ELECTROSTATIC DISCHARGE CONTACT

What is ESD?

Electrostatic Discharge (ESD) is a phenomenon where static electricity discharge happens between two electrically charged objects when they are in close proximity, such as the human finger approaching an electronic device. The high current pulse generated by the discharge process can flow into the electronic device, causing damage to internal PCBs and IC devices. With the trend in the electronics industry to increase operating speeds and decrease operating voltages of electronic components, devices are even more susceptible to ESD and designing-in protection to avoid damage, upset or failure is essential.

ESD IEC standard

To ensure the reproducibility of test results, the majority of available ESD generators are built in compliance with specifications defined in the IEC 61 000-4-2 standard. IEC 61000-4-2 describes the procedure for the calibration of the injected waveform by the ESD generator. The waveform characteristics i.e. first peak current, rise time, current at 30 ns and 60 ns are compared with the ideal generator waveform characteristics.

The ESD IEC standard defines the ESD generator test setup which is modeled using SIMULIA CST Studio Suite and the simulations are carried out for different test levels specified in the standard i.e. 2kV, 4kV, 6kV, 8kV as mentioned in table 1. Simulation results are compared with the performance requirements specified in the standard. The plot of time (ns) vs current (A) in fig 1 below shows the ideal performance of an ESD generator. The waveform is mainly characterized by its rise time, first peak current of discharge, current at 30ns and 60ns.

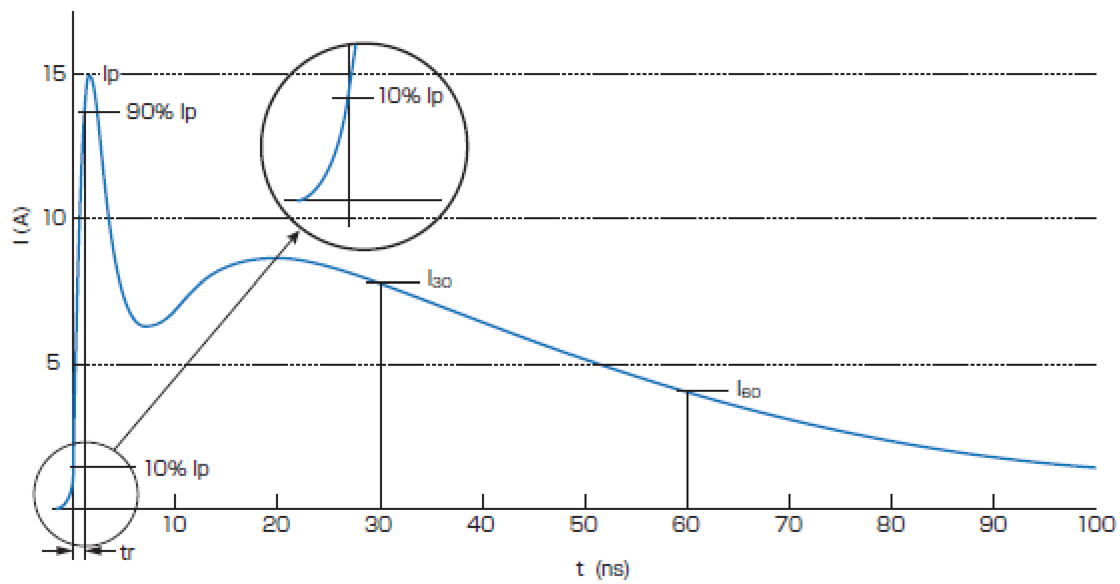

Fig1: Contact discharge current waveform as per the IEC 61000-4-2 standard

Level	Indicated voltage	1st peak current of discharge (±15%) Ip	Rise time (±25%)	Current (±30%) at 30ns	Current (±30%) at 60ns
1	2kV	7.5A	0.8ns	4A	2A
2	4kV	15A	0.8ns	8A	4A
3	6kV	22.5A	0.8ns	12A	6A
4	8kV	30A	0.8ns	16A	8A

Table 1: Contact discharge current waveform parameters as per IEC 61000-4-2 standard

Objective

Although there have been various ESD generator design studies already performed to closely match their performance with the ESD standard, there is little information regarding the tuning of ESD generator performance using its sub components. This paper investigates the effect of varying ESD generator design parameters through simulation. The ESD generator is designed and its behavior evaluated for different configurations using the CST Studio Suite TLM solver. The ESD generator performance is validated against the requirements specified in the standard and also by comparing with measurement results in various publications.

Methods of ESD testing

The standard defines two methods of ESD testing: **contact discharge and air discharge**. In the contact discharge method, the electrode of the test generator is held in direct contact with a conducting part of the equipment under test (EUT) and the discharge actuated by the discharge switch within the generator. In the air discharge method, the charged electrode of the test generator is brought close to the EUT and the discharge results from an arc forming between the electrode and EUT.

ESD generator model for Contact Discharge

ESD generators are commonly used to reproduce typical human body discharges, enabling products to be tested for ESD susceptibility. Accurate and efficient 3D modeling and meshing of the generator is a critical aspect of ESD simulation.

Since the practical design of ESD generators is complex, an equivalent simplified 3D model is developed using CST Studio Suite. The ESD generator model contains various metallic and dielectric parts, lumped element circuits and ports for excitation. As we can see in fig 2 the CST Studio Suite SESD generator model, with a 2m ground strap, is placed against a 1.2m x 1.2m metal wall, as per the calibration configuration defined in the IEC standard, and simulated in CST Studio Suite to study its behavior and validate its performance.

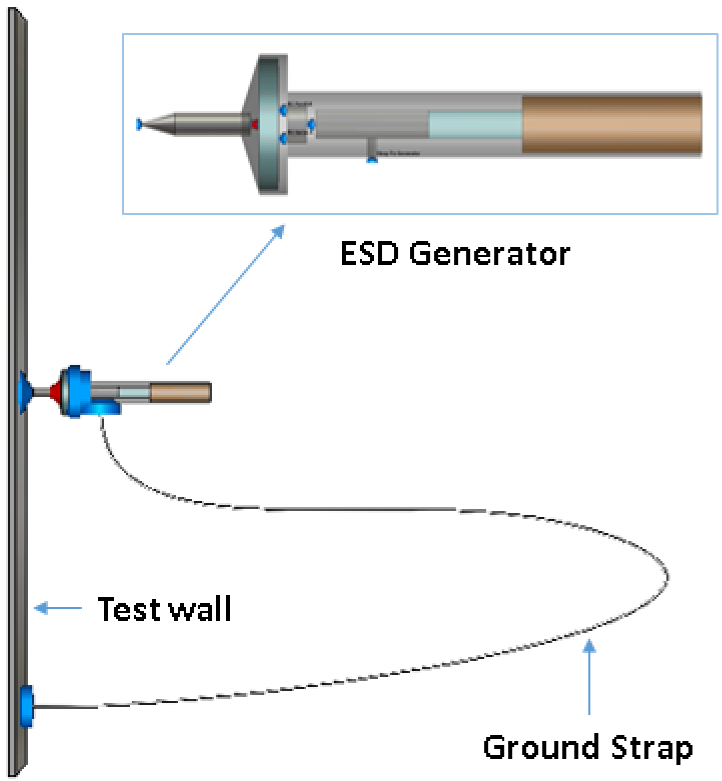

Fig 2: ESD generator design and calibration setup

Fig 3 shows the tip current of the simulated ESD generator model which closely follows the IEC ESD standard waveform at 4kV discharge voltage. Similar simulations are carried out for 5 different excitation voltage levels as can be seen in fig 4. All the results satisfy the criteria such as rise time, peak current level and voltages at different time instances as mentioned in the IEC standard.

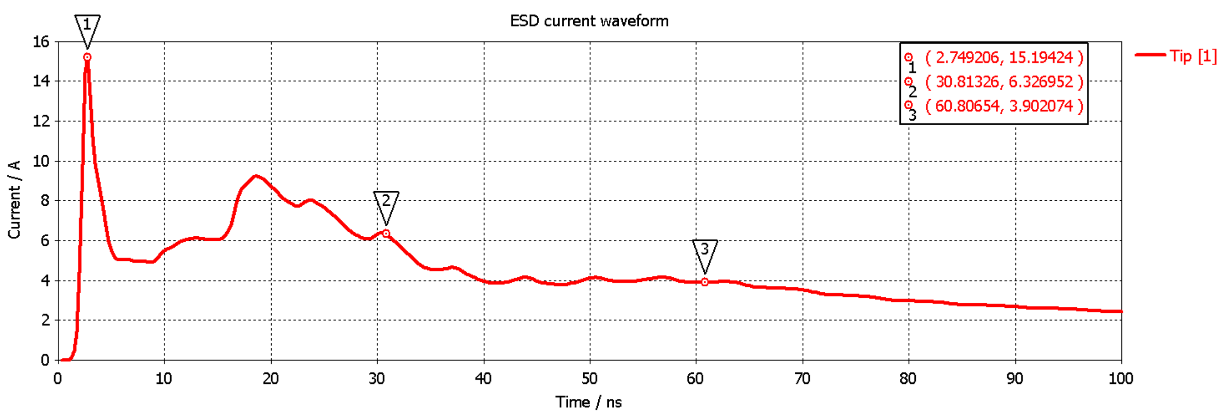

Fig 3: Contact discharge current waveform of designed ESD generator

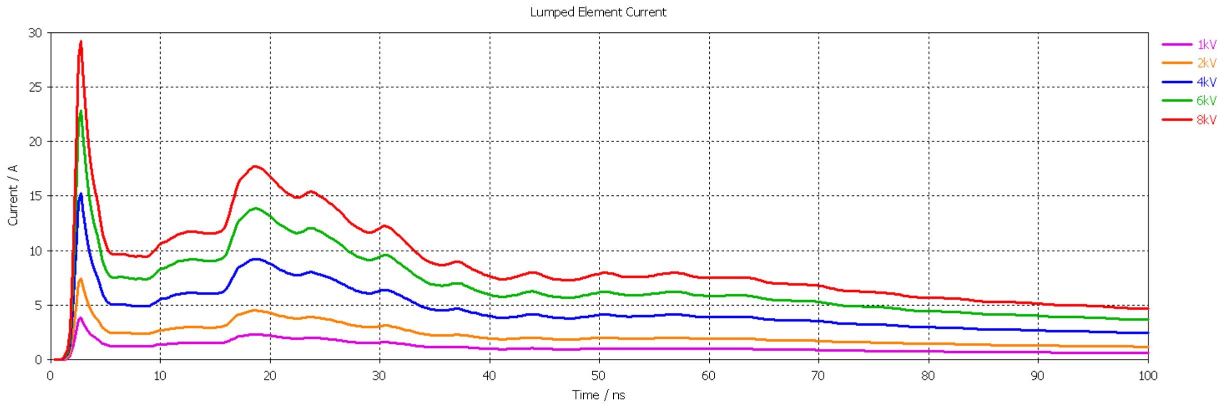

Fig 4: Contact discharge current waveform for different discharge voltage levels

This compliant behavior of the ESD generator is obtained by tuning certain parameters such as the tip design, ground strap geometry, strap inductance etc. Some of these major parameters are investigated in the following sections for input excitation voltage of 4kV.

Effect of ground strap thickness

With reference to the ESD standard, the ESD generator is equipped with a 2m long grounding cable which provides a return path for the discharge current. The ESD standard does not specify a value for the ground strap thickness or diameter. It is important to understand the role of the ground strap thickness, since it directly contributes to the overall inductance and therefore affects the discharge waveform

Theoretically the self-inductance of a wire is controlled by its physical parameters such as length and radius, which affects the current flowing through the cable. Similar behavior can be observed by simulating a 2m long strap with different thicknesses or radii using the CST Studio Suite Partial RLC solver. As we can see in fig 5, the partial inductance is inversely proportional to the strap radius.

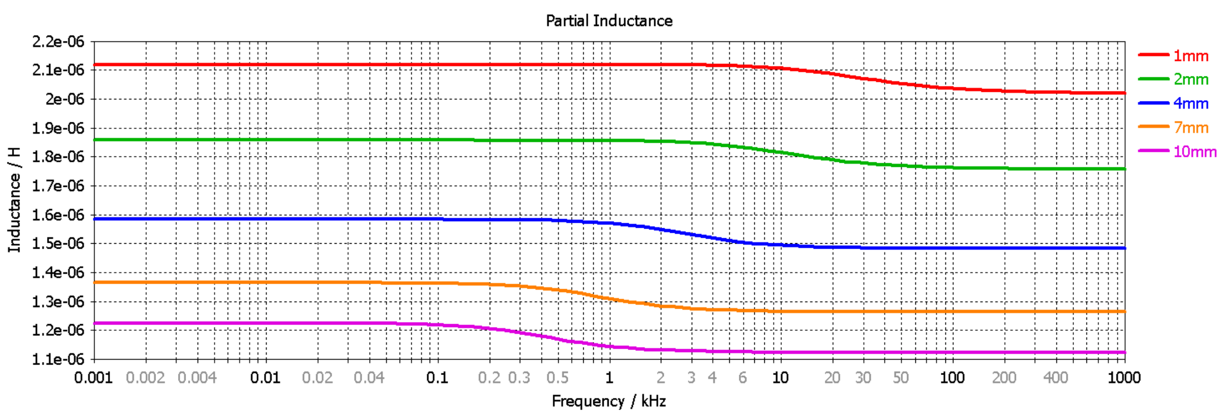

Fig 5: Partial inductance of ground strap at low frequency for different radii

The ESD generator ground strap evaluated in this paper is approximately 2m. As we can see in fig 6, the ESD generator discharge performance after the 1st peak is affected by strap radius, due to the variance in self-inductance, which plays a major role in shifting the second peak of the ESD waveform.

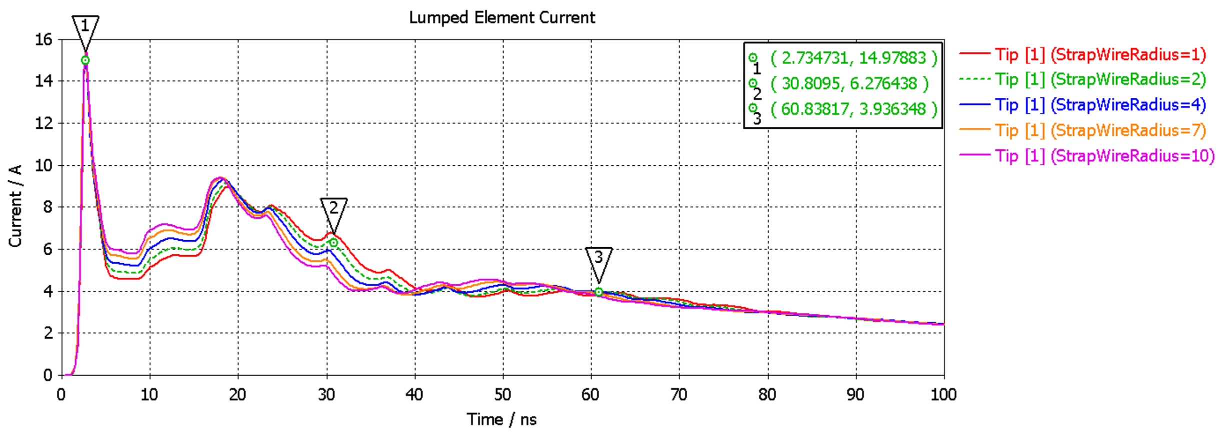

Fig 6: Contact discharge current waveform for different strap radii

Effect of ground strap Length

As per the ESD standard, the minimum length of ground strap required for calibration is 2m, and if this is not sufficient, the length may be extended up to 3m to match performance with the standard. The ground strap length contributes to the position of the second peak, due to loop inductance. Some publications show the use of a shorter ground strap by adding lumped elements in series with the ground strap to increase its length electrically. Though this approximation may be reasonable in some circumstances, we generally recommend modeling the true length of the ground strap to ensure that its impact on the electromagnetic fields and discharge waveform is modeled accurately.

As can be seen in fig 7, the partial inductance is directly proportional to ground strap length at low frequencies. In fig 8 we can observe that increasing the length of the ground strap to 3m reduces ringing in the ESD waveform, particularly after the first peak.

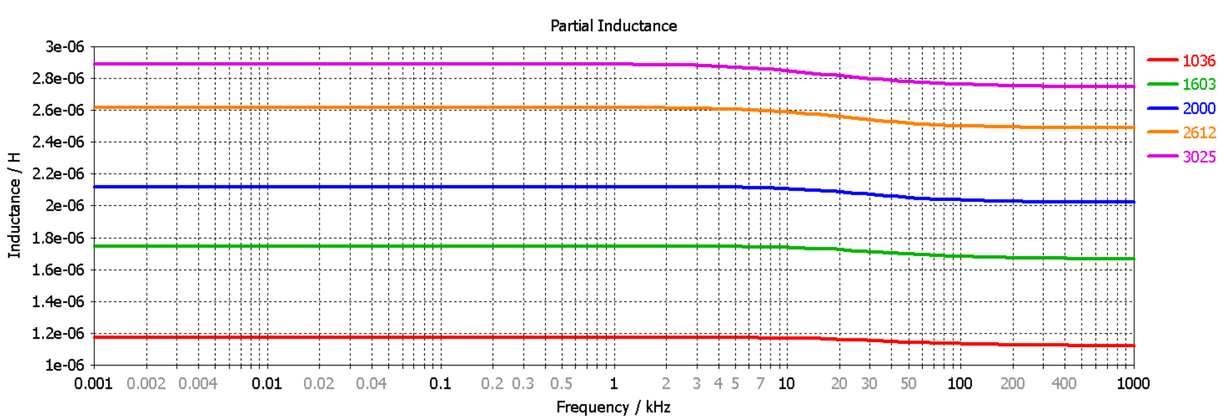

Fig 7: Partial inductance of ground strap at low frequency for different strap length (mm)

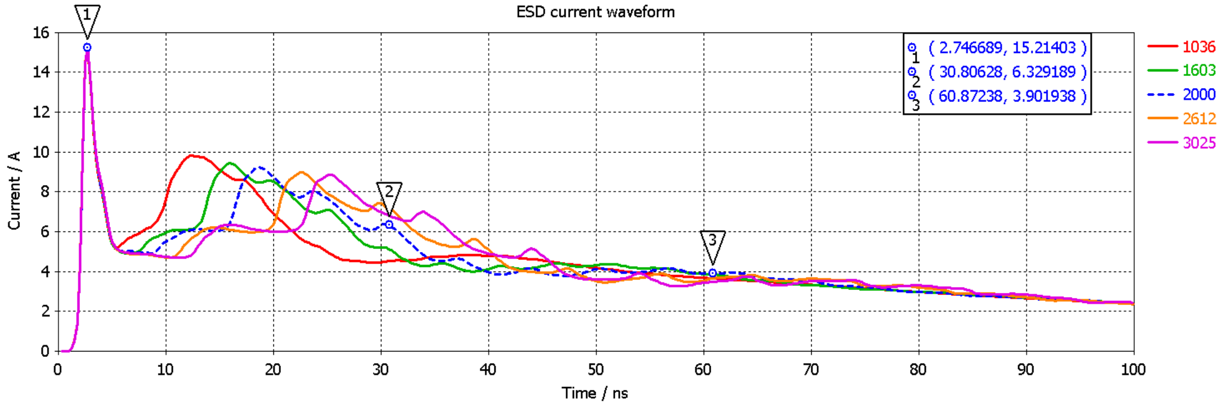

Fig 8: Contact discharge current waveform for different strap length (mm)

The increase in length of the ground strap, increases loop inductance in the return path, which produces less deviation from the ideal values in the second and higher peaks of the generated ESD waveform.

Effect of ground strap shape on its partial Inductance

During practical ESD testing it is possible that the ground strap can take different paths, forming different loop configurations, some of which are shown in fig 9. This ultimately affects the loop inductance associated with the ground strap, which influences the ESD discharge profile after the first peak. These type of analysis can be performed using the CST Studio Suite Partial RLC solver. We can observe in fig 9 how different loop configurations of a constant 2m long ground strap affect partial inductance. Using this kind of study one can decide on ground strap shape to be considered during the physical test.

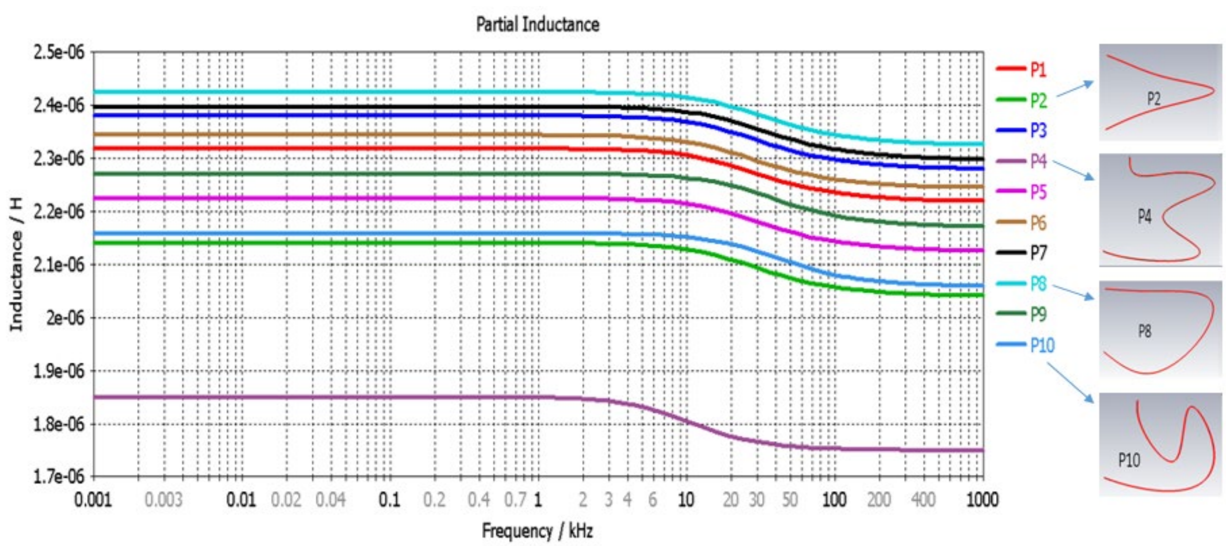

Fig 9: Partial inductance of ground strap for different loop configurations

Effect of lumped Inductance between ground strap and ESD generator

Due to limitations of ground strap length it may be difficult to control the overall inductance of the ESD generator to produce a desired ESD pulse. Extending the length may introduce more ringing in the pulse after the first peak. These challenges can be mitigated by attaching a lumped inductance of e.g. 1nH between the ground strap and ESD generator. Since this series lumped inductance will add to the ground strap self-inductance we should choose its value carefully. In a physical ESD generator it, is not practical to tune a lumped element value for each test. But through simulation we can decide on the value suitable for a specific ESD generator performance.

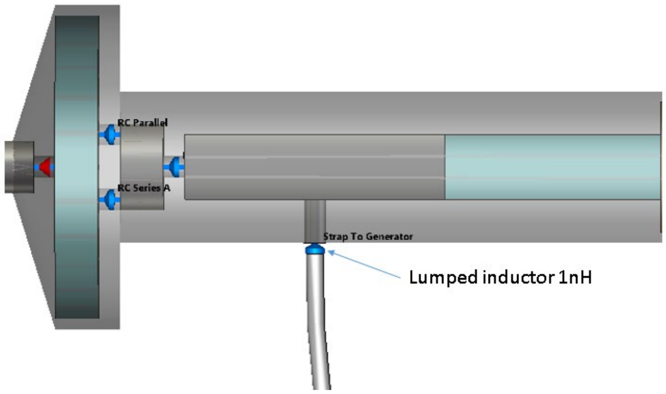

Fig 10: Lumped element between ESD generator and ground strap

The model in this paper uses a 1nH lumped inductor between the ground strap and ESD generator a shown in fig 10, since this represents a good tradeoff between cable length and generator performance. As we can see in fig 11, adding a higher value of inductance affects the waveform severely, which can violate the IEC standard specifications for the ESD generator. The behavior of the ESD waveform when using a 1nH inductor closely matches the IEC standard, so it the value chosen for the design.

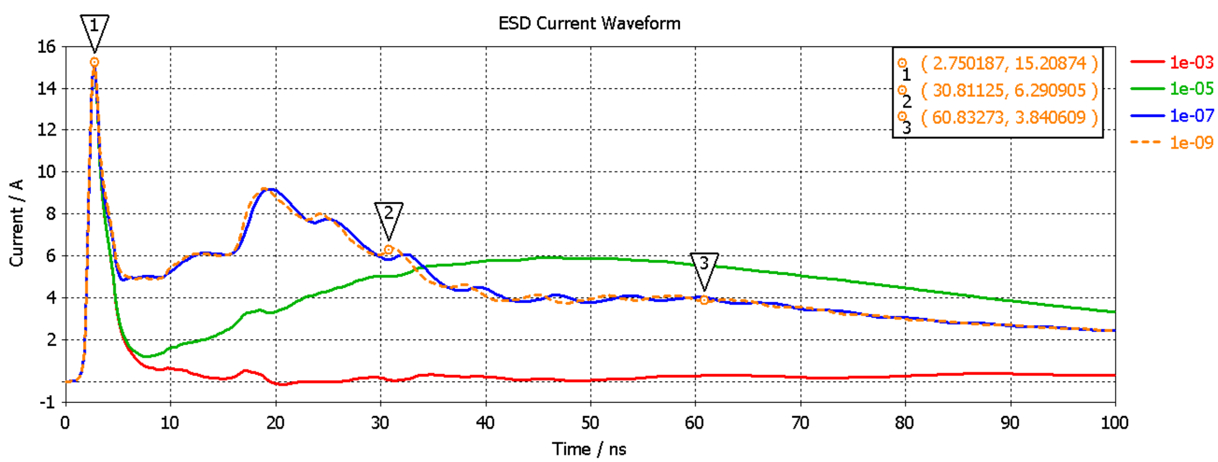

Fig 11: Contact discharge current waveform for different strap lumped inductance values

ESD generator behavior at test setup

Before validation of the ESD generator with a EUT, its behavior is studied over a test setup as shown in fig 12. The test setup arrangement is modeled as per the guidelines of IEC 61 000-4-2 standard using CST Studio Suite. The bleed resistor used at both ends of the discharge resistance wire eliminates ESD gradually.

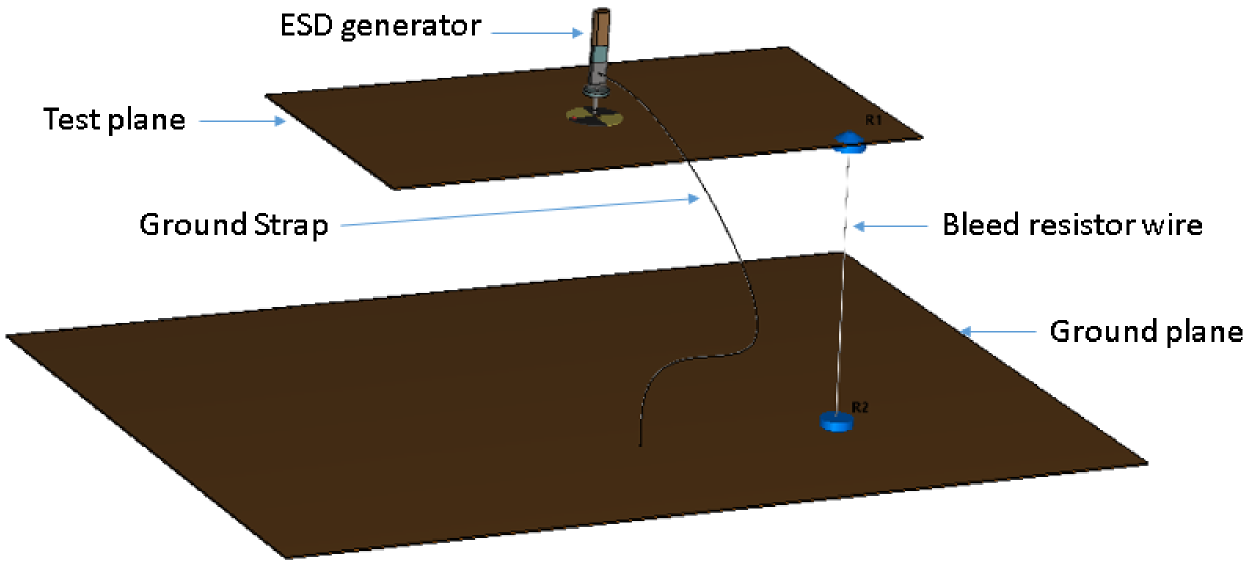

Fig 12: ESD generator with test setup

The behavior of the ESD generator for 4kV input voltage is monitored without any EUT as shown in fig 13. We can see that the early response and initial peak of the ESD generator is the same as the original model, while there is only variation in the “tail” of the discharge profile as expected. So during a virtual ESD test simulation, one can place the EUT over the test plane and exclude the ground plane and bleed resistor wire.

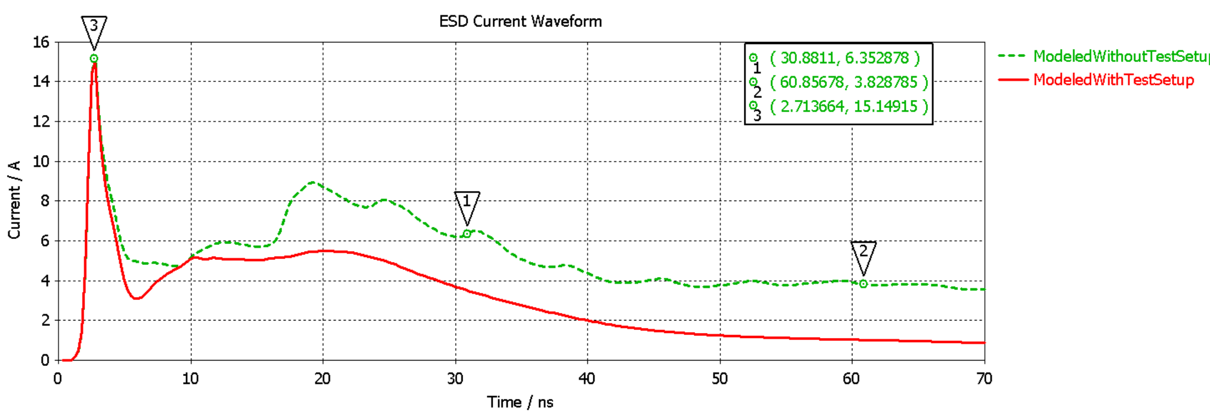

Fig 13: Behavior of ESD generator

Validation with measurement results

To validate the designed ESD generator with measurement results a reference has been taken from the conference paper, “ESD excitation model for susceptibility study”, published in the proceedings of the 2003 IEEE Symposium on Electromagnetic Compatibility [Ref]

In fig 14 we can see a cross sectional view of the model using CST Studio Suite. In this approach the ESD generator is contact discharged onto a metal enclosure with a rectangular slot in center. The voltage induced in a square loop located inside and top center of the enclosure is recorded and validated with measurement results.

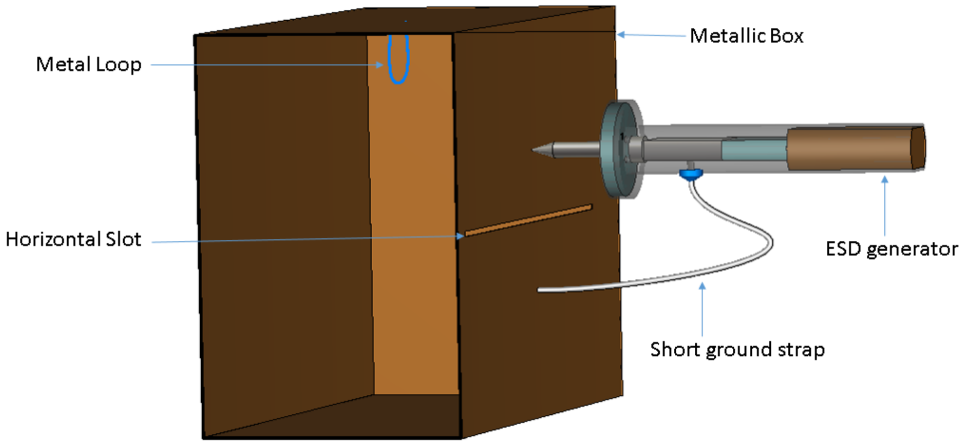

Fig 14: ESD generator discharging onto metal enclosure

As measurements were carried out for a 1kV discharge, similar conditions are setup in the simulation as well. Fig 15 shows the voltage induced on the loop. The sinusoidal behavior is due to the slot filtering the response and resonating at a frequency where the slot length is equivalent to ½ wavelength. The simulated and measured data show good agreement.

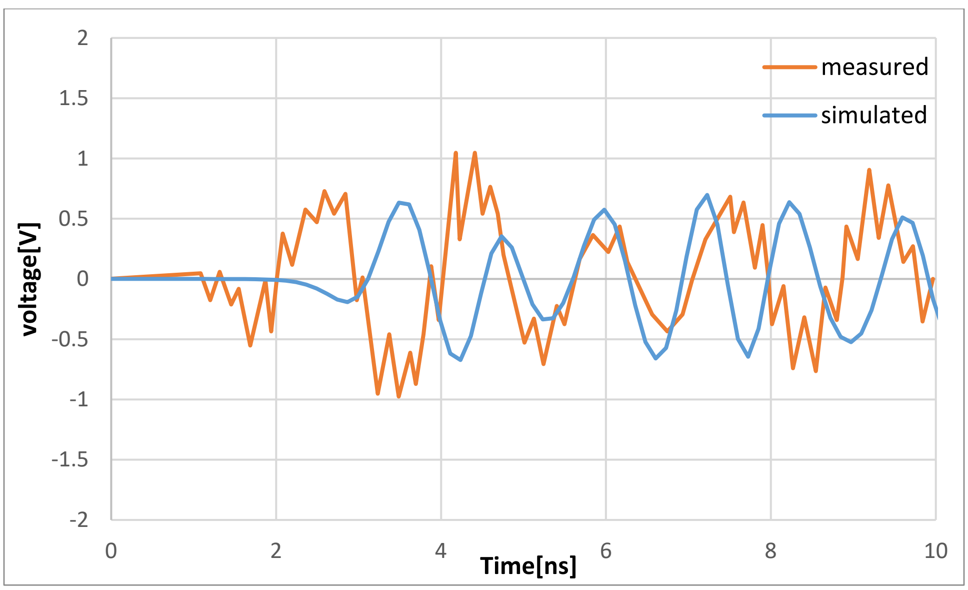

Fig 15: Voltage induced in the enclosed square loop for the first 10 ns

As shown in fig 16 and 17 the ESD generator tip current and strap current also show good agreement between simulated and measurement results.

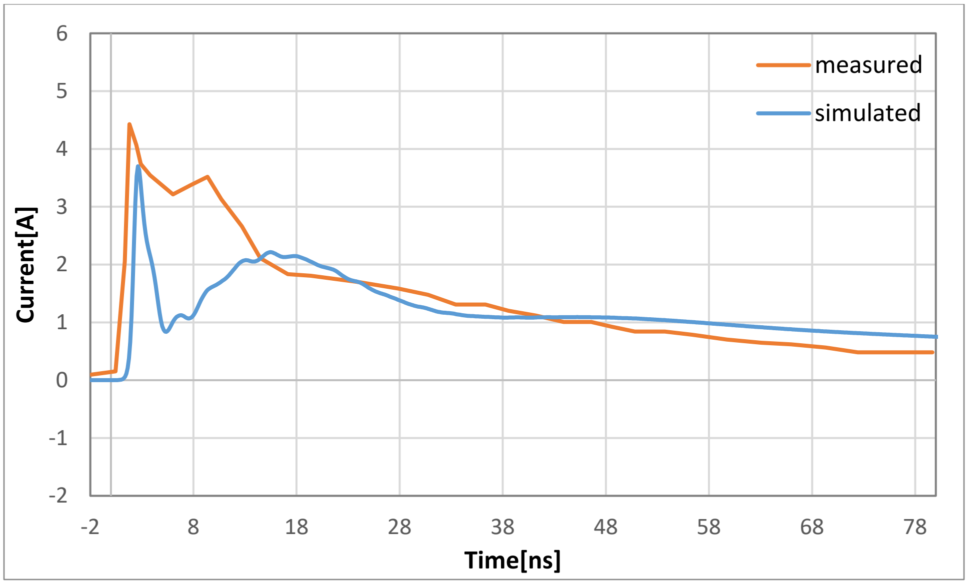

Fig 16: Current in the tip of the ESD generator

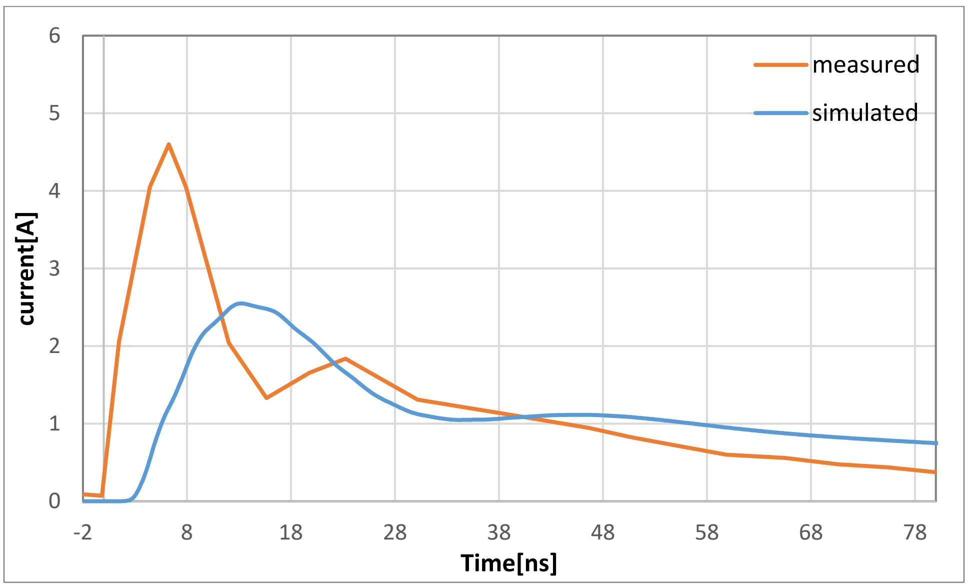

Fig 17: Current in the strap of the ESD generator

Surface current visualization over the setup gives us insight into the current distribution and intensity. Fig 18 plots the surface current at a frequency of 1 GHz. The current return path from the ESD generator tip, to the enclosure, around the horizontal slot and back through the ground strap can be clearly seen. We can also animate the surface current phase to visualize current flow propagation. Time animations can also be generated to show the time varying current flow.

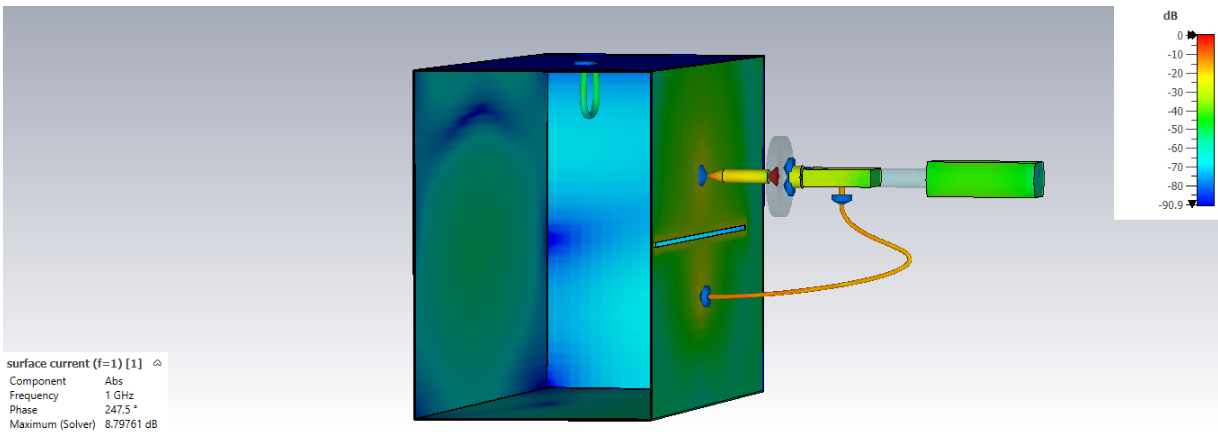

Fig 18: Surface current on box and loop inside due to slot

Discharge into the HORZIONTAL and VERTICAL coupling planes

To test the robustness of the ESD generator model for indirect discharges, it is configured with a horizontal coupling plane (HCP) and vertical coupling plane (VCP). A wire representing a computer mouse wire is placed near to the VCP. The test setup and measurement values shown in fig 19 are from the following conference paper, “ESD excitation model for susceptibility study”, published on 2003 IEEE Symposium on Electromagnetic Compatibility [Ref].

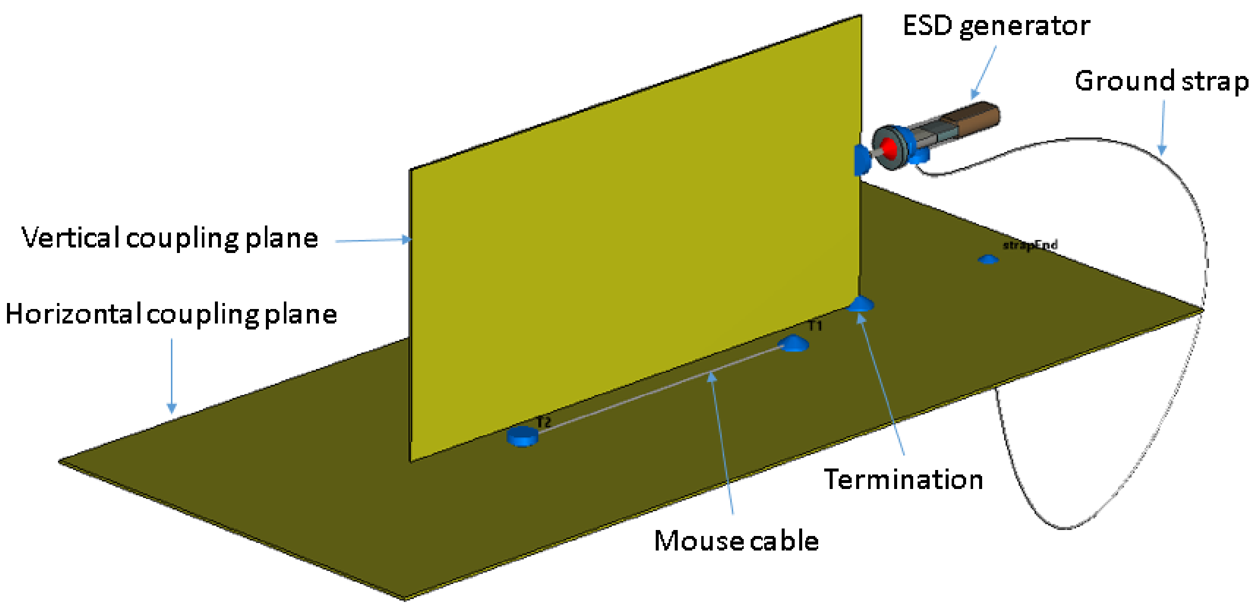

Fig19: Horizontal and Vertical coupling plane setup

For validation purposes, the voltage induced in the near end of the mouse cable is outputted for two scenarios. In the first case, fig 20, the VCP was not terminated to the HCP using a 50 Ohm resistor while in another case, fig 21, the VCP was terminated.

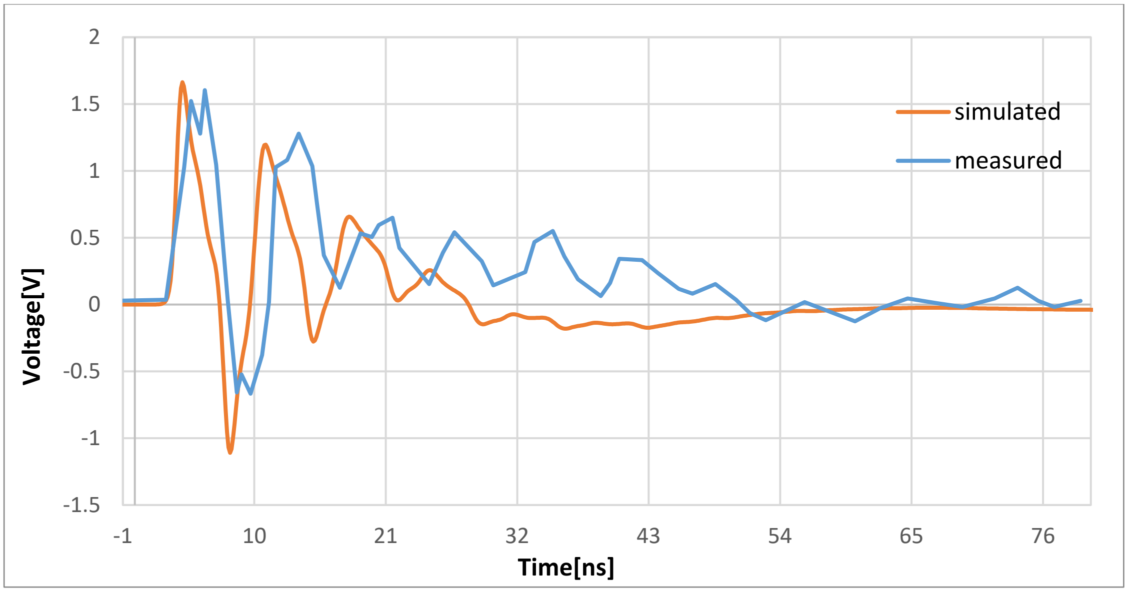

Fig 20: Voltage induced in the near end of the mouse cable when the VCP was not terminated

Good agreement seen between measured and simulated results in its characteristic part. We can observe more resonance in terminated case fig 21 than the non-terminated case fig 20. The delay in first peak of induced voltages is due to the delay in rise time of input pulse.

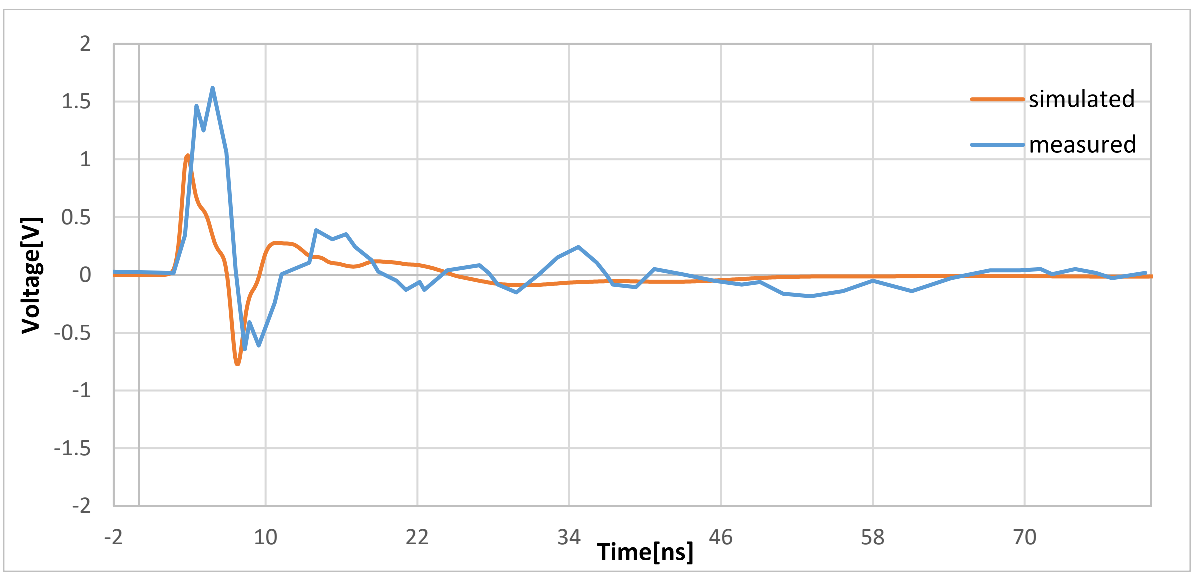

Fig 21: Voltage induced in the near end of the mouse cable when VCP was terminated

Virtual ESD test of a smartphone device

A smartphone model is placed over a test plane and contact discharge is performed on its conducting body to test its ESD susceptibility. Two different discharge locations are considered, which are typically more prone to ESD, first is the charging slot connector shield and another is the metal frame ring.

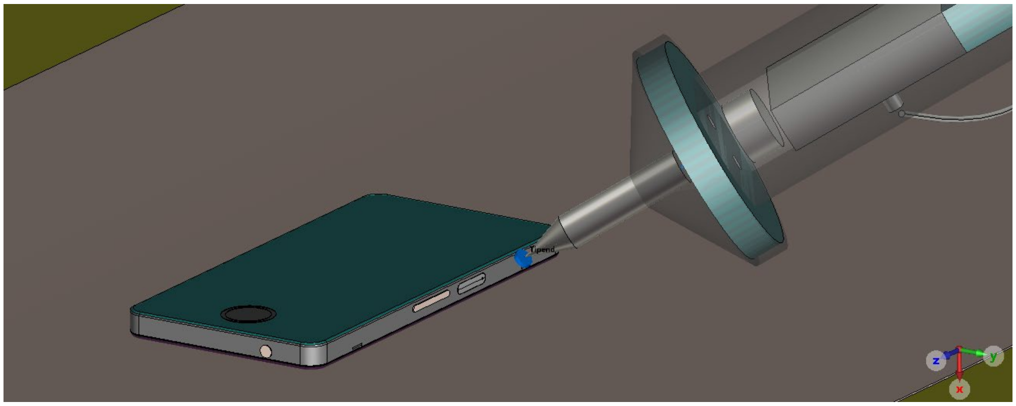

Fig 22: contact discharge on the metal frame of the phone

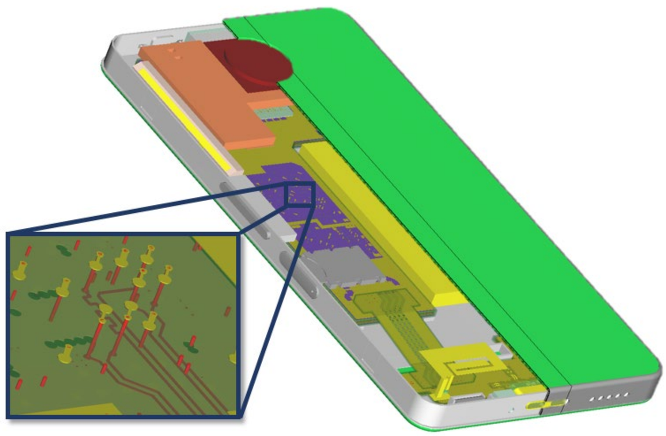

Fig 23: PCB ports where effect of induced current is recorded

As we can see in fig 22, an 8kV ESD pulse from the generator is injected through contact discharge to the outer metallic frame of the smartphone. This ESD may damage IC's inside the smartphone, if it crosses the standard USB current limits. So as to monitor the same, current levels at the IC pins as shown in fig 23 are observed. Using these levels one can decide on severity of induced current on the pins. As we can see in fig 24 these current levels are well below the current limits specified in the USB standard. If these levels exceed the standard levels, protection methods should be used.

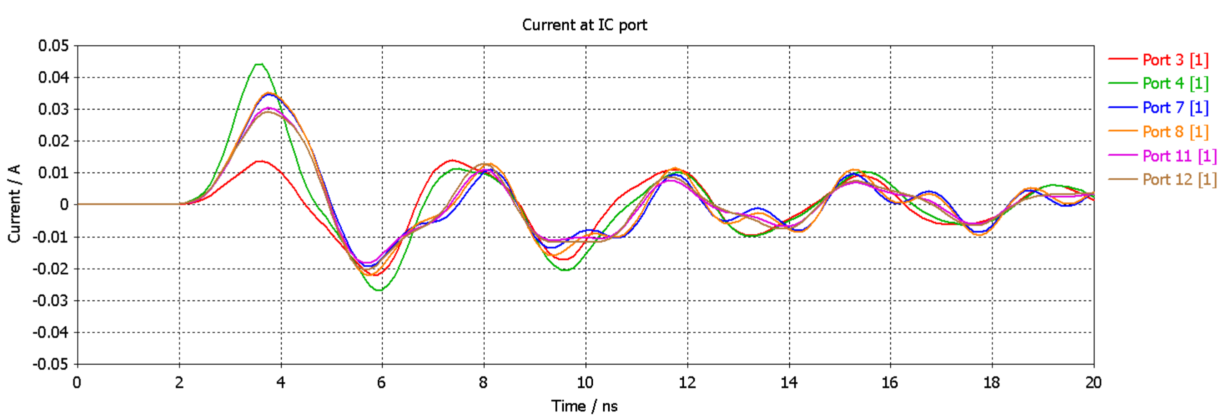

Fig 24: Current levels at port pins due to contact discharge of 8kV

During actual ESD test, EUT is rotate in various directions and ESD signal is applied at various test points of EUT. So, as we can see in fig 25 a virtual ESD test is also performed for direct contact to the connector shield of smartphone to study its impact on the IC pins. As we can see in fig 26 the induced current level on IC pins is lower than the standard USB current limits.

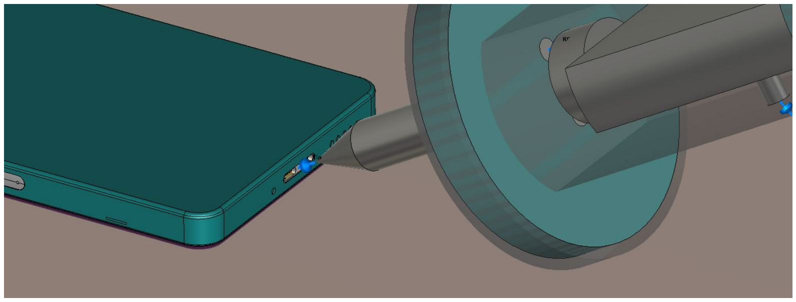

Fig 25: contact discharge on the charging pin connector shield of phone

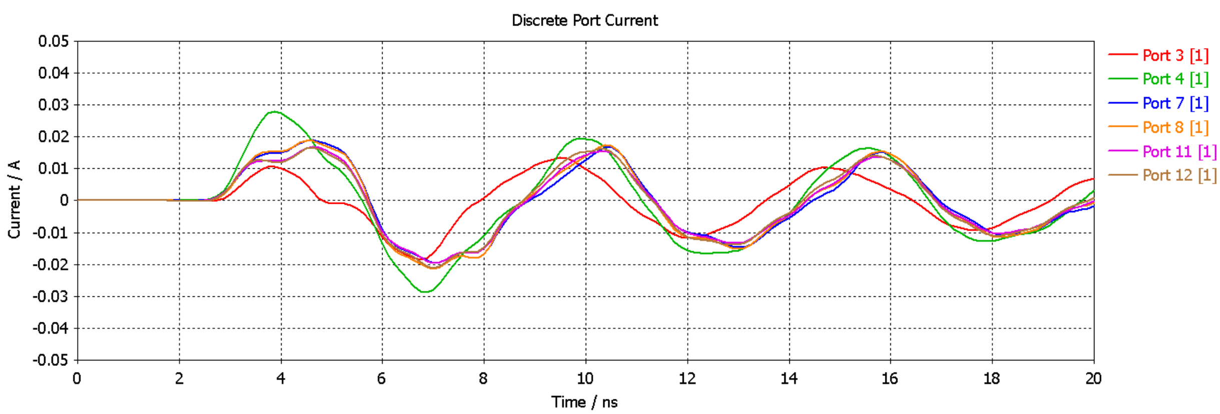

Fig 26: current levels at port pins due to contact discharge of 8kV on the charging pin connector shield

Conclusion

ESD is a very important phenomenon in the electronics world. Before a physical lab test one can predict adverse effects on a EUT through 3D ESD simulation.

A simplified model of a typical ESD generator has been developed for CST Studio Suite. It allows for the accurate modeling of ESD current and field responses. It is possible to evaluate ESD performance virtually through simulation before fabrication or manufacturing. One can analyze the effects of various parts of the ESD generator on its performance and it can be matched as per the IEC standard.

The virtual prototypes designed and simulated to compare the performance of ESD generator with measurement values shows the good accuracy. It is also showcased that how one can setup the ESD test setup for electronic EUT before actual ESD test using CST Studio Suite. This practices helps in minimizing human efforts and development of go to market product in less time.

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