

TECHNICAL REPORT



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

IECNORM.COM : Click to view the full PDF of ISO/IEC TR 11801-9903:2015



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2015 ISO/IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about ISO/IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in 15 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

More than 60 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IECNORM.COM : Click to view the full PDF at IECNORM.COM 1801-9903-2015

TECHNICAL REPORT



**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

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	8
2 Normative references	8
3 Terms, definitions and abbreviations	8
3.1 Terms and definitions.....	8
3.2 Abbreviations	9
4 Matrix model.....	9
5 Matrix definition	10
5.1 Quadriports.....	10
5.2 Matrix port definition for a two pair system representative for modelling purposes.....	10
5.3 Operational scattering matrix	10
5.4 General naming convention.....	11
5.5 S-Matrix.....	11
5.6 Passivity	12
5.7 Operational reflexion loss matrix	12
5.8 Transmission matrix (T-matrix).....	13
5.9 S-matrix of cabling	13
6 Calculation with matrices using limit lines	13
7 Extracting limit lines	14
7.1 General.....	14
7.2 Equations to extract the cabling limit lines	14
7.2.1 Operational attenuation	14
7.2.2 Near end crosstalk.....	15
7.2.3 Attenuation to far end crosstalk ratio	15
7.2.4 Reflection	15
8 Component values to be used as input to the model	15
8.1 General.....	15
8.2 Cable.....	16
8.2.1 General	16
8.2.2 Wave attenuation.....	16
8.2.3 Near end crosstalk.....	16
8.2.4 Far end crosstalk.....	16
8.2.5 Reflection	16
8.3 Connections.....	17
8.3.1 General	17
8.3.2 As point source of disturbance.....	17
8.3.3 As a transmission line.....	18
Annex A (informative) S to T and T to S-matrix conversion formulas	19
A.1 Overview.....	19
A.2 Formulas.....	19
Annex B (informative) Calculation examples	20
B.1 Overview.....	20
B.2 Component assumptions for modelling purposes.....	20

B.2.1	Cables	20
B.2.2	Connections	21
B.3	Model results	21
B.3.1	General	21
B.3.2	Insertion loss	21
B.3.3	NEXT	22
B.3.4	ACR-F	22
B.3.5	Return loss	22
Annex C (informative)	Terms and definitions	23
C.1	Comparison of namings	23
C.2	General	24
C.3	Background of terms and definitions	24
C.3.1	Operational attenuation	24
C.3.2	Operational transfer function (T_B)	26
C.3.3	Image or wave transfer function (T)	26
C.3.4	Insertion transfers function of a two-port (T_{BI})	26
C.3.5	Insertion transfer function (T_{BI}) measured with a NWA	26
C.3.6	Operational reflection loss transfer function ($T_{ref} = S_{ref}$) of a junction	26
Bibliography		28
Figure 1	Link configurations of ISO/IEC 11801:2002	6
Figure 2	Matrix definition of a 4 port 2 twisted pair system	10
Figure 3	Operational scattering parameters example from port 2	11
Figure 4	All 4 ports operational scattering parameter definition	11
Figure 5	S -Matrix definition showing corresponding S parameters	11
Figure 6	Equal S parameters for real components	12
Figure 7	Final operational scattering matrix for real components	12
Figure 8	Definition of the operational reflection loss matrix with unitarity included (see C.3.6)	13
Figure 9	Transmission matrix concatenation showing an example of a 2 connector permanent link	13
Figure 10	Graphical example of a <i>NEXT-L</i> calculation showing statistical results (red) and final calculation (blue)	14
Figure 11	100 m cable return loss without reflection at both ends	17
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)	17
Figure C.1	Defining the operational attenuation and the operational transfer functions of a two-port	25
Figure C.2	Defining the reflection transfer functions and the return loss of a junction	27
Table B.1	Modelling assumptions for cable transmission parameters	20
Table B.2	Modelling assumptions for connection transmission parameters	21
Table B.3	Insertion loss	21
Table B.4	NEXT	22
Table B.5	ACR-F	22
Table B.6	Return loss	22
Table C.1	Comparison of naming in ISO/IEC 11081:2002 and this technical report	23

INFORMATION TECHNOLOGY – GENERIC CABLING SYSTEMS FOR CUSTOMER PREMISES –

Part 9903: Matrix modelling of channels and links

FOREWORD

- 1) ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.
- 2) The formal decisions or agreements of IEC and ISO on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees and ISO member bodies.
- 3) IEC, ISO and ISO/IEC publications have the form of recommendations for international use and are accepted by IEC National Committees and ISO member bodies in that sense. While all reasonable efforts are made to ensure that the technical content of IEC, ISO and ISO/IEC publications is accurate, IEC or ISO cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees and ISO member bodies undertake to apply IEC, ISO and ISO/IEC publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any ISO, IEC or ISO/IEC publication and the corresponding national or regional publication should be clearly indicated in the latter.
- 5) ISO and IEC do not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. ISO or IEC are not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or ISO or its directors, employees, servants or agents including individual experts and members of their technical committees and IEC National Committees or ISO member bodies for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication of, use of, or reliance upon, this ISO/IEC publication or any other IEC, ISO or ISO/IEC publications.
- 8) Attention is drawn to the normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this ISO/IEC publication may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

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.

IECNORM.COM : Click to view the full PDF of ISO/IEC TR 11801-9903:2015

INTRODUCTION

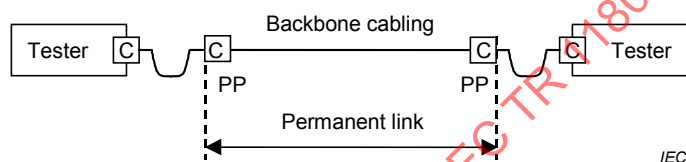
The pass/fail limits for defined channel and permanent link cabling configurations have an implicit impact on the component limits for the cabling components used. The channel configurations are described in Clause 5, the link configurations in Clause 6 of ISO/IEC 11801:2002 with its amendments 1:2008 and 2:2010.

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

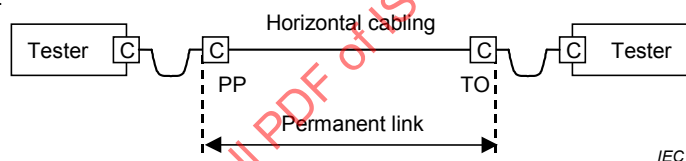
A connection plus a segment of cable plus a connection (2 connector topology).

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

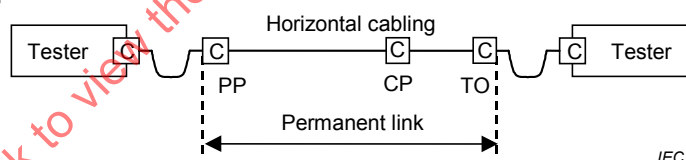
a) Configuration PL1



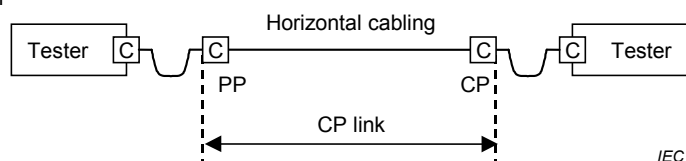
b) Configuration PL2



c) Configuration PL3



d) Configuration CP1



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.

IECNORM.COM : Click to view the full PDF of ISO/IEC TR 11801-9903:2015

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 11801¹.

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 2:2010²

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.

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
RI	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.

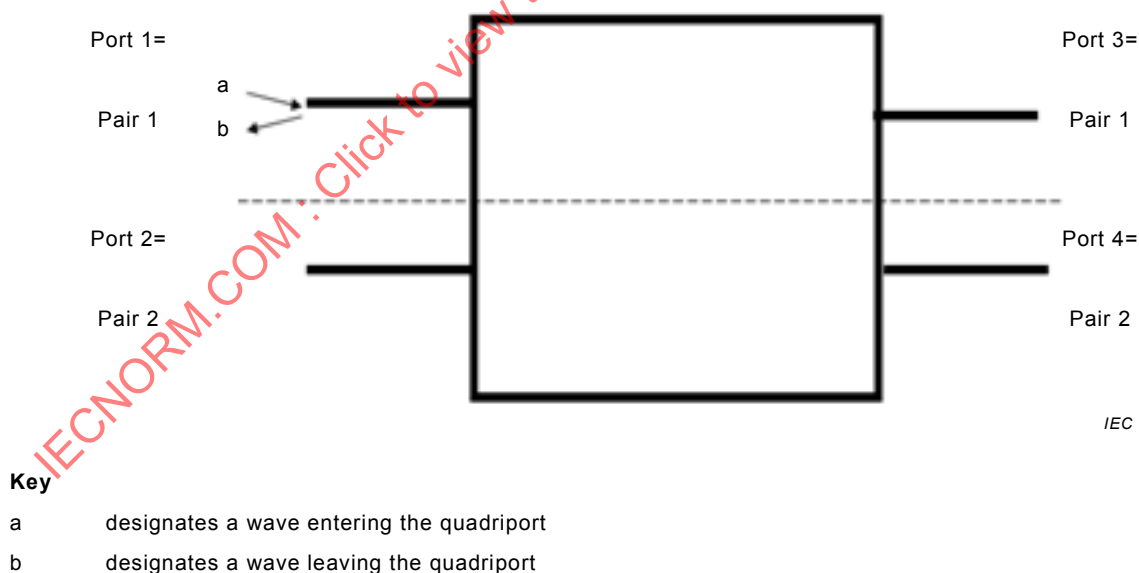
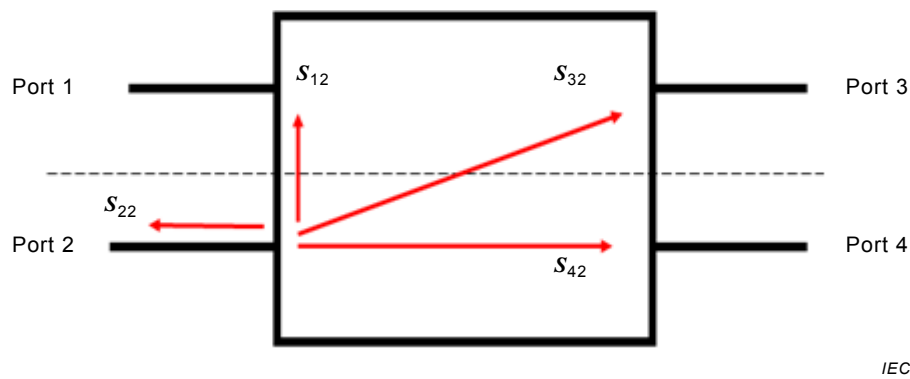


Figure 2 – Matrix definition of a 4 port 2 twisted pair system

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

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.

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

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:

$S_{13}=S_{31}$ <i>attenuation-T</i>	pair 1
$S_{24}=S_{42}$ <i>attenuation-T</i>	pair 2
$S_{14}=S_{41}$ <i>FEXT-T</i>	pair 1-2
$S_{23}=S_{32}$ <i>FEXT-T</i>	pair 1-2
$S_{21}=S_{12}$ <i>NEXT-T</i>	pair 1-2
$S_{34}=S_{43}$ <i>NEXT-T</i>	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.

$$\begin{array}{ll} \rho: & S_{11}, S_{22}, S_{33}, S_{44} \\ \text{NEXT-T:} & S_{12}, S_{34} \\ \text{FEXT-T:} & S_{14}, S_{23} \\ \text{attenuation-T:} & S_{13}, S_{24} \end{array}$$

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

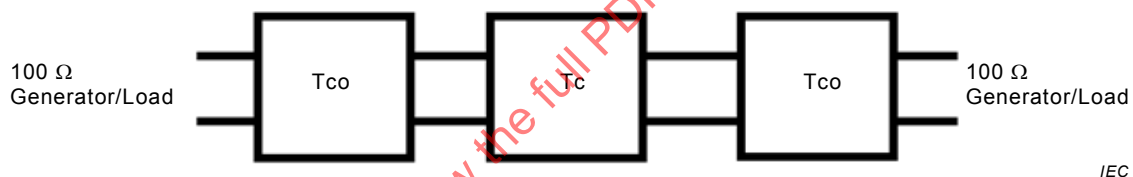
Figure 8 – Definition of the operational reflection loss matrix with unitarity included (see C.3.6)

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.



IEC

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):

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

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.

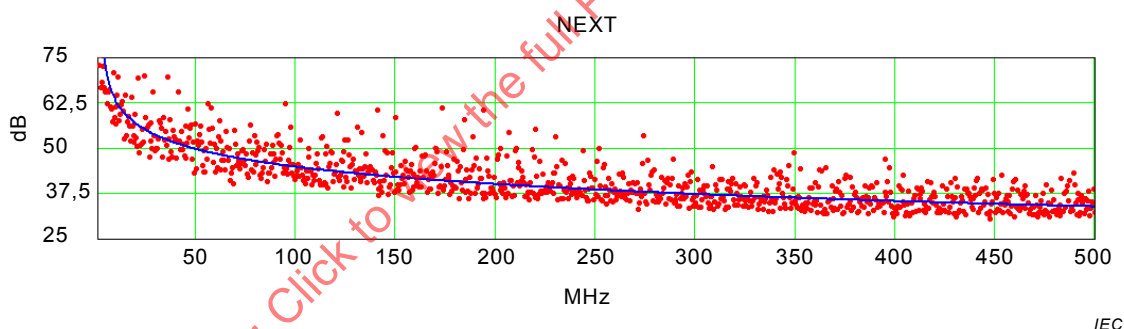


Figure 10 – Graphical example of a *NEXT-L* calculation showing statistical results (red) and final calculation (blue)

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:

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

7.2.2 Near end crosstalk

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

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

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:

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

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):

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

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

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

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

8.2.3 Near end crosstalk

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

8.2.4 Far end crosstalk

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

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

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).

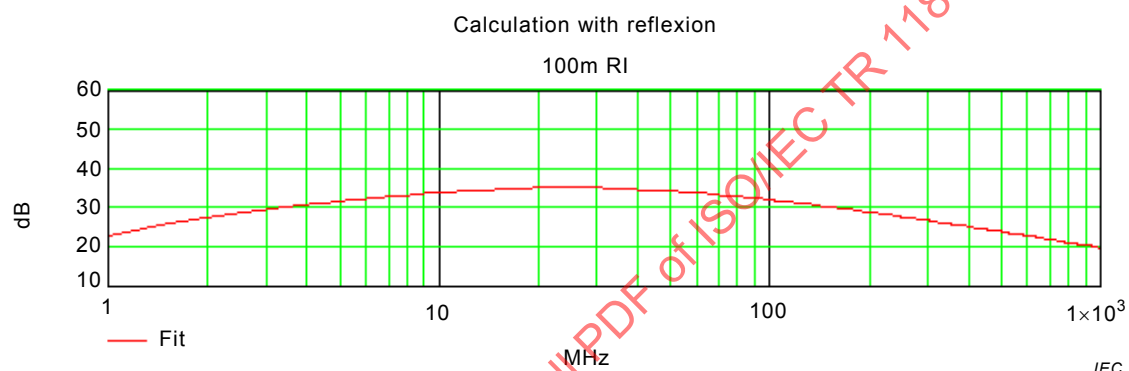
For lower frequencies (<50 MHz) and very short cables (<10 m) the impedance mismatch at the ends is the predominant factor and accounted for by the reflection matrix.

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

- as simple point source of disturbance;
- 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:

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

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

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.

IECNORM.COM : Click to view the full PDF of ISO/IEC TR 11801-9903:2015

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

$S_to_T :=$	$N \leftarrow S_{4,1} \cdot S_{3,2} - S_{3,1} \cdot S_{4,2}$ $T_{1,1} \leftarrow \frac{-S_{4,2}}{N}$ $T_{1,2} \leftarrow \frac{S_{3,3} \cdot S_{4,2} - S_{4,3} \cdot S_{3,2}}{N}$ $T_{1,3} \leftarrow \frac{S_{3,2}}{N}$ $T_{1,4} \leftarrow \frac{S_{3,4} \cdot S_{4,2} - S_{4,4} \cdot S_{3,2}}{N}$ $T_{2,1} \leftarrow \frac{S_{4,1} \cdot S_{1,2} - S_{4,2} \cdot S_{1,1}}{N}$ $T_{2,2} \leftarrow S_{1,3} + \frac{(S_{3,3} \cdot S_{4,2} - S_{4,3} \cdot S_{3,2}) \cdot S_{1,1} + (S_{4,3} \cdot S_{3,1} - S_{3,3} \cdot S_{4,1}) \cdot S_{1,2}}{N}$ $T_{2,3} \leftarrow \frac{S_{3,2} \cdot S_{1,1} - S_{3,1} \cdot S_{1,2}}{N}$ $T_{2,4} \leftarrow S_{1,4} + \frac{(S_{3,4} \cdot S_{4,2} - S_{4,4} \cdot S_{3,2}) \cdot S_{1,1} + (S_{4,4} \cdot S_{3,1} - S_{3,4} \cdot S_{4,1}) \cdot S_{1,2}}{N}$ $T_{3,1} \leftarrow \frac{S_{4,1}}{N}$ $T_{3,2} \leftarrow \frac{S_{4,3} \cdot S_{3,1} - S_{3,3} \cdot S_{4,1}}{N}$ $T_{3,3} \leftarrow \frac{-S_{3,1}}{N}$ $T_{3,4} \leftarrow \frac{S_{4,4} \cdot S_{3,1} - S_{3,4} \cdot S_{4,1}}{N}$ $T_{4,1} \leftarrow \frac{S_{4,1} \cdot S_{2,2} - S_{4,2} \cdot S_{2,1}}{N}$ $T_{4,2} \leftarrow S_{2,3} + \frac{(S_{3,3} \cdot S_{4,2} - S_{4,3} \cdot S_{3,2}) \cdot S_{2,1} + (S_{4,3} \cdot S_{3,1} - S_{3,3} \cdot S_{4,1}) \cdot S_{2,2}}{N}$ $T_{4,3} \leftarrow \frac{S_{3,2} \cdot S_{2,1} - S_{3,1} \cdot S_{2,2}}{N}$ $T_{4,4} \leftarrow S_{2,4} + \frac{(S_{3,4} \cdot S_{4,2} - S_{4,4} \cdot S_{3,2}) \cdot S_{2,1} + (S_{4,4} \cdot S_{3,1} - S_{3,4} \cdot S_{4,1}) \cdot S_{2,2}}{N}$	$T_to_S :=$ $N \leftarrow T_{3,1} \cdot T_{1,3} - T_{1,1} \cdot T_{3,3}$ $S_{1,1} \leftarrow \frac{T_{3,1} \cdot T_{2,3} - T_{3,3} \cdot T_{2,1}}{N}$ $S_{1,2} \leftarrow \frac{T_{1,3} \cdot T_{2,1} - T_{1,1} \cdot T_{2,3}}{N}$ $S_{1,3} \leftarrow T_{2,2} + \frac{(T_{1,2} \cdot T_{3,3} - T_{3,2} \cdot T_{1,3}) \cdot T_{2,1} + (T_{1,1} \cdot T_{3,2} - T_{1,2} \cdot T_{3,1}) \cdot T_{2,3}}{N}$ $S_{1,4} \leftarrow T_{2,4} + \frac{(T_{1,4} \cdot T_{3,3} - T_{3,4} \cdot T_{1,3}) \cdot T_{2,1} + (T_{1,1} \cdot T_{3,4} - T_{1,4} \cdot T_{3,1}) \cdot T_{2,3}}{N}$ $S_{2,1} \leftarrow \frac{T_{3,1} \cdot T_{4,3} - T_{3,3} \cdot T_{4,1}}{N}$ $S_{2,2} \leftarrow \frac{T_{1,3} \cdot T_{4,1} - T_{1,1} \cdot T_{4,3}}{N}$ $S_{2,3} \leftarrow T_{4,2} + \frac{(T_{1,2} \cdot T_{3,3} - T_{3,2} \cdot T_{1,3}) \cdot T_{4,1} + (T_{1,1} \cdot T_{3,2} - T_{1,2} \cdot T_{3,1}) \cdot T_{4,3}}{N}$ $S_{2,4} \leftarrow T_{4,4} + \frac{(T_{1,4} \cdot T_{3,3} - T_{3,4} \cdot T_{1,3}) \cdot T_{4,1} + (T_{1,1} \cdot T_{3,4} - T_{1,4} \cdot T_{3,1}) \cdot T_{4,3}}{N}$ $S_{3,1} \leftarrow \frac{-T_{3,3}}{N}$ $S_{3,2} \leftarrow \frac{T_{1,3}}{N}$ $S_{3,3} \leftarrow \frac{T_{1,2} \cdot T_{3,3} - T_{3,2} \cdot T_{1,3}}{N}$ $S_{3,4} \leftarrow \frac{T_{1,4} \cdot T_{3,3} - T_{3,4} \cdot T_{1,3}}{N}$ $S_{4,1} \leftarrow \frac{T_{3,1}}{N}$ $S_{4,2} \leftarrow \frac{-T_{1,1}}{N}$ $S_{4,3} \leftarrow \frac{T_{1,1} \cdot T_{3,2} - T_{1,2} \cdot T_{3,1}}{N}$ $S_{4,4} \leftarrow \frac{T_{1,1} \cdot T_{3,4} - T_{1,4} \cdot T_{3,1}}{N}$
return T	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

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

Electrical characteristic dB	Component category ^a		
	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 $1 \leq f \leq 100$	$83 - 20 \lg(f)$		
NEXT $1 \leq f \leq 250$		$94 - 20\lg(f)$	
NEXT $250 < f \leq 500$		$46,04 - 30\lg(f/250)$	
NEXT $1 \leq f \leq 600$			$116,3 - 20\lg(f)$
NEXT $600 < f \leq 1\,000$			$60,73 - 40\lg(f/600)$
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

Class	Coefficients			
	(see 7.2.1, Equation (2))			
	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 61×10 ⁻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	$8,833\ 16 \times 10^{-4}$	$1,136\ 47 \times 10^{-4}$	$1,320\ 32 \times 10^{-6}$	$-1,264\ 37 \times 10^{-8}$
E _A	$5,438\ 02 \times 10^{-4}$	$4,458\ 36 \times 10^{-5}$	$5,327\ 46 \times 10^{-8}$	$-9,56 \times 10^{-11}$
F _A	$2,702\ 98 \times 10^{-7}$	$2,743\ 41 \times 10^{-8}$	$-4,001\ 56 \times 10^{-10}$	$5,478\ 27 \times 10^{-13}$

B.3.4 ACR-F

Table B.5 – ACR-F

	Coefficients (see 7.2.3, Equation (4))			
Class	a	b		
D	$9,520\ 04 \times 10^{-4}$	$-4,795\ 066 \times 10^{-5}$		
E _A	$5,0312\ 88 \times 10^{-4}$	$-1,398\ 203 \times 10^{-5}$		
F _A	$2,959\ 785 \times 10^{-5}$	$-1,241\ 365 \times 10^{-5}$		

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	$-4,906\ 97 \times 10^{-3}$	$1,268\ 33 \times 10^{-4}$	$-7,377\ 68 \times 10^{-7}$
E _A	0,051 96	$-2,248\ 24 \times 10^{-4}$	$2,307\ 68 \times 10^{-6}$	$-2,786\ 86 \times 10^{-9}$
F _A	0,046 48	$1,383\ 2 \times 10^{-4}$	$2,747\ 73 \times 10^{-7}$	$-1,927\ 82 \times 10^{-10}$

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	abbreviation
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 diminishing of signal strength	—	—
Insertion loss deviaton	Insertion loss deviaton	Insertion loss deviaton	Insertion loss deviation (in dB)	ILD
<i>NEXT</i>		NEXT transfer function	Near-end Crosstalk Transfer Function	NEXT-T
	NEXT loss	NEXT loss	Near-end Crosstalk loss (in dB)	NEXT-L
<i>FEXT</i>		FEXT transfer function	Far-end Crosstalk Transfer Function	FEXT-T
	FEXT loss	FEXT loss	Far-end Crosstalk loss (in dB)	FEXT-L
<i>Return loss</i>		Reflection coefficient	Operational reflection Coefficient	ρ
	Return loss	Return loss	Return loss (in dB)	RI