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Abstract

The paper provides a simplified model of a known ESD generator that allows modeling the ESD impulses (current and fields) in CST-Microwave Studio. The model is suitable for simulating the excitation of structures by ESD, but it is not intended to predict the fields and current of an ESD generator for its development purpose. The aim is to simultaneously model the ESD generator and a susceptible structure with as few details as possible but to obtain as good a match on current and fields as possible.

Keywords

ESD generator, numerical modeling, CST-Microwave Studio.

INTRODUCTION

ESD generators are widely used for testing the robustness of electronic equipment against human-metal ESD. ESD can disturb systems by its current and the associated fields. To predict the susceptibility of a system, a sufficiently accurate model of the ESD generator is needed. A numerical model of a known ESD generator is presented in different applications, using CST-Microwave Studio (MWS) [7], which uses the Finite Integration Technique. It has been shown [1] that a fully detailed model representing the physical process of charging and rapid discharging is possible using time dependent material in FDTD, which allows designing ESD generators numerically.

However, this method is limited to time domain algorithms, takes many time steps to stabilize the static field and requires many cells to achieve the accuracy needed. Most commercial numerical codes, including MWS, do not support time dependent materials. For the purpose of predicting susceptibility, the simplest method is to enforce a current as given in the standard or measured [2],[3].

In this case the geometry of the generator and the ground strap are not part of the model. The consequence is that the current distribution on the generator is not predicted, the fields will not be reproduced correctly and the accuracy of the results will be dependent on the size of the EUT.

The model proposed here is an intermediate model between a fully detailed model and a model simply enforcing the ESD current on the EUT. The ESD generator and the strap are modeled here in a simplified fashion. A known simulator was used to inject an ESD current into a large metal plane.

The current and the fields were measured [6], the complete geometry was modeled in MWS, and the model of the generator was optimized to match those measurements.

The ESD generator model contains metallic parts, some lumped elements that are derived from the internal schematic of the simulator, and other parts that were used to obtain a better match between the measured and the simulated results.

For these reasons the model presented cannot be used to design an ESD generator but is relatively simple and the solver time needed for the simulation is consequently short. In this model, even if the model of the generator was optimized for a discharge in a large metal plane, it can be used to simulate discharges in small objects, e.g., a cell phone.

Table 1 summarizes pro and cons of the generator models mentioned.

Table 1. main characteristics of ESD generator models

	Fully detailed model	Simplified Model	Only enforced current
Injected Current	Accurate	Quite Accurate	Accurate
H-field	Accurate	Quite Accurate	Accurate close to EUT
E-field	Accurate	Only its main characteristic	Not correct
Strap current	Accurate	Quite Accurate	Depend on EUT size
EUT size	Correctly modeled	Moderately correct	Strong effect if EUT is small
Numerical design of simulator	Yes	No	No
'unwanted' radiation caused by fast switching	Included	Not included	Not included
Calculation Time	Long	Short	Short

Note: Every discharge will cause electromagnetic fields. But contact mode ESD generators use a relay to create the discharge current. The voltage collapses very fast in the relay. The fast voltage collapse may not be visible in the discharge current, due to filtering, but it might be visible in the fields, leading to "unwanted" high frequency field components.

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MODEL OF THE ESD SIMULATOR

1.1 Excitation Model

The ESD generator used for the measurement is a modified EM-Test Dito ESD simulator. In the real ESD generator a relay and pulse forming R-C-R network excite the structure. In a contact mode the ESD impulse is initiated by a relay, not by a spark in the air.

The voltage across that relay drops within a few 10 to 100 picoseconds from the charge voltage to a voltage in the range of 20 Volts. These picoseconds fast currents, within the relay and the pulse forming structure, produce high frequency radiations and induced currents. The R-C-R network, as a low-pass filter, increases the rise time of the value internally to the relay to about 1 ns. This process was modeled using a step function voltage source with a given rise time of 1 ns instead of the relay. The proposed method does not require using time dependent material, as a rapid charging process is simulated instead of the slow charging, switching, rapidly discharging sequence as in [1]. The transient response is identical but the electrostatic field, which has little or no effect on most circuits, is not modeled correctly. By setting the pulse rise-time to 1ns, modeling the pulse forming structure was avoided. In this way, providing that the geometry was modeled in detail, the physical processes on the real simulator were modeled in general as they are in reality but the highest frequency content of the fields is not taken into account since the pulse forming structure was not modeled. The amplitude of the voltage step function used to excite the MWS model of the simulator is about 10 V so all the results and the measurements were normalized for a discharge voltage of 1 KV.

1.2 Microwave Studio Model

The ESD generator modeled in MWS consists of some metallic parts and some lumped elements. Figure 1 shows the geometry modeled in MWS. The complete geometry and the internal equivalent circuit of the Dito ESD simulator can be found in [1]. Figure 1 also shows the lumped element network and the excitation port for the model.
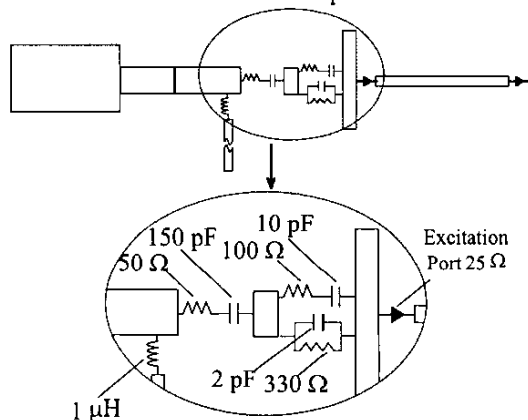

Figure 1. ESD simulator modeled in MWS and a detail of the lumped element network used.
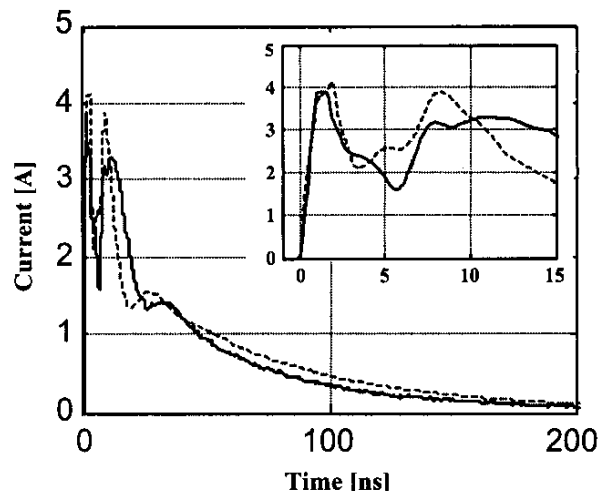

Figure 2. Injected current in the metal wall. Measurement, solid line, and simulation result, dashed line.

The current injected from the modified Dito simulator into a large metal plane was measured using the same procedure reported in detail in [6], using a current target and an oscilloscope. The metal wall and the simulator were then modeled in MWS, and the simulated injected current was compared with the measurement, as shown in Figure 2. The modeled geometry of the simulator and the value of the lumped elements used were then optimized to obtain a better match between the measurements and the simulation results. The E and H-fields were also measured, at 10 cm away from the ESD simulator, and the comparison with the simulated results is shown in Figure 3 and Figure 4.
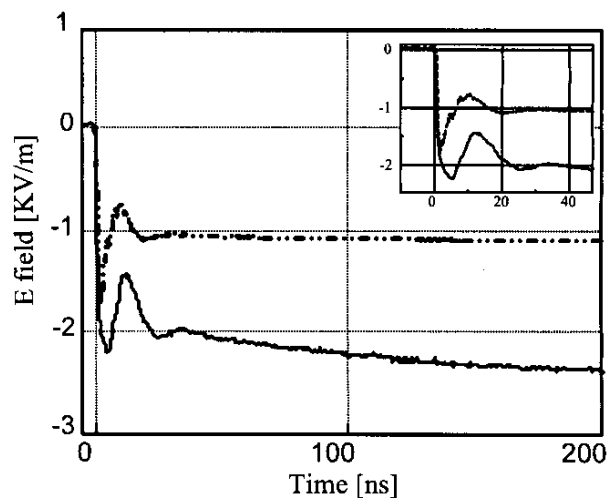

Figure 3. E-Field at 10 cm from the ESD simulator. Measurement, solid line, simulation result, dashed line.

In the real ESD simulator the static E-field has a finite value before the discharge and goes to zero after the discharging process. In the MWS model of the ESD simulator the discharge process is simulated as a rapid charging proc-

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ess. Consequently the static E-field simulated is zero before the discharge and reaches a final value after the discharging process. Comparing the measured and the simulated E-field, in Figure 3, the measured E-field was given an offset equal to the initial measured static value; the same offset was given to the simulation result. The measured and the simulated static E-fields do not match, after the discharging process, most likely because the E-field is very sensitive to the geometry of the ESD simulator. As a result, small changes in the geometry could end in variations in the static E-field.
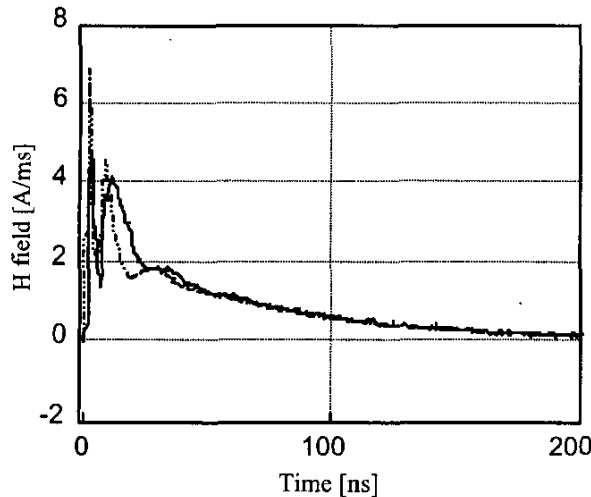

Figure 4. H-Field at 10 cm from the ESD simulator. Measurement, solid line, simulation result, dashed line.

The spectra of the measured and simulated injected current were calculated and compared. For the ESD simulator used, the upper frequency limit is about 600 MHz. After a relative good agreement between the current and the fields generated from the real ESD simulator and the model was obtained, the same ESD model was tested on devices of different size. The ESD generator was discharged first on a test enclosure then on a cellular phone similar device and at the end on the Horizontal and Vertical coupling planes configuration.

DISCHARGE ON A TEST ENCLOSURE

A test enclosure was built using aluminum plates and copper tape. Figure 5 shows the test enclosure and the ESD simulator modeled with MWS. The dimensions of the rectangular box were 20 cm x 50 cm x 30 cm; the thickness of the wall was 1 mm. A rectangular slot of length 35 cm and height 0.4 cm was placed at the center of the enclosure front side. Inside the test enclosure, a 4 cm square loop was connected in the center of the top wall using an SMA connector. One end of the internal loop was shorted to the top wall of the enclosure; the other end was connected to the oscilloscope through the SMA connector and a coaxial cable.

The ESD simulator was discharged on the front panel of the enclosure, point A in Figure 5, at 5 cm away from the slot.
The strap was also attached on the front panel at 5 cm away from the slot but at the other side of the slot, point B in Figure 5.
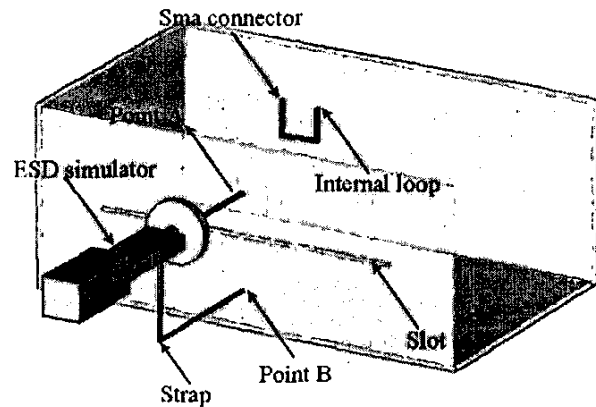

Figure 5. Test enclosure used to test the model of ESD generator.

The length of the strap was 26 cm. A field due to an ESD current on the enclosure, between the points A and B, excites the enclosure. An electromagnetic coupling between the external region and the internal region occurs because of the long slot. The square loop placed into the cavity, senses the internal electromagnetic field and it is used to compare theoretical and experimental values.
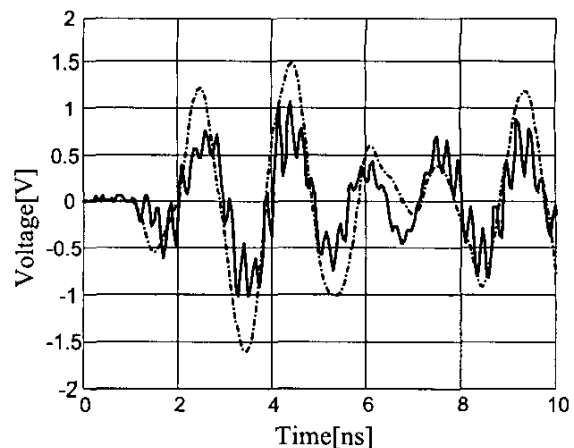

Figure 6. Voltage induced in the square loop for the first 10 ns. Measurement, solid line, simulation, dashed line.

The same experiment presented here, on the same enclosure, was performed using a different ESD simulator in [4]. The induced voltage on the internal loop, for a 1-KV discharge of the ESD simulator, was measured and compared with the MWS results in Figure 6. From Figure 6, it can be noticed that the high frequency ringing is not shown in the

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simulated result since the pulse rise-time was set to 1 ns and the pulse forming structure was not modeled. The currents on the tip of the ESD simulator, point A, and in the strap, point B, were also measured using a current clamp probe.

The comparison between those measurements and the simulated results are shown in Figure 7 and Figure 8.
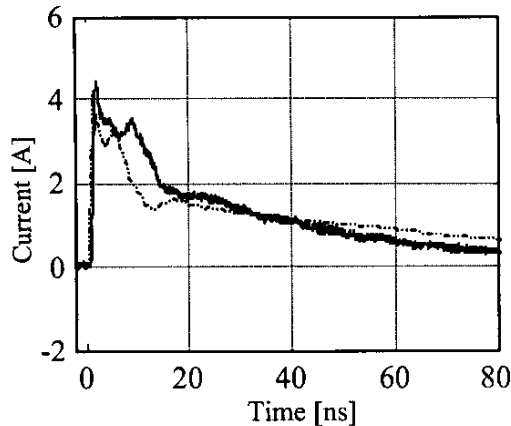

Figure 7. Current in the tip of the ESD simulator. Measurement, solid line, simulation, dashed line.
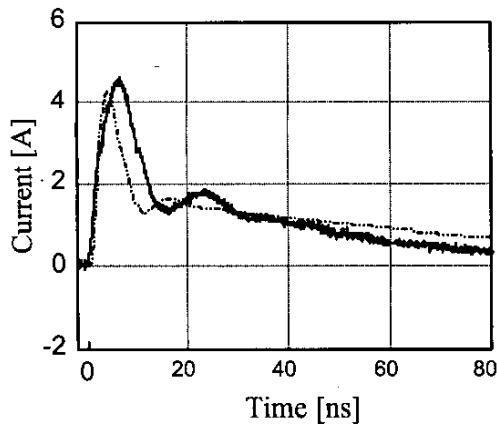

Figure 8. Current in the strap of the ESD simulator. Measurement, solid line, simulation, dashed line.

Considering that the ESD simulator modeled in MWS was a highly simplified model, there is a good agreement between the simulated and the measured results.

To understand better the physics of the model, a spice model was also built as in Figure 9. The lumped element network, already used in the numerical simulation, was reported again in the spice model. A voltage source provides a step function equal to the one used in MWS. The stray capacitance, the strap and electrode inductances have been estimated but not calculated. The results obtained with the spice model were very close to the measurement, but the stray capacitance between the simulator and the enclosure was found to be a critical parameter.
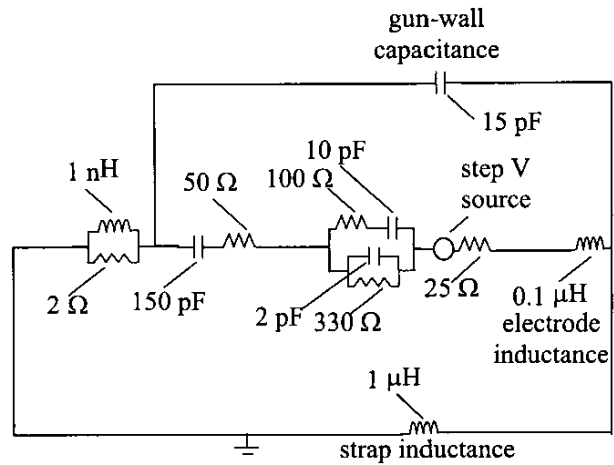

Figure 9. Equivalent spice model for the ESD simulator and the enclosure.

DISCHARGE ON A CELLULAR PHONE SIMILAR DEVICE.

A device, similar to a cellular phone was built using an aluminum box and an antenna. The size of the box was 5 cm x 11 cm x 3 cm. The antenna was 5 cm long and the ground strap used had a length of 30 cm. A 2.5 cm thick styrofoam board was placed in between the ground plane and the cellular phone. Since the permittivity of the styrofoam is very close to 1, it was modeled in MWS model as vacuum.
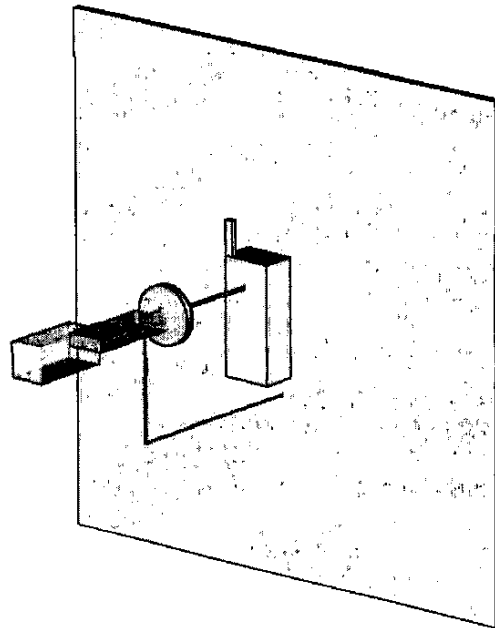

Figure 10. Perspective view of the cellular phone similar device modeled in MWS.
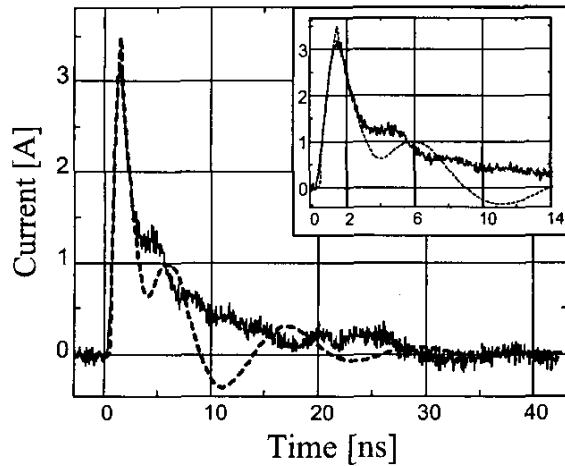
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Figure 11.Current in the tip of the ESD simulator. Measurement, solid line, simulation, dashed line.

Due to the small size of the enclosure under test, simply enforcing the standardized discharge current will not predict the fields and the current correctly. The ESD simulator and the enclosure under test were modeled in MWS, as shown in Figure 10. The current enforced in the tip of the ESD simulator was measured and simulated.

The simulated result was then compared to the measured result in Figure 11. The results agree quite well for the discharge point, but did not agree for the current in the ground strap at the ground strap connection point.

DISCHARGE INTO THE HORZIONTAL AND VERTICAL COUPLING PLANES

The horizontal coupling plane (HCP) and the vertical coupling plane (VCP) are essential elements of the standardized electrostatic discharge (ESD) test. They are used to test the robustness of equipment against indirect (nearby) discharges. The analysis of the induced voltage on a mouse cable, using the same geometry as in [5], is presented here using Microwave Studio (MWS). In [5], the Keytek 2000 was used as the ESD generator for the measurement and the VCP-HCP transmission line and the mouse cable-HCP were modeled as two coupled transmission lines for the simulation. In this paper, the ESD generator was modeled with a simplified structure as in the previous applications. The ESD generator was used to inject an ESD current on the VCP. Part of the injected current propagates using the VCP and the HCP as a transmission line another part it returns as displacement current directly into the simulator. A perspective view of the MWS model is shown in Figure 12. Two different configurations were analyzed with the MWS. First the VCP was terminated on the HCP using a 50-Ohm resistor and the induced voltage on the mouse cable was measured at his near end. The result of the simulation was then compared with the result obtained [5]. From Figure 14 it can be seen that the simulations match the

measurements in its main characteristics even if the simulated data shows a larger peak value.
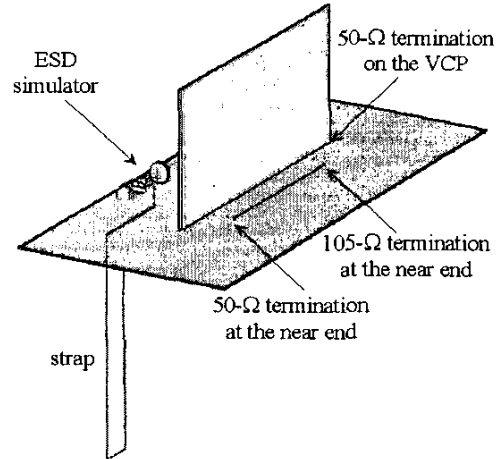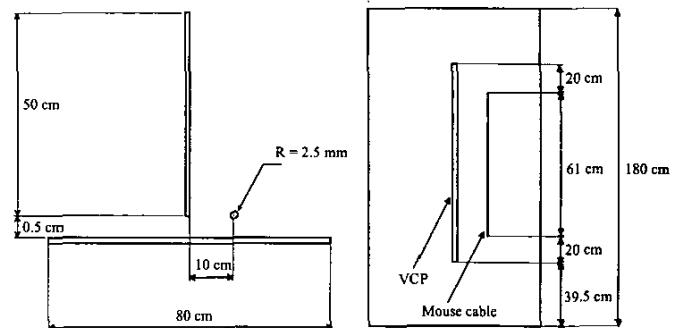

Figure 12. Perspective view of the VHCP modeled in

Figure 13. Front and top view of the HCP-VCP geometry.
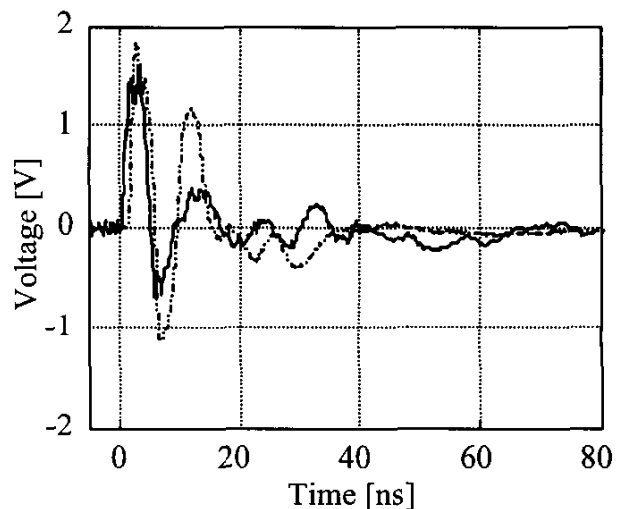

Figure 14. Voltage induced in the near end of the mouse cable when the VCP was terminated.

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This is most likely because the ESD generator used for the measurement, the Keytek 2000, is different from the ESD generator simulated, the EM-Test Dito.
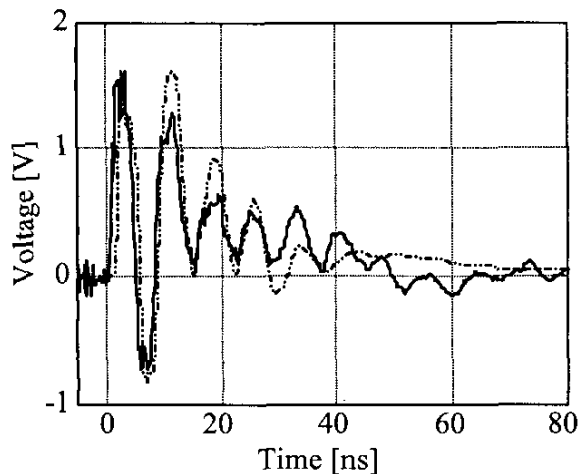

Figure 15. Voltage induced in the near end of the mouse cable when the VCP was not terminated.

Later the 50-Ohm termination was removed and the induced voltage on the mouse cable was measured again at the near end. Figure 15 shows the comparison between the measured and the simulated results.

CONCLUSIONS

A simplified model of a known ESD generator was developed. It allows modeling the ESD impulses (current and fields) in MWS. The voltage breakdown in the relay was emulated by using a step voltage function.

Relative to a fully detailed model of the charging and rapid discharging process, the ability to design ESD generators via numerical techniques is lost. However, the geometry and the lumped elements of the ESD generator are modeled in a simplified fashion hence the calculation time is less than 1 hour on a 1.4 GHz machine. Within the accuracy bandwidth of the model, the simulated currents and fields agree well with the measurements. The model presented was intended to be an intermediate model between a fully

detailed model and a model simply enforcing the standardized current on the device under test.

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