ESD

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ESD Events

What ESD events do you have experienced ?

ESD Events (unusual forms)

Office Chair

Figure 1. Standard Office Chair

ESD Events (unusual forms)

Measurement setup

Figure 3. Test Setup to Measure Number of ESD Events

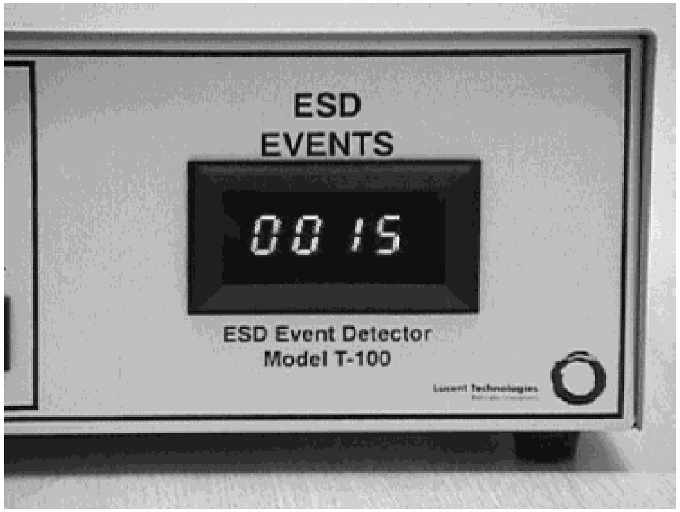


Figure 4. Event Count After Rising From Chair

ESD Events (unusual forms)

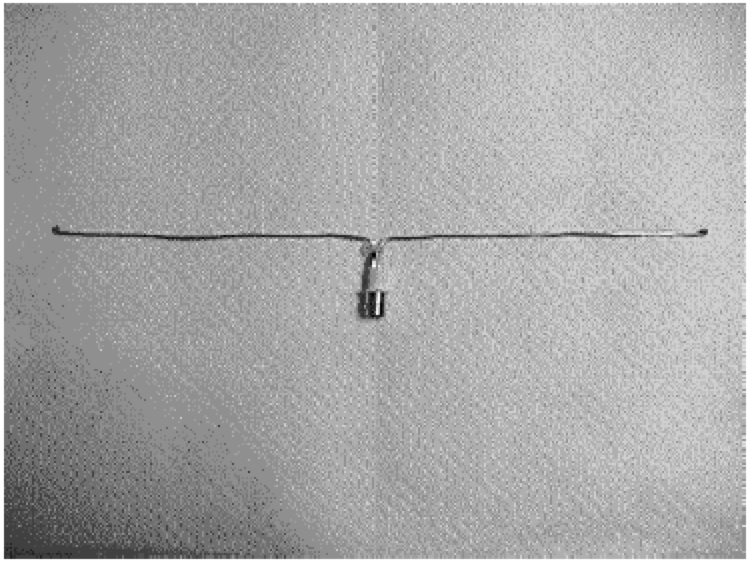


Figure 5. 30 cm Dipole

4V peak to peak

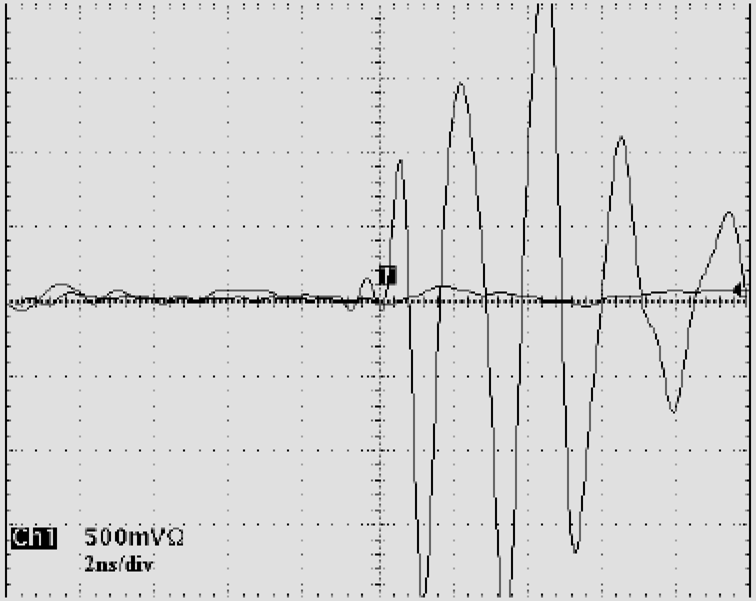


Figure 6. EMI Picked up by a 30 cm Dipole Near Chair

ESD Events (unusual forms)

Jingling Change ESD

Figure 7. Plastic Bag with Change

ESD Events (unusual forms)

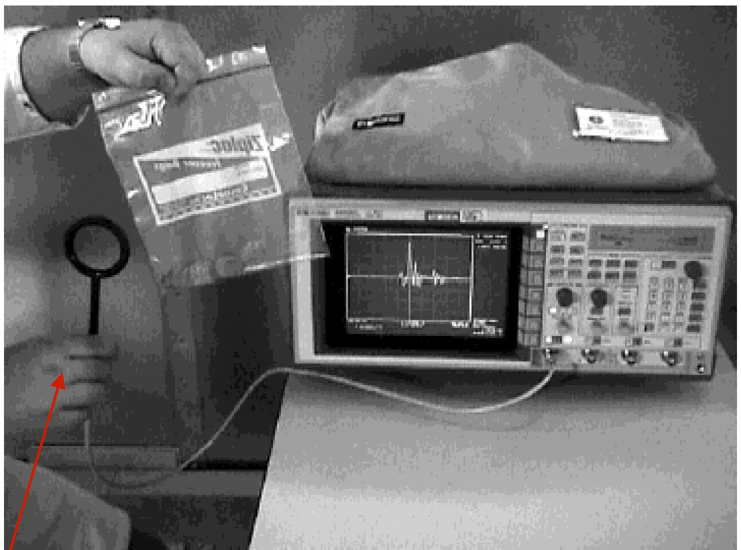


Figure 8. Jingling Change Test Setup

Loop antenna

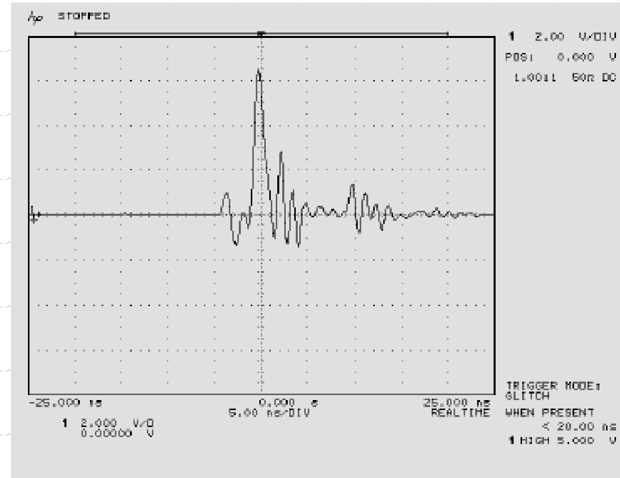
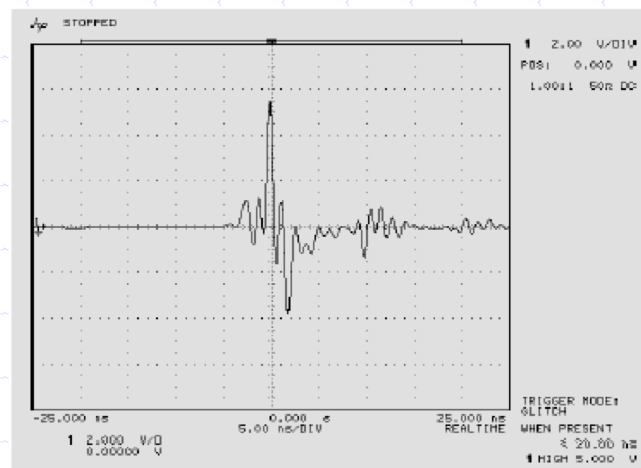


Figure 9. Loop Output Caused by Jingling Change

6V peak to peak



ESD Events (unusual forms)

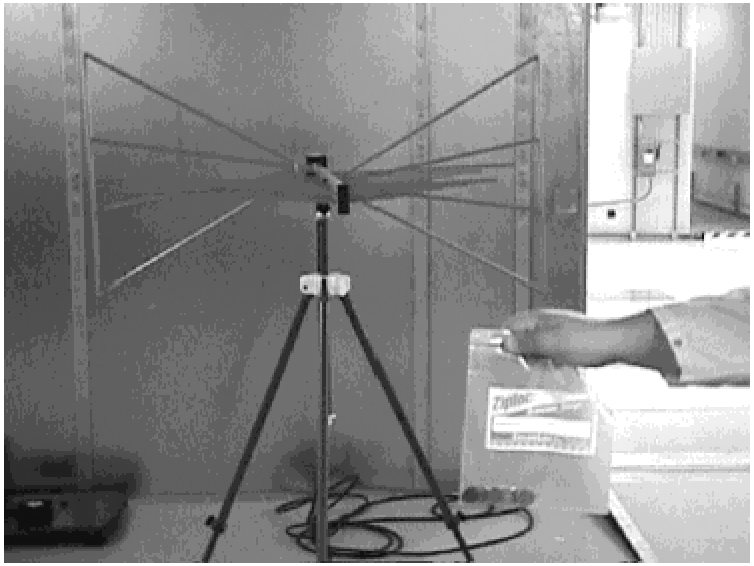
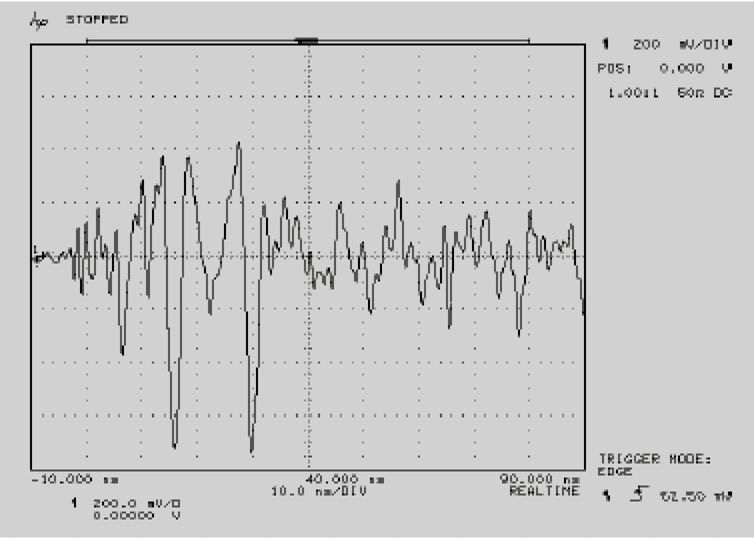


Figure 11. Pickup of Jingling Change EMI by Broadband Antenna



氣球
開車後
電視機外殼
電梯按鈕
冬天脫毛衣

……

ESD Mechanism

- Charge Generations
- Charge Transfer

Charge Generation

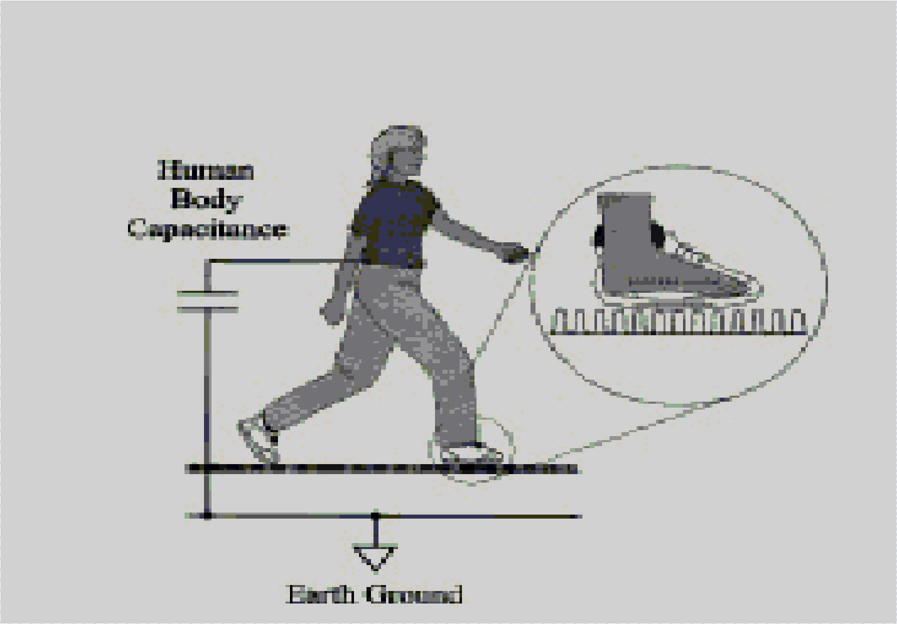
- *Triboelectric charge*
- *Inductive charge*
- *Conductive charge*

Triboelectric charge

- A triboelectric charge is developed on an insulator through the action of being rubbed against another insulator.
- Inductive charging occurs when a charged object is brought near to a conductor with separable distance.
- Conductive charging involves the physical contact and balancing of voltage between two systems or objects at different potentials.

Triboelectric charge

A triboelectric charge is developed on an insulator through the action of being rubbed against another insulator.



Triboelectric charge

- The act of rubbing the materials together increases the charge concentrations.
- The amount of charge generated depends on the contact area, pressure, and friction between the two materials.
- Triboelectrification is enhanced by a smooth surface,large contact area,high applied pressure,and high rubbing speed.

Triboelectric charge

- Every object has a “free space” capacitance.This capacitance is a function of the object’s surface area.
- For example,a capacitance exists between the soles of the feet of the human body and ground,and has a value of approximately 100pF.
- As the capacitance decreases the potential difference will increase.

Triboelectric charge

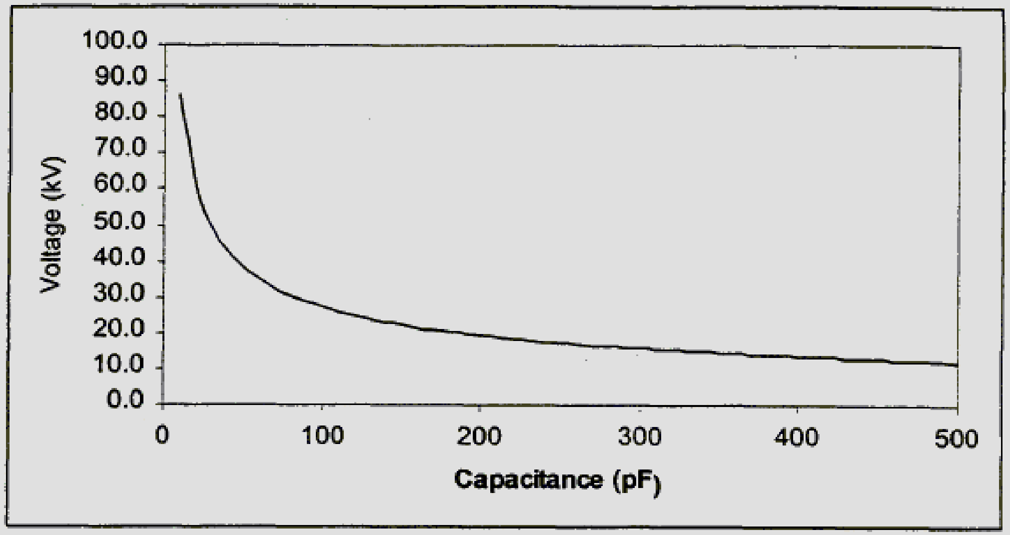


Figure 2: Capacitor voltage and capacitance for energy of 37 mJ

Polarity decision

POSITIVE			
1	Air	16	Hard rubber
2	Human skin	17	Epoxy, glass
3	Glass	18	Nickel, copper
4	Mica	19	Brass, silver
5	Human hair	20	Gold, platinum
6	Nylon	21	Polystyrene foam
7	Wool	22	Acrylic
8	Fur	23	Polyester
9	Lead	24	Celluloid
10	Silk	25	Polyurethane foam
11	Aluminium	26	Polyethelene
12	Paper	27	Polypropelene
13	Cotton	28	PVC (vinyl)
14	Wood	29	Silicon
15	Steel	30	Teflon
		NEGATIVE	

Table 1: An example triboelectric series

Humidity Effect:

Table 2 shows typical electrostatic voltages produced in both high and low humidity environments.

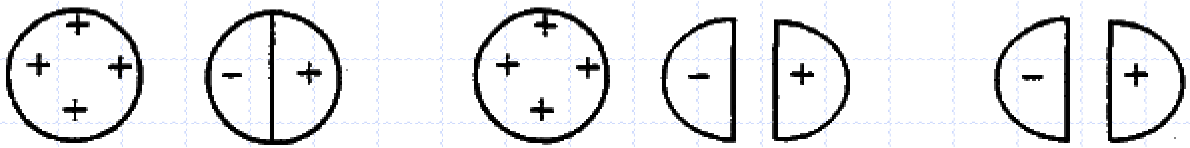
Means of static generation	Electrostatic potential (V) 10 - 20 % Relative humidity	Electrostatic potential (V) 65 – 90 % Relative humidity
Walking across a carpet	35,000	1,500
Walking on a vinyl floor	12,000	250
Picking up a polythene bag	20,000	1,200
Getting up from a polyurethane foam chair	18,000	1,500

Table 2: Electrostatic voltages and humidity

Why ?

Inductive charge

The charge on the insulator is transferred to a conductor either by contact or by induction. Inductive charging occurs when a charged object is brought near to a conductor with separable parts. The presence of the charge causes a charge separation on the conductor. If the parts of the conductor are now separated with the original charge still present, and the original object is then removed, the net result is to leave charges on the conductor. This is illustrated in Figure 1.



Stage 1: Charged object brought near conductor

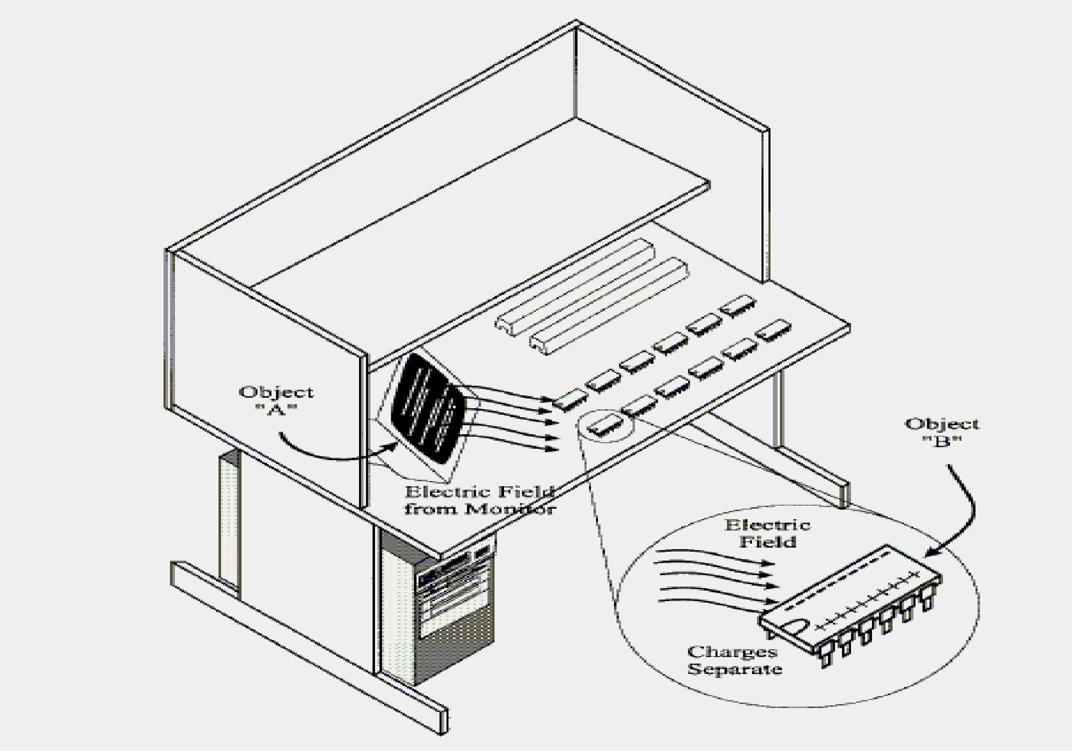
Stage 2: Separation of parts of conductor

Stage 3: Object removed – charge remains on conductor

Figure 1: Inductive charging

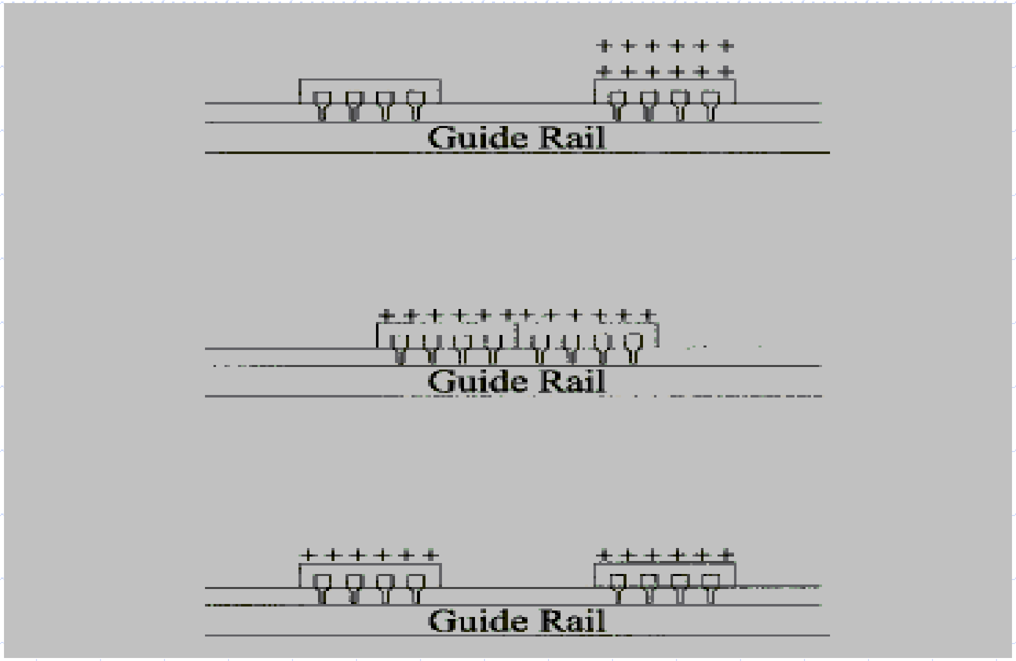
Inductive charge

Electric field in monitor induces charges on IC



Conductive charge

Conductive charging involves the physical contact and balancing of voltage between two systems or objects at different potentials.

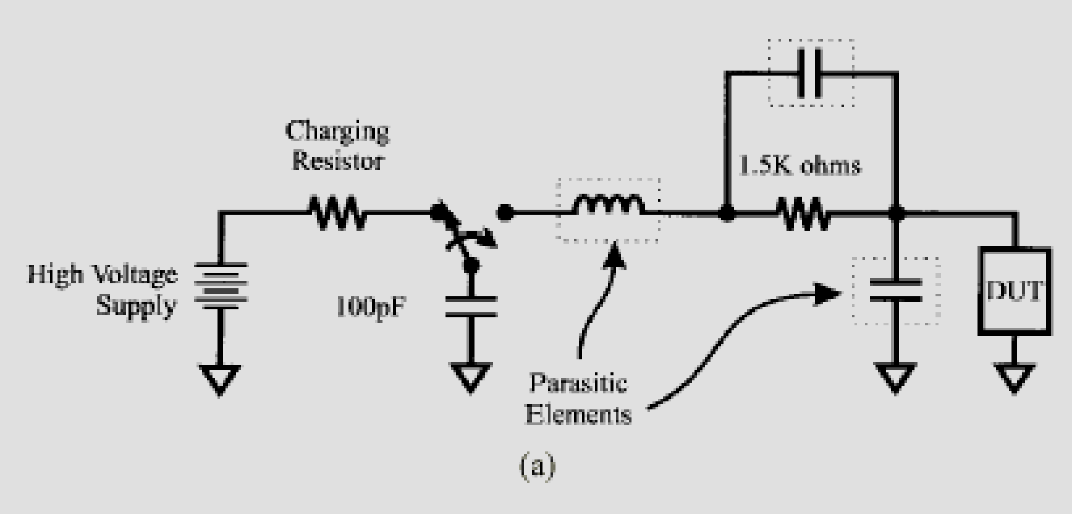


Charge transfer

- Human Body Model (HBM)
- Machine Model (MM)
- Charged-Device Model (CDM)

HBM

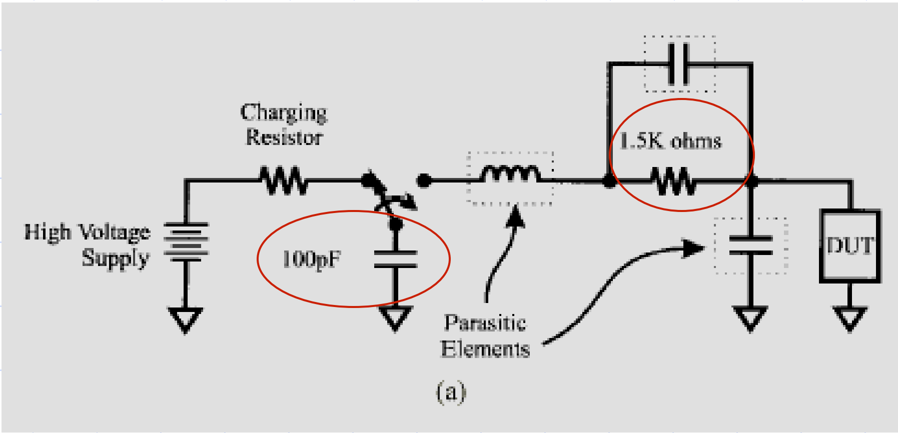
The human body is represented as a capacitor in series with a resistor.



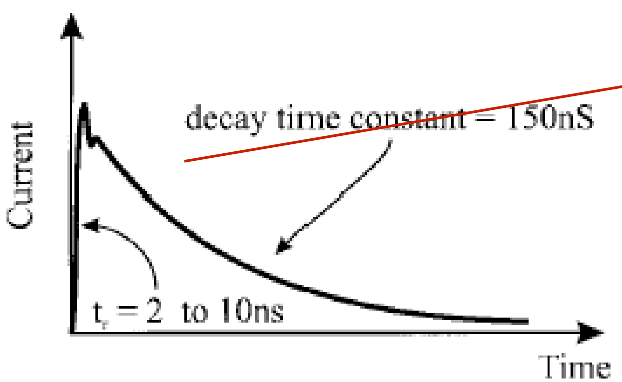
Human capacitance can vary from 100pF to 500pF depending on the type of footwear worn.

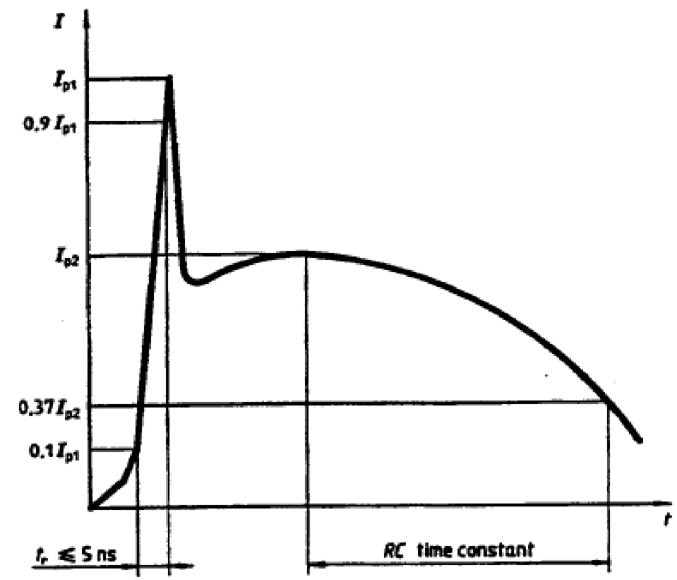
Human skin resistance can vary from 1000 to 100k ohm depending on the Level of oiliness.

HBM: discharged current



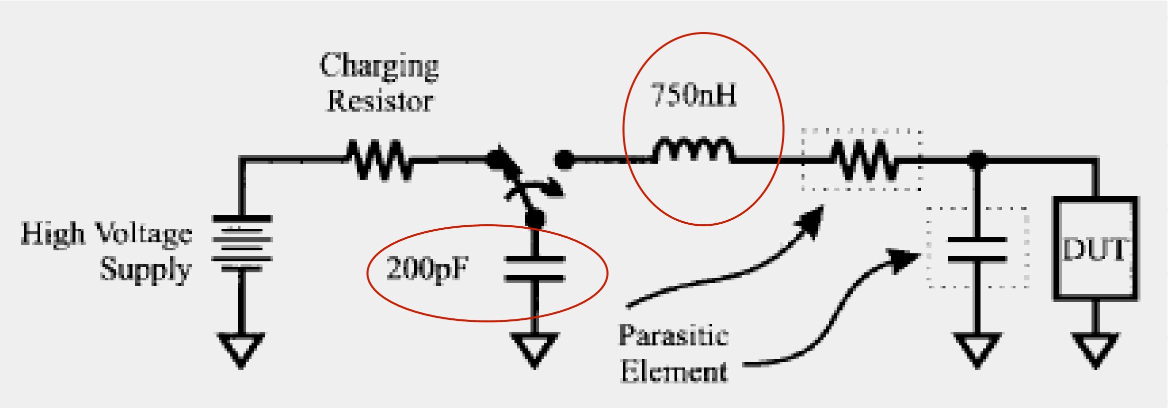
Rapid rise is due to the arc discharge
And slower falling off is due to the
RC time constant.



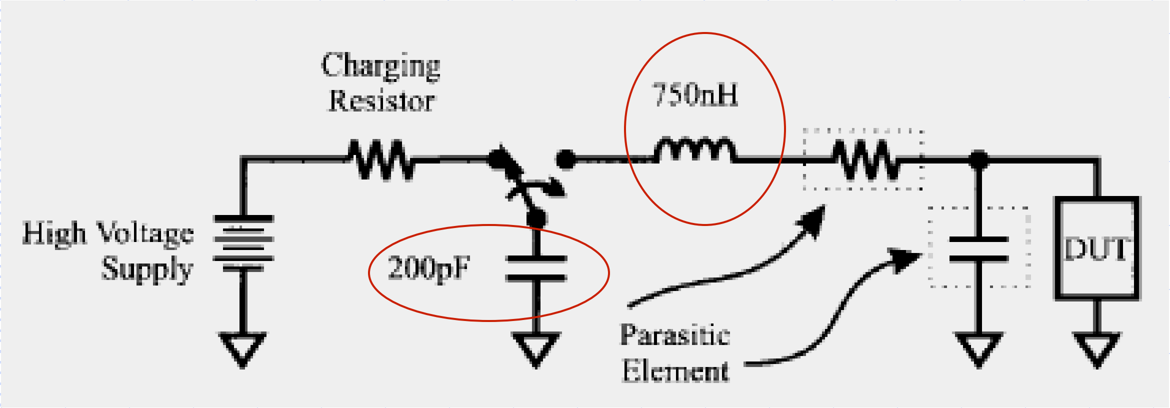


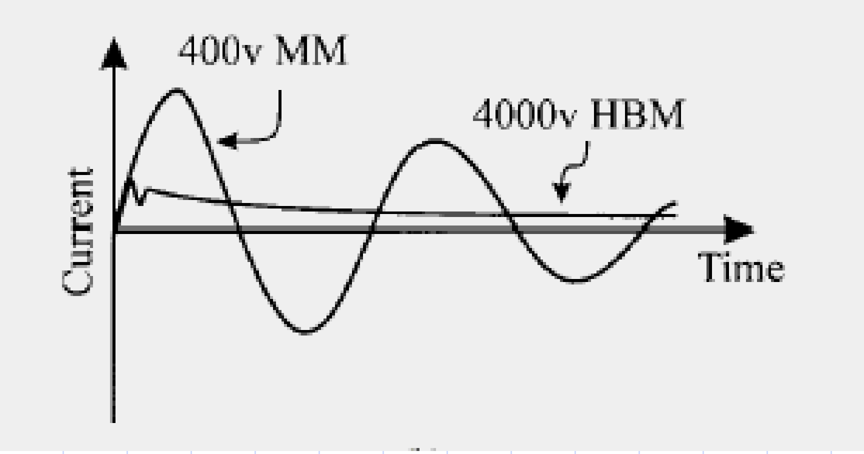
MM

This model intend to model the damage caused by equipment used in manufacturing



MM: discharged current

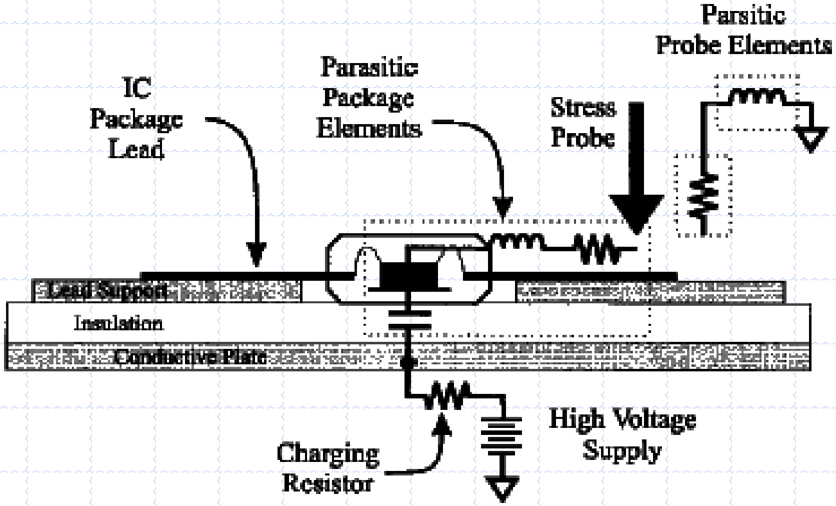




CDM

This model is intended to simulate the event that occurs from charged Packaged parts subsequently discharging into a low impedance ground.

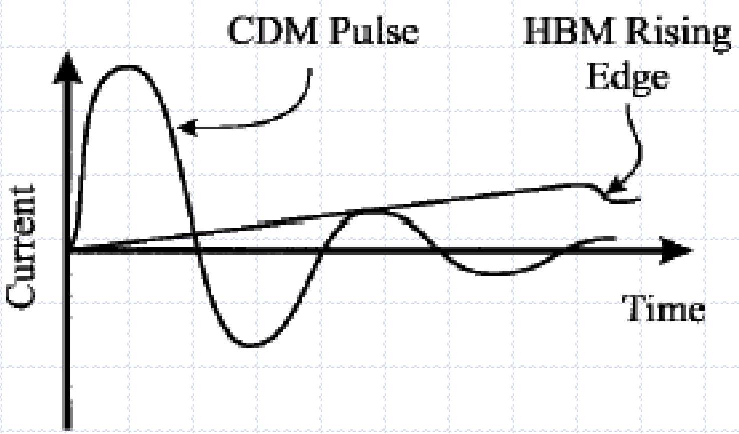
Non-socket version of test setup



CDM

A CDM event occurs so rapidly that the protection circuit may not turn on in Time to clamp the voltage to an acceptable level.

The peak current is much higher than in the HBM and the rise time as well as Duration is much shorter.



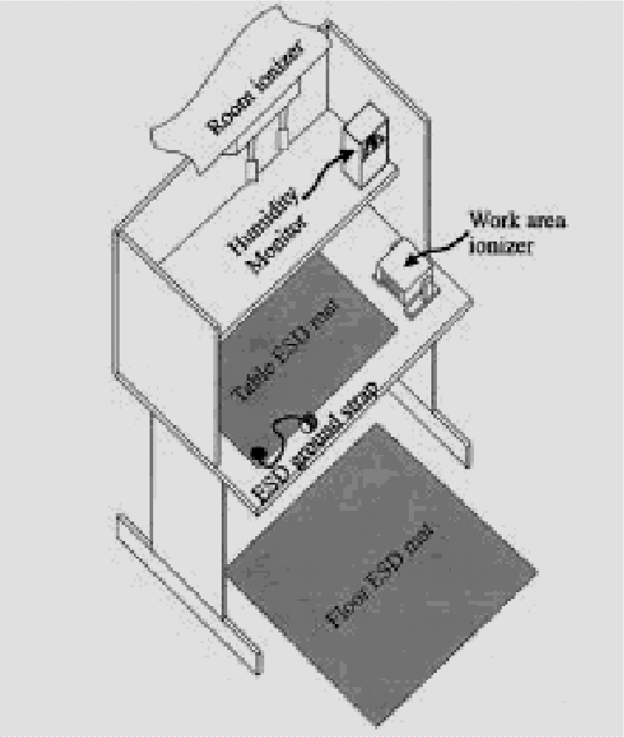
Mitigation Design Technique

1. Preventing the ESD Event
2. Hardware Immunity
3. Software Immunity

Preventing the ESD Event

Electronic components such as IC's are placed in pink polyethylene (聚乙烯) bags or have their pins inserted in antistatic form for transport.

These material has lower surface resistance to redistribute the charges.

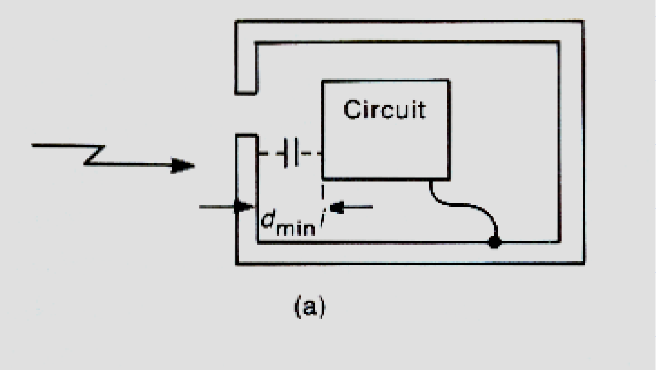


Hardware Immunity (I) : secondary arcing

1. **Reducing the secondary arcing** :
   - (a) Grounding the exposed metal parts of the enclosure to chassis ground.
   - (b) Insulating the exposed parts from the nearby electronics.

2. Interior circuits should be separated
   - (a) 1cm from the ungrounded parts of the enclosure
   - (b) 1mm from the grounded parts of the enclosure.

Why ?



Hardware Immunity (I)

The breakdown electric field strength in air is of order 30kV/cm, and

Human body can be charged to about 25KV

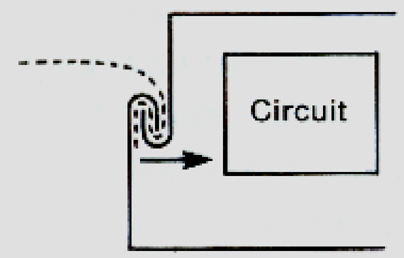
The ungrounded metal can rise in potential to the potential of the charged body

So, d_{min} = 25kV / (30kV/cm) ~ 1cm

If the metal part is grounded, the voltage across the inductance of the Green Wire Ground due to the ESD discharge current is about 1500V

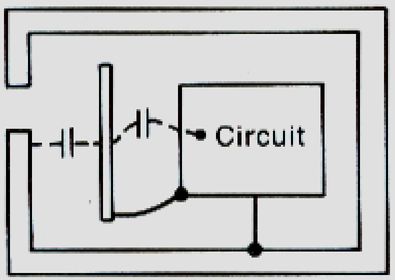
So , d_{min} = 1500V / (30kV/cm) ~ 1mm

Hardware Immunity (I)



(b)

Another way is to lengthen the discharge path



(c)

Or, using the secondary shield to the circuit ground
To break up the capacitance.

Hardware Immunity (II): conduction current

Preventing the ESD discharge current from flowing through the sensitive circuits
By direct conduction.

Via point A to chassis will not destroy
The circuit

But if via point B, the circuits will be damaged

The ESD discharge current will
Follow the lowest impedance path

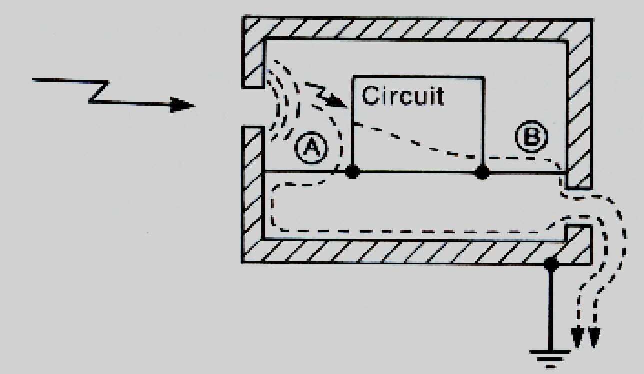


FIGURE 12.5 Effect of geometry on the discharge path.

Hardware Immunity (II)

Grounding the circuit is the key to reduce the conduction current through the circuits

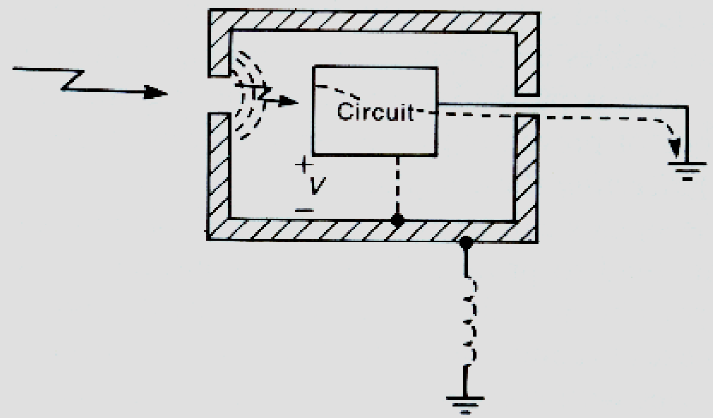


FIGURE 12.6 Illustration of the principle of preventing differences in potential during an ESD discharge by connecting all components to chassis (Green Wire) ground.

Hardware Immunity (II)

Cables act like an antenna to pick up and coupled the field produced by the ESD event to the interior of the enclosure and thus to the electronic circuits.

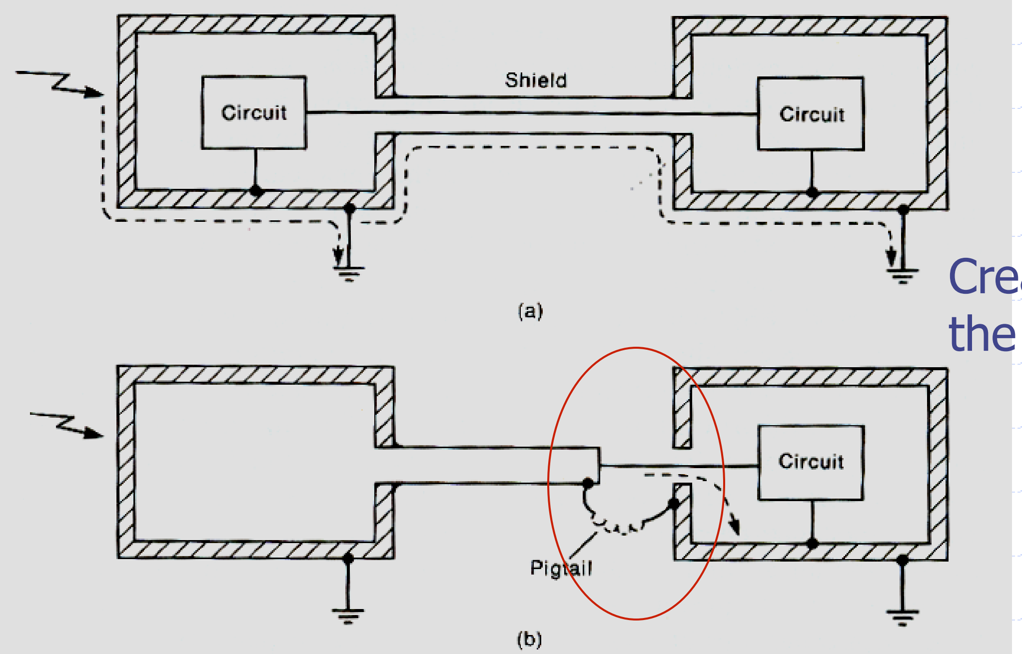


FIGURE 12.7 Use of shielded cables to exclude ESD coupling: (a) circumferentially bonded shields; (b) degradation of shielding due to pigtails.

Create a large voltage difference by the ESD current on the pigtail

Hardware Immunity (II)

Common-mode choke

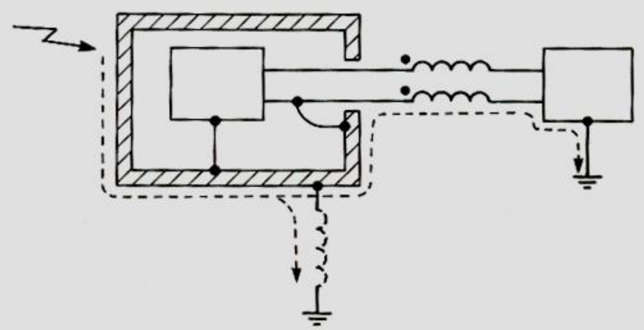


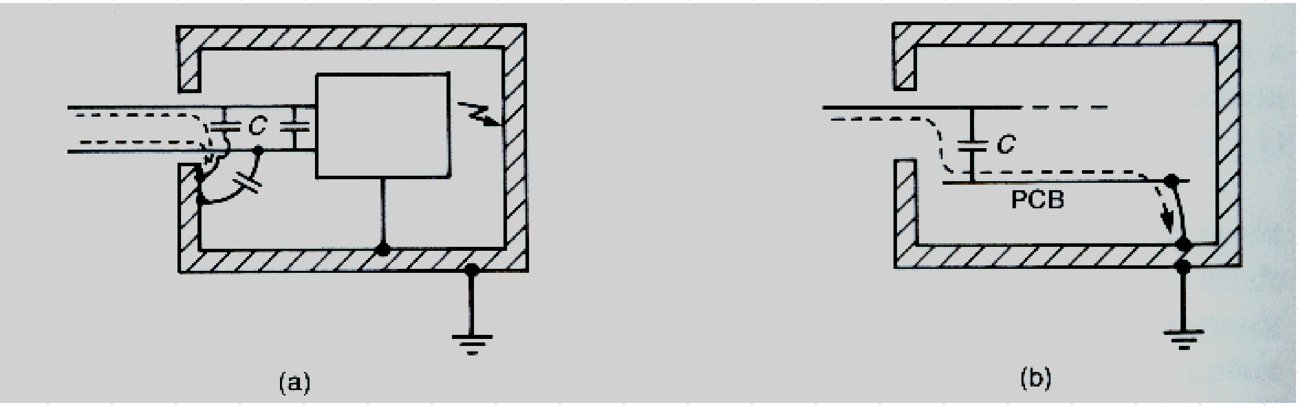
FIGURE 12.8 Use of a common-mode choke to prevent coupling of common-mode ESD signals between subsystems on cables.

1. Prevent the EMI problem
2. Eliminate ESD issue.

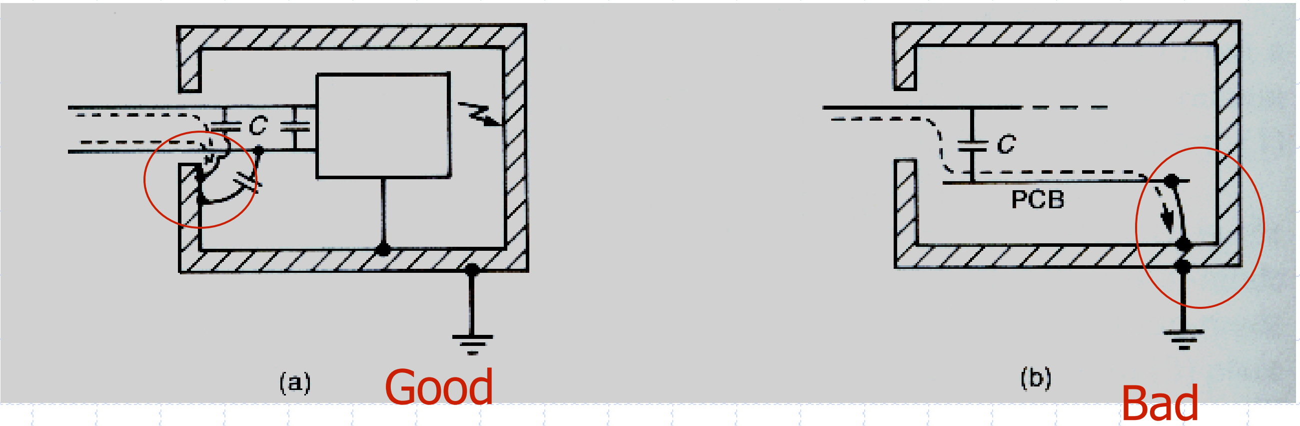
Hardware Immunity (II)

Decoupling Capacitance

Which one is better?



Hardware Immunity (II)



Connecting all ground conductors and diversion device to the enclosure
To one point tends to prevent other less easily observed low impedance path.

Because the low impedance path is **not easy** to predict for the ESD current,
Which covers very broad bandwidth.

Hardware Immunity (II)

Zener diode

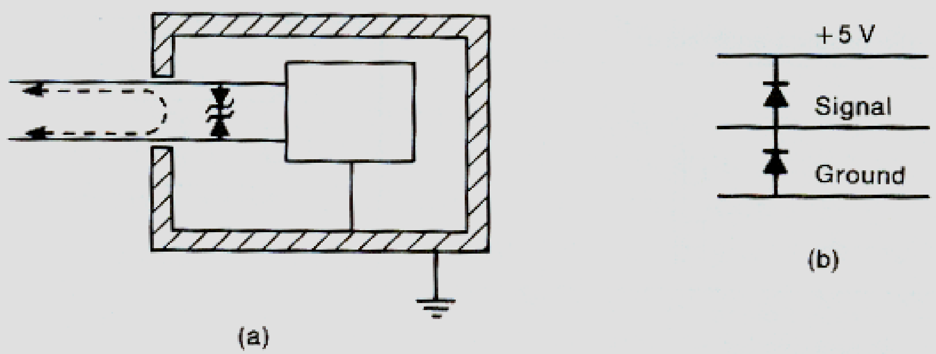


FIGURE 12.10 Use of diodes to clamp ESD-induced voltages to safe levels: (a) a zener diode; (b) back-to-back diodes at circuit inputs to prevent overvoltages.

Hardware Immunity (III): E or H field coupling

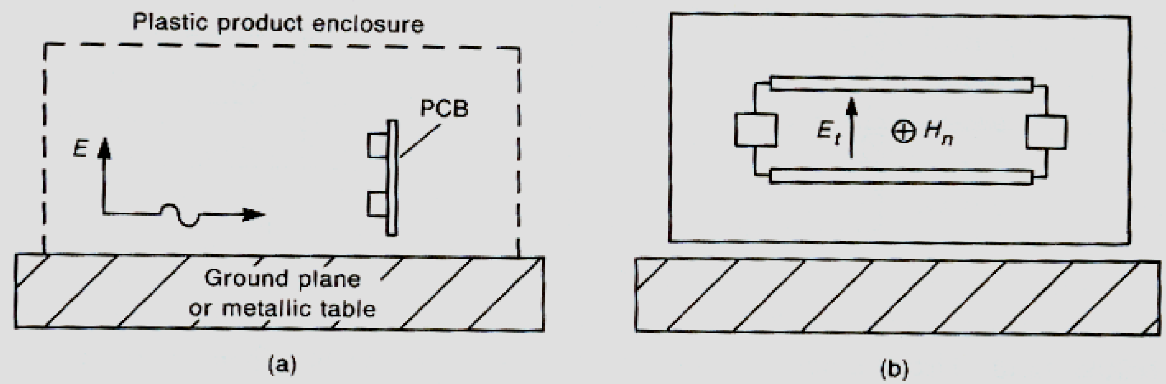


FIGURE 12.12 Illustration of the effect of PCB orientation on their susceptibility to ESD fields: (a) problem dimensions; (b) the ESD fields are oriented with respect to the circuit loop for maximum susceptibility.

Ill condition of the E and H field to the orientation of PCB circuits

Hardware Immunity (III): E or H field coupling

Loop area

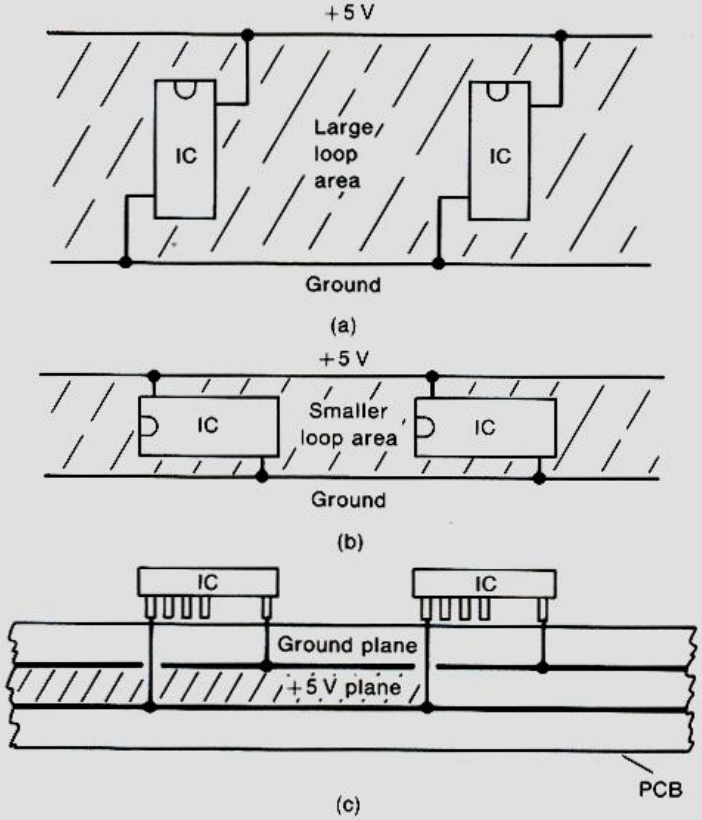


FIGURE 12.13 Reduction of loop area in power distribution circuits to reduce pickup of the ESD field: (a) large loop area; (b) smaller loop area; (c) use of an innerplane (multilayer) board to reduce the loop area and the characteristic impedance of the power distribution circuit.

PCB Layout v.s. ESD

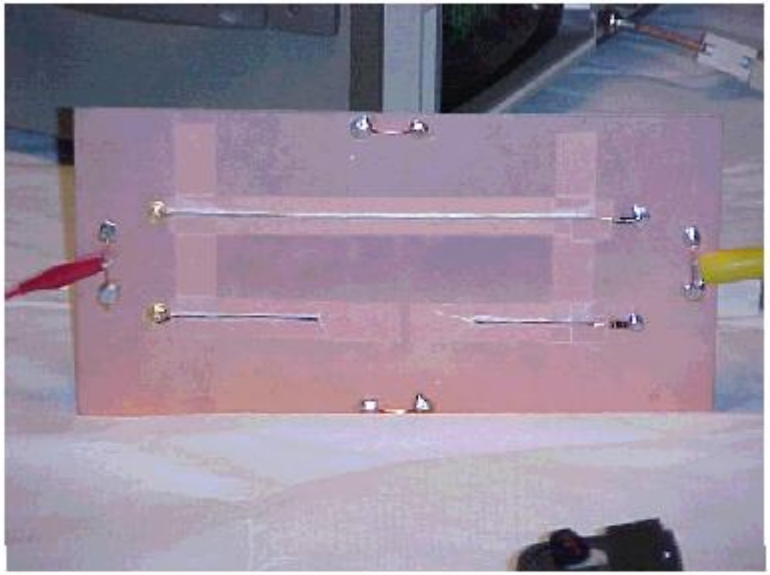


Figure 1. Test Board with Two Test Paths

PCB Layout v.s. ESD

Testing setup

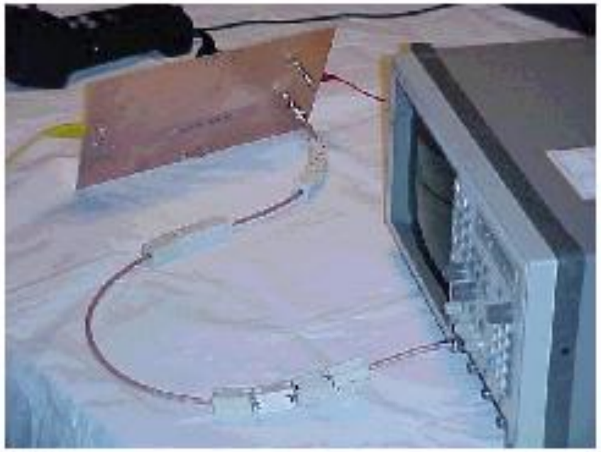


Figure 2. Connection to Oscilloscope

Figure 3. Complete Test Setup

PCB Layout v.s. ESD

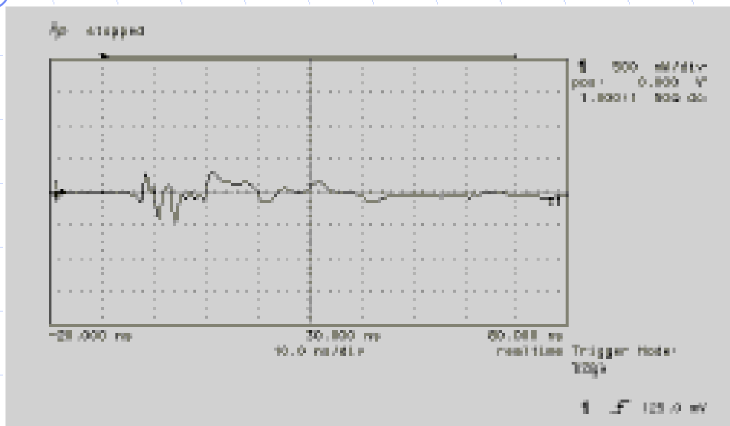


Figure 4. Apparent Signal on Straight Path

Straight line

Crossing line

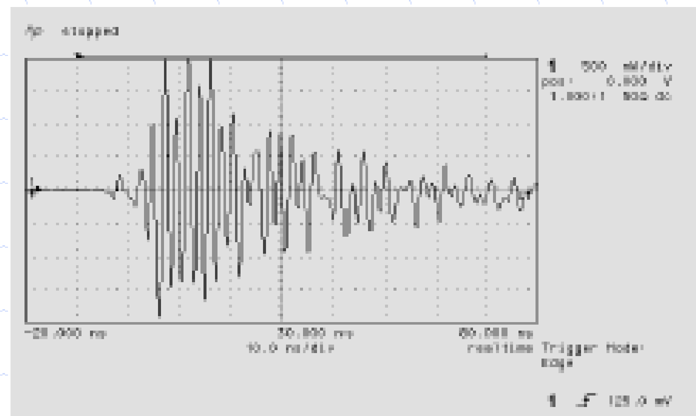


Figure 5. Apparent Signal on Path Crossing Planes

PCB Layout v.s. ESD

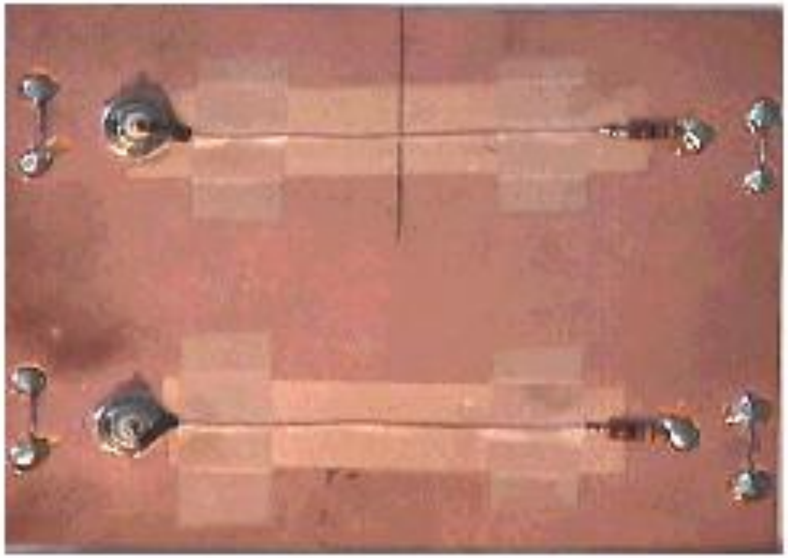


Figure 6. Split Plane Test Board

PCB Layout v.s. ESD

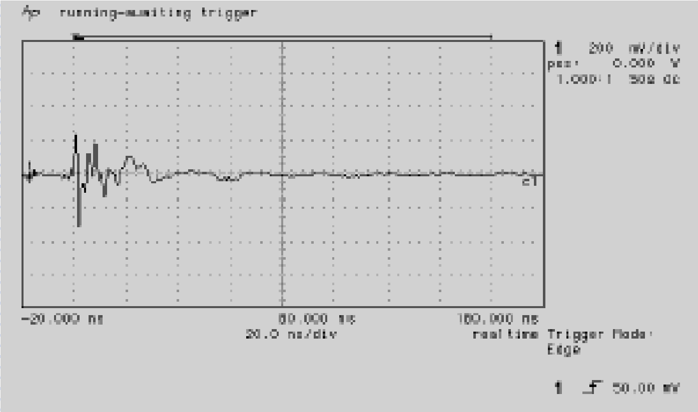


Figure 8. Apparent Signal on Straight Path

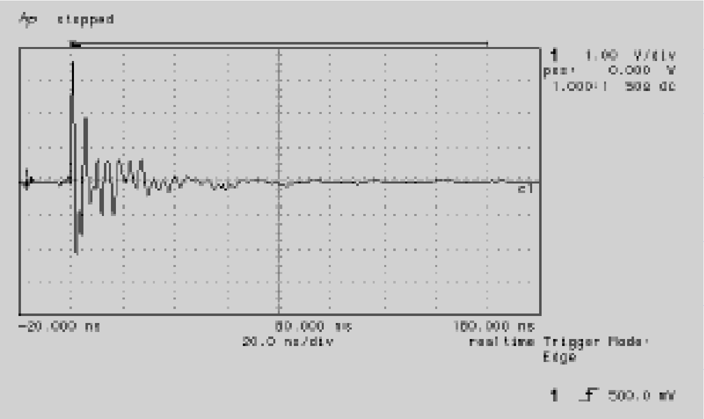


Figure 9. Apparent Signal on Path Crossing Planes

Air Discharge v.s. Contact Discharge

The air discharge test method uses the air as the discharge path to the EUT for The ESD pulse.

The contact discharge directly injects the ESD pulse through the conductive part of the EUT.

The air discharge test method most closely simulates a human body ESD event, but it is not a repeat able methodology.

Why ? Since the rise time of the discharge pulse is dependent on the approach **speed** of the ESD simulator toward the EUT, the speed of approach plays a vital Role in the ESD testing.

The contact discharge test method does not recreate the ESD event as it naturally occurs in life. The reason for using contact discharge is the reproducibility of this method.

Air Discharge v.s. Contact Discharge

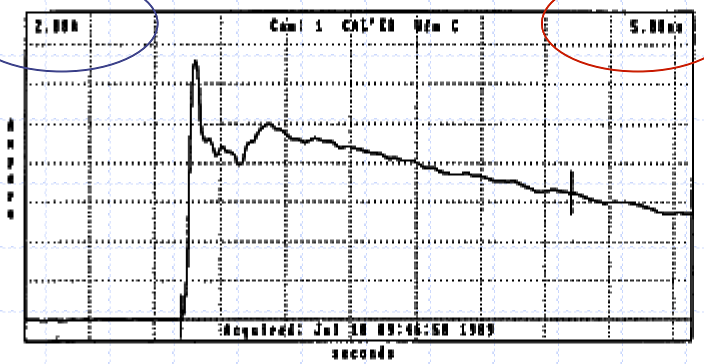


Figure 3 ESD Air Discharge

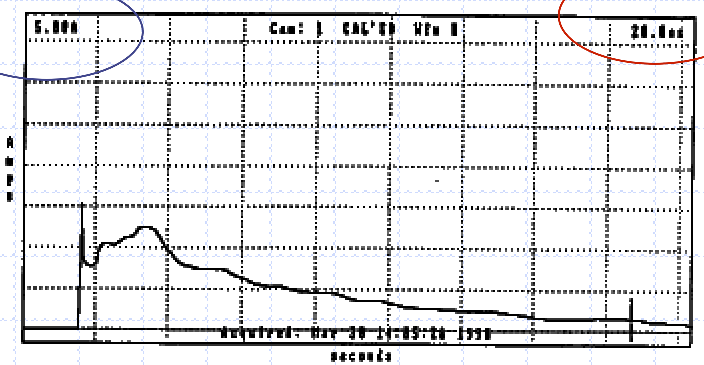


Figure 4 ESD Contact Discharge

4kV air discharge with simulator 150pF and 330 ohm

Air Discharge Mechanism

The air discharge event can be characterized in terms of the following Conditions (or mechanism):

1. Static Electric Field
2. Corona Predischarge
3. Dynamic Electric Field
4. Magnetic Field
5. Current Injection

Prior to the ESD event, the stored charge held by the human body results in a potential difference between the human body and the equipment to be Touched. This potential creates a static electric field.

At relatively high voltage level, the air in the immediate vicinity of the ESD event ionized creating a corona predischrage.

As the discharge occurs, the field collapses resulting a dynamic electric field.

The associated transfer of charge between the human body and the EUT establishes a magnetic field.

Finally, as the charge flows, current is injected into the equipment.

Air Discharge Current Waveform

At relatively high voltage levels (> 2kV),
A corona discharge typically occurs which
Lengthens the rise time and lower the peak current.

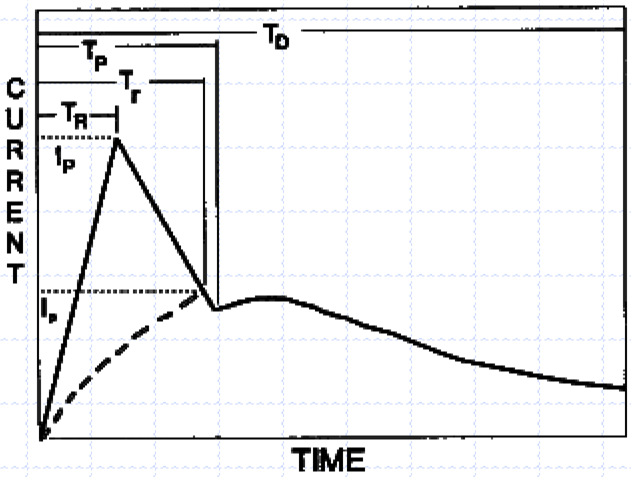


Figure 5 Generic ESD Current Waveform

•Referring to "ESD Multiple Discharge", IEEE EMC Symposium, pp. 253 – 258, 1991

ESD Multiple Air Discharge

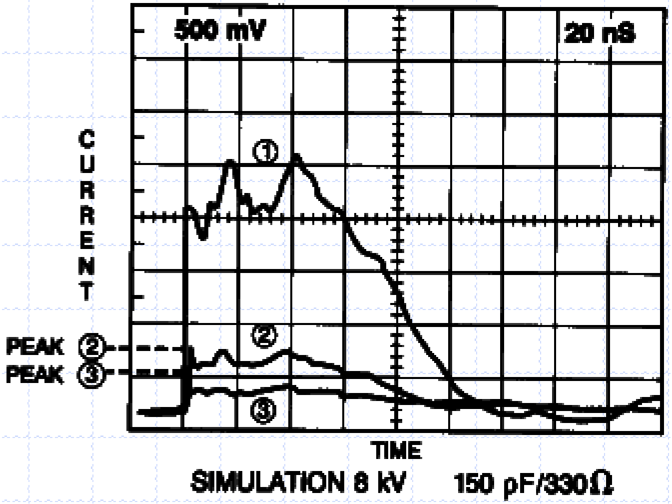


Figure 7 Simulated ESD Multiple Discharge

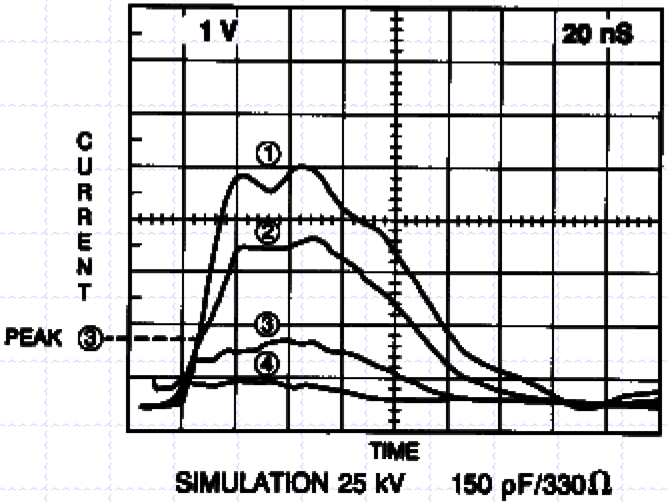


Figure 8 Simulated ESD Multiple Discharge

What do you find ? And Why ?

ESD Multiple Air Discharge

At a particular distance between the finger and an object, the stored energy is sufficient for a spark to propagate.

The arc will disappear when the energy required to maintain the air ionization path is not enough.

As the finger moves closer to the object, the energy required to initiate the Spark is reduced and the spark again propagates.

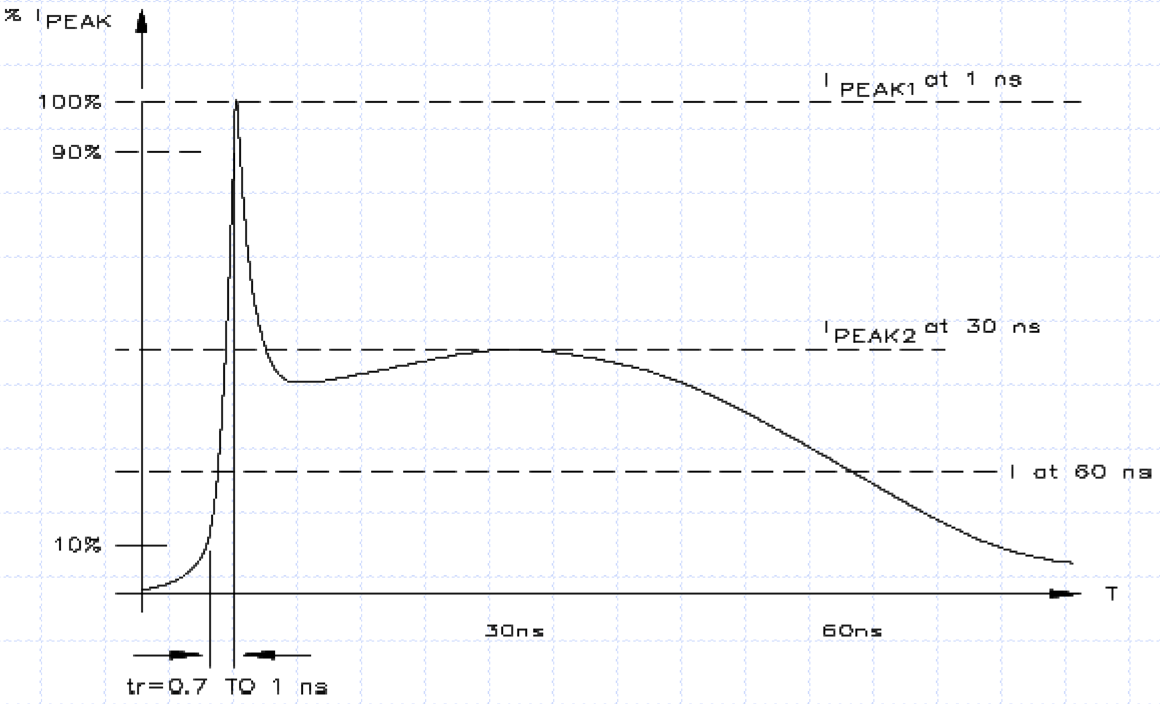
The discharge continues until the stored charge is completely exhausted.

Subsequent pulses can be separated by a time period ranging from 10 us To 200 ms.

ESD Discharge Pulse (Standard)

Table 1—Wave-shape characteristics—contact discharge

Discharge voltage	First peak of current	Rise time, *tr* 10% – 90% I_p	Current at 30 ns	Current at 60 ns
8 kV, ± 5%	30 A, ±10%	0.7 to 1 ns	16 A, ±30%	8 A, ±30%



Measured at 1GHz bandwidth

ESD Discharge Current Waveform (practical)

Measurement setup

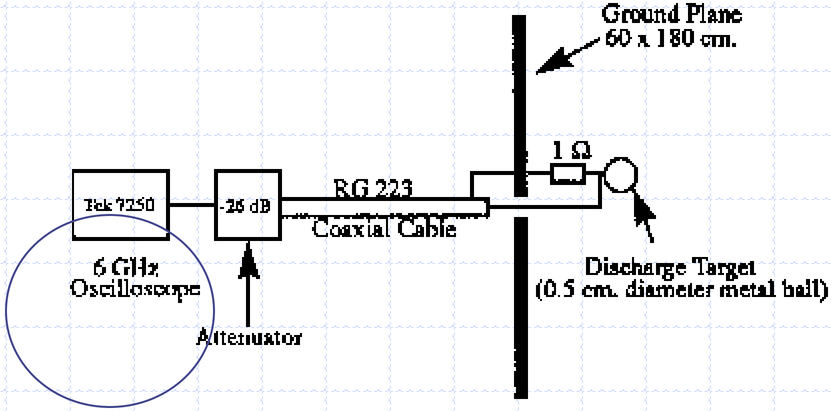


Fig. 1. Block diagram of the experimental setup.

- Referring to “6GHz Time Domain Measurement of Fast-Transient Events”, IEEE EMC Symposium, pp. 460 – 463, 1992

ESD Contact Discharge Current (Standard v.s. Practical)

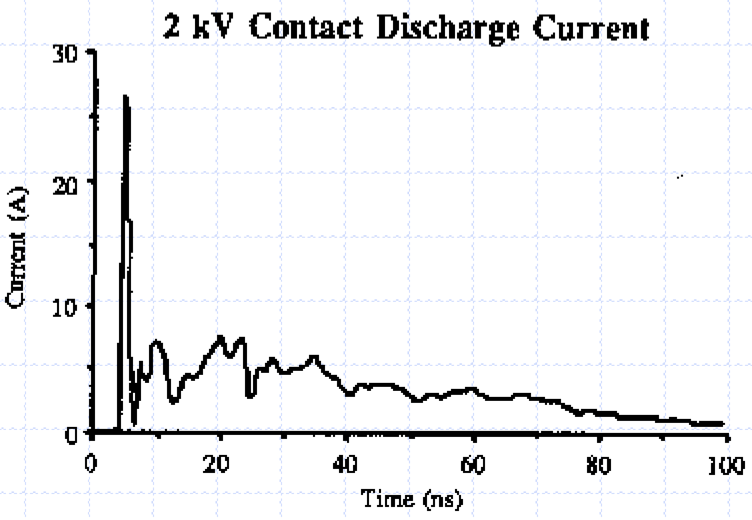


Fig. 2. The discharge current waveform produced by a 2 kV contact discharge, measured with a 6 GHz bandwidth system.

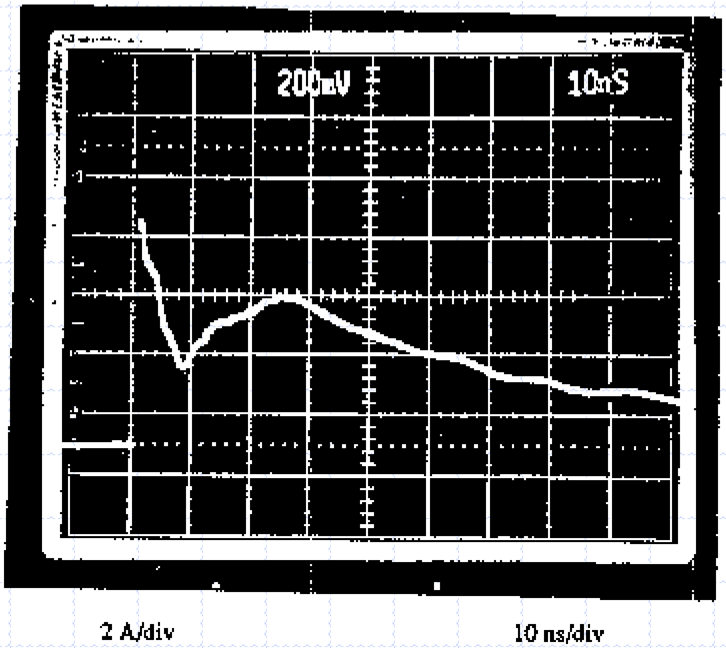


Fig. 4. The discharge current waveform produced by a 2 kV contact discharge, measured according to IEC 801-2.

What difference ?

Rise time	117ps	840ps
Peak current	33.4A	7.6A
Current at 30ns	6A	5A

ESD Contact Discharge Current (Standard v.s. Practical)

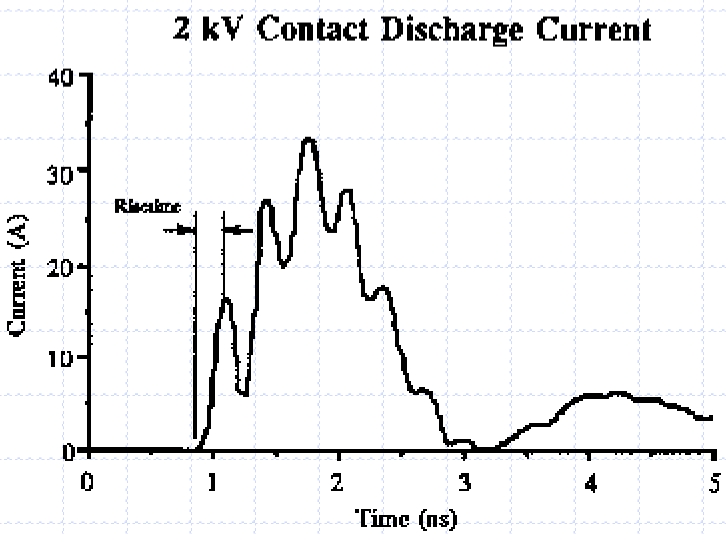


Fig. 3. The initial peak of the discharge current waveform shown in Figure 2. The time interval over which the risetime is calculated is also shown.

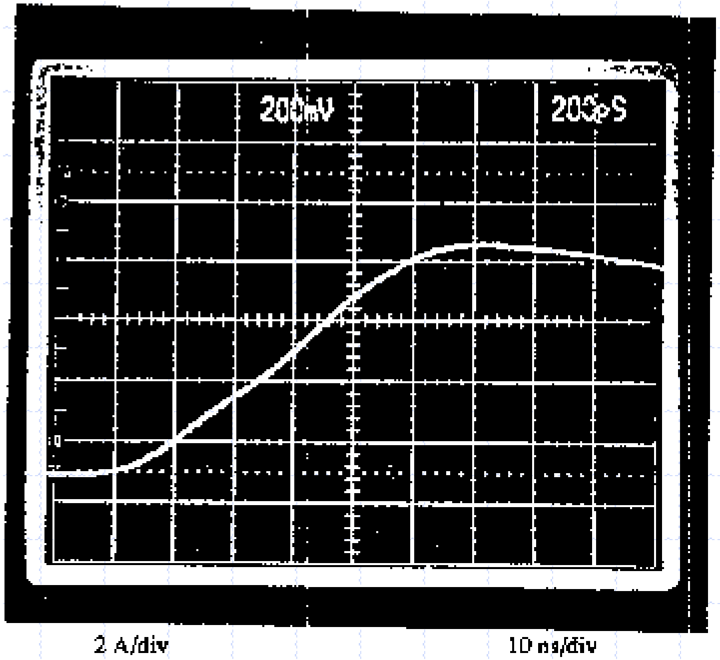


Fig. 5. The initial peak of the discharge waveform shown in Figure 4.

ESD Contact Discharge Current (Standard v.s. Practical)

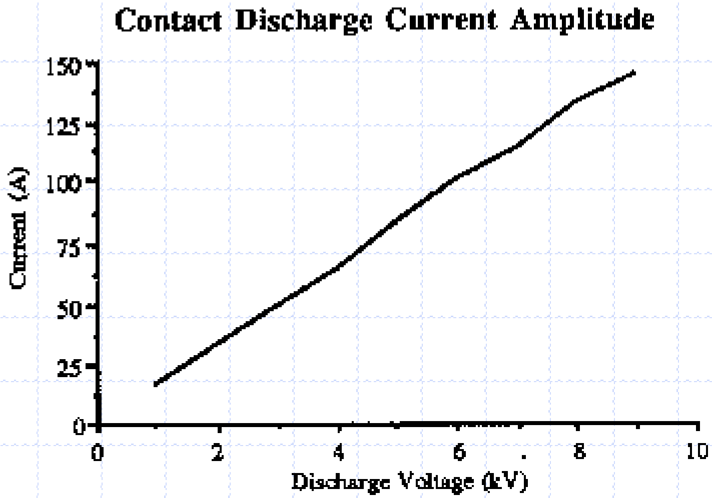


Fig. 6. Peak contact discharge current versus discharge voltage, as measured with a 6 GHz bandwidth system.

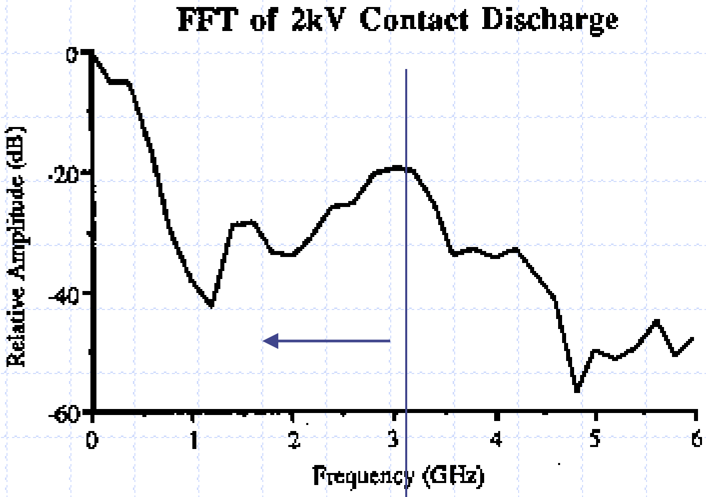


Fig. 7. Fast-Fourier transform of the waveform shown in Figure 3.

ESD Contact Discharge Current (Standard v.s. Practical)

TABLE I

COMPARISON OF 6 GHZ MEASUREMENTS WITH ANSI AND IEC SPECIFICATIONS FOR CONTACT DISCHARGE

Voltage (kV)	ANSI C63.16		IEC 801-2		6 GHz Measurement	
	I_{peak} (A)	Risetime (ns)	I_{peak} (A)	Risetime (ns)	I_{peak} (A)	Risetime (ns)
2	12	< 0.4	7.5	0.7 – 1.0	33.41	0.117
4	24	< 0.4	15	0.7– 1.0	63.96	0.117
6	36	< 0.4	22.5	0.7– 1.0	100.74	0.107
8	48	< 0.4	30	0.7– 1.0	133.66	0.117

ESD Air Discharge Current

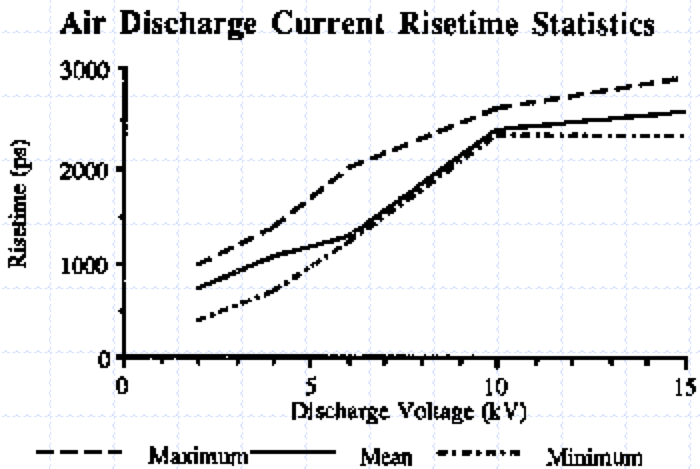


Fig. 9. Average air discharge current impulse risetime versus discharge voltage, as measured with the 6 GHz measurement system. Maximum and minimum measured values are also shown.

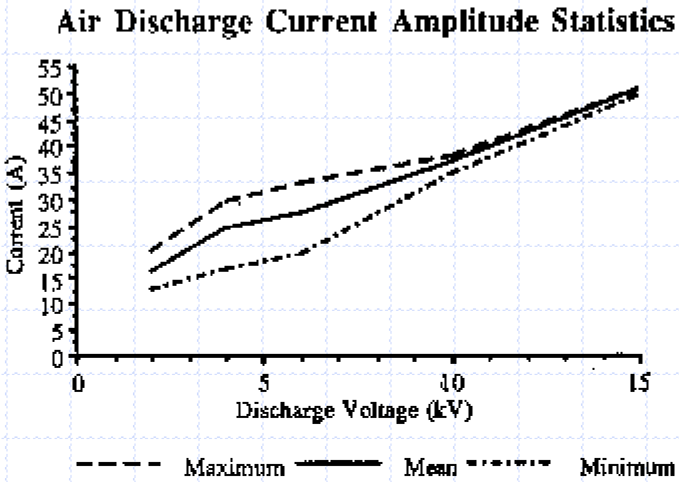


Fig. 8. Average peak air discharge current amplitude versus discharge voltage, as measured with the 6 GHz measurement system. Maximum and minimum measured values are also given.

Unlike the contact ESD, air discharges display significant variability
Both in peak current and rise time.

1GHz bandwidth is sufficient to characterize the air discharge current

Susceptibility for air v.s. contact discharge

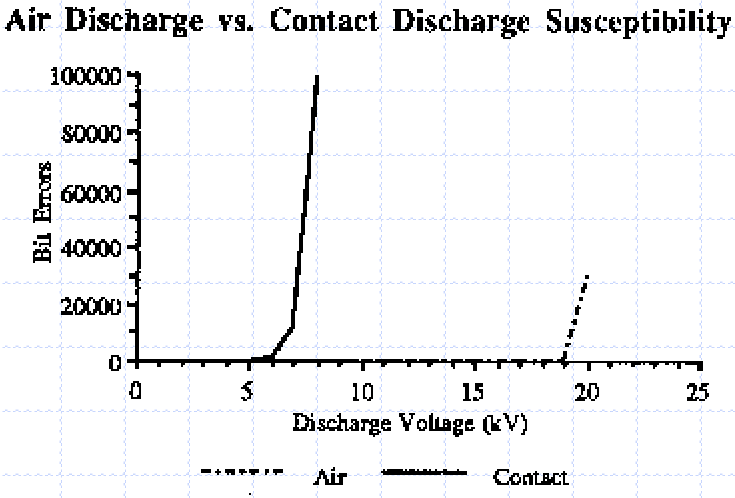


Fig. 10. Comparison of the susceptibility level resulting from air discharge testing and contact discharge testing, for an EUT.

Radiated Fields by ESD

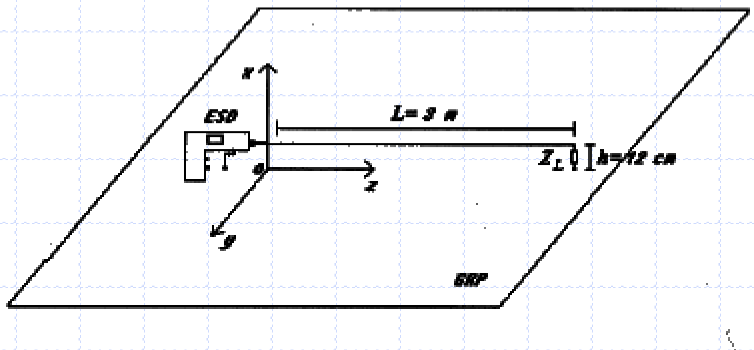


Fig. 1. Geometry of the problem

How large is the E or H fields ??

- Referring to "Theoretical and Experimental Evaluation of EM fields Radiated by ESD", IEEE EMC Symposium, 2001

Radiated Fields by ESD

4kV contact discharge v.s. current profile

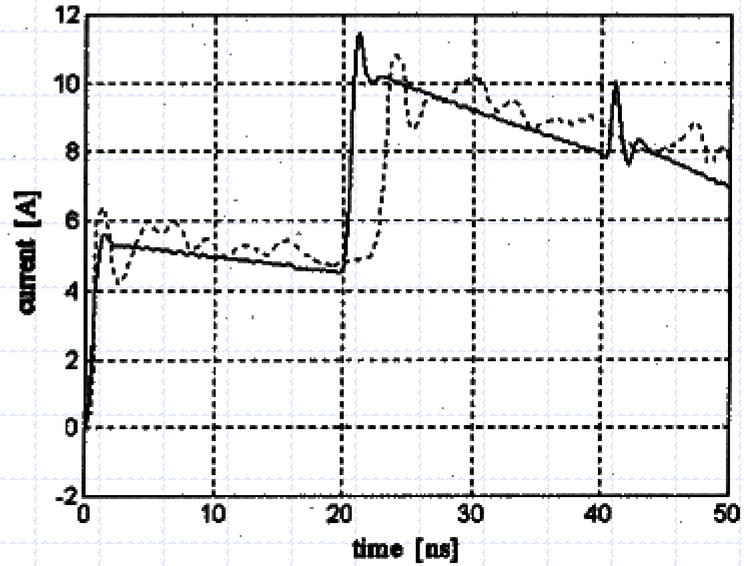


Fig.3a. Theoretical (continuos line) and experimental (dashed line) current waveform at the input port of the line and for a shorted termination.

Radiated Fields by ESD

Comparison of measured H filed

What difference between them ?? Why ?

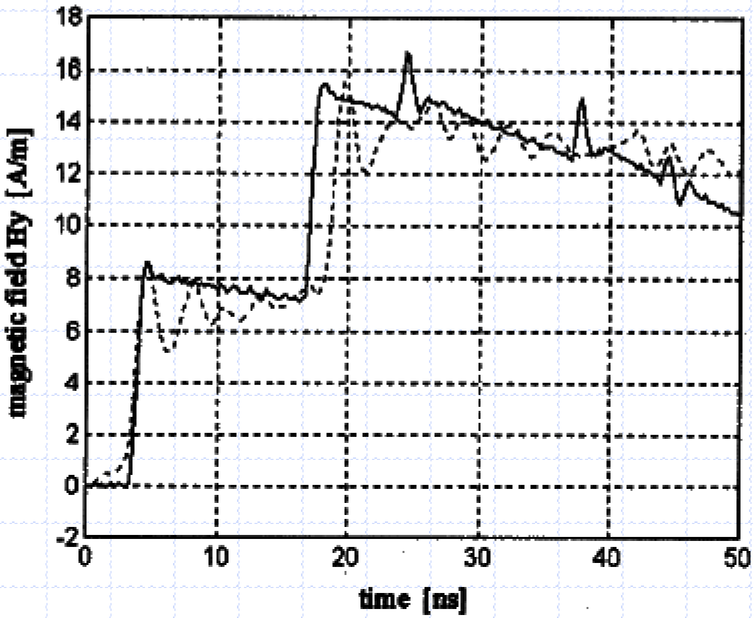


Fig.4. Radiated theoretical (continuos curve) and measured (dashed curve) magnetic field in the point at 8 cm above the line.

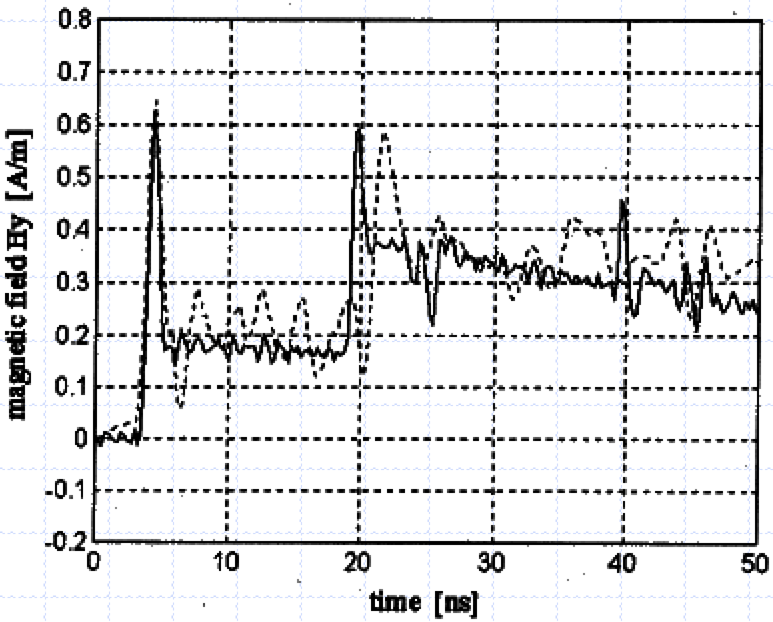


Fig.5. Radiated theoretical (continuos curve) and measured (dashed curve) magnetic field in the point B(1m, 0m, 0.5m).

About 8cm distance

About 1m distance

Radiated Fields by ESD

- Amplitude
- Near field v.s. far field

Radiated Fields by ESD

At the near field region, the H filed is proportional to **the current i(t)**

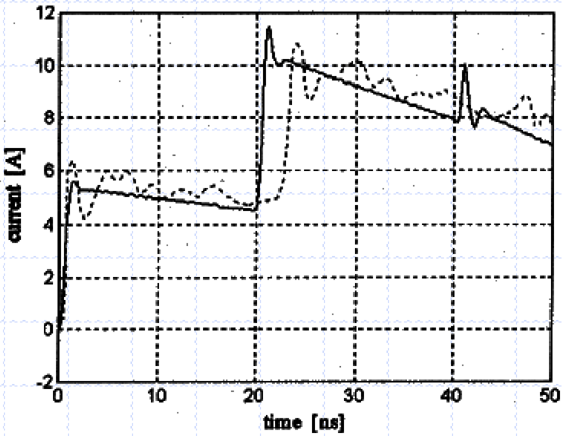


Fig.3a. Theoretical (continuos line) and experimental (dashed line) current waveform at the input port of the line and for a shorted termination.

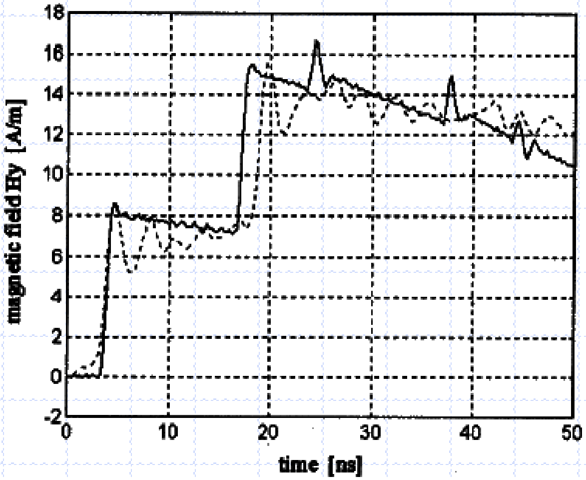


Fig.4. Radiated theoretical (continuos curve) and measured (dashed curve) magnetic field in the point at 8 cm above the line.

Radiated Fields by ESD

At the far field region,
the H filed is proportional to the **current derivative d i(t)/dt**

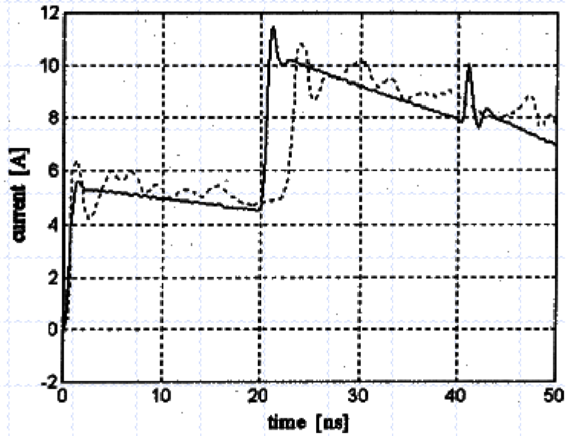


Fig.3a. Theoretical (continuos line) and experimental (dashed line) current waveform at the input port of the line and for a shorted termination.

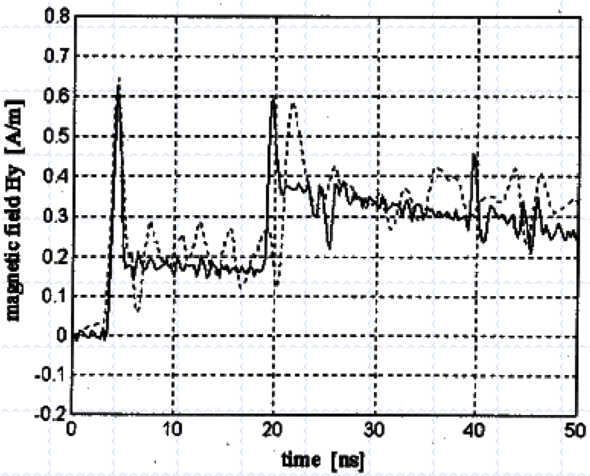


Fig.5. Radiated theoretical (continuos curve) and measured (dashed curve) magnetic field in the point B(1m, 0m, 0.5m).

Do you have any idea that how large is this level of H field ??

Radiated Fields by ESD

Using the wave impedance of plane wave (377 ohm), the corresponding E filed is about 200V/m. Is that large !

Question: At the near field, is E or H field dominant ?

Radiated Fields by ESD (near field measurement)

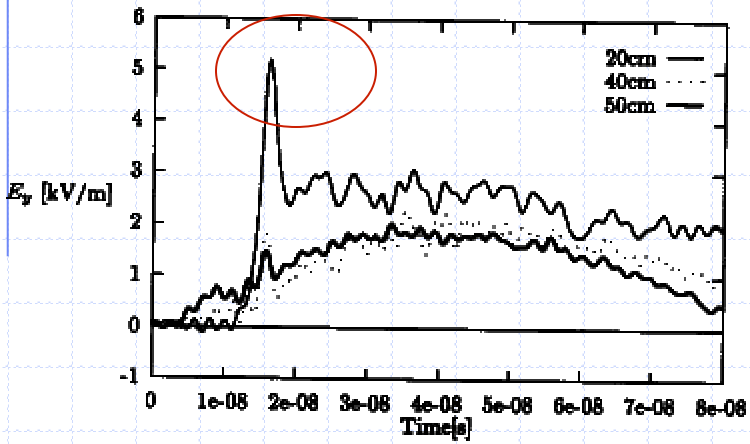


Figure 4: Measured vertical E-field.

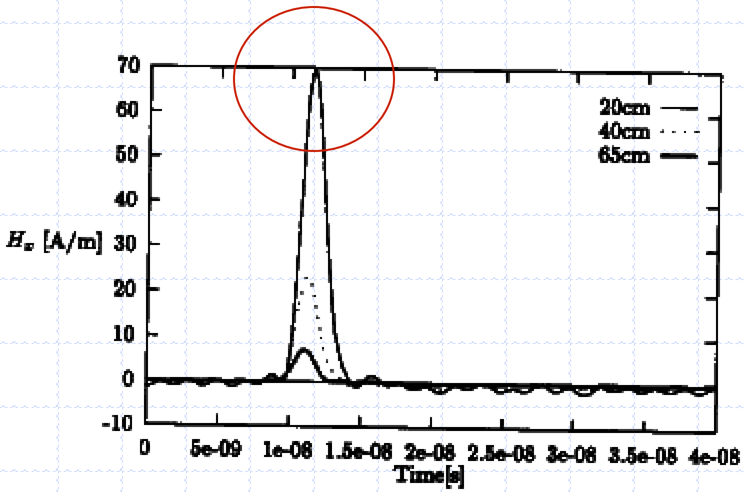


Figure 6: Measured H-field.

The impedance is only about 5kV / 70 (A/m) = 70 ohm !!