ESD control and protection

Customer Quality Engineering
Texas Instruments

课程纲要（Outlines)

1. Introduction of ESD and component level ESD
   介绍静电放电和器件级ESD

2. Introduction of typical ESD check points and ESD control
   介绍静电检查点和静电管控

3. Introduction of system level ESD
   介绍系统级ESD

4. Introduction of system level ESD design guidelines
   介绍系统级ESD设计准则

5. Summary
   总结

Definitions 定义

- **Static Electricity 静电**

  It is an electrical charge caused by an imbalance of electrons on the surface of a material. 物体表面电子间的不平衡所产生的一种电

  This imbalance of electrons produces an electric field that can be measured and that can influence other objects at a distance. 这种电子间的不平衡能够产生一个可被测量的电场，而这个电场能在一定距离影响其他物体

Definitions 定义

⇨ **Electrostatic Discharge (ESD)静电放电**
The transfer of electrostatic charge between bodies or surfaces at different electrostatic potential. ESD is a subset of EOS.
在不同的电位情况下，静电离子从一处体表转移至另一处体表所产生的效应。静电放电效应(ESD)基本上属于电过应力(EOS)的范畴。

It is caused by direct contact or induced by an eletrostatic field.
静电放电通常由直接接触或静电电场感应所致。

Definitions 定义

- **Electrical Overstress (EOS) 电过应力**
  The exposure of an item to a current or voltage beyond its maximum ratings. 对物品施加超过其所承受的最高电流或电压所产生的效应。

  EOS is an electrical transient, surge, or other electromagnetic disturbance that results in malfunction or degradation of the performance of electronic components 电过应力是一种因电瞬时变化，浪涌或电磁干扰下对电子零件造成故障或退化的一种现象。

Definitions 定义

EOS General

Lightning 闪电

Extremely High Voltage

极高电压

Extremely High Power

极高功率

EOS Specific（电过应力）

Low Voltage
低电压
Longer Duration
瞬时较长
Low Power
低功率

ESD静电放电

High Voltage
高电压
Short Duration
瞬时较短
Very Low Power
较低功率
Fast Rise Time
上升时间快

How electrostatic charge occurs? 静电如何产生？

⇨Electrostatic charge is most commonly created by the contact and separation of two similar or dissimilar materials.静电通常是通过两种性质相同或不同的材料经常接触与分离的过程所产生的。

Creating electrostatic charge by contact and separation of materials is known as “triboelectric charging”.这一过程称为“ 摩擦起电 ”

The amount of charge created by triboelectric charging is affected by the area of contact, the speed of separation, relative humidity, and other factors. 摩擦起电所产生的电荷与其接触面积。接触速度，相对湿度及其他因数有关。

Triboelectric Series

Factors to consider:
- Humidity
- Speed of separation
- Type of material
- Contact area

Increasing Positive

Air
Human Hand
Rabbit Fur
Glass
Mica
Human Hair
Nylon
Wool
Silk
Aluminum
Paper
Cotton
Steel
Wood
Amber
Hard Rubber
Nickel, Copper
Brass, Silver
Polyester
Polyethylene
Polypropylene
PVC (Vinyl)
Teflon

Increasing Negative

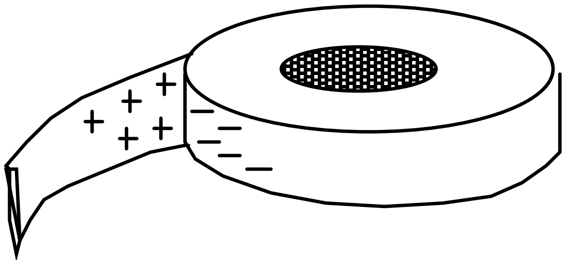


Table of Typical Generated Electrostatic Voltages*

(Values shown in volts)

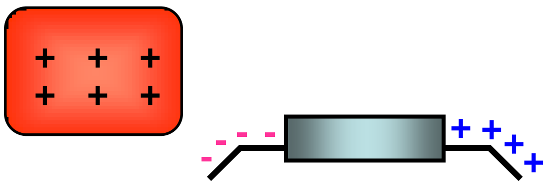
Event	Relative Humidity		
	10%	40%	50%
Walking across a vinyl floor	12,000	5,000	3,000
Motion of bench employee	6,000	800	400
Removing DIPS from plastic tube	2,000	700	400
Packing PWBs in foam line box	21,000	11,000	5,500

* TED DANGELMAYER, *ESD PROGRAM MANAGEMENT,* KLUWER ACADEMIC PUBLISHERS, 1999

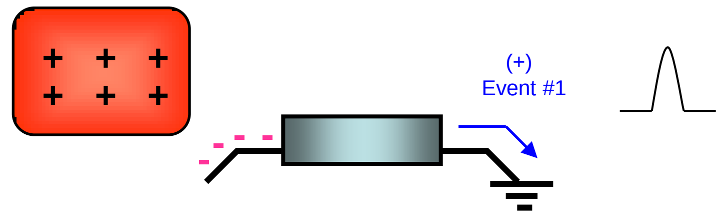
Induction（感应)

A situation where a charge is induced on an isolated conductor due to an influence of an electrostatic field.

ESD By Induction

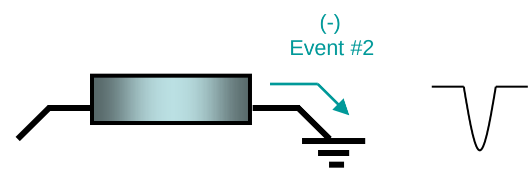


**Device in presence of electric field.
(A)**



**Device momentarily grounded results in 1st discharge event.
(B)**

**Device left with net charge.
(C)**



**Second discharge event when grounding in a later step.
(D)**

CDM concerns involving equipment

➢ **CDM failures can occur in any equipment that handles/tests/ processes unprotected wafer/device by picking up a charge through:**

- **Rubbing against an insulator or**
- **Rubbing against an ungrounded conductor or**
- **Coming in close proximity to a charged surface**

➢ **And then discharges when it subsequently touches a grounded metal surface such as a probe tip or an electrical test head.**

In order to mitigate field-induced CDM damage, the ESD program shall include a plan for the handling of process-required insulators.

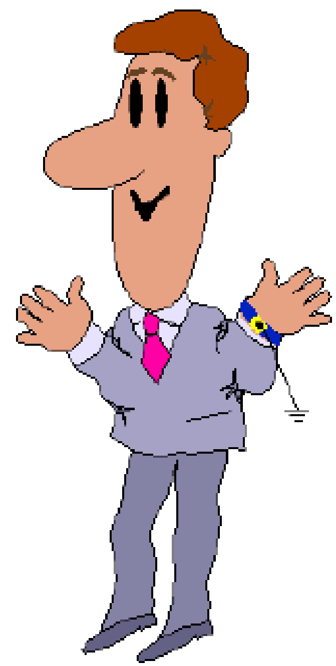
A) Separate the insulator from the ESD-sensitive device by a distance of **30 cm (12 inches)** or

B) Use ionization or other charge mitigating techniques to neutralize the charge.

Personnel As Static Generator

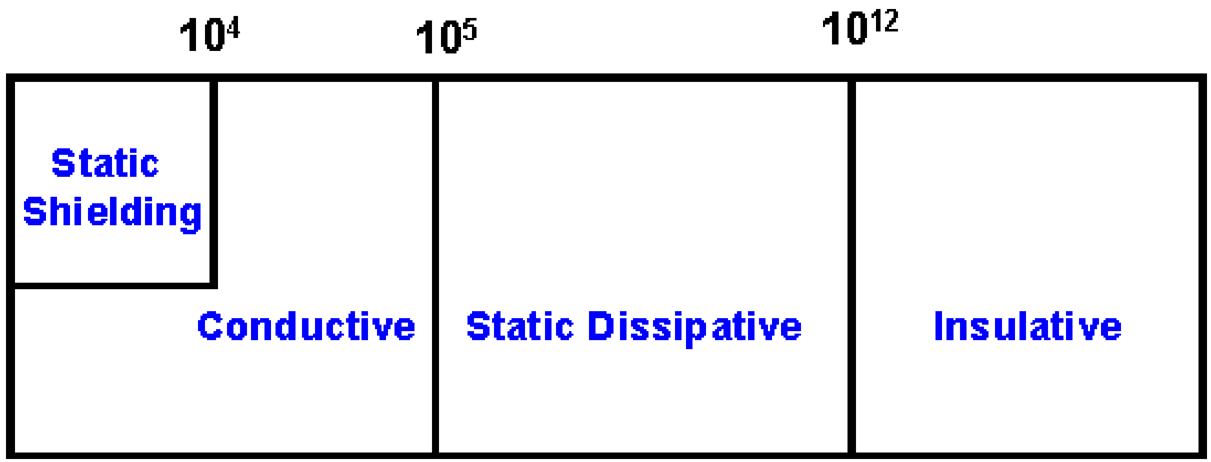
Contact between footwear and non-ESD safe floor generates charge due to contact/separation and friction.

If the person does not discharge to ground, charge will persist or increase with movement. Voltage will vary with capacitance changes due to body movement.



Surface Resistivity (ρ_s)
Ohms/Square Classification

(Present classification)



Conductive	$\rho_s < 10^5$ Ω/sq.
Static Dissipative	$10^5 \leq \rho_s < 10^{12}$ Ω/sq.
Insulative	$\rho_s \geq 10^{12}$ Ω/sq.

Testing For Component Level

ESD Sensitivity

（器件级ESD测试）

ESD Models

（ESD模型）

Human Body Model (**HBM**)（人体模型）

Machine Model (**MM**)（机器模型）

Charged Device Model (**CDM**)）（器件带电模型）

Human Body Model人体模型

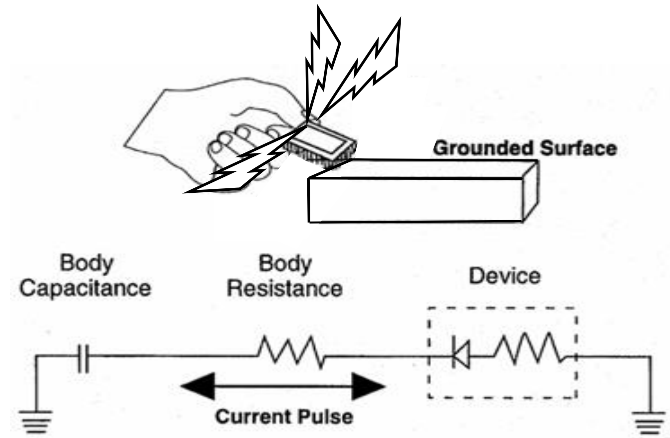
- Simulated a human body discharging accumulated static charge through a grounded device.
  模拟人体释放累积静电电荷的模型

- Is the oldest ESD model. Is the most widely used and quoted model.
  是最悠久，最普遍，最常被引用的模型

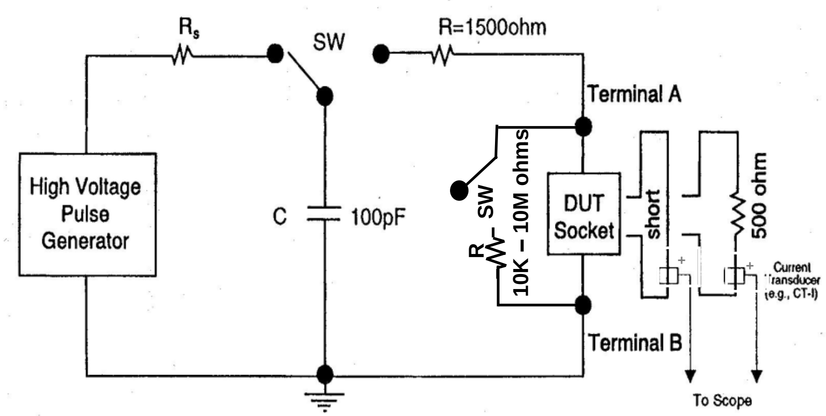
- Is the only model called out in the MIL-STD-3015.7 at the present time.

- Does not represent a worst-case HBM.
  并不能代表人体释放静电电荷的最坏状况

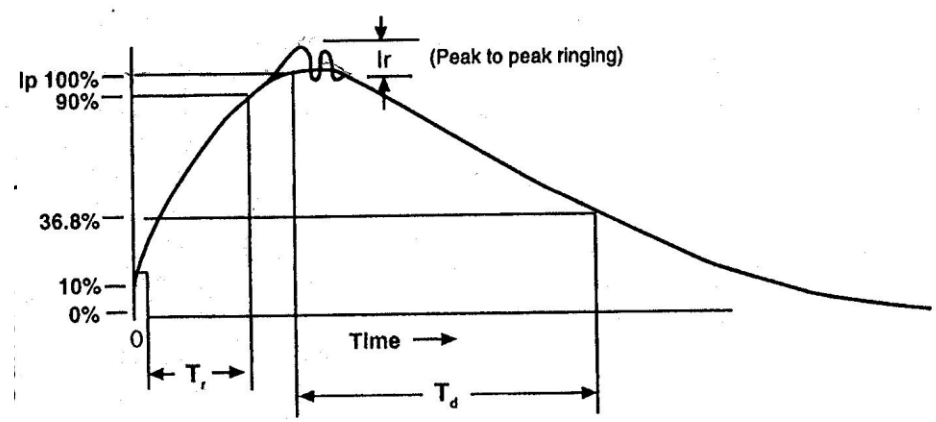
Human Body Model（人体模型）



Equivalent Circuit of Human Body Model



Schematic of HBM Simulator

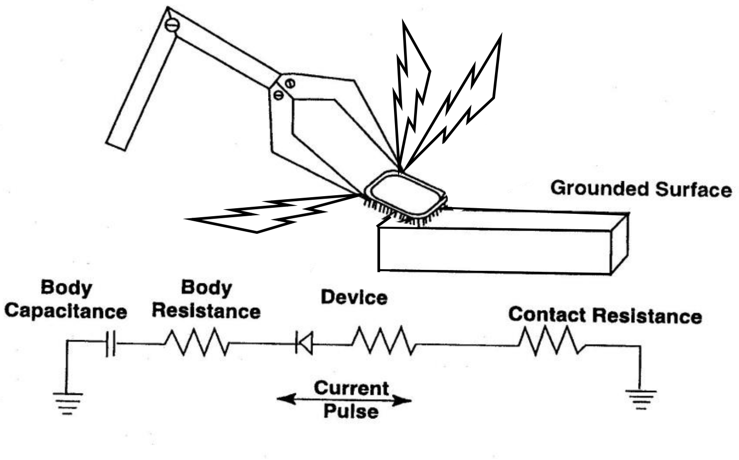


HBM Current Waveform

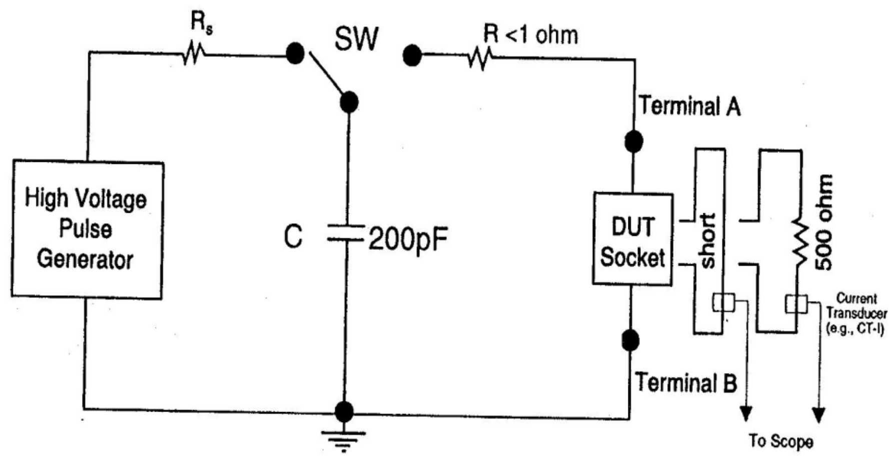
Machine Model（机器模型）

- Simulated a robotic arm discharging accumulated static charge through a grounded device模拟自动机器释放累积电荷的模型
- Originated in Japan.起源于日本
- Could be considered as a worst-case HBM.能代表人体模型释放静电电荷的最坏状况。
- Used by the US automotive industry.用于美国汽车工业

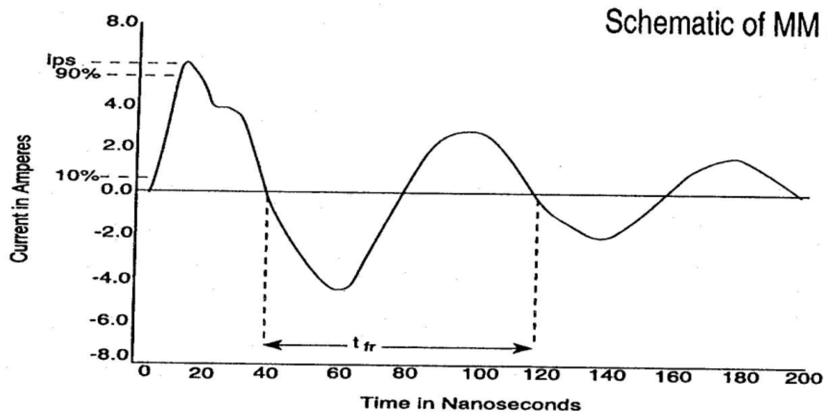
Machine Model机器模型



Equivalent Circuit of Machine Model



Schematic of MM Simulator:



Current Waveform through a shorting wire, 400 volt discharge

Charged Device Model（器件带电模型）

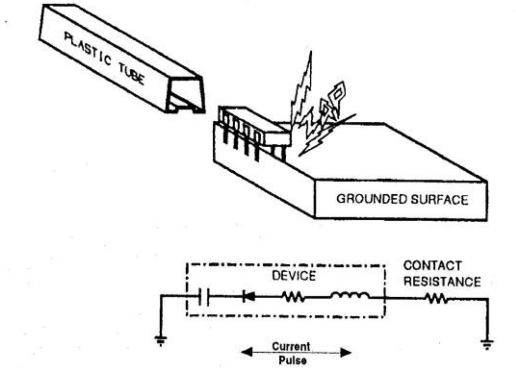
- Simulated a charged device (due to a manufacturing process) that is subsequently grounded.模拟因生产过程而带电的材料接地后释放累积静电电荷的模型）

- Discharge current is limited by the parasitic impedance and capacitance of the device.放电电流受材料本身电容和寄生电阻所限制 。

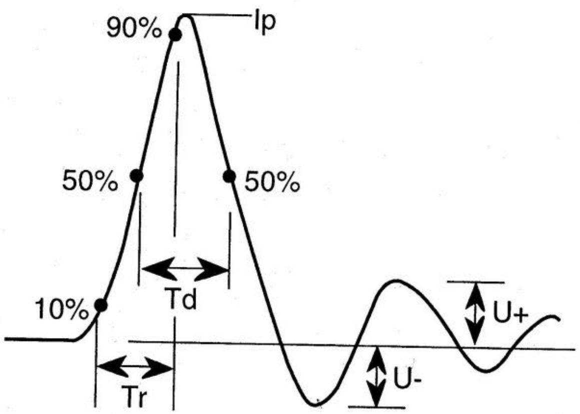
- Duration of discharge is less than 1 nanosecond, the peak current can reach several tens of amperes释放静电电荷的瞬间少于1ns， 电流则高达几十安培。

Charged Device Model

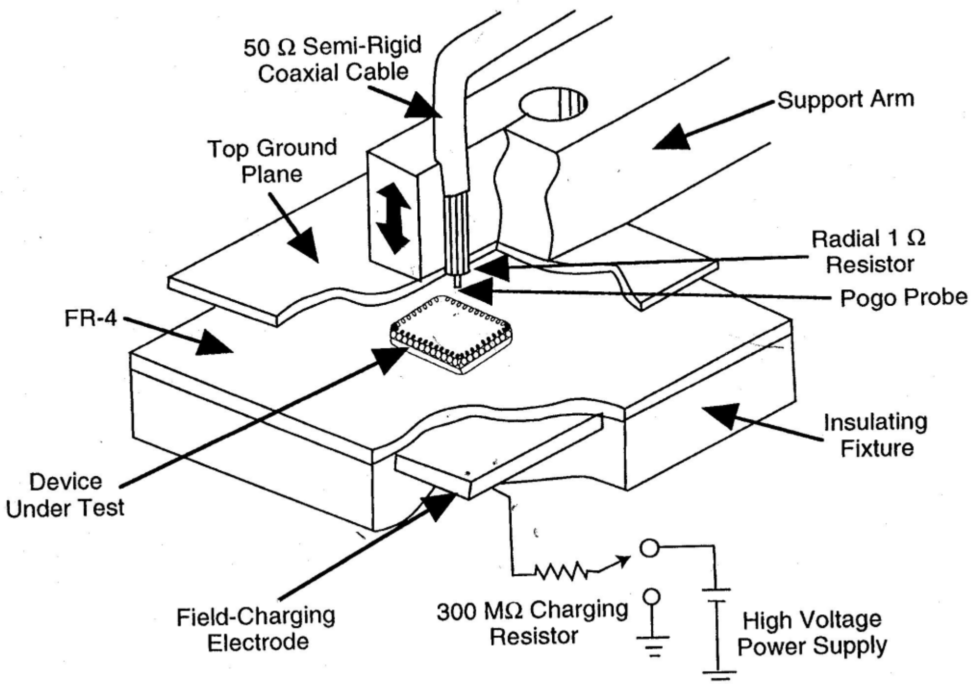
器件带电模型



Equivalent Circuit of Charged Device Model



CDM Current Waveform



Field-Induced CDM Simulator

ESD Models Comparison（三种模型比较）

Model	HBM	MM	CDM
Test Levels (Volts)	500, 1000, 2000, 3000, 4000	50, 100, 150, 200	100, 200, 500, 750, 1000
Pulse Width (ns)	~ 150	~ 80	~ 1
Rise Time	2-10 ns	N/A	< 400 ps
Typical ESD Failures	• Junction Damage • Metal Penetration (Silver Filament) • Metal Melt • Contact Spiking • Gate Oxide Damage		• Gate Oxide Damage • Charge Trapping • Junction Damage

ESD Waveforms Comparison

HBM vs CDM vs MM
(500v) (500v) (400v)

How Device Fail?静电放电如何造成故障

- Electrostatic damage to electronic devices can occur at any point from manufacture to field service.静电放电所造成的故障可以在生产作业的任何一个点上甚至在市场应用发生。

- Damage results from handling the devices in uncontrolled surroundings or when poor ESD control practices are used. 故障往往是因为在缺乏静电控制的环境或静电防护不足时操作所造成的。

- Generally damage is classified as either catastrophic failure or a latent failure。一般上来说故障可分成严重性故障及潜伏性故障。

Catastrophic vs. Latent “Walking Wounded”

严重性故障和潜伏性故障

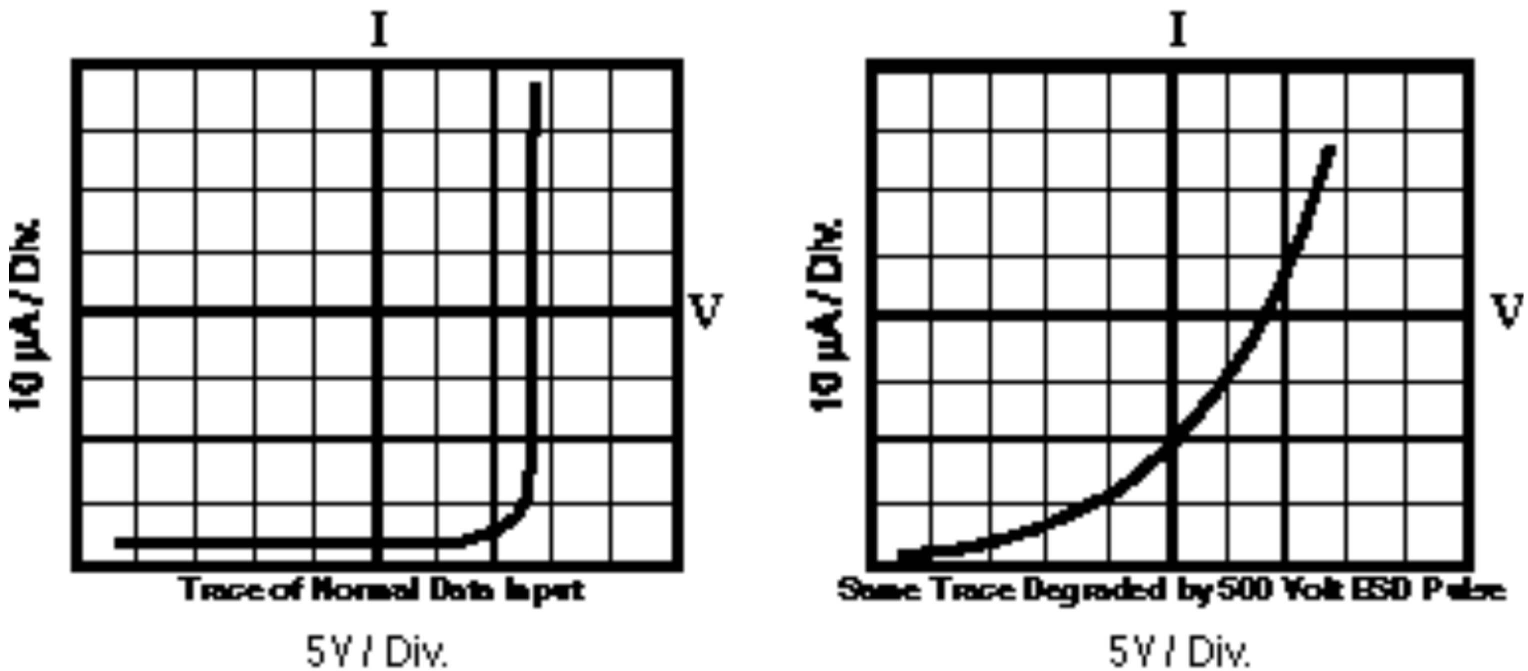
Catastrophic Damage: 严重损伤

- Causes a device to be non-functional.功能丧失
- The device‘s circuitry is permanently damaged causing the device fail. Such failures usually can be detected when the device is tested before shipment.
  故障在出厂前可被测试出。

Latent “Walking Wounded”:潜伏性损伤

- Degrades a device parameter (e.g., leakage, breakdown).
- May still pass functional and parametric test.
- Major reliability problem.

Example of Latent "Walking Wounded"



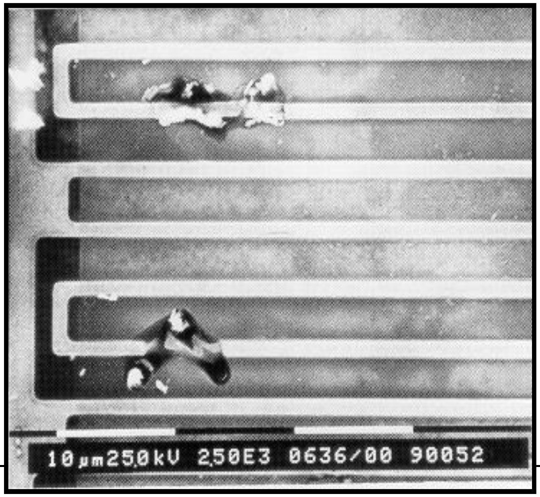
Passing Criterion (single point measurement)

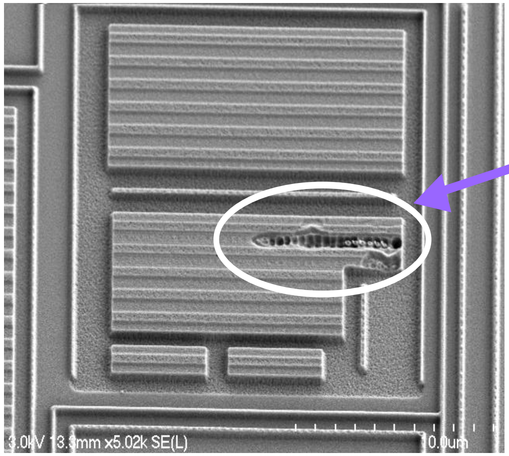
$I_{leakage} \leq 10\mu A$ @ 5V

D. Frank, Soft Failures – The Invisible Mode, 1982, McDonnell Douglas Corporation

ESD Fail Signature 静电损伤特征

- Small focused area of failures
- Filaments can appear at random areas of the same device
- If concentrated at one spot, usually small
- Filaments between diffusions
- No multiple device damage
- One type of damage mode only





Melting of the drain contacts

Basic Principles of Static Control
静电控制原理

1. Design In Immunity 将防静电功能设计入产品内
   providing appropriate input protection
   在入口处使用适当的保护电路
   smaller geometries are more susceptible to ESD
   集成电路的体积越小则对静电放电越敏感。
2. Eliminate and Reduce Generation
   消除和减少静电的产生
   no charge - no discharge没有贮电就没有放电
   reducing static generating processes or materials
   减少使用能产生静电的作业程序及材料
   keeping processes and materials at the same electrostatic potential 使各个作业程序及材料保持在同电位
   provide ground paths to reduce charge generation and accumulation 提供接地点使电荷的产生及累积减至最低程度

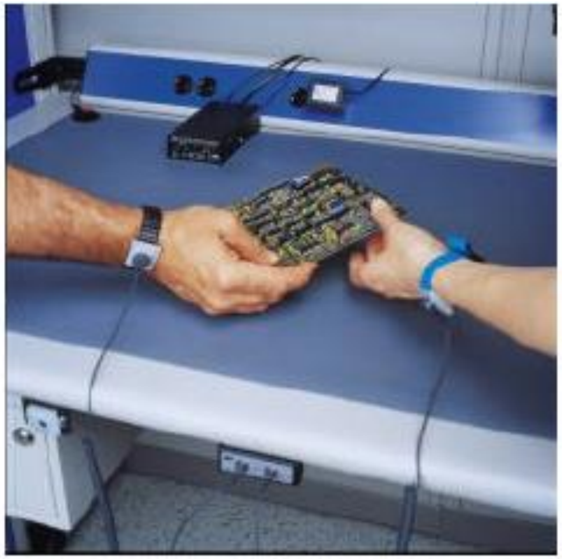
Basic Principles of Static Control
静电控制原理

3. Dissipate and Neutralize泄漏与中和
   safely dissipate or neutralize those electrostatic charges that do occur 将已产生的电荷安全的泄漏与中和
   proper grounding and the use of conductive or dissipative materials 适当的接地点及使用导体或静电驱散体材料
   ionization can be used to neutralize charges on insulating materials 离子化过程可以用来中和绝缘体上的电荷

4. Protect Products from ESD 保护产品以免遭受静电放电效应
   provide proper grounding that will dissipate any discharge away from the product 提供适当的接地点以驱散释放的电荷
   to package and transport susceptible devices in proper packaging and materials handling products 在包装与运输方面使用能屏蔽静电的材料

Basic Tools for Static Control
静电控制基本工具

Basic Tools for Static Control
静电控制基本工具



Environmental Protection
环境因素的预防

PERSONNEL人员

WORK STATION工作站

PACKAGING包装

FACILITY配备

→ Wrist straps/monitors
→ Smocks/footwear
→ ESD gloves/finger coats
→ Dissipative tables/mat
→ ESD chairs
→ ESD tools
→ Shield bags
→ ESD tote boxes
→ ESD tubes/trays/reels
→ Humidity control
→ Ionization
→ ESD flooring

Basic ESD Requirements基本静电控制要求

√ Post ESD sign at all entrances

√ ESD smocks required for all personnel in area

√ Must wear ground strap when handling static sensitive items

√ ESD flooring & footwear required for all personnel

√ Static dissipative tabletops connected to ground

√ No unessential static generators allowed in area

√ ESD audits on regular basis

√ ESD safe packaging materials/incoming inspection

√ Grounded machinery/tables/carts/chairs

√ Continuous monitoring of grounds

√ ESD training & recertification for all personnel

√ “Extraordinary Measures”, whenever necessary

ESD Control Items

- Personnel Grounding Devices
- Work Surface
- Static Dissipative Floor/mat
- Packaging
- Ionizers
- Topical Antistats
- Static Dissipative Garment
- Glove and Finger Cots
- Furniture
- Awareness Symbols

Personnel Grounding Devices

Wrist Straps:

- Shall be checked at least daily.
- **Should fit snug against bare skin.**
- Should include a 1 MΩ safety resistor.
- Provides a safe discharge path to ground.
- Do not use wrist strap if live voltages
  > ± 240 volts are in immediate area.

Personnel Grounding Devices (Cont.)

Continuous Wrist Straps Monitors:

- Resistive (dual cord) or Capacitive (single cord)
- Audio and visual alarms
- Monitor personnel
- Some also monitor work surface ground

Highly Recommended!!!

✓ Checking continuously (instant alarm)

✓ No additional paperwork/record is needed

Personnel Grounding Devices (Cont.)

ESD Footwear:

- Shall be checked at least daily.
- Shall be worn on ***both*** feet.
- **Must be used with grounded static dissipative flooring or floor mat to be effective.**
- Relied upon only at standing operations.
- Provides a safe discharge path to ground.
- Includes ESD shoes, toe grounders, heel straps and bootstraps.

For personnel grounding, either wrist straps or ESD footwear is needed.

ESD Protected Work Surface

ESD Protected Work Surface:

- Used where unprotected ESD sensitive wafers/devices are handled, tested, repaired, or assemble.
- Connect each work surface/station individually to ground.

  Do not "daisy chain" the stations to ground
- Shall be conductive or static dissipative and clean.
- May be soft mat or hard laminated table top (key 5S consideration).

ESD Protected Floor and Mat

ESD Protected Floor:

- Used in conjunction with ESD footwear.
- Must be properly grounded.
- Audits for measurements and maintenance of its effectiveness is required.
- Include tile, wax or carpet.

ESD Protected Floor Mat:

- Used in conjunction with ESD footwear.
- Must be properly grounded.
- Used as an antifatigue and/or provide a dissipative surface where no dissipative floor or floor finish is available.

Packaging

- Antistatic Bags
- Conductive Bags
- Static Shielding Bags
- Package Filler
- Magazines/shipping tubes
- Tote Boxes
- Tape and Reel
- Trays
- Wafer Cassette/Box/Flat Pack

Ionizers

Types:

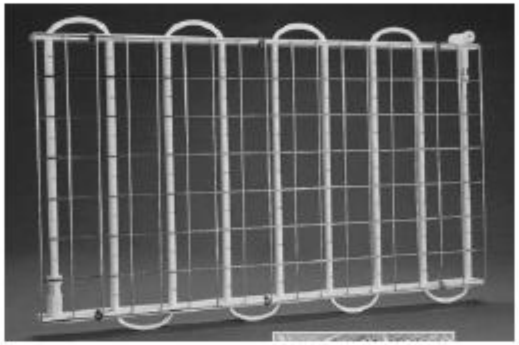
Nuclear (alpha energy)
Electronic (Corona Discharge)
-- AC, DC, Pulse DC

Applications:

Bench Type
Whole Room (ceiling)
Laminar Hood
Bar Type
Blow-off Gun or Nozzle

Ionizer Types

Overhead (workstation)



Grid (whole room)

Benchtop (workstation)

Discrete Emitters (whole room)

Compressed Gas

Ionizing Bars

General Comments about Ionizers

- ✓ Required when necessary insulative materials are present at the workstation or for handling sensitive devices.
- ✓ Good ionizers generate equal balance of positive and negative ions.
- ✓ Need to be tested and cleaned periodically.
- ✓ Need to be checked for balance and charge decay.
- ✓ Do keep bench ionizer placement to be within a 3-foot distance
- ✓ *Must point towards the direction of the work area!!!*

General Comments on Ionizers

- ✓ Used in cleanrooms for particle control.
- ✓ Ionization is not a replacement for grounding, but a part of a comprehensive static control program.
- ✓ Some factors to consider: decay time, application, product sensitivity, airflow, cleanroom compatibility, maintenance, cost, etc.
- ✓ *Must point towards the direction of the work area!!!*

Topical Antistats:

- Used to inhibit tribocharging of materials.
- Reduce friction by increasing lubricity and increasing surface conductivity by absorbing moisture-layer from the air.

Possible Problems:

- Must be monitored and labeled with application date (tough to implement).
- Some antistats can cause corrosion on device leads.
- Relative humidity dependent.
- Not clean room compliant (flakes).

Static Dissipative Garments:

- Suppress electric field present from personnel clothing.
- Should be periodically monitored for triboelectric charging.
- Include coveralls, smocks, coats, etc.

Gloves and Finger Cots:

- Only cotton gloves, antistatic/conductive gloves or static dissipative finger cots should be used.
- Minimize tribocharging and transfer of body oils to devices during handling (solderability concern)

Furniture

- Tables
- Chairs
- Cabinets
- Storage shelves
- Carts
- Mobile stations

Some applications may require special ESD control furniture listed above. All products' ESD-safe characteristics must be evaluated before purchase to ensure suitability and effectiveness

At a minimum, ensure proper grounding!

Grounding Chain

- Grounding chain is ***not*** a full substitute for proper cart grounding.
- It is used to make intermittent contact to the ESD-safe flooring to prohibit charge built-up on cart.
- Typical (and recommended) length touching the floor is 30-45 cm.
- For safety purpose, 2 separate chains can be used if the total length touching the floor is equal to >= 30cm.
- Chains need to be cleaned often to ensure maximum effectiveness.
- Heavy, zinc-plated steel links are preferred.

Note: Grounding chain must be used with ESD-safe flooring.

ESD Labels:

- Required on each ESD protected package.
- Shall clearly indicate by words and/or symbol that ESDs devices are inside the package and that the package cannot be opened except at a designated ESD protected area or workstation.

ESD Caution Sign and Posting:

- Clearly indicate the ESD protected area boundaries and workstations.
- Shall indicate by words and/or symbols that **ESD-safe handling is required**.

Typical Instruments Used in Auditing and Monitoring the Effectiveness of ESD Control Items

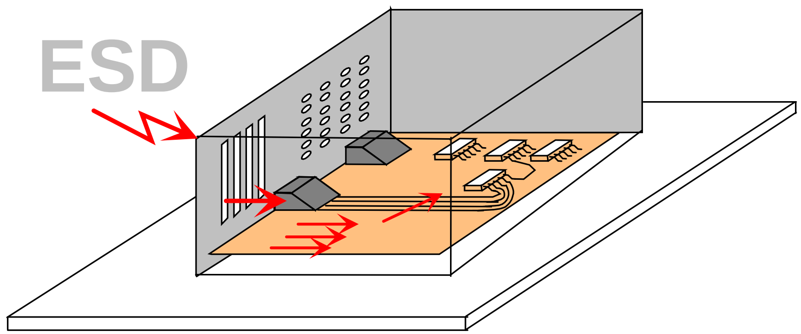
- Wrist strap checker
- Footwear checker
- Electrostatic field meter
- Non-contact voltmeter
- Hygro-Thermometer
- Surface resistivity meter
- Charge plate monitor
- Megohmmeter
- Ohm/volt meter
- Faraday Cup and electrometer

(All equipment requires calibration)

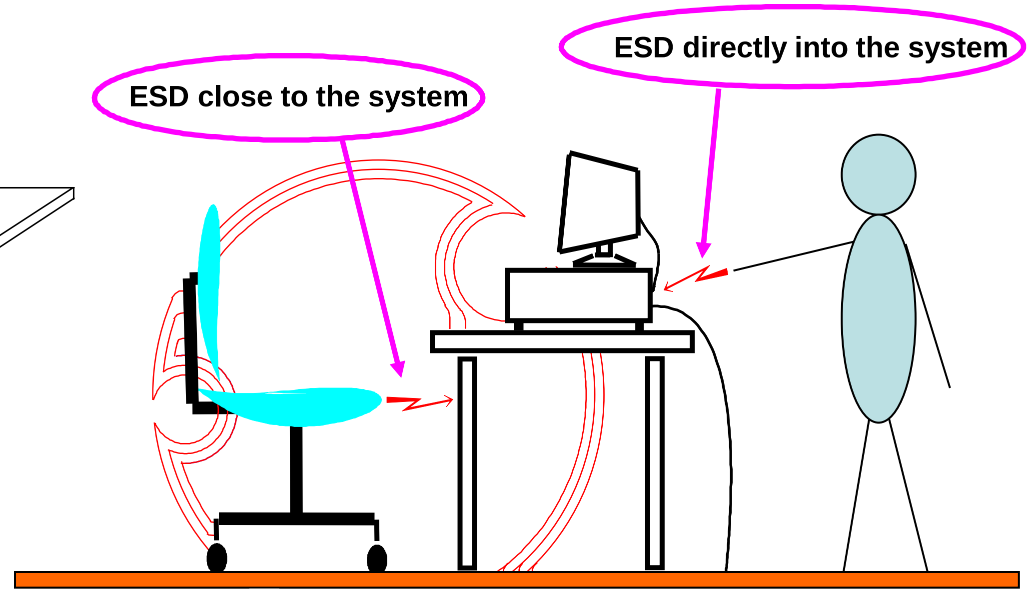
System Level ESD

Electric and magnetic fields produced by ESD couple to the system in multiple ways, causing failures.

A human holding a metallic object (e.g. keys, screwdriver) discharging accumulated static charge through an electronic product (e.g. cellular phone, computer).

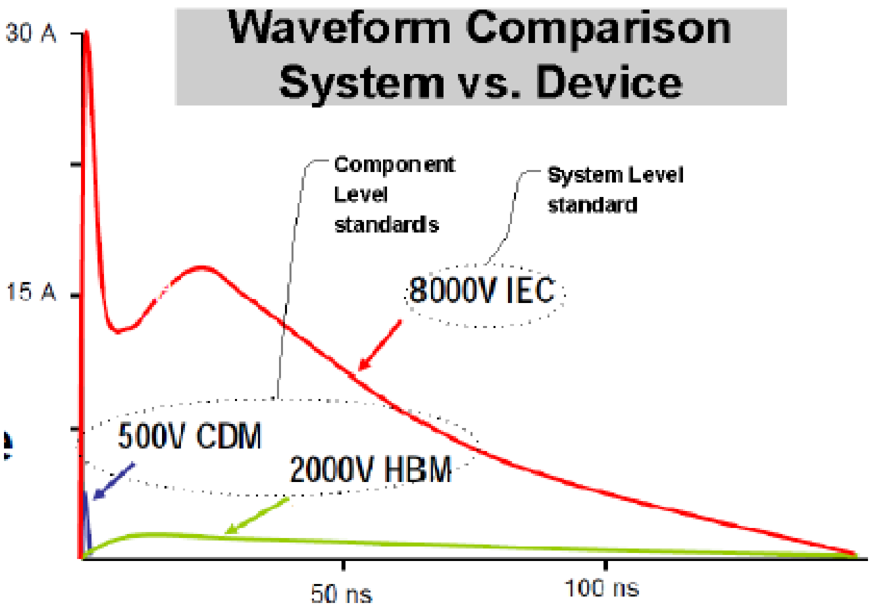


The impact is severe for pins that interface with the outside (USB, Ethernert, etc.)



System Level ESD

- Threat results from Electrostatic charges accumulated either on **objects**(cable,..) or **Human bodies** discharging into the Electronic Systems or Sub-Systems.
  - **- A direct contact to a system I/O pin / case**
  - **- An arc through a vent hole or seam to a PCB**
  - **- Pickup of EM radiation from indirect ESD**
  - **- A secondary discharge event within the system**



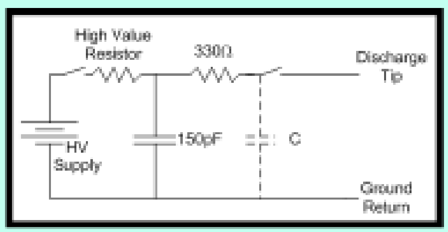
- **Stress is stronger than the one used for IC qualification**

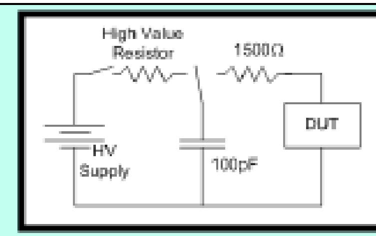
- Goal is to assess, for final applications, the immunity to electrostatic discharges of locations which people have access to in normal use.

System Level ESD vs. Component Level ESD

Parameter	System level ESD - IEC	Component level ESD HBM
Event example	Charged human discharging through a metallic tool to a system	Charged human discharging through the skin to a component (IC)
Model	IEC system level ESD	Human Body Model (HBM)
Environment	End customer's normal operation	Factory assembly
Standard example Test	IEC 61000-4-2 (Powered) ISO 10605 (Unpowered / Powered)	JS-001-2013 (Unpowered only)

R-C network





✓ The two tests are distinctly different and serve different purposes

Parameter	System level ESD - IEC	Component level ESD HBM
Peak current	3.75 A / kV	0.7 A / kV
Typical requirement	8 KV	1 KV (Formerly 2kV)
Rise time	0.6 ~ 1 ns	2 ~ 10 ns
Pulse width	~50 ns	150 ns
Failures	Soft and Hard	Hard
Application	PC, Cell phone, Modem, etc…	IC
Tester examples	KeyTek Minizap, Noiseken ESS2000	KeyTek Zapmaster MK2, Oryx

System Level ESD

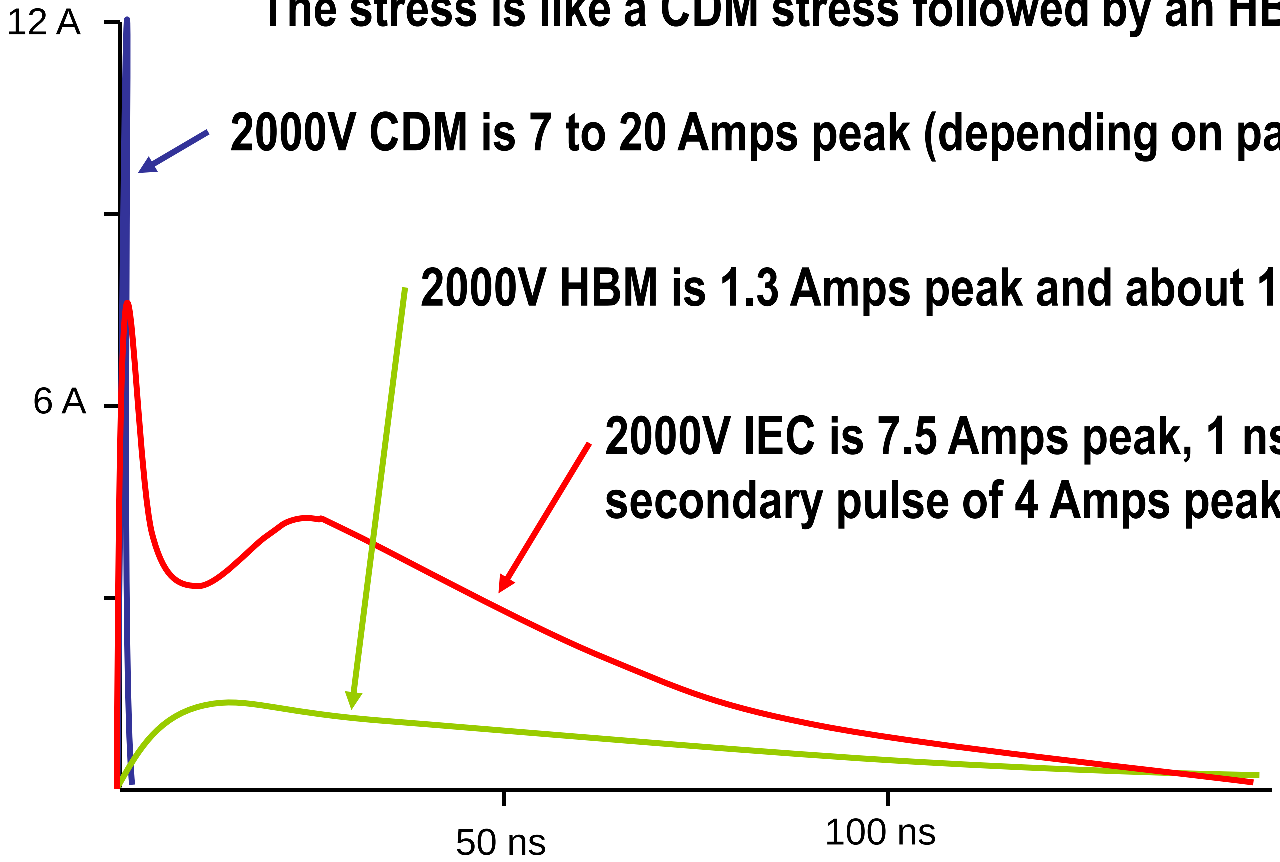
How does the IEC ESD stress differ from the tests we've been doing?

The stress is like a CDM stress followed by an HBM stress.

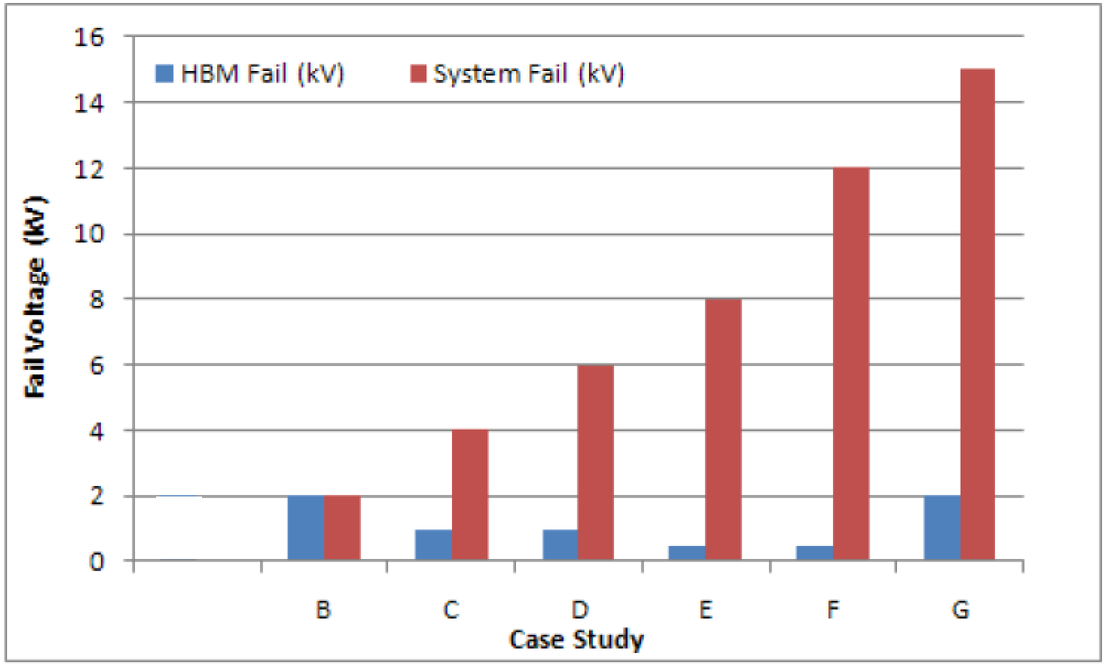
2000V CDM is 7 to 20 Amps peak (depending on package) and 1 ns wide.

2000V HBM is 1.3 Amps peak and about 150 ns wide.

2000V IEC is 7.5 Amps peak, 1 ns wide *plus* a secondary pulse of 4 Amps peak, about 50 ns wide.



Component Vs. System Test Result Correlation



Case Study	HBM Fail (kV)	System Fail (kV)
B	2	2
C	1	4
D	1	6
E	0.5	8
F	0.5	12
G	2	15

C

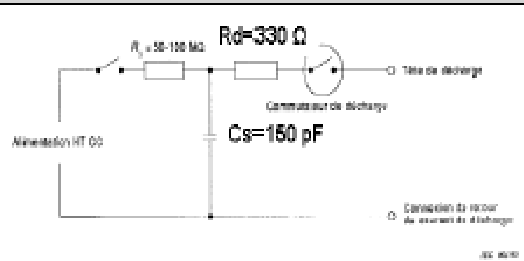
- Case studies B through G represent data on products which had failure voltages characterized for both HBM and system level ESD test
- Data indicates no correlation of HBM failure voltage to system ESD failure voltage

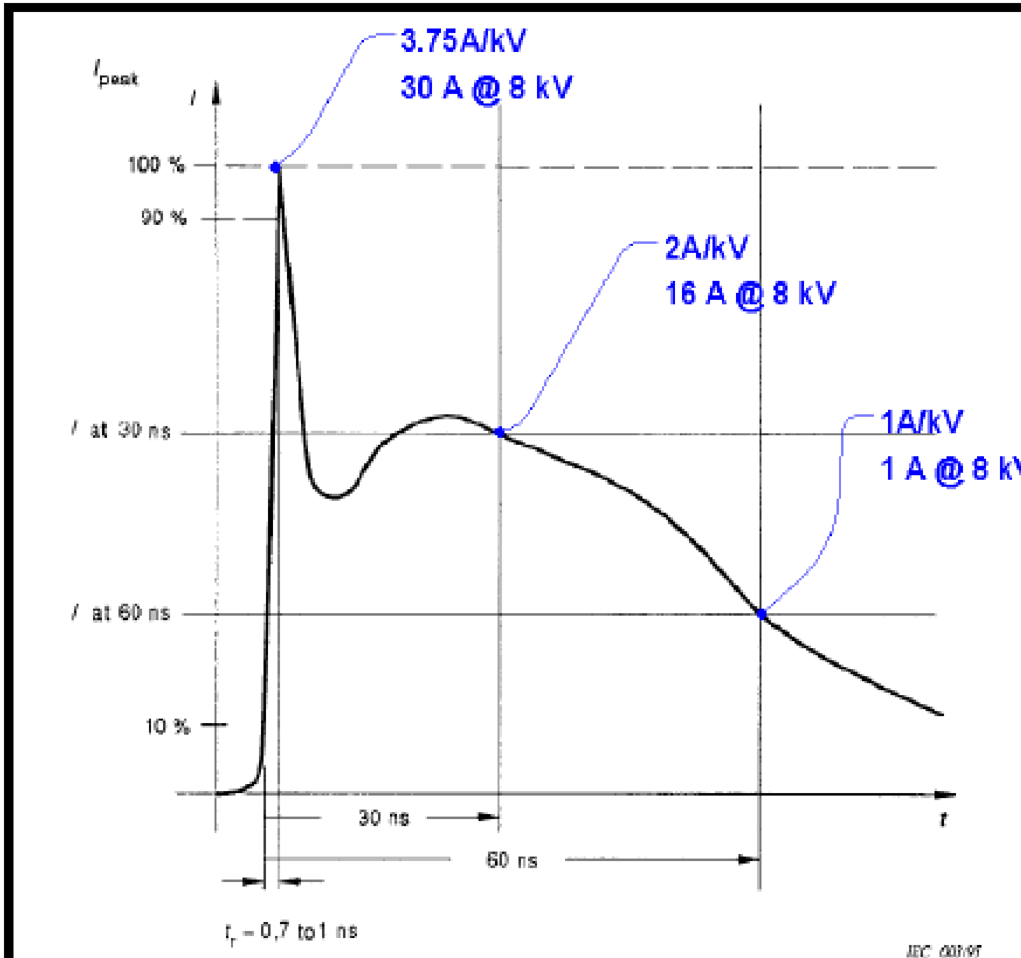
IEC 61000-4-2 standard

- Manufacturers of electronic systems test system level ESD robustness of products per IEC 61000-4-2 standard
- A charged human discharging through a metallic tool into or close to an electronic system is considered a system level ESD event by the IEC
- The IEC standard defines test pulse, test setup, methodology, failure criteria, etc.
- IEC standard defines two test methods:
  - Indirect application of the discharge: simulate ESD close to the system
  - Direct application of the discharge: simulate ESD into the system
- IEC standard defines two discharge modes:
  - Contact discharge: ESD generator is placed in contact with the system and a trigger is pressed to inject the current
  - Air discharge: ESD generator is moved rapidly towards the system causing the intervening air to breakdown resulting in an arc
- Contact discharge mode is the preferred discharge method for better repeatability

IEC61000-4-2 Generator & Waveform Characteristic

Contact Discharge		Air Discharge	
Level	Test Voltage [+/- kV]	Level	Test Voltage [+/- kV]
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15

Generator Characteristic	
Charging Model	 This network does not represent the initial peak in the waveform
Rise time	**0.7~ 1 ns**



IEC-61000-4-2 Test Method

Direct discharge:

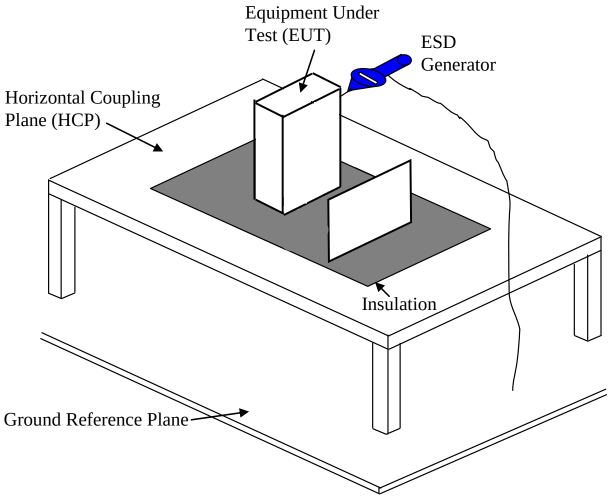
- Apply directly to the surface or structure of EUT.
- Include both contact discharge and air discharge modes.

Indirect discharge:

- Apply to a coupling plane in the vicinity of EUT.
- To simulate personnel discharge to objects which are adjacent to EUT.
- Contact discharge mode only.

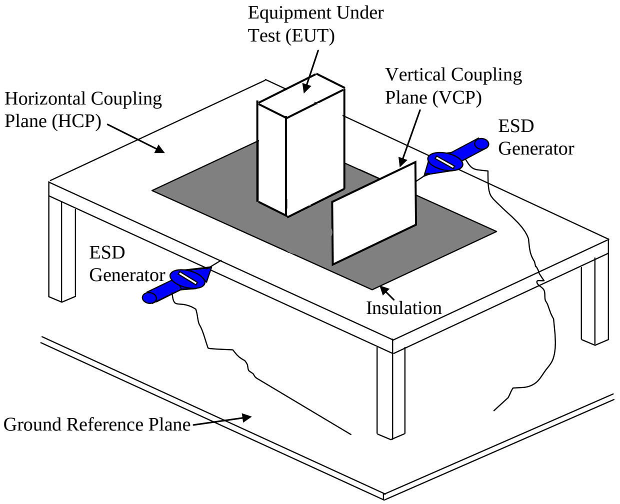
IEC 61000-4-2 – Direct ESD

- To test susceptibility of a system to ESD discharges directly into the system
- ESD current could cause permanent damage to the components as well as soft failures
- Prefer contact discharge mode to air discharge for its better repeatability
- Use contact discharge mode wherever possible (on all the conductive surfaces of the system)
- Use air discharge mode only on non-conductive surfaces
- Start at 2 kV and ramp up in 2 kV increments until a failure
- Testing is performed with both positive and negative polarities at each test level
- 10 discharges are to be applied at each level with a rate of 1 pulse/second
- Any abnormal operations or permanent damages of the EUT are considered failures



IEC 61000-4-2 – Indirect ESD

- To test susceptibility of a system to ESD discharges to nearby metallic structures
- Electromagnetic fields produced by indirect ESD couple to the system and cause soft failures
- Discharges to the horizontal coupling plane (HCP) and vertical coupling plane (VCP)
- Testing is performed in contact discharge mode
- Start at 2 kV and ramp up in 2 kV increments until a failure
- Testing is performed with both positive and negative polarities at each level
- 10 discharges at each level with a rate of 1 pulse/second
- Any abnormal operations of the EUT are considered failures
- The HCP and VCP are connected to the ground reference plane through two 470 kΩ resistors



IEC-61000-4-2 Test Mode

Contact discharge mode:

- The electrode of ESD generator is held in contact with equipment-under-test (EUT) or a coupling plane prior to discharge.
- Arc formation is under controlled conditions (inside a relay), resulting in repeatable waveforms.
- Preferred way to apply on conductive surfaces of EUT.

Air discharge mode:

- The charged electrode of ESD generator is brought close to EUT, and a spark in air to the EUT actuates the discharge.
- More realistic to the actual ESD occurrence.
- May not produce repeatable waveforms due to variations of the arc length (electrode approaching speed, humidity, etc.).
- Usually applied on non-conductive surfaces of EUT.

IEC-61000-4-2 Test Result

- System level ESD (qualification) testing is intended to ensure that finished products can continue normal operation during and after a system level ESD strike.

ESD Result Classification:

a) Normal performance within limits specified by the manufactures

b) Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and the system recovers its normal performance without operator intervention

c) Temporary loss of function or degradation of performance, the correction of which requires operator intervention

d) Loss of function or degradation of performance which is not recoverable, due to damage to hardware or software, or loss of data

ESD generators and discharge guns

Keytek Minizap

Haefely

Keytek 2000

Modified Schaffner

EMC Partner

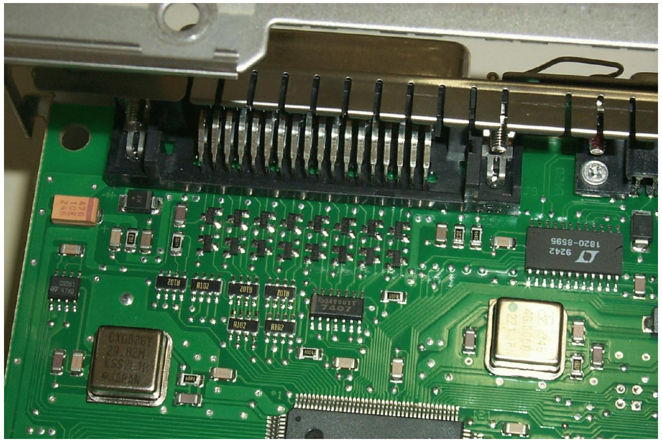
EM-Test Dito

Noiseken

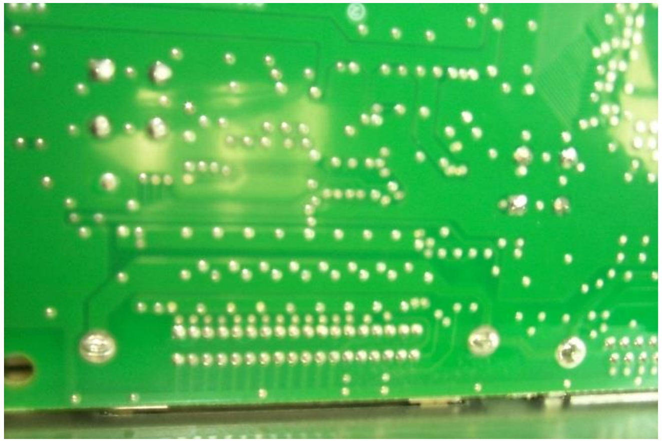
Schaffner 432

IEC ESD Protections in a System

- Metallic shielding for both ESD and EMI
- Chassis GND isolation from board GND
- Air gap designed on board to absorb ESD energy
- Clamping diodes to absorb ESD energy (External ESD Protection)
- Capacitors to divert ESD energy (External ESD Protection)



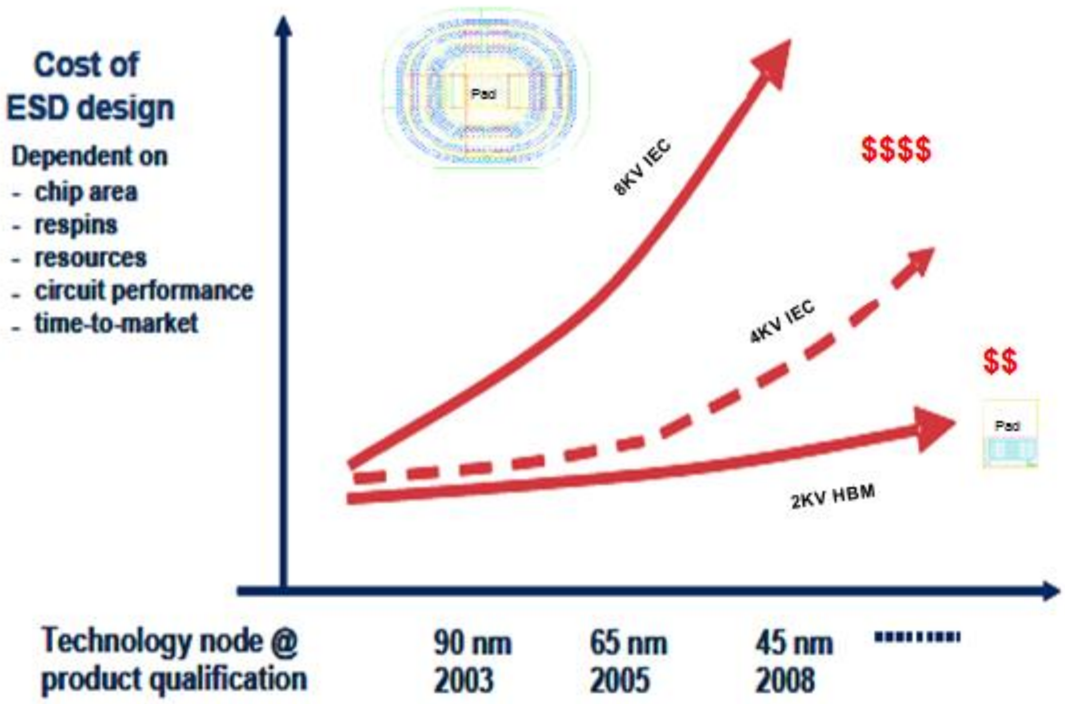
Interface with clamp diodes



Board layout with isolated chassis GND

Why External ESD Protection?

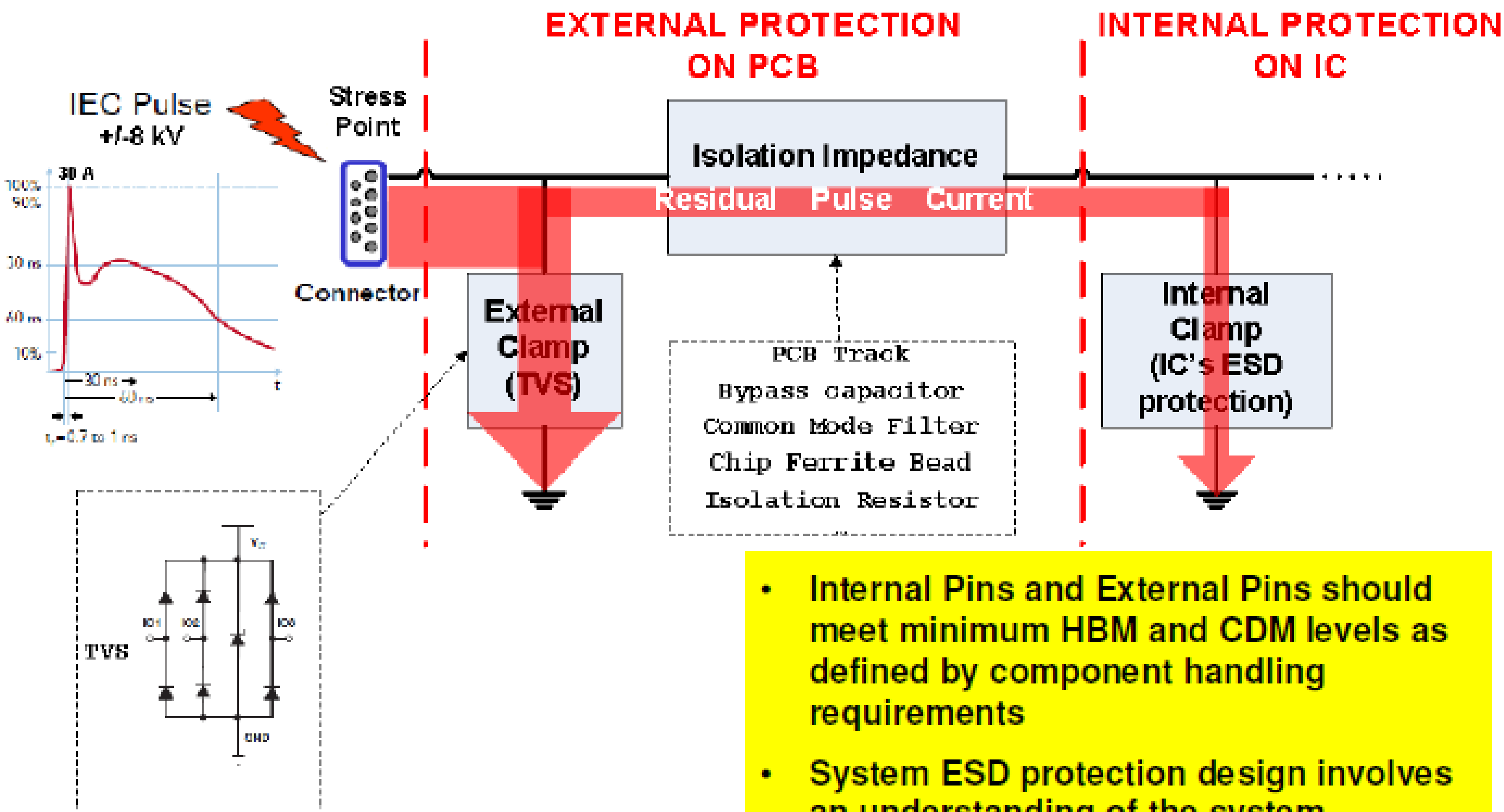
It becomes very expensive to design IEC Clamp at low geometry process



Why Not Just Increase Chip Level ESD?

- Extra cost of area and capacitance.
- Routing large currents into Chip Level ESD protection cell is dangerous.
- Latchup concern – powered system.
- HBM improvement with the use of primary clamp may not improve System Level ESD protection.

Designing for the Overall System

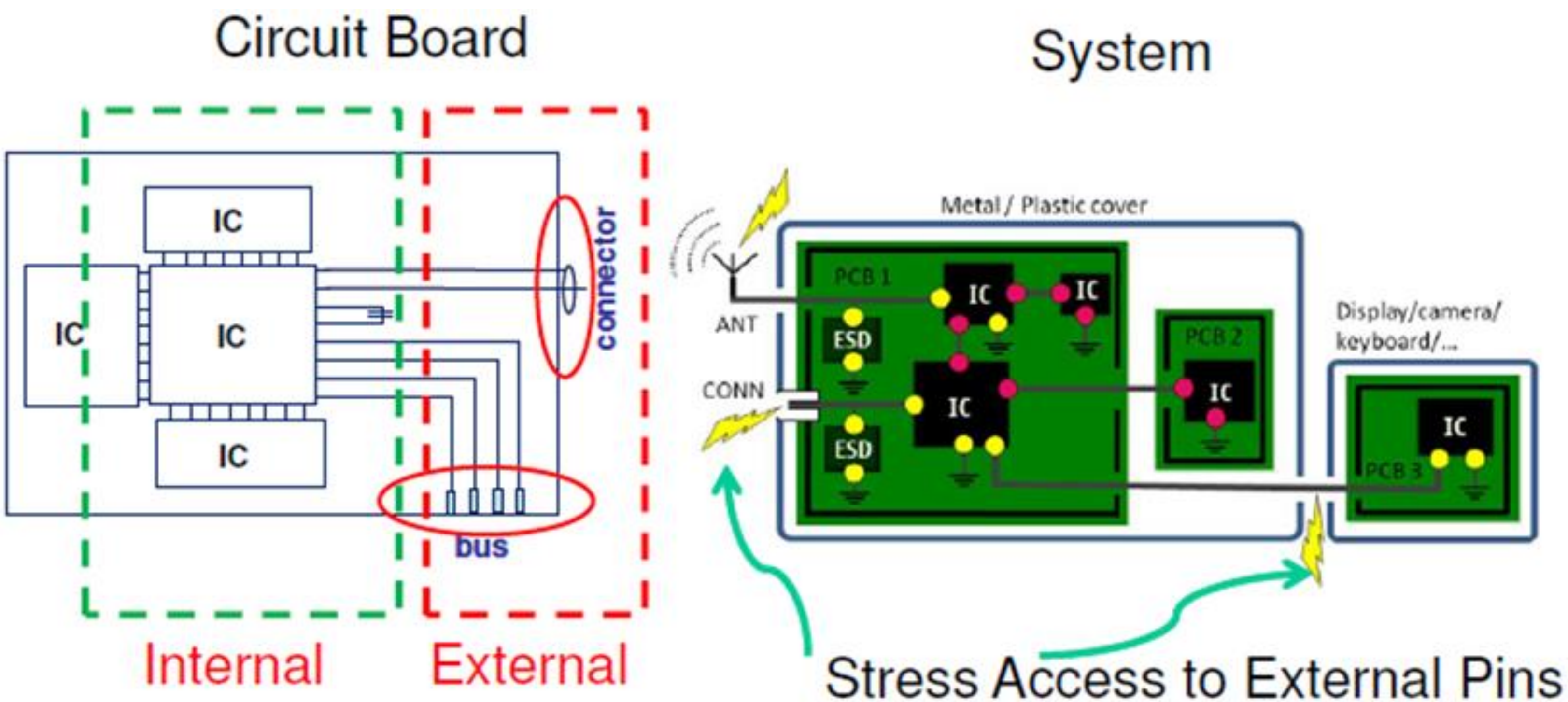


- Internal Pins and External Pins should meet minimum HBM and CDM levels as defined by component handling requirements
- System ESD protection design involves an understanding of the system, independent of component ESD levels

System Efficient ESD Design (SEED)

- A co-design methodology of on-board and on-chip ESD protection to achieve system-level ESD robustness.
- For efficient system ESD design, the Internal versus the External pins must first be defined.
- The interaction from the external pin stress to the internal pin must then be analyzed.
- Both Internal Pins and External Pins should meet minimum HBM and CDM levels as defined by component handling requirement; however, this is not a system requirement.
- For achieving system level ESD robustness, the External Pins must be designed with a proper system protection strategy; which is independent of their HBM/CDM protection levels.

Differentiation of Internal Vs. External Pins



- As identified here all the external pins are stressed with the IEC pulses

System Efficient ESD Design (SEED) Concept

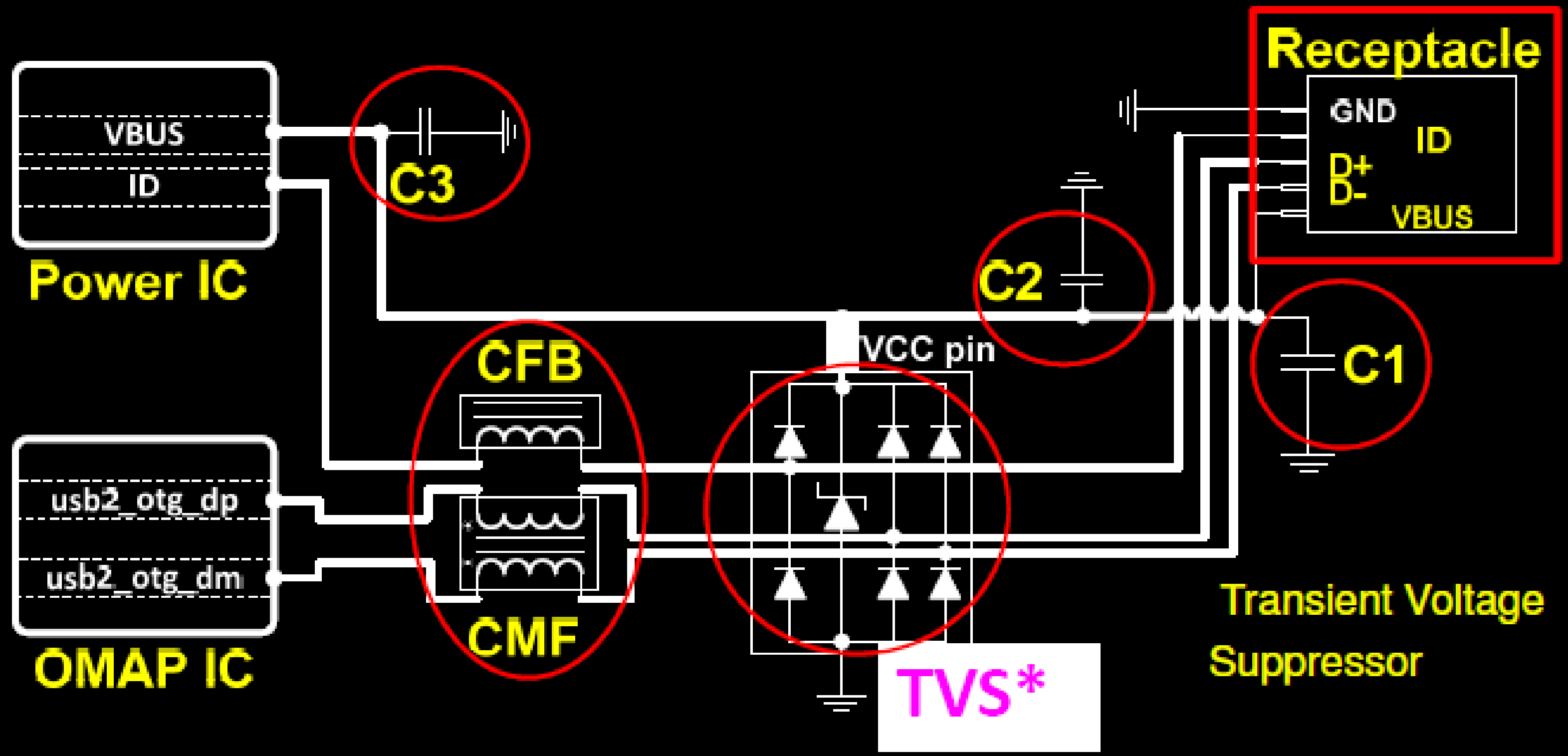
Do all pins on a device need to be tested using system level events?

- Only the external pins (e.g. USB data lines, Vbus line, ID and other control lines; codec, battery pins, etc.) need to be tested if the IC is not protected with on-board components.

- Other internal ESD sensitive pins (e.g. control pins, reset pins, and high speed data lines, etc.) can be inductively coupled during a discharge to the case and/or to an adjacent trace of an exposed pin undergoing system testing.

- These sensitive internal pins need to be identified and may need to be monitored during system level events.

USB2 Interface Example with SEED



4 Pins to be protected (**D+,D-,ID,VBUS**)

High Speed Data Rate (480Mbit/s)

EMI/ IEC ESD and Signal Integrity requirements

System level ESD design is important

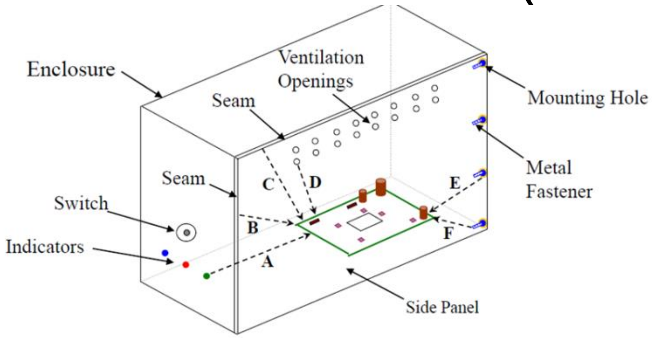
- ESD is not just electrostatics (charge and voltage) but is a strong high frequency signal
- ESD is a wideband (1 MHz ~ 3 GHz) noise source that tries to penetrate a system through every means possible
- The robustness of a system to ESD depends on the overall system design
- Good system design techniques have to be followed to protect the systems against ESD
- Many of these techniques can also improve system's Electromagnetic Compatibility (EMC) performance
- ESD testing throughout product's design cycle helps to find and fix weak spots
- The guidelines (methods) are divided into different sections based on how they work to offer protection

System level ESD design guidelines

- Plastic enclosures, insulation and air space
  - Insulation (solid material or air space) prevents ESD arcs from reaching the electronics
- Metal enclosures and shielding
  - Metal shield keeps direct and indirect ESD from entering the system
- Grounding and bonding
  - Bonding metal pieces and providing a way of grounding avoid secondary discharges and capacitive coupling
- Power distribution and decoupling
  - Good power distribution/plane design and decoupling reduce ESD coupling
- PCB design and placement
  - Good PCB design and layout techniques are important methods for ESD
- Cable design and routing
  - Proper cable selection and cable length are important to reduce ESD coupling
- Filters and transient suppressors
  - Properly designed filters and transient suppressors block and divert ESD to ground
- Software

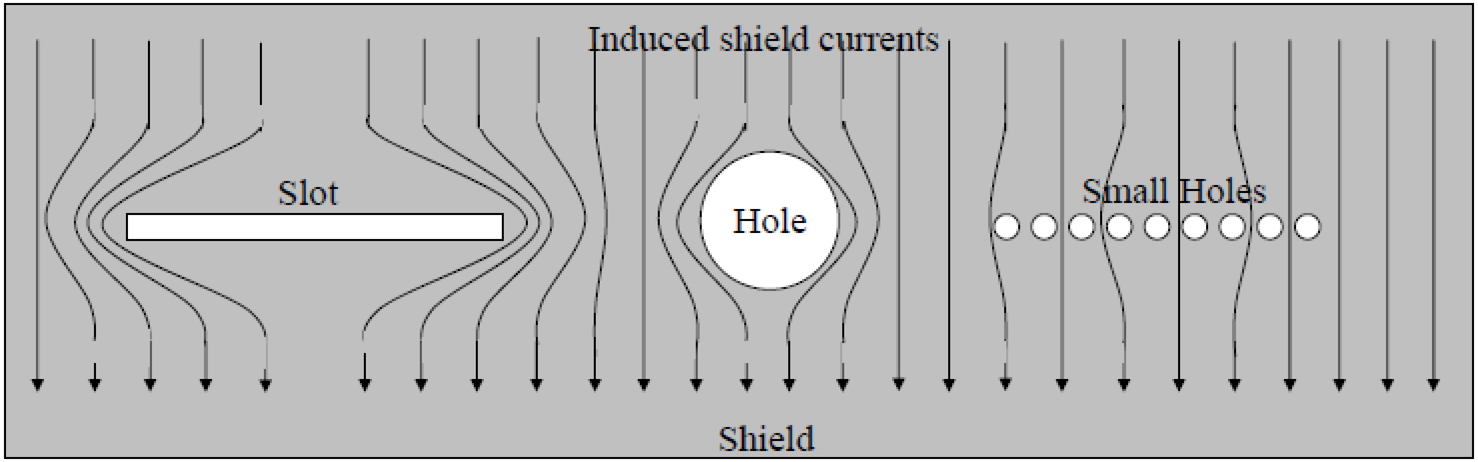
1. Plastic enclosures and air space

- Plastic enclosures, air space and insulation prevent ESD discharges to the electronic system: first line of defense
- Prevent ESD arcs from reaching the electronics by providing physical barrier and increasing the path
- Plastic enclosure offers no protection against electromagnetic fields generated by ESD close to the system (indirect ESD)
- Enclosures made of conductive plastics can prevent indirect ESD from entering the system
- To establish breakdown voltage of 20 kV, ensure > 20 mm path length between the electronics and each point (A, B, C, D, E and F)
  - Any points users can touch (seams, ventilating holes, etc.)
  - Any ungrounded metal users can touch (fasteners, switches, etc.)



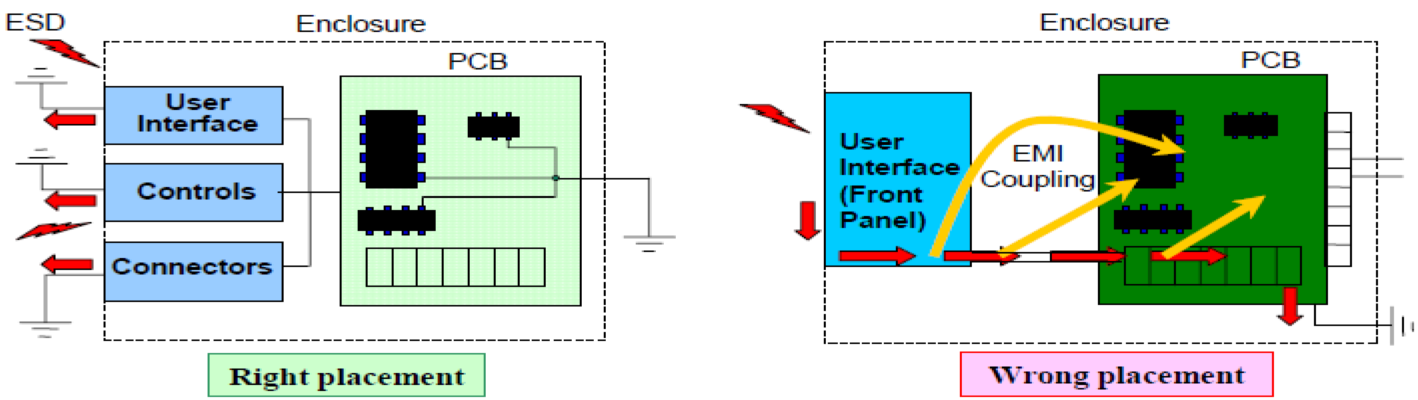
2. Metal enclosures and shielding

- A completely closed enclosure made of thick metal offers excellent shielding to direct and indirect ESD
- Between ungrounded enclosures and electronics, provide for >= 20 kV breakdown voltage (> 20 mm air space)
- Between grounded enclosures and electronics, provide for >= 2 kV breakdown voltage (> 2 mm air space)
- If ventilation openings are needed, prefer holes to slots and prefer many small holes instead of a few big ones



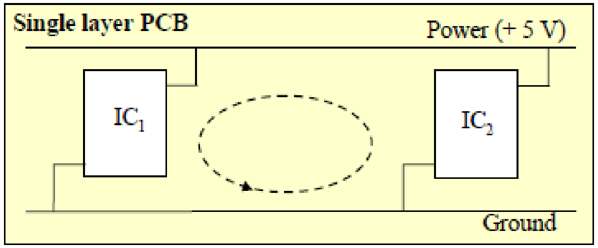
3. Grounding and Bonding

- Connect metal portions of the enclosure, connector housings and metal switch housings to chassis ground
- Keep bonding jumpers and wires away from susceptible electronics or their cables to avoid EMI coupling from ESD strikes

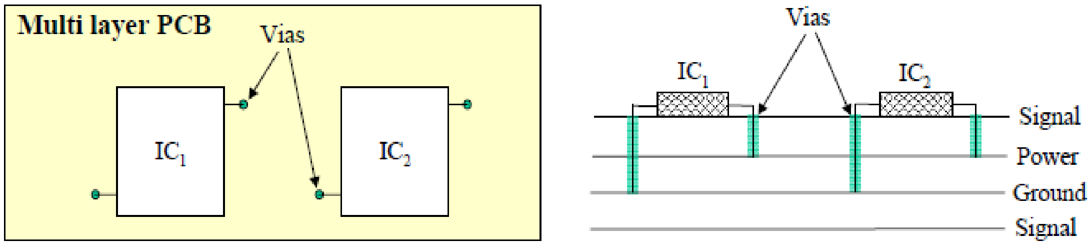


- Use multi-point grounds where ESD current flow is desired - to provide low impedance path for ESD current
- Use single-point grounds where ESD current flow is not wanted
- Right placement of a ground connection prevents ESD current from entering the system.

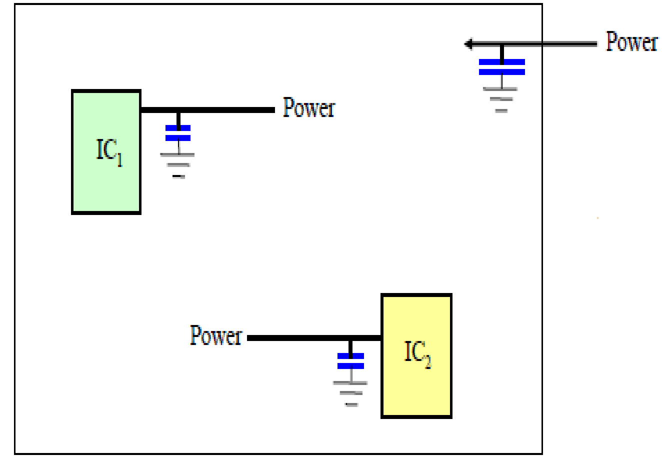
4. Power distribution and Decoupling



Power and ground connections on single layer PCBs form large loops that pick up EMI and cause failures

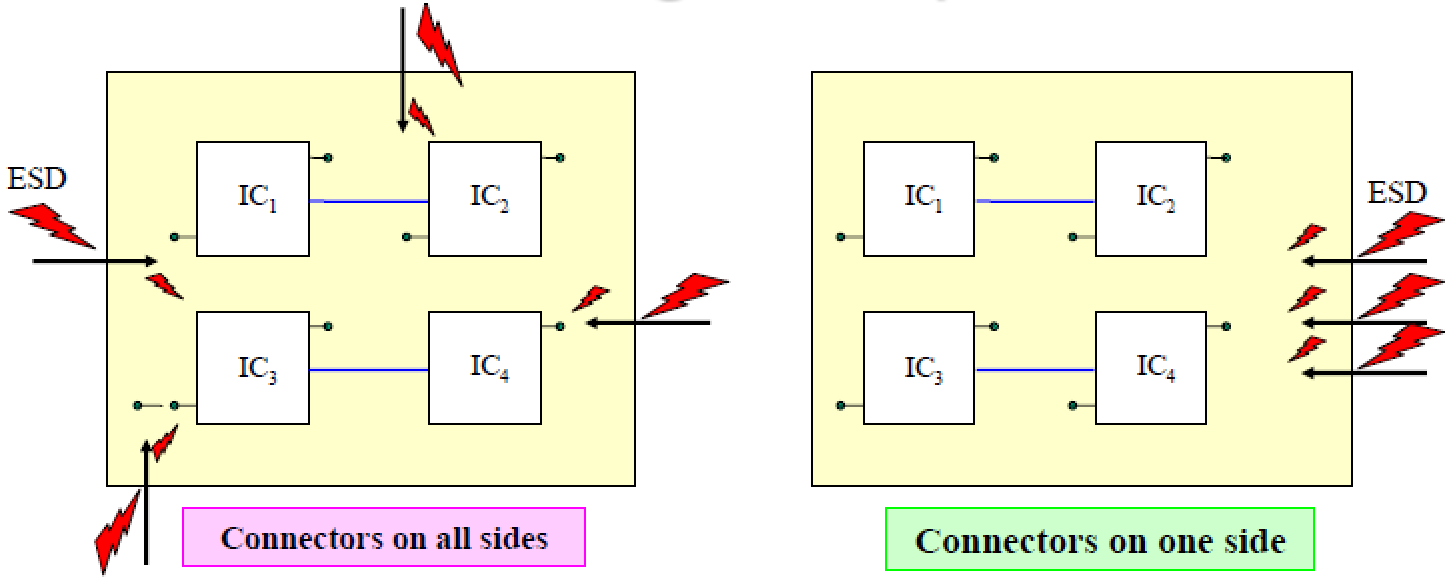


(A) Top View (B) Cross Section



- Prefer multi-layered PCBs with separate power and ground planes
- Dimensions on multi-layer (4-layer in this case) PCBs are in mils as opposed to inches on 1-layer PCBs
  - Less EMI pick-up and lower impedance with multi-layer PCBs
- Provide plenty of decoupling capacitors on power distribution system of PCBs
  - At least one decoupling capacitor for each IC
  - Bulk decoupling capacitors where power comes on to the board directly
- Minimize the series inductance of any decoupling capacitors – provide short connections

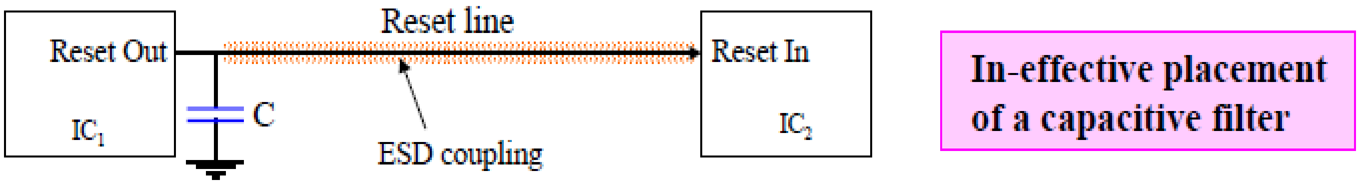
5. PCB design and placement

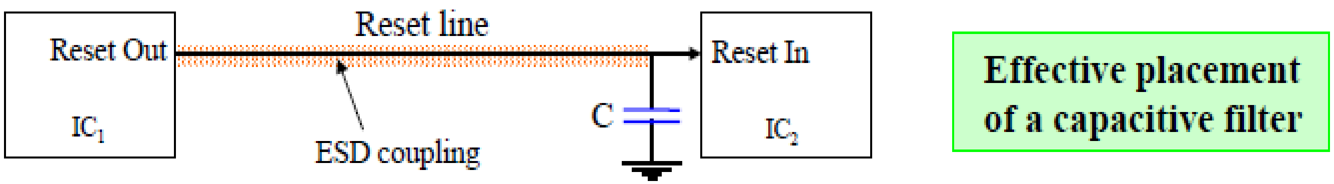


- Put all connectors on one edge of the enclosure, if possible
- Limiting ESD strikes on one side allows sensitive circuits to be placed in other areas and minimizes circuit areas susceptible to inductive coupling due to ESD strikes
- Place ESD susceptible circuits close to the center of the PCB

5. PCB design and placement (contd)

- Pay special attention to status lines such as resets, interrupts, and control signals
  - Add high frequency filtering : Decoupling capacitors
  - Keep away from input/output circuits & the edges of PCB



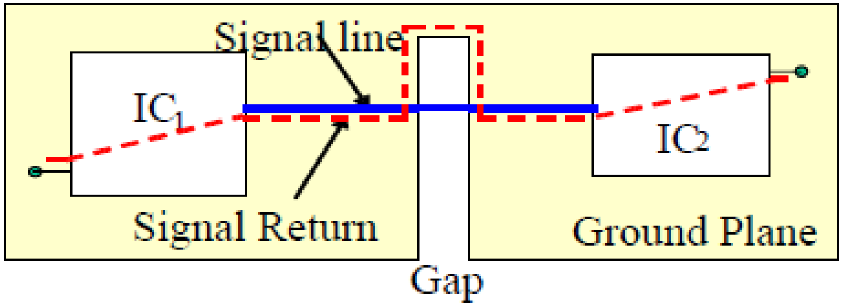


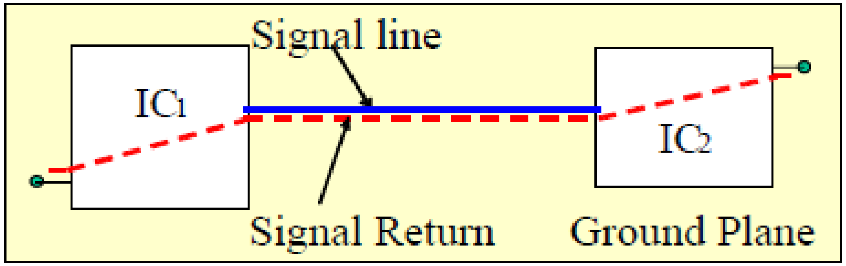
- Placement of a filter is critical
- Put filters close to the receivers rather than close to the drivers to minimize ESD coupling into status lines

5. PCB design and placement (contd)

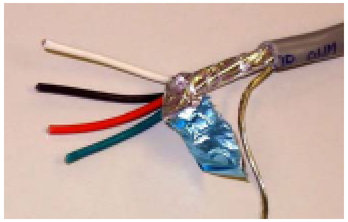
- Prefer multi-layered PCBs with separate power and ground planes
- High speed signals need to be on layers adjacent to ground or power plane
- Do not connect clocks, resets & interrupts to long or thick traces or cables

- Avoid running any signals over gaps in reference planes
  - This increases inductance associated with the return path resulting in poor ESD/EMC performance
- When a reference plane is gapped, the high frequency return current has to go around the gap.

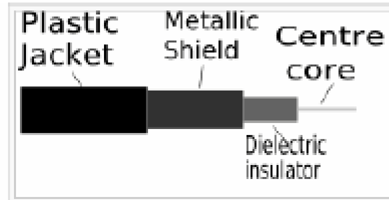




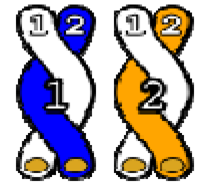
6. Cable design and routing



Shielded cable

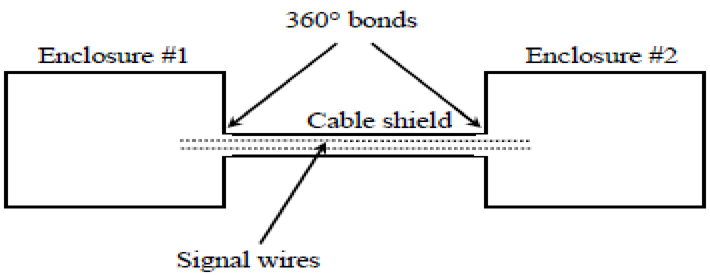


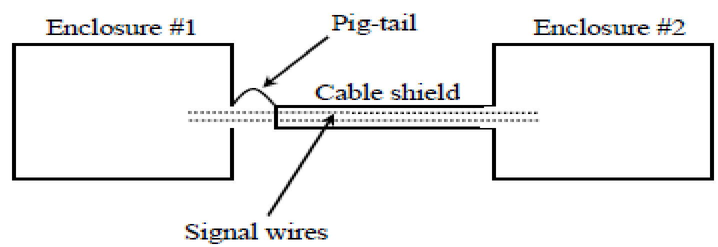
Co-ax cable



Twisted pairs

- Use shielded cables, co-ax cables or twisted wire pairs to minimize coupling from ESD





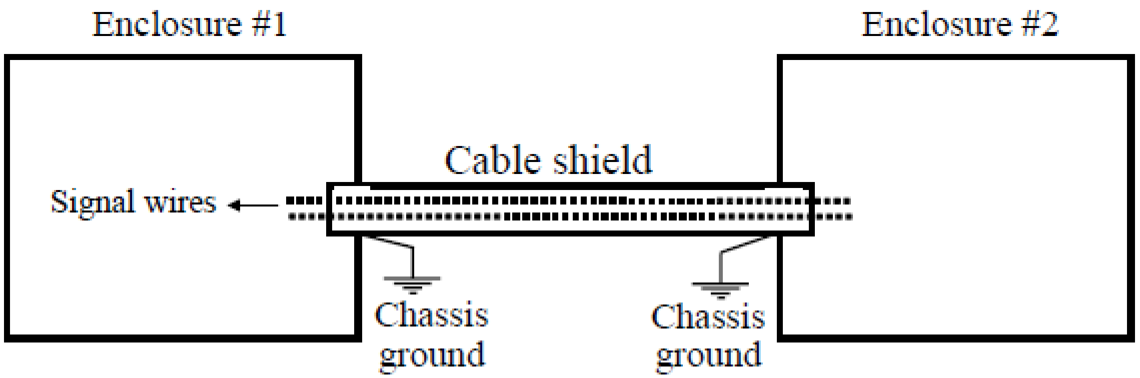
360° bonds at both ends of the cable transforms two enclosures into one enclosure

No loss in shielding performance

Pig-tail connection causes the shield current to be concentrated on one side of the shield and increases noise coupling to the cable

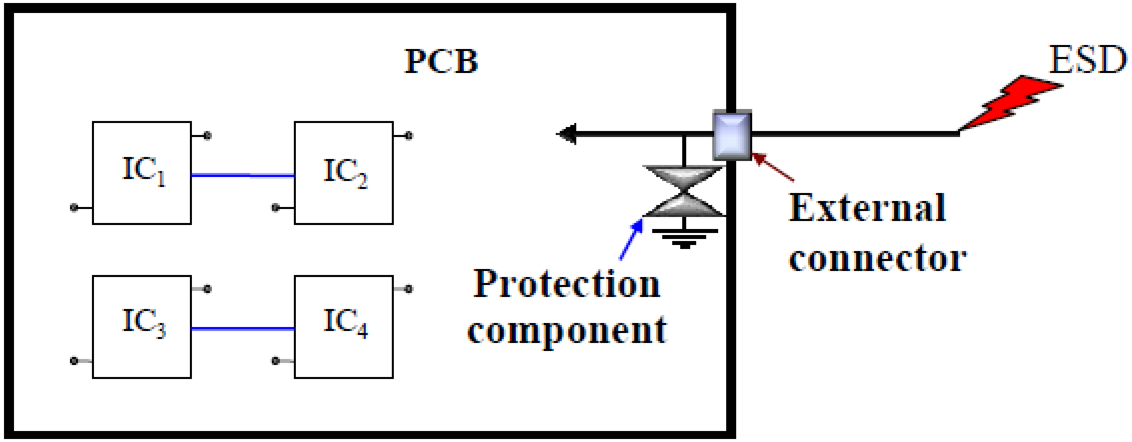
- Cable shield termination - Terminate cable shields to the outside of the metal enclosure, preferably with 360 degree bonds.
- Avoid pig-tail connections

6. Cable design and routing (contd)



- Connect cable shields to chassis ground at each connector to provide a low impedance path for ESD current
- Keep cables as short as possible to reduce ESD/EMI coupling

7. Filters and transient suppressors

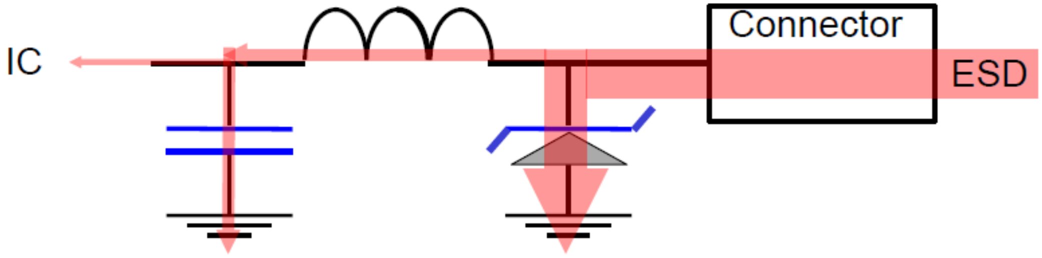


- Place primary protection components close to the connectors (ESD source) to prevent ESD current from flowing onto the PCB
- Choose protection components to withstand IEC level ESD voltages and currents (ex. 30 A at 8 kV contact discharge)
- Do not use components that are rated too close to the signal levels they are intended to protect
- Place series components (ferrite beads or resistor) and shunt devices (diode, capacitor) toward the ESD source and toward drivers and receivers

7. Filters and transient suppressors (contd)

- Passive components
  - Capacitor
  - Resistor
  - Inductors, beads, and CM chokes

- Transient suppressors are non-linear devices
  - Transient Voltage Suppressor (TVS) diodes
  - Varistors (MOV: metal oxide varistors)
  - Zenor diodes
  - Diodes
  - Polymers



pi-network

7. Filters and transient suppressors (contd)

- Low dynamic resistance to drain the ESD current and to keep the residual potential low
- Use maximum capacitive load if allowed
- Low capacitive load for high frequency lines (>100 MHz signal lines)
- Application specific trigger voltage and low clamping voltage at relevant current levels
- Sufficient turn-on speed to protect against IEC ESD pulses
- Capability to withstand multiple ESD pulses with low impedance and return to a normal high impedance state immediately after stress

8. Software

- Use watchdog timer to monitor any software lockups. Ensure software does not stop watchdog timer once started. Design the software or firmware to reset the watchdog timer periodically (preferably in one or two places in the main loop).
- Enable smaller timeouts in functions to identify fault states and regain control (before watchdog timer time-outs).
- Oversample critical hardware inputs and do simple averaging of results to confirm input states.
- Check parity and framing on incoming data.
- Acknowledge reception of correct data; else return error code for incorrect data reception.
- Re-transmit data if acknowledge is not received.

Summary

- ESD is the transfer of electrostatic charge between bodies or surfaces at different electrostatic potential. ESD is a subset of EOS.
- Two ways to create ESD: triboelectric charging and induction by eletrostatic field.
- Three component level ESD models: HBM, MM, CDM.
- Basic ESD control including many items like personal grounding, work surface, packaging, ionizers…
- Continuous wrist straps monitors are highly recommended.
- ESD footwear must be used with grounded static dissipative flooring or floor mat to be effective.
- Separate the insulator from the ESD-sensitive device by a distance of 30 cm (12 inches) or use ionization or other charge mitigating techniques to neutralize the charge.
- The ionizers must point towards the working area, need test the balance voltage and charge decay time.

Summary

- ESD is a strong wideband noise trying to penetrate a system through every means possible
- Need good system design techniques to improve ESD protection
- Some important points to remember:
  - Insulation prevents ESD arcs from reaching the electronics
  - Metal shield keeps ESD from entering the system
  - Bonding and grounding avoids secondary discharges and capacitive coupling
  - Good PCB design and layout techniques are important for ESD
  - Filters and transient suppressors block and divert ESD to ground
  - ESD testing throughout product's design cycle helps to find and fix weak spots

Thank you for your time!

Q&A