Radiated Emission Effects from Multiple Via Stimulation Within a Printed Circuit Board

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ABSTRACT

Radiated emissions propagate from printed circuit boards (PCB) due to common-mode RF currents developed by digital components switching logic states. Transmission lines connect an output to an input pin, generally on another component, and are usually routed on different planes within a PCB, jumping layers through vias. Vias themselves may propagate an undesired RF field causing significant EMI.

Research on field propagation from a single via exists. However, radiated effects from the phasing of multiple internally created common-mode current sources simultaneously have not been examined with extensive analysis. This paper investigates the phasing of 100 vias (stimulus sources) simultaneously in the Gigahertz range, emulating a real printed circuit board using today's high-speed technology, and not a typical theoretically perfect model and single stimulus.

Simulated results are presented with field propagation plots illustrating what an antenna could observe at three meters distance due to multiple field propagating sources, illustrating the complexity of the field patterns and the difficulty in determining, or measuring accurate field strength in the far field.

Index Terms — Radiating field pattern, multiple source stimulation, propagating field, field reception, far field measurement, multiple vias.

INTRODUCTION

In a high-density, high-frequency PCB, digital circuits communicate using transmission lines. Transmission lines usually traverse layers from source to load through vias. Due to impedance discontinuities presented to any transmission line by vias, and the current density present, a voltage potential difference is established across the via causing common-mode RF energy and EMI. A transmission line also provides a voltage or current driven mechanism that stimulates a dipole antenna at a particular resonant frequency. Depending on the current amplitude present, the magnitude of the propagated RF field could be substantial. The field propagation from a single via is typically assumed to be a simplified field plot that is easily measured with some degree of accuracy.

There are generally hundreds of vias in a real-world PCB. Depending on their physical location, relative to each other and the edge of the assembly, a reflected wave will bounce back to the center of the printed circuit board causing phasing effects to occur, the same net effect that generally causes a signal integrity problem.

Phasing of multiple reflections may permit large amplitudes of voltage overshoot and planar bounce, which can couple to other transmission lines and vias causing a signal integrity problem (crosstalk) or undesired field propagation [1].

A complex radiated field pattern will exist when multiple vias radiate at the same time. In order to determine the maximum RF field strength, we need to take into account measurement uncertainty of our antenna in 3-axis (x-, y-, and z) and its relationship to the beamwidth of an antenna for GHz signals.

ANALYSIS CONFIGURATION AND MODEL

The analysis configuration is shown in Figure 1.

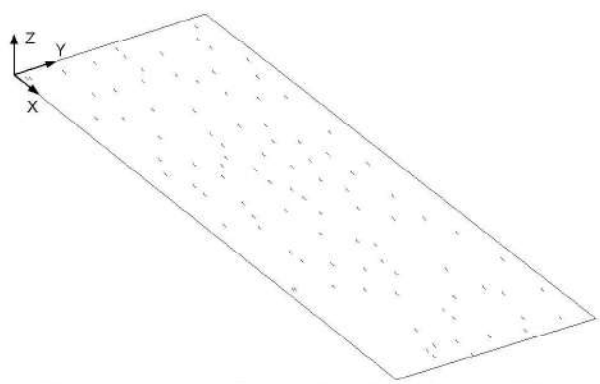

Figure 1. Printed Circuit Board Model with 100 Randomly Located Via Stimulation Sources

PCB Characteristics

- Dimensions: Lx=30.48 cm (12 inches)
  Ly=10.16 cm (4 inches)
- Distance between power and return plane:
  h=0.127/0.254/0.508 mm (5/10/20 mils)
- Dielectric constant: $\varepsilon_r = 3.3$
- Loss tangent: $\delta = 0.002$
- Copper thickness: 0.7 mils = $17.5e^{-3}$ mm (0.5 oz)

Stimulation Characteristics

- Stimulation source: 1 mA/via
- Stimulation frequencies: 1.8, 2.45, 3.0, 5.0 GHz
- Total number of vias: 100 located randomly with regard to x- and y-axis (Figs. 1 and 2).

To analyze an RF propagating field along with reflected wave reflections present within the power distribution network, HFSS, a Finite Element Method simulation program by Ansoft Corp is used. Due to complexity of the analysis, it is very difficult to validate simulated results with instrumentation.

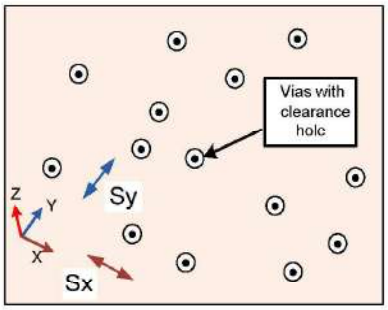

Figure 2. Top view of sample via locations.

Via dimensions (Figure 3)

- Via radius = 0.127 mm
- Via clearance hole = 0.508 mm
- Spacing between vias (center to center) S_x=10 mm; S_y=8 mm
- Height of via: h = 0.127/0.254/0.508 mm
- Via impedance (at 3 GHz): 3.30/6.61/13.22 ohms

The input impedance of the via is defined as the impedance looking into one end of the via while the other end of the via is connected to the return plane.

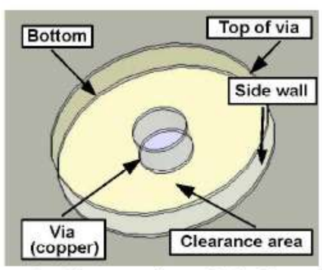

Figure 3. Close up view of via dimensions.

DISCUSSION

When examining field propagation plots, one must determine if the RF energy measured is in the near-field or far-field.

When in the near-field, any measurement taken with a broadband antenna is invalid if the antenna is located too close to the source, or less than $\lambda/(2\pi)$ at a frequency of concern. This near-field region is identified as the reactive field. RF signals that exist in this reactive zone do not propagate as one generally may assume, unlike a pure plane wave in the far field. However, in the far field (R_{ff}), we observe the propagating field as a plane wave consisting primarily of two components; electric field (E_θ) and magnetic field (H_ϕ).

When the measurement distance between device and antenna, r, is much less than R_{ff}, the radial field component E_r (from a dipole-equivalent antenna/wire) should be taken into consideration but is generally ignored. By ignoring E_r we significantly invalidate, or improperly measure the propagating field. We would also be distorting the propagating radial pattern compared to that which would be expected if the propagating field is greater than $\lambda/(2\pi)$, or in the far-field.

All field patterns exist in three dimensions, which we measure usually with a 2-D antenna. Is the field intensity and pattern a true representation of the RF energy present? When performing commercial radiated emission testing, we first rotate the turntable 360 degrees to maximize the signal from the EUT. After this, we vary the height of the antenna from 1-3 meters, repeating the process for both vertical and horizontal polarizations. The question is, "After we maximize antenna height, is the turntable angle still at a maximum value since the 3-D propagating field is complex and may now be outside the field pattern of the antenna. With a 2-D measurement arrangement, we may be missing a portion of the propagating field.

Should we use a short dipole or monopole antenna instead of a horn antenna in the GHz range since the field pattern of a dipole is broader than a horn? With a horn antenna, we must be on axis with the field pattern unlike a dipole with a broader beamwidth. A horn antenna might work under certain conditions, especially if we know that the propagating field pattern is from a simple transmitting source or plane wave. We must avoid having the pattern of the measurement probe not affect measurement accuracy.

If the equipment under test (EUT) is placed in an irregular polarity, or in a position not typically considered normal (i.e., horizontal or vertical polarity), the true high frequency emission pattern may not be properly measured. What if the propagating field from a PCB does not travel in a straight-line path from EUT to the mid-point of the antenna, but instead to a point beyond where the antenna efficiency is high?

By assuming the propagating field is a simple nodal pattern, which we would expect from a single source or stimulus, it was discovered that the propagating field from multiple stimulation sources, (vias or components) will vary based on frequency and parametric values within the PCB. To investigate the magnitude of any phase relationship and field pattern created, the only change made is distance spacing between the planes. Changing distance spacing between planes alters the resonant frequency characteristics of the PCB, which in turn affects propagating field patterns.

ANALYSIS

Figures 4-6 illustrates what a propagating field looks like within one plane of the PCB based on numerous phasing of signals bouncing between vias and the edge of the board. All plots display the E-field parallel to the plane structure. The distance spacing between planes for Figures 4-6 is 0.127mm (5 mils).

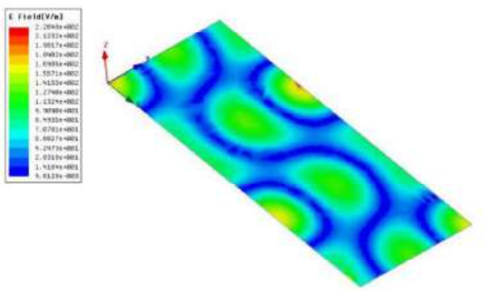

Figure 4. E-field distribution-power plane (***f*=1.8 GHz**).

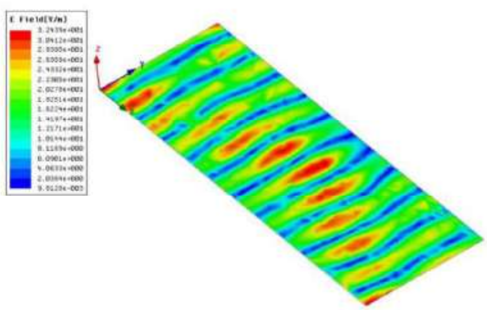

Figure 5. E-field distribution-power plane (***f*=3 GHz**).

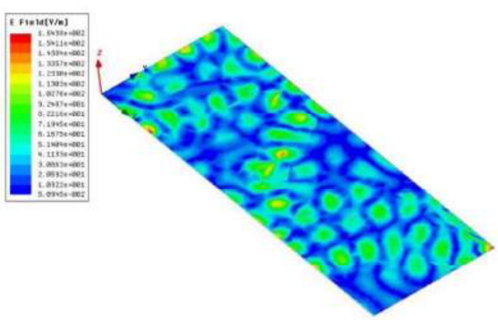

Figure 6. E-field distribution-power plane (***f*=5 GHz**).

We can pick any observation point and determine the actual E-field value. For example, in Figure 4, the strongest E-field present is 226.48 V/m. It is generally assumed that the propagating wave will be cylindrical and spread out in a circular manner, which may be true *only* if one stimulus source exist. Due to reflections from other vias, the shape of the wave is deformed. Also, reflected waves from the edges of the board will also phase add/subtract creating a very interesting visualization of field propagation. Due to board resonances at different stimulus frequencies, interesting wave patterns are observed.

The uniqueness of this research lies in understanding what really occurs when analyzing a model that emulates a real PCB layout. Although vias are used instead of active components, regardless, there are many different sources that generate common-mode currents and EMI. We used vias to emulate signal sources. Our primary concern related to EMC is to prevent harmful interference to electrical equipment. How can this be achieved when we may not understand, recognize, or properly measure what the real field propagaton looks like to a victim system?

Figure 7 shows a far-field sphere that surrounds the test vehicle. Rotation of the system on a turntable is required to determine the maximum signal amplitude present at 3-meters (far-field). Figure 8 illustrates the RF propagating field pattern for different configurations. Signals in the GHz range, now common with many commercial products, have interesting radiation patterns.

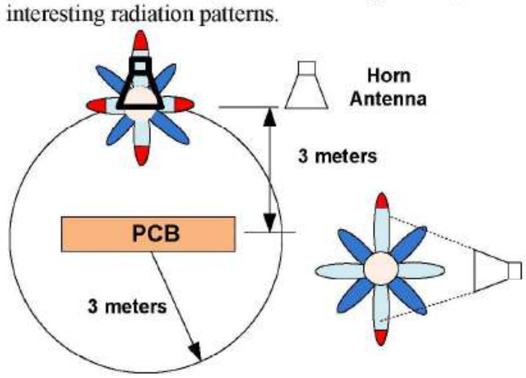

Figure 7. Antenna beamwidth in the far-field.

In studying the plots of Figure 8, the propagating field has a maximum value somewhere within the vicinity of the beamwidth of the antenna which may not be captured properly. It is also easily observed that the higher the frequency, the more complex the propagating wave pattern becomes, especially with phasing of multiple RF sources. Where the antenna is physically located relative to the maximum node of the field pattern determines if the measured signal is truly accurate.

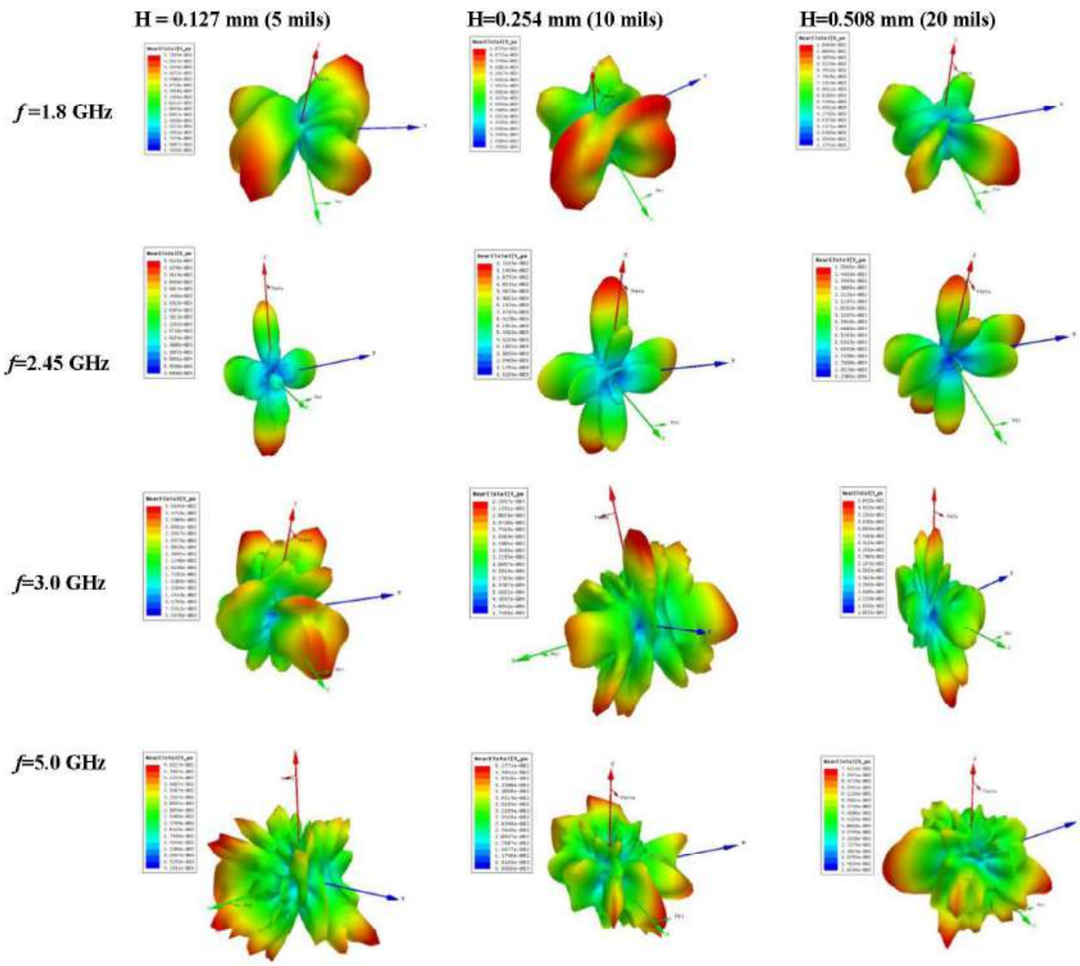

Figure 8. Plots of the radiated field at 3-meter distance parallel to the PCB.

CONCLUSION

A PCB always contains numerous stimulation sources. Sources include digital components creating and propagating RF fields due to transmission line lossess and via transitions. The amplitude of a propagating RF field is measured to determine maximum field intensity, whose value is only accurate when located in the far-field for GHz signals. Near-field measurements are meaningless when associated with regulatory compliance limits.

Higher frequency propagating fields have smaller wavelengths that appear differently to an antenna. If only one stimulus source is analyzed in a PCB model, we would probably see only a single planar wave. With multiple stimulation sources, phasing of signals bouncing back and forth between vias and the board's physical edge creates a complex propagating field pattern that when radiated from a PCB may not be uniform. The maximum RF node may thus be outside the beamwidth of the antenna. The physical dimensions of the PCB also affect field propagation patterns significantly as well as frequency. The pattern observed is similar to the expected radiated field of a patch antenna or an array of radiators, but in this case is from unintentional EMI due to via radiation.

REFERENCES

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