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Edition 1.0 2021-03

TECHNICAL SPECIFICATION

colour inside

Information technology – Generic cabling systems for customer premises – Part 9903: Matrix modelling of channels and links

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Information technology – Generic cabling systems for customer premises – Part 9903: Matrix modelling of channels and links

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CONTENTS

INFORMATION TECHNOLOGY – GENERIC CABLING SYSTEMS FOR CUSTOMER PREMISES –

Part 9903: Matrix modelling of channels and links

FOREWORD

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ISO/IEC TS 11801-9903 has been prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology. It is a Technical Specification.

This first edition of ISO/IEC TS 11801-9903 cancels and replaces ISO/IEC TR 11801-9903 published in 2015. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the addition of further clarifications of the relations of parameters described in this edition and referenced analogous parameters in IEC TR 62152, e.g. operational attenuation versus operational transfer loss;
b) the introduction and description of the higher order M-parameters 8 × 8 matrix of mixed-mode parameters, which includes the 4 × 4 submatrix of 4-port differential-mode-to-differential-mode (DD) parameters, among three other submatrices of mixed-mode parameters;
c) Annex A, matrix conversion formulas, covers up to 16-port parameters matrices;
d) the expanded Annex B description of example calculations for channel and permanent link, and updated component parameter tables.

The list of all currently available parts of the ISO/IEC 11801 series, under the general title *Information technology – Generic cabling for customer premises*, can be found on the IEC and ISO web sites.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
JTC1-SC25/2959/DTS	JTC1-SC25/2993/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, available at www.iec.ch/members_experts/refdocs.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

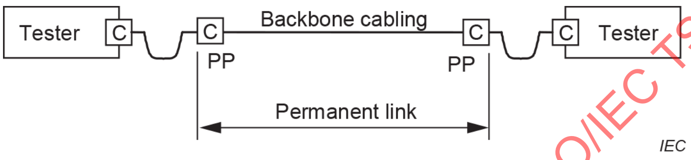
The pass/fail limits for defined channel and permanent link cabling configurations have an implicit impact on the component limits for the cabling components used. The channel configurations and the link configurations are specified in ISO/IEC 11801-1:2017, Clause 6 and Clause 7, respectively.

The permanent link configurations, which represent the fixed portion of the cabling, have two possible topologies:

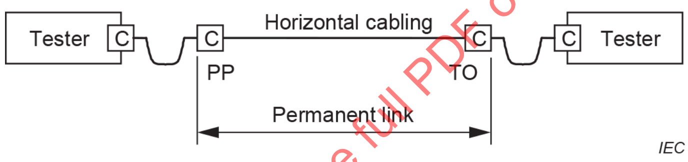
– a connection plus a segment of cable plus a connection (2-connector topology);

– a connection plus a segment of cable plus a connection plus another segment of cable plus another connection (3-connector topology).

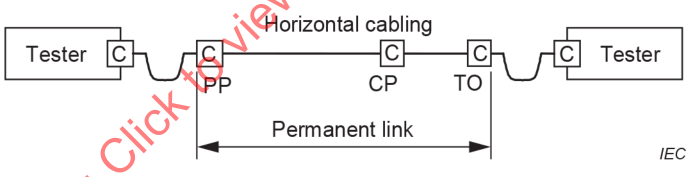
The link configurations of ISO/IEC 11801-1 are shown in Figure 1.



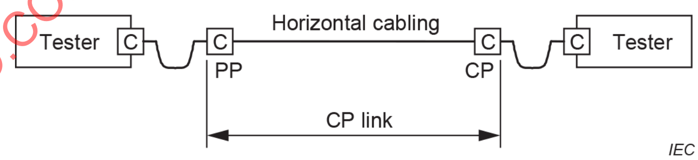
a) Configuration PL1



b) Configuration PL2



c) Configuration PL3



d) Configuration CP1

Figure 1 – Link configurations of ISO/IEC 11801-1

This document includes models and assumptions, which support pass/fail limits for the channel and permanent link test configurations in ISO/IEC 11801-1. These are based on the performance requirements of cable and connecting hardware as specified in IEC standards.

This document provides reasonable assurance that a channel created by adding compliant patch cords to a previously certified permanent link will meet the applicable channel performance limits.

Over the years the frequencies of the classes increased, but the theory for calculating the limits stayed the same. Especially the higher order effects had to be considered and in the end only by doing a Monte Carlo calculation, assuming that not all components would be at the limit at the same time, allowed compliance to be proved.

The model uses two pairs for all calculations. The limits are equal for pairs or pair combinations but in reality measured values could be different. If results are required that need more pairs to be considered, then this calculation can be done based on the results from multiple two-pair calculations with appropriate inputs (worst case). An example of such a calculation is the power sum and average limit lines for four pairs.

Symmetry and additional contributions that result from unbalanced signals and differential-to-common and common-to-differential mode coupling are included in this document by increasing the matrix size.

For details on the naming of transmission parameters, see Clause 3 and Clause C.1.

INFORMATION TECHNOLOGY – GENERIC CABLING SYSTEMS FOR CUSTOMER PREMISES –

Part 9903: Matrix modelling of channels and links

1 Scope

This part of ISO/IEC 11801, which is a Technical Specification, establishes a matrix-model for formulating limits for mixed-mode parameters within and between two pairs of balanced cabling. This is for the purpose of supporting new, improved balanced cabling channel and link specifications.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 11801-1, *Information technology – Generic cabling for customer premises – Part 1: General requirements*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 11801-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
attenuation
diminishing of signal strength

Note 1 to entry: Details need to be added to indicate the exact usage.

3.1.2
connection
two mated connectors

EXAMPLE Jack and plug.

3.1.3
image attenuation
wave attenuation
attenuation when a two-port is terminated by its input and output characteristic impedances with no reflections at input and output

Note 1 to entry: The wave attenuation of cables is length scalable.

3.1.4
insertion loss
attenuation or loss caused by a two-port inserted into a system

3.1.5
insertion loss deviation
deviation of attenuation loss with regard to the wave attenuation due to mismatches or internal reflections

3.1.6
operational attenuation
ratio of the square root of the maximum available power wave vector emitted by the generator and the square root of the power wave vector absorbed by the load of the two-port

Note 1 to entry: The operational attenuation is not length scalable (see also C.3.1 and C.3.2).

Note 2 to entry: The operational attenuation is expressed in decibels (dB) and radians (rad).

3.1.7
passivity
property of an electrical system that the output power at all ports does not exceed the input power at all ports

3.1.8
unitarity
mathematical concept for matrices to define passivity

3.1.9
operational reflection
loss due to the reflection at a junction

Note 1 to entry: See also C.3.6.

3.2 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in ISO/IEC 11801-1 and the following apply.

f	frequency (MHz)
RL	return loss limit (dB)
ρ	(rho) operational reflection transfer function, junction reflection coefficient
DRL	distributed return loss (dB)
IL	insertion loss limit (dB)
A	operational wave attenuation (Np)
A_T	operational wave transfer function (Np)
B	operational phase (rad)
B_T	operational phase transfer function (rad)
B_{RAND}	random phase (rad)
NEXT	operational near-end crosstalk loss limit (dB)
$NEXT_T$	operational near-end crosstalk transfer function (dB)
FEXT	operational far-end crosstalk loss limit (dB)
$FEXT_T$	operational far-end crosstalk transfer function (dB)

4 Matrix model

The model to be used is a concatenated matrix calculation as discussed in IEC TR 62152 [1][1] for a 2-port system. For a 2-pair balanced cabling calculation, a 4-port differential matrix as shown in Figure 2 shall be used.

The model assumes that all components are specified with S-parameters and these parameters are used then to fill an S-matrix for every cabling component.

To concatenate components these S-matrices are transformed into transmission T-matrices which can then be multiplied in the appropriate order to simulate the transmission characteristics of the concatenated components (for details see IEC TR 62152:2009, Annex C).

To evaluate the transmission performance of the modelled channel or permanent link, the calculated T-matrix of the cabling is transformed back into an S-matrix providing the expected transmission parameters of the cabling system.

The matrix calculation is done mathematically with S-parameters in amplitude and phase.

a) Measured S-parameters are usually known in amplitude and phase.
b) Parameter limit lines for components and for cabling are specified in amplitude only, usually in decibel. For modelling purposes these amplitudes shall be transformed into a linear value.
c) For the calculation of matrix terms representing limit lines, the phase is added as a random value to simulate power sum addition (see Clause 6).

5 Matrix definition

5.1 General

In Clause 5 only the part with the balanced components is described. For the unbalanced part see 8.2.

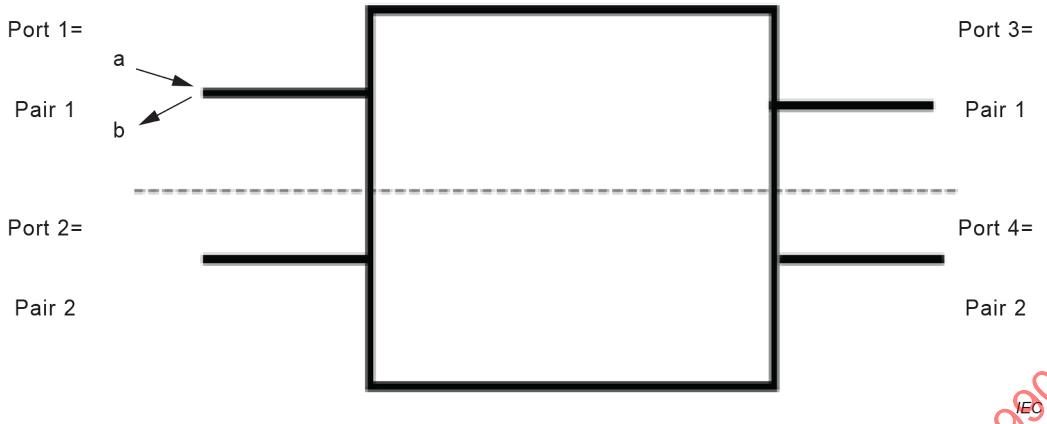
5.2 Quadriports

In IEC TR 62152 [1] voltage and currents of the input and output waves are specified for two ports. In Figure 2, Figure 3, Table 1, and Formula (1), the cabling specific notation needed for quadriports (two pairs) is detailed.

5.3 Matrix port definition for a two-pair system representative for modelling purposes

In Figure 2, a 4-port matrix is presented. The definition is one line per port per twisted pair.

[1] Numbers in square brackets refer to the Bibliography.



Key

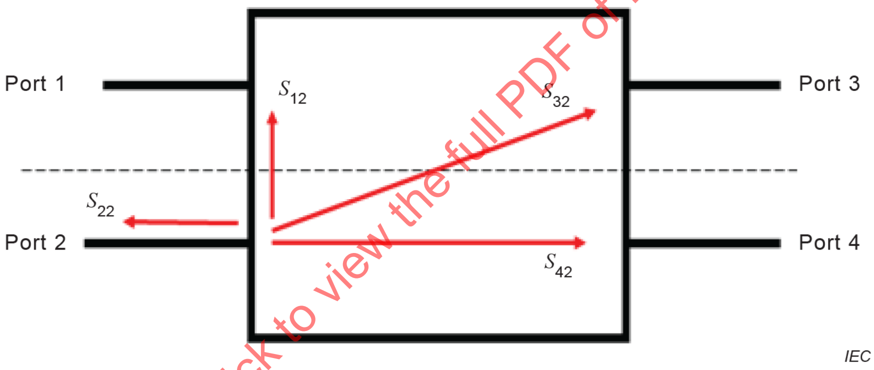
a designates a wave entering the quadriport

b designates a wave leaving the quadriport

Figure 2 – Matrix definition of a 4-port two twisted pair system

5.4 Operational scattering matrix

In Figure 3, the S-parameters for a source at port 2 are shown. For all definitions, see 5.5.



Key

Definition of S-parameters: $S_{\text{output, input}}$

S_{12} = operational near-end crosstalk transfer function ($NEXT_T$)

S_{22} = operational reflections coefficient (ρ)

S_{32} = operational far-end crosstalk transfer function ($FEXT_T$)

S_{42} = operational forward transfer function (A_T)

Figure 3 – Operational scattering parameters example from port 2

5.5 General naming convention

The naming convention for the four ports is given in Table 1.

Table 1 – All four ports operational scattering parameter definition

From Port 1:	From Port 2:	From Port 3:	From Port 4:
S_{21} $NEXT_T$	S_{12} $NEXT_T$	S_{43} $NEXT_T$	S_{34} $NEXT_T$
S_{11} ρ	S_{22} ρ	S_{33} ρ	S_{44} ρ
S_{41} $FEXT_T$	S_{32} $FEXT_T$	S_{23} $FEXT_T$	S_{14} $FEXT_T$
S_{31} A_T	S_{42} A_T	S_{13} A_T	S_{24} A_T

5.6 S-matrix

For each cabling component (for cables for each length and type involved, for connections for each type) an S-matrix needs to be developed, see Formula (1). The matrix numbering starts with 1 to be compatible with scattering parameters and generally used definitions (see 5.5) and IEC TR 62152.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad (1)$$

The following transmission parameters can be substituted into the matrix in Formula (1).

ρ: S_{11}, S_{22}, S_{33}, S_{44}

$NEXT_T$: S_{12}, S_{34}

$FEXT_T$: S_{14}, S_{23}

A_T: S_{13}, S_{24}

The equal scattering coefficient due to symmetrical nature of component parameters results in the set of equalities in Table 2.

Table 2 – Equal S-parameters for real components

Parameter	Equality	For pair number(s)
A_T	$S_{13} = S_{31}$	1
A_T	$S_{24} = S_{42}$	2
$FEXT_T$	$S_{14} = S_{41}$	1 and 2
$FEXT_T$	$S_{23} = S_{32}$	1 and 2
$NEXT_T$	$S_{21} = S_{12}$	1 and 2
$NEXT_T$	$S_{34} = S_{43}$	1 and 2

The equalities provided in Table 2 apply to the component scattering matrix in Formula (1).

5.7 Passivity

There is a general assumption that all transmission parameter loss values, e.g. NEXT and FEXT, are much less than one, in linear value, or much greater than 0, in dB.

At higher frequencies this needs to be taken care of. Otherwise, the output power at ports in total can be calculated as being higher than the input power.

This is defined as passivity and should be implemented. An example is shown in 5.8.

5.8 Operational reflection loss matrix

To account for the impedance mismatch between two cabling segments a reflection matrix is defined. Unitarity should be taken care of especially when phase randomization is applied. As in the cabling matrix only the wave attenuation is inserted, it is important to add this operational reflection transfer function to get the operational attenuation as defined, see Formula (2), see C.3.6.

$$S_\rho = \begin{bmatrix} \rho & 0 & \sqrt{1-\rho^2} & 0 \\ 0 & \rho & 0 & \sqrt{1-\rho^2} \\ \sqrt{1-\rho^2} & 0 & \rho & 0 \\ 0 & \sqrt{1-\rho^2} & 0 & \rho \end{bmatrix} \qquad (2)$$

where

S_ρ is the operational reflection loss, transfer function matrix;

ρ (rho) is the operational reflection transfer function, junction reflection coefficient.

The reflection loss between two cabling sections is defined as ρ, reflection transfer function (rho), where:

ρ is constant over frequency (for similar cable types);

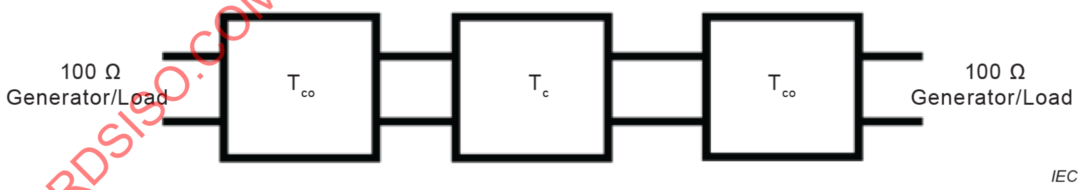
ρ is a function of frequency, e.g. at the end of cables (cabling) and connectors;

ρ is a real function assuming the reflected wave is in phase, or

ρ is a complex function taking a phase shift of the reflected wave into account.

5.9 Transmission matrix (T-matrix)

The component S-matrices are transformed into component transmission matrices (for an example mathematical transform see Annex A) which can then be multiplied in the appropriate order to calculate a chain of cabling elements forming a cable assembly channel; see the example illustration in Figure 4.



Key

T_{CO} T-matrix of a connection

T_C T-matrix of a cable

Figure 4 – Transmission matrix concatenation showing an example of a 2-connector permanent link

5.10 S-matrix of cabling

The resulting concatenated T-matrix is then transformed back to an S-matrix. The derived S-parameters describe the parameters of the cascaded components, i.e. of the cabling.

6 Calculation with matrices using limit lines

For the calculation of matrix terms representing limit lines, the phase is added as a random value to simulate power sum addition.

For the components a random uniform phase distribution from $-\pi$ to $+\pi$ is added to the scalar amplitude; see Formula (3).

This is done by multiplying the scalar amplitude by a complex rotation factor with the randomized phase in its imaginary exponent. Clause 10 indicates to which parameters this operation is applied.

$$B_{\mathrm{T}} = B + B_{\mathrm{RAND}} \tag{3}$$

where

B_{T} is the operational phase transfer function, expressed in (rad);

B is the operational phase, expressed in (rad);

B_{RAND} is the random phase, expressed in (rad).

The calculation of the random phase term is shown in Formula (4).

$$B_{\mathrm{RAND}} = e^{j(\mathrm{RAND}(x)(2\pi)-\pi)} \tag{4}$$

where

B_{RAND} is the random phase, expressed in (rad);

RAND(x) is the random function used in Formula (4); example RAND(), which returns an evenly distributed random real number greater than or equal to 0 and less than 1.

7 Extracting limit lines

Due to the randomized phase of the components, the cabling calculation results in values which can change randomly within a range of total constructive and total destructive interferences.

To derive the requested limit curve, a least mean square curve-fit of these values shall be determined.

A calculation sweep with more than five calculation points per megahertz sweep should be applied (e.g. sweep 1 MHz to 2 000 MHz, more than 10 000 calculation points).

Logarithmic sweep is advisable to get sufficient data points at low frequencies. Additionally, the frequency sweep should be extended to higher frequencies by about 20 % to improve stability at the high end of interest.

The limit lines are derived by a least mean square curve-fit using specific formulas for each of IL, NEXT, FEXT, and RL; see 9.2.

A graphical example of a near-end crosstalk (NEXT) calculation in decibel over frequency is shown in Figure 5. The red dots represent the statistical matrix calculation and the blue line represents the fitted curve.

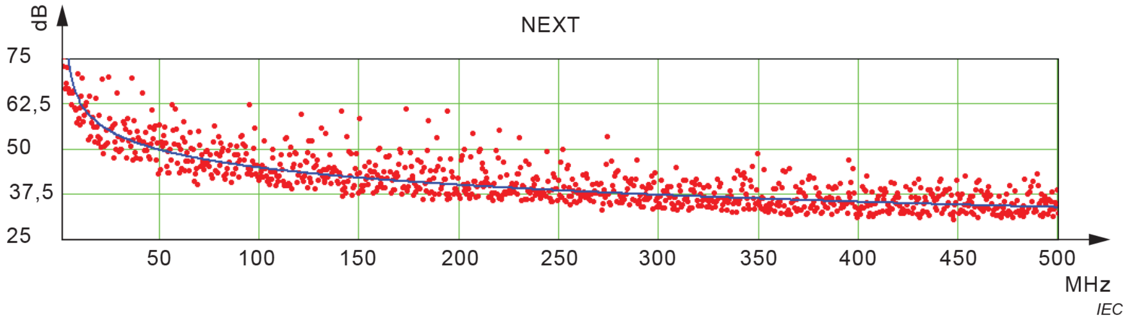


Figure 5 – Graphical example of a NEXT calculation showing statistical results (red) and final calculation (blue)

8 General case using mixed-mode matrices

8.1 General

S-parameters can only be used for differential mode analysis. In the general case the parameters are called M-parameters

8.2 M-parameters

Figure 6 shows the M-matrix in its general form in an example of one pair.

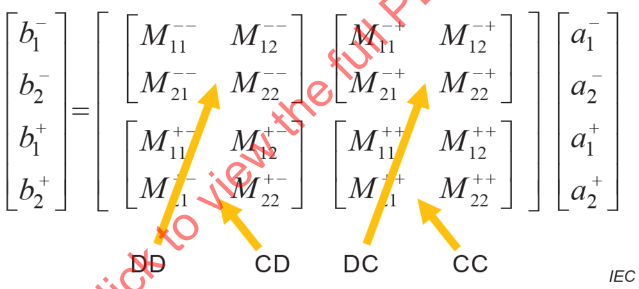


Figure 6 – One pair M-matrix showing the submatrices

In this case the submatrices are 2×2. For the two-pair simulation the structure remains, just the submatrices grow to 4×4. To compare it to practical components each submatrix is given a special name.

a) DD – differential (in) differential (out) submatrix. This submatrix includes values of insertion loss, return loss, near-end crosstalk and far-end crosstalk, as known.

b) CD – differential (in) common mode (out) submatrix. This submatrix includes the transverse conversion loss (TCL) and the transverse conversion transfer loss (TCTL) values.

c) DC – common mode (in) differential (out) submatrix. This submatrix includes the longitudinal conversion loss (LCL) and longitudinal conversion transfer loss (LCTL) values.

d) CC – common mode (in) common mode (out) submatrix: This submatrix includes the same values as the DD submatrix but for the common mode.

As done with the DD submatrix and S-parameters for all submatrices, the cabling components need to be inserted. The component parameter symmetry stays as shown in 5.6.

9 Submatrix DD

9.1 General

Submatrix DD contains the following parameters:

$$\mathrm{DD} = \begin{pmatrix} \mathrm{RL_{dd11}} & \mathrm{NEXT_{dd12}} & \mathrm{IL_{dd13}} & \mathrm{FEXT_{dd14}} \\ \mathrm{NEXT_{dd21}} & \mathrm{RL_{dd22}} & \mathrm{FEXT_{dd23}} & \mathrm{IL_{dd24}} \\ \mathrm{IL_{dd31}} & \mathrm{FEXT_{dd32}} & \mathrm{RL_{dd33}} & \mathrm{NEXT_{dd34}} \\ \mathrm{FEXT_{dd41}} & \mathrm{IL_{dd42}} & \mathrm{NEXT_{dd43}} & \mathrm{RL_{dd44}} \end{pmatrix}$$

9.2 Equations to extract the cabling limit lines

9.2.1 General

Limit lines are normally given in decibel values.

If necessary, the equations to extract the resulting limit lines are applied to the parameters' calculated linear values, before transforming them back to decibel values, when averaging the decibel values overemphasizes high values.

9.2.2 Operational attenuation

The limit line is averaged in decibel because the deviations from the expected formula are minor.

The result will depend strongly on connector attenuation specification and how it is specified therefore in the connector matrix.

1) No reflections included in connector attenuation (wave attenuation): Model result will be the addition of component operational attenuations.
2) Return loss is included in connector attenuation (operational attenuation): Model result will be the insertion loss deviation.

The curve-fit formula for operational attenuation values in decibel is given in Formula (5).

$$A = a\sqrt{f} + bf + \frac{c}{\sqrt{f}} \tag{5}$$

9.2.3 Near-end crosstalk

The curve-fit formula for operational $\mathrm{NEXT_T}$ transfer function in linear values is given in Formula (6).

$$\mathrm{NEXT_T} = a + bf + cf^2 + df^3 \tag{6}$$

9.2.4 Attenuation to far-end crosstalk ratio

The curve-fit formula for operational $\mathrm{FEXT_T}$ transfer function in linear values is given in Formula (7).

NOTE Components and cabling normally define far-end crosstalk as attenuation-to-crosstalk-ratio-far end (ACR-F); ACR is the decibel sum of attenuation and crosstalk, thus FEXT = ACR-F − IL.

$$\mathrm{FEXT_T} = af + \frac{b}{f^2} \tag{7}$$

9.2.5 Reflection (RL)

9.2.5.1 High frequency

The curve-fit formula for operational RL transfer function in linear values is given in Formula (8).

$$\rho = a + bf + cf^2 + df^3 \tag{8}$$

9.2.5.2 Low frequency

At frequencies below ~50 MHz, as no randomization is applied to connections, the calculation shows the phase impact on return loss.

The reflection from 5.8 is applied until it intercepts the curve from Formula (8). If only higher frequencies are of interest this can be neglected.

10 Component values to be used as input to the model

10.1 General

All limit lines shall be in value (not in decibels) to be used in matrix operations.

B_{RAND} is the definition for random phase, from Clause 6; it can be applied independently to cables and connectors.

B_{T} is the definition for operational phase transfer function; it defines the length of the component.

The operational phase transfer function, in free air, is calculated according to Formula (9):

$$B = e^{j(2\pi)(f)(l)/(300/\mathrm{NVP})} \tag{9}$$

where

B is the operational phase, expressed in radians (rad);

f is the frequency, expressed in megahertz (MHz);

l is the length, expressed in metres (m);

NVP is the nominal velocity of propagation, fraction of the speed of light.

NOTE 300 m is the wavelength at 1 MHz in free air, with relative permittivity = 1, corresponding to NVP = 1; this can be scaled up, in dielectric, with relative permittivity > 1, corresponding to NVP < 1; see B.5.1.

The component parameter limit is the component linear limit value (not in decibel).

10.2 Cable

10.2.1 General

For each cable segment, length and type, a unique S-matrix shall be obtained.

The component parameter limits are length scaled values and thus a function of length, see IEC TR 61156-1-3 [2].

10.2.2 Wave attenuation

The operational wave attenuation transfer function is calculated according to Formula (10):

$$A_{\text{T}} = \text{IL}(l) \times B(l) \tag{10}$$

where

IL(l) is the insertion loss limit, given in Table B.2;

$B(l)$ is the operational phase, expressed in radians (rad), Formula (9).

To calculate operational attenuation the reflections shall be added; see 10.2.5.

10.2.3 Near-end crosstalk

The operational near-end crosstalk transfer function is calculated according to Formula (11):

$$\text{NEXT}_{\text{T}} = \text{NEXT}(l) \times B(l) \times B_{\text{RAND}} \tag{11}$$

where

NEXT(l) is the near-end crosstalk loss limit, given in Table B.2;

$B(l)$ is the operational phase, expressed in radians (rad), Formula (9);

B_{RAND} is the random phase, expressed in radians (rad), see Clause 6.

10.2.4 Far-end crosstalk

The operational far-end crosstalk transfer function is calculated according to Formula (12):

$$\text{FEXT}_{\text{T}} = \text{FEXT}(l) \times B(l) \times B_{\text{RAND}} \tag{12}$$

where

FEXT(l) is the far-end crosstalk loss limit, given in Table B.2;

$B(l)$ is the operational phase, expressed in radians (rad), Formula (9);

B_{RAND} is the random phase, expressed in radians (rad), see Clause 6.

10.2.5 Reflection

10.2.5.1 General

The method used is defined in B.5.2.1 for values and length dependency. The length dependency is defined as NEXT length dependency. At higher frequencies (> 100 MHz) return loss is only cable related (called DRL (distributed return loss), which is an approximation of structural return loss in B.5.2.1).

For lower frequencies (< 50 MHz) and very short cables (< 10 m), the impedance mismatch at the ends is the predominant factor and accounted for by the reflection matrix.

10.2.5.2 High frequency

The operational reflection transfer function is calculated according to Formula (13):

$$\rho = \mathrm{RL}(l) \times B(l) \times B_{\mathrm{RAND}} \tag{13}$$

where

ρ (rho) is the operational reflection transfer function, junction reflection coefficient;

$\mathrm{RL}(l)$ is the return loss limit, given in Table B.2;

$B(l)$ is the operational phase, expressed in radians (rad), Formula (9);

B_{RAND} is the random phase, expressed in radians (rad), see Clause 6.

10.2.5.3 Low frequency

For low frequency, to simulate minimal reflections, use Formula (13), with no random phase; that is, $B_{\mathrm{RAND}} = 1$.

EXAMPLE A 100 m cable was calculated for return loss using a limit of 65 − 15 log(*f*) first without mismatch at the end and second with reflections at the ends.

Figure 7 – 100 m cable return loss without reflection at both ends

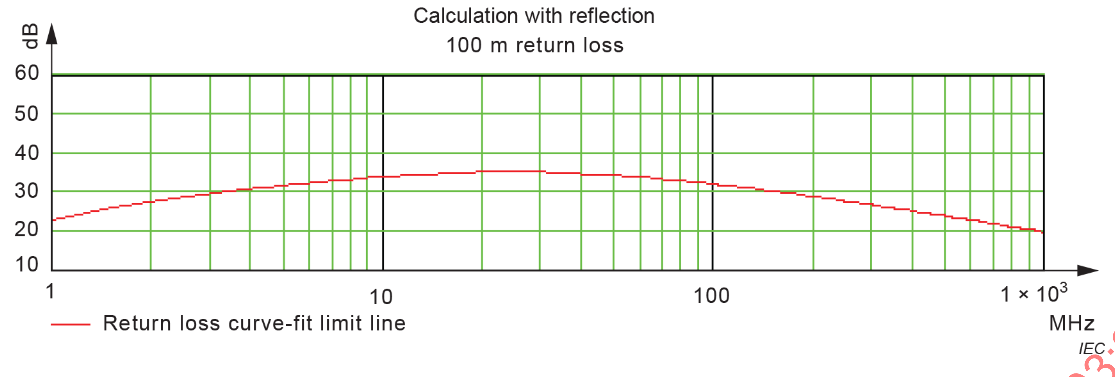


Figure 8 – 100 m cable return loss with a reflection of 0,03 at both ends (6 Ω mismatch, ~23 dB return loss at 1 MHz)

The curves in Figure 7 and Figure 8 do not resemble return loss measurements, because they are calculated limit lines.

10.3 Connections

10.3.1 General

Values and models are available for connections in two forms:

a) as a simple point source of disturbance;

b) as a transmission line.

10.3.2 As a point source of disturbance

Limit lines as in Annex B are used and inserted in an S-matrix, no randomness or phase is applied.

There are two cases for attenuation at connectors to consider:

a) ρ (and maybe other values like NEXT) is included in the insertion loss definition. Then the operational attenuation value is taken as is.

b) ρ is not included. Then before inserting the wave transfer function in the connector S-matrix, ρ (and maybe other values like NEXT) shall be added to the wave attenuation (passivity) as in Formula (14).

$$A_{\mathrm{T}} = A \times \sqrt{1-\rho^2} \tag{14}$$

10.3.3 As a transmission line

It would look like a simplified short transmission line. The input and output impedance shall be known as function of frequency and can be different. The ρ definition of the connection is used in the S-matrix, length and impedance are added. The characteristic wave impedance varies along the connector easily between about 75 Ω and 130 Ω. A reflection loss matrix shall be added at the output (at the input it is one from the end of the cable). See Annex C for details.

11 Submatrices CC, CD and DC

11.1 General

For real components some values in these matrices will be equal because there is no difference if the transmitter is differential and the result is common mode or vice versa. Some values and length are still to be developed.

If we assume that the second pair has the same characteristic as the first pair, only four values need to be known for each submatrix.

11.2 Submatrix CD

Submatrix CD contains the following parameters:

$$CD = \begin{pmatrix} TCL_{cd11} & & & TCTL_{cd14} \\ & TCL_{cd22} & TCTL_{cd23} & \\ & TCTL_{cd23} & TCL_{cd33} & \\ TCTL_{cd14} & & & TCL_{cd44} \end{pmatrix}$$

TCTL shall be calculated from ELTCTL.

For this case we know two values for connectors and cables and miss another two (corresponding to NEXT and IL of submatrix DD):

- IL_{cd} is not defined;
- $NEXT_{cd}$ is not defined.

11.3 Submatrix DC

With the assumptions done, submatrix DC will have the same values as submatrix CD.

$$DC = \begin{pmatrix} LCL_{dc11} & & & LCTL_{dc14} \\ & LCL_{dc22} & LCTL_{dc23} & \\ & LCTL_{dc23} & LCL_{dc33} & \\ LCTL_{dc12} & & & LCL_{dc44} \end{pmatrix}$$

11.4 Submatrix CC

Submatrix CC is similar to submatrix DD and the four values are roughly known and therefore also the length dependency.

$$CC = \begin{pmatrix} RL_{cc11} & NEXT_{cc12} & IL_{cc13} & FEXT_{cc14} \\ NEXT_{cc12} & RL_{cc22} & FEXT_{cc23} & IL_{cc24} \\ IL_{cc13} & FEXT_{cc23} & RL_{cc33} & NEXT_{cc34} \\ FEXT_{cc14} & IL_{cc24} & NEXT_{cc34} & RL_{cc44} \end{pmatrix}$$

Annex A
(informative)

Matrix conversion formulas

A.1 Overview

Generally, only the four formulas for 2-port matrices are presented like in IEC TR 62152:2009, Annex C. The corresponding formulas for a 16-port matrix (using the port numbering introduced in Figure 3) are provided here for convenience.

A.2 Formulas

A.2.1 Mixed-mode to T-matrix

$$[T]=\left([X_{ca}]+[X_{cb}][M]\right)\left([X_{da}]+[X_{db}][M]\right)^{-1}$$

where

M is the mixed-mode matrix of a component;

X_{xy} are conversion matrices;

T is the calculated chain matrix.

A.2.2 T-matrix to M-matrix

$$[M_C]=\left([T_C][X_{db}]-[X_{cb}]\right)^{-1}\left([X_{ca}]-[T_C][X_{da}]\right)$$

$$[T_C]=[T_1][T_2]\ldots$$

A.2.3 Conversion matrices

The values of the X matrices can be seen in Figure A.1.

$$M_{ca} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

$$M_{da} = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$M_{cb} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$M_{db} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

IEC

Figure A.1 – X matrices

Annex B
(normative)

Channel and permanent link models for balanced cabling

B.1 General

The limits for defined channel and permanent link cabling configurations depend on the performance of the cabling components used. The channel configurations are described in 5.6. The permanent link configurations, which represent the fixed portion of the cabling, have two possible topologies:

– a connection plus a segment of cable plus a connection (2-connector topology);
– a connection plus a segment of cable plus a connection plus another segment of cable plus another connection (3-connector topology).

This Annex B includes models and assumptions, which support limits for the channel and permanent link test configurations in ISO/IEC 11801-1. These are based on the performance requirements of cable and connecting hardware as specified in IEC standards.

The limits for the permanent link are designed to be tighter than the channel limits in all cases. This provides reasonable assurance that a channel created by adding compliant patch cords to a previously certified permanent link will meet the applicable performance limits.

NOTE This Annex B specifically does not address possible fixed test configurations of cabling that are portions of the permanent link configuration that is made into a channel by adding a patch cord at each end. The methods shown in this Annex B can be used to develop appropriate limits for these subsections.

B.2 Insertion loss

B.2.1 Insertion loss of the channel configuration

The limit for insertion loss (IL) of the channel configuration, for all class types, equals:

– the sum total of the insertion loss (IL) of four connectors, 90 m of horizontal cable and 10 m of patch cable;
– an allowance for insertion loss deviation.

$$IL_{CH} = IL_{cable\ 90\,m} + IL_{cord\ 10\,m} + 4\ IL_{connector} + ILD \quad (B.1)$$

where

IL_{CH} is the limit for insertion loss of the channel in decibel.

$IL_{connector}$ is the insertion loss limit for a single connector in decibel.

ILD is the insertion loss deviation in decibel.

NOTE Insertion loss deviation is the result of reflections within the link configuration. The actual insertion loss of the link is the sum total of the insertion losses of the cabling components in the link plus the insertion loss deviation.

$$IL_{cable\ 90\,m} = 0{,}9\ \alpha_{cable\ 100\,m\ \theta} \quad (B.2)$$

is the insertion loss limit for 90 m of horizontal cable in decibel. This equals 0,9 times the limit for 100 m of solid conductor cable at temperature θ °C.

$$\mathrm{IL}_{\mathrm{cord\ 10\,m}} = 0{,}1\mathrm{IL}_{\mathrm{cord\,100\,m}\,\theta} = 0{,}15\,\alpha_{\mathrm{cable\,100\,m}\,\theta} \quad \text{(B.3)}$$

is the limit for 10 m of stranded conductor cable in decibel, with insertion loss per unit length that is 50 % higher than solid conductor cable.

Table B.1 summarizes the significance of ILD for Class C, Class D, Class E and Class F channel configurations.

Table B.1 – Insertion loss deviation

Class	Significance of ILD for channel configuration	Estimated
Class C	Insignificant	0 dB (1 MHz to 16 MHz)
Class D	Insignificant	0 dB (1 MHz to 100 MHz)
Class E	Significant, accommodated by reduced total cabling length or use of improved components	1,0 dB at 250 MHz
Class F	Significant, accommodated by reduced total cabling length or use of improved components	2,0 dB at 600 MHz

All cable contributions can be combined, resulting in Formula (B.4):

$$\mathrm{IL}_{\mathrm{CH}} = 1{,}05\,\alpha_{\mathrm{cable\ 100\ m}\,\theta} + 4\mathrm{IL}_{\mathrm{connector}} + \mathrm{ILD} \quad \text{(B.4)}$$

B.2.2 Insertion loss of the permanent link configurations

The limit for insertion loss (IL) of all permanent link test configurations, for all class types, equals the sum total of the insertion loss performance requirements of the cabling components, assuming maximum length of horizontal cabling and patch cabling and three (3) connectors plus an allowance for insertion loss deviation.

Formula (B.5) applies:

$$\mathrm{IL}_{\mathrm{PL}} = 0{,}9\,\alpha_{\mathrm{cable\ 100m}\,\theta} + 3\mathrm{IL}_{\mathrm{connector}} + \mathrm{ILD} \quad \text{(B.5)}$$

B.2.3 Assumptions for insertion loss

B.2.3.1 Temperature dependence of insertion loss of cable

Insertion loss (IL) of twisted-pair cable is sensitive to temperature. The performance requirement for cable is specified at 20 °C. The insertion loss per 100 m at a temperature θ °C is calculated by Formula (B.6):

$$\alpha_{\mathrm{cable100m}\theta} = \alpha_{\mathrm{cable100m}} \left(1 + (\theta - 20)\frac{\theta\_\mathrm{coeff}}{100}\right) \quad \text{(B.6)}$$

where

$\alpha_{\mathrm{cable\,100\,m}\,\theta}$ is the insertion loss in decibel of 100 m cable at temperature θ °C;

$\alpha_{\text{cable 100 m}}$ is the insertion loss in decibel of 100 m cable at 20 °C;

θ_coeff is the temperature coefficient in %/°C.

Formula (B.6) can be used to compute channel and permanent link limits at operating temperatures other than 20 °C. Refer to ISO/IEC 11801-2 [3] and ISO/IEC 11801-1 for information on temperature coefficient values.

B.2.3.2 Assumptions for insertion loss of permanent links

The following assumptions are applicable to the channel and permanent link models for insertion loss.

The assumption of 3 connectors in the permanent link is a relaxation when testing a permanent link with only 2 connectors. The channel obtained by adding a compliant patch cord at each end will always result in a compliant channel. However, if cabling is added that includes a consolidation point resulting in a 3-connector permanent link, this new permanent link configuration should be tested again. The ILD of the permanent link is less than the ILD of the channel.

B.3 NEXT

B.3.1 NEXT of the channel configuration

The limit for NEXT of the channel configuration, for all class types, is computed by adding as a voltage sum the NEXT for cable and twice the NEXT for connecting hardware as shown in Formula (B.7):

$$\text{NEXT}_{\text{CH}} = -20\lg\left(10^{\frac{-\text{NEXT}_{\text{cable 100 m}}}{20}} + 2\times 10^{\frac{-\text{NEXT}_{\text{connector}}}{20}}\right) \quad \text{(dB)} \qquad \text{(B.7)}$$

where

NEXT_{CH} is the limit for NEXT of the channel in decibel;

$\text{NEXT}_{\text{cable 100 m}}$ is the NEXT specified for 100 m cable in decibel;

$\text{NEXT}_{\text{connector}}$ is the NEXT limit specified for a single connector in decibel.

Only two of four possible connectors at the near end significantly influence the channel NEXT performance.

B.3.2 NEXT of the permanent link configurations

The limit for NEXT of all permanent link configurations, for all class types, equals the voltage sum total of the NEXT for cable and once the NEXT for connecting hardware as shown in Formula (B.8):

$$\text{NEXT}_{\text{PL}} = -20\lg\left(10^{\frac{-\text{NEXT}_{\text{cable 100 m}}}{20}} + 10^{\frac{-\text{NEXT}_{\text{connector}}}{20}}\right) \quad \text{(dB)} \qquad \text{(B.8)}$$

where

NEXT_{PL} is the limit for NEXT of the permanent link in decibel.

Although the permanent link can contain an extra connector (CP), the limit computation reflects no additional connector. The impact of the CP is accommodated by using the higher precision model as described in B.3.3.1.

B.3.3 Assumptions for NEXT

B.3.3.1 Modelling of NEXT with higher precision

B.3.3.1.1 General

The method to compute the limits for the channel and permanent links is not a very accurate representation of the NEXT that can be expected when using the NEXT specifications for cable and connecting hardware. Although the more detailed method of channel and permanent link NEXT estimation from cabling component performances will result in more accurate predictions, this model contains also accuracy limitations, as further indicated in B.3.3.2.

The principles of this more detailed method are as follows.

a) For each component in the channel or permanent link, determine the impact of NEXT, referred back to the input. This means that a component not directly at the point of observation will have its NEXT improved by the round-trip insertion loss of all the components between itself and the point of observation.
b) Add up all contributions from connectors in a voltage sum (worst case) manner, since with appropriate selection of distances and test frequencies, the phase of NEXT can add up in phase.
c) Add up all contributions from segments of cable in a power sum manner, since there is no correlation of phase of NEXT contributions.
d) Add up the total of NEXT from connectors and NEXT from cable in a power sum manner, since there is no correlation between the two.

An example of this method is based on a three-connector permanent link configuration, measured from the work area location (with a CP and TO in close proximity). See Figure B.1.

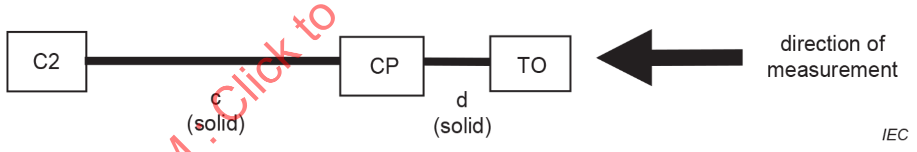


Figure B.1 – Example of computation of NEXT with higher precision

B.3.3.1.2 Step 1: Contribution from the TO

$$NEXT_{connector,\ TO} = NEXT_{connector} \quad (B.9)$$

where

$NEXT_{connector,\ TO}$ is the impact of the NEXT of the TO as seen at the end.

The TO is the component directly connected with the point of observation.

B.3.3.1.3 Step 2: Contribution from cable segment d

The NEXT of a cable segment shorter than 100 m is approximated by Formula (B.10) (see IEC 61156-1 [4], this equation is used for all lengths):

$$\mathrm{NEXT}_{\mathrm{cable},\,L} = \mathrm{NEXT}_{\mathrm{cable\,100\,m}} - 10\lg\left(\frac{1-10^{\frac{-\mathrm{IL}_{\mathrm{cable},\,L}}{5}}}{1-10^{\frac{-\alpha_{\mathrm{cable\,100\,m}}}{5}}}\right) \tag{B.10}$$

where

$\mathrm{NEXT}_{\mathrm{cable},\,L}$ is the NEXT from a cable segment that is L metres long;

$\alpha_{\mathrm{cable\,100\,m}}$ is the insertion loss from a cable segment that is 100 m long;

and

$$\mathrm{IL}_{\mathrm{cable},\,L} = K\frac{L}{100}\alpha_{\mathrm{cable\,100\,m}}$$

K = 1 for solid conductor cable and K = 1,5 for stranded conductor cable.

Therefore the NEXT contribution from cable segment d with length L_{d} (which is improved by twice the insertion loss of the TO; K = 1) is calculated by Formula (B.11):

$$\mathrm{NEXT}_{\mathrm{cable,\,d}} = \mathrm{NEXT}_{\mathrm{cable\,100\,m}} - 10\lg\left(\frac{1-10^{\frac{-\frac{L_{\mathrm{d}}}{100}\alpha_{\mathrm{cable\,100\,m}}}{5}}}{1-10^{\frac{-\alpha_{\mathrm{cable\,100\,m}}}{5}}}\right) + 2\,\mathrm{IL}_{\mathrm{connector}} \quad (\mathrm{dB}) \tag{B.11}$$

B.3.3.1.4 Step 3: Contribution from the consolidation point connector

$$\mathrm{NEXT}_{\mathrm{connector,\,CP}} = \mathrm{NEXT}_{\mathrm{connector}} + 2\left(\mathrm{IL}_{\mathrm{connector}} + \frac{L_{\mathrm{d}}}{100}\alpha_{\mathrm{cable\,100\,m}}\right) \quad (\mathrm{dB}) \tag{B.12}$$

where

$\mathrm{NEXT}_{\mathrm{connector,\,CP}}$ is the impact of the NEXT of the CP as seen at the end.

B.3.3.1.5 Step 4: Contribution from cable segment c

$$\mathrm{NEXT}_{\mathrm{cable,\,c}} = \mathrm{NEXT}_{\mathrm{cable\,100\,m}} + 10\lg\left(\frac{1-10^{\frac{-\frac{L_{\mathrm{c}}}{100}\alpha_{\mathrm{cable\,100\,m}}}{5}}}{1-10^{\frac{-\alpha_{\mathrm{cable\,100\,m}}}{5}}}\right) + 2\left(2\,\mathrm{IL}_{\mathrm{connector}} + \frac{L_{\mathrm{d}}}{100}\alpha_{\mathrm{cable100\,m}}\right) \tag{B.13}$$

B.3.3.1.6 Step 5: Contribution from the floor distributor connector C2

$$\mathrm{NEXT}_{\mathrm{connector,\,C2}} = \mathrm{NEXT}_{\mathrm{connector}} + 2\left(2\,\mathrm{IL}_{\mathrm{connector}} + \frac{(L_{\mathrm{d}} + L_{\mathrm{c}})}{100}\alpha_{\mathrm{cable\,100\,m}}\right) \quad \mathrm{(dB)} \qquad \text{(B.14)}$$

where

$\mathrm{NEXT}_{\mathrm{connector,\,C2}}$ is the impact of the NEXT of C2 as seen at the end.

B.3.3.1.7 Step 6: Add all NEXT contributions from connectors in a voltage sum manner

$$\mathrm{NEXT}_{\mathrm{connectors,\,all}} = -20\,\lg\left(10^{\frac{-\mathrm{NEXT}_{\mathrm{connector,\,TO}}}{20}} + 10^{\frac{-\mathrm{NEXT}_{\mathrm{connector,\,CP}}}{20}} + 10^{\frac{-\mathrm{NEXT}_{\mathrm{connector,\,C2}}}{20}}\right) \qquad \text{(B.15)}$$

B.3.3.1.8 Step 7: Add all NEXT contributions from cable segments in a power sum manner

$$\mathrm{NEXT}_{\mathrm{cable,\,all}} = -10\,\lg\left(10^{\frac{-\mathrm{NEXT}_{\mathrm{cable,\,d}}}{10}} + 10^{\frac{-\mathrm{NEXT}_{\mathrm{cable,\,c}}}{10}}\right) \qquad \text{(B.16)}$$

B.3.3.1.9 Step 8: Add NEXT contributions from all cable segments and all connectors in a power sum manner

$$\mathrm{NEXT}_{\mathrm{PL,\,TO}} = -10\,\lg\left(10^{\frac{-\mathrm{NEXT}_{\mathrm{cable,\,all}}}{10}} + 10^{\frac{-\mathrm{NEXT}_{\mathrm{connectors,\,all}}}{10}}\right) \qquad \text{(B.17)}$$

where

$\mathrm{NEXT}_{\mathrm{PL,\,TO}}$ is the NEXT of the permanent link, as seen from the TO end.

The same method can be applied for the channel configuration and for all permanent link configurations and from either end.

When the results of this detailed model are compared to the predictions according to B.3.2, the simple model is found to be 2 dB to 3 dB pessimistic for Class D and Class E channels and permanent links. This margin is virtually independent of length. (For short links the NEXT of the cable is less significant, but the NEXT from far-end connectors has more influence; for longer links, these conditions are reversed. In a first approximation, these effects offset each other.) For Class F links, the detailed predictions are pessimistic for short channels and permanent links. Therefore, the limits for Class F links can not apply when the total insertion loss is below a threshold value as specified in this document.

Another consequence of the margin in the computed limits is that cabling components can fail their individual requirements, and the installed link using such components can still pass the appropriate link requirements.

B.3.3.2 Additional assumptions for NEXT

The following information can be applied to the channel and permanent link models for NEXT.

- FEXT and ACR-F in combination with reflections that occur within the channel and link can add NEXT. The major reflections are from connectors and impedance mismatches between connected cables. These reflections add to the NEXT that reaches the channel, permanent link or cord endpoints. This effect can be estimated with an approach similar to that demonstrated in B.3.3.1. Cable segment ACR-F can be scaled using the formula in B.4.3. Cable segment NEXT is scaled with Formula (B.10). The effect is more significant at higher frequencies because of the 20 dB per decade slope of FEXT and RL of connecting hardware, and ACR-F of cable. The near end components have the greatest influence.
- Additional NEXT contributions that result from unbalanced signals and differential-to-common and common-to-differential mode coupling are not included in the model and are for further study.
- In modelling calculations, various combinations of a given statistically variable parameter (FEXT, NEXT or return loss) can be added in either voltage sum or power sum, or combinations of each summation type. Each method is used for simplified representations of different distributions of component performance and of distributions in phase delays. Voltage sum represents the worst case and assumes that all components are at the limit. At some frequencies all the phases will add in phase and this worst case can occur. To avoid this worst case theoretical scenario, voltage sum was used but a statistical approach was chosen where all the components have an average value better than the limit and a three-sigma normal distribution. The three-sigma worst case is at the component limit line. Then a statistical simulation (250 runs) was applied. The assumption is that not only components that just meet the limit will be included in a link. The input values used are seen in Table B.3 for Class E_A and in Table B.4 for Class F_A in Clause B.8.

B.4 ACR-F

B.4.1 ACR-F of the channel configuration

The limit for ACR-F of the channel configuration, for all classes, is computed by adding as a voltage sum the ACR-F for 100 m cable and four times (4) the FEXT for connecting hardware as shown in Formula (B.18):

$$\text{ACR-F}_{CH} = -20\ \lg\left(10^{\frac{-\text{ACR-F}_{\text{cable100 m}}}{20}} + 4 \times 10^{\frac{-\text{FEXT}_{\text{connector}}}{20}}\right) \qquad (B.18)$$

where

ACR-F_{CH}	is the limit for ACR-F of the channel in decibel;
$\text{ACR-F}_{\text{cable 100 m}}$	is the ACR-F specified for 100 m cable in decibel;
$\text{FEXT}_{\text{connector}}$	is the FEXT limit specified for a single connector in decibel.

B.4.2 ACR-F for the permanent link configurations

The limit for ACR-F of all permanent link configurations, for all class types, equals the voltage sum total of the ACR-F for 100 m cable and three (3) times the FEXT for connecting hardware as shown in Formula (B.19) (FEXT and insertion loss measurements are significantly affected by all connectors in the permanent link):

$$\text{ACR-F}_{\text{PL}} = -20\lg\left(10^{\frac{-\text{ACR-F}_{\text{cable 100 m}}}{20}} + 3\times 10^{\frac{-\text{FEXT}_{\text{connector}}}{20}}\right) \quad \text{(B.19)}$$

where

ACR-F_{PL} is the limit for ACR-F of the permanent link in decibel.

B.4.3 Assumptions for ACR-F

The following assumptions are applicable to the channel and permanent link models for ACR-F:

– ACR-F of a cable segment depends on its length L by:

$-10\lg\left(\frac{L}{100}\right)$ (the ACR-F improves as the cable segment is reduced in length).

– This provides a slight measurement margin for a permanent link:

$-10\lg\left(\frac{90}{100}\right)$ = 0,46 dB.

– The method to compute channel and permanent link performance is quite precise as all FEXT coupled signals travel approximately the same distance. At high frequencies, delay skew causes phase differences and thereby nulls in the response.
– There is no ACR-F margin present in channels. However, in practice, the ACR-F of cable is generally better than the specified requirements.
– Excess FEXT contributions that can be due to unbalanced signals and the resulting cross modal crosstalk coupling are ignored.
– Reflected crosstalk and tertiary crosstalk are ignored.
– The crosstalk mechanism involves cross-modal crosstalk phenomena. Hence, common mode terminations affect the crosstalk coupling substantially.

B.5 Return loss

B.5.1 Return loss of the channel and permanent link configurations

Circuit analysis methods need to be used for the most accurate prediction of return loss (RL) of channel and permanent link configurations from cable and connecting hardware specifications. The return loss (RL) of channels and permanent links is obtained by matrix multiplication of the transmission chain matrices of all components in the channels or permanent links, respectively.

$$\begin{bmatrix} \cosh(\gamma L) & Z\sinh(\gamma L) \\ \frac{\sinh(\gamma L)}{Z} & \cosh(\gamma L) \end{bmatrix} \quad \text{(B.20)}$$

where

$\gamma = \alpha + j\beta$ is the complex propagation constant and Z is the complex characteristic impedance;

$\alpha = \frac{\text{IL}}{20\lg(\text{e})}$;

where

IL is the insertion loss of the component in decibel;

and e ≈ 2,718 28 (base of natural logarithm).

$$\beta = \frac{2\pi f \times 10^6}{\mathrm{NVP}\, c} \text{ rad/m}$$

where

f is the frequency in MHz;

NVP is the nominal velocity of propagation relative to the speed of light;

c is the speed of light in vacuum, 3 × 10^8 m/s;

L is the length of the component in metres.

The return loss (RL) is computed from the overall transmission matrix $\begin{bmatrix} \mathrm{A} & \mathrm{B} \\ \mathrm{C} & \mathrm{D} \end{bmatrix}$ by Formula (B.21):

$$Z_{\mathrm{in}} = \frac{\mathrm{A}\, Z_{\mathrm{term}} + \mathrm{B}}{\mathrm{C}\, Z_{\mathrm{term}} + \mathrm{D}}, \text{ and } \mathrm{RL} = -20 \lg\left(\left|\frac{Z_{\mathrm{in}} - Z_{\mathrm{term}}}{Z_{\mathrm{in}} + Z_{\mathrm{term}}}\right|\right) \quad \text{(B.21)}$$

with the nominal impedance Z_{term} = 100 Ω.

B.5.2 Assumptions for the return loss circuit analysis method

B.5.2.1 Assumptions for the transmission matrix for cable

For cable, the specified insertion loss divided by the 100 m test length is given by Formula (B.22):

$$\mathrm{IL} = \frac{k_1\sqrt{f} + k_2 f + \frac{k_3}{\sqrt{f}}}{100} \text{ (dB)} \quad \text{(B.22)}$$

where k_1, k_2 and k_3 are the constants in the equation for cable insertion loss.

The properties of the characteristic impedance Z include a fitted (average) characteristic impedance Z_{fit}, which is assumed constant along the length of the cable, and a random variation around the fitted characteristic impedance. The fitted characteristic impedance can be represented by Formula (B.23):

$$Z_{\mathrm{fit}} = Z_0 \left(1 + 0{,}055\, \frac{1 - \mathrm{j}}{\sqrt{f}}\right) \quad \text{(B.23)}$$

where Z_0 is the asymptotic value of the fitted characteristic impedance. For this quantity the value of the mean characteristic impedance as specified in Clause 9 shall be used.

The allowed values for Z_0 can be determined by assuming that contributions to cable return loss from structural variations can be ignored at low frequencies. The value of Z_0 is adjusted so that at the lowest possible frequency the computed return loss using the transmission matrix method matches the return loss specification for cable (the test length is 100 m).

Pair structural variations can be represented by dividing the cable into many interval segments of randomly varying impedance, and performing a Monte-Carlo analysis of the cable return loss. The amplitude of these variations is adjusted so that the overall return loss is approximated. This is rather computation intensive and requires many iterations.

A simpler way is to assume that return loss caused by structural variations is uncorrected with the interface return loss that is the result of reflections at the beginning and end of a cable segment. The distributed return loss (DRL, an approximation of structural return loss) is obtained by power sum subtracting the interface return loss from the specified return loss in this document.

$$\mathrm{DRL} = -10\,\lg\left(10^{\frac{-\mathrm{RL}_{\mathrm{cable}}}{10}} - 10^{\frac{-\mathrm{RL}_{\mathrm{interface}}}{10}}\right) \tag{B.24}$$

DRL at frequencies > 50 MHz can be approximated by Formula (B.25):

$$\mathrm{DRL}_{100\,\mathrm{m}} = \mathrm{DRL}_0 - 10\,\lg(f) \tag{B.25}$$

where DRL_0 is a constant.

The approximate DRL value of DRL_0 is 43,5 dB for Category 5 and Category 6 cable, and 48,3 dB for Category 7 cable.

This approximation can be used to represent the contributions from all distributed sources of return loss in cabling for most lengths of cabling. The contribution from DRL over a short length of cable can be approximated using the same equation as that used for scaling NEXT in accordance with IEC 61156-1 [4]. The DRL from all of the cable segments are added together in a power sum manner to obtain the DRL for the whole link. Since the DRL contributions from all cable segments are uncorrected, the same DRL from the previous cable addition can also be obtained directly by assuming the total length in the length dependency equation and computing the correction only once. The changes caused by the length dependency equation are minimal when the total length of cabling exceeds 30 m, and therefore one can use the DRL approximation for all practical cabling lengths.

B.5.2.2 Assumptions for the transmission matrix for connectors

For a connector, the product of the propagation delay constant and length L is used.

$$\gamma L = \alpha\ L + \mathrm{j}\beta L \tag{B.26}$$

For a connector, the propagation constant is calculated according to Formula (B.26). The magnitude of the propagation constant is obtained from insertion loss of the connector, and the phase constant is calculated from the propagation delay at a certain frequency, and is assumed to be proportional to frequency. See Formula (B.29).

The electrical length $L_{\text{connector}}$ is obtained from Formula (B.27):

$$L_{\text{connector}} = \text{NVP}\, c \frac{\varphi_x}{360\, f_x} \tag{B.27}$$

where

φ_x is the measured phase angle in degrees between the output and input of the connector at a high frequency f_x (for example 100 MHz).

The connector is now modelled as a short transmission line of electrical length $L_{\text{connector}}$. The frequency response for connector return loss exhibits a 20 dB/decade slope within the frequency range of interest. The value of the characteristic impedance $Z_{\text{connector}}$ for the connector is adjusted so that the specified return loss at a certain frequency is matched. Practical values of $L_{\text{connector}}$ lie between 50 mm and 100 mm. Values of $Z_{\text{connector}}$ lie between 130 Ω and 150 Ω for a connector with 20 dB at 100 MHz of return loss.

The insertion loss constant is given by Formula (B.28):

$$\alpha L = k_{\text{c}} \sqrt{f} \tag{B.28}$$

where k_{c} is the constant in the connector insertion loss equation.

The phase constant is given by Formula (B.29):

$$\beta L = \frac{\pi}{180} \varphi_x \frac{f}{f_x} \tag{B.29}$$

B.5.2.3 Typical results

Reflections at the cable interfaces can result from characteristic impedance mismatches between cable segments or from the mismatch between connectors and cable segments. The phase dependencies and potential for in-phase addition of return loss between the different components in the channel are very much dependent on the physical separation of these interfaces from each other. Worst case in-phase addition most likely occurs in the frequency range from 15 MHz to 30 MHz, where physical distances, typical for patch cords, match one-quarter wavelengths. By carefully selecting the distances between connectors' multiples of a fixed low value (2 m for example), it is possible to show that the computed return loss exceeds the limits for the channel or permanent link. This is an unlikely situation and will manifest itself only when the cabling components perform near their individual performance limits and under the following conditions:

– in channels that use a cross-connect;

– in channels and permanent links that use a consolidation point.

B.6 PS ANEXT link modelling

B.6.1 General

The PS ANEXT model is similar to the model used for NEXT.

Each pair-to-pair ANEXT contribution is modelled in the same manner as internal link NEXT; see Clause B.3.

Simple models assume equal lengths of disturbed and disturbing links and co-location of connecting hardware (patch panels). In situations where the lengths of disturbed and disturbing are different, corrections need to be applied which depend on the length over which alien crosstalk coupling occurs.

B.6.2 PS ANEXT between connectors

The PS ANEXT between connectors is modelled as shown in Formula (B.30):

$$\text{PS ANEXT}_{\text{connector,dB}} = \text{PS ANEXT}_{\text{connector,const,dB}} - 20\lg(f/100) \tag{B.30}$$

B.6.3 PS ANEXT between cable segments

The PS ANEXT between cables is modelled as shown in Formula (B.31):

$$\text{PS ANEXT}_{\text{cable,dB}} = \text{PS ANEXT}_{\text{cable,const,dB}} - 15\lg(f/100) - 10\lg\left(\frac{1-10^{-\frac{\frac{L_\text{d}}{100}\alpha_{\text{cable, 100 m, dB}}}{5}}}{1-10^{-\frac{\alpha_{\text{cable, 100 m, dB}}}{5}}}\right) \tag{B.31}$$

where

PS ANEXT$_{\text{cable,const,dB}}$	is the PS ANEXT for 100 m of cable at 100 MHz;
L_d	is the length over which the ANEXT coupling takes place.

Refer to B.3.3.1 for a description of the length dependency portion of Formula (B.31).

B.6.4 Principles of link modelling

Worst case conditions occur where ANEXT coupling occurs over the full length of disturbing and disturbed cabling and where all connections within each link are co-located. If ANEXT coupling does not occur right from the beginning of the point of measurement, the impact is reduced by the sum insertion loss of the uncoupled cabling segments of disturbing and disturbed links. The highest influence on the overall ANEXT coupling originates from the beginning of the cabling.

PS ANEXT computations for the link are analogous to the PS NEXT computations in Clause B.3.

Additional ANEXT contributions that result from unbalanced signals and differential-to-common and common-to-differential mode coupling are for further study. These can be significant at high frequencies.

B.7 PS AACR-F link modelling

B.7.1 General

The PS AACR-F model is similar to the model used for ACR-F.

Each pair-to-pair AACR-F contribution is modelled in the same manner as internal link ACR-F; see Clause B.4.

Simple models assume equal lengths of disturbed and disturbing links and co-location of connecting hardware (patch panels). In situations where the lengths of disturbed and disturbing are different, corrections need to be applied which depend on the length over which alien crosstalk coupling occurs.

The length dependency is as described in B.4.3. The PS AACR-F between links is obtained by subtracting the insertion loss of the disturbed pair from the PS AFEXT coupling into that pair.

B.7.2 PS AFEXT between connectors

The PS AFEXT between connectors is modelled as shown in Formula (B.32):

$$\text{PS AFEXT}_{\text{Conn,dB}} = \text{PS AFEXT}_{\text{Conn,const,dB}} - 20\ \lg\,(f/100) \qquad \text{(B.32)}$$

where

PS AFEXT$_{\text{Conn,const,dB}}$ is the PS AFEXT of connecting hardware at 100 MHz.

B.7.3 PS AACR-F between cable segments

The PS AACR-F between cables is modelled as shown in Formula (B.33):

$$\text{PS AACR-F}_{\text{cable,dB}} = \text{PS AACR-F}_{\text{Cable,const,dB}} - 20\ \lg\,(f/100) - 10\ \lg\left(\frac{L_{\text{d}}}{100}\right) \qquad \text{(B.33)}$$

where

PS AACR-F$_{\text{Cable,const,dB}}$ is the PS AACR-F for 100 m cable at 100 MHz;

L_{d} is the length over which the AACR-F coupling takes place.

Refer to B.4.3 for a description of the length dependency portion of Formula (B.33).

B.7.4 Principles of link modelling

Worst case conditions occur where AFEXT coupling occurs over the full length of disturbing and disturbed cabling, or a short cabling section runs in parallel over its length with a long cabling section, and where all connections within each link are co-located.

PS AACR-F computations for the link are analogous to the PS ACR-F computations in Clause B.4.

Additional AFEXT contributions that result from unbalanced signals and differential-to-common and common-to-differential mode coupling are for further study. These can be significant at high frequencies.

B.7.5 Impact of PS AACR-F in channels and links with substantially different lengths

B.7.5.1 General

The impact of AFEXT can be substantially increased when considering a short channel or link running in parallel with a long channel or link. This can be the case when considering the conditions at a patch panel where one link terminates from a nearby location and another channel or link terminates from a distant location (see Figure B.2). The disturbing channel or link j has pairs i from 1 to 4, and is disturbing the selected channel or link, pair k. The intent is to evaluate the performance of the cabling based on the coupling length. This coupling length is effectively determined by the minimum insertion loss of the disturbing channel or link IL_j and disturbed channel or link IL_k.

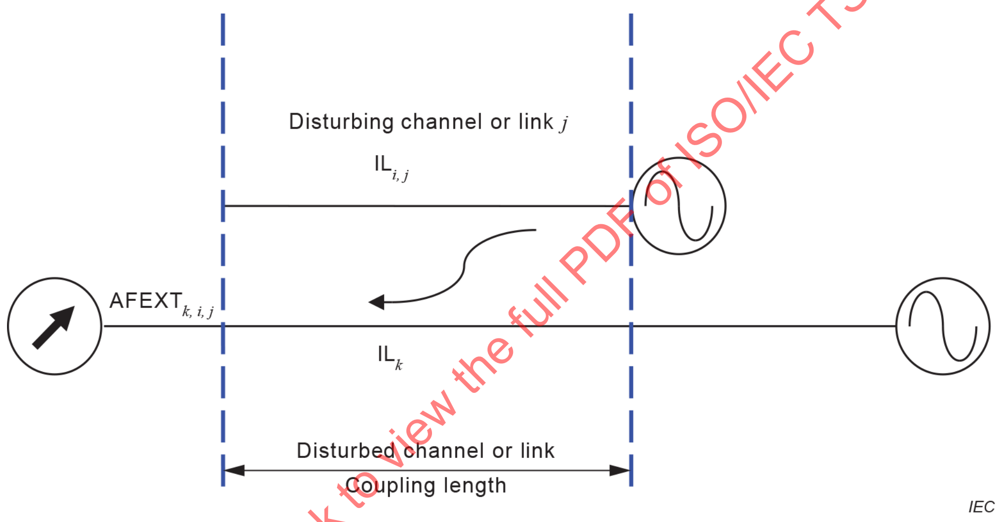


Figure B.2 – Example of increased impact of PS AFEXT

B.7.5.2 Normalization for the coupling length

It is assumed that the coupling properties of cabling are consistent over length.

Over the coupling length, the AACR-F is defined as in Formula (B.34):

$$\text{AACR-F}_{\text{coupled},\,i,k} = \text{AFEXT}_{i,k} - \text{IL}_k \qquad \text{(B.34)}$$

where

$\text{AACR-F}_{\text{coupled},\,i,k}$	is the AACR-F coupled between pair i of a disturbing channel or link and pair k of a disturbed channel or link;
i	is a pair in a disturbing channel or link;
k	is a pair in a disturbed channel or link;
$\text{AFEXT}_{i,k}$	is the AFEXT coupling between pair i of a disturbing channel or link and pair k of a disturbed channel or link;
IL_k	is the insertion loss of pair k of the disturbed channel or link.

Assuming that the length L_k of pair k of the disturbed channel or link is longer than the length L_i of pair i of the disturbing channel or link, the coupled length is given by the length L_i of the disturbing channel or link.

For nominally compliant cabling, the scaled AACR-F over the coupled length AACR-F$_{\text{coupled}}$ between pairs i of the disturbing channel or link and pair k of the disturbed channel or link is given by Formula (B.35):

$$\text{AACR-F}_{\text{coupled},\,i,k} = \text{AACR-F}_{\text{100m}} - 10\,\text{lg}\left(\frac{L_i}{100}\right) \tag{B.35}$$

where

L_i is the length of pair i of the disturbing link or channel.

Therefore

$$\text{AACR-F}_{\text{100m}} = \text{AACR-F}_{\text{coupled},\,i,k} + 10\,\text{lg}\left(\frac{L_i}{100}\right) \tag{B.36}$$

If the coupling were to take place over the length L_k of the disturbed channel or link, the relationship for nominally compliant cabling will be

$$\text{AACR-F}_{\text{normalized},\,i,k} = \text{AACR-F}_{\text{100m}} - 10\,\text{lg}\left(\frac{L_k}{100}\right) \tag{B.37}$$

where

L_k is the length of pair k of the disturbed channel or link.

Substituting for AACR-F$_{\text{100m}}$ gives:

$$\text{AACR-F}_{\text{normalized},\,i,k} = \text{AACR-F}_{\text{coupled},\,i,k} + 10\,\text{lg}\left(\frac{L_i}{100}\right) - 10\,\text{lg}\left(\frac{L_k}{100}\right) \tag{B.38}$$

$$\text{AACR-F}_{\text{normalized},\,i,k} = \text{AACR-F}_{\text{coupled},\,i,k} - 10\,\text{lg}\left(\frac{\text{IL}_k}{\text{IL}_i}\right) \tag{B.39}$$

The logarithmic ratio of lengths can be converted to a logarithmic ratio of insertion losses. For simplification, the average insertion loss of all pairs at 250 MHz can be used to compute the ratio.