Radiated Emission Analysis from Printed Circuit Board Edges Using Multiple Stimulus Sources

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Abstract – Printed circuit boards (PCBs) are the primary source of EMI. The manner of propagation of an undesired RF field depends on the type of antenna configuration present within the structure. Unwanted EMI is also created within cable interconnects, lead-bond wires, poor power distribution networks, simultaneously switching noise, crosstalk, and from the physical edge of the PCB assembly between a power and return plane pair. This paper examines the magnitude of the RF field that may cause harmful EMI to adjacent assemblies only from the edge of the board.

Designers are faced with numerous obstacles when creating a PCB due to increasing demand for higher operating frequencies and greater functionality. Engineers generally do not concern themselves with board edge radiated emissions, thus this study.

I. INTRODUCTION

In a high-density count component PCB, digital circuits must be placed physically close to each other. After placement based on functional demands, the location of components (i.e., 1000+ BGA pins, sub-picosecond edge rates, with amps of inrush surge current), may not be physically located adjacent to the edge of the PCB. The physical distance of a component from the edge of the PCB is a contributing source that allows RF currents to be propagated off the edges [1]. This propagating field may cause harmful EMI.

The x-H Rule is a rule-of-thumb layout technique used to minimize board edge radiated emissions. The power plane is physically small than the return plane by "x" times the distance spacing between the plane pair. The value of "x" is typically 20, however any integer value can be used.

Previous research on the x-H Rule validated this rule-of-thumb as being fact, not fiction [2]-[3]. This rule was first released to the public in 1996 after being used by many Fortune 500 companies for nearly 25 years [4]. The item to note about the x-H rule is that this is applicable *only* for RF emissions in the near-field, and only for those fields that may cause localized EMI. Correlation to far-field propagation is not investigated.

Only by simulating numerous configurations can one begin to understand field propagation off the edge of the PCB. Because of the complexity of transmission line theory involved, debates on the x-H rule have occurred, both favorable and unfavorable.

Rather than study edge radiation effects using a single source at one location [5]-[6], this research simulates three digital components (sources) located at different physical distances from the edge of the assembly. Each location was stimulated simultaneously, which emulates multiple power/return pins source/sinking current during a state transition. The transmission line stub (physical distance) between components and the PCB edge causes propagating RF waves to be developed [1]. We examine what happens when more than one propagating wave front is present, as one would observe in a real-world PCB; phasing of multiple stimulus and their relationship to the development of a RF propagating field off the edge of the board.

II. TEST CONFIGURATION

The test configuration is detailed in Fig. 1.

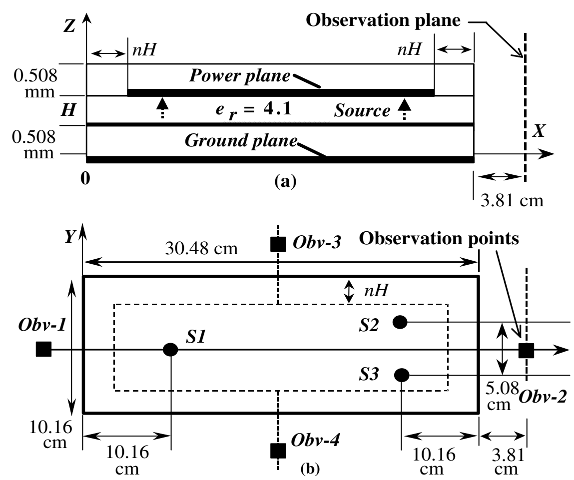

Fig. 1. Four-layer PCB configuration (not to scale). (a) Side view; (b) Top view.

In Fig. 1, *S1*, *S2* and *S3* is the physical location of the three stimulus sources. The small solid rectangles denote four observation points.

Figure 2 illustrates the model used for simulation. The observation plane ABCD (solid line rectangle) and the observation point (the small solid rectangle) is located in the Z plane perpendicular to X/Y axis at 3.81 cm.

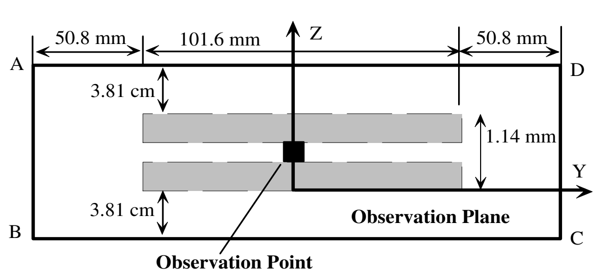

Fig. 2. Observation plane (ABCD) and point location.

Regarding the observation plane/point in Figure 2, the PCB (dashed lines) is not actually located in the observation plane; it is used only to indicate the position relative to this point. We selected an observation plane for the purpose of seeing how the PCB affects neighboring circuits (e.g., other PCB/MCM modules nearby, adjacent cable assemblies, or a metal chassis). This is justified by the distance spacing between the observation plane and the edge of the PCB at 3.81 cm away. The observation points are fixed for all configurations.

The test parameters for simulation were:

- Distance spacing between the edge of the PCB and the observation point:
  3.81 cm (1.5 inches)

- Distance spacing between power/return plane (H):
  0.127/0.254/0.508 mm (5/10/20 mils)

- Dimension of the PCB for all configurations:
  30.48 cm x 10.16 cm (12 x 4.0 inches)

- Stimulus frequencies:
  300, 600, 900 MHz and 1.5 GHz

- Simulation software:
  Enhanced FDTD with integrated SPICE

- Stimulation source:
  Line voltage source: 1-Volt amplitude between the power and return plane in sinusoidal form (1).

$$E_{source} = \sin(2\pi fkdt)/H \quad (V/m) \tag{1}$$

where: f = frequency, k = number of FDTD time steps, dt = a single time step, and H = distance separation.

III. Impedance Analysis of the PCB

We chose location S1 as the observation point to determine the self-resonant frequency of the power and return plane pair. The lower the impedance value, the less probability of EMI. Results from simulation using a Gaussian pulse is detailed in Table 1.

Results in Table 1 are from multiple configurations. The change in actual resonant frequency shown in Fig. 3 between 0-H, 10-H and 20-H was negligible however, the further apart the planes are separated, the higher the impedance. As observed, board impedance varies significantly depending on physical dimensions, even though the resonant frequency did not change to any degree.

Frequency	Distance spacing between planes		
	H=0.127mm	H=0.254mm	H=0.508mm
0.3 GHz	0.13 ohms	0.25 ohms	0.50 ohms
0.6 GHz	0.59 ohms	1.19 ohms	2.38 ohms
0.9 GHz	0.79 ohms	1.59 ohms	3.18 ohms
1.53 GHz	0.61 ohms	1.22 ohms	2.45 ohms

TABLE I Impedance of the PCB, different configurations

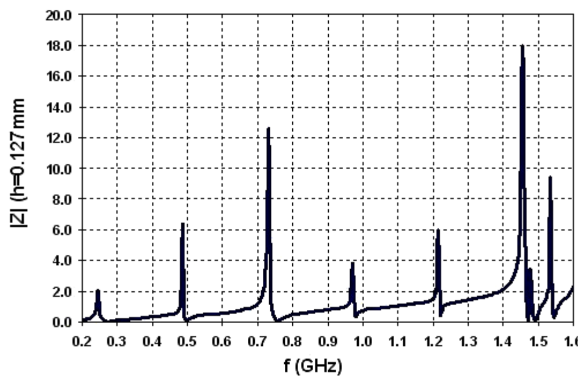

Fig. 3. Resonant frequencies of the PCB model.

IV. Analysis of Test Results

We now investigate what happens under the following stimulus conditions.

1) Three sources operating individually, and then simultaneously; 300 MHz, 600 MHz, 900 MHz and 1.5 GHz.

2) Two configurations, three sources simultaneously: 0.3/0.6/0.9 GHz and 0.6/0.9/1.5 GHz.

3) The above two configurations with three different spacings between the power and return plane pair: 0.127/0.254/0.508 mm (5/10/20 mils).

For the case of H=0.254 mm (10 mils), 10-H configuration, 600 MHz, we compared results of Ez at all four observation points. Data showed that ($Ez3$=$Ez4$) > ($Ez1$ or $Ez2$) (Fig. 4). A similar relation held for all other cases, therefore we select observation point $Ez4$ as the location to monitor the radiated field.

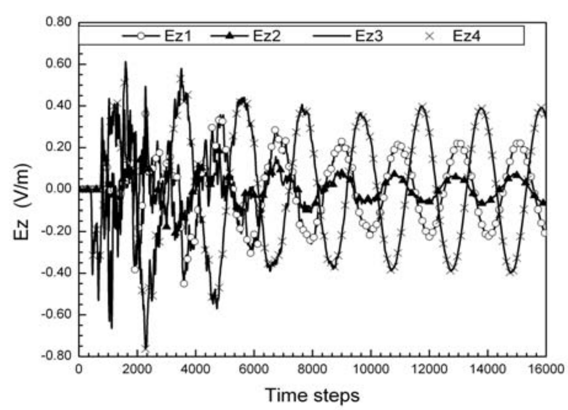

Fig. 4. Location of maximum RF (middle of PCB).

To analyze radiated emissions from many different configurations, we calculate the total radiating electric field intensity per (2).

$$|E|_{max} = \sqrt{E_x^2 + E_y^2 + E_z^2} \tag{2}$$

$|E|_{max}$ refers to the total electric field intensity with three components, E_x, E_y and E_z. E_z is dominant over E_y and E_x for this power/return configuration ($Ez >> Ey$ or Ex). When we simulated E_z in the time domain, *Obv-4* had the largest $|E|$ component in frequency domain. When considering both electric and magnetic flux in the near field, it is difficult to determine which one is dominant.

The location where the E and H fields converge into the intermediate region, between the near and far field, or the starting point of where the far field begins is described by (3).

$$\lambda = (c/f)/2\pi \quad (3)$$

where λ=wavelength distance, c=speed of light ($3*10^8$ m/s) and f=frequency. The far-field begins at approximately $\lambda/6$ from the source location, or:

300 MHz=15.9cm (6.26 in.); 600 MHz=7.9cm (3.11 in.)
900 MHz=5.3cm (2.08 in.); 1.5 GHz =3.1cm (1.22 in.)

What is unique about this simulation versus previous research is that three different frequencies (sources) are used simultaneously. Depending upon the physical distance between the source and observation point, after achieving steady state conditions, phasing of signals will occur. For some configurations, we have phase addition, or subtraction, due to resonances present within the assembly. Depending on the resonant frequency of the power and return plane pair, radiated EMI will either increase or be significantly smaller.

A designer should only be concerned about the total magnitude and phasing of the propagating field at a specific distance from the edge of the PCB, not what field contour plots look like.

To evaluate the maximum amount of RF energy propagating from the PCB due to board resonances, three different distance spacings between planes, each with three stimulus sources were performed. Only by using a large matrix of data can we begin to understand the effect of board edge radiated emissions.

The maximum amplitude of the normalized E-field at the observation point is listed in Tables 2, 3 and 4, and are visually plotted in Fig. 5. The single source stimulus is identified as (x1), observed at *Obv-1*. Multiple stimulus are listed as (x3), with observation point *Obv-4*. For the single source stimulus, the magnitude of the signal at *Obv-1* was greater than *Obv-4* during preliminary analysis, the reason this point is selected; worst case analysis.

Unlike the results in [1] which prove definitively that x-H implementation reduces EMI, *use of multiple stimulus sources will increase radiated energy due to the phase amplitude addition of multiple signals when observed in the near field.*

Abnormalities are however observed at H=0.058 mm (20 mils) separation distance, 20-H configuration. These abnormalities are due to the self-resonant frequency of the PCB, which validates the concern that the X-H rule is applicable to only certain physical board dimensions [1-3].

Due to the physical dimensions of the PCB model, the longer side approaches the efficiency level of a dipole antenna which explains why we see higher levels of emissions. This amount of increased EMI is still neglibible, if attempting to coorelate to what is observed in the far field, which is where radiated EMI testing occurs.

Frequency	0-H (V/m)	10-H (V/m)	20-H (V/m)
0.3 GHz (x1)	**0.107**	**0.180**	**0.227**
0.3 GHz (x3)	0.326	0.525	0.656
0.6 GHz (x1)	**0.256**	**0.570**	**0.760**
0.6 GHz (x3)	0.725	1.619	2.166
0.9 GHz (x1)	**0.811**	**1.283**	**1.576**
0.9 GHz (x3)	2.107	3.514	4.365
1.5 GHz (x1)	**5.284**	**6.092**	**7.178**
1.5 GHz (x3)	7.153	7.979	9.185
0.3/0.6/0.9 GHz	1.843	2.822	3.427
0.6/0.9/1.5 GHz	1.737	1.873	1.998

TABLE II
MAXIMUM RADIATED ELECTRIC FIELD INTENSITY AT OBSERVATION POINT $|E|_{MAX}$ ***H* = 0.127 MM (5 MILS)**

Frequency	0-H (V/m)	10-H (V/m)	20-H (V/m)
0.3 GHz (x1)	**0.053**	**0.075**	**0.087**
0.3 GHz (x3)	0.160	0.222	0.254
0.6 GHz (x1)	**0.135**	**0.283**	**0.362**
0.6 GHz (x3)	0.383	0.804	1.029
0.9 GHz (x1)	**0.421**	**0.685**	**0.785**
0.9 GHz (x3)	1.096	1.883	2.180
1.5 GHz (x1)	**1.155**	**1.258**	**3.335**
1.5 GHz (x3)	3.588	4.507	4.711
0.3/0.6/0.9 GHz	0.938	1.474	1.507
0.6/0.9/1.5 GHz	0.874	0.962	0.784

TABLE III
MAXIMUM RADIATED ELECTRIC FIELD INTENSITY AT OBSERVATION POINT $|E|_{MAX}$ ***H* = 0.254 MM (10 MILS)**

Frequency	0-H (V/m)	10-H (V/m)	20-H (V/m)
0.3 GHz (x1)	**0.012**	**0.025**	**0.011**
0.3 GHz (x3)	0.034	0.072	0.212
0.6 GHz (x1)	**0.096**	**0.138**	**0.248**
0.6 GHz (x3)	0.282	0.397	0.433
0.9 GHz (x1)	**0.214**	**0.311**	**0.421**
0.9 GHz (x3)	0.565	0.855	0.734
1.5 GHz (x1)	**1.383**	**1.689**	**1.486**
1.5 GHz (x3)	1.670	2.219	1.875
0.3/0.6/0.9 GHz	0.576	0.628	0.465
0.6/0.9/1.5 GHz	0.439	0.334	0.584

TABLE IV
MAXIMUM RADIATED ELECTRIC FIELD INTENSITY AT OBSERVATION POINT $|E|_{MAX}$ ***H* = 0.058 MM (20 MILS)**

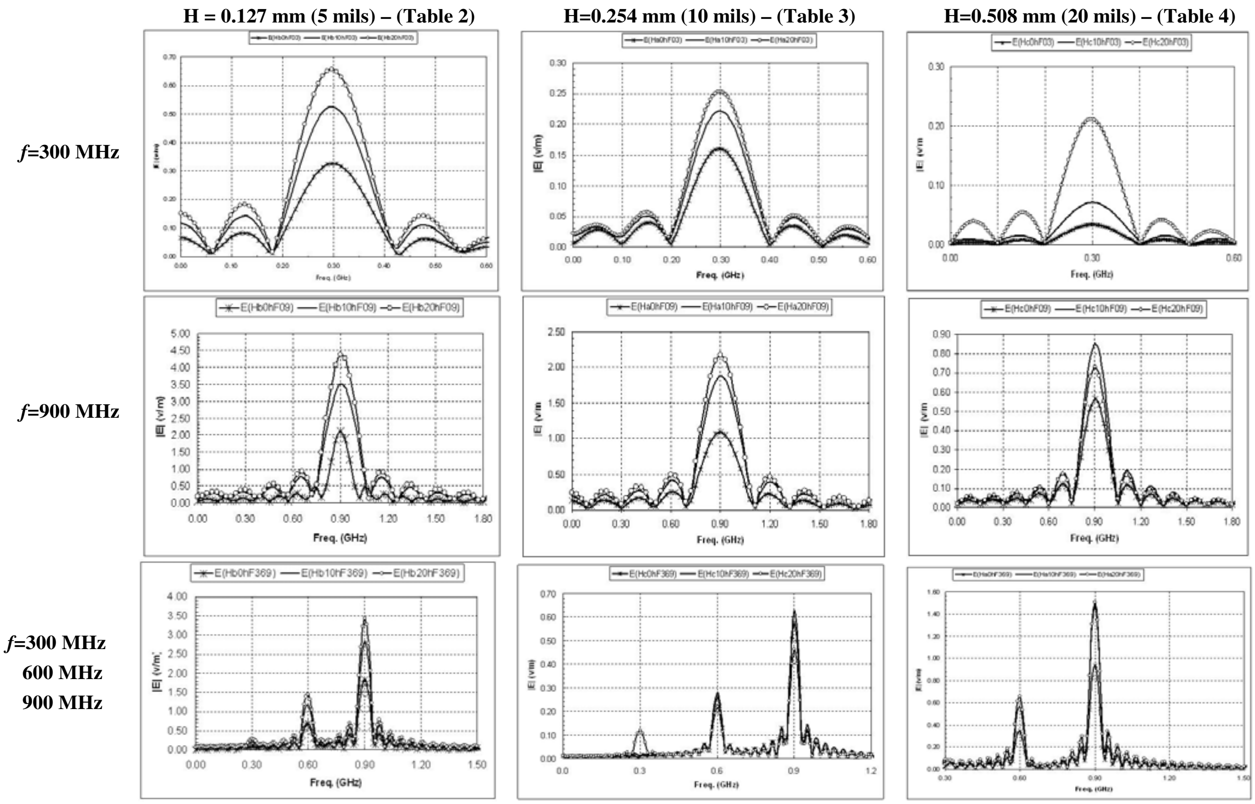

Fig. 5. Sample plots of radiated power from the long edge of the PCB (Observation Point #4).
Each plot contains 0-H, 10-H and 20-H, detailed in Tables 2-4. Legend: ✶ = 0H — =10H –O– =20H

V. Conclusion

A real-world PCB has numerous stimulation sources. Using transmission line theory and applying it to planes instead of typical signal lines, a transmission line stub exist between the physical location of a component and the board edge, driving this stub as a dipole antenna at switching frequencies [1]. Capturing magnetic flux present on the power plane into the return plane will minimize the propagating field that radiates off the edge of the assembly. Radiated emissions will be maximized if the board is self-resonant at stimulus frequencies. It is rare when both stimulus and self-resonant frequency are identical in a real PCB.

The x-H Rule applies to near-field analysis, as the magnetic field component is minimal at these dimensions [2]-[3]. Far-field emissions make use of the plane wave that includes both *E* and *H* fields.

When multiple stimulus sources are simulated, representing a real-world PCB, an increase in field propagation from the edge of the board assembly occurs over that of a simplified single-source stimulus.

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