A Measurement Technique for ESD Current Spreading on A PCB using Near Field Scanning

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***Abstract*—Electrostatic discharge (ESD) can cause interference or damage in circuits in many ways e.g., by E- or H-field coupling or via conduction paths. Although we can roughly estimate the voltage and current at the injection point during an ESD event, the real offending parameter is mostly the ESD current spreading throughout the system. Those currents can be simulated if great simplifications of the system are accepted. However, even in moderately complex systems the ability to simulate is limited by lack of models and computational resources. Independent of the complexity, but obviously not free of its own limitations is a measurement technique that captures the current as a function of time and location through the system.**

This article describes the proof on concept of ESD such a measurement technique that allows reconstructing the spreading current as a movie from magnetic field measurements.

It details the technique, question of probe selection and how to process the data to present the current spread as a movie.

I. INTRODUCTION

ESD can damage or disrupt a system. Understanding of system level ESD has been approached from different directions, such as ESD generator modelling [1], in circuit measurements [2], air discharge analysis [3], numerical simulation of currents and fields, protection circuit analysis, etc.

One of the effective methods for analysing ESD robustness is using a three dimensional scanning system to localize ESD sensitive areas or traces [4, 5, 6]. In conjunction with the circuit information the root cause of a system level problem often can be fully understood.

However, as in near field scanning, it is not obvious to connect local results (e.g., sensitive area, or strong fields in near field EMI scanning) to system level performance. For ESD one needs to understand which current densities, field strengths and derivatives are to be expected at one location if an ESD is injected into a test point.

The sensitive areas found by near field susceptibility scanning might not be those, which will receive a lot of current or field strength during an ESD. Thus, the current spreading during an ESD needs to be known to connect local sensitivity data with system level responses.

This article reports on our proof of concept for a current spreading measurement method. The main objective of the research is to develop a method to measure and reconstruct current spreading and field coupling in or close to circuits by scanning; to correlate system level ESD with scanning level ESD in time and spatial domain; and at the end to analyze and extract circuit and layout design strategies for ESD current protection.

This paper is mainly describing the methods of ESD current reconstruction on PCB. Research beyond this simple PCB will be continued in the future.

II. TEST STRUCTURE

For a proof of concept the structure of the device under test (DUT) and the experiments based on it have to be simple but meaningful. Fig. 1 shows the PCB structure we used:

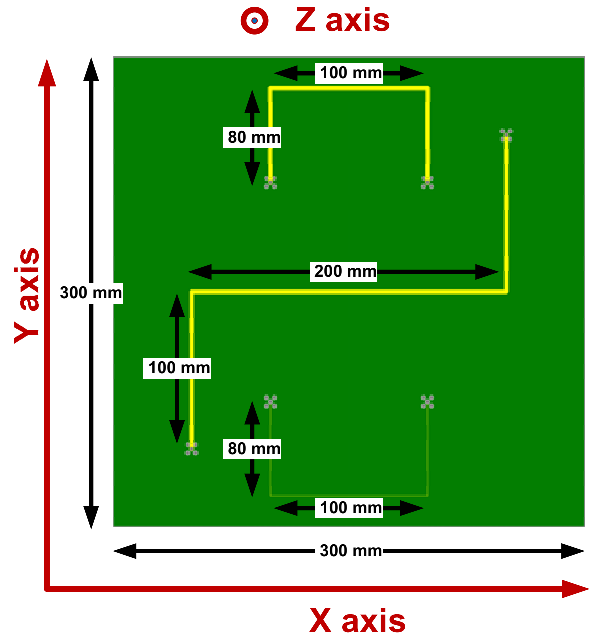

Fig. 1: Layout of the PCB for ESD current spread scanning

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It is a simple two layer PCB with 3 traces on the top layer and a solid ground plane on the bottom layer. Signal probing (for traces) is performed via SMA male to male connectors at the back side of the PCB. Their ground connects to a large ground plane. Injection is performed via a coax connection on the edge of ground layer. This allows easy numerical modelling. Fig. 2 is the setup picture:

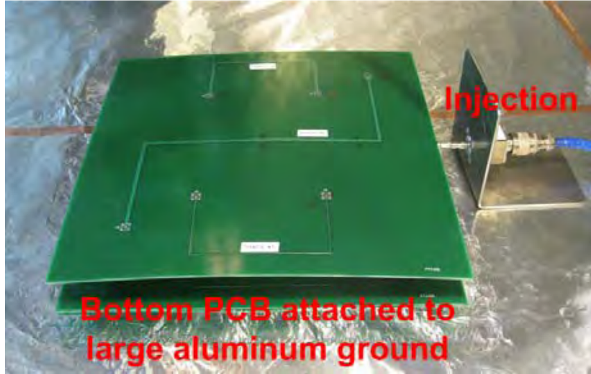


Fig. 2: Picture of the real setup

For the test setup above, the injected current from the cable centre conductor will spread on the top PCB ground layer (both sides of the copper) and return via the 6 SMA connectors outer conductors to the large aluminium ground, then return to the injection cable through the injection structure. This current spreading and return is shown in fig.3 (top view) and fig.4 (side view).

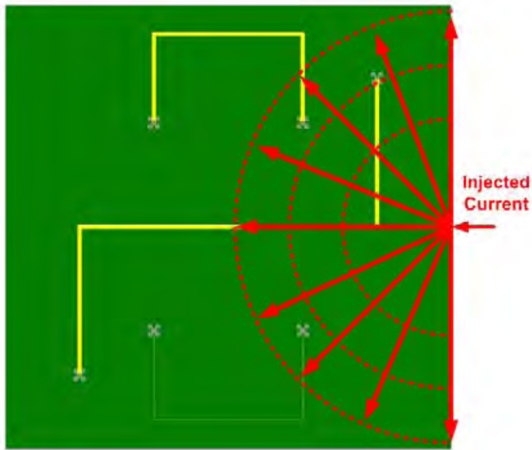


Fig. 3: Injected current spreading at ground layer

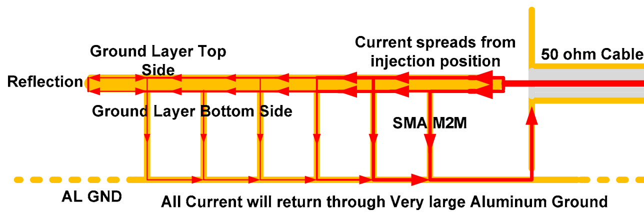


Fig. 4: Current return of the PCB injection structure (side view)

III. Measurement Method

To capture the current, the magnetic field is measured by placing a probe close to the surface of the PCB. An ESD pulse is injected into the PCB and the magnetic field is captured. Due to the close proximity of the probe to the PCB one can approximately equate the magnetic field to the surface current density. Then the probe is moved to the next location and another pulse is injected. This is repeated until a sufficient number of locations have been measured. There are a couple of choices for setting up the measurements:

a) Probe Selection.

Before choosing current probes, we need to understand the E and H field coupling of the ESD scenario [7, 8, 9]. Fig. 5 shows the 3 field coupling paths we are concerned about:

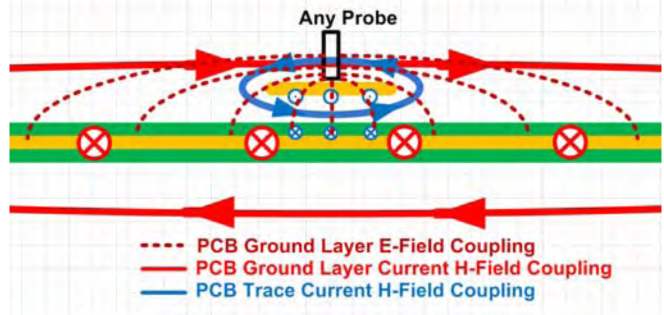


Fig. 5: Three relevant coupling paths

We want to suppress the E-field. There are two relevant currents: The current density on the PCB and the currents on the traces. We are interested in both. The magnetic fields of the trace currents are often much weaker than the magnetic field of the surface current density.

Therefore it is difficult to measure trace currents by the same H-field probe that is used for the ground layer current. However, the field components are different. The trace current has an H_z field component. It is possible to separate the trace current by measuring the H_z component over the PCB. Probe selection requirements are:

1) The probe needs to suppress the E-Field, otherwise the E-field coupling will easily override the H-field coupling from the current.
2) The probe for measuring the ground layer current can be a shielded vertical loop probe measuring H_x or H_y. The trace current that is induced into the traces generates much weaker H_x H_y components, they are mostly overwhelmed by the H_x and H_y components from the ground layer current. In the test we used a 6 by 8 mm coaxial shielded vertical loop probe to capture H_x and H_y from the PCB ground layer current.
3) A good probe of measuring trace current in this scenario needs to well reject ground layer current coupling. For this application, a 3 by 3 mm patent pending trace current probe was designed to capture the trace current. It measures the trace currents H_z components since H_z is dominated by trace current locally and incorporate other features.

b) Time or Frequency Domain.

The first set of data presented here has been captured using a transmission line pulser (TLP) as source (about 300 ps rise time) and a real time oscilloscope to capture the signal. The use of a Network analyser (NWA) is also discussed further down this article.

A. TLP and Oscilloscope Scanning Method Setup

Fig.6 shows the test setup for current reconstruction scanning using a TLP and an oscilloscope.

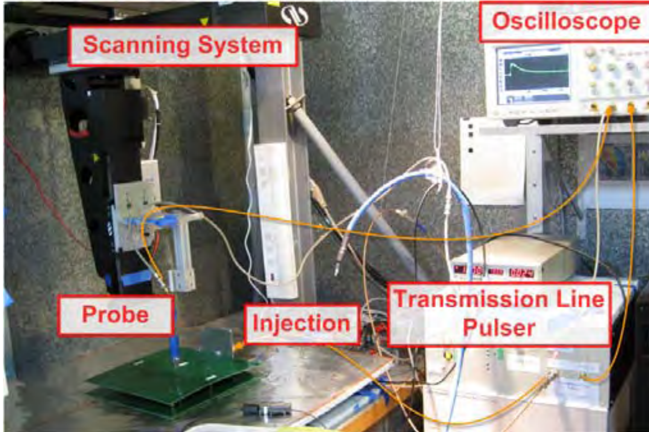


Fig. 6: TLP and oscilloscope scanning method

The current is injected from the right middle edge (x =300mm, y = 150mm) of the PCB into the ground layer. From the injection point current spreads over the ground layer as fig. 3 showed before, and couples to the 3 traces. All traces are terminated by matched loads. A shielded vertical loop will measure the current spread on the surface of the PCB with 2 orthogonal directions (measuring H_x and then H_y components separately). In this way, two sets of data will be created for data processing.

The oscilloscope records data after receiving a trigger from the TLP. Providing the TLP repeats well all measurements are "synchronized" and show the current spread when plotted as a function of time. The probe couples to the time derivative of the current density via a probe factor. Thus multiplication by the factor (yet unknown, but a pure function of geometry) and integration would allow determining the current in absolute values.

B. Network Analyzer Scanning Method Setup

Our test setup is linear with respect to current. Thus, one is not forced to use a high voltage generator as injection. A network analyzer with time domain transformation can be used instead as setup in fig. 7 shows. The setup of the network analyzer is very similar to the TLP and oscilloscope method, the only difference is that the injection part is connected to network analyzer port 1; the probe is connected to the network analyzer port 2. S21 is measured and transformed to the time domain. To improve the signal to noise ratio, a 20 dB amplifier is added at the receiving port.

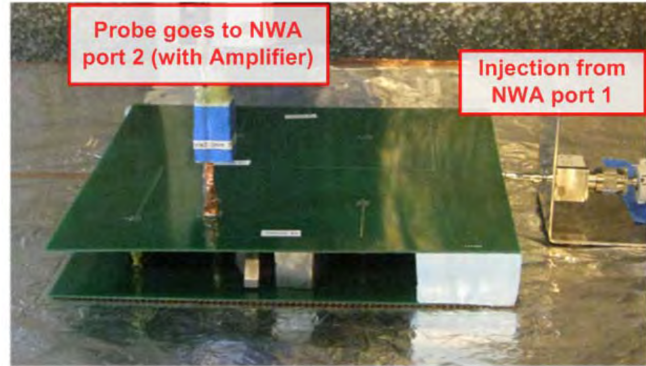


Fig. 7: Network analyzer method setup

Its excitation equals the excitation of a step function (or the user could select an impulse transformation instead) [10]. For a linear system a network analyzer has many advantages over a direct time domain measurement:

- It has better repeatability as it is frequency domain measurement, unlike TLP which uses a High Voltage relay to produce pulses.
- Network analyzers have much better dynamic range than oscilloscopes
- The time domain image of the signal injected by the Network analyzer is clean, e.g., there is no ringing, or overshoot. Fig. 8 shows the voltage waveform comparison.

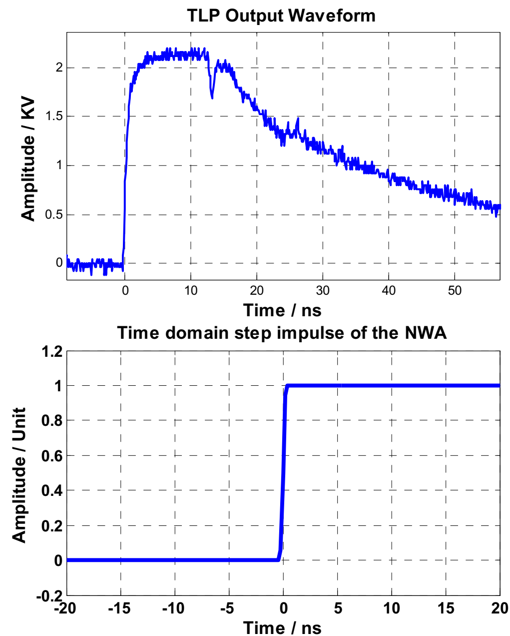


Fig. 8: TLP and NWA time domain waveforms

IV. Scanning Results

A. Reconstructed Movie using the TLP and Oscilloscope Scanning Method on PCB Ground Layer

Fig. 9-12 show 4 fames of the reconstructed current spreading on the PCB surface when the shielded vertical loop probe is oriented at x-axis direction.

The first frame shows a very large current density at the injection moment. The current spreads in a circular fashion on both sides of the board as shown in frame 2 and 3. All frames here illustrate only the H_x component on the top side of the board. The board is connected to a large ground plane via SMA male to male connectors on PCB bottom side so most of the current will return through them. After the waveform reaches the left side of the board, reflections are visible in the last frame.

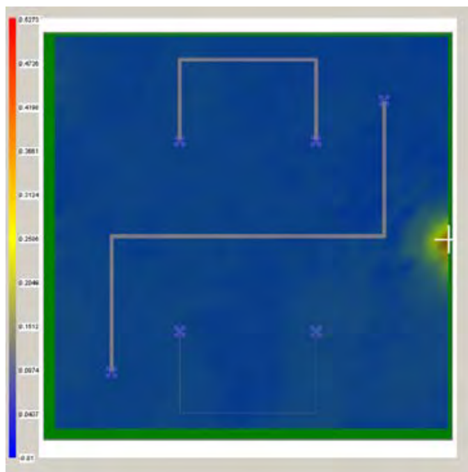


Fig. 9: Measured current at the injection moment

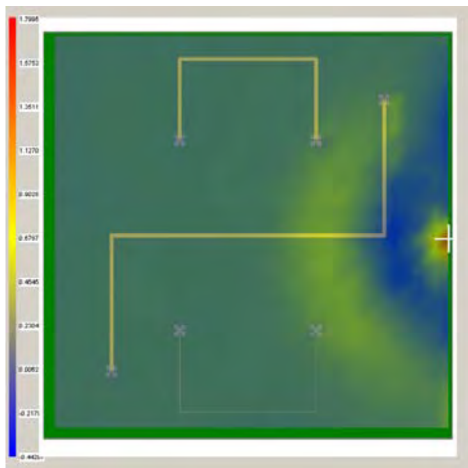


Fig. 10: Measured current wave front spreads

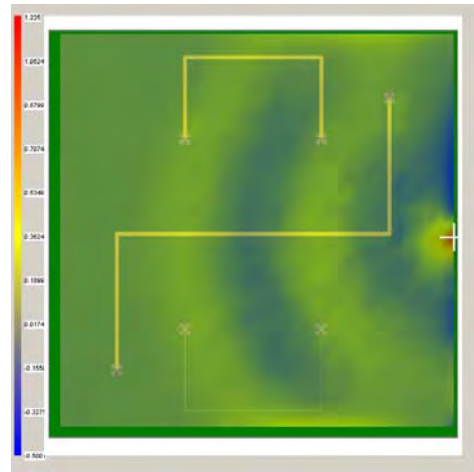


Fig. 11: Measured current wave front spreads further

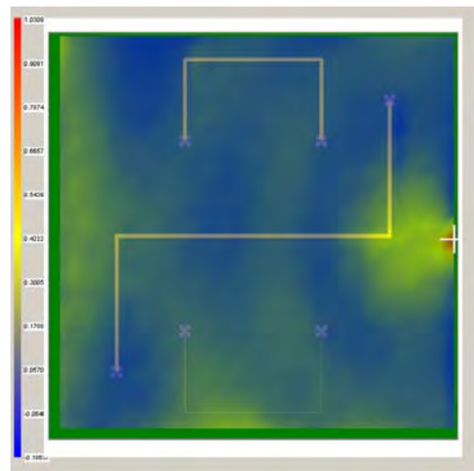
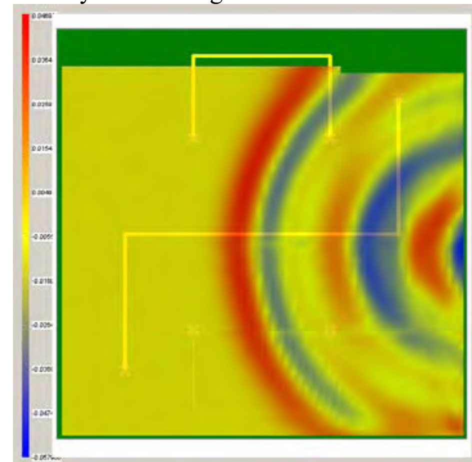


Fig. 12: Measured current reaches the edge and reflections occur

B. Reconstructed Movie for the Network Analyzer Scanning Method on PCB Ground Layer

Below are 2 current reconstruction frames obtained using the network analyzer scanning method:



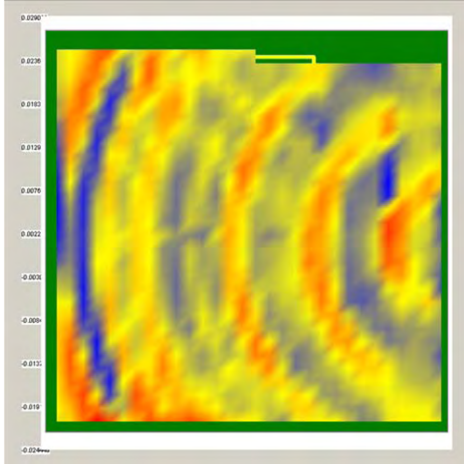


Fig. 13: Measured current reconstruction frame using network analyser method

The data shown in Fig.13 indicate that the wavefronts are better visible using the network analyser method. The large dynamic range of the NWA allows us to follow the current wave front over a larger distance.

However, it is necessary to use a network analyser that can cover the frequency range from 100 KHz - 3GHz; otherwise the missing frequency component will distort the time domain signal, especially the tails.

C. Data Process in MATLAB

The total field is reconstructed using MATLAB from two orthogonal scans (H_x and H_y). The scanning resolution was set to 1 by 1 cm. This leads to 30 by 30 scanning points for each scan. Fig. 14 shows 3 plots resulting from the recovering process.

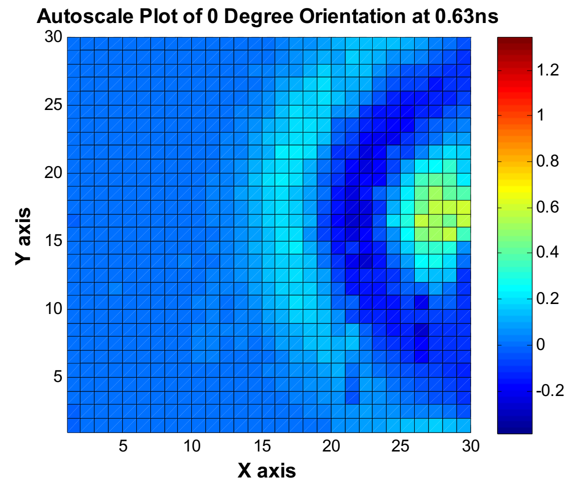
The first plot is using the raw data taken from the H_y scanning. When the vertical loop probe is oriented such that the loop is normal to Y-axis, it measures the Hy component which is mainly generated by the current flowing in the direction of the X-axis.

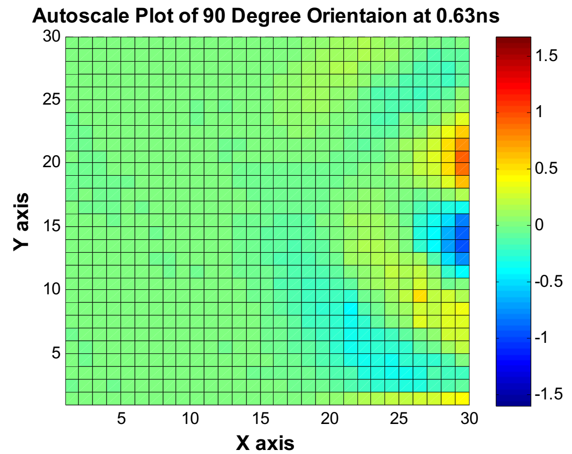
The second plot shows the result of the H_x scanning. When the vertical loop probe is oriented such that the loop is normal to the X-axis, it measures the H_x component which is mainly generated by current flowing in Y direction. The first and second frames are snapshots at the same moment for better understanding and comparison.

The third plot in fig. 15 plots the root square sum of the raw data from the two orthogonal scanning results:

$$data_{Overall} = \sqrt{data_{D0}{}^{2} + data_{D90}{}^{2}}$$

This is the magnitude of the total horizontal H-field strength close to the plane which equals the current density on the PCB ground layer.





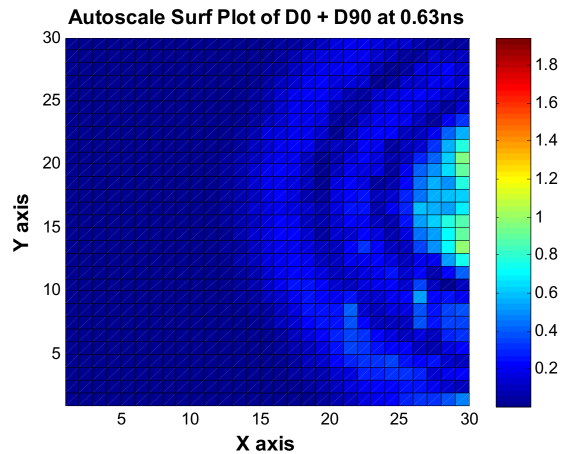


Fig. 14: Post processed data

D. Trace Current Reconstruction

If the vertical loop is used, we can hardly see the H-field of the trace current (the trace current caused by the current injected into the PCB). It is overwhelmed by the magnetic field of the ground plane current.

Different probes have been designed a special probe just for the trace current. These probes detect the magnetic field from the trace while suppressing other field components. Fig.15 shows the comparison of the probe response when moving it across a trace during ground layer injection:

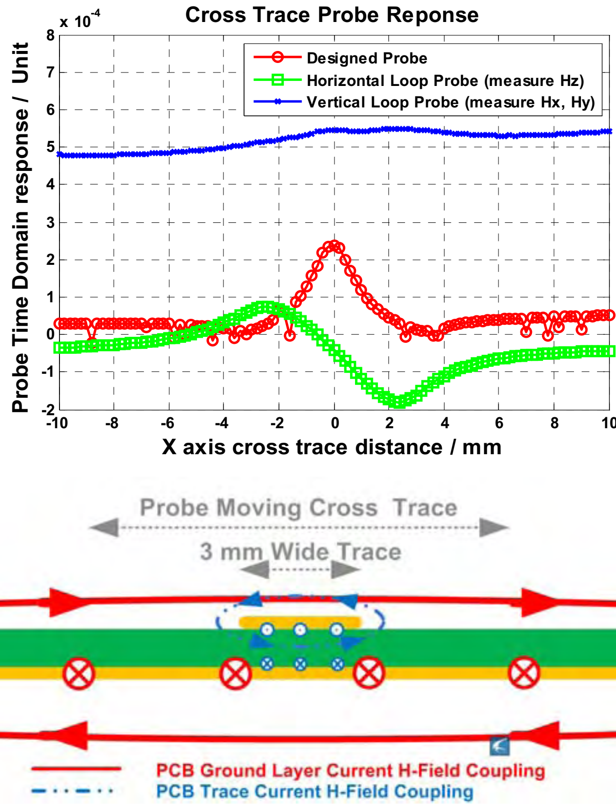


Fig. 15: Comparison of shielded horizontal loop probe, shielded vertical probe and trace current probe

The vertical loop can hardly detect the trace current (blue trace). The horizontal loop detects the Hz component; it can detect the magnetic field of the trace current (green trace). The response of the trace current probe (red) detects only the trace current as one peak, which is located above the center of the trace.

Fig. 16 shows one frame of the current reconstruction using the trace current probe and a frame from the CST simulation movie. In both the trace current is visible.

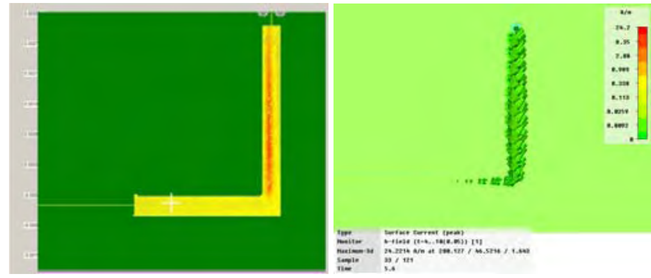


Fig. 16: Measured & simulated trace current movie frame

One final remark on the trace current probe: It recovers the trace current well, but it is only sensitive to the Ix or Iy current, thus two scans need to be conducted for full reconstruction.

V. Conclusion

The paper presents a prove of concept for a measurement method that reconstructs currents spread as a function of time for ESD or other pulses injected into a system. A special probe is able to suppress the ground plane current to extract trace currents; its principle function has been shown.

The next steps are a comparison to simulated data and a comparison of local current density and field strength, as seen during a system level ESD tests compared to local current density and field strength as they are caused by local injection during ESD scanning. This will further help to connect local to system level results.

References

[1] Cai Qing, Jayong Koo, Argha Nandy, and David Pommerenke, “Advanced Full-Wave ESD Generator Model for System-Level Coupling Simulation”, IEEE EMC Symposium, Aug 2008

[2] Chong Ding, David Pommerenke, “ Laser Optical In-Circuit Measurement System for Immunity Applications”, IEEE EMC Symposium, Aug 2006

[3] David Pommerenke, Martin Aidam, Technical University Berlin, Einsteinufer, “To what extent do contact-mode and indirect ESD test methods reproduce reality?”, Electrical Overstress/Electrostatic Discharge Symposium Proceedings, 1995

[4] Kai Wang, Jayong Koo, Giorgi Muchaidze, Dr. David J. Pommerenke, " ESD Susceptibility Characterization of an EUT by Using 3D ESD Scanning System”, IEEE EMC Symposium, Aug 2005.

[5] Kai Wang, Dr. Pommerenke, Jian Min,Zhang, Ramachandran Chundru, “The PCB level ESD immunity study by using 3 dimension ESD scan system”, IEEE EMC Symposium, Aug 2004.

[6] Frederic Lafon, Francois De-Daran, Julien Dupois, “Near field imunity cartography method to characterize an IC to fields radiated by an ESD,” Blaise Pascal University, Clermont Ferrand.

[7] Tun Li, Kuifeng Hu, Shaohua Li, Qing Cai, Wenfeng Pan, Jayong Koo, Zhe Li, David Pommerenke, “Overview on electric field, magnetic field, current and voltage probes used in the EMC lab for EMI analysis and for injecting signals during immunity analysis”, UMR EMC Laboratory Technical Brief, Mar 2007.

[8] David Pommerenke, Tun Li, Weifeng Pan, Thomas Van Doren, “Probe Selection Strategy”, UMR EMC Laboratory Technical Brief, Mar 2007.

[9] Qing Cai, Jayong Koo, Tun Li, David Pommerenke, “Characterization of different types of PCB loop probes”, UMR EMC Laboratory Technical Brief, Mar 2007

[10] Agilent 8753ES Manual