Probe Characterization and Data Process for Current Reconstruction by Near Field Scanning Method

Wei Huang#1, Dazhao Liu#1, Jiang Xiao#1, David Pommerenke#1 Jin Min*2, Giorgi Muchaidze*2

1# *Electromagnetic Compatibility Laboratory, Missouri University of Science and Technology*
Rolla, MO, USA, Email: davidjp@mst.edu

2* *Amber Precision Instruments*
Santa Clara, CA, USA, Email: jinmin@amberpi.com

***Abstract*— previously a measurement technique for ESD current spreading on a PCB using near field scanning was developed in order to connect the local ESD sensitivity to system level ESD failures in time and spatial domain. The concept of such scanning methodology is proved and several scanning results were processed. However the validation, precision and weakness of such methodology need to be further investigated before the application of such scanning methodology on complex circuit or system.**

This article investigates the current reconstruction by near field scanning technique and methodology. It studies the probe factors including coupling frequency response characterization and deconvolution method, spatial resolution for scanning and orthogonal-scan data combine process.

I. Introduction

This article is a research continuation of a previous paper "A Measurement Technique for ESD Current Spreading on A PCB using Near Field Scanning". The ESD injection setup and current return paths are shown in Fig.1 and Fig.2

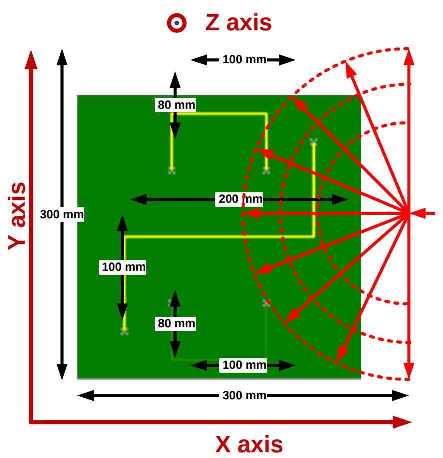

Fig 1. The ESD injection and expected current spreading on the PCB

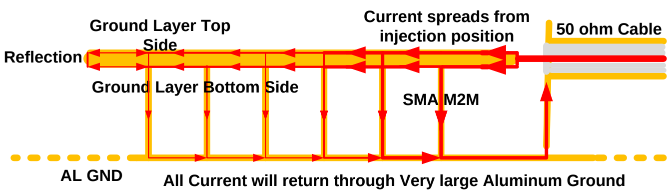

Fig 2. Injected current return paths of the PCB structure

II. Probe Characteristics

To successfully recover both the magnitude and direction of injected surface current or coupled trace current from probe's near field induced voltage signal, the understanding of probe characteristics is of great significance. A probe's coupling frequency response; loss, spatial resolution and directional response need to be evaluated to estimate how well the injected surface current or coupled trace current can be recovered. Then the reverse process from local induced probe signals to desired surface or trace current vectors can be constructed based on the probes characteristics.

A. Frequency Response and Deconvolution Method

For using a magnetic probe to capture a transient magnetic field or current and recover it numerically, the probe's magnetic coupling frequency response is one of the most important factors to construct the reverse process, or probe frequency response deconvolution.

The probe should have enough inductive coupling bandwidth to cover the main spectrum of the transient magnetic field or current. Then a compensation function of the coupling frequency response can be calculated to recover the transient magnetic field or current from the induced probe voltage signal. In addition, the experimental measurement including the probe should have enough signal noise ratio and dynamic range of H-field or current coupling to get recoverable measurement results.

A probe's coupling factor for surface current or trace current can be measured by a terminated TEM cell or trace as Fig. 3 shows:

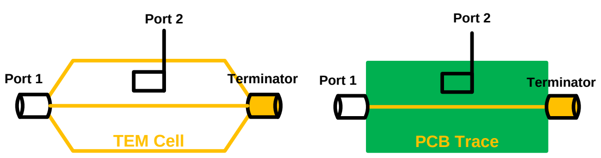

Fig 3. Use TEM Cell and PCB Trace for probe coupling factor measurement

The coupling mechanism between the probe and the excitation can be modelled as Fig 4.

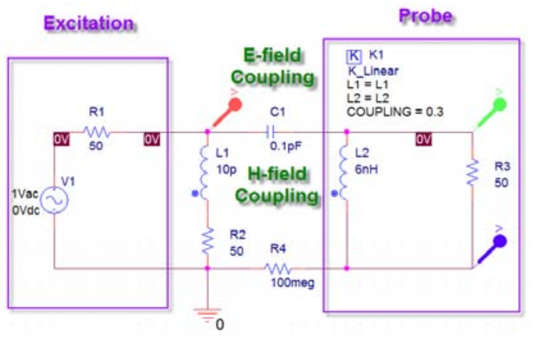

Fig 4. Circuit model of probe's coupling mechanism

From the model, the frequency response is inductive coupling dominated and the excitation recovery process can be achieved with a process as Fig 5 shows:

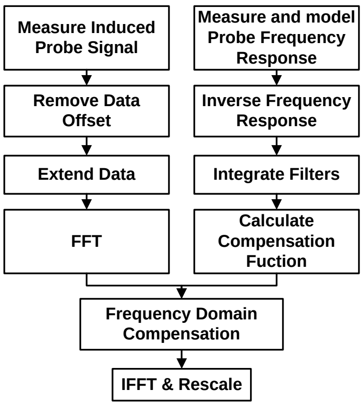

Fig 5. Probe frequency response deconvolution process

A compensation function of the probe's frequency coupling response and loss with filters is then created with steps as Fig 6 shows:

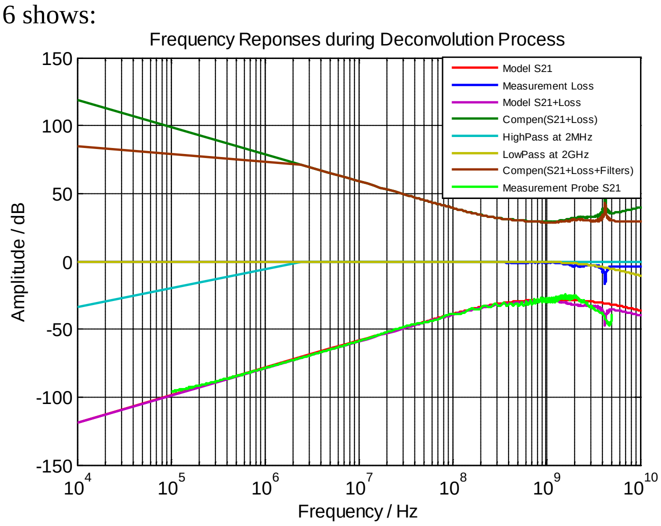

Fig 6. Created frequency responses during deconvolution process

Finally the desired field or current data can be rescaled from the recovered excitation. An example of probe deconvolution is followed. Fig. 6 is the measured probe voltage signal from TEM Cell excitation. After the deconvolution process a comparison of transient H-field from processed probe signal and directly measured H-field are shown in Fig 8:

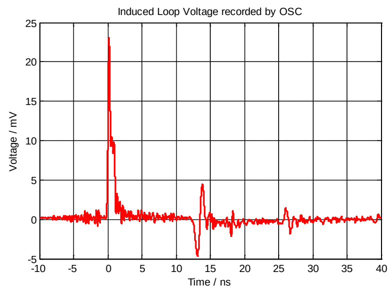

Fig 7. Measured probe signal from transient H-field coupling

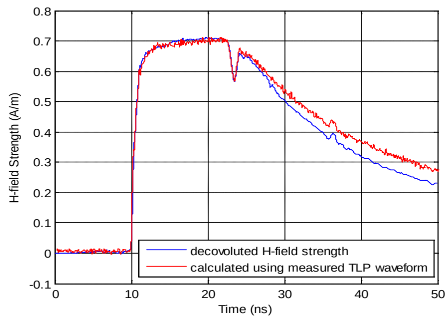

Fig 8. Comparison of deconvoluted and measured H-field results

Some of the high frequency and low frequency components are lost due to the filters integrated into the compensation function, but they are important to reject low frequency noise and high frequency resonance. Overall the method works well and the recovery result matches direct measurement.

B. *Spatial Resolution*

Spatial resolution of a probe reflects how well a magnetic field probe can resolve the field strength variation or a trace current probe can resolve the trace current underneath during the probe's spatial offset.

A shielded single loop probe is usually good for magnetic field measurement since it captures the magnetic flux crossing the loop and the loop size can be reduced to increase spatial resolution.

A shielded trace current probe against plane current coupling was design with complex structure for ESD current reconstruction scanning. Its spatial resolution is measured and simulated over a 2.8 mm wide trace with sideway offsets as Fig 9 shows:

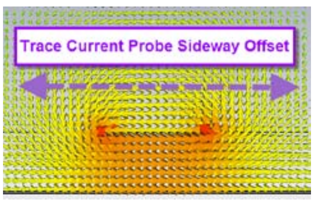

Fig 9. Trace current probe sideway offset

The probe frequency coupling responses of all the sideway offsets are obtained as Fig 10 shows:

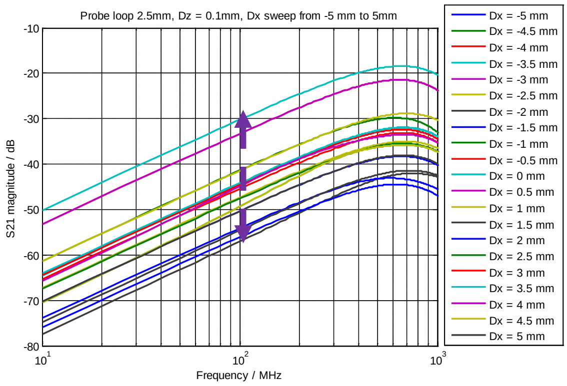

Fig 10. Frequency responses for several probe sideway offset

Then the responses at the same frequency (in the inductive coupling frequency range) for all the sideway offsets are plotted in Fig.11:

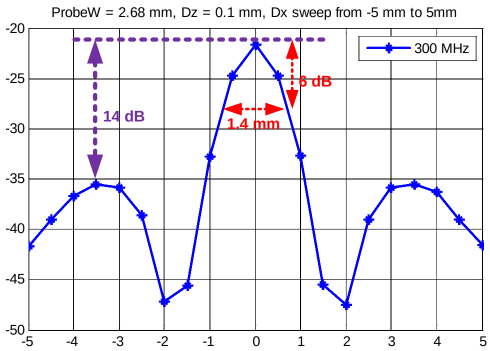

Fig 11. Spatial resolution of a designed trace current probe

For a trace current probe, the spatial resolution indicates the scanning resolution should be much smaller than the 6 dB width to get the maximum coupling position scanned. And the side peaks coupling should be reduced as good as possible in order to avoid "fake trace current" from scanning result.

C. *Directional Response and Orthogonal Data Combine*

The directional response of a probe reflects how it couples to field or current during rotation, usually from the maximum to the minimum coupling direction.

A shielded single loop probe usually has good directional response that follows cosine drop from the maximum to minimum coupling direction. If a probe's directional response follows cosine drop, the orthogonal measurement signals such as V_x and V_y can be separately processed and directly mapped to vectors H_x and H_y, or J_x and J_y.

A shielded trace current probe, depending on the coupling mechanism, may not have good directional response that follows cosine drop. Thus the process of orthogonal scanning data needs to compensate for its directional response.

The directional response of a probe is only compensable in its linear dynamic range, or inductive coupling range. Fig 12 shows a trace current probe with deficient directional response. The linear region is from 50 MHz to 1 GHz.

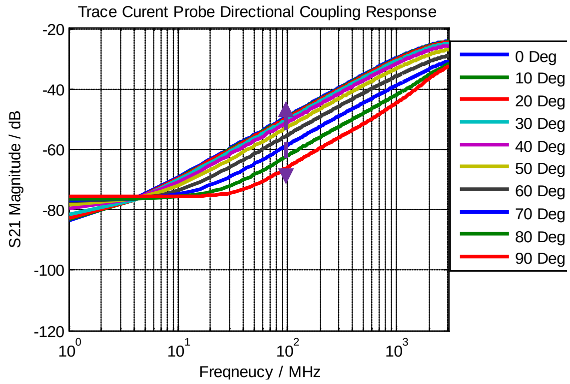

Fig 12. Probe with deficient directional frequency response

The normalized directional response of the probe is shown in Fig 13. The 90 degree rejection is less than 20 dB, which suggests certain common mode coupling exists.

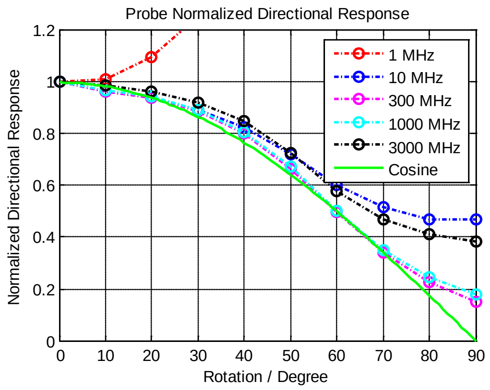

Fig 13. Probe's normalized directional response in several frequencies

The coupling frequency responses of a probe with better directional response are shown in Fig 14. The probe has wider inductive coupling range and dynamic range (from 5MHz to 3GHz). In addition, its normalized directional responses in this range are shown in Fig 15.

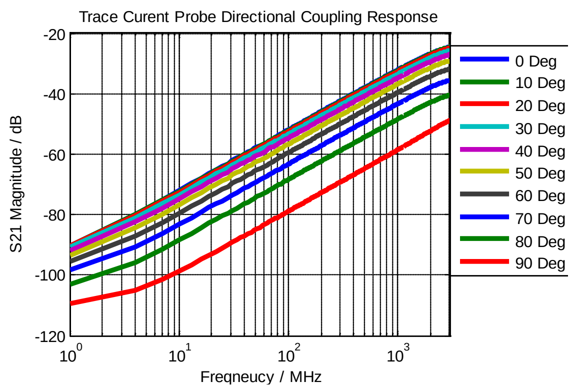

Fig 14. Probe with good directional frequency response

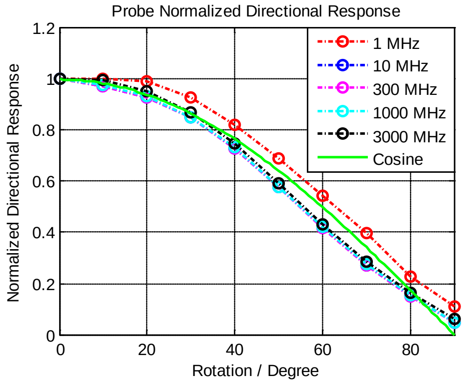

Fig 15. Probe's normalized directional response in several frequencies

The orthogonal scanning data can be compensated if its directional response is symmetry between [0, 90] and [0, -90], and also monotone decreasing in [0, 90], like Fig 15. Suppose an orthogonal data set of V_x and V_y is measured from scanning using this probe as Fig 16 shows.

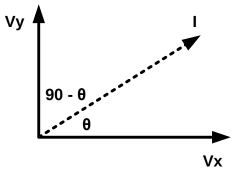

Fig 16. Commonly measured orthogonal data set

The trace current under the probe is θ degree off the X direction and 90-θ degree off the Y direction. The process to calculate I and θ from V_x and V_y is to map the V_x/V_y in the interpolated V_x/V_y curve as the Fig.17 shows.

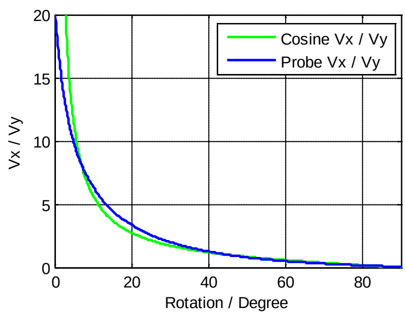

Fig 17. Probe's V_x/V_y monotone decreasing curve

Since the probe's normalized directional response is monotone decreasing, the V_x/V_y curve is also monotone decreasing and there is a one-to-one correspondence relation between the V_x/V_y and θ. Then the maximum coupling response V can be calculated from the probe's normalized directional response as Fig 18 shows. Finally, the trace current vector I can be recovered from previous deconvolution process.

In this way, the current vector I can be recovered precisely as long as the probe's normalized directional response is monotone decreasing, even it doesn't follow cosine drop. The common mode h-field coupling maximized at 90 degree direction won't be added into the recovered vector I.

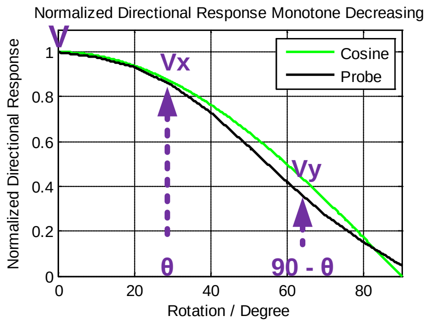

Fig 18. Relations of Vx, Vy and V on the normalized directional response

III. Conclusions

In this paper, several important probe characteristics for recovering surface current density J or trace current I by near field scanning method are analysed. The probe's coupling frequency response characterization and compensation methodology are described; probe's spatial resolution and relation to minimum scanning resolution are illustrated; and probe's directional response and compensation method for orthogonal scanning data are explained.

In the next step, probe design and optimization for current reconstruction by near field scanning should be continued for better frequency response, spatial resolution, unwanted coupling rejection, sensitivity and directional response. Secondly how a probe or structure can influence the near-field around the measurement target should be studied, especially when the measurement interest is the coupled signal on the target, not the driven signal on the target.

References

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