IEEE 100BASE-T1
EMC Test Specification for ESD suppression devices

Version 2.0

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This measurement specification shall be used as a standardized common scale for EMC evaluation of ESD suppression devices for 100BASE-T1 in automotive applications.

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Contents

1 Introduction

1.1 Scope

ESD suppression devices can be used to increase the ESD robustness of 1000BASE-T1 Ethernet transceivers according to [IEEE1] and can have a significant effect on EMC test results in communication networks. In principle there are two possible positions of ESD suppression device implementation within an Ethernet interface: between the transceiver and the CMC or between the MDI connector and the common mode termination network as described in Figure 2-1.

This measurement specification shall be used as a standardized common scale for EMC evaluation of ESD suppression devices intended to use for position between MDI connector and common mode termination network within the 100BASE-T1 interface. It contains recommended limits. The final judgment of the tested device is left to the customer.

This instruction includes test procedures and test setups concerning:

- evaluation of datasheet parameters
- mixed mode S-Parameter measurement
- test of damage from ESD
- test of unwanted clamping effect at RF immunity tests
- impact to ESD discharge current in a defined 100BASE-T1 network.

It shall be used for evaluation of ESD suppression devices or passive components with internal ESD suppression unit (e.g. combination of ESD suppression and common mode termination circuit).

1.2 References

[IEEE1] IEEE Std. 802.3bw

[IEC1] IEC 62615, Electrostatic discharge sensitivity testing - Transmission line pulse (TLP) - Component level

[ISO1] ISO 10605, Road vehicles – Test methods for electrical disturbances from electrostatic discharge

[OPEN1] OPEN ALLIANCE, IEEE 100BASE-T1 EMC Test Specification for Common mode chokes

[OPEN2] OPEN ALLIANCE, IEEE 100BASE-T1 EMC Test Specification for Transceivers

1.3 List of Abbreviations and Definitions

BIN	Bus Interface Network
CMC	Common Mode Choke
CMR	Common Mode Rejection
DCMR	Differential to Common Mode Rejection, common mode single ended measured
ESD	Electro Static Discharge
IL	Insertion Loss
MDI	Medium Dependent Interface
RF	Radio Frequency
RL	Return Loss
S-Parameter	Scattering Parameter
VNA	Vector Network Analyzer

2 General Definitions and Requirements for ESD Suppression Devices

2.1 Arrangement of ESD Suppression Device within 100BASE-T1 MDI network

This measurement specification shall be used for an arrangement of ESD suppression device within the 100BASE-T1 MDI interface network as given in Figure 2-1.

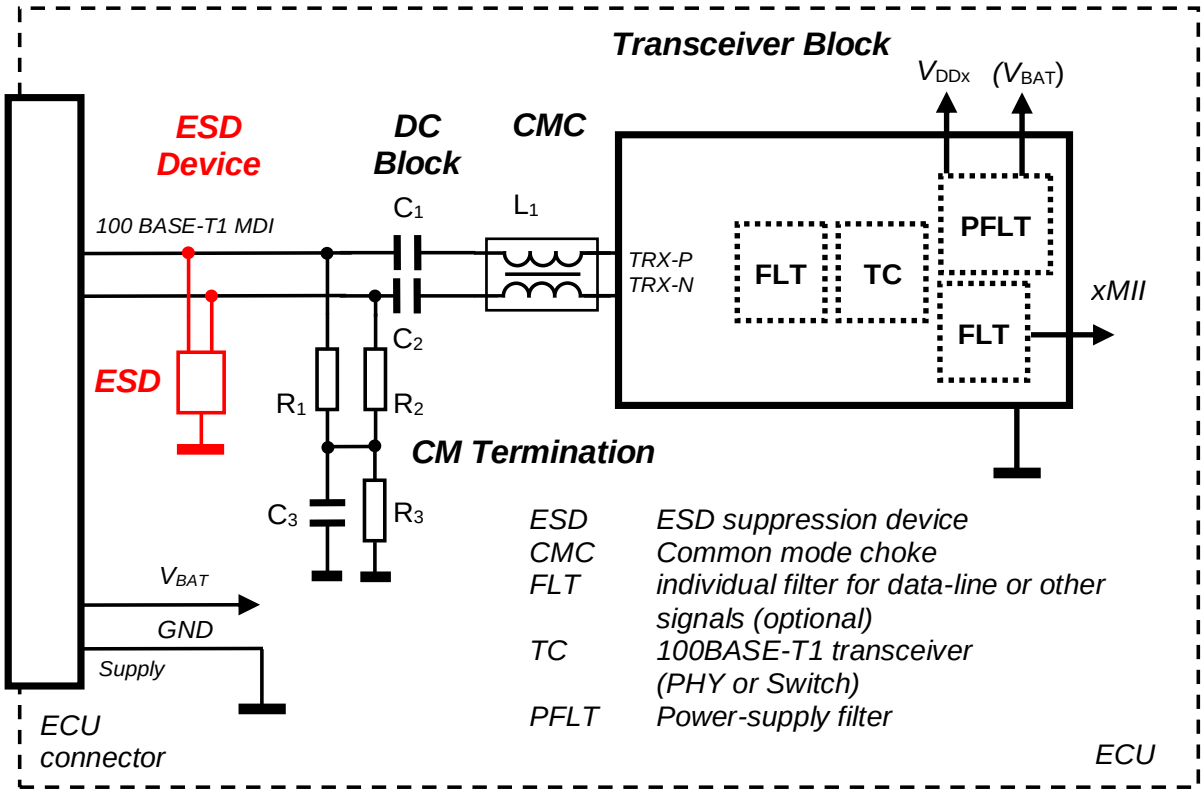


Figure 2-1: Arrangement of ESD suppression device within the 100BASE-T1 MDI interface

2.2 Evaluation of Datasheet Parameters

The following parameters for ESD suppression device shall be ensured and documented in the datasheet.

Parameter	Target Value
Working direction	bi-directional
Operation voltage (V_{DCmax})	≥ 24 V
ESD trigger voltage	≥ 100 V
ESD robustness	+/- 15kV contact discharge for unpowered device using discharge module according to ISO 10605 (discharge storage capacitor C = 150 pF and discharge resistor R = 330 Ω)
Minimum number of discharges	> 1000
TLP characteristic according to [IEC1]	I/V characteristics

Table 2-1: Target values for ESD suppression device

The given target values for operation voltage and ESD trigger voltage are related to the position of ESD protection device within the BIN as given in Figure 2-1.

3 Required Tests

3.1 General

For evaluation of EMC behavior of the ESD suppression device the following tests are defined:

- mixed mode S-Parameter measurement
- test of damage from ESD
- impact to ESD discharge current in a defined 100BASE-T1 network
- test of unwanted clamping effect at RF immunity tests.

All test are defined at a two-line ESD suppression device used in a 100BASE-T1 MDI. If the ESD suppression device has more than two lines the test setup should be adapted accordingly. For single devices the test should be performed with a combination of two devices of the same type.

Prior to performing any RF and ESD tests, the S-Parameter measurements shall be performed on a minimum of 10 samples.

3.2 Mixed Mode S-Parameter Measurement

3.2.1 Test setup

For measuring the mixed mode S-Parameters a 4-port VNA in combination with a special test fixture (adapter test board) as given in Figure 3-1 shall be used. The test fixture without mounted DUT has to be included into the test setup during calibration of VNA test setup.

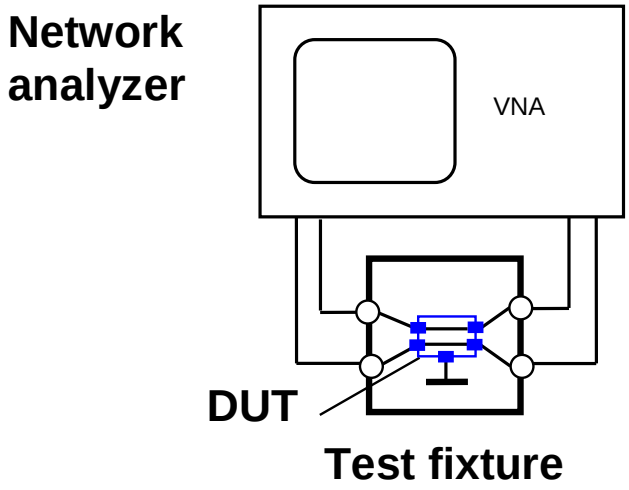


Figure 3-1: Test setup for S-Parameter measurements

Test equipment requirements:

Network analyser:	4-port vector network analyser f = 1 MHz to 1000 MHz (in minimum)
Test fixture:	according to Appendix A

3.2.2 Test procedure and parameters

The test procedure and parameter for S-Parameter measurements are defined in Table 3-1.

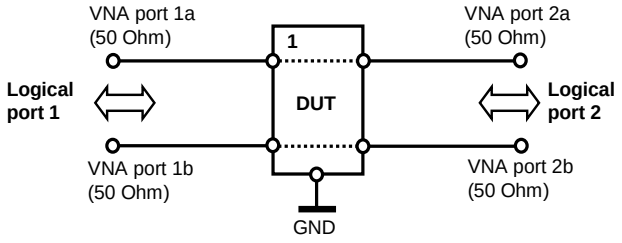
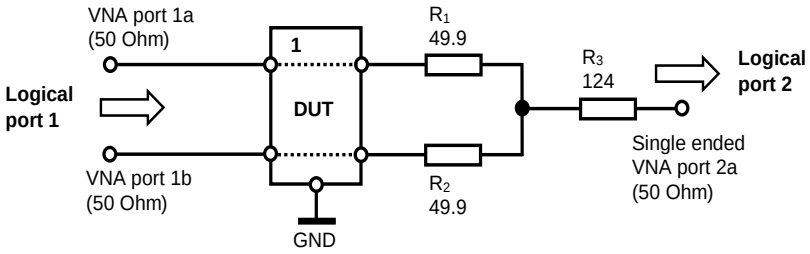
Parameter	Description
Frequency range:	1 MHz to 1 GHz, logarithmic scale
S-Parameter per single path:	S_{dd11} (RL), log. magnitude in dB / transceiver side S_{dd21} (IL), log. magnitude in dB S_{sd21} (DCMR), log. magnitude in dB / transceiver side
VNA measurement circuit:	Port definitions: Mixed mode logic port 1: physical port 1a and port 1b / transceiver side Mixed mode logic port 2: physical port 2a and port 2b / connector side Pin 1 of DUT is placed on transceiver side (logic port 1). S_{dd11} and S_{dd21} measurement: 50 Ω input impedance at each measurement port  S_{sd21} measurement: Differential mode input (logical port 1): 50 Ω impedance each Common mode output (logical port 2): symmetrical single ended network with 200 Ω impedance $R = R_1 \|\| R_2 + R_3 + R_{VNA\ port\ 2a}$  Note: The accuracy of resistor values should be ≤ 1 %. The difference between matching resistors should be ≤ 0.1 %.

Table 3-1: Test parameters for S- Parameter measurements

The measurements shall be performed and documented according the scheme given in Table 3-2.

Test	S- Parameter	Sample
S1	S_{dd11} (RL)	10 samples
S2	S_{dd21} (IL)	
S3	S_{sd21} (DCMR)	

Table 3-2: Required S-Parameter measurements

For each test case the results for all 10 samples has to be documented as diagram in the test report. Recommended limits for evaluation are given in Appendix B.1.

3.3 Damage from ESD

3.3.1 Test setup

The setup given in Figure 3-2 shall be used for testing the ESD robustness of ESD suppression device.

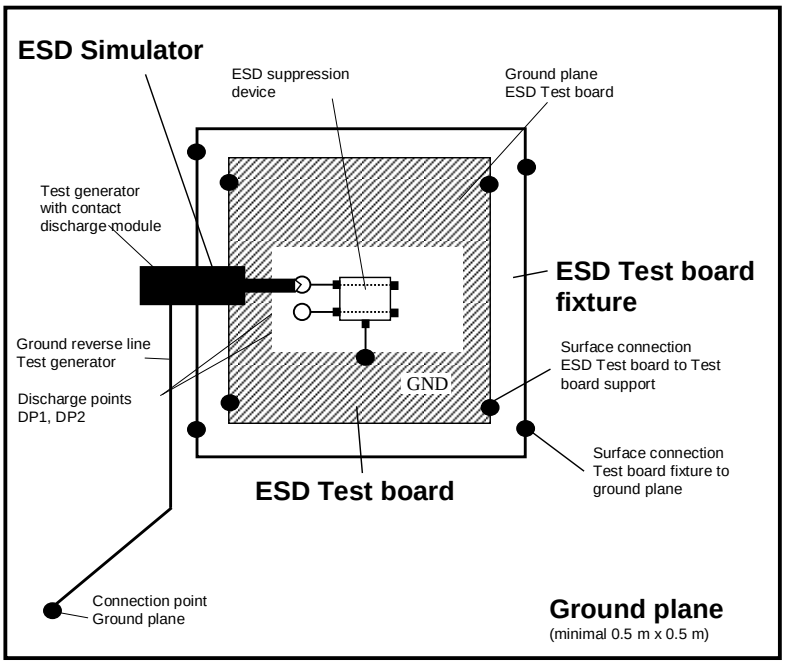


Figure 3-2: Test setup for ESD damage tests

The ground plane with a minimum size of 0.5 m x 0.5 m builds the reference ground plane for the ESD Test setup and must be connected with the electrical grounding system of the test laboratory. The ESD Test generator ground cable shall be connected to this reference plane. The test board fixture realizes the positioning of the ESD Test board and the electrical connection of the ESD Test board ground plane with the reference ground plane. This connection must have low impedance (R < 25 mΩ) and should be built by a surface contact.

During testing the tip of the ESD Test generator discharge module shall be directly contacted with one of the discharge pads DP1 or DP2 of the ESD test board. For this purpose, the discharge points DP1 and DP2 are implemented as rounded vias in the layout of the ESD test board and are directly connected by a trace 15 (-0 +5) mm with the respective pin of the ESD suppression device.

Test Equipment Requirements:

ESD test generator:	according to [ISO1]; contact discharge module with discharge capacitor 150 pF and discharge resistor 330 Ω
ESD test board:	according to Appendix A

3.3.2 Test procedure and parameters

The required tests are defined in Table 3-3 and should be done on three samples.

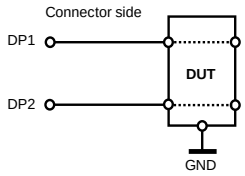
Parameter	Description
Coupling of ESD:	direct galvanic coupled using a contact discharge module according to [ISO1] (C = 150 pF, R = 330 Ω)
Test circuit:	
ESD test voltage:	± 8 kV, ± 15 kV
Number of discharges:	20 per polarity
Time between discharges:	5 s
Damage evaluation criteria:	– degrade by more than 1 dB from the initial value after performing the tests for S-Parameter S_{dd11}, and S_{cd21})$_1$ for frequencies f ≤ 200 MHz – degrade by more than 0.1 dB from the initial value after performing the tests for S-Parameter S_{dd21} for frequencies f ≤ 200 MHz Note: The S-Parameter measurements should be done according to 3.2. Level at noise floor or strong resonances shall be ignored for evaluation.)$_1$ for simplification of measurement the S-Parameter S_{cd21} shall be measured with the same test setup as used for the other required parameters.
Test procedure:	1. S-Parameter reference measurement before ESD test 2. Apply ESD discharges at DP1 (± 8 kV, 20 per polarity, 5 s delay) 3. Apply ESD discharges at DP2 (± 8 kV, 20 per polarity, 5 s delay) 4. Evaluate damage using damage evaluation criteria 5. apply 20 ESD discharges per polarity at DP1 with ± 15 kV and 5 s delay in between 6. apply 20 ESD discharges per polarity at DP2 with ± 15 kV and 5 s delay in between 7. evaluate damage using damage evaluation criteria

Table 3-3: Test parameters for ESD damage tests

The tests shall be performed and documented according the scheme given in Table 3-4.

Test	Discharge points	Comment	Sample
E1	DP1	Line 1	3 samples
E2	DP2	Line 2	

Table 3-4: Required ESD tests for damage

Recommended limits for ESD test voltages are given in Appendix B.2.

3.4 ESD discharge current measurement

3.4.1 Test setup

The setup given in Figure 3-3 shall be used for measuring the ESD discharge current through a 100BASE-T1 transceiver simulation network if the ESD suppression device is used as a part of the MDI network.

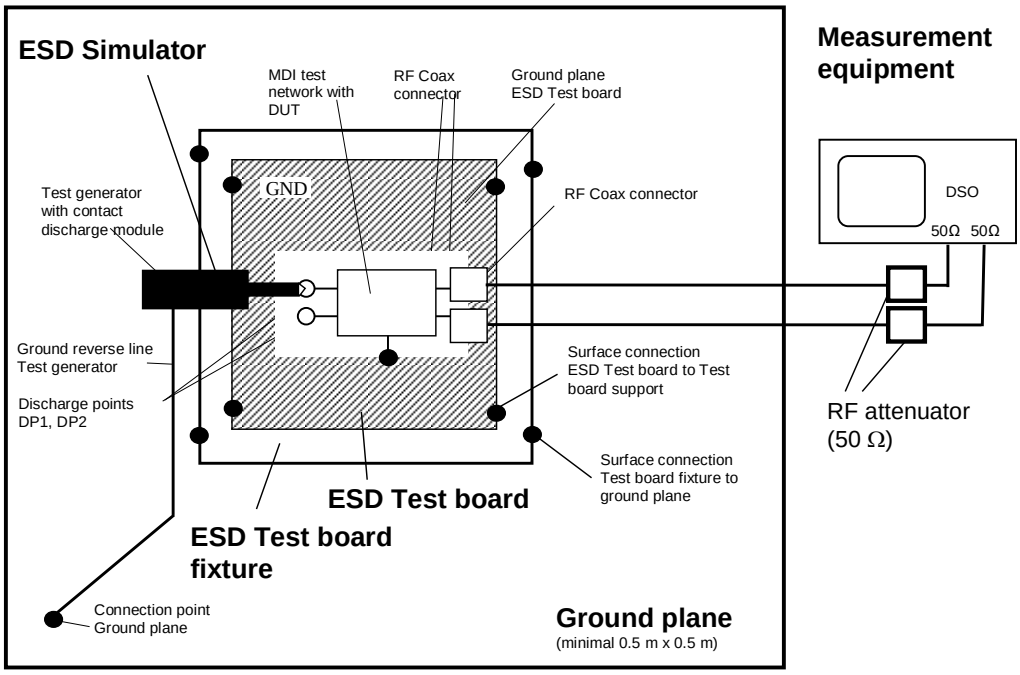


Figure 3-3: Test setup for ESD discharge current measurement

The ground plane with a minimum size of 0.5 m x 0.5 m builds the reference ground plane for the ESD Test setup and must be connected with the electrical grounding system of the test laboratory. The ESD Test generator ground cable shall be connected to this reference plane. The test board fixture realizes the positioning of the ESD Test board and the electrical connection of the ESD Test board ground plane with the reference ground plane. This connection must have low impedance (R < 25 mΩ) and should be built by a surface contact. Copper tapes can be used in addition. For reduction of parasitic field coupling from ESD generator into the test circuit it is recommended to position the ESD test board with passive components on bottom side into the metallic test fixture.

During testing the tip of the ESD Test generator discharge module shall be directly contacted with one of the discharge pads DP1 or DP2 of the ESD test board. For this purpose, the discharge points DP1 and DP2 are implemented as rounded vias in the layout of the ESD test board and are directly connected by a trace 15 (-0 +5) mm with the MDI test network.

Shielded cables are used for connection of measurement outputs of the MDI test network on the ESD test board to the DSO with 50Ω input impedance. An additional attenuator prevents the DSO inputs from damage. Care should be taken that the used DSO is not influenced by the ESD discharge event.

Test Equipment Requirements:

ESD test generator:	according to [ISO1]; contact discharge module with discharge capacitor 150 pF and discharge resistor 330 Ω
DSO	50 Ω input impedance, minimum 1GHz analog input bandwidth
RF attenuator	50 Ω input impedance, minimum 10 dB attenuation
ESD test board:	according to Appendix A

3.4.2 Test procedure and parameters

The required tests are defined in Table 3-5 and should be done on three samples.

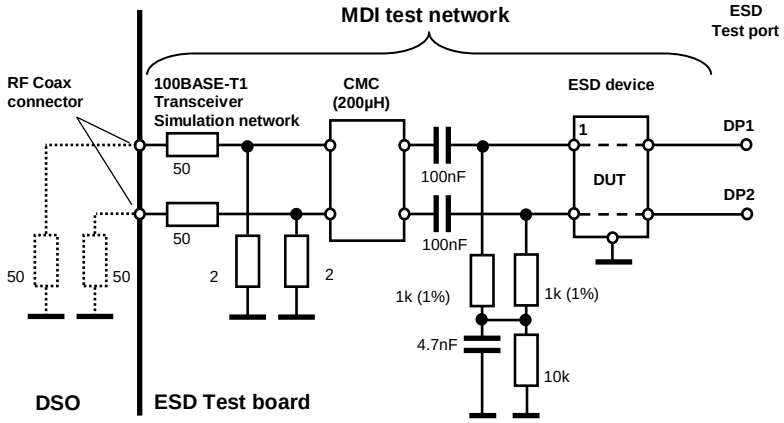
Parameter	Description
Coupling of ESD:	direct galvanic coupled using a contact discharge module according to [ISO] (C = 150 pF, R = 330 Ω)
Test circuit:	 Note: The used CMC should fulfil the requirements of [OPEN1]. If available, a representing CMC for each CMC ESD saturation class I and II should be used for testing. The resistors for common mode termination network shall be from the SMD design 1206 or 0805 with a maximum tolerance of 1 %. The exact type ID and manufacturer of the used resistors must be documented in the test report. The resistors for transceiver simulation network shall be SMD types design 0603 or 0402. A parallel circuit of resistors is recommended to achieve low impedance of network.
ESD test voltage:	± 3 kV, ± 5 kV, ± 6 kV, ± 7 kV, ± 15 kV
Evaluation criteria:	measured ESD discharge current waveform

Table 3-5: Test parameters for ESD discharge current measurement

The tests shall be performed and documented according the scheme given in Table 3-6.

Test	Discharge points	Comment	ESD saturation class of used CMC according to [OPEN1]	Sample
E1	DP1	Line 1	I	3 samples each
E2			II	
E3	DP2	Line 2	I	
E4			II	

Table 3-6: Required ESD discharge current measurement

For each test case the remaining ESD discharge current waveform, measured after MDI test network, shall be measured and documented in the test report. It is recommended that the measured ESD discharge current waveform remain below the limits given in Appendix B.3.

3.5 Test of unwanted Clamping Effect at RF immunity Tests

3.5.1 Test setup

For testing the unwanted clamping effect of ESD suppression device at RF immunity tests a RF generation unit, consisting of RF generator, RF amplifier, RF power meter with directional coupler, in combination with a special test board, RF attenuator and RF power analyzer according to Figure 3-4 shall be used.

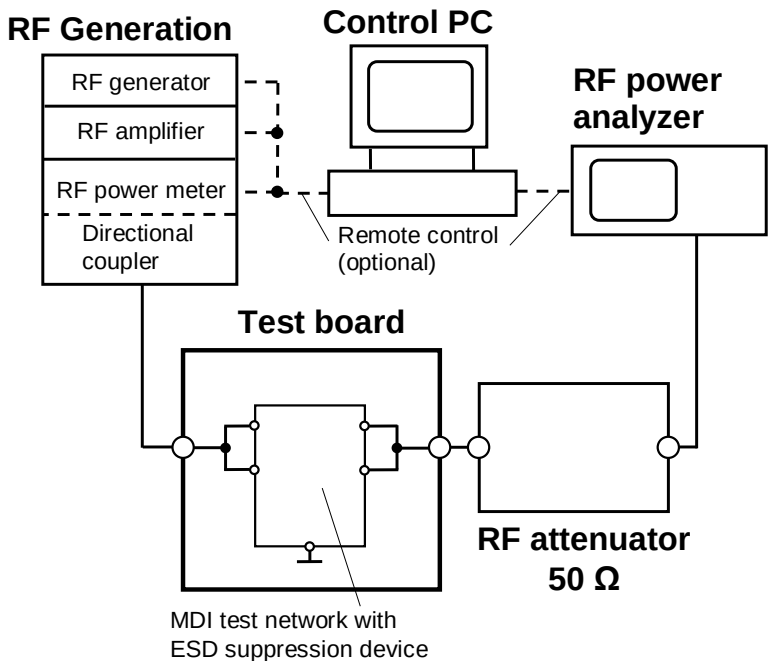


Figure 3-4: Test setup for RF clamping test

Test equipment requirements:

RF generator:	f = 1 MHz – 1000 MHz, modulation AM
RF amplifier:	P ≥ 10 W
RF power meter with directional coupler:	f = 1 MHz - 1000 MHz
RF attenuator:	P ≥ 10 W, ≥ 30 dB attenuation
RF analyser:	RF power meter or spectrum analyzer
Control PC	
Test fixture:	mixed mode test circuit board according to Appendix A, figure A.1 or two port test circuit board in dependence on Appendix A, figure A.1

3.5.2 Test procedure and parameters

The required tests are defined in Table 3-7 and should be performed on one samples.

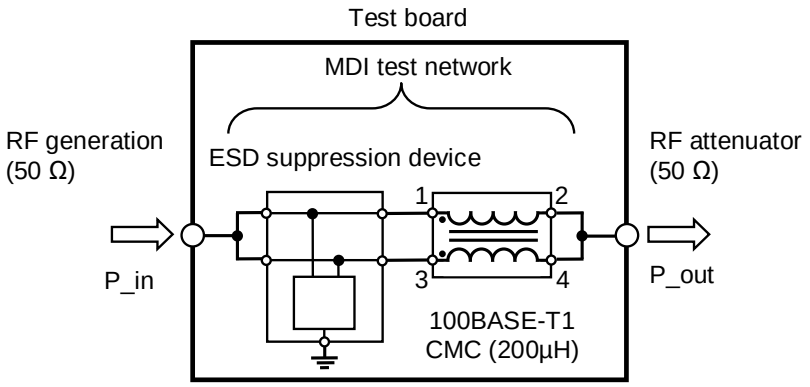
Parameter	Description	
Frequency:	Range	Step
	1 MHz to 10 MHz	0.25 MHz
	10 MHz to 100 MHz	1 MHz
	100 MHz to 200 MHz	2 MHz
	200 MHz to 400 MHz	4 MHz
	400 MHz to 1000 MHz	10 MHz
Dwell time per step:	1 s	
Modulation:	AM 80 % 1 kHz ($\hat{P}_{AM} = \hat{P}_{CW}$)	
Test parameter:	CMR value	
Test circuit:	 Note: The used CMC should fulfil the requirements of [OPEN1]. Calculation of MDI test network CMR value: CMR(f) = *P_in*(f) – *P_out*(f)	
Test power level:	Controlled forward power [dBm] for classes according to Figure B-5	
Evaluation of clamping effect:	Maximum deviation of 1 dB from CMR reference value at 20 dBm for test power level according to limit classes	
Test procedure:	1. test with test power 20 dBm for setting the reference value for CMR 2. test with power level class I according to Figure B-5 3. test with power level class II according to Figure B-5 4. test with power level class III according to Figure B-5	

Table 3-7: Test parameters for RF clamping test

The tests shall be performed and documented according the scheme given in Table 3-8.

Test	S- Parameter	Sample
RF-CL	S_{21} (CMR)	1 sample

Table 3-8: Required RF clamping test

The ESD suppression device should not show an unwanted clamping effect during the RF immunity test according to the evaluation criteria. Recommended limits are given in Appendix B.4.

Appendix A - Test Circuit Boards

A.1 General requirements for test fixtures

A printed circuit board design with RF board-to-coax connectors shall be used for all test fixtures. To ensure reliable RF parameters of the test fixture, a PCB with at least two layers with enlarged GND reference plane is required. The traces on the test board should be designed as 50 (+/- 5) Ohm single ended transmission line with a length as short as possible. For design of footprint the related specification of ESD suppression device manufacturer have to be meet.

For S-Parameter 3-Port test fixture additional specific requirements are defined in section A.2.

In general the test fixture design and the method of connecting the ESD suppression device with the test fixture shall allow high accuracy and reproducible test results.

A.2 Self-balance requirements for S-Parameter test fixture

The 3-Port test fixture (test circuit board with soldered RF connectors) used for balance measurement shall have a very high grade of self-balance. To ensure the test fixture self-balance characteristic of symmetrical network at logical port 2 (common mode), the traces between the DUT and all resistors (R_1, R_2 and R_3) must kept highly symmetric and as short as possible.

To prove the test fixture self-balance characteristic, the test parameter and requirements given in Table A-1 are defined.

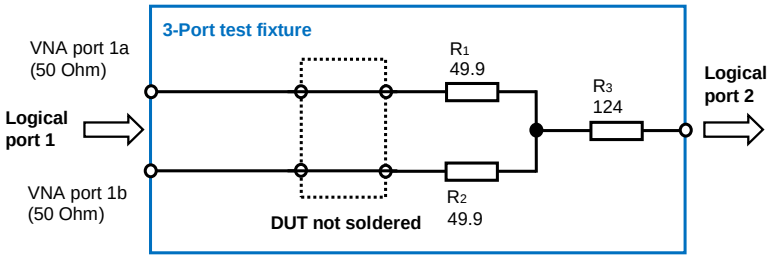
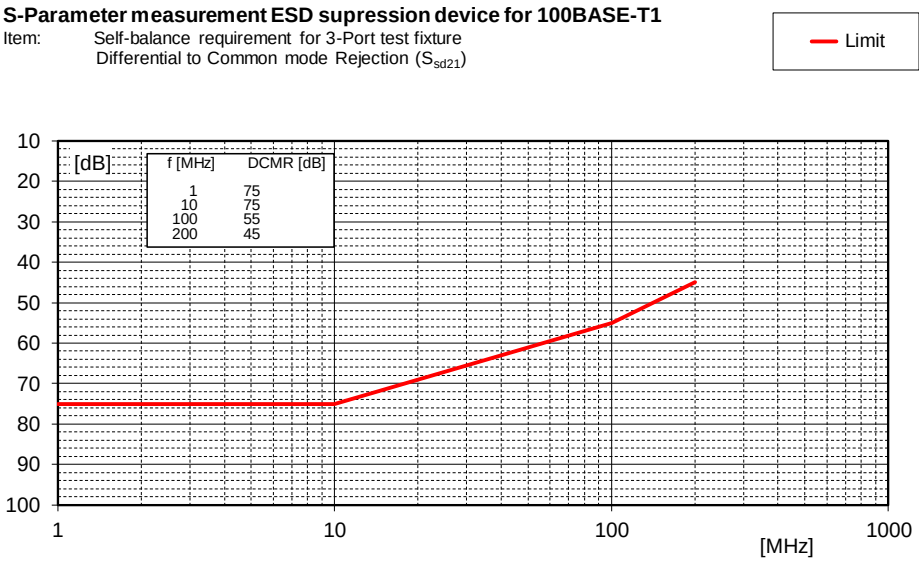
Parameter	Description
Frequency range:	1 MHz to 1 GHz, logarithmic scale
S-Parameter:	S_{sd21} (DCMR), log. magnitude in dB
VNA measurement circuit:	Port definitions: Differential mode input (logical port 1): 50 Ω impedance each Common mode output (logical port 2): symmetrical single ended network with 200 Ω impedance $R = R_1 \mid\mid R_2 + R_3 + R_{VNA\ port\ 2a}$  Note: The DUT shall be not soldered at the fixture self-balance measurement.
Requirement:	$DCMR \geq \begin{pmatrix} 75 & 1 \leq f \leq 10 \\ 75 - 20log\left(\frac{f}{10}\right) & 10 \leq f \leq 100 \\ 55 - 33log\left(\frac{f}{100}\right) & 100 \leq f \leq 200 \end{pmatrix} dB$, frequency f in MHz 

Table A-1: Test parameters and requirements for 3-Port test fixture

A.3 Example for test fixture S-Parameter measurement

The reference points by calibration are the pads of the DUT at the test fixture board.

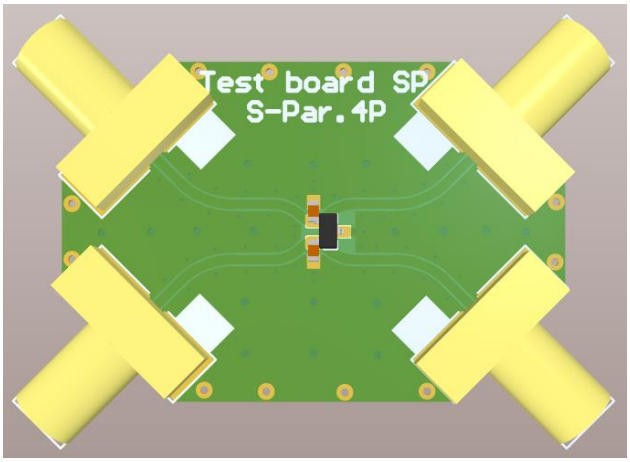


Figure A-1: Example Test fixture S-Parameter measurement - mixed mode, top layer

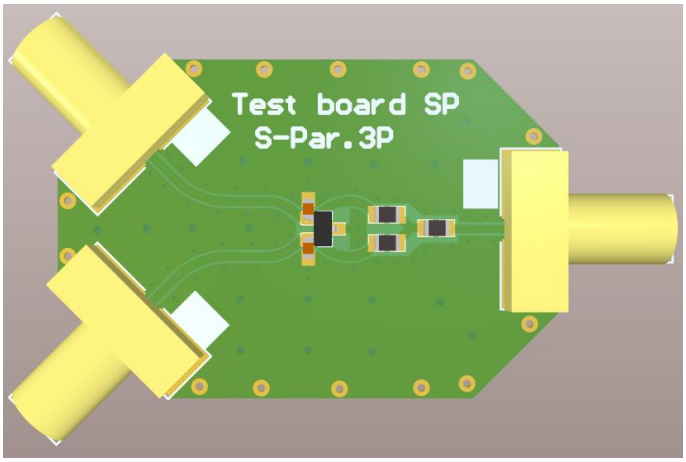


Figure A-2: Example Test fixture S-Parameter measurement - single ended, top layer

A.4 Example for test fixture ESD tests

The reference points by calibration are the input of RF connector (SMA) at the test fixture board.

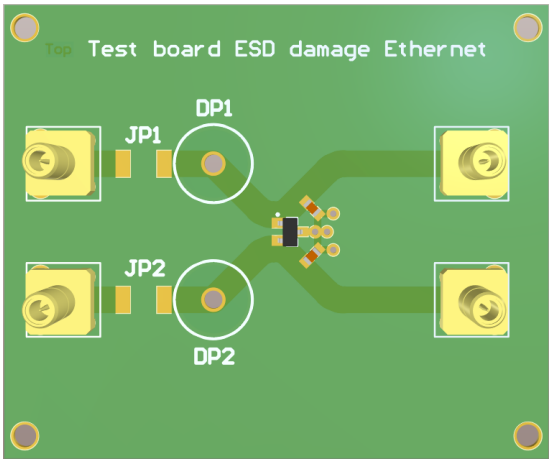


Figure A-3: Example Test fixture ESD tests, top layer

A.5 Example for Test Fixture ESD Discharge Current Measurement

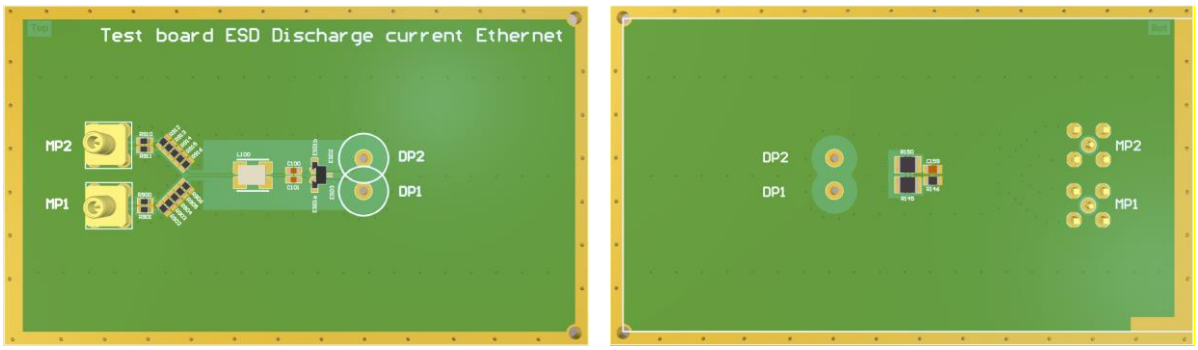


Figure A-4: Example Test fixture ESD discharge current measurement, top and bottom layer

Appendix B – Recommended Limits for Tests

B.1 S-Parameter Measurements

For evaluation of mixed mode S-Parameters limits for each parameter are given in Figure B-1 through Figure B-3 are recommended for stand-alone ESD suppression devices. The limits are valid for test cases S1 through S3. For passive components with internal ESD suppression unit in combination with a common mode termination circuit limits will be different and are under discussion.

$$RL \geq \begin{pmatrix} 27 & 1 \leq f \leq 10 \\ 27 - 9.75log\left(\frac{f}{10}\right) & 10 \leq f \leq 66 \end{pmatrix} dB, \text{ frequency } f \text{ in MHz}$$

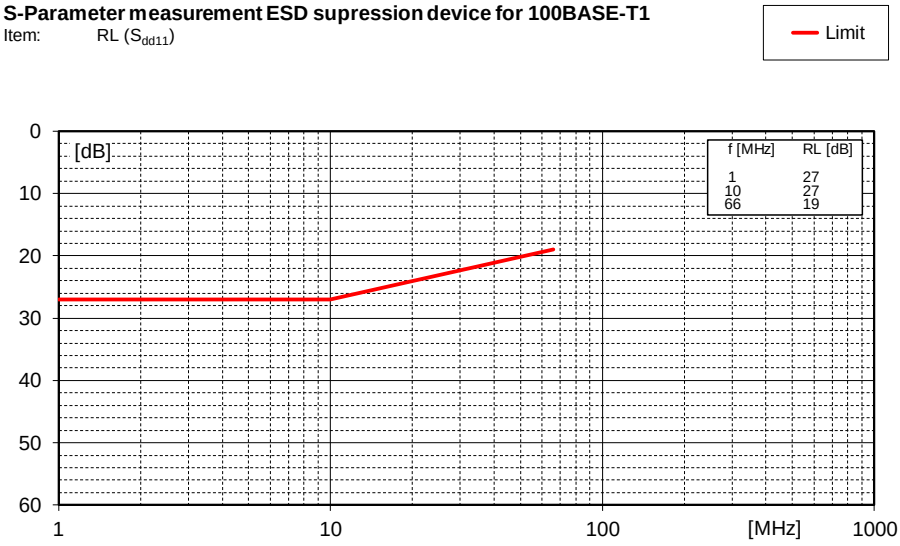


Figure B-1: Recommended limit for S_{dd11} (RL)

$$IL \leq \begin{pmatrix} 0.3 & 1 \leq f \leq 10 \\ 0.3 + 0.2log\left(\frac{f}{10}\right) & 10 \leq f \leq 33 \\ 0.4 + 0.67log\left(\frac{f}{33}\right) & 33 \leq f \leq 66 \end{pmatrix} dB, \text{ frequency } f \text{ in MHz}$$

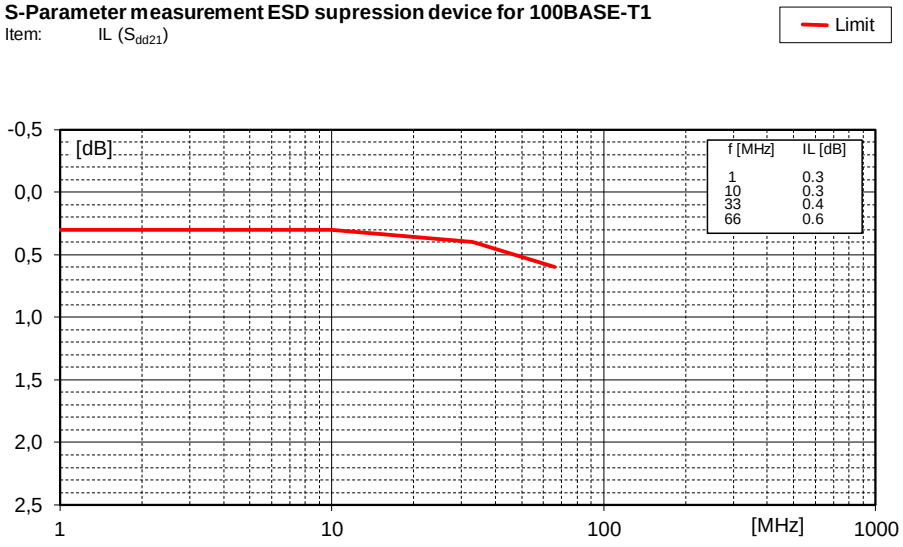


Figure B-2: Recommended limit for S_{dd21} (IL)

$$DCMR \geq \begin{pmatrix} 70 & 1 \leq f \leq 10 \\ 70 - 20log\left(\frac{f}{10}\right) & 10 \leq f \leq 100 \\ 50 - 33log\left(\frac{f}{100}\right) & 100 \leq f \leq 200 \end{pmatrix} dB, \text{ frequency } f \text{ in MHz}$$

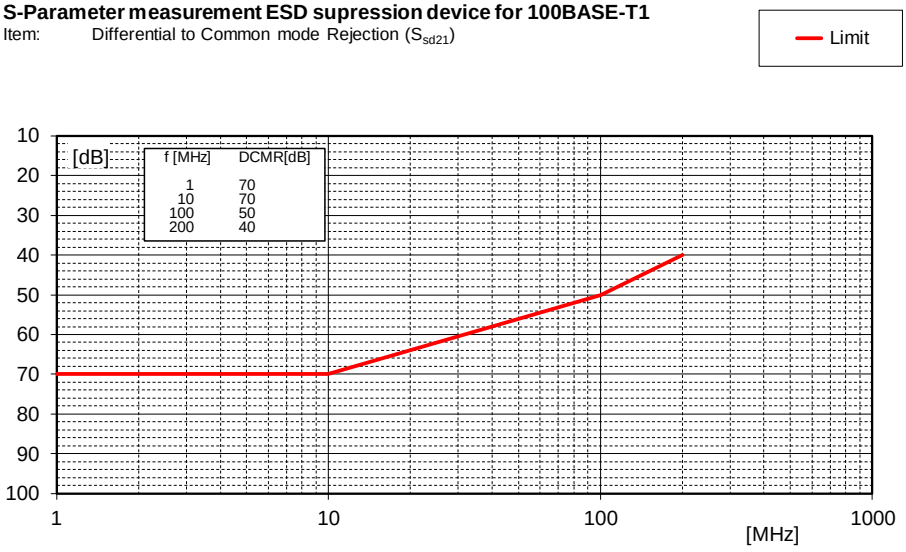


Figure B-3: Recommended limit for S_{sd21} (DCMR)

B.2 Damage from ESD

It is recommended that the ESD suppression device must withstand the ESD discharge with discharge voltage amplitude of +/- 15 kV without damage.

B.3 ESD Discharge Current Measurement

For evaluation of the impact of ESD suppression device to ESD discharge current through a 100BASE-T1 transceiver simulation network limits given in Figure B-4 for positive ESD test voltages are recommended. For negative ESD test voltages the given limits with inverted amplitudes should be applied.

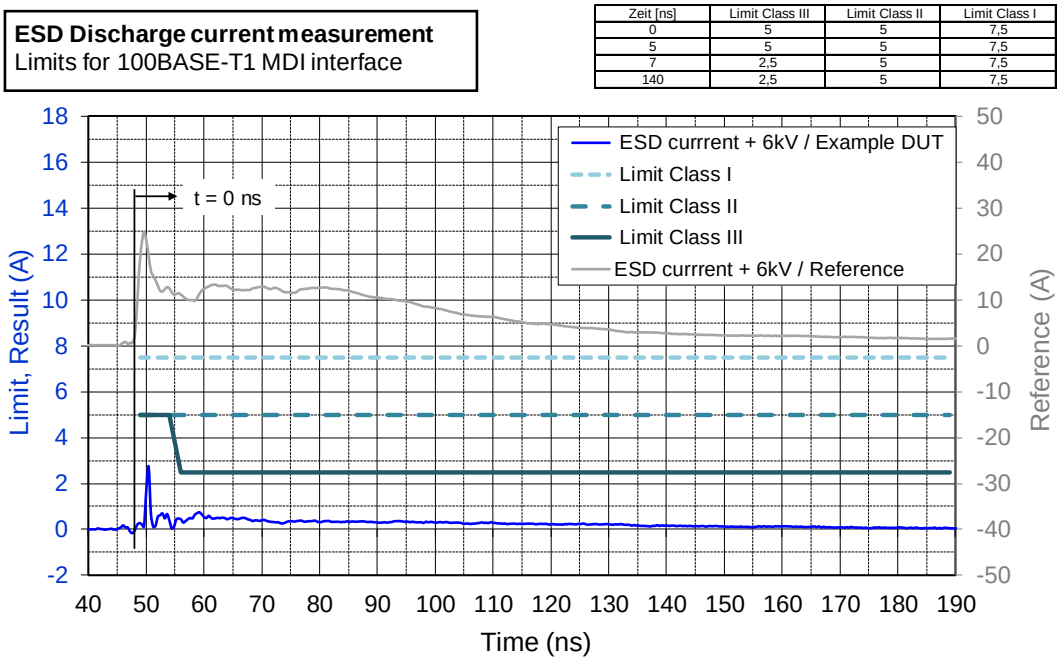


Figure B-4: Recommended limits for ESD discharge current

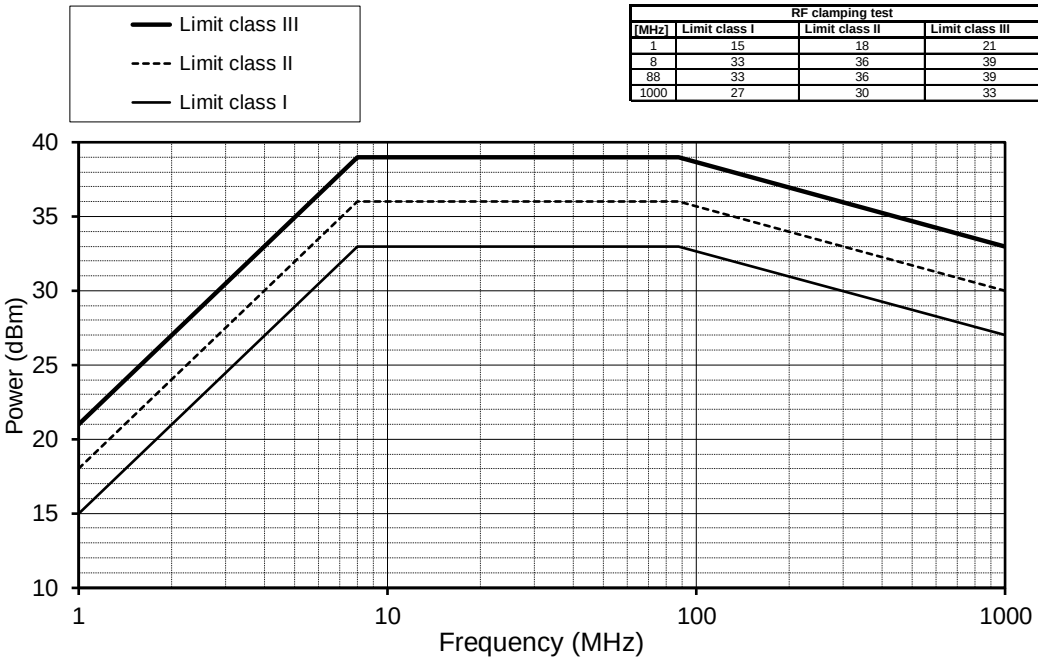
Table B-1 shows the relation between the required ESD robustness of the MDI interface that should be achieved using the ESD suppression device, the ESD robustness of Ethernet transceiver to be protected, applicable ESD test voltages and the related limit classes for the ESD suppression device.

ESD robustness requirement on MDI interface	**ESD robustness of transceiver to be protected**	**ESD test voltages to be applied at MDI test network**	**Limit class for ESD suppression device**
± 6 kV	at least ± 2 kV and less than ± 6 kV	± 3 kV and ± 6 kV	III
± 6 kV	at least ± 4 kV and less than ± 6 kV	± 5 kV and ± 6 kV	II
± 15 kV	at least ± 2 kV and less than ± 15 kV	± 3 kV and ± 15 kV	III
± 15 kV	at least ± 4 kV and less than ± 15 kV	± 5 kV and ± 15 kV	II
± 15 kV	at least ± 6 kV and less than ± 15 kV	± 7 kV and ± 15 kV	I
Note: The ESD robustness of transceiver to be protected is a result of ESD test according to [OPEN2].			

Table B-1: Limit classes and related applied ESD test voltages

B.4 Test of unwanted Clamping Effect at RF Immunity Tests

It is recommended that the ESD suppression device doesn't show an unwanted clamping effect during the RF immunity test with a power level of limit class III according to Figure B-5.



RF clamping test			
[MHz]	Limit class I	Limit class II	Limit class III
1	15	18	21
8	33	36	39
88	33	36	39
1000	27	30	33

Figure B-5: Test power levels for RF clamping tests at ESD suppression device

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