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Amendment 1
(03/2003)

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

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Very high speed digital subscriber line foundation

Amendment 1: New Annex F: Regional requirements for environment coexisting with TCM-ISDN DSL as defined in Appendix III of ITU-T Recommendation G.961

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ITU-T Recommendation G.993.1

Very high speed digital subscriber line foundation

Amendment 1

New Annex F: Regional requirements for environment coexisting with TCM-ISDN DSL as defined in Appendix III of ITU-T Recommendation G.961

Summary

This amendment intends provided detailed text for Annex F of ITU-T Rec. G.993.1 (2001), dealing with regional requirements for environment co-existing with TCM-ISDN DSL as defined in ITU-T Rec. G.961 Appendix III.

Source

Amendment 1 to ITU-T Recommendation G.993.1 was approved by ITU-T Study Group 15 (2001-2004) under the ITU-T Recommendation A.8 procedure on 16 March 2003.

FOREWORD

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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.

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Amendment 1

New Annex F: Regional requirements for environment coexisting with TCM-ISDN DSL as defined in Appendix III of ITU-T Recommendation 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 band between 25 kHz and 138 kHz is for further study, and the case which is not use the band is specified below.

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 in 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.

The other PSD masks are for further study, including PSD boost option.

NOTE 1 – The VDSL PSD is currently under study in the body of this Recommendation. 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	
	$5.025 \le f \le 5.2$	$-80 + (20 / 0.175) \times (f - 5.2)$	–	

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]
DS2	$5.2 < f < 8.5$	$-60 + 3.5$ (= -56.5)	–	8.4
	$8.5 \leq f \leq 8.675$	$-80 - (20 / 0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	–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 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
	$0.12 \leq f < 0.225$	–110	–	
	$0.225 \leq f < 3.575$	–100	–	
	$3.575 \leq f \leq 3.75$	$-80 + (20 / 0.175) \times (f - 3.75)$	–	
US1	$3.75 < f < 5.2$	$-60 + 3.5$ (= -56.5)	–	
	$5.2 \leq f \leq 5.375$	$-80 - (20 / 0.175) \times (f - 5.2)$	–	
	$5.375 < f < 8.325$	–100	–52	
	$8.325 \leq f \leq 8.5$	$-80 + (20 / 0.175) \times (f - 8.5)$	–	
US2	$8.5 < f < 12$	$-60 + 3.5$ (= -56.5)	–	
	$12 = f \leq 12.175$	$-80 - (20 / 0.175) \times (f - 12)$	–	
	$12.175 < f < 30$	–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 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 guard band.

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.

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 6.2.2.

The other PSD masks are for further study, including PSD boost option.

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.

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 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 nominal transmit PSD within one or more of the amateur radio bands shall be able to be reduced below –80 dBm/Hz. The minimum number of notches is for further study. The amateur frequency bands are defined in Table F.5 which contains several different frequency band allocations from those defined in Table 6-2.

A transmit notch which covers several amateur radio bands by merging closely adjacent amateur radio bands within both Table 6-2 and Table F.5 may be implemented.

Table F.5/G.993.1 – Amateur radio bands

Item	Band start [MHz]	Band stop [MHz]
01	1.810	1.825
02	1.9075	1.9125
03	3.500	3.575
04	3.747	3.754
05	3.791	3.805
06	7.000	7.100
07	10.100	10.150
08	14.000	14.350

Table F.5/G.993.1 – Amateur radio bands

Item	Band start [MHz]	Band stop [MHz]
09	18.068	18.168
10	21.000	21.450
11	24.890	24.990
12	28.000	29.700

F.2 Service splitter and electrical characteristics

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 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 in this. 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 (HPF) function 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 Requirement

The POTS splitter designed for use with the VDSL shall be compliant to the requirements specified in the aforementioned 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 the 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 the 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 the C and L (e.g., $C \geq 0.2$ μF and $L \geq 5$ 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 function location

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 consist 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.

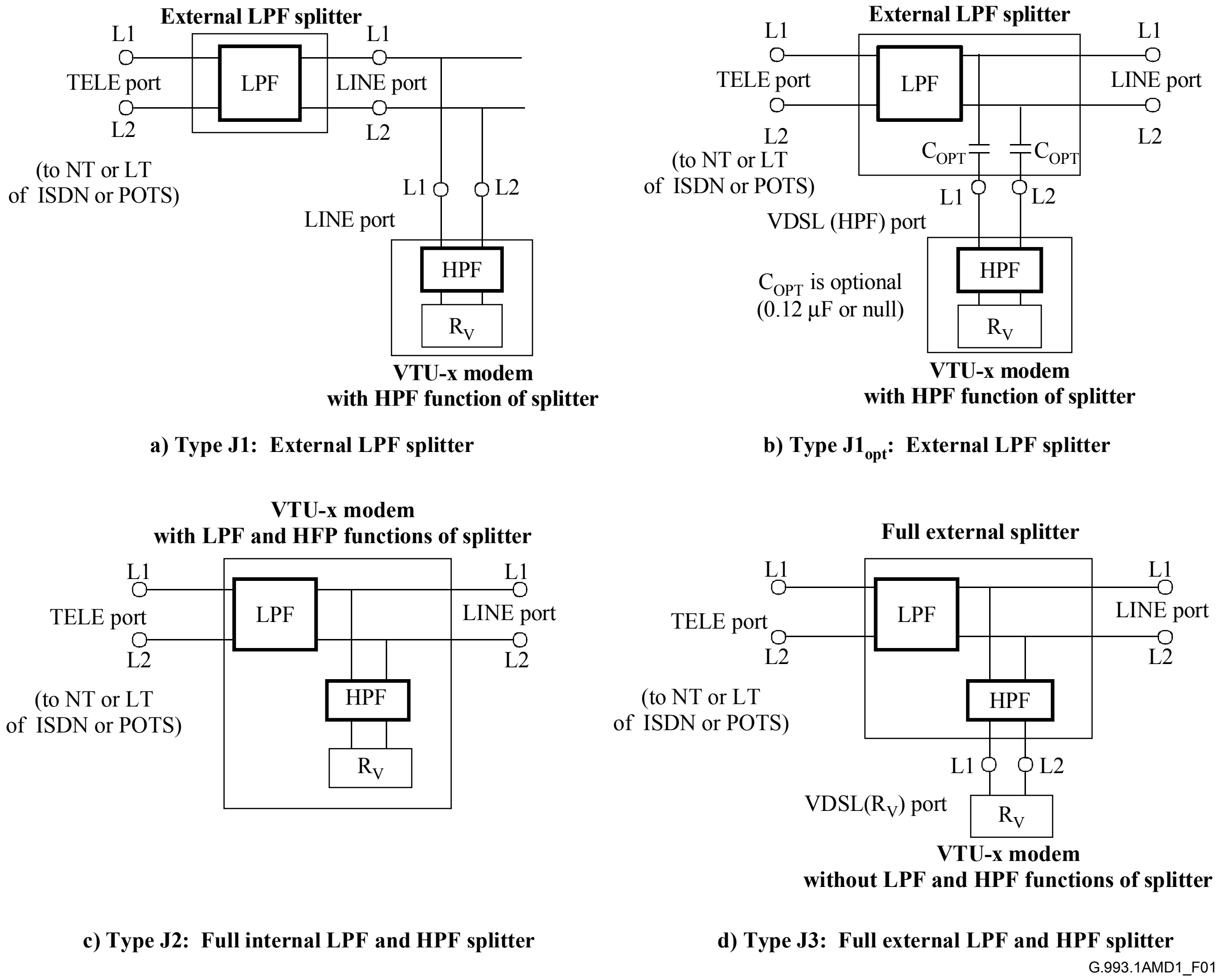


Figure F.1/G.993.1 – ISDN splitter LPF and HPF function location

F.2.3.2 General definition

F.2.3.2.1 Test frequency band

Three bands of frequencies are used for test.

- Voice band 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 and 640 kHz (320 kHz $< f <$ 640 kHz) is a guard band. The specific requirements in the guard band are not defined, and test is not performed for the guard band. It is, however, expected that LPF and HPF should well behave in the guard band.

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.

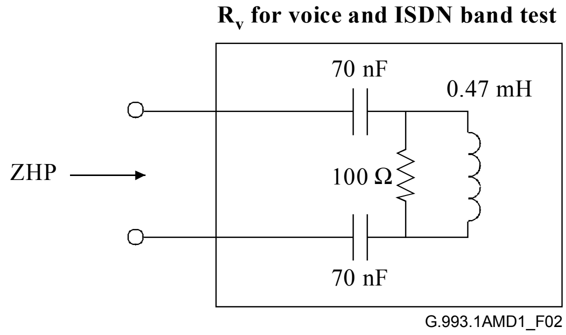


Figure F.2/G.993.1 – ZHP definition as R_V for voice and ISDN band test

R_V for VDSL band test shall be pure resistive 100 Ω.

Note that 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.

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 Vrms 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 it 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 lightening 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 that 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 be dependent of 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 that 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 that 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 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; 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) Voice band (LPF signal path characteristics with and without HPF loading)

f = 1.0 kHz:	-1.0 dB $\le$ LS(1 kHz) $\le$ $+1.0$ dB
0.2 kHz $\le f \le$ 3.4 kHz:	-1.0 dB $\le$ {LS(f) – LS(1 kHz)} $\le$ $+1.0$ dB
3.4 kHz $< f \le$ 4.0 kHz:	-1.5 dB $\le$ {LS(f) – LS(1 kHz)} $\le$ $+1.5$ 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) Guard band

320 kHz < f < 640 kHz: Not specified

NOTE 2 – The suggested requirements in the guard band 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) Voice band (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(fx) ≤ 250 µs

0.6 kHz ≤ f ≤ 3.2 kHz: GD(f) – GD(fx) ≤ 200 µs

3.2 kHz < f ≤ 4.0 kHz: GD(f) – GD(fx) ≤ 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 fx kHz is defined as the frequency which appears the minimum absolute group delay. GD(f) – GD(fx) denotes the increase in µs at f kHz from the minimum absolute group delay at fx 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 × $\log_2$ (f/160)} µs (where f in kHz)

3) Guard band

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.

$$RL(f) = -20 \times \log_{10}\left[Abs\left[\left\{Zref(jf) - Zin(jf)\right\} / \left\{\left(Zin(jf) + Zref(jf)\right)\right]\right]\text{dB}$$

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) Voice band (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: $\{15.0 - 6.02 \times \log_2 (10/f)\}$ dB ≤ RL(f) (where f in kHz)

10 kHz ≤ f ≤ 160 kHz: 15.0 dB ≤ RL(f)

160 kHz < f ≤ 220 kHz: $\{15.0 - 6.02 \times \log_2 (f/160)\}$ dB ≤ RL(f) (where f in kHz)

220 kHz < f ≤ 320 kHz: Not specified

3) Guard band

320 kHz < f < 640 kHz: Not specified

4) VDSL band (LPF loading effect on HPF signal path characteristics)

640 kHz ≤ f < 1.28 MHz: $\{12.0 - 6.02 \times \log_2(1280/f)\}$ ≤ 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.

$$LB(f) = -20 \times \log_{10}\{Vm(f)/Vt(f)\}\,\mathrm{dB}$$

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) Voice band (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: $\{63.0 - 6.02 \times \log_2 (f/250)\}$ dB ≤ LB(f)

3) Guard band

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) Voice band (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 × $\log_2$ (640/f) dB ≤ LS(f) (where f in kHz)

3) Guard band

   320 kHz < f < 640 kHz: Not specified

   NOTE – The suggested requirements in the guard band is 36.1 × $\log_2$ (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 × $\log_2$ (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) Voice band

   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) Guard band

   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 × {3.0 – 2.01 × $\log_2$ (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.

$$RL(f) = -20\times\log_{10}\left[Abs\left[\left\{Zref(jf) - Zin(jf)\right\}/\left\{\left(Zin(jf) + Zref(jf)\right)\right]\right]\text{dB}$$

where Zin(jf) is measurements of a complex input impedance and Zref(jf) is the complex reference impedance.

1) Voice band (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: $\{15.0 - 6.02 \times \log_2 (10/f)\}$ dB ≤ RL(f) (where f in kHz)

10 kHz ≤ f ≤ 160 kHz: 15.0 dB ≤ RL(f)

160 kHz < f ≤ 220 kHz: $\{15.0 - 6.02 \times \log_2 (f/160)\}$ dB ≤ RL(f) (where f in kHz)

220 kHz < f ≤ 320 kHz: Not specified

3) Guard band

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: $\{12.0 - 6.02 \times \log_2(1280/f)\}$ ≤ 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.

$$LB(f) = -20 \times \log_{10}\{Vm(f)/Vt(f)\}\,\mathrm{dB}$$

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) Voice band (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: $\{69.0 - 6.02 \times \log_2 (f/250)\}$ dB ≤ LB(f)

3) Guard band

320 kHz < f < 640 kHz: Not specified

4) VDSL band (HPF signal path characteristics with and without LPF loading)

640 kHz ≤ f ≤ 12 MHz: 40.0 dB ≤ LB(f)

F.2.3.8 Splitter 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.

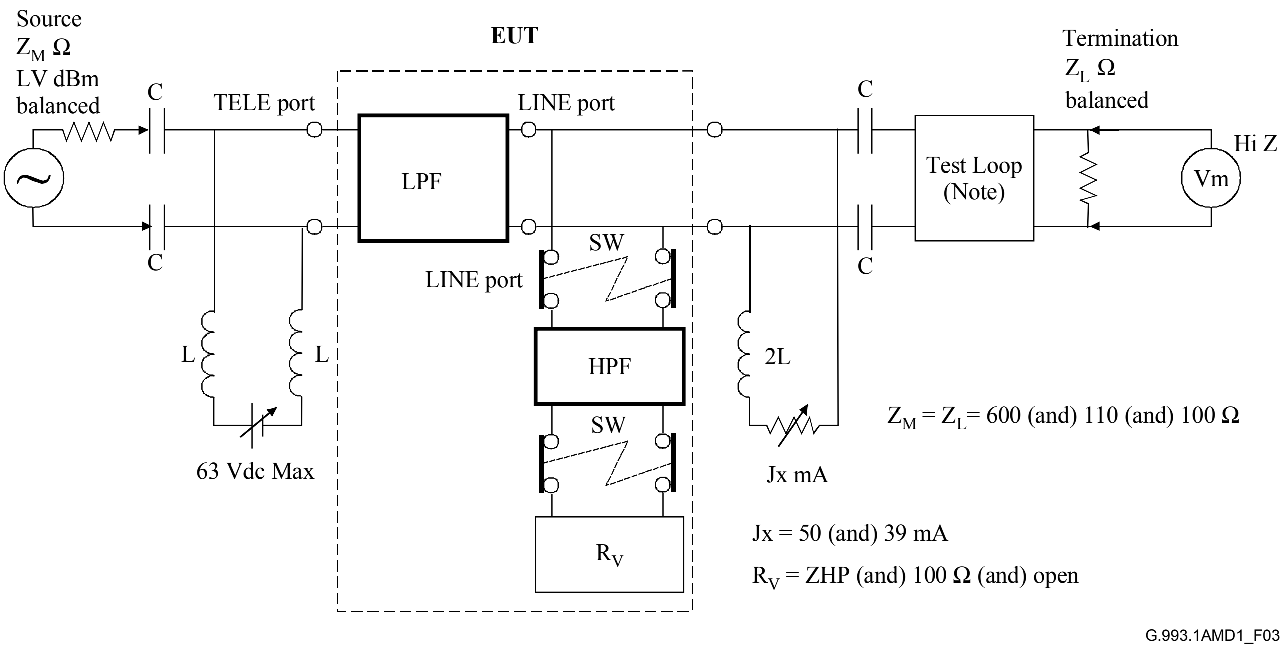
The test methods for HPF signal path characteristics with and without LPF and discrete HPF loading effect without connecting LPF are specified in F.2.3.8.2.

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 voice band test and defined in Figure F.4. Null loop is applied for ISDN and VDSL band test.



NOTE – Test loop is used only for voiceband 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

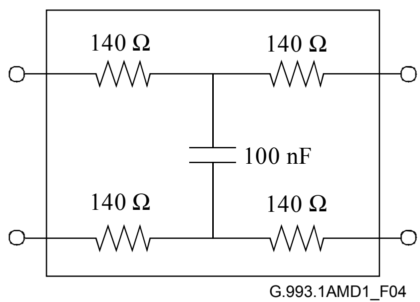


Figure F.4/G.993.1 – Voice band test loop (approximately 2 km)

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 Jx 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 Jx mA. Proper values of the C and L should be set for testing each band.

LV dBm, Z_M Ω, Z_L Ω, Jx mA, and the conditions of HPF loading are test band dependent and shall be as follows.

1) Voice band (0.2 kHz ≤ f ≤ 4.0 kHz)

   LV = 0 dBm

   $Z_M = Z_L = 600\ \Omega$

   Jx = 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

   $Z_M = Z_L = 110\ \Omega$

   Jx = 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) Guard band (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

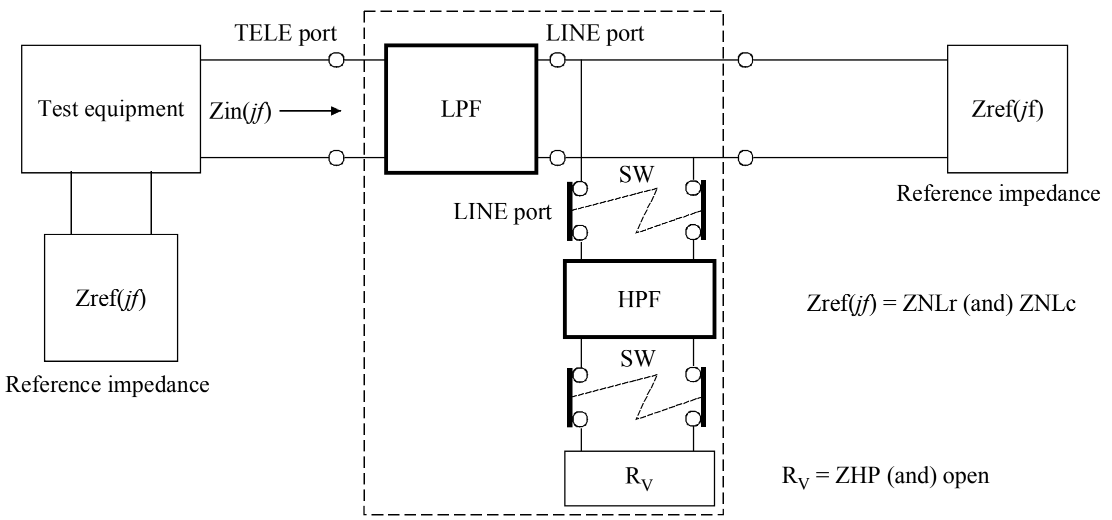
   $Z_M = Z_L = 100\ \Omega$

   Jx = 39 mA (e.g., C ≥ 0.2 μF and L ≥ 5 mH)

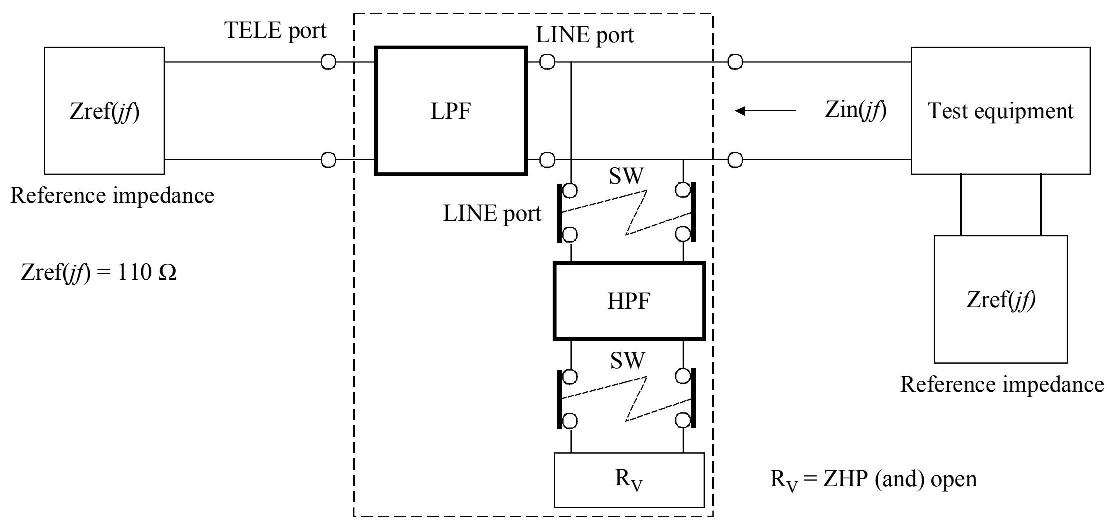
   Connecting HPF terminated with R_V = 100 Ω to the line

F.2.3.8.1.2 LPF return loss test

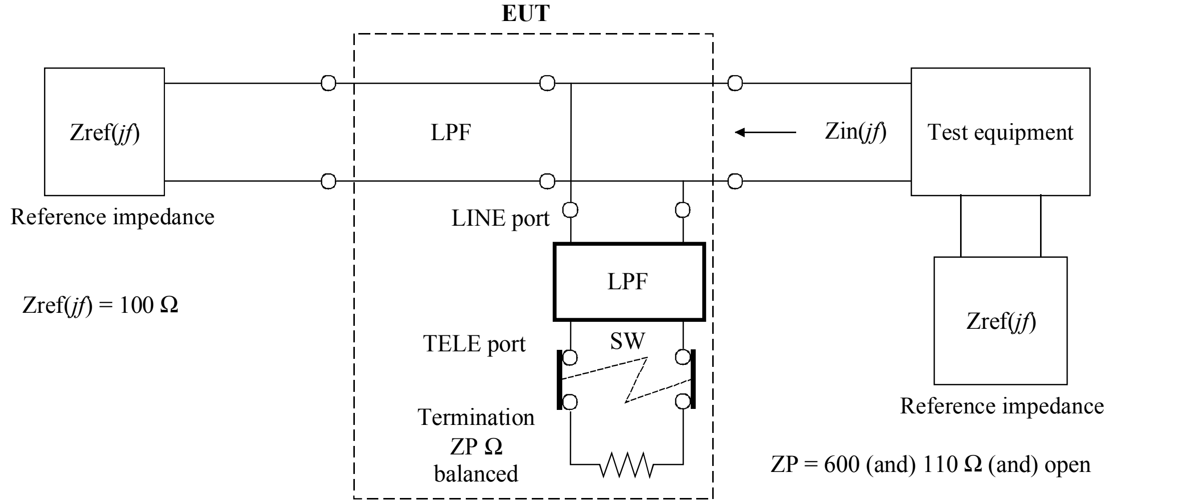
The test set-up is shown in Figure F.5. The return loss is measured in terms of a complex input impedance of Zin(*jf*). Zin(*jf*) shall be measured with inserting EUT and terminating the opposite side by the complex reference impedance of Zref(*jf*). Note that the port where Zin(*jf*) is measured is 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) 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

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) Voice band (0.2 kHz $\leq f \leq$ 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 $< f \leq$ 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) Guard band (320 kHz $< f <$ 640 kHz)

   Not specified

4) VDSL band (640 kHz $\leq f \leq$ 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

F.2.3.8.1.3 LPF 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.

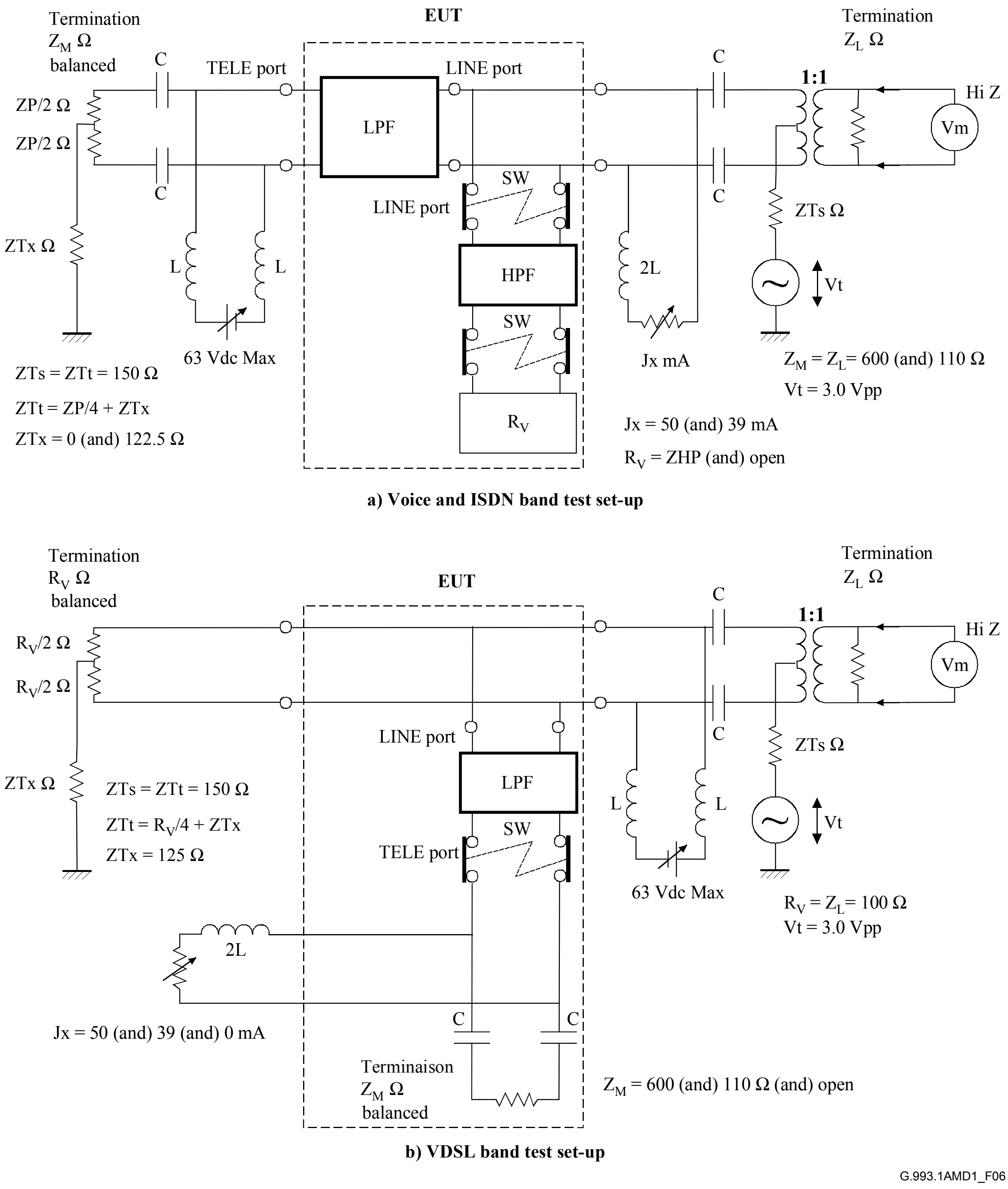


Figure F.6/G.993.1 – Test set-up for LPF longitudinal balance

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 (e.m.f.), 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 Jx 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, Jx mA, and the conditions of HPF and LPF loading are test band dependent, and shall be as follows.

1) Voice band (0.2 kHz $\leq f \leq$ 4.0 kHz)

   Vt(f) = 3.0 Vpp (e.m.f.)

   $Z_M = Z_L$ = 600 Ω

   ZTx = 0 Ω

   Jx = 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 $< f \leq$ 320 kHz)

   Vt(f) = 3.0 Vpp (e.m.f.)

   $Z_M = Z_L$ = 110 Ω

   ZTx = 122.5 Ω

   Jx = 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) Guard band (320 kHz $< f <$ 640 kHz)

   Not specified

4) VDSL band (640 kHz $\leq f \leq$ 12 MHz)

   Vt(f) = 3.0 Vpp (e.m.f.)

   $R_V = Z_L$ = 100 Ω

   ZTx = 125 Ω

   a1) Connecting LPF only in parallel to the line and terminating with Z_M = 600 Ω

   Jx = 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

   Jx = 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.

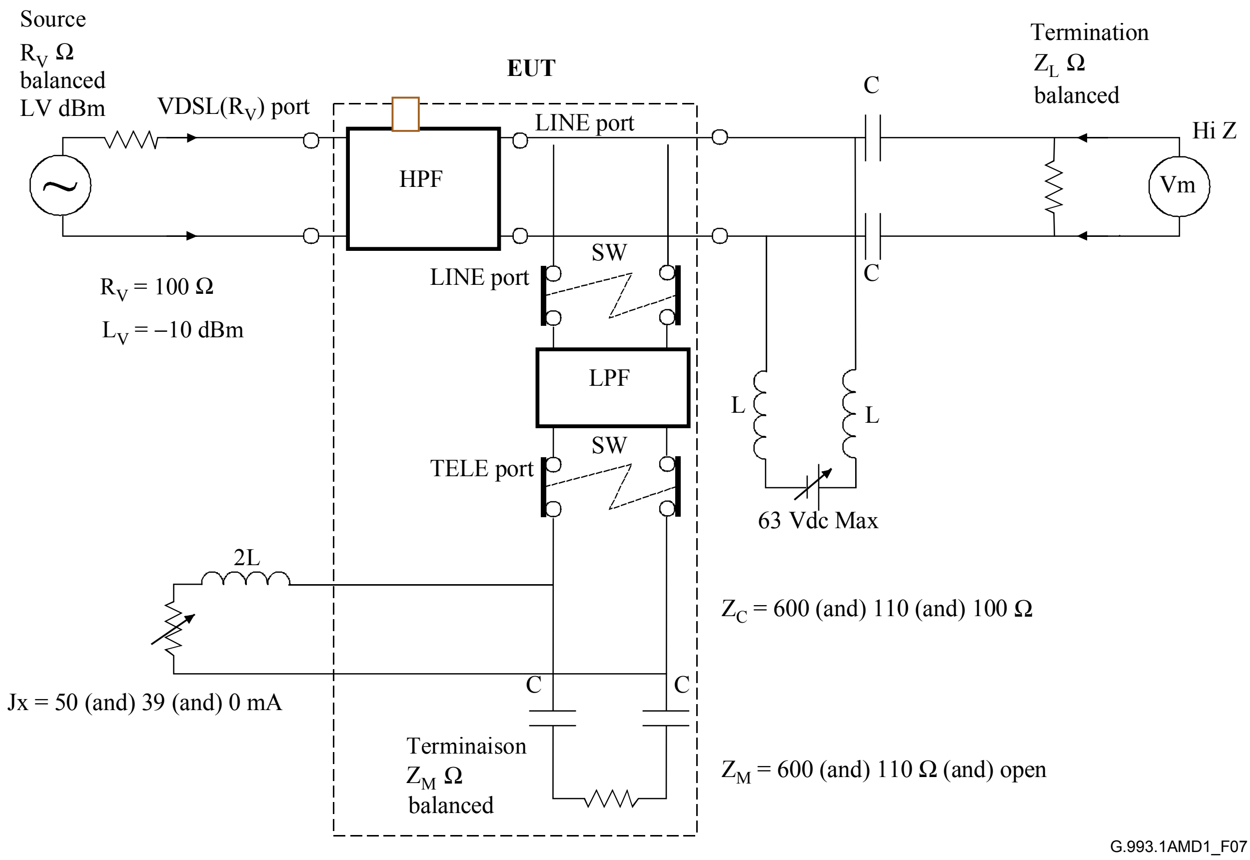


Figure F.7/G.993.1 – Test set-up for HPF insertion loss and absolute group delay

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 all conditions defined below.

A DC bias current of Jx 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, Jx mA and the conditions of LPF loading shall be as follows, where the Z_L Ω, Jx mA and conditions of LPF loading are test band dependent.

1) Voice band (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

   Jx = 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 Ω

Z_L = 110 Ω

Connecting LPF terminated with Z_M = 110 Ω to the line

Jx = 39 mA (e.g., C ≥ 10 μF and L ≥ 0.5 H)

3) Guard band (320 kHz < f < 640 kHz)

Not specified

4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

LV = –10 dBm

R_V = Z_L = 100 Ω

a1) Connecting LPF terminated with Z_M = 600 Ω to the line

Jx = 50 mA (e.g., C ≥ 0.2 μF and L ≥ 5 mH)

a2) Connecting LPF terminated with Z_M = 110 Ω to the line

Jx = 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.

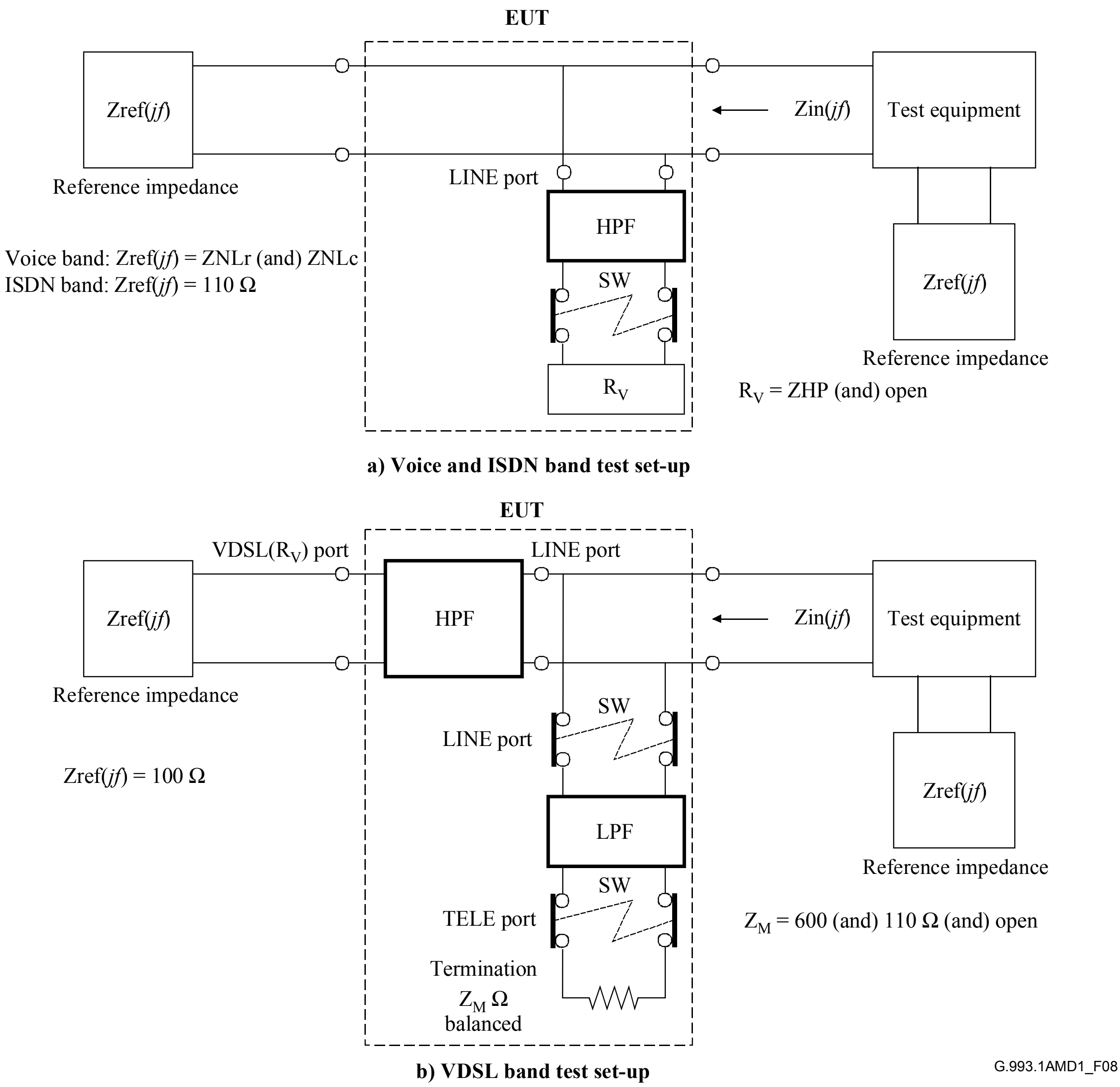


Figure F.8/G.993.1 – Test set-up for HPF return loss

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) Voice band (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) Guard band (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.

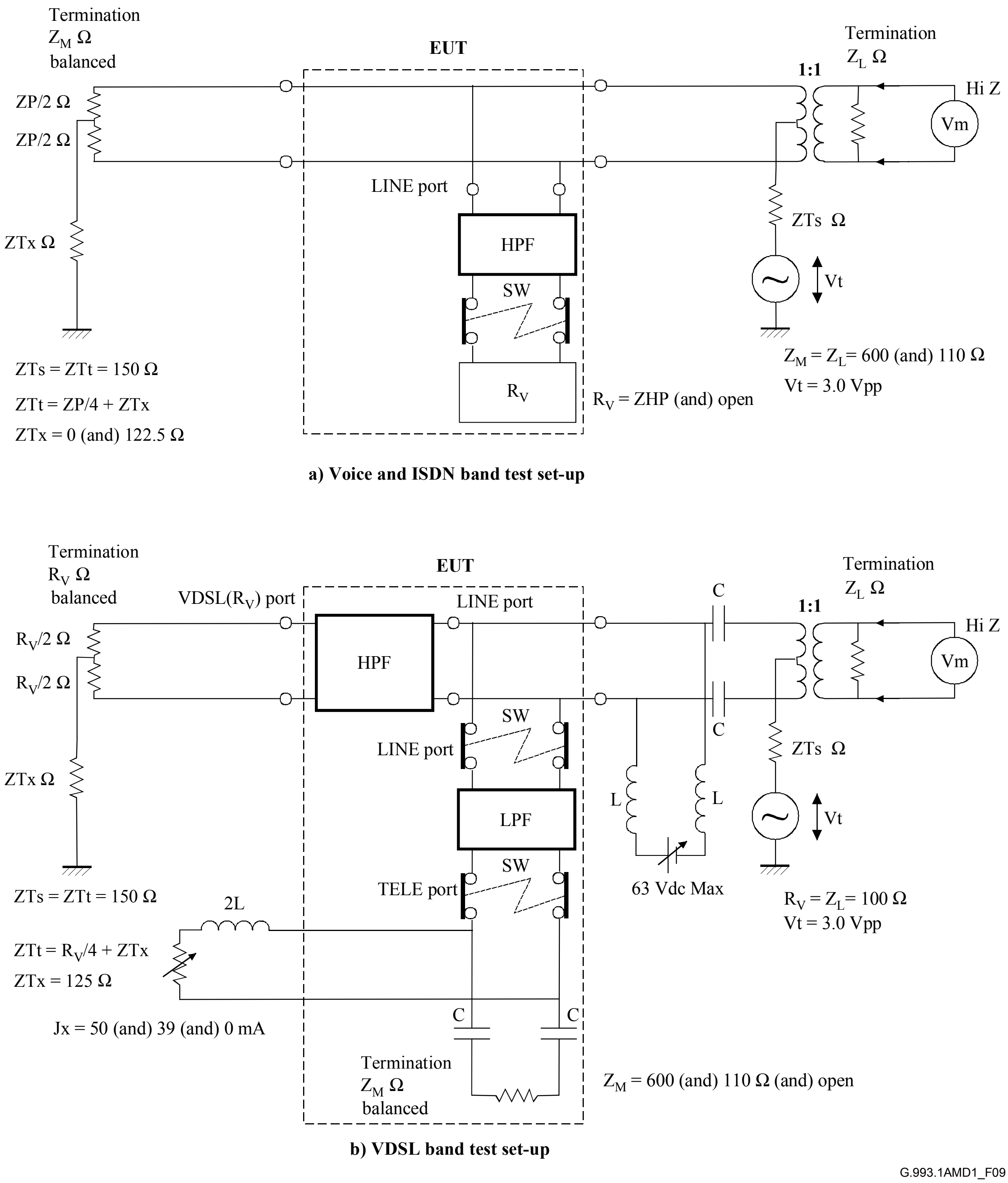


Figure F.9/G.993.1 – Test set-up for HPF longitudinal balance

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 (e.m.f.), 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 Jx 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, Jx mA and the conditions of LPF and HPF loading are test band dependent, and shall be as follows.

1) Voice band (0.2 kHz ≤ f ≤ 4.0 kHz)

   Vt(f) = 3.0 Vpp (e.m.f.)

   $Z_M = Z_L$ = 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 (e.m.f.)

   $Z_M = Z_L$ = 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) Guard band (320 kHz < f < 640 kHz)

   Not specified

4) VDSL band (640 kHz ≤ f ≤ 12 MHz)

   Vt(f) = 3.0 Vpp (e.m.f.)

   $R_V = Z_L$ = 100 Ω

   ZTx = 125 Ω

   a1) Connecting LPF terminated with Z_M = 600 Ω to the line

   Jx = 50 mA (e.g., C ≥ 0.2 μF and L ≥ 5 mH)

   a2) Connecting LPF terminated with Z_M = 110 Ω to the line

   Jx = 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.

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 – 2) and Y_j (j = 0 – 2) marked in Figure F.10 as adjustable-length sections are as follows. The lengths of TP range 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

   NOTE – It is for further study whether the step size of 5 m of the BT length shows a sufficient degree of precision on VDSL transmission performance test.

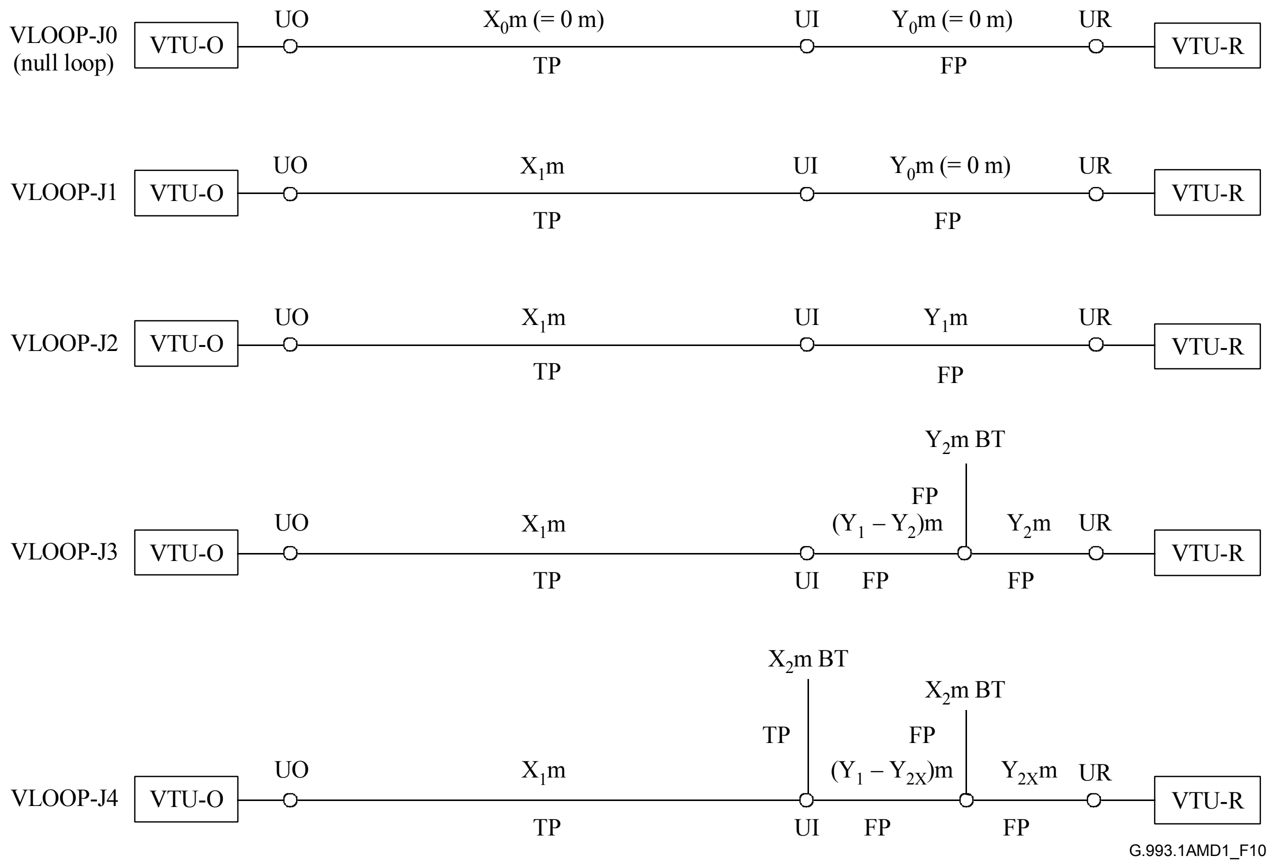


Figure F.10/G.993.1 – VDSL test loops for environment coexisting with TCM-ISDN DSL

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.6.

$$R = 2(Ri + Rn + Rns) \qquad [\text{ohm/m}]$$

$$L = 2(La + Li + Ln + Lns) \qquad [\text{H/m}]$$

$$C = C_i + \frac{C_{0a}}{(f+1)^{ce}} \qquad [\text{F/m}]$$

$$G = 2\pi f^{ge} C \tan\delta \qquad [\text{mho/m}]$$

$$Ri = \frac{1}{\pi_{r_i}{}^{2}\sigma_i} \operatorname{Re}\left[\frac{\lambda}{2}\frac{J_0(\lambda)}{J_1(\lambda)}\right] \text{ : skin effect}$$

$$Rn = \frac{1}{\pi d_i{}^{2}\sigma_i} \operatorname{Re}\left[-\lambda \frac{J_1(\lambda)}{J_0(\lambda)}\right] \text{ : intra-pair eddy current effect}$$

$$Rns = \frac{1}{\pi d_i{}^{2}\sigma_i} 4 \operatorname{Re}\left[-\lambda \frac{J_1(\lambda)}{J_0(\lambda)}\right] \text{ : intra-quad eddy current effect (in case of 0.4 mm PE)}$$

Rns = 0 : intra-quad eddy current effect (in case of 0.5 mm PVC FP)

$$La = \frac{\mu_0}{2\pi}\ln\left(\frac{d_i}{r_i}\right)$$: external inductance

$$Li = \frac{\mu_i}{2\pi}\mathrm{Re}\left[-\frac{1}{\lambda}\frac{J_0(\lambda)}{J_1(\lambda)}\right]$$: skin effect

$$Ln = -\frac{\mu_0}{2\pi}\left(\frac{r_i}{d_i}\right)^2 \mathrm{Re}\left[-\frac{J_2(\lambda)}{J_0(\lambda)}\right]$$: intra-pair eddy current effect

$$Lns = -\frac{\mu_0}{2\pi}\left(\frac{r_i}{d_i}\right)^2 4\,\mathrm{Re}\left[-\frac{J_2(\lambda)}{J_0(\lambda)}\right]$$: 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

$\mathrm{Re}[\ ]$: real part in [ ]

$$\lambda \equiv (1+j)\frac{r_i}{\delta_i}$$

r_i : radius of conductor [m]

$\delta_i = \sqrt{\frac{2}{\omega\sigma_i\mu_i}}$: 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]: = μ_r μ_0

μ_r : relative permeability of copper (conductor)

ω : angular frequency [rad/m]

d_i : distance between wire (conductor) centers of a pair [m]

$d_i = 2\sqrt{2}(r_i + CO_i)$: in case of 0.4 mm PE

$d_i = 2(r_i + CO_i)$: incase of 0.5 mm PVC FP

CO_i : thickness of insulator for wire (conductor) [m]

Table F.6/G.993.1 – Coefficient values

Item	TP (0.4 mm PE)	FP (0.5 mm 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
tanδ	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.

$$H(f) = e^{\gamma_{TP} X} e^{\gamma_{FP} Y}$$

$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$: propagation constant

X, Y: line distance [m]

The test loop characteristics for reference are presented in Tables F.7, F.8 and F.9 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.7/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
FT	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.8/G.993.1 – Test loop group delay in µs (microsecond) 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
FT	50 m	0.24 µs	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22

Table F.9/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	106	106	105	105
FT	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).

1) Two kinds of noise models are defined as follows. Noise A and Noise B_j (j = 1 – 4).

   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 as for the disturber PSD)

   Noise B_2 = 9 ADSL NEXT and FEXT (see ITU-T Rec. G.996.1 as for the disturber PSD)

   Noise B_3 = 9 PNT NEXT (see F.3.2.2 and ITU-T Rec. G.989.1 as for the disturber PSD)

   Noise B_4 = 9 TCM-ISDN DSL alternate NEXT and FEXT (see ITU-T Rec. G.996.1 as for the disturber PSD)

   NOTE 1 – PNT NEXT and FEXT appear alternately in the same frequency band, and are not cyclostationary. Annex F adopts only NEXT injection for VDSL test purpose as significant crosstalk.

   NOTE 2 – TCM-ISDN DSL NEXT and FEXT appear alternately in the same frequency band, and are cyclostationary. Annex F adopts cyclostationary crosstalk injection of NEXT and FEXT for VDSL test purpose as defined in ITU-T Rec. G.996.1 for ADSL test purpose.

   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. Namely, 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 it 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 by 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 by 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 by 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.

$$PSD_{VDSL-P-DS}(f) = 10\frac{KDS - P(f)}{10} - 3 \qquad \text{watts/Hz}$$

$$PSD_{VDSL-I-DS}(f) = 10\frac{KDS - I(f)}{10} - 3 \qquad \text{watts/Hz}$$

$$PSD_{VDSL-US}(f) = 10\frac{KUS - I(f)}{10} - 3 \qquad \text{watts/Hz}$$

where:

$f_1 = 0.138 \times 10^6$ Hz

$f_{1J} = 0.64 \times 10^6$ Hz

$f_2 = 3.75 \times 10^6$ Hz

$f_3 = 5.2 \times 10^6$ Hz

$f_4 = 8.5 \times 10^6$ Hz

$f_5 = 12 \times 10^6$ Hz

$\Delta f_T = 0.175 \times 10^6$ Hz: transition band at f_{1J}, f_2, f_3, f_4 and f_5

$\Delta f_{TX} = 0.018 \times 10^6$ Hz: transition band at f_1

$$KDS-P(f) = \begin{cases} -120 \text{ dBm/Hz} & 0 \text{ Hz} < f < 0.12 \times 10^6 \text{ Hz} \\ -60 + (50/\Delta f_{TX}) \times (f - f_1) \text{ dBm/Hz} & f_1 - \Delta f_{TX} \le f \le f_1 \\ -60 \text{ dBm/Hz} & f_1 < f < f_2 \\ -80 - (20/\Delta f_T) \times (f - f_2) \text{ dBm/Hz} & f_2 \le f \le f_2 + \Delta f_T \\ -100 \text{ dBm/Hz} & f_2 + \Delta f_T < f < f_3 - \Delta f_T \\ -80 + (20/\Delta f_T) \times (f - f_3) \text{ dBm/Hz} & f_3 - \Delta f_T \le f \le f_3 \\ -60 \text{ dBm/Hz} & f_3 < f < f_4 \\ -80 - (20/\Delta f_T) \times (f - f_4) \text{ dBm/Hz} & f_4 \le f \le f_4 + \Delta f_T \\ -100 \text{ dBm/Hz} & f_4 + \Delta f_T < f < 30 \times 10^6 \text{ Hz} \\ -120 \text{ dBm/Hz} & 30 \times 10^6 \text{ Hz} \le f < \infty \end{cases}$$

$$KDS-I(f) = \begin{cases} -120 \text{ dBm/Hz} & 0 \text{ Hz} < f < 0.12 \times 10^6 \text{ Hz} \\ -110 \text{ dBm/Hz} & 0.12 \times 10^6 \text{ Hz} \le f < 0.225 \times 10^6 \text{ Hz} \\ -100 \text{ dBm/Hz} & 0.225 \times 10^6 \text{ Hz} \le f < f_{1J} - \Delta f_T \\ -60 + (40/\Delta f_T) \times (f - f_{1J}) \text{ dBm/Hz} & f_{1J} - \Delta f_T \le f \le f_{1J} \\ -60 \text{ dBm/Hz} & f_{1J} < f < f_2 \\ -80 - (20/\Delta f_T) \times (f - f_2) \text{ dBm/Hz} & f_2 \le f \le f_2 + \Delta f_T \\ -100 \text{ dBm/Hz} & f_2 + \Delta f_T < f < f_3 - \Delta f_T \\ -80 + (20/\Delta f_T) \times (f - f_3) \text{ dBm/Hz} & f_3 - \Delta f_T \le f \le f_3 \\ -60 \text{ dBm/Hz} & f_3 < f < f_4 \\ -80 - (20/\Delta f_T) \times (f - f_4) \text{ dBm/Hz} & f_4 \le f \le f_4 + \Delta f_T \\ -100 \text{ dBm/Hz} & f_4 + \Delta f_T < f < 30 \times 10^6 \text{ Hz} \\ -120 \text{ dBm/Hz} & 30 \times 10^6 \text{ Hz} \le f < \infty \end{cases}$$

$$KUS(f) = \begin{cases} -120 \text{ dBm/Hz} & 0 \text{ Hz} < f < 0.12 \times 10^6 \text{ Hz} \\ -110 \text{ dBm/Hz} & 0.12 \times 10^6 \text{ Hz} \le f < 0.225 \times 10^6 \text{ Hz} \\ -100 \text{ dBm/Hz} & 0.225 \times 10^6 \text{ Hz} \le f < f_2 - \Delta f_T \\ -80 + (20/\Delta f_T) \times (f - f_{1J}) \text{ dBm/Hz} & f_2 - \Delta f_T \le f \le f_2 \\ -60 \text{ dBm/Hz} & f_2 < f < f_3 \\ -80 - (20/\Delta f_T) \times (f - f_3) \text{ dBm/Hz} & f_3 \le f \le f_3 + \Delta f_T \\ -100 \text{ dBm/Hz} & f_3 + \Delta f_T < f < f_4 - \Delta f_T \\ -80 + (20/\Delta f_T) \times (f - f_4) \text{ dBm/Hz} & f_4 - \Delta f_T \le f \le f_4 \\ -60 \text{ dBm/Hz} & f_4 < f < f_5 \\ -80 - (20/\Delta f_T) \times (f - f_5) \text{ dBm/Hz} & f_5 \le f \le f_5 + \Delta f_T \\ -100 \text{ dBm/Hz} & f_5 + \Delta f_T < f < 30 \times 10^6 \text{ Hz} \\ -120 \text{ dBm/Hz} & 30 \times 10^6 \text{ Hz} \le f < \infty \end{cases}$$

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 $PSD_{VDSL\text{-}US}(f)$.

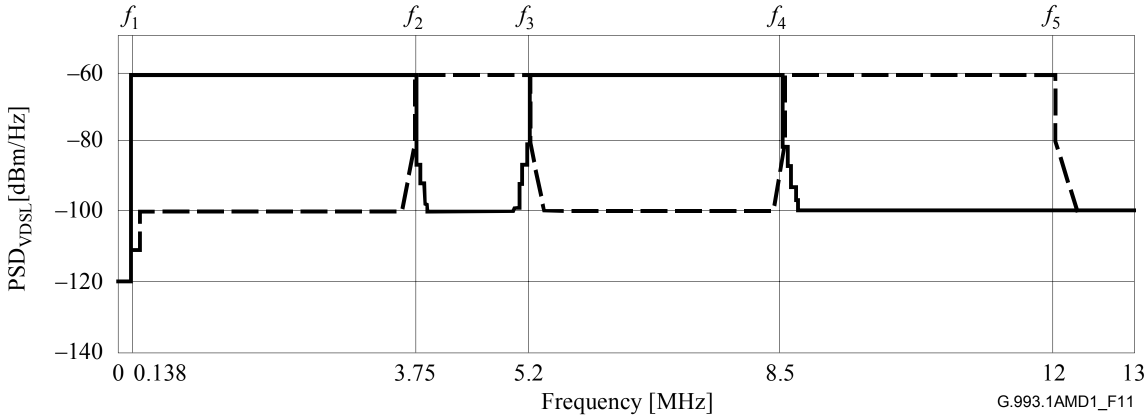


Figure F.11/G.993.1 – VDSL-P downstream and upstream disturber PSD

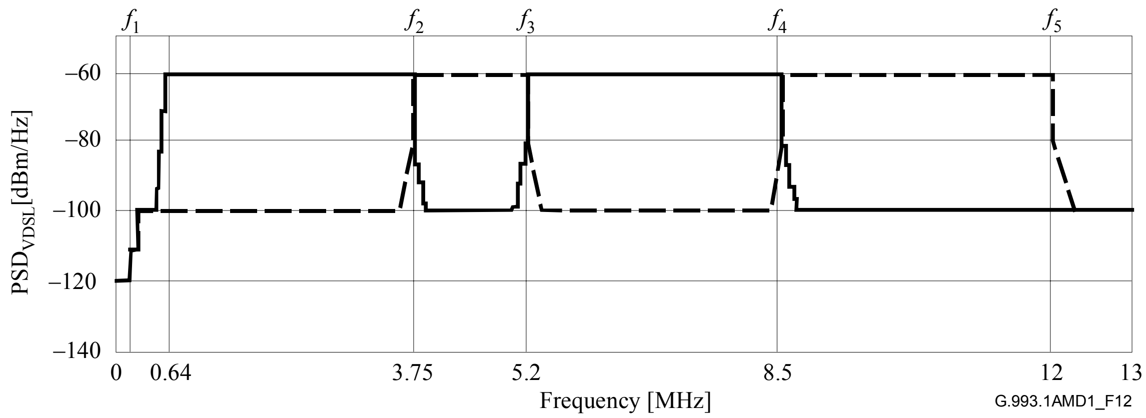


Figure F.12/G.993.1 – VDSL-I downstream and upstream disturber PSD

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.

$$PSD_{PNT}(f) = 10\frac{KPNT(f)}{10} - 3 \qquad \text{watts/Hz}$$

where:

$$KDS - P(f) = \begin{cases} -140\ \text{dBm/Hz} & 0.015\times10^6\ \text{Hz} < f \le 1.7\times10^6\ \text{Hz} \\ -140 + (50.0/1.8)\times(f/10^6 - 1.7)\ \text{dBm/Hz} & 1.7\times10^6\ \text{Hz} < f \le 3.5\times10^6\ \text{Hz} \\ -90 + 17.0\times(f/10^6 - 3.5)\ \text{dBm/Hz} & 3.5\times10^6\ \text{Hz} < f \le 4.0\times10^6\ \text{Hz} \\ -71.5\ \text{dBm/Hz} & 4.0\times10^6\ \text{Hz} < f < 7.0\times10^6\ \text{Hz} \\ -81.5\ \text{dBm/Hz} & 7.0\times10^6\ \text{Hz} \le f \le 7.3\times10^6\ \text{Hz} \\ -71.5\ \text{dBm/Hz} & 7.3\times10^6\ \text{Hz} < f < 10.0\times10^6\ \text{Hz} \\ -81.5 - (43.5/3.0)\times(f/10^6 - 10.0)\ \text{dBm/Hz} & 10.0\times10^6\ \text{Hz} \le f < 13.0\times10^6\ \text{Hz} \\ -125\ \text{dBm/Hz} & 13.0\times10^6\ \text{Hz} \le f < 25.0\times10^6\ \text{Hz} \\ -140\ \text{dBm/Hz} & 25.0\times10^6\ \text{Hz} \le f < 30.0\times10^6\ \text{Hz} \end{cases}$$

The PNT disturber $PSD_{PNT}(f)$ in dBm/Hz is presented in Figure F.13.

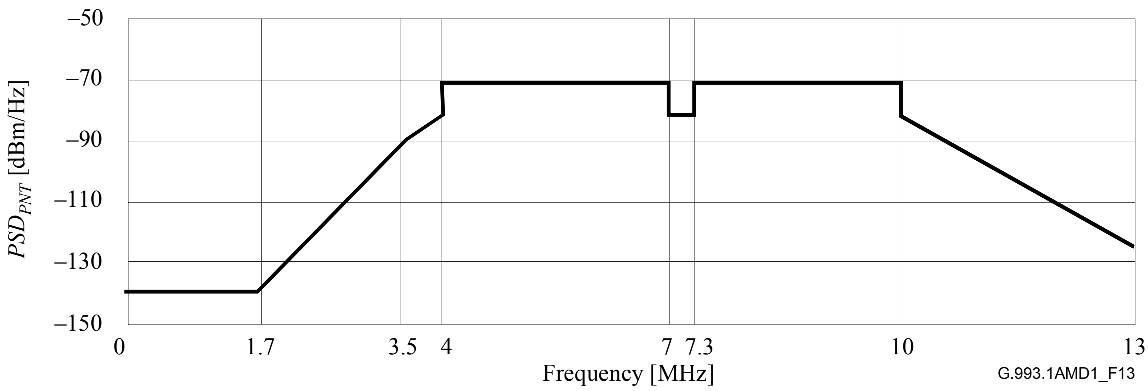


Figure F.13/G.993.1 – PNT (Phoneline Networking Transceiver) disturber PSD

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 below 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.

$XTPSD_{VDSL\text{-}x\text{-}DS\text{-}NEXT}(f) = PSD_{VDSL\text{-}x\text{-}DS}(f)\ XT_{NEXT}(f)$ watts/Hz

$XTPSD_{VDSL\text{-}x\text{-}DS\text{-}FEXT}(f) = PSD_{VDSL\text{-}x\text{-}DS}(f)\ XT_{FEXT}(f)$ watts/Hz

where x = P or I.

The single-sided XTPSD of VDSL upstream NEXT and FEXT are given below.

$XTPSD_{VDSL\text{-}US\text{-}NEXT}(f) = PSD_{VDSL\text{-}US}(f)\ XT_{NEXT}(f)$ watts/Hz

$XTPSD_{VDSL\text{-}US\text{-}FEXT}(f) = PSD_{VDSL\text{-}US}(f)\ XT_{FEXT}(f)$ 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 the equations below are adopted.

$XTPSD_{VDSL\text{-}US\text{-}NEXT}(f) = PSD_{VDSL\text{-}US}(f)\ |\exp(-4\gamma_{FP} Y_1)|\ XT_{NEXT}(f)$ watts/Hz

$XTPSD_{VDSL\text{-}US\text{-}FEXT}(f) = PSD_{VDSL\text{-}US}(f)\ |\exp(-2\gamma_{FP} Y_1)|\ XT_{FEXT}(f)$ 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.

$XTPSD_{VDSL\text{-}x\text{-}UI}(f) = XTPSD_{VDSL\text{-}US\text{-}NEXT}(f) + XTPSD_{VDSL\text{-}x\text{-}DS\text{-}FEXT}(f)$ watts/Hz

$XTPSD_{VDSL\text{-}x\text{-}UO}(f) = XTPSD_{VDSL\text{-}x\text{-}DS\text{-}NEXT}(f) + XTPSD_{VDSL\text{-}US\text{-}FEXT}(f)$ 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.

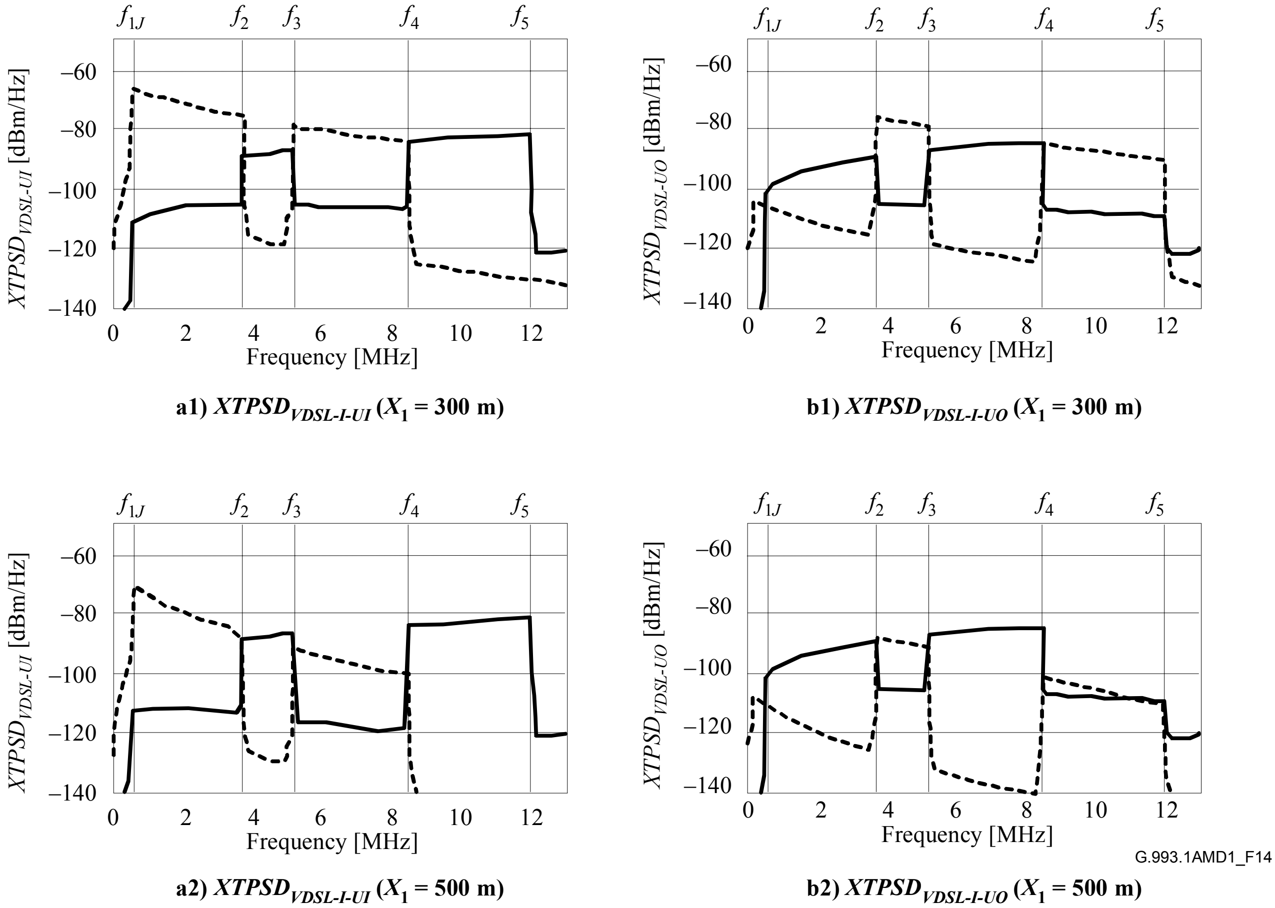


Figure F.14/G.993.1 – 9-disturber VDSL-I NEXT and FEXT PSD for injection at UI and UO ports

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.

$$XTPSD_{PNT}(f) = PSD_{PNT}(f)\ XT_{NEXT}(f) \qquad \text{watts/Hz}$$

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.

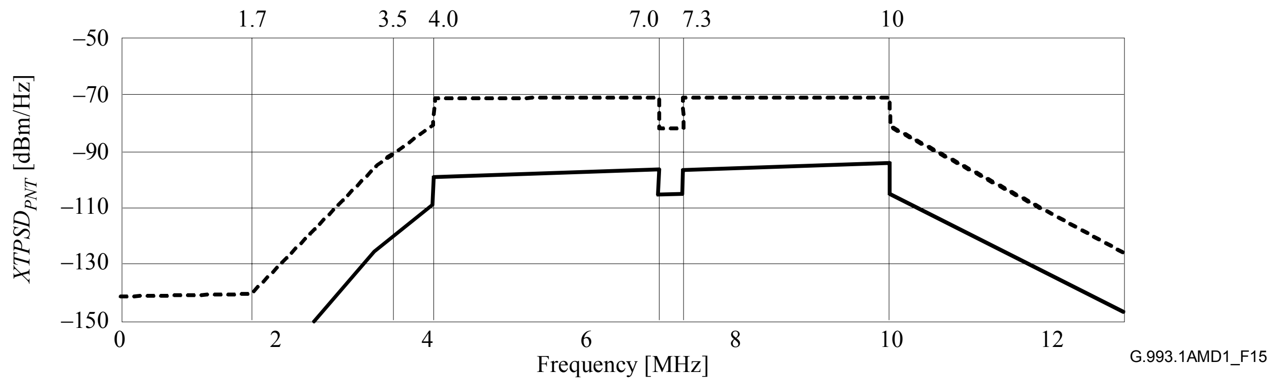


Figure F.15/G.993.1 – 9-disturber PNT NEXT PSD for injection at UI and UO ports

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.10 for reference.

NOTE 1 – ADSL disturber crosstalk power for non-overlapped spectrum defined in Annex A/G.992.1 is given in Table F.10.

NOTE 2 – NEXT and FEXT power of TCM-ISDN DSL disturber in Table F.10 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.10/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	$XTPSD_{VDSL\text{-}P\text{-}UI}$	$XTPSD_{VDSL\text{-}P\text{-}US\text{-}NEXT}$	–16.4	←	←	←	←	←
			$XTPSD_{VDSL\text{-}P\text{-}DS\text{-}FEXT}$	–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	$XTPSD_{VDSL\text{-}P\text{-}UO}$	$XTPSD_{VDSL\text{-}P\text{-}DS\text{-}NEXT}$	–19.1	←	←	←	←	←
			$XTPSD_{VDSL\text{-}P\text{-}US\text{-}FEXT}$	–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	$XTPSD_{VDSL\text{-}I\text{-}UI}$	$XTPSD_{VDSL\text{-}I\text{-}US\text{-}NEXT}$	–16.4	←	←	←	←	←
			$XTPSD_{VDSL\text{-}I\text{-}DS\text{-}FEXT}$	–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	$XTPSD_{VDSL\text{-}I\text{-}UI}$	$XTPSD_{VDSL\text{-}I\text{-}DS\text{-}NEXT}$	–19.1	←	←	←	←	←
			$XTPSD_{VDSL\text{-}I\text{-}US\text{-}FEXT}$	–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	$XTPSD_{ADSL\text{-}UI}$	$XTPSD_{ADSL\text{-}US\text{-}NEXT}$	–43.1	←	←	←	←	←
			$XTPSD_{ADSL\text{-}DS\text{-}FEXT}$	–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	$XTPSD_{ADSL\text{-}UO}$	$XTPSD_{ADSL\text{-}DS\text{-}NEXT}$	–24.5	←	←	←	←	←
			$XTPSD_{ADSL\text{-}US\text{-}FEXT}$	–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	$XTPSD_{PNT}$	$XTPSD_{PNT\text{-}NEXT}$	–28.7	←	←	←	←	←
TCM-ISDN DSL	UI and UO	$XTPSD_{TCM\text{-}ISDN}$	$XTPSD_{TCM\text{-}ISDN\text{-}NEXT}$	–29.6	←	←	←	←	←
			$XTPSD_{TCM\text{-}ISDN\text{-}FEXT}$	–41.8	–40.4	–40.1	–40.8	–44.5	–49.0

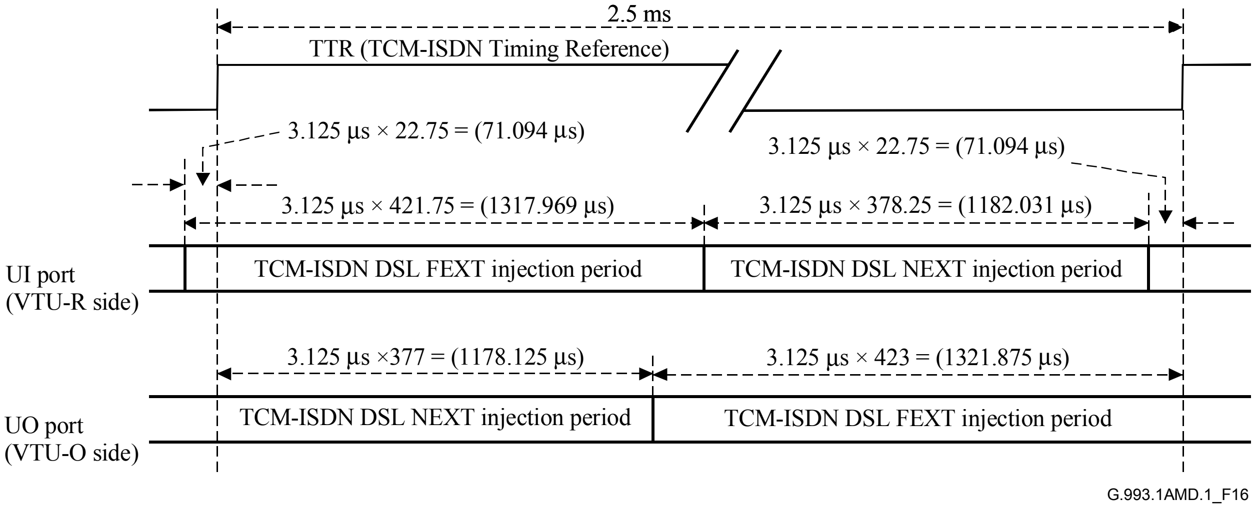


Figure F.16/G.993.1 – TCM-ISDN DSL alternate NEXT and FEXT injection timing

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