Channel and Component Requirements for 1000BASE-T1 Link Segment Type A (STP)

Version 2.0

Author & Company	See Contributing Members on Page 2
Title	Channel and Components Requirements for 1000BASE-T1 Link Segment Type A (STP)
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This document contains electrical requirements and measurement specifications on 1000BASE-T1 channel and components link segment type A (STP). It shall be used as a standardized common scale for the evaluation of the RF properties for physical layer communication channels to enable 1000BASE-T1 technology.

Version Control of Document

Version	Author	Description	Date
2.0	Contributing Members	Status and disclaimer changed to “Public”	2020-06-24
1.10	Contributing Members	LCL requirement for MDI test head added, editorial comments from All Technical Members review solved	2020-05-12
1.9	Contributing Members	LCL / LCTL entry added in Table 3-2, list of contributing members updated, version status changed to “Interim”	2020-02-24
1.8	Contributing Members	LCL / LCTL entry with “no requirements” added for class 2 in all tables in Section 6.1 for clarity	2020-02-13
1.7	Contributing Members	Comments from version 1.5 TC circulation solved, all drawings reviewed and reworked for consistency	2020-02-04
1.5	Contributing Members	Coupling and screening attenuation measurements and limits added for cable assemblies, minor corrections	2019-11-19
1.2	Contributing Members	Cable assemblies added, environmental conditions rephrased for clarity, minor corrections	2019-09-10
1.0	Contributing Members	First publication with restriction to all OPEN Alliance members	2019-07-11
0.9	Contributing Members	Comments from TC9 review solved	2019-06-19
0.8	Contributing Members	New specification template and comments from TC9 review solved	2019-05-21
0.6	Contributing Members	Connector test method in Section 5.1 reworked	2019-04-09
0.2	Contributing Members	Comments from TC9 review solved	2018-06-19
0.1	Contributing Members	First baseline draft	2018-03-01

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Foreword (Disclaimer)

OPEN Alliance: Public OPEN Specification

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Introduction

The specification describes shielded link segments and their components for use in 1000BASE-T1 Type A Ethernet applications. The shielded link segments are intended to be used complementarily to unshielded link segments depending on the application specific electromagnetic compatibility requirements.

The specification defines measurement setups, test methodology, test fixtures and limits for measuring signal integrity parameters, crosstalk and shielding for connector and cable components as well as for cable harnesses.

Abbreviation/Symbols

AACRF	Alien attenuation to crosstalk ratio – far end
a_C	Coupling attenuation
AFEXT	Alien far end crosstalk
ANEXT	Alien near end crosstalk
a_S	Screening attenuation
AUT	Area under test
CIDM	Characteristic impedance differential mode
c_0	Speed of light in vacuum
DUT	Device under test
ECU	Electronic control unit
EMC	Electromagnetic compatibility
ES	Environment system
GND	Electrical reference ground
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
IL	Insertion loss
LCL	Longitudinal conversion loss
LCTL	Longitudinal conversion transfer loss
MDI	Media dependent interface
OEM	Original equipment manufacturer
PCB	Printed circuit board
PHY	Physical layer transceiver
PSAACRF	Power sum attenuation to alien crosstalk ratio – far end
PSAFEXT	Power sum alien far end crosstalk
PSANEXT	Power sum alien near end crosstalk

RF	Radio frequency
RL	Return loss
S-parameter	Scattering parameter
SCC	Standalone communication channel
STP	Shielded twisted pair
TCL	Transverse conversion loss
TCTL	Transverse conversion transfer loss
TDR	Time domain reflectometry
UTP	Unshielded twisted pair
VNA	Vector network analyzer
WCC	Whole communication channel
Z_1	Common mode impedance of a shielded pair cable

1 Scope

The intention of this specification is to present the general RF requirements for a physical layer communication channel according to Figure 1-1 to enable 1000BASE-T1 technology using STP cables for Automotive Ethernet applications. These requirements are related to signal integrity and EMC behavior of the communication channel. The link segment requirements for 1000BASE-T1 according [1] shall be met with the exception of balance (mode conversion), as EMC relevant parameters are covered by defining balance, coupling- and screening attenuation requirements instead.

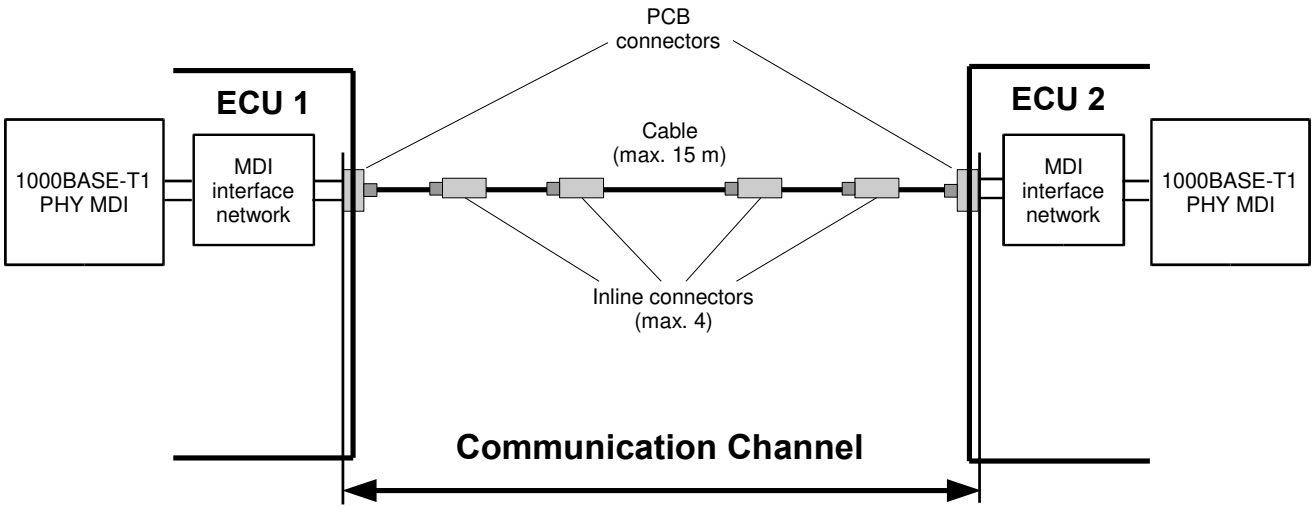

Figure 1-1: Definition of communication channel

The qualification of shielded cabling systems and components shall be done under well-defined setup, in order to make results comparable. This document defines various parameters to be tested for the complete communication channel between two Ethernet nodes, for cable assemblies and also for cables and connectors as a single component of this communication channel. It contains test procedures, test setups and electrical requirements and shall be used as a standardized common scale for the evaluation of complete channels, cable assemblies, cables and connectors.

Electrical requirements on the communication channel are also stated in [1]. Other functional requirements such as mechanical and climatic stress as well as application dependent EMC relevant parameters may also be required but would be specified by the customer (OEM) and are not the focus of this document.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[1] IEEE Std 802.3bp™: 2016, *Standard for Ethernet Amendment 4: Physical Layer Specification and Management Parameters for 1 Gb/s Operation over a Single Twisted Pair Copper Cable*

[2] ISO554: 1976, *Standard atmospheres for conditioning and/or testing – Specifications*

[3] OPEN Alliance TC9, *Channel and Components Requirements for 1000BASE-T1 Link Segment Type A (UTP)*

[4] DIN EN 61935-1: 2010, *Specification for the testing of balanced and coaxial information technology cabling – Part 1: Installed balanced cabling as specified in the standards series EN 50173 (IEC 61935-1:2009, modified)*

[5] DIN EN 50289-1-7: 2001, *Communication cables – Specifications for test methods – Part 1-7: Electrical test methods; Velocity of propagation*

[6] IEC 62153-4-7: 2015, *Metallic communication cable test methods – Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies up to and above 3 GHz – Triaxial tube in tube method*

[7] IEC 62153-4-9: 2018, *Metallic communication cable test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method*

[8] IEEE P370™, *Electrical Characterization of Printed Circuit Board and Related Interconnects at Frequencies up to 50 GHz*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1 Standalone Communication Channel (SCC)

The SCC consists of two PCB connectors, cable and up to four inline connectors. PCB and inline connectors can be single or multiport type. Multiport means that the connector provides more than one differential port. Hybrid multiport connectors additionally can have single pins to connect single ended data signals or power supply lines.

The maximum length of WCC and SCC is not defined as it depends on the electrical characteristics of the components that are used. The component requirements in Chapter 6 are defined in a way to allow a length of up to 15 m with up to 4 inline connectors. The maximum insertion loss and propagation delay time for link segment type A shall not exceed the requirement in Table 6.1.4-1 in any case (see [1]).

3.2 Environmental System (ES)

The ES consists of power and signal cables for other application than 1000BASE-T1 Ethernet within the same cable harness.

3.3 Whole Communication Channel (WCC)

The WCC is the complete electrical wired connection, i.e. the cable harness, between two ECUs with Ethernet interfaces as shown in Figure 3-1. In contrast to the link segment definition in [1], PCB end connectors belong to the communication channel.

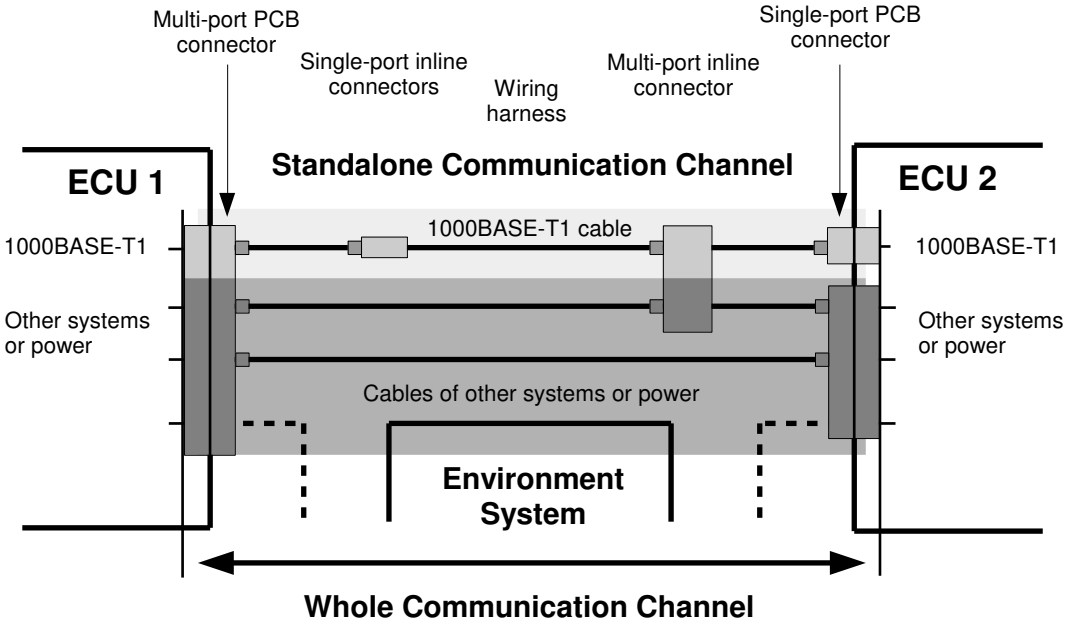

Figure 3-1: Whole communication channel and its components

A WCC consists of the standalone communication channel that is used for the 1000BASE-T1 Ethernet data transmission between the ECUs and an additional environment system for data or power transmission. This model is used to consider the electromagnetic interaction between the Ethernet and other systems that can occur as crosstalk within multiport connectors, multi-pair cables or bundles of cables.

The WCC, SCC and ES that are measured shall be manufactured as close as possible to the real application as installed within the vehicle. As usually there is a large diversity of wiring harnesses among an OEM, the DUT can be a simplified generic representation of the complete wiring harness in collaboration with the involved departments. To allow comparing the electrical properties of components from different suppliers and comparing the measurement results of different test houses, Annex A.3 shows the reference communication channel.

3.4 Cable Assembly

A cable assembly consists of a single cable segment with a cable connector attached on each end as shown in Figure 3-2. The cable connector can be either a receptacle or a pin terminal as typically used in inline connectors. The length of the cable assembly depends on the specific application. Annex A.4 defines a reference cable assembly that can be used as common base and if an application specific definition is not available.

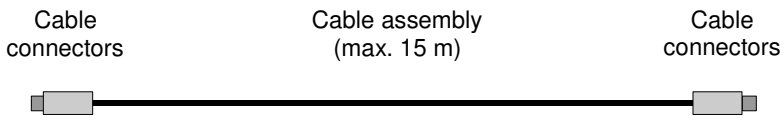

Figure 3-2: Definition of cable assemblies

3.5 Environmental Conditions

The limits in Chapter 6 for communication channels, cable assemblies, cables and connectors shall be met for all operating conditions of the application. In scope of this document, measurements are generally carried out at room temperature between 20 °C and 26 °C and at standard atmosphere condition based on [2]. It is recommended to keep the temperature constant during the measurements with a tolerance of ±1 °C to ensure sufficient stability of test equipment calibration.

Measurements at other environmental conditions are outside the scope of this document.

3.6 Electromagnetic Environment Classes

Channels using UTP cabling rely on balance to provide decoupling between the differential data signal and common mode interference. Certain electromagnetic environments (e.g. cabling close to antennas) may demand additional requirements beyond what was specified for UTP channels as in [1] and in [3]. STP channels shall provide additional EMC margin, taking benefit of combined unbalance attenuation and screening attenuation to an effective coupling attenuation. Adding shielding also reduces common mode interference emissions. The common mode may be emitted by the PHY or caused by unbalance of components along the channel that convert the wanted differential signal power spectrum into unwanted common mode interference.

The amount of additional EMC margin, i.e. the degree of shielding and coupling attenuation, may depend on the specific implementation in the vehicle. Two electromagnetic environment classes are defined to provide most flexibility for choosing suitable components. Class 1 relies on lower mode conversion allowing simpler shielding while class 2 requires full shielding. The coupling and screening attenuation limits for class 1 are more

relaxed compared to class 2. The selection of the appropriate limit class depends on the specific application in the vehicle and is not subject of this specification.

Table 3-1 describes the possible mixing of STP components with different EMC classes within the same SCC:

Table 3-1: Mixing of components with different EMC class

Possible mixing of EMC classes	Additional requirements	Resulting system performance
Mixing connectors of STP class 1 and STP class 2 within the same SCC	All cables shall meet STP class 1 cable requirements as specified in Table 6.1.2-1 and Table 6.2.2-1. The STP class 2 connectors additionally shall meet STP class 1 connector balance requirements as specified in Table 6.1.1-1.	STP class 1 system
Mixing cables of STP class 1 and STP class 2 within the same SCC	All connectors shall meet STP class 2 requirements as specified in Table 6.1.1-1 and Table 6.2.1-1.	STP class 2 system

Mixing of UTP and STP components in one system is not scope of this document.

3.7 Multiport Connector

Figure 3-3 defines the port numbering for a multiport connector, corresponding to the S-parameter port numbering in Table 3-2.

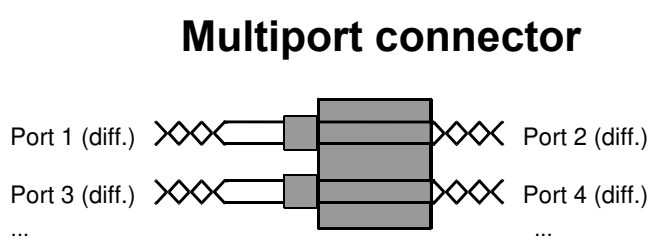

Figure 3-3: Typical definition of S-parameter ports for multiport connectors

3.8 Definition of RF Parameters

For all parts of the communication channel, the RF requirements are defined in terms of the following RF- and S-parameters:

Table 3-2: Definitions for RF and S-parameter

Test parameter	Symbol or related S-parameter	Description
Impedance		
CIDM	Z_{RF}	Characteristic impedance differential mode (TDR measurement)

Single channel characteristics (e.g. Port 1,2)		
Propagation Delay	t_d	Propagation delay, i.e. phase delay according to [5], see equation (3-5)
RL	S_{dd11}, S_{dd22}	Return loss
IL	S_{dd21}	Insertion loss
LCL[1]	S_{dc11}, S_{dc22}	Longitudinal Conversion Loss
LCTL[1]	S_{dc12}, S_{dc21}	Longitudinal Conversion Transfer Loss
Crosstalk to neighbor ports on multiport connectors		
ANEXT	S_{dd31}, S_{ddyx}	Alien near end crosstalk loss
AFEXT	S_{dd41}, S_{ddyx}	Alien far end crosstalk loss
PSANEXT	see equation (3-1)	Power sum alien near end crosstalk loss
PSAFEXT	see equation (3-2)	Power sum alien far end crosstalk loss
PSAACRF	see equation (3-3)	Power sum attenuation to alien crosstalk loss ratio far end
Single channel characteristics (e.g. Port 1,2)		
Coupling Attenuation	a_C , see equation (3-6)	Coupling attenuation
Screening Attenuation	a_S, see equation (3-7)	Screening attenuation

The following equations can be used to calculate the power sum crosstalk of connectors.

PSANEXT for a disturbed signal N can be calculated for every port by means of the following equation:

$$PSANEXT(f)_N = -10\,log_{10} \sum_{j=1}^{m} 10^{\frac{-ANEXT(f)_{N,j}}{10}}\,dB \qquad (3\text{-}1)$$

where the function $ANEXT(f)_{N,j}$ represents the magnitude (in dB) of the ANEXT loss at frequency f of the disturbing signal j (1 to m of the relevant disturbing neighbor signals) for the disturbed signal N.

PSAFEXT for a disturbed signal N can be calculated for every port by means of the following equation:

$$PSAFEXT(f)_N = -10\,log_{10} \sum_{j=1}^{m} 10^{\frac{-AFEXT(f)_{N,j}}{10}}\,dB \qquad (3\text{-}2)$$

[1] For compliance to the specification measurements of LCL and LCTL are sufficient as LCL and TCL are considered reciprocal and LCTL and TCTL are considered reciprocal (see [1]). The reciprocal parameters TCL and TCTL can be measured instead of LCL and LCTL.

where the function $AFEXT(f)_{N,j}$ represents the magnitude (in dB) of the AFEXT loss at frequency f of the disturbing signal j (1 to m of the relevant disturbing neighbor signals) for the disturbed signal N.

PSAACRF for a disturbed signal N can be calculated for every port by means of the following equation:

$$PSAACRF(f)_N = -10\,log_{10} \sum_{j=1}^{m} 10^{\frac{-AACRF(f)_{N,j}}{10}}\,dB \tag{3-3}$$

where the function $AACRF(f)_{N,j}$ represents the magnitude (in dB) of the AACRF at frequency f of the disturbing signal j (1 to m of the relevant disturbing neighbor signals) for the disturbed signal N. The AACRF is calculated by the difference of the AFEXT loss and the insertion loss magnitudes (in dB) of the disturbed link by the following equation:

$$AACRF(f)_{N,j} = AFEXT(f)_{Nj} - IL(f)_N \quad dB \tag{3-4}$$

The propagation delay is defined as the phase delay of the transmitted signal. It can be calculated from the expanded phase angle of the S_{dd21} parameter by equation (3-5) as described in [5].

$$t_d = -Phase\ \ (S_{dd21})/(360\ \cdot f) \qquad f \text{ in Hz, } t_d \text{ in s, phase angle in degree} \tag{3-5}$$

The coupling attenuation a_C of the device under test is calculated by equation (3-6) as follows as described in [6] and [7].

$$a_C = a_{m,min} + 4.77\ dB \tag{3-6}$$

where

a_C is the coupling attenuation related to the normalized radiating impedance of 150 Ω in dB;

$a_{m,min}$ is the attenuation recorded as minimum envelope curve of the measured values in dB;

4.77 is the correction factor for a characteristic differential mode impedance of 100 Ω of the device under derived from the formula $10 \cdot log_{10} \left|\frac{300\ \Omega}{100\ \Omega}\right|$ in dB.

The screening attenuation a_S of the device under test is calculated by equation (3-7) as described in [6] and [7].

3-port measurement setup using VNA without balun shall be used with the differential feeding port set to excite in common mode.

$$a_S = a_{m,min} + 10\ log_{10}\left(\frac{300\ \Omega}{Z_1}\right)\ dB \tag{3-7}$$

where

a_S is the screening attenuation related to the normalized radiating impedance of 150 Ω in dB;

$a_{m,min}$ is the attenuation recorded as minimum envelope curve of the measured values in dB;

Z_1 is the characteristic impedance common mode of the cable under test in Ω. It is recommended to use TDR equipment for determining this value.

3.9 ISO and IEC Terminology

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org

4 General Setup and Measurement Fixtures

4.1 Required Measurement Equipment

For all measurements, a VNA and a TDR measurement system in combination with test fixtures and specific additional arrangements such as a test tube apparatus with the following parameters shall be used:

Table 4.1-1: Required measurement equipment

Measured parameter	Equipment	Parameter	Value
S-parameter	VNA	Type	4-port vector network analyzer
		Port reference Impedance	50 Ω single ended
		Frequency range	f = 1 MHz to 1000 MHz (for cables, communication channel and MDI test heads) f = 1 MHz to 2000 MHz (for connectors)
Characteristic Impedance (CIDM)	TDR test system	Type	2 channel differential mode
		Port reference impedance	50 Ω single ended / 100 Ω differential mode
		Rise time	Pulse generator: ≤ 25 ps internal (≤ 50 ps at measurement fixture) Rise time needs to be adjustable to the required values (50 ps and 500 ps) All values 10 % to 90 %

Coupling Attenuation and Screening Attenuation	VNA	Type	3-port vector network analyzer
		Port reference Impedance	50 Ω single ended
		Frequency range	f = 1 MHz to 1000 MHz
	Test tube apparatus	<u>Connector and communication channel measurements:</u> Metallic non ferromagnetic triaxial test tube arrangement according to [6] with lengths as specified in 5.1.3 and 5.2.6 with inner extension tube of variable length (tube in tube) <u>Cable measurements:</u> Metallic non ferromagnetic standard test tube arrangement according to [7] with lengths as specified in 5.2.3 The test tube diameter depends on the geometric dimension of the DUT. If there are no DUT specific restrictions, a diameter of 40 mm is recommended. Commercially available tube devices can be used.	
All	Measurement fixture	Depending on the used test standard (see special definitions for cables and connectors)	

Time Domain based measurement instruments may also be used to measure mixed mode S-parameters if they can translate to the VNA settings in Table 4.2-1 and fulfill the calibration accuracy requirements in Table 4.2-3.

VNAs may also be used to perform impedance measurements, normally performed with a TDR test system if it can provide an equivalent pulse with 50 ps / 500 ps rise time as specified in Table 4.1-1. In this case, the requirement for 25 ps internal and 50 ps at the measurement fixture does not apply. The measurement should be carried out with the VNA settings given in Table 4.2-4. The comparability of the time domain results measured with a VNA to results captured with a TDR should be demonstrated depending on the specific equipment type.

4.2 Vector Network Analyzer Settings

To assure a high degree of reliability for the measurements, the following precautions are required ([4]):

1. The reference plane of the calibration shall coincide with the measurement reference plane. In case of differences, the magnitude of errors shall be determined and the measurement fixture parameters shall be characterized to meet the requirements in Section 4.4. For connector S-parameter measurements, the measurement reference plane shall be shifted towards the evaluation windows by using de-embedding methods.
2. Accurate and consistent resistor loads shall be used for each pair throughout the test sequence.
3. The cables shall be placed to satisfy the requirements of the specific test and needs to be fixed throughout the test sequence.
4. Stress on cables and adapters, as caused by physical flexing, sharp bends and restraints shall be avoided before, during and after the tests. Test cables and adapters shall be selected for high phase stability in

order to meet the requirements in Section 4.4 during the complete test sequences including handling operations for connecting and disconnecting the DUTs.

5. Test cables, i.e. coaxial cables between measurement instruments and measurement fixtures, shall be chosen in a way that the calibration requirements in Table 4.2-3 are fulfilled.
6. Overload conditions of the measurement instruments shall be avoided.
7. The VNA shall provide sufficient stability with low electrical drift in order to meet the accuracy requirements in Table 4.2-3 during the entire test sequence.

To achieve high degree of comparability of test results, the VNA settings given in Table 4.2-1 are recommended. The used VNA setting for each parameter of Table 4.2-1 shall be documented in the test report.

Table 4.2-1: Recommended VNA settings for frequency domain measurements

Parameter	Value
Sweep f_{start}	1 MHz
Sweep f_{stop}	1 GHz
Sweep type	Linear
Sweep points	1600
Output power	Minimum -10 dBm
Measurement bandwidth	≤ 500 Hz
Port reference impedance differential mode	100 Ω
Port reference impedance common mode	25 Ω
Data calibration kit (VNA)	Used kit for calibration
Averaging function	May be applied, but not mandatory
Smoothing function	Deactivated

To measure connectors, the VNA shall support de-embedding methods. The de-embedding functions may also be provided by equivalent post-processing software. The VNA settings shall be chosen as specified by the software or equipment providers. Table 4.2-2 gives an example.

Table 4.2-2: Recommended VNA settings for connector de-embedding measurements

Parameter	Value
Sweep f_{Start}	1 MHz
Sweep f_{Stop}	≥ 2 GHz
Sweep type	Linear
Sweep points	≥ 2000
Output power	Minimum -10 dBm
Measurement bandwidth	≤ 3 kHz

Port reference impedance differential mode	100 Ω
Port reference impedance common mode	25 Ω
Data calibration kit (VNA)	Used kit for calibration
Averaging function	May be applied, but not mandatory
Smoothing function	Deactivated
Filtering for TDR functions	Hann window

The VNA calibration accuracy shall be verified by measuring the return loss parameters for a direct thru-thru connection between the different ports at the calibration plane (Figure 4.2-1). A pair of high precision matching female-female adaptors is recommended be used to connect the test cables.

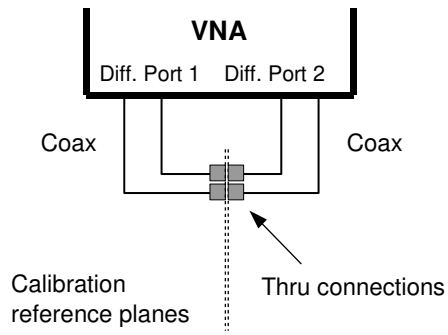

Figure 4.2-1: Thru-thru connection for verification of VNA calibration accuracy

The LCL, LCTL and RL parameters shall comply with the requirements given in Table 4.2-3. The LCL calibration accuracy may also be verified with measurement cables in open condition at the calibration plane.

Table 4.2-3: VNA calibration accuracy requirements

Test parameter	Related S-parameter	Requirement
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 36 & 1 \leq f < 190 \\ 26 - 20\,log\left({}^{f}/_{600}\right) & 190 \leq f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
LCL LCTL	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12}	$\geq \begin{pmatrix} 56 & 10 \leq f \leq 50 \\ 81.2 - 14.83\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz

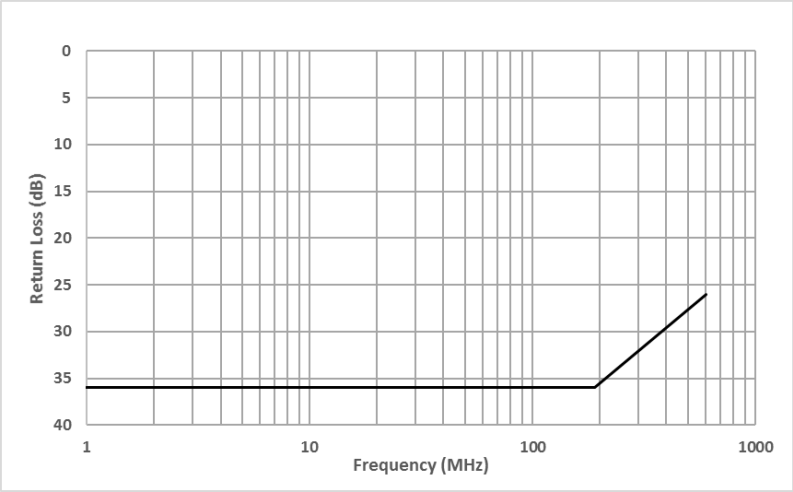

Figure 4.2-2: Return loss requirements for VNA calibration accuracy

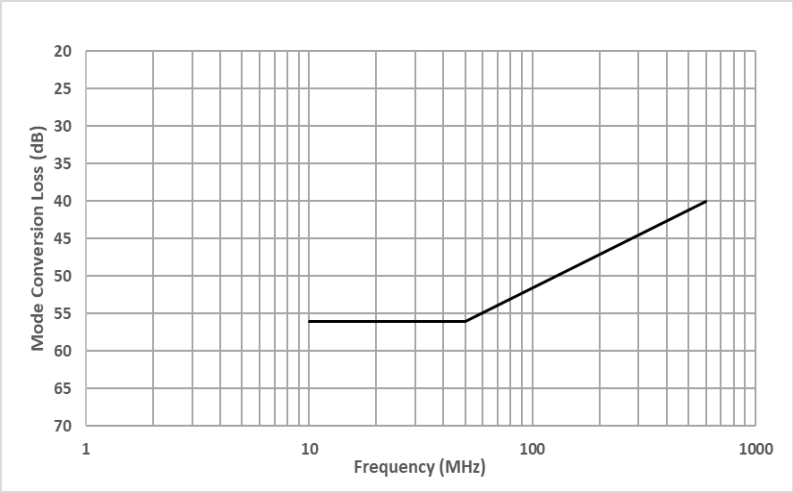

Figure 4.2-3: LCL / LCTL requirement for VNA calibration accuracy

If impedance measurements are carried out with VNA the following settings are recommended to ensure equivalent results to a TDR based measurement.

Table 4.2-4: Recommended VNA settings for time domain impedance measurement

Parameter	**Value**
Frequency range	f = 1 MHz to 2000 MHz (for cables, connectors and communication channels) f = 10 MHz to 20 GHz (for characterization of measurement fixtures and MDI test heads)
Sweep type	Linear

Sweep points	2000
Filtering	Hann window
TDR Type	Step
Output power	Minimum -10 dBm
Measurement bandwidth	≤ 3 kHz
Port reference impedances	50 Ω single ended port impedances (This results in 100 Ω differential mode reference impedance after conversion to mixed mode parameters.)
Data calibration kit (VNA)	Used kit for calibration
Averaging function	May be applied, but not mandatory
Smoothing function	Deactivated

To achieve high degree of comparability of test results, the VNA settings given in Table 4.2-5 are recommended for coupling attenuation measurements. The used VNA setting for each parameter of Table 4.2-5 shall be documented in the test report.

Table 4.2-5: Recommended VNA settings for coupling and screening attenuation measurements

Parameter	Value
Sweep f_{Start}	1 MHz
Sweep f_{Stop}	1 GHz
Sweep type	Linear
Sweep points	1000
Output power	Minimum -10 dBm
Measurement bandwidth	≤ 1 kHz
Port reference impedance differential mode	100 Ω
Port reference impedance common mode	25 Ω
Data calibration kit (VNA)	Used kit for calibration
Averaging function	May be applied, but not mandatory
Smoothing function	Deactivated

4.3 Presentation of Measurement Results

Test results shall be documented in the following way:

- Documentation of test conditions (e.g. humidity, temperature, cable length)
- Documentation of cable types and production number (also for S-parameter and coupling attenuation measurements of connectors)
- Documentation of used calibration kit and of calibration accuracy in thru-thru configuration
- Pictures of test set-up and measurement fixture
- Documentation of measurement fixture characterization and of optional correction methods such as fixture de-embedding, phase correction, re-normalization etc.
- Results for S-parameter
    - Result as dB value with related limit
    - Diagram with logarithmic frequency axis up to minimal f = 1000 MHz
- Results for TDR Measurements
    - Result as differential impedance (Ohms) with related limit
    - Measurement result and corrected data (according to Annex B) are to be presented in one diagram in the following format:
        - Linear scale for X- axis in time
        - Linear scale for additional X- axis in length (m, calculated using 2/3 of c_0 or real phase velocity of cable / connector and correction of two-way of pulse propagation)

4.4 Measurement Fixtures

4.4.1 General Recommendations for Measurement Fixtures

Measurement fixtures shall provide a sufficient electrical and mechanical quality, so that the measurement result is not dominated by the characteristics of the measurement fixtures. The used measurement fixtures need to have low insertion loss and very good matching to 50 Ω single ended impedance. For coupling attenuation measurements also high balance within the two lines of a differential pair is recommended.

The electrical limits in Subsections 4.4.2 to 4.4.4 shall be met. The measurement fixtures or hints for proper design should be provided by the connector or cable manufacturer. Examples of appropriate measurement fixtures are given in Annex A.1.

Phase stable VNA test cables shall be used. The phase reference plane may optionally be moved to the DUT by VNA features such as “port extension”. The detailed description of such techniques is not scope of this document and the correct application shall be demonstrated and documented. Serial numbers shall be assigned to the measurement fixtures to allow individual identification.

Test fixtures based on printed circuit boards as shown in Figure 4.4.1-1 are recommended for connector and channel tests. PCB based test fixtures are also recommended for connecting receptacle terminals in cable assembly measurements. Pin terminals of cable assemblies, i.e. inline connector terminals, can be connected

with MDI test heads as described in Chapter 7. Examples of appropriate PCB based measurement fixtures are given in Annex A.1, Figure A.1-1 and Figure A.1-2.

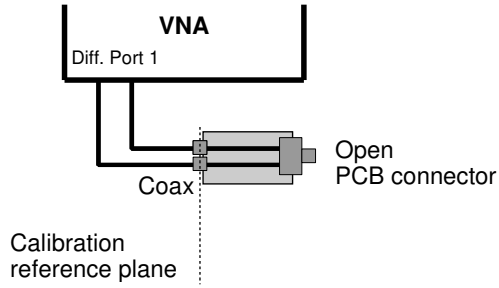

Figure 4.4.1-1: PCB based measurement fixture example

Direct test fixtures as shown in Figure 4.4.1-2 are recommended for cable tests. Direct fixtures shall provide a low impedance connection from the coaxial connectors to the cable shield. An example of an appropriate direct measurement fixture is given in Annex A.1, Figure A.1-3.

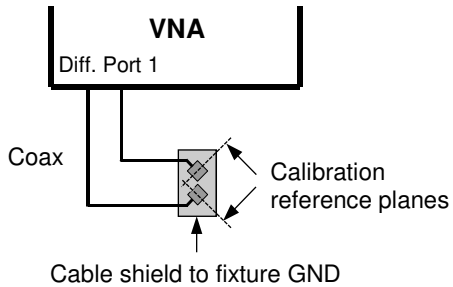

Figure 4.4.1-2: Direct measurement fixture example

4.4.2 Impedances and Termination

The characteristic impedance differential mode is 100 Ω for any measurements. This impedance is matched by dual 50 Ω load terminations. The impedance of test fixtures shall be within 100 Ω ± 5 % at a rise time of 50 ps. An impedance tolerance of ± 10 % is permitted if the 5 % limit is exceeded no longer than 120 ps round trip time or 60 ps propagation time (see Figure 4.4.2-1). The PCB connector including its footprint shall be excluded from the measurement fixture impedance requirement.

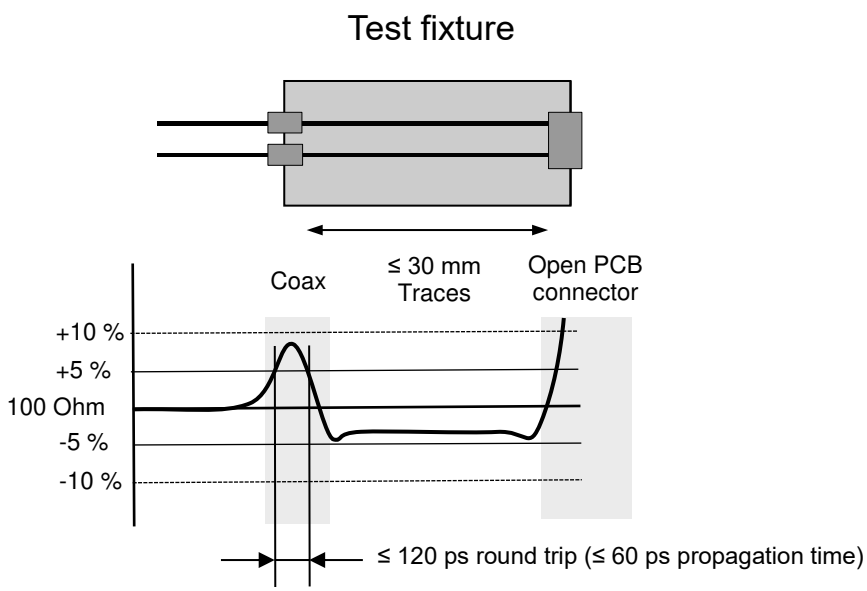

Figure 4.4.2-1: Characteristic impedance of test fixtures

The maximum trace length on PCB based test fixtures shall not exceed 30 mm to ensure sufficient fixture return loss. Longer trace lengths are permitted in case of design constraints, e.g. for larger size multiport connectors if the following requirements are met to avoid inaccurate return loss results:

- Impedance tolerance of the traces smaller than ± 5 %

or

- Removing the fixture by de-embedding techniques or by shifting the calibration plane to the DUT leads; the detailed description of such techniques is not scope of this document. The correct application of these methods needs to be demonstrated and documented.

When a measurement fixture is used as termination and is not connected to the VNA, it shall provide 50 Ω single ended terminations to common ground for each line of the differential pair.

4.4.3 Balance

Unbalance within measurement fixtures can be caused by length differences within the differential pairs or capacitive or inductive unbalance. The type of PCB material with its structure and orientation of the glass weave have a major impact, as well as the thickness of the traces.

The mode conversion properties of the measurement fixture can be measured against the open port in a differential one port measurement to obtain LCL (S_{dc11}).

After calibrating to the reference plane at the coaxial end of the measurement cables, connect to the measurement fixture and measure mode conversion against the open end of the fixture as shown in Figure 4.4.3-1. For PCB connectors that require a specific design of PCB footprint, then an alternative characterization method may be specified by the connector supplier.

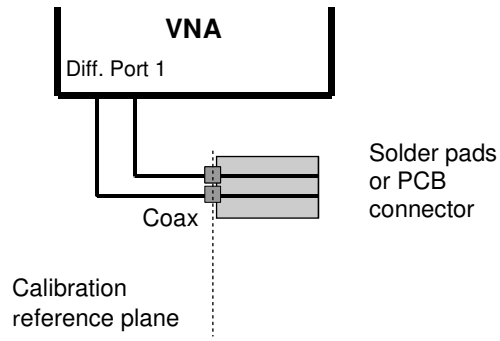

Figure 4.4.3-1: Validation of measurement fixture balance

The mode conversion parameter LCL (S_{dc11}) of the measurement fixture shall comply with the requirements given in Table 4.4.3-1.

Table 4.4.3-1: Measurement fixture balance requirements

Test parameter	Related S-parameter	Requirement
LCL	S_{dc11}, S_{dc22}	$\geq \begin{pmatrix} 56 & 10 \leq f \leq 50 \\ 81.2 - 14.83\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz

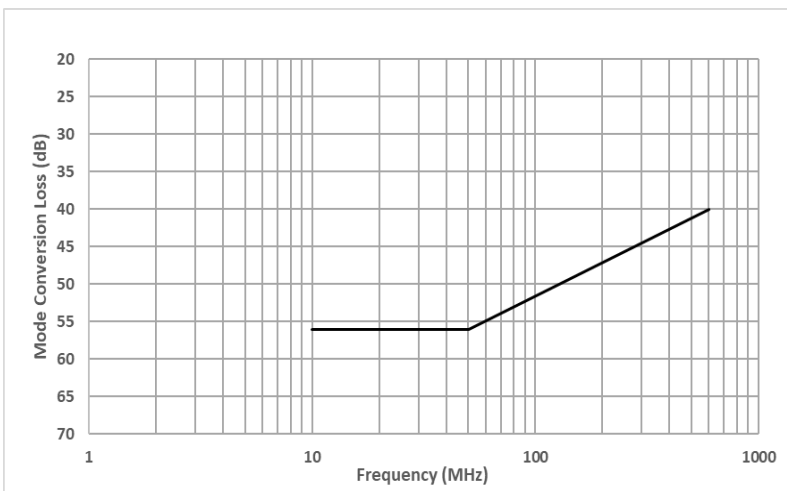

Figure 4.4.3-2: LCL requirement for fixture balance

4.4.4 Crosstalk

The internal crosstalk within test fixtures for multiport connectors shall be lower than the limit to measure against. The near end crosstalk of the test fixture needs to be measured without the PCB connector soldered to it. The transmission from each port shall be measured to any other neighboring port. For PCB connectors that require a specific footprint design an alternative characterization method may be specified by the connector supplier. Identical trace length for all pairs on the fixture PCB is recommended.

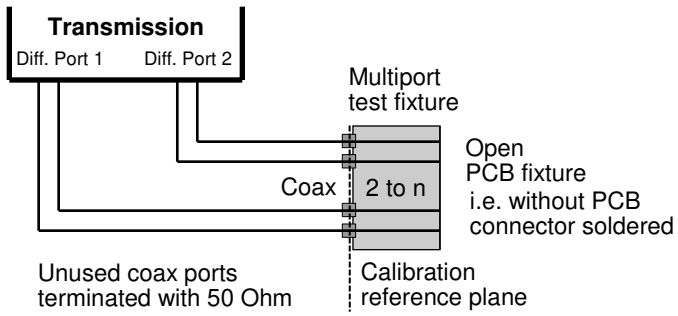

Figure 4.4.4-1: Validation of multiport measurement fixture crosstalk

The validation of measurement fixtures crosstalk needs to be carried out exemplarily on an appropriate number of samples per measurement fixture type and not for the specific instance that is used in a multiport connector test, assuming that the electrical variations on PSANEXT caused by manufacturing tolerances of the measurement fixture are low enough. This aims at allowing the connector manufacturer to provide multiport connectors that are pre-mounted to a measurement fixture instead of the need to solder them after the measurement fixture characterization.

The crosstalk within multiport measurement fixtures shall comply with the requirements given in Table 4.4.4-1.

Table 4.4.4-1: Measurement fixture crosstalk requirements

Test parameter	Related S-parameter	Requirement
PSANEXT Loss	S_{dd31}, S_{ddyx}	$\geq \begin{pmatrix} 63 - 10\,log\left({}^{f}/_{100}\right) & 1 \leq f \leq 100 \\ 63 - 15\,log\left({}^{f}/_{100}\right) - 6\left({}^{f\,-\,100}/_{400}\right) & 100 < f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz

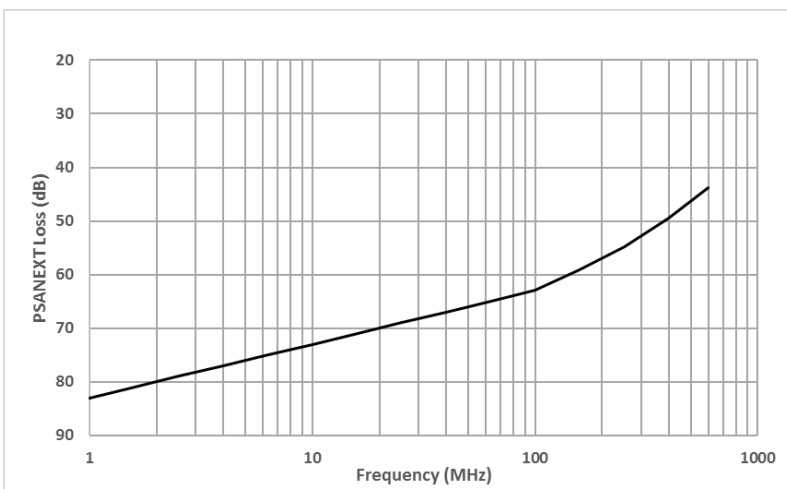

Figure 4.4.4-2: PSANEXT requirement for fixture crosstalk

5 Measurement Setups

5.1 Measurement Setups for Connectors

5.1.1 Connector Setups for SCC

Connectors are measured as part of a whole cable assembly. This allows capturing the properties of the connector including the area of wire transition from contacts to the cable. The transition area therefore is part of the measurement result and shall be assembled as used in the application. De-embedding techniques are used for removing the effects of cables and fixtures from the measurement results in a post-processing step. This method allows to measure connector properties without the need to de-embed them physically by cutting off cable and probing the cable ends directly by fixtures. The cable used for the connector test shall meet the electrical requirements in Table 6.1.2-1 with characteristic differential impedance as close as possible to 100 Ω.

While the total cable assembly length L_A is measured from the connectors mating faces, the cable length L shall be measured for the length within that the cable geometry is unaffected by the termination, e.g. by possible cable squeezing in the crimp zones or other mechanical support such as sealings and cable ties. This is typically the cable distance between that locations where the cable comes out of the cable crimp ferrules. These locations can be inside or outside the plug housings depending on the connector design. This definition ensures consistency of the measurement setups independent from individual connector styles and dimensions. Figure 5.1.1-1 shows how the cable length L is measured.

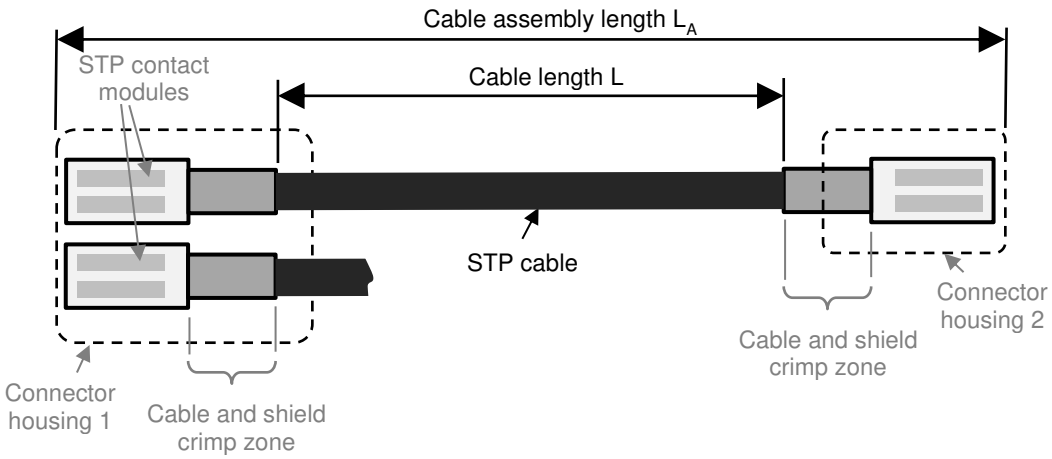

Figure 5.1.1-1: Cable length definition for cable assemblies

The cable assemblies shall be manufactured according to the specifications of the assembly and connector manufacturers. This includes the wire transition length between cable and contacts. The cable lengths for the cable assemblies used to measure PCB- or inline connectors are given in Figure 5.1.1-2 to Figure 5.1.1-4.

Connectors shall be measured as part of a test assembly, where measurement fixtures (Figure 4.4.1-1) are attached to the connectors on both sides of the cable assembly. PCB connectors are mounted directly onto the measurement fixture as specified for the individual component by the manufacturer.

Figure 5.1.1-2 shows the test setup to measure return loss and insertion loss of mated inline connectors and Figure 5.1.1-3 of the mated PCB connectors.

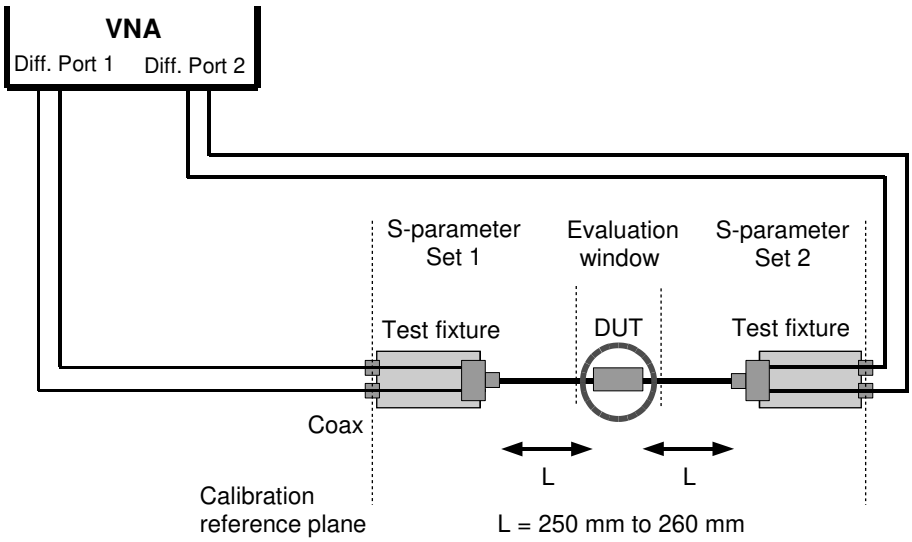

Figure 5.1.1-2: Inline connector VNA setup for return loss, insertion loss and propagation delay measurement

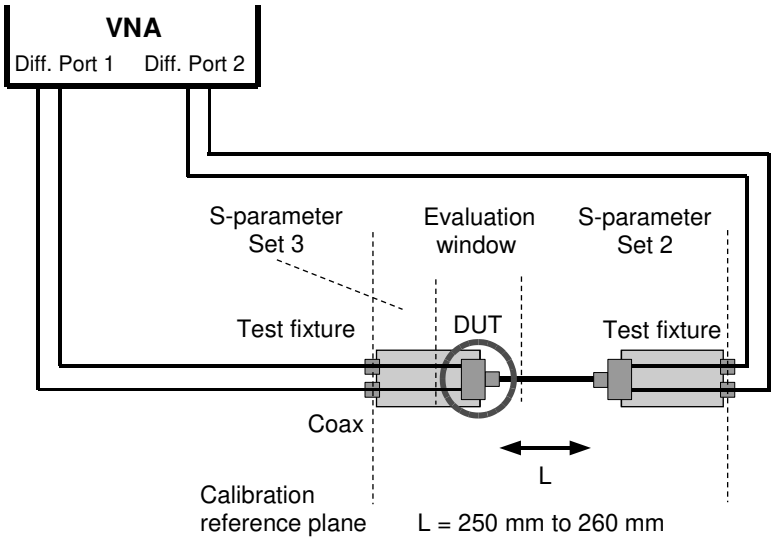

Figure 5.1.1-3: PCB connector VNA setup for return loss, insertion loss and propagation delay measurements

For connector return loss and insertion loss measurements, internal de-embedding functions of the VNA or equivalent post processing software shall be used. The procedures are based on de-embedding methods described in [8]. The VNA settings for connector measurements are given in Table 4.2-2.

The test assembly can be split into different S-parameter sections. Figure 5.1.1-2 and Figure 5.1.1-3 show the S-parameter sections before and after the actual evaluation window (S-parameter sets 1, 2 and 3). The evaluation window covers the connector under test including the transition from contacts to the cable.

S-parameter sets 1 and 2 for de-embedding the measurement fixtures and sections of the cable assemblies shall be determined by a measuring a thru cable assembly as shown in Figure 5.1.1-4.

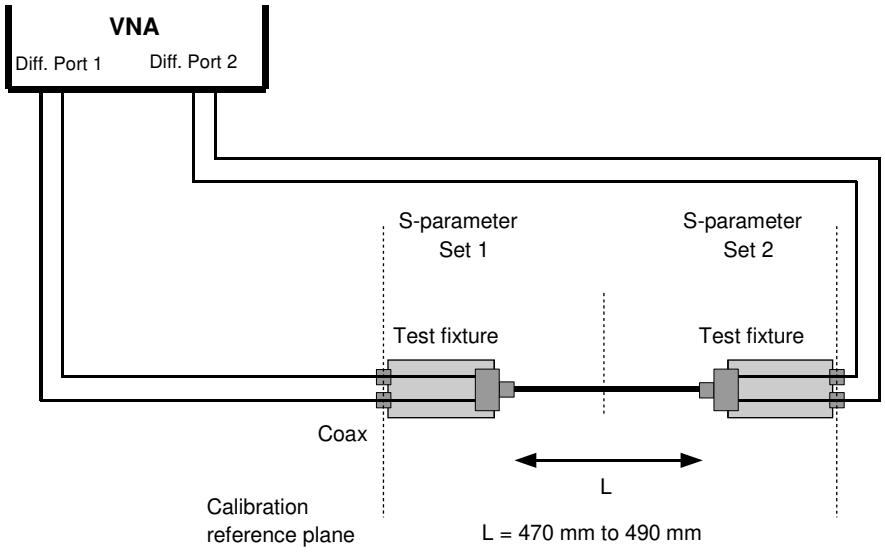

Figure 5.1.1-4: Thru cable assembly VNA setup for return loss, insertion loss and propagation delay measurements

S-parameter sets 1 and 2 are calculated by splitting the S-parameters of the whole thru cable assembly into halves. The thru cable assembly shall have a cable length of 470 mm to 490 mm. This assumes that the mated connector under test includes approximately 15 mm homogeneous cable length on each side of the connector. S-parameter set 1 derived from the thru cable assembly measurement is not needed for de-embedding in a PCB connector measurement.

The same connector and cable type from the same production lot shall be used for the later measurement to minimize the deviations between thru measurement and actual connector measurement. The mated PCB connectors attached to the cable assembly used in a connector measurement also shall fulfil all electrical requirements for connectors as defined in Table 6.1.1-1. This can be confirmed by a PCB connector measurement before testing an inline connector.

De-embedding the measurement fixture (S-parameter set 3) in a PCB connector measurement is optional and not mandatory. If used, S-parameter set 3 for PCB connector measurements shall be derived from measuring a pair of PCB thru lines, that have twice the length of the length of the traces from the coaxial connector to the PCB connector footprint. Preferably the traces shall have the same configuration and orientation as the ones going to the PCB connector under test. The trace length is calculated up to the point where the homogeneous traces from the coaxial connectors to the PCB connector end and a specific layout related to the PCB connector starts. Optimized PCB connector layout or any kind of compensation on the layout shall be excluded from the PCB thru line measurement.

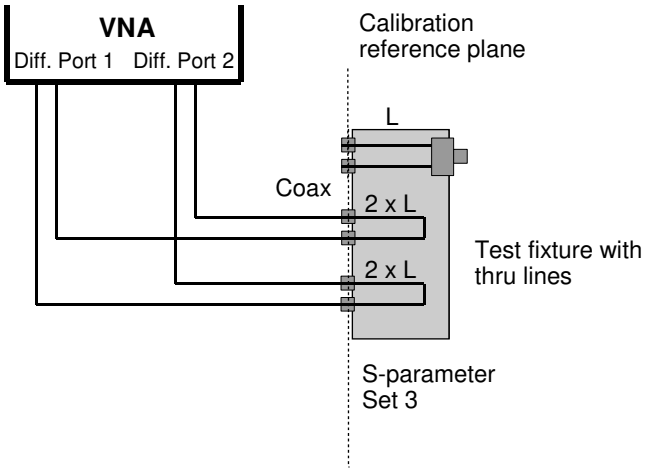

Figure 5.1.1-5: PCB thru lines VNA measurement setup (optional)

The S-parameters derived from the thru cable assembly and thru PCB line measurements shall be split in the middle to derive S-parameter sets 1, 2 and 3. The splitting may be carried out by procedures described in [8], by equivalent processing software within the VNA or external postprocessing software.

The described de-embedding methods shall be applied to propagation delay, return loss and insertion loss measurements. The connector under test shall comply with the specified propagation delay, return loss and insertion loss in Table 6.1.1-1.

To measure mode conversion of the connector, the same setups as in Figure 5.1.1-2 and Figure 5.1.1-3 of the mated PCB connectors shall be used, but without using de-embedding functions for the cable assemblies (S-parameter sets 1 and 2). De-embedding of the measurement fixture (S-parameter set 3) is optional and shall be documented in the test report if applied. The evaluation window includes both PCB connectors with mated cable assemblies in between as shown in Figure 5.1.1-6 and Figure 5.1.1-7.

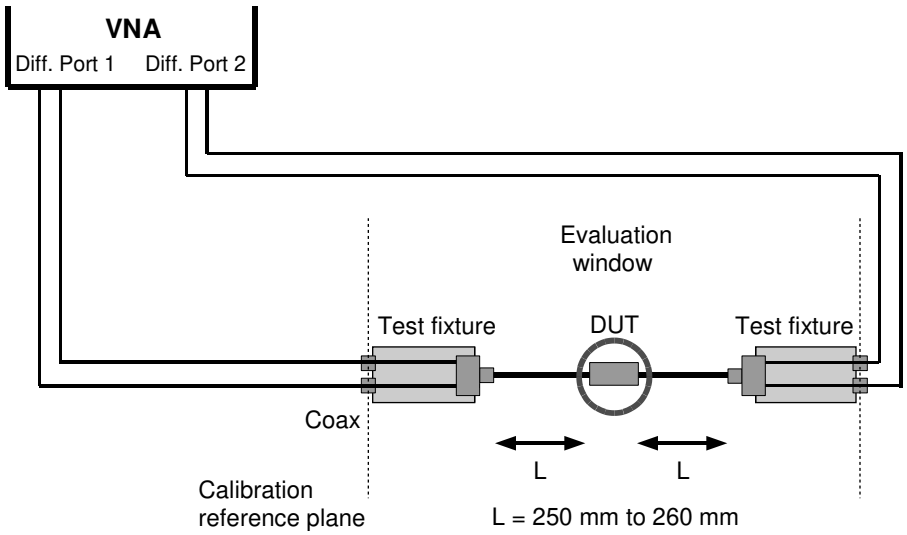

Figure 5.1.1-6: Inline connector VNA setup for balance measurements

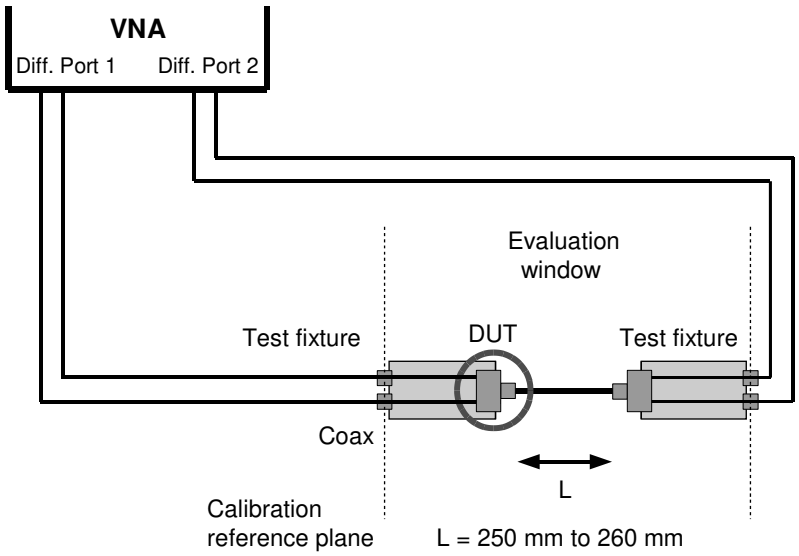

Figure 5.1.1-7: PCB connector VNA setup for balance measurements

The assembly under test shall fulfill the connector balance requirements as in Table 6.1.1-1.

CIDM measurements are carried out in a one port differential setup. The same setup as used for VNA measurements may be used, but with the termination of the measurement fixture with 50 Ω loads on the far end side. The rise-time for the measurements shall be chosen as specified in Table 6.1.1-1 and may be applied by software filtering within the TDR scope.

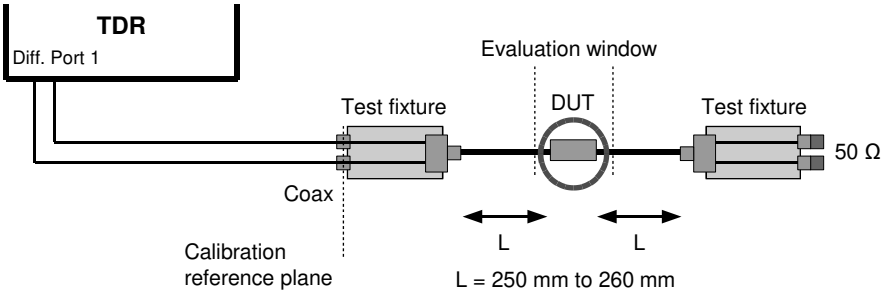

Figure 5.1.1-8: Inline connector CIDM measurement setup

The differential impedance of PCB connectors is measured in combination with its corresponding cable connector counterpart in a cable assembly with 250 mm to 260 mm cable length. The far end side of the cable is terminated at the test fixture. The electrical length on the test fixture between the coaxial ports and the DUT needs to be sufficiently long to separate the DUT from the coaxial connectors at the rise time specified in Table 6.1.1-1.

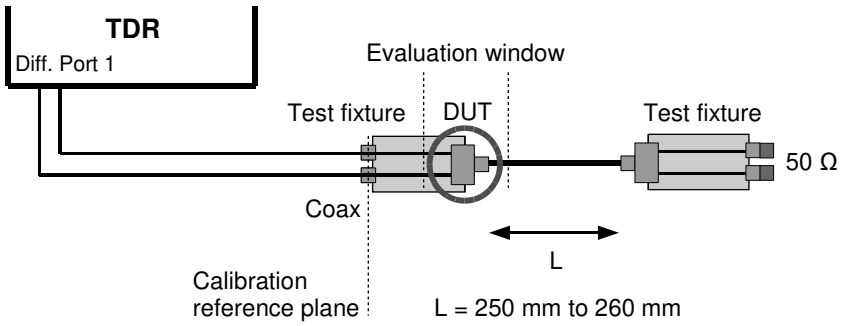

Figure 5.1.1-9: PCB connector CIDM measurement setup

The connector under test shall comply with the specified impedance requirements in Table 6.1.1-1.

5.1.2 Connector Setups for ES – Crosstalk

Additional crosstalk parameters are introduced by the environmental system within multiport connectors. Such connectors consist of one or more Ethernet differential pairs (see Figure 3-3). The individual pairs of multiport connectors shall be tested like single port connectors according to the measurement setup described in Chapter 5.1.1. Suitable PCB based multiport test fixtures shall be used for the multiport PCB connector under test. The test fixture shall fulfill the impedance requirements including trace length given in 4.4.2, balance requirements in 4.4.3, as well as the crosstalk requirements in 4.4.4. The multiport board connectors are mounted directly on the multiport fixture PCB as specified for the individual component by the manufacturer. The requirements on the cable lengths for the cable assemblies are the same as specified in Section 5.1.1 for single port connectors. The cable assembly ends that are not connected to the multiport connector under test shall be terminated using a multiport connector test fixture or individual measurement fixtures. The arrangement and distance of the individual test fixtures to each other shall be chosen in a way that the crosstalk requirements for multiport fixtures in 4.4.4 are fulfilled. Unused fixture ports shall be terminated during the measurements.

Figure 5.1.2-1 shows the differential port 1 of the VNA connected to the far end port to measure AFEXT of the multiport PCB connector. Unused ports are terminated with 50 Ω loads.

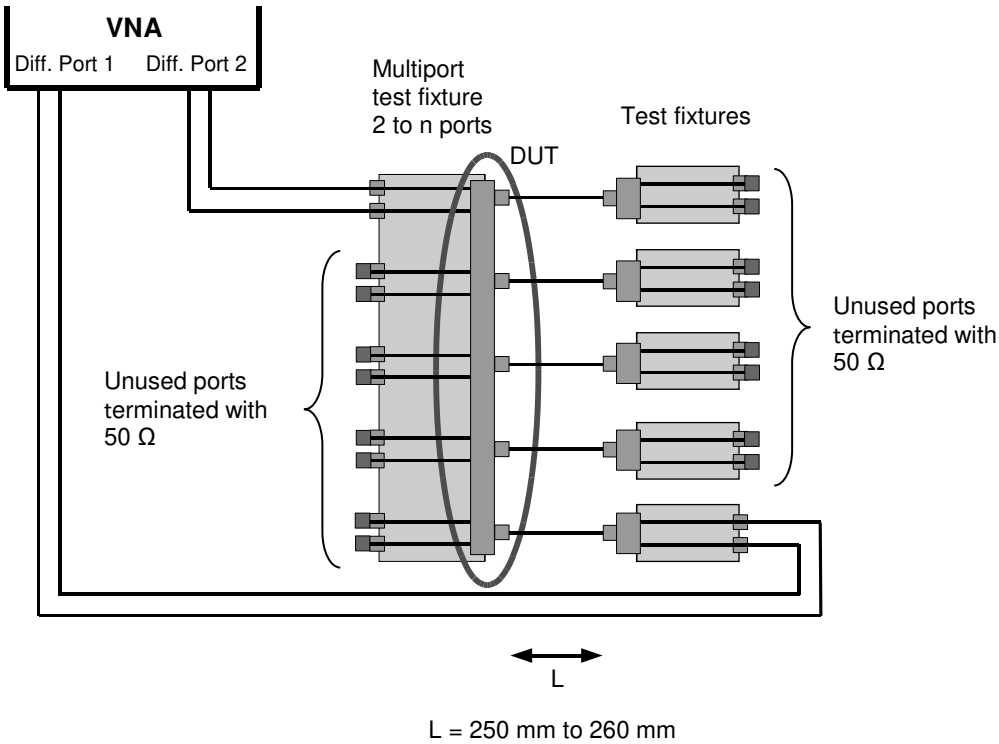

Figure 5.1.2-1: Multiport PCB connector measurement setup for AFEXT

Figure 5.1.2-2 shows port 1 connected to the near end measurement fixture to measure ANEXT of the multiport PCB connector.

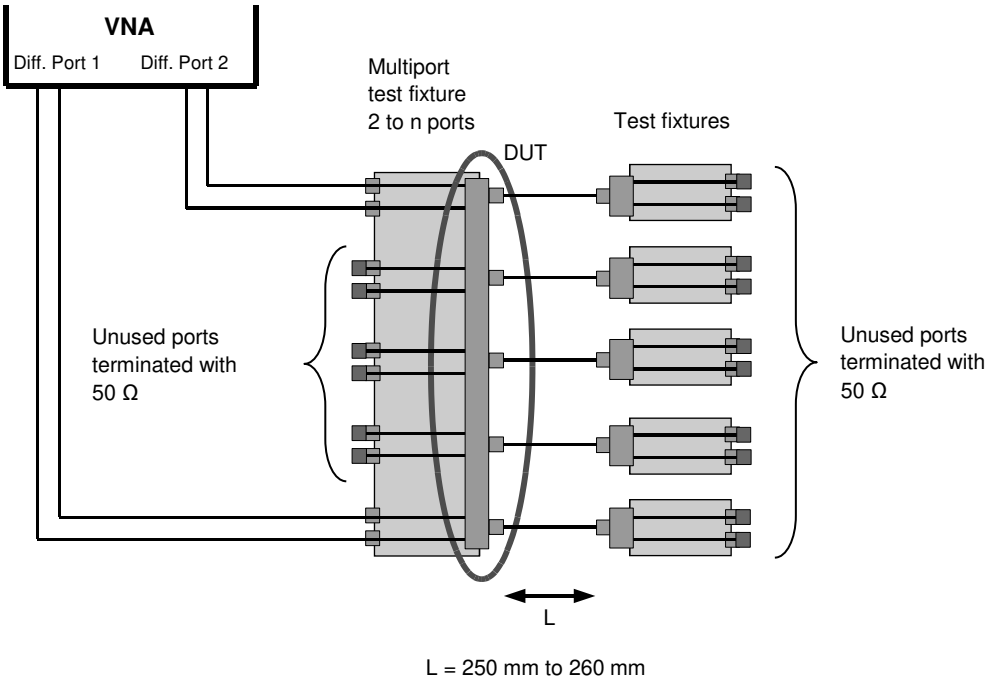

Figure 5.1.2-2: Multiport PCB connector measurement setup for ANEXT

Figure 5.1.2-3 shows the differential port 1 of the VNA connected to the far end port, in order to measure AFEXT of the multiport inline connector. The mated PCB connectors used to measure the mated inline connector shall fulfill the electrical requirements for connectors as defined in Table 6.1.1-1.

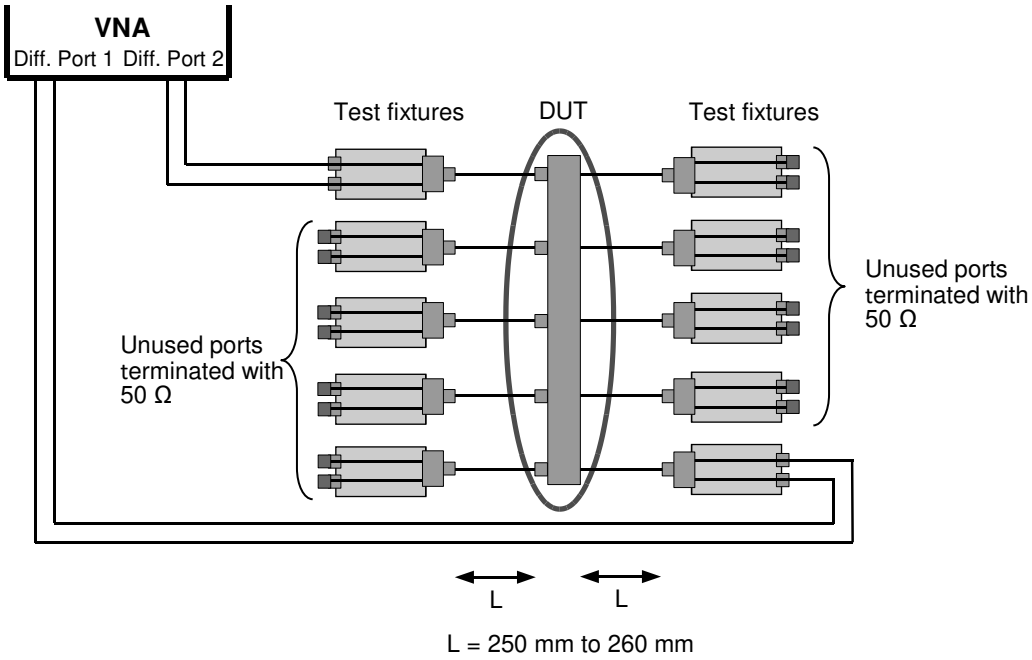

Figure 5.1.2-3: Multiport inline connector measurement setup for AFEXT

Figure 5.1.2-4 shows port 1 connected to the near end measurement fixture in order to measure ANEXT of the multiport inline connector.

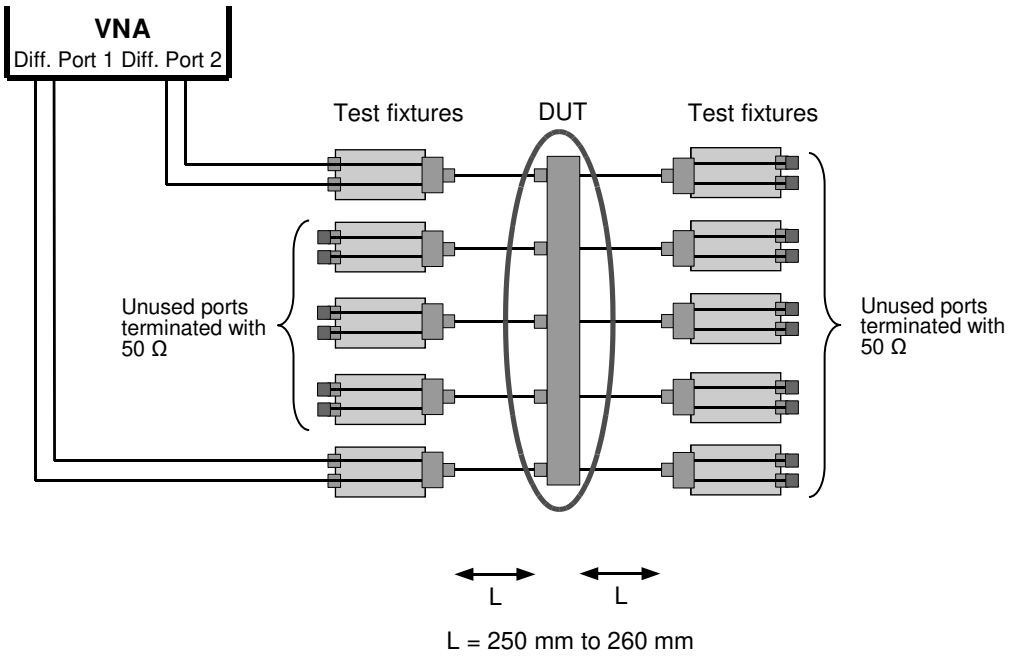

Figure 5.1.2-4: Multiport inline connector measurement setup for ANEXT

The measurement shall be repeated for every pair of the multiport measurement fixture. To calculate the power sum crosstalk (PSANEXT and PSAFEXT) for each port, the measurement results for all ports need to be summed up. Equations showing how to calculate the power sum crosstalk from individual transmission measurements are given in Chapter 3. Each port to be used with 1000BASE-T1 shall comply with the specified alien-crosstalk limits in Section 6.2.1.

5.1.3 Connector Setups for ES – Coupling and Screening Attenuation

Balance, coupling attenuation and screening attenuation are the main parameters for balanced systems defining the EMC properties apart from internal crosstalk. The coupling and screening attenuation of PCB and inline connectors is measured by means of the triaxial tube in tube method as described in [6].

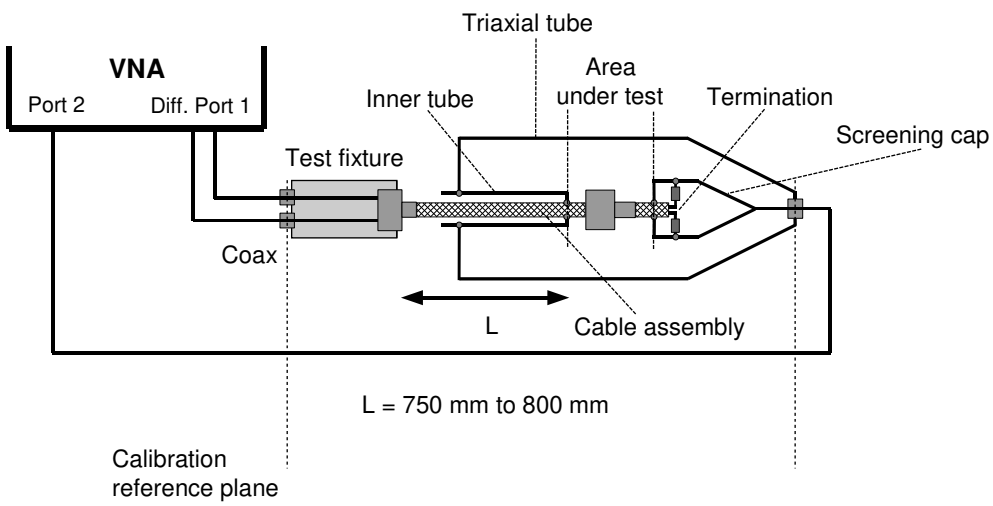

Figure 5.1.3-1: Inline connector measurement setup for coupling and screening attenuation

3-port measurement setup using VNA without balun shall be used. The differential port of the VNA acts as generator and the single ended port as receiver. To measure coupling attenuation, differential port 1 shall be operated in differential mode. To measure screening attenuation, differential port 1 shall be operated in common mode.

The length of the cable from the measurement fixture to the connector under test shall be between 750 mm and 800 mm. As the length of one segment of tube for tube in tube measurements typically is 500 mm long this allows easy handling while keeping the influence of the cable on insertion loss and balance low. With respect to these dimensions, the use of a triaxial tube with nominal length 0.5 m is implied.

The cable used for connector coupling and screening attenuation measurements shall fulfill the electrical requirements as specified in Section 6.1.2 and Section 6.2.2 of the same environment class as the connector under test.

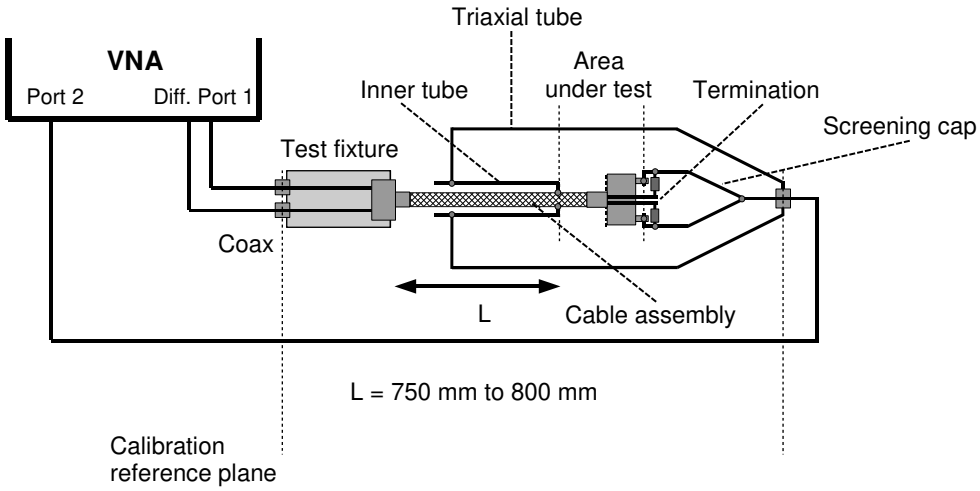

Figure 5.1.3-2: PCB connector measurement setup for coupling and screening attenuation

The connection points from the inner tube to the cable shield and from the cable shield to the termination shall be directly after the connector (≤ 30 mm) in order to include the transition from the connector to the cable to the measurement while keeping the overall cable length exposed within the measurement low as shown in Figure 5.1.3-3.

The connector under test shall be aligned concentrically along the longitudinal axis in reference to its mated connector counterpart to avoid unduly mechanical stress onto the connector. Making use of the allowed exposed cable length of up to 30 mm may provide axial clearance to accommodate slight misalignment.

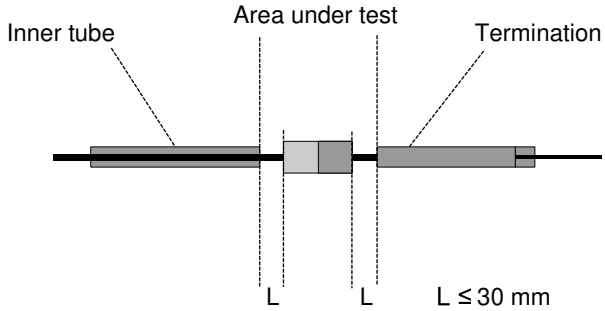

Figure 5.1.3-3: Definition of inline connector AUT for coupling and screening attenuation

The area under test for PCB connectors includes the mated connector including the transition to the PCB or equivalent termination fixture. Therefore, the termination resistors need to be placed between the signal contacts and ground of a PCB or equivalent termination fixture as shown in Figure 5.1.3-4. Placing the termination resistors between the signal contacts and the shield contacts respectively shielded housing directly, in order to omit including the transition to the PCB is not allowed.

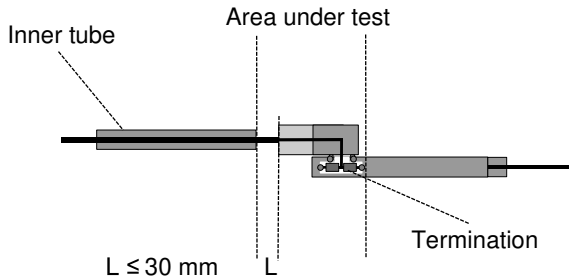

Figure 5.1.3-4: Definition of PCB connector AUT for coupling and screening attenuation

For connectors that provide additional shield contact from the connector housing to a shielded enclosure, the reference plane at the PCB connector side may be set at the point, where the EMC seal is attached. In this case, the connector housing and the transition to the PCB should not be part of the measurement but within the shield cap referenced in Figure 5.1.3-5.

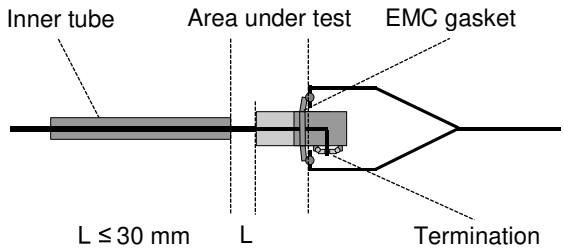

Figure 5.1.3-5: Definition of PCB AUT for coupling and screening attenuation for connectors with EMC gasket

The termination shall be nominal 100 Ω in differential mode. It is recommended to terminate each wire of the differential pair directly to the shield to ensure a high degree of balance for the DUT arrangement. This method results in a common mode termination impedance of 25 Ω. A common and differential mode termination according to [6] can be done alternatively. The requirements on the single ended termination of every conductor of the differential pair are 50 Ω ± 1 % against ground. The two resistors of the differential pair shall be matched against each other with a tolerance of ± 0.1 Ω at DC. The resistors need to be suitable for RF applications in the frequency range under test.

For inline connectors it is recommended to solder the termination loads directly between cable conductors and the shield. Alternatively, a terminating PCB based fixture or a termination within an attached connector may be used.

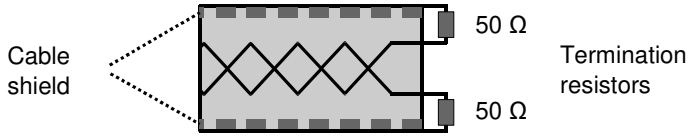

Figure 5.1.3-6: Cable termination to measure inline connector coupling and screening attenuation

For PCB connectors the termination loads are attached between the PCB connector conductors and ground. Alternatively, the PCB connector may be attached to a PCB based termination fixture.

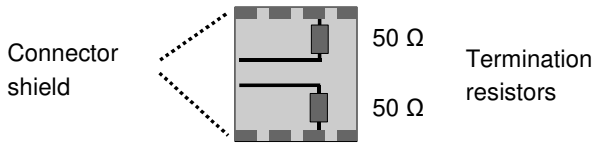

Figure 5.1.3-7: PCB based termination to measure PCB connector coupling and screening attenuation

In any case the termination shall not be exposed within the triaxial tube measurement area so that it does not contribute to the measurement result directly via its own shielding properties. Annex A.2 gives an example of a PCB connector triaxial measurement setup, including examples of a PCB connector under test and terminations.

The connector shall comply with the coupling and screening attenuation requirements in Section 6.2.1.

With multiport connectors, the coupling and screening attenuation of one port per row shall be measured. Especially for angled connectors, the length of the data and screening contacts is different between upper and lower row, which will affect the coupling and screening attenuation. It is assumed that the shielding properties of each port in one row is comparable. If the ports within one row differ in design substantially, each port shall be measured. Unused ports shall be terminated on PCB side and left open at the cable connector side, expecting that the crosstalk between the pairs has only got a minor influence on the coupling and screening attenuation measurement results (Figure 5.1.3-8).

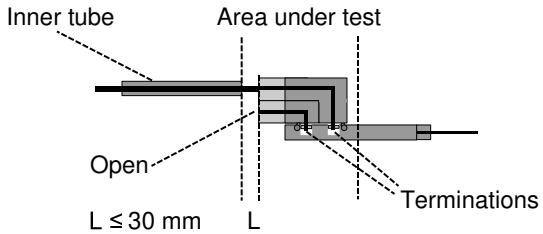

Figure 5.1.3-8: Definition of multiport PCB connector AUT for coupling and screening attenuation

Unused ports within a multiport inline connector shall be terminated left open for packability reasons (Figure 5.1.3-9).

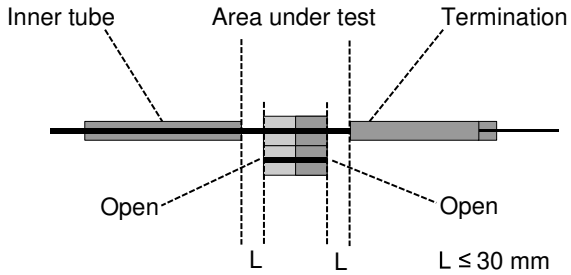

Figure 5.1.3-9: Definition of multiport inline connector AUT for coupling and screening attenuation

5.2 Measurement Setups for Cables, Cable Assemblies and Channels

5.2.1 General Remarks for Cable, Cable Assembly and Channel Measurements

The basic methodology for measuring cable assemblies and complete channel assemblies consisting of one or more cable assemblies is similar to measuring cables as component. Therefore, both topics are described jointly in this chapter. Measuring of crosstalk parameters is not applicable for cable assemblies.

Common for all cable, cable assembly and channel measurements is that the minimum bending radius of the DUT and coaxial test cables shall be considered.

5.2.2 Cable, Cable Assembly and Channel Setups for SCC

To measure SCC parameters of cables, cable assemblies and complete channels, transmission and reflection shall be measured by means of a VNA or equivalent time domain based equipment. The parameters are measured on single cables, i.e. cables without connectors attached, cable assemblies and channel assemblies and not within the context of an environmental system, i.e. wiring harness. However, the insertion loss and return loss limits shall also be met within the environmental system.

To allow comparing the electrical properties of components from different suppliers and comparing the measurement results of different test houses, Annex A.3 defines a reference communication channel and Annex A.4 defines a reference cable assembly.

The DUT shall be placed on a table as shown in Figure 5.2.2-1. PCB and inline connectors that are shown in the drawings are valid for communication channel measurements only. Cable assemblies do not comprise inline connectors. PCB based text fixtures as described in Section 4.4 are recommended for connecting receptacle terminals of cable assemblies and channels. MDI test heads as described in Chapter 7 are recommended as test fixtures for pin terminals, i.e. inline connectors, on cable assemblies. In case of cable measurements, the conductors are attached directly to measurement fixtures without any connectors. The transition length between cable and test fixture shall be as short as possible depending on the actual fixture design. The total DUT length for cable measurements shall be 10 m.

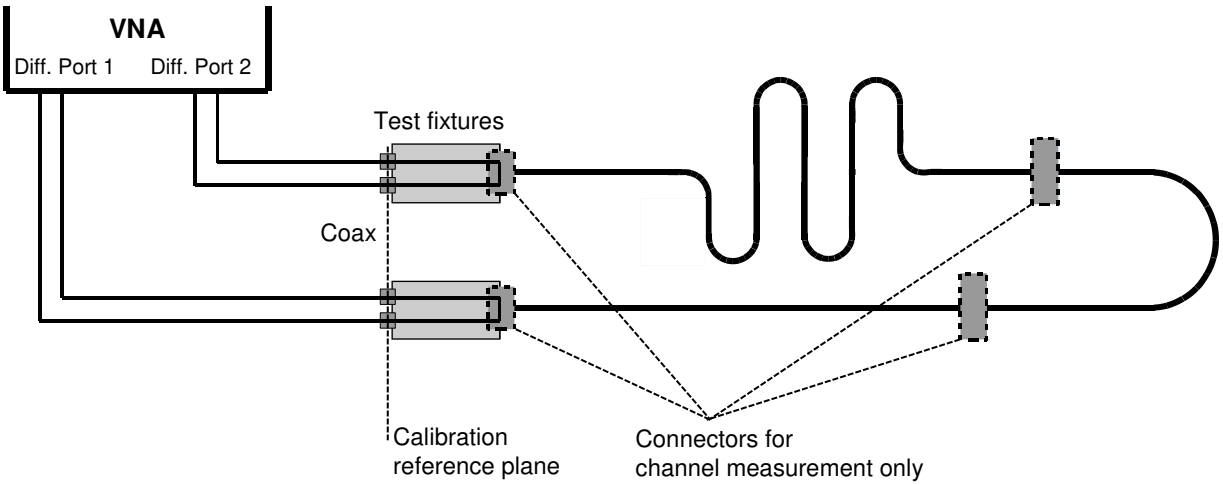

Figure 5.2.2-1: VNA measurement setup for cables, cable assemblies and channels

TDR measurements are carried out in a one port differential setup as shown in Figure 5.2.2-2. The same setup as for VNA measurements may be used, except that the far end measurement fixture may be terminated or be connected to a differential port of the measurement instrument. For cable measurements within the evaluation window of 0.5 m to 1.5 m, the far end of the DUT may also be left open to ease handling. In this case, it shall be made sure that the results are unambiguous and not falsified by reflections at the open end of the DUT.

The rise-time for the measurements is 500 ps and may be applied by software filtering of the reflected signal within the TDR scope. The measurements may also be carried out by means of VNA and transformation into time domain. Recommended parameters for using a VNA to perform impedance measurements are given in Table 4.2-4. For long channels the TDR measurement technique leads to incorrect measuring results. To prevent getting faulty results the correction procedure as described in Annex B should be used.

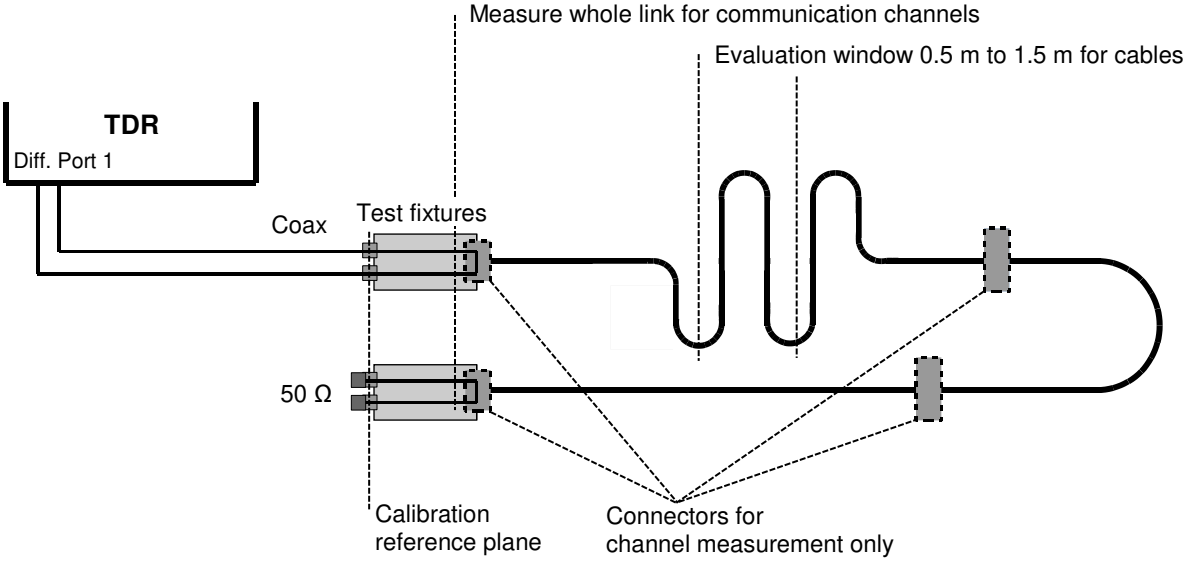

Figure 5.2.2-2: TDR measurement setup for cables and channels

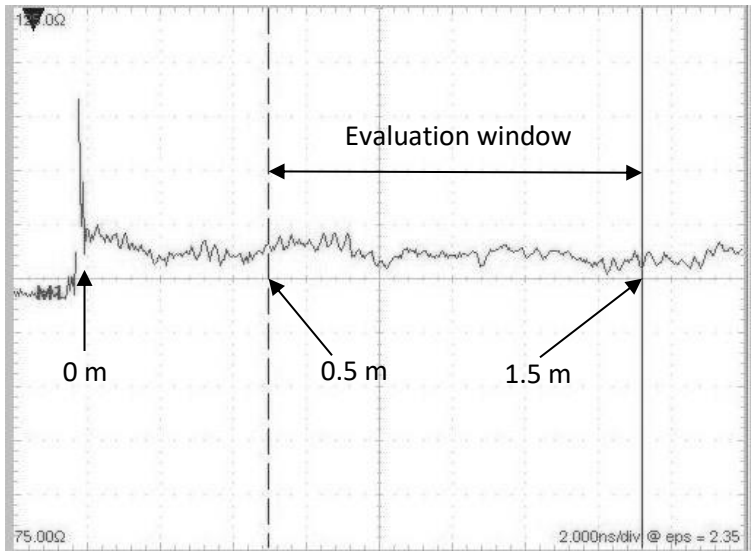

Figure 5.2.2-3: Example for TDR measurement with definition of evaluation window for CIDM limit

The impedance of the cable shall comply with the limit specified in Table 6.1.2-1 within an evaluation window of 0.5 m to 1.5 m. The impedance of a communication channel is measured over the whole length of the link for information purposes only.

5.2.3 Cable Setup for ES

The coupling attenuation, screening attenuation and balance are the main parameter for STP channels defining the EMC properties apart from internal crosstalk. The coupling and screening attenuation is also directly related to alien crosstalk from and to other cables within a wiring harness. This applies to crosstalk from differential and single ended interference sources.

The coupling- and screening attenuation of cables is measured by means of the triaxial tube method as described in [7].

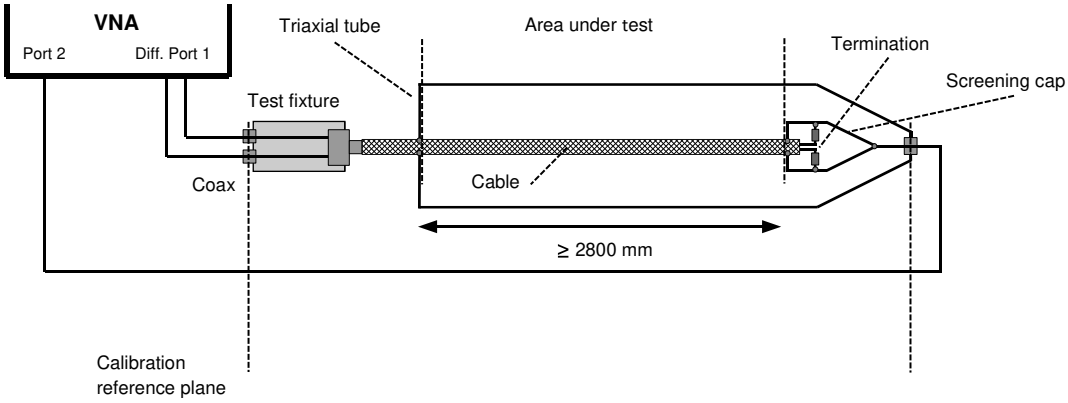

Figure 5.2.3-1: Cable measurement setup for coupling and screening attenuation

3-port measurement setup using VNA without balun shall be used. The differential port of the VNA acts as generator and the single ended port as receiver. To measure coupling attenuation, differential port 1 shall be operated in differential mode. To measure screening attenuation, differential port 1 shall be operated in common mode.

The overall length of the cable under test shall be between 3400 mm and 3600 mm. The exposed cable length within the triaxial tube shall be at least 2800 mm. With respect to the dimensions of the cable under test, the use of a triaxial tube with nominal length 3 m is implied.

The termination shall be nominal 100 Ω in differential mode. It is recommended to terminate each wire of the differential pair directly to the shield to ensure a high degree of balance for the DUT arrangement. This method results in a common mode termination impedance of 25 Ω. A common and differential mode termination according to [7] can be used alternatively. The requirements on the single ended termination of every conductor of the differential pair are 50 Ω ± 1 % against ground. The two resistors of the differential pair shall be matched against each other with a tolerance of ± 0.1 Ω at DC. The resistors need to be suitable for RF applications in the frequency range under test.

It is recommended to solder the termination loads directly between cable conductors and the shield of the cable. Alternatively, a terminating PCB based fixture or a termination within an attached connector may be used.

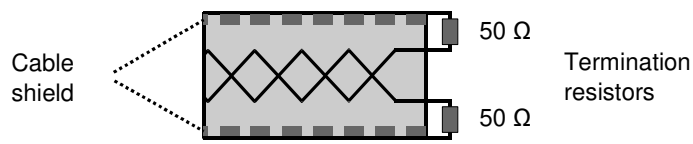

Figure 5.2.3-2: Cable termination to measure cable coupling and screening attenuation

For PCB connectors the termination loads are attached between the PCB connector conductors and ground. Alternatively, the PCB connector may be attached to a PCB based termination fixture.

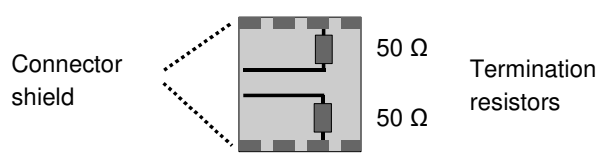

Figure 5.2.3-3: PCB based termination to measure cable coupling and screening attenuation

In any case the termination shall not be exposed within the triaxial tube measurement area so that it does not contribute to the measurement result directly via its own coupling attenuation. Annex A.2 gives an example of a cable coupling attenuation measurement setup, including examples of a PCB connector under test and terminations.

The cable shall comply with the coupling and screening attenuation requirements in Table 6.2.2-1.

5.2.4 Cable Assembly Setup for ES – Coupling and Screening Attenuation

Decoupling within the context of whole communication channels in the environmental system is ensured by meeting the coupling attenuation requirements for connectors (Table 6.2.1-1) and cables (Table 6.2.2-1). To make sure that cable assemblies have compliant shielding properties, the reference cable assembly described in A.4 shall be measured as shown in Figure 5.2.4-1. With respect to the dimensions of the cable assembly, the use of a tube with nominal length 3 m is implied.

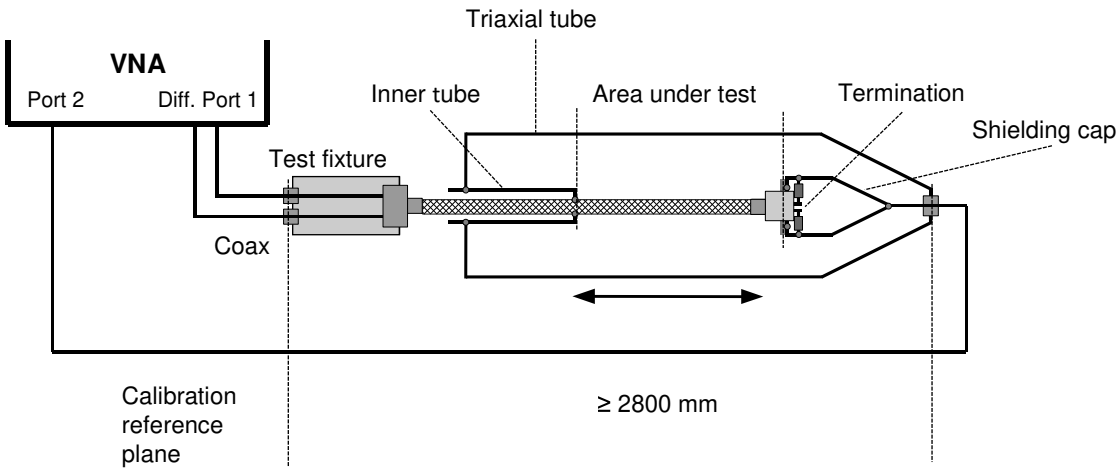

Figure 5.2.4-1: Coupling and screening attenuation reference cable assembly

The cable connector inside the test tube can be either a receptacle or a pin terminal as typically used in inline connectors. This connector shall be mated to a counterpart that is terminated within a shielded containment inside the test tube. Objective of this test is to demonstrate a compliant cable shield termination in the connectors of a cable assembly. For that reason, a complete shielding of the mating counterpart and direct connection of the counterparts shield contacts to the shielded containment is recommended. EMC gaskets may be used depending on the specific design.

5.2.5 Whole Communication Channel Setup for ES – Crosstalk

The relevant coupling parameter of whole communication channels in the environmental system is the differential crosstalk to neighbor wires in a bundle of cables, that is a meaningful representation of a wiring harness as it is intended to be used in the real application. To allow comparing the electrical properties of components from different suppliers and comparing the measurement results of different test houses, Annex A.5 defines a reference wiring harness for information only. The crosstalk within the cable bundle assembly is determined by a number of transmission measurements which are performed between the individual channels of the harness.

The DUT shall be placed on a table or drum as shown in Figure 5.2.5-2. All ports of measurement fixtures that are not connected to the VNA but still part of the wiring harness shall be terminated at the coaxial ports of the measurement fixture with single ended 50 Ω.

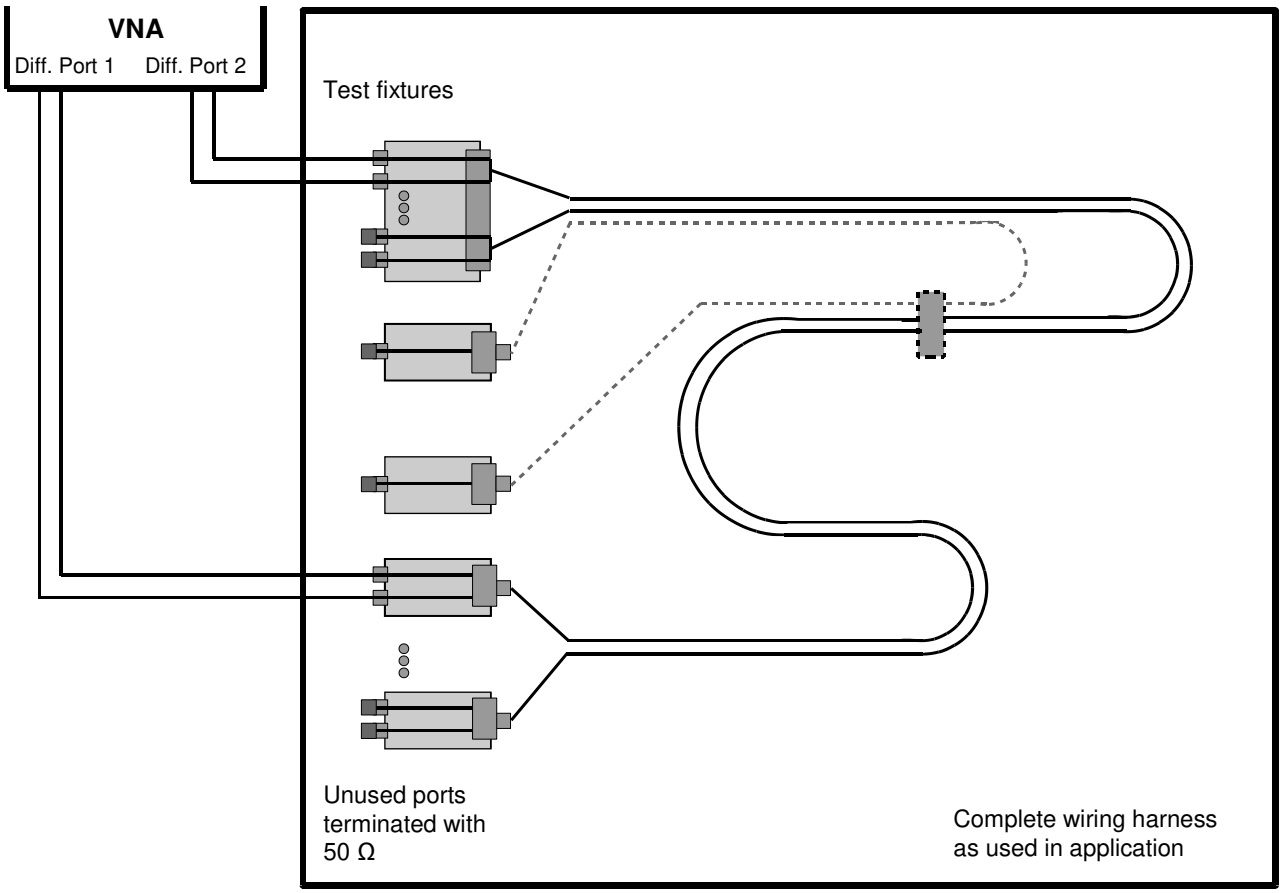

Figure 5.2.5-2: Wiring harness measurement setup for AFEXT and THRU

Figure 5.2.5-2 shows the differential port 1 of the VNA connected to the far end side and port 2 connected to the near end side of the wiring harness, allowing measuring AFEXT and the through connections (THRU). The measurement of the THRU connection for each channel provides the insertion loss and return loss in context of the environmental system. The insertion loss is also used to calculate PSAACRF.

Figure 5.2.5-3 shows port 1 and port 2 of the VNA connected to the near end side of the wiring harness to measure alien near end crosstalk parameters ANEXT.

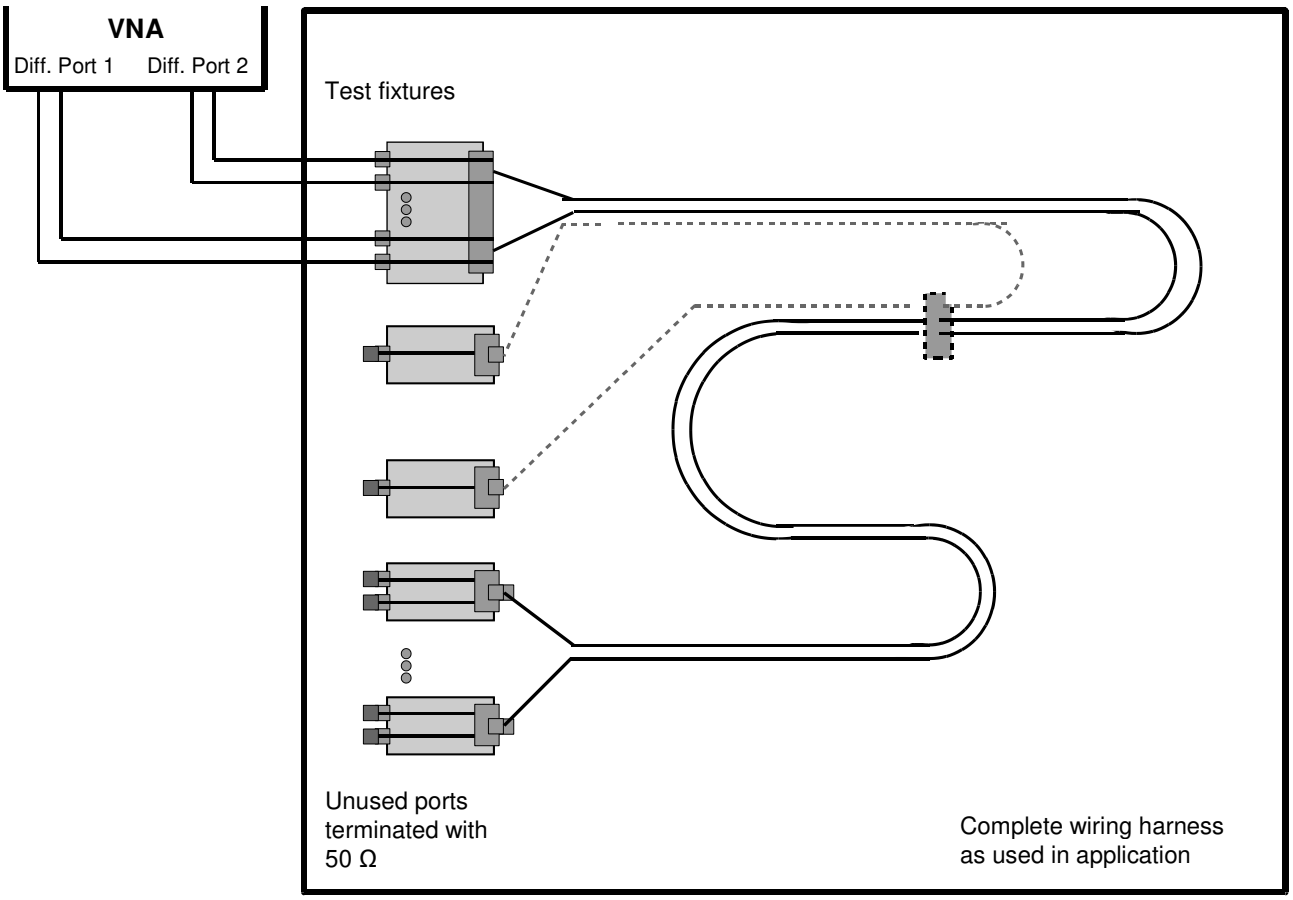

Figure 5.2.5-3: Wiring harness measurement setup for ANEXT

The measurement needs to be repeated for every port combination of the wiring harness. For each port, the power sum crosstalk can be calculated as the sum of crosstalk introduced by each neighbouring port. Equations how to calculate the power sum crosstalk from individual transmission measurements are given in Chapter 3. Each port to be used with 1000BASE-T1 shall comply with the specified alien crosstalk limits in Section 6.2.3.

5.2.6 Whole Communication Channel Setup for ES – Coupling and Screening Attenuation

Decoupling within the context of whole communication channels in the environmental system is ensured by meeting the coupling attenuation requirements for connectors (Table 6.2.1-1) and cables (Table 6.2.2-1). To make sure that connector and cable properties in terms of balance and shielding are matched in order to reach sufficient coupling attenuation, the reference channel assembly as shown in Figure 5.2.6-1 shall be measured. Additional information on the channel assembly is given in Annex A.6. With respect to the dimensions of the channel assembly, the use of a triaxial tube with nominal length 1 m is implied.

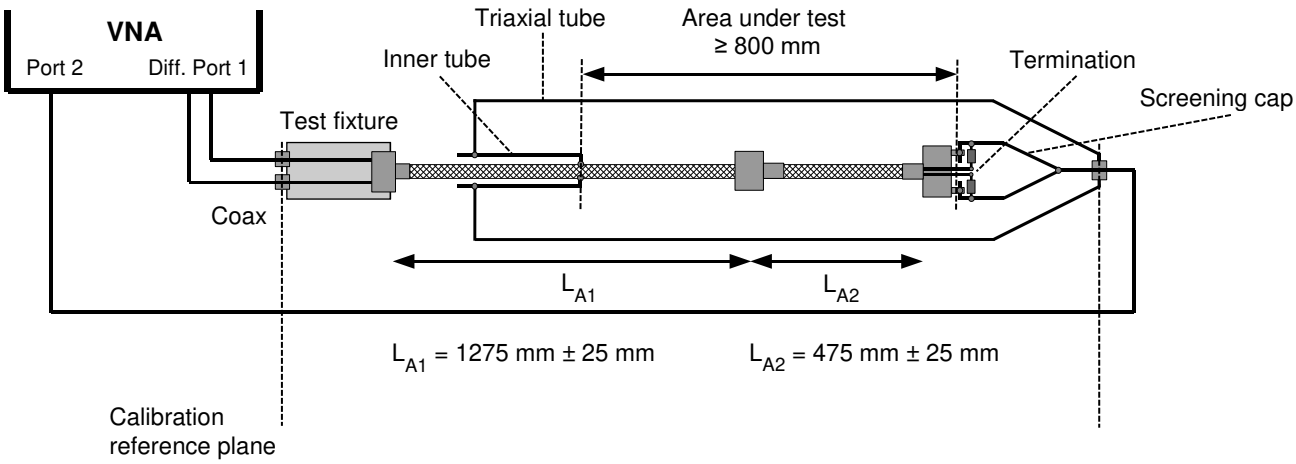

Figure 5.2.6-1: Coupling and screening attenuation reference channel assembly

This topology serves as common reference to compare different components in terms of their electrical properties and their influence on the whole communication channel. It also allows to compare the results of different test houses.

The reference channel assembly shall comply with the coupling and screening attenuation requirements in Table 6.2.4-2.

6 Electrical Requirements

6.1 Basic Requirements for Standalone Communication Channel

6.1.1 Requirements for Connectors in Context of SCC

This section specifies the connector requirements in context of the standalone communication channel without the coupling parameters to neighbor wires.

Table 6.1.1-1: Electrical limits for connectors (SCC context)

Test parameter	Symbol or related S-parameter	Requirement
CIDM	Z_{RF}	Informative parameter only (not required) 100 Ω ± 5 % (at 500 ps rise time)
Propagation Delay	t_d	$\leq 667ps$ $2 \leq f \leq 600$, frequency f in MHz
IL	S_{dd21}	$\leq \left(0.01\sqrt{f}\right)dB$ $1 \leq f \leq 600$, frequency f in MHz
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 30 & 1 \leq f < 190 \\ 20 - 20\,log\left({}^{f}/_{600}\right) & 190 \leq f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
LCL LCTL	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} class 1	$\geq \begin{pmatrix} 50 & 10 \leq f \leq 50 \\ 75.2 - 14.83\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz
	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} class 2	No requirement

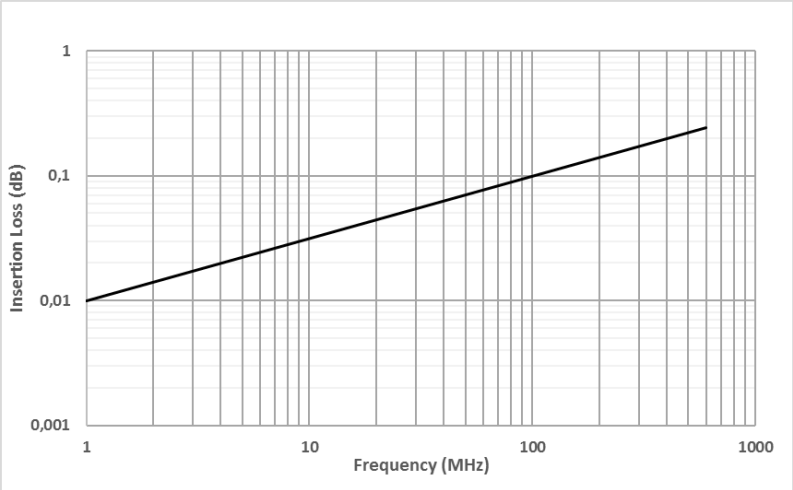

Figure 6.1.1-1: Insertion loss limit for connectors

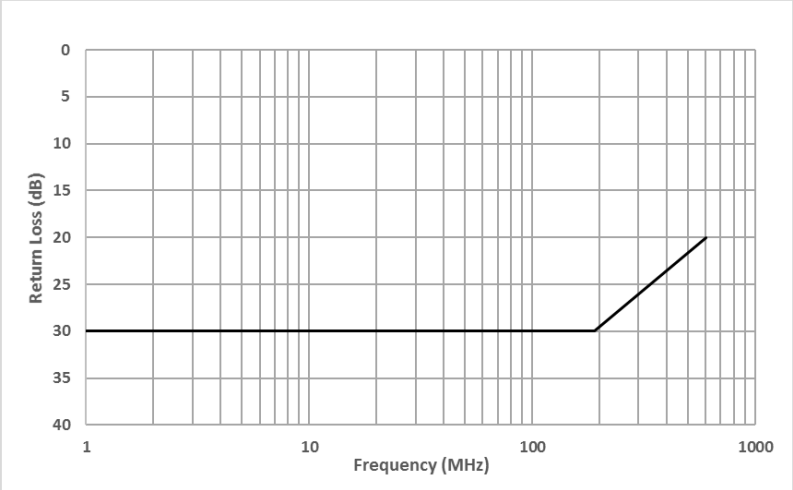

Figure 6.1.1-2: Return loss limit for connectors

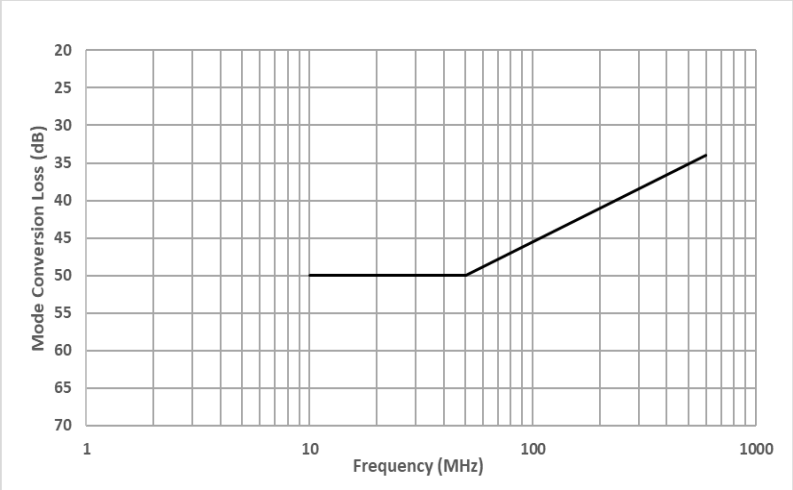

Figure 6.1.1-3: Mode conversion limit for connectors class 1

6.1.2 Requirements for Cables in Context of SCC

This section specifies the cable requirements in context of the standalone communication channel without the coupling parameters to neighbor wires.

Table 6.1.2-1: Electrical limits for cables (SCC context)

Test parameter	Symbol or related S-parameter	Requirement
CIDM	Z_{RF}	100 Ω ± 5 % (at 500 ps rise time)
Propagation Delay	t_d	<u>For use in SCC with maximum length of 15 m</u> $\leq 6\ ns/m$ <u>For use in SCC with maximum length of 10 m</u> $\leq 9\ ns/m$ $2 \leq f \leq 600$, frequency f in MHz
IL	S_{dd21}	<u>For use in SCC with maximum length of 15 m</u> $\leq \frac{1}{15}\left(0.0023f + 0.5907\sqrt{f} - 6 * 0.01\sqrt{f} + {}^{0.0639}\!/_{\sqrt{f}}\right) dB/m$ <u>For use in SCC with maximum length of 10 m</u> $\leq \frac{1}{10}\left(0.0023f + 0.5907\sqrt{f} - 6 * 0.01\sqrt{f} + {}^{0.0639}\!/_{\sqrt{f}}\right) dB/m$ $1 \leq f \leq 600$, frequency f in MHz
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 22 & 1 \leq f < 10 \\ 27 - 5\,log\,f & 10 \leq f < 40 \\ 19 & 40 \leq f < 130 \\ 40 - 10\,log\,f & 130 \leq f < 400 \\ 14 & 400 \leq f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
LCL	S_{dc11}, S_{dc22} class 1	$\geq \begin{pmatrix} 50 & 10 \leq f \leq 50 \\ 81.5 - 18.53\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz
	S_{dc11}, S_{dc22} class 2	No requirement
LCTL	S_{dc21}, S_{dc12} class 1	$\geq \begin{pmatrix} 46 & 10 \leq f \leq 50 \\ 71.2 - 14.83\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz
	S_{dc21}, S_{dc12} class 2	No requirement

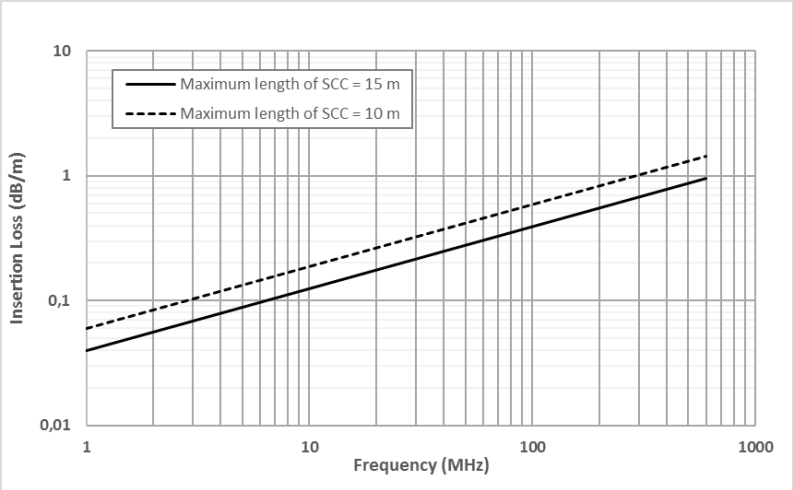

Figure 6.1.2-1: Insertion loss limit for cables

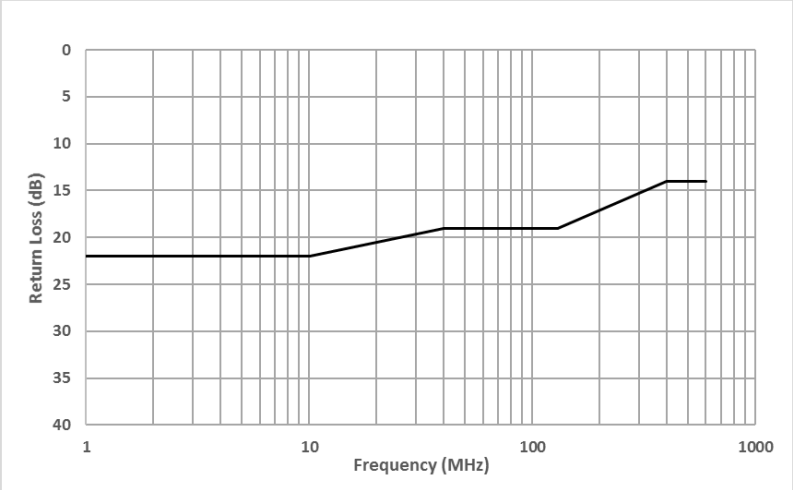

Figure 6.1.2-2: Return loss limit for cables

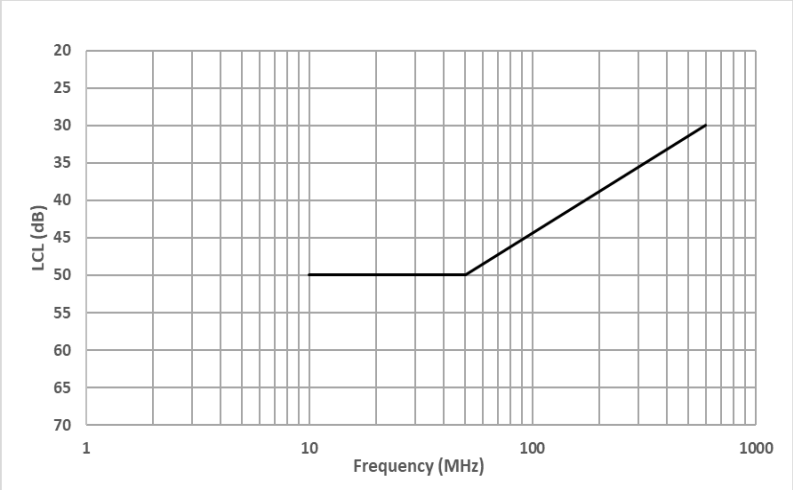

Figure 6.1.2-3: LCL limit for cables class 1

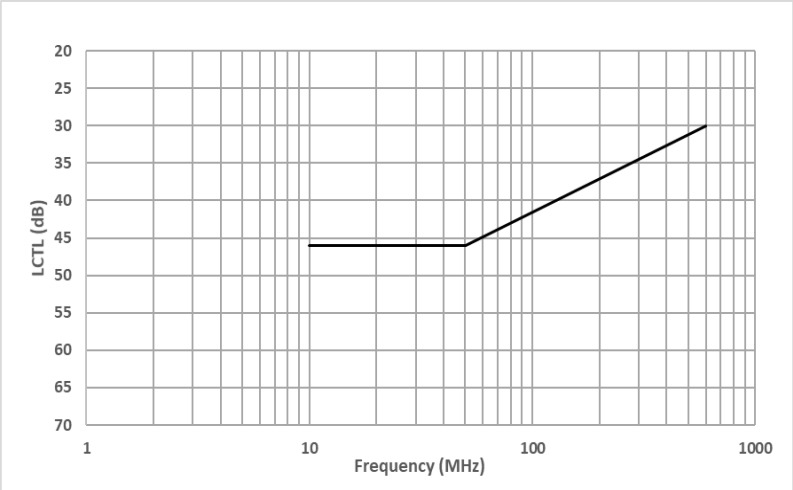

Figure 6.1.2-4: LCTL limit for cables class 1

6.1.3 Requirements for Cable Assemblies in Context of SCC

This section specifies the requirements for cable assemblies in context of the standalone communication channel without the coupling parameters to neighbor wires.

Table 6.1.3-1: Electrical limits for cable assemblies (SCC context)

Test parameter	Related S-parameter	Requirement
IL	S_{dd21}	Informative parameter only (not required)
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 22 & 1 \leq f < 130 \\ 56.64 - 16.38\,log\,f & 130 \leq f < 400 \\ 14 & 400 \leq f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
LCL LCTL	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} class 1	$\geq \begin{pmatrix} 41 & 10 \leq f \leq 50 \\ 66.2 - 14.83\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz
	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} class 2	No requirement

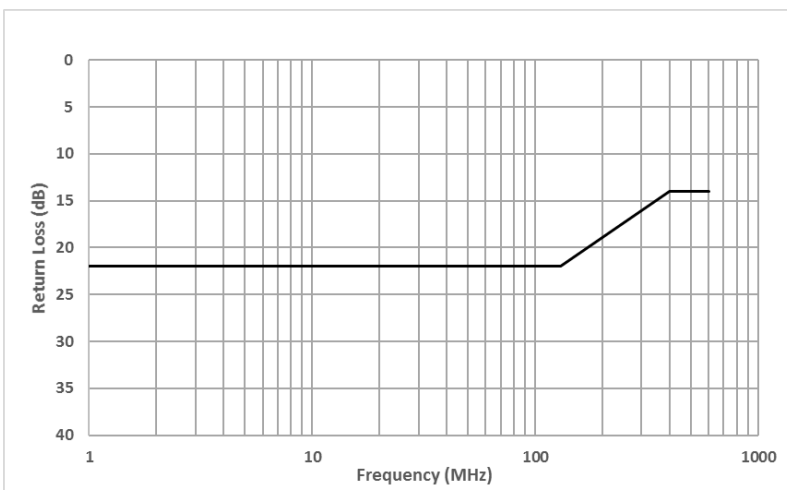

Figure 6.1.3-1: Return loss limit for cable assemblies

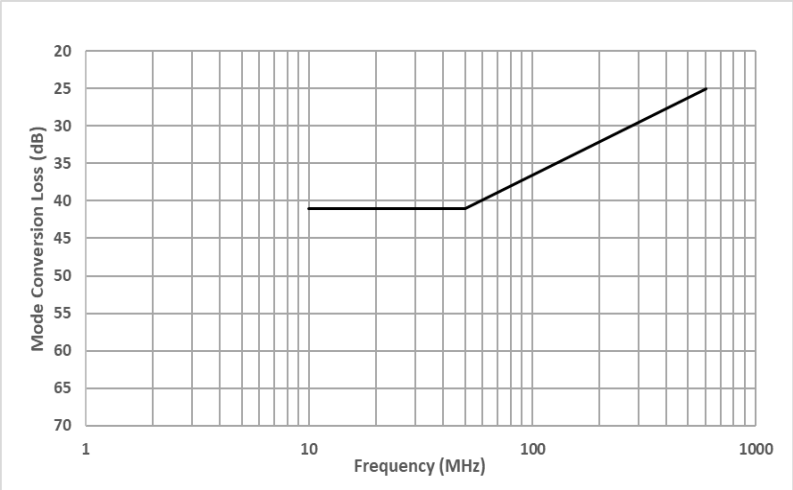

Figure 6.1.3-2: Mode conversion limit for cable assemblies class 1

6.1.4 Requirements for Whole Communication Channel in Context of SCC

This section specifies the channel requirements in context of the standalone communication channel without the coupling parameters to neighbor wires.

Table 6.1.4-1: Electrical limits for whole communication channel (SCC context)

Test parameter	Symbol or related S-parameter	Requirement
CIDM	Z_{RF}	Informative parameter only (not required) 100 Ω ± 10 % (at 500 ps rise time)
Propagation Delay	t_d	$\leq 94\ ns$ $2 \leq f \leq 600$, frequency f in MHz
IL	S_{dd21}	$\leq \left(0.0023f + 0.5907\sqrt{f} + {}^{0.0639}\!/_{\sqrt{f}}\right) dB$ $1 \leq f \leq 600$, frequency f in MHz
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 19 & 1 \leq f < 10 \\ 24 - 5\,log\,f & 10 \leq f < 40 \\ 16 & 40 \leq f < 130 \\ 37 - 10\,log\,f & 130 \leq f < 400 \\ 11 & 400 \leq f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
LCL LCTL	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} class 1	$\geq \begin{pmatrix} 41 & 10 \leq f \leq 50 \\ 66.2 - 14.83\,log(f) & 50 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz
	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} class 2	No requirement

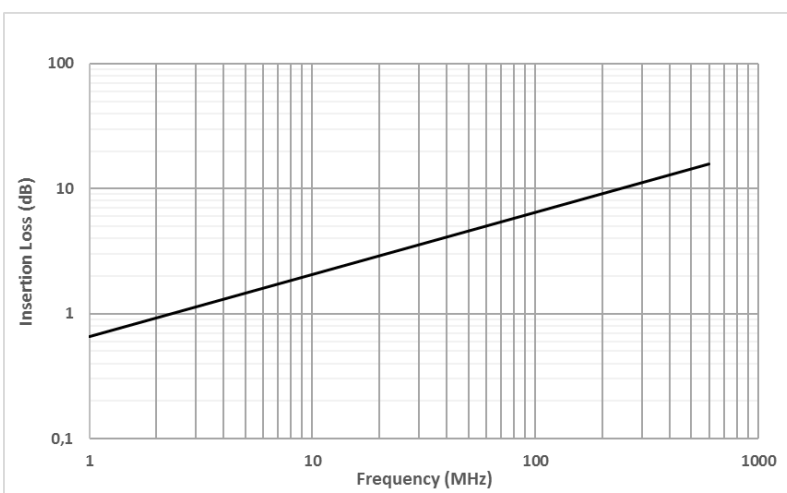

Figure 6.1.4-1: Insertion loss limit for whole communication channel

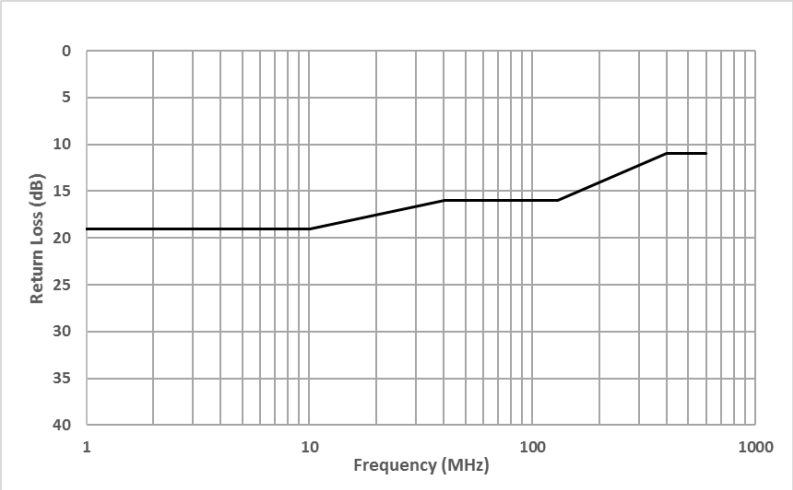

Figure 6.1.4-2: Return loss limit for whole communication channel

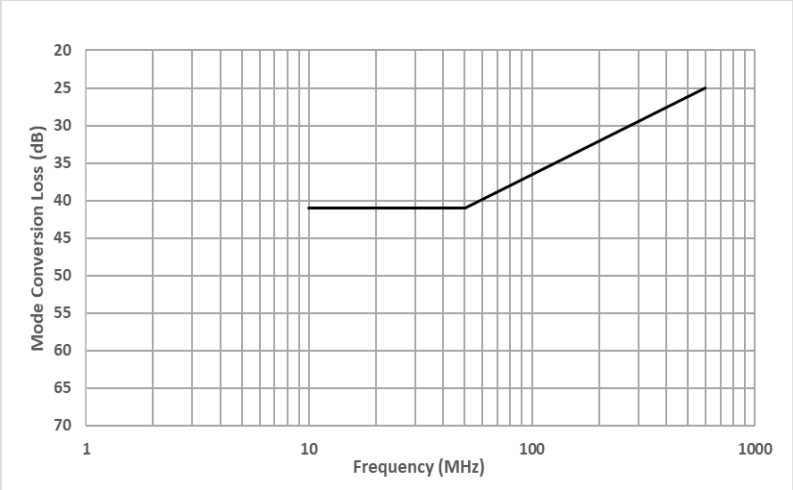

Figure 6.1.4-3: Mode conversion limit for whole communication channel class 1

6.2 Additional Requirements for Alien Coupling within Environmental System

6.2.1 Requirements for Connectors in Context of ES

This section specifies the coupling parameter requirements for connectors. The test parameters and limits according to Table 6.2.1-1 are required for multi-pair connectors additionally to the parameters in Section 6.1.1.

Table 6.2.1-1: Electrical limits for connectors (ES context)

Test parameter	Symbol or related S-parameter	Requirement
PSANEXT Loss	S_{dd31}, S_{ddyx}	$\geq \begin{pmatrix} 57 - 10\,log\left({}^{f}/_{100}\right) & 1 \leq f \leq 100 \\ 57 - 15\,log\left({}^{f}/_{100}\right) - 6\left({}^{f-100}/_{400}\right) & 100 < f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
PSAFEXT Loss	S_{dd41}, S_{ddyx}	$\geq \left(46.67 - 20\,log\left({}^{f}/_{100}\right)\right) dB$ $1 \leq f \leq 600$, frequency f in MHz
Coupling attenuation	$a_{c\ class1}$	$\geq \begin{pmatrix} 70 & 30 \leq f \leq 100 \\ 70 - 19.3\,log\left({}^{f}/_{100}\right) & 100 < f \leq 600 \end{pmatrix} dB$ $30 \leq f \leq 600$, frequency f in MHz
	$a_{c\ class2}$	≥ 70 dB $30 \leq f \leq 600$, frequency f in MHz
Screening attenuation	$a_{s\ class1}$	≥ 28 dB $30 \leq f \leq 600$, frequency f in MHz
	$a_{s\ class2}$	≥ 45 dB $30 \leq f \leq 600$, frequency f in MHz

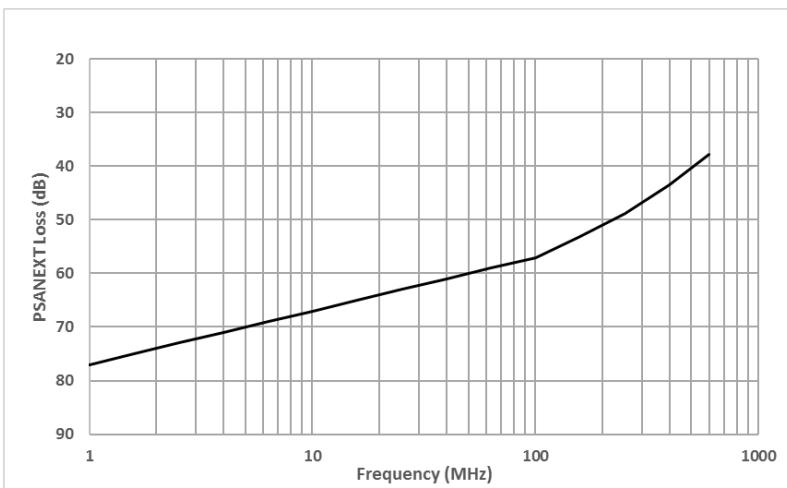

Figure 6.2.1-1: PSANEXT loss limit for connectors

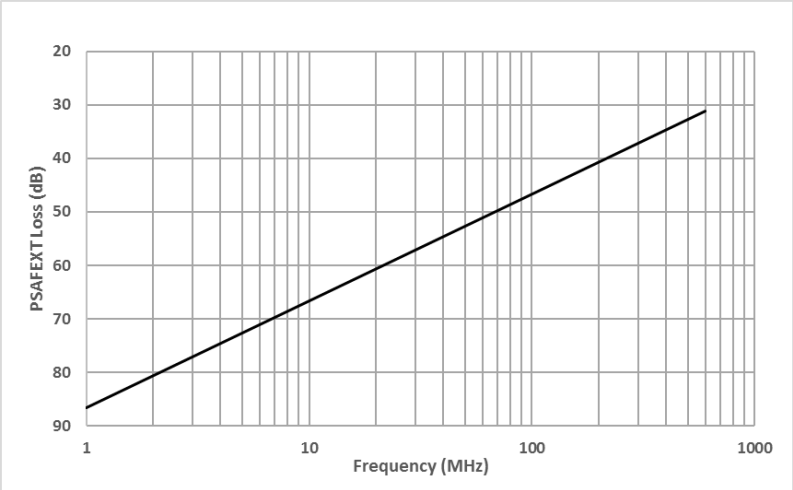

Figure 6.2.1-2: PSAFEXT loss limit for connectors

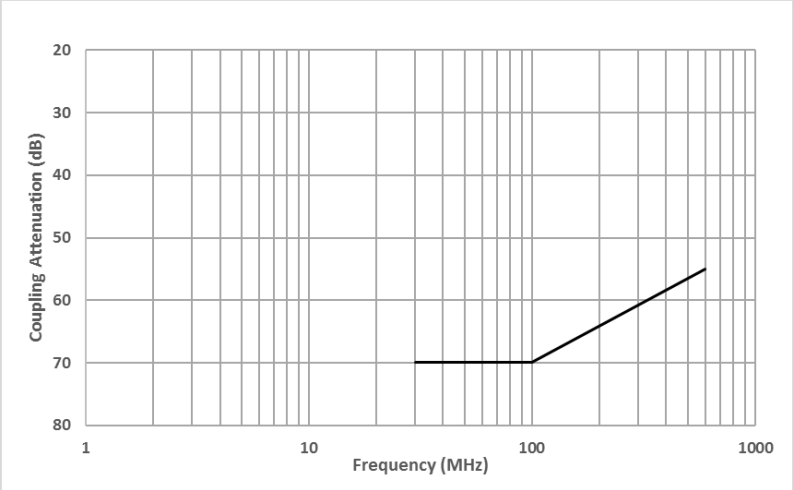

Figure 6.2.1-3: Coupling attenuation limit class 1 for connectors

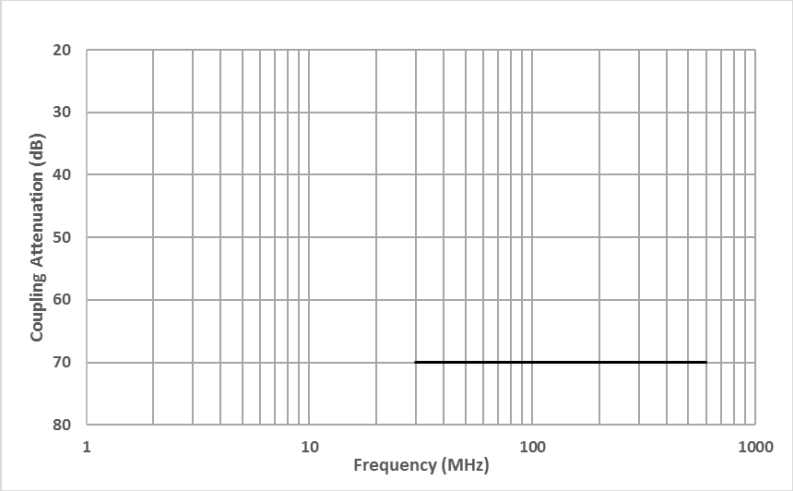

Figure 6.2.1-4: Coupling attenuation limit class 2 for connectors

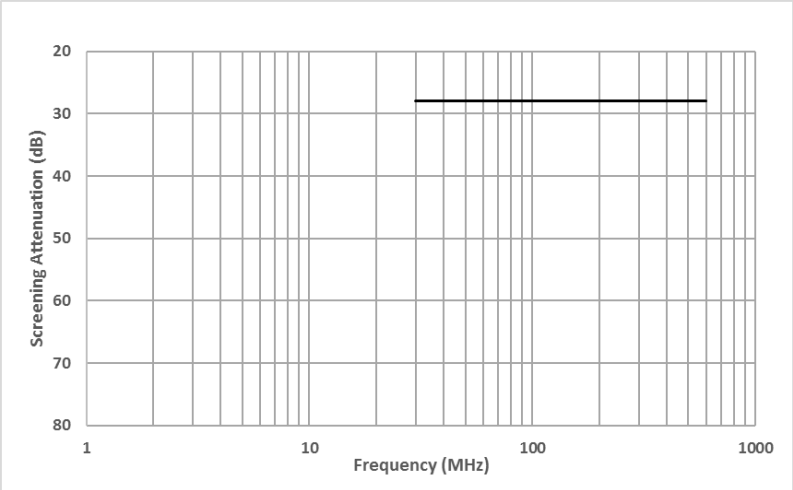

Figure 6.2.1-5: Screening attenuation limit class 1 for connectors

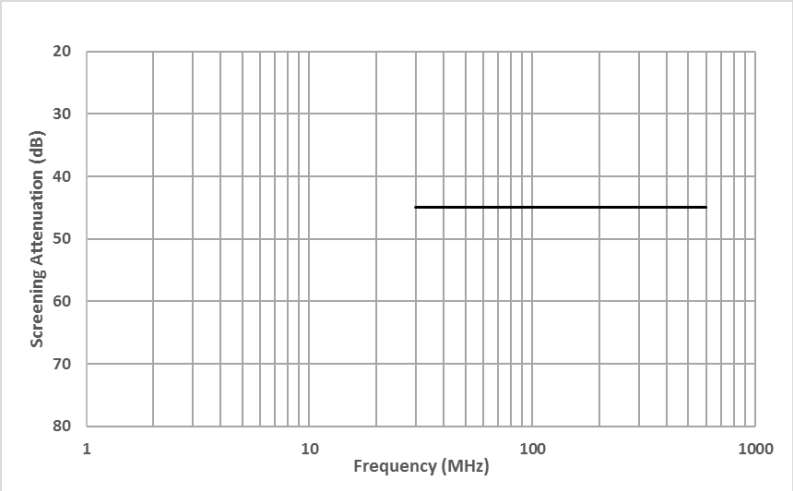

Figure 6.2.1-6: Screening attenuation limit class 2 for connectors

6.2.2 Requirements for Cables in Context of ES

This section specifies the coupling parameter requirements for cables. The test parameters and limits according to Table 6.2.2-1 are required additionally to the parameters in Section 6.1.2.

Table 6.2.2-1Electrical limits for cables (ES context)

Test parameter	Symbol	Requirement
Coupling attenuation	$a_{c\ class1}$ $a_{c\ class2}$	≥ 70 dB $30 \leq f \leq 600$, frequency f in MHz
Screening attenuation	$a_{s\ class1}$	≥ 35 dB $30 \leq f \leq 600$, frequency f in MHz
	$a_{s\ class2}$	≥ 45 dB $30 \leq f \leq 600$, frequency f in MHz

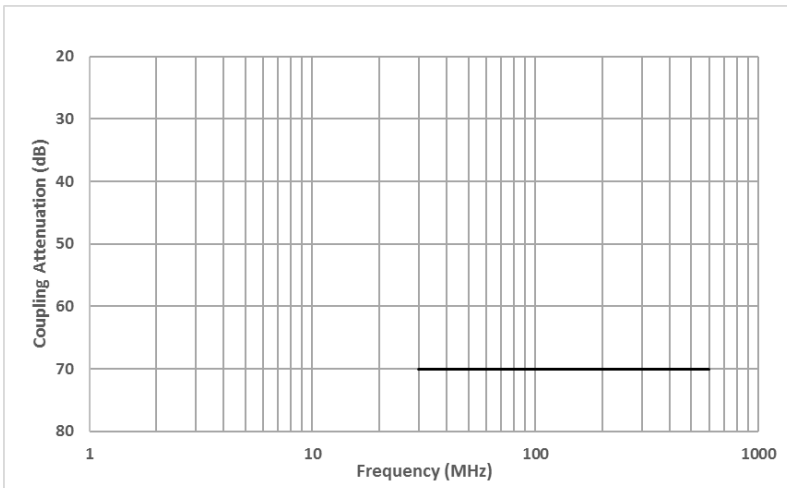

Figure 6.2.2-1: Coupling attenuation limit for cables class 1 and class 2

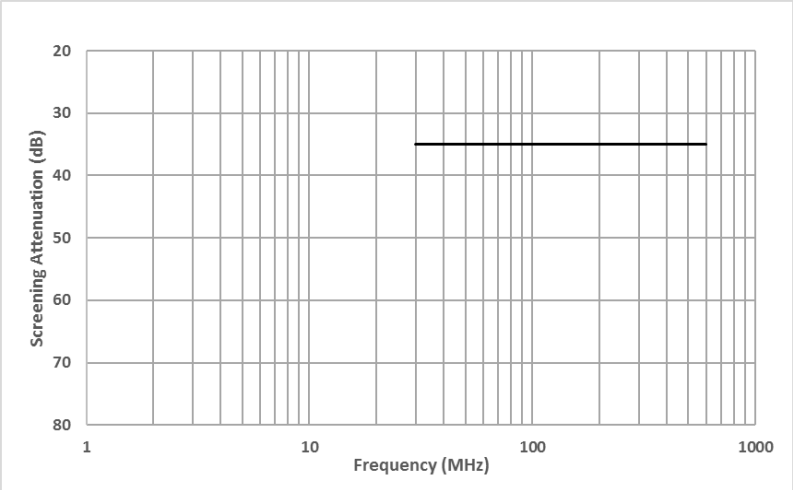

Figure 6.2.2-2: Screening attenuation limit for cables class 1

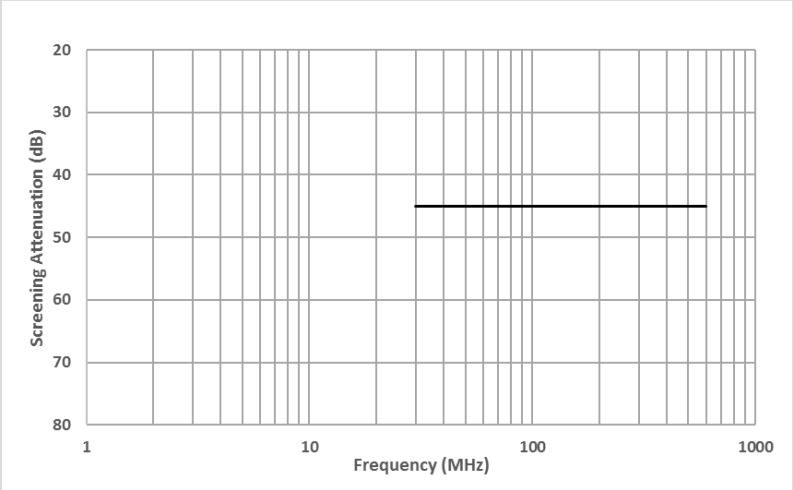

Figure 6.2.2-3: Screening attenuation limit for cables class 2

6.2.3 Requirements for Cable Assemblies in Context of ES

This section specifies the coupling parameter requirements for cable assemblies. The test parameters and limits according to Table 6.2.3-1 are required additionally to the parameters in Section 6.1.3.

Table 6.2.3-1: Electrical limits for cable assemblies (ES context)

Test parameter	Symbol	Requirement
Coupling attenuation	$a_{c\ class1}$	$\geq \begin{pmatrix} 70 & 30 \leq f \leq 100 \\ 70 - 14.95\, log\left({}^{f}/_{100}\right) & 100 < f \leq 400 \\ 61 - 5.68\, log\left({}^{f}/_{400}\right) & 400 < f \leq 600 \end{pmatrix} dB$ $30 \leq f \leq 600$, frequency f in MHz
	$a_{c\ class2}$	≥ 70 dB $30 \leq f \leq 600$, frequency f in MHz
Screening attenuation	$a_{s\ class1}$	≥ 28 dB $30 \leq f \leq 600$, frequency f in MHz
	$a_{s\ class2}$	≥ 45 dB $30 \leq f \leq 600$, frequency f in MHz

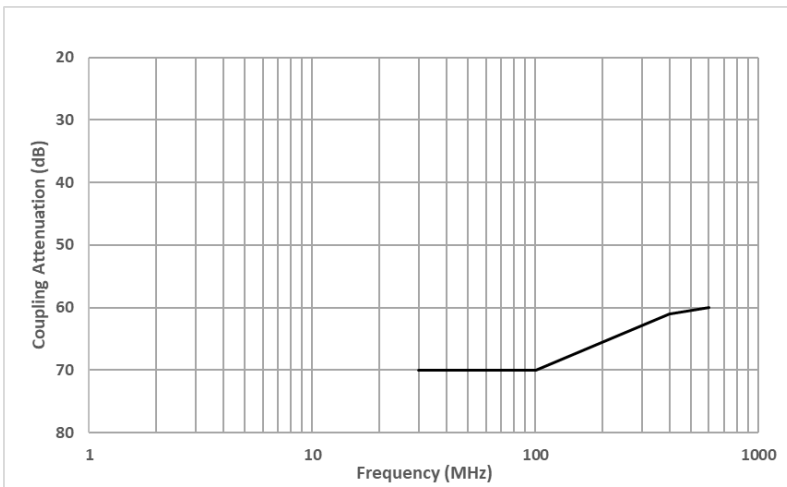

Figure 6.2.3-1: Coupling attenuation limit class 1 for cable assemblies

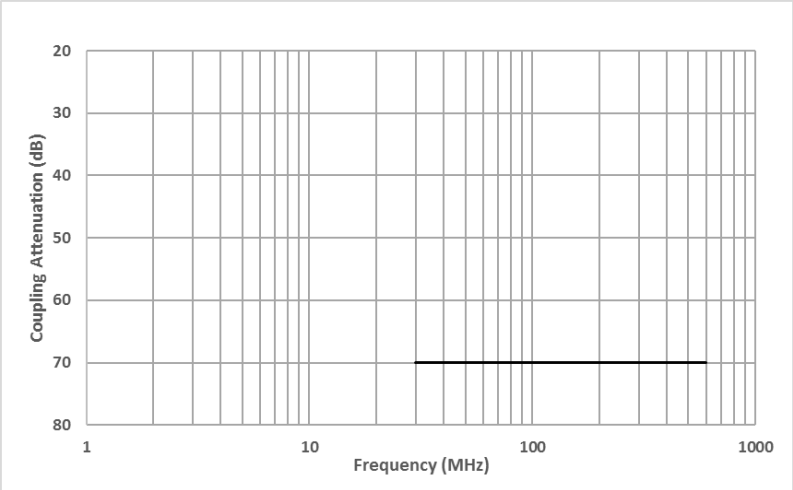

Figure 6.2.3-2: Coupling attenuation limit class 2 for cable assemblies

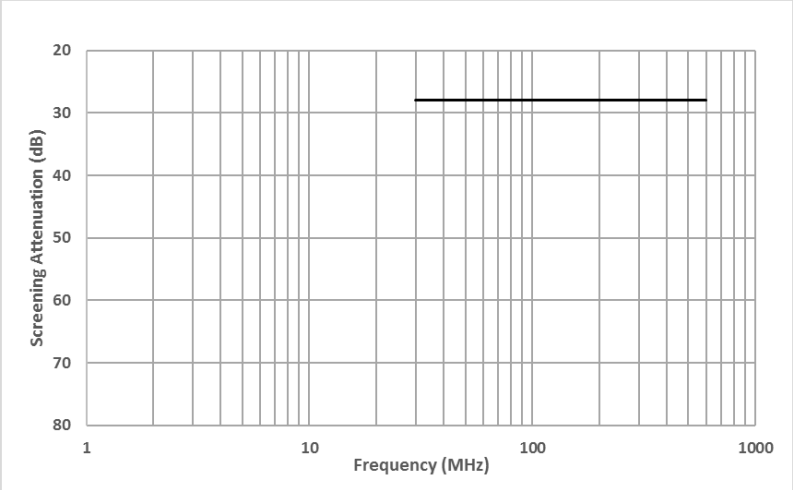

Figure 6.2.3-3: Screening attenuation limit class 1 for cable assemblies

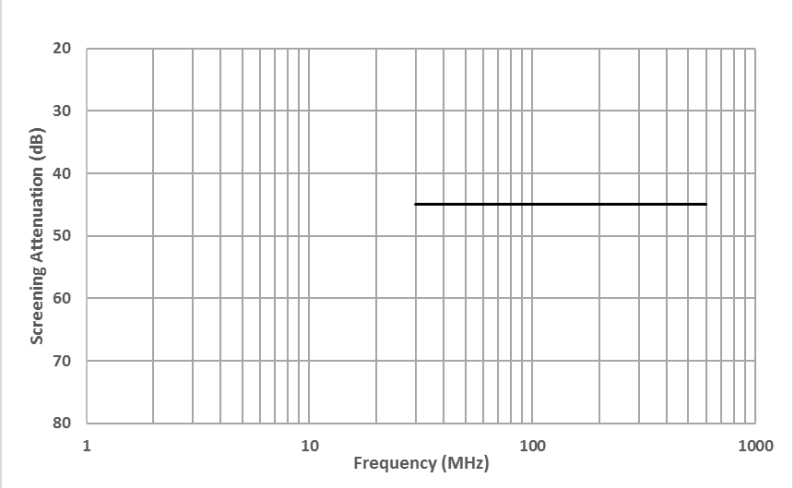

Figure 6.2.3- 4: Screening attenuation limit class 2 for cable assemblies

6.2.4 Requirements for Whole Communication Channel in Context of ES

This section specifies the coupling parameter requirements for communication channels. The test parameters and limits according to Table 6.2.4-2 are required for cable harnesses additionally to the insertion loss and return loss parameters in Section 6.1.4.

Table 6.2.4-2: Electrical limits for WCC (ES context)

Test parameter	Symbol or related S-parameter	Requirement
PSANEXT Loss	S_{dd31}, S_{ddyx}	$\geq \begin{pmatrix} 54 - 10\,log\left({}^{f}/_{100}\right) & 1 \leq f \leq 100 \\ 54 - 15\,log\left({}^{f}/_{100}\right) - 6\left({}^{f-100}/_{400}\right) & 100 < f \leq 600 \end{pmatrix} dB$ $1 \leq f \leq 600$, frequency f in MHz
PSAACRF	S_{dd41}, S_{ddyx}	$\geq \left(43.67 - 20\,log\left({}^{f}/_{100}\right)\right) dB$ [1] $1 \leq f \leq 600$, frequency f in MHz
Coupling attenuation	$a_{c\ class1}$	$\geq \begin{pmatrix} 65 & 30 \leq f \leq 100 \\ 65 - 19.3\,log\left({}^{f}/_{100}\right) & 100 < f \leq 600 \end{pmatrix} dB$ $30 \leq f \leq 600$, frequency f in MHz
	$a_{c\ class2}$	≥ 65 dB $30 \leq f \leq 600$, frequency f in MHz
Screening attenuation	$a_{s\ class1}$	≥ 25 dB $30 \leq f \leq 600$, frequency f in MHz
	$a_{s\ class2}$	≥ 40 dB $30 \leq f \leq 600$, frequency f in MHz
NOTE [1] The equation for PSAACRF is the simplified expression of the same limit as defined in [1].		

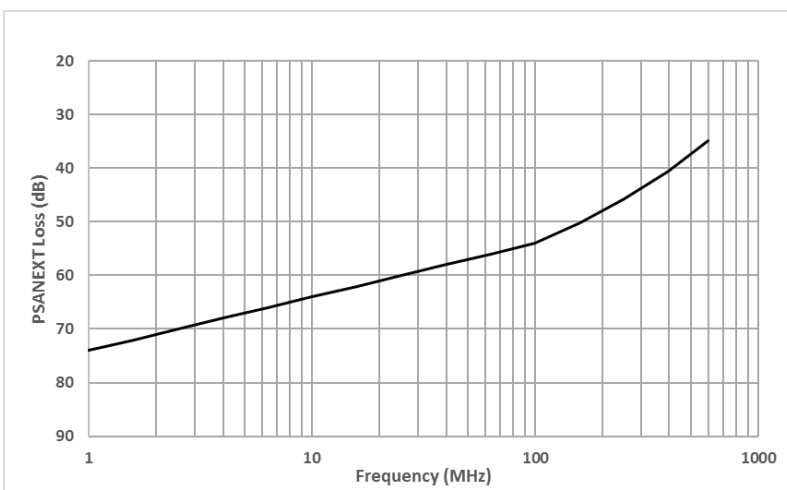

Figure 6.2.4-5: PSANEXT loss limit for WCC

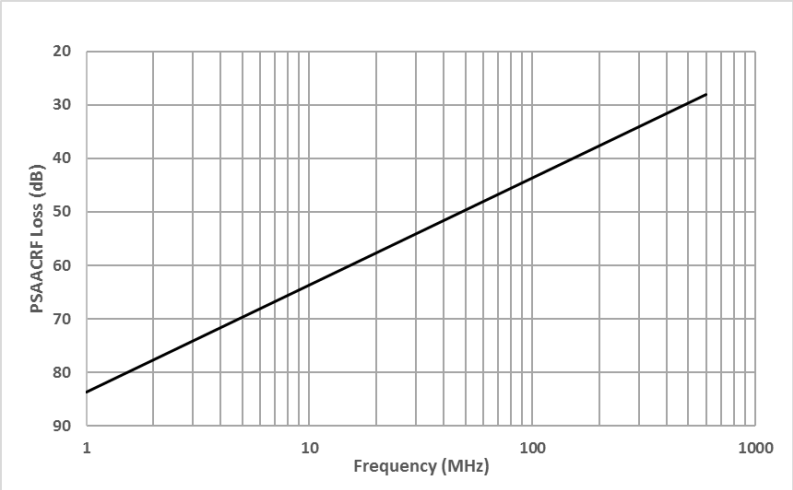

Figure 6.2.4-6: PSAACRF loss limit for WCC

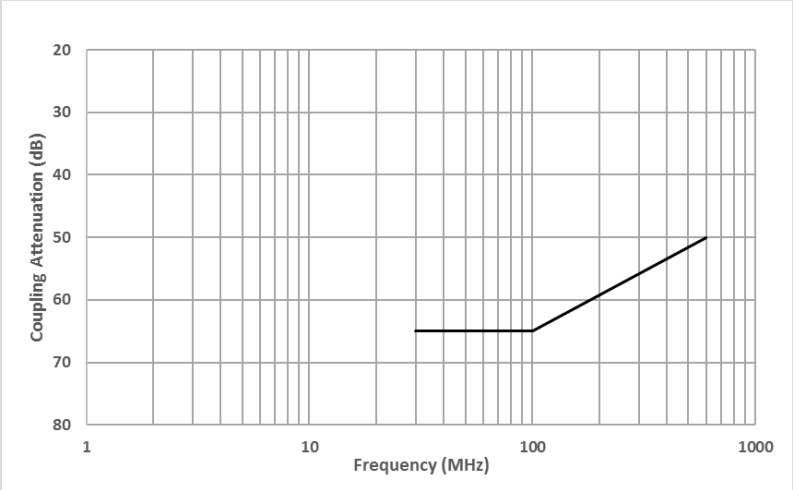

Figure 6.2.4-7: Coupling attenuation limit class 1 for the reference channel assembly

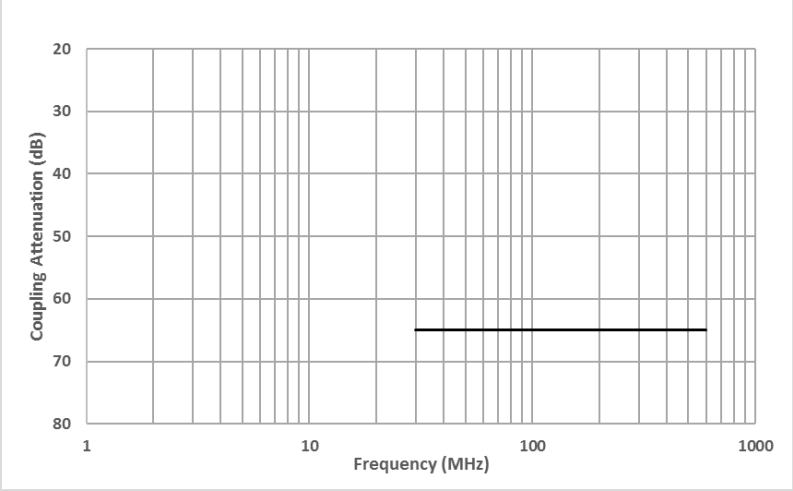

Figure 6.2.4-8: Coupling attenuation limit class 2 for the reference channel assembly

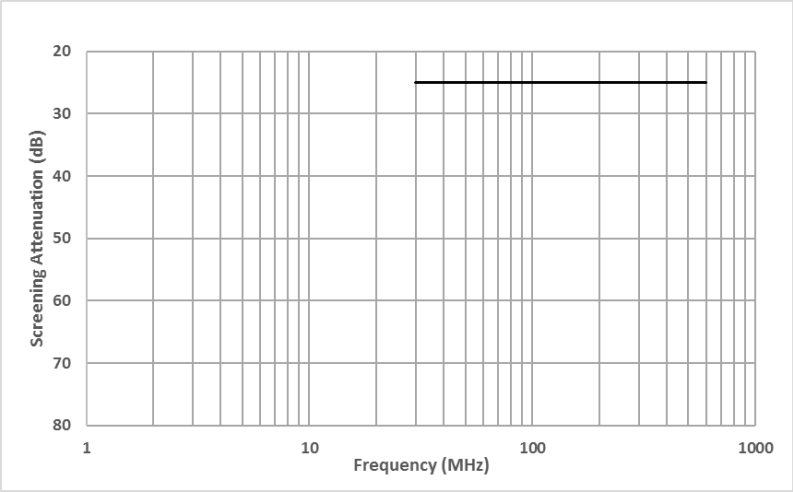

Figure 6.2.4-9: Screening attenuation limit class 1 for the reference channel assembly

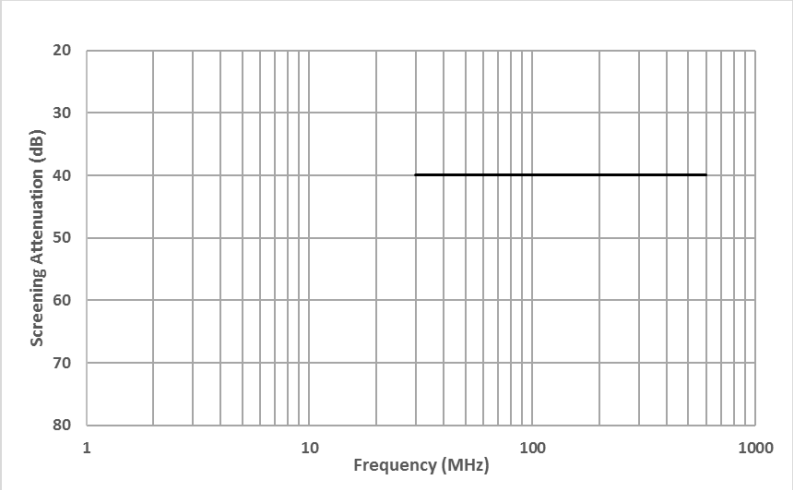

Figure 6.2.4-10: Screening attenuation limit class 2 for the reference channel assembly

7 MDI Test Head

7.1 General MDI Test Head Description

This chapter describes the electrical requirements and basic design guidelines for MDI test heads. A MDI test head is a test fixture for measuring S-parameters (i.e. return loss and mode conversion) of the MDI circuit implementation within an ECU. The measurements are performed from outside the ECU into the MDI connector, which is equivalent to a PCB connector. These measurements are part of the ECU compliance test procedure and further details are not within the scope of this document. The test head shall consist of a cable side connector that can mate to the ECU MDI connector (PCB connector) and coaxial connectors that can attach to the coaxial measurement cables. A continuous low impedance ground connection from the ECU PCB connector shield to the outer contact of the coaxial connectors shall to be provided.

A MDI test head is also recommended for connecting pin terminals, i.e. inline connector terminals, in cable assembly measurements.

Figure 7.1-1 shows a basic drawing of a MDI test head. The MDI test head shall fulfill the definitions in Chapter 4.4 for measurement fixtures. If possible, the cable connector as used in the original harness shall be used. The calibration reference plane is defined at the coax connectors on the MDI test head.

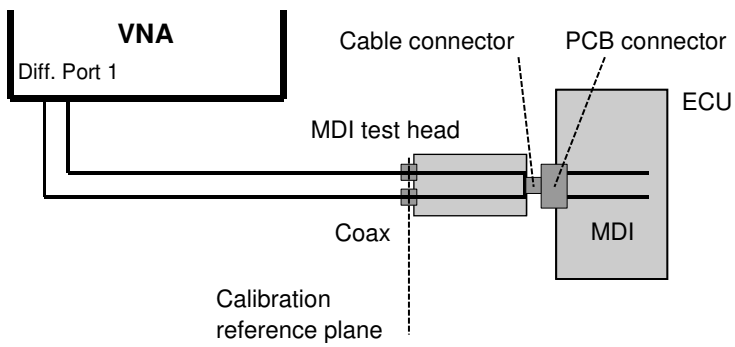

Figure 7.1-1: Example for MDI test head

7.2 Characterization of MDI Test Head and Limits

The characterization of the MDI test head is done by TDR impedance measurement and VNA mode conversion measurement, similar to the fixture characterization in Chapter 4.4. The MDI test head needs to be measured including the cable side connector. The cable side connector is not mated with its counterpart (open). The characteristic impedance differential mode of the MDI test head shall be within 100 Ω ± 5 % at a rise time of 50 ps. An impedance tolerance of ± 10 % at the location of the coaxial connectors is permitted if the 5 % limit is exceeded no longer than 120 ps round trip time or 60 ps propagation time (see Figure 7.2-1). The PCB connector including its footprint shall be excluded from the measurement fixture impedance requirement.

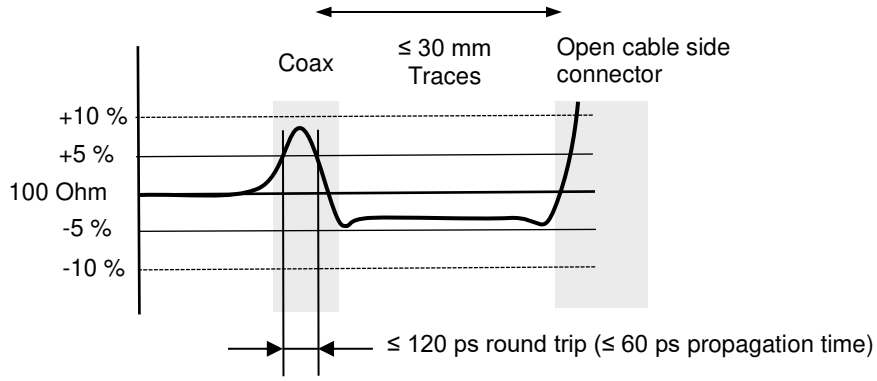

Figure 7.2-1: Characteristic impedance of MDI test head

The maximum trace length on the MDI test head shall not exceed 30 mm to ensure sufficient return loss. Longer trace lengths are permitted in case of design constraints if the following requirements are met to avoid inaccurate return loss results:

- Impedance tolerance of the traces smaller than ± 5 %

or

- Removing the test head traces by de-embedding techniques or by shifting the calibration plane to the leads of the cable side plug connector; the detailed description of such techniques is not scope of this document. The correct application of these methods needs to be demonstrated and documented.

The mode conversion of the MDI test head is characterized by measuring the LCL (S_{dc11}) with the cable side plug in open condition as shown in Figure 7.2-2. The mixed mode port reference impedances of the network analyzer shall be set to 100 Ohm for differential mode and to 25 Ohm for common mode. Correction features of the VNA like port extension or fixture compensation may optionally be used to improve the fixture balance. The correct application of such methods shall be demonstrated.

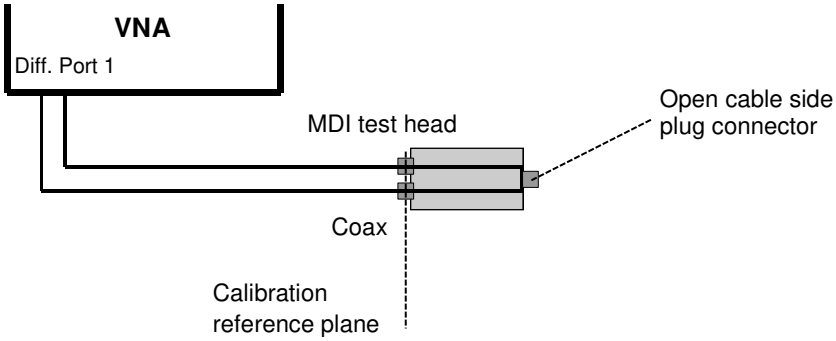

Figure 7.2-2: Mode conversion measurement setup for MDI test head

The mode conversion parameter LCL (S_{dc11}) of the MDI test head shall comply with the requirements given in Table 7.2-1. This limit is more severe than the test fixture balance requirement in Table 4.4.3-1 since the MDI test head can be used for measuring the ECU MDI balance in addition to the use as test fixture for cable assemblies with pin terminals (see Section 5.2.2). ECU MDI balance requirements are given in [1]. Related measurements are not scope of this document.

Table 7.2-1: MDI test head balance requirement

Test parameter	Related S-parameter	Requirement
LCL	S_{dc11}	$\geq \begin{pmatrix} 61 & 10 \leq f \leq 80 \\ 83 - 11.51\,log(f) & 80 < f \leq 600 \end{pmatrix} dB$ $10 \leq f \leq 600$, frequency f in MHz

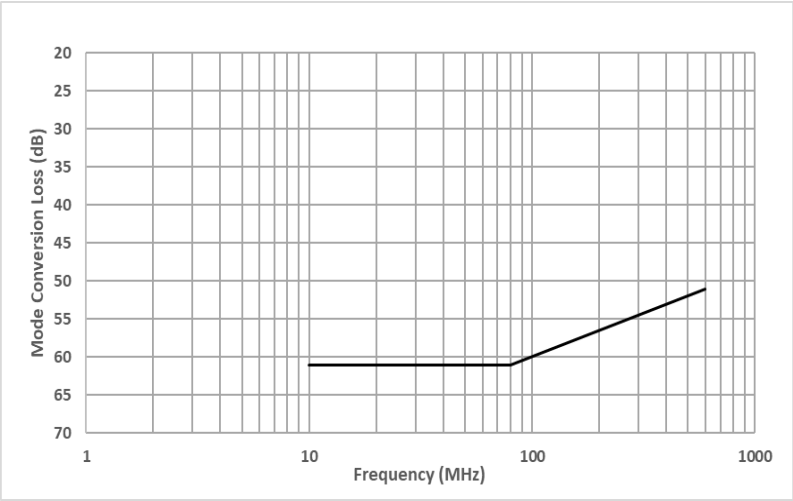

Figure 7.2-3: MDI test head LCL requirement

Annex A
(informative)

Additional Measurement Setup Definitions

A.1 Measurement Fixture Examples

The connector measurement fixture shall provide optimum connection of the PCB connector with the measurement equipment. PCB based measurement fixtures with impedance controlled traces should be used. The length of the traces should be kept as short as possible. Appropriate coaxial connectors are recommended. An example of a PCB based connector measurement fixture with mated PCB connector in Figure A.1-1.

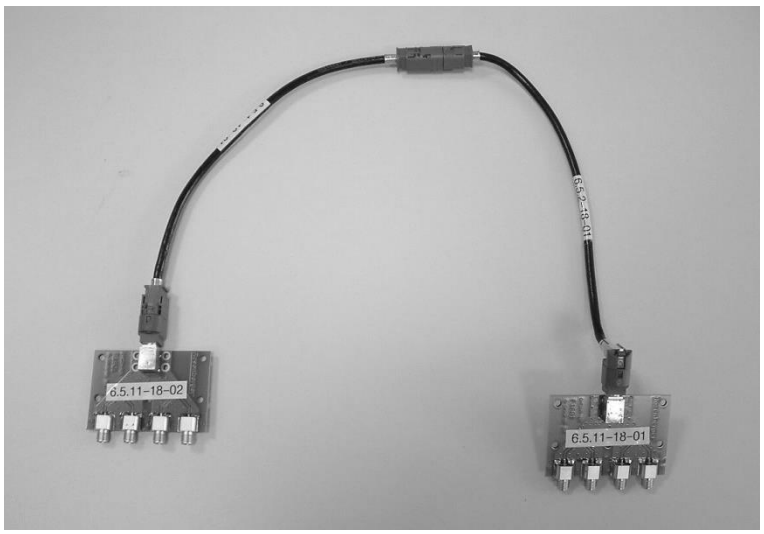

Figure A.1-1: PCB based measurement fixture

For multiport connectors, measurement fixtures with ground layers on bottom and top are recommended to reduce the crosstalk between pairs. An example of a PCB based multiport connector measurement fixture is shown in Figure A.1-2.

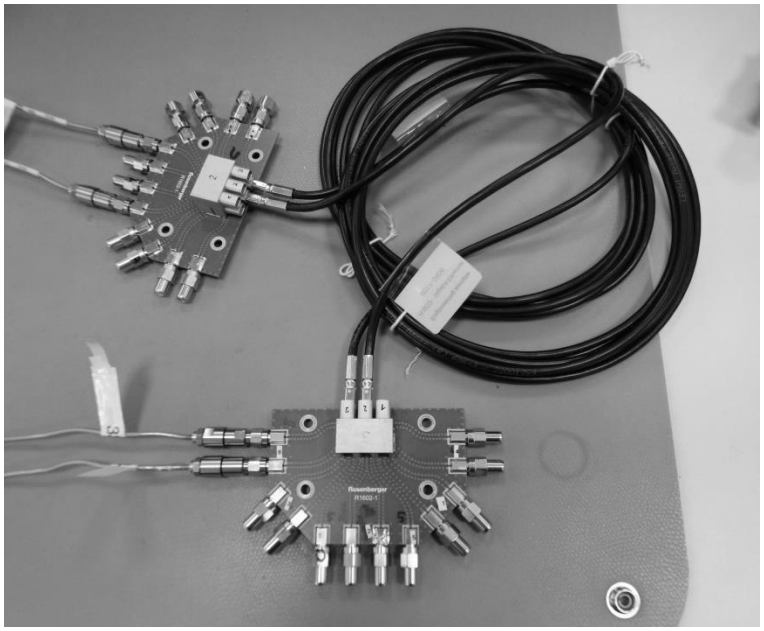

Figure A.1-2: PCB based multiport connector measurement fixture

Direct measurement fixtures can be used for cable measurements. Direct measurement fixtures need to provide a low impedance connection from the cable shield along the measurement fixture to the outer conductor of the coaxial connectors. Figure A.1-3 shows an example of a direct measurement fixture, where the cable conductors are clamped for ease of handling.

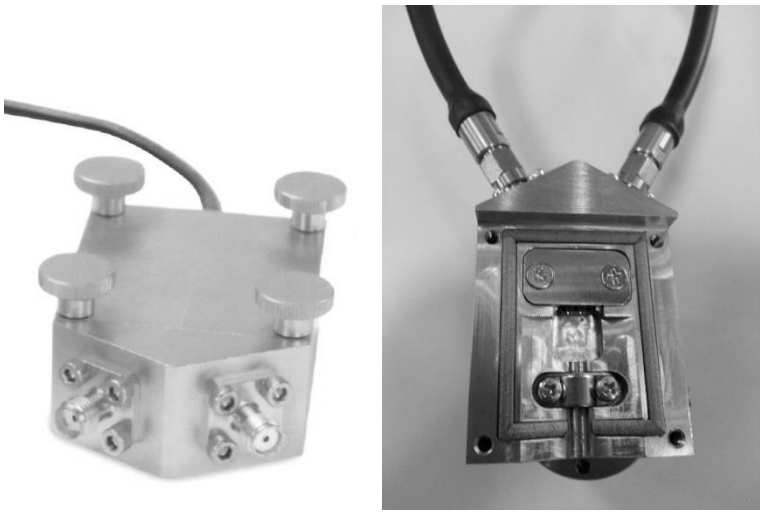

Figure A.1-3: Direct measurement fixture example

A.2 Coupling and Screening Attenuation Measurement Examples

The coupling and screening attenuation of connectors is measured in triaxial setup according to [6]. Figure A.2-1 shows an example of the overall setup for coupling- and screening attenuation measurements of connectors. The differential port of the VNA is connected to the DUT via measurement fixture and differential cable of the specified length by means of tube in tube method. The other side of the triaxial tube is connected to the single ended port of the VNA.

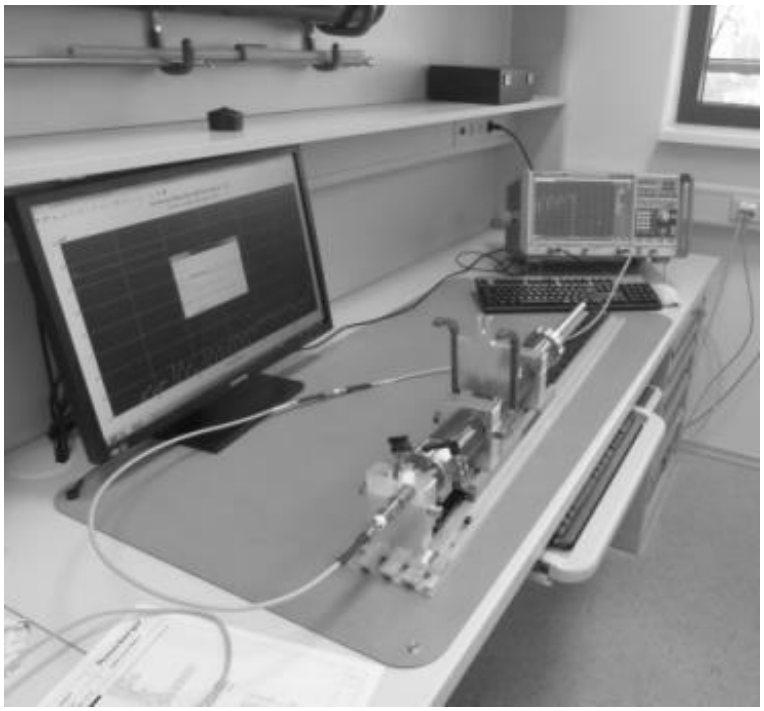

Figure A.2-1: Connector coupling and screening attenuation measurement setup example

Figure A.2-2 and Figure A.2-1 show examples of mated PCBs connector under test.

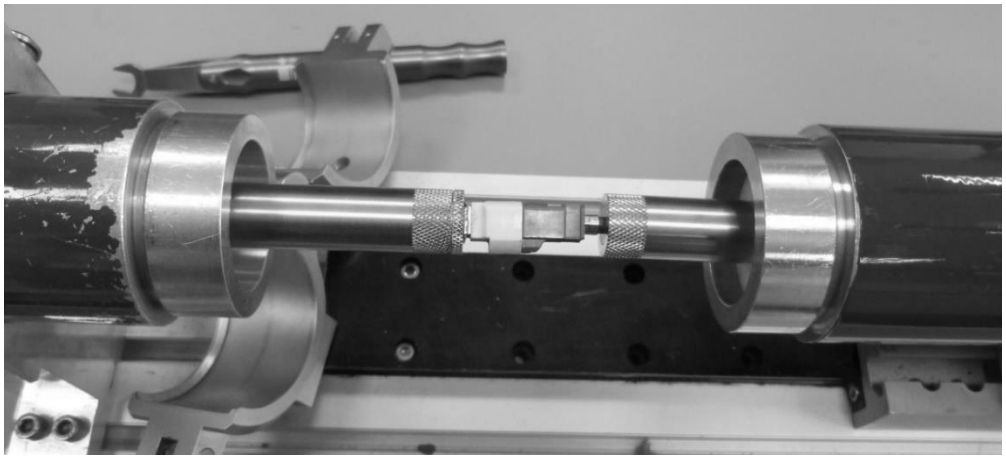

Figure A.2-2: Connector coupling and screening attenuation measurement setup example for straight PCB connectors

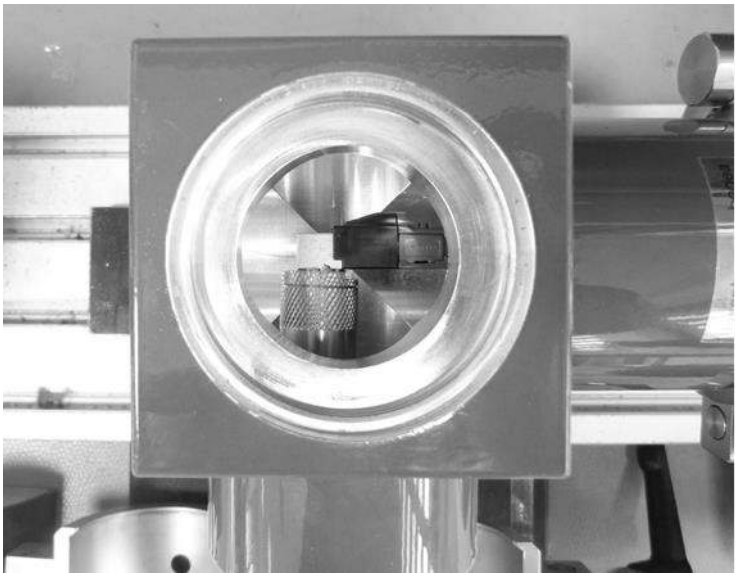

Figure A.2-3: Connector coupling and screening attenuation measurement setup example for right angled PCB connectors

The jacket of the cable is removed right next to the connector and clamps are used to provide a low impedance connection from the inner tube respectively the termination to the cable shield (Figure A.2-4).

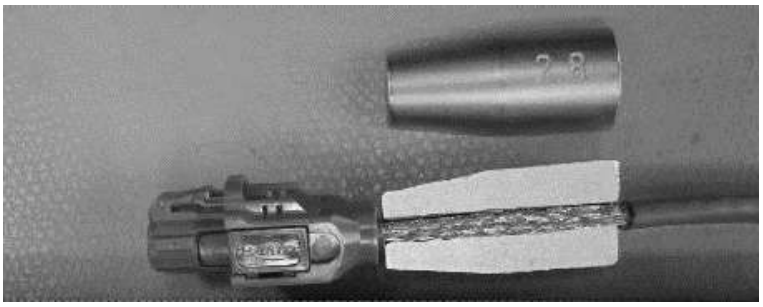

Figure A.2-4: Inline and PCB connector shield contact preparation for coupling and screening attenuation measurement example

Figure A.2-5 shows an example of a PCB connector under test with integrated termination.

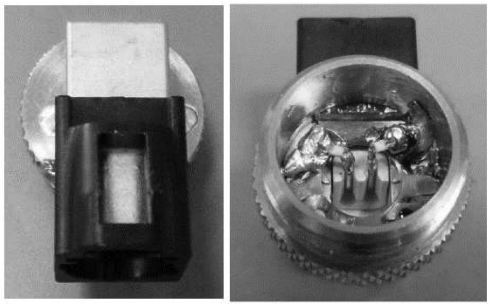

Figure A.2-5: PCB connector coupling attenuation measurement termination example,
where the reference plane is set at the position of the EMC seal

Figure A.2-6 shows an example of a cable termination for an inline connector coupling- and screening attenuation measurement.

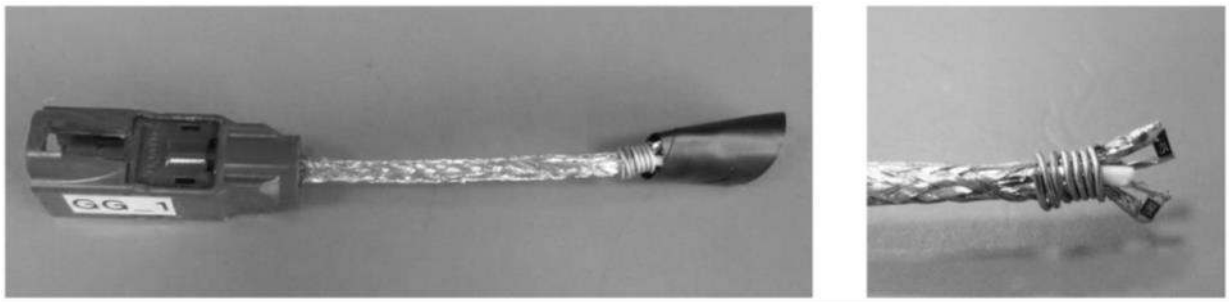

Figure A.2-6: Inline connector and cable coupling and screening attenuation measurement termination example

A.3 Reference Communication Channel

The reference communication channel has got a length of 15 m, consisting of two PCB connectors and four inline connectors that are equally spaced in 3 m distance as shown in Figure A.3-1.

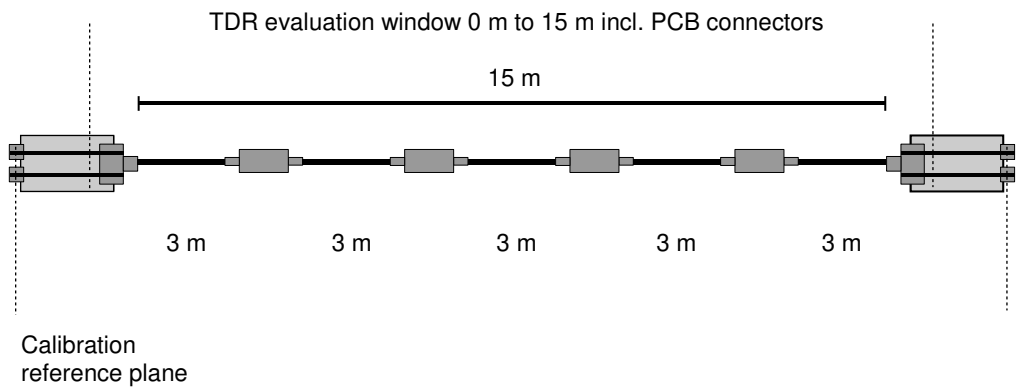

Figure A.3-1: Reference communication channel

This topology serves as common reference to compare different components in terms of their electrical properties and their influence on the whole communication channel. It also allows to compare the results of different test houses.

A.4 Reference Cable Assembly

The reference cable assembly has got a cable length of 3.5 m with cable connectors on each end as shown in Figure A.4-1. This topology serves as common reference to compare cable assemblies in terms of their electrical properties. It also allows comparing measurement results from different test laboratories.

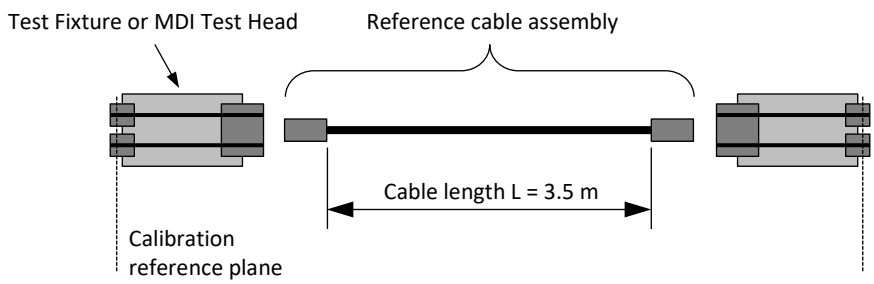

Figure A.4-1: Reference cable assembly

A.5 Reference Wiring Harness

The channel assembly as described in this chapter serves as common reference to compare different components in terms of their electrical properties in the context of a whole wiring harness. It also allows comparing the results of different test houses. The reference wiring harness was derived from a worst-case camera application scenario. It consists of a bundle of five cables in a 4 around 1 configuration as shown in Figure A.5-1 and Figure A.5-2. The total cable length of the bundled part of the wiring harness is 5 m including two equally spaced inline connectors, resulting in 1.66 m length for each cable segment. One communication channel is extended by two segments of 1.5 m length including one additional inline connector. This extended channel is centered in the four around one cable bundle arrangement shown in Figure A.5-2.

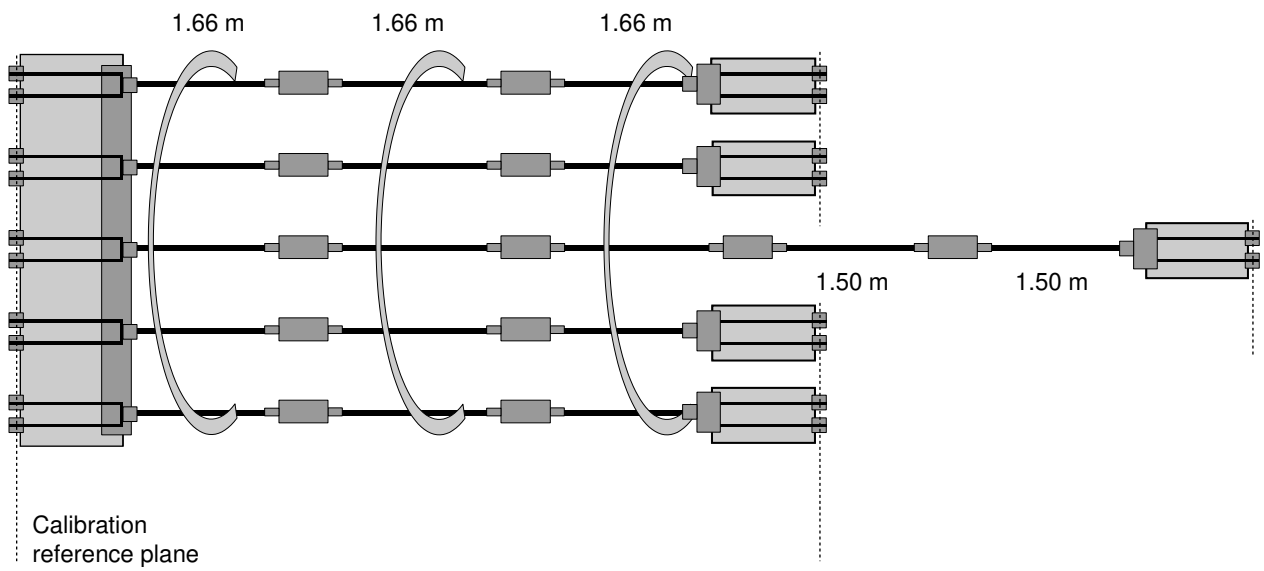

Figure A.5-1: Reference wiring harness cable bundling

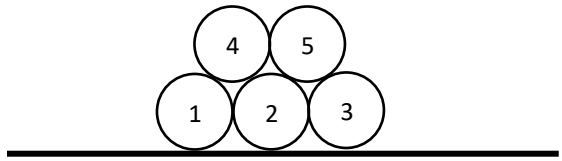

Figure A.5-2: Four around one cable bundling

For each port, the crosstalk results to all other ports need to be summed. Equations how to calculate the power-sum crosstalk from individual transmission measurements are given in Chapter 3.

A.6 Reference Coupling and Screening Attenuation Channel Assembly

Sufficient decoupling within the context of whole communication channels in the environmental system is ensured by meeting the coupling and screening attenuation requirements for connectors (Table 6.2.1-1) and cables (Table 6.2.2-1). To make sure that connector and cable properties in terms of balance and shielding properties are matched in order to reach sufficient coupling attenuation, a reference channel assembly shall be measured with tube-in-tube method. The whole channel assembly has got a nominal length of 1.75 m, including one inline connector and one PCB connector with termination as shown in Figure A.6-1.

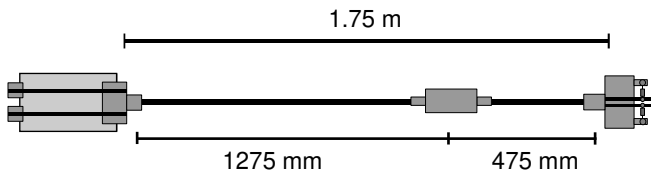

Figure A.6-1: Reference coupling and screening attenuation channel assembly, nominal lengths

Figure A.6-2 gives more details about the assembly tolerances. The overall channel assembly length shall be between 1700 mm and 1800 mm. The exposed channel length within the triaxial tube shall be at least 800 mm. The nominal cable assembly lengths shall be 1275 mm and 475 mm. With respect to the dimensions of the cable under test, the use of a triaxial tube with nominal length 1 m is implied.

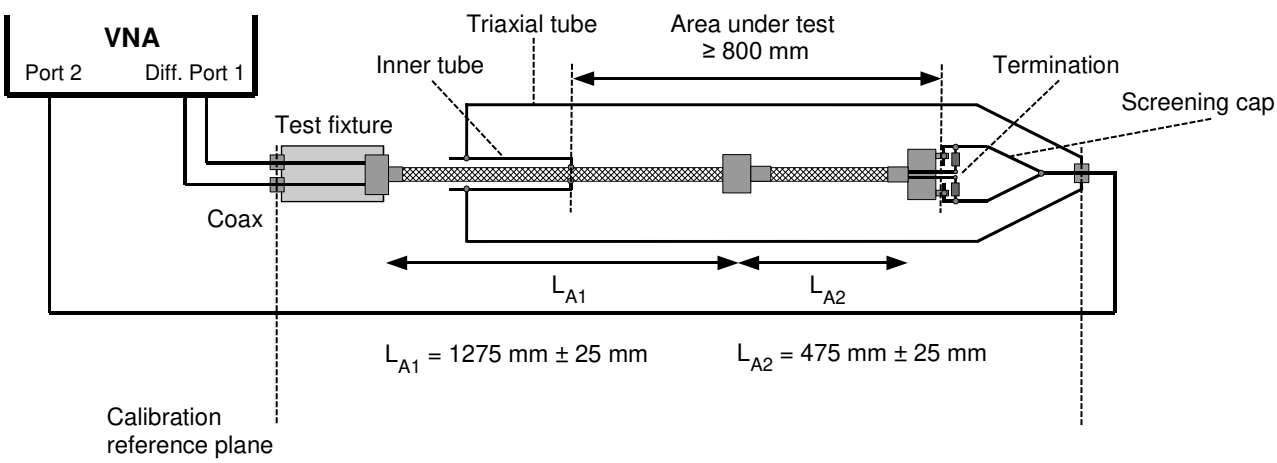

Figure A.6-2: Reference coupling and screening attenuation channel assembly tolerances

This topology serves as common reference to compare different components in terms of their electrical properties and their influence on the whole communication channel. It also allows to compare the results of different test houses.

Annex B
(informative)

Correction Method for TDR Measurements

For long channels the TDR measurement technique leads to incorrect measuring results. To prevent getting fault results the following correction procedure shall be used:

a) TDR measurement from both sides of the investigated channel using system rise time 500 ps

b) If the measured CIDM value increases with a linear slope over length for both particular measurements the correction given below is applicable, otherwise the correction is not allowed.

I. Calculation of slope of measured CIDM function over time at the region of cable:
$S(t, CIDM_{measured}(t))$

Note: The impedance of measurement fixture and ECU connector must be out of focus for this calculation. Possible calculation method: EXCEL function "Slope" or comparable functions at other software tools

II. Correct slope
$CIDM1(t) = CIDM_{measured}(t) - S * t$

III. Getting offset O at the beginning of channel ($t = t_{DUT0}$)
$O = CIDM_{measured}(t_{DUT0}) - CIDM1(t_{DUT0})$

Note: Needed to avoid correction of slope in measurement cables used for connection the TDR measuring equipment with the measurement fixture

IV. Correct offset
$CIDM_{corrected}(t) = CIDM1(t) + O$

The limit is valid for CIDMcorrected (t). Both results for CIDMmeasured (t) and CIDMcorrected (t) shall be given in the resulting diagram. An example of correction results is given in Figure B-1.

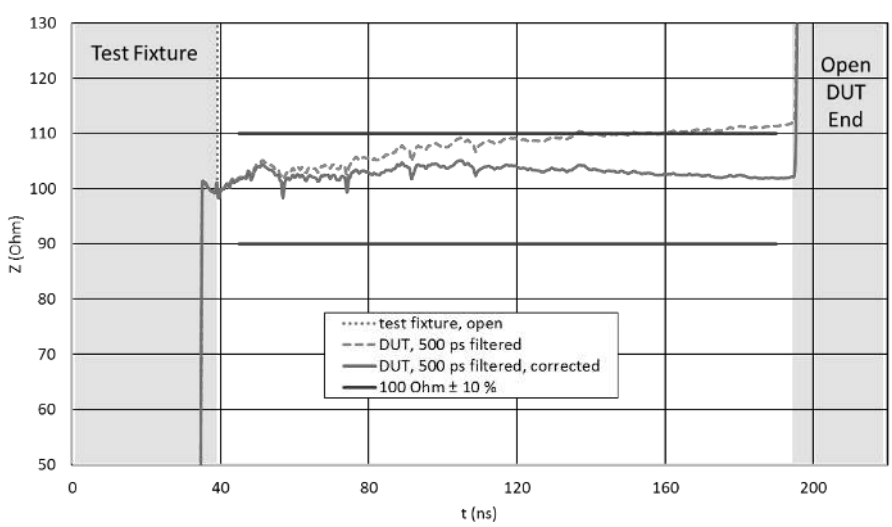

Figure B-1: Example for correction of TDR measurement results for long communication channels