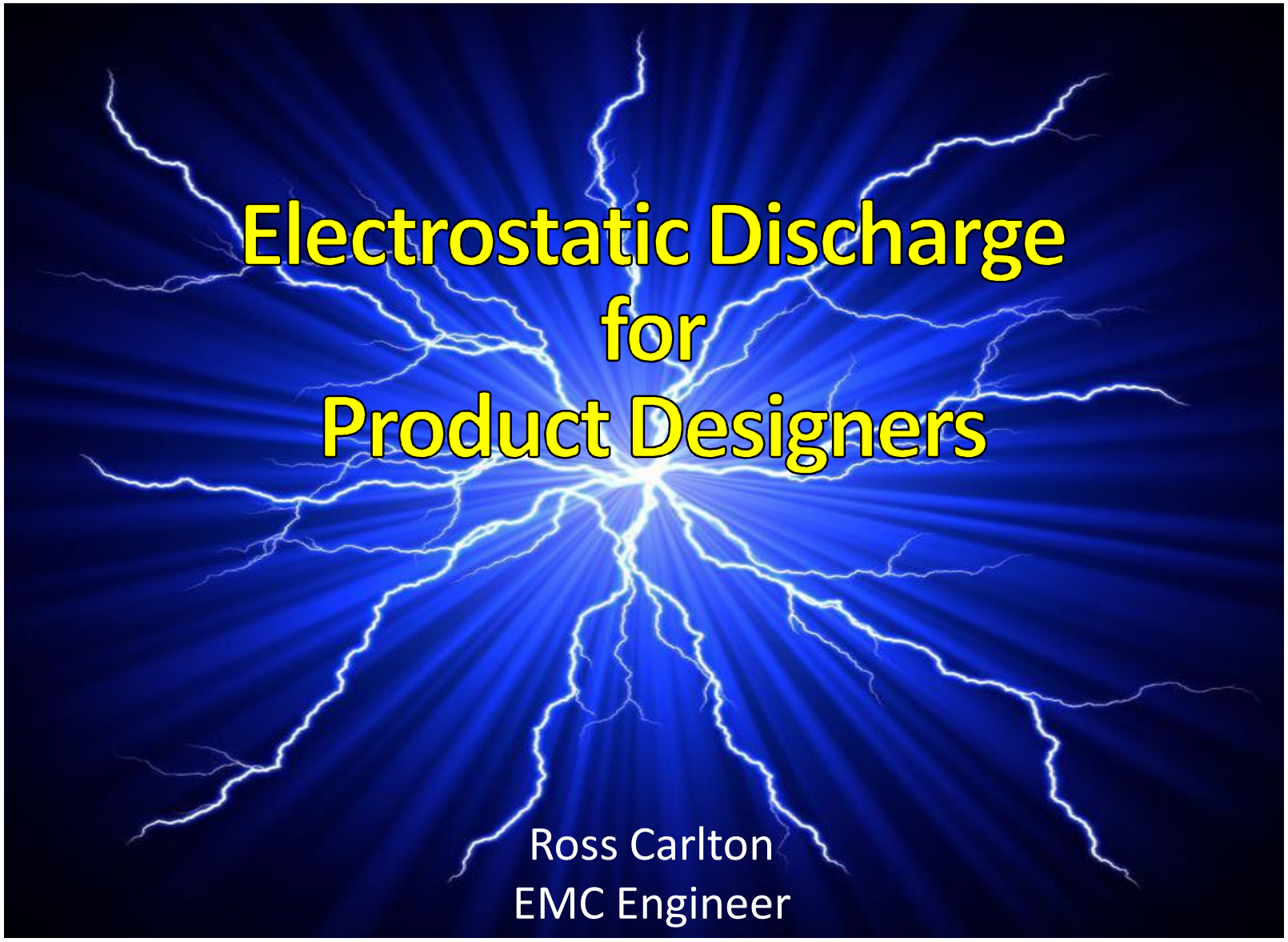

NATIONAL INSTRUMENTS

My Background

Over 27 years in EMC of components, equipments & systems

- National Instruments (test, measurement, control, industrial PCs, etc.)
- Freescale Semiconductor (microcontroller I/O, EMC & ESD design)
- Harris Government & Aerospace Systems (military & aerospace)
- Dell (commercial PCs)
- R&B Enterprises (military EMC consulting)
- Tracor Aerospace (military & aerospace)
- SPAWAR (military)

Component vs. Product ESD

Many differences

Difference	Components	Products
Purpose	Prevent damage due to material handling	Prevent malfunction due to operator use
Operating State	Unpowered	Powered & operating
Test Process	Automated	Manual
Test Setup	Ideal	Real-world
Test Points	Package pins	Enclosure and I/O
Waveforms	HBM, MM, CDM	HBM, HMM

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The ESD Phenomenon

Standards for Product ESD Testing

ESD Simulator

Test Planning

Test Setup

Test Procedure

Calibration and Verification

Testing Lessons Learned

Product Design for ESD Immunity

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The ESD Phenomenon

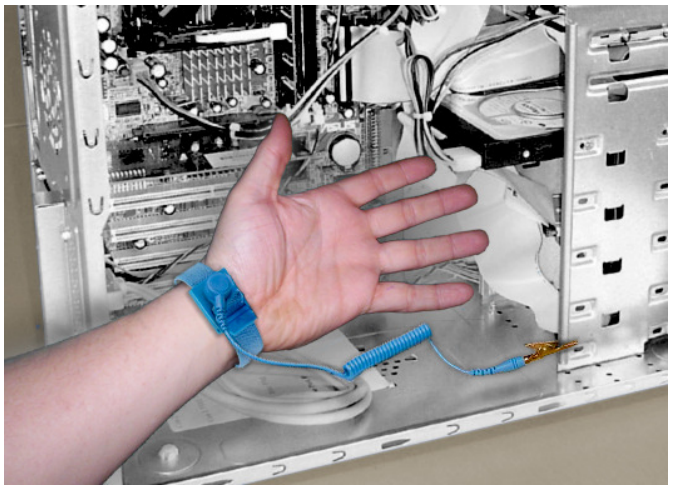
Electrostatic Discharge (ESD)

The discharge of a static electric potential.

The ESD Phenomenon

Electrostatic Discharge (ESD)

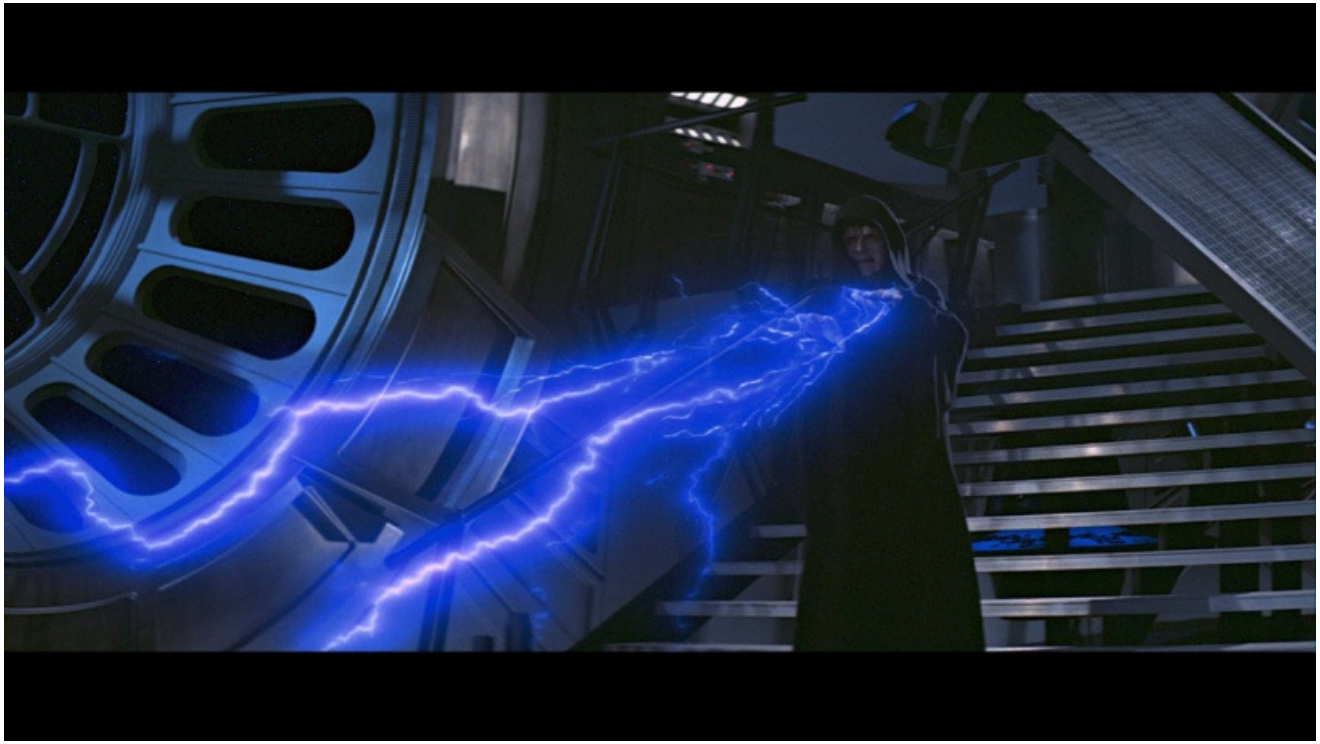
If only every user of electronics wore and ESD strap….



The ESD Phenomenon

Electrostatic Discharge (ESD)

But reality is more like this…



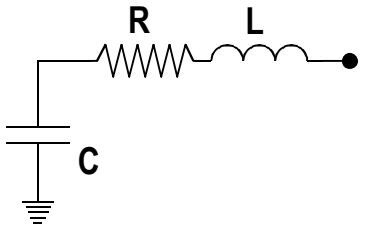
The ESD Phenomenon

Electrostatic Discharge (ESD)

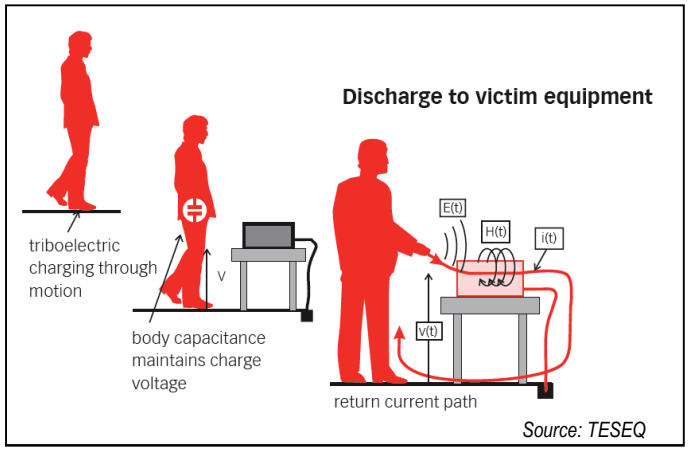
The discharge of a static electric potential.

Characteristics:

- Based on the human body model (HBM)
  - Capacitance of the human body to ground (C)
    - 50 pF to 300 pF
  - Resistance of the discharge loop (R)
    - 1 kΩ to 30 kΩ
  - Inductance of the discharge loop (L)
    - 0.3 µH to 1.5 µH
- Potentials up to ±35 kV referenced to earth ground
- High peak current (up to 30 A ±15 %)
- Fast rise time (0.8 ns ±25 %)



Equivalent circuit of human body

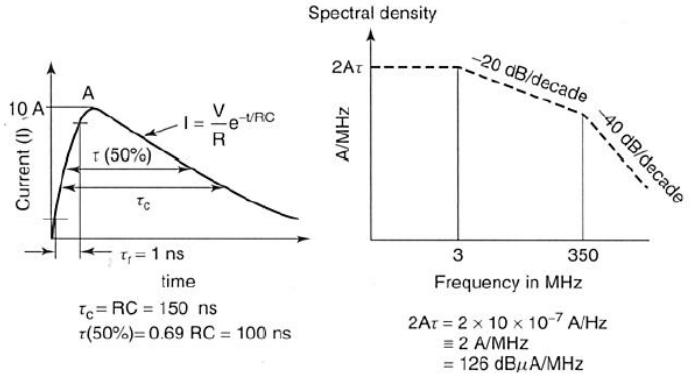


The ESD Phenomenon

Electrostatic Discharge (ESD)

Characteristics:

- Wide bandwidth
  - For a simplified ESD current waveform
    - R = 1 kΩ, C = 150 pF
    - First breakpoint frequency ($1/\pi\tau$) = 3.18 MHz
    - Second breakpoint frequency ($1/\pi\tau_r$) = 318 MHz ➡ "occupied bandwidth"



Source: Mardiguian, Michael, "Electrostatic Discharge: Understand, Simulate and Fix ESD Problems", Wiley & Sons, 2009.

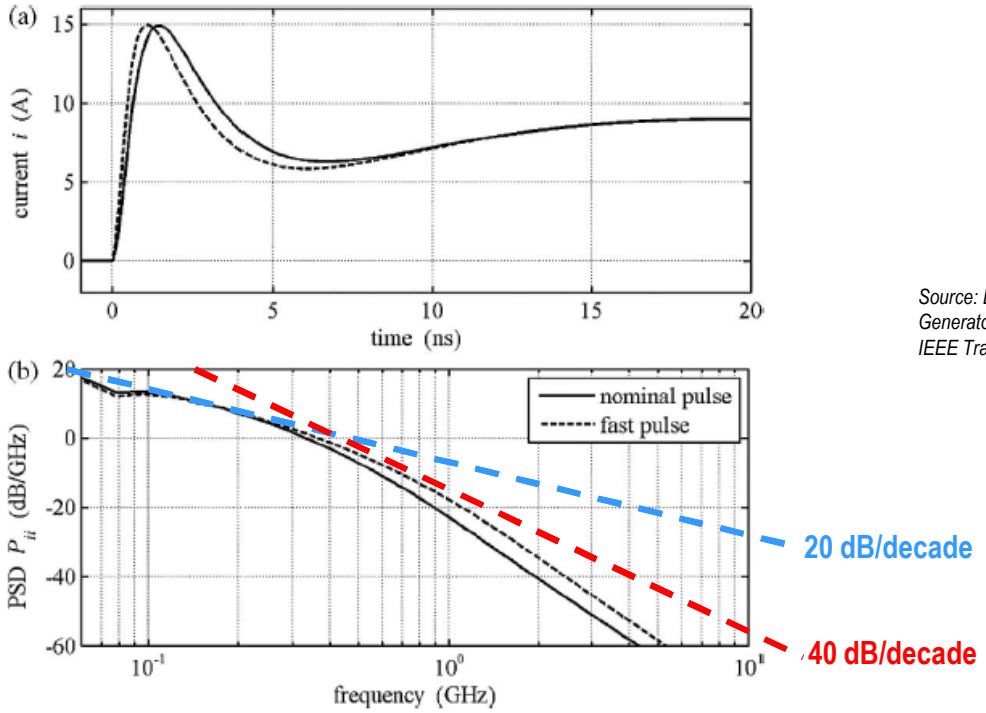
  - Considering the specified rise time of 0.8 ns ±25 %, an ESD solution must be effective up to a maximum frequency in the 318 - 530 MHz range!

The ESD Phenomenon

Electrostatic Discharge (ESD)

Characteristics:

- Wide bandwidth
  - Simulation of spectral power density for ideal waveform for 4 kV ESD

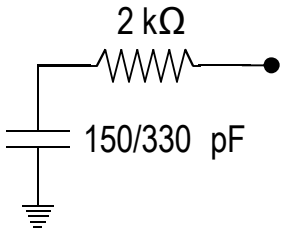


Source: Baran, Janusz and Sroka, Jan, "Distortion of ESD Generator Pulse Due to Limited Bandwidth Verification Path", IEEE Transactions on EMC, Vol. 52, No. 4, November 2010

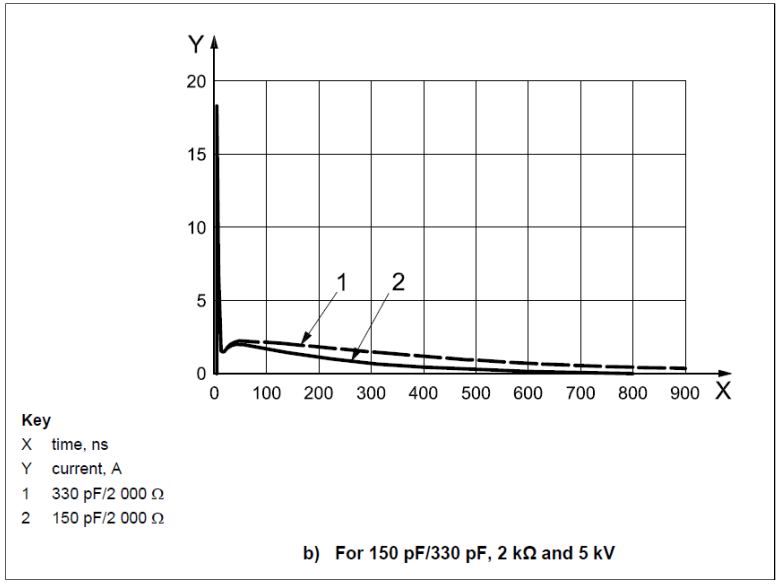
The ESD Phenomenon

Human Body Model (HBM)

- Models a discharge from the skin of a human body to a device.



Simplified Circuit Model

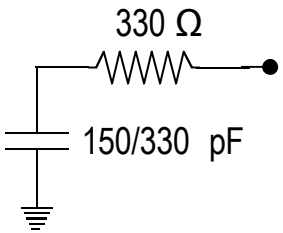


Current Waveform for 5 kV Discharge (ISO 10605)

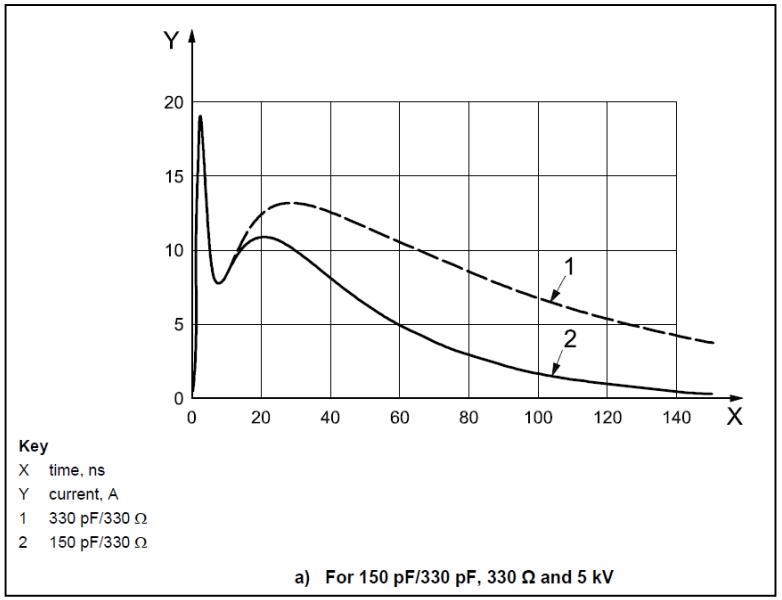
The ESD Phenomenon

Human Metal Model (HMM)

- Models a discharge from a hand-held metal tool to a device.
- Models a discharge from one object to another in close proximity to a device.



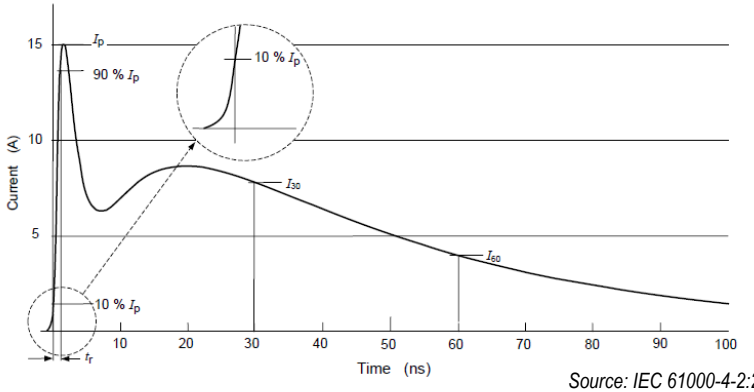
Simplified Circuit Model



Current Waveform for 5 kV Discharge (ISO 10605)

The ESD Phenomenon

Human Body Model (HBM) vs. Human Metal Model (HMM)



Source: IEC 61000-4-2:2008

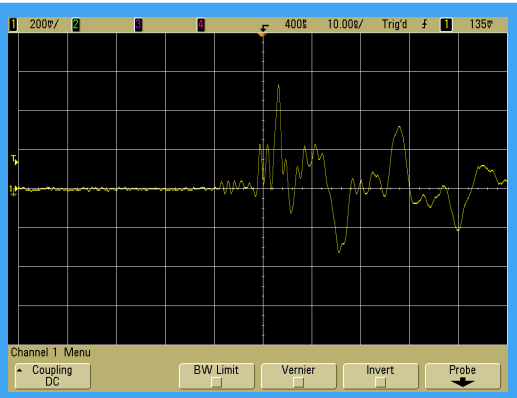
	Typical capacitance/ resistance values	Peak current/ charge voltage A/kV	Tolerance %	Current at t_1/ charge voltage A/kV	Tolerance %	Current at t_2/ charge voltage A/kV	Tolerance %
HMM	150 pF / 330 Ω	3,75	± 10	2 (at t_1 = 30 ns)	± 30	1 (at t_2 = 60 ns)	± 30
HMM	330 pF / 330 Ω	3,75	± 10	2 (at t_1 = 65 ns)	± 30	1 (at t_2 = 130 ns)	± 30
HBM	150 pF / 2 000 Ω	3,75	+30 0	0,275 (at t_1 = 180 ns)	± 30	0,15 (at t_2 = 360 ns)	± 50
HBM	330 pF / 2 000 Ω	3,75	+30 0	0,275 (at t_1 = 400 ns)	± 30	0,15 (at t_2 = 800 ns)	± 50

Source: ISO 10605:2008

The ESD Phenomenon

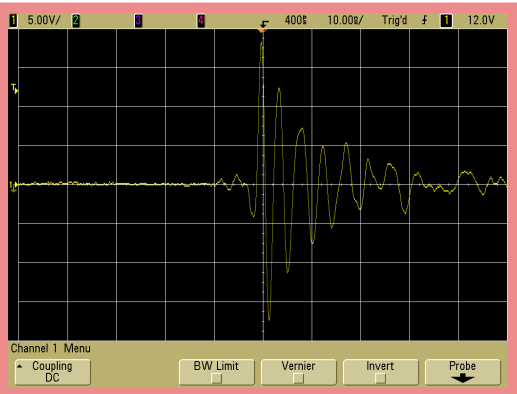
Human Body Model (HBM) vs. Human Metal Model (HMM)

HBM



Voltage Induced in Shorted Scope Probe by HBM ESD
(Vertical Scale = 200 mV/div, Horizontal Scale = 10 ns/div)

HMM



Voltage Induced in Shorted Scope Probe by HMM ESD
(Vertical Scale = 5 V/div, Horizontal Scale = 10 ns/div)

Source: Doug Smith, www.emcesd.com

The ESD Phenomenon

Summary

- A fast pulse (t_r = ~1 ns, t_f = ~100 ns) delivering up to 30 A of current.
- Two primary ESD models for electronic products
  - Human Body Model (150/330 pF and 2 kΩ)
  - Human Metal Model (150/330 pF and 330 Ω)
- HMM delivers about 7x more current at 30 ns and 60 ns than HBM.
- Both models deliver significant power at frequencies ≥ 300 MHz.

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Standards for Product ESD Testing

Principal Test Method Standards

ANSI C63.16-1993 - American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment

IEC 61000-4-2, Ed. 2.0, 2008—Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 2: Electrostatic discharge immunity test

IEC 60255-22-2, Ed. 3.0, 2008—Electrical relays—Part 22: Electrical disturbance tests for measuring relays and protection equipment—Section 2: Electrostatic discharge tests.

ISO 10605, 2008—Road vehicles—Test methods for electrical disturbances from electrostatic discharge.

SAE J1113/13, 2011—Electromagnetic Compatibility Measurement Procedure for Vehicle Components-Part 13: Immunity to Electrostatic Discharge

Standards for Product ESD Testing

Product	Standard	Criteria	ESD Model
Electronic Equipment	ANSI C63.16	Malfunction	HMM
Electronic Equipment	IEC 61000-4-2	Malfunction	HMM
Measuring Relays & Protection Equipment	IEC 61255-22-2	Malfunction	HMM
Aircraft Electronics	RTCA DO-160	Malfunction	HMM
Vehicle Components	ISO 10605	Malfunction Damage	HBM, HMM
Vehicle Components	SAE J1113/13	Malfunction Damage	HBM, HMM

Standards for Product ESD Testing

Product	Standard	Criteria	Waveform
Electronic Equipment	ANSI C63.16	Malfunction	HMM
Electronic Equipment	IEC 61000-4-2	Malfunction	HMM
Measuring Relays & Protection Equipment	IEC 61255-22-2	Malfunction	HMM
Aircraft Electronics	RTCA DO-160	Malfunction	HMM
Vehicle Components	ISO 10605	Malfunction Damage	HBM, HMM
Vehicle Components	SAE J1113/13	Malfunction Damage	HBM, HMM

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Test Levels
  - Contact discharge
    - Preferred method
    - Test only at specified test level
  - Air discharge
    - Used where a contact discharge cannot be applied
    - Test at all levels up to and including the specified test level

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
x [a]	Special	x [a]	Special

[a] "x" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Test Levels
  - Contact discharge
    - Preferred method
    - Test only at specified test level
  - Air discharge
    - Used where a contact discharge cannot be applied
    - Test at all levels up to and including the specified test level

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
x [a]	Special	x [a]	Special

[a] "x" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Performance Requirements
  - Criteria
    - Criterion A: Normal performance within limits specified by the manufacturer, requestor or purchaser;
    - Criterion B: Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;
    - Criterion C: Temporary loss of function or degradation of performance, the correction of which requires operator intervention;
    - Criterion D: Loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Performance Requirements
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    - ~~Criterion C: Temporary loss of function or degradation of performance, the correction of which requires operator intervention;~~
    - ~~Criterion D: Loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.~~

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Performance Requirements
  - Criteria
    - Criterion A: Normal performance within limits specified by the manufacturer, requestor or purchaser;
    - Criterion B: Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;
    - ~~Criterion C: Temporary loss of function or degradation of performance, the correction of which requires operator intervention;~~
    - ~~Criterion D: Loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.~~
  - Manufacturer's documentation may define effects on the EUT which may be considered insignificant, and therefore acceptable.

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Any requirement may be modified by a referencing generic or product family standard
  - Performance criteria
  - Test levels
  - Test point selection
  - Test procedure
  - Evaluation of test results
  - Requirements for product documentation

Standards for Product ESD Testing

IEC 61000-4-2:2008

- Any requirement may be modified by a referencing generic or product family standard
  - Performance Criteria Example

Test Method Standard

IEC 61000-4-2:2008

a) normal performance within limits specified by the manufacturer, requestor or purchaser;

b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;

Generic Standard for Residential, Commercial & Light-Industrial Environments

IEC 61000-6-1:2007

Performance criterion A: The apparatus shall continue to operate as intended during and after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended. The performance level may be replaced by a permissible loss of performance. If the minimum performance level or the permissible performance loss is not specified by the manufacturer, either of these may be derived from the product description and documentation and what the user may reasonably expect from the apparatus if used as intended.

Performance criterion B: The apparatus shall continue to operate as intended after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended. The performance level may be replaced by a permissible loss of performance. During the test, degradation of performance is however allowed. No change of actual operating state or stored data is allowed. If the minimum performance level or the permissible performance loss is not specified by the manufacturer, either of these may be derived from the product description and documentation and what the user may reasonably expect from the apparatus if used as intended.

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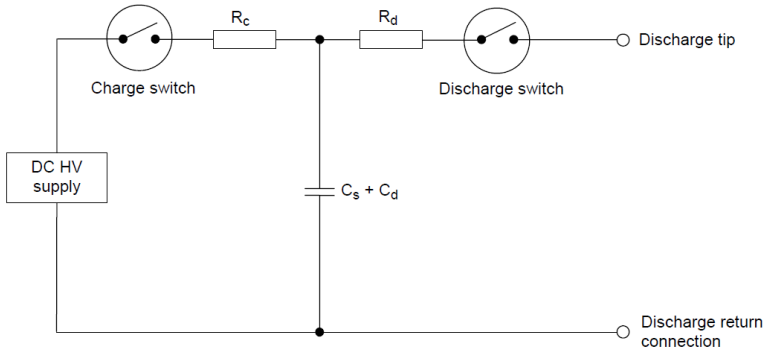
ESD Simulator

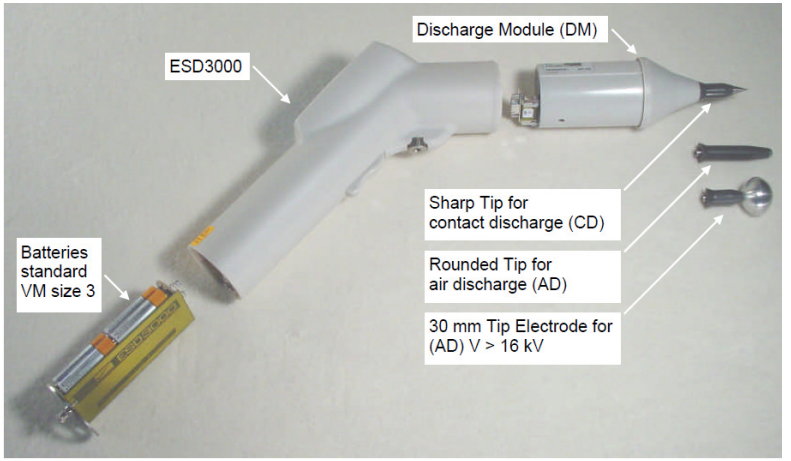
Many possible form factors

ESD Simulator

Construction



Simplified Block Diagram



One Vendor's Implementation

DM-Modules	Standards	Cap /Res.	Voltage range (CD) Contact Discharge	Voltage range (AD) Air Discharge
DM1	IEC 61000-4-2	150 pF / 330 Ohm	+/- 0.2 up to 10 kV	+/- 0.2 up to 16 kV
DM2	ISO TR10605	330 pF / 2000 Ohm	+/- 0.2 up to 10 kV	+/- 0.2 up to 16 kV
DM3	ISO TR10605	150 pF / 2000 Ohm	no CD	+ and -1 up to 32 kV
DM4	MIL-STD-883 GR78-CORE	100 pF / 1500 Ohm	+/- 0.2 up to 10 kV	+/- 0.2 up to 16 kV
DM5	RTCA/DO-160	150 pF / 330 Ohm	no CD	+ and -1 up to 32 kV
DM6	IEC 61340-3-1	100 pF / 1500 Ohm	+/- 0.2 up to 8 kV	no AD
DM7	IEC 61340-3-2	200 pF / 500 Ohm	+/- 0.08 up to 2.5 kV	no AD
DM10	IEC 61000-4-2 ANSI C63.16	rise time 0.7-1 ns rise time < 400 ps	+/- 0.2 up to 10 kV	+/- 0.2 up to 16 kV

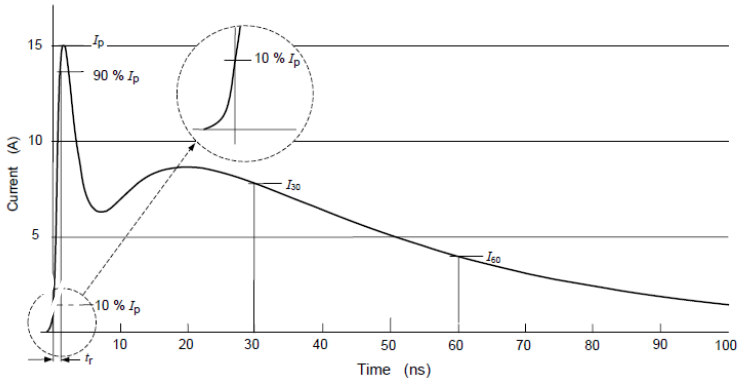
Discharge Modules

ESD Simulator

Specifications

Parameters	Values
Output voltage, contact discharge mode (see NOTE 1)	At least 1 kV to 8 kV, nominal
Output voltage, air discharge mode (see NOTE 1)	At least 2 kV to 15 kV, nominal (see NOTE 3)
Tolerance of output voltage	±5 %
Polarity of output voltage	Positive and negative
Holding time	≥5 s
Discharge mode of operation	Single discharges (see NOTE 2)
NOTE 1 Open circuit voltage measured at the discharge electrode of the ESD generator. NOTE 2 The generator should be able to generate at a repetition rate of at least 20 discharges per second for exploratory purposes. NOTE 3 It is not necessary to use a generator with 15 kV air discharge capability if the maximum test voltage to be used is lower.	

Specifications



Current Waveform

Level	Indicated voltage kV	First peak current of discharge ±15 % A	Rise time t_r (±25 %) ns	Current (±30 %) at 30 ns A	Current (±30 %) at 60 ns A
1	2	7,5	0,8	4	2
2	4	15	0,8	8	4
3	6	22,5	0,8	12	6
4	8	30	0,8	16	8
The reference point for measuring the time for the current at 30 ns and 60 ns is the instant when the current first reaches 10 % of the 1st peak of the discharge current. NOTE The rise time, t_r, is the time interval between 10 % and 90 % value of 1st peak current.					

Current Waveform Parameters

Source: IEC 61000-4-2:2008

ESD Simulator

ESD Testing Can Be Hazardous

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Test Planning

A formal test plan is required (and highly recommended)

- Contents
  - Operating conditions of the EUT
  - Whether the EUT should be tested as table-top or floor-standing
  - The points at which discharges are to be applied
    - For each point
      - Whether contact or air discharges are to be applied
      - The test level to be applied
    - Preliminary or exploratory testing may be required to define the plan
  - The number of discharges to be applied at each point
  - Whether post-installation tests are also to be applied.
- Benefits
  - Ensure expectations are met
  - Maximize productivity of test time
  - Historical reference

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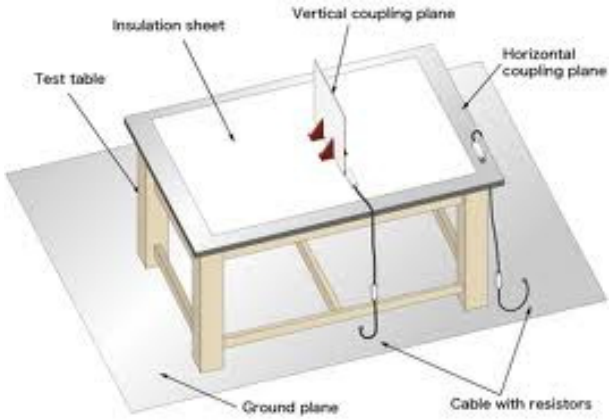
Test Setup (Lab)



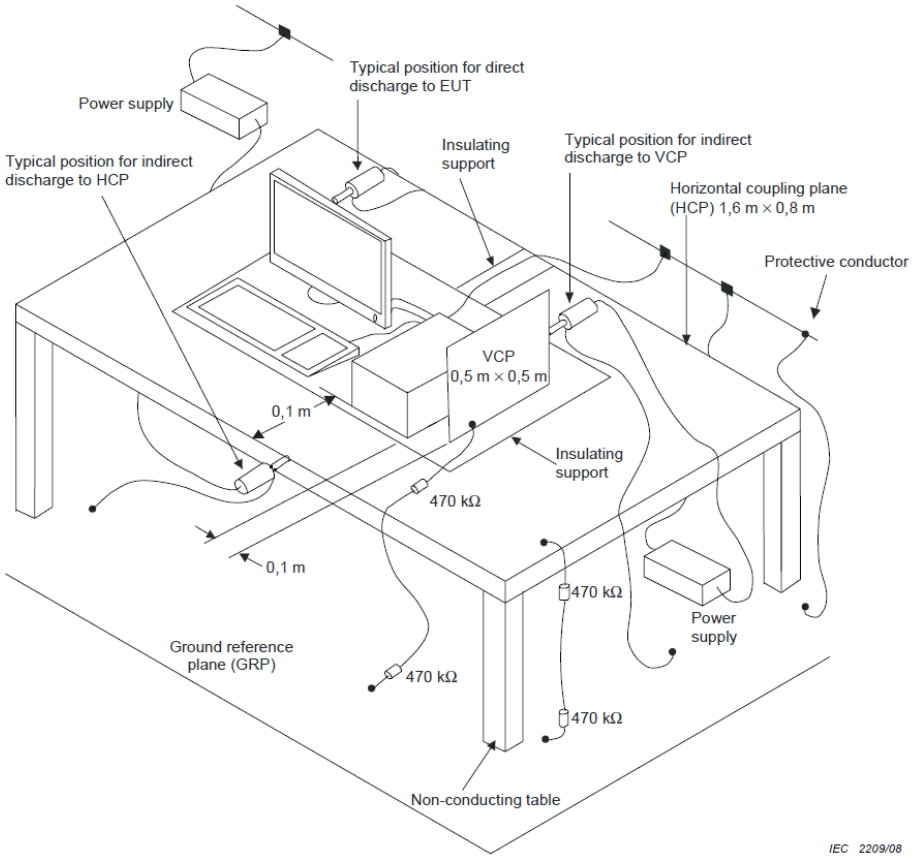
Common Requirements

- Ground reference plane (GRP)
  - Connected to earth ground
  - Reference for the ESD Simulator
  - Prefer copper or aluminum of ≥0.25 mm thickness
  - Extends 0.5 m beyond equipment under test (EUT)
- Coupling planes
  - Prefer copper or aluminum of ≥0.25 mm thickness
  - Connected to the GRP using a bleeder cable
    - Wire with one 470 kΩ resistor installed at each end (~940 kΩ total)
- EUT Setup
  - Arranged, connected, and grounded per manufacturer instructions
  - Power and signal cables placed in a typical arrangement
  - EUT isolated from HCP by insulator 0.5 mm thick

Test Setup (Lab)

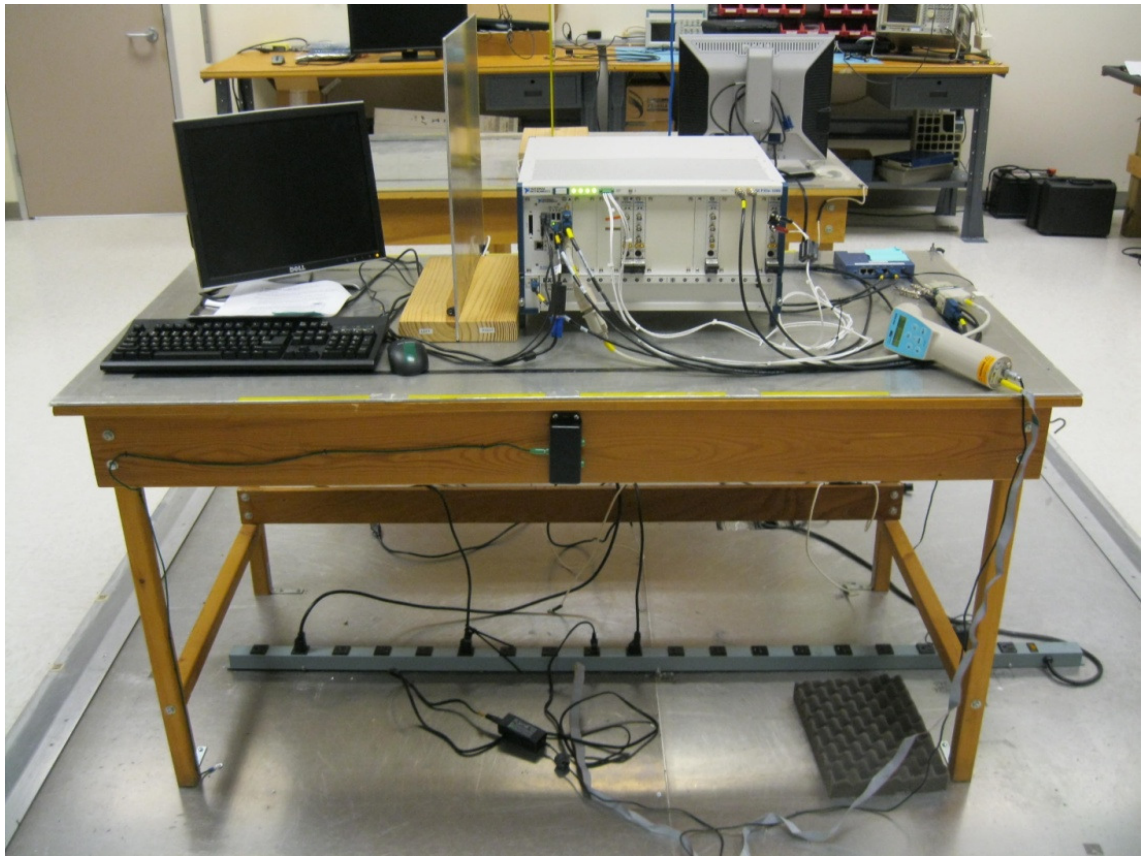
Table-Top Equipment

- EUT
  - Placed on HCP at least 0.1 m from the edge of the HCP
  - Isolated from HCP by insulator 0.5 mm thick
- Horizontal coupling plane (HCP)
  - Size is 1.6 x 0.8 m
  - Placed on a non-conductive table 0.8 m high
- Vertical coupling plane (VCP)
  - Size is 0.5 x 0.5 m
  - Spaced 0.1 m from side of EUT
  - May need to test multiple positions for large EUTs



Test Setup (Lab)

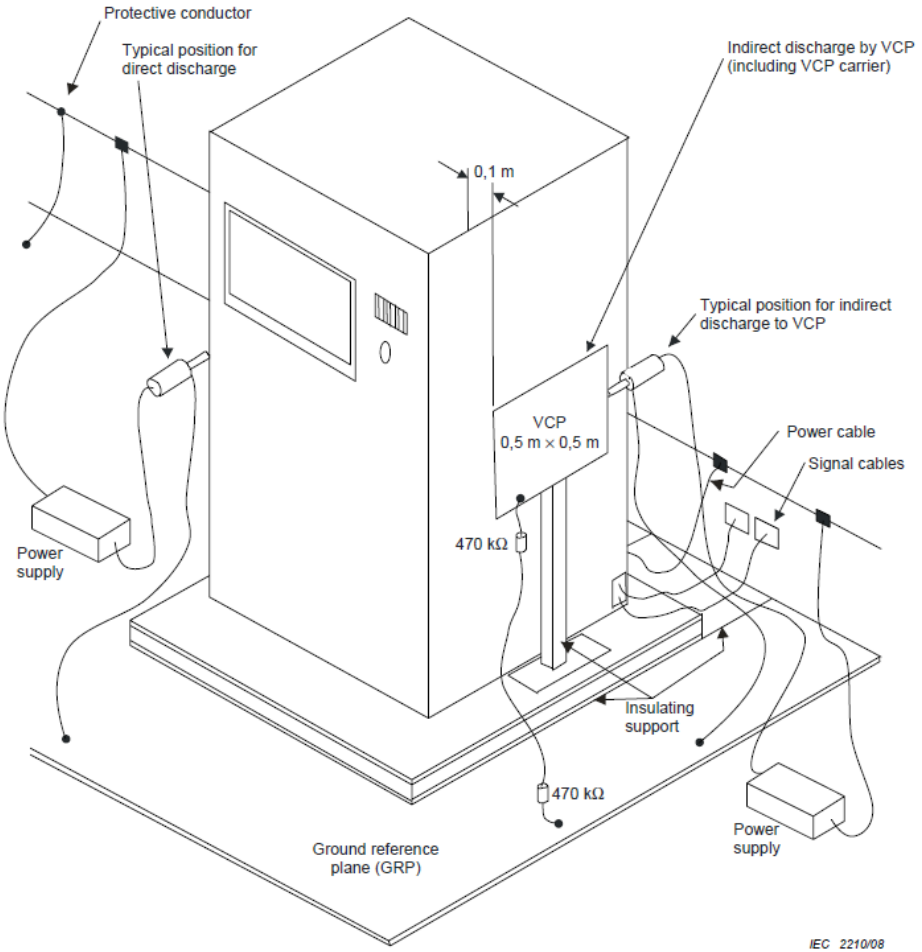
Table-Top Equipment



Test Setup (Lab)

Floor-Standing Equipment

- EUT
  - Isolated from GRP by insulator 0.05 – 0.15 m thick
  - Cables isolated from GRP by insulator 0.5 mm thick
- Horizontal coupling plane (HCP)
  - Not used
- Vertical coupling plane (VCP)
  - Size is 0.5 x 0.5 m
  - Spaced 0.1 m from side of EUT
  - May need to test multiple positions for large EUTs



Test Setup (Lab)

Modifications for Ungrounded Equipment

- For products whose installation or design precludes connection to any grounding system
  - Since the isolated EUT cannot dissipate the applied charge, it must removed prior to each applied ESD pulse
- Charge is removed from the point of application
  - A wire with a 470 kΩ resistor installed at each end is used
  - One end is attached to the HCP (table-top) or GRP (floor-standing)
  - The other end is connected as close as possible to the discharge location (less than 20 mm is preferred)
  - The wire may remain connected between pulses if is does not impact the test result
- Alternately, the time between discharges may be lengthened to allow natural decay of the charge

Test Setup (Lab)

Modifications for Ungrounded Equipment

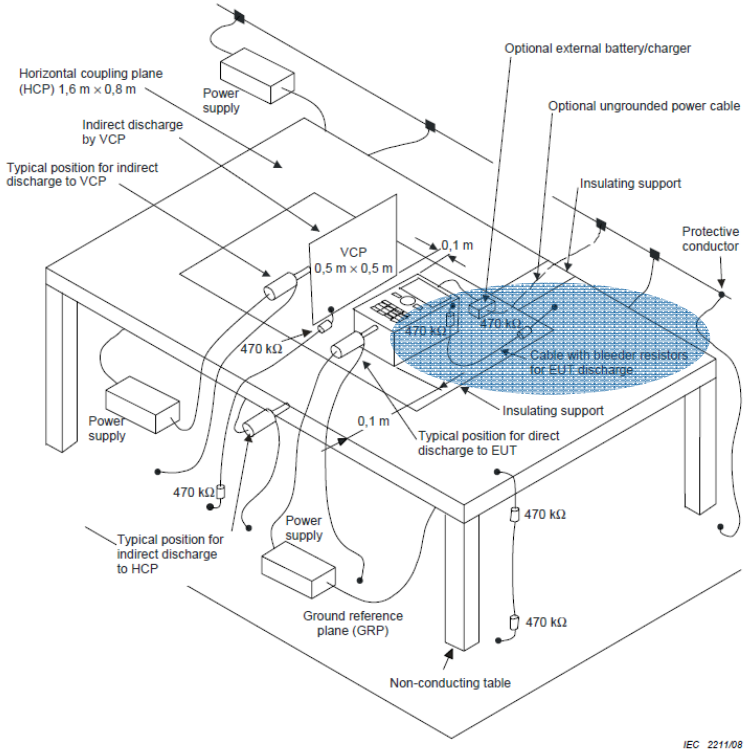
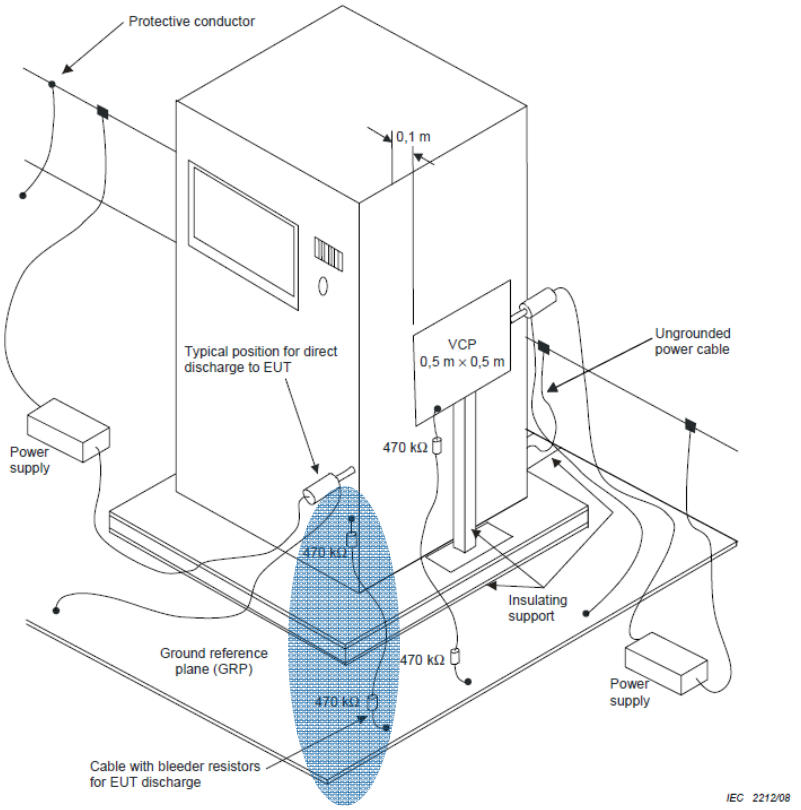


Table-Top Setup

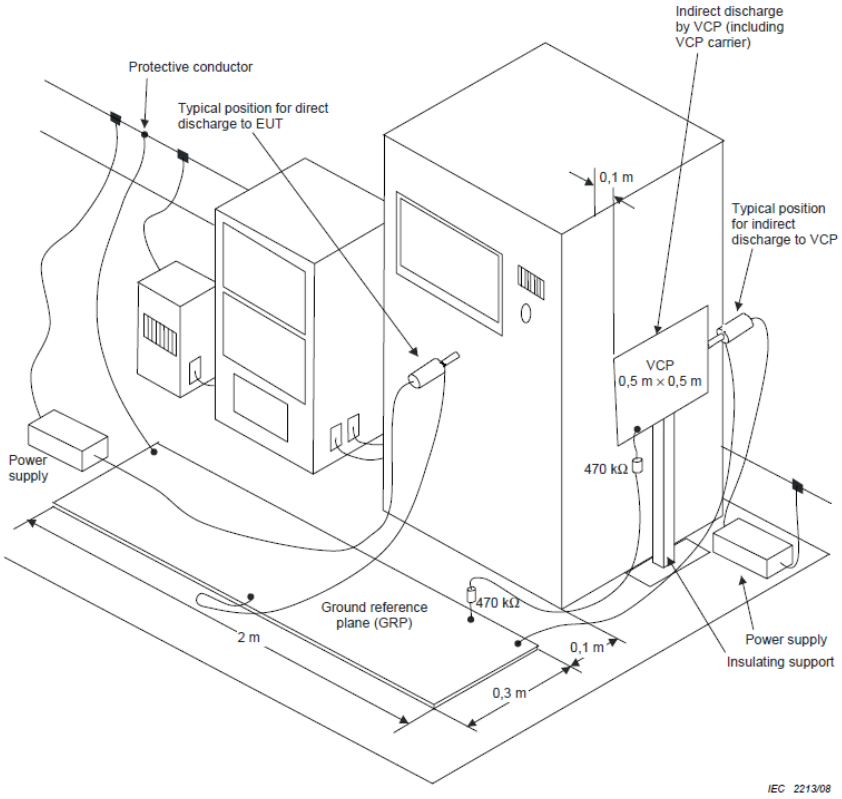


Floor-Standing Setup

Test Setup (Post-Installation)

Any Installation Type

- EUT
  - As installed
- Ground reference plane (GRP)
  - Prefer copper or aluminum of ≥0.25 mm thickness
  - Desired size is 0.3 x 2.0 m
  - Placed on the floor
  - Connected to earth ground
- Other requirements
  - If installed on a metal table, connect the table to the GRP using a wire with a 470 kΩ resistor installed at each end
  - Ungrounded metal parts are tested as for ungrounded equipment



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ESD Simulator

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Test Setup

Test Procedure

Calibration and Verification

Testing Lessons Learned

Product Design for ESD Immunity

Test Procedure

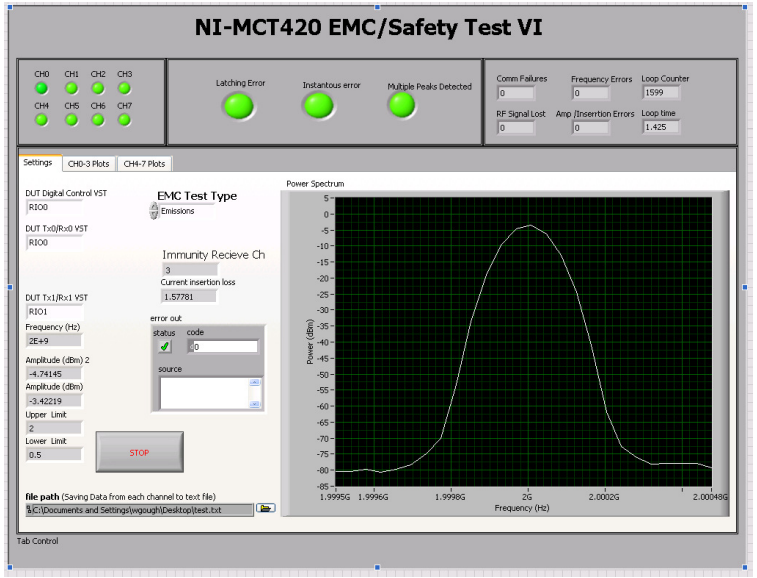
Laboratory Conditions

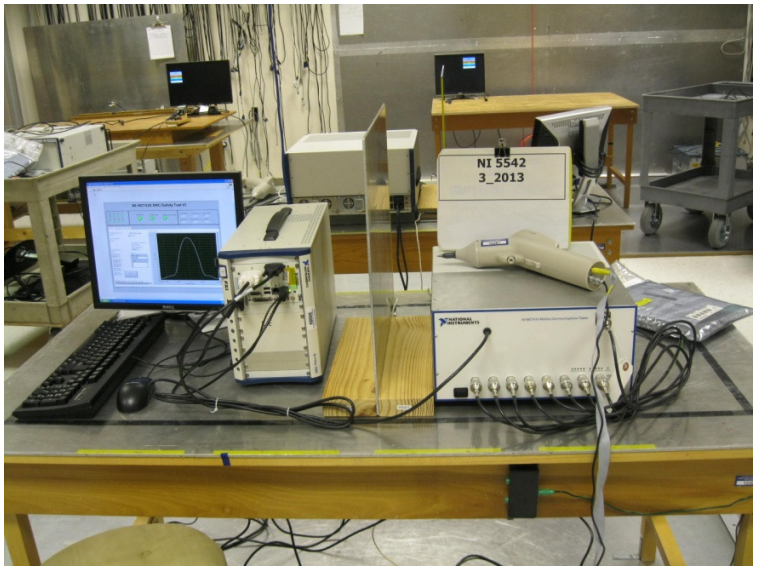
- The environment is controlled to ensure reproducible results
  - Ambient temperature: 15 °C to 35 °C (59 °F to 95 °F)
  - Relative humidity: 30 % to 60 %
    - Typically, additional steps must be taken to control humidity.
  - Atmospheric pressure: 86 kPa to 106 kPa (860 mbar to 1060 mbar)
- May be modified for published product specifications
- Conditions are measured before testing begins and are documented in the test report

Test Procedure

EUT Operation

- Operate in its most sensitive mode
- Monitor and assess against defined performance
  - Guaranteed specifications
  - Other agreed indicators of proper operation
- Performance monitoring example





Test Procedure

Application of Discharges

- Two methods
  - Direct
    - Discharges are applied directly to the product
    - Simulates a discharge to the product by its operator during normal operation
  - Indirect
    - Discharges are applied to nearby coupling planes
      - Horizontal coupling plane
      - Vertical coupling plane
    - Simulates the effects of a discharge in close proximity to the product during normal operation
- General Requirements
  - Apply at least 10 discharges in the most sensitive polarity
    - Recommend testing both polarities at each point anyway
  - Apply discharges at the initial rate of 1 discharge/second
    - Longer intervals may be required for some products

Test Procedure

Direct Application of Discharges

- Selecting test points
  - Points or surfaces which are accessible to persons during normal use
  - Exclusions
    - Points or surfaces which are only accessible during maintenance.
    - Points or surfaces which are only accessible during service by end-user.
    - Points and surfaces of equipment which are no longer accessible after fixed installation or after following the instructions for use
    - Contacts of coaxial and multi-pin connectors which are provided with a metallic connector shell.
    - Contacts of connectors or other accessible parts that are ESD sensitive because of functional reasons and are provided with an ESD warning label, for example, r.f. inputs from measurement, receiving or other communication functions.
  - Exclusions require ESD mitigation procedures in user documentation

Test Procedure

Direct Application of Discharges

- Selecting test points
  - Summary guidance for connectors

Case	Connector shell	Cover material	Air discharge to:	Contact discharge to:
1	Metallic	None	–	Shell
2	Metallic	Insulated	Cover	Shell when accessible
3	Metallic	Metallic	–	Shell and cover
4	Insulated	None	[a]	–
5	Insulated	Insulated	Cover	–
6	Insulated	Metallic	–	Cover
NOTE In case a cover is applied to provide (ESD) shielding to the connector pins, the cover or the equipment near to the connector to which the cover is applied should be labelled with an ESD warning.				
[a] If the product (family) standard requires testing to individual pins of an insulated connector, air discharges shall apply.				

  - Exploratory testing is useful/required to determine the actual test points
    - Apply discharges at a repetition rate of 20 discharges/second, or more

Test Procedure

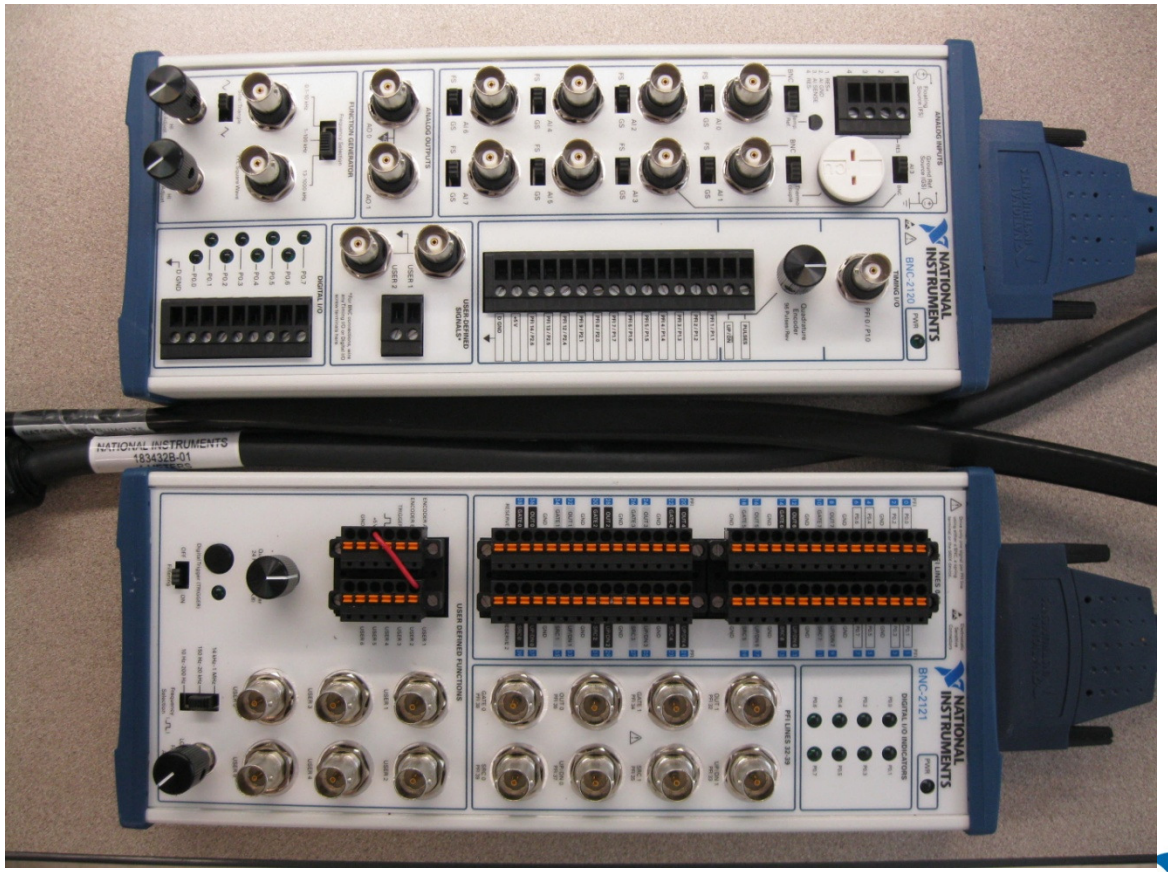
Direct Application of Discharges

- Test point selection examples

Test Procedure

Direct Application of Discharges

- Test point selection examples



Test Procedure

Direct Application of Discharges

- For each selected test point
  - Configure the ESD Simulator for contact or air discharge as required
  - Apply the required number and polarity of discharge
  - Evaluate the performance of the product after each discharge
- Handling the ESD Simulator
  - Hold the ESD simulator perpendicular to the surface of the product
  - Keep the discharge return cable ≥0.2 m from the product
  - Do not hold the discharge return cable
  - Air discharge technique
    - The discharge switch is operated to charge the tip
    - The tip must approach the product as fast as possible & touch the product
  - Contact discharge technique
    - The tip must touch the product before the discharge switch is operated
    - The tip must pierce non-insulating coatings (i.e. paint) to contact a conducting substrate

Test Procedure

Indirect Application of Discharges

- For each coupling plane
  - Configure the ESD Simulator for contact discharge
  - Apply the discharges as follows:
    - HCP: to the front edge of the plane opposite the center point of the product
    - VCP: to the center of one vertical edge of the plane
  - Evaluate the performance of the product after each discharge
- Handling the ESD Simulator
  - Hold the ESD simulator such that
    - It is perpendicular to the front edge of the plane
    - The long axis of the discharge electrode is in the plane of the coupling plane
  - Do not hold the discharge return cable of the ESD simulator
  - The tip must touch the coupling plane before the discharge switch is operated

Test Procedure

Evaluation of Test Results

- Assess the performance of the product after each discharge with respect to the performance criteria required by the product standard
- Pass/fail determination for a test point (from informative Annex F)
  - Step A: Initial set of discharges
    - All discharges pass => Test is passed
    - One discharge fails => Go to Step B
    - More than one discharge fails => Test is failed
  - Step B: Second set of discharges (twice the initial number of discharges)
    - All discharges pass => Test is passed
    - One discharge fails => Go to Step C
    - More than one discharge fails => Test is failed
  - Step C: Third set of discharges (twice the initial number of discharges)
    - All discharges pass => Test is passed
    - One or more discharge fails => Test is failed

Test Procedure

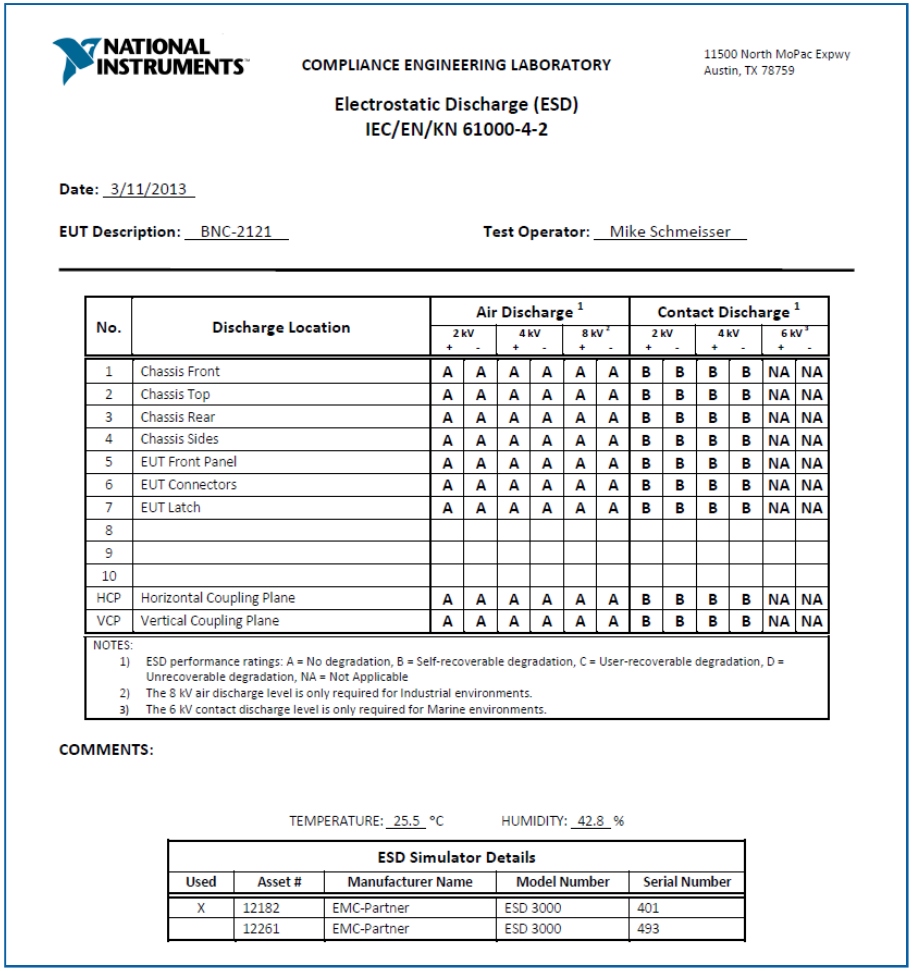
Evaluation of Test Results

- Basic Failure Modes
  - Upset/damage due to ESD current flowing directly into a device
  - Upset/damage due to ESD current flowing through ground system
  - Upset due to electromagnetic field coupling
- Upset
  - Unexpected state change of an input
  - Excessive noise voltage on an input
- Damage
  - Breakdown of insulators
  - Heating of conductors
  - Initiating a effect that can cause upset/damage (i.e. latchup)
  - Parametric changes

Test Procedure

Evaluation of Test Results

- Sample test data sheet
  - Identifies product
  - Test equipment
  - Discharge locations
  - Performance per discharge type and polarity
  - Climatic conditions
  - Notes on performance observations
- Forms part of the formal Test Report
  - Must conform to content requirements



NATIONAL INSTRUMENTS

COMPLIANCE ENGINEERING LABORATORY

11500 North MoPac Expwy
Austin, TX 78759

Electrostatic Discharge (ESD)
IEC/EN/KN 61000-4-2

Date: 3/11/2013

EUT Description: BNC-2121 **Test Operator:** Mike Schmeisser

No.	Discharge Location	Air Discharge [1]						Contact Discharge [1]					
		2 kV		4 kV		8 kV [2]		2 kV		4 kV		6 kV [3]	
		+	-	+	-	+	-	+	-	+	-	+	-
1	Chassis Front	A	A	A	A	A	A	B	B	B	B	NA	NA
2	Chassis Top	A	A	A	A	A	A	B	B	B	B	NA	NA
3	Chassis Rear	A	A	A	A	A	A	B	B	B	B	NA	NA
4	Chassis Sides	A	A	A	A	A	A	B	B	B	B	NA	NA
5	EUT Front Panel	A	A	A	A	A	A	B	B	B	B	NA	NA
6	EUT Connectors	A	A	A	A	A	A	B	B	B	B	NA	NA
7	EUT Latch	A	A	A	A	A	A	B	B	B	B	NA	NA
8													
9													
10													
HCP	Horizontal Coupling Plane	A	A	A	A	A	A	B	B	B	B	NA	NA
VCP	Vertical Coupling Plane	A	A	A	A	A	A	B	B	B	B	NA	NA

NOTES:
1) ESD performance ratings: A = No degradation, B = Self-recoverable degradation, C = User-recoverable degradation, D = Unrecoverable degradation, NA = Not Applicable
2) The 8 kV air discharge level is only required for Industrial environments.
3) The 6 kV contact discharge level is only required for Marine environments.

COMMENTS:

TEMPERATURE: 25.5 °C HUMIDITY: 42.8 %

ESD Simulator Details				
Used	Asset #	Manufacturer Name	Model Number	Serial Number
X	12182	EMC-Partner	ESD 3000	401
	12261	EMC-Partner	ESD 3000	493

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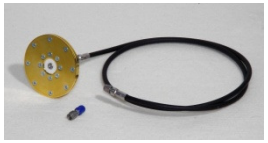
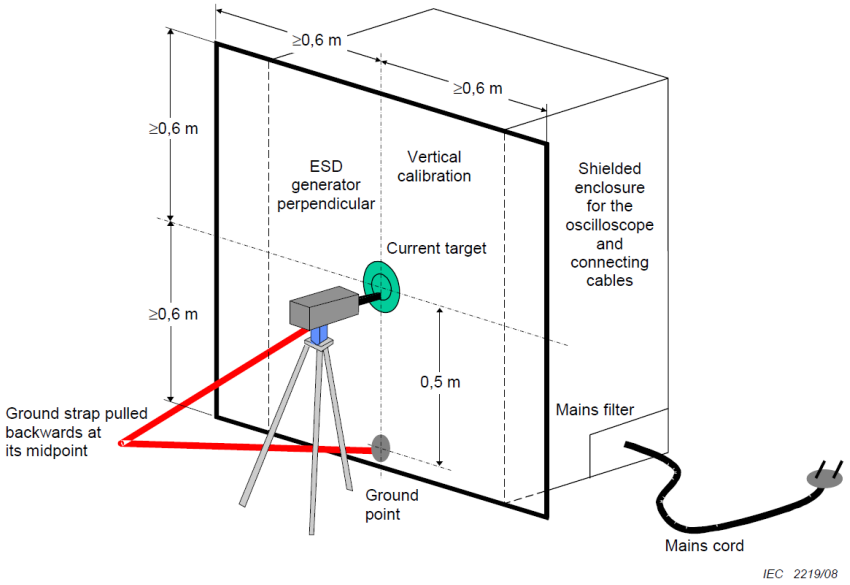
Calibration & Verification

Performance of the ESD Simulator

- Waveform verification requires an oscilloscope (≥2 GHz analog bandwidth) and calibration target-attenuator-cable fixture.
- Voltage verification requires a high-voltage voltmeter.





Calibration Setup (standard)

Calibration Setup (actual)

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Testing Lessons Learned

Lessons Learned

- Performed at an accredited test lab.
  - Methods meet the requirements of test accreditation bodies.
  - More expensive and allows little to no disruption in the test.
- Prepare and follow a Test Plan
- Take schematics, layout, BOM, etc.
- Take a troubleshooting kit with resistors, capacitors, TVS, etc.
- Take more than one sample (just in case first one get damaged).
- Archive the test sample
- Question the lab about their waveform verification, check the bleeder wires, verify the test equipment, etc.
- Retain an expert witness

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Product Design for ESD Immunity

ESD Immunity begins with a Plan

- Determine likely ESD test points early in the design process
  - Declaring a port or device “ESD-sensitive”
- Understand the impact on testing of design choices
  - Conductive vs. non-conductive enclosure
  - Shielded vs. unshielded (plastic) connectors
  - Insulating vs. non-insulating coatings
- Have a design strategy
  - For each test point or class of test points
  - For each function or IC pin where an unexpected state-change is a problem
- Have a backup plan (PCB population options, connector backshell, etc)

Product Design for ESD Immunity

Best Practices

- Prevent the discharge
  - Applicability
    - Only applicable to direct discharge to the product
    - Still have to design for coupling from indirect discharge to HCP and VCP
  - Methods
    - Use non-conductive or insulating materials for the enclosure to prevent direct discharge
      - Does not address coupling from HCP or VCP
      - May require board-level shielding, metal shields, or conductive paint
      - Watch out for screws or PCB mounting hardware
    - Use connectors recessed sufficiently to prevent direct discharge
      - Recess should be >10 mm
    - Use a shielded enclosure to prevent coupling due to indirect discharge

Product Design for ESD Immunity

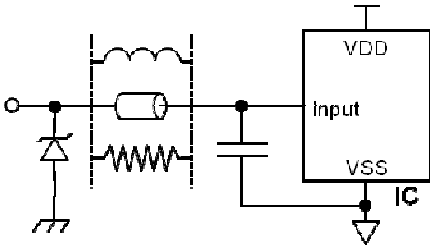
Best Practices

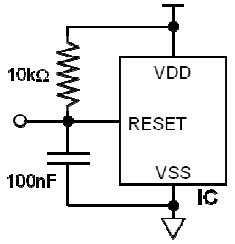
- Divert the induced current away from sensitive circuitry
  - Applicability
    - Direct and indirect discharge
  - Methods
    - Mechanical
      - Use conductive materials to form as perfect of a shielded enclosure as possible
      - Connect all pieces using low-impedance connections (allow no floating metal)
      - Use connectors with metal overall shields
      - Directly connect connector shield to shielded enclosure
    - Electrical
      - Use transient protection, referenced to metal enclosure, close to connector
      - Use transient protection, referenced to power ground, close to sensitive circuit
      - Use solid reference planes
      - Keep sensitive traces away from PCB edge or outer layers

Product Design for ESD Immunity

Best Practices

- Protect/harden sensitive circuitry
  - Select components with internal ESD protection
    - Understand the issues associated with manufacturer specification of ESD performance
  - Select components with high thresholds or noise margins
  - Select slower technology components
  - Protect (filter) critical pins close to receiver (input)
    - Decoupling (divert to ground) – capacitor, clamp diode
    - Blocking (oppose with impedance) – inductor
    - Absorbing (dissipate as heat) – resistor, ferrite
    - Increase strength of pull up/down on sensitive inputs.
  - Implement fault-tolerant functionality/software
    - Sample inputs multiple times
    - Fill unused memory with known instructions
    - Refresh critical data
    - Watchdog operation may be possible

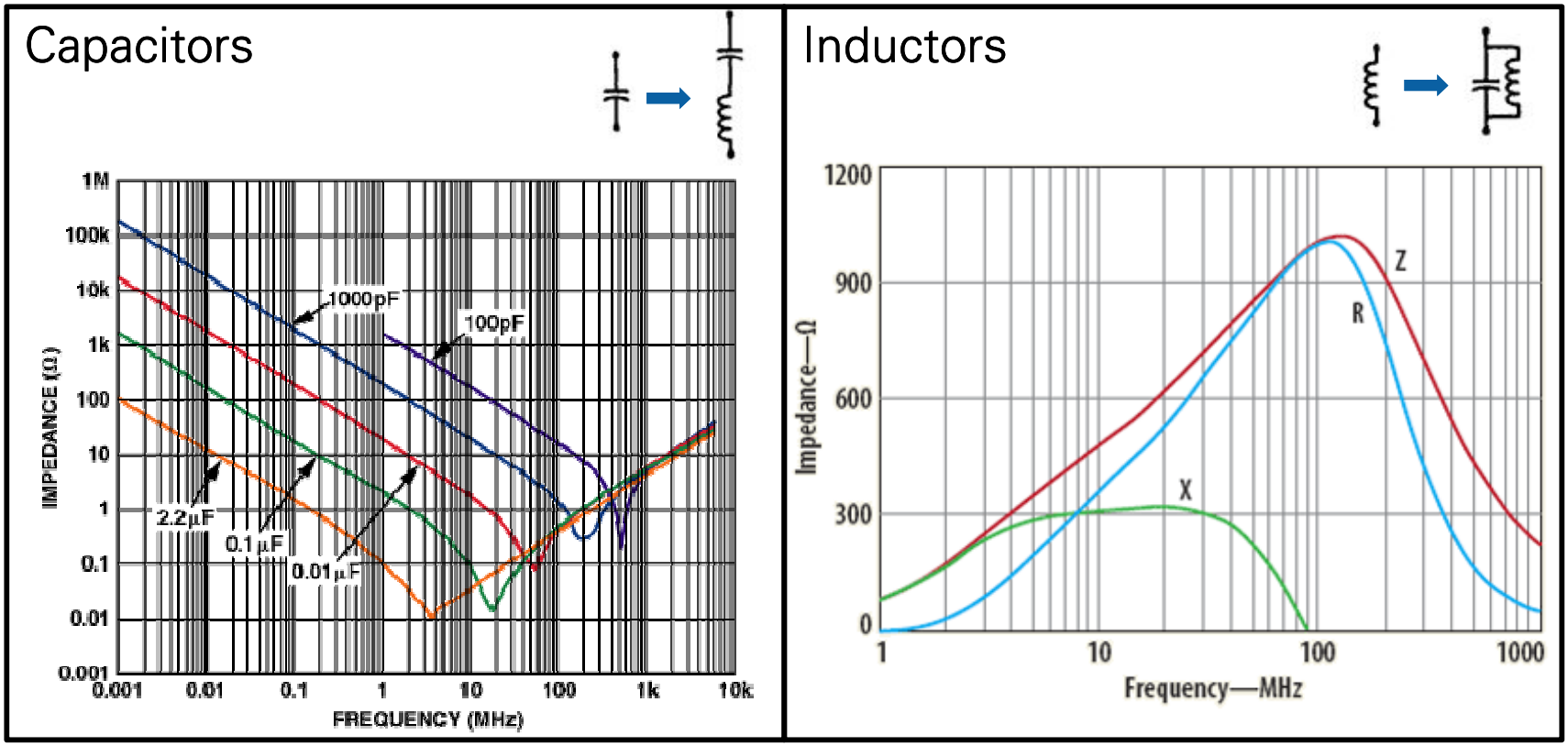




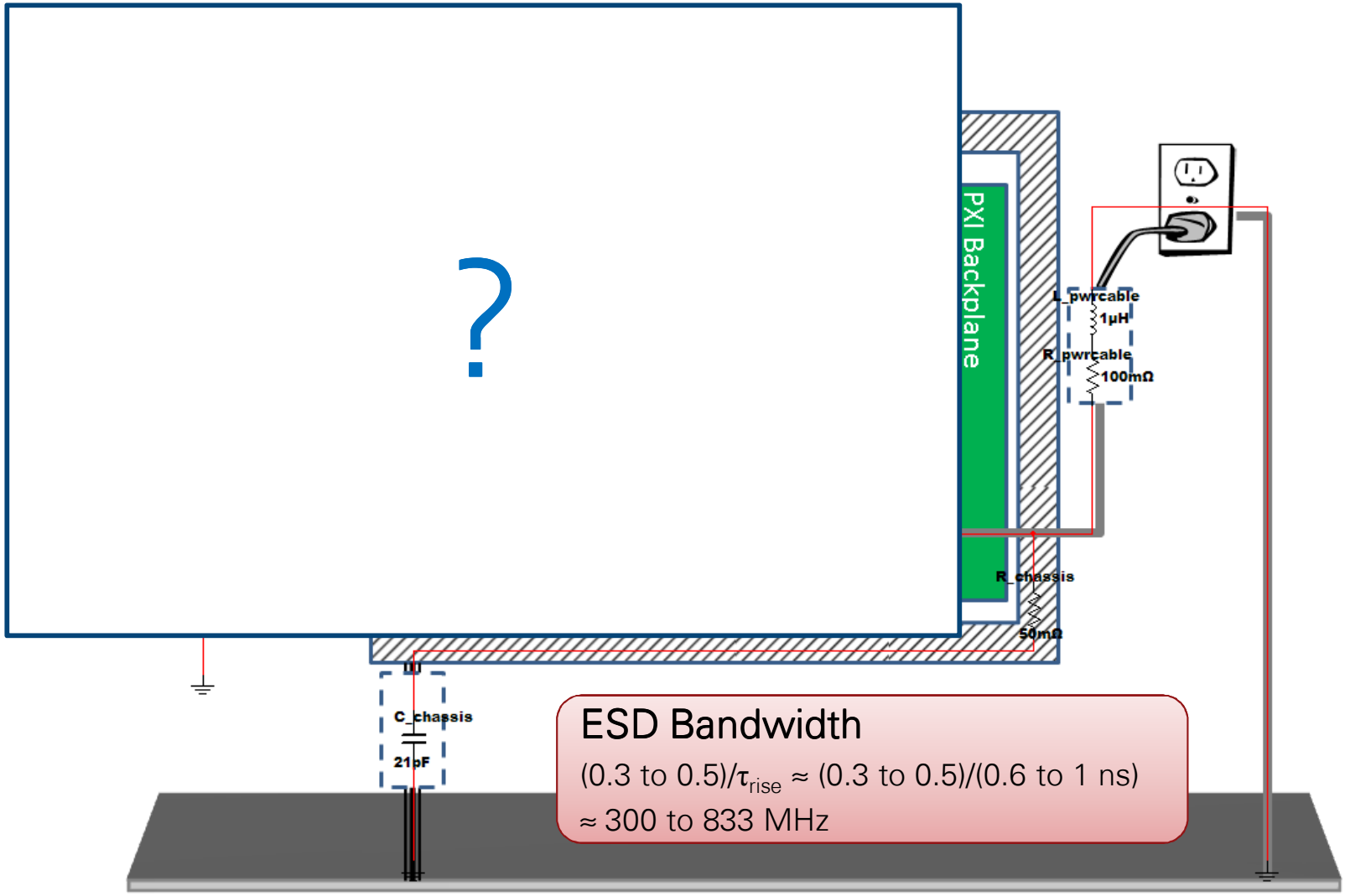
Product Design for ESD Immunity

Best Practices

- Understand how component performance changes with frequency



Product Design for ESD Immunity



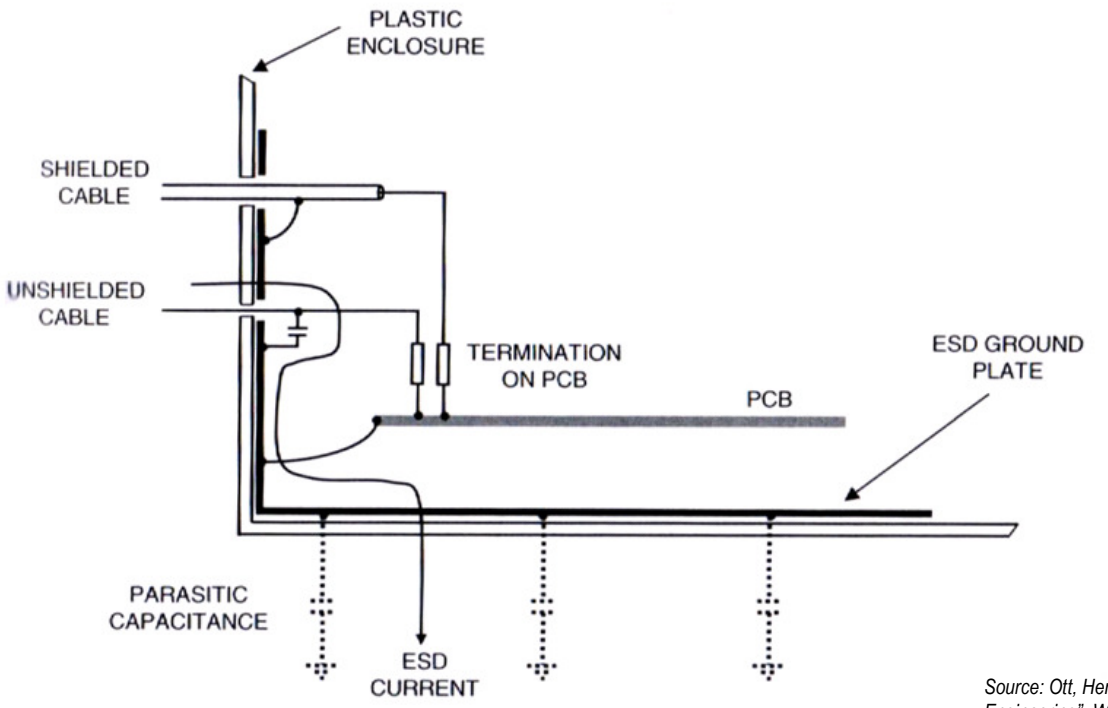
ESD Bandwidth

$(0.3 \text{ to } 0.5)/\tau_{rise} \approx (0.3 \text{ to } 0.5)/(0.6 \text{ to } 1 \text{ ns})$

$\approx 300 \text{ to } 833 \text{ MHz}$

Product Design for ESD Immunity

Use the Fact that the Majority of the ESD Currents Return using the Parasitic Capacitance between the Product and the Table



Source: Ott, Henry, "Electromagnetic Compatibility Engineering", Wiley & Sons, 2009.

Product Design for ESD Immunity

Understanding IC Manufacturer ESD Specifications

- Device Specifications

Table A-3. ESD Protection Characteristics

Parameter	Symbol	Value	Unit
ESD Target for Machine Model (MM) MM circuit description	V_{THMM}	200	V
ESD Target for Human Body Model (HBM) HBM circuit description	V_{THHBM}	2000	V

Features
- Four Channels of ESD Protection
- ±8 kV ESD Protection (IEC61000–4–2, Contact Discharge)
- ±16 kV ESD Protection (HBM)

- How is ESD performance tested?

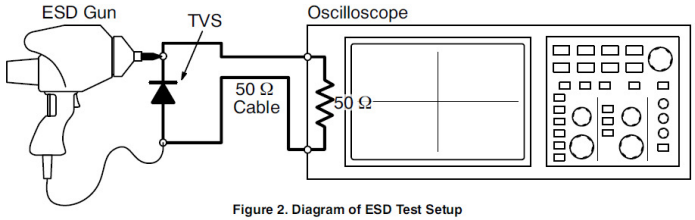
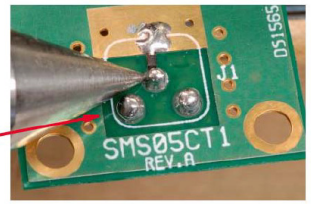
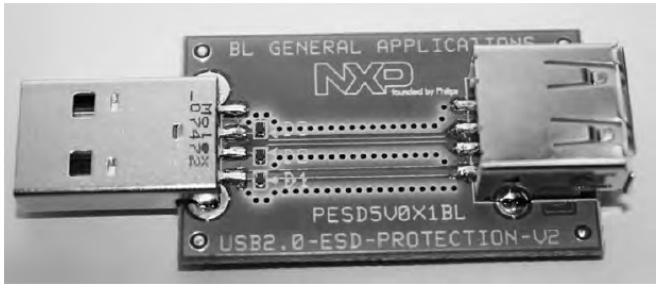


Figure 2. Diagram of ESD Test Setup





- How does it relate to performance in a system?

Questions

A final thought….