ELECTROSTATIC DISCHARGE
AIR

What is ESD?

Electrostatic Discharge (ESD) is a phenomenon where static electricity discharge happens between two electrically charged objects when they come into contact with each other, such as the human body and an electronic device. This high voltage ESD pulse generated from the human body can enter the electronic device if touched, causing damage to IC circuits inside it. With increasing operating speed and decreasing operating voltage of electronic components the problem of ESD is a severe source of interference which can produce damage, upset or failure in electronic systems.

ESD IEC standard

To ensure the reproducibility of test results, the majority of available ESD generators are built in compliance with the specifications of the IEC 61 000-4-2 standard. This standard describes the procedure for the calibration of the injected waveform by the ESD generator. The waveform characteristics of the ESD generator are compared with ideal waveform characteristics documented in the standard.

The plot of current (A) vs time (ns) shown in fig 1 below presents the ideal performance of an ESD generator in contact discharge mode. The behavior of the waveform is mainly determined by its rise time, first peak current of discharge, current at 30ns and current at 60ns.

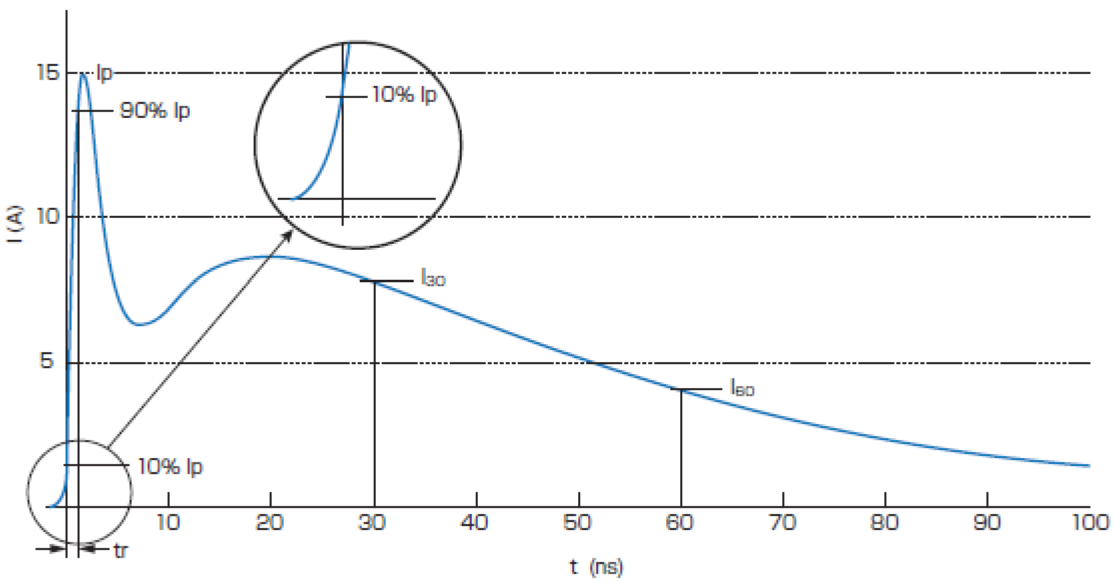

Fig 1: ESD current waveform as per the IEC 61000-4-2 standard

Objective

Air discharge is used when there are no exposed conducting parts, for example to the insulating plastic or glass cover of a smart phone. An arc forms between the tip of the ESD generator and the device under test (DUT). Air discharge current rise time and peak amplitude varies depending on arc discharge path length. Arc path length depends on both humidity and speed of approach of the generator towards the DUT.

This paper proposes a method that combines the linear ESD generator full-wave model and the nonlinear arc model to simulate currents and fields in air-discharge mode. The ESD generator is designed and its behavior is evaluated for different configurations using the CST Studio Suite Transient TLM solver.

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 contact with an exposed conductor on the equipment under test (EUT) and the discharge actuated by the discharge switch within the generator. Contact discharge current enables reproducibility in the testing and certification process. In the air discharge method, the charged electrode of the test generator is brought close to the DUT and the discharge actuated by a spark to the device. The IEC 61000-4-2 standard adopts air discharge testing when contact discharge is not feasible due to the lack of exposed conductors, however this mode of testing is less reproducible than contact discharge testing.

IEC 61000-4-2 Level	Contact Discharge	Air Discharge
1	2kV	2kV
2	4kV	4kV
3	6kV	8kV
4	8kV	15kV
X	special	special

Table 1: IEC 61000-4-2 Test Levels and ESD generator parameters

In this paper ESD generator test setup is modeled using SIMULIA CST Studio Suite and the simulations are carried out for different test levels for air discharge as specified in the IEC standard i.e. 2kV, 4kV, 8kV, 15kV as mentioned in table 1. Simulation results are compared with the specific values in the standard.

ESD generator model for Air 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 for air discharge is complex, it needs to be separated into the linear sections comprising the metallic elements, resistors, capacitors and the nonlinear arc. The equivalent simplified 3D model is developed using CST Studio Suite as shown in fig 2. In case of air discharge, a round discharge tip is used for ESD generator. The advantage of this shape is dispersion strength of the electric charge compared to the conical tip used in contact discharge.

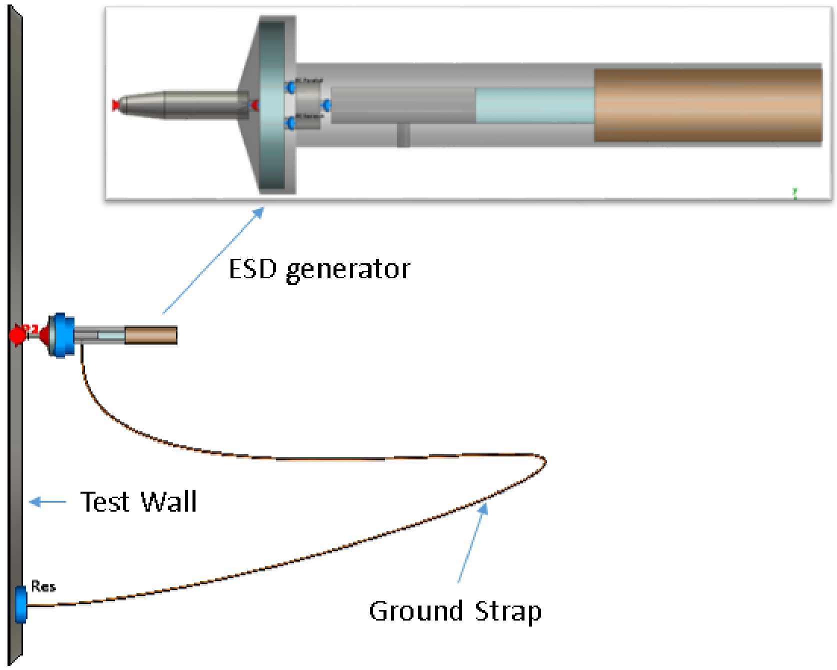

Fig 2: ESD generator design and calibration setup for air discharge

The Rompe-Weizel model

In the physical testing of an air discharge event, the charged tip is moved from a distance towards the EUT until an arc occurs. The arc is caused by the breakdown of the air in the gap between the ESD generator tip and DUT. The Rompe-Weizel model is used to model the electrical behavior of the arc and implemented using transient electromagnetic co-simulation in CST Studio Suite. The time dependent arc resistance can then be represented in the simulation and parameters varied to compare simulation results with physical test data for different arc lengths.

The Rompe and Weizel model describes the effect of the arc length on the rise time and peak current. The arc resistance is calculated as follows

$$R(t) = \frac{d}{\mathrm{sqrt}(2a \int_0^t i(\xi)^2 d\xi}$$

Where, R is the arc resistance (Ω), d is the arc length (m), a is the empirical ionization constant and $i(\xi)$ is the discharge current (A).

Transient co-simulation

CST Studio Suite provides the capability to simultaneously solve Maxwell's equations and the arc resistance equations in the time domain to estimate the currents and fields for a given geometry, charge voltage and arc length.

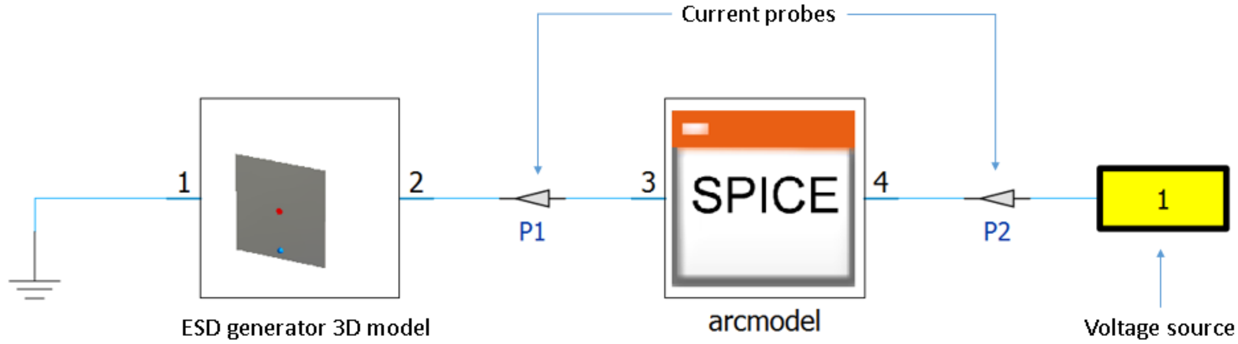

Fig 3: CST Studio Suite Cosimulation setup

In the transient co-simulation setup shown in Fig 3, the arc resistance is modeled using a SPICE block directly attached to the 3D structure. The ports in the 3D modeler connect to the circuit simulator which allows for modeling non-linear elements such as SPICE models. The SPICE model implements the Rompe Weizel law and includes arc length and ionization factor parameters which can be varied to study the effect on the ESD generator performance. During each time step, voltage and current information is exchanged between the schematic model and the 3D solver.

Effect of different Arc lengths

It is well known that air-discharge currents badly repeat even if the voltage and speed of approach are kept the same. These variations are mainly due to different arc lengths. Arc lengths longer than Paschen's limit value are possible in strongly nonhomogeneous fields.

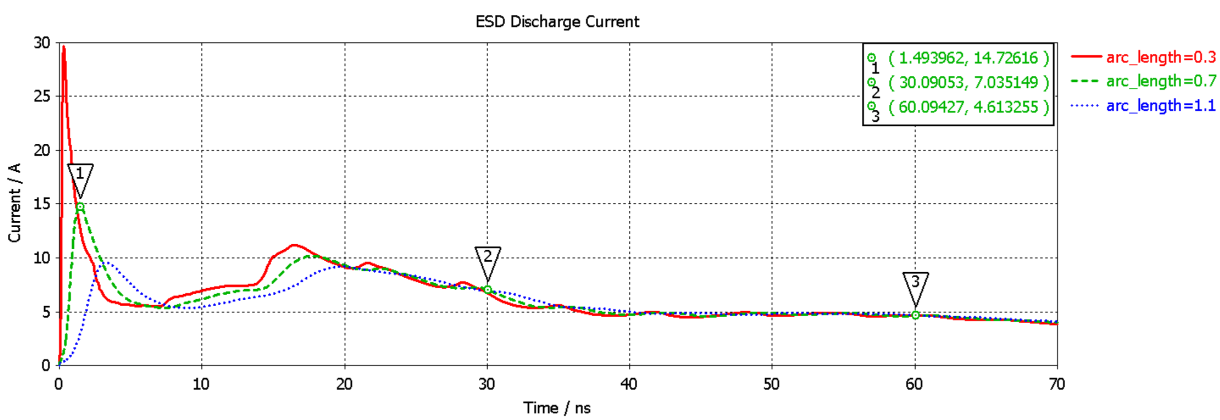

Fig 4: ESD discharge currents for different arc lengths

Fig. 4 illustrates the effect of arc length on ESD current waveform for a 5kV charge voltage. An arc length of 1.1mm equals the Paschen length; such a discharge current occurs at high humidity and slow approach speeds. This leads to a slow rise time (1.76ns) and lower current peak value (8.64A) as compared with shorter arc lengths. A moderate approach speeds occurs at arc length of 0.7mm. At this value, the rise time (0.72ns) will be somewhat similar to the rise time of a contact discharge ESD, as given in the IEC 61000-4-2 standard (0.7ns–1ns). Very short arc lengths occur at high approach speeds and in dry air; we show an example of 0.3mm in Fig 4. The simulated current peak value is 29.54A and the rise time is 0.16 ns.

Effect of Tip gap spacing

During a physical ESD test, the generator tip is moved towards EUT with different speeds until an arc occurs. At the time of discharge, the arc length equals the distance between the DUT and generator tip. An similar setup is simulated in CST Studio Suite with three different arc lengths for a discharge voltage of 5kV is shown in fig 5. This analysis helps in the selection of an appropriate arc length for a desired peak current value.

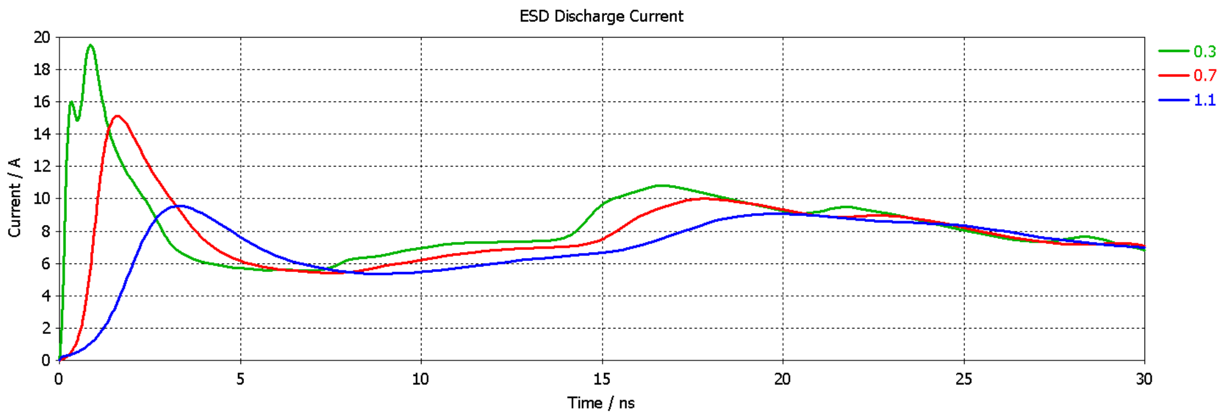

Fig 5: ESD discharge currents for same arc length and tip gap from test wall

Effect of *aR* variation

Ideally, the empirical ionization constant, *aR* would be a constant. But due to the simplifications in Rompe and Weizel's law, there will be some deviations between the real arc resistance and the calculated values. Literature values for *aR* in air under normal pressure are mostly in the range of 0.5x10^{-4} to 4x10^{-4} m^2/V^2sec. The reference values of *aR* for some voltage levels can be referred from, "Computer Simulation of ESD from voluminous objects compared to transient fields of humans" [1].

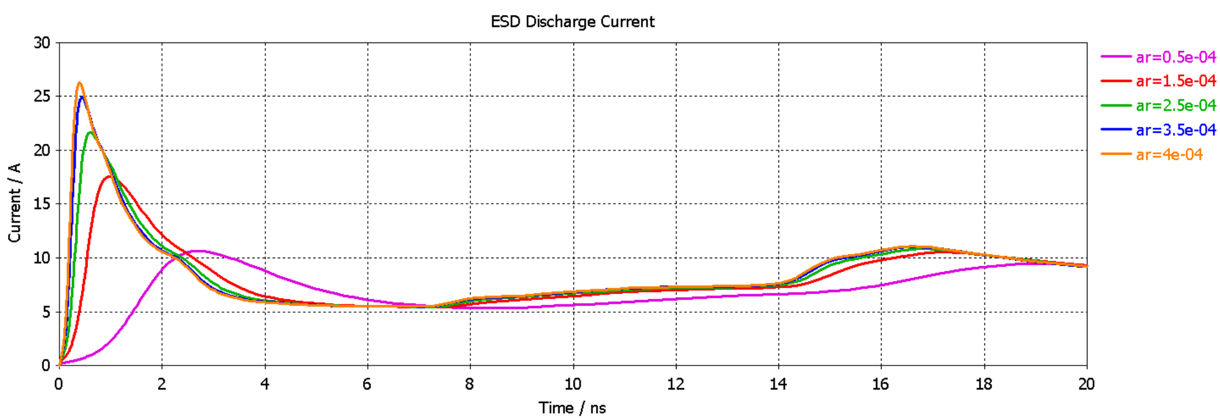

Fig 5: ESD discharge currents for different aR values

Using CST Studio Suite, a parametric analysis for *aR* is completed as shown in fig 6. This can help in the selection of appropriate *aR* values to match ESD generator performance with the IEC standard. Generally for lower operating voltages a higher *aR* value is needed to match the performance with the IEC ESD standard.

Performance for different voltage levels

As the designed ESD generator should comply with the IEC ESD standard it is necessary to verify its performance for different supply voltages as per the standard. The ESD generator designed in CST Studio Suite is simulated with different supply voltages as shown in fig 6. The results show good agreement with the levels documented in the ESD IEC standard.

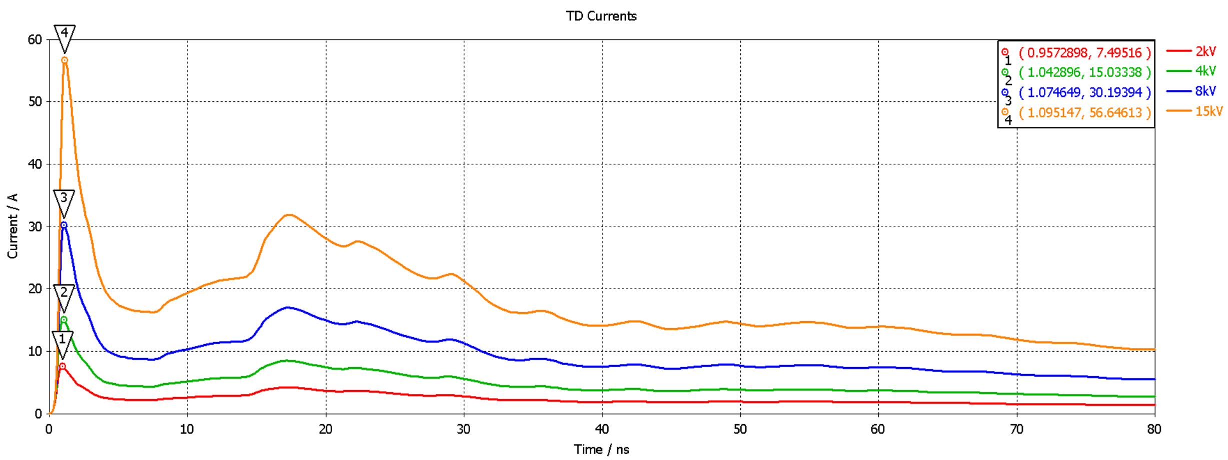

Fig 6: ESD discharge currents for different voltages

Validation with measurement

Since air discharge currents show poor repeatability, it is difficult to match simulated current waveform with measurement. So, it is common practice to evaluate the current derivative for the ESD current waveform. Current derivatives are calculated using the peak current and current rise time of the ESD generator current waveform. Fig 7 shows that the current derivative increases with reduced arc length. Bandwidth should be properly selected during physical testing or simulation, so that fast transients are not missed.

Validation for SPICE model

To validate the accuracy of the spice model used in CST Studio Suite co-simulation, its performance is compared with the reference, "Methodology for 3D full-wave simulation of electrostatic breakdown across an air gap" [2]. The rod model described in reference is modeled and simulated in CST Studio Suite to compare peak current and peak current derivative. Simulated results shown in fig 7 correlate very well with measurement data from the reference. This validates the spice model and provides confidence in using it for parametric studies.

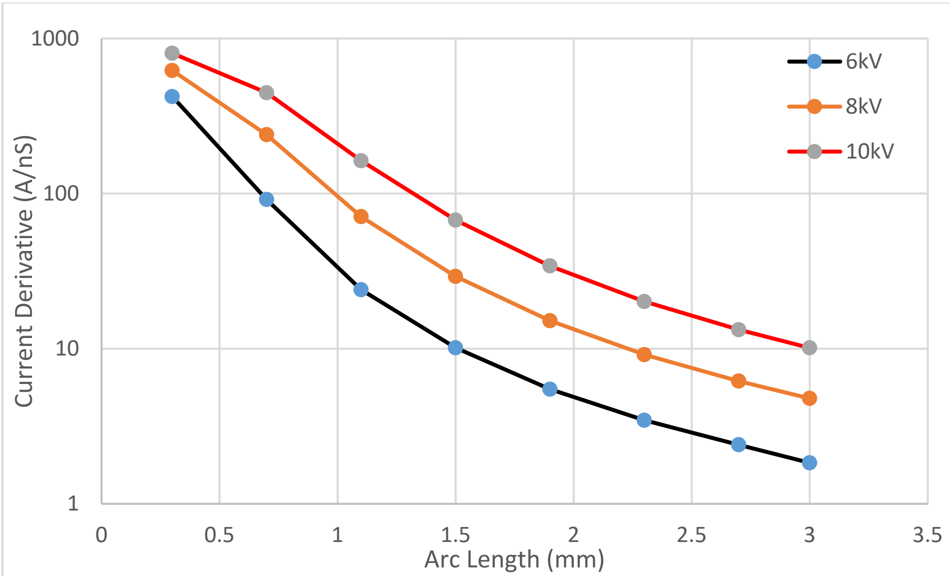

Fig 7: Comparison of maximum time derivative of current for different input voltages

Validation of ESD generator

To further validate the designed ESD generator a reference has been taken from, "Full-Wave Simulation of an Electrostatic Discharge Generator Discharging in Air-Discharge Mode into a Product" [3]. The ESD generator model used in the reference is different to the CST Studio Suite generator model used for validation in this paper, but we would expect similar current derivative results. The peak current derivative data for the reference model shows a good match with the CST Studio Suite model simulated in this paper for a test voltage of 5kV as shown in fig 8.

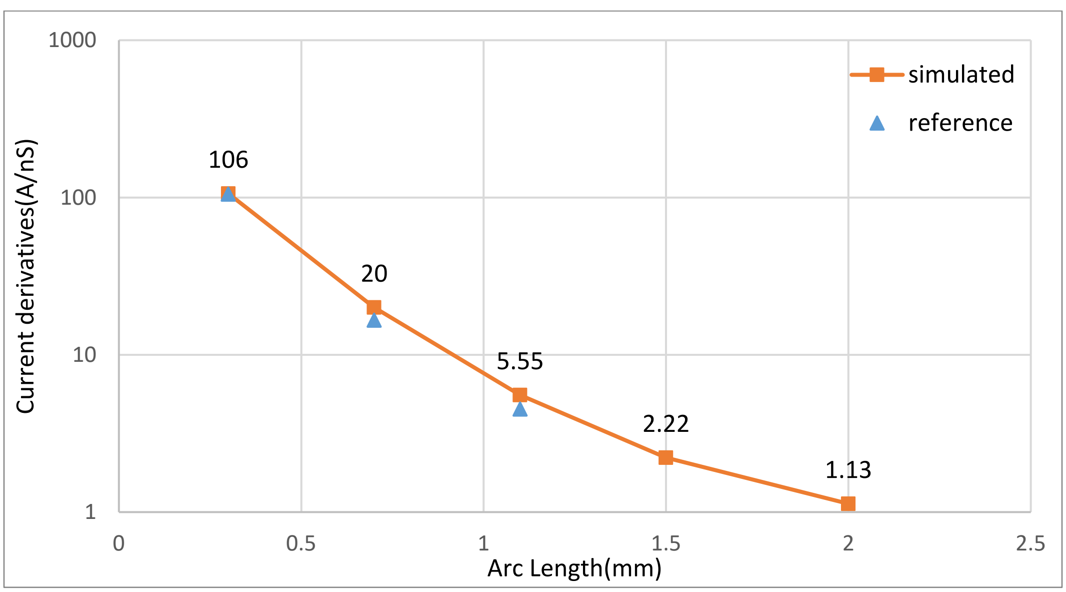

Fig 8: Current derivatives for 5kV air discharge

A third validation is performed with reference to the model from, "Computer Simulation of ESD from voluminous objects compared to transient fields of humans" [4]. The simulated peak current and current derivatives data for a test voltage of 10kV, are compared with measurements values from the reference as shown in fig 9 and fig 10. We can see that the model simulated in CST Studio Suite shows close agreement with the measurement result.

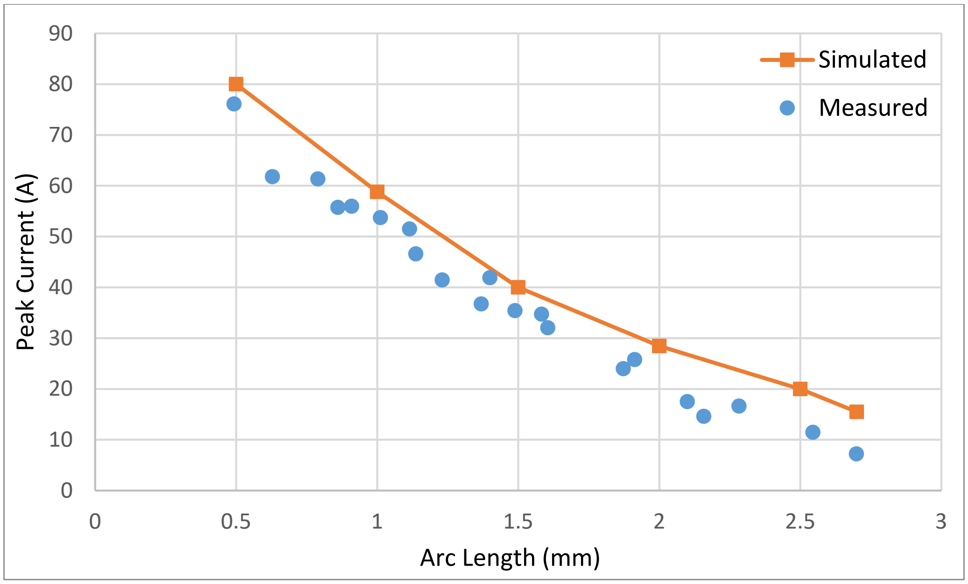

Fig 9: Simulated Peak current for 10kV

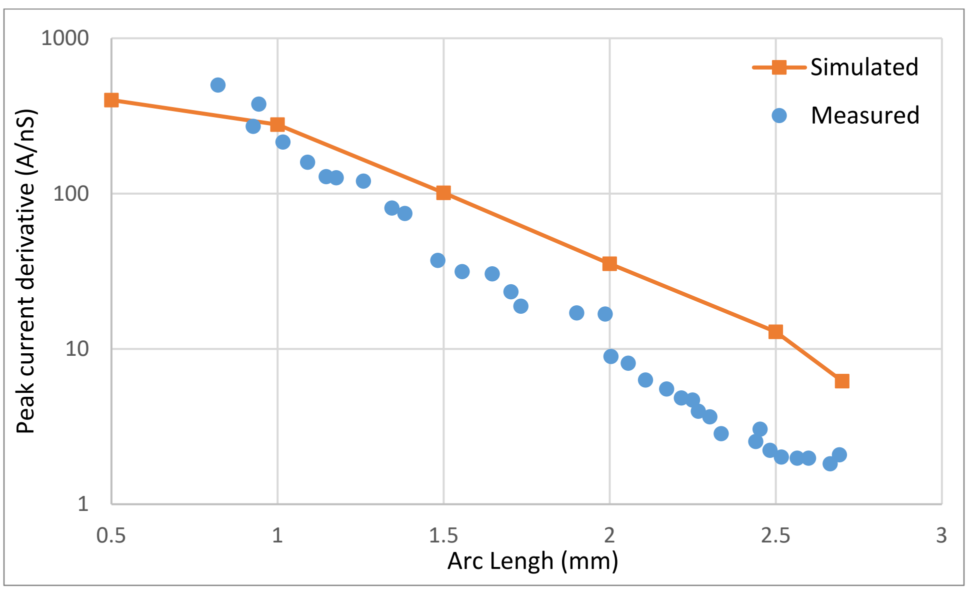

Fig 10: Simulated Peak current derivative for 10kV

Although it is difficult to obtain high repeatability in physical testing, we have been able to validate the behavior of the CST Studio Suite ESD generator model for different air discharge arc lengths. This analysis is useful to understand the behavior of the generator for specified design parameters such as the tip to DUT gap distance, ionization factor *aR*, arc length etc. The performance of the ESD simulation complies with the IEC ESD standard, enabling virtual ESD testing and validation to be performed during prototype development.

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