ISO/IEC TR 11801-9903

Edition 1.0 2015-10

TECHNICAL REPORT

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

ISO/IEC TR 11801-9903:2015-10(en)

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ISO/IEC TR 11801-9903

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colour inside

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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 35.200

ISBN 978-2-8322-2923-1

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INFORMATION TECHNOLOGY – GENERIC CABLING SYSTEMS FOR CUSTOMER PREMISES –

Part 9903: Matrix modelling of channels and links

FOREWORD

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ISO/IEC TR 11801-9903, which is a technical report, has been prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

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 web site.

This Technical Report has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the second title page.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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.

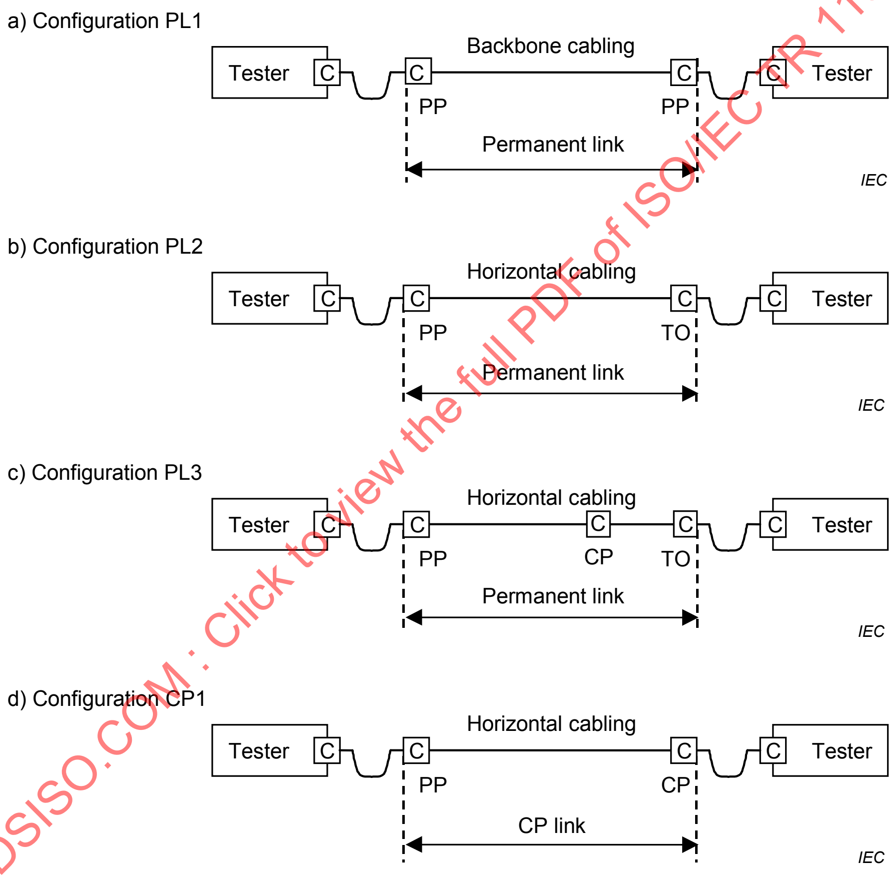
INTRODUCTION

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 are described in Clause 5, the link configurations in Clause 6 of ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010.

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).



PP = patch panel; C = connection; CP = consolidation point;

TO = telecommunications outlet

Figure 1 – Link configurations of ISO/IEC 11801:2002

This Technical Report includes models and assumptions, which support pass/fail limits for the channel and permanent link test configurations in this standard. These are based on the performance requirements of cable and connecting hardware as specified in IEC standards.

This Technical Report 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 at the end only by doing a Monte Carlo calculation, assuming that not all components would be at the limit at the same time, allowed to prove compliance.

The model uses 2 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 2 pair calculations with appropriate inputs (worst case). An example of such a calculation is the power sum and average limit lines for 4 pairs.

Symmetry and additional contributions that result from unbalanced signals and differential-to-common and common-to-differential mode coupling are not included in this Technical Report but can be added easily in a next step by increasing the matrix size.

For details on the naming of transmission parameters, see definitions 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 establishes a matrix-model for formulating limits for differential mode parameters for return loss, insertion loss, and near and far end crosstalk, within and between two pairs of balanced cabling. This is for the purpose of supporting new, improved balanced cabling channel and link specifications, which are expected to be included in the next edition of ISO/IEC 11801[1].

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 11801:2002, *Information technology – Generic cabling for customer premises*
Amendment 1:2008
Amendment 2:2010[2]

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
attenuation
general term to indicate 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.

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1 A new edition of ISO/IEC 11801 is under consideration and is planned as ISO/IEC 11801-1 (first edition).

2 A consolidated version of this publication exists, comprising ISO/IEC 11801:2002, ISO/IEC 11801:2002/AMD 1:2008 and ISO/IEC 11801:2002/AMD 2:2010.

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 loss (attenuation) with regard to the wave attenuation due to mismatches (not only at the ends)

3.1.6
operational attenuation
ratio of the square root of the maximum available (complex) power wave from the generator and the square root of the (complex) power consumed (taken) 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 a passive electrical system

Note 1 to entry: The output power at all ports that 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 of a junction
loss due to the reflection at a junction

Note 1 to entry: See also C.3.6.

3.2 Abbreviations

For the purposes of this document, the abbreviations given in ISO/IEC 11801 and the following apply.

DRL	distributed return loss
NEXT-L	near end crosstalk loss
NEXT-T	near end crosstalk transfer function
FEXT-L	far end crosstalk loss
FEXT-T	far end crosstalk transfer function
ρ	Reflection transfer function
Rl	Return loss
attenuation-L	attenuation loss
attenuation-T	attenuation transfer function

4 Matrix model

The model to be used is a concatenated matrix calculation as discussed in IEC TR 62152 for a 2 port system. For a 2 pair balanced cabling calculation a 4 port differential matrix as shown in Figure 1 shall to 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. For the matrix calculation the phase is added as a random value to reflect power sum addition (see Clause 6).

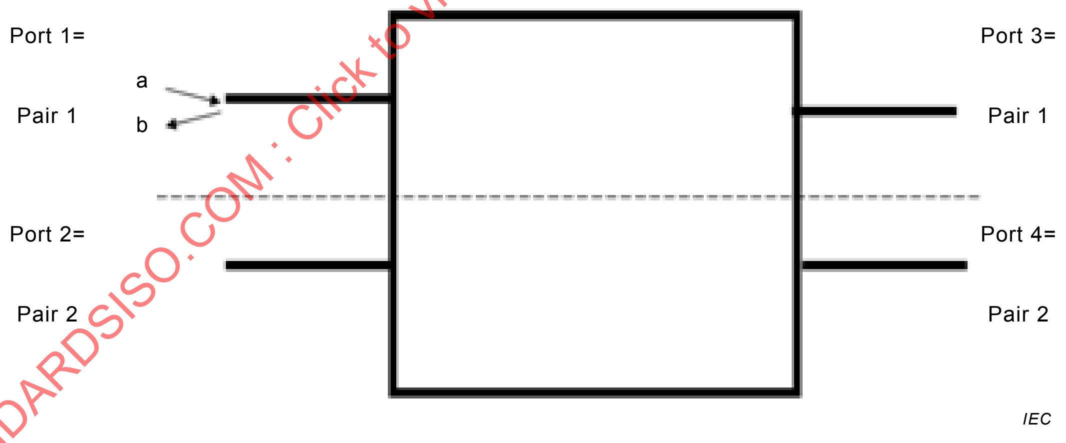
5 Matrix definition

5.1 Quadriports

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

5.2 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/twisted pair.



Key

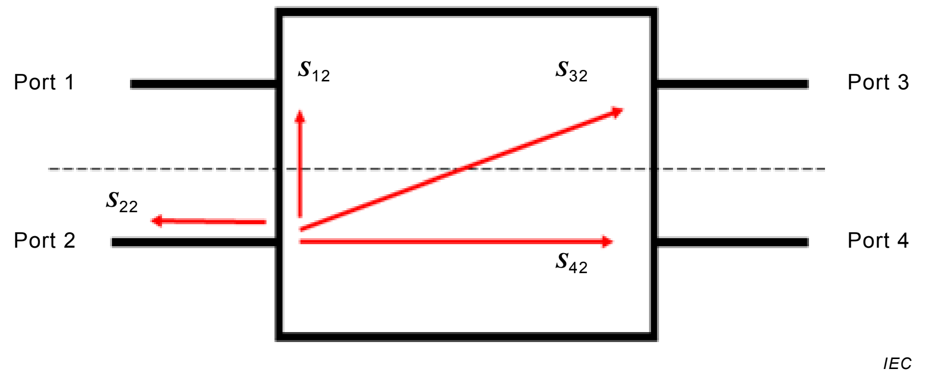
a designates a wave entering the quadriport

b designates a wave leaving the quadriport

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

5.3 Operational scattering matrix

Here, the S parameters for a source at port 2 are shown. For all definitions, see 5.4.



Key

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

S_{12} = Near-end operational crosstalk transfer function (NEXT-T)

S_{22} = Operational reflections coefficient (ρ)

S_{32} = Far-end operational crosstalk transfer function (FEXT-T)

S_{42} = Forward operational transfer function (attenuation-T)

Figure 3 – Operational scattering parameters example from port 2

5.4 General naming convention

The naming convention for the four ports is given in Figure 4.

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} *attenuation-T*	S_{42} *attenuation-T*	S_{13} *attenuation-T*	S_{24} *attenuation-T*

IEC

Figure 4 – All 4 ports operational scattering parameter definition

5.5 S-Matrix

For each cabling component (for cables for each length and type involved, for connections for each type) an S-Matrix has to be developed. It is advised to start the matrix numbering with 1 to be compatible with scattering parameters and generally used definitions (see 5.4) and IEC TR 62152.

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

IEC

Figure 5 – S-Matrix definition showing corresponding S parameters

The equal scattering coefficient due to symmetrical nature of components results in the following set of equalities:

S13=S31 attenuation-T	pair 1
S24=S42 attenuation-T	pair 2
S14=S41 FEXT-T	pair 1-2
S23=S32 FEXT-T	pair 1-2
S21=S12 NEXT-T	pair 1-2
S34=S43 NEXT-T	pair 1-2

IEC

Figure 6 – Equal S parameters for real components

The equalities provided above results in the following component scattering matrix:

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{23} & S_{24} \\ S_{13} & S_{23} & S_{33} & S_{34} \\ S_{14} & S_{24} & S_{34} & S_{44} \end{bmatrix}$$

IEC

Figure 7 – Final operational scattering matrix for real components

The following transmission parameters can be substituted into the matrix shown in Figure 7.

ρ:	$S_{11}, S_{22}, S_{33}, S_{44}$
NEXT-T:	S_{12}, S_{34}
FEXT-T:	S_{14}, S_{23}
attenuation-T:	S_{13}, S_{24}

5.6 Passivity

There is a general assumption that all values ***(NEXT, FEXT….)*** are much less than one (in linear value) or much greater than 0 dB.

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

This is defined as passivity and should be implemented. An example is shown in 5.7.

5.7 Operational reflexion loss matrix

To account for the impedance mismatch between two cabling segments a reflexion 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 reflexion transfer function to get the operational attenuation as defined, see Figure 8.

$$S_{ref} = \begin{bmatrix} ref & 0 & \sqrt{1-ref^2} & 0 \\ 0 & ref & 0 & \sqrt{1-ref^2} \\ \sqrt{1-ref^2} & 0 & ref & 0 \\ 0 & \sqrt{1-ref^2} & 0 & ref \end{bmatrix}$$

IEC

Figure 8 – Definition of the operational reflection loss matrix with unitarity included (see C.3.6)

ref is the reflection between two cabling sections and is defined as:

a) constant over frequency (for similar cable types),

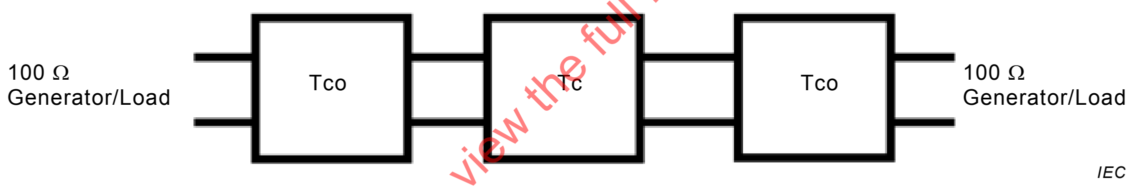
b) a function of frequency, e.g. at the end of cables (cabling) and connectors,

c) a real function assuming the reflected wave in phase or

d) a complex function taking a phase shift of the reflected wave into account.

5.8 Transmission matrix (T-matrix)

The component S-matrices are transformed into component transmission matrices (for a mathematical example see Annex A) which can then be multiplied in the appropriate order.



Key

Tco T matrix of a connection

Tc T matrix of a cable

Figure 9 – Transmission matrix concatenation showing an example of a 2 connector permanent link

5.9 S-matrix of cabling

The resulting 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 components a random uniform phase distribution from $-\pi$ to $+\pi$ is added to the scalar amplitude.

This is done by multiplying the scalar amplitude by a complex rotation factor with the randomized phase in its imaginary exponent. Clause 8 indicates, to which parameters this operation is applied.

One example of random is (rnd should be replaced by the code specific random function from 0 to 1):

$$\text{random} := \exp[(\text{rnd}(2 \cdot \pi) - \pi) \cdot i] \qquad (1)$$

7 Extracting limit lines

7.1 General

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

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

A calculation sweep with more than 5 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.

This least mean square fit is called "fit" in the following.

A graphical example of a near end crosstalk calculation in decibel over frequency (*NEXT-L)* is shown in Figure 8. The red dots represent the statistical matrix calculation while the blue line represents the fitted curve.

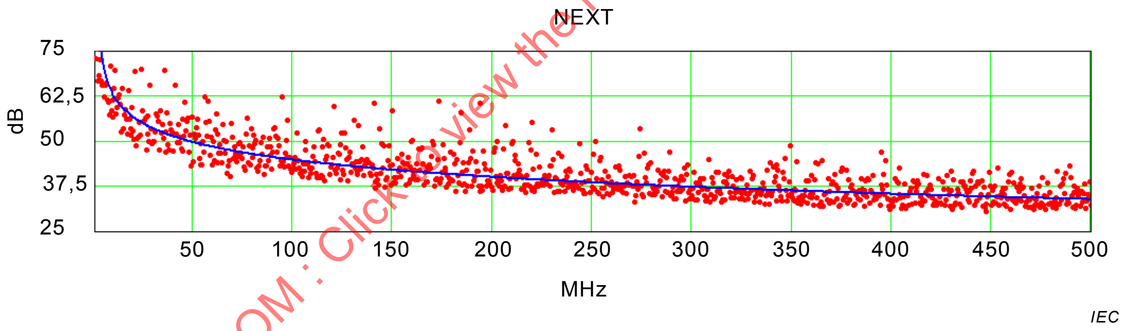


Figure 10 – Graphical example of a *NEXT-L* calculation showing statistical results (red) and final calculation (blue)

7.2 Equations to extract the cabling limit lines

Limit lines are usually given in dB.

The equations to extract the resulting limit lines are applied to the calculated linear values before transforming them into dB because averaging in dB overestimates high values.

7.2.1 Operational attenuation

The limit line is averaged in dB 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 fit formula is proposed as follows and it is applied to the values in dB:

$$attenuation\text{–}L = a\sqrt{f} + bf + \frac{c}{\sqrt{f}} \text{ dB} \quad (2)$$

7.2.2 Near end crosstalk

The fit formula is proposed as follows and applied to linear values:

$$NEXT\text{–}T = a + bf + cf^2 + df^3 \quad (3)$$

7.2.3 Attenuation to far end crosstalk ratio

The matrix calculation calculates *FEXT-T*. As components and cabling usually defines ACR-F the following formula is proposed and it is applied to linear values:

$$ACR\text{–}F = af + \frac{b}{f^2} \quad (4)$$

7.2.4 Reflection

High frequency:

The fit formula is proposed as follows and applied to linear values:

$$\rho = a + bf + cf^2 + df^3 \quad (5)$$

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 5.7 is applied till it intercepts the curve from formula (5). If only higher frequencies are of interest this can be neglected.

8 Component values to be used as input to the model

8.1 General

All limit lines have to be in value (not in dB) to be used in matrix operations.

a) Random is the definition from Clause 6, it can be applied independently to cables and connectors.

b) Phase is the value to define the length of the component.

Example: The phase in free air is calculated according to formula (6):

$$Phase = e^{\frac{j\pi fl}{150}} \quad (6)$$

where

f is frequency in MHz,

l is length in m.

c) Limit is the component linear limit value (not in dB).

8.2 Cable

8.2.1 General

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

The limits are length scaled values and thus a function of length, see [2].

8.2.2 Wave attenuation

$$Wave.attenuation = Limit_{Il}(l) \times Phase(l) \quad (7)$$

NOTE To get the operational attenuation the reflections need to be added.

8.2.3 Near end crosstalk

$$NEXT\text{–}T = Limit_{NEXT}(l) \times Phase(l) \times Random \quad (8)$$

8.2.4 Far end crosstalk

Far end crosstalk has to be calculated from ACR-F limit line.

$$FEXT\text{–}T = Limit_{FEXT}(l) \times Phase(l) \times Random \quad (9)$$

8.2.5 Reflection

The method used is defined in ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010, Annex G.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 ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010).

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.

- High frequency $\rho = Limit_{Rl}(l) \times Phase(l) \times Random$ (10)
- Low frequency using reflexion matrix (nothing to be entered in Rl limit line)

Example: A 100 m cable was calculated for return loss using a Llimit of 65-15Log(f)

Figure 11 – 100 m cable return loss without reflection at both ends

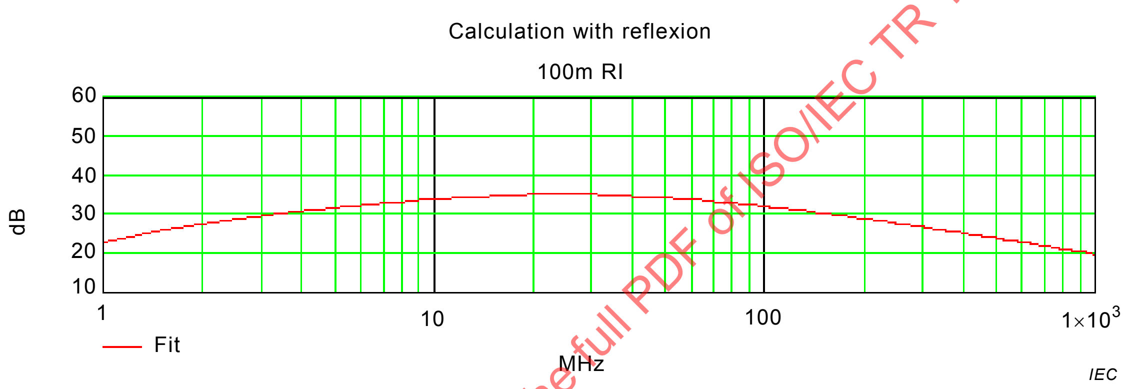


Figure 12 – 100 m cable return loss with a reflection of 0,03 at both ends (6 Ω mismatch, ~23 dB return loss at 1 MHz)

The curves in Figure 11 and Figure 12 do not resemble return loss measurements, because they are calculated limit lines.

8.3 Connections

8.3.1 General

Values and models are available for connections in two forms:

a) as simple point source of disturbance;

b) as a transmission line.

8.3.2 As point source of disturbance

Limit lines as in ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010 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):

$$Operational\ transfer\ function\,(attenuation\text{–}T) = Wave\ transfer\ function \times \sqrt{1-\rho^2} \quad (11)$$

8.3.3 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 may 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 reflexion loss matrix shall be added at the output (at the input it is one from the end of the cable). See Annex C and Annex G. 5.2.1 of ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010:2002 for details.

Annex A
(informative)

S to T and T to S-matrix conversion formulas

A.1 Overview

Generally, only the 4 formulas for 2-port matrices are presented like in IEC TR 62152:2009, Annex C. The corresponding 16 formulas for a 4 port matrix (using the port numbering introduced in Figure 3) are provided here for convenience.

Mathematically, this conversion assumes that the determinant of the S-Matrix can be calculated. In our case it means that N shall be different from zero (first line of formulas). For cabling elements this is always true. Looking into the parameters, N is the difference of

$FEXT^2 - IL^2$ and this difference will never be zero for real components.

For the backward conversion N cannot be related easily to real limits, but because S to T is possible the backward computation is possible, too.

A.2 Formulas

S_to_T:=

$$N \leftarrow S_{4,1} \cdot S_{3,2} - S_{3,1} \cdot S_{4,2}$$
$$T_{1,1} \leftarrow \frac{-S_{4,2}}{N}$$
$$T_{1,2} \leftarrow \frac{S_{3,3} \cdot S_{4,2} - S_{4,3} \cdot S_{3,2}}{N}$$
$$T_{1,3} \leftarrow \frac{S_{3,2}}{N}$$
$$T_{1,4} \leftarrow \frac{S_{3,4} \cdot S_{4,2} - S_{4,4} \cdot S_{3,2}}{N}$$
$$T_{2,1} \leftarrow \frac{S_{4,1} \cdot S_{1,2} - S_{4,2} \cdot S_{1,1}}{N}$$
$$T_{2,2} \leftarrow S_{1,3} + \frac{(S_{3,3} \cdot S_{4,2} - S_{4,3} \cdot S_{3,2}) \cdot S_{1,1} + (S_{4,3} \cdot S_{3,1} - S_{3,3} \cdot S_{4,1}) \cdot S_{1,2}}{N}$$
$$T_{2,3} \leftarrow \frac{S_{3,2} \cdot S_{1,1} - S_{3,1} \cdot S_{1,2}}{N}$$
$$T_{2,4} \leftarrow S_{1,4} + \frac{(S_{3,4} \cdot S_{4,2} - S_{4,4} \cdot S_{3,2}) \cdot S_{1,1} + (S_{4,4} \cdot S_{3,1} - S_{3,4} \cdot S_{4,1}) \cdot S_{1,2}}{N}$$
$$T_{3,1} \leftarrow \frac{S_{4,1}}{N}$$
$$T_{3,2} \leftarrow \frac{S_{4,3} \cdot S_{3,1} - S_{3,3} \cdot S_{4,1}}{N}$$
$$T_{3,3} \leftarrow \frac{-S_{3,1}}{N}$$
$$T_{3,4} \leftarrow \frac{S_{4,4} \cdot S_{3,1} - S_{3,4} \cdot S_{4,1}}{N}$$
$$T_{4,1} \leftarrow \frac{S_{4,1} \cdot S_{2,2} - S_{4,2} \cdot S_{2,1}}{N}$$
$$T_{4,2} \leftarrow S_{2,3} + \frac{(S_{3,3} \cdot S_{4,2} - S_{4,3} \cdot S_{3,2}) \cdot S_{2,1} + (S_{4,3} \cdot S_{3,1} - S_{3,3} \cdot S_{4,1}) \cdot S_{2,2}}{N}$$
$$T_{4,3} \leftarrow \frac{S_{3,2} \cdot S_{2,1} - S_{3,1} \cdot S_{2,2}}{N}$$
$$T_{4,4} \leftarrow S_{2,4} + \frac{(S_{3,4} \cdot S_{4,2} - S_{4,4} \cdot S_{3,2}) \cdot S_{2,1} + (S_{4,4} \cdot S_{3,1} - S_{3,4} \cdot S_{4,1}) \cdot S_{2,2}}{N}$$

return T

T_to_S:=

$$N \leftarrow T_{3,1} \cdot T_{1,3} - T_{1,1} \cdot T_{3,3}$$
$$S_{1,1} \leftarrow \frac{T_{3,1} \cdot T_{2,3} - T_{3,3} \cdot T_{2,1}}{N}$$
$$S_{1,2} \leftarrow \frac{T_{1,3} \cdot T_{2,1} - T_{1,1} \cdot T_{2,3}}{N}$$
$$S_{1,3} \leftarrow T_{2,2} + \frac{(T_{1,2} \cdot T_{3,3} - T_{3,2} \cdot T_{1,3}) \cdot T_{2,1} + (T_{1,1} \cdot T_{3,2} - T_{1,2} \cdot T_{3,1}) \cdot T_{2,3}}{N}$$
$$S_{1,4} \leftarrow T_{2,4} + \frac{(T_{1,4} \cdot T_{3,3} - T_{3,4} \cdot T_{1,3}) \cdot T_{2,1} + (T_{1,1} \cdot T_{3,4} - T_{1,4} \cdot T_{3,1}) \cdot T_{2,3}}{N}$$
$$S_{2,1} \leftarrow \frac{T_{3,1} \cdot T_{4,3} - T_{3,3} \cdot T_{4,1}}{N}$$
$$S_{2,2} \leftarrow \frac{T_{1,3} \cdot T_{4,1} - T_{1,1} \cdot T_{4,3}}{N}$$
$$S_{2,3} \leftarrow T_{4,2} + \frac{(T_{1,2} \cdot T_{3,3} - T_{3,2} \cdot T_{1,3}) \cdot T_{4,1} + (T_{1,1} \cdot T_{3,2} - T_{1,2} \cdot T_{3,1}) \cdot T_{4,3}}{N}$$
$$S_{2,4} \leftarrow T_{4,4} + \frac{(T_{1,4} \cdot T_{3,3} - T_{3,4} \cdot T_{1,3}) \cdot T_{4,1} + (T_{1,1} \cdot T_{3,4} - T_{1,4} \cdot T_{3,1}) \cdot T_{4,3}}{N}$$
$$S_{3,1} \leftarrow \frac{-T_{3,3}}{N}$$
$$S_{3,2} \leftarrow \frac{T_{1,3}}{N}$$
$$S_{3,3} \leftarrow \frac{T_{1,2} \cdot T_{3,3} - T_{3,2} \cdot T_{1,3}}{N}$$
$$S_{3,4} \leftarrow \frac{T_{1,4} \cdot T_{3,3} - T_{3,4} \cdot T_{1,3}}{N}$$
$$S_{4,1} \leftarrow \frac{T_{3,1}}{N}$$
$$S_{4,2} \leftarrow \frac{-T_{1,1}}{N}$$
$$S_{4,3} \leftarrow \frac{T_{1,1} \cdot T_{3,2} - T_{1,2} \cdot T_{3,1}}{N}$$
$$S_{4,4} \leftarrow \frac{T_{1,1} \cdot T_{3,4} - T_{1,4} \cdot T_{3,1}}{N}$$

return S

Annex B
(informative)

Calculation examples

B.1 Overview

This annex describes calculation examples for the following configuration. It matches a 100 m 4 connection, 10 m cord ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010 channel. No plateaus or get outs considered. Calculation was done from side a).

a) 2,5 m cord
b) connection
c) 2,5 m cord
d) connection
e) 2,5 m cord
f) connection
g) 90 m horizontal
h) connection
i) 2,5 m cord

B.2 Component assumptions for modelling purposes

B.2.1 Cables

Table B.1 is an excerpt of ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010, Table G.2.

Table B.1 – Modelling assumptions for cable transmission parameters

	Component category [a]		
Electrical characteristic dB	**5**	**6_A**	**7_A**
Distributed Return loss [c] (horizontal and cord cable)	43,5 – 10lg(f)	48,3 – 10lg(f)	48,3 – 10lg(f)
Insertion loss [b]	$1{,}910\,8\sqrt{f} + 0{,}022\,2\,f + \frac{0{,}2}{\sqrt{f}}$	$1{,}82\sqrt{f} + 0{,}009\,1\,f + \frac{0{,}25}{\sqrt{f}}$	$1{,}8\sqrt{f} + 0{,}005\,f + \frac{0{,}25}{\sqrt{f}}$
NEXT	65,3 – 15lg(f)	74,3 – 15 lg(f)	108,4 – 15lg(f)
ACR-F	63,8 – 20lg(f)	67,8 – 20 lg(f)	105,3 – 20lg(f)

[a] All equations apply from 1 MHz to the upper frequency of the category unless otherwise indicated.

[b] The insertion loss of cord cables is 50 % higher than the insertion loss of the corresponding category horizontal cable that is shown in this table.

[c] See ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010, G.5.2.1, equation G.25.

A cable segment mismatch of 2 Ω is assumed at cable junctions as in ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010.

B.2.2 Connections

Connections are specified in ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010:2010, Clause 10. Table B.2 is an excerpt of this clause.

Table B.2 – Modelling assumptions for connection transmission parameters

	Component category [a]		
Electrical characteristic **dB**	**5**	**6_A**	**7_A**
Return loss [b]	$60 - 20\lg(f)$	$68 - 20\lg(f)$	$68 - 20\lg(f)$
Insertion Loss [b]	$0{,}04\sqrt{f}$	$0{,}02\sqrt{f}$	$0{,}02\sqrt{f}$
NEXT $1 \le f \le 100$	$83 - 20\lg(f)$		
NEXT $1 \le f \le 250$		$94 - 20\lg(f)$	
NEXT $250 < f \le 500$		$46{,}04 - 30\lg(f/250)$	
NEXT $1 \le f \le 600$			$116{,}3 - 20\lg(f)$
NEXT $600 < f \le 1\,000$			$60{,}73 - 40\lg(f/600)$
FEXT [c]	$75{,}1 - 20\lg(f)$	$83{,}1 - 20\lg(f)$	$103{,}9 - 20\lg(f)$

[a] All equations apply from 1 MHz to the upper frequency of the category unless otherwise indicated.

[b] The connection is assumed to be a lumped element, no length or impedance considered. In a first step no different results were obtained.

[c] For connectors, the difference between *FEXT* and *ACR-F* is minimal. Therefore, connector *FEXT* requirements are used to model *ACR-F* performance for links and channels.

B.3 Model results

B.3.1 General

The coefficients of the calculated fit curve defined as defined in 7.2 are presented in the following for classes D, E_A and F_A.

B.3.2 Insertion loss

Table B.3 – Insertion loss

	Coefficients (see 7.2.1, Equation (2))			
Class	a	b	c	
D	2,158 45	0,025 18	0,184 85	
E_A	1,973 25	0,011 41	0,27 835	
F_A	1,913 64	$9{,}585\ 61\times10^{-3}$	0,410 2	

B.3.3 NEXT

Table B.4 – NEXT

	Coefficients (see 7.2.2, Equation (3))			
Class	a	b	c	d
D	$8{,}833\ 16\times10^{-4}$	$1{,}136\ 47\times10^{-4}$	$1{,}320\ 32\times10^{-6}$	$-1{,}264\ 37\times10^{-8}$
E_A	$5{,}438\ 02\times10^{-4}$	$4{,}458\ 36\times10^{-5}$	$5{,}327\ 46\times10^{-8}$	$-9{,}56\times10^{-11}$
F_A	$2{,}702\ 98\times10^{-7}$	$2{,}743\ 41\times10^{-8}$	$-4{,}001\ 56\times10^{-10}$	$5{,}478\ 27\times10^{-13}$

B.3.4 ACR-F

Table B.5 – ACR-F

	Coefficients (see 7.2.3, Equation (4))			
Class	a	b		
D	$9{,}520\ 04\times10^{-4}$	$-4{,}795\ 066\times10^{-5}$		
E_A	$5{,}0312\ 88\times10^{-4}$	$-1{,}398\ 203\times10^{-5}$		
F_A	$2{,}959\ 785\times10^{-5}$	$-1{,}241\ 365\times10^{-5}$		

B.3.5 Return loss

Table B.6 – Return loss

	Coefficients (see 7.2.4, Equation (5))			
Class	a	b	c	d
D	0,084 37	$-4{,}906\ 97\times10^{-3}$	$1{,}268\ 33\times10^{-4}$	$-7{,}377\ 68\times10^{-7}$
E_A	0,051 96	$-2{,}248\ 24\times10^{-4}$	$2{,}307\ 68\times10^{-6}$	$-2{,}786\ 86\times10^{-9}$
F_A	0,046 48	$1{,}383\ 2\times10^{-4}$	$2{,}747\ 73\times10^{-7}$	$-1{,}927\ 82\times10^{-10}$

Annex C
(informative)

Terms and definitions

C.1 Comparison of namings

Table C.1 provides a comparative table of naming conventions.

Table C.1 – Comparison of naming in ISO/IEC 11081:2002 and this technical report

General usage	Current ISO/IEC 11801	Used in ISO/IEC/TR 11801-9903	Definition	abreviation
Insertion loss		**Operational attenuation**	Forward operational transfer function (not length scalable)	**attenuation-T**
	Insertion loss	**Operational attenuation loss** in dB	Forward operational transfer loss (not length scalable)	**attenuation-L**
		Wave or image attenuation	Forward wave transfer function (no reflections, length scalable)	—
Attenuation	Only in definition	As a general term for dimishing of signal strength	—	—
Insertion loss deviaton	Insertion loss deviaton	**Insertion loss deviaton**	Insertion loss deviation (in dB)	ILD
NEXT		**NEXT transfer function**	Near-end Crosstalk Transfer Function	**NEXT-T**
	NEXT loss	**NEXT loss**	Near-end Crosstalk loss (in dB)	**NEXT-L**
FEXT		**FEXT transfer function**	Far-end Crosstalk Transfer Function	**FEXT-T**
	FEXT loss	**FEXT loss**	Far-end Crosstalk loss (in dB)	**FEXT-L**
Return loss		**Reflection coefficient**	Operational reflection Coefficient	ρ
	Return loss	**Return loss**	Return loss (in dB)	**Rl**