

In-vehicle Networks System ESD Protection Design: ESD / EMC Solution and Latch-up Prevention

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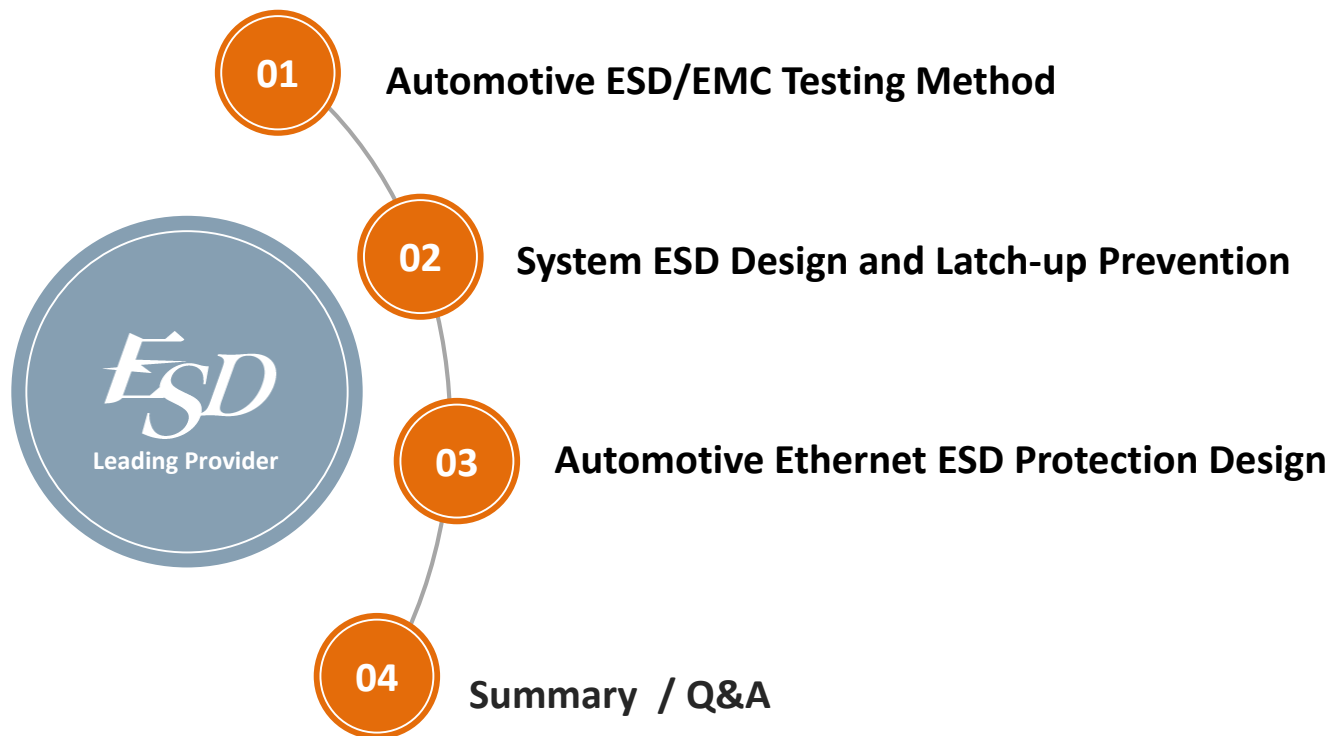
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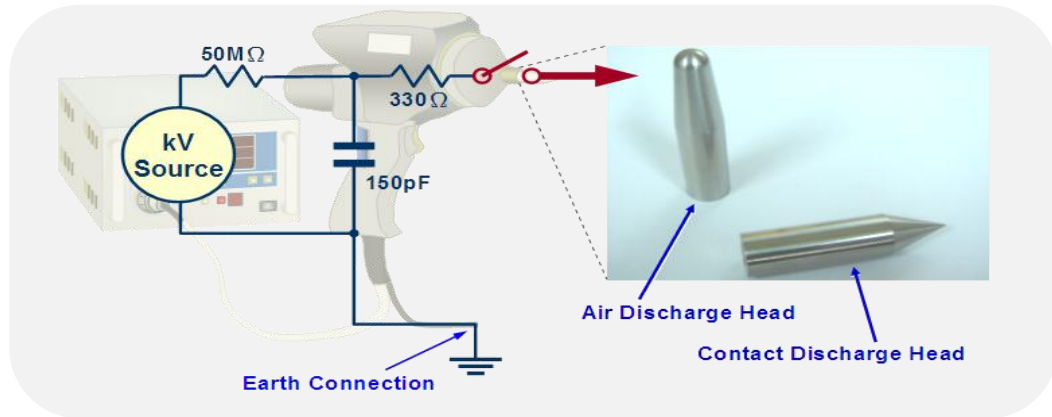
Presentation Agenda:

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ESD ISO10605 ESD Immunity Test & Method



1. Air Discharge



2. Contact Discharge



3. Direct Pin Injection



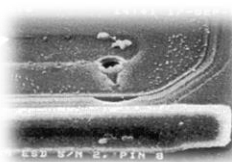
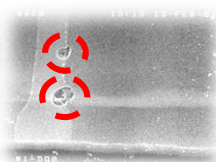
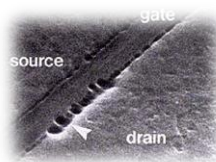
Cable Discharge



Hot Plug

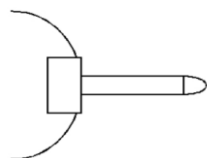
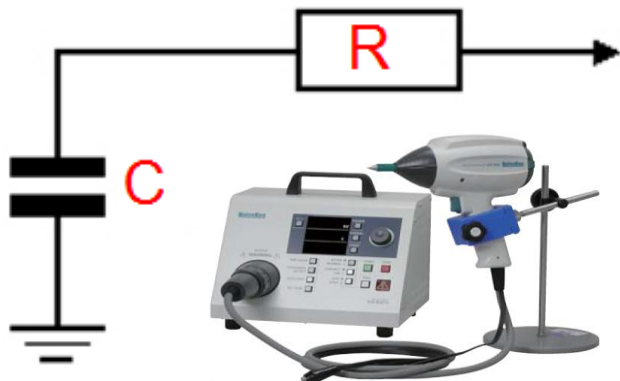


Class	Criterion	Result
A	No abnormal phenomenon occurs during ESD stress	Pass
B	Abnormal phenomenon occurs during ESD stress, but will recover automatically	Pass/Fail
C	Abnormal phenomenon occurs after ESD stress, manual revise is needed	Pass/Fail
D	Hardware damage	Fail

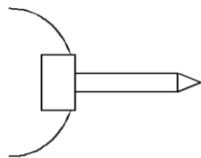




ESD ISO10605 ESD Immunity Test & Method



Air Discharge



Contact Discharge



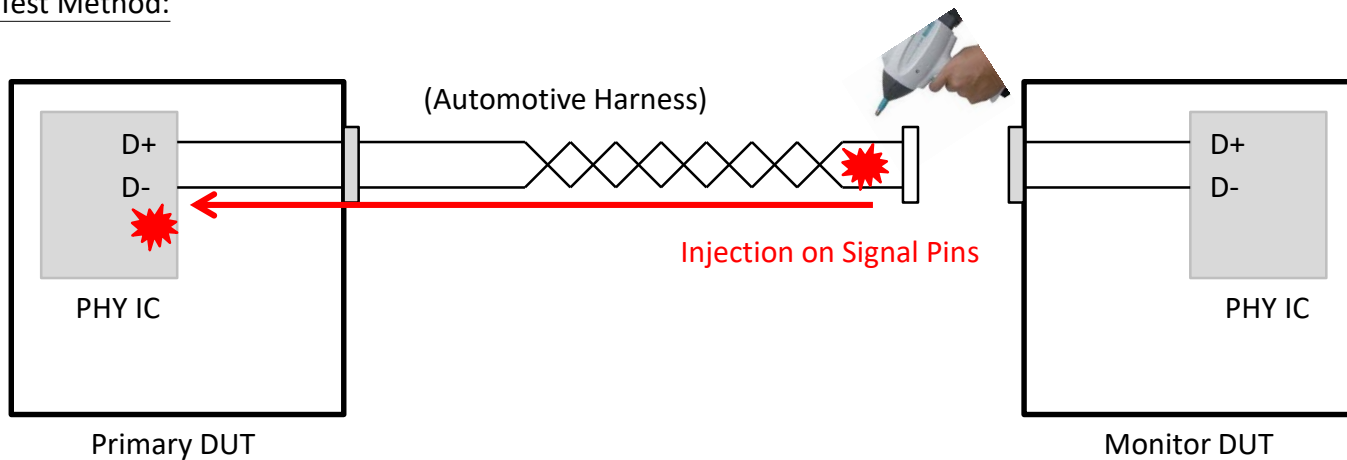
Air > 15kV (avoid pre discharge)

R/C Value	Meaning
C : 150pF	Inside Vehicle Human Cap.
C : 330pF	Outside Vehicle Human Cap.
R : 330ohm	Discharge through Metal
R : 2000ohm	Discharge through Skin



ESD ISO10605 ESD Immunity Test & Method

Powered ESD Test Method:



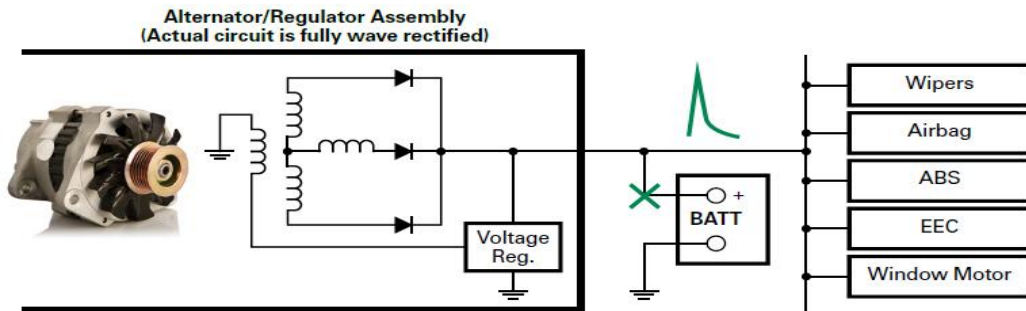
The powered ESD tested method required by OEM customer.



The PHY IC of ECU could be easily damaged.



Automotive Transient Noise & Test Standard

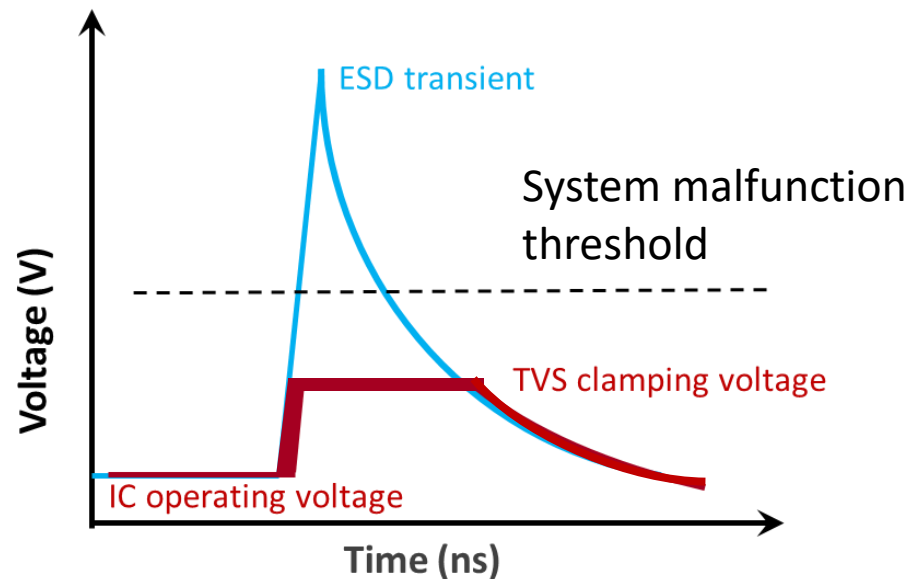
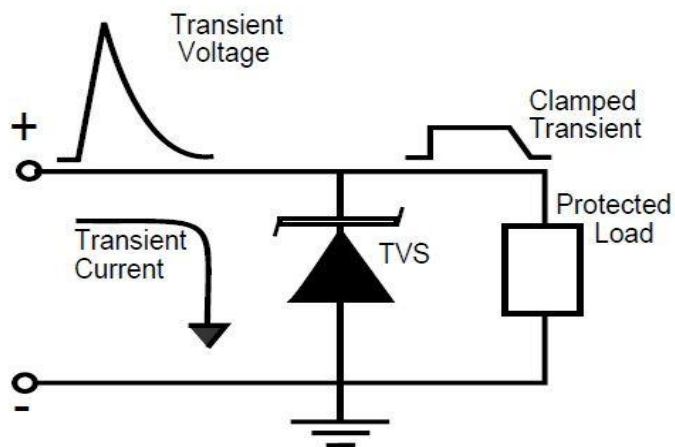


Transient : Alternator/Battery Power/Relay/DC Motor/Human User/Thunder

Test Items	Standard
ESD	IEC61000-4-2 / ISO10605
EOS	IEC61000-4-5
EFT	IEC61000-4-4
Road Vehicles Electrical Disturbance from Conduction & Coupling	Power Conduction : ISO7637-2
	Signal Coupling : ISO7637-3
Road Vehicles Environmental Conditions and Testing for Electrical and Electronic Equipment – Part2 Electrical Loads	Power Quality : ISO16750-2
EMC Document Requirement from OEM Customer	



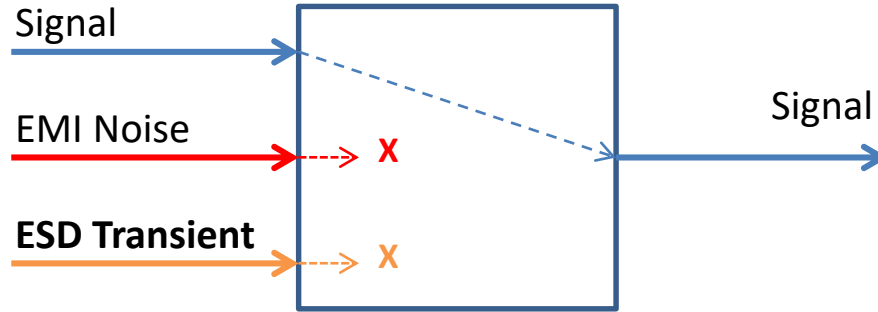
ESD Protection Diodes / TVS Diodes



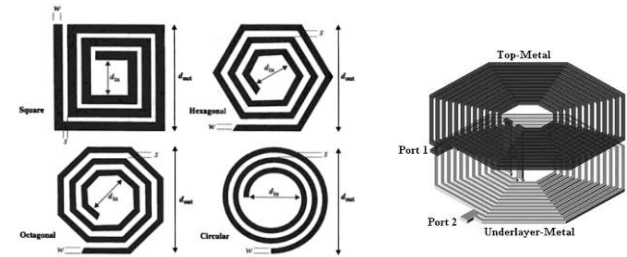


EMI Filter and Silicon Inductor CMF

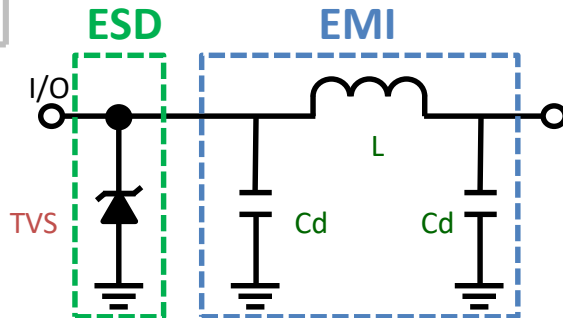
ESD + EMI Filter



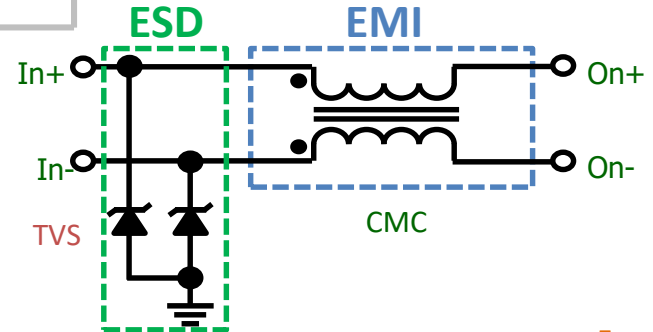
Silicon Inductor CMF



Low-speed



High-speed





How to Select the ESD Protection Device

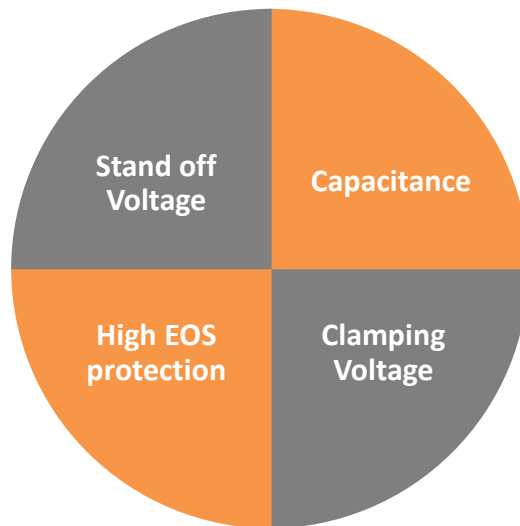
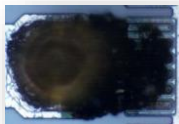
The Factors of ESD Selection

Various Low Voltage ESD

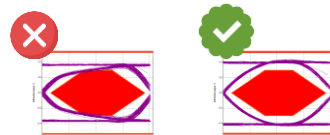
1.2V
1.8V
2.5V
3.3V



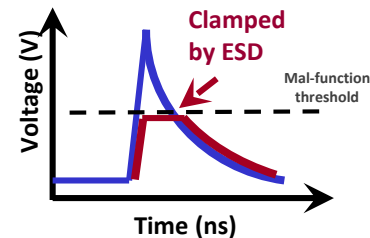
High Surge Level for Reducing EOS



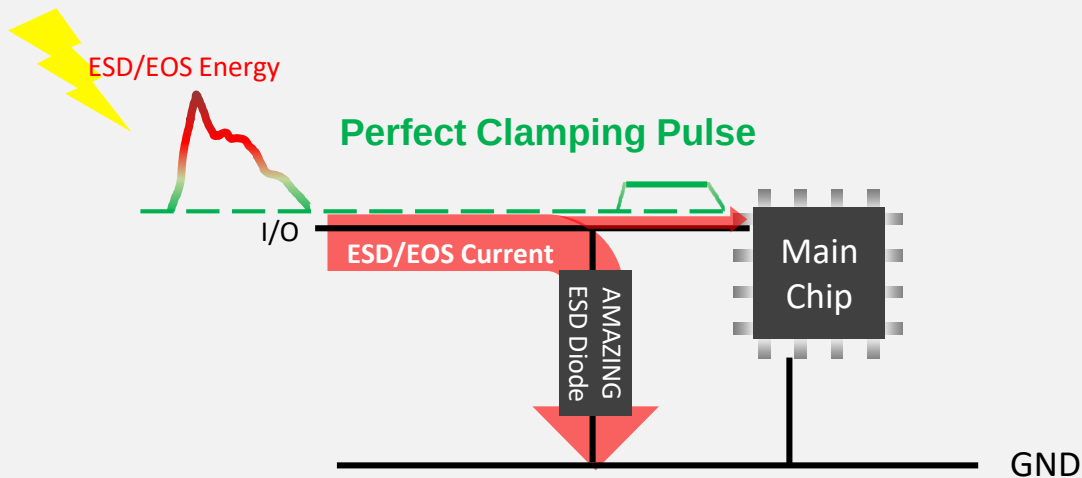
Ultra Low Capacitance



Low Clamping Voltage



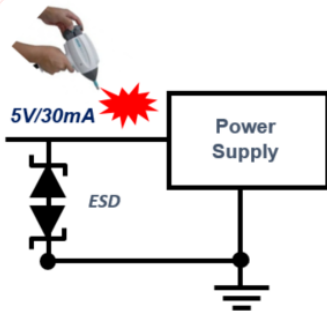
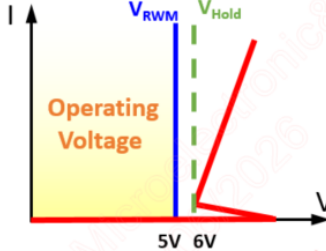
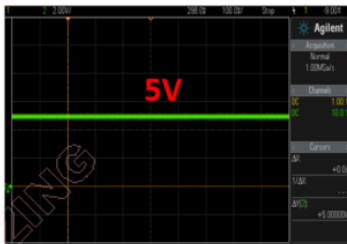
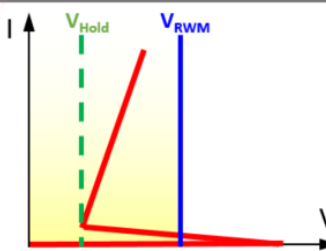
The Most Important Parameter: **Clamping Voltage**



- Bypass the ESD/EOS Current
- Clamp the Voltage at Low Value
- Improve System Robustness



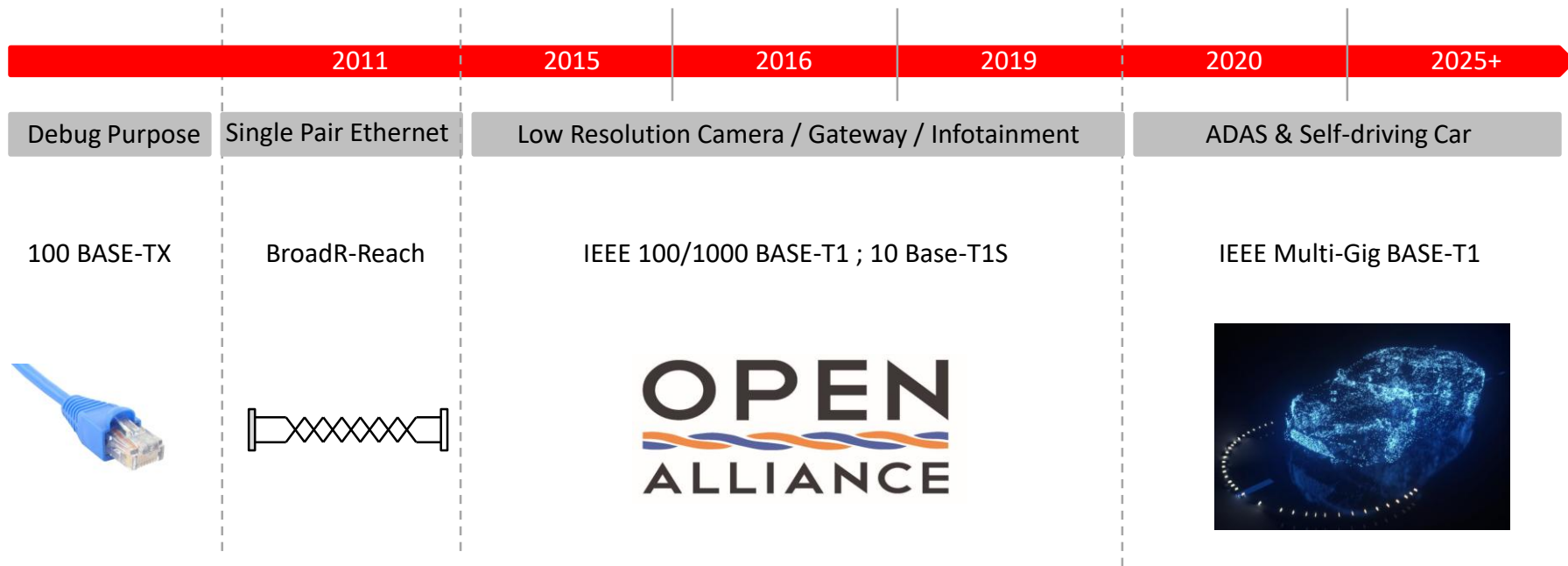
Warning of Latch-up Risk

Latch-up Test Setup	TVS with Latch-up Free	Before ESD Injection	After ESD Injection	Test Result & Summary												
	 $V_{hold} > V_{RWM}$			<table><tr><th>ESD Injection</th><th>ESD Level</th><th>Result</th></tr><tr><td>Air (Radiation)</td><td>$\pm 8kV$</td><td>Pass</td></tr><tr><td>I/O</td><td>$\pm 8kV$</td><td>Pass</td></tr><tr><td>GND</td><td>$\pm 8kV$</td><td>Pass</td></tr></table> Latch-up Free	ESD Injection	ESD Level	Result	Air (Radiation)	$\pm 8kV$	Pass	I/O	$\pm 8kV$	Pass	GND	$\pm 8kV$	Pass
ESD Injection	ESD Level	Result														
Air (Radiation)	$\pm 8kV$	Pass														
I/O	$\pm 8kV$	Pass														
GND	$\pm 8kV$	Pass														
	 $V_{hold} < V_{RWM}$			<table><tr><th>ESD Injection</th><th>ESD Level</th><th>Result</th></tr><tr><td>Air (Radiation)</td><td>$\pm 2kV$</td><td>Latch Up</td></tr><tr><td>I/O</td><td>$\pm 1kV$</td><td>Latch Up</td></tr><tr><td>GND</td><td>$\pm 1kV$</td><td>Latch Up</td></tr></table> High Latch-up Risk	ESD Injection	ESD Level	Result	Air (Radiation)	$\pm 2kV$	Latch Up	I/O	$\pm 1kV$	Latch Up	GND	$\pm 1kV$	Latch Up
ESD Injection	ESD Level	Result														
Air (Radiation)	$\pm 2kV$	Latch Up														
I/O	$\pm 1kV$	Latch Up														
GND	$\pm 1kV$	Latch Up														

Automotive Ethernet ESD Protection



Evolution of Automotive Ethernet

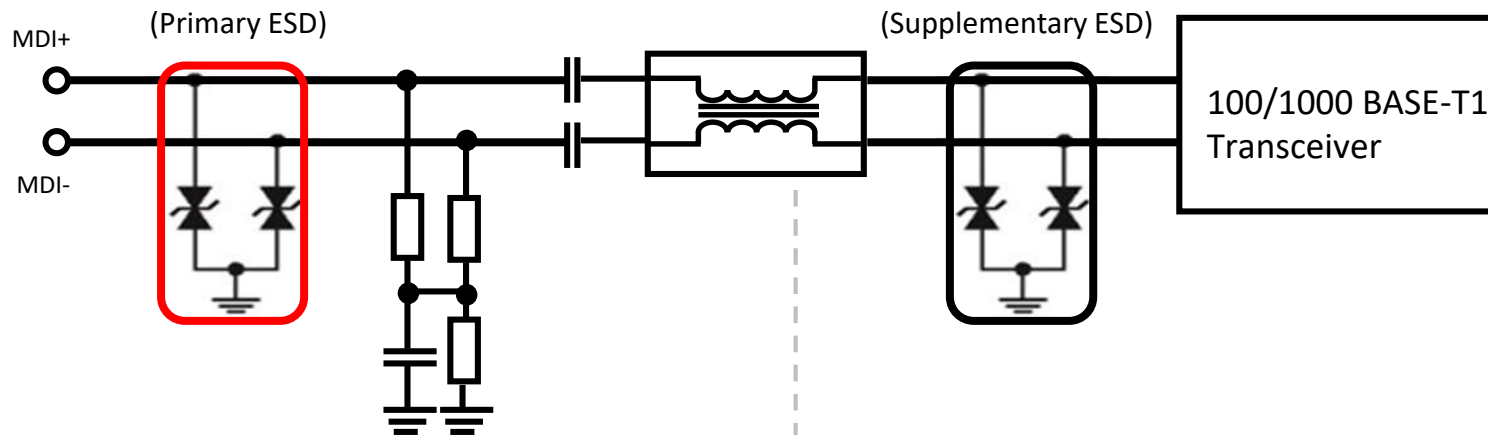


High robust single pair Ethernet could simplify the complexity of Automotive In-vehicle network

Automotive Ethernet Snapshot

Automotive Ethernet	10 Base-T1S	100 Base-T1	1000 Base-T1	Multi-Gig Base-T1
Protocol	IEEE 802.3cg	IEEE 802.3bw	IEEE 802.3bp	IEEE 802.3ch
Cable / Harness	UTP	UTP	UTP	STP
Signal Modulation	DME	PAM3	PAM3	PAM4
Symbol Rate	12.5M Baud	66M Baud	750M Baud	1.4 / 2.8 / 5.6G Baud
Data Rate	10 Mbps	100 Mbps	1000 Mbps	Up to 10Gbps
Open Alliance	OA TC14	Since OA TC1	OA TC12	OA TC15

IEEE 100/1000 Base-T1 ESD Protection



Spec. Requirement

- ⚡ Low parasitic capacitance ($< 1.1\text{pF}$)
- ⚡ High V_{trigger} ($> 100\text{V}$) for RF immunity test
- ⚡ Open Alliance TC12 qualified (by FTZ)

Spec. Requirement

- ⚡ Low working voltage for supplementary ESD protection
- ⚡ Low clamping voltage for better protection ability

⚡ Open Alliance 100/1000 Base-T1 ESD Protection

ESD
Leading Provider

EMC Test report
No. FTZ 01-11-23

ESD protection device for 1000BASE-T1 application
AZ9400-02S

1.2 Conclusion of Test results

Conclusion of test results:

according to
OPEN Alliance:
IEEE 1000BASE-T1
EMC Test Specifica-
tion for ESD suppres-
sion devices,
version 1.0,
October 30, 2020

Single test	Result	Comment / Resulting class
S-Parameter	Pass	
Damage ESD	Pass	
ESD Dis-charge Current Measurement / CMC Saturation class I	Pass) ₂	± 3 kV: class III ± 5 kV: class III ± 6 kV: class III ± 7 kV: class III ± 15 kV: class III
RF Clamping	Pass) ₂	Class III

From Automotive **System Point of View**

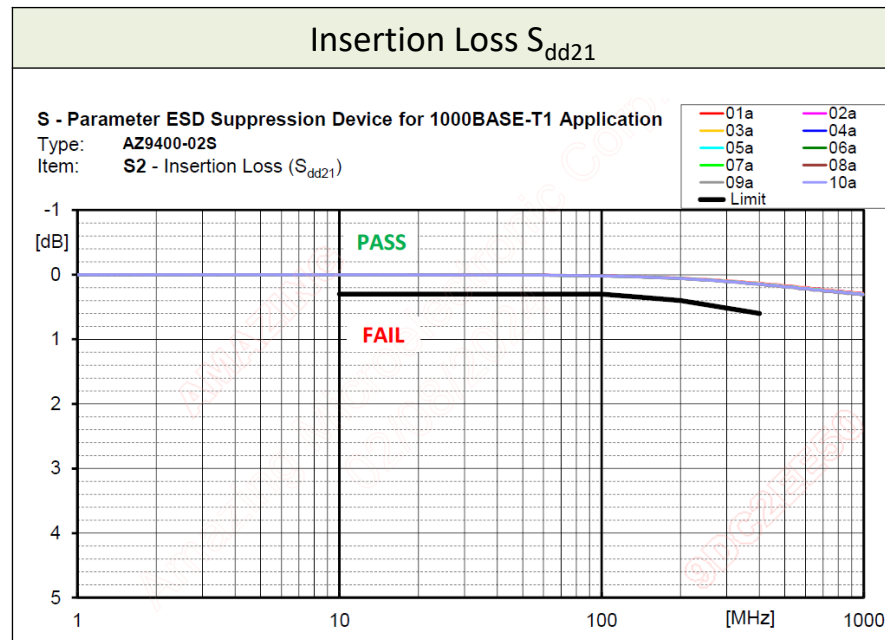
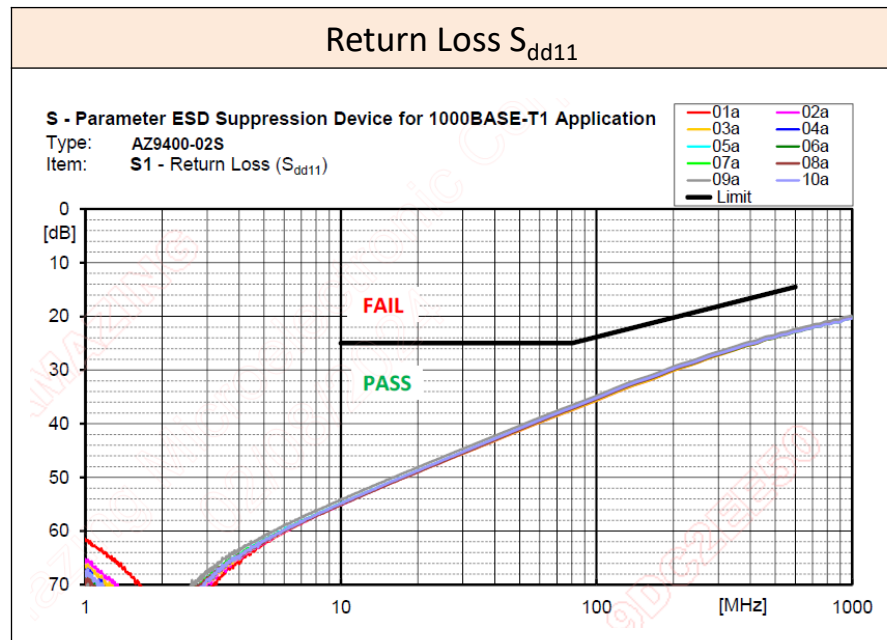
Signal integrity evaluation

Aging issue or decline evaluation after ESD strike

ESD clamping performance evaluation

Unwanted clamping effect evaluation
(during RF immunity test)

Mixed Mode S-parameter Measurement



TVS diode hardly causes side effect on signal reflection and signal attenuation due to RL and IL.

⚡ Damage from ESD Event

Return Loss S_{dd11}

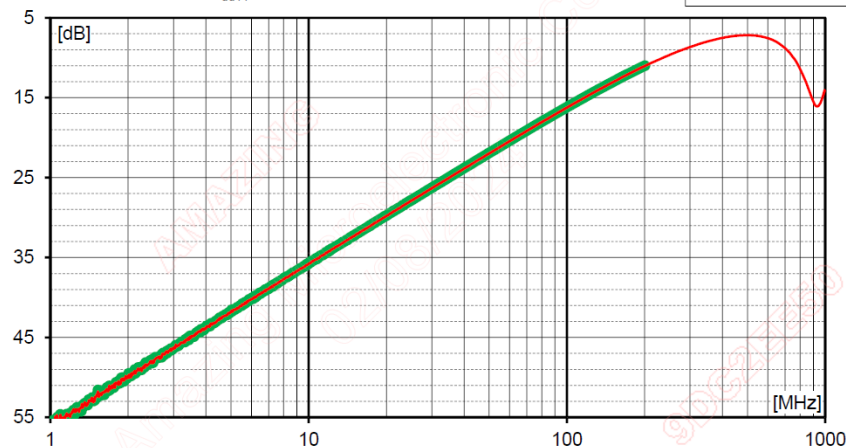
ESD Test / ESD Suppression Device for 1000BASE-T1 Application

Type: **AZ9400-02S**

Item: Return Loss (S_{dd11})

Sample: #11

— pre ESD
— post ESD 8kV



Insertion Loss S_{dd21}

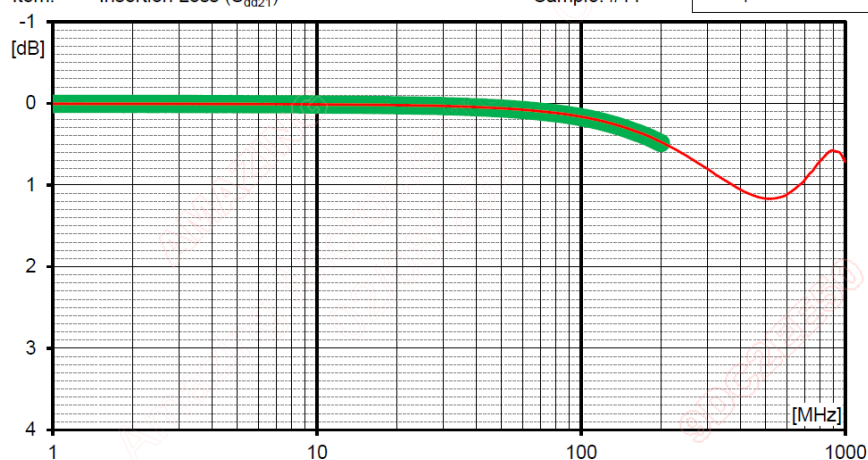
ESD Test / ESD Suppression Device for 1000BASE-T1 Application

Type: **AZ9400-02S**

Item: Insertion Loss (S_{dd21})

Sample: #11

— pre ESD
— post ESD 8kV



⚡ TVS diode won't show any aging issue or decline on S-parameter characteristic after ESD strike.

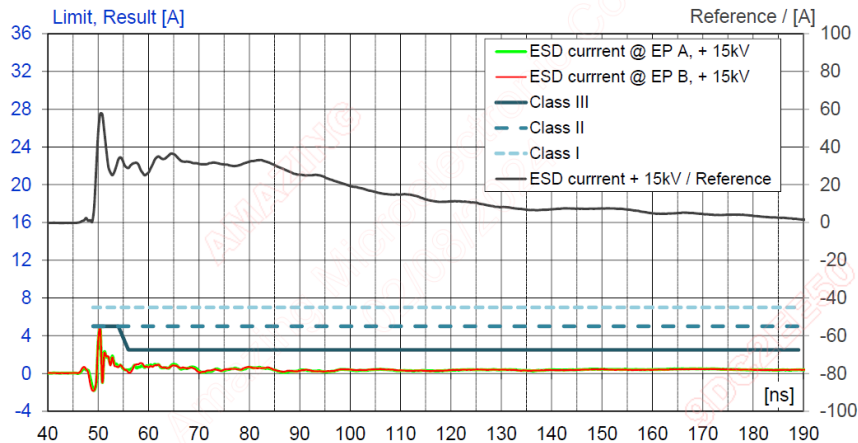
ESD Discharge Current Measurement

Positive 15kV ESD Discharge Current

ESD Test / ESD Suppression Device for 1000BASE-T1 Application

Type: **AZ9400-02S** Sample: #1

Item: Discharge Current Measurement / $V_{ESD} = +15\text{ kV}$

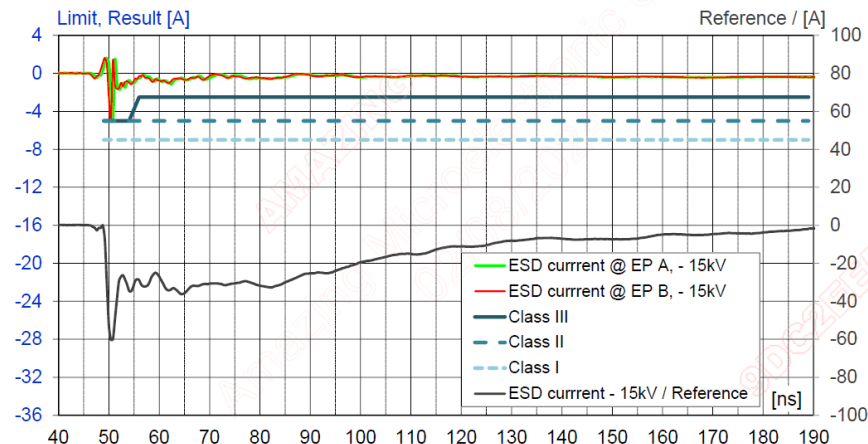


Negative 15kV ESD Discharge Current

ESD Test / ESD Suppression Device for 1000BASE-T1 Application

Type: **AZ9400-02S** Sample: #1

Item: Discharge Current Measurement / $V_{ESD} = -15\text{ kV}$

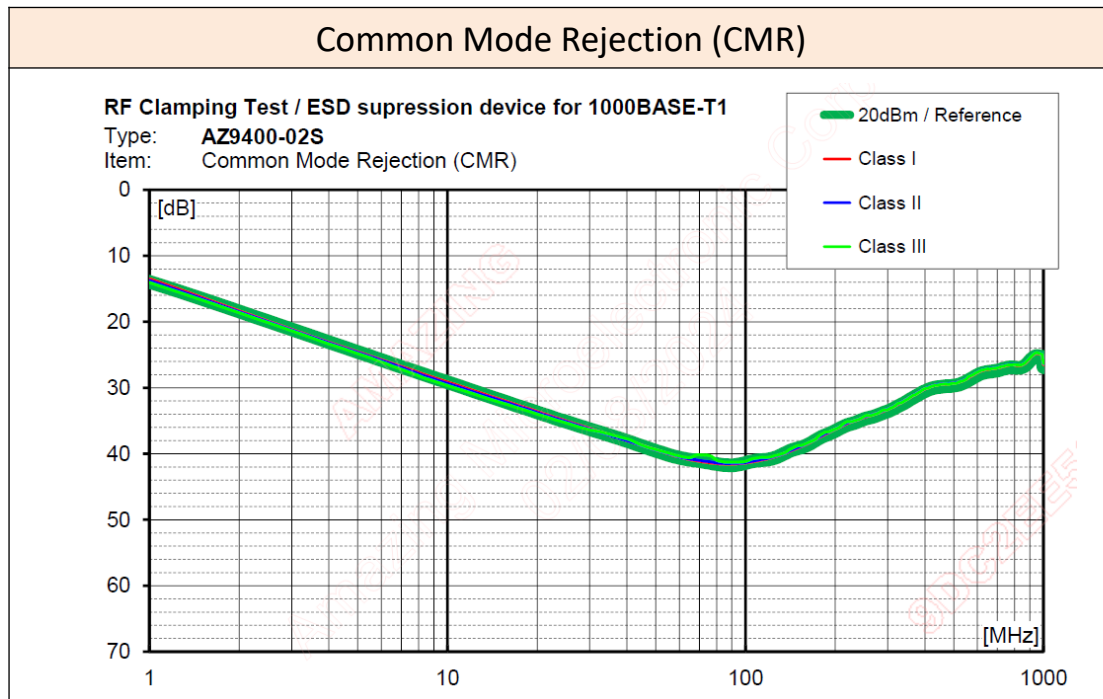


The maximum defined limit class is fulfilled by the TVS diode.



TVS diode could contribute excellent clamping performance for Ethernet PHY ESD protection.

⚡ Unwanted Clamping Effect at RF Immunity Test



Comment : TVS diode won't show unwanted clamping effect during RF immunity test.

Open Alliance 100/1000 Base-T1 ESD Selection Guideline

Check Datasheet Parameters

PASS

Parameter	Target Value	Value DUT	Status
Working direction	bi-directional	yes	o.k.
Operation voltage (V _{DCmax})	≥ 24 V	26.4 V	o.k.
ESD trigger voltage	≥ 100 V	≥ 100 V	o.k.
ESD robustness	IEC [1] level 4	15 kV	o.k.
Minimum number of discharges	> 1000	-	-

Signal Integrity due to S-parameter

PASS

#	S-Parameter	Result	Comment
S1	S _{dd11} (RL)	Pass	
S2	S _{dd21} (IL)	Pass	
S3	S _{sd21} (DCMR)	Pass	

Damage from ESD Strike

PASS

#	ESD test voltage V _{ESD}	Evaluation criteria S-Parameter	Result Sample	Comment
E1, E2	± 8 kV	S _{dd11} (RL)	P P P	
		S _{dd21} (IL)	P P P	
		S _{cd21} (DCMR)	P P P	Small deviation at very low level was not evaluated.
	± 15 kV	S _{dd11} (RL)	P P P	
		S _{dd21} (IL)	P P P	
		S _{cd21} (DCMR)	P P P	Small deviation at very low level was not evaluated.

Unwanted Clamping Effect due to CMR

PASS

Conclusion of test results
RF clamping test:

#	Evaluation criteria	Test power	Result	Comment
RF-CL	CMR value	Class I (max. 33 dBm)	Pass	
		Class II (max. 36 dBm)	Pass	
		Class III (max. 39 dBm)	Pass	

Summary

Summary: Next Generation IVN ESD Protection

Signal Integrity

- 1. Next gen. EV, higher data rate
- 2. Low capacitance ESD protection
- 3. Low attenuation due to Insertion Loss

Reliability

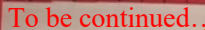
- 1. Reliability is a major issue for Automotive
- 2. The deviation should be tested/checked during evaluation
- 3. High Surge Robustness for minimize EOS failure/field return

Clamping Voltage

- 1. Next gen. EV, advanced process chips
- 2. Low clamping voltage ESD diode for better protection
- 3. $V_{\text{hold}} > V_{\text{RWM}}$ for Latch-up free

RF Immunity

- 1. ESD diodes, no unwanted clamping effect during RF immunity
- 2. High linearity to minimize signal distortion



Thank you

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