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Digital sections and digital line system – Access networks

Test procedures for digital subscriber line (DSL) transceivers

ITU-T Recommendation G.996.1

(Formerly CCITT Recommendation)

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ITU-T Recommendation G.996.1

Test procedures for digital subscriber line (DSL) transceivers

Summary

This Recommendation describes the testing procedures for ITU-T Digital Subscriber Line (DSL) Recommendations. The testing procedures described herein include methods for testing DSL transceivers in the presence of crosstalk from other services, Radio Frequency ingress, impulse noise and POTS signalling. Test loops and in-home wiring models are specified for different regions of the world for use during DSL performance testing. Other DSL Recommendations reference this Recommendation for testing procedures and configurations. This Recommendation does not specify performance requirements for these other Recommendations; it only specifies the procedures for measuring the performance requirements for a particular Recommendation.

Source

ITU-T Recommendation G.996.1 was revised by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 9 February 2001.

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.

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ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

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.996.1

Test procedures for digital subscriber line (DSL) transceivers

1 Scope

This Recommendation describes the testing procedures for ITU-T DSL Recommendations. The testing procedures described in this Recommendation include methods for testing DSL transceivers in the presence of crosstalk from other services, Radio Frequency ingress, impulse noise and POTS signalling. Test loops and in-home wiring models are specified for different regions of the world for use during DSL performance testing. Other DSL Recommendations reference this Recommendation for testing procedures and configurations. This Recommendation does not specify performance requirements for these other Recommendations. This Recommendation only specifies the procedures for measuring the performance requirements for a particular Recommendation.

An overview of Digital Subscriber Line (DSL) transceivers can be found in ITU-T G.995.1.

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.

– ITU-T G.992.1 (1999), *Asymmetric digital subscriber line (ADSL) transceivers.*

– ITU-T G.992.2 (1999), *Splitterless asymmetric digital subscriber line (ADSL) transceivers.*

3 Definitions

This Recommendation defines the following terms:

3.1 downstream: ATU-C to ATU-R direction.

3.2 upstream: ATU-R to ATU-C direction.

3.3 splitter: A filter that separates the high frequency signals (DSL) from the voiceband signals.

3.4 voiceband: The frequency band from 0 to 4 kHz.

3.5 voiceband services: POTS and all data services that use the voiceband.

4 Abbreviations

This Recommendation uses the following abbreviations:

ADC	Analogue-to-Digital Converter
ADSL	Asymmetric Digital Subscriber Line
ATU-C	ADSL Transceiver Unit, Central office end
ATU-R	ADSL Transceiver Unit, Remote terminal end
BER	Bit Error Rate
CO	Central Office
DAC	Digital-to-Analogue Converter

DMT	Discrete multitone
DSL	Digital Subscriber Line
ES	Errored Seconds
FEXT	Far-End crosstalk
kbit/s	kilobits per second
NEXT	Near-End crosstalk
POTS	Plain Old Telephone Service
PSD	Power Spectral Density
QoS	Quality of Service
RF	Radio Frequency
RFI	Radio Frequency Ingress
RMS	Root-Mean-Square
RT	Remote Terminal
	exclusive-or; modulo-2 addition
xDSL	Any of the various types of Digital Subscriber Lines (DSL)
XT	Crosstalk
xTU-C	xDSL Transceiver Unit – Central office end
xTU-R	xDSL Transceiver Unit – Remote Terminal end

5 Test procedures and laboratory setup

The methods in this Recommendation test DSL system transmission performance. These laboratory methods evaluate a system's ability to minimize digital bit errors caused by interference from:

– crosstalk coupling from other systems;

– differential and common mode Radio Frequency (RF) ingress

– background noise;

– impulse noise;

– POTS signalling.

These potential sources of impairment are simulated in a laboratory setup that includes test loops, test sets, and interference injection equipment, as well as the test system itself.

The crosstalk and impulse noise interfering signals are simulations that are derived from a consideration of real loop conditions and measurements. The test procedure is to inject the interference into the test loops and measure the effect on system performance by a bit error test simultaneously run on the system information channels.

For crosstalk an initial, or reference, power level for the interference represents the expected worst case. If the interference power can be increased without exceeding a specified error threshold, the system has a positive performance margin. Performance margin, expressed in dB, is the difference between the interference level at which the error threshold is reached, and the reference (or 0 dB) level.

In the case of impulse noise, an increasing interference level is similarly applied up to the error threshold, and the estimated performance is computed from this information. Because the impulse noise characteristics of the loop plant are not completely understood, the estimation method is based on measured data from several sites. The estimated number of error-causing impulses is compared to a specified errored-seconds (ES) criterion. The test procedure makes separate determinations of crosstalk margins and impulse error thresholds, although a background crosstalk interference is applied during impulse tests.

The POTS measurement uses a number of signalling and alerting activities done with real phones and CO lines, and also has crosstalk interference present. The BER test sets check for ES or a BER threshold.

5.1 DSL operation with splitters

5.1.1 Laboratory setup

Figure 1 shows the test setup for measuring performance margins for the downstream channel in DSL systems with splitters. Figure 2 shows the test setup for measuring performance margins for the upstream channel in DSL systems with splitters. The test setup permits differential and common mode signals to be superimposed on a working link, to simulate ingress situations. The test system consists of a central office transceiver (ATU-C), a remote end transceiver (ATU-R), and associated splitters. The two transceivers are connected together by the test loop. Crosstalk, impulses and Radio Frequency ingress (RFI) are injected at the ATU-R for downstream tests, and at the ATU-C for upstream channel tests.

For downstream testing, as shown in Figure 1, pseudo-random binary data from the transmitter of the bit error rate (BER) test set is presented at the downstream channel input of the ATU-C. The downstream channel output from the ATU-R is connected to the receiver of the same or a similar BER test set. The test set measures BER or errored seconds (ES), as needed. Similar error testing is done in the upstream direction at the rate needed for the particular system under test (see Figure 2).

A telephone set is connected to the telephone jack of the splitter at the ATU-R, and a working telephone line circuit is connected to the telephone jack on the splitter at the ATU-C.

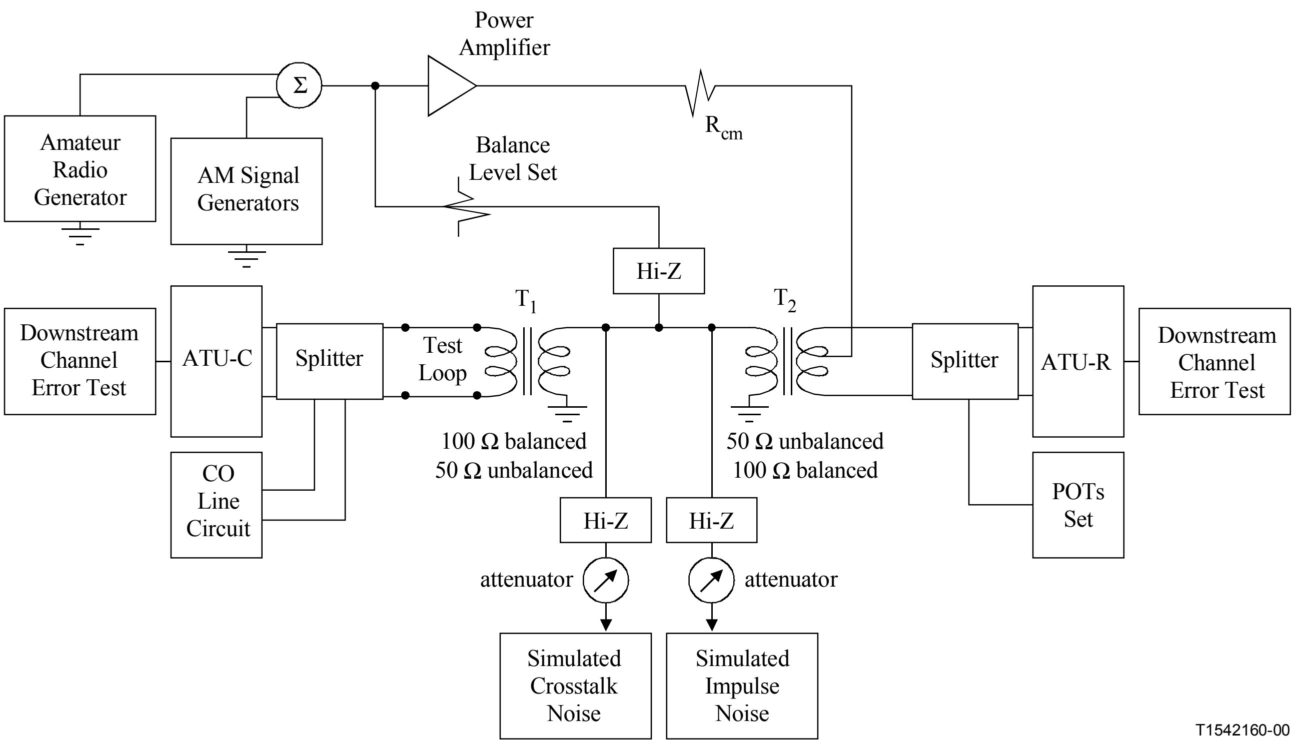


Figure 1/G.996.1 – Laboratory test setup for measuring performance margins for the downstream channel with splitters

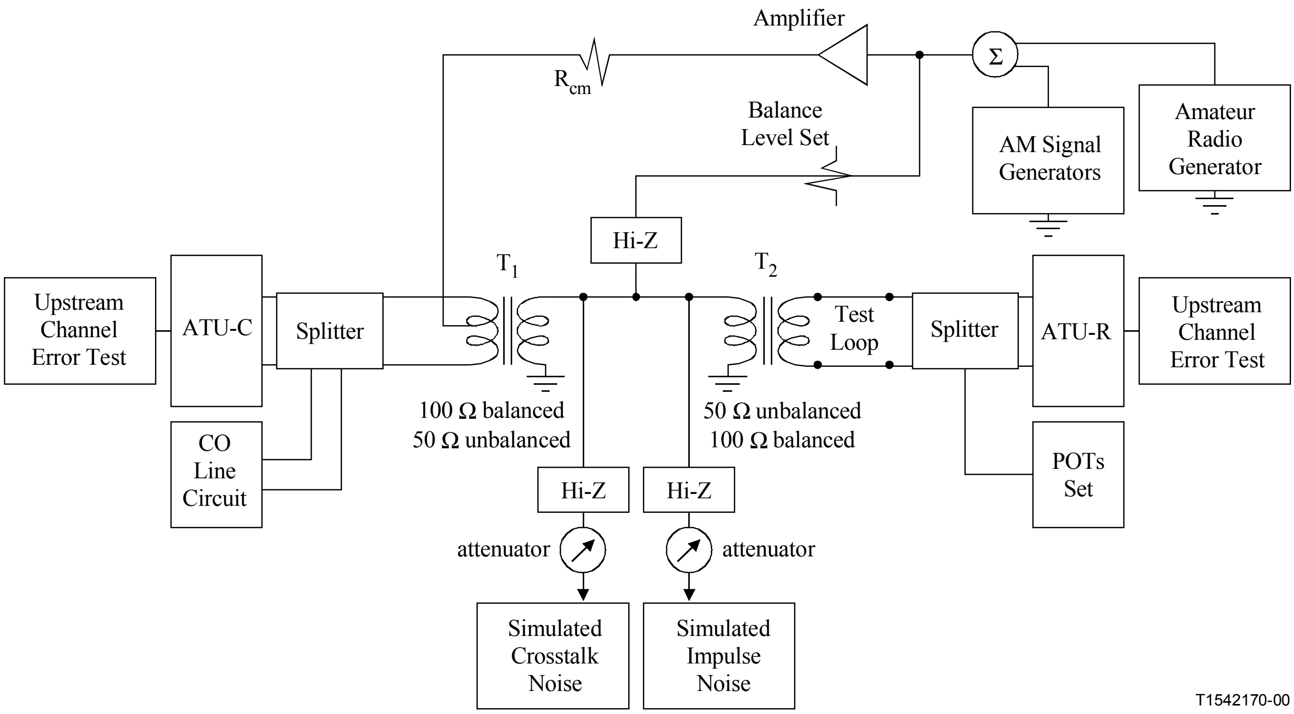


Figure 2/G.996.1 – Laboratory test setup for measuring performance margins for the upstream channel with splitters

The test set is essentially transparent in both directions between the transformers T_1 and T_2, so a normal working connection can be set up in the presence or absence of ingress.

T_1 is a precision balun transformer. This minimizes the effects of any ingress that may be present. Note, however, that it will not compensate for pickup due to a poorly balanced facility connected to this port. The 50-ohm unbalanced signal from T_1 passes via T_2 to the receiving modem. Crosstalk and voice signals and the differential portion of the ingress signal are applied via hi-Z attenuators to the 50-ohm link between the transformers. T_2 is a precision balun transformer, so it does not contribute significant imbalance at the receiving modem. Any imbalance at this port will be due to the modem itself.

The common mode ingress signal is applied via linear power amplifier A_l and resistor R_{cm} to the centre tap of T_2. Amplifier A_l must be capable of producing the required signal level while keeping any resulting differential intermodulation products that fall in-band ≤113 dBm in any channel (this is equivalent to –150 dBm/Hz across 4.3125 kHz). Assuming that the modem under test has a differential balance of 35 dB, to make the resulting differential component from the 0 dBm common mode signal be ≤113 dBm in any channel requires the common mode intermodulation products at the centre tap of T_2 to be –78 dBm. Filtering at the amplifier output may be used to achieve this.

R_{cm} is included so that the differential longitudinal of the facility is properly modelled. This is necessary because this impedance, together with the common-mode input impedance of the modem under test, can affect the test result. A value of 200 ohms is recommended for R_{cm}. It is assumed here that the amplifier has negligible output impedance; if it does not, the circuit can be modified accordingly. Similarly, any filter inserted at the amplifier output should be sufficiently transparent within the pass band that this impedance is maintained.

No phase alignment between the common mode and differential signals is required. It is possible that in some modems that a specific alignment may be beneficial. By testing in two alignments differing by 90 degrees this advantage could be removed. However, this would double the test time. By not specifying the alignment it is intended that modems will by designed for all possible alignments, as in the field no specific alignment can be assumed.

Required attributes of test equipment

- The Thevenin impedance of all differential noise-coupling circuits connected to the test loop shall be greater than 4000 ohms referred to a 100-ohm impedance point.
- Common Mode Source Impedance = 200 ohms.
- The attenuation of the combining circuit must be correctly compensated for in the signal and interference paths. There is an advantage to a minimized loss in the signal path, as this flat loss would need to be removed from the line model loss.
- The test setup should have a minimum balance of 60 dB. This is 20 dB better than the specified ratio of common mode to differential of 40 dB.

The test circuit must not create excessive spurious products that fall within the band of the test signal. The specification of –113 dBm in a 4.3125 kHz window corresponds to –150 dBm/Hz, and should be sufficient not to bias the tests as it is 10 dB below the white noise floor.

5.1.2 Crosstalk and RFI test

Crosstalk and RFI testing is performed to evaluate the performance of DSL systems in the presence of crosstalk from other services in the loop and RF ingress.

5.1.2.1 Crosstalk and RFI injection

One method for injecting impairment is shown in Figure 3 using the crosstalk impairment as an example.

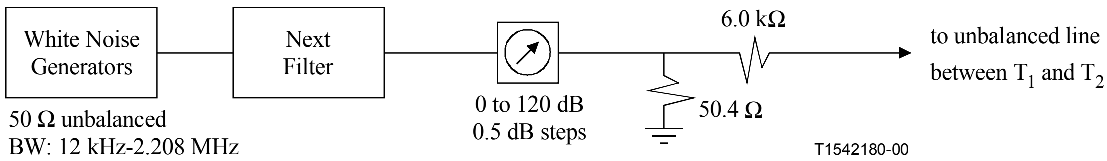


Figure 3/G.996.1 – High impedance crosstalk injection circuit

The method for calibrating the impairment levels is shown in Figure 3a. Both modems and the test loops have been removed and 100-ohm loads put in their place. The differential impairments are adjusted until their value is achieved across the 100-ohm load that replaces the receiver. The common-mode levels refer to the reading on a 50-ohm instrument connected at V_{cmOC} (note that when this technique is used the definition of 0 dBm is 223.6 mV_{rms}). This does not constitute a double termination as the 100-ohm impedance across T_2 only creates a differential load. If this measurement is made with a high impedance instrument the levels would be 12 dB higher.

It should be noted that the levels that appear during the actual test may vary from the calibration levels as the modem differential and common mode impedances may vary widely from the 100 ohms and 50 ohms used for calibration.

The actual level of the differential and common mode impairments with the modems present will be a function of the common mode and differential impedances of the modems and test loops.

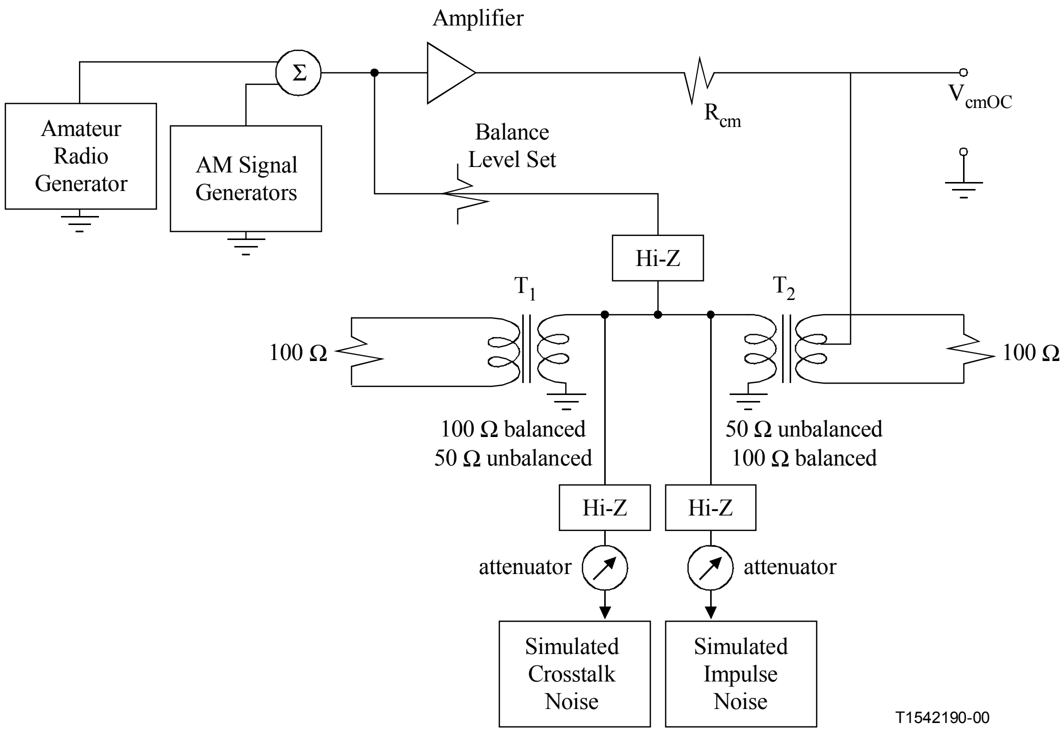


Figure 3a/G.996.1 – Calibration circuit for impairments

Crosstalk testing

The simulated XT should ideally have the power and spectral density defined by the equations for NEXT and FEXT in clause 7, "Power spectral density of crosstalk disturbers." It is acknowledged, however, that if the method of generating the simulated XT is similar to that shown in Figure 3, then its accuracy will depend on the design of the filter used to shape the white noise. Therefore, a calculated XT PSD may be defined for which a tolerance on f_0 of ±2% is allowed at each null. Then the accuracy of the simulated XT shall be within ±1 dB of the calculated XT for all frequencies at which the calculated value is less than 45 dB below the peak value. The total power of the simulated XT shall be within ±0.5 dB of the specified value using the same calibration termination.

The simulated XT PSD shall be verified using the calibration termination shown in Figure 3 and a selective voltmeter or true RMS metre with a bandwidth of approximately 3 kHz. For DSL and HDSL crosstalk the circuit shall be calibrated for 1.3 dB less crosstalk than specified in clause 7, in order to compensate for the use of 100-ohm terminations instead of 135 ohms.

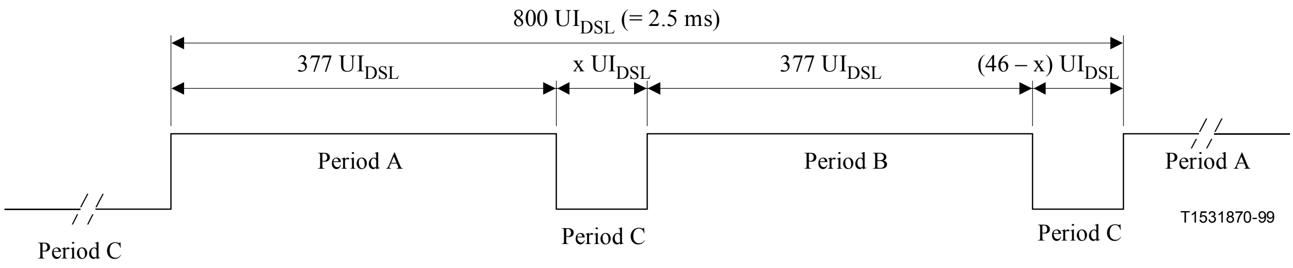
Care should be taken when specifying the white noise generator in Figure 3; consideration should be given to the following factors:

– The probability distribution of the peak amplitude: The noise shall be Gaussian within all frequency bands.
– Crest factor: The crest factor is an indication of the number of standard deviations to which the noise follows a Gaussian distribution; the required minimum crest factor is 5.
– The frequency spectrum: If the noise is generated using digital methods the sequence repetition rate will affect the correlation of the samples, and hence the frequency spectrum.
– The noise BW shall be at least from 12 kHz to 2.208 MHz.

5.1.2.1.1 Crosstalk injection for TCM-ISDN environment

For testing transmission performance of an ADSL system conforming to Annex C/G.992.1 and Annex C/G.992.2 (ADSL operating in an environment coexisting with TCM-ISDN DSL), the calibrated simulated TCM-ISDN DSL NEXT PSD and TCM-ISDN DSL FEXT PSD defined in clause 7 shall be alternately injected in burst mode as specified in Figure 4, which is the same as the TCM-ISDN DSL signal transceiver scheme. The value of x in the figure may be fixed during testing transmission performance.

The specified error threshold and minimum performance margin shall be met for an arbitrary value of x in the range of $6 \le x \le 40$.



Period A DSL NEXT noise injection
Period B DSL FEXT noise injection
Period C DSL XT noise non-injection
$6 \le x \le 40$
NOTE – 1 UI_{DSL} = 3.125 µs

Figure 4/G.996.1 – TCM-ISDN DSL crosstalk injection method

5.1.2.2 Crosstalk test and RFI method

Before testing, the DSL units are trained with the required crosstalk and RFI interference present. The simulated crosstalk power and RFI is injected at the appropriate reference level. This power level is considered the 0 dB margin level for that type and number of disturbers. For example, the 0 dB margin level for 24-disturber DSL NEXT is –52.6 dBm. Margin measurements are made by changing, in whole dB steps, the power level of the crosstalk and RFI injected at the transceiver and monitoring the BER over the test loops. A tested system has positive margin for a given type of crosstalk and RFI on a given loop if the system was able to operate at the specified BER with injected crosstalk power greater than the 0 dB margin level. If the simulated crosstalk and RFI are summed with background noise to obtain the simulated interference, the power level of the background noise is increased with the power level of the crosstalk and RFI interference during margin testing.

Note that for RFI testing, Amateur Radio interference is not injected during training. Amateur radio interference is only injected at full power level during margin testing.

The criteria for margin level determination shall include a check that the DSL unit can train at the margin level.

The minimum testing times to determine BERs with 95% confidence are shown in Table 1.

Table 1/G.996.1 – Minimum test time for crosstalk

Bit rate	Minimum test time
Above 6 Mbit/s	100 s
1.544 Mbit/s to 6 Mbit/s	500 s
Less than 1.544 Mbit/s	20 min

5.1.3 Impulse noise test

Impulse noise testing is performed to evaluate the performance of DSL systems in the presence of impulse noise.

5.1.3.1 Impulse noise injection

The same coupling circuit as in 5.1.2.1 is used for impulse noise injection. The amplitude level of the impulses may be measured with an oscilloscope.

5.1.3.2 Impulse noise test method

Before testing, the DSL units are trained with the required crosstalk interference. The test procedure consists of injecting the selected impulse waveform at varying amplitude levels and random phase. At each level the impulse is applied 15 times with a spacing of at least one second while an error measurement is made on the DSL channels. The amplitude (u_e) in millivolts at which half the impulses cause an error is determined for each wave form.

Using the above amplitude determinations, the following equation gives the estimated probability that a second will be errored:

$$E = 0.0037\, P(u > u_e 1) + 0.0208\, P(u > u_e 2)$$

where:

$$P(u > u_e) = \frac{25}{u_e^2}, \quad \text{for} \quad 5\,mV = u_e = 40\,mV$$

$$P(u > u_e) = \frac{0.625}{u_e}, \quad \text{for} \quad u_e > 40\,mV$$

$u_e 1$ refers to waveform 1

$u_e 2$ refers to waveform 2

The resulting probability of errored seconds (ES) value shall be less than 0.14%.

5.1.4 POTS interference test

POTS interference test is performed to evaluate the performance of DSL systems in the presence of POTS signalling.

5.1.4.1 POTS interference injection

The interference due to POTS service on the same line is generated by use of actual telephones and central office circuits connected in the normal way to the system under test. The following POTS signalling and alerting activities shall be performed:

– call phone at ATU-R and allow to ring 25 times;
– pick up ringing phone at ATU-R, 25 times;
– perform off-hook and on-hook activity on phone at ATU-R, 25 times;
– perform pulse and tone dialling.

5.1.4.2 POTS interference test method

Before testing, the DSL units are trained with the required crosstalk interference. Signalling disturbances are created through use of the CO line connected to the splitter at the ATU-C, and the telephone set connected to the telephone jack of the splitter at the ATU-R. During these activities the DSL channels shall be monitored while noting any test conditions that cause errored seconds.

5.2 DSL operation without a splitter at the ATU-R

5.2.1 Laboratory setup

Figure 5 shows the test setup for measuring performance margins for the downstream channel in DSL systems without a splitter at the ATU-R. Figure 6 shows the test setup for measuring performance margins for the upstream channel in DSL systems without a splitter at the ATU-R. The test setup permits differential and common mode signals to be superimposed on a working link, to simulate ingress situations. The test system consists of a central office transceiver (ATU-C), a remote end transceiver (ATU-R), and splitter at the ATU-C. The two transceivers are connected together by the test loop and the in-home wiring model. Crosstalk, impulses and RFI are injected at the ATU-R for downstream tests, and at the ATU-C for upstream channel tests.

For downstream testing, pseudo-random binary data from the transmitter of the bit error rate (BER) test set is presented at the downstream channel input of the ATU-C. The downstream channel output from the ATU-R is connected to the receiver of the same or a similar BER test set. The test set measures BER or errored seconds (ES), as needed. Similar error testing is done in the upstream direction both at the rates needed for the particular system under test.

A working telephone line circuit is connected to the telephone jack on the splitter at the ATU-C. At the ATU-R, telephones may be added places in the in-home wiring model.

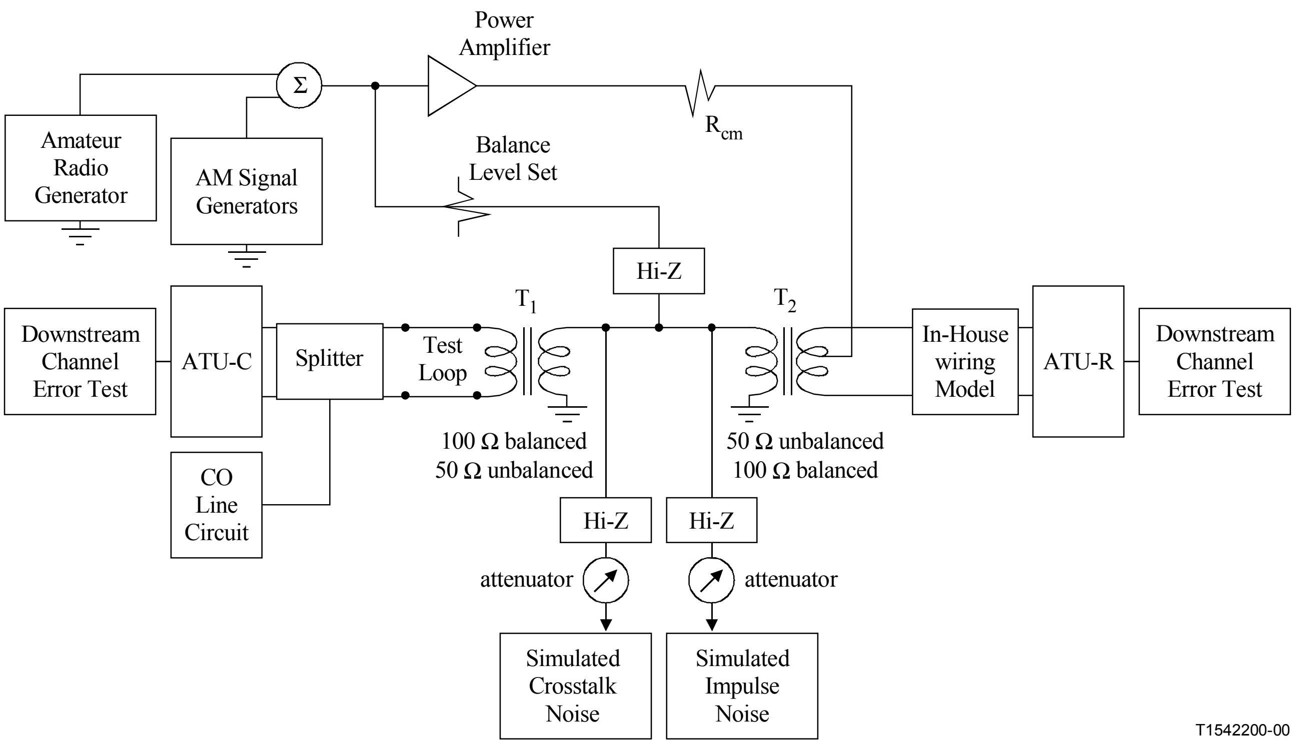


Figure 5/G.996.1 – Laboratory test setup for measuring performance margins for the downstream channel without a splitter at the ATU-R

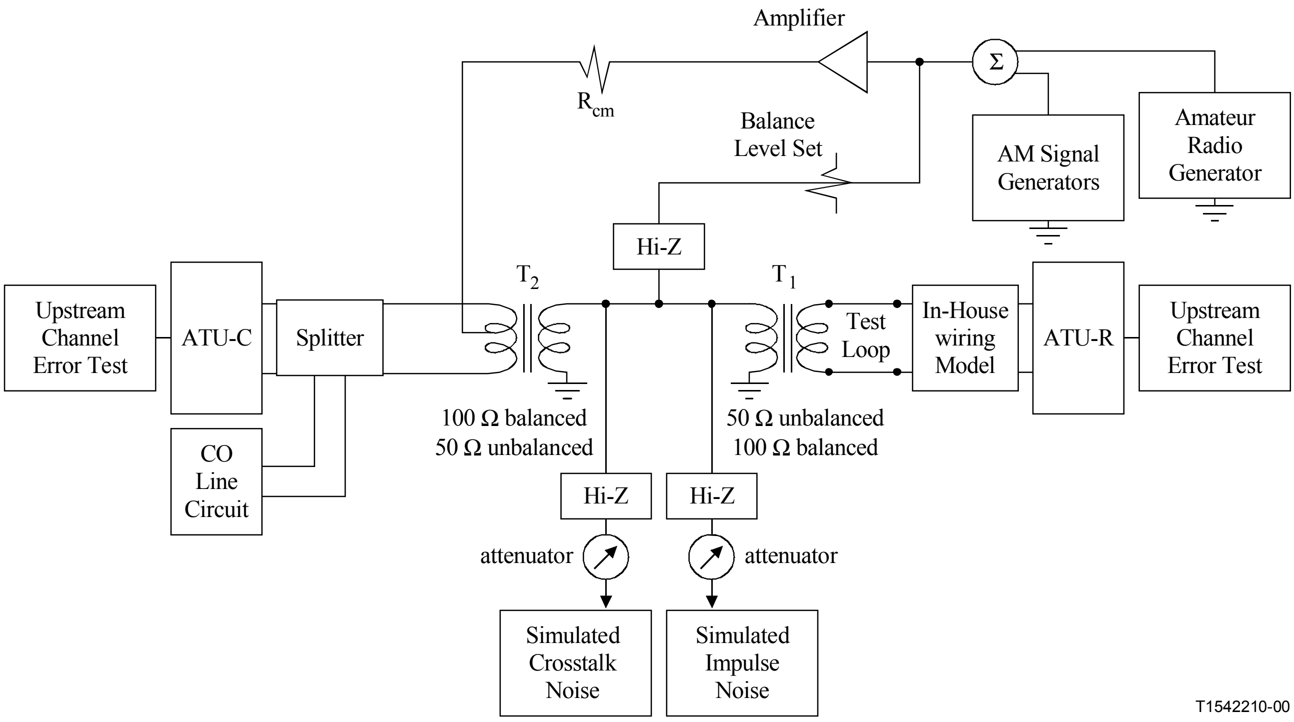


Figure 6/G.996.1 – Laboratory test setup for measuring performance margins for the upstream channel without a splitter at the ATU-R

The test set is essentially transparent in both directions between the transformers T_1 and T_2, so a normal working connection can be set up in the presence or absence of ingress.

T_1 is a precision balun transformer. This minimizes the effects of any ingress that may be present. Note, however, that it will not compensate for pickup due to a poorly balanced facility connected to this port. The 50-ohm unbalanced signal from T_1 passes via T_2 to the receiving modem. Crosstalk and voice signals and the differential portion of the ingress signal are applied via hi-Z attenuators to the 50-ohm link between the transformers. T_2 is a precision balun transformer, so it does not contribute significant imbalance at the receiving modem. Any imbalance at this port will be due to the modem itself.

The common mode ingress signal is applied via linear power amplifier A_1 and resistor R_{cm} to the centre tap of T_2. Amplifier A_1 must be capable of producing the required signal level while keeping any resulting differential intermodulation products that fall in-band ≤113 dBm in any channel (this is equivalent to –150 dBm/Hz across 4.3125 kHz). Assuming that the modem under test has a differential balance of 35 dB, to make the resulting differential component from the 0 dBm common mode signal be ≤113 dBm in any channel requires the common mode intermodulation products at the centre tap of T_2 to be –78 dBm. Filtering at the amplifier output may be used to achieve this.

R_{cm} is included so that the longitudinal impedance of the facility is properly modelled. This is necessary because this impedance, together with the common-mode input impedance of the modem under test, can affect the test result. A value of 200 ohms is suggested for R_{cm}. It is assumed here that the amplifier has negligible output impedance; if it does not, the circuit can be modified accordingly. Similarly, any filter inserted at the amplifier output should be sufficiently transparent within the pass band that this impedance is maintained.

No phase alignment between the common mode and differential signals is proposed. It is possible that in some modems a specific alignment may be beneficial. By testing in two alignments differing by 90 degrees this advantage could be removed. However, this would double the test time. By not specifying the alignment it is intended that modems will by designed for all possible alignments, as in the field no specific alignment can be assumed.

Required attributes of test equipment

- The Thevenin impedance of all differential noise-coupling circuits connected to the test loop shall be greater than 4000 ohms referred to a 100-ohm impedance point.
- Common Mode Source Impedance = 200 ohms.
- The attenuation of the combining circuit must be correctly compensated for in the signal and interference paths. There is an advantage to a minimized loss in the signal path, as this flat loss would need to be removed from the line model loss.
- The test setup should have a minimum balance of 60 dB. This is 20 dB better than the specified ratio of common mode to differential of 40 dB.

The test circuit must not create excessive spurious products that fall within the band of the test signal. The specification of –113 dBm in a 4.3125 kHz window corresponds to –150 dBm/Hz, and should be sufficient not to bias the tests as it is 10 dB below the white noise floor.

5.2.2 Crosstalk and RFI test

Crosstalk and RFI testing is performed to evaluate the performance of DSL systems in the presence of crosstalk from other services in the loop and RF ingress.

5.2.2.1 Crosstalk and RFI injection

Simulated crosstalk, XT (NEXT and/or FEXT) and RFI is introduced into the test loop as described in 5.1.2.1.

5.2.2.1.1 Crosstalk injection for TCM-ISDN environment

For testing transmission performance of an ADSL system conforming to Annex C/G.992.2 (ADSL operating in an environment coexisting with TCM-ISDN DSL), the calibrated simulated TCM-ISDN DSL NEXT PSD and TCM-ISDN DSL FEXT PSD defined in clause 7 shall be injected into the test loop as described in 5.1.2.1.1.

5.2.2.2 Crosstalk test method

Crosstalk testing shall be performed as described in 5.1.2.2.

5.2.3 Impulse noise test

Impulse noise testing is performed to evaluate the performance of DSL systems in the presence of impulse noise.

5.2.3.1 Impulse noise injection

The same coupling circuit as in 5.1.2.1 is used for impulse noise injection. The amplitude level of the impulses may be measured with an oscilloscope.

5.2.3.2 Impulse noise test method

Impulse noise testing shall be performed as described in 5.1.3.2.

5.2.4 POTS interference test

POTS interference test is performed to evaluate the performance of DSL systems in the presence of POTS signalling.

5.2.4.1 POTS interference injection

The interference due to POTS service on the same line is generated by use of a telephone model structure and central office circuits connected in the normal way to the system under test. The telephone structure is described in clause 9 and should be connected to the appropriate points in the in-home wiring model (see 6.2). The following POTS signalling and alerting activities shall be performed:

– call ATU-R phones and allow to ring 25 times;

– pick up ringing phone "A" (see Figure 12) and hold in off-hook position;

– return phone "A" to on-hook position.

Repeat above steps 25 times.

5.2.4.2 POTS testing without a splitter at the ATU-R

Before testing, the DSL units are trained with the required crosstalk interference. Signalling disturbances are created through use of the CO line connected to the splitter at the ATU-C, and the telephone model structure connected to telephone jacks in the in-home wiring model (see 6.2). During the signalling activities described in 5.1.4.1, the system is tested by measuring:

– the time required to achieve errorless transmission after a signalling event has occurred (measure fast retrain time);

– the data rates in the on-hook and off-hook states.

Note that in the first on-hook to off-hook transition the retrain time will be much longer since a full initialization is required in order to generate the off-hook profile that is matched to phone "A". Subsequent on-hook to off-hook transitions should use a fast retrain and the stored profile for phone "A".

5.3 POTS QoS testing

5.3.1 Telephone circuitry

Figure 7 shows a simplified block diagram of a typical telephone, with signal flow direction indicated by arrows in the connections between blocks. Signal flow on the left side of the 2W/4W hybrid is generally bidirectional, and non-linear distortion generated in this area can result in reflected harmonic and intermodulation components appearing across tip and ring. Signal flow on the right side of the hybrid is generally unidirectional. Non-linear distortion of DSL signals in the speaker driver can result in audible energy at the speaker, but will generally not result in energy seen on the local loop. The microphone interface, of course, is not exposed to DSL energy in the first place, so non-linear distortion in that area is not an issue.

Within the bidirectional line interface, most components are on the side of the hook switch away from tip and ring. This includes the vast majority of sources of non-linear distortion, which are isolated from the loop when the telephone is on-hook.

Measurement criteria

The following criteria must be incorporated when evaluating interference between DSL and POTS channels for a splitterless DSL technology:

– The primary configuration for measurement of channel interference shall be with one or more telephone devices in an off-hook condition. Most of the circuitry in a typical telephone (including, in nearly all cases, any components which cause non-linear distortion of a DSL signal) is located on the telephone side of the hook switch, and is isolated from DSL signals when the phone is on-hook (see Figure 7). While measurement of energy in the POTS band during on-hook conditions is an appropriate parameter for both splitterless and conventional

DSL systems, it is not sufficient by itself for evaluation of splitterless systems – in fact, it is considerably less meaningful than measurements taken with phones off-hook.

– Interference measurements must include the sound pressure output at the telephone speaker. It is not sufficient to measure the non-linear and intermodulation components generated across tip and ring, as some or all of the distortion can take place on the four-wire side of the telephone hybrid, causing audible noise at the speaker even in the absence of audio band energy on the line. Direct measurement of electrical power at the speaker terminals may not be sufficient due to varying speaker conversion characteristics. For POTS modem and facsimile devices, other measurements related to performance degradation would of course replace a sound pressure measurement.

– Interference measurements should also include components generated across tip and ring. Excessive harmonic content on the line may result in reduced performance or even failure to connect in the downstream direction over longer loops.

– There is a broad range of telephone devices which must be accommodated by any splitterless DSL solution. Test results based on a narrow sampling of devices will not accurately reflect performance in the field. Test results presented should include the types and numbers of devices used, to provide some indication of how representative the database may be.

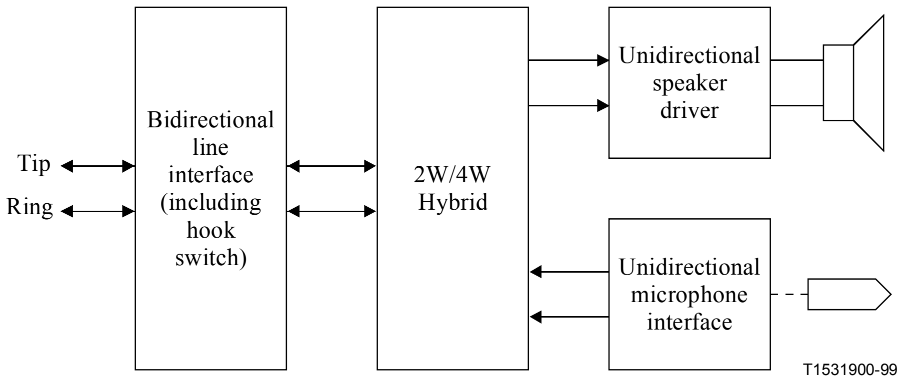


Figure 7/G.996.1 – Typical telephone signal flow

5.3.2 Test conditions

The configuration used for testing DSL transceivers for interference with off-hook telephones is shown in Figure 8. A control telephone (with microphone disconnected) is routed through a POTS network simulator to provide switching and signalling functions for the POTS connection. The POTS network simulator shall be capable of introducing GSTN-band electrical noise as is commonly available in simulators designed to test dial modems per ITU-T V.56 *bis*. The other side of the POTS network simulator is routed through a central office POTS splitter to isolate the DSL channel from the POTS network simulator. The DSL/POTS combined port of the CO POTS splitter is routed through a wideband local loop simulator to the local telephone and the local (ATU-R) transceiver. The central office transceiver (ATU-C) is connected to the appropriate port on the CO POTS splitter. A condenser microphone is acoustically coupled to the telephone handset by positioning it approximately 1 mm away from, and aligned with, the centre axis of the handset speaker. The space between the microphone and the speaker is left unsealed. The microphone and handset are placed in an isolated environment to minimize ambient noise. Sound levels from the handset speaker are measured using a sound level meter, using B weighting per IEC 651 and slow response time. The zero dB sound power reference is 20 µPa.

A signal analyser is used to view the signal characteristics directly across tip and ring using a differential high impedance probe. This analyser is used to set and verify signal levels from the DSL transmitter and to verify test conditions.

For each test case, a POTS connection is established and the sound output of the telephone speaker is recorded without a DSL signal present to establish a control level. Some Recommendations specify or allow the use of a filter in series with the local telephone (e.g. customer premise POTS splitter, in-line filter, etc). The position of this optional filter is shown in Figure 8 with a dashed box.

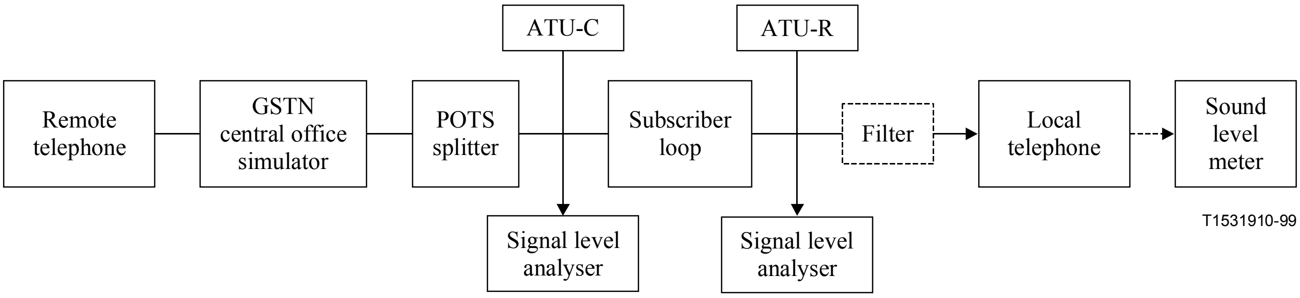


Figure 8/G.996.1 – Test configuration

5.3.3 Summary of test procedure

1) ATU-C/ATU-R transmitters are off. GSTN simulator noise is off. Remote telephone is quiet. Loop length is zero.
2) A GSTN connection is established between remote telephone and local telephone.
3) The acoustic energy of the local telephone speaker is measured for reference: **SP1** (this establishes the acoustic noise floor as measured at the local telephone).
4) The GSTN noise is turned on at the acceptable GSTN service dBrn level of the GSTN service requirement.
5) The acoustic energy of the local telephone speaker is measured: **SP2** (SP2 is thus the acoustic equivalent of the acceptable GSTN service noise on this particular telephone).
6) GSTN simulator noise is turned off. ATU-C/ATU-R transmitters are turned on at their prescribed transmit levels.
7) The acoustic energy of the local telephone speaker is measured: **SP3**. The test result is the difference between SP2 and SP3 in dB. If the test result is positive, i.e. SP3 < SP2, then the DSL equipment does not introduce audio noise in excess of that allowed by the GSTN service for the local telephone used.

Test variations

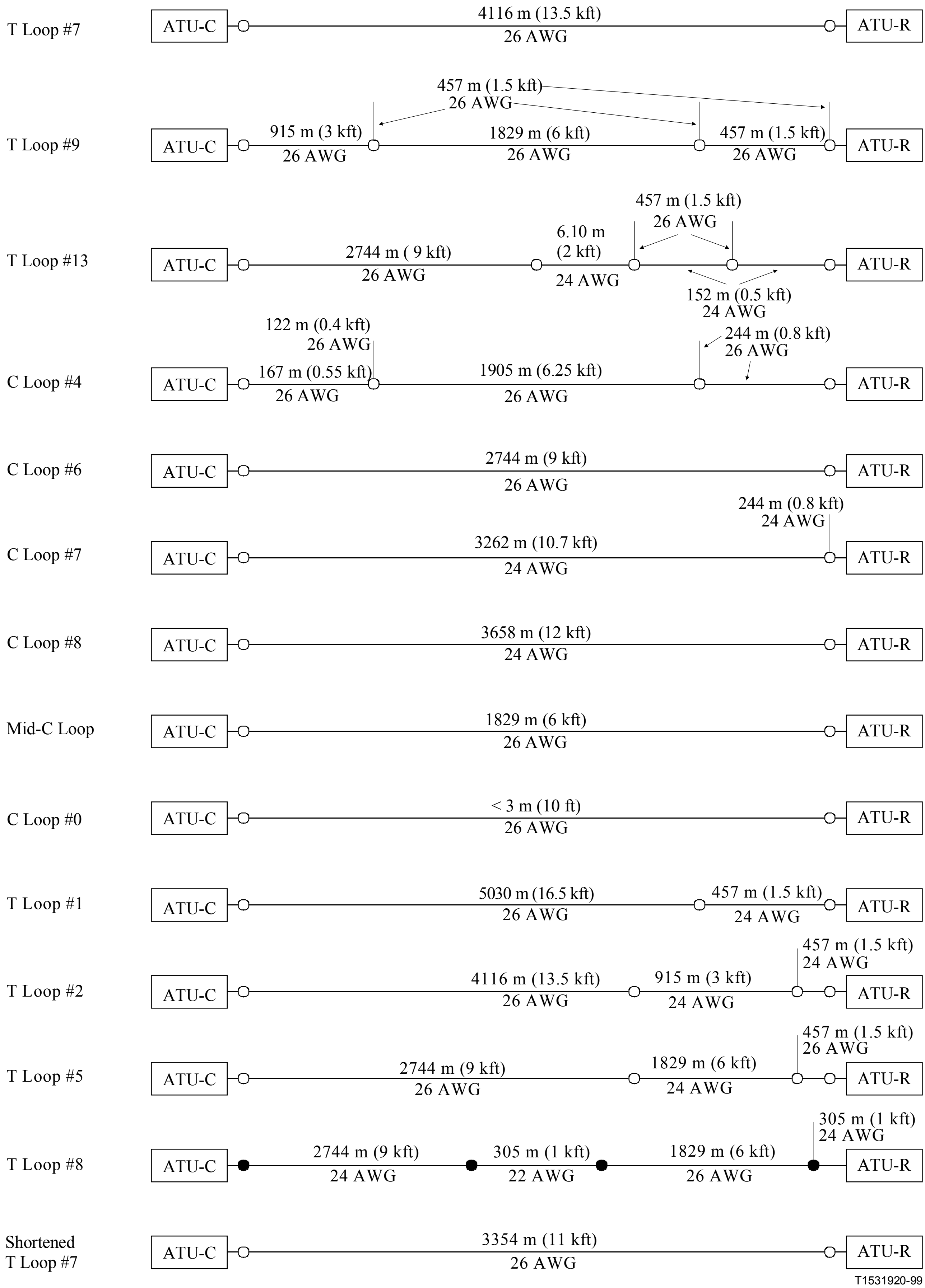
The GSTN requirement may have two dBrn thresholds that require testing. For example, <20 dBrnC may represent preferred service and >30 dBrnC may be unacceptable service.

6 Test loops

6.1 Local loop configurations

6.1.1 North American test loops

See Figure 9.



NOTE – AWG (*American Wire Gauge*) (26 AWG = 0.4 mm, 24 AWG = 0.5 mm, 22 AWG = 0.65 mm).

Figure 9/G.996.1 – North American test loop

Resistance and insertion loss

Tables 2, 3 and 4 provide the calculated resistance and insertion loss between 100-ohm terminations of the loops shown in Figure 9.

Table 2/G.996.1 – Resistance and insertion loss in dB for test loops at 70° F (21.1° C)

Loop #	Resistance (ohms)	Frequency (kHz)											
		20	40	100	200	260	300	400	500	600	780	1100	
T # 7	1127	29.8	36.7	45.2	52.8	57.3	60.2	67.7	74.8	81.7	93.0	110	Insertion loss (dB)
T # 9	877	27.6	36.4	52.5	47.5	55.7	62.0	60.3	71.5	72.2	82.7	96.2	
T # 13	909	26.6	34.1	47.9	48.3	55.7	61.3	62.2	71.4	74.1	85.3	100	
C # 4	634	17.6	22.0	29.6	39.6	40.1	42.5	49.2	50.2	53.8	55.7	70.7	
C # 6	751	20.0	24.4	30.1	35.2	38.2	40.2	45.1	49.9	54.4	62.0	73.6	
C # 7	562	17.3	20.9	26.8	33.6	37.8	38.6	43.1	49.9	57.9	60.2	72.7	
C # 8	630	19.2	22.8	27.7	34.4	38.3	40.8	46.9	52.4	57.4	65.4	77.8	
Mid-C	501	13.3	16.2	20.0	23.4	25.4	26.8	30.1	33.2	36.3	41.3	49.1	

Table 3/G.996.1 – Resistance and insertion loss in dB for test loops at 90° F (32.2° C)

Loop #	Resistance (ohms)	Frequency (kHz)											
		20	40	100	200	260	300	400	500	600	780	1100	
T # 7	1176	30.6	37.9	46.9	54.6	59.1	62.1	69.6	76.6	83.4	95.0	113	Insertion loss (dB)
T # 9	915	28.4	37.5	53.4	49.1	57.2	63.1	61.9	72.8	73.6	84.2	98.1	
T # 13	948	27.4	35.2	49.0	49.9	57.2	62.5	63.7	72.8	75.6	87.0	102	
C # 4	658	18.0	22.6	30.4	40.3	41.0	43.5	50.0	50.9	54.3	56.6	71.6	
C # 6	784	20.5	25.2	31.2	36.4	39.4	41.4	46.4	51.1	55.6	63.3	75.2	
C # 7	586	17.9	21.6	27.7	34.0	38.7	39.5	44.1	50.9	58.8	61.4	74.0	
C # 8	657	19.8	23.6	28.7	35.4	39.3	41.8	47.9	53.5	58.6	66.8	79.4	
Mid-C	523	13.8	16.7	20.7	24.2	26.2	27.6	30.9	34.0	37.1	42.2	50.1	

Table 4/G.996.1 – Resistance and insertion loss in dB for test loops at 120° F (48.9° C)

Loop #	Resistance (ohms)	Frequency (kHz)											
		20	40	100	200	260	300	400	500	600	780	1100	
T # 7	1250	31.9	39.6	49.4	57.4	61.8	64.8	72.3	79.3	86.1	97.9	116	Insertion loss (dB)
T # 9	972	29.5	39.1	54.7	51.5	59.5	65.0	64.1	74.4	75.7	86.4	101	
T # 13	1008	28.5	36.8	50.7	52.3	59.5	64.5	66.0	74.9	77.9	89.4	105	
C # 4	704	18.9	23.8	32.2	41.9	42.8	45.2	51.5	52.8	56.0	58.7	74.1	
C # 6	833	21.4	26.3	32.8	38.2	41.2	43.2	48.2	52.9	57.4	65.3	77.5	
C # 7	623	18.7	22.6	29.1	36.2	40.0	43.2	45.5	52.5	60.2	63.2	76.0	
C #8	699	20.7	24.8	30.2	36.9	40.8	43.3	49.4	55.1	60.4	68.8	81.7	
Mid-C	555	14.4	17.5	21.8	25.5	27.5	28.8	32.1	35.1	38.3	43.5	51.6	

Primary constants

The primary constants R, L, C, and G of polyethylene-insulated cable (PIC), at 0° F, 70° F, and 120° F, are tabulated in Annex A.

The variation of R and L with frequency can be accurately modelled as follows:

$$R = \left(roc^4 + ac \times f^2\right)^{\frac{1}{4}}$$

and

$$L = \frac{L_0 + L_8 \times xb}{1 + xb}$$

where: $xb = \left(\frac{f}{fm}\right)^b$

The six coefficients for 24 and 26 AWG PIC cable per km at 70° F are given in Table 5.

Table 5/G.996.1 – Coefficients for calculation of *R* and *L*
[24 and 26 AWG PIC at 70° F (21.1° C)]

	roc	ac	L_0	L_8	*fm*	*b*
24 AWG	174.559	0.05307	617.295	478.971	553.76	1.15298
26 AWG	286.176	0.14769620	675.369	488.952	806.339	0.929

For PIC cable, the C values are constant with frequency 51.56 nF/km, and the G values are negligibly small.

6.1.2 European local test loops

The variation of the primary line constants (R, L and C) with frequency for the different reference cable types are given in Tables 7 and 8. Note that G is assumed to be zero. The RLC values are quoted per km at a temperature of 20° C and are measured values that have been smoothed.

The variation of R and L with frequency can be accurately modelled as follows:

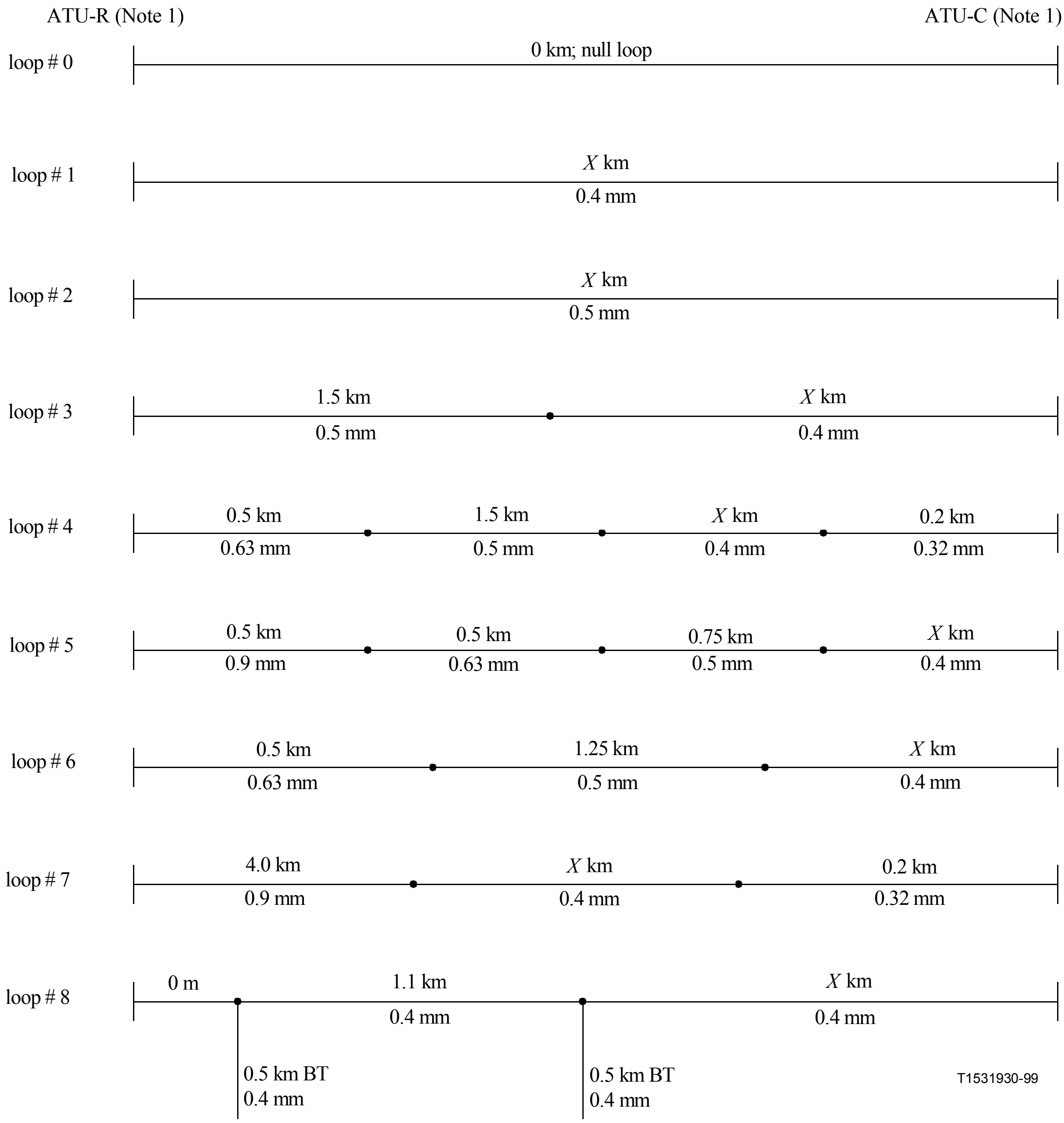
$$R = \left(roc^4 + ac \times f^2\right)^{\frac{1}{4}}$$

and

$$L = \frac{L_0 + L_8 \times xb}{1 + xb}$$

where: $xb = \left(\frac{f}{fm}\right)^b$

The six coefficients for the cable types referenced in Figure 10 are given in Table 9. Note also that there are adjustable sections (marked "X") in Table 10. The nominal lengths of these sections are shown in Table 6. The lengths of the sections are based on the reference RLC values for each cable type shown in Tables 7 and 8. For repeatability of measurement results, however, the lengths of these section lengths shall be adjusted to give the overall insertion loss given in Table 6. Insertion loss is measured at 300 kHz with 100 Ω (balanced resistive) source and termination impedances.



NOTE 1 – These test loops are shown with the ATU-Rs on the left; this is the European convention, which is in contrast to Figure 9, where the ATU-Rs are on the right.

NOTE 2 – All cable is Polyethylene insulated.

NOTE 3 – 1 km = 3.28 kft.

NOTE 4 – BT = Bridged tap (i.e. section of unterminated cable).

Figure 10/G.996.1 – ETSI test loops

Table 6/G.996.1 – Examples of loop set insertion loss, nominal lengths for European testing

Loop #	Loop insertion loss 36 dB at 300 kHz	Loop insertion loss 36 dB at 300 kHz	Loop insertion loss 51 dB at 300 kHz	Loop insertion loss 61 dB at 300 kHz
	Nominal value of adjustable length "X" (km)	Nominal value of adjustable length "X" (km)	Nominal value of adjustable length "X" (km)	Nominal value of adjustable length "X" (km)
1	2.55	2.55	3.60	4.30
2	3.40	3.40	4.80	5.70
3	1.40	1.40	2.45	3.15
4	0.90	0.90	1.90	2.65
5	1.45	1.45	2.50	3.20
6	1.30	1.30	2.35	3.05
7	0.60	0.60	1.60	2.20
8	0.75	0.75	1.80	2.50

Table 7/G.996.1 – RLC values for 0.32, 0.4, and 0.5 mm PE cables

	0.32 mm C = 40 nF/km		0.4 mm C = 50 nF/km		0.5 mm C = 50 nF/km	
Freq. (kHz)	**R (ohm/km)**	**L (mH/km)**	**R (ohm/km)**	**L (mH/km)**	**R (ohm/km)**	**L (mH/km)**
0	409.000	607.639	280.000	587.132	179.000	673.574
2.5	409.009	607.639	280.007	587.075	179.015	673.466
10	409.140	607.639	280.110	586.738	179.244	672.923
20	409.557	607.639	280.440	586.099	179.970	671.980
30	410.251	607.639	280.988	585.322	181.161	670.896
40	411.216	607.639	281.748	584.443	182.790	669.716
50	412.447	607.639	282.718	583.483	184.822	668.468
100	422.302	607.631	290.433	577.878	199.608	661.677
150	437.337	607.570	302.070	571.525	218.721	654.622
200	456.086	607.327	316.393	564.889	239.132	647.735
250	477.229	606.639	332.348	558.233	259.461	641.208
300	499.757	605.074	349.167	551.714	279.173	635.119
350	522.967	602.046	366.345	545.431	298.103	629.489
400	546.395	596.934	383.562	539.437	316.230	624.309
450	569.748	589.337	400.626	533.759	333.591	619.557
500	592.843	579.376	417.427	528.409	350.243	615.202
550	615.576	567.822	433.904	523.385	366.246	611.211
600	637.885	555.867	450.027	518.677	381.657	607.552
650	659.743	544.657	465.785	514.272	396.528	604.192
700	681.138	534.942	481.180	510.153	410.907	601.104
750	702.072	526.991	496.218	506.304	424.835	598.261
800	722.556	520.732	510.912	502.707	438.348	595.639
850	742.601	515.919	525.274	499.343	451.480	593.217
900	762.224	512.264	539.320	496.197	464.258	590.975
950	781.442	509.503	553.064	493.252	476.71	588.896
1000	800.272	507.415	566.521	490.494	488.857	586.966
1050	818.731	505.831	579.705	487.908	500.720	585.169
1100	836.837	504.623	592.628	485.481	512.317	583.495
NOTE – G = 0 at all frequencies.						

Table 8/G.996.1 – RLC values for 0.63 and 0.9 mm PE cables

	0.63 mm C = 45 nF/km		0.9 mm C = 40 nF/km	
Freq. (kHz)	**R (ohm/km)**	**L (mH/km)**	**R (ohm/km)**	**L (mH/km)**
0	113.000	699.258	55.000	750.796
2.5	113.028	697.943	55.088	745.504
10	113.442	693.361	56.361	731.961
20	114.737	687.008	59.941	716.775
30	116.803	680.714	64.777	703.875
40	119.523	674.593	70.127	692.707
50	122.768	668.690	75.586	682.914
100	143.115	642.718	100.769	647.496
150	164.938	622.050	121.866	625.140
200	185.689	605.496	140.075	609.652
250	204.996	592.048	156.273	598.256
300	222.961	580.960	170.987	589.504
350	239.764	571.691	184.556	582.563
400	255.575	563.845	197.208	576.919
450	270.533	557.129	209.104	572.237
500	284.753	551.323	220.365	568.287
550	298.330	546.260	231.081	564.910
600	311.339	541.809	241.326	561.988
650	323.844	537.868	251.155	559.435
700	335.897	534.358	260.615	557.183
750	347.542	531.212	269.745	555.183
800	358.819	528.378	278.577	553.394
850	369.758	525.813	287.138	551.784
900	380.388	523.480	295.452	550.327
950	390.734	521.352	303.538	549.002
1000	400.816	519.402	311.416	547.793
1050	410.654	517.609	319.099	546.683
1100	420.264	515.956	326.602	545.663
NOTE – G = 0 at all frequencies.				

Table 9/G.996.1 – Coefficients for calculation of *R* and *L*

	roc	ac	L_0	L_8	*fm*	*b*
0.32 mm	0.4090	0.3822	0.6075	0.5	0.6090	5.269
0.4 mm	0.2800	0.0969	0.5873	0.4260	0.7459	1.385
0.5 mm	0.1792	0.0561	0.6746	0.5327	0.6647	1.195
0.63 mm	0.113	0.0257	0.6994	0.4772	0.2658	1.0956
0.9 mm	0.0551	0.0094	0.7509	0.5205	0.1238	0.9604

6.1.3 Test loops in an environment coexisting with TCM-ISDN DSL

To test the performance of the G.992.1 and G.992.2 transceivers, the test loops specified in Figure 11 shall be used. Note that there are adjustable sections (marked "X") in the figure. The nominal lengths of these sections corresponding to each loop coverage are shown in Table 10. The lengths of the sections are based on the reference RLC values for each cable type shown below. The calculated overall loop insertion loss at 300 kHz and d.c. loop resistance are also provided in Table 10.

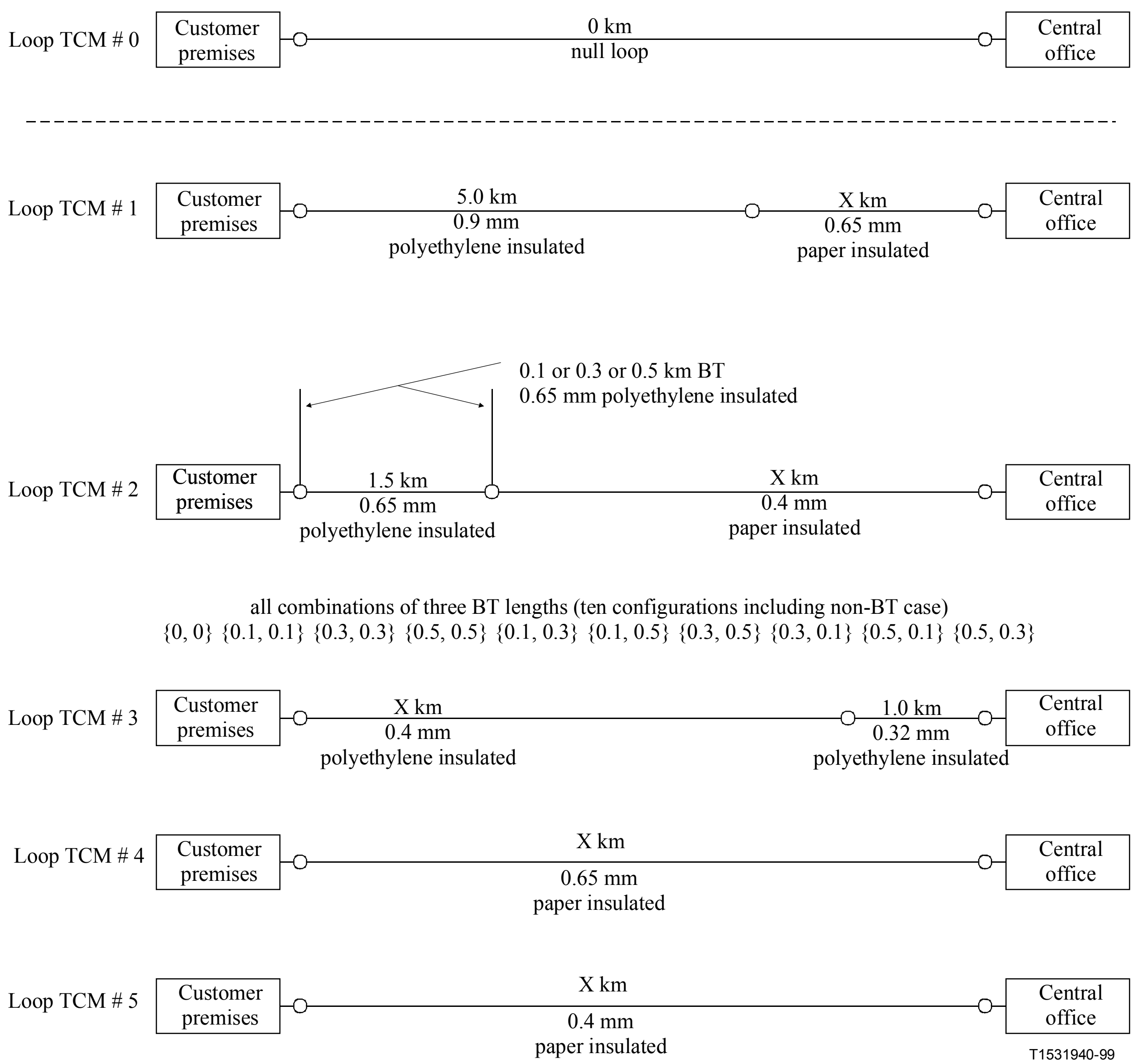


Figure 11/G.996.1 – Test loop in an environment coexisting with TCM-ISDN DSL

Table 10/G.996.1 – Loop-set insertion loss and nominal lengths

Loop insertion loss (160 kHz)	Loop TCM #	Nominal value of "X"	Total loop length	Loop insertion loss (300 kHz)	Group delay (µs) (160 kHz)	d.c. loop resistance
26.0 dB (60% coverage)	1	0.42 km	5.42 km	36.1 dB	28.8	314 ohms
	2	1.32 km	2.82 km	34.6 dB	15.5	518 ohms
	3	0.78 km	1.78 km	31.9 dB	9.8	642 ohms
	4	3.62 km	3.62 km	37.0 dB	19.3	376 ohms
	5	2.07 km	2.07 km	34.0 dB	11.4	567 ohms
37.0 dB (90% coverage)	1	1.95 km	6.95 km	51.8 dB	37.0	474 ohms
	2	2.19 km	3.69 km	49.0 dB	20.2	758 ohms
	3	1.75 km	2.75 km	45.6 dB	15.4	910 ohms
	4	5.15 km	5.15 km	52.7 dB	27.5	536 ohms
	5	2.94 km	2.94 km	48.3 dB	16.1	807 ohms
50.0 dB (99% coverage)	1	3.76 km	8.76 km	70.3 dB	46.6	662 ohms
	2	3.23 km	4.73 km	66.0 dB	25.9	1041 ohms
	3	2.91 km	3.91 km	61.7 dB	22.0	1227 ohms
	4	6.97 km	6.97 km	71.2 dB	37.2	724 ohms
	5	3.97 km	3.97 km	65.3 dB	21.8	1090 ohms
65.0 dB (99.9% coverage) (for G.992.2 only)	1	5.85 km	10.85 km	91.7 dB	57.8	879 ohms
	2	4.42 km	5.92 km	85.6 dB	32.5	1368 ohms
	3	–	–	–	–	–
	4	9.06 km	9.06 km	92.6 dB	48.3	941 ohms
	5	5.16 km	5.16 km	84.9 dB	28.3	1417 ohms

NOTE 1 – The values in the table for Loop TCM #2 are given by considering only the section terminated by Customer Premises and Central Office, on condition of detaching the bridge taps (BTs). The effect on the overall insertion loss characteristics caused by the BTs is not taken into account.

NOTE 2 – Test loops of the 60-99% coverage are for use with the G.992.1 performance testing. Test loops of the 60-99.9% coverage are for use with the G.992.2 performance testing. It is not necessary to comply with NEXT/FEXT PSL values ($NPSL_n/FPSL_n$) defined in 7.9 for test loops of the 99.9% coverage. The resultant net data rates may be given as a function of $NPSL_n/FPSL_n$ values for this case.

NOTE 3 – TCM #3 for 99.9% coverage is removed from the list because the d.c. loop resistance is greater than 1500 ohms.

Primary line constants

The primary line constants are R, L, C, and G. The variation of *R*, *L*, and *G* with frequency can be accurately calculated by the equations shown below. The coefficients for the calculation of R, L, and G are given in Table 11. The equations below give the value of *R* in ohm/m, *L* in H/m, *G* in mho/m, *C* in F/m, and *f* in Hz by using the coefficient values shown in the table. Note that the capacitance C is assumed constant with frequency (C = 50 pF/m).

The primary line constants (R, L, G, and C) calculated by the equations below for the cable types referenced in Figure 11 are shown in Tables 13 to 17, as a function of frequency, where the values are indicated *R* in ohm/km, *L* in µH/km, *G* in µmho/km, *C* in nF/km, *f* in kHz, and at a temperature of 20° C.

$$R = 2(Ri + Rn + Rns) \qquad [\text{ohm/m}]$$
$$L = 2(La + Li + Ln + Lns) \qquad [\text{H/m}]$$
$$G = \varpi C \tan\delta \qquad [\text{mho/m}]$$
$$C = 50 \times 10^{-12} \qquad [\text{F/m}]$$

$$Ri = \frac{1}{\pi r^2 \sigma} f_i^{(R)} = \frac{1}{\pi r^2 \sigma} \mathrm{Re}\left[\frac{1+j}{2\delta} r \frac{J_0\left(\frac{1+j}{\delta} r\right)}{J_1\left(\frac{1+j}{\delta} r\right)} \right]$$

$$Rn = \frac{1}{\pi \sigma d^2} f_n^{(R)} = \frac{1}{\pi \sigma d^2} \mathrm{Re}\left[-\frac{1+j}{\delta} r \frac{J_1\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

$$Rns = \frac{1}{\pi \sigma d^2} 4 f_n^{(R)} = \frac{4}{\pi \sigma d^2} \mathrm{Re}\left[-\frac{1+j}{\delta} r \frac{J_1\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

$$La = \frac{\mu_0}{2\pi} 1n\left(\frac{d}{r}\right)$$

$$Li = \frac{\mu_r \mu_0}{2\pi} f_i^{(L)} = \frac{\mu}{2\pi} \mathrm{Re}\left[-\frac{\delta}{(1+j)r} \frac{J_0\left(\frac{1+j}{\delta} r\right)}{J_1\left(\frac{1+j}{\delta} r\right)} \right]$$

$$Ln = -\frac{\mu_0}{2\pi}\left(\frac{r}{d}\right)^2 f_n^{(L)} = -\frac{\mu_0}{2\pi}\left(\frac{r}{d}\right)^2 \mathrm{Re}\left[-\frac{J_2\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

$$Lns = -\frac{\mu_0}{2\pi}\left(\frac{r}{d}\right)^2 4 f_n^{(L)} = -\frac{\mu_0}{2\pi}\left(\frac{r}{d}\right)^2 4\,\mathrm{Re}\left[-\frac{J_2\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

where:

$\omega =$ $2\pi f$ angular frequency

r the radius of a conductor

σ conductivity of copper (conductor)

$\delta = \sqrt{\frac{2}{\omega\sigma\mu_r\mu_0}}$ skin depth

$d =$ $2\sqrt{2}(r + c_0)$ the distance between the conductor centres of a pair

c_0 the insulator thickness of a wire

μ_r relative permeability of copper (conductor)

μ_0 permeability of vacuum

Table 11/G.996.1 – Coefficients for calculation of *R* and *L*

Coefficient	Paper				Polyethylene				
	0.4 mm	**0.5 mm**	**0.65 mm**	**0.9 mm**	**0.32 mm**	**0.4 mm**	**0.5 mm**	**0.65 mm**	**0.9 mm**
r(m)	0.2×10^{-3}	0.25×10^{-3}	0.325×10^{-3}	0.45×10^{-3}	0.16×10^{-3}	0.2×10^{-3}	0.25×10^{-3}	0.325×10^{-3}	0.45×10^{-3}
c_0 (m)	0.09×10^{-3}	0.11×10^{-3}	0.17×10^{-3}	0.24×10^{-3}	0.05×10^{-3}	0.13×10^{-3}	0.15×10^{-3}	0.20×10^{-3}	0.27×10^{-3}
μ_r	1								
μ_0(H/m)	4π × 10–7								
σ (mho/m)	5.8×10^7								
tan δ	2.5×10^{-2}				4.0×10^{-4}	5.0×10^{-4}			

The variation of *R* and *L* with frequency can be accurately modelled as follows. The five coefficients for the cable types referenced in Figure 11 are given in Table 12. The approximate equations below give the values of *R* in ohm/m, *L* in H/m, *G* in mho/m, *C* in F/m, and *f* in Hz by using the coefficient values shown in the table.

$$R = \left(roc^4 + ac \times f^2\right)^{\frac{1}{4}} \qquad \text{[ohm/m]}$$

$$L = xa + xb \times f^{\frac{1}{2}} + xc \times f^{\frac{1}{3}} \qquad \text{[H/m]}$$

$$G = \omega C \tan\delta \qquad \text{[mho/m]}$$

$$C = 50 \times 10^{-12} \qquad \text{[F/m]}$$

Table 12/G.996.1 – Coefficients calculation of *R* and *L* (at 20° C)

Cable type		roc	ac	xa	xb	xc
Paper	0.4 mm	2.688×10^{-1}	2.267×10^{-13}	6.834×10^{-7}	-2.094×10^{-10}	7.205 × 10–10
	0.5 mm	1.724×10^{-1}	9.374×10^{-14}	7.351×10^{-7}	1.930×10^{-11}	-2.330×10^{-9}
	0.65 mm	1.041×10^{-1}	2.787×10^{-14}	8.006×10^{-7}	2.696×10^{-10}	-5.340×10^{-9}
	0.9 mm	5.589×10^{-2}	7.180×10^{-15}	8.304×10^{-7}	5.111×10^{-10}	-8.161×10^{-9}
Polyethylene	0.32 mm	4.175×10^{-1}	6.998×10^{-13}	6.003×10^{-7}	-3.919×10^{-10}	3.081×10^{-9}
	0.4 mm	2.714×10^{-1}	1.705×10^{-13}	7.257×10^{-7}	-2.059×10^{-10}	9.678×10^{-10}
	0.5 mm	1.742×10^{-1}	7.346×10^{-14}	7.618×10^{-7}	-1.547×10^{-11}	-1.656×10^{-9}
	0.65 mm	1.048×10^{-1}	2.436×10^{-14}	8.139×10^{-7}	2.354×10^{-10}	-4.801×10^{-9}
	0.9 mm	5.630×10^{-2}	6.486×10^{-15}	8.407×10^{-7}	4.816×10^{-10}	-7.721×10^{-9}

Table 13/G.996.1 – RLC values for 0.4 and 0.5 mm paper-insulated cables

Frequency (kHz)	0.4 mm	C = 50 nF/km	0.5 mm	C = 50nF/km
	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)
0.00	274.41	664.51	175.62	661.75
2.50	274.42	664.51	175.64	661.73
10.00	274.62	664.42	175.97	661.52
20.00	275.28	664.15	176.99	660.85
30.00	276.36	663.69	178.68	659.74
40.00	277.87	663.07	180.99	658.24
50.00	279.78	662.27	183.88	656.37
100.00	294.75	656.09	204.86	643.13
150.00	316.56	647.33	231.49	627.35
200.00	342.22	637.42	258.98	612.46
250.00	369.40	627.46	285.41	599.57
300.00	396.69	618.03	310.31	588.68
350.00	423.38	609.41	333.73	579.47
400.00	449.19	601.65	355.79	571.61
450.00	474.02	594.68	376.61	564.83
500.00	497.90	588.42	396.34	558.92
550.00	520.87	582.79	415.08	553.73
600.00	542.99	577.69	432.93	549.13
650.00	564.30	573.06	449.98	545.03
700.00	584.86	568.84	466.34	541.34
750.00	604.72	564.98	482.06	538.02
800.00	623.92	561.42	497.22	535.00
850.00	642.50	558.15	511.88	532.24
900.00	660.52	555.11	526.09	529.71
950.00	678.00	552.30	539.88	527.38
1000.00	694.99	549.69	553.30	525.23
1050.00	711.52	547.25	566.38	523.23
1100.00	727.62	544.96	579.14	521.37

Table 14/G.996.1 – RLC values for 0.65 and 0.9 mm paper-insulated cables

Frequency (kHz)	0.65 mm	C = 50nF/km	0.9 mm	C = 50nF/km
	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)
0.00	103.92	684.18	54.20	686.87
2.50	103.95	684.15	54.27	686.73
10.00	104.45	683.60	55.20	684.79
20.00	106.02	681.89	57.98	679.07
30.00	108.52	679.19	62.04	670.97
40.00	111.83	675.66	66.81	661.83
50.00	115.78	671.51	71.88	652.64
100.00	140.25	647.61	96.11	616.45
150.00	165.42	626.69	116.50	594.37
200.00	188.55	610.67	133.77	579.83
250.00	209.58	598.33	148.81	569.58
300.00	228.77	588.57	162.27	561.93
350.00	246.38	580.67	174.61	555.98
400.00	262.68	574.16	186.08	551.17
450.00	277.89	568.69	196.86	547.19
500.00	292.19	564.04	207.06	543.81
550.00	305.73	560.02	216.77	540.90
600.00	318.64	556.51	226.06	538.36
650.00	331.01	553.41	234.97	536.11
700.00	342.90	550.65	243.55	534.10
750.00	354.37	548.17	251.83	532.30
800.00	365.47	545.92	259.84	530.67
850.00	376.23	543.88	267.60	529.18
900.00	386.68	542.00	275.14	527.82
950.00	396.85	540.27	282.47	526.57
1000.00	406.77	538.67	289.61	525.41
1050.00	416.44	537.19	296.58	524.33
1100.00	425.88	535.81	303.38	523.33

Table 15/G.996.1 – RLC values for 0.32, 0.4 and 0.5 mm polyethylene-insulated cables

Frequency (kHz)	0.32 mm C = 50nF/km		0.4 mm C = 50nF/km		0.5 mm C = 50nF/km	
	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)
0.00	428.76	624.66	274.41	716.20	175.62	703.89
2.50	428.77	624.66	274.42	716.19	175.64	703.88
10.00	428.92	624.62	274.59	716.13	175.91	703.70
20.00	429.41	624.48	275.12	715.91	176.79	703.14
30.00	430.23	624.26	276.02	715.55	178.23	702.23
40.00	431.37	623.94	277.25	715.05	180.20	700.98
50.00	432.83	623.54	278.83	714.42	182.66	699.43
100.00	444.67	620.31	291.19	709.50	200.68	688.42
150.00	463.20	615.30	309.35	702.50	223.85	675.19
200.00	486.98	608.97	330.92	694.53	248.16	662.55
250.00	514.44	601.81	354.05	686.44	271.91	651.46
300.00	544.17	594.24	377.58	678.73	294.59	641.96
350.00	575.05	586.61	400.91	671.59	316.14	633.82
400.00	606.26	579.16	423.72	665.08	336.56	626.79
450.00	637.24	572.03	445.91	659.18	355.93	620.66
500.00	667.67	565.31	467.42	653.82	374.32	615.28
550.00	697.37	559.03	488.25	648.94	391.79	610.53
600.00	726.25	553.18	508.41	644.49	408.45	606.30
650.00	754.29	547.75	527.90	640.42	424.36	602.52
700.00	781.52	542.72	546.76	636.68	439.60	599.12
750.00	807.95	538.05	565.01	633.23	454.24	596.04
800.00	833.64	533.70	582.67	630.05	468.35	593.25
850.00	858.61	529.65	599.77	627.10	481.98	590.69
900.00	882.92	525.88	616.36	624.36	495.18	588.35
950.00	906.60	522.34	632.44	621.82	508.00	586.20
1000.00	929.68	519.03	648.07	619.45	520.46	584.20
1050.00	952.21	515.92	663.27	617.23	532.60	582.35
1100.00	974.20	513.00	678.07	615.15	544.44	580.62

Table 16/G.996.1 – RLC values for 0.65 mm and 0.9 mm polyethylene-insulated cables

Frequency (kHz)	0.65 mm	C = 50nF/km	0.9 mm	C = 50nF/km
	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)
0.00	103.92	707.72	54.20	703.89
2.50	103.95	707.69	54.26	703.77
10.00	104.41	707.19	55.14	701.96
20.00	105.84	705.66	57.75	696.66
30.00	108.14	703.22	61.57	689.13
40.00	111.17	700.03	66.08	680.63
50.00	114.81	696.28	70.89	672.04
100.00	137.50	674.59	94.16	637.90
150.00	161.20	655.37	113.97	616.72
200.00	183.24	640.46	130.78	602.67
250.00	203.43	628.83	145.41	592.72
300.00	221.91	619.57	158.49	585.30
350.00	238.88	612.03	170.48	579.52
400.00	254.58	605.79	181.62	574.85
450.00	269.22	600.55	192.09	570.98
500.00	282.98	596.08	202.00	567.70
550.00	296.00	592.23	211.44	564.88
600.00	308.41	588.86	220.46	562.41
650.00	320.29	585.88	229.12	560.22
700.00	331.71	583.23	237.45	558.28
750.00	342.73	580.85	245.50	556.53
800.00	353.40	578.69	253.28	554.94
850.00	363.73	576.73	260.82	553.50
900.00	373.78	574.93	268.14	552.18
950.00	383.55	573.27	275.27	550.96
1000.00	393.07	571.73	282.20	549.83
1050.00	402.36	570.31	288.97	548.79
1100.00	411.44	568.98	295.58	547.81

Table 17/G.996.1 – G values

Frequency (kHz)	0.4, 0.5, 0.65, 0.9 mm paper (μmho/km)	0.32 mm polyethylene (μmho/km)	0.4, 0.5, 0.65, 0.9 mm polyethylene (μmho/km)
0.00	0.00	0.00	0.00
2.50	19.64	0.31	0.39
10.00	78.54	1.26	1.57
20.00	157.08	2.51	3.14
30.00	235.62	3.77	4.71
40.00	314.16	5.03	6.28
50.00	392.70	6.28	7.85
100.00	785.40	12.57	15.71
150.00	1178.10	18.85	23.56
200.00	1570.80	25.13	31.42
250.00	1963.50	31.42	39.27
300.00	2356.19	37.70	47.12
350.00	2748.89	43.98	54.98
400.00	3141.59	50.27	62.83
450.00	3534.29	56.55	70.69
500.00	3926.99	62.83	78.54
550.00	4319.69	69.12	86.39
600.00	4712.39	75.40	94.25
650.00	5105.09	81.68	102.10
700.00	5497.79	87.96	109.96
750.00	5890.49	94.25	117.81
800.00	6283.19	100.53	125.66
850.00	6675.88	106.81	133.52
900.00	7068.58	113.10	141.37
950.00	7461.28	119.38	149.23
1000.00	7853.98	125.66	157.08
1050.00	8246.68	131.95	164.93
1100.00	8639.38	138.23	172.79

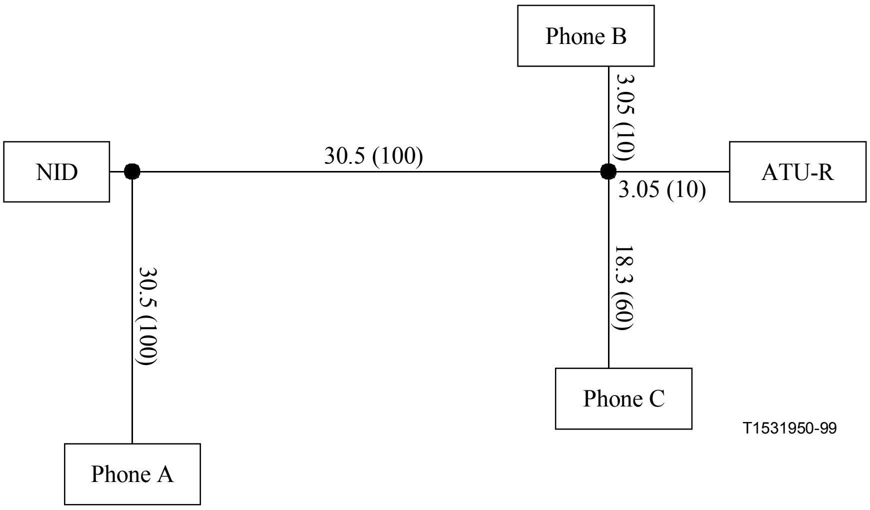
6.2 In-home wiring models

6.2.1 In-home wiring model #1

In the model in Figure 12, note that phone "A" will be used for off-hook testing. All wire shown is Category 3 wire.

Category 3 wire has attenuation (a) in dB/100 m (328 ft) that is calculated based on the equation:

Category 3 Attenuation (a) = $2.320\sqrt{f} + 0.238\,f$, f in MHz.

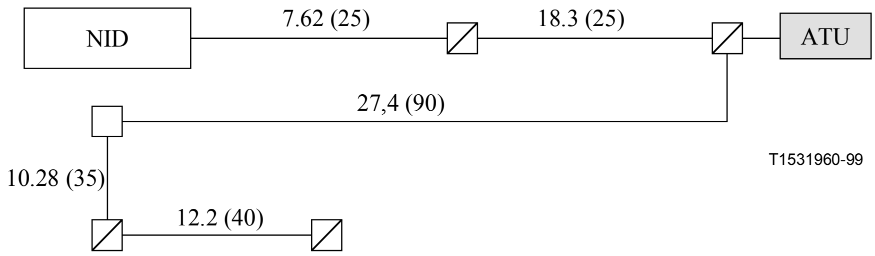


NOTE – Lengths are in metres; the equivalent in feet is in parenthesis.

Figure 12/G.996.1 – Customer premise in-home wiring model #1

6.2.2 In-home wiring model #2: Daisy Chain 4-conductor, 24 AWG, non-paired station wire

See Figure 13.



NOTE 1 – Line across jack indicates attached telephone.

NOTE 2 – 1.83 m (6 ft) of cable (same type as run) connects each phone and ATU-R to each jack.

NOTE 3 – Lengths are in metres; the equivalent in feet is in parenthesis.

NOTE 4 – Both pairs daisy chained to all jacks.

NOTE 5 – Second service may be present.

Figure 13/G.996.1 – Customer premise in-home wiring model #2

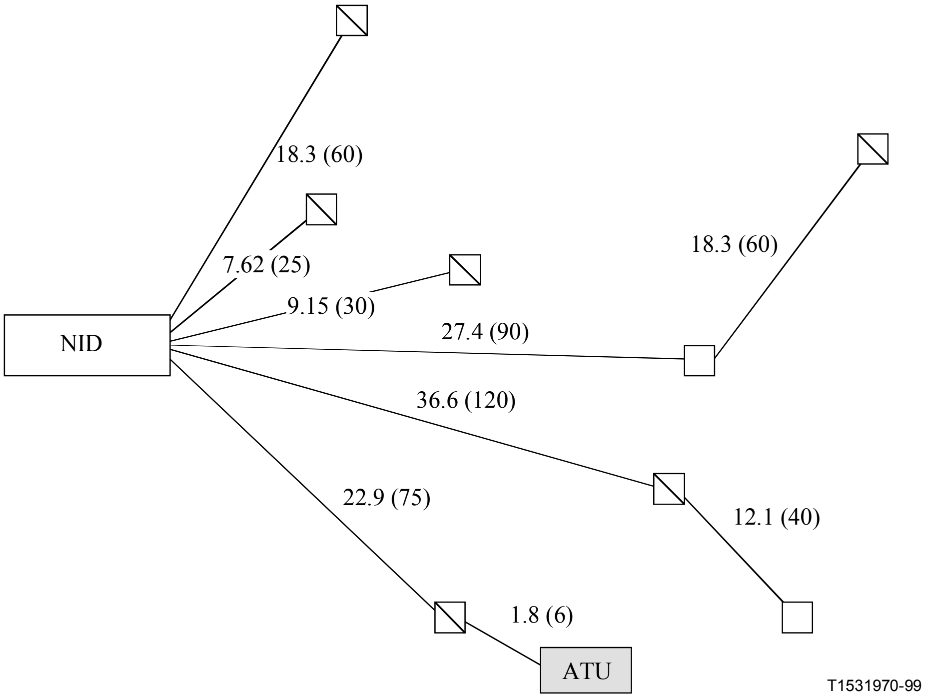
Electrical performance – Station wire

Property	Performance
Conductor Resistance – Maximum 22 AWG 24 AWG	 59.1 ohms/km (18.1 ohms/kft) 93.8 ohms/km (28.6 ohms/kft)
Spark testing Voltage – Minimum Fault rate – Maximum	 1750 V a.c. or 2500 V d.c. 1 per 915 m (3000 ft)
Coaxial capacitance – Maximum (at 1000 Hz and 20°C)	279 nF/km (85 nF/kft)
Pair-to-pair capacitance unbalance – Maximum(at 1000 Hz)	410 pF/500 m (125 pF/500 ft)
High voltage Withstand voltage Time – Minimum	 2500 V d.c. 2 s
Dielectric strength rating – Jacket ac voltage potential – Minimum Current flow, peak during 90 s test – Maximum	 1500 V rms 10 mA
Insulation resistivity: Each conductor – Minimum	152 Mohm × km (500 Mohm × kft)
OPENS: Each length CROSSES: Each length SHORTS: Each length	None allowed None allowed None allowed
NOTE – 22 AWG = 0.65 mm; 24 AWG = 0.5 mm.	

6.2.3 In-home wiring model #3: Star – 152.4 m (500 ft), 4-pair Category 3 wire

In Figure 14, Category 3 wire has attenuation (a) in dB/100 m (328 ft) that is calculated based on the equation:

Category 3 Attenuation (a) = $2.320\sqrt{f} + 0.238\,f$, f in MHz

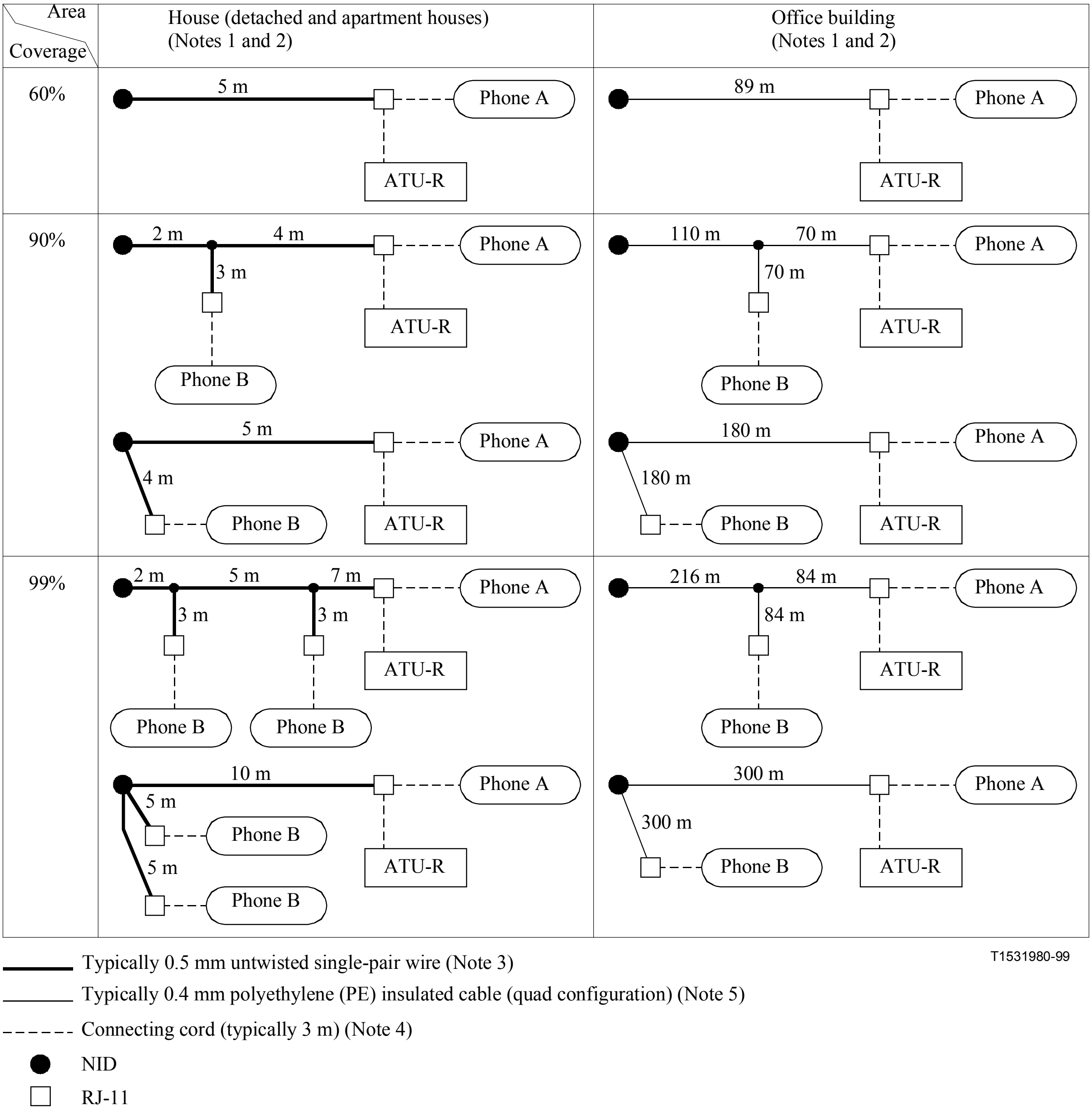


NOTE 1 – Line across jack indicates attached telephone.
NOTE 2 – 1.83 m (6 ft) of cable (same type as run) connects each phone and ATU-R to each jack.
NOTE 3 – Second service may be present.
NOTE 4 – Lengths are in metres; the equivalent in feet is in parenthesis.

Figure 14/G.996.1 – Customer premise in-home wiring model #3

6.2.4 In-home wiring model for TCM-ISDN DSL environment

See Figure 15.



NOTE 1 – In-home wiring modes in the figure are to be substituted for the box labelled "Customer premises" in the test loops (Figure 11) for G.992.2 system performance test, where system performance should be tested with one phone off-hook (phone A). G.992.1 system performance test is not required to comply with in-home wiring models shown in this figure.

NOTE 2 – In clause 9, a linear phone model is provided for testing purposes where only steady-state impedances are considered and transients are not considered. Notice that the phone models are moderate ones, they are neither typical, nor representative, nor average, nor worst. They are specified to provide a unified test condition so as to validate test results comparison. Test results do not guarantee G.992.2 system performance for any cases of splitterless operation.

NOTE 3 – The equations to calculate primary lines constants R, L, C and G with frequency for in-home wiring cables are shown in 6.1.3. The coefficients for the calculation are given in Table 37. Notice that the in-home wiring cables defined in Figure 15 do not adopt a quad structure (unlike the cables defined in Figure 11), so the distance between the conductor centres of a pair "d" used in the equations is to be "$d = 2 (r + c_0)$"; the distance is not multiplied by $\sqrt{2}$ as in the case of a quad-structured cable.

NOTE 4 – The insertion loss characteristics of a 3 m connecting cord is shown in Figure 48.

NOTE 5 – The equations and coefficients for the calculation are shown in 6.1.3 and in Table 11.

Figure 15/G.996.1 – In-home wiring models in an environment coexisting with TCM-ISDN DSL

7 Power spectral density of crosstalk disturbers

Crosstalk margin measurements are performed with several types of disturbers, DSLs, HDSLs, T_1s and ADSL lines. DSL, HDSL, and ADSL crosstalk is from pairs in the same binder group; T_1 crosstalk is from pairs in an adjacent binder group.

7.1 Simulated DSL PSD and induced NEXT

The power spectral density (PSD) of basic access DSL disturbers is expressed as:

$$PSD_{DSL\text{-}Disturber} = K_{DSL} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\frac{\pi f}{f_0}\right)\right]^2}{\left(\frac{\pi f}{f_0}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^4}, \quad f_{3dB} = 80 \text{ kHz}, 0 \le f < \infty$$

where: $f_0 = 80\,\text{kHz}$, $K_{DSL} = \frac{5}{9} \times \frac{V_p^2}{R}$, $V_p = 2.50$ volts and $R = 135$ ohms

This equation gives the single-sided PSD; that is, the integral of PSD, with respect to f, from 0 to infinity, gives the power in watts. $PSD_{DSL\text{-}Disturber}$ is the PSD of an 80 ksymbols/s 2B1Q signal with random equiprobable levels, with full-band square-topped pulses and with 2nd order Butterworth filtering ($f_{3dB} = 80$ kHz). Figure 16 shows the PSD of 24-disturber DSL-NEXT.

The PSD of the DSL-NEXT can be expressed as:

$$PSD_{DSL\text{-}NEXT} = PSD_{DSL\text{-}Disturber} \times \left(x_n \times f^{3/2}\right) \qquad \text{for } 0 \le f < \infty, n < 50$$

where: $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{14} \times n^{0.6}$

The integration of $PSD_{DSL\text{-}Disturber}$ and $PSD_{DSL\text{-}NEXT}$ over various frequency ranges of interest is presented in Table 18.

Table 18/G.996.1 – DSL transmit and DSL-induced NEXT power

Frequency range	Transmit power (dBm)	NEXT power 24-disturber (dBm)
0-0.16 MHz	13.60	–52.62
0-0.32 MHz	13.60	–52.62
0-1.544 MHz	13.60	–52.62
0-3 MHz	13.60	–52.62
0-10 MHz	13.60	–52.62

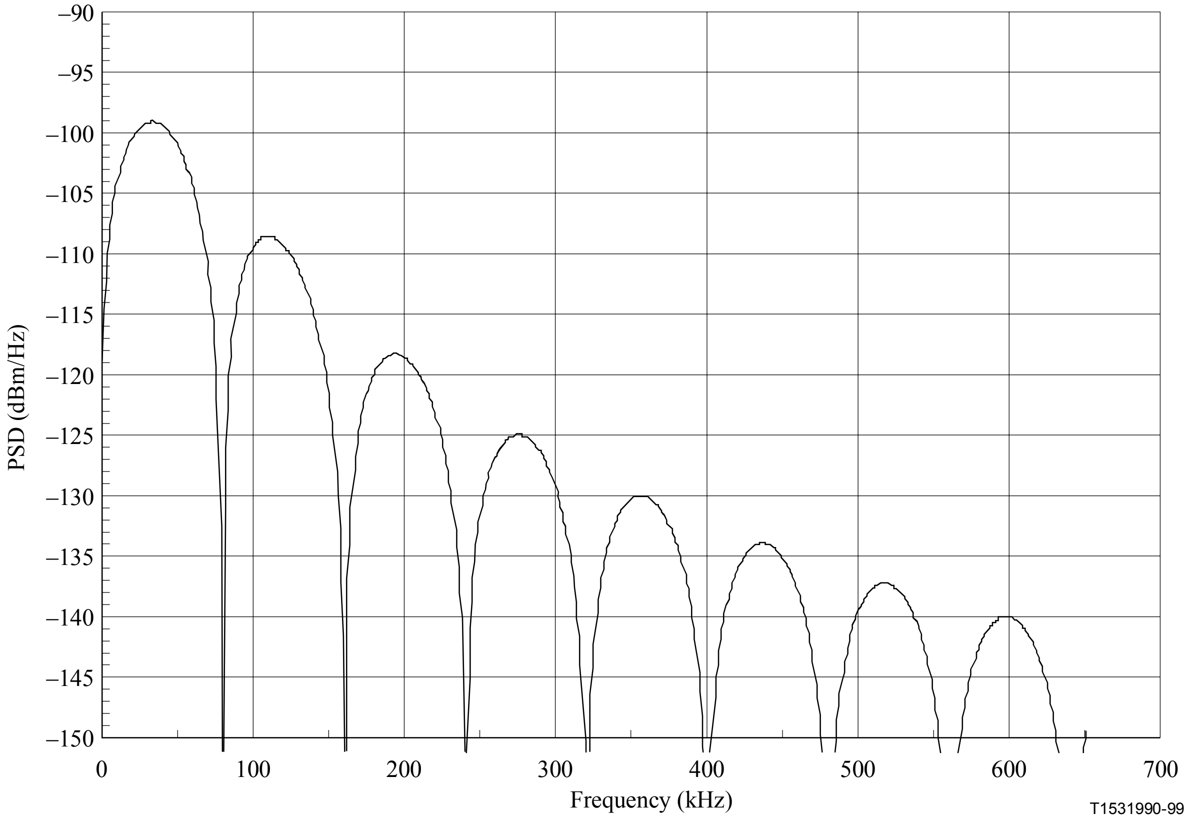


Figure 16/G.996.1 – 24-disturber DSL-NEXT

7.2 Simulated HDSL PSD and induced NEXT

The PSD of HDSL disturbers is expressed as:

$$PSD_{HDSL\text{-}Disturber} = K_{HDSL} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\frac{\pi f}{f_0}\right)\right]^2}{\left(\frac{\pi f}{f_0}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^8}, \quad f_{3dB} = 196 \text{ kHz}, \ 0 \le f < \infty$$

where: $f_0 = 392$ kHz, $K_{DSL} = \frac{5}{9} \times \frac{V_p^2}{R}$, $V_p = 2.70$ volts, and $R = 135$ ohms

This equation gives the single-sided PSD; that is, the integral of PSD, with respect to f, from 0 to infinity, gives the power in watts. $PSD_{HDSL\text{-}Disturber}$ is the PSD of a 392 ksymbols/s 2B1Q signal with random equiprobable levels, with full-band square-topped pulses and with 4th order Butterworth filtering (f_{3dB} = 196 kHz). Figure 17 shows the PSD of 10-disturber HDSL-NEXT.

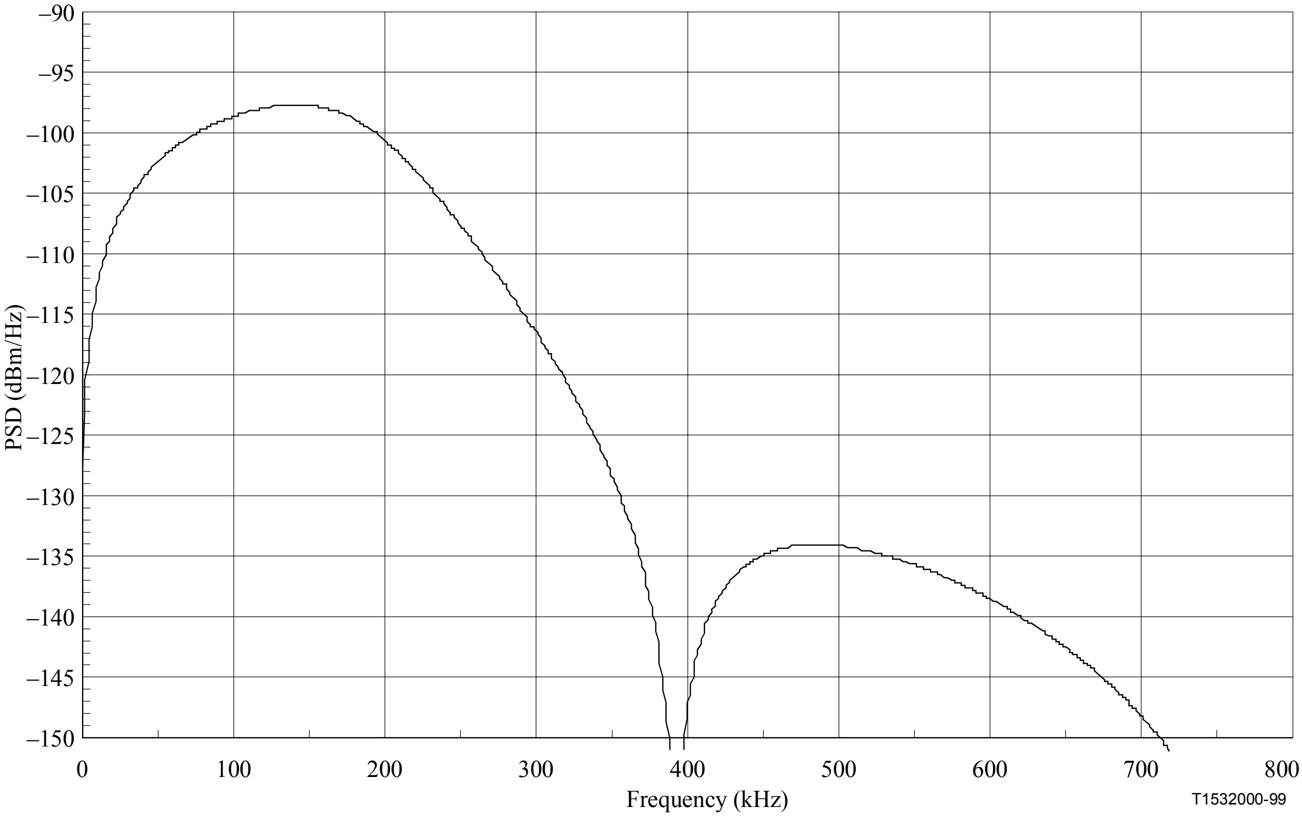


Figure 17/G.996.1 – 10-disturber HDSL NEXT

The PSD of the HDSL-NEXT is expressed as:

$$PSD_{HDSL\text{-}NEXT} = PSD_{HDSL\text{-}Disturber} \times \left(x_n \times f^{3/2} \right) \qquad \text{for } 0 \leq f < \infty,\ n < 50$$

where: $f_0 = 8.818 \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of $PSD_{HDSL\text{-}Disturber}$ over various frequency ranges of interest is presented in Table 19 along with the induced NEXT power.

Table 19/G.996.1 – HDSL transmit and induced NEXT power

Frequency range	Transmit power (dBm)	NEXT power 10-disturbers (dBm)
0-0.196 MHz	13.44	–46.9
0-0.392 MHz	13.60	–46.3
0-0.784 MHz	13.60	–46.3
0-1.544 MHz	13.60	–46.3
0-1.568 MHz	13.60	–46.3
0-3 MHz	13.60	–46.3

7.3 Simulated T_1 line PSD and induced NEXT

The PSD of the T_1 line disturber is assumed to be the 50% duty-cycle random Alternate Mark Inversion (AMI) code at 1.544 Mbit/s. The single-sided PSD has the following expression.

$$PSD_{T_1\text{-}Disturber} = \frac{V_P^2}{R_L} \times \frac{2}{f_0} \left[\frac{\sin\left(\frac{\pi f}{f_0}\right)}{\left(\frac{\pi f}{f_0}\right)} \right]^2 \sin^2\left(\frac{\pi f}{2 f_0}\right) \times \frac{1}{1 + \left(\frac{f}{f_{3\text{dB}}}\right)^6} \times \frac{f^2}{f^2 + f_{3\text{dB}}^2}, \qquad (0 \le f < \infty)$$

The total power of the transmit T_1 signal is computed by:

$$P_{T_1\text{-}total} = \frac{1}{4} \frac{V_P^2}{R_L}$$

It is assumed that the transmitted pulse passes through a low-pass shaping filter. The shaping filter is chosen as a third order low-pass Butterworth filter with 3 dB point at 3.0 MHz. The filter magnitude squared transfer function is:

$$\left| H_{shaping}(f) \right|^2 = \frac{1}{1 + \left(\frac{f}{f_{3\text{dB}}}\right)^6}$$

In addition, the coupling transformer is modelled as a high-pass filter with 3 dB point at 40 kHz as:

$$\left| H_{Transformer}(f) \right|^2 = \frac{f^2}{f^2 + f_{3\text{dB}}^2}$$

Furthermore, it is assumed that $V_p = 3.6$ volts, $R_L = 100$ ohms, and $f_0 = 1.544$ MHz.

Figure 18 shows the PSD of 4- and 24-disturber T_1 NEXT.

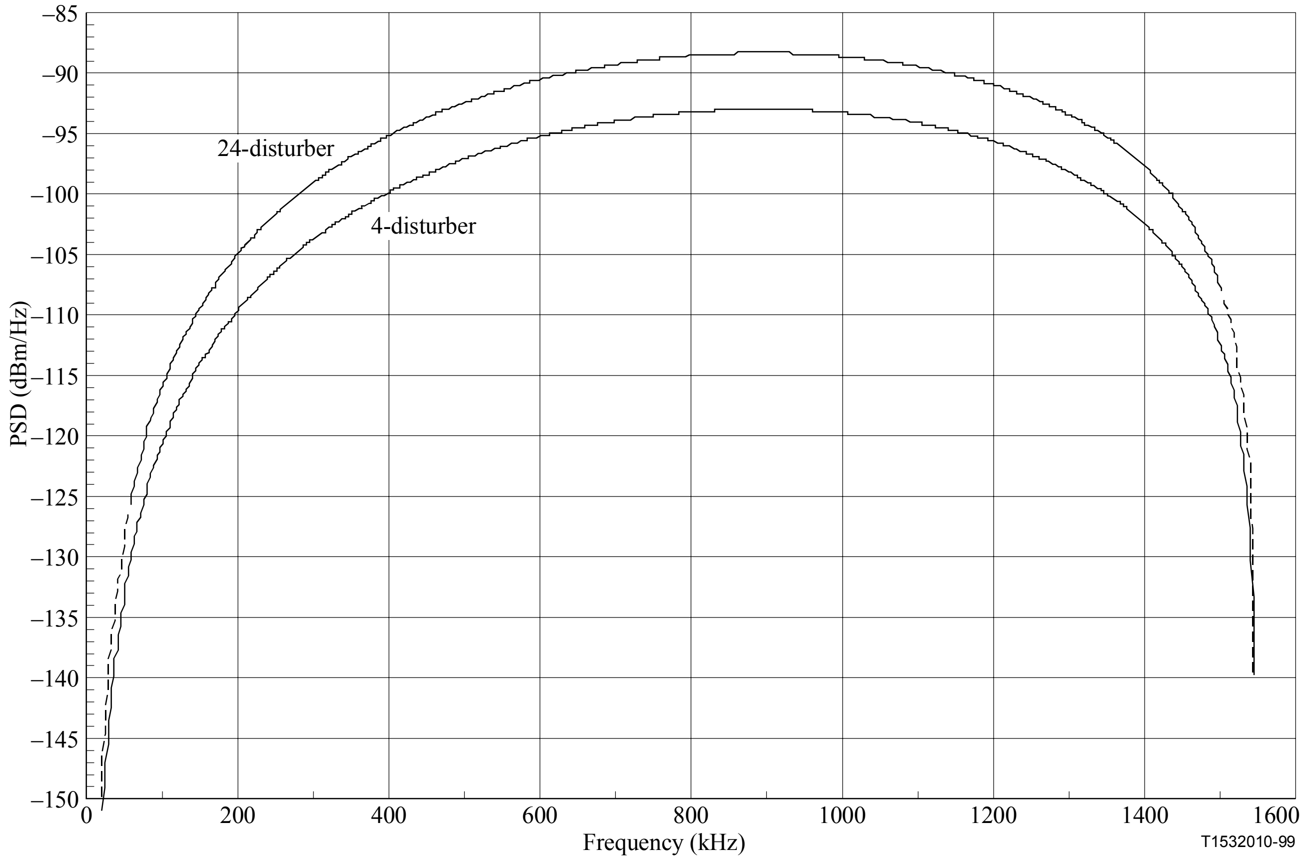


Figure 18/G.996.1 – 4- and 24-disturber T_1 NEXT

The PSD of the T_1 NEXT is expressed as:

$$PSD_{T_1\text{-}NEXT} = PSD_{T_1\text{-}Disturber} \times \left(x_n \times f^{3/2} \right) \quad \text{for } 0 \le f < \infty,\ n < 50$$

where: $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The T_1 transmit and T_1-induced NEXT power using n-crosstalk models (x_n) is presented in Table 20.

Table 20/G.996.1 – T_1 transmit and induced NEXT power with shaping and coupling transformer

Frequency range	Transmit power (dBm)	NEXT power 4-disturbers (dBm)	NEXT power 24-disturbers (dBm)
0-1.544 MHz	14.1	–34.7	–30.0
0-3 MHz	14.57	–32.8	–28.1

For testing, the T_1 interferer power and the PSD curve are adjusted downward by a total of 15.5 dB to allow for the adjacent binder effect and an averaging factor which accounts for non-collocation of the T_1 and ADSL terminals.

7.4 Simulated G.992.1 downstream PSD and induced NEXT and FEXT

The PSD of G.992.1 disturbers is expressed as:

$$PSD_{G.992.1\text{-}Disturber} = K_{G.992.1} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\frac{\pi f}{f_0}\right)\right]^2}{\left(\frac{\pi f}{f_0}\right)^2} \times |LPF(f)|^2 \times |HPF(f)|^2, \quad (0 \le f < \infty)$$

where: $f_0 = 2.208 \times 10^6$ Hz, $K_{G.992.1} = 0.1104$ watts.

This equation gives the single-sided PSD, where $K_{G.992.1}$ is the total transmitted power in watts for the downstream G.992.1 transmitter before shaping filters, and is set such that the PSD will not exceed the maximum allowed PSD. f_0 is the sampling frequency in Hz and

$$|LPF(f)|^2 = \frac{f_h^{\alpha}}{f^{\alpha} + f_h^{\alpha}}, f_h = 1.104 \times 10^6 \text{ Hz}, \alpha = \frac{36}{10\log(2)} = 11.96$$

is a low-pass filter with a 3 dB point at 1104 kHz and 36 dB/octave rolloff, and

$$|HPF(f)|^2 = \frac{f^{\alpha} + f_l^{\alpha}}{f^{\alpha} + f_h^{\alpha}}, f_l = 4000 \text{ Hz}, f_h = 25\,875 \text{ Hz}, \alpha = \frac{57.5}{10\log\frac{f_h}{f_l}} = 7.09$$

is a high-pass filter with 3 dB points at 4 and 25.875 kHz and 57.5 dB attenuation in the voiceband, separating G.992.1 from POTS. With this set of parameters, the $PSD_{G.992.1}$ is the PSD of a downstream transmitter that uses all the sub-carriers.

7.4.1 FEXT

The FEXT loss model is:

$$|H_{FEXT}(f)|^2 = |H_{channel}(f)|^2 \times k \times l \times f^2 \times p$$

where:

$H_{channel}(f)$ is the channel transfer function

k is the coupling constant and is $8 \times 10^{-20} \times (n/49)^{0.6}$ for $n < 50$ or 3.083×10^{-20} for 10, 1% worst-case disturbers

l is the coupling path length in metres and equals 2744 m for C #6

f is in Hz

p is a metres-to-feet conversion constant and is 3.28 ft/m

The FEXT noise PSD is therefore:

$$PSD_{G.992.1\text{-}FEXT} = PSD_{G.992.1\text{-}Disturber} \times \left|H_{FEXT}(f)\right|^2$$

The integration of $PSD_{G.992.1}$ and $PSD_{G.992.1\text{-}FEXT}$ over the various frequency ranges is presented in Table 21.

Table 21/G.996.1 – G.992.1 and G.992.1-FEXT power with shaping and coupling transformer

Frequency range	Transmit power (dBm)	FEXT power 10-disturbers (dBm)
0-1.104 MHz	18.99	–69.61
0-2.204 MHz	19.15	–69.61
0-4.416 MHz	19.15	–69.61

Figure 19 shows the theoretical PSD of 10-disturber downstream G.992.1 FEXT on C loop #6.

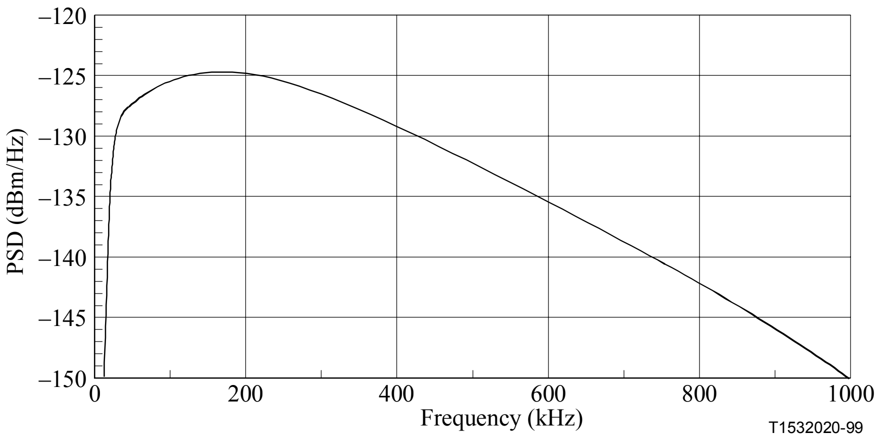


Figure 19/G.996.1 – 10-disturber downstream G.992.1 FEXT on C loop #6

7.4.2 NEXT

The PSD of the G.992.1 NEXT into the upstream is defined as:

$$PSD_{G.992.1\text{-}NEXT} = PSD_{G.992.1\text{-}Disturber} \times \left(x_n \times f^{3/2} \right) \qquad \text{for } 0 \le f < \infty,\ n < 50$$

where: $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of the induced NEXT over the band from 0 to 1.104 MHz for $n = 49$ is −25.4 dBm.

Figure 20 shows the theoretical PSD of 10-disturber downstream G.992.1 NEXT.

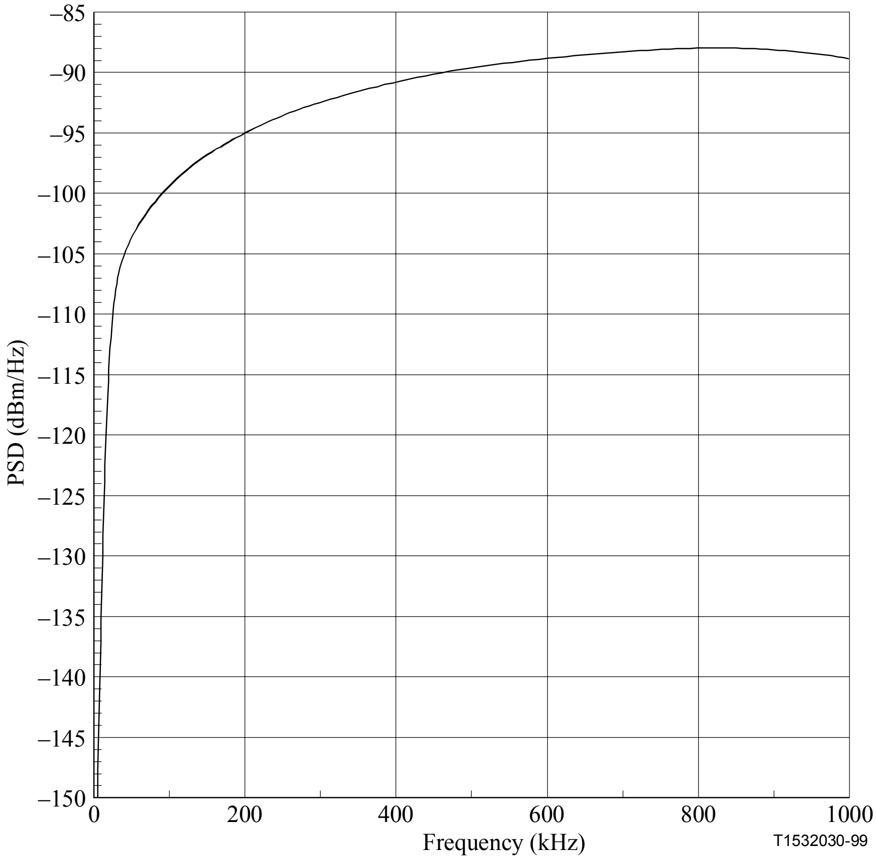


Figure 20/G.996.1 – 10-disturber downstream G.992.1 NEXT into the upstream

7.5 Simulated G.992.1 upstream PSD and induced NEXT and FEXT

The PSD of G.992.1 disturbers is expressed as:

$$PSD_{G.992.1\text{-}Disturber} = K_{ADSL} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\frac{\pi f}{f_0}\right)\right]^2}{\left(\frac{\pi f}{f_0}\right)^2} \times |LPF(f)|^2 \times |HPF(f)|^2, \qquad (0 \le f < \infty)$$

where: $f_0 = 276 \times 10^3$ Hz, $K_{G.992.1} = 0.02185$ watts.

This equation gives the single-sided PSD, where $K_{G.992.1}$ is the total transmitted power in watts for the upstream G.992.1 transmitter before shaping filters, and is set such that the PSD will not exceed the maximum allowed PSD. f_0 is the sampling frequency in Hz, and

$$|LPF(f)|^2 = \frac{f_h^\alpha}{f^\alpha + f_h^\alpha}, f_h = 138 \times 10^3 \text{ Hz}, \ \alpha = \frac{24}{10\log(181.125/138)} = 20.32$$

is a low-pass filter with a 3 dB point at 138 kHz and 24 dB attenuation at 181.125 kHz, and

$$|HPF(f)|^2 = \frac{f^\alpha + f_l^\alpha}{f^\alpha + f_h^\alpha}, f_l = 4000\,\text{Hz},\ f_h = 25\,875\,\text{Hz}, \alpha = \frac{59.5}{10\log\frac{f_h}{f_l}} = 7.34$$

is a high-pass filter with 3 dB points at 4 and 25.875 kHz and 59.5 dB attenuation in the voiceband, separating G.992.1 from POTS. With this set of parameters the $PSD_{G.992.1}$ is the PSD of an upstream transmitter that uses all the sub-carriers.

7.5.1 FEXT

The FEXT loss model is:

$$|H_{FEXT}(f)|^2 = |H_{channel}(f)|^2 \times k \times l \times f^2 \times p$$

where: $H_{channel}(f)$ is the channel transfer function, k is the coupling constant and is

$$8 \times 10^{-20} \times (n/49)^{0.6}$$

for $n < 50$ or 3.083×10^{-20} for 10, 1% worst-case disturbers, l is the coupling path length in metres, f is in Hz, p is a metres-to-feet conversion constant and is 3.28 ft/m.

The FEXT noise PSD is therefore:

$$PSD_{G.992.1} = PSD_{G.992.1} \times |H_{FEXT}(f)|^2$$

Figure 21 shows the theoretical PSD of 10-disturber upstream G.992.1 FEXT on C loop #6.

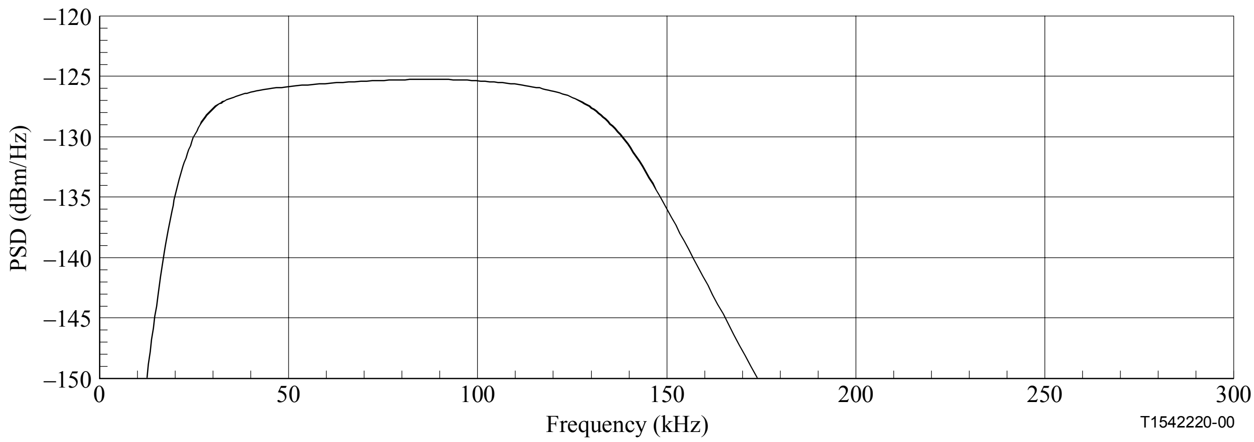


Figure 21/G.996.1 – Theoretical 10-disturber upstream G.992.1 FEXT on C loop #6

7.5.2 NEXT

The upstream G.992.1 signal nominally occupies the band from 25 to 138 kHz, but the upper sidelobes of the passband signal beyond 138 kHz may also contribute to the NEXT into the downstream signal. Their effect will depend on the method of anti-aliasing used in the remote transmitter. The PSD of the upstream G.992.1 NEXT is expressed as:

$$PSD_{G.992.1} = PSD_{G.992.1\text{-}Disturber} \times \left(x_n \times f^{3/2} \right) \quad \text{for } 0 \le f < \infty,\ n < 50$$

where: $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

Figure 22 shows the theoretical PSD of 10-disturber upstream G.992.1 NEXT into the downstream.

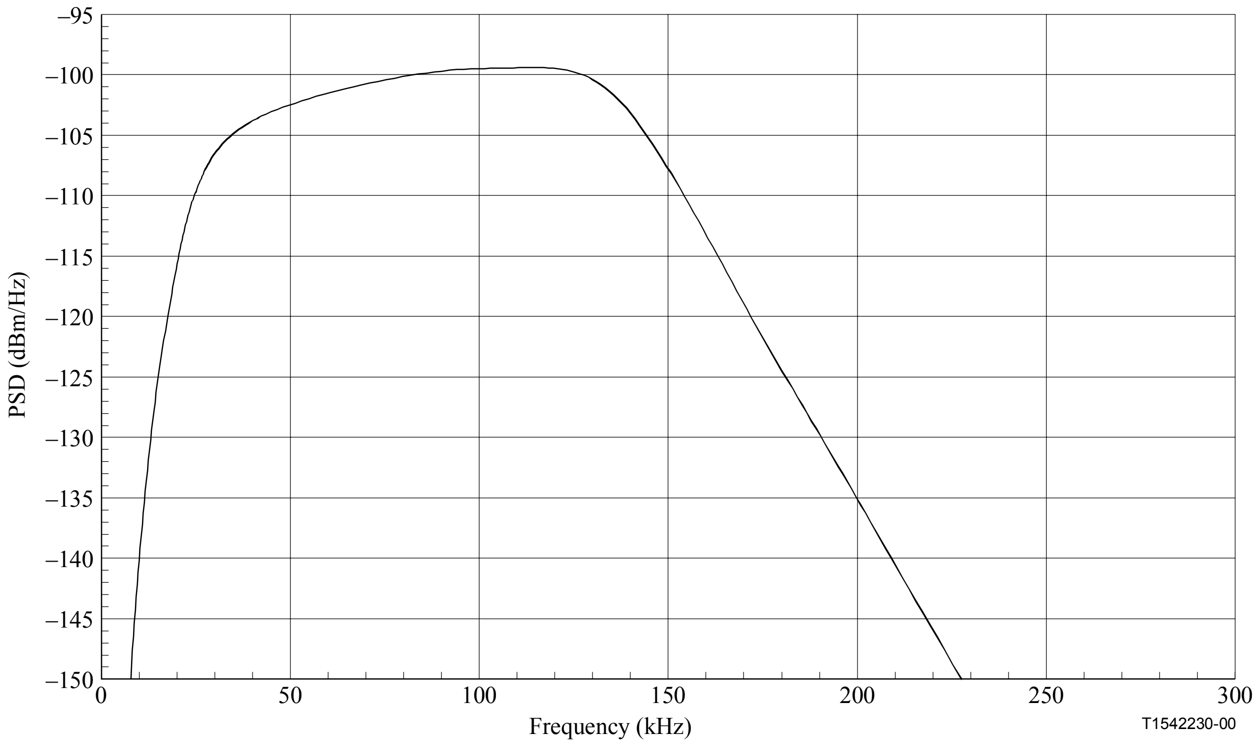


Figure 22/G.996.1 – 10-disturber upstream G.992.1 NEXT into the downstream

7.6 Simulated G.992.2 downstream NEXT and FEXT

The single-sided PSD of G.992.2 disturbers is expressed as:

$$PSD_{G.992.2\text{-}Disturber} = PSD_{G.992.2\text{-}AnnexA} - 3.5\ \text{dB}$$

7.6.1 FEXT

The FEXT loss model is:

$$|H_{FEXT}(f)|^2 = |H_{channel}(f)|^2 \times k \times l \times f^2 \times p$$

where: $H_{channel}(f)$ is the channel transfer function, k is the coupling constant and is

$$8 \times 10^{-20} \times (n/49)^{0.6}$$

for n < 50 or 3.083×10^{-20} for 10, 1% worst-case disturbers, l is the coupling path length in metres, f is in Hz, p is a metres-to-feet conversion constant and is 3.28 ft/m.

The FEXT noise PSD is therefore:

$$PSD_{G.992.2\text{-}FEXT} = PSD_{G.992.2\text{-}Disturber} \times |H_{FEXT}(f)|^2$$

The integration of the induced FEXT over the band from 0 to 1.104 MHz and using T loop #7 is –83.9 dBm for $n = 49$, and is –85.8 for $n = 24$.

Figure 23 shows the theoretical PSD of 49-disturber downstream G.992.2 FEXT on T loop #7.

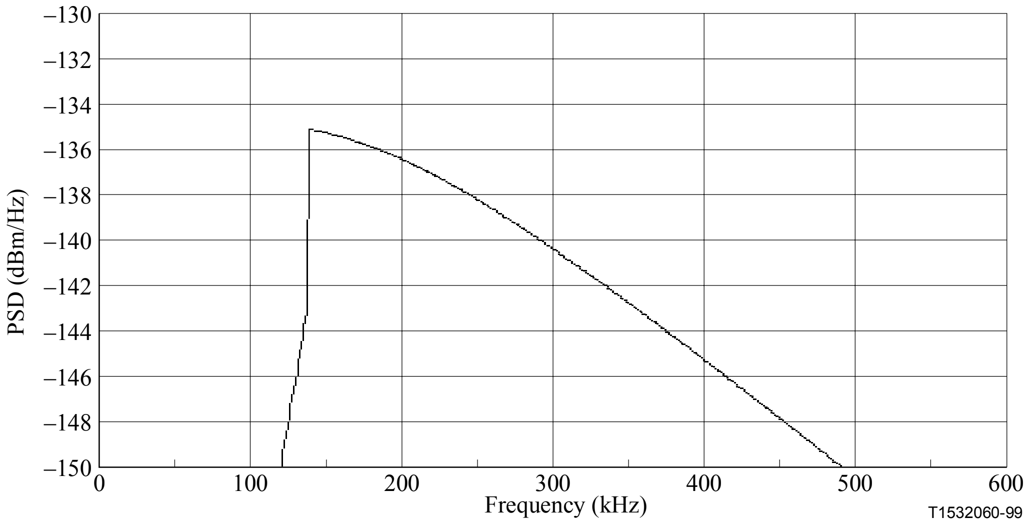


Figure 23/G.996.1 – 49-disturber downstream G.992.2 FEXT on T loop #7

7.6.2 NEXT

The PSD of the downstream G.992.2 NEXT into the upstream is defined as:

$$PSD_{G.992.2\text{-}NEXT} = PSD_{G.992.2\text{-}Disturber} \times \left(x_n \times f^{2/3} \right) \quad \text{for } 0 \le f < \infty,\ n < 50$$

where: $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of the induced NEXT over the band from 0 to 1.104 MHz for $n = 49$ is –23.3 dBm, and –25.2 for $n = 24$. Figure 24 shows the theoretical PSD of 49-disturber downstream G.992.2 NEXT into the upstream.

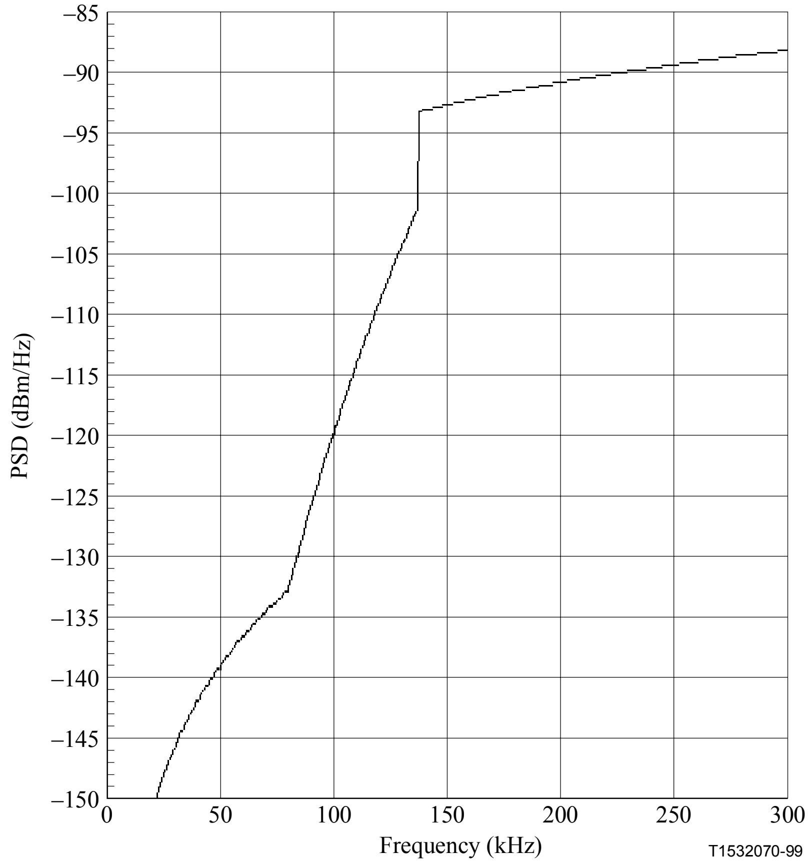


Figure 24/G.996.1 – 49-disturber downstream G.992.2 NEXT into the upstream

7.7 Simulated G.992.2 upstream NEXT and FEXT

The PSD of G.992.2 upstream disturbers is expressed as:

$$PSD_{G.992.2\text{-}Disturber} = PSD_{G.992.2\text{-}AnnexA} - 3.5\,\text{dB}$$

7.7.1 FEXT

The FEXT loss model is:

$$|H_{FEXT}(f)|^2 = |H_{channel}(f)|^2 \times k \times l \times f^2 \times p$$

where: $H_{channel}\,(f)$ is the channel transfer function, k is the coupling constant and is:

$$8 \times 10^{-20} \times (n/49)^{0.6}$$

for $n < 50$ or 3.083×10^{-20} for 10, 1% worst-case disturbers, l is the coupling path length in meters, f is in Hz , p is a metres-to-feet conversion constant and is 3.28 ft/m.

The FEXT noise PSD is therefore:

$$PSD_{G.992.2\text{-}FEXT} = PSD_{G.992.2\text{-}Disturber} \times |H_{FEXT}(f)|^2$$

The integration of the induced FEXT over the band from 0 to 1.104 MHz for $n = 49$ and using T loop #7 is –81.8 dBm, and –83.7 for $n = 24$.

Figure 25 shows the theoretical PSD of 49-disturber upstream G.992.2 FEXT on T loop #7.

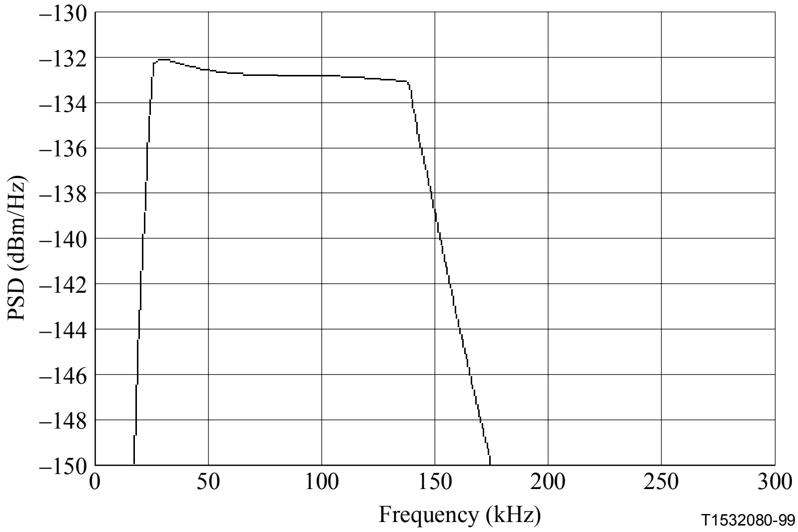


Figure 25/G.996.1 – Theoretical 49-disturber upstream G.992.2 FEXT on T loop #7

7.7.2 NEXT

The upstream G.992.2 signal nominally occupies the band from 25 to 138 kHz, but the upper sidelobes of the passband signal beyond 138 kHz may also contribute to the NEXT into the downstream signal. Their effect will depend on the method of anti-aliasing used in the remote transmitter. The PSD of the upstream G.992.2 NEXT is expressed as:

$$PSD_{G.992.2\text{-}NEXT} = PSD_{G.992.2\text{-}Disturber} \times \left(x_n \times f^{3/2} \right) \quad \text{for } 0 \le f < \infty,\ n < 50$$

where: $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of the induced NEXT over the band from 0 to 1.104 MHz for $n = 49$ is −43.2 dBm, and –45.1 for $n = 24$.

Figure 26 shows the theoretical PSD of 49-disturber upstream G.992.2 NEXT into the downstream.

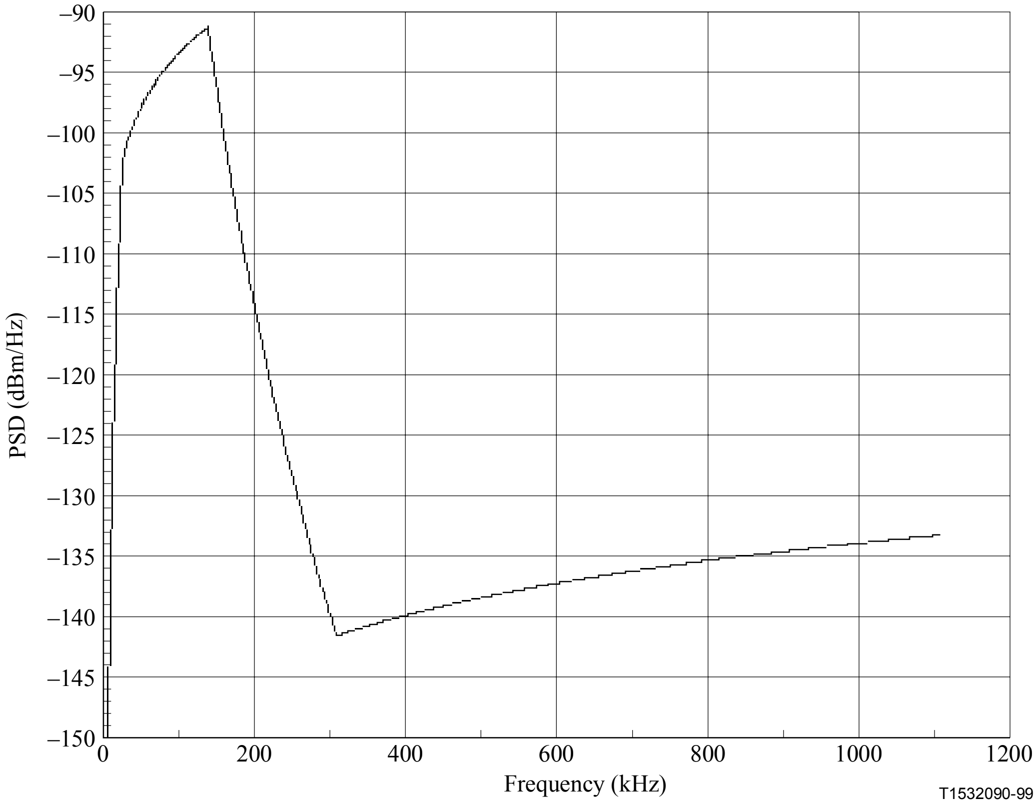


Figure 26/G.996.1 – Theoretical 49-disturber upstream G.992.2 NEXT into the downstream

7.8 ETSI A, ETSI B and Euro-K crosstalk

The power spectral density of the crosstalk noise sources used for performance testing is given in Figure 27 for ETSI A, and in Figure 28 for ETSI B. ETSI A includes discrete tones, which represent radio frequency interference that is commonly observed, especially on wire pairs routed above ground. Further details of the specification of these noise models are shown in Tables 22, 23 and 24.

The resulting wideband noise power over the frequency range 1 kHz to 1.5 MHz for model A is –49.4 ±0.5 dBm and for model B is –43.0 ±0.5 dBm.

The noise probability density function should be approximately Gaussian with a crest factor = 5.

The accuracy of the power spectral density shall be within ±1 dB over the frequency range 1 kHz to 1.5 MHz, when measured with a resolution bandwidth of 1 kHz.

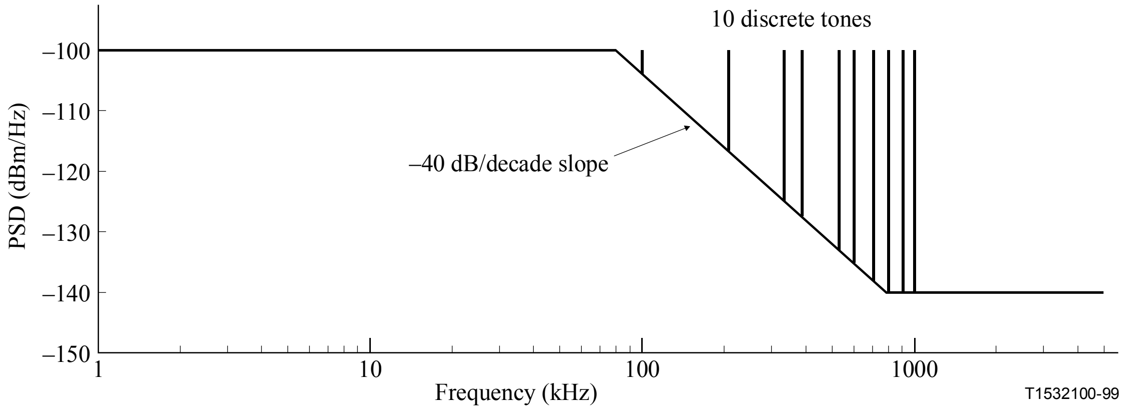


Figure 27/G.996.1 – Single-sided noise power spectral density into 100 Ω for ETSI A

Table 22/G.996.1 – Coordinates for noise ETSI A

Frequency (kHz)	PSD (dBm/Hz)
1	–100
79.5	–100
795	–140
1500	–140

Table 23/G.996.1 – Tone frequencies and powers for noise ETSI A

Frequency (kHz)	Power (dBm)
99	–70
207	–70
333	–70
387	–70
531	–70
603	–70
711	–70
801	–70
909	–70
981	–70

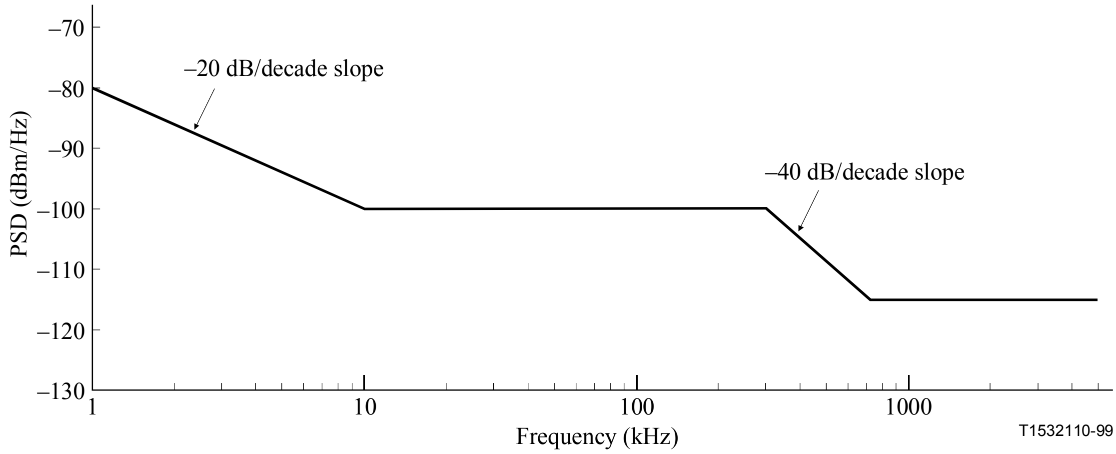


Figure 28/G.996.1 – Single-sided noise power spectral density into 100 Ω for ETSI B

Table 24/G.996.1 – Coordinates for noise ETSI B

Frequency (kHz)	PSD (dBm/Hz)	PSD (µV/√Hz)
1	–80	31.62
10	–100	3.16
300	–100	3.16
711	–115	0.56
1500	–115	0.56

The Euro-K model has a floor at –140 dBm/Hz, its maximum at –94 dBm/Hz between 135 kHz and 260 kHz. Below 135 kHz it rolls off towards the floor at +7 dB/decade. Above 260 kHz it rolls off towards the floor at –75 dB/decade.

Note that Euro-K is based on a recalculation of ETSI A crosstalk interference at the ATU-C end. It basically removes the secondary HDSL NEXT effects which are exploited at the ATU-R end by noise ETSI A but which do not apply at the ATU-C end.

7.9 Power spectral density of crosstalk disturbers in an environment coexisting with TCM-ISDN DSL

7.9.1 Crosstalk disturber type

This clause specifies the crosstalk disturbers in an environment coexisting with TCM-ISDN DSL, in terms of the power spectral density (PSD) and crosstalk characteristics. Crosstalk margin measurements are made for the following types of disturbers from pairs in the same binder group.

1) TCM-ISDN DSL NEXT and FEXT:
   - continuous NEXT;
   - continuous FEXT;
   - alternate NEXT and FEXT (for Annex C/G.992.2).
2) HDSL PSD NEXT:
   - continuous NEXT.

3) ADSL downstream NEXT and FEXT:

– continuous NEXT;

– continuous FEXT;

– alternate NEXT and FEXT (for FEXT bitmap mode of Annex C/G.992.2).

4) ADSL upstream NEXT and FEXT:

– continuous NEXT;

– continuous FEXT;

– alternate NEXT and FEXT (for FEXT bitmap mode of Annex C/G.992.2).

NOTE 1 – The term "ADSL" is used to indicate both G.992.1 and G.992.2, unless otherwise stated.

NOTE 2 – TCM-ISDN DSL alternate NEXT and FEXT injection timing is defined in 7.9.3.4.

7.9.2 Crosstalk test parameters

The crosstalk loss as the result of multiple interfering pairs is known as the Power Sum Loss (PSL), and 99% cumulative (1% worst case) values are adopted for ADSL performance test. PSL values vary depending on the number of disturber pairs, the insulation material of the pair conductors (paper, polyethylene), and line conditioning states (pair selection conditions) for DSL installation into a cable pair in the same binder.

NEXT Power Sum Loss in dB for the disturber pair number of "n" is abbreviated to "$NPSL_n$". FEXT Power Sum Loss in dB for the disturber pair number of "n" is abbreviated to "$FPSL_n$". The value of "n = 24" is adopted for all crosstalk tests. The values of $NPSL_{24}$ and $FPSL_{24}$ are summarized in Table 25 for each insulation material of the pair conductors (paper, polyethylene) and for each line conditioning states (pair selection conditions).

Table 25/G.996.1 – Power sum loss values

NEXT/FEXT power sum loss	Line conditioning state	Interfering and interfered system attribute	Insulation material of pair conductor	
			Paper-insulated	Polyethylene-insulated
$NPSL_{24}$ [dB] at $f_{NXT} = 160 \times 10^3$ [Hz]	Intra-quad	Inter/intra-system	47.0 dB	49.5 dB
	Inter-quad	Inter-system (Note 1)	52.5 dB	53.5 dB
		Intra-system (Note 2)	53.5 dB	55.5 dB
$FPSL_{24}$ [dB] at $f_{FXT} = 160 \times 10^3$ [Hz] at $d_{FXT} = 1.0 \times 10^3$ [m]	Intra-quad	Inter/intra-system	45.0 dB	51.0 dB
	Inter-quad	Inter-system (Note 1)	45.0 dB	51.0 dB
		Intra-system (Note 2)	45.5 dB	53.0 dB
NOTE 1 – Mutual interference between different transmission systems. NOTE 2 – Mutual interference between identical transmission systems.				

The test loops defined in 6.1.3 contain combined loops that consist of two segments: a paper-insulated cable segment and a polyethylene-insulated cable segment. In cases where such test loops consist of mixed cable type connection, the following NEXT/FEXT simulated noises should be injected.

a) The NEXT noise should be simulated by using NEXT PSL (NPSL) values corresponding to the insulation material of the cable connected at the near end of a NEXT injection point.

b) The FEXT noise should be simulated by a power sum of each FEXT coupling path by using the equation below, and should be injected at a far end.

$$PSD_{FEXT} = PSD_{Disturber} \times \prod_k \left(\left| H_{channel[k]}(f, d[k]) \right|^2 \right) \times$$
$$\times \sum_k \left(10^{-\frac{FPSL_n[k]}{10}} \times d[k] \times d_{FXT}{}^{-1} \right) \times \left(f^2 \times f_{FXT}{}^{-2} \right)$$

where:

$H_{channel[k]}(f,d[k])$:	channel transfer function of each cable segment [k] consisting test loop
$d[k]$:	distance of each cable segment [k] consisting test loop
$FPSL_n[k]$:	FEXT PSL value of each cable segment [k] consisting test loop

The circuit for crosstalk injection shall be calibrated for 0.4 dB less crosstalk than specified in this clause in order to compensate for the use of 100-ohm terminations of ADSL instead of 110 ohms of TCM-ISDN DSL for TCM-ISDN DSL crosstalk injection testing. The circuit shall also be calibrated for 1.3 dB less crosstalk than specified in this clause in order to compensate for the use of 100-ohm terminations of ADSL instead of 135 ohms of HDSL for HDSL crosstalk injection testing.

The above calibration can be described in the equation below.

$$PSD[injection]_{NEXT(or)FEXT} = PSD_{NEXT(or)FEXT} \times \left(\frac{Z0_{interfered}}{Z0_{interfering}} \right)$$

where:

$PSD[injection]_{NEXT(or)FEXT}$:	PSD for injection in the receiver
$PSD_{NEXT(or)FEXT}$:	simulated PSD given in 7.9
$Z0_{interfered}$:	termination impedance of interfered system
	= 100-ohm terminations of ADSL
$Z0_{interfering}$:	termination impedance of interfering system
	= 100-ohm terminations of TCM-ISDN DSL
	= 135-ohm terminations of HDSL

7.9.3 Simulated TCM-ISDN DSL PSD and induced NEXT and FEXT

7.9.3.1 TCM-ISDN DSL PSD

The PSD of Basic Rate Access (BRA) DSL disturbers using a Time Compression Multiplex (TCM) method is expressed as:

$$PSD_{DSL\text{-}Disturber} = K_{DSL} \times \frac{2}{f_0} \times \left[\sin\left(\pi \frac{f}{f_0} \right) \right]^2 \times \frac{\left[\sin\left(\pi \frac{f}{2f_0} \right) \right]^2}{\left(\pi \frac{f}{2f_0} \right)^2} \times \frac{1}{1 + \left(\frac{f}{f_{3dB}} \right)^4}, \quad (0 \le f < \infty)$$

where: f in Hz, $f_0 = 320 \times 10^3$ Hz, $f_{3dB} = 2 \times f_0$, $K_{DSL} = \frac{V_{0p}{}^2}{4R}$, $V_{0p} = 6.00$ volts and $R = 110$ ohms

The equation $PSD_{DSL\text{-}Disturber}$ gives the single-sided PSD of a 320 kBaud Alternate Mark Inversion (AMI) signal with random continuous symbol sequence, with 50% duty-cycle pulses and with 2nd order low-pass Butterworth filtering (f_{3dB} = 640 kHz).

7.9.3.2 TCM-ISDN DSL NEXT

The PSD of the DSL NEXT can be expressed as:

$$PSD_{DSL\text{-}NEXT} = PSD_{DSL\text{-}Disturber} \times \left[10^{-\frac{NPSL_n}{10}} \times f_{NXT}^{-\frac{3}{2}} \right] \times f^{\frac{3}{2}}, \qquad (0 \le f < \infty)$$

where: f in Hz, $f_{NXT} = 160 \times 10^3$ Hz

The integration of $PSD_{DSL\text{-}Disturber}$ and $PSD_{DSL\text{-}NEXT}$ over various frequency ranges is presented in Table 26 for the case of the paper-insulated cable with intra-quad line conditioning state.

Table 26/G.996.1 – TCM-ISDN DSL transmit and induced NEXT power

Frequency range	Transmit power	NEXT power ($NPSL_{24}$ = 47.0 dB)
0 ~ 640 kHz	18.6 dBm	–27.3 dBm
0 ~ 1280 kHz	18.6 dBm	–26.8 dBm
0 ~ 1920 kHz	18.6 dBm	–26.7 dBm
0 ~ 2560 kHz	18.6 dBm	–26.7 dBm
0 ~ 3200 kHz	18.6 dBm	–26.7 dBm

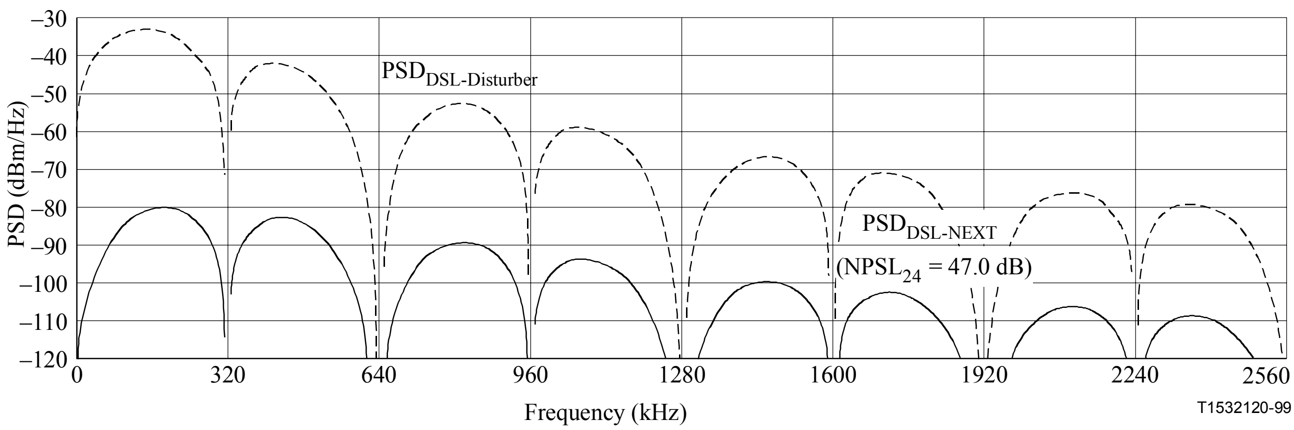


Figure 29/G.996.1 – 24-disturber TCM-ISDN DSL NEXT

7.9.3.3 TCM-ISDN DSL FEXT

The PSD of the DSL FEXT can be expressed as:

$$PSD_{DSL\text{-}FEXT} = PSD_{DSL\text{-}Disturber} \times \left| H_{channel}(f,d) \right|^2 \times$$
$$\times \left[10^{-\frac{FPSL_n}{10}} \times d_{FXT}^{-1} \times f_{FXT}^{-2} \right] \times d \times f^2, \qquad (0 \le f < \infty)$$

where: f in Hz, d in metre, $f_{FXT} = 160 \times 10^3$ Hz, $d_{FXT} = 1.0 \times 10^3$ metres

$H_{channel}$ (f,d) is the channel transfer function; "d" is the coupling path distance in metres, and depends on test loops defined in 6.1.3. The power sum of $PSD_{DSL\text{-}FEXT}$ is required for the test loops consisting of mixed cable type connection, as described in 7.9.2.

The integration of $PSD_{DSL\text{-}Disturber}$ and $PSD_{DSL\text{-}FEXT}$ over various frequency ranges is presented in Table 27 for the case of the 0.4 mm gauge paper insulated cable with intra-quad line conditioning state and with $d = 2.07 \times 10^3$, 2.94×10^3, 3.97×10^3, and 5.16×10^3 metres.

Table 27/G.996.1 – TCM-ISDN DSL transmit and induced FEXT power

Frequency range	Transmit power	FEXT power ($FPSL_{24}$ = 45.0 dB)			
		d = 2.07 km	d = 2.94 km	d = 3.97 km	d = 5.16 km
0 ~ 640 kHz	18.6 dBm	–50.3 dBm	–59.5 dBm	–70.4 dBm	–82.7 dBm
0 ~ 1280 kHz	18.6 dBm	–50.3 dBm	–59.5 dBm	–70.4 dBm	–82.7 dBm
0 ~ 1920 kHz	18.6 dBm	–50.3 dBm	–59.5 dBm	–70.4 dBm	–82.7 dBm
0 ~ 2560 kHz	18.6 dBm	–50.3 dBm	–59.5 dBm	–70.4 dBm	–82.7 dBm
0 ~ 3200 kHz	18.6 dBm	–50.3 dBm	–59.5 dBm	–70.4 dBm	–82.7 dBm

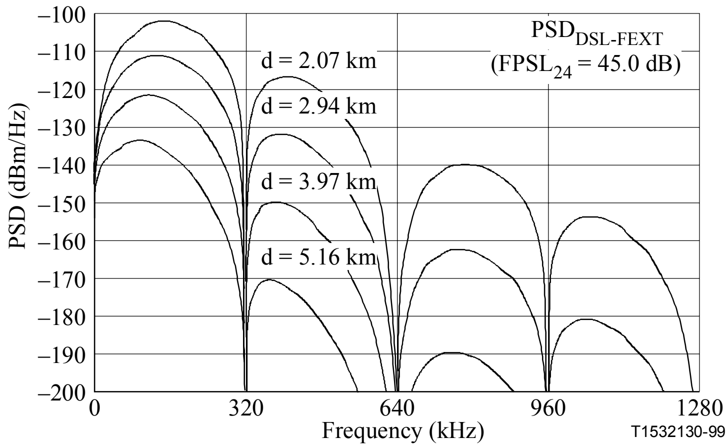


Figure 30/G.996.1 – 24-Disturber TCM-ISDN DSL FEXT

7.9.3.4 TCM-ISDN DSL alternate NEXT and FEXT injection timing

For testing transmission performance of an ADSL system conforming to G.992.1/Annex C/G.992.2 (ADSL operating in an environment coexisting with TCM-ISDN DSL), the calibrated simulated TCM-ISDN DSL NEXT/FEXT PSD defined above shall be alternately injected in burst mode as specified in Figure 31, which is the worst-case simplified model shown in relation to TTR (TCM-ISDN Timing Reference described in G.992.1/Annex C/G.992.2), and is derived from the TCM-ISDN DSL signal transceiver scheme.

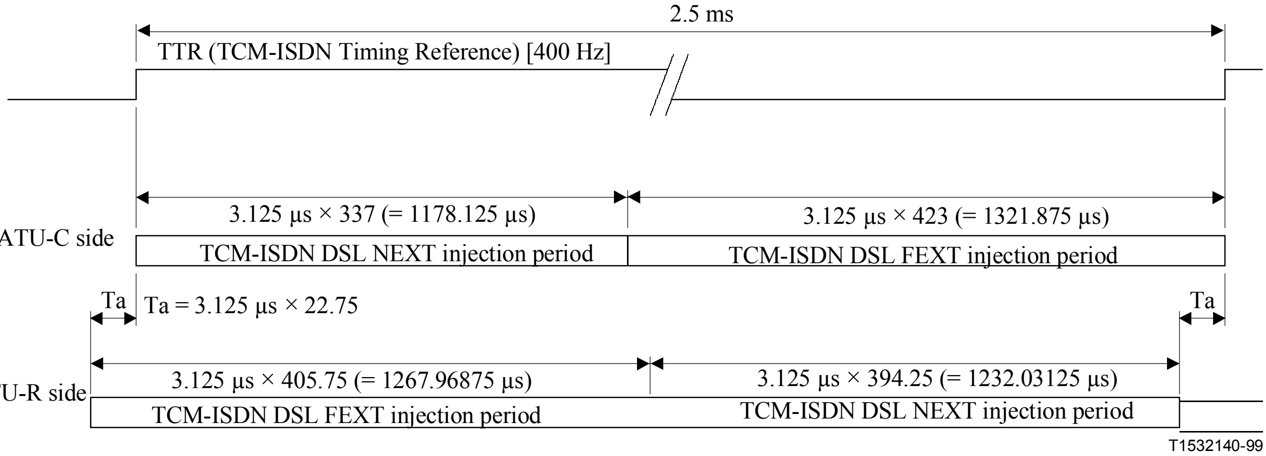


Figure 31/G.996.1 – TCM-ISDN DSL alternate NEXT and FEXT injection timing

NOTE 1 – For testing transmission performance of an ADSL system conforming to G.992.1/G.992.2 main body, it is permitted to inject TCM-ISDN DSL NEXT/FEXT PSD in continuous mode. In this case, the specified error threshold for ADSL with TCM-ISDN DSL crosstalk interference is a BER of 2.12 × objective-BER. This is because the TCM-ISDN DSL transmits signals in burst mode. The ratio of burst signal transmitting period to the burst repetition period of 2.5 ms is 377-pulse-periods/800-pulse-periods (= 1/2.12), and the transmit signal in burst mode only causes NEXT/FEXT noise.

NOTE 2 – The FEXT injection timing in Figure 31 is also applicable for testing intra-system crosstalk interference of ADSL system conforming G.992.1/Annex C/G.992.2 FBM. In this test, TCM-ISDN DSL FEXT in ATU-C side should be replaced by ADSL upstream FEXT defined in 7.9.6.3. Also, TCM-ISDN DSL FEXT in ATU-R side should be replaced by ADSL downstream FEXT defined in 7.9.5.3. TCM-ISDN DSL NEXT in ATU-C and ATU-R sides should be replaced by no noise.

7.9.4 Simulated HDSL PSD and induced NEXT

7.9.4.1 HDSL PSD

The PSD of HDSL disturbers is expressed as:

$$PSD_{HDSL\text{-}Disturber} = K_{HDSL} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\pi \frac{f}{f_0}\right)\right]^2}{\left(\pi \frac{f}{f_0}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3\mathrm{dB}}}\right)^8}, \qquad (0 \le f < \infty)$$

where:

f in Hz, $f_0 = 392 \times 10^3$ Hz, $f_{3\mathrm{dB}} = \frac{f_0}{2}$, $K_{HDSL} = \frac{5}{9} \times \frac{{V_{0p}}^2}{R}$, $V_{0p} = 2.70$ volts and $R = 135$ ohms

The equation $PSD_{HDSL\text{-}Disturber}$ gives the single-sided PSD of a 392 kBaud 2B1Q signal with random continuous equiprobable level symbol sequence, with 100% duty-cycle pulses and with 4th order low-pass Butterworth filtering ($f_{3\mathrm{dB}}$ = 196 kHz).

7.9.4.2 HDSL NEXT

The PSD of HDSL NEXT can be expressed as:

$$PSD_{HDSL\text{-}NEXT} = PSD_{HDSL\text{-}Disturber} \times \left[10^{-\frac{NPSL_n}{10}} \times f_{NXT}^{-\frac{3}{2}} \right] \times f^{\frac{3}{2}} \qquad (0 \le f < \infty)$$

where: f in Hz, $f_{NXT} = 160 \times 10^3$ Hz

The integration of $PSD_{HDSL\text{-}Disturber}$ and $PSD_{HDSL\text{-}NEXT}$ over various frequency ranges is presented in Table 28 for the case of the paper-insulated cable with intra-quad line conditioning state.

Table 28/G.996.1 – HDSL transmit and induced NEXT power

Frequency range	Transmit power	NEXT power ($NPSL_{24}$ = 47.0 dB)
0 ~ 196 kHz	13.4 dBm	–37.4 dBm
0 ~ 392 kHz	13.6 dBm	–36.8 dBm
0 ~ 784 kHz	13.6 dBm	–36.8 dBm
0 ~ 1568 kHz	13.6 dBm	–36.8 dBm
0 ~ 3136 kHz	13.6 dBm	–36.8 dBm

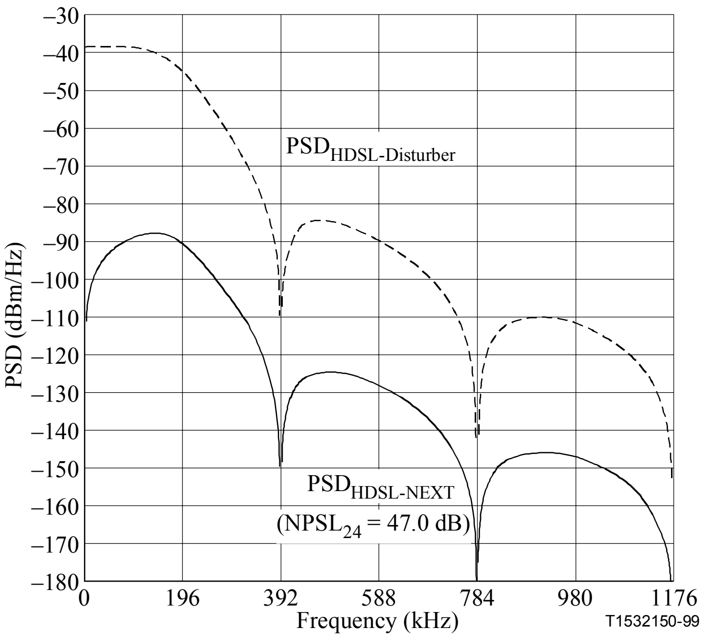


Figure 32/G.996.1 – 24-disturber HDSL NEXT

7.9.5 Simulated ADSL downstream PSD and induced NEXT and FEXT

7.9.5.1 ADSL downstream PSD

The PSD of the G.992.1/G.992.2 disturbers is expressed as:

$$PSD_{ADSL,ds\text{-}Disturber} = K_{ADSL,ds} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\pi \frac{f}{f_0}\right)\right]^2}{\left(\pi \frac{f}{f_0}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{LP3dB}}\right)^{12}} \times \frac{1}{1+\left(\frac{f_{HP3dB}}{f}\right)^{N}},$$

$(0 \le f < \infty)$

where:

f in Hz, $f_0 =$ 2.208×10^6 Hz, $f_{LP3\mathrm{dB}} = \frac{f_0}{2}$ (for G.992.1), $f_{LP3\mathrm{dB}} = \frac{f_0}{4}$ (for G.992.2)

$f_{HP3\mathrm{dB}} =$ 25.875×10^3 Hz, $N = 8$ (for EC)

$f_{HP3\mathrm{dB}} =$ 138×10^3 Hz, $N = 16$ (for FDM)

$K_{ADSL,\mathrm{ds}} =$ 0.1104 watts (corresponding to the maximum passband PSD of −40 dBm/Hz)

The equation $PSD_{ADSL,ds\text{-}Disturber}$ gives the single-sided PSD with 6th order low-pass Butterworth filtering [$f_{LP3\mathrm{dB}}$ = 1104 kHz (G.992.1) or 552 kHz (G.992.2)], rejecting stop-band PSD and with Nth order high-pass filtering [$f_{HP3\mathrm{dB}}$ = 25.875 kHz, $N = 8$ (EC) or 138 kHz, $N = 16$ (FDM)], separating ADSL signal from POTS signal for EC, or separating ADSL downstream signal from ADSL upstream signal for FDM.

7.9.5.2 ADSL downstream NEXT into the upstream

The PSD of the G.992.1/G.992.2 downstream NEXT into the upstream can be expressed as:

$$PSD_{ADSL,ds\text{-}NEXT} = PSD_{ADSL,ds\text{-}Disturber} \times \left[10^{-\frac{NPSL_n}{10}} \times f_{NXT}^{-\frac{3}{2}}\right] \times f^{\frac{3}{2}}, \qquad (0 \le f < \infty)$$

where: f in Hz, $f_{NXT} = 160 \times 10^3$ Hz

The integration of $PSD_{ADSL,ds\text{-}NEXT}$ over various frequency ranges is presented in Table 29 (G.992.1, FDM) and in Table 30 (G.992.2, FDM) for the case of the paper-insulated cable with intra-quad line conditioning state.

Table 29/G.996.1 – G.992.1 FDM downstream transmit and induced NEXT power

Frequency range	Transmit power	NEXT power ($NPSL_{24}$ = 47.0 dB)
0 ~ 1104 kHz	18.4 dBm	–20.4 dBm
0 ~ 2208 kHz	18.5 dBm	–20.0 dBm
0 ~ 4416 kHz	18.5 dBm	–20.0 dBm

Table 30/G.996.1 – G.992.2 FDM downstream transmit and induced NEXT power

Frequency range	Transmit power	NEXT power ($NPSL_{24}$ = 47.0 dB)
0 ~ 552 kHz	15.5 dBm	–26.7 dBm
0 ~ 1104 kHz	15.8 dBm	–25.9 dBm
0 ~ 2208 kHz	15.8 dBm	–25.9 dBm

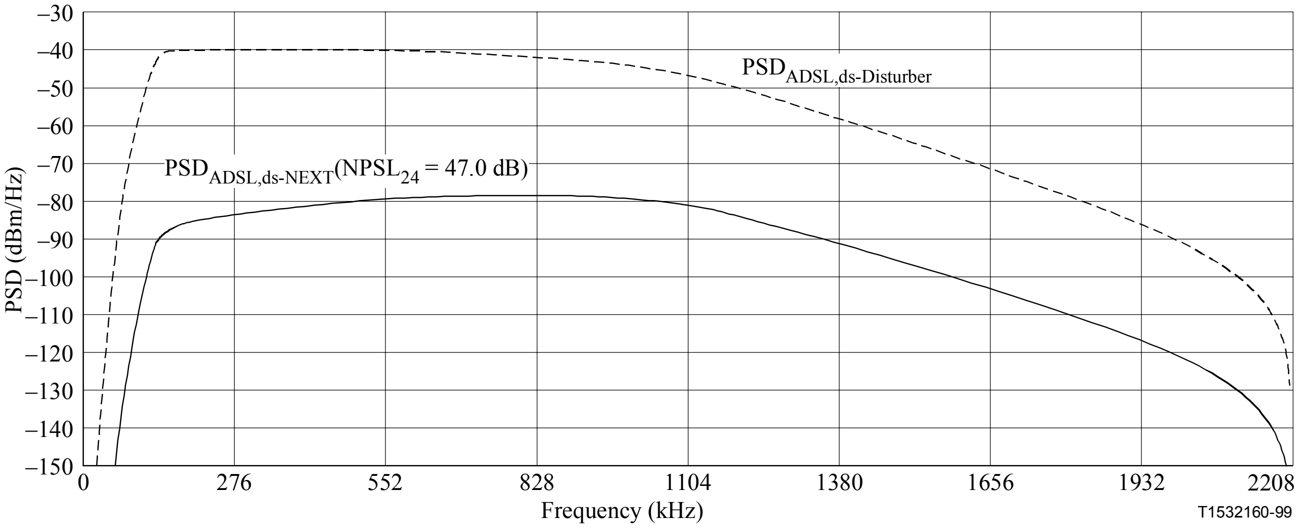


Figure 33/G.996.1 – 24-disturber G.992.1 (FDM) downstream NEXT

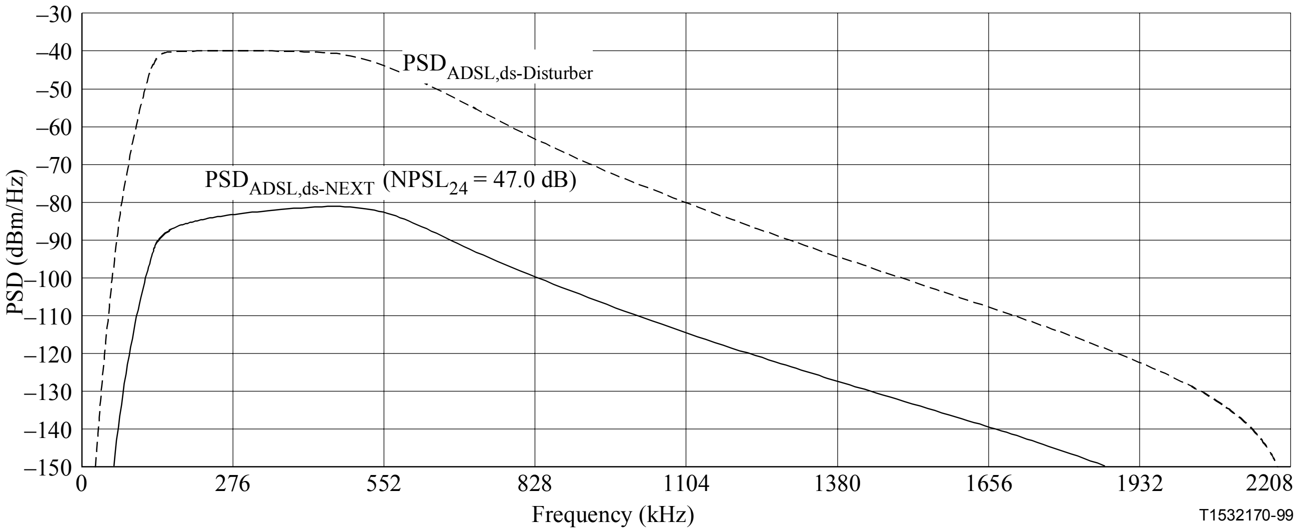


Figure 34/G.996.1 – 24-disturber G.992.2 (FDM) downstream NEXT

7.9.5.3 ADSL downstream FEXT into the downstream

The PSD of the G.992.1/G.992.2 downstream FEXT into the downstream can be expressed as:

$$PSD_{ADSL,ds\text{-}FEXT} = PSD_{ADSL,ds\text{-}Disturber} \times \left|H_{channel}(f,d)\right|^2 \times \\ \times \left[10^{-\frac{FPSL_n}{10}} \times d_{FXT}{}^{-1} \times f_{FXT}{}^{-2} \right] \times d \times f^2, \qquad (0 \le f < \infty)$$

where: f in Hz, d in metre, $f_{FXT} = 160 \times 10^3$ Hz, $d_{FXT} = 1.0 \times 10^3$ metres

$H_{channel}(f, d)$ is the channel transfer function, "d" is the coupling path distance in metres. The power sum of $PSD_{ADSL,ds\text{-}FEXT}$ for a combined test loop is described in 7.9.2.

The integration of $PSD_{ADSL,ds\text{-}Disturber}$ and $PSD_{ADSL,ds\text{-}FEXT}$ over various frequency ranges is presented in Table 31 (G.992.1, FDM) and in Table 32 (G.992.2, FDM) for the case of the 0.4 mm gauge paper-insulated cable with intra-quad line conditioning state and with $d = 2.07 \times 10^3$, 2.94×10^3, 3.97×10^3, and 5.16×10^3 metres.

Table 31/G.996.1 – G.992.1 FDM downstream transmit and induced FEXT power

Frequency range	Transmit power	FEXT power ($FPSL_{24}$ = 45.0 dB)			
		d = 2.07 km	d = 2.94 km	d = 3.97 km	d = 5.16 km
0 ~ 1104 kHz	18.4 dBm	–54.9 dBm	–66.5 dBm	–79.5 dBm	–94.2 dBm
0 ~ 2208 kHz	18.5 dBm	–54.9 dBm	–66.5 dBm	–79.5 dBm	–94.2 dBm
0 ~ 4416 kHz	18.5 dBm	–54.9 dBm	–66.5 dBm	–79.5 dBm	–94.2 dBm

Table 32/G.996.1 – G.992.2 FDM downstream transmit and induced FEXT power

Frequency range	Transmit power	FEXT power ($FPSL_{24}$ = 45.0 dB)			
		d = 2.07 km	d = 2.94 km	d = 3.97 km	d = 5.16 km
0 ~ 552 kHz	15.5 dBm	–55.2 dBm	–66.5 dBm	–79.5 dBm	–94.2 dBm
0 ~ 1105 kHz	15.8 dBm	–55.1 dBm	–66.5 dBm	–79.5 dBm	–94.2 dBm
0 ~ 2208 kHz	15.8 dBm	–55.1 dBm	–66.5 dBm	–79.5 dBm	–94.2 dBm

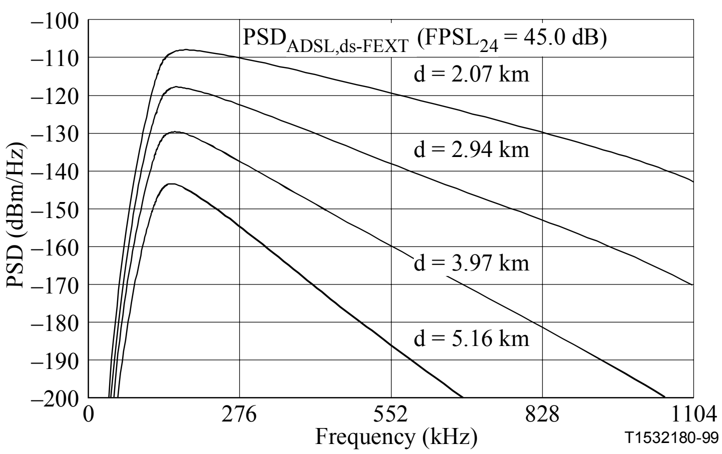


Figure 35/G.996.1 – 24-disturber G.992.1 (FDM) downstream FEXT

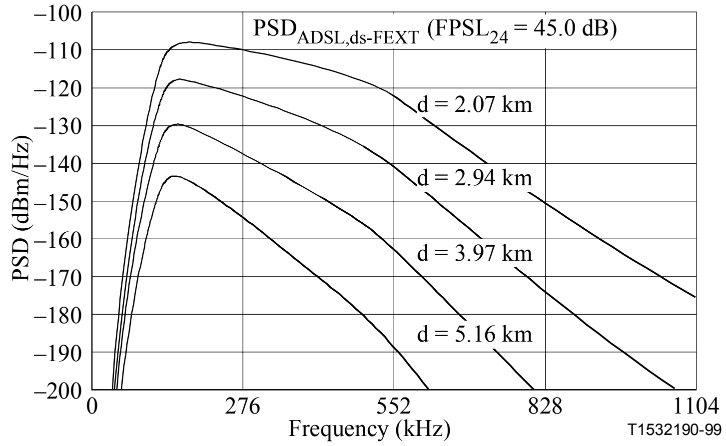


Figure 36/G.996.1 – 24-disturber G.992.2 (FDM) downstream FEXT

7.9.6 Simulated ADSL upstream PSD and induced NEXT and FEXT

7.9.6.1 ADSL upstream PSD

The single-sided PSD of the G.992.1/G.992.2 upstream disturbers can be assumed as:

$$PSD_{ADSL,us\text{-}Disturber} = K_{ADSL,us} \times \frac{2}{f_0} \times \frac{\left[\sin\left(\pi \frac{f}{f_0}\right)\right]^2}{\left(\pi \frac{f}{f_0}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{LP3dB}}\right)^{16}} \times \frac{1}{1+\left(\frac{f_{HP3dB}}{f}\right)^{8}},$$

$(0 \le f < \infty)$

where: f in Hz, $f_0 = 276 \times 10^3$ Hz, $f_{LP3\text{dB}} = 138 \times 10^3$, $f_{HP3\text{dB}} = 25.875 \times 10^3$ Hz,

$K_{ADSL,us} = 0.02187$ watts (corresponding to the maximum pass band PSD of –38 dBm/Hz)

7.9.6.2 ADSL upstream NEXT into the downstream

The PSD of the G.992.1/G.992.2 upstream NEXT into the downstream can be expressed as:

$$PSD_{ADSL,us\text{-}NEXT} = PSD_{ADSL,us\text{-}Disturber} \times \left[10^{-\frac{NPSL_a}{10}} \times f_{NXT}^{-\frac{3}{2}}\right] \times f^{\frac{3}{2}}, \quad (0 \le f < \infty)$$

where: f in Hz, $f_{NXT} = 160 \times 10^3$ Hz

The integration of $PSD_{ADSL,us\text{-}Disturber}$ and $PSD_{ADSL,us\text{-}NEXT}$ over various frequency ranges is presented in Table 33 for the case of a paper-insulated cable with intra-quad line conditioning state.

Table 33/G.996.1 – G.992.1/G.992.2 upstream transmit and induced NEXT power

Frequency range	Transmit power	NEXT power (NPSL$_{24}$ = 47.0 dB)
0 ~ 138.000 kHz	10.9 dBm	–40.9 dBm
0 ~ 181.125 kHz	11.0 dBm	–40.6 dBm
0 ~ 224.250 kHz	11.0 dBm	–40.6 dBm

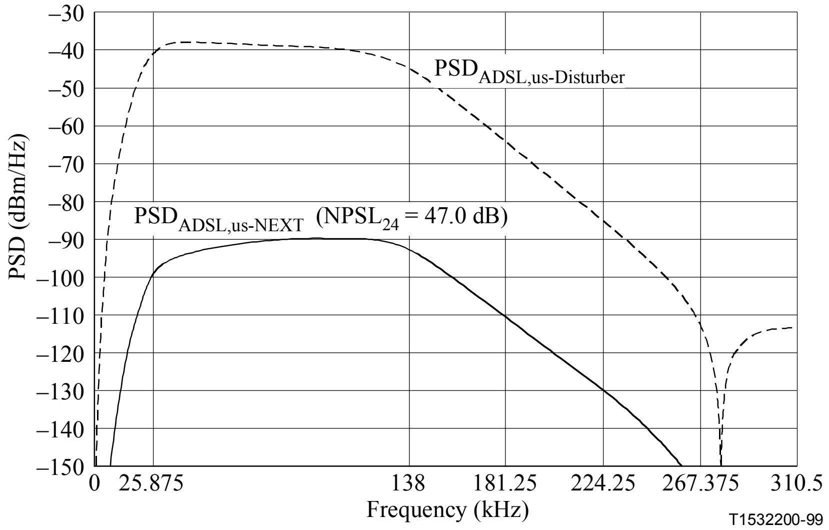


Figure 37/G.996.1 – 24-disturber G.992.1/G.992.2 upstream NEXT

7.9.6.3 ADSL upstream FEXT into the upstream

The PSD of the G.992.1/G.992.2 upstream FEXT into the upstream can be expressed as:

$$PSD_{ADSL,us\text{-}FEXT} = PSD_{ADSL,us\text{-}Disturber} \times \left|H_{channel}(f,d)\right|^2 \times$$
$$\times \left[10^{-\frac{FPSL_n}{10}} \times d_{FXT}{}^{-1} \times f_{FXT}{}^{-2}\right] \times d \times f^2, \qquad (0 \le f < \infty)$$

where: f in Hz, d in metre, $f_{FXT} = 160 \times 10^3$ Hz, $d_{FXT} = 1.0 \times 10^3$ metres

$H_{channel}$ (f, d) is the channel transfer function, "d" is the coupling path distance in metres. The power sum of $PSD_{ADSL,us\text{-}FEXT}$ for a combined test loop is described in 7.9.2.

The integration of $PSD_{ADSL,us\text{-}Disturber}$ and $PSD_{ADSL,us\text{-}FEXT}$ over various frequency ranges is presented in Table 34 for the case of the 0.4 mm gauge paper-insulated cable with intra-quad line conditioning state and with $d = 2.07 \times 10^3$, 2.94×10^3, 3.97×10^3, and 5.16×10^3 metres.

Table 34/G.996.1 – G.992.1/G.992.2 upstream transmit and induced FEXT power

Frequency range	Transmit power	FEXT power ($FPSL_{24}$ = 45.0 dB)			
		d = 2.07 km	d = 2.94 km	d = 3.97 km	d = 5.16 km
0 ~ 138.000 kHz	10.9 dBm	–59.1 dBm	–66.5 dBm	–75.5 dBm	–86.0 dBm
0 ~ 181.125 kHz	11.0 dBm	–58.9 dBm	–66.4 dBm	–75.4 dBm	–85.9 dBm
0 ~ 224.250 kHz	11.0 dBm	–58.9 dBm	–66.4 dBm	–75.4 dBm	–85.9 dBm

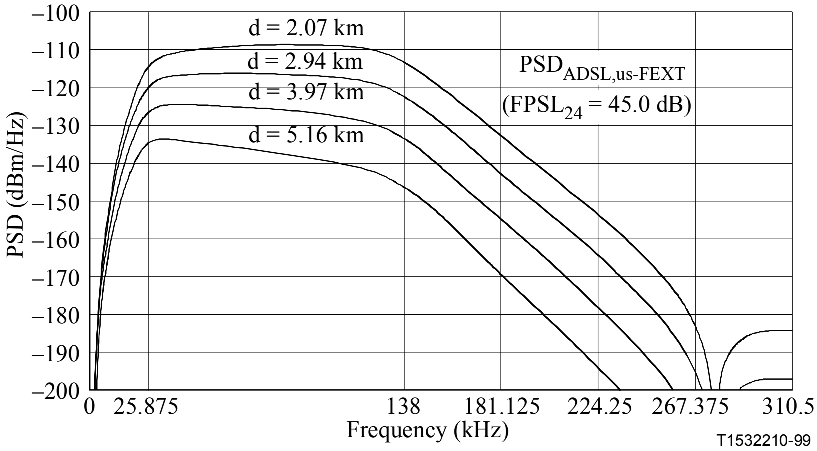


Figure 38/G.996.1 – 24-disturber G.992.1/G.992.2 upstream FEXT

8 Characteristics of impulse noise waveforms

The two test impulse waveforms are shown in Figures 39 and 40. Tables 35 and 36 contain the impulse wave amplitude given in millivolts at 160 nanosecond time intervals.

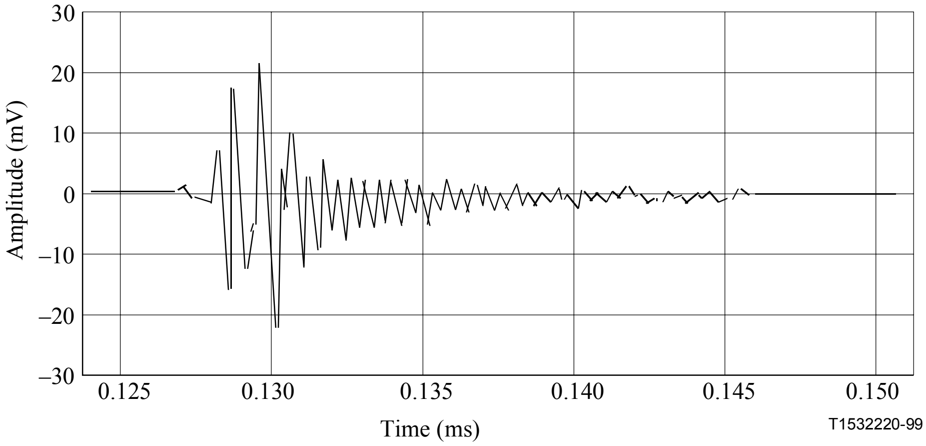


Figure 39/G.996.1 – Test impulse 1

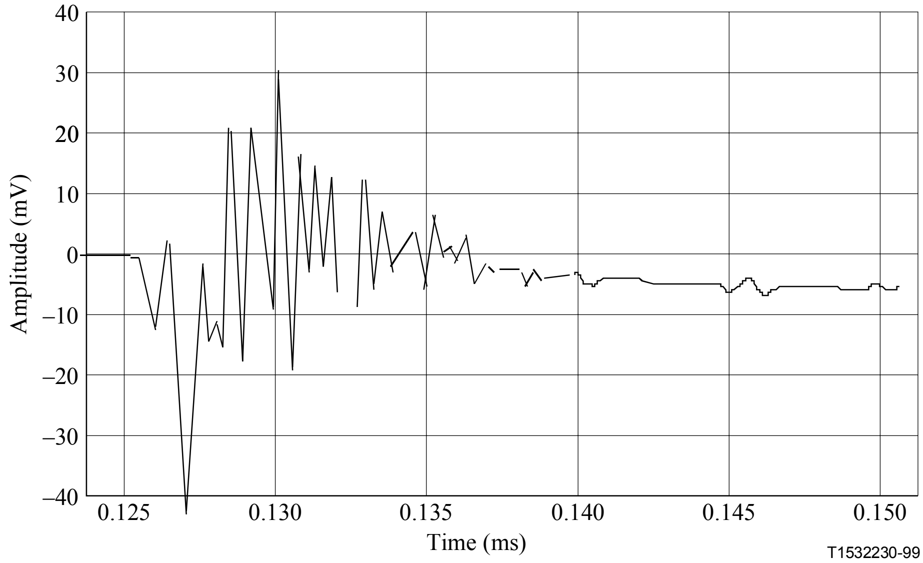


Figure 40/G.996.1 – Test impulse 2

Table 35/G.996.1 – Impulse number 1

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
1	0.0000	51	–6.3934	101	0.1598
2	0.0000	52	1.7582	102	–1.7582
3	0.0000	53	2.2377	103	0.1598
4	0.0000	54	–4.9549	104	0.4795
5	0.0000	55	2.2377	105	–1.2787
6	0.0000	56	1.7582	106	0.7992
7	0.0000	57	–5.5943	107	1.2787
8	0.0000	58	1.4385	108	–0.7992
9	0.0000	59	2.3975	109	0.0000
10	0.9590	60	–3.6762	110	–0.3197
11	–0.4795	61	1.4385	111	–2.2377
12	–1.2787	62	0.4795	112	–1.1188
13	–1.1188	63	–5.7541	113	–0.7992
14	–1.4385	64	–0.4795	114	–1.5984
15	–1.5984	65	0.3197	115	0.1598
16	–2.2377	66	–3.3566	116	0.4795
17	–1.4385	67	2.3975	117	–0.9590
18	7.6721	68	2.3975	118	0.0000
19	6.7131	69	–3.1967	119	–0.3197
20	–16.6229	70	0.7992	120	–1.5984
21	–12.9467	71	0.6393	121	0.0000
22	18.7008	72	–3.5164	122	0.4795
23	9.5902	73	1.1188	123	–0.7992
24	–13.5861	74	1.7582	124	0.4795
25	–5.2746	75	–2.3975	125	0.7992
26	–6.3934	76	1.2787	126	–0.9590
27	–1.9180	77	0.9590	127	–0.9590
28	23.0164	78	–3.3566	128	–0.4795
29	3.9959	79	0.0000	129	–0.6393
30	–23.4959	80	0.1598	130	0.4795
31	–3.1967	81	–3.0369	131	1.1188
32	4.3156	82	1.1188	132	0.0000
33	–3.0369	83	1.5984	133	0.0000
34	10.7090	84	–2.0779	134	0.0000
35	2.2377	85	0.1598	135	0.0000
36	–12.9467	86	0.3197	136	0.0000

Table 35/G.996.1 – Impulse number 1

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
37	3.1967	87	–2.5574	137	0.0000
38	1.9180	88	0.1598	138	0.0000
39	–9.9098	89	0.1598	139	0.0000
40	5.5943	90	–2.0779	140	0.0000
41	5.9139	91	0.6393		
42	–6.7131	92	0.9590		
43	2.3975	93	–1.7582		
44	1.2787	94	–0.1598		
45	–8.4713	95	–0.6393		
46	2.5574	96	–3.0369		
47	2.8771	97	–0.3197		
48	–6.0738	98	0.4795		
49	2.2377	99	–1.4385		
50	1.7582	100	0.4795		

Table 36/G.996.1 – Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
1	0.0000	51	0.6404	101	0.6404
2	0.0000	52	15.5295	102	0.6404
3	0.0000	53	18.8916	103	–0.4803
4	0.0000	54	–3.8424	104	–0.3202
5	0.0000	55	–3.0419	105	–0.9606
6	0.0000	56	11.6872	106	–2.8818
7	0.0000	57	–0.3202	107	–2.5616
8	0.0000	58	–7.5246	108	–0.8005
9	0.0000	59	13.4483	109	–0.4803
10	–0.6404	60	18.4113	110	–0.8005
11	0.9606	61	–0.4803	111	–0.4803
12	0.1601	62	–3.0419	112	–0.9606
13	–5.4433	63	9.7660	113	–1.1207
14	–12.3276	64	11.2069	114	–0.6404
15	–12.1675	65	4.0025	115	–0.4803
16	0.0000	66	0.6404	116	–0.9606
17	5.2832	67	0.6404	117	–1.4409
18	0.1601	68	1.7611	118	–1.6010
19	–20.8128	69	3.3621	119	–1.2808
20	–45.3078	70	5.6034	120	–0.9606
21	–46.7487	71	7.8448	121	–0.9606
22	–28.9778	72	2.5616	122	–1.2808
23	–13.4483	73	–4.6428	123	–1.1207
24	0.6404	74	0.6404	124	–1.1207
25	0.9606	75	10.7266	125	–1.4409
26	–14.4089	76	8.3251	126	–1.4409
27	–13.7685	77	1.9212	127	–1.4409
28	–9.4458	78	3.6823	128	–2.0813
29	–17.4507	79	4.3227	129	–2.4015
30	–2.5616	80	0.3202	130	–1.9212
31	26.5763	81	2.7217	131	–1.4409
32	16.1699	82	7.2044	132	–1.1207
33	–17.7709	83	3.2020	133	–1.2808
34	–17.1305	84	–2.7217	134	–1.9212
35	13.6084	85	–1.4409	135	–2.2414
36	27.0566	86	1.2808	136	–2.2414

Table 36/G.996.1 – Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
37	18.0911	87	1.4409	137	–2.5616
38	14.2488	88	0.8005	138	–3.0419
39	5.6034	89	0.1601	139	–3.0419
40	–8.1650	90	0.0000	140	–2.5616
41	12.4877	91	1.1207	141	–1.2808
42	37.3029	92	1.1207	142	–0.1601
43	9.6059	93	0.6404	143	–0.6404
44	–18.8916	94	1.1207	144	–2.5616
45	5.1231	95	0.6404	145	–3.2020
46	22.2537	96	–1.1207	146	–3.0419
47	1.1207	97	–0.8005	147	–2.5616
48	–0.9606	98	0.1601	148	–2.0813
49	20.4926	99	–1.2808	149	–1.4409
50	14.2488	100	–1.4409	150	–1.6010
151	–1.9212	201	–0.8005	251	–1.2808
152	–1.9212	202	–0.9606	252	–1.6010
153	–2.0813	203	–1.6010	253	–1.6010
154	–2.4015	204	–2.4015	254	–1.4409
155	–2.5616	205	–2.5616	255	–0.4803
156	–2.5616	206	–2.8818	256	0.4803
157	–1.9212	207	–2.7217	257	0.4803
158	–1.6010	208	–1.9212	258	–0.4803
159	–1.6010	209	–1.1207	259	–0.9606
160	–1.9212	210	–0.9606	260	–1.1207
161	–1.9212	211	–1.1207	261	–1.4409
162	–2.0813	212	–1.4409	262	–1.2808
163	–2.2414	213	–1.7611	263	–0.1601
164	–2.5616	214	–2.4015	264	0.3202
165	–2.7217	215	–2.5616	265	0.0000
166	–2.2414	216	–2.2414	266	–0.4803
167	–1.2808	217	–1.7611	267	–0.4803
168	–1.2808	218	–1.7611	268	–0.4803
169	–2.2414	219	–1.4409	269	–0.6404
170	–3.0419	220	–0.9606	270	–0.4803
171	–2.8818	221	–0.8005	271	–0.1601
172	–2.5616	222	–0.9606	272	0.0000

Table 36/G.996.1 – Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
173	–2.2414	223	–1.6010	273	0.0000
174	–1.9212	224	–2.2414	274	–0.1601
175	–1.9212	225	–2.4015	275	–0.1601
176	–2.2414	226	–2.2414	276	–0.4803
177	–2.5616	227	–1.9212	277	–0.6404
178	–2.7217	228	–1.4409	278	–0.3202
179	–2.5616	229	–0.4803	279	0.1601
180	–2.4015	230	0.0000	280	0.4803
181	–2.2414	231	–0.6404	281	0.3202
182	–2.0813	232	–1.6010	282	–0.1601
183	–1.7611	233	–1.7611	283	–0.3202
184	–1.6010	234	–1.6010	284	–0.4803
185	–1.7611	235	–1.9212	285	–0.6404
186	–2.2414	236	–1.9212	286	–0.4803
187	–3.0419	237	–1.4409	287	0.1601
188	–3.2020	238	–0.4803	288	0.6404
189	–2.7217	239	0.0000	289	0.6404
190	–1.9212	240	0.0000	290	0.4803
191	–1.2808	241	–0.6404	291	0.0000
192	–0.9606	242	–1.6010	292	–0.6404
193	–1.1207	243	–2.4015	293	–0.6404
194	–2.0813	244	–1.9212	294	–0.4803
195	–2.8818	245	–0.9606	295	–0.1601
196	–3.0419	246	–0.4803	296	0.4803
197	–2.7217	247	–0.1601	297	0.6404
198	–2.7217	248	–0.1601	298	0.4803
199	–2.0813	249	0.0000	299	0.6404
200	–1.4409	250	–0.8005	300	0.4803
301	–0.1601	351	0.8005	401	0.9606
302	–0.9606	352	1.4409	402	0.6404
303	–0.9606	353	1.6010	403	0.4803
304	–0.1601	354	1.2808	404	0.6404
305	0.6404	355	0.6404	405	0.6404
306	0.8005	356	0.0000	406	0.4803
307	0.8005	357	–0.4803	407	0.3202
308	0.4803	358	–0.6404	408	0.1601

Table 36/G.996.1 – Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
309	0.1601	359	0.0000	409	0.3202
310	–0.1601	360	0.8005	410	0.4803
311	–0.3202	361	1.4409	411	0.9606
312	–0.1601	362	1.6010	412	1.2808
313	0.0000	363	1.2808	413	0.9606
314	0.1601	364	0.6404	414	0.1601
315	0.6404	365	0.0000	415	–0.1601
316	0.8005	366	–0.4803	416	0.0000
317	0.6404	367	–0.1601	417	0.4803
318	0.4803	368	0.1601	418	0.8005
319	0.0000	369	0.9606	419	0.6404
320	–0.4803	370	1.4409	420	0.4803
321	–0.4803	371	1.6010	421	0.8005
322	0.1601	372	1.1207	422	0.8005
323	0.8005	373	0.3202	423	0.4803
324	0.8005	374	–0.4803	424	0.1601
325	0.6404	375	–0.4803	425	0.0000
326	0.1601	376	0.1601	426	0.0000
327	0.4803	377	0.8005	427	0.1601
328	0.4803	378	1.1207	428	0.3202
329	0.3202	379	1.1207	429	0.6404
330	–0.3202	380	0.9606	430	0.9606
331	–0.4803	381	0.6404	431	0.8005
332	0.0000	382	0.1601	432	0.3202
333	0.6404	383	0.0000	433	0.1601
334	1.1207	384	0.1601	434	0.0000
335	1.2808	385	0.6404	435	0.1601
336	0.6404	386	1.1207	436	0.1601
337	0.1601	387	0.9606	437	0.1601
338	–0.1601	388	0.6404	438	0.1601
339	0.0000	389	0.6404	439	0.6404
340	0.0000	390	0.6404	440	1.1207
341	0.1601	391	0.3202	441	0.9606
342	0.3202	392	0.0000	442	0.4803
343	0.8005	393	0.4803	443	0.0000
344	1.2808	394	1.1207	444	–0.3202
345	1.2808	395	1.1207	445	–0.3202

Table 36/G.996.1 – Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
346	0.9606	396	0.6404	446	0.0000
347	0.1601	397	0.1601	447	0.1601
348	–0.8005	398	0.0000	448	0.6404
349	–0.9606	399	0.1601	449	0.9606
350	–0.1601	400	0.8005	450	0.8005
451	0.6404	461	0.0000	471	0.0000
452	0.0000	462	–0.9606	472	0.0000
453	–0.8005	463	–1.1207	473	0.0000
454	–0.8005	464	–0.4803	474	0.0000
455	0.0000	465	0.4803	475	0.0000
456	0.4803	466	1.1207	476	0.0000
457	0.6404	467	1.1207	477	0.0000
458	0.6404	468	0.6404	478	0.0000
459	0.8005	469	0.0000	479	0.0000
460	0.6404	470	0.0000	480	0.0000

9 Phone model structures for testing DSL systems without a splitter at the ATU-R

9.1 Off-hook phone model #1

Off-hook phone model #1 was generated for testing in the TCM-ISDN noise environment. It could be used for testing in other noise environments as well.

Figures 41, 42 and 43 give the measured off-hook impedance for off-hook phone #1, the measured and modelled off-hook impedance for off-hook phone #1, and the off-hook impedance for off-hook phone model #1.

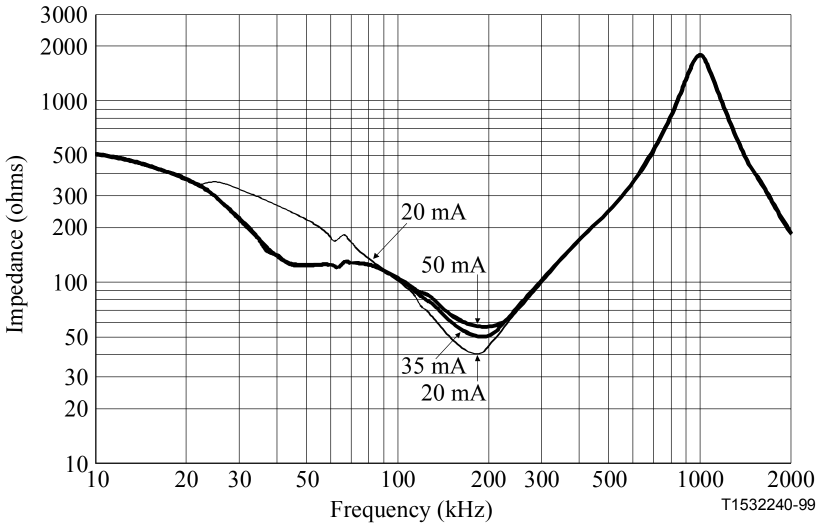


Figure 41/G.996.1 – Measured off-hook impedance for off-hook phone #1

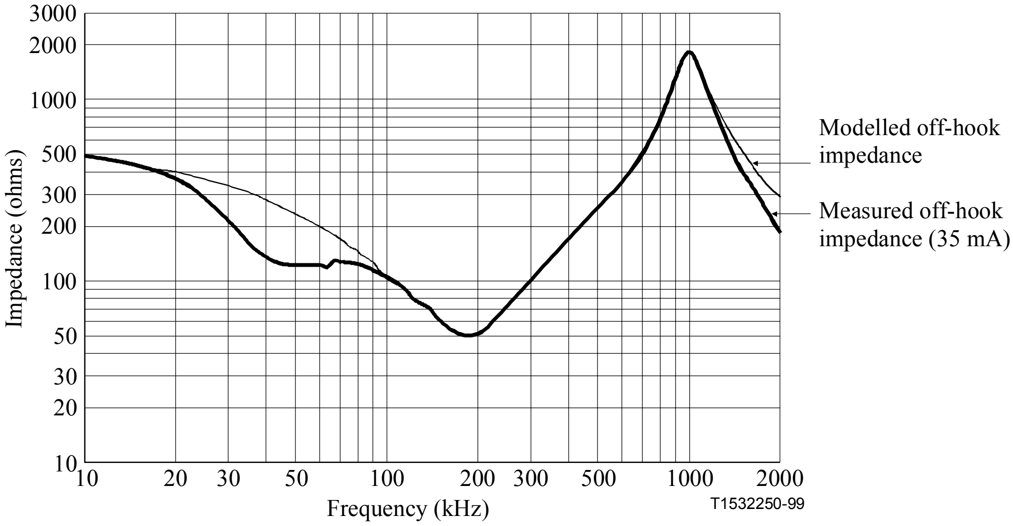


Figure 42/G.996.1 – Measured and modelled off-hook impedance for off-hook phone #1

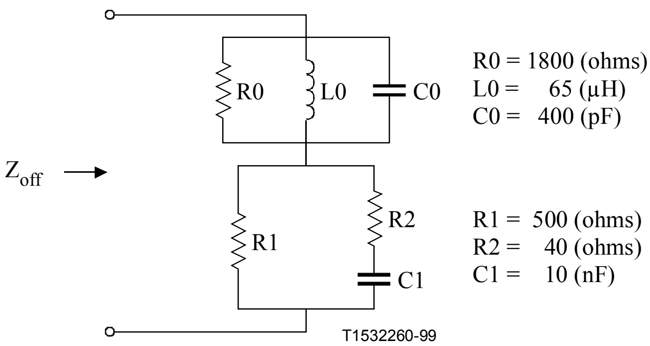
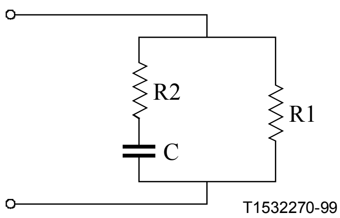


Figure 43/G.996.1 – Off-hook impedance for off-hook phone model #1

9.2 Off-hook phone model #2

Off-hook phone model #2 (see Figures 44 and 45) was generated for testing in the splitterless North American noise environment. It could be used for testing in other noise environments as well.



(R1 = 720 Ω, R2 = 183 Ω, C = 4300 pF)

Figure 44/G.996.1 – Simple model of an off-hook telephone

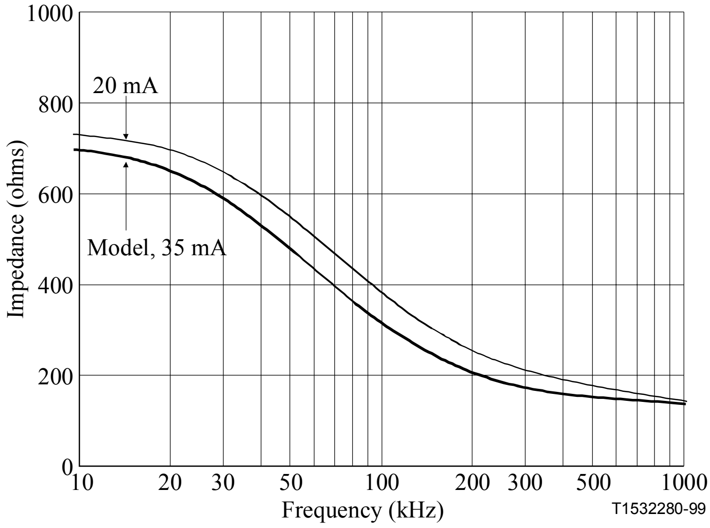


Figure 45/G.996.1 – Off-hook impedance of measured telephone compared with model

9.3 On-hook phone model

This on-hook phone model (see Figures 46 to 48 and Table 37) was generated for testing in the TCM-ISDN noise environment. It could be used for testing in other noise environments as well.

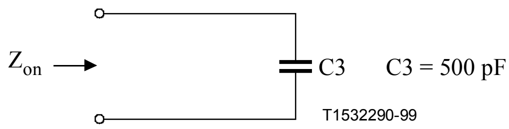


Figure 46/G.996.1 – On-hook impedance model

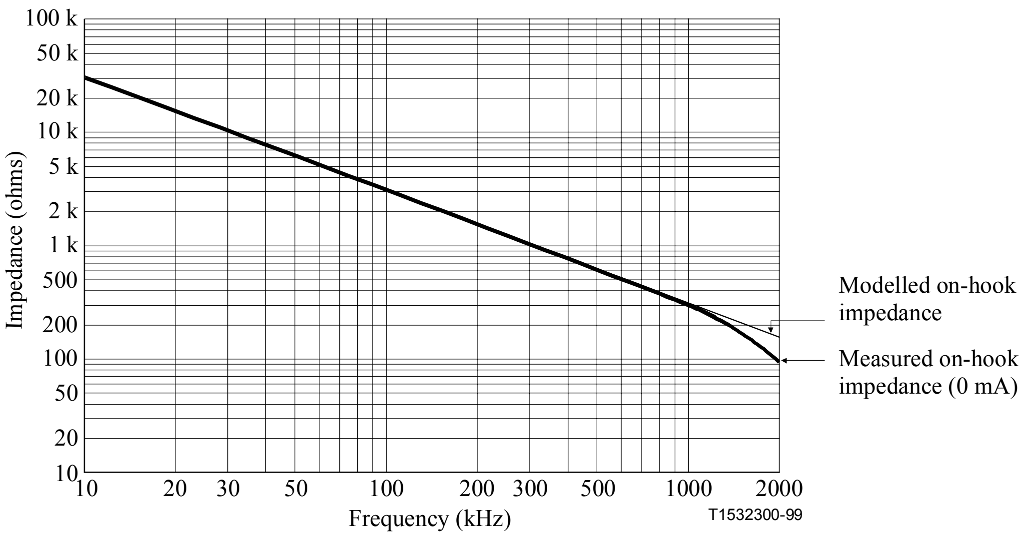


Figure 47/G.996.1 – Measured and modelled on-hook impedance

Table 37/G.996.1 – Coefficients for calculation of primary line constants for in-home wiring

Coefficient	0.5 mm untwisted single-pair wire
r(m)	0.25×10^{-3}
c_0(m)	0.75×10^{-3}
μ_r	1
μ_0 (H/m)	$4\pi \times 10^{-7}$
σ(mho/m)	5.8×10^{7}
tan δ	5.0×10^{-4}
C(F/m)	55×10^{-12}
NOTE – $d = 2(r + c_0)$	

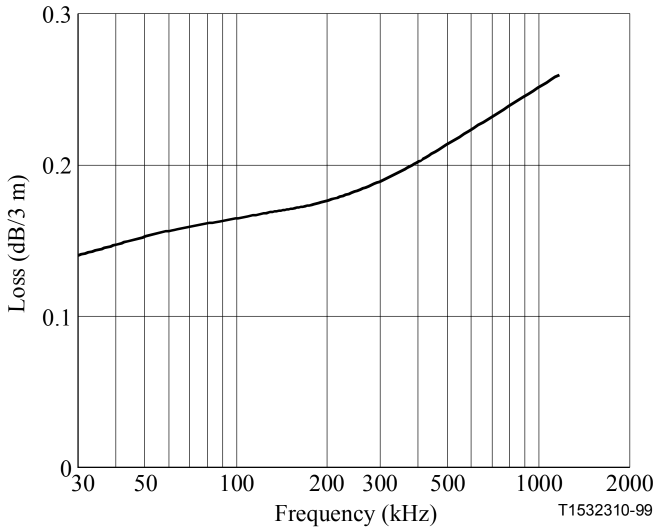


Figure 48/G.996.1 – Insertion loss characteristics of 3 m connecting cord

RFI Models

Two RFI models are provided to provide for different distribution of ingressors. The first model, shown in Figure 49, is distinguished by a large ingressor at 540 kHz, which is inside the G.992.2 band. This model is used to stress the G.992.2 performance in the presence of an in-band ingressor. The second model, shown in Figure 50, has all ingressors above 620 kHz.

Levels of the ingress signals are specified for 80 percentile coverage. The frequencies of the highest level tones have been selected to keep their in-band 2nd and 3rd order products either below 440 kHz or at the same frequency as an intentional ingress tone. Intermod tones below 440 kHz can be practically filtered and intermod products above 540 kHz can be masked by intentional tones with any necessary level adjustments made at calibration. Thus the linearity requirement of the test amplifiers can be reduced.

A minimum spacing of 30 kHz between AM ingressors was maintained as it is unlikely that two significant ingressors will occur at closer spacing given the regulations on AM broadcasters.

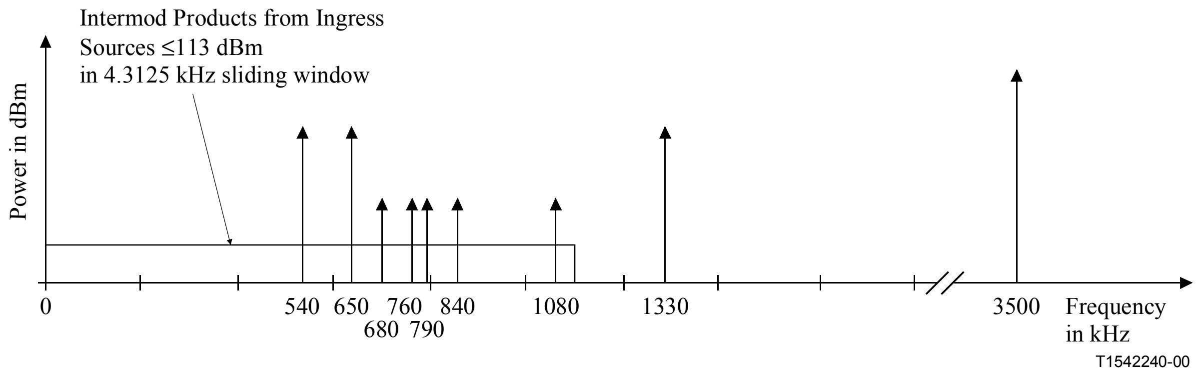


Figure 49/G.996.1 – Model 1 RFI Ingress

Table 38/G.996.1 – RFI Model 1

Ingress Type	Center Frequency (kHz)	Common Mode (dBm)	Differential (dBm)	Comment
AM1	540	0	–40	Inside G.992.2 band
AM2	650	0	–40	Outside G.992.2 inside G.992.1
AM3	680	–30	–70	Outside G.992.2 inside G.992.1
AM4	760	–30	–70	Outside G.992.2 inside G.992.1
AM5	790	–30	–70	Outside G.992.2 inside G.992.1
AM6	840	–30	–70	Outside G.992.2 inside G.992.1
AM7	1080	–30	–70	Outside G.992.2 inside G.992.1
AM8	1330	0	–40	Outside G.992.2 and G.992.1 possible alias susceptibility
Amateur radio	3500	10	–30	Outside G.992.2 and G.992.1 possible alias susceptibility Absent during training, present while measuring margin

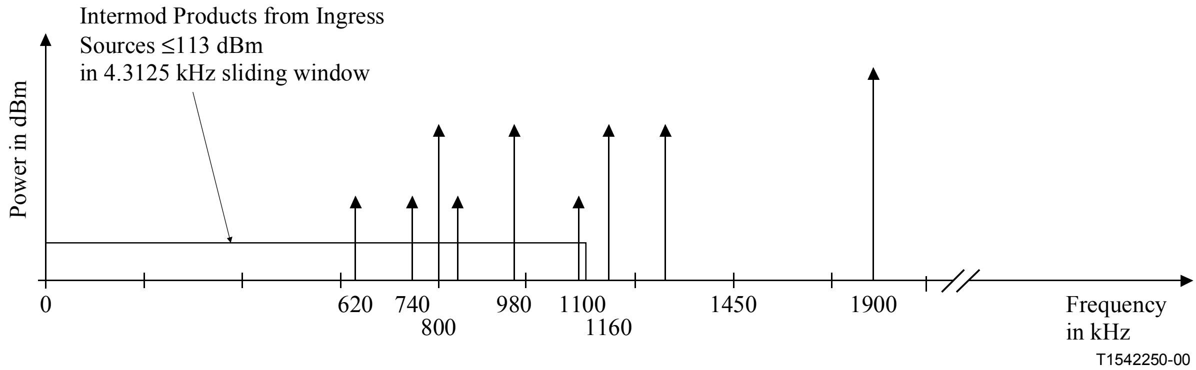


Figure 50/G.996.1 – Model 2 RFI Ingress

Table 39/G.996.1 – RFI Model 2

Ingress Type	Center Frequency (kHz)	Common Mode (dBm)	Differential (dBm)	Comment
AM1	620	–30	–70	Outside G.992.2 inside G.992.1
AM2	740	–30	–70	Outside G.992.2 inside G.992.1
AM3	800	0	–40	Outside G.992.2 inside G.992.1
AM4	980	0	–40	Outside G.992.2 inside G.992.1
AM5	1100	–30	–70	Outside G.992.2 inside G.992.1
AM6	1160	0	–40	Outside G.992.2 inside G.992.1
Amateur radio	1900	10	–30	Outside G.992.2 and G.992.1 possible alias susceptibility Absent during training, present while measuring margin

Interference Models

AM Model: The AM radio signal and crosstalk interference are present during initialization.

An unmodulated sinusoid is used for simplicity of test equipment and to make the management of cross products easier. The actual AM signal does occupy a 10 kHz band. However, the peak of the modulating signal will usually be around 500 Hz, so most of the energy will fall within 500-1000 Hz of the carrier (usually well within one DMT bin).

It is possible that the dynamic behaviour of AM ingress is a significant factor in the bit swapping and retrain behavior of G.992.1 modems. If further study shows this to be the case, a new model for AM ingress may need to be used for performance testing.

Amateur Radio Model: A model where the amateur radio signal is not present during training, but is present during operation, is used for performance testing. Thus, the amateur radio signal will be applied at full strength at the beginning of margin testing. With the amateur signal present, the level of cross-talkers will be raised until the specified BER is reached. The margin is determined by the amount the cross-talkers were raised. As in the AM radio case, an unmodulated sinusoid is used to model the amateur radio signal.

ANNEX A

Primary constants of polyethylene-insulated cable (PIC)

NOTE – For the conversion of the primary constants values, in Tables A.1 to A.3, for miles (mi) to kilometres (km) divide by 1.61.

Table A.1/G.996.1 – 26 AWG PIC cable primary constants 1 Hz and 5 MHz

Frequency (Hz)	at 120° F				at 70° F				at 0° F			
	R (ohms/mi)	L (mH/mi)	G (µmho/mi)	C (µF/mi)	R (ohms/mi)	L (mH/mi)	G (µmho/mi)	C (µF/mi)	R (ohms/mi)	L (mH/mi)	G (µmho/mi)	C (µF/mi)
1	488.83	0.9935	0.000	0.08300	440.75	0.9861	0.000	0.08300	373.45	0.9758	0.000	0.08300
5	488.83	0.9935	0.001	0.08300	440.75	0.9861	0.001	0.08300	373.45	0.9758	0.001	0.08300
10	488.83	0.9935	0.002	0.08300	440.75	0.9861	0.002	0.08300	373.45	0.9758	0.002	0.08300
15	488.83	0.9935	0.003	0.08300	440.76	0.9861	0.003	0.08300	373.45	0.9758	0.003	0.08300
20	488.83	0.9935	0.004	0.08300	440.76	0.9861	0.004	0.08300	373.45	0.9758	0.004	0.08300
30	488.83	0.9935	0.005	0.08300	440.76	0.9861	0.005	0.08300	373.45	0.9758	0.005	0.08300
50	488.83	0.9935	0.008	0.08300	440.76	0.9861	0.008	0.08300	373.45	0.9758	0.008	0.08300
70	488.83	0.9935	0.011	0.08300	440.76	0.9361	0.011	0.08300	373.45	0.9757	0.011	0.08300
100	488.83	0.9935	0.016	0.08300	440.76	0.9861	0.016	0.08300	373.45	0.9757	0.016	0.08300
150	488.83	0.9935	0.022	0.08300	440.76	0.9861	0.022	0.08300	373.45	0.9757	0.022	0.08300
200	488.83	0.9934	0.028	0.08300	440.76	0.9860	0.028	0.08300	373.46	0.9757	0.028	0.08300
300	488.84	0.9934	0.040	0.08300	440.76	0.9660	0.040	0.08300	373.46	0.9757	0.040	0.08300
500	488.84	0.9933	0.063	0.08300	440.77	0.9859	0.063	0.08300	373.46	0.9756	0.063	0.08300
700	488.85	0.9933	0.084	0.08300	440.78	0.9859	0.084	0.08300	373.47	0.9755	0.084	0.08300
1 000	488.86	0.9932	0.115	0.08300	440.79	0.9858	0.115	0.08300	373.48	0.9754	0.115	0.08300
1 500	488.89	0.9930	0.164	0.08300	440.81	0.9856	0.164	0.08300	373.50	0.9752	0.164	0.08300
2 000	488.91	0.9928	0.210	0.08300	440.83	0.9854	0.210	0.08300	373.52	0.9751	0.210	0.08300
3 000	488.97	0.9924	0.299	0.08300	440.88	0.9850	0.299	0.08300	373.56	0.9747	0.299	0.08300
5 000	489.11	0.9917	0.466	0.08300	441.01	0.9843	0.466	0.08300	373.67	0.9740	0.466	0.08300
7 000	489.26	0.9910	0.625	0.08300	441.15	0.9836	0.625	0.08300	373.78	0.9733	0.625	0.08300
10 000	489.53	0.9899	0.853	0.08300	441.39	0.9825	0.853	0.08300	373.99	0.9722	0.853	0.08300
15 000	490.07	0.9881	1.213	0.08300	441.37	0.9807	1.213	0.08300	374.40	0.9704	1.213	0.08300
20 000	490.71	0.9863	1.558	0.08300	442.83	0.9789	1.558	0.08300	376.89	0.9687	1.558	0.08300
30 000	492.30	0.9826	2.213	0.08300	443.88	0.9758	2.217	0.08300	376.10	0.9651	2.217	0.08300
50 000	496.65	0.9733	3.458	0.08300	447.81	0.9660	3.458	0.08300	379.43	0.9559	3.458	0.08300
70 000	502.51	0.9617	4.634	0.08300	453.09	0.9546	4.634	0.08300	383.91	0.9446	4.634	0.08300
100 000	513.93	0.9502	6.320	0.08300	463.39	0.9432	6.320	0.08300	392.63	0.9333	6.320	0.08300
150 000	536.26	0.9375	8.993	0.08300	485.80	0.9306	8.993	0.08300	415.15	0.9208	8.993	0.08300
200 000	561.79	0.9281	11.550	0.08300	513.04	0.9212	11.550	0.08300	444.79	0.9115	11.550	0.08300
300 000	622.63	0.9139	16.436	0.08300	575.17	0.9062	16.436	0.08300	508.72	0.8955	16.436	0.08300
500 000	746.31	0.8910	25.633	0.08300	699.61	0.8816	25.633	0.08300	634.23	0.8655	25.633	0.08300
700 000	862.21	0.8717	34.351	0.08300	812.95	0.8614	34.351	0.08300	743.98	0.8468	34.351	0.08300
1 000 000	1013.99	0.8495	46.849	0.08300	956.65	0.8331	46.849	0.08300	876.38	0.8222	46.849	0.08300
1 500 000	1398.54	0.8271	66.665	0.08300	1154.38	0.8146	66.665	0.08300	1058.74	0.7972	66.665	0.08300
2 000 000	1693.35	0.8133	85.624	0.08300	1321.07	0.8001	85.624	0.08300	1212.60	0.7816	85.624	0.08300
3 000 000	1693.35	0.7965	121.841	0.08300	1600.68	0.7823	121.841	0.08300	1470.94	0.7624	121.841	0.08300
5 000 000	2160.47	0.7794	190.021	0.08300	2044.07	0.7638	190.021	0.08300	1881.11	0.7420	190.021	0.08300

Table A.2/G.996.1 – 24 AWG PIC cable primary constants 1 Hz and 5 MHz

Frequency (Hz)	at 120° F				at 70° F				at 0° F			
	R (ohms/mi)	L (mH/mi)	G (μmho/mi)	C (μF/mi)	R (ohms/mi)	L (mH/mi)	G (μmho/mi)	C (μF/mi)	R (ohms/mi)	L (mH/mi)	G (μmho/mi)	C (μF/mi)
1	307.43	0.9935	0.000	0.08300	277.19	0.9861	0.000	0.08300	234.87	0.9758	0.000	0.08300
5	307.43	0.9935	0.001	0.08300	277.19	0.9861	0.001	0.08300	234.87	0.9758	0.001	0.08300
10	307.43	0.9935	0.002	0.08300	277.19	0.9861	0.002	0.08300	234.87	0.9758	0.002	0.08300
15	307.43	0.9935	0.003	0.08300	277.19	0.9861	0.003	0.08300	234.87	0.9758	0.003	0.08300
20	307.43	0.9935	0.004	0.08300	277.19	0.9861	0.004	0.08300	234.87	0.9758	0.004	0.08300
30	307.43	0.9935	0.005	0.08300	277.19	0.9861	0.005	0.08300	234.87	0.9758	0.005	0.08300
50	307.43	0.9935	0.008	0.08300	277.19	0.9861	0.008	0.08300	234.87	0.9757	0.008	0.08300
70	307.43	0.9935	0.011	0.08300	277.19	0.9861	0.011	0.08300	234.87	0.9757	0.011	0.08300
100	307.43	0.9935	0.016	0.08300	277.19	0.9861	0.016	0.08300	234.87	0.9757	0.016	0.08300
150	307.43	0.9934	0.022	0.08300	277.20	0.9860	0.022	0.08300	234.87	0.9757	0.022	0.08300
200	307.43	0.9934	0.028	0.08300	277.20	0.9860	0.028	0.08300	234.87	0.9757	0.028	0.08300
300	307.43	0.9934	0.040	0.08300	277.20	0.9860	0.040	0.08300	234.87	0.9756	0.040	0.08300
500	307.44	0.9933	0.063	0.08300	277.21	0.9859	0.063	0.08300	234.88	0.9755	0.063	0.08300
700	307.45	0.9932	0.084	0.08300	277.22	0.9858	0.084	0.08300	234.89	0.9755	0.084	0.08300
1000	307.47	0.9931	0.115	0.08300	277.23	0.9857	0.115	0.08300	234.90	0.9753	0.115	0.08300
1500	307.49	0.9928	0.164	0.08300	277.25	0.9854	0.164	0.08300	234.92	0.9751	0.164	0.08300
2000	307.52	0.9926	0.210	0.08300	277.28	0.9852	0.210	0.08300	234.94	0.9749	0.210	0.08300
3000	307.59	0.9921	0.299	0.08300	277.34	0.9848	0.299	0.08300	234.99	0.9744	0.299	0.08300
5000	307.75	0.9912	0.466	0.08300	277.48	0.9839	0.466	0.08300	235.11	0.9735	0.466	0.08300
7000	307.94	0.9903	0.625	0.08300	277.66	0.9829	0.625	0.08300	235.26	0.9726	0.625	0.08300
10 000	308.27	0.9889	0.853	0.08300	277.96	0.9816	0.853	0.08300	235.51	0.9713	0.853	0.08300
15 000	308.97	0.9866	1.213	0.08300	278.58	0.9793	1.213	0.08300	236.04	0.9690	1.213	0.08300
20 000	309.82	0.9843	1.558	0.08300	279.35	0.9770	1.558	0.08300	236.69	0.9667	1.558	0.08300
30 000	311.98	0.9796	2.217	0.08300	281.30	0.9723	2.217	0.08300	238.35	0.9621	2.217	0.08300
50 000	318.10	0.9649	3.458	0.08300	286.82	0.9577	3.458	0.08300	243.02	0.9476	3.458	0.08300
70 000	326.39	0.9535	4.634	0.08300	294.29	0.9464	4.634	0.08300	249.35	0.9365	4.634	0.08300
100 000	339.90	0.9417	6.320	0.08300	308.41	0.9347	6.320	0.08300	264.34	0.9249	6.320	0.08300
150 000	367.43	0.9273	8.993	0.08300	337.22	0.9204	8.993	0.08300	294.92	0.9107	8.993	0.08300
200 000	398.81	0.9166	11.550	0.08300	369.03	0.9087	11.550	0.08300	327.32	0.8976	11.550	0.08300
300 000	460.98	0.8978	16.436	0.08300	431.55	0.8885	16.436	0.08300	390.34	0.8756	16.436	0.08300
500 000	574.39	0.8678	25.633	0.08300	541.69	0.8570	25.633	0.08300	495.92	0.8419	25.633	0.08300
700 000	669.84	0.8467	34.351	0.08300	632.08	0.8350	34.351	0.08300	579.22	0.8186	34.351	0.08300
1 000 000	790.12	0.8273	46.849	0.08300	746.04	0.8146	46.849	0.08300	684.34	0.7969	46.849	0.08300
1 500 000	955.50	0.8084	66.665	0.08300	902.84	0.7947	66.665	0.08300	829.13	0.7756	66.665	0.08300
2 000 000	1094.84	0.7970	85.624	0.08300	1035.03	0.7825	85.624	0.08300	951.29	0.7623	85.624	0.08300
3 000 000	1328.44	0.7831	121.841	0.08300	1256.77	0.7676	121.841	0.08300	1156.42	0.7459	121.841	0.08300
5 000 000	1698.58	0.7729	190.021	0.08300	1608.38	0.7523	190.021	0.08300	1482.09	0.7235	190.021	0.08300

Table A.3/G.996.1 – 22 AWG PIC cable primary constants 1 Hz and 5 MHz

Frequency (Hz)	at 120° F				at 70° F				at 0° F			
	R (ohms/mi)	L (mH/mi)	G (µmho/mi)	C (µF/mi)	R (ohms/mi)	L (mH/mi)	G (µohm/mi)	C (µF/mi)	R ohms/mi	L mH/mi	G µohm/mi	C µF/mi
1	193.28	0.9935	0.000	0.08300	174.27	0.9861	0.000	0.08300	147.66	0.9758	0.000	0.08300
5	193.28	0.9935	0.001	0.08300	174.27	0.9861	0.001	0.08300	147.66	0.9758	0.001	0.08300
10	193.28	0.9935	0.001	0.08300	174.27	0.9861	0.001	0.08300	147.66	0.9758	0.001	0.08300
15	193.28	0.9935	0.001	0.08300	174.27	0.9861	0.001	0.08300	147.66	0.9758	0.001	0.08300
20	193.28	0.9935	0.002	0.08300	174.27	0.9861	0.002	0.08300	147.66	0.9758	0.002	0.08300
30	193.28	0.9935	0.003	0.08300	174.27	0.9861	0.003	0.08300	147.66	0.9758	0.003	0.08300
50	193.28	0.9935	0.005	0.08300	174.27	0.9861	0.005	0.08300	147.66	0.9758	0.005	0.08300
70	193.28	0.9935	0.006	0.08300	174.27	0.9861	0.006	0.08300	147.66	0.9757	0.006	0.08300
100	193.28	0.9935	0.009	0.08300	174.27	0.9861	0.009	0.08300	147.66	0.9757	0.009	0.08300
150	193.28	0.9934	0.013	0.08300	174.27	0.9860	0.013	0.08300	147.66	0.9757	0.013	0.08300
200	193.28	0.9934	0.017	0.08300	174.27	0.9860	0.017	0.08300	147.66	0.9757	0.017	0.08300
300	193.29	0.9934	0.024	0.08300	174.28	0.9860	0.024	0.08300	147.67	0.9756	0.024	0.08300
500	193.29	0.9932	0.040	0.08300	174.29	0.9858	0.040	0.08300	147.67	0.9755	0.040	0.08300
700	193.30	0.9931	0.054	0.08300	174.29	0.9857	0.054	0.08300	147.68	0.9754	0.054	0.08300
1000	193.32	0.9930	0.076	0.08300	174.31	0.9856	0.076	0.08300	147.69	0.9752	0.076	0.08300
1500	193.35	0.9927	0.110	0.08300	174.34	0.9853	0.110	0.08300	147.72	0.9749	0.110	0.08300
2000	193.39	0.9924	0.145	0.08300	174.37	0.9850	0.145	0.08300	147.74	0.9747	0.145	0.08300
3000	193.47	0.9918	0.211	0.08300	174.44	0.9844	0.211	0.08300	147.80	0.9741	0.211	0.08300
5000	193.66	0.9906	0.341	0.08300	174.62	0.9833	0.341	0.08300	147.95	0.9729	0.341	0.08300
7000	193.90	0.9895	0.467	0.08300	174.83	0.9821	0.467	0.08300	148.13	0.9718	0.467	0.08300
10 000	194.33	0.9877	0.652	0.08300	175.22	0.9804	0.652	0.08300	148.47	0.9701	0.652	0.08300
15 000	195.26	0.9847	0.954	0.08300	176.06	0.9778	0.954	0.08300	149.17	0.9671	0.954	0.08300
20 000	196.43	0.9817	1.248	0.08300	177.11	0.9744	1.248	0.08300	150.07	0.9642	1.248	0.08300
30 000	199.48	0.9744	1.824	0.08300	179.86	0.9672	1.824	0.08300	152.39	0.9570	1.824	0.08300
50 000	208.10	0.9562	2.943	0.08300	187.64	0.9491	2.943	0.08300	158.98	0.9391	2.943	0.08300
70 000	217.24	0.9443	4.032	0.08300	197.71	0.9372	4.032	0.08300	170.37	0.9274	4.032	0.08300
100 000	234.48	0.9309	5.630	0.08300	215.55	0.9237	5.630	0.08300	189.06	0.9137	5.630	0.08300
150 000	266.20	0.9141	8.229	0.08300	247.57	0.9055	8.229	0.08300	221.40	0.8935	8.229	0.08300
200 000	296.40	0.8993	10.772	0.08300	277.95	0.8898	10.772	0.08300	252.11	0.8765	10.772	0.08300
300 000	353.55	0.8749	15.744	0.08300	333.39	0.8642	15.744	0.08300	305.18	0.8492	15.744	0.08300
500 000	446.65	0.8430	25.396	0.08300	421.57	0.8309	25.396	0.08300	386.45	0.8140	25.396	0.08300
700 000	522.27	0.8252	34.796	0.08300	493.24	0.8123	34.796	0.08300	452.58	0.7941	34.796	0.08300
1 000 000	617.56	0.8090	48.587	0.08300	583.59	0.7950	48.587	0.08300	536.03	0.7756	48.587	0.08300
1 500 000	748.59	0.7933	71.014	0.08300	707.91	0.7783	71.014	0.08300	650.97	0.7574	71.014	0.08300
2 000 000	858.98	0.7838	92.958	0.08300	812.72	0.7681	92.958	0.08300	747.95	0.7460	92.958	0.08300
3 000 000	1044.05	0.7759	135.865	0.08300	988.53	0.7557	135.865	0.08300	910.79	0.7275	135.865	0.08300
5 000 000	1337.29	0.7685	219.158	0.08300	1267.31	0.7429	219.158	0.08300	1169.33	0.7071	219.158	0.08300

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