Protection Against Electrostatic Discharges (ESD)

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Agenda

- Electrostatic discharge ESD - Introduction
- ESD Models
- Protection Structures
- Practical Examples - Measurement, Simulation

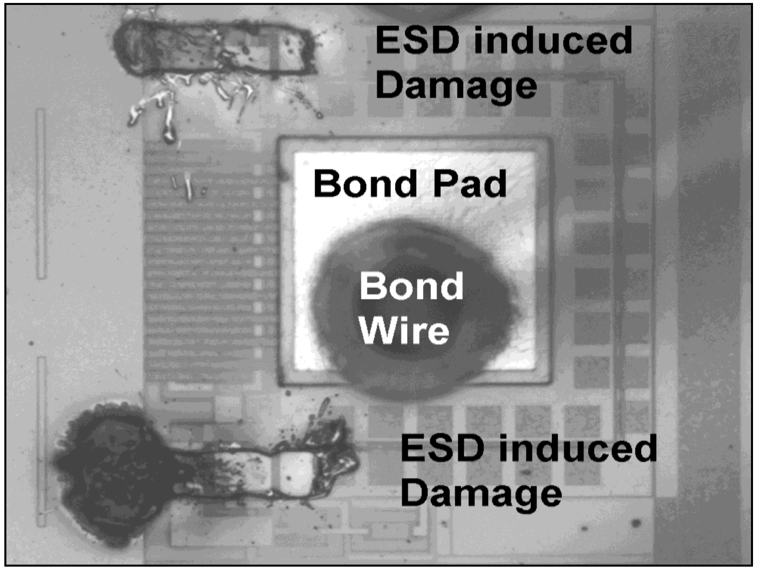
Introduction to ESD

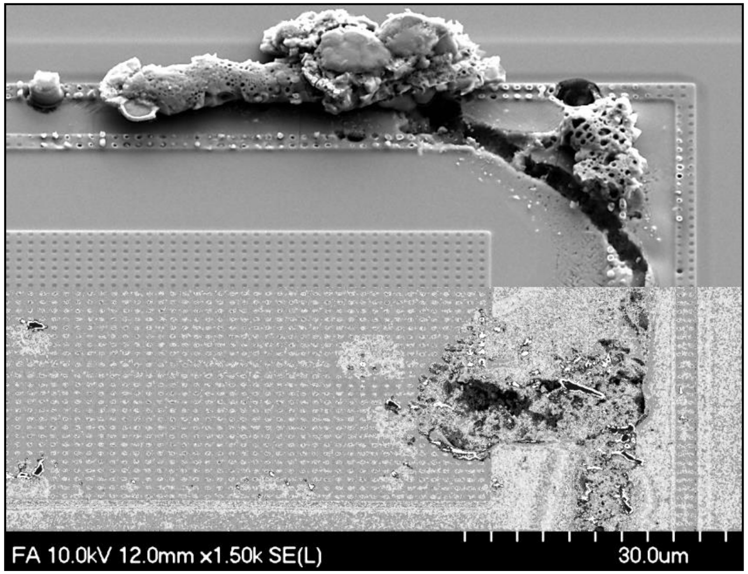
ESD at the gas station

Elektrostatic Discharge (ESD)

Electrostatic Discharge - Introduction

Among all transient disturbances ESD is still one of the most important reliability problems in the semiconductor industry and one should never overlook the damage that has been caused by this re-balancing of charge between objects brought into close contact.





Electrostatic Discharge - Introduction

Where does electrostatic charge come from?

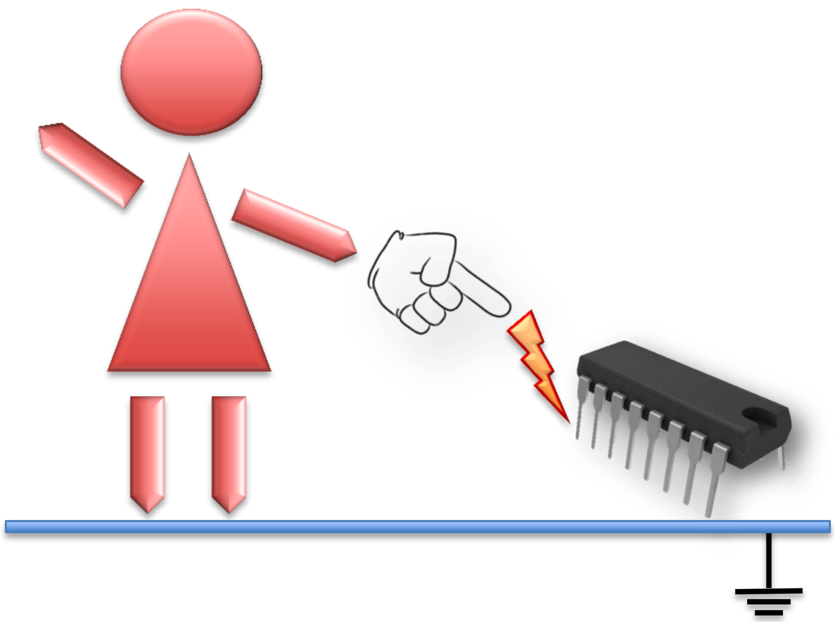
- Triboelectric charging
  - Mechanical contact and separation (e.g. walking on a carpet)
- Ionic charging
  - Not properly balanced Air Ionizer
- Direct charging
  - Mobile charge transfer
  - Plug a cable to an IC (e.g. USB to PC)
- Field induced charging
  - IC brought into an electric field

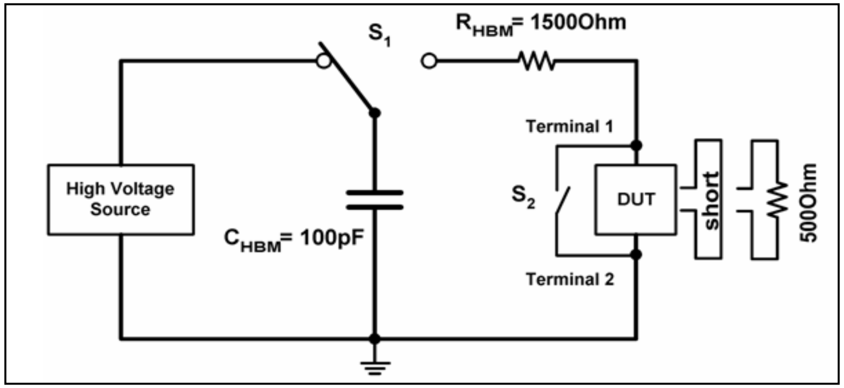
ESD Test Models - History

- Back in the 1960's, the first ESD model, which was used to stress IC's was the ***HBM (Human Body Model*****).**
- But soon it has been noticed that the HBM could not explain all ESD failures and with the increasing use of automated handling machines the ***MM*** **(*****Machine Model*****)** has been introduced.
- Still other types of ESD damage exist, which can not be covered by these two test models. For example when an IC slides down a shipping tube it becomes charged and it will be discharged when it hits a grounded steel table.
  Therefore the ***CDM*** **(*****Charged Device Model*****)** was developed in the early eighties to explain this type of damage.

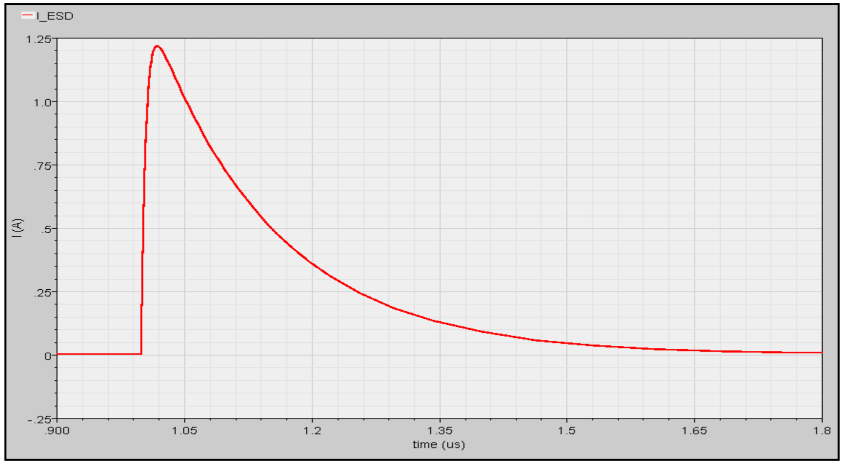
IC Level ESD Test Models (1)

Human Body Model (HBM):





MIL-STD-883x



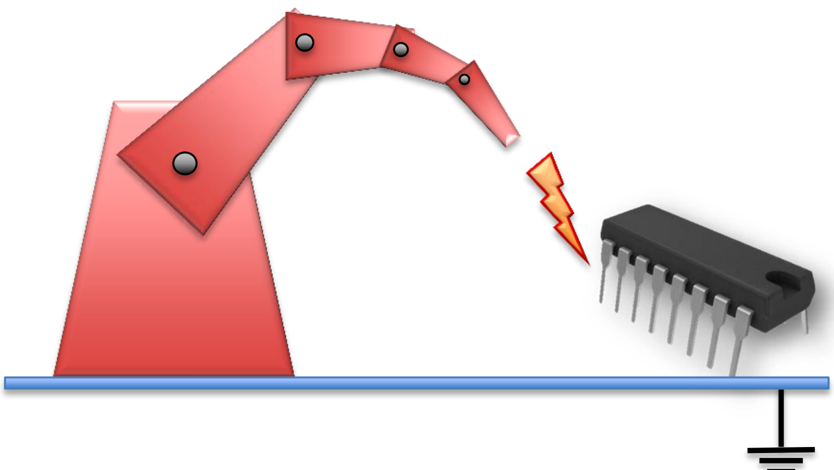
Discharge current waveform into a short wire (2kV ESD)

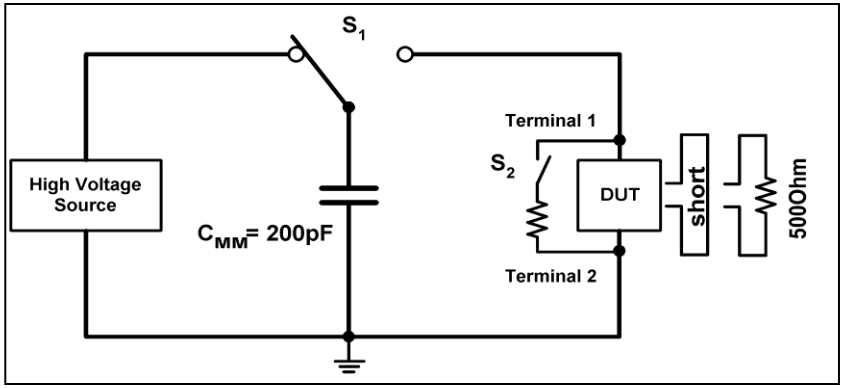
It describes the discharge procedure that occurs if a standing charged human person approaches a grounded IC.

Test levels: 250V – 8kV (2kV)

IC Level ESD Test Models (2)

Machine Model (MM):

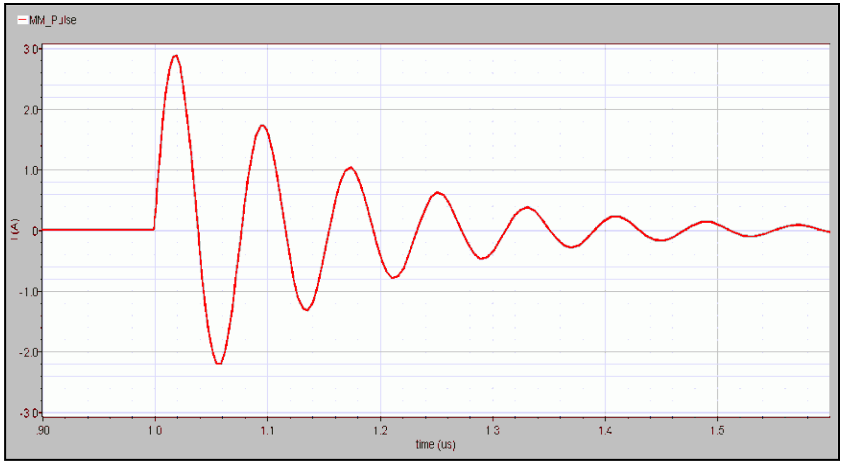




AEC-Q100-003-REV-F.

It describes an ESD stress, which is caused by a machine during the handling of an IC (i.e. metallic machinery in an IC manufacturing or testing process).

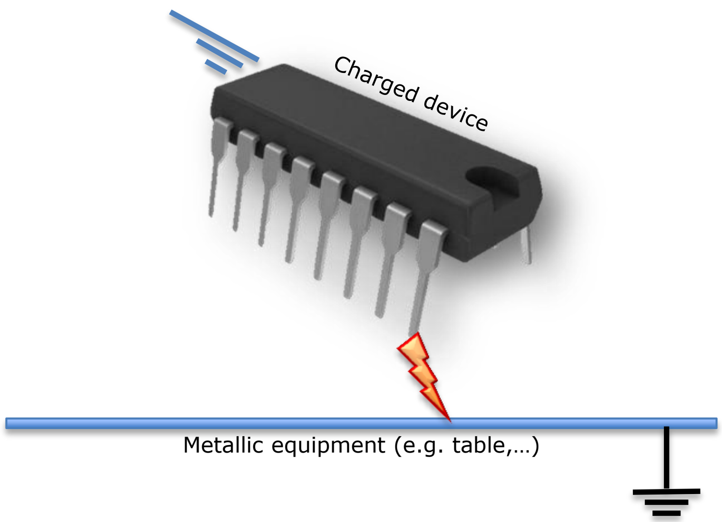
Test levels: 100V – 800V (200V)

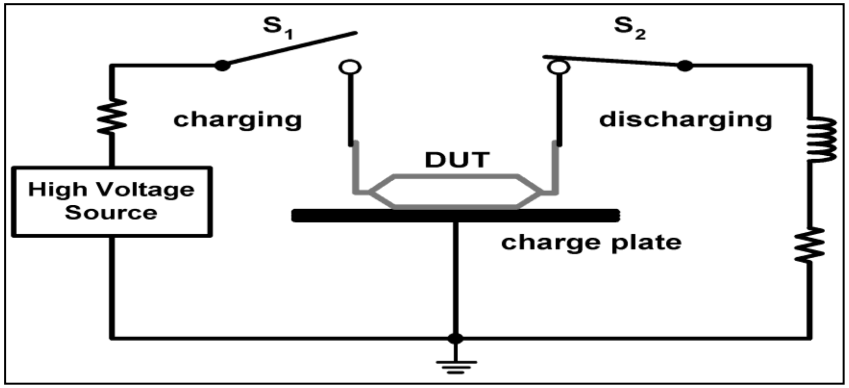


Discharge current waveform into a short wire (200V ESD)

IC Level ESD Test Models (3)

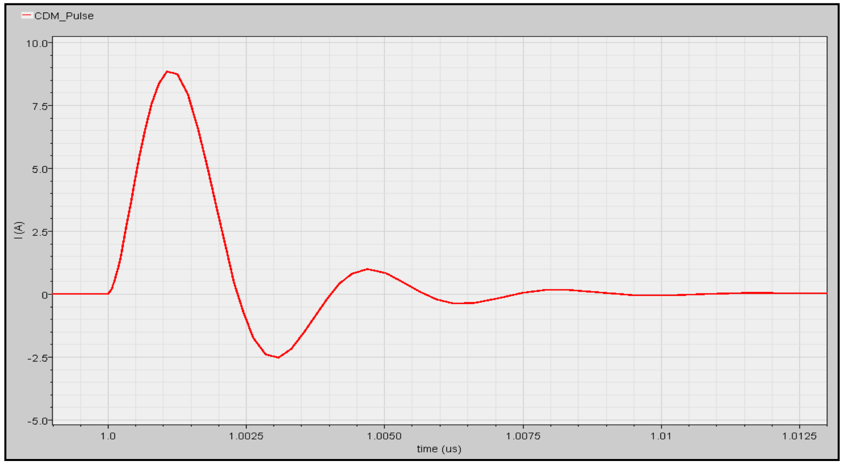
Charged Device Model (CDM):





JEDEC JESD22-C101-A

It describes an ESD stress, that occurs during the manufacturing and assembly processes, where the IC charges when it slides down a feeder in a tester or a shipping tube.



Discharge current waveform into a short wire (500V ESD)

Test levels: 125V – 2kV (500V)

System Level ESD Test Models (1)

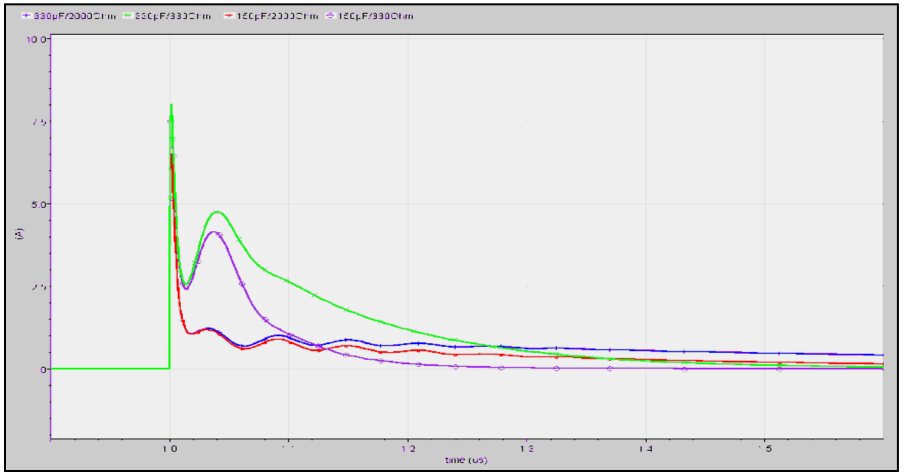
Gun Model (HBM) for Automotive according to ISO10606:

150pF/330Ω
330pF/330Ω
150pF/2000Ω
330pF/2000Ω

It describes the discharge procedure of a human person either directly or through a metallic part (e.g. tool, key, stick,…).

Test levels:
Contact discharge: 3kV – 20kV
Air discharge: 4kV – 25kV

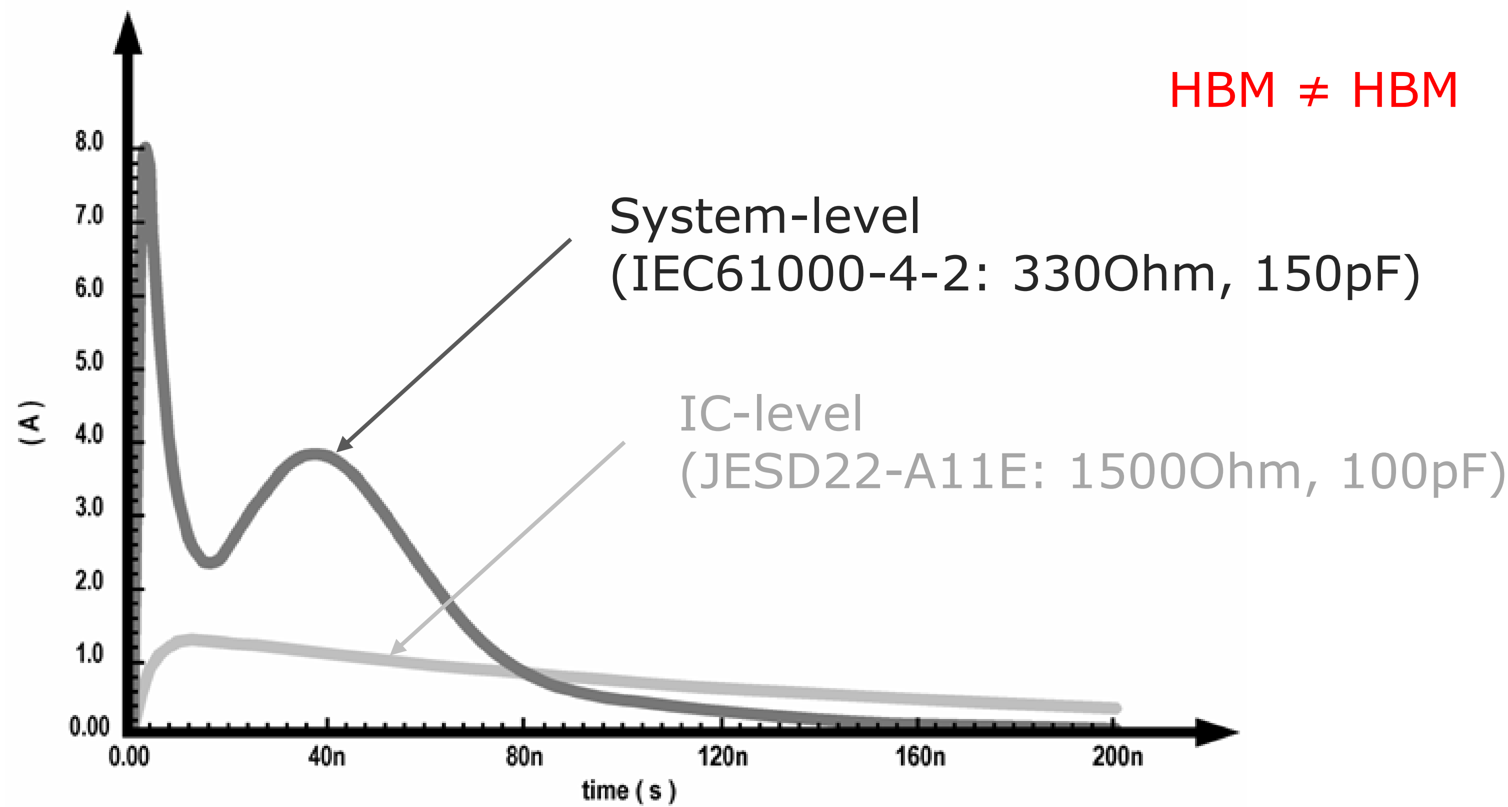
330pF: Applications accessed only from the inside of the vehicle
150pF: Applications accessed only from the outside of the vehicle
2000Ω: Discharge of a human body directly through the skin
330Ω: Discharge of a human body through a metallic part (e.g. tool, key, stick,…)



Discharge current waveform into a 2Ω current target of the GUN 330pF/2000Ω, GUN 330pF/330Ω, GUN 150pF/2000Ω, and GUN 150pF/330Ω model for a (2kV ESD)

IC Level vs. System Level ESD

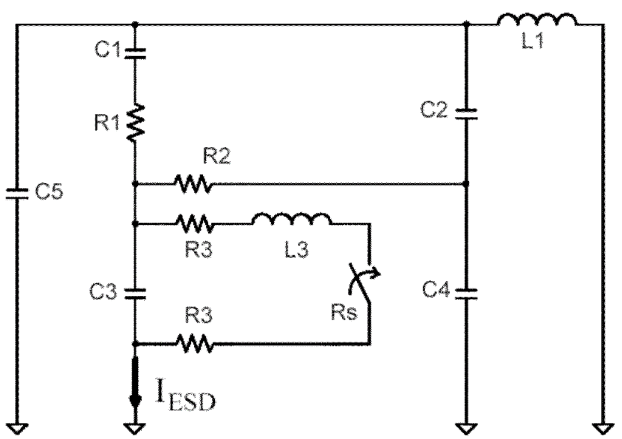
Discharge current waveform of a 2kV ESD



Discharge current waveform of a 2kV system-level (EN 61000-4-2) and IC-level (JESD22-A114E) HBM ESD pulse

ESD Pulse Simulation (1)

Simulation model according to IEC 61000-4-2 - ESD (electrostatic discharge)

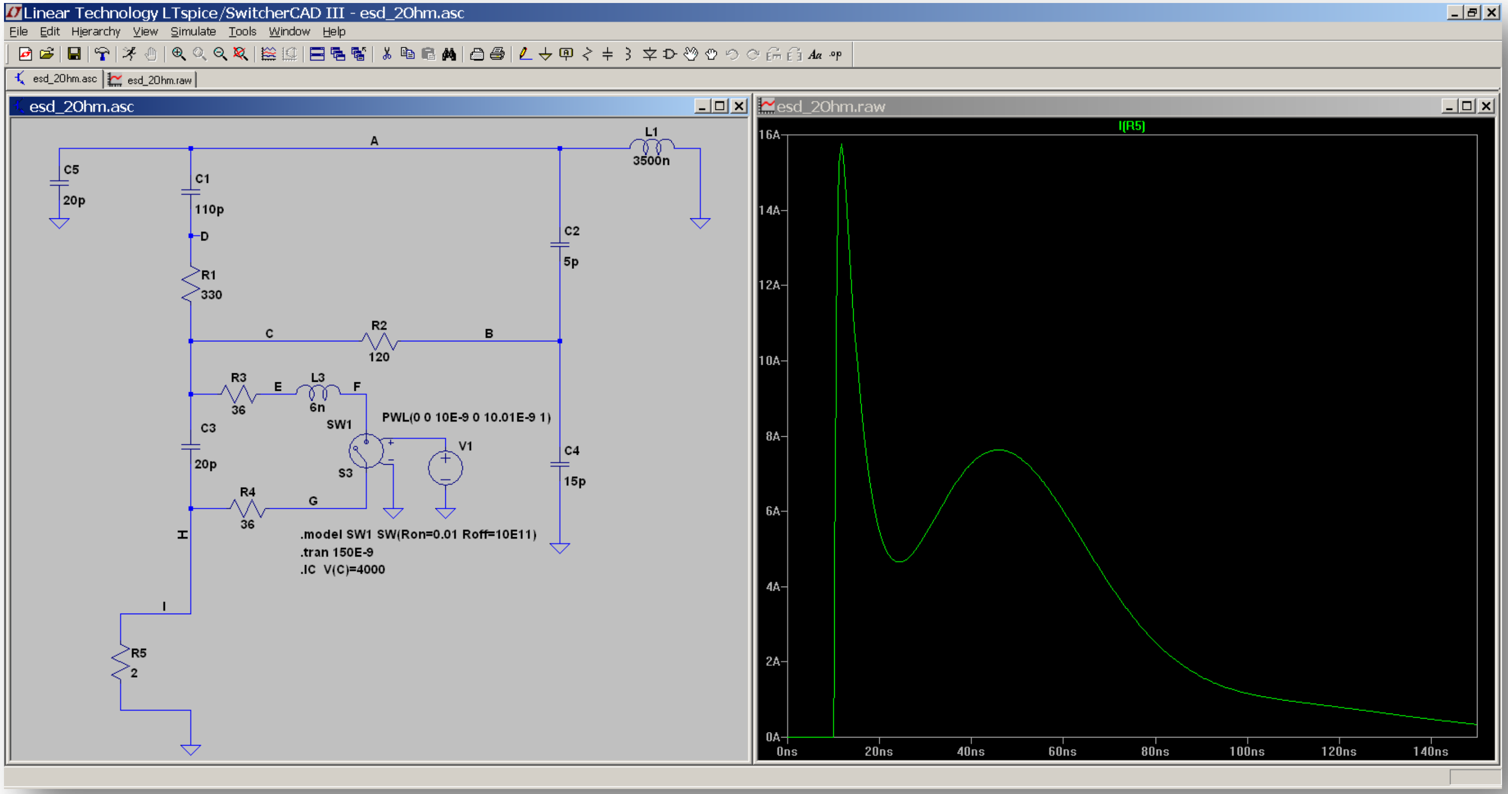


	Component	Value	Function	Modeling method
Group 1	C3	20 pF, PCB board	Pulse forming R-C-R filter, L3 is its loop inductance	C: Two metal layers with dielectric material in between
	R3	36 Ω, lumped		R: Single cell, σ = 13.9 S/m.
Rise-time	L3	About 6 nH, distributed	Loop inductance	The loop's geometry is part of the ESD generator geometry model.
	C4	In the SPICE model 15 pF, distributed	Capacitance between discharge tip and ground plane.	The geometry model includes the structural elements.
	C5	In the SPICE model 20 pF, distributed	Capacitance between the simulator body and the ground plane.	The geometry model includes the structural elements.
Group 2 Pulse width and height	C2	In the SPICE model 5 pF, distributed	Influences the width of the initial pulse	This capacitance is simulated by the structure itself.
	R2	120 Ω, lumped		Single cell, σ = 0.9 [S/m].
Group 3	C1	110 pF, lumped	Determines the tail of the waveform. L1, the ground strap loop inductance, is estimated to be 3500 nH (rectangular loop assumption).	C: Two metal layers with dielectric material in between
Falling edge	R1	330 Ω, lumped		Single cell σ = 0.756 S/m
	L1	3500 nH, distributed		The ground strap is included in the numerical model geometry.

[1] K. Wang, D. Pommerenke, R. Chundru, T. Doren, J. Drewniak, A. Shashindranath:
Numerical Modeling of Electrostatic Discharge Generators, IEEE Transactions on Electromagnetic Compatibility, Vol. 45, No. 2, May 2003, pp 258-271

ESD Pulse Simulation (2)

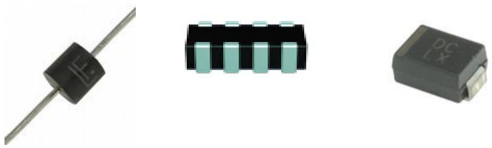
Simulation in LTSPICE:
Discharge waveform into a 2 Ohm resistor



Protection Elements (1)

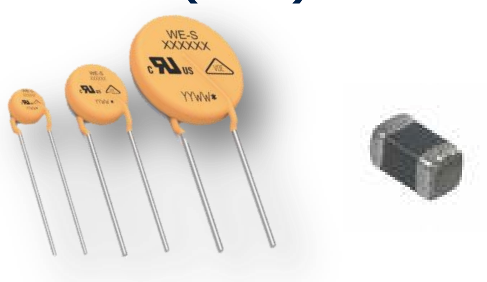
Over voltage protection

Transient Voltage Suppression (TVS)



Gas Discharge Tube (GDT)

Varistor (VDR)



Over current protection

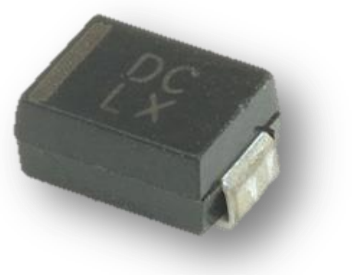
Thermistor (PTC)

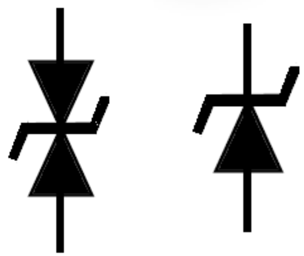
Fuse

Resistor

Protection Elements (2)

Transient Voltage Suppressor (TVS)





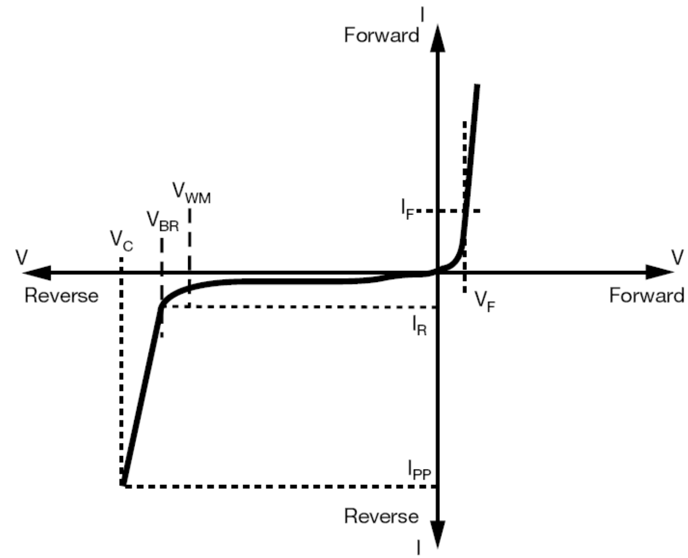
uni-directional bi-directional

+ very fast response times (sub ns)
+ do not wear out

- low surge capability
- leakage current

TVS diodes are specially designed for a controlled breakdown that allows the current to keep the voltage across the diode.

Typical V/I characteristic (uni-directional)

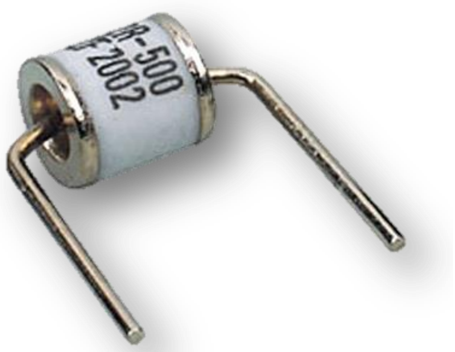


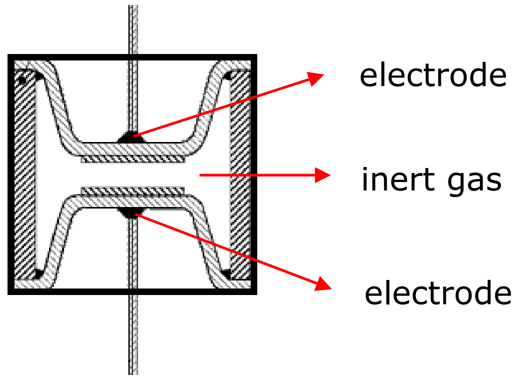
V_C: clamping voltage
V_{WM}: stand-off reverse voltage
V_{BR}: breakdown voltage

Protection Elements (3)

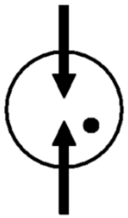
Gas Discharge Tube (GDT)

Gas discharge tubes operate by ionizing the gas with applied voltage to start electrical conduction.

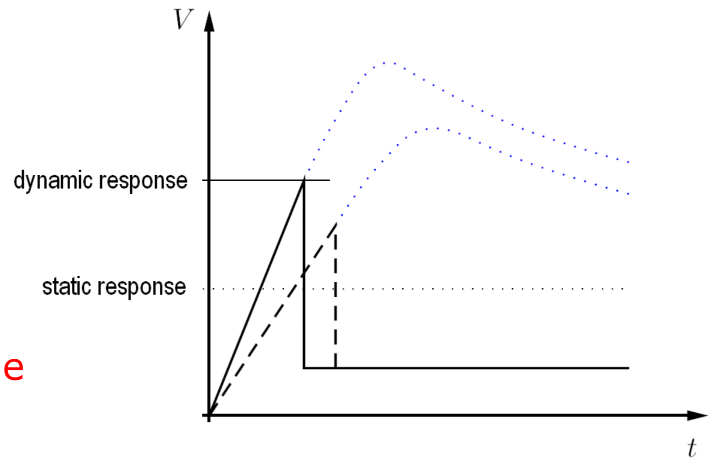




The spacing and size of the two electrodes determines the voltage and current ratings.



Typical V/t characteristic

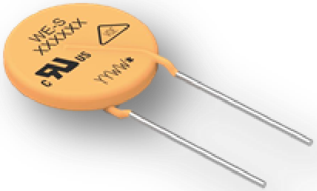


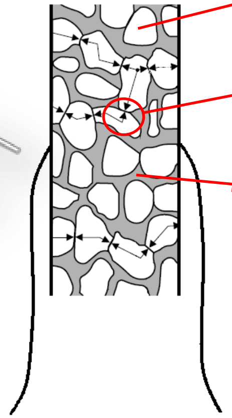
+ very low capacitance
+ high surge capability
+ very low leakage current

- response time depends on the dynamic voltage change

Protection Elements (4)

Voltage Dependent Resistor (VDR) - Varistor

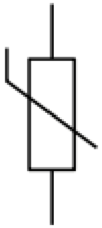




Zinc oxide grains

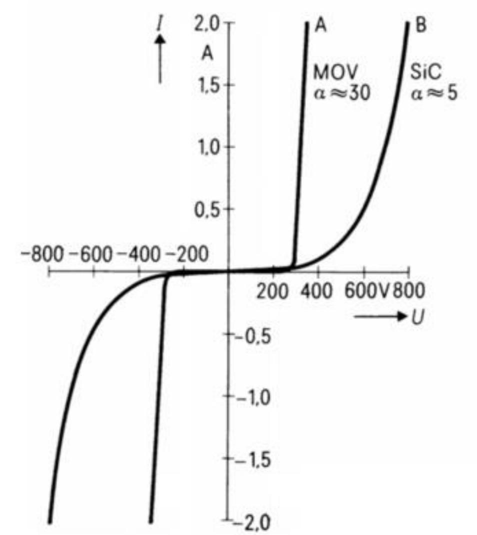
Microvaristor
(breakdown voltage 2-5V)

Intergranular boundary



The electrical behavior of the MOV results from the number of microvaristors connected in series or in parallel.

Typical V/I characteristic



+ fast response times (ns)
+ low standby power
+ capacitance

- low surge capability
- leakage current
- capacitance

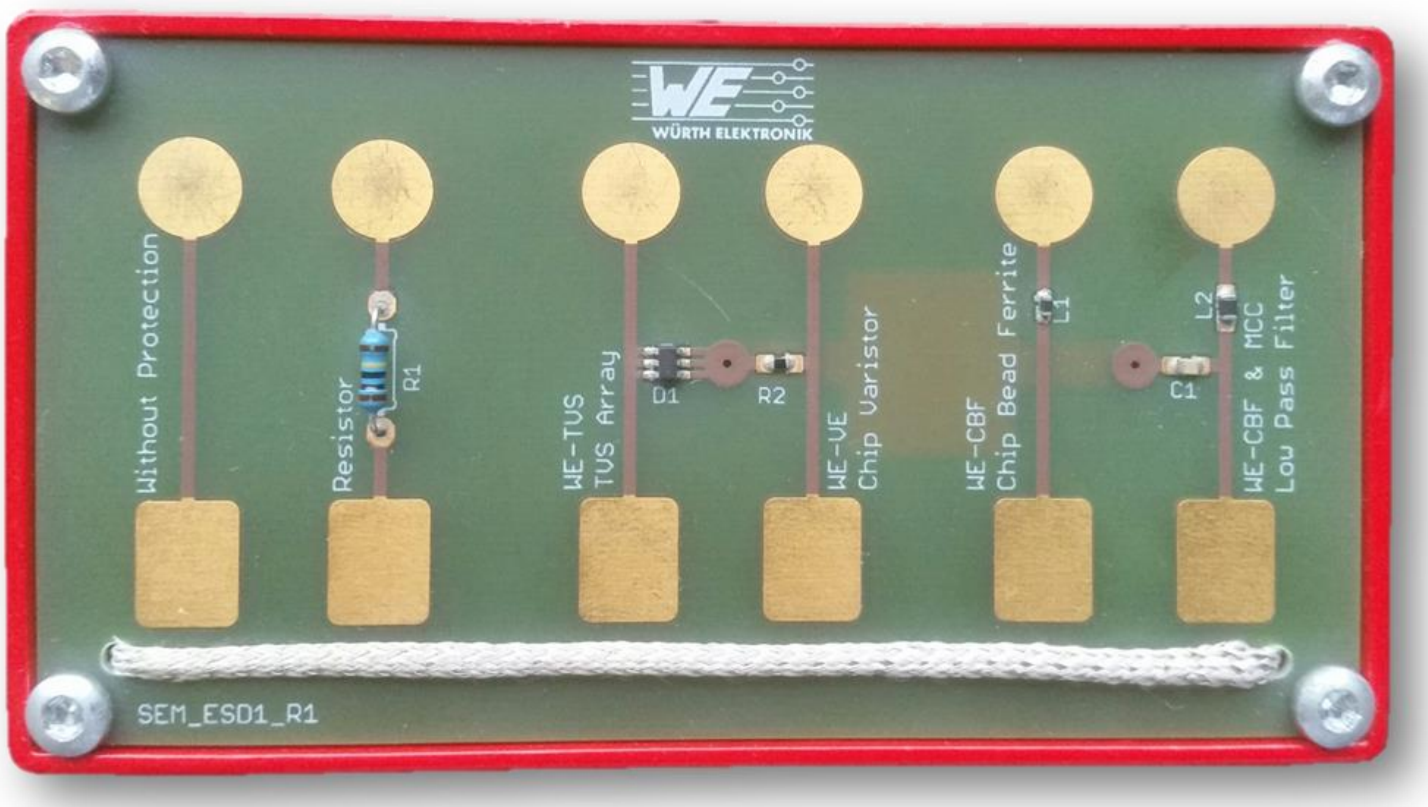
$$I = K \cdot V^{\alpha}$$

K geometry factor
α nonlinearity exponent
depending on the material

Quiz (1)

Which ESD protection element is the best?

1.) 2.) 3.) 4.) 5.)



Quiz (2)

Participate to this quiz with the following link:

www.fbr.io/esd

Appendix – ESD Standards

- **IEC 61000-4-2 ED2.0:** Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test, 2008-12-09
- **MIL-STD-883D Method 3015.7:** Electrostatic Discharge Sensitivity Classification, Microelectronic Test Method Standard, Defense Supply Center Columbus (DSCC), US Department of Defense 1991
- **JEDEC JESD22-A114-B:** Electrostatic Discharge Sensitivity Testing Human Body Model, Electronics Industries Alliance, JEDEC 2000
- **ANSI/ESD STM5.1-2001:** Electrostatic Discharge Sensitivity Testing - Human Body Model (HBM) Component Level, ESD Association, 1998
- **AEC-Q100-002-Rev C:** Human Body Model Electrostatic Discharge Test, Automotive Electronics Council, AEC, 1998
- **ISO 10605:2007(E):** Road vehicles — Test methods for electrical disturbances from electrostatic discharge, ISO, 2007