10BASE-T1S Channel and Component Requirements for Link Segments

Electrical Requirements and Measurement Specification for 10BASE-T1S Channels and Components

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4 ABBREVIATION/SYMBOLS

AACRF	Alien attenuation to crosstalk ratio – far end
AFEXT Loss	Alien far end crosstalk loss
AFEXTDC Loss	Alien far end cross conversion loss common to differential
AFEXTDS Loss	Alien far end cross conversion loss single-ended to differential
ANEXT Loss	Alien near end crosstalk loss
ANEXTDC Loss	Alien near end cross conversion loss common to differential
ANEXTDS Loss	Alien near end cross conversion loss single-ended to differential
CC	Communication channel
CIDM	Characteristic impedance differential mode
CM	Common mode
DM	Differential mode
DUT	Device under test
ECU	Electronic control unit
EMC	Electromagnetic compatibility
ES	Environmental system
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
IL	Insertion loss
$IL_{2\text{-way}}$	Insertion loss for two-way connector
$IL_{3\text{-way L-mode}}$	Insertion loss for three-way connector in listener mode
L	Cable length
LCL	Longitudinal conversion loss
$LCL_{2\text{-way}}$	Longitudinal conversion loss for two-way connector
$LCL_{3\text{-way T-mode}}$	Longitudinal conversion loss for three-way connector in transmitting mode
LCTL	Longitudinal conversion transfer loss
$LCTL_{2\text{-way}}$	Longitudinal conversion transfer loss for two-way connector
$LCTL_{3\text{-way L-mode}}$	Longitudinal conversion transfer loss for three-way connector in listener mode

LCTL $_{\text{3-way T-mode}}$	Longitudinal conversion transfer loss for three-way connector in transmitting mode
MDI	Media dependent interface
MS-C	Mixing segment channel
OEM	Original equipment manufacturer
P2P-C	Point-to-point channel
PCB	Printed circuit board
PHY	Physical layer transceiver
PSAACRF	Power sum attenuation to alien crosstalk ratio – far end
PSAFEXT Loss	Power sum alien far end crosstalk loss
PSANEXT Loss	Power sum alien near end crosstalk loss
RF	Radio frequency
RL	Return loss
RL $_{\text{2-way}}$	Return loss for two-way connector
RL $_{\text{3-way T-mode}}$	Return loss for three-way connector in transmitting mode
RL $_{\text{3-way L-mode}}$	Return loss for three-way connector in listener mode
S-parameter	Scattering parameter
SCC	Standalone communication channel
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

5 TERMS AND DEFINITIONS

5.1 Definition of Speed Grades

This specification covers 10BASE-T1S channels and components within a single document.

5.2 Environmental Conditions

The electrical requirements in chapter 11 for communication channels, cables and connectors shall be met for all operating conditions of the application. Within the scope of this document, measurements are carried out at a temperature of (23 ± 5) °C and a relative humidity of (50 ± 25) %. The atmospheric pressure shall be equivalent to altitudes between sea level and 2000 m above. Measurements at other environmental conditions are outside the scope of this document.

It is recommended to keep the temperature constant during measurements with a tolerance of ±1 °C to ensure sufficient stability of test equipment calibration. The equipment including optional electronic calibration devices shall be switched on some time before calibration and measurements according to the recommendations of the equipment manufacturers to allow temperature accommodation of the devices.

5.3 Standalone Communication Channel (SCC)

The SCC for a 10BASE-T1S channel is not limited in length or number of cable connectors. In addition, for the mixing segment implementations the number of Ethernet nodes is not limited as far as the electrical characteristics of the link channel according to [1] are fulfilled.

The SCC consists of two (P2P-C) or more (MS-C) PCB connectors, cables and an unspecified number of inline connectors. PCB and inline connectors can be single or multiport type. Multiport means that the connector provides more than one differential port. Hybrid connectors additionally can have single pins to connect single ended data signals or power supply lines.

The maximum allowed insertion loss for SCCs is independent from the SCC length and shall not exceed the requirements in Table 12 (see [1]). The achievable SCC length depends on the insertion loss of the components, i.e. cables and connectors, that are used.

The component requirements given in chapters 11.2.1 and 11.2.2 are defined in a way to fulfill the SCC requirements for MS-C with a maximum number of 8 Ethernet nodes and a maximum channel length of 15 m while using standard loss cables and a maximum channel length of 25 m while using low loss cables according to Table 11. For other implementations (e.g. more or less than 25 m channel length and/or more or less than 8 nodes), the component requirements need to be adapted accordingly.

5.4 Environmental System (ES)

The ES consists of power and signal cables that may also include other applications than 10BASE-T1S Ethernet within the same wiring harness.

5.5 Whole Communication Channel (WCC)

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

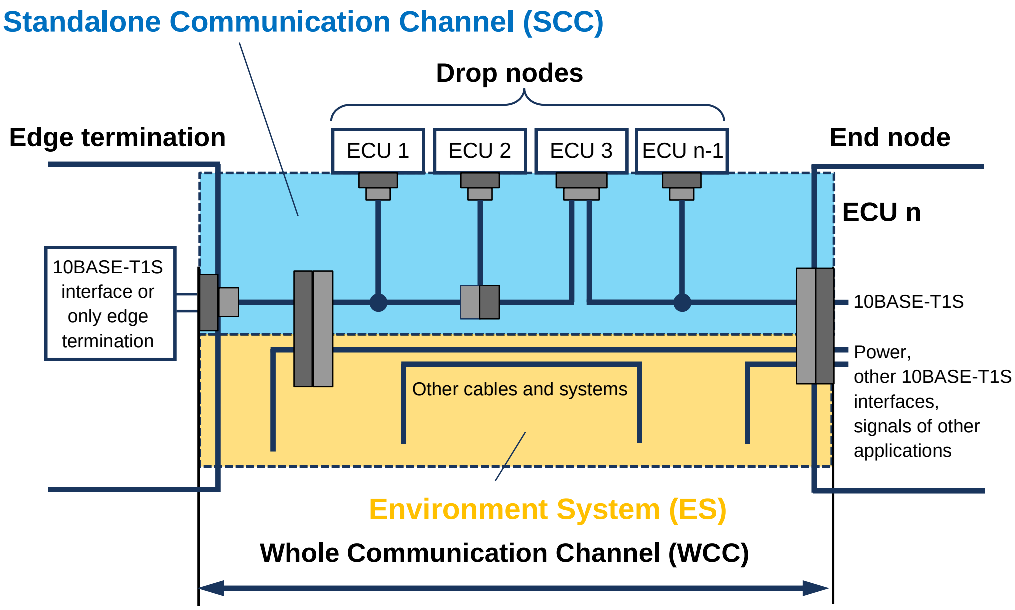

Figure 1: Example for whole communication channel and its components for a mixing segment topology

A whole communication channel (WCC) consists of the standalone communication channel (SCC) that is used for the 10BASE-T1S data transmission between the ECUs and an additional environment system (ES) for data or power transmission. This model is used to consider the electromagnetic interaction between the Ethernet channel and other systems that can occur as crosstalk within multiport connectors, hybrid connectors, multi-pair cables or bundles of cables.

Although the scope of this document is on 10BASE-T1S only, specific applications may require the characterization of crosstalk parameters between Ethernet channels and other data channels in the same component or system such as multiport connectors with UTP ports for other data applications in proximity to a 10BASE-T1S port. If no specific requirements are defined by these other applications, the recommendations for 10BASE-T1S on multiport measurement fixtures, related measurement methods and crosstalk requirements are applicable. Further signal integrity and EMC parameters for data channels other than 10BASE-T1S are not within the scope of this specification. Power and other multi-purpose contacts and cables are also not covered by this specification.

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 usual, 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.

The requirements on connectors and cables as components have been derived from the channel type 2 definition of [3] (MS-C in bus-stub configuration with separated edge terminations and 8 Ethernet nodes).

5.6 Types of Connectors

Connectors can be single port, multiport or hybrid type if it consists of more than one Ethernet port in a common housing. Connectors can be cable and PCB connector types. Cable connectors are assembled on a cable. PCB connectors are assembled on a PCB. A connector typically is socket or plug type. Figure 2 defines the port numbering for a single port connector that is used for a two-way or a three-way connection, corresponding to the S-parameter port numbering in Table 1.

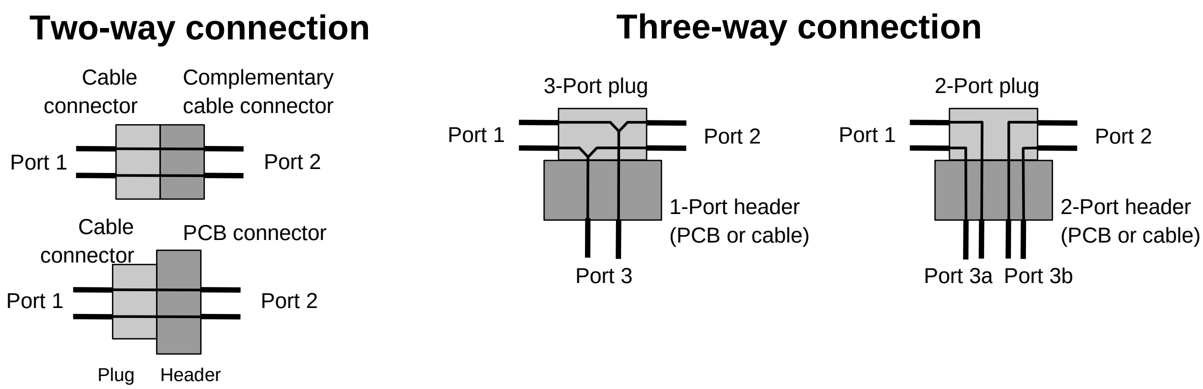

Figure 2: Typical definition of S parameter ports for single PCB connectors

5.7 Definition of RF Parameters

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

Table 1: Definitions for RF and S-parameters

Test parameter	**Symbol or related S-parameter**	**Description**
Impedance		
CIDM	Z_{RF}	Characteristic impedance differential mode Comment: there is no test requirement defined on components and channels for CIDM but it is used for measurement fixture evaluation.
Single channel characteristics		
RL	S_{dd11}, S_{dd22}, S_{dd33}	Return loss
IL	S_{dd21}	Insertion loss
LCL[1]	S_{dc11}, S_{dc22}, S_{dc33}	Longitudinal conversion loss
LCTL[1]	S_{dc12}, S_{dc21}	Longitudinal conversion transfer loss
Crosstalk environment system to Ethernet channel		
PSANEXT Loss	see equation (3-1)	Power sum alien near end crosstalk loss (optional, only used for 5-around-1 cable bundle test setup)
PSAACRF	see equation (3-2)	Power sum attenuation to alien crosstalk loss ratio far end (optional, only used for 5-around-1 cable bundle test setup)
ANEXTDC Loss[2]	S_{dcyx}	Alien near end cross conversion loss common to differential
ANEXTDS Loss[2]	S_{dsyx}	Alien near end cross conversion loss single-ended to differential

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.
2 The subscription y indicates one of the SCC logical ports 1, 2 or 3. The subscriptions x and z indicate any other logical port which is analyzed for crosstalk to SCC but not being a part of SCC, while x is near end side and z is far end side.

AFEXTDC Loss[2]	S_{dcyz}	Alien far end cross conversion loss common to differential
AFEXTDS Loss[2]	S_{dsyz}	Alien far end cross conversion loss single-ended to differential

There is not a test requirement defined for characteristic impedance differential mode (CIDM) in time domain because it is indirectly determined by return loss for channels and components. To fulfill these return loss requirements the usage of components with a CIDM value of Z_{RF} = (100 ± 10) Ω is recommended.

The power sum crosstalk parameters PSANEXT Loss and PSAACRF are optional parameters and not applicable for any kind of WCC. Based on the definitions of [1], they can be used for analysis of components in a 5-around-1 cable bundle arrangement (up to 15 m length and up to four in-line connectors, equally spaced).

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

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

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

where the function $ANEXT\ Loss(f)_{N,j}$ 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.

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

$$PSAACRF(f)_N = -10\, log_{10} \sum_{j=1}^{m} 10^{\frac{-AACRF(f)_{N,j}}{10}}\, dB \tag{3-2}$$

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:

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

5.8 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 https://www.electropedia.org

6 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all 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 802.3cg™: 2019, *IEEE Standard for Ethernet - Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors*

[2] 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)*

[3] OPEN ALLIANCE: *IEEE 10BASE-T1S Implementation Specification – TC14 System implementation*

[4] IBIS Open Forum, *Touchstone® File Format Specification*

7 INTRODUCTION

The specification describes unshielded link segments and their components for use in 10BASE-T1S Automotive Ethernet applications. It defines test methodologies, measurement setups, measurement fixtures and electrical requirements for measuring signal integrity parameters and crosstalk of connector and cable components as well as for harnesses.

8 SCOPE

The intention of this specification is to define the general RF requirements and test methodologies for physical layer communication channel and its components according to Figure 3 and Figure 4 to enable 10BASE-T1S technologies that use unshielded twisted pair cables and unshielded connectors for Automotive Ethernet applications.

These requirements are related to signal integrity and EMC behavior of the communication channel. The link segment requirements for 10BASE-T1S according to [1] shall be met as well.

The qualification of the cabling systems and components shall be done under a well-defined setup to make results comparable. This document defines electrical parameters to be tested for the complete communication channel between two (P2P-C) or more (MS-C) Ethernet nodes and for cables and connectors as a single component of this communication channel. It contains test procedures, measurement 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.

Based on the definitions in [1], the communication channel can be implemented in two different ways:

- Point-to-point channel (P2P-C), example given in Figure 3 and
- Mixing segment channel (MS-C), example given in Figure 4.

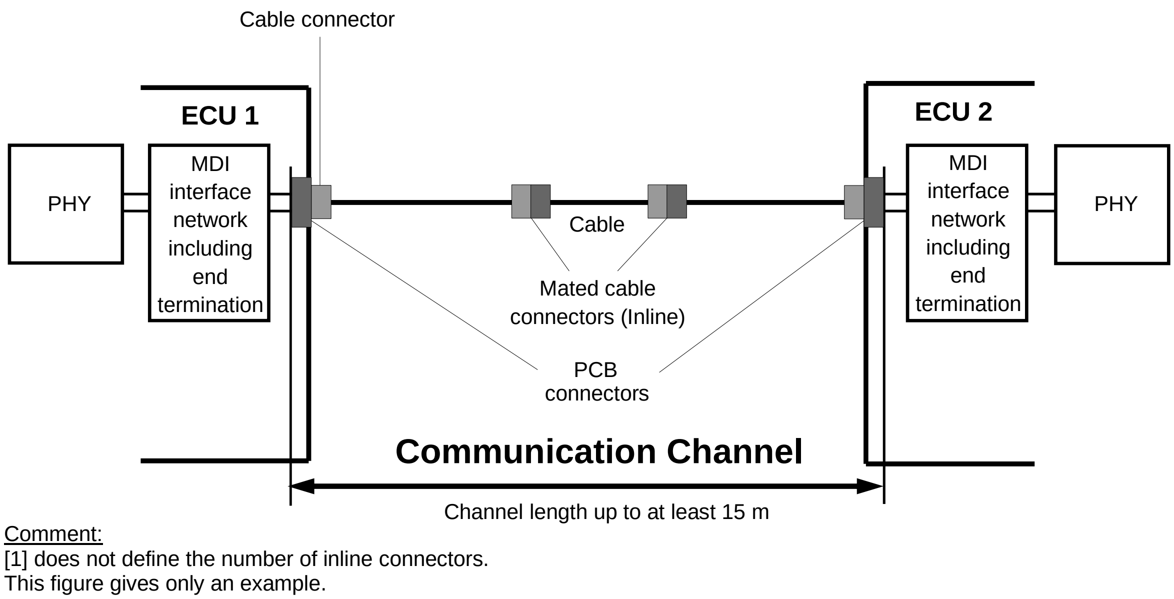

Figure 3: Definition of communication channel for point-to-point implementation

The mixing segment topology is implemented as a bus with 100 Ω line impedance, 100 Ω edge termination at both ends and short stubs (maximum 0.1 m) to connect a certain number of drop nodes. The connection points of bus and stubs are the bus junctions. A bus junction can be set up as a simple wire connection or a three-way connector. If the bus junction becomes a part of the PCB connector of the drop nodes the topology changes to a daisy chain configuration. For integration of 100 Ω edge termination into a 10BASE-T1S node it becomes an end node (see Figure 4).

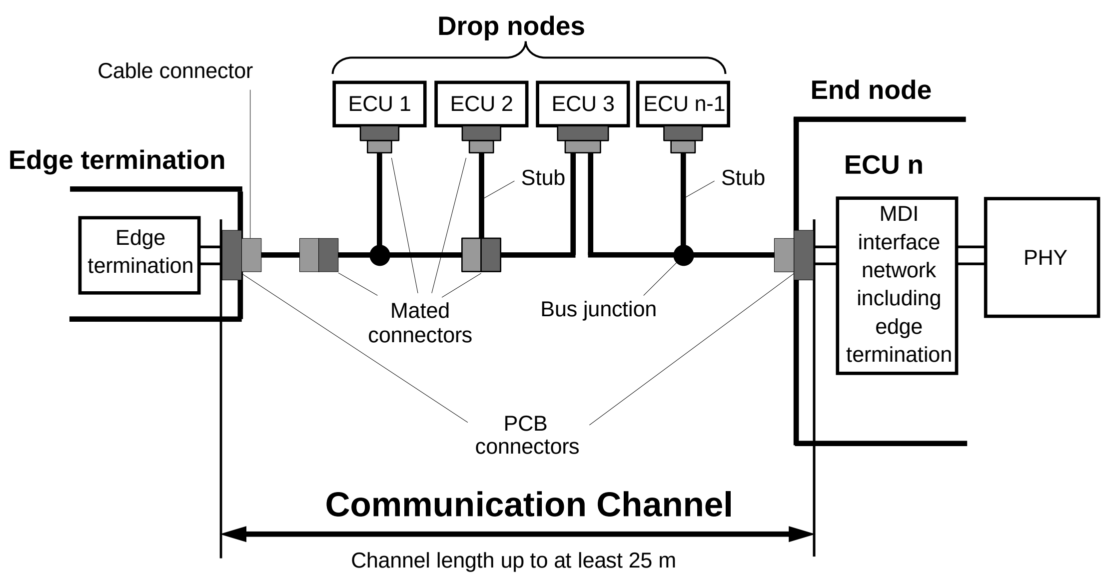

Figure 4: Definition of communication channel for mixing segment implementation

Because of 10BASE-T1S uses half duplex communication scheme, each Ethernet node (end node or drop node) can be in active transmitting mode or in receiving mode (listener mode). In consequence, the test conditions for connectors and channels need to be differentiated.

While using a point-to-point channel in half duplex mode according to [1], it can be interpreted as a subcase of the mixing segment channel that includes only two end nodes but no drop nodes and no bus junctions. In this case the end nodes include the 100 Ω edge termination and the MDI interface network with PHY. Furthermore, all definitions for test conditions and test setups are done for the mixing segment channel but are also valid for the point-to-point channel where applicable.

9 GENERAL SETUP AND SETTINGS

9.1 Required Measurement Instruments

The measurement instruments used shall fulfill the technical requirements in Table 2.

Table 2: Required parameters for used measurement instruments

Measured parameter	Equipment	Parameter	Value
S-parameter	VNA	Type	Minimum 4-ports
		Port reference impedance	50 Ω single ended
		Frequency range	f = 300 kHz to 1000 MHz
Characteristic impedance differential mode (CIDM)	TDR test system	Type:	2 channel differential mode
		System impedance:	50 Ω single ended / 100 Ω differential mode
		Rise time:	Pulse generator: ≤ 25 ps internal (≤ 100 ps at measurement fixture) Analyzer: no filter / 100 ps internally adjustable (digital filtering of the reflected signal by using the filtering function of the test equipment) All values 10 – 90 %
All	Measurement fixture	Depending on the test method used (see special definitions for cables and connectors).	

Time domain based measurement instruments may also be used to measure mixed mode S-parameter if they can support the VNA settings given in Table 3 and fulfill the calibration accuracy requirements of Table 4.

VNAs may also be used to perform characteristic impedance measurements of test fixtures if it can provide an equivalent pulse with 100 ps rise time as specified in Table 2. The time domain measurement shall be carried out with the VNA settings given in Table 5.

9.2 Measuring Device Settings and Calibration

To achieve a high degree of comparability of test results, the VNA settings given in Table 3 are recommended. The value used for each parameter of Table 3 shall be documented in the measurement report. For measurement of cable and connectors as well as for SCC and ES measurements at the two possible channel implementations P2P-C and MS-C partly different values for some parameters shall apply.

Table 3: Recommended VNA settings for measurements in frequency domain

<table>
<tr><th rowspan="2">Parameter</th><th colspan="4">Value</th></tr>
<tr><th>Cable</th><th>Connector</th><th>P2P-C</th><th>MS-C</th></tr>
<tr><td>Sweep f_{start}</td><td colspan="4">300 kHz</td></tr>
<tr><td>Sweep f_{stop}</td><td colspan="4">1 GHz</td></tr>
<tr><td>Sweep type</td><td colspan="4">logarithmic</td></tr>
<tr><td>Sweep points</td><td colspan="4">1601</td></tr>
<tr><td>Measurement bandwidth</td><td colspan="4">≤ 3 kHz</td></tr>
<tr><td>Port reference impedance differential mode</td><td>100 Ω</td><td>Cable side: 100 Ω
MDI side: 50 Ω</td><td>100 Ω</td><td>End node: 100 Ω
Drop node (transmitting): 50 Ω</td></tr>
<tr><td>Port reference impedance common mode</td><td>200 Ω</td><td>Cable side: 200 Ω
MDI side: 100 Ω</td><td>200 Ω</td><td>End node: 200 Ω
Drop node (transmitting): 100 Ω</td></tr>
<tr><td>Data calibration kit (VNA)</td><td colspan="4">used kit for calibration</td></tr>
<tr><td>Averaging function</td><td colspan="4">may be applied, but not mandatory</td></tr>
<tr><td>Smoothing function</td><td colspan="4">deactivated</td></tr>
</table>

The VNA calibration accuracy shall be verified by a direct thru-thru connection between the differential ports at the calibration plane (Figure 5). If the connectors of the coaxial measurement cables are of the same gender on both differential ports, a matched pair of coaxial precision adaptors is recommended to connect the measurement cables.

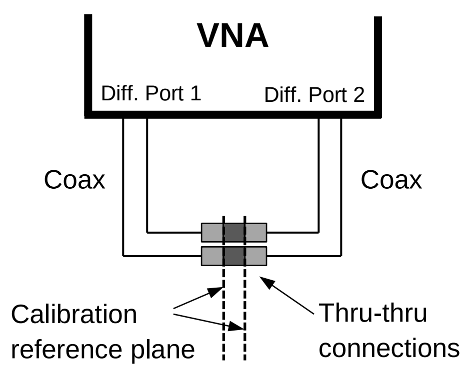

Figure 5: Thru-thru connection for verification of VNA calibration accuracy

The thru-thru connection of the VNA (including the coaxial cables) shall comply with the requirements given in Table 4. The values are derived from the most stringent electrical parameter to be measured, plus an additional margin to reduce measurement uncertainty. The LCL, LCTL and RL parameters shall fulfill the requirements given in Table 4. The LCL calibration accuracy may also be verified with measurement of cables in open condition at the calibration plane.

Table 4: VNA calibration accuracy requirements

Test parameter	Related S-parameter	Requirement
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 35 & 0.3 \leq f < 12.35 \\ 35 - 19.59 \log\left(f/_{12.35}\right) & 12.35 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40$, frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
LCL LCTL	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12}	$\geq \begin{pmatrix} 51 & 0.3 \leq f \leq 50 \\ 39 - 20 \log\left(\frac{f}{200}\right) & 50 < f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200$, frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)

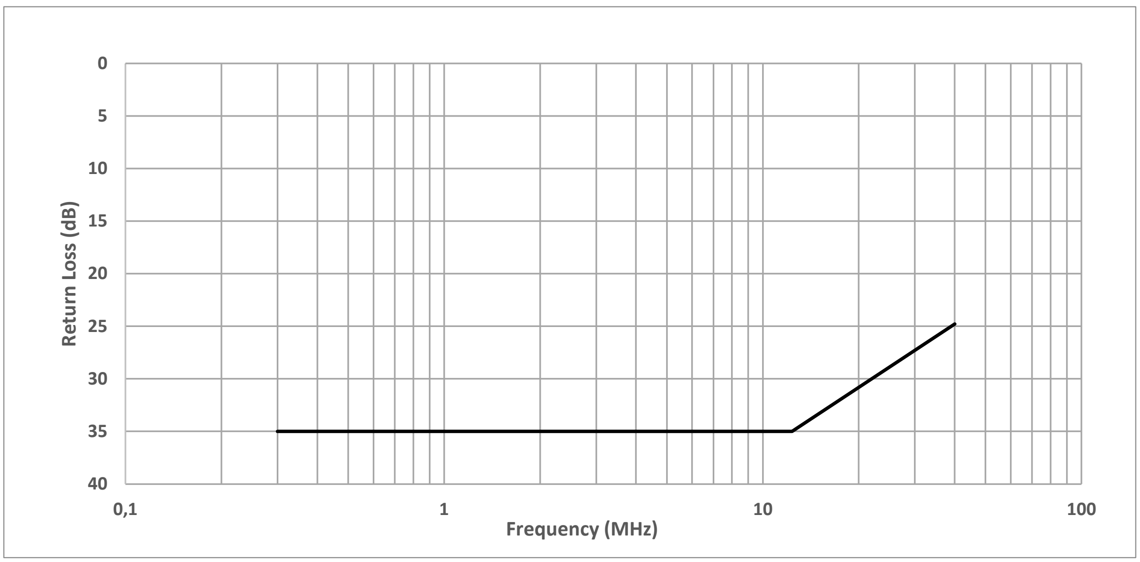

Figure 6: Return loss requirements for VNA calibration accuracy

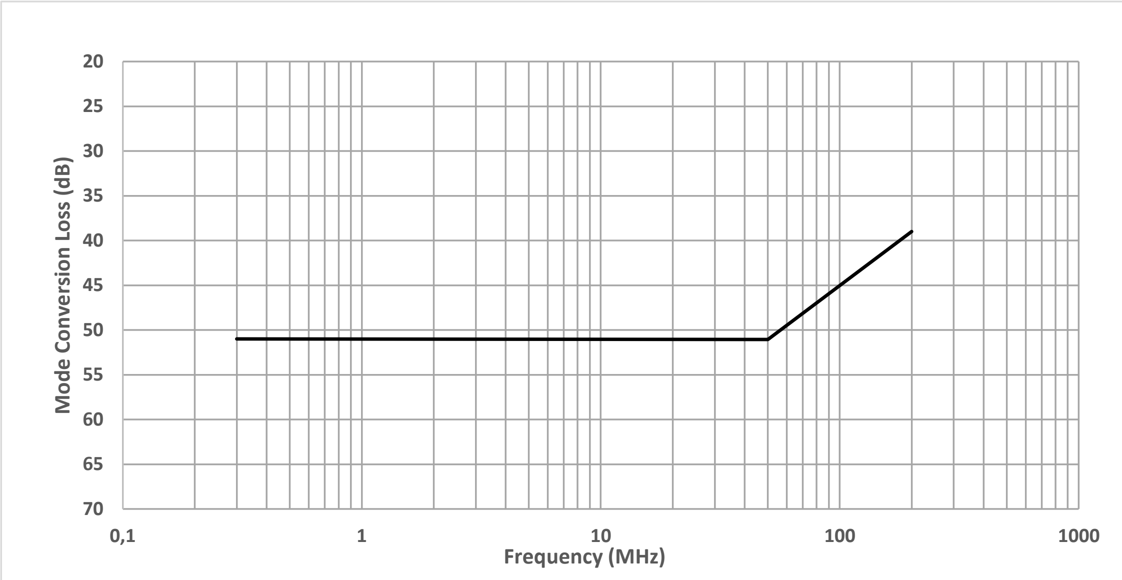

Figure 7: LCL / LCTL requirements for VNA calibration accuracy

If characteristic impedance measurements are carried out by a VNA, the following settings are recommended to get results equivalent to a TDR test system.

Table 5: Recommended VNA settings for time domain impedance measurement

Parameter	Value
Sweep f_{start}	1 MHz
Sweep f_{stop}	9.7 GHz (resulting rise time: 100 ps for fixture characterization)
Sweep type	linear
Sweep step size	1 MHz
Filtering[3]	von Hann window
TDR Type	Step
Measurement bandwidth	≤ 500 Hz
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

[3] Other window functions may be used. In this case, the required sweep stop frequency f_{stop} shall be adjusted accordingly.

9.3 Measurement Fixtures

9.3.1 General

Measurement fixtures are used to adapt an automotive connector or cable to coaxial connectors and shall provide sufficient electrical and mechanical quality, so that the measurement result is not dominated by the characteristics of the measurement fixture. The phase stability of VNA test cables and test fixtures is essential to ensure sufficient accuracy of mode conversion measurements.

In general, the measurement fixtures used need to have low insertion loss, high symmetry within the two lines of a differential pair and very good matching to 50 Ω single ended impedance. In opposite to the general definition of 100 Ω differential line impedance, fixtures used for board connectors including a bus junction need to be designed for 50 Ω differential line impedance at the MDI port (see Figure 2, port 3 or port 3a, 3b respectively).

Because of test fixtures are used in combination with a ground reference plane, they shall provide a low resistance and low inductance connection from fixture ground to the surface of the conductive table or conductive drum, e.g. by using conductive plates or stands. This reference ground connection shall be direct, reaching up 10 mm to the connection point of the DUT.

The measurement fixtures or design hints for them should be provided by the connector or cable manufacturer. Examples of appropriate measurement fixtures are given in Annex A.1.

The electrical requirements for the measurement fixtures shown in sub-sections 9.3.4 shall be met. Correction features of the VNA like "port extension" or "fixture compensation" may optionally be used to improve the fixture balance. The measurement reference plane may optionally be moved to the DUT by VNA features such as "port extension". The open fixture balance requirements shown in Table 6 shall still be met after applying the phase correction features mentioned above. Serial numbers shall be assigned to the measurement fixtures to allow individual identification.

9.3.2 Fixtures for Connector and Channel Measurements

For measurements of connectors and channels, PCB based test fixtures are recommended. Examples with principal definition are given in Figure 8 for single port fixtures and in Figure 9 for multiport fixtures.

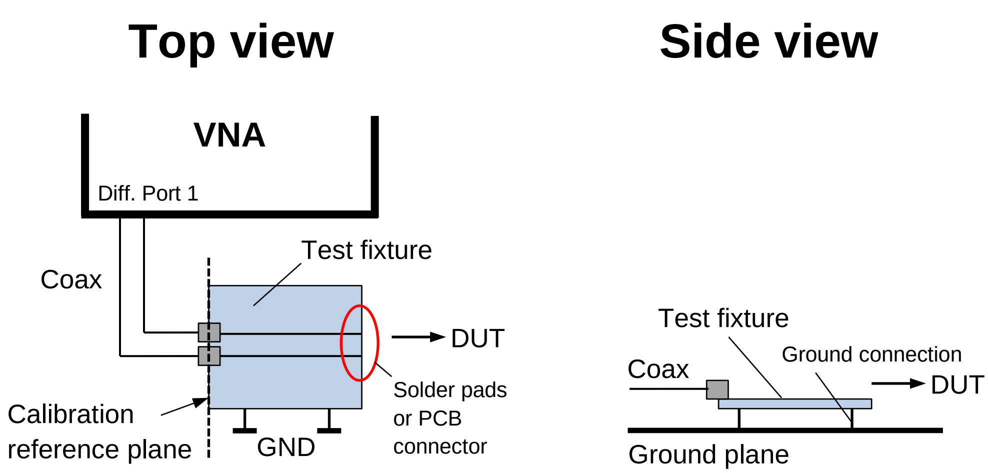

Figure 8: PCB based measurement fixture example for SCC analysis

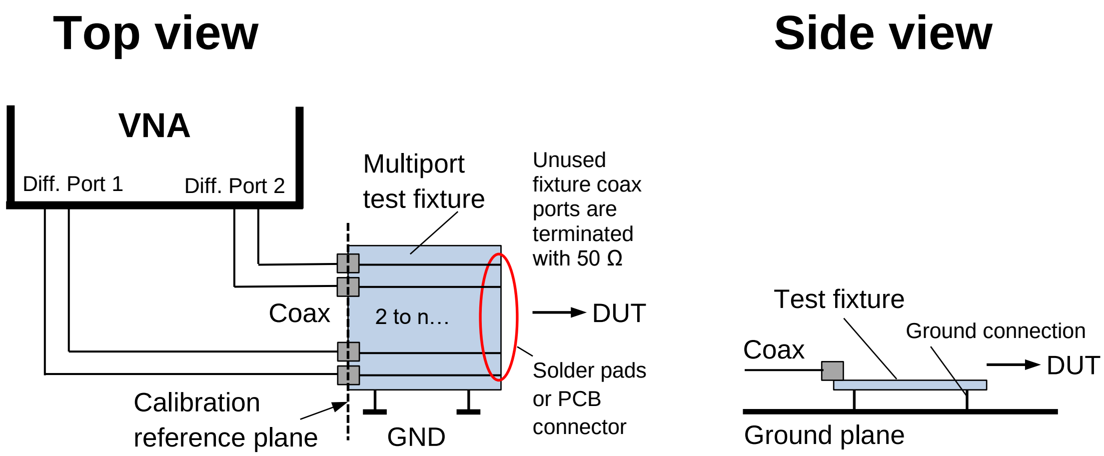

Figure 9: PCB based measurement fixture example for crosstalk analysis in respect to ES

For fixtures used for hybrid connectors, the same definitions and requirements as for single and multiport connectors shall be applied.

9.3.3 Fixtures for Cable Measurements

To minimize the fixture length when attaching the bare cable leads, a direct test fixture is recommended for cable measurements. Figure 10 gives an example for a direct test fixture with principal definitions of connections and calibration reference planes. Alternatively, PCB based test fixtures can be used as well for cable measurements.

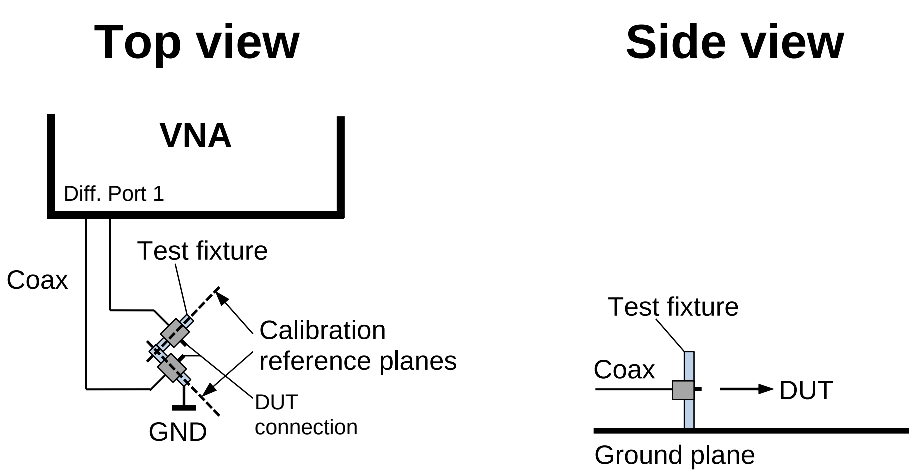

Figure 10: Direct measurement fixture example for SCC analysis

9.3.4 Electrical Requirements on Test Fixtures

The characteristic impedance differential mode is defined to 50 Ω for a board connector test fixtures at MDI port and 100 Ω for all other measuring paths of test fixtures. The impedance of the test fixture shall be within the reference value (50 Ω or 100 Ω) ± 5 % at a rise time of 100 ps. As shown in Figure 11 an impedance tolerance of ± 10 % is permitted if the 5 % limit is exceeded no longer than 240 ps round trip time or 120 ps propagation time.

The maximum trace length on PCB based test fixtures shall not exceed 60 mm to ensure sufficient fixture return loss. Longer trace lengths are permitted in case of design constraints like measuring larger size multiport or hybrid connectors. To avoid inaccurate return loss results the impedance tolerance of the individual traces shall be smaller than ± 5 %. As an alternative to this requirement, compensation of the fixture by de-embedding techniques or by shifting the calibration plane to the DUT leads is also possible. Those procedures may be different for specific test equipment and are not described in this document. The open fixture balance requirements in Figure 13 shall still be met after applying the correction methods mentioned above.

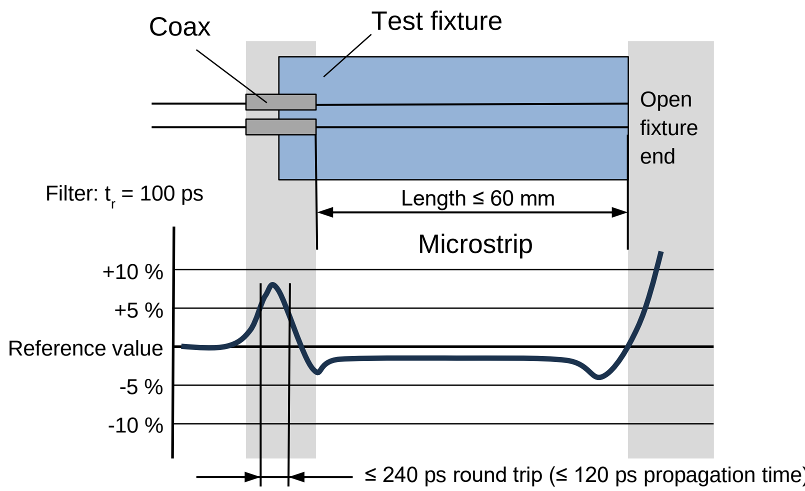

Figure 11: Characteristic impedance differential mode of test fixtures

PCB based test fixtures that are used for measurements of three-way connection in listener mode (see Figure 20) shall have a parasitic differential capacitance $C \leq 2$ pF at the MDI side measurement path.

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 fabric has a major impact, as well as the thickness of the traces. The mode conversion properties of the measurement fixture shall be measured as LCL (S_{dc11}) value without the connected DUT while using the setup according to Figure 12. For this measurement, the reference plane for calibration shall be at the coaxial end of the measurement cables. If the measurement fixture contains a PCB connector to be tested, the characterization of the measurement fixture shall be performed without the connector soldered to it. For board connectors that require a specific design of PCB footprint, an alternative characterization method may be specified by the connector supplier.

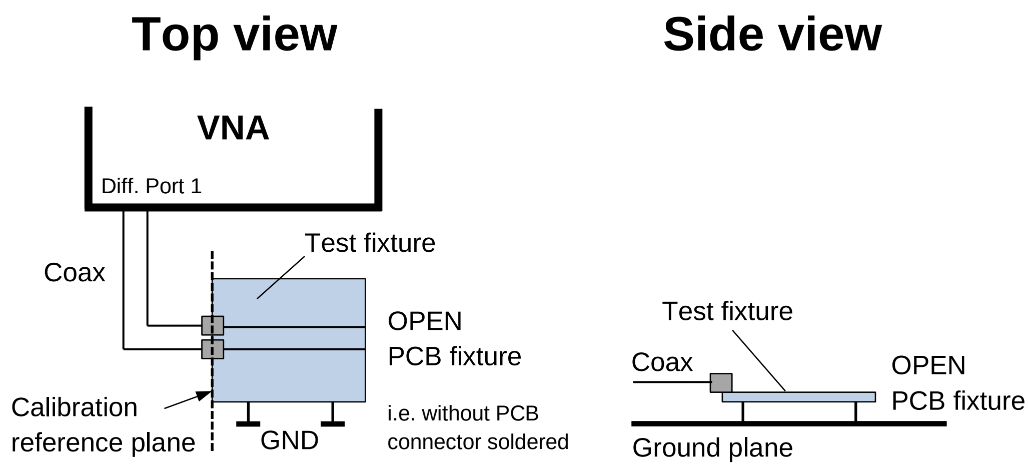

Figure 12: Setup for validation of measurement fixture balance

The mode conversion parameter LCL (S_{dc11}) of the measurement fixture shall comply with the requirements given in Table 6 and Figure 13.

Table 6: LCL requirement for measurement fixture balance

Test parameter	**Symbol or related S-parameter**	**Requirement**
LCL	S_{dc11}	$\geq \begin{pmatrix} 51 & 0.3 \leq f \leq 50 \\ 39 - 20\,log\left(\frac{f}{200}\right) & 50 < f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200$, frequency *f* in MHz Port reference impedances: • in general: 100 Ω (DM), 200 Ω (CM) • MDI port of connector fixture: 50 Ω (DM), 100 Ω (CM)

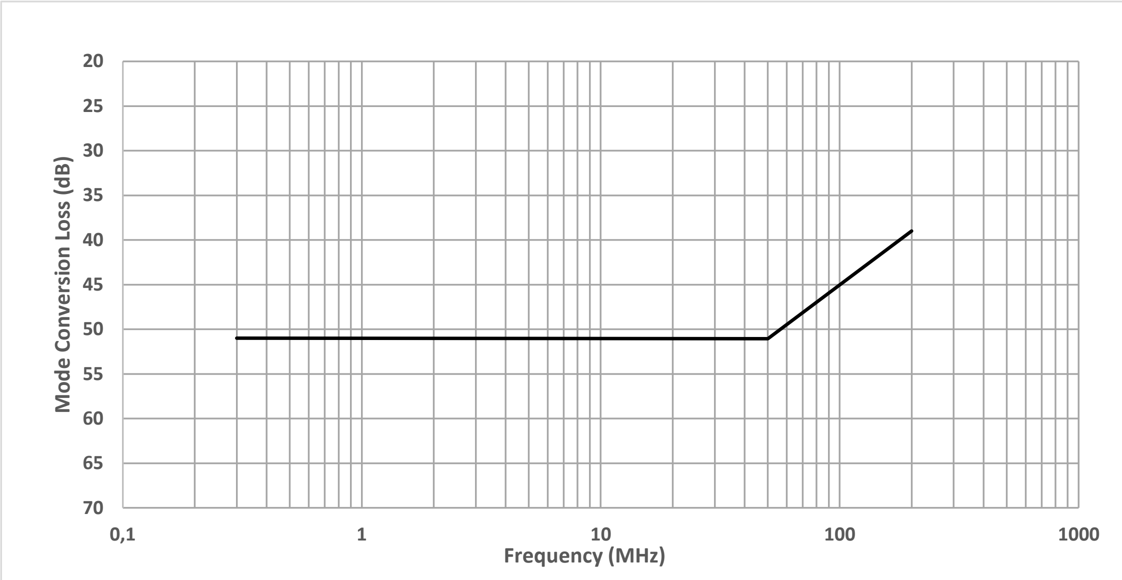

Figure 13: LCL requirement for measurement fixture balance

The crosstalk between the differential ports of test fixtures for multiport connectors shall be lower than the limit that needs to be measured against. The near end crosstalk of the test fixture shall be measured without the PCB connector under test soldered to it (see Figure 14). The transmission from every port shall be measured to any other neighboring port. For board connectors that require a specific design of PCB footprint, then an alternative characterization method could be specified by the connector supplier.

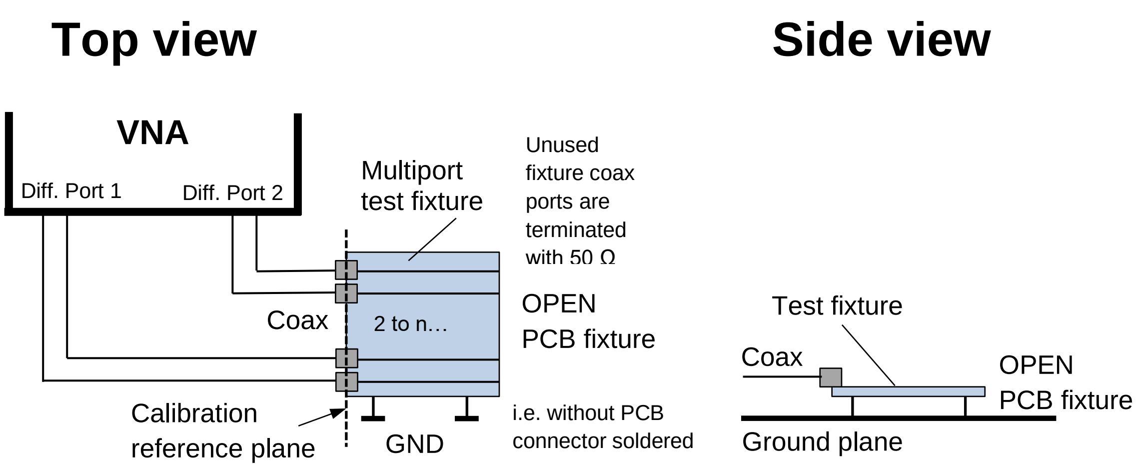

Figure 14: Setup for validation of multiport measurement fixture crosstalk

The crosstalk within multi-port measurement fixtures shall comply with the requirements given in Table 7 and Figure 15.

Table 7: Measurement fixture crosstalk requirements

Test parameter	Symbol or related S-parameter	Requirement
ANEXTDC Loss ANEXTDS Loss	S_{dcyx} S_{dsyx}	$\begin{pmatrix} 51 & 0.3 \le f \le 50 \\ 39 - 20\,log\left(\frac{f}{200}\right) & 50 < f \le 200 \end{pmatrix} dB$ $0.3 \le f \le 200$, frequency *f* in MHz Port reference impedances: • in general: 100 Ω (DM), 200 Ω (CM) • MDI port of connector fixture: 50 Ω (DM), 100 Ω (CM)

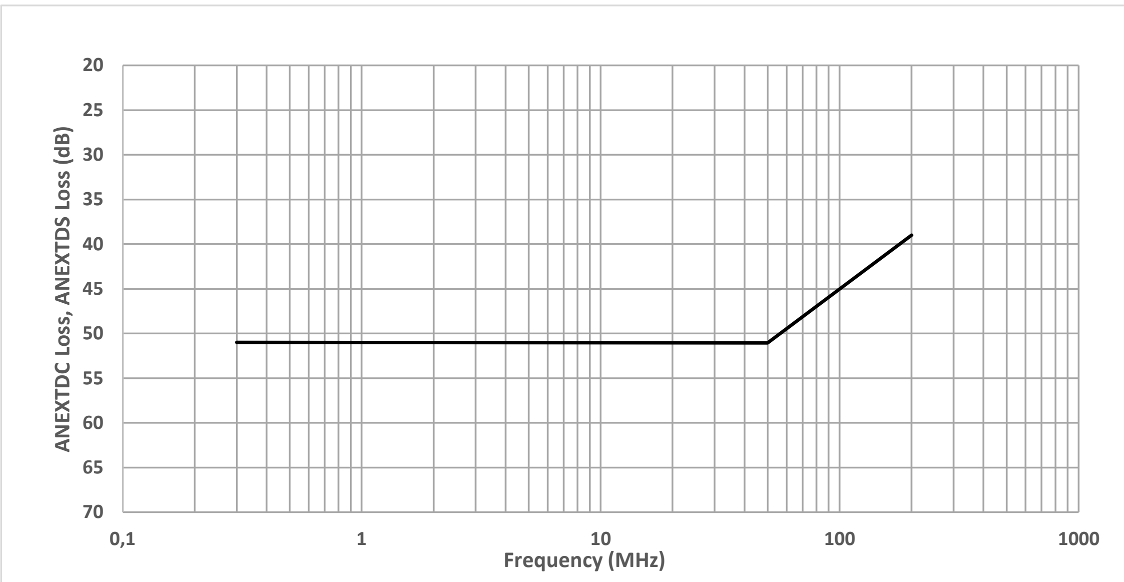

Figure 15: ANEXTDC Loss and ANEXTDS Loss requirement for fixture cross mode conversion

9.4 Handling Instructions

To ensure a high degree of reliability for the measurements, the definitions in [2] and the following precautions shall be fulfilled.

Measurement fixtures shall fulfill the requirements in chapter 9.3.

The reference plane of the calibration shall coincide with the measurement reference plane. In case of differences, the magnitude of errors shall be determined. For connector measurements, the measurement reference plane can be shifted towards the evaluation windows by using gating methods.

The following additional requirements are given:

1. Accurate and consistent resistor loads shall be used for each pair throughout the test sequence.

2. The coax cables shall be placed to satisfy the requirements of the specific test and needs to be fixed throughout the test sequence.
3. Stress on coax 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 to meet the requirements in Table 4 during the complete test sequences including handling operations for connecting and disconnecting the DUTs.
4. 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 in the scope of this document and the correct application shall be demonstrated and documented.
5. Phase stable VNA test cables shall be used. Coaxial cables between measurement instruments and measurement fixtures shall be chosen in a way that the calibration requirements in Table 4 are fulfilled.
6. Overload conditions of the measurement instruments shall be avoided.
7. The VNA shall provide sufficient stability with low electrical drift to meet the accuracy requirements in Table 4 during the entire test sequence.

9.5 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 test cable types, cable length and production number
- Documentation of used calibration kit and of calibration accuracy in thru-thru configuration
- Pictures of test set-up and measurement fixtures
- Documentation of measurement fixture characterization and of optional correction methods such as fixture de-embedding, phase correction, re-normalization, absolute gate positions etc.
- Results for S-parameter
- Result as dB value with related limit
- Diagram with logarithmic or linear frequency axis up to minimal f = 1000 MHz

The S-parameters may be provided as data files for further use. In this case, the use of data exchange formats according to [4] is recommended.

10 MEASUREMENT SETUPS

10.1 Measurement Setups for Connectors

In general, connectors shall be measured in a mated pair configuration using test fixtures according to section 9.3. The measurement result is valid for the specific combination of socket and plug connector type.

For evaluation of PCB connectors, it will be connected directly to the measurement fixture by soldering or other connection technologies like press fit connection as specified for the individual component by the manufacturer.

Cable connectors are measured including a short piece of cable on each cable connector in combination with PCB based fixtures according to section 9.3.3. This allows the properties of the whole connector to be captured, including the area of wire transition from the contacts to the cable. Therefore, the transition area between the connector and the adapter cable (also described as untwist length) is part of the measurement result and shall be assembled as used in the application. The free cable leads of the test fixture side (see Figure 16: transition to fixture) are attached to the PCB traces by soldering or by other appropriate methods. The resulting transition length between cable and test fixture shall be as short as possible depending on the actual fixture design.

The adapter cable length, including the area to the test fixture, shall be as short as possible but not longer than 60 mm to keep the influence of the cable on the measurement result relatively low. The maximum length of 60 mm is defined to enable the test of larger multiport connectors. For inline connectors the length of the cable shall be identical on both sides. The cable length is measured along that cable section where the cable geometry remains unchanged compared to the original cable construction, i.e. the length of the remaining cable jacket. In case of unjacketed cables, the distance between the first and the last crossing location of the twisted wires shall be measured (see Figure 16). A multiple of half of the cable twist length from the contact area to the measurement fixture will provide the same orientation of the conductors and ease handling. Omitting the cable, i.e. cable length zero, is not permitted.

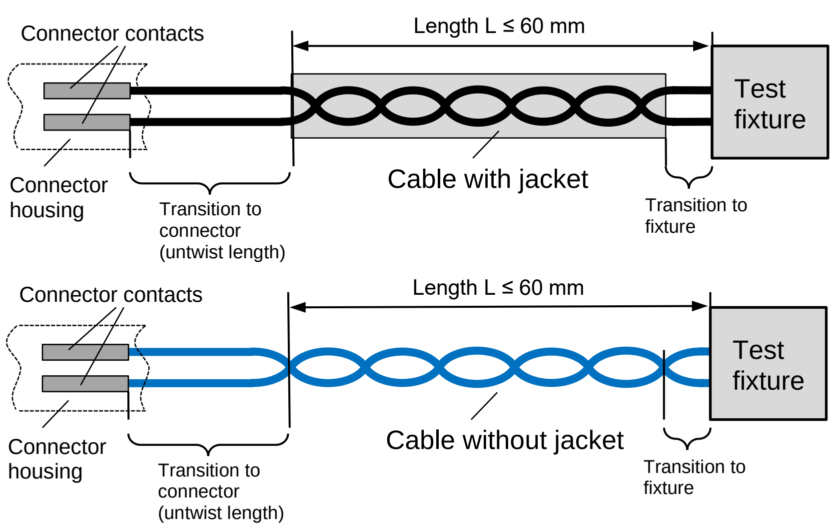

Figure 16: Maximum cable length for connector measurements

The transition length between cable and connector is the remaining untwist length of the cable to be connected and is part of the DUT and shall comply with the specifications of the component manufacturers.

In case of multiport or hybrid connectors, all individual pairs intended to be used for 10BASE-T1S communication shall be evaluated for SCC. In the measurement procedure other non-evaluated differential or single ended pins are terminated as defined in Figure 26. In principle, the crosstalk in between the intended SCC pairs and all other differential pairs or single pins of the connector shall be evaluated according to the ES definition. It can be reduced to the critical pins next to 10BASE-T1S pins. This reduction shall be agreed between supplier and customer.

10.1.1 Single Port and Multiport Connectors for SCC

Because of different possible connector implementations for a single pair connector and/or connection with integrated or associated bus junction, there are different test configurations for connector measurements defined in Figure 17, Figure 18, Figure 19 and Figure 20. Each of these figures define the measurement parameters, S-parameter measurement ports and reference port impedances for differential mode and common mode depending on the specific use case.

Figure 17 describes the test condition for a two-way connection of a single pair which is valid for transmitting mode and listener mode of an Ethernet node or a simple inline connection.

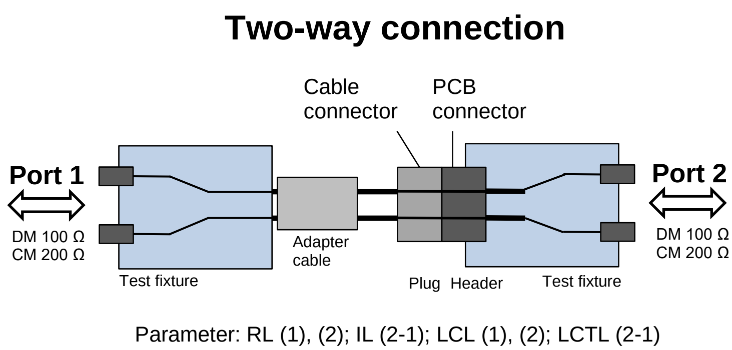

Figure 17: Test conditions for connectors for two-way connections

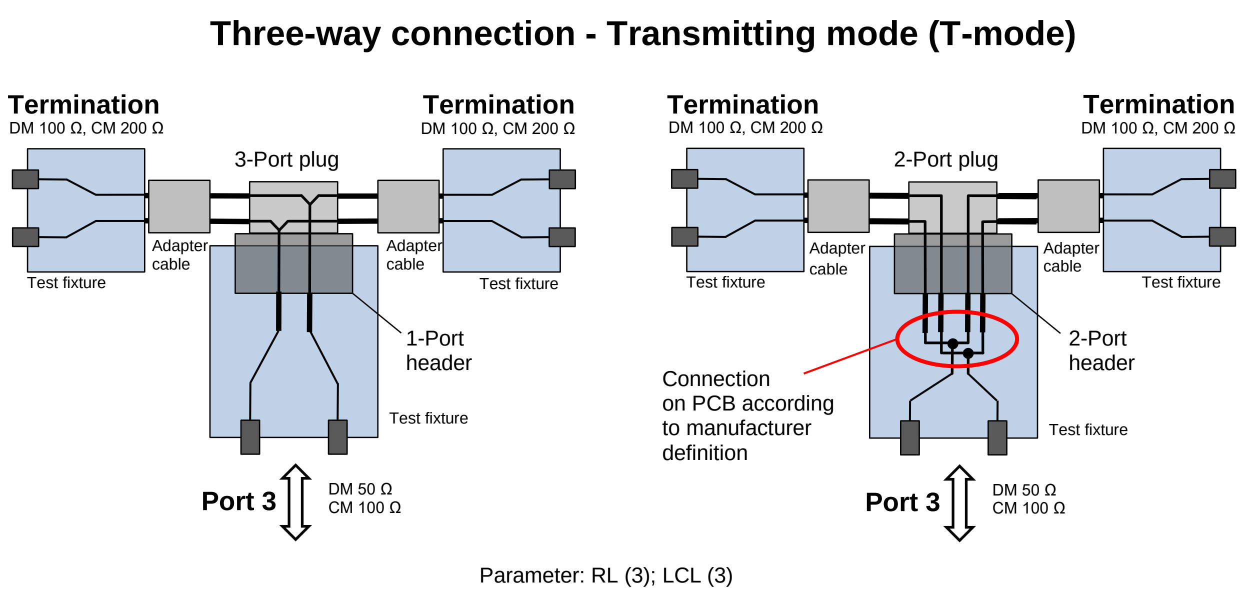

Figure 18: Test conditions for connectors for three-way connections in transmitting mode, reflected parameters

Figure 18 gives the definition for connectors in a three-way connection used as bus junction in transmission mode of an Ethernet node. There are two possible implementations for the bus junction: inside the cable plug or at the PCB close to the connector header pins. For the PCB junction point implementation, the definitions of the connector manufacturer need to be followed. For transmitting mode only, the reflected S-parameter RL and LCL at the MDI side are evaluated while the cable connections of the connector plug are terminated with the defined reference impedances.

The port configuration for LCTL measurements of three-way connections in transmitting mode are given in Figure 19. Depending on the evaluated path (3-1 or 3-2) one of cable side ports port 1 and 2 is used for measurement and the second is passive terminated.

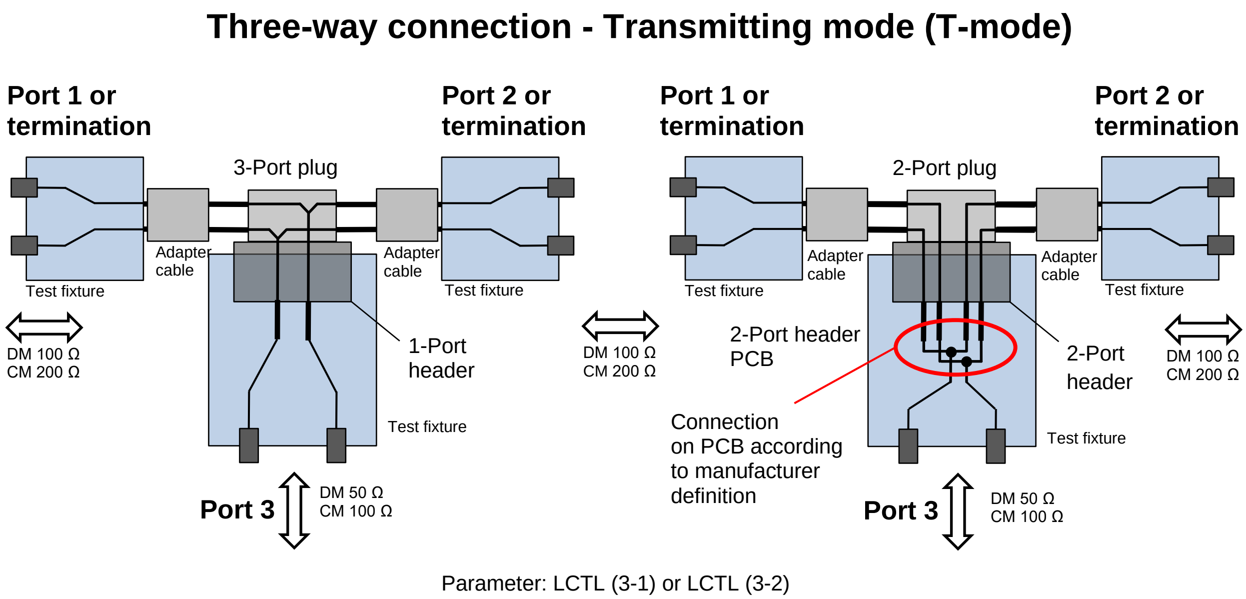

Figure 19: Test conditions for connectors for three-way connections in transmitting mode, transmission parameters

Figure 20 describes the three-way connection used as bus junction in listener mode of an Ethernet node. For connector evaluation in listener mode, the MDI port (port 3) remains unconnected (open) and the S-parameter between the cable connections of the connector plug (port 1 and port 2) are evaluated.

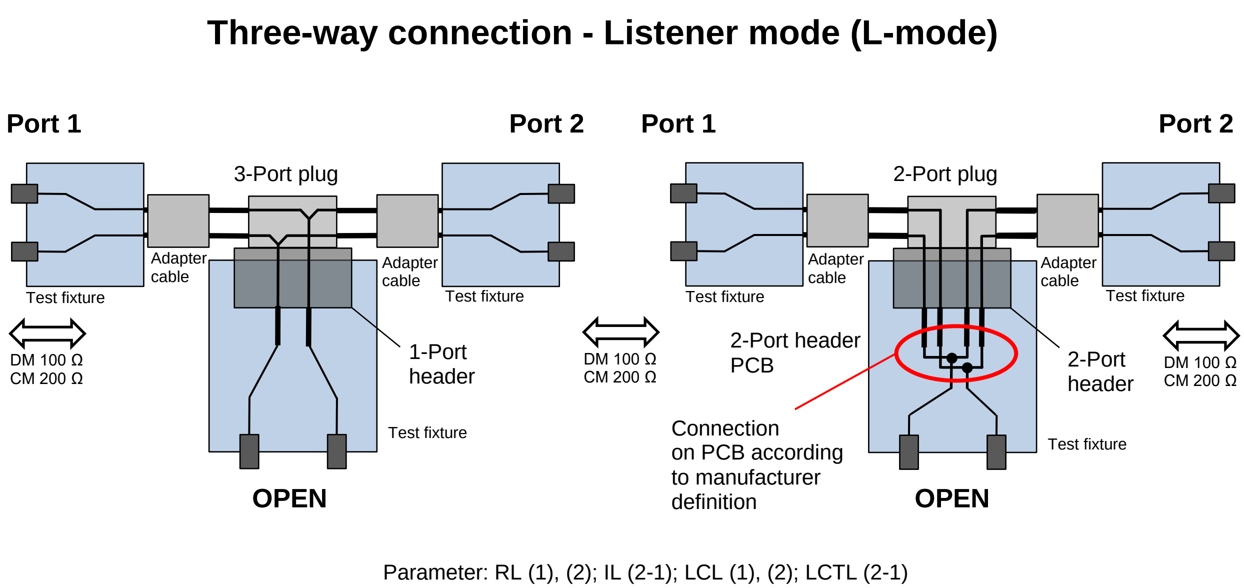

Figure 20: Test conditions for connectors for three-way connections in transmitting mode

In general, the cable ends and the contacts within the DUT shall be placed in 10 mm height over a contiguous conducting ground plane. This distance may be increased as necessary in case of mechanical constraints, e.g. due to large connector housings. A dielectric insulation material ($\varepsilon_r \leq 1.4$) between the connector and the ground plane may be used for mechanical support. The dimensions of the ground plane need to be large enough to support the DUT including 30 mm distance to the ground perimeter (3 x height above the ground plane).

Following the separation of connectors in chapter 5.6 into two-way and three-way connectors, different test setups are defined. For two-way connectors used as inline connector the test setup is described in Figure 21 where Figure 22 shows the setup for PCB connectors.

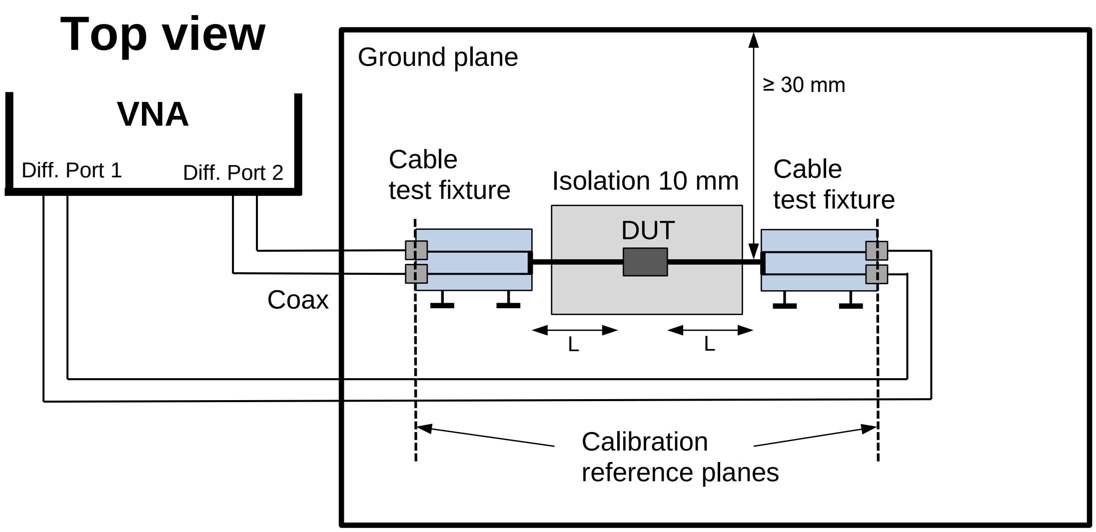

Figure 21: Inline connector measurement setup

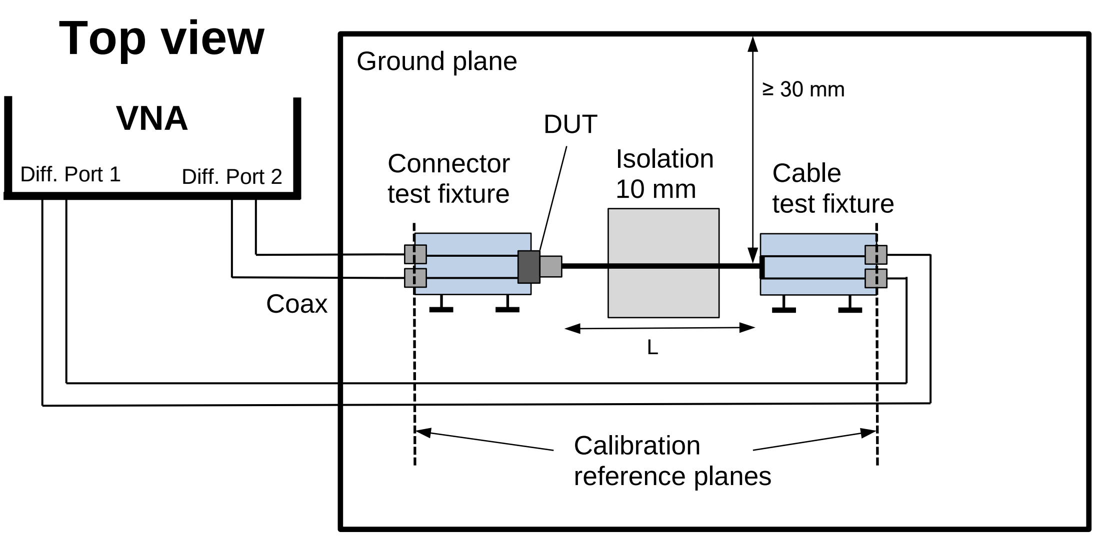

Figure 22: PCB connector measurement setup for two-way connections

The insertion loss of test fixtures and the adapter cable may be subtracted from the transmission measurement result of the PCB or inline connector. Therefore, the DUT is replaced by a direct thru cable connection as shown in Figure 23. The same cable type shall be used with a length of 1 x L for PCB connectors and 2 x L for inline connectors, where L is identical to the length used in the connector measurement. This compensation method is only applicable for measuring the insertion loss parameter.

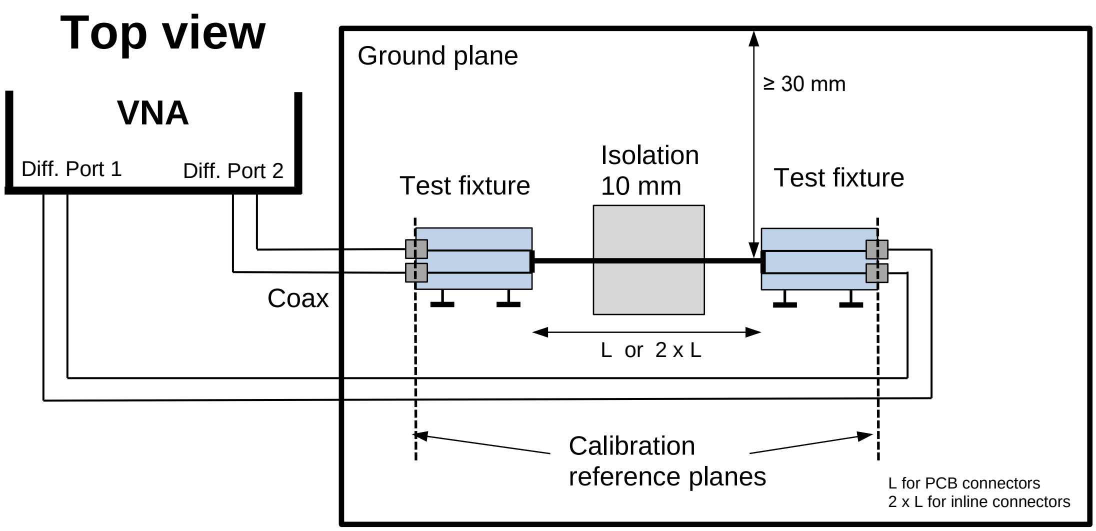

Figure 23: Thru connection to measure insertion loss and propagation delay of fixtures and cable leads

Connectors for three-way connection needs to be measured in two different modes: transmitting mode (local 10BASE-T1S transceiver is sending) and listener mode (local 10BASE-T1S transceiver is only receiving).

Figure 24 shows the measurement setup for three-way connection in transmitting mode and Figure 25 defines it for three-way connection in listener mode.

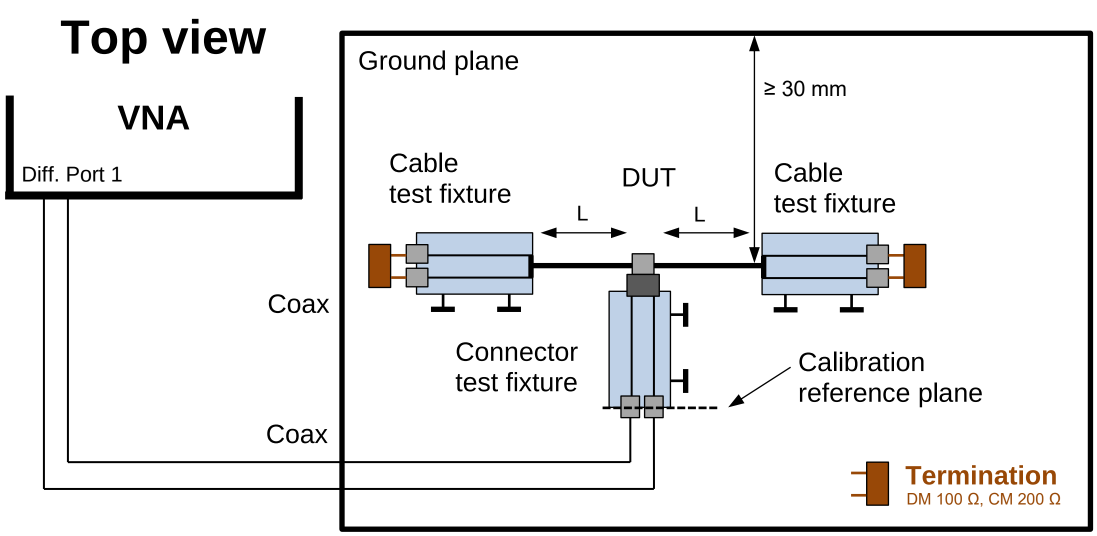

Figure 24: PCB connector measurement setup for three-way connection – transmitting mode

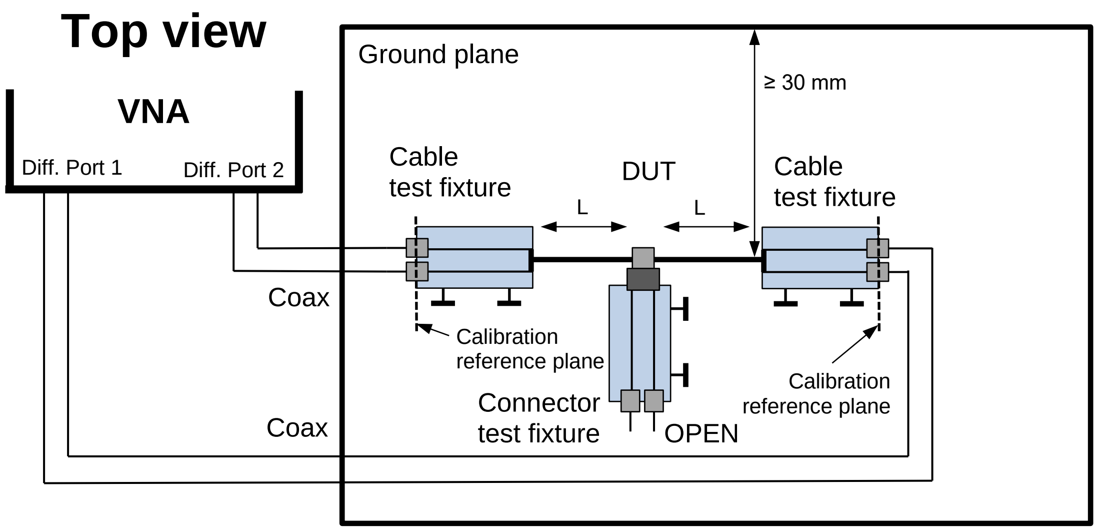

Figure 25: PCB connector measurement setup for three-way connection – listener mode

10.1.2 Connector Setups for ES – Crosstalk

The additional parameter to be evaluated in the environmental system is cross conversion in multiport and hybrid connectors. Such connectors consist of one or more 10BASE-T1S Ethernet differential pairs and potentially additional other contacts. These additional contacts can be used as general-purpose signal line, power supply, differential signals for other Ethernet systems like 100BASE-T1 or differential signals other than Ethernet.

In general, the definition of 10.1.1 shall apply to ES crosstalk measurements of multiport and hybrid connectors. Unused fixture ports shall be terminated with their characteristic impedance during the individual measurements.

The individual 10BASE-T1S pairs of multiport connectors shall be tested like single port connectors according to the measurement setup described in section 10.1.1. Suitable PCB based multiport test fixtures shall be used for the multiport board connectors on both DUT sides. The test fixtures shall fulfill in addition the requirement on cross conversion attenuation described in section 9.3.4, Table 7.

Figure 26 shows the test setup for ES-crosstalk evaluation of multiport PCB connectors. The differential port 1 of the VNA is connected to the far end port to measure AFEXTDC Loss and AFEXTDS Loss of the multi-port PCB connector. For measuring, the near and crosstalk parameter ANEXTDC Loss and AFEXTDS Loss the VNA port 1 needs to be connected to the near end of test setup same as port 2. All unused signals are terminated with their characteristic impedance(s). If the characteristic impedance is unknown, unused unshielded differential pairs are terminated with 100 Ω differential mode / 200 Ω common mode, and single ended ports are terminated with 50 Ω loads.

For measuring multiport inline connectors, the general setup for multiport PCB connectors shall be applied while using a multiport cable test fixture with attached adapter cable at both sides of the connector.

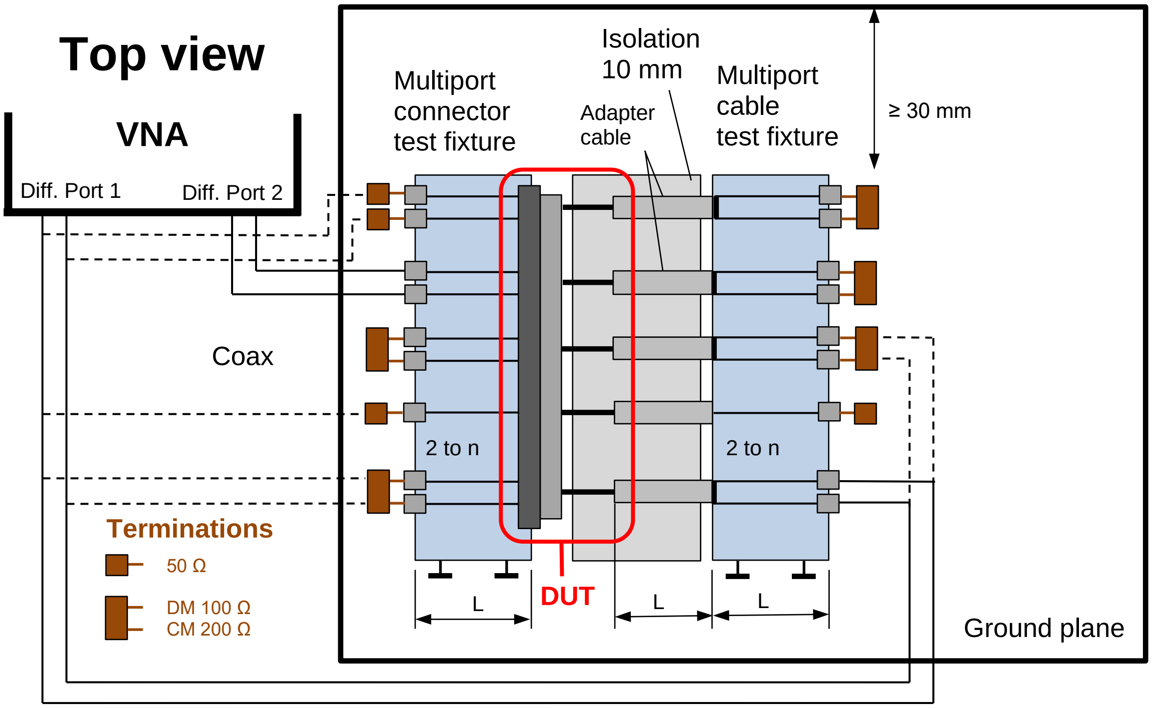

Figure 26: Multi-port PCB connector measurement setup for all cross conversion measurements

10.2 Measurement Setups for Cables

The minimum bending radii of the DUT and coaxial test cables shall not violate the values specified by the manufacturer.

10.2.1 Cable Setups for SCC

To measure the SCC parameters (transmission, reflection and mode conversion) of cables, a VNA or equivalent time domain-based equipment shall be used. The parameters are measured on single cables but not within the context of the environmental system, i.e. wiring harness. However, insertion loss and return loss limits for SCC shall also be met within the environmental system.

For cable measurements the DUT shall have a length of 10 m and shall be placed on a table with conducting ground plane and 10 mm isolation material height as shown in Figure 27 or on a conducting drum with 10 mm isolation material height as shown in Figure 28. More detailed information on a proper cable arrangement using conduction drum is given in Annex A.2. The wires are attached directly to the fixtures with an untwist length as short as the fixture allows.

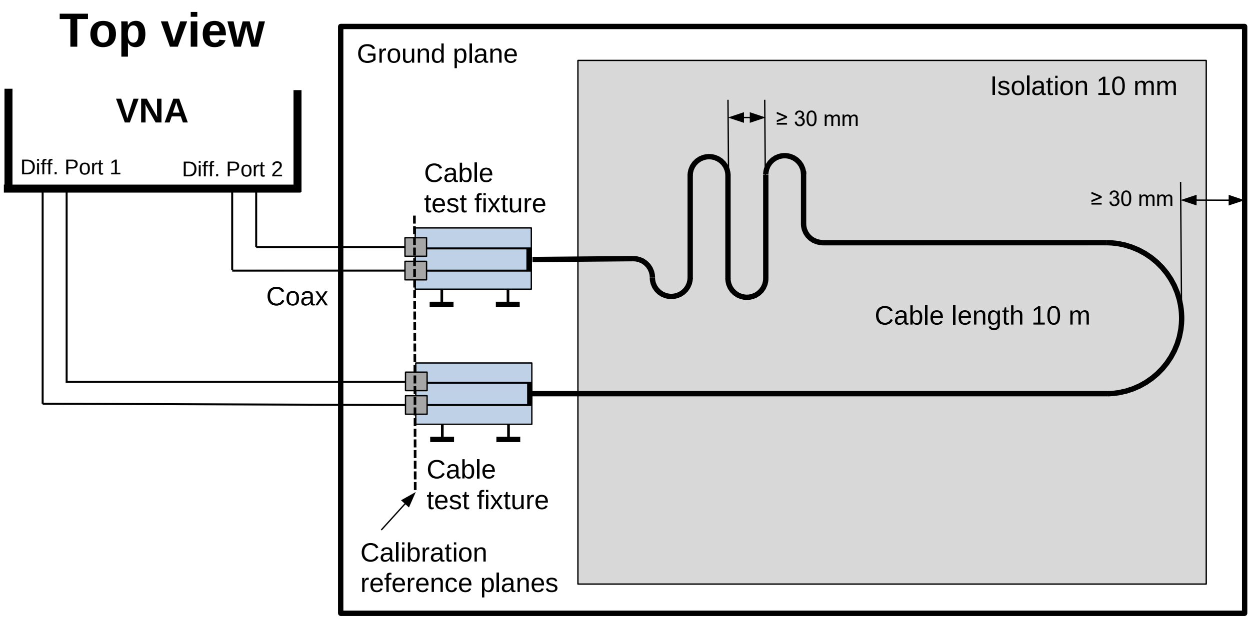

Figure 27: Setup for measurement on cables using a conductive ground plane

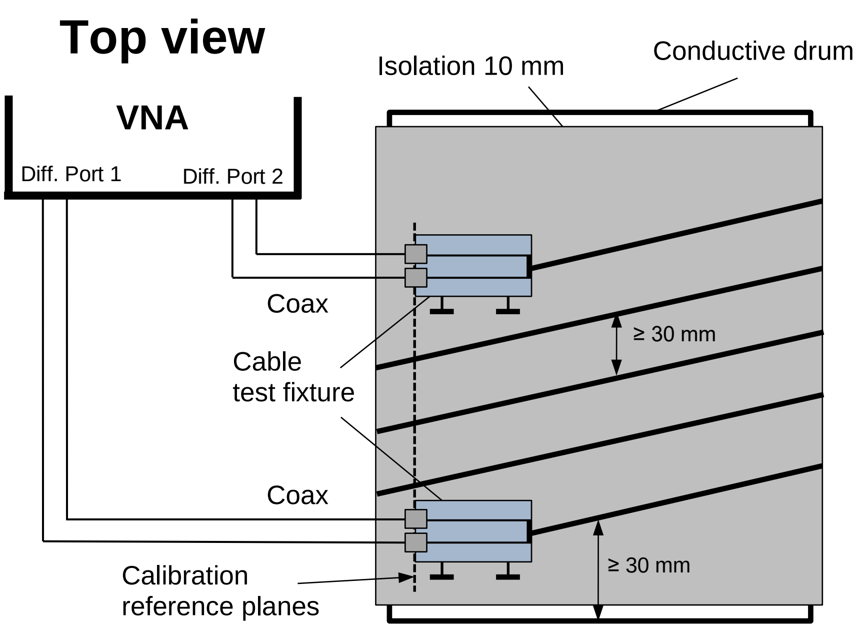

Figure 28: Setup for measurement on cables using a conductive drum

10.3 Measurement Setups for Channels

The minimum bending radii of the DUT and coaxial test cables shall not violate the values specified by the manufacturer.

10.3.1 Channel setups for SCC

To measure the SCC parameters (transmission, reflection and mode conversion) of complete channels, a VNA or equivalent time domain-based equipment shall be used. The parameters are measured on a single channel arrangement but not within the context of the environmental system, i.e. wiring harness. However, insertion loss and return loss limits for SCC shall also be met within the environmental system.

For channel measurements the DUT shall be placed on a table with conducting ground plane and 10 mm isolation material height (see Figure 29 and Figure 30). The measurement fixtures shall be connected to the ground reference plane.

Because of different requirements on MS-Cs there are two measurement setups defined.

To evaluate the channel RF transmission characteristics from end to end of a MS-C and the reflected S-parameters at the end node terminals, the test setup given in Figure 29 shall be used. The connection of existing drop node MDI access points depend on the implementation of the mixing segment topology as well as on the type of PCB three-way connection (see Figure 2) and shall be chosen as defined in Table 8.

Table 8: Connection of mixing segment drop node access points for channel measurements

Mixing segment topology	**Drop node** **PCB connector (header)**	**Drop node** **PCB test fixture**
Bus with stubs for drop nodes	Cable connector and PCB connector assembled	PCB connector not mounted to test fixture and no test fixture used
Daisy chain with bus junction in cable plug	Cable connector and PCB connector assembled	PCB connector not mounted to test fixture and no test fixture used
Daisy chain with bus junction on PCB	Cable connector and PCB connector assembled	PCB connector mounted to test fixture with bus junction close to the connector header pins; test fixture coaxial ports remain open (see Figure 29)

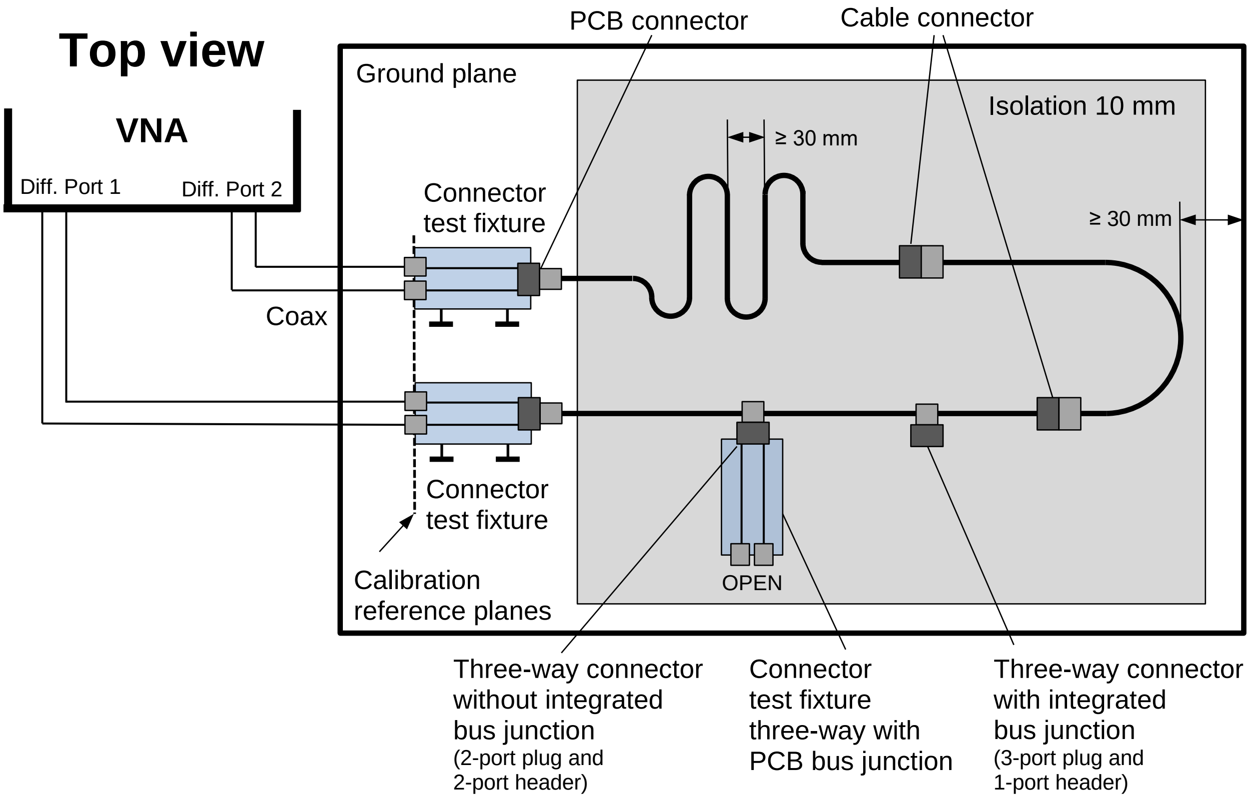

Figure 29: Setup for end-to-end measurement on channels using a conductive ground plane

For measuring the RF transmission characteristics from each existing drop node terminal to both end nodes of a MS-C and for measuring the reflected S-parameter at each existing drop node terminal, the test setup given in Figure 30 shall be used. The access points on the drop node that are not measured shall be connected according to Table 8.

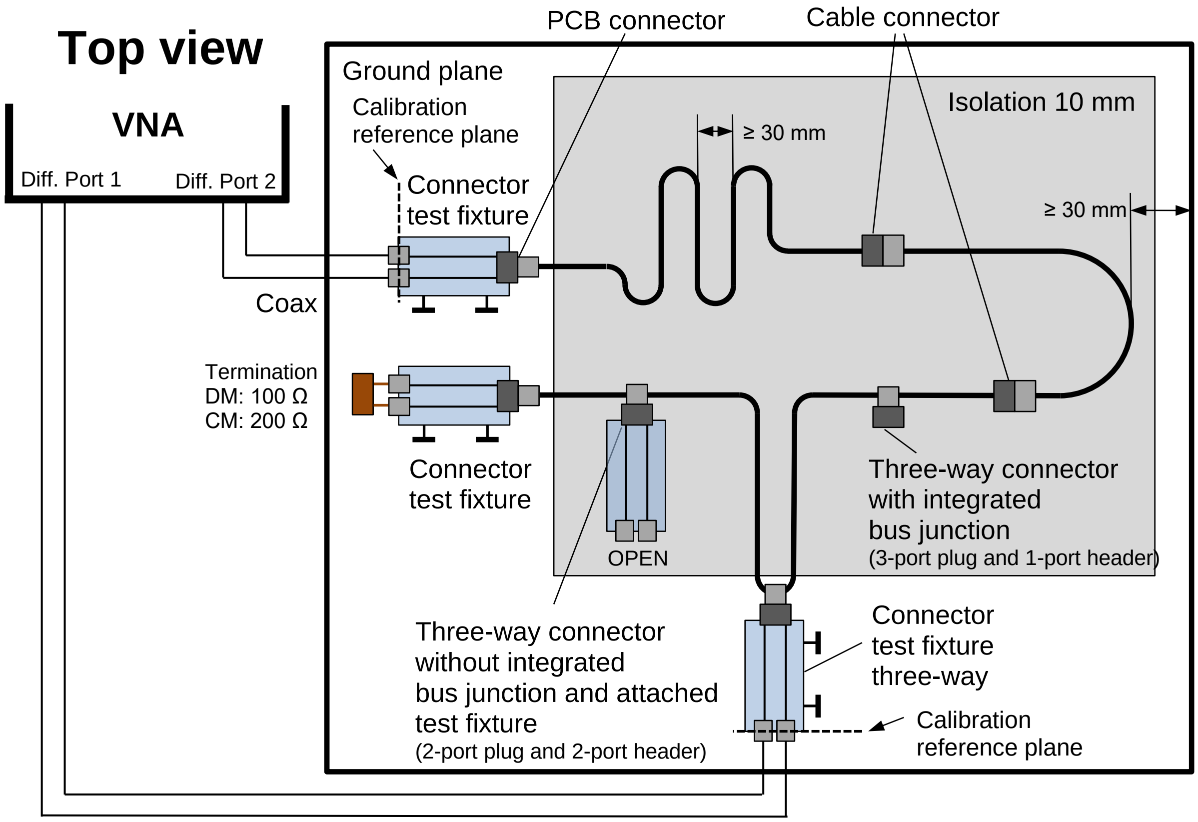

Figure 30: Setup for drop node to end node measurement on channels using a conductive ground plane

10.3.2 Channel Setup for ES – Crosstalk

In general, the coupling parameters of whole communication channels in the environmental system are crosstalk and cross conversion 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.

For 10BASE-T1S, there are only crosstalk requirements defined for a specific 5-around-1 cable bundle arrangement (up to 15 m length and up to four in-line connectors, equally spaced [1]) that is not practical for 10BASE-T1S communication channels.

This chapter describes only test setups for cross conversion analysis of channels.

In general, the definitions for SCC measurements (see chapter 10.3.1) are valid also for ES analysis. In addition, all ports of the measurement fixtures that are not connected to the VNA but are still a part of the wiring harness shall be terminated at the coaxial ports of the measurement fixture with single ended 50 Ω. All measurement fixtures shall be grounded. The DUT shall be placed on a table with conducting ground plane and 10 mm isolation material height as shown in Figure 31. The red dashed line in this figure represents a neighboring line to which the crosstalk is measured. Depending on the application, the disturbing line can be a single ended line as shown in Figure 31, or it can be a differential line.

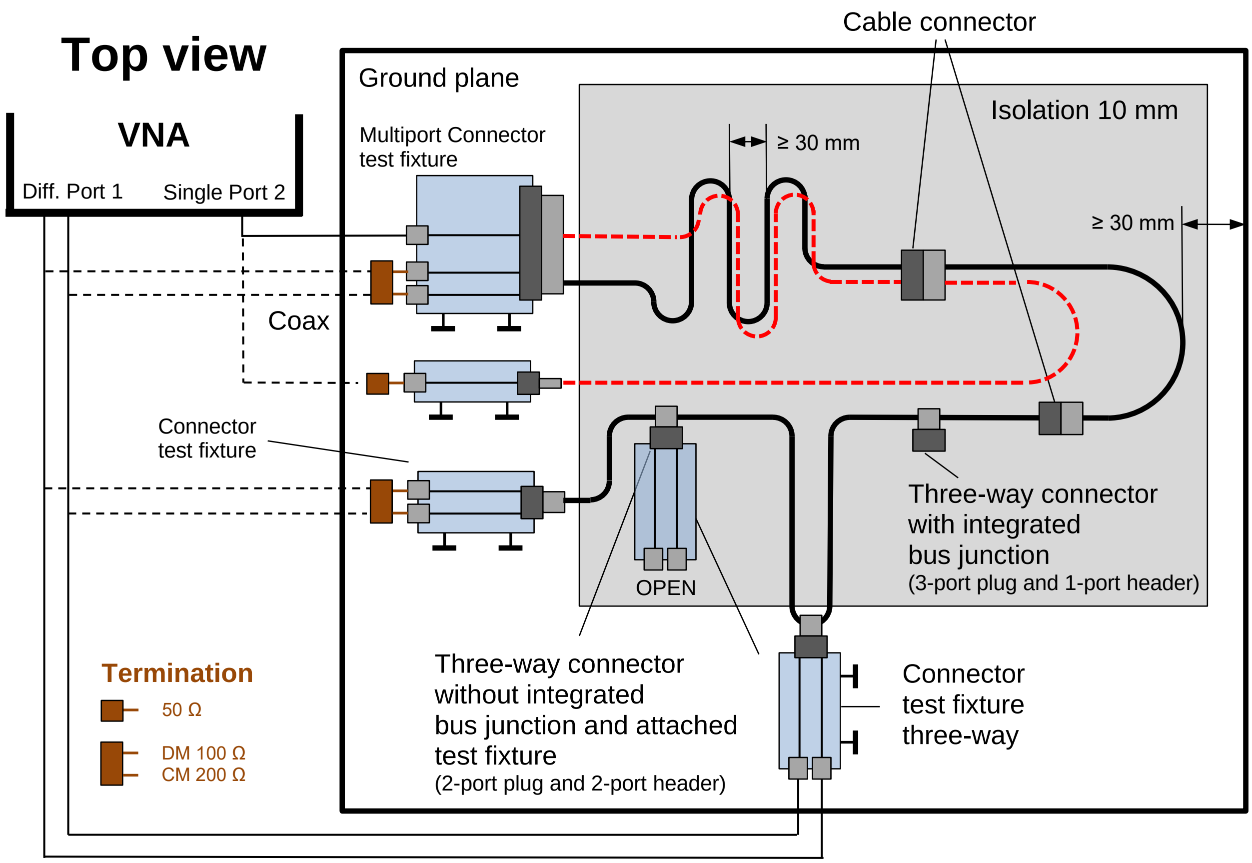

Figure 31: Setup for cross conversion measurement on channels using a conductive ground plane

11 ELECTRICAL REQUIREMENTS

11.1 Overview of Requirements

An overview of required measurements of channels, cables and connectors in respect to SCC and ES evaluation is given in Table 9.

Table 9: Overview of required measurements

Requirement	Measuring point / measuring path	Test parameter
WCC		
RL	end node or edge termination	$\mathrm{RL}_{end\ node}$
	each drop node	$\mathrm{RL}_{drop\ node}$
IL	from end-to-end node / termination	$\mathrm{IL}_{end\ to\ end}$
LCTL	from end-to-end node / termination	$\mathrm{LCTL}_{end\ to\ end}$
	from each drop node to both end nodes / terminations	$\mathrm{LCTL}_{drop\ to\ end}$
Cross conversion loss	far end crosstalk from each end node of the disturbing line to each drop node and to the far end node of the disturbed WCC	AFEXTDC Loss AFEXTDS Loss
Cable		
RL	both sides	RL
IL	end to end	IL
LCTL	end to end	LCTL
Connector		
RL	two-way connection, each port	$\mathrm{RL}_{2\text{-}way}$
	three-way connection, MDI port in transmitting mode	$\mathrm{RL}_{3\text{-}way\ T\text{-}mode}$
	three-way connection, each cable port in listener mode	$\mathrm{RL}_{3\text{-}way\ L\text{-}mode}$
IL	two-way connection, port to port	$\mathrm{IL}_{2\text{-}way}$
	three-way connection, cable port to cable port in listener mode	$\mathrm{IL}_{3\text{-}way\ L\text{-}mode}$
LCL	two-way connection, each port	$\mathrm{LCL}_{2\text{-}way}$
	three-way connection, MDI port in transmitting mode	$\mathrm{LCL}_{3\text{-}way\ T\text{-}mode}$
LCTL	two-way connection, port to port	$\mathrm{LCTL}_{2\text{-}way}$
	three-way connection, MDI port to both cable ports in transmitting mode	$\mathrm{LCTL}_{3\text{-}way\ T\text{-}mode}$
	three-way connection, cable port to cable port in listener mode	$\mathrm{LCTL}_{3\text{-}way\ L\text{-}mode}$
Cross conversion loss	near end crosstalk	ANEXTDC Loss ANEXTDS Loss
	far end crosstalk	AFEXTDC Loss AFEXTDS Loss

11.2 Basic Requirements for Standalone Communication Channel

11.2.1 Requirements for Connectors in Context of SCC

This section specifies the connector requirements in context of SCC. Additional coupling parameters in context of ES are defined in chapter 11.3.1.

Table 10: Electrical requirements for mated connector pairs

Test parameter	Symbol or related S-parameter	Requirement
RL $_{3\text{-way T-mode}}$	S_{dd33}	$\geq \begin{pmatrix} 29 & 0.3 \leq f < 12.35 \\ 29 - 20\,log_{10}\left({}^{f}/_{12.35}\right) & 12.35 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 50 Ω (DM), 100 Ω (CM)
RL $_{2\text{-way}}$ RL $_{3\text{-way L-mode}}$	S_{dd11}, S_{dd22}	$\geq (29 \quad 0.3 \leq f < 40)\ dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
IL $_{2\text{-way}}$ IL $_{3\text{-way L-mode}}$	S_{dd21}, S_{dd21}	$\leq \begin{pmatrix} 0.025 + \frac{0.013(f-1)}{9} & 0.3 \leq f < 10 \\ 0.038 + \frac{0.012(f-10)}{23} & 10 \leq f < 33 \\ 0.055 + \frac{0.005(f-40)}{7} & 33 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
LCL $_{2\text{-way}}$ LCTL $_{2\text{-way}}$ LCTL $_{3\text{-way L-mode}}$	S_{dc11}, S_{dc22} S_{dc21}, S_{dc12} S_{dc21}, S_{dc12}	$\geq \begin{pmatrix} 46 & 0.3 \leq f < 50 \\ 34 - 20\,log_{10}\left({}^{f}/_{200}\right) & 50 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
LCL $_{3\text{-way T-mode}}$ LCTL $_{3\text{-way T-mode}}$	S_{dc33} S_{dc13}, S_{dc23}	$\geq \begin{pmatrix} 46 & 0.3 \leq f < 50 \\ 34 - 20\,log_{10}\left({}^{f}/_{200}\right) & 50 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances: 50 Ω (DM), 100 Ω (CM)

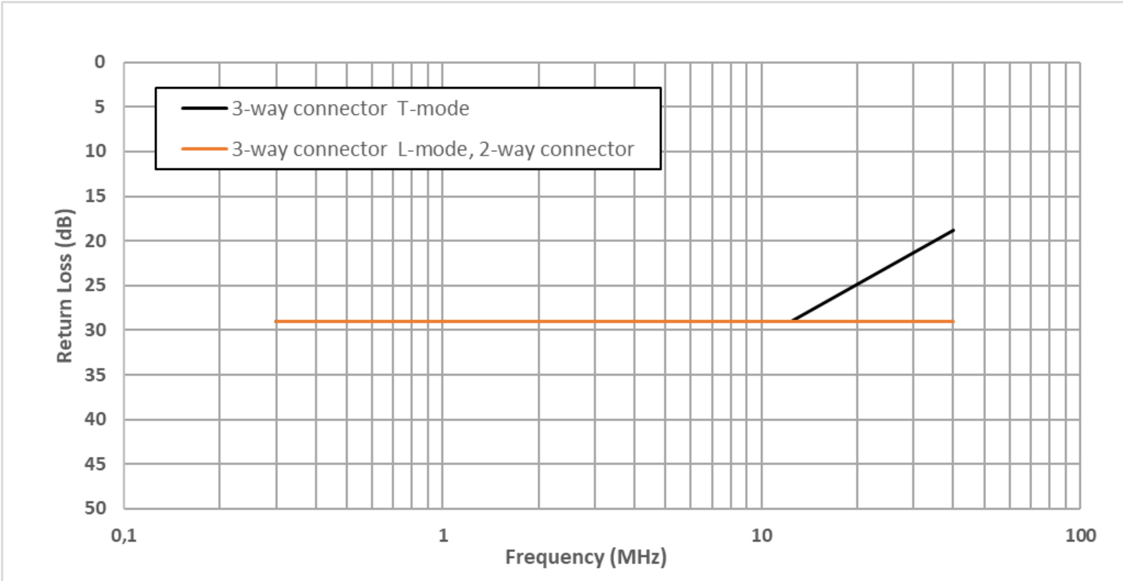

Figure 32: Return loss requirements for mated connector pairs

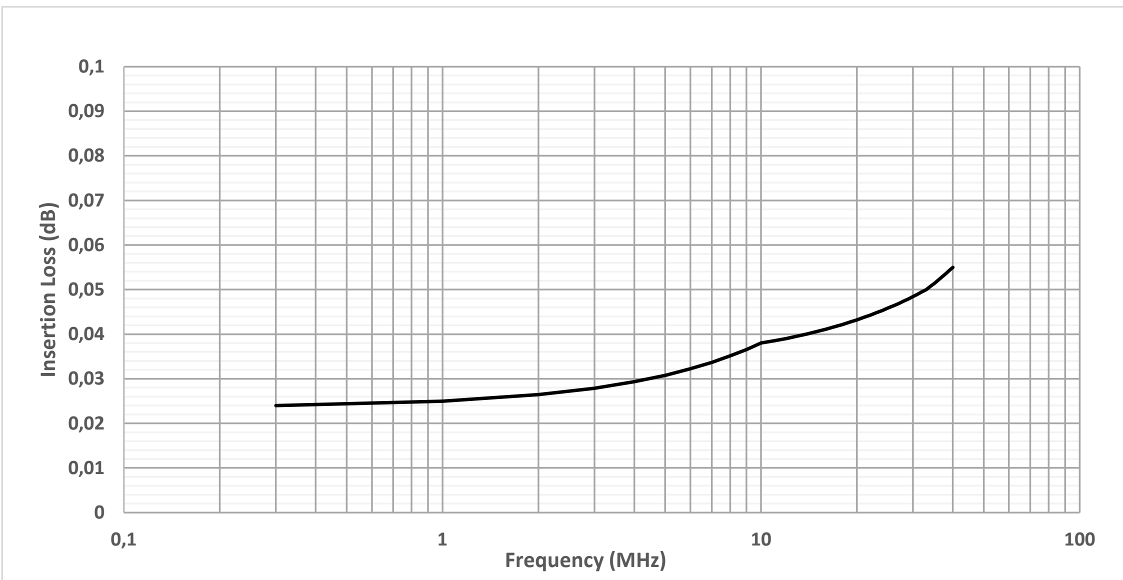

Figure 33: Insertion loss requirements for mated connector pairs

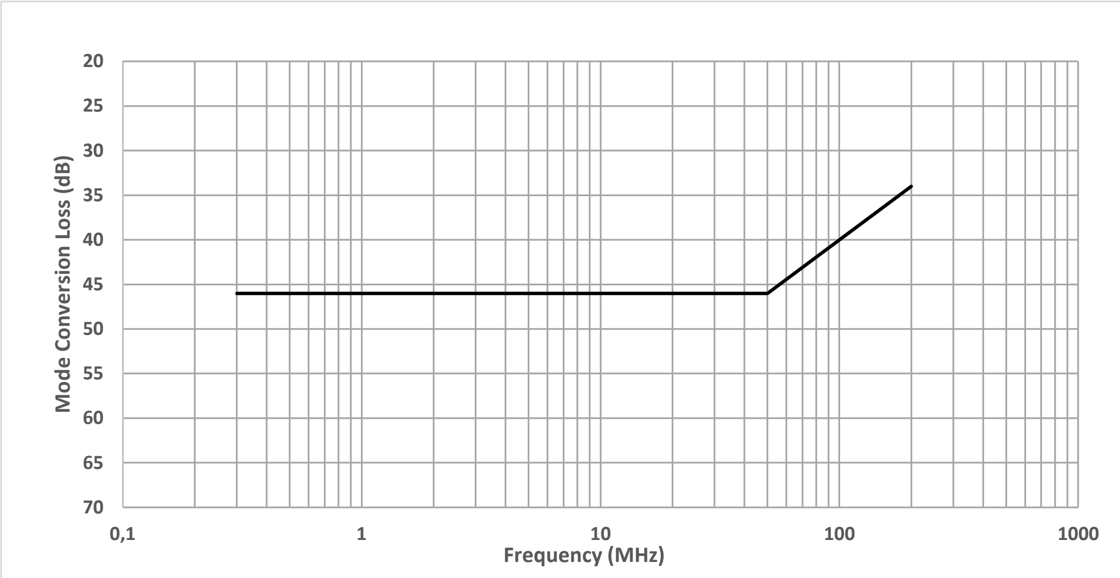

Figure 34: LCL, LCTL requirements for mated connector pairs

11.2.2 Requirements for Cables in Context of SCC

This section specifies the cable requirements in context of the SCC. Additional coupling parameters in context of ES defined in chapter 11.3.2.

Table 11: Electrical requirements for cable

Test parameter	Symbol or related S-parameter	Requirement
RL	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 20 & 0.3 \leq f < 10 \\ 20 + 1.67\,log_{10}\left(f/10\right) & 10 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
IL	S_{dd21}, S_{dd21}	<u>Low loss case: Low loss cables for use in SCC with total length up to at least 25 m</u> $\leq \begin{pmatrix} 0.03 + \frac{0.059(f-1)}{9} & 0.3 \leq f < 10 \\ 0.089 + \frac{0.087(f-10)}{23} & 10 \leq f < 33 \\ 0.194 + \frac{0.018(f-40)}{7} & 33 \leq f \leq 40 \end{pmatrix} dB/m$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
		<u>Standard loss case: Standard cables for use in SCC with total length up to at least 15 m</u> $\leq \begin{pmatrix} 0.05 + \frac{0.098(f-1)}{9} & 0.3 \leq f < 10 \\ 0.148 + \frac{0.145(f-10)}{23} & 10 \leq f < 33 \\ 0.323 + \frac{0.03(f-40)}{7} & 33 \leq f \leq 40 \end{pmatrix} dB/m$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
LCTL	S_{dc21}, S_{dc12}	$\geq \begin{pmatrix} 46 & 0.3 \leq f < 50 \\ 34 - 20\,log_{10}\left(f/200\right) & 50 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)

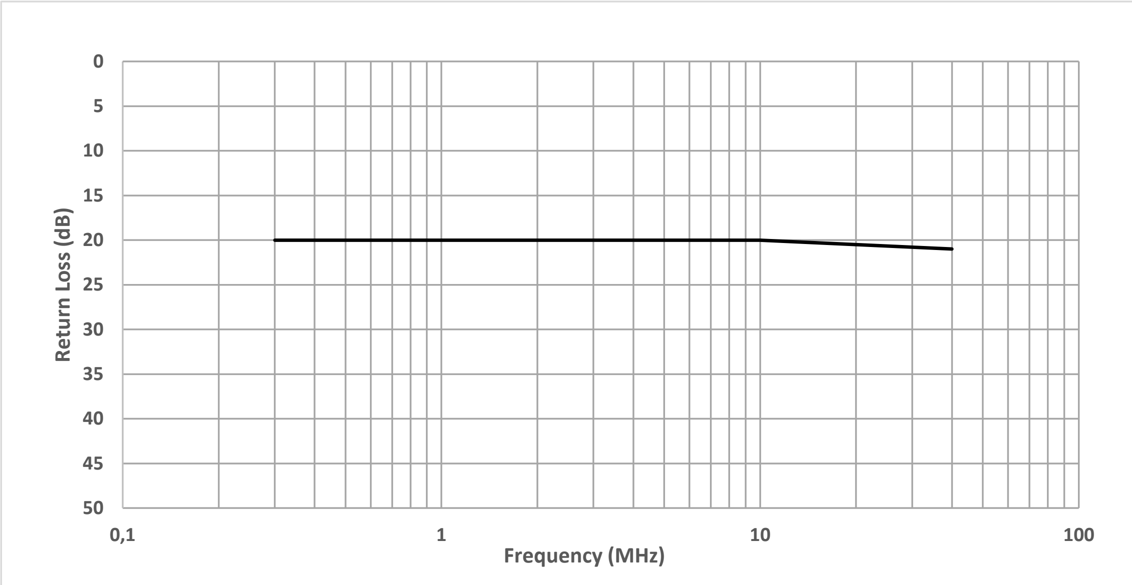

Figure 35: Return loss requirements for cables

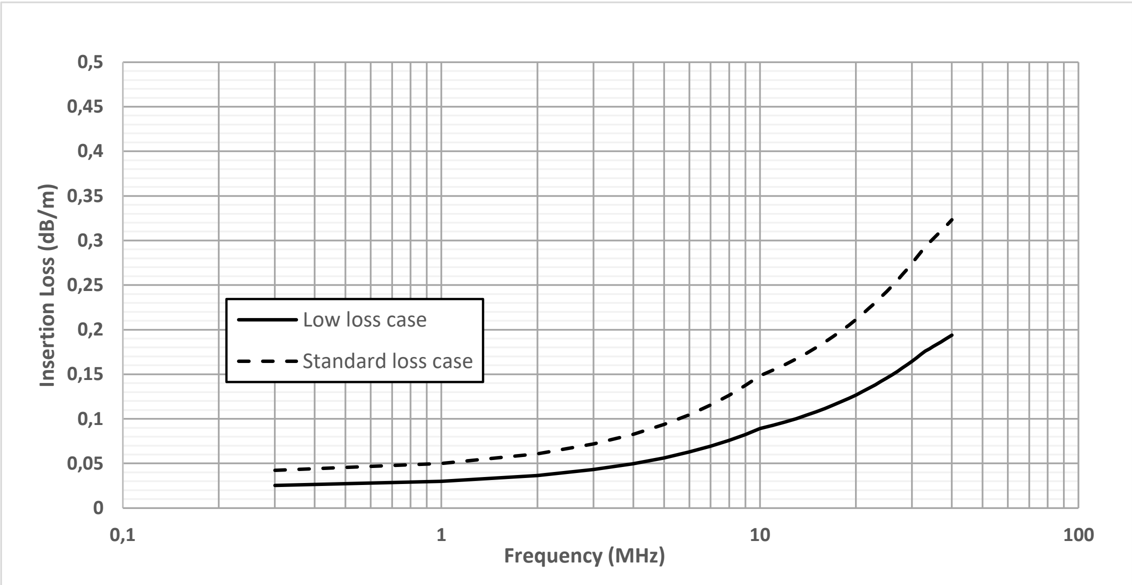

Figure 36: Insertion loss requirements for cables

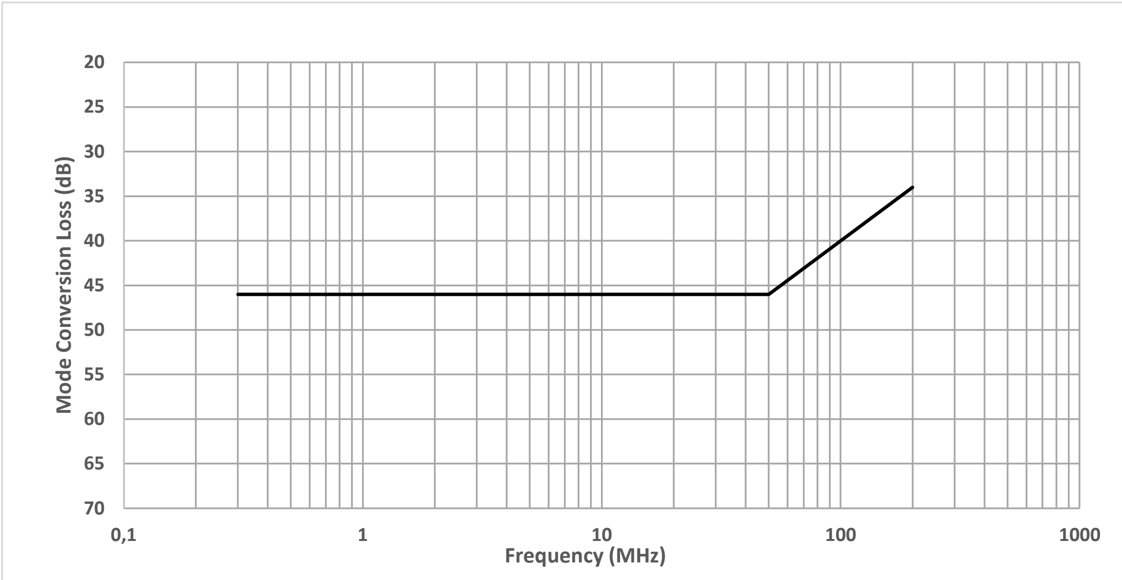

Figure 37: LCTL requirements for cables

11.2.3 Requirements for Whole Communication Channel in Context of SCC

This section specifies the channel requirements in context of the SCC. Additional coupling parameters in context of ES are defined in chapter 11.3.3.

Table 12: Electrical requirements for whole communication channel (SCC context)

Test parameter	Symbol or related S-parameter	Requirement
RL $_{end\ node}$	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 14 & 0.3 \leq f < 10 \\ 14 - 10\,log_{10}\left(^{f}/_{10}\right) & 10 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
RL $_{drop\ node}$	S_{dd11}, S_{dd22}	$\geq \begin{pmatrix} 14 & 0.3 \leq f < 10 \\ 14 - 10\,log_{10}\left(^{f}/_{10}\right) & 10 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 50 Ω (DM), 100 Ω (CM)
IL $_{end\ to\ end}$	S_{dd21}, S_{dd21}	$\leq \begin{pmatrix} 1.0 + \frac{1.6(f-1)}{9} & 0.3 \leq f < 10 \\ 2.6 + \frac{2.3(f-10)}{23} & 10 \leq f < 33 \\ 4.9 + \frac{2.3(f-33)}{33} & 33 \leq f \leq 40 \end{pmatrix} dB$ $0.3 \leq f \leq 40,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
LCTL $_{end\ to\ end}$	S_{dc21}, S_{dc12}	$\geq \begin{pmatrix} 43 & 0.3 \leq f < 20 \\ 43 - 20\,log_{10}\left(^{f}/_{20}\right) & 20 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)
LCTL $_{drop\ to\ end}$	S_{dc21}, S_{dc12}	$\geq \begin{pmatrix} 43 & 0.3 \leq f < 20 \\ 43 - 20\,log_{10}\left(^{f}/_{20}\right) & 20 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances end node: 100 Ω (DM), 200 Ω (CM) Port reference impedances drop node: 50 Ω (DM), 100 Ω (CM)

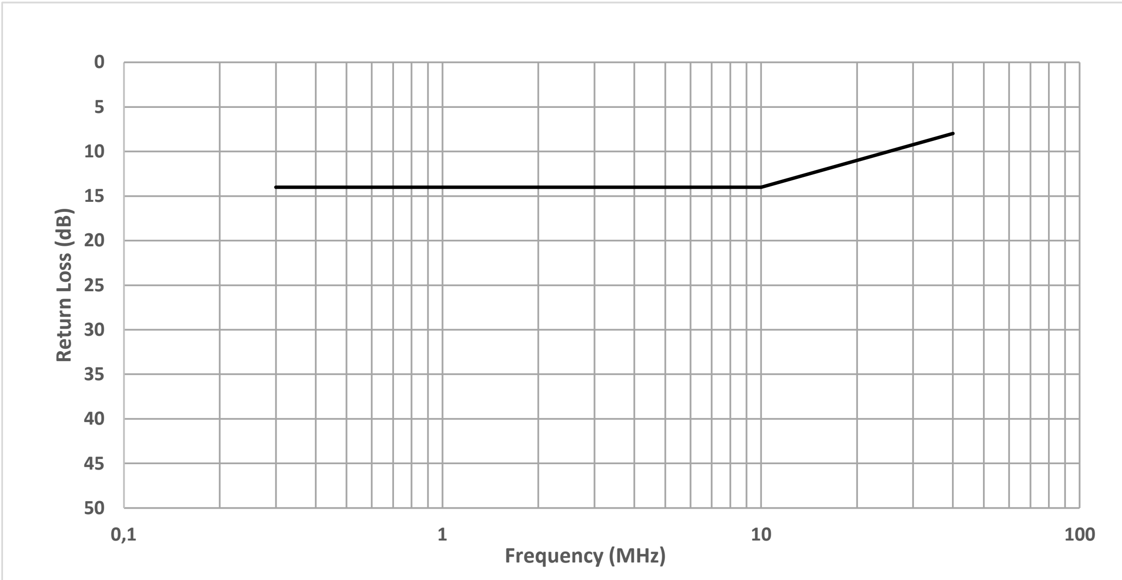

Figure 38: Return loss requirements for whole communication channel

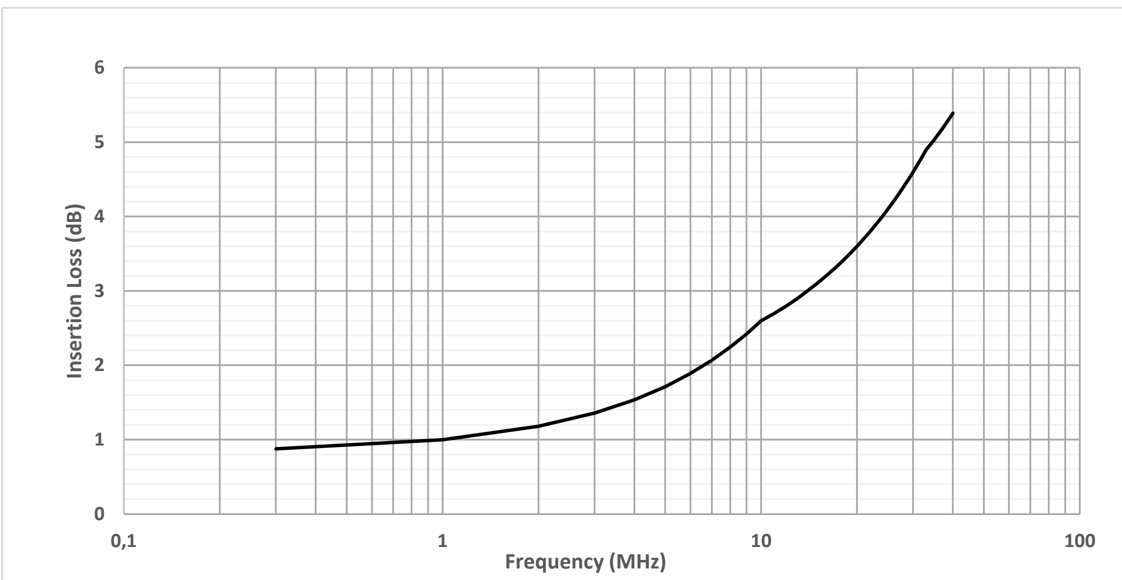

Figure 39: Insertion loss requirements for whole communication channel

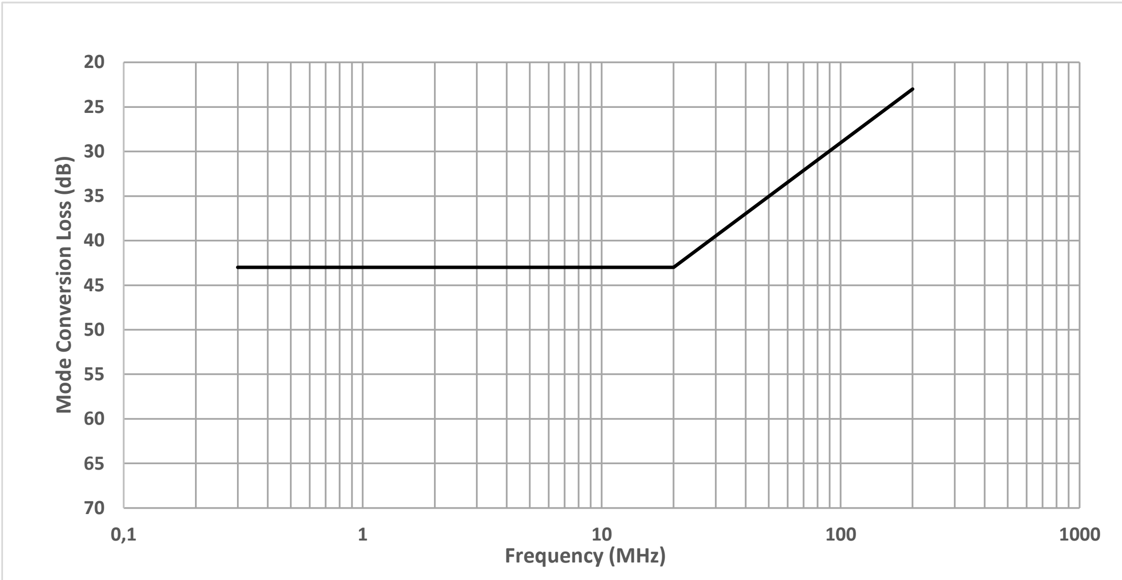

Figure 40: LCTL requirements for whole communication channel

11.3 Additional Requirements for Alien Coupling within Environmental System

11.3.1 Requirements for Connectors in Context of ES

This section specifies the coupling parameter requirements for connectors in context of ES. The test parameters and limits according to Table 13 are required for multiport connectors in addition to the SCC parameters in Section 11.2.1.

Table 13: Electrical requirements for connectors (ES context)

Test parameter	Symbol or related S-parameter	Requirement
ANEXTDC Loss ANEXTDS Loss AFEXTDC Loss AFEXTDS Loss	S_{dcyx} S_{dsyx} S_{dcyz} S_{dsyz}	$\geq \begin{pmatrix} 46 & 0.3 \leq f < 50 \\ 34 - 20\,log_{10}\left({}^{f}/_{200}\right) & 50 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances: 100 Ω (DM), 200 Ω (CM)

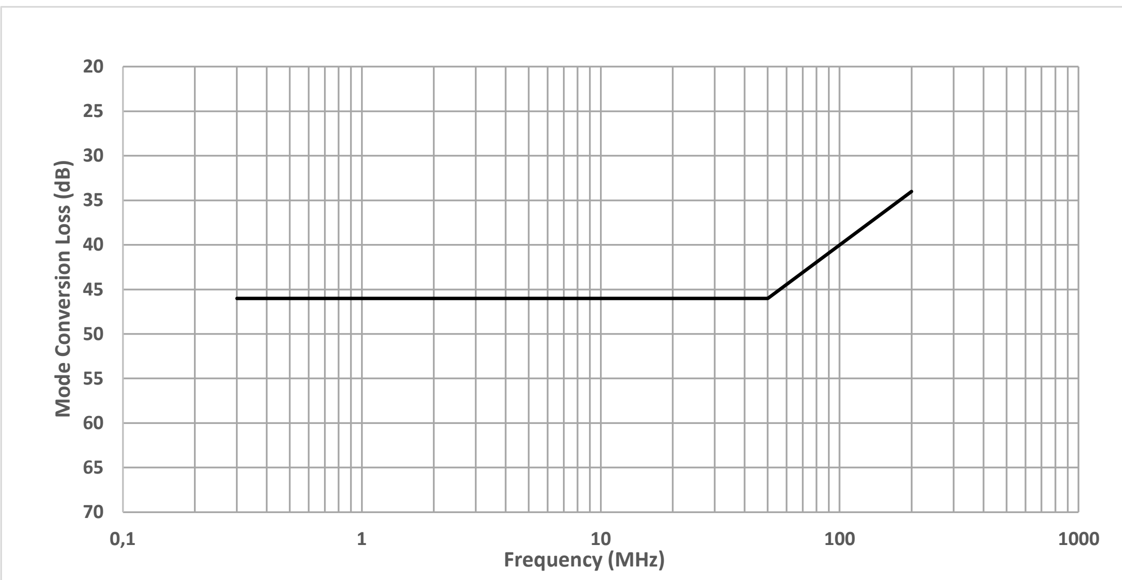

Figure 41: Cross conversion requirements for mated connector pairs

11.3.2 Requirements for Cables in Context of ES

No requirements are defined for cables in context of ES, since multi-pair cables are not typically used for Automotive Ethernet applications.

11.3.3 Requirements for Whole Communication Channel in Context of ES

This section specifies the coupling parameter requirements for communication channels in context of ES. The test parameters and requirements according to Table 14 are required for wiring harnesses in addition to SCC parameters in Table 12.

Table 14: Electrical requirements for WCC (ES context)

Test parameter	Symbol or related S-parameter	Requirement
AFEXTDC Loss AFEXTDS Loss	S_{dcyx} S_{dsyz}	$\geq \begin{pmatrix} 43 & 0.3 \leq f < 20 \\ 43 - 20\,log_{10}\left({}^{f}/_{20}\right) & 20 \leq f \leq 200 \end{pmatrix} dB$ $0.3 \leq f \leq 200,$ frequency *f* in MHz Port reference impedances end node: 100 Ω (DM), 200 Ω (CM)

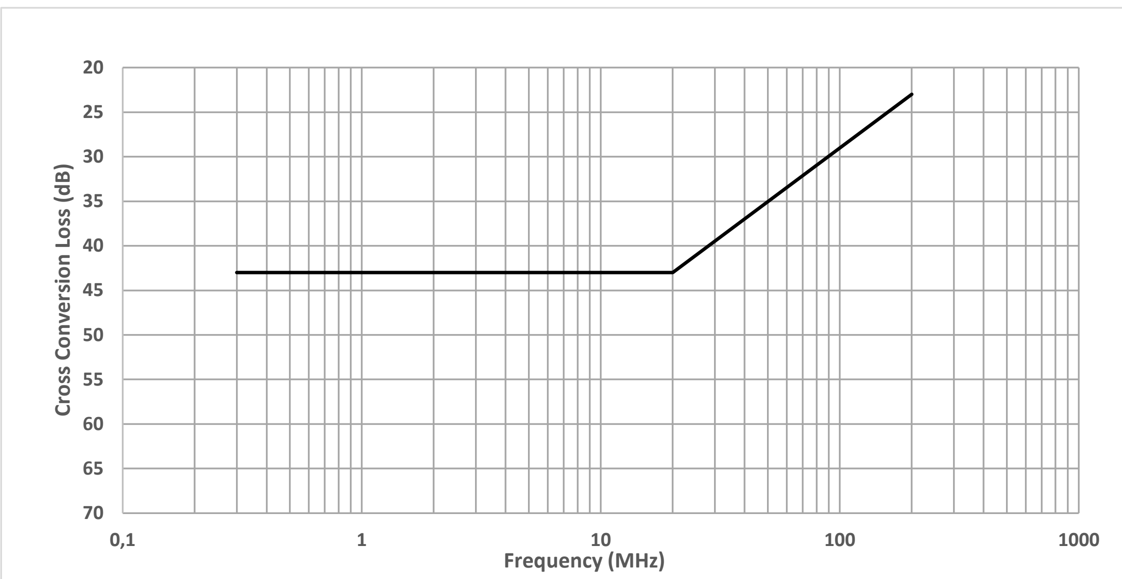

Figure 42: Cross conversion requirements for whole communication channel

A ANNEX (INFORMATIVE) – ADDITIONAL MEASUREMENT SETUP DEFINITIONS

A.1 Examples of Measurement Fixtures

The connector measurement fixture shall provide an optimal connection of connector terminals with the measurement equipment. To avoid parasitic effects caused by the test fixture, it is recommended to use a printed circuit board with impedance-controlled traces (which shall be as short as possible) and RF board connectors. An example of a PCB based connector measurement fixture without ground layer is given in Figure 43.

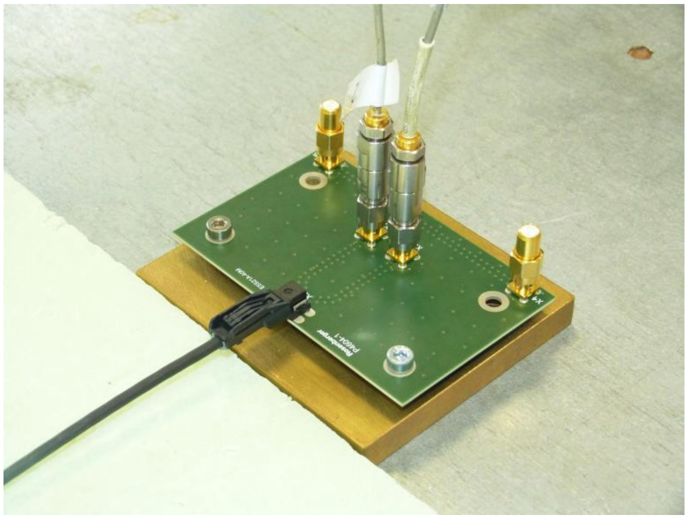

Figure 43: Example for PCB based measurement fixture

Multiport connectors need additional shielding ground on signal layer to reduce the crosstalk within pairs. An example of a PCB based multiport connector measurement fixture is shown in Figure 44.

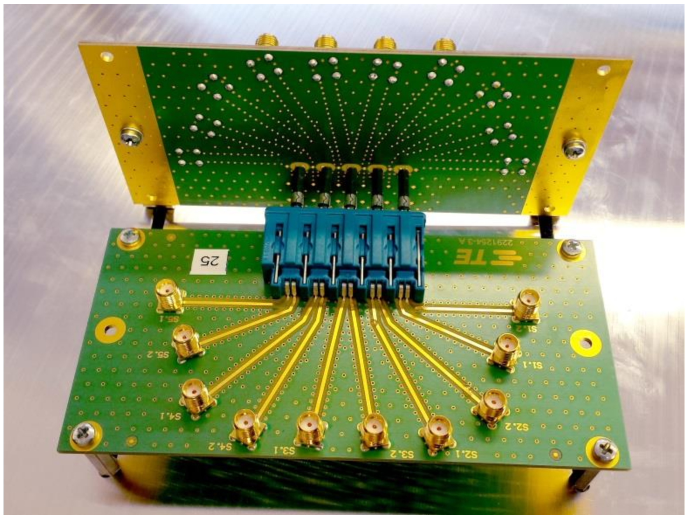

Figure 44: Example for PCB based multiport connector measurement fixture

Coaxial connector-based measurement fixtures can be used as direct fixtures. They are especially suitable for measuring cables and inline connectors. An example of a connector measurement fixture is given in Figure 45.

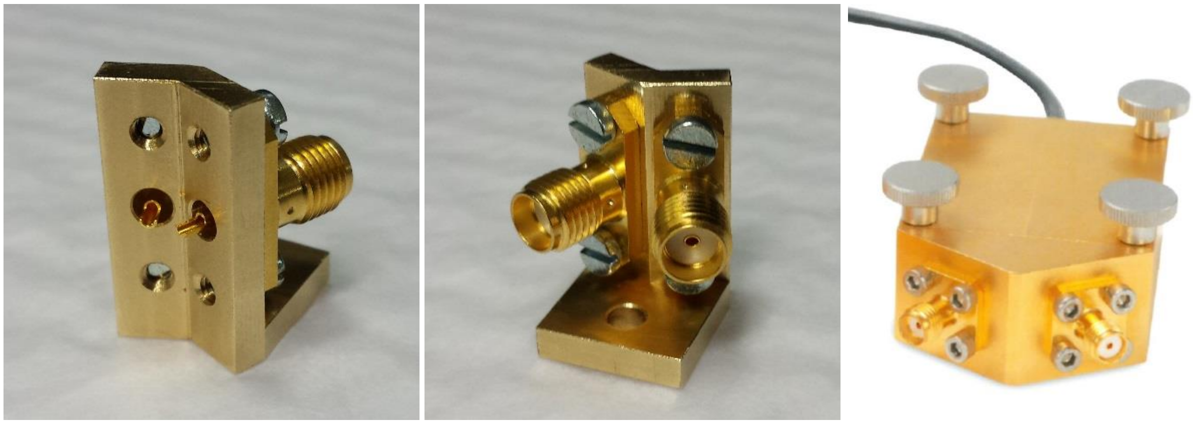

Figure 45: Example for Coaxial connector based direct measurement fixtures

A.2 Example of Cable Arrangement

The usage of a compact setup like a conductive drum is suitable for climate chamber measurements. For this application, the cable under test shall be loose wound on a conducting drum with b = 10 mm isolation ($\varepsilon_r \leq 1.4$) at drum outside. A loose winding of the cable under test is required to avoid a mechanical impact on the cable during the test at low and high temperatures. Each winding shall be separated by a minimum of a = 30 mm which will eliminate inter-winding coupling for unscreened cables. The ground reference of the used measurement fixture for connecting the cable under test with the measurement equipment is shorted with low impedance to the conducting drum at both ends.

The distance of windings at the drum arrangement is calculated as follows:

$$a = 3 * b \qquad \text{(A.2-1)}$$

with: a distance between single windings of cable under test
b thickness of isolation (equal to height above ground reference plane) = 10 mm

An example for drum with loose wound unscreened cable is given in Figure 46.

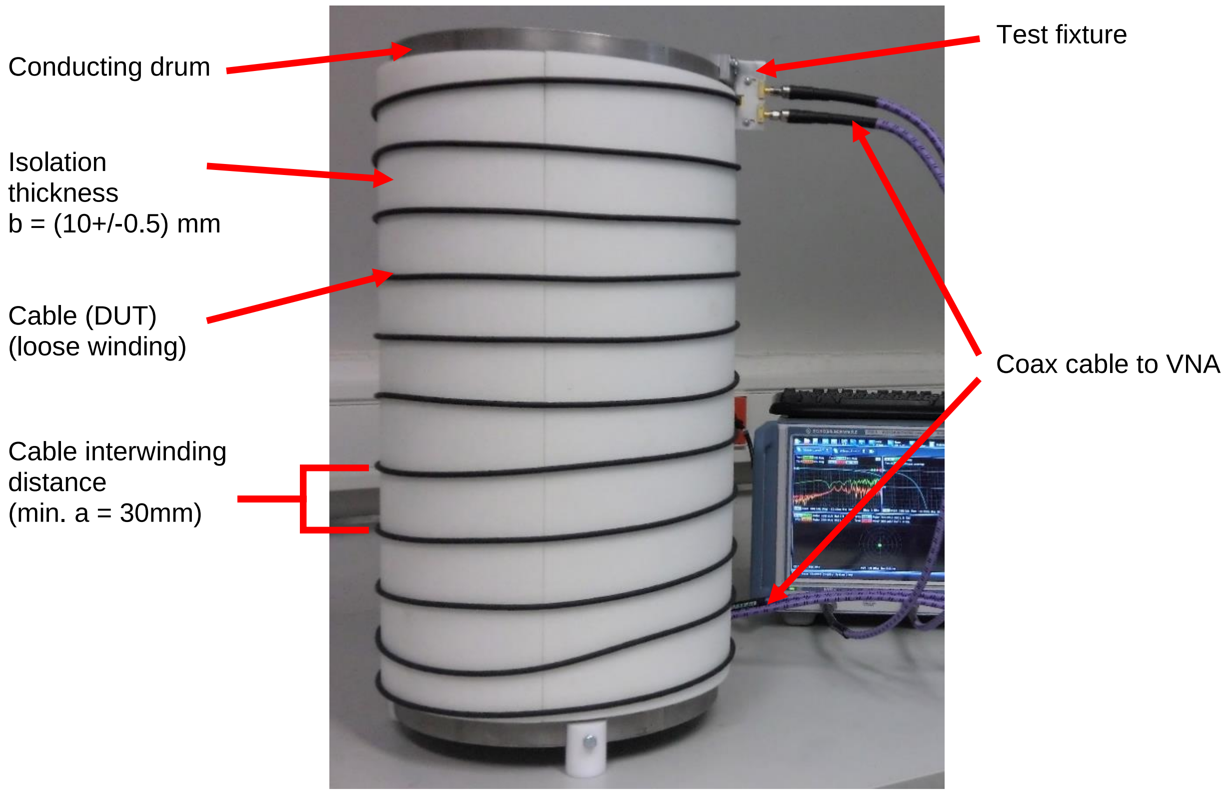

Figure 46: Example for cable arrangement on a conductive drum