

**EMC test of TVS for automotive Ethernet**

**Table of Contents**

## Table of Contents

Table of Contents.....	2
1. General .....	4
2. ESD .....	4
2.1. What is an ESD?.....	4
2.2. System level tests. ....	4
2.3. ESD protection diodes .....	6
2.4. ESD protection devices within the Automotive networks.....	7
3. Automotive Ethernet EMC Requirement.....	7
3.1. Recommended circuit example by OA .....	8
3.2. Evaluation of general parameter in the datasheet.....	8
4. EMC tests for ESD suppression devices .....	9
4.1. general .....	9
4.2. Mixed Mode S-parameter measurement .....	9
4.2.1. Test procedure and parameters of Mixed Mode S-parameter measurement .....	10
4.3. ESD damage test .....	11
4.3.1. Test setup .....	11
4.3.2. Test procedure and parameters for ESD damage test.....	11
4.4. Unwanted clamping effect at RF immunity tests .....	12
4.4.1. Test setup .....	12
4.4.2. Test Procedure and parameters for RF clamping test .....	12
4.5. ESD Discharge Current measurement .....	13
4.5.1. Test setup .....	13
4.5.2. Test procedure and parameters for ESD Discharge current measurement.....	14
Changelog.....	15
RESTRICTIONS ON PRODUCT USE .....	16

---

**List of Figures**

Figure 2-1: IEC 61000-4-2 test .....	4
Figure 2-2: IEC 61000-4-5 test .....	5
Figure 2-4: System operation in the event of an ESD strike .....	6
Figure 2-3: Normal system operation .....	6
Figure 2-5: Conductive (on) and non-conductive (off) states of an ESD .....	6
Figure 2-6: Selection of ESD protection diodes according to the application. (Frequency) .....	7
Figure 3-1: recommended circuit example by Open Alliance.....	8
Figure 4-1: Arrangement example of ESD protection device with 100 Base-T1/1000 Base-T1 MDI interface .....	9
Figure 4-2: setup for S-parameter measurement.....	9
Figure 4-3: setup and port definition for 4-port measurement board .....	10
Figure 4-4: setup and port definition for 3-port measurement board .....	10
Figure 4-5: setup for ESD damage test .....	11
Figure 4-6: Test setup for RF clamping test at ESD suppression device .....	12
Figure 4-7: Test circuit for ESD clamping.....	12
Figure 4-8: Test setup for ESD Discharge Current .....	13
Figure 4-9: Test circuit for ESD Discharge Current.....	14

**List of Table**

Table 3-1: Target values for ESD suppression device .....	8
---	---

### 1. General

The Ethernet standard is widely used in industrial and commercial applications, and the scope is also expanding to automotive applications. Automotive Ethernet protocol standards are standardized as IEEE (Institute of Electrical and Electronic Engineers) 802.3bw for 100BASE-T1 and IEEE 802.3bp for 1000BASE-T1.

In addition to these standards, EMC requirements have been added by the OPEN (One Pair Ethernet) Alliance consortium and published as specifications.

Furthermore, the IEC (International Electrotechnical Commission) has standardized the EMC test methods for Ethernet Transceivers as IEC 62228-5, and this standard includes requirements for ESD protection devices used in Ethernet applications. The contents are almost the same as the OPEN specifications.

This application note explains basic ESD items and ESD protection devices for Ethernet applications. It also is explained the EMC test requirements for ESD devices by the Open Alliance and IEC.

### 2. ESD

#### 2.1. What is an ESD?

Static electricity is the charge generated on the surface of dielectric materials. Static electricity is discharged when positively and negatively charged objects are brought into contact with or close to each other. This phenomenon is called an electrostatic discharge (ESD). When a charged human body touches an electronic device, the resulting ESD can be several thousand volts.

#### 2.2. System level tests.

This test is designed to ensure that electronic systems will not be degraded or destroyed by ESD in the everyday environment.

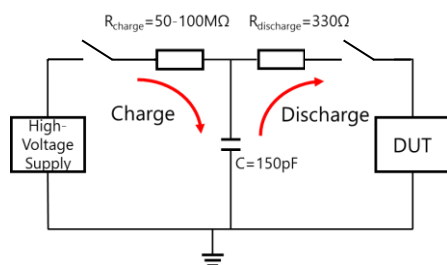
##### ① IEC 61000-4-2 (ESD immunity test: Human body model)

As is the case with the HBM (Human Body Model), this test simulates a discharge that might be released from a charged human body. Two methods are used for ESD testing.

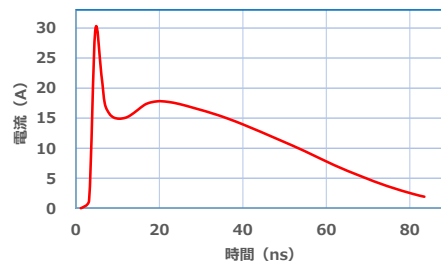
- Direct discharge: Tests a discharge that might occur when a human directly touches an exposed metal surface of a system or a device.
- Air discharge: Tests a discharge that might occur between a device under test (DUT) and a discharge gun through an air layer when the surface of a system or a device is coated with resin or other coating materials.

These ESD tests are stipulated in IEC 61000-4-2.

Toshiba's ESD protection (TVS) diodes are tested using both the direct and air discharge methods.



Test circuit example

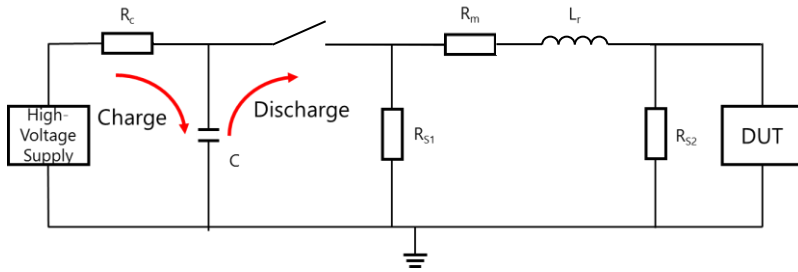


Test waveform example

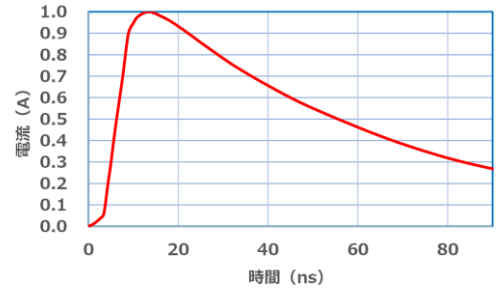
Figure 2-1: IEC 61000-4-2 test

### ② IEC 61000-4-5 test (Surge immunity test)

Also known as a lightning surge test, a surge immunity test models voltage and current surges induced by a nearby lightning strike. This test also includes transient switching phenomena such as a sharp load variation and a load short circuit that might occur when the power switch is turned on. IEC 61000-4-5 test is the most stringent system-level surge immunity test in terms of the level and cycle time of the surge current applied. The surge immunity test is stipulated in IEC 61000-4-5.



Test circuit example



Test waveform example

Figure 2-2: IEC 61000-4-5 test

### 2.3. ESD protection diodes

This section describes the operation of ESD protection diodes. While no ESD pulse is being introduced into a system (i.e., while a system is in normal operation), ESD protection diodes should ideally be disconnected from a device under protection (DUP) so as not to affect its operation. The cathode and anode of each ESD protection diode are connected to a signal line and GND respectively as shown below. When ESD protection diodes are connected in this manner, they do not act as transient voltage suppressors while a system is in normal operation. When an ESD pulse is introduced into the system, it is necessary to ensure that ESD protection diodes conduct to prevent the ESD pulse from reaching the DUP. From the connector, the ESD protection diodes and the DUP can be seen as being connected in parallel. It is therefore important to ensure that ESD protection diodes have low impedance so that most of the ESD energy is shunted through the ESD protection diodes.

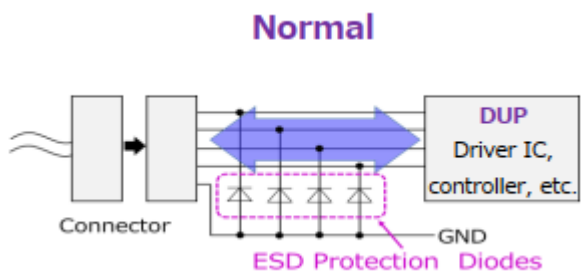


Figure 2-4: Normal system operation

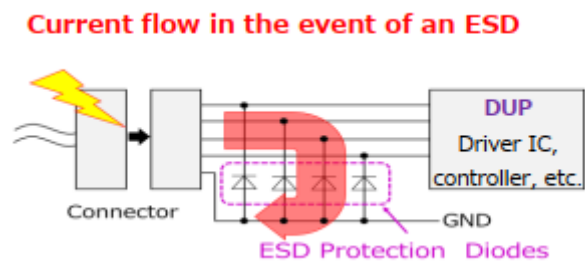


Figure 2-3: System operation in the event of an ESD strike

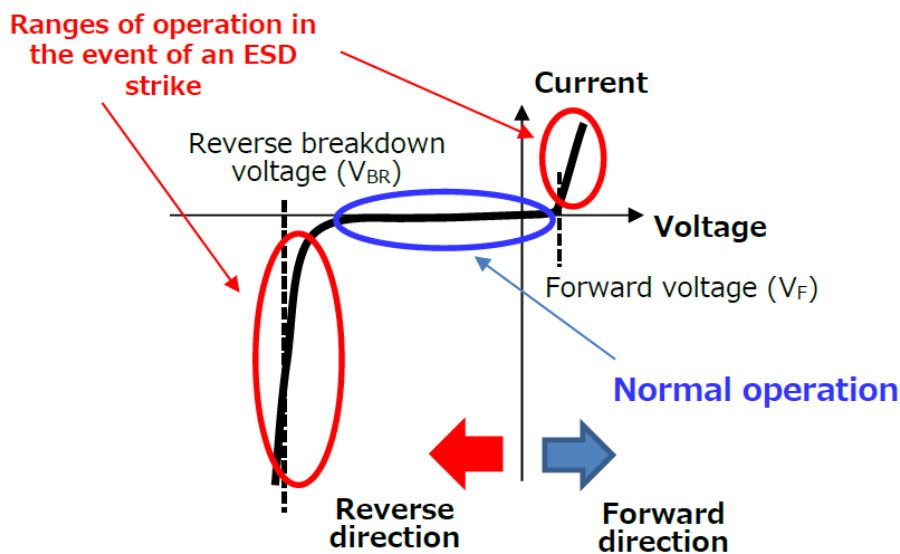


Figure 2-5: Conductive (on) and non-conductive (off) states of an ESD

### 2.4. ESD protection devices within the Automotive networks

Multiple communication standards have been established as a means of communication between ECUs and devices in vehicles, depending on the characteristics required for communication, maximum communication speed, amount of data, etc. Based on each communication standard, it is necessary to select an ESD protection element with appropriate withstand voltage and capacitance between terminals. Figure 2-6 shows the selection criteria for each communication protocol.

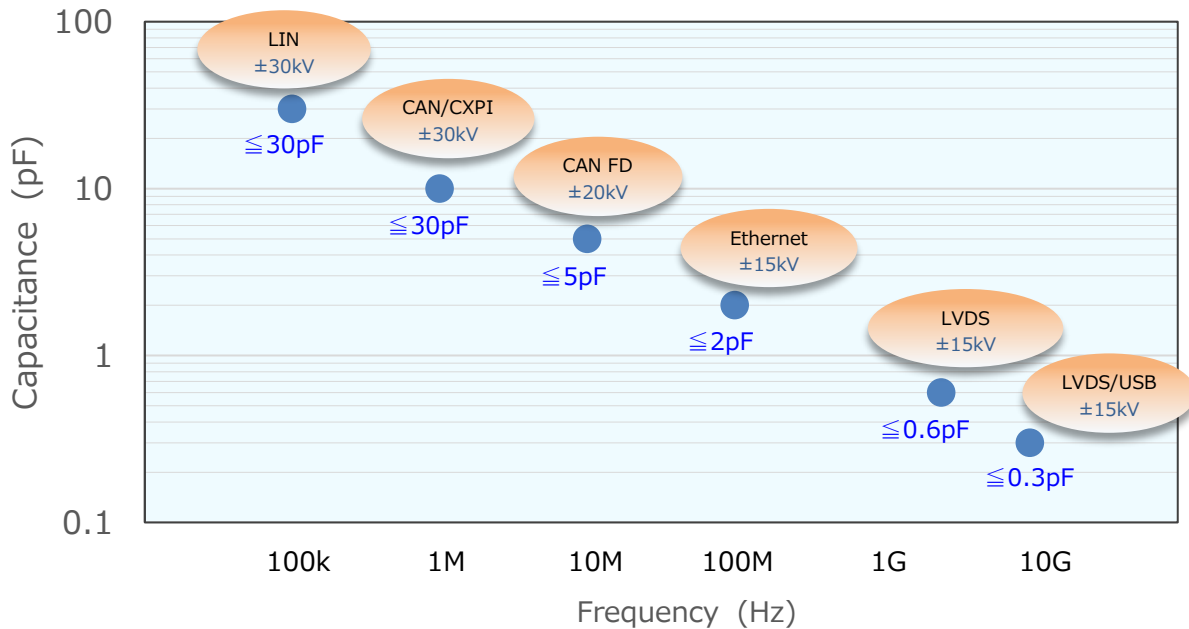


Figure 2-6: Selection of ESD protection diodes according to the application. (Frequency)

## 3. Automotive Ethernet EMC Requirement

The Open Alliance, an in-vehicle Ethernet standardization consortium, has formulated and published the following specifications regarding EMC requirements. (You can download them from the Open Alliance website below with the License Agreement. <https://www.opensig.org/Automotive-Ethernet-Specifications/>)

- 100BASE-T1 EMC Test Specification for Common Mode Chokes
- 100BASE-T1 EMC Test Specification for Transceivers
- 100BASE-T1 EMC Test Specification for ESD Suppression Devices
- 1000BASE-T1 EMC Test Specification for Common Mode Chokes
- 1000BASE-T1 Transceiver EMC Specification
- 1000BASE-T1 ESD Device Test Specification

In addition, the following international standards have been published for EMC evaluation of automotive Ethernet transceivers.

- IEC 62228-5 Integrated circuits – EMC evaluation of transceivers – Part.5: Ethernet transceivers

This standard defines test conditions, test methods, setup, etc. for 100BASE-T1, 100BASE-TX, and 1000BASE-TX. Since these characteristics greatly affect the EMC performance of the transceiver, the following Annex requires that the characteristics of the components used be checked before testing.

- Annex E: Characterization of common mode chokes for EMC evaluation of Ethernet transceivers
- Annex F: Characterization of ESD suppression devices for EMC evaluation of Ethernet transceivers

As part of the EMC evaluation standard for transceiver ICs, IEC standards require EMC characteristics for CMC and ESD protection elements used during testing. These test requirements are almost equivalent to the Open Alliance specifications.

### 3.1. Recommended circuit example by OA

The example of recommended circuit by Open Alliance is shown in Figure 3.1.

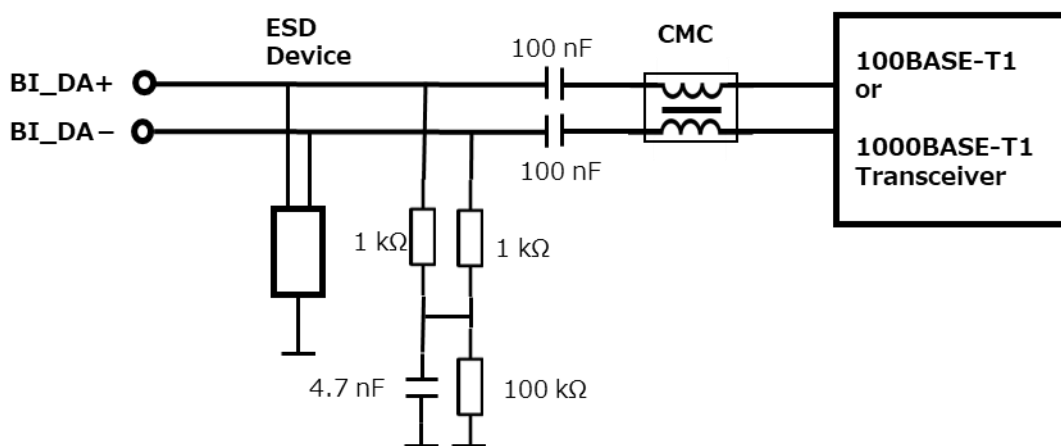


Figure 3-1: recommended circuit example by Open Alliance

### 3.2. Evaluation of general parameter in the datasheet

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

Table 3-1: Target values for ESD suppression device

Parameter	Target values
Working direction	Bi-directional
Operation voltage ( $V_{DCmax}$ )	$\geq 24$ V
ESD trigger voltage	$\geq 100$ V
ESD robustness	+/- 15 kV contact discharge for unpowered device using discharge module according to ISO 10605 (discharge storage capacitor 150 pF, discharge resistor 330 $\Omega$ )
Minimum number of discharges	1000 times
TLP characteristics according to IEC 62615	I/V characteristics



### 4. EMC tests for ESD suppression devices

#### 4.1. general

EMC testing of Ethernet networks is performed on networks that use ESD protection devices based on actual applications, so it is required to check the characteristics of a single ESD protection device that will not deteriorate the EMC characteristics of the entire network.

The following four tests are defined as characteristics evaluation methods.

- Mixed mode S-parameter measurement
- ESD damage test
- Clamping effect during RF immunity test
- ESD Discharge Current measurement on 100(0)Base-T1 network

These measurements are performed using a network assuming a 100BASE-T1 or 1000BASE-T1 MDI interface.

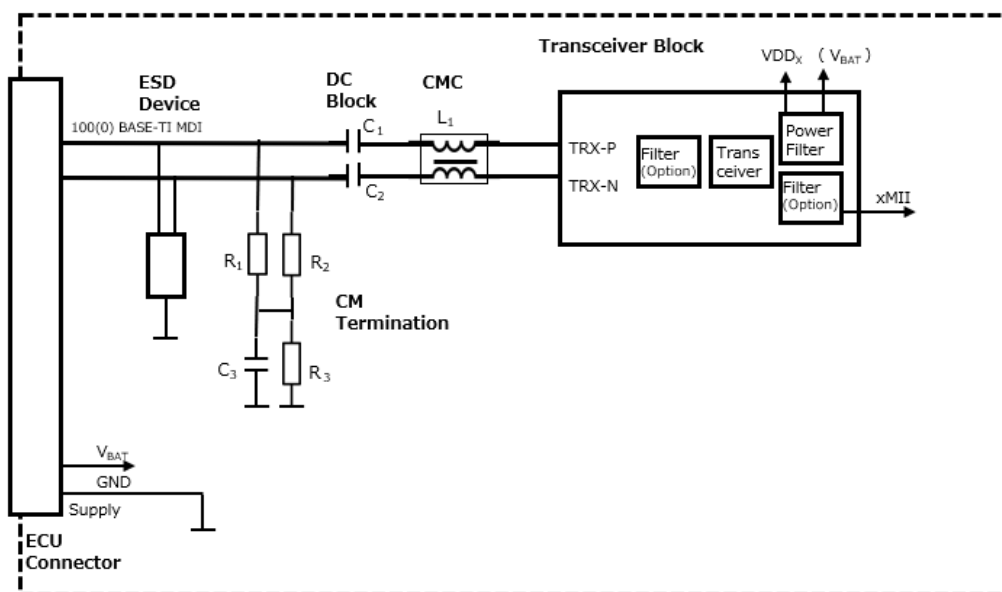


Figure 4-1: Arrangement example of ESD protection device with 100 Base-T1/1000 Base-T1 MDI interface

#### 4.2. Mixed Mode S-parameter measurement

For Mixed Mode S-parameter measurement, prepare a dedicated test board and VNA. Check the effect of ESD protection device onto the signal characteristics. The test setup is shown in Figure 4-2.

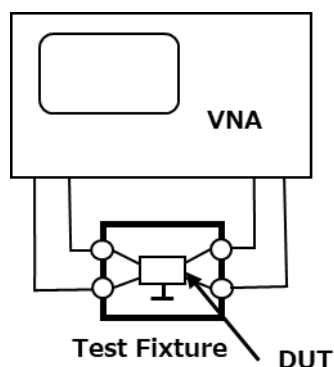


Figure 4-2: setup for S-parameter measurement

The parameters and frequency ranges to be measured are as follows: 10 samples are measured and recorded of each item.

3 ports measurement

- Ssd21 (DCMR) Logarithmic magnitude in dB 1 MHz – 1 GHz

4 ports measurement

- Sdd11 (RL) , Logarithmic magnitude in dB 1 MHz - 1 GHz
- Sdd21 (IL) , Logarithmic magnitude in dB 1 MHz - 1 GHz

\*Note : Frequency ranges in IEC standards are defined from 0.3 MHz to 1 GHz.

### 4.2.1. Test procedure and parameters of Mixed Mode S-parameter measurement

Port settings during measurement are shown in Figures 4-3 and 4-4.

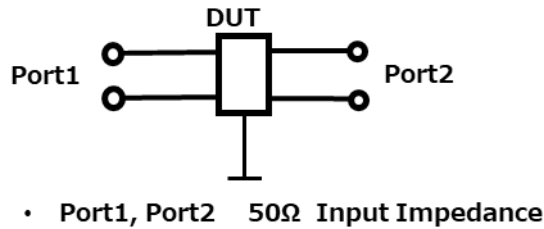


Figure 4-3: setup and port definition for 4-port measurement board

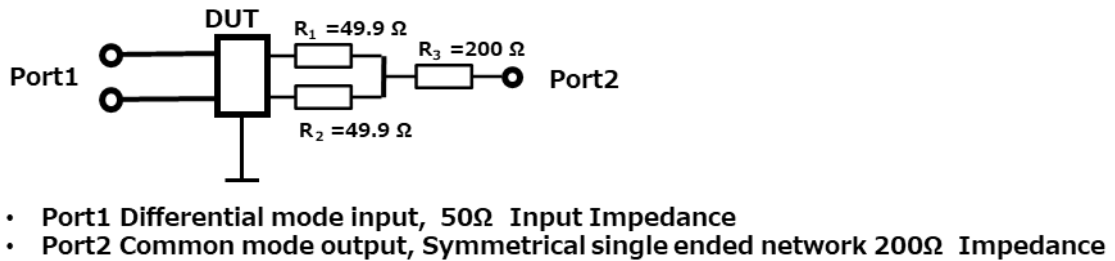


Figure 4-4: setup and port definition for 3-port measurement board

### 4.3. ESD damage test

#### 4.3.1. Test setup

For ESD damage test, compare the S-parameters before and after applying ESD pulse to check the effect on signal characteristics. The test setup is shown in Figure 4-5. The requirements for the testing system are as follows:

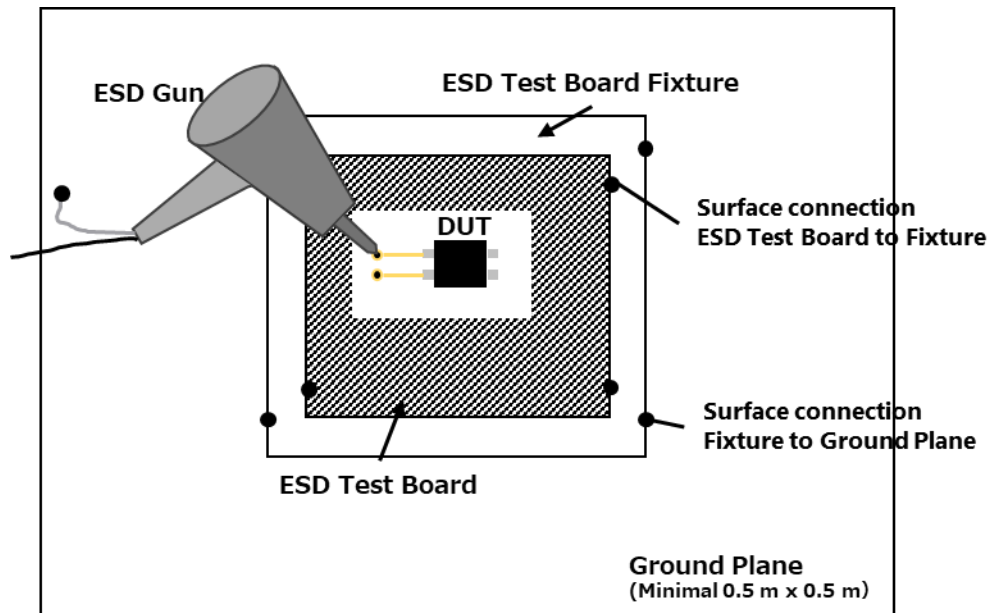


Figure 4-5: setup for ESD damage test

- Minimum 0.5 m x 0.5 m reference ground plane
- Reference ground plane connected to laboratory ground
- ESD Generator ground connected to reference ground plane
- Connect the test board to the reference ground brain with a low impedance of 25 mΩ or less.
- ESD Generator applies directly to points on the board
- Connection from the application point to the ESD protection element at 15 mm-0/+5)
- To reduce parasitic coupling through the ESD Generator space, it is recommended that components be placed on the opposite side of the application plane and placed within a metal test fixture.

#### 4.3.2. Test procedure and parameters for ESD damage test

For the test, an ESD gun generates a contact discharge at the application points (DP1 and DP2) on the test board. 3 samples are measured and recorded.

The test procedure is as follows:

- 1) Measure S-parameter before applying ESD discharge
- 2) Apply ±8 kV 20 times at 5 second intervals to discharge point 1 (DP1)
- 3) Apply ±8 kV 20 times at 5 second intervals to discharge point 2 (DP2)
- 4) Evaluate the impact based on criteria
- 5) Apply ±15 kV 20 times at 5 second intervals to application point 1 (DP1)
- 6) Apply ±15 kV 20 times at 5 second intervals to application point 2 (DP2)
- 7) Evaluate impact based on criteria

Criteria for determining the ESD damage.

- 1) S-parameter measurement S<sub>dd11</sub> and S<sub>cd21</sub>  
Deviation within 1 dB in frequency band below 200 MHz
- 2) S-parameter measurement S<sub>dd21</sub>  
Deviation within 0.1 dB in frequency band below 200 MHz

### 4.4. Unwanted clamping effect at RF immunity tests

#### 4.4.1. Test setup

To confirm that clamping of the ESD protection element does not occur during immunity testing, we conduct tests using an RF generator, RF amplifier, and RF power meter (with bidirectional coupler).

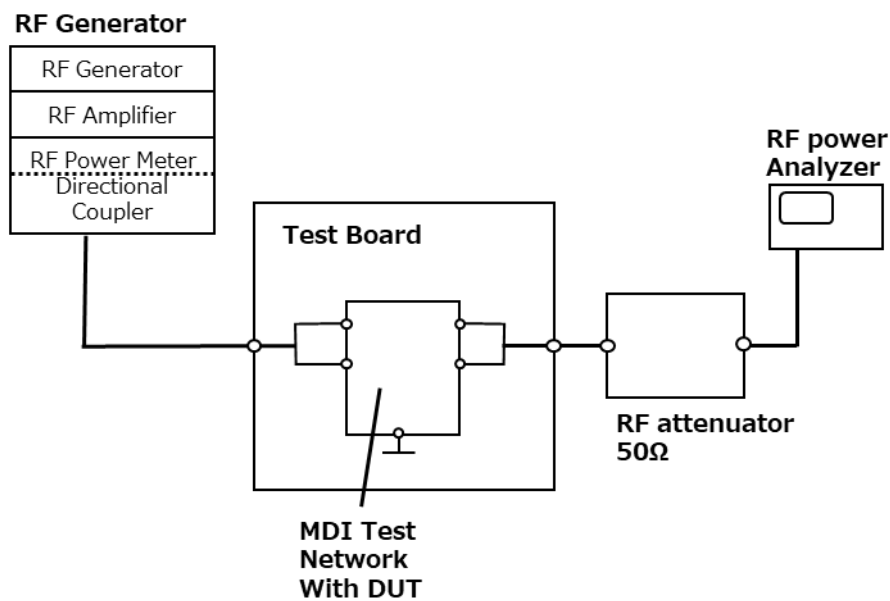


Figure 4-6: Test setup for RF clamping test at ESD suppression device

#### 4.4.2. Test Procedure and parameters for RF clamping test

For unwanted RF clamping test, an interference RF power is applied to the MDI test network according to Figure 4-7.

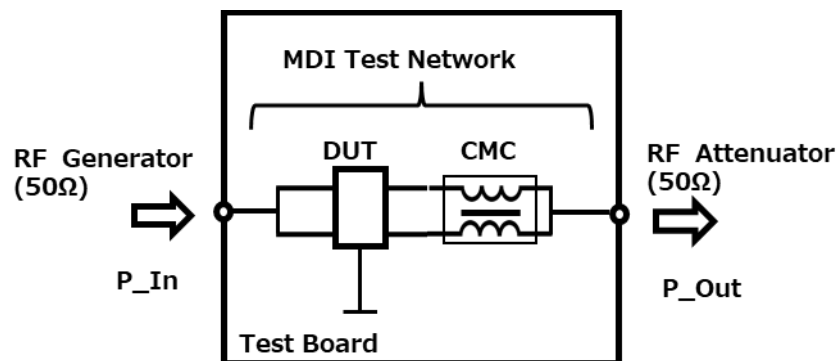


Figure 4-7: Test circuit for ESD clamping

The test procedure is as follows:

- 1) Measured based on CMR (Common Mode Rejection) when 20 dBm is applied.
- 2) Measure CMR after Class 1 level injection
- 3) Measure CMR after Class2 level injection.
- 4) Measure CMR after Class3 level injection.

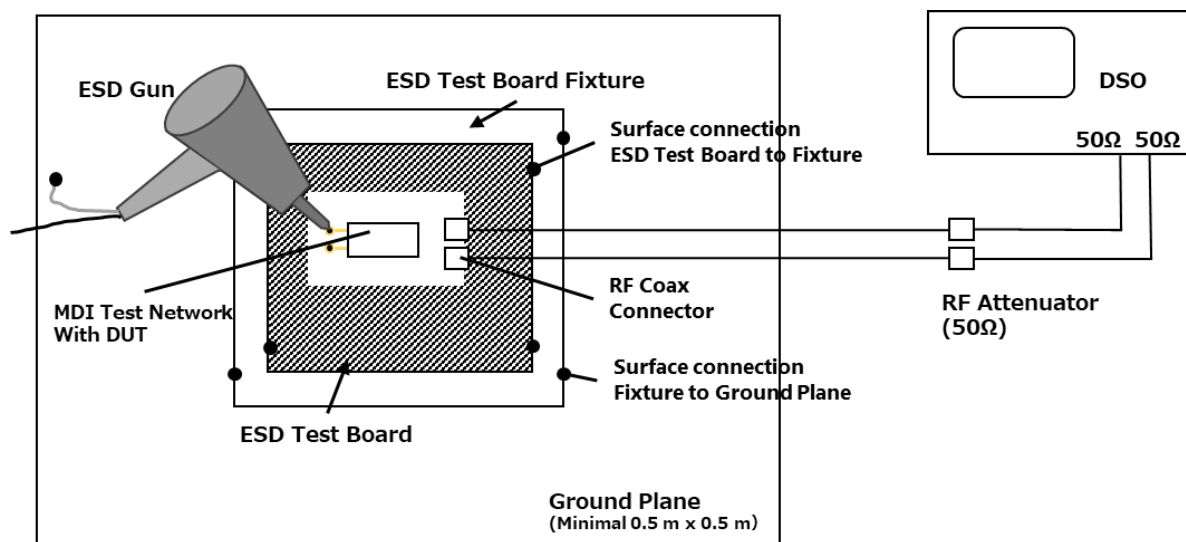
Evaluation criteria

The CMR after injection must change within 1 dB from the reference value when 20 dBm is injected.

### 4.5. ESD Discharge Current measurement

#### 4.5.1. Test setup

For ESD Discharge current measurement, evaluate the residual current flowing through the transceiver PHY when ESD is applied. The test setup is shown in Figure 4-8. The requirements for the testing system are as follows:



**Figure 4-8: Test setup for ESD Discharge Current measurement**

- Minimum 0.5m x 0.5m reference ground plane
- Reference ground plane connected to laboratory ground
- ESD Generator ground connected to reference ground plane
- Connect the test board to the reference ground plane with a low impedance of 25 mΩ or less
- ESD Generator applies directly to points on the board
- Connection from the application point to the ESD protection element is 15 mm (-0/+5)

### 4.5.2. Test procedure and parameters for ESD Discharge current measurement

For the test, mount the MDI test network on the test board as shown in Figure 4-9, and measure the current with an oscilloscope when the ESD voltages are applied. 3 samples are measured and recorded.

Applied voltage:  $\pm 3$  kV,  $\pm 5$  kV,  $\pm 6$  kV,  $\pm 7$  kV,  $\pm 15$  kV

Evaluation criteria: The current value after through the network must be below the limit.

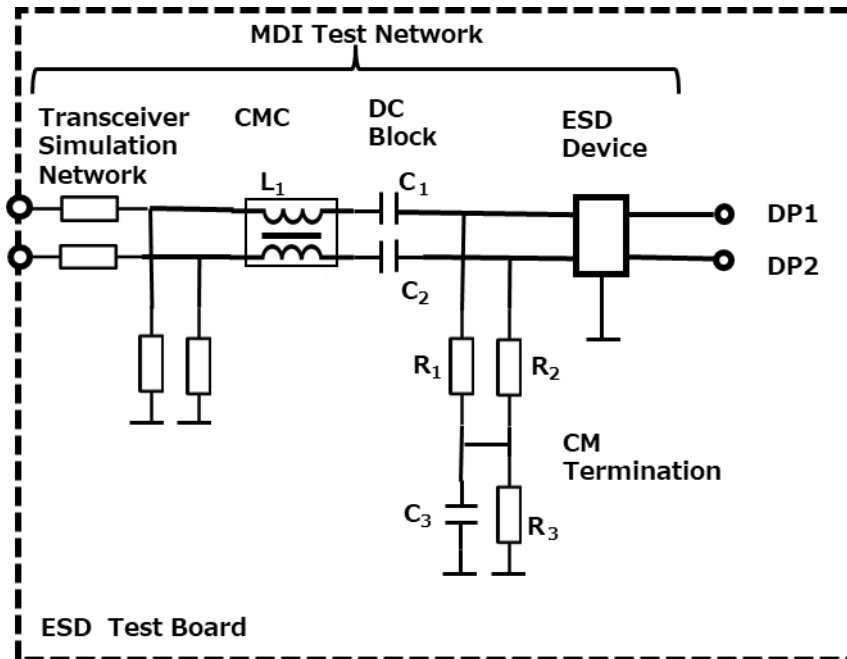


Figure 4-9: Test circuit for ESD Discharge Current

**Reference standards**

IEC 61000-4-2:2008, Electromagnetic compatibility (EMC)–Part 4-2: Testing and measurement techniques–Electrostatic discharge immunity test

IEC 61000-4-5:2005, Electromagnetic compatibility (EMC)–Part 4-5: Testing and measurement techniques–Surge immunity test

IEC 62228-5:2021, Integrated circuits – EMC evaluation of transceivers –Part 5: Ethernet transceivers

IEEE 100BASE-T1 EMC Test Specification for Common Mode Chokes, Version 2.0

IEEE 100BASE-T1 EMC Test Specification for Transceivers, Version 2.0

IEEE 100BASE-T1 EMC Test Specification for ESD suppression Devices, Version 2.0

IEEE 1000BASE-T1 EMC Test Specification for Common Mode Chokes, Version 2.0

IEEE 1000BASE-T1 EMC Test Specification for Transceivers, Version2.1

IEEE 1000BASE-T1 EMC Test Specification for ESD suppression Devices, Version1.0

**Changelog**

<b>Version</b>	<b>Date</b>	<b>Items</b>
Rev. 1.0	2023-11-15	Initial release

## RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA".

Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**

- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.

- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**