power failure occurs, or if a transceiver restart is desired, or as a part of the power-down process. *QUIET* may be initiated while the link resides in any state or during any activation process. In any case, except the *Cold-Start*, after *QUIET* deactivation the link shall be moved into the *Power-Down* state. *QUIET* deactivation during the *Cold-Start* moves the link into the initial (Power-off) state.

– *Idle Request* shall move the link from the Steady-state transmission into the Idle state (if supported). The *Idle Request* command (see I.4.3.2) may be applied on receipt of a broadband call release while the link resides in *Steady-State Transmission* state only.

NOTE – The *Warm-Resume* activation procedure is applied to return the link from the *Idle* state to a *Steady-State Transmission* state.

I.4.1.4 Delay to service

Delay to service is defined by the activation time, which is the time interval from the beginning of the activation process until the link reaches the steady-state transmission. The activation time shall not exceed the values of the time constants T1-T5, listed in Table I.21.

Table I.21/G.993.1 – Activation time constants

Process	Time constant	Maximum value [ms]
Cold-Start activation	T1	10 000
Warm-Start activation	T2	5 000
Warm-Resume activation	T3	100
Resume-on-Error activation	T4	300
Sync. Loss recovery	T5	200

I.4.2 VDSL link transmission parameters

I.4.2.1 Set of transmission parameters

Transmission characteristics of the link are specified by the Set of Transmission Parameters (STP) presented in Table I.22. The same STP shall be set at both the VTU-O and VTU-R. When STP is modified in one VTU, the change should occur in the other as well.

Table I.22/G.993.1 – Set of transmission parameters (STP)

Parameter	Downstream carrier-1	Downstream carrier-2	Upstream carrier-1	Upstream carrier-2	Parameter range
Symbol rate	1D_SR	2D_SR	1U_SR	2U_SR	33.75 kBaud × *s* (s = 1, 2, …)
Excess bandwidth	1D_EB	2D_EB	1U_EB	2U_EB	α = 0.1-0.2
Constellation	1D_C	2D_C	1U_C	2U_C	1-12 bit/symbol
Centre frequency	1D_CF	2D_CF	1U_CF	2U_CF	16.875 kHz × *k* (*k* = 1, 2, …)
Transmit PSD	1D_PSD	2D_PSD	1U_PSD	2U_PSD	As specified in 6.2.1
Interleaver	D_M, D_I		U_M, U_I		*M*, *I*, as specified in I.1.2.8
Frame format	D_FR		U_FR		In accordance with I.1.2.1

I.4.2.1.1 Current STP

The *Current STP* (CR_STP) contains transmission parameters currently in use by the upstream and downstream transmitters.

I.4.2.1.2 Standard STPs

The following five standard STPs shall be supported.

Default STP (DF_STP) shall be used to perform *Cold-Start* activation. DF_STP shall be available at both sides of the link prior to the post-handshake activation/deactivation process, and shall be kept constant until the link is returned to *Power-off* state or G.994.1 handshake state to change the type of service. The parameter values for DF_STP depend on the used bandplan. For band plans specified in Annexes A, B and C, the recommended DF_STP values are presented in Table I.23. The relevant values of DF_STP setting are delivered to the VTU-R using ITU-T Rec. G.994.1.

Table I.23/G.993.1 – Parameter values of DF_STP applicable for Annexes A, B and C

Parameter	1D	2D	1U	2U (Note 1)
Symbol rate [kBaud]	573.75 (17 × 33.75)	0	Annexes A, B: 742.5 (22 × 33.75) Annex C 945 (28 × 33.75)	67.5 (2 × 33.75)
Excess bandwidth	0.2			
Constellation	4	–	4	4
Centre frequency [kHz]	1451.25 (86 × 16.675)	–	Annexes A, B 4455 (264 × 16.875) Annex C 3138.75 (186 × 16.875)	84.375 (5 × 16.875)
Transmit PSD [dBm/Hz]	–60	–	≤–60 (Note 2)	–40
Interleaver	Disabled			
Frame format	Type [0/0] (single latency)			

NOTE 1 – The 2U component is an alternative to 1U component, intended to be used when the optional band is in use. The 2U component shall be disabled if ISDN service splitter is involved.

NOTE 2 – The actual transmit PSD value will be reduced in accordance with the upstream power back-off procedure defined in I.4.3.5.

NOTE 3 – Specific regions may use other values of DF_STP parameters, compatible with local regulations and interoperability (backwards compatibility) issues.

Warm-Start STP (WS_STP) shall be used to perform *Warm-Start* activation. WS_STP shall initially be set equal to the DF_STP. A VOC communication may be used to negotiate changes to WS_STP.

Warm-Resume STP (WR_STP) shall be used to perform *Warm-Resume* activation. As the link enters *Steady-State Transmission* state, WR_STP shall be set equal to CR_STP. This setting shall be completed prior to execution of *Idle Request*.

Resume-on-Error STP (RE_STP) shall be used to perform a *Resume-on-Error* activation. As the link enters either *Steady-State Transmission* state or *Idle* state, and during these states, RE_STP shall be set equal to CR_STP. This setting shall be completed prior to a *Resume-on-Error* activation.

Idle STP (I_STP) shall be used to execute an *Idle Request* (transition to *Idle* state, if supported). By default I_STP shall be set equal to CR_STP, except for constellation size, which shall be set to 4, and the transmit PSD level, which shall be reduced by the values presented in Table I.24. Alternative settings for I_STP shall be completed prior to execution of *Idle Request* using the VOC communication to negotiate the I_STP setting.

Table I.24/G.993.1 – Maximum PSD reduction

Steady-state transmission constellation	4	8	16	32	64 and more
Maximum PSD reduction, dB	3	7	10	12	12

I.4.2.2 Transmission parameters modification

At the discretion of the network operator, both CR_STP and any standard STPs, excepting DF_STP, can be modified, as appropriate for the required service characteristics. Modification of STP can be initiated only by the VTU-O. The VTU-R is not required to accept the requested STP modification if the value of its transmission parameters is not a standard setting.

NOTE – DF_STP may be changed upon the service re-installation by procedures that are described in I.4.2.1.2.

I.4.2.2.1 Standard STP modification

Of the five standard STPs described in I.4.2.1.2, only WS_STP and I_STP may be modified independently. Modification of WS_STP or I_STP may be done only during the *Steady-State Transmission* state of the link. The modification technique shall be as follows. The VTU-O gets the new settings for the intended STP from the local management system. It sends to the VTU-R (using the VOC) a copy of the new STP, and requests to make corresponding changes to its own copy of the corresponding STP. Once accepted by the VTU-R, the new STP settings are stored in both the VTU-O and VTU-R.

The RE_STP shall be automatically updated to equal the CR_STP each time the link enters *Steady-State Transmission* state or *Idle* state. Similarly, WR_STP shall be automatically updated to equal the CR_STP each time the link enters *Steady-State Transmission* state.

I.4.2.2.2 CR_STP modification

The CR_STP may be modified in two different ways.

– The CR_STP shall be automatically overwritten with DF_STP, WS_STP or RE_STP when the link enters *Cold-Start*, *Warm-Start,* or *Resume-on-Error*, respectively. During these changes the link is usually interrupted (or disconnected).

– The CR-STP shall be overwritten with a new setting after successful communication of a VOC trigger message (either CHANGE or BTSERVC or IDLEREQ), followed by a trigger handshake (see I.4.3.5). The procedure shall be used both to make generic modifications to CR_STP, and to modify CR_STP to I_STP or to WR_STP upon transition into *Idle* state or entering *Warm-Resume*, respectively. The CR_STP modification shall be initiated by a special control signal from the VTU-O (CHNG_PRM, B_SERV or I_REQ, see I.4.3.2). It can be performed either during *Steady-State Transmission* state (if initiated by CHNG_PRM or I_REQ), or during *Idle* state (if initiated by B_SERV).

Modifications of CR_STP are accompanied by appropriate changes in both transmitter and receiver parameters, and in transmit signal parameters, as defined by the new CR_STP.

For a generic CR_STP modification, the CR_STP modification request and the new CR_STP shall be conveyed to the VTU-R from the VTU-O over the VOC. After all parameters of the new CR_STP are successfully communicated, the VTU-O management system uses a CHANGE VOC message to request that the current CR_STP be overwritten with the new parameter settings. A trigger handshake activated after successful communication of the CHANGE message overwrites CR_STP and RE_STP at both the VTU-O and the VTU-R with the new parameter settings, and triggers the desired change in their transmitter/receiver parameters.

In the same manner, for transition into *Idle* state or for *Warm-Resume* activation, the CR_STP and RE_STP are overwritten with I_STP or WR_STP, respectively, after successful communication of IDLEREQ or BTSERVC VOC messages followed by a trigger handshake.

If due to the CR_STP change the link moves into *Loss of Sync* state (caused by symbol rate change, for example), it will try to recover synchronization within time T5 and thereby return to *Steady-State Transmission* state with the new parameters in place. If the synchronization is not recovered, the link will attempt a *Resume-on-Error* activation with RE_STP set equal to the modified CR_STP. If this *Resume-on-Error* activation is successful, the link returns to *Steady-State Transmission* with the successfully accomplished parameter change. If not, the parameter change process fails, and *Warm-Start* activation is automatically attempted to return the link into the *Steady-State Transmission* state.

NOTE – With some additional delay, a generic CR_STP modification can also be done without use of the CHANGE VOC command and the trigger handshake. The method is to load new transmission parameters into WS_STP, and then to force a *Warm-Start* by deactivating the link applying the *QUIET* control signal at either end of the link. Failure to acquire the link with the new parameter values automatically initiates *Cold-Start*, which returns the link into *Steady-State Transmission* state with DF_STP, ready for the next parameter modification attempt.

I.4.2.2.3 STP modification summary

A summary of the STP modification rules is presented in Table I.25.

Table I.25/G.993.1 – Summary of STP modification rules

Parameter	Overwritten automatically	Overwritten by the operator
DF_STP	N/A	N/A
WS_STP I_STP	N/A	– with an arbitrary parameter setting during *Steady-State Transmission* state.
WR_STP	– with the CR_STP upon entry to *Steady-State Transmission* state.	N/A
RE_STP	– with the CR_STP upon entry to either *Steady-State Transmission* or *Idle* state; – with the CR_STP, immediately after CR_STP was overwritten with the new parameter settings (I_STP, WR_STP or generic).	N/A
CR_STP	– with the DF_STP, WS_STP, or RE_STP at the beginning of *Cold-Start*, *Warm-Start*, or *Resume-on-Error* activation, respectively.	– with an arbitrary transmission parameter setting during *Steady-State Transmission*, after successful communication of the CHANGE VOC message followed by a trigger handshake (generic CR_STP modification); – with I_STP upon entering *Idle* state after successful communication of the IDLEREQ VOC message followed by a trigger handshake (moving into *Idle* state); – with WR_STP upon entry to *Warm-Resume*, after successful communication of the BTSERVC VOC message followed by a trigger handshake (moving back from *Idle* state to *Steady-State Transmission*).

NOTE – All listed STP modifications are fully provided by the VTU-O and VTU-R state machines described in I.4.3.6 and I.4.3.7.

I.4.3 Post-G.994.1 Handshake VTU activation/deactivation

I.4.3.1 Functional diagram

The VTU post-G.994.1 handshake activation/deactivation functional diagram is shown in Figure I.20. The post-G.994.1 handshake activation/deactivation process is performed by the VTU state machine, described in I.4.3.6 and I.4.3.7. Prior to post-G.994.1 handshake activation, the VTU state machine shall be supplied with the appropriate CR_STP to be used in the activation. (In Figure I.20, CR_STP is stored in CR_STP Memory (CR_STPM) of the VTU Activation database.) The CR_STP is loaded by the VTU management entity for the subsequent activation type, and could be either an appropriate standard STP (DF_STP, WS_STP, or RE_STP) or a generic STP. Thus, the VTU management entity supports the desired link characteristics and all the required activation types, as defined in Figure I.19. The post-G.994.1 handshake activation/deactivation is driven by the Control signals originated by the VTU management entity, which shall also monitor the state machine states and flags.

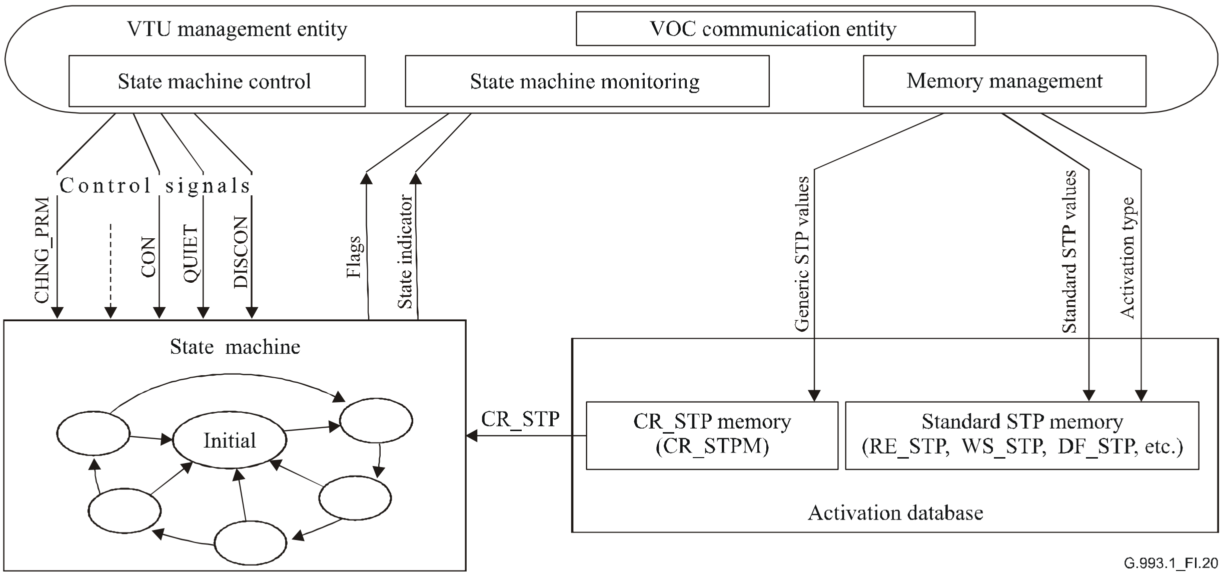


Figure I.20/G.993.1 – VTU activation/deactivation functional diagram

The CR_STPM shall contain the STP for the pending activation process. Identical STP shall be loaded into the CR_STPM at both the VTU-O and VTU-R at the start of the activation and kept constant until the activation process is completed, either successfully or not. If the activation process is completed successfully, the loaded CR_STP will be used during the following steady-state transmission until a new parameter modification request. If the activation process fails, a new STP will be automatically loaded into CR_STPM in accordance with the next activation type, as described in Figure I.19.

I.4.3.2 Control signals

The following Control signals shall be supported to drive the VTU post-G.994.1 handshake activation/deactivation process:

– *Connect (CON)* – to initiate the activation process after the link was terminated (i.e., initiates either *Cold-Start* or *Warm-Start*). As *CON* is set, the VTU shall move from the STANDBY state (see I.4.3.6 and I.4.3.7) to start the link activation. *CON* is applied at the VTU-R in case of activation from the CPE site, and at the VTU-O in the case of activation from the ONU/CO site. *CON* shall be ignored by the VTU in all states except STANDBY.

– *Quiet (QUIET)* – to terminate the link. As *QUIET* is set, the activated VTU shall move from its current state into the POWER-UP state (see I.4.3.6 and I.4.3.7). *QUIET* should be applied for the VTU restart or as a part of the power-down process. *QUIET* is applicable for both the VTU-O and VTU-R.

– *Change parameter (CHNG_PRM)* – to initiate a generic parameter modification process. *CHNG_PRM* may be applied only at the VTU-O while the link is in *Steady-State Transmission* state.

– *Idle Request (I_REQ)* – to initiate the link deactivation into *Idle* state. As *I_REQ* is set, the link shall move from *Steady-State Transmission* into *Idle* state. *I_REQ* may be applied at the VTU-O only while the link is in *Steady-State Transmission* state. *I_REQ* shall be supported only if *Idle* state is supported.

– *Back-to-Service (B_SERV)* – to initialize a *Warm-Resume* activation. As *B_SERV is set* the link shall move from *Idle* state into *Steady-State Transmission* state. *B_SERV* may be applied at both the VTU-O and VTU-R while the link is in *Idle* state. *B_SERV* shall be supported only if *Idle* state is supported.

– *Disconnect (DISCON)* – to disable the link activation attempt from the VTU-R (to prevent uncontrolled link activation). *DISCON* may be applied at the VTU-O only. Support of the *DISCON* is optional.

I.4.3.3 Flags and indicators

The local VTU management entity shall use the following Flags and Indicators to monitor the state machine.

– *State Indicator (SI)* – to indicate the current state of the state machine. Used by the VTU management entity to set or reset user data and *eoc* throughput.

– *Complied Flag (CF)* – to indicate that the last command initiated by a particular Control signal was successfully executed.

– *Unable-to-Comply Flag (UTCF)* – to indicate that the last command initiated by a particular Control signal was not executed.

– *Remote Activation Request Flag (RAF)* – to indicate that an activation request from the VTU-R has been received; applicable at the VTU-O while in STANDBY state only.

– *Back to Service Request Flag (BTSF)* – indicates that a back-to-service request from the VTU-R has been received; applicable at the VTU-O while the link is in *Idle* state only. Shall be supported only if *Idle* state is supported.

I.4.3.4 Transmit signals and timers

A particular type of transmit signal is specified for each state of the VTU state machine. The VTU shall support all types of transmit signal specified in Table I.26.

Transmit signals O_QUIET and R_QUIET shall drive the line with zero volts (silence). Other transmit signals shall be formatted as a standard transmission frame (see I.1.2) and specified by the contents of the OC field, and the *o_trig*, *r_trig*, *r_flag* signals (see I.1.2.2.2), and the values of indicators IB-7 through IB-9. Transmit signals O_ACQUIRE and R_ACQUIRE, O/R_TRIG always carry, respectively, the PSD_REFS VOC message and IDLE VOC message; signals O/R_DATA can carry both IDLE messages, and valid VOC and *eoc* messages.

The *o_trig* bits in the downstream transmission frame header shall be set to 1 for the O_TRIG signal and to 0 for all other VTU-O transmit signals. The *r_trig* bit shall be equal to 0 for all VTU-R transmit signals, except for R_TRIG, where it is set to 1. The *r_flag* shall be set to 0 in all signals except R_DATA, in which it shall be set to 1 when the B_SERV control signal is applied at the VTU-R.

Table I.26/G.993.1 – Transmit signals summary

Signal	OC field	Control field	Note
O_QUIET	No transmission		
O_ACQUIRE	OC = IDLE	*o_trig* = 0, IB-9 = 1	User Data: Denied VOC: PSD_REFS command *eoc*: Denied
O_TRIG	OC = IDLE	*o_trig* = 1, IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: IDLE *eoc*: Denied
O_DATA	OC = valid message	*o_trig* = 0, IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: Applicable *eoc*: Applicable (Note 1)
R_QUIET	No transmission		
R_ACQUIRE	OC = IDLE	*r_trig* = 0, *r_flag* = 0, IB-9 = 1	User Data: Denied VOC: IDLE *eoc*: Denied Variable transmit level (Note 3)
R_TRIG	OC = IDLE	*r_trig* = 1, *r_flag* = 0, IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: IDLE *eoc*: Denied
R_DATA	OC = valid message	*r_trig* = 0, *r_flag* = 0/1 (Note 2) IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: Applicable *eoc*: Applicable (Note 1)
NOTE 1 – User data throughput is optional if the link is in *Idle* state. NOTE 2 – See detailed description on *r_flag* setting in I.4.3.7. NOTE 3 – Set to support the upstream startup power back-off as described in I.4.3.5.			

The following timers listed in Table I.27 are involved in the VTU-activation/deactivation process.

Table I.27/G.993.1 – VTU-state machine timers

Timer	Function	Value
t_{p_o}	Duration of the O_QUIET signal detection at VTU-O to complete the O_POWERUP state.	10 ms ≤ t_{p_o}, t_{p_r} ≤ 100 ms
t_{p_r}	Duration of the R_QUIET signal detection at VTU-R to complete the R_POWERUP state.	
t_{1_r}	DS equalizer convergence time-out	4 s
t_{1_o}	US equalizer convergence time-out	4 s
t_{2_o}	Time-out for VTU-O activation process	Depends on startup type: T1 for *Cold-Start*, T2 for *Warm-Start*, T3 for *Warm-Resume*, T4 for *Resume-on-Error*, T4+T5 following the CHANGE VOC message
t_{2_r}	Time-out for VTU-R activation process	

Table I.27/G.993.1 – VTU-state machine timers

Timer	Function	Value
t_{3_o}	Time-out for VTU-O trigger handshake	1000 ms
t_{3_r}	Time-out for VTU-R trigger handshake	100 ms
t_{4_o}	Time-out to recover VTU-O frame synchronization	T5 (200 ms; see 11.1.4 of Part 1)
t_{4_r}	Time-out to recover VTU-R frame synchronization	T5 (200 ms; see 11.1.4 of Part 1)

I.4.3.5 Startup power back-off

The startup power back-off shall be performed during Cold-start only by applying a frequency independent (flat) transmit PSD reduction on the upstream carriers at the beginning of Cold-Start activation (see I.4.1.2 and I.4.3.7). The VTU-R receiver shall resolve the value of the transmit PSD template for each upstream carrier (*TxPSD_U*) autonomously (with no assistance from the VTU-O) by analysing the received downstream signal from and using the following rule:

$$TxPSD = PSD\_REF(f_C) + LOSS(f_C) - LOSS\_CORR$$

where:

– *PSD_REF*, *LOSS* are the variables defined in 6.3.2;

– f_C is the centre frequency of the upstream carrier;

– $LOSS\_CORR$ is an additional reduction of the upstream transmit PSD which compensates for possible inaccuracy in the estimated value of the electrical length of the loop. If the resolved value *TxPSD_U* exceeds the limiting upstream template PSD_0 defined in 6.3.2, the value of the limiting template shall be used.

The recommended value of *LOSS_CORR* is 3 dB for the regions where bridged taps is not an issue, and 6 dB for regions where bridged taps are expected. The specified value of *LOSS_CORR* is valid for the VDSL link transmission parameters used during *Cold-Start* and specified in I.4.2.1.2, Table I.23. For other transmission parameters the value of *LOSS_CORR* may be revised based on the regionally specific issues.

I.4.3.6 VTU-O state machine

The VTU-O state machine is shown in Figure I.21. Each ellipsoid block in Figure I.21 represents a state and contains the state number (*S1 – S7*) followed by the state title. The type of transmit signal, while residing in the state, is placed below the state title.

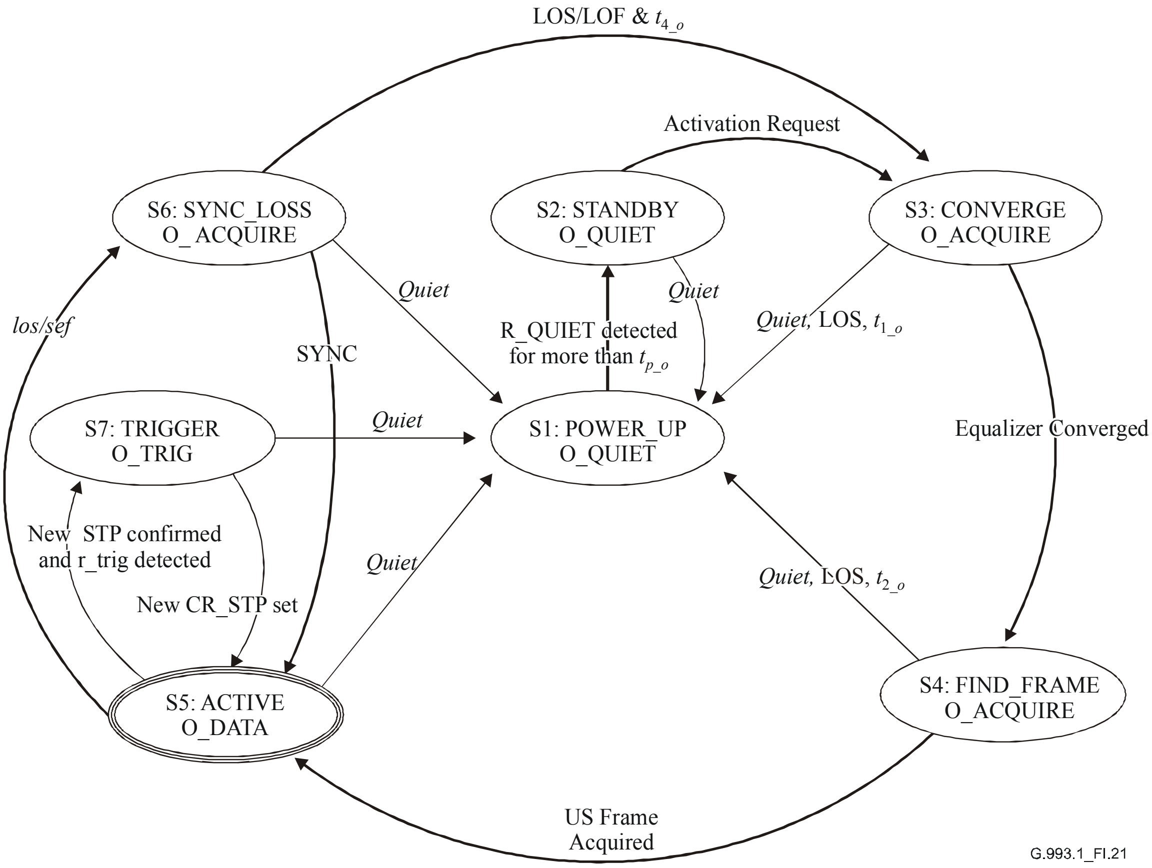


Figure I.21/G.993.1 – VTU-O activation/deactivation state machine

S1: O_POWERUP

This state is the initial state of the state machine. It corresponds to the start of the activation process and shall be entered in the following cases:

– a *QUIET* control signal or a Power-up request is applied. This is the first step in pending *Cold-Start* or *Warm-Start* activation, as shown by Figure I.19.

– Loss of upstream signal (*US_LOS*) is detected while in states *S3, S4,* or time-out of states *S3, S4* occurs. This *S1* entry follows a failed activation attempt and is the first step in a pending re-activation attempt of the type specified by Figure I.19.

In state *S1*, the VTU-O shall transmit O_QUIET. The VTU-O transmitter and receiver shall be configured with the STP stored in CR_STPM. The VTU-O shall enter state *S2* if loss of the received upstream signal (*US_LOS*) is detected for more than t_{p_o} ms.

NOTE – The definition of *US_LOS* is specified in I.3.1 (*LOS* primitive).

S2: O_STANDBY

In state *S2* the VTU-O shall transmit O_QUIET and wait for an activation request. The latter could be either the *CON* control signal if the link is activated from the VTU-O, or detection of the upstream received signal energy if the link is activated from the VTU-R. The *DISCON* control signal, if enabled, shall override any activation request from the VTU-R.

Once the activation request is performed, timer t_O shall be started from zero and state *S3* shall be entered. If *QUIET* is applied while in this state, the VTU-O shall return to state *S1*.

NOTE – Timer t_O is intended for monitoring of the VTU-R synchronization process.

S3: O_CONVERGE

This state is entered from state *S2* following an activation request, or from state *S6* following a non-recovered synchronization loss. In state *S3* the VTU-O shall transmit the O_ACQUIRE signal while attempting to converge the upstream equalizer(s). The IB-9 (*rdi*) shall be set to 1 indicating that the upstream direction is not synchronized.

NOTE – The transition from *S6* to *S3* corresponds to initiation of a *Resume-On-Error* activation attempt. It also includes the case when synchronization loss is due to a change in the upstream transmission parameters through a CHANGE VOC message.

The VTU-O should converge its upstream equalizer(s) before the timer t_O reaches t_{p_o} ms. If convergence is not achieved within this time, the VTU-O shall return to state *S1*. If convergence is reached before this time, the VTU-O shall enter state *S4*, without waiting for the full time-out period to elapse. If *QUIET* is applied or if *US_LOS* occurs while in this state, VTU-O shall return to state *S1*.

S4: O_FINDFRAME

While in state *S4*, the VTU-O shall transmit O_ACQUIRE and IB-9 (*rdi*) shall be set to 1, indicating that the upstream direction is not synchronized yet. In state *S4*, the VTU-O shall process the received upstream signal to acquire the transmission frame (see I.1.2, "Transmission frame"). The VTU-O shall enter state *S5* as soon as the frame acquisition is complete and stable for at least 100 ms. The VTU-O shall return to state *S1* if frame acquisition is not complete before the timer t_O reaches t_{2_o} ms, or if *QUIET* is applied, or if *US_LOS* occurs while in this state.

S5: O_ACTIVE

The VTU-O shall reside in this state while the upstream channel is acquired. While in *S5*, the VTU-O shall transmit O_DATA, and the state of the link is either *Steady-State Transmission* or *Idle*.

In *S5* the VTU-O may transmit VOC messages to modify CR_STP, WS_STP or I_STP if required by the VTU-O management entity. If the link is in *Idle* state, the VTU-O shall also track the *Back-to-Service* request from the VTU-R by monitoring the *r_flag* bits in the received transmission frame header. After *r_flag* = 1 is detected, the VTU-O shall transmit the BTSERV VOC message to confirm the request. If the BTSERV message is transmitted successfully, the B_SERV control signal shall be applied to initiate the transition of the link from *Idle* state back to *Steady-State Transmission* state.

To perform a generic CR_STP modification, a *CHNG_PRM* control signal shall be applied. It forces the VTU-O to transmit VOC messages containing new values of transmission parameters. Once all the necessary new parameter values are successfully transmitted (no ECHO response from the VTU-R on the requested parameter change is UTC), the VTU-O shall transmit a CHANGE VOC message. The CHANGE message confirms that both the VTU-O and VTU-R are ready to change their transmission parameters for a new parameter setting. After the CHANGE message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R_TRIG by monitoring the *r_trig* bits in the received transmission frame header. Once the received value *r_trig* = 1 is detected, the VTU-O shall move to state *S7*.

If the VTU-O is in *Idle* state and a *B_SERV* Control signal is applied (initiated either by the VTU-O or upon *r_flag* = 1 reception), the VTU-O shall transmit a BTSERVC VOC message. The BTSERVC confirms that both the VTU-O and VTU-R are ready to change their transmission parameters to WR_STP to return the link back to *Steady-State Transmission* state from *Idle* state. After the BTSERVC message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R_TRIG by monitoring the *r_trig* bits in the received transmission frame header. Once the received value *r_trig* = 1 is detected, the VTU-O shall move to state *S7*.

If the VTU-O is in *Steady-State Transmission* state and an *I_REQ* Control signal is applied, the VTU-O shall transmit a IDLEREQ VOC message. The IDLEREQ confirms that both the VTU-O and VTU-R are ready to change their transmission parameters with I_STP to pull the link into *Idle* state from *Steady-State Transmission* state. After the IDLEREQ message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R_TRIG by monitoring the *r_trig* bits in the received transmission frame header. Once the received value *r_trig* = 1 is detected, the VTU-O shall move to state *S7*.

If R_TRIG is not received in t_{3_o} ms after any CHANGE, BTSERVC or IDLEREQ message is transmitted successfully, the VTU-O shall make no changes in CR_STP and shall remain in ACTIVE state. If US_*los* or US_*sef* occurs while in this state, the VTU-O shall enter state *S6*. If *QUIET* is applied, the VTU-O shall return to state *S1*.

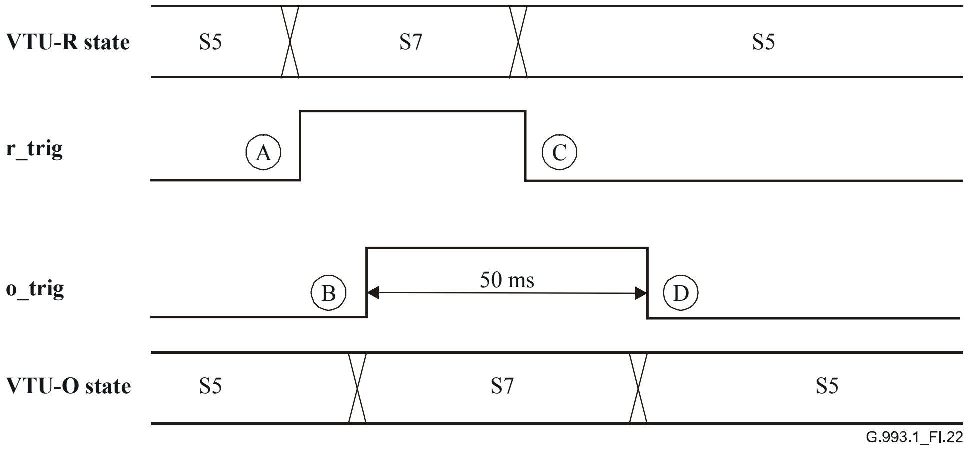
S6: O_SYNC LOSS

In this state the VTU-O attempts to recover the lost transmission frame synchronization. During this state O_ACQUIRE shall be transmitted to inform the VTU-R of the VTU-O synchronization loss by setting IB-9 (*rdi*) = 1. After synchronization is recovered, the VTU-O shall return to state *S5*. If synchronization is not recovered during the time-out interval of t_{4_o} ms, the VTU-O shall move to state *S3* to initiate a *Resume-On-Error* activation request. The VTU-O shall move to state *S1* if *QUIET* is applied.

S7: O_TRIGGER

In state *S7*, the VTU-O shall transmit the O_TRIG signal with *o_trig* = 1 for 50 ms ± 1 ms. Following this the VTU-O shall overwrite CR_STP with a new parameter setting, with WR_STP, or with I_STP, depending on whether the CHANGE, BTSERVC, or IDLEREQ VOC message, respectively, was last transmitted. Then the VTU-O shall make the corresponding changes to its transmission parameters, and return to state *S5* with a new CR_STP parameter setting. Upon entering *S5*, RE_STP shall be automatically overwritten with CR_STP. If *QUIET* is applied, the VTU-O shall return to state *S1*.

NOTE – Transmission of *o_trig* is to synchronize transmission parameter modification at the VTU-R with the same modification at the VTU-O. The timing diagram of the VTU-O to VTU-R interaction during the O/R_TRIG state is presented in Figure I.22. In accordance with Figure I.22, the VTU-R executes the parameter change after point "C" and the VTU-O executes the parameter change after point "D". Thus, the maximum difference between parameter modification at the VTU-O and VTU-R cannot exceed 50 ms.



Trigger transitions:

A) CHANGE/BTSERVC/IDLEREQ VOC confirmed, VTU-R enters state S7.
B) CHANGE /BTSERVC/IDLEREQ VOC confirmed, VTU-O detects r_trig = 1, VTU-O enters state S7.
C) VTU_R detects o_trig = 1 and enters S5.
D) 50 ms after entering S7, VTU-O enters S5.

Figure I.22/G.993.1 – Trigger transitions following CHANGE, BTSERV and IDLEREQ VOC messages

I.4.3.7 VTU-R state machine

The VTU-R state machine is shown in Figure I.23. The conventions for interpreting this figure are the same as those for Figure I.21.

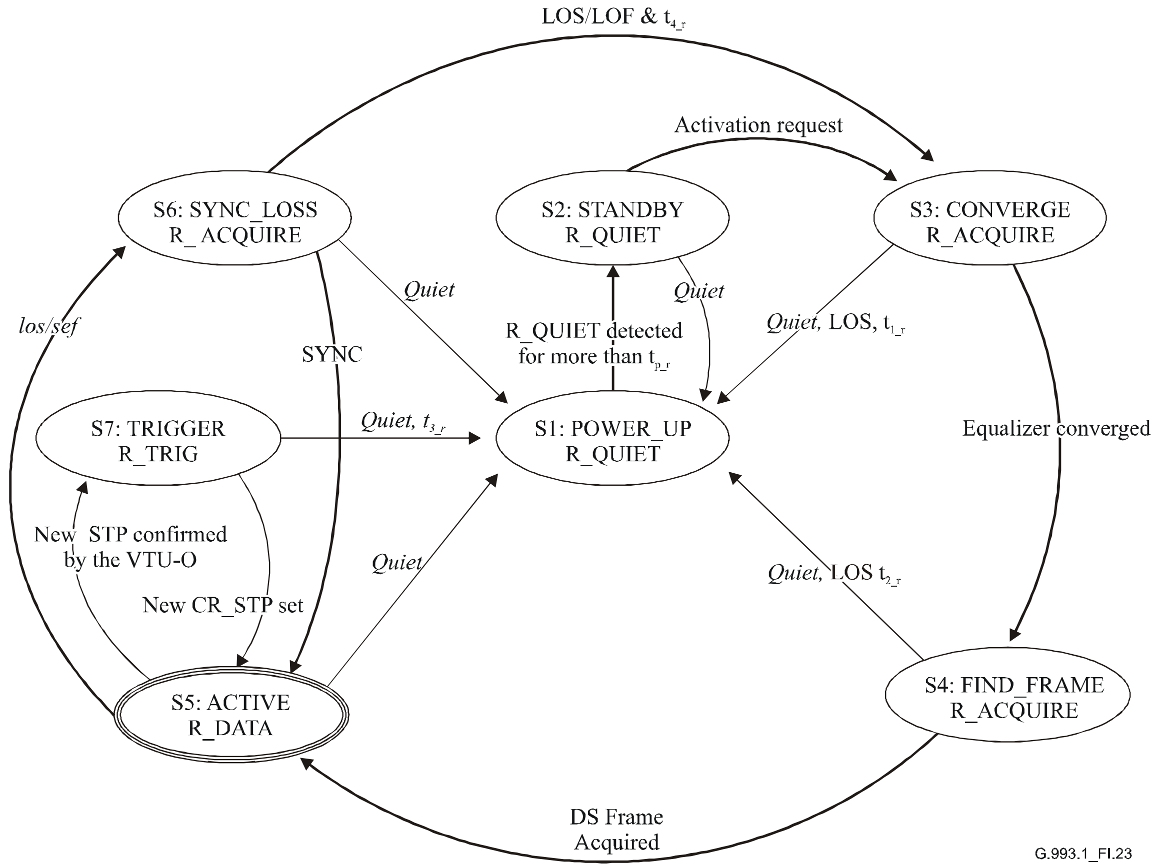


Figure I.23/G.993.1 – VTU-R activation/deactivation state machine

S1: R_POWERUP

This state is the initial state of the state machine. It corresponds to the start of the process and shall be entered in the following cases:

– a *QUIET* control signal or a Power-up request is applied. This is the first step in pending a *Cold-Start* or *Warm-Start* attempt, as shown by Figure I.19.

– Loss of downstream signal (*DS_LOS*) is detected while in states *S3*, *S4*, or time-out of states *S3*, *S4* occurs. This *S1* entry follows a failed activation attempt and is the first step in a pending re-activation attempt of the type specified by Figure I.19.

In state *S1* the VTU-R shall transmit R_QUIET. The VTU-R transmitter and receiver shall be configured with the STP stored in CR_STPM. The VTU-R shall enter state *S2* if loss of the received downstream signal (*DS_LOS*) is detected for more than t_{p_r} ms.

NOTE – The definition of *DS_LOS* is specified in I.3.1 (*LOS* primitive).

S2: R_STANDBY

In state *S2* the VTU-R shall transmit R_QUIET and wait for an activation request. The latter could be either the *CON* control signal, if the link is activated from the VTU-R, or detection of the downstream received signal energy, if the link is activated from the VTU-O. Once the activation request is performed, timer t_R shall be started from zero, and state *S3* is entered. If *QUIET* is applied while in this state, the VTU-R shall return to state *S1*.

NOTE – Timer t_R is used for monitoring of the VTU-O synchronization process.

S3: R_CONVERGE

This state is entered from state *S2* following an activation request, or from state *S6* following a non recovered synchronization loss. In state *S3* the VTU-R shall transmit the R_ACQUIRE signal while attempting to converge the downstream equalizer(s). The IB-9 (*rdi*) bit shall be set to 1 indicating that the downstream direction is not synchronized.

NOTE – The transition from *S6* to *S3* corresponds to initiation of a *Resume-On-Error* activation attempt. It also includes the case when synchronization loss is due to a change in the upstream transmission parameters through a CHANGE VOC message.

The VTU-R should converge its downstream equalizer(s) before the timer t_R reaches t_{1_r} ms. If convergence is not achieved within this time the VTU-R shall return to state *S1*. If convergence is reached before this time, the VTU-R shall enter state *S4*, without waiting for the full time-out period to elapse. If *QUIET* is applied or if *DS_LOS* occurs while in this state, the VTU-R shall return to state *S1*.

If state *S3* is entered from state *S2*, an upstream power back-off (UPBO) procedure (see 6.3.2) shall be applied. Upon entering state *S3* the VTU-R shall start to transmit the R_ACQUIRE signal with the default (low) power level, as specified in I.4.3.5. In the beginning of the downstream equalizer converging, the required UPBO shall be calculated, as described in 0, and the R_ACQUIRE signal power level shall be set to the nominal value, including the UPBO. The functional diagrams describing activation from both the VTU-O and the VTU-R are presented in Figures I.24 and I.25, respectively.

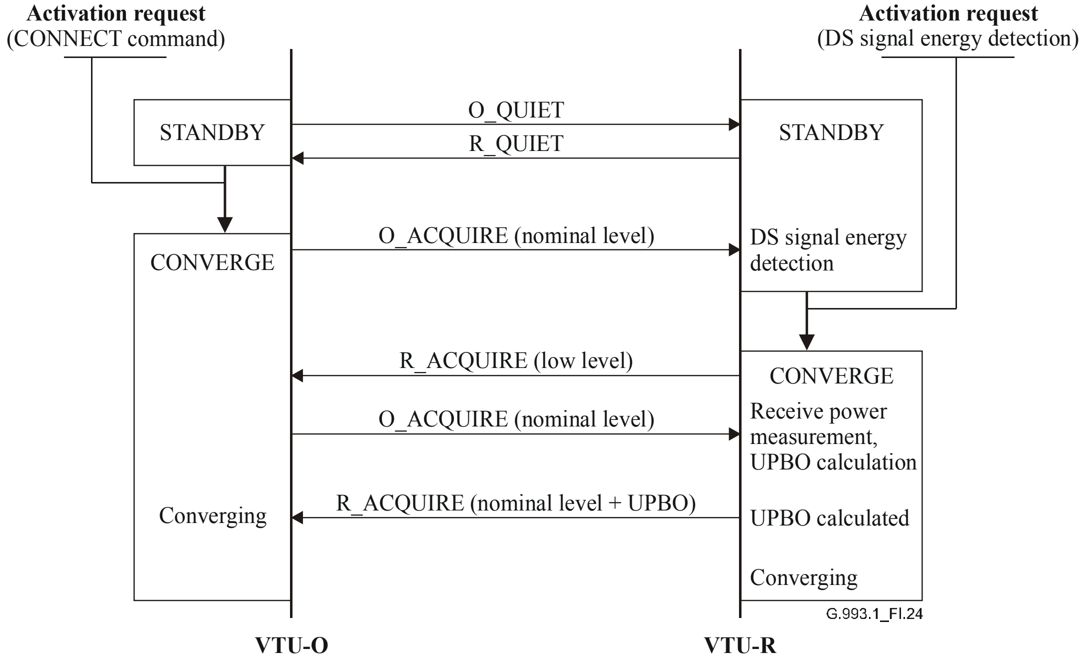


Figure I.24/G.993.1 – Activation from the VTU-O

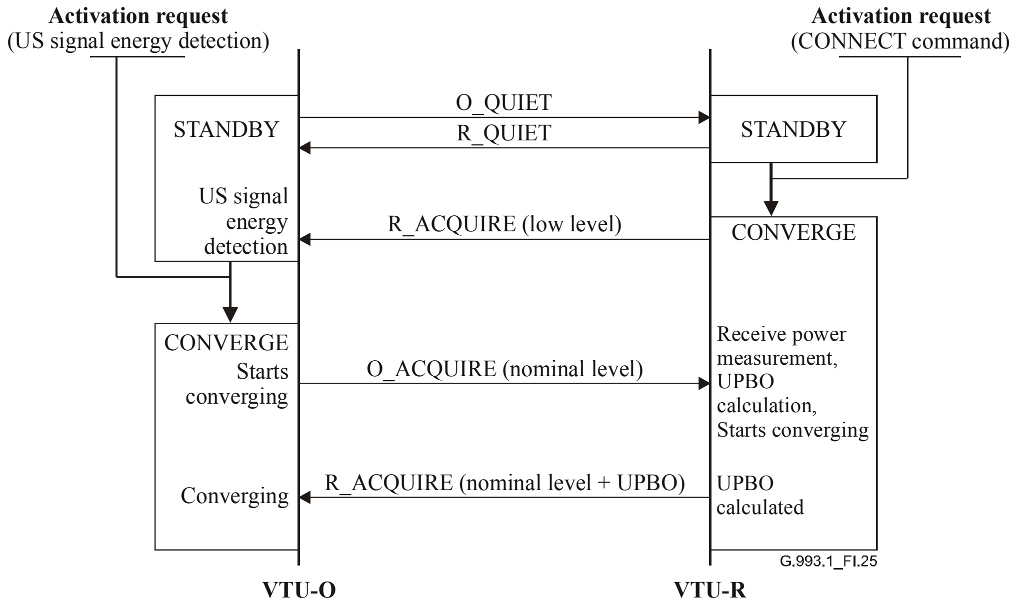


Figure I.25/G.993.1 – Activation from the VTU-R

S4: R_FINDFRAME

While in state *S4* the VTU-R shall transmit R_ACQUIRE and IB-9 (*rdi*) bit shall be set to 1 indicating that the downstream direction is not synchronized yet. In state *S4* the VTU-R shall process the received downstream signal to acquire the transmission frame (see I.1.2). The VTU-R shall enter state *S5* as soon as frame acquisition is complete and stable for at least 100 ms. The VTU-R shall return to state *S1* if frame acquisition is not complete before t_R reaches t_{2_r} ms, or if *QUIET* is applied, or if *DS_LOS* occurs while in this state.

S5: R_ACTIVE

The VTU-R resides in this state while the downstream channel is acquired. While in *S5* the VTU-R shall transmit R_DATA and the state of the link is either *Steady State Transmission* or *Idle*.

In *S5* the VTU-R may receive VOC messages delivering modified transmission parameters values for CR_STP, WS_STP or I_STP, as directed by the VTU-O. If a *B_SERV* control signal is applied, the VTU-R shall transmit *r_flag* = 1 and shall wait for the successful reception of the BTSERV VOC message, which confirms that the *B_SERV* signal applied in the VTU-R was received by the VTU-O. If the VTU-R successfully receives the CHANGE, BTSERVC, or IDLEREQ VOC message, it shall enter state *S7*. If DS_*los* or DS_*sef* occurs while in this state, VTU-R shall enter state *S6*. If *QUIET* is applied VTU-R shall return to state *S1*.

S6: R_SYNC LOSS

In this state the VTU-R attempts to recover the lost transmission frame synchronization. During this state R_ACQUIRE shall be transmitted to inform the VTU-O of the VTU-R synchronization loss by setting IB-9 (*rdi*) = 1. After synchronization is recovered, the VTU-R shall return to state *S5*. If synchronization is not recovered during the time-out interval of t_{4_r} ms, the VTU-R shall move to state *S3* to initiate a *Resume-On-Error* activation request. The VTU-R shall move to state *S1* if *QUIET* is applied.

S7: R_TRIGGER

In state *S7* the VTU-R shall transmit the R_TRIG signal with *r_trig* = 1, and shall monitor the *o_trig* bit in the received transmission frames. Once *o_trig* = 1 is detected, the VTU-R shall overwrite CR_STP with a new parameter setting, with WR_STP, or with I_STP, depending on whether the CHANGE, BTSERVC or IDLEREQ VOC message, respectively, was last transmitted. Then the VTU-R shall make the corresponding changes in its transmission parameters, and shall return to state *S5* with a new CR_STP parameter setting. Upon entering *S5*, RE_STP shall be automatically overwritten to CR_STP. If *o_trig* = 1 is not detected within the time-out interval of t_{3_r} ms after entering state *S7*, the VTU-R shall return to state *S1*. If *QUIET* is applied, the VTU-R shall return to state *S1*.

I.4.3.8 Two-step activation

Both the VTU-O and the VTU-R may support a two-step activation process:

Step 1: Activation with 4-point constellation.

Step 2: Modifying the constellation to the required size using a standard CR-STP modification procedure (see 9.2.2.2).

The two-step activation shall use the standard activation diagram described in 9.1 and the standard VTU state machine described in I.4.3.6 and I.4.3.7 for both steps. It shall be performed in the following sequence:

1) Start the link and reach steady-state transmission with DF_STP.
2) Assign the first-step transmission profile with all the transmission parameters equal to the parameters of the required transmission profile, except setting the constellation equal to 4 for both carriers in both directions.
3) Modify CR_STP from DF_STP to the first-step transmission profile using the CHANGE command and reach steady-state transmission.
4) Assign constellation size equal to the original constellation size of the required transmission profile (by CONSTEL command).
5) Modify CR_STP to the assigned constellation size using the CHANGE command and reach steady-state transmission.

Any performance monitoring VOC messages are allowed between the listed five steps. If the VTU-R is capable for 2-step activation only, the constellation size applied for WS_STP shall always be set to QAM-4.

I.4.4 G.994.1 Handshake bit definitions

I.4.4.1 CL messages

A VTU-O wishing to indicate this annex's capabilities in a G.994.1 CL message shall do so by setting to ONE at least one of the Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in and shown in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 CL message {NPar(2) and Spar(2)} fields are defined in Tables I.28 and I.29.

Table I.28/G.993.1 – Annex I VTU-O CL message NPar(2) bit definitions

G.994.1 bit	Definition
OptUp	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O can be configured to reduce the PSD in the frequency region below 1.104 MHz.

Table I.28/G.993.1 – Annex I VTU-O CL message NPar(2) bit definitions

G.994.1 bit	Definition
PTM	If set to ONE, signifies that the VTU-O can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-O can be configured for ATM cell transport (see Annex G).
EOC-Clear	If set to ONE, signifies that the VTU-O supports transmission and reception of G.997.1 OAM frames.

Table I.29/G.993.1 – Annex I VTU-O CL message SPar(2) bit definitions

G.994.1 bit	Definition
DF_STP	If set to ONE, signifies that the VTU-O CL message transmitted DF_STP shall be used.

I.4.4.2 VTU-O MS messages

A VTU-O selecting this annex's mode of operation in a G.994.1 MS message shall do so by setting to ONE the appropriate Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 MS message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Tables I.30 and I.31.

Table I.30/G.993.1 – Annex I VTU-O MS message NPar(2) bit definitions

G.994.1 bit	Definition
OptUp	If set to ONE, signifies to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

Table I.31/G.993.1 – Annex I VTU-O MS message SPar(2) bit definitions

G.994.1 bit	Definition
DF_STP	If set to ONE, signifies that the VTU-O CL message transmitted DF_STP shall be used.

I.4.4.3 VTU-R CLR messages

A VTU-R wishing to indicate this annex's capabilities in a G.994.1 CLR message shall do so by setting to ONE at least one of the Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 CLR message {NPar(2) and Spar(2)} fields are defined in Tables I.32 and I.33.

Table I.32/G.993.1 – Annex I VTU-R CLR message NPar(2) bit definitions

G.994.1 bit	Definition
OptUp	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-R can be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	If set to ONE, signifies that the VTU-R can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-R can be configured for ATM cell transport.
EOC-Clear	If set to ONE, signifies that the VTU-R supports transmission and reception of G.997.1 OAM frames.

Table I.33/G.993.1 – Annex I VTU-R CLR message SPar(2) bit definitions

G.994.1 bit	Definition
DF_STP	Shall be set to ONE.

I.4.4.4 VTU-R MS messages

A VTU-R selecting this annex's mode of operation in a G.994.1 MS message shall do so by setting to ONE the appropriate Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 MS message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Tables I.34 and I.35.

Table I.34/G.993.1 – Annex I VTU-R MS message NPar(2) bit definitions

G.994.1 bit	Definition
OptUp	If set to ONE, signifies to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.

Table I.34/G.993.1 – Annex I VTU-R MS message NPar(2) bit definitions

G.994.1 bit	Definition
OptDn	If set to ONE, signifies to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

Table I.35/G.993.1 – Annex I VTU-R MS message SPar(2) bit definitions

G.994.1 bit	Definition
DF_STP	If set to ONE in CL message, shall be set to ONE.

I.4.4.5 VTU-R MP messages

A VTU-R proposing this annex's mode of operation in a G.994.1 MP message shall do so by setting to ONE the appropriate Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 MP message {NPar(2) and Spar(2)} fields corresponding to the {SPar(1)} bit are defined in Tables I.36 and I.37.

Table I.36/G.993.1 – Annex I VTU-R MP message NPar(2) bit definitions

G.994.1 bit	Definition
OptUp	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to propose to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for PTM transport.

Table I.36/G.993.1 – Annex I VTU-R MP message NPar(2) bit definitions

G.994.1 bit	Definition
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

Table I.37/G.993.1 – Annex I VTU-R MP message SPar(2) bit definitions

G.994.1 bit	Definition
DF_STP	If set to ONE in CL message, shall be set to ONE.

I.5 Complementary information on QAM implementation (informative)

I.5.1 Spectral allocation of the transmit signal

In accordance with transmit filter characteristics, described in I.2.2.3.2.2, all carriers shall have a square-root raised-cosine power spectral shaping with α excess bandwidth. Thus, the lowest frequency (f_{LOW}) and the highest frequency (f_{HIGH}) for each carrier should be calculated as:

$$f_{LOW} = f_C - 0.5(1 + \alpha \times SR)$$

$$f_{HIGH} = f_C + 0.6 \times SR$$

where f_C and SR are the carrier frequency and its symbol rate, respectively. The 3-dB bandwidth of a carrier occupies the frequency range between $f_C - 0.5 \times SR$ and $f_C + 0.5 \times SR$.

I.5.2 Transport capability of the PMS-TC

The Aggregate Transport Capability (ATC) of the PMS-TC is determined by the format of the transmission frame. The ATC for the Fast channel, the Slow channels and the total ATC, respectively, are calculated as follows:

$$ATC\_f = TR \times \frac{2(F - RF)}{405} \text{ Mbit/s}$$

$$ATC\_s = TR \times \frac{2(S - 19)}{405} \text{ Mbit/s}$$

$$ATC = TR \times \frac{362}{405} \text{ Mbit/s}$$

where TR [Mbit/s] is the total bit rate of the applied transmission profile in the given direction.

The maximum ATC of the Operations channel (shared between the *eoc* and VOC) is calculated as:

$$ATC\_OC = TR \times \frac{6}{405} \text{ Mbit/s}$$

The maximum ATC of the *eoc* channel equals to 0.66 × ATC_OC.

If the ATC of either the Slow or the Fast channel is shared among different services (multi-user configuration), the ATC intended for a particular service k is calculated as:

$$ATC\_k = TR \times \frac{2K}{405} \text{ Mbit/s}$$

where K denotes the number of octets (in either the Slow or the Fast codeword) dedicated for this service (see I.1.2.3).

I.5.3 Transmission frame delineation algorithm

This transmission frame delineation algorithm is based on Sync_Events (Syncword detection at the expected locations). The frame delineation state machine, comprising HUNT, PRESYNC and SYNC states, is shown in Figure I.26. In HUNT state frame synchronization is lost and the state machine attempts to acquire frame synchronization by searching the frame Sync_Event. After the first Sync_Event occurs the state machine moves from HUNT state to PRESYNC state. The state machine moves from PRESYNC state to SYNC state when Sync_Event occurs consecutively at least n = 2 times. If a violated Sync_Event occurs during PRESYNC state, the state machine returns to HUNT state. The state machine moves from SYNC state to HUNT state when Sync_Event is violated consecutively at least m = 6 times.

NOTE – For data rates higher than 26 Mbit/s, the number of consecutively violated Sync_Event to move from SYNC state to HUNT state should be at least m = 8 times.

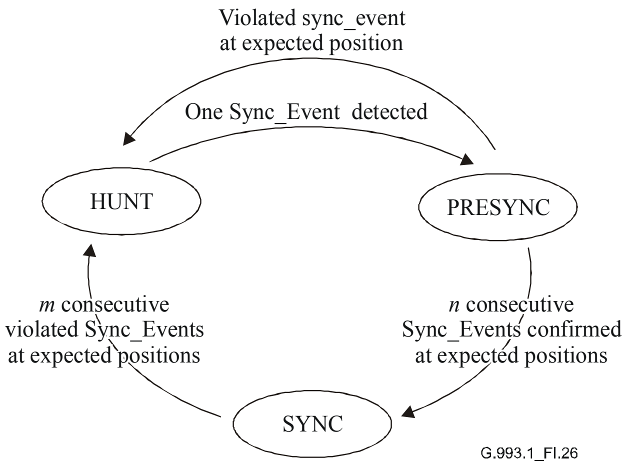


Figure I.26/G.993.1 – Frame delineation state machine

I.5.4 Parameters of the interleaver

I.5.4.1 Parameters

The main characteristics of the interleaver are presented in Table I.38.

Table I.38/G.993.1 – Interleaver characteristics

Parameter	Value	Notes
Block Length (I)	$I = S/4, S/8, S/16$ [octets]	$S = PS + 19$ [octets]
Depth (D)	$D = M \times I + 1$ [octets]	$M = 0 – 64$, programmable
Erasure Correction (E)	$E = \lfloor t \times I / S \rfloor \times (M \times I + 1)$ [octets]	$t = 8$ (RS error correction ability)
End-to-End Delay (DL)	$DL = M \times I \times (I - 1)$ [octets]	
Interleaver Memory Size	$MEM = M \times I \times (I - 1)/2$ [octets]	

NOTE – Symbol "$\lfloor\ \rfloor$" indicates truncating to the lower integer.

The interleaver erasure correction E defines the maximum number of sequential corrupted octets in the data stream that can be corrected by the RS algorithm when interleaving is applied. Accordingly, the duration of noise pulses that the system is protected from can be calculated as $E \times 8/R$, where R is the bit rate of the transmit signal.

Some typical values of the interleaving parameters M, E and of the end-to-end delay calculated for $S/I = 8$, $t = 8$ and different line bit rates are presented in Table I.39.

Table I.39/G.993.1 – Interleaving parameters

Line rate [Mbit/s]		1.62	3.24	6.48	12.96	25.92
Value of N/I		8				
250 µsec of erasure correction	M [octets]	2	4	8	16	32
	Delay [msec]	5.9				
500 µsec of erasure correction	M [octets]	4	8	16	32	64
	Delay [msec]	11.8				

I.5.4.2 Implementation example

Interleaving is performed at the transmit side by writing the octets of the incoming Reed-Solomon codeword into a bank of I virtual shift registers numbered $j = 0, 1, \dots (I - 1)$. The length of virtual shift register j in the interleaving memory is: $M \times j$.

De-interleaving is performed at the receive side by writing the octets of the incoming codeword into a bank of I virtual shift registers numbered $j = 0, 1, \dots (I - 1)$. The length of virtual shift register j in the de-interleaving memory is: $M \times (I - 1 - j)$.

The codeword is input either into the interleaving or de-interleaving memory by blocks of I octets at a time. The first octet from the codeword is written into the first shift register, the second octet into the second shift register, and so on, up to the register $(I - 1)$. This process is repeated S/I times until the complete codeword is input into the bank of shift registers.

The codeword is output from the interleaving or the de-interleaving memory by reading blocks of I octets at a time. The first octet from the codeword is read from the first shift register, the second octet from the second shift register and so on, up to register $(I - 1)$. This process is repeated S/I times until the complete codeword is extracted from the bank of shift registers.

Figure I.27 shows the structure of the interleaver. The I parallel branches, numbered 0, 1, …, $(I - 1)$ are implemented with a delay increments of $M \times I$ octets per branch. Each branch is a shift register with a length of 0, $M \times I$, $2M \times I$, …, $(I - 1) \times M \times I$ bytes. The de-interleaver is similar to the interleaver, but the branch indexes are reversed, so that the largest interleaver delay corresponds to the smallest de-interleaver delay. De-interleaver synchronization is achieved by routing the first octet of an interleaved block of *I* bytes into the branch 0.

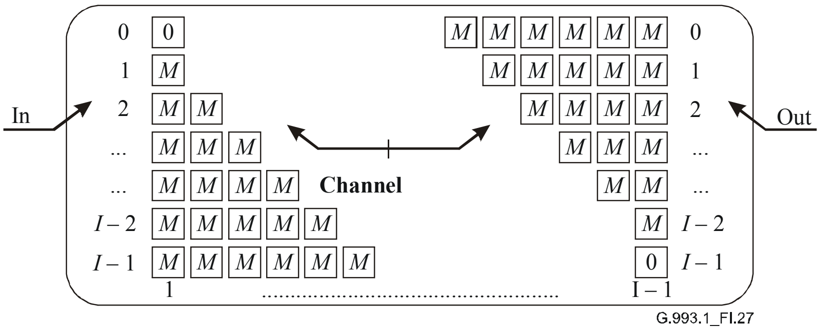


Figure I.27/G.993.1 – Interleaver/de-interleaver implementation example

Appendix I

UTOPIA implementation of the ATM-TC interface

This Appendix describes the implementation of the interface between the ATM-specific TPS-TC sublayer and ATM layer at the VTU-O, called γ_O, interface in the G.993.1 reference model. The implementation is also applicable to the VTU-R.

The ATM layer performs cell multiplexing from and de-multiplexing to the appropriate physical port (i.e., latency path – Fast or Slow) based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header. Configuration of the cell de-multiplexing process is done by ATM Layer management.

An ATM TPS-TC sublayer is provided for each latency path separately. ATM-TC functionality is described in Annex G.

The logical input and output interfaces at the reference point γ_O for ATM transport is based on the UTOPIA Level 2 interface with cell level handshake. The logical interface is given in Tables I.1 and I.2 and shown in Figure I.1. When a flow control flag is activated by the VTU-O (i.e., the VTU-O wants to transmit or receive a cell), the ATM layer initiates a cell Tx or cell Rx cycle (53 byte transfer). The VTU supports transfer of a complete cell within 53 consecutive clock cycles. The UTOPIA Tx and Rx clocks are mastered from the ATM layer. The same logical input and output interfaces based on the UTOPIA Level 2 interface can be used at the γ_R reference point in the VTU-R.

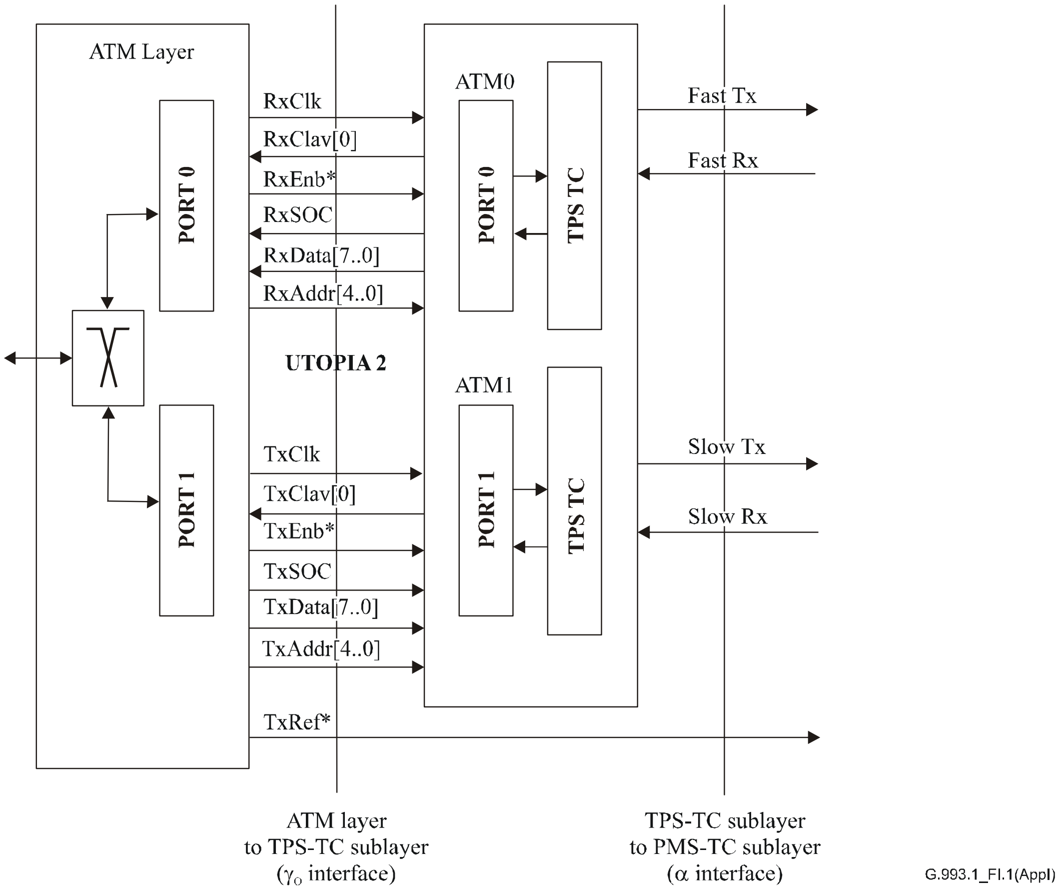


Figure I.1/G.993.1 – UTOPIA-2 implementation of the ATM-TC application interface (VTU-O)

Table I.1/G.993.1 – UTOPIA Level 2 ATM interface signals for Tx

Signal name	Direction	Description
		Transmit interface
TxClk	ATM to PHY	Timing signal for transfer
TxClav[0]	PHY to ATM	Asserted to indicate that the PHY layer has buffer space available to receive a cell from the ATM layer (de-asserted 4 cycles before the end of the cell transfer)
TxEnb*	ATM to PHY	Asserted to indicate that the PHY layer must sample and accept data during the current clock cycle
TxSOC	ATM to PHY	Identifies the cell boundary on TxData
TxData[7..0]	ATM to PHY	ATM Cell Data transfer (8-bit mode)
TxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for TxClav status
TxRef*	ATM to PHY	Network Timing Reference (8-kHz timing signal) (only at γ_O interface)

Table I.2/G.993.1 – UTOPIA Level 2 ATM interface signals for Rx

Signal Name	Direction	Description
Receive interface		
RxClk	ATM to PHY	Timing signal for transfer
RxClav[0]	PHY to ATM	Asserted to indicate to the ATM layer that the PHY layer has a cell ready for transfer to the ATM layer (de-asserted at the end of the cell transfer)
RxEnb*	ATM to PHY	Asserted to indicate that the ATM layer will sample and accept data during the next clock cycle
RxSOC	PHY to ATM	Identifies the cell boundary on RxData
RxData[7..0]	PHY to ATM	ATM Cell Data transfer (8-bit mode)
RxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for RxClav status
RxRef*	PHY to ATM	Network Timing Reference (8-kHz timing signal) (only at γR interface)

More details on the UTOPIA Level 2 interface can be found in [ATMF].

Appendix II

International amateur radio bands

Table II.1/G.993.1 – International amateur radio bands

ITU-R Radio Regulations Region 1		ITU-R Radio Regulations Region 2		ITU-R Radio Regulations Region 3	
Band start [kHz]	**Band stop [kHz]**	**Band start [kHz]**	**Band stop [kHz]**	**Band start [kHz]**	**Band stop [kHz]**
1 810	1 850	1 800	2 000	1 800	2 000
3 500	3 800	3 500	4 000	3 500	3 900
7 000	7 100	7 000	7 300	7 000	7 100
10 100	10 150	10 100	10 150	10 100	10 150
14 000	14 350	14 000	14 350	14 000	14 350
18 068	18 168	18 068	18 168	18 068	18 168
21 000	21 450	21 000	21 450	21 000	21 450
24 890	24 990	24 890	24 990	24 890	24 990
28 000	29 700	28 000	29 700	28 000	29 700

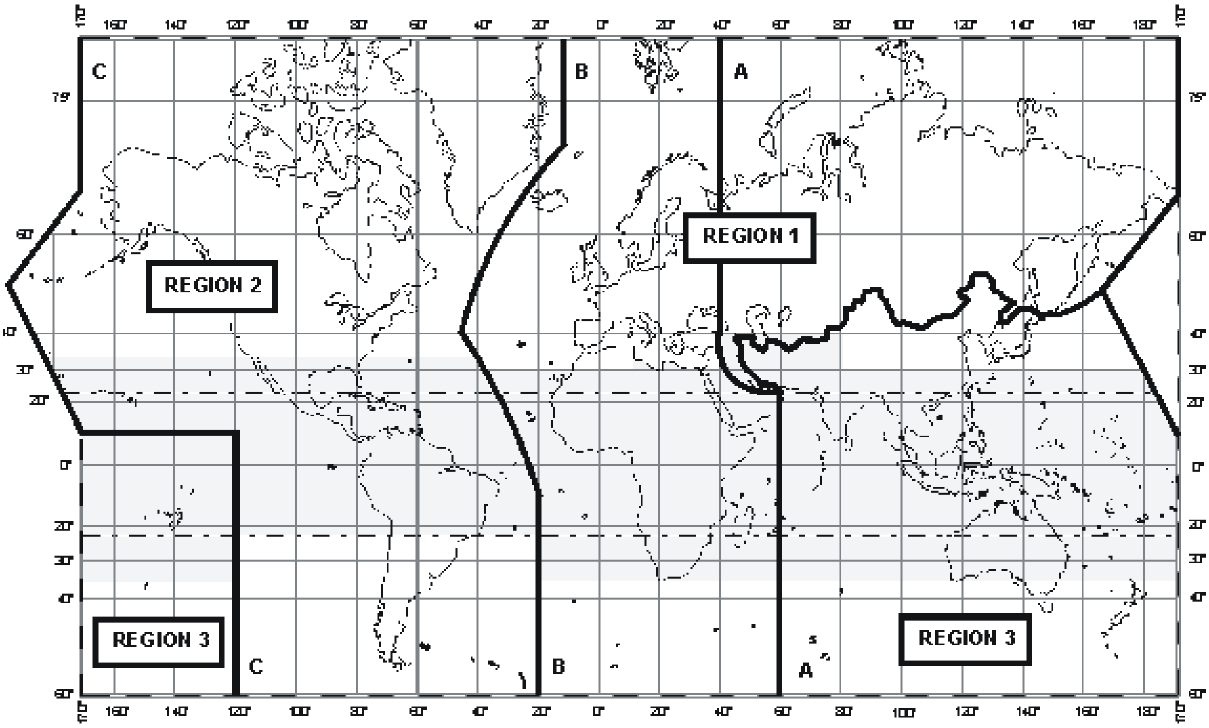


Figure II.1/G.993.1 – International amateur radio band regions

Appendix III

8.625-kHz tone spacing

III.1 Scope

This appendix describes an MCM VDSL system operating in 8.625-kHz tone spacing mode. The primary application of the 8.625 kHz tone spacing could be for shorter loops where the 8.625-kHz tone spacing allows a smaller FFT/IFFT size, without additional changes to the PMD layer. The remainder of this appendix describes items, relative to the clauses in the main body of this Recommendation, which could be considered for an MCM VDSL system operating with 8.625-kHz tone spacing.

III.2 PMD functional characteristics

The PMD layer is implemented as defined in 9.2 using $\Delta f = 8.625\,\text{kHz}$.

NOTE 1 – This mode is targeted to loops less than 600 metres. Therefore, the typical cyclic extension lengths presented in 9.2.2 will be sufficient.

NOTE 2 – Clause 9.2.3.4 provides an optional mode for the users in a binder to synchronize. This mode is used to mitigate the effects of the NEXT due to the side lobes of the other users in that binder. Assuming that there exists a mix of 8.625- and 4.3125-kHz carrier spaced systems in a binder, given all-users-synchronization option is deployed, it is easily shown that 4.3125-kHz carrier spaced signals are orthogonal to 8.625-kHz carrier spaced signals in the opposite direction. However, the reverse is not true, i.e., 4.3125-kHz spaced tones could be affected by the 8.625-kHz spaced tones in the opposite direction. Therefore, service providers may choose not to utilize 8.625-kHz tone spacing where binder synchronization is used. Otherwise, in asynchronous operation mode, two systems using different tone spacing do not disturb each other more than two systems using 4.3125-kHz tone spacing.

III.3 Transmission Convergence (TC) sublayer

The TC layer of the 8.625-kHz tone spacing mode will follow 7 and 8, with the exception of the modification of the framing definition in 8.5.1, as presented in III.3.1.

III.3.1 Frame description

When using 8.625-kHz tone spacing, a TC layer data frame is a set of bytes carried by two DMT frames (i.e., DMT symbols). Otherwise, the framing description is the same as the 4.3125-kHz frame description.

III.4 Initialization

Upon completion of some negotiation to indicate mutual support for 8.625-kHz tone spacing (further referred to as "First Negotiation"), the "ES" phase is entered. The "First Negotiation" procedure is beyond the scope of this appendix. The timeline of the ES phase is shown in Figure III.1. The names of the newly defined SOC messages and symbol types have the suffix 'ES' and are described in Table III.1.

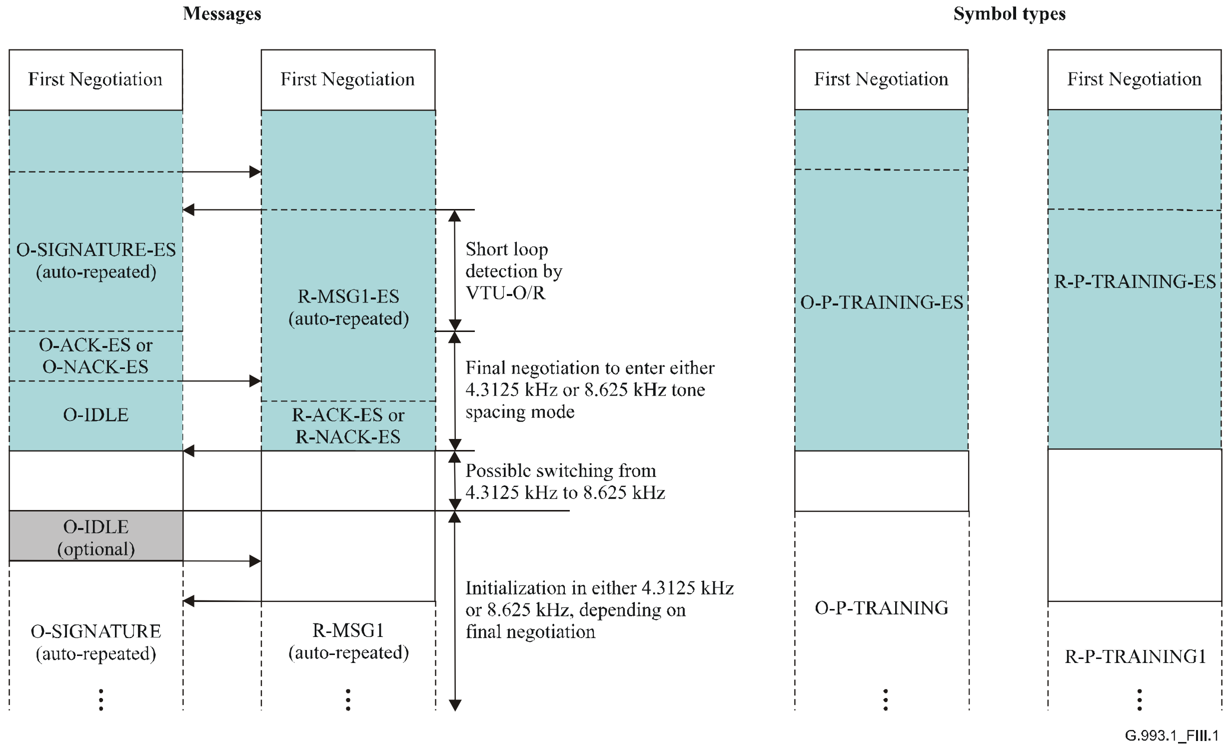


Figure III.1/G.993.1 – Timeline of ES phase

Table III.1/G.993.1 – Message codes for the SOC messages used in the ES phase

SOC Message	Message code
O/R-ACK-ES	0x33 (Note)
O/R-NACK-ES	0xCC (Note)
O-SIGNATURE-ES	0x31
R-MSG1-ES	0xB1
NOTE – This is the entire payload of the message.	

During the ES phase, short loop detection and final mode negotiation are performed. The VTU-O initiates the ES phase by transmitting the symbol O-P-TRAINING-ES. The message O-SIGNATURE-ES is sent in parallel over the SOC channel (automatically repeated). O-P-TRAINING-ES is identical to O-P-TRAINING. O-SIGNATURE-ES is also identical to O-SIGNATURE, except for the message code (see Table III.1).

Once the VTU-R is synchronized and has successfully decoded O-SIGNATURE-ES, the VTU-R transmits R-P-TRAINING-ES that is identical to R-P-TRAINING1. The message R-MSG1-ES is sent in parallel over the SOC channel (automatically repeated). R-MSG1-ES is identical to R-MSG1, except for the message code (see Table III.1).

The VTU-O and VTU-R perform the short loop detection simultaneously while receiving R-MSG1-ES and O-SIGNATURE-ES, respectively. The decision to enter the 8.625-kHz tone spaced initialization may be based on the PSD level of the received signal at higher frequencies where the 8.625-kHz tone spacing would provide an advantage.

The final negotiation takes place after the completion of the short loop detection. If the measured loop length is short enough so that the use of the 8.625-kHz tone spacing is advantageous, both the VTU-O and VTU-R acknowledge each other by transmitting O-ACK-ES and R-ACK-ES, respectively. The final negotiation period is followed by the 8.625-kHz tone spaced initialization if and only if O-ACK-ES and R-ACK-ES are received by the VTU-R and VTU-O, respectively.

Depending on the final negotiation, the modem configuration can be switched from 4.3125 kHz to 8.625 kHz during the QUIET period followed by the symbol O-P-TRAINING and R-P-TRAINING1 transmitted from the VTU-O and VTU-R, respectively.

The flow chart of the overall initialization procedure for the 8.625-kHz tone spacing mode is shown in Figure III.2.

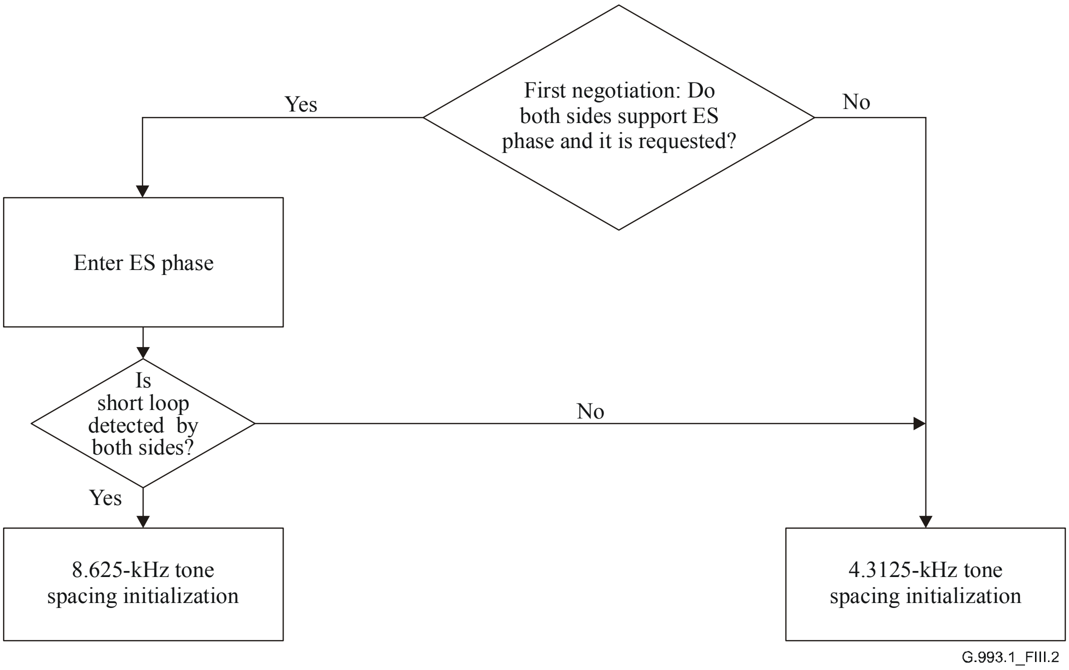


Figure III.2/G.993.1 – Flow chart of the 8.625 kHz tone spaced initialization

The message codes for the SOC messages sent during the ES phase are shown in Table III.1.

In an 8.625-kHz tone spaced system, the training and channel analysis detailed in 12 are the same as for the 4.3125-kHz tone spaced version, with the exception that tone indexes are calculated based on the 8.625-kHz tone spacing.

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