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Experimental Study of Radiated Emission from High Speed Power Plane

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Abstract— Power plane has been used commonly for high-speed PCB design to delivery stable power for the circuits as well as to provide low impedance paths for the power delivery currents. Using an experimental approach, the impacts of placement of decoupling capacitors and plane separation on radiated emission from high-speed board are carefully investigated and studied.

I. INTRODUCTION

With ever-increasing number of ICs on a PCB, power delivery design to these ICs has become a challenging task. Without careful consideration of power delivery to the ICs, large power-to-ground loops carrying high current during gate switching are formed and result in significant radiated emissions from board. In order to meet the stringent regulatory radiated emission limits [1], early planning of power delivery design for high-speed board is no longer an option. Power-ground plane pair and large number of decoupling capacitors have been used extensively by the designers to reduce radiated emissions from the board to meet the required EMI limits [2].

This paper aims to provide a comprehensive study on the impacts of different decoupling strategies and power-ground plane separation on radiated emission from the board. To facilitate the study, a two-layer board of 25.6 cm by 15.3 cm, as shown in Fig.1, is fabricated as a test board. There are a total of 15 SMA connectors (3 rows with 5 connectors for each row) to facilitate the tapping of power at different board locations and 104 capacitors on the board for power supply decoupling purposes. The SMA connectors are placed in such a way that the there are 5.2 cm apart and those near the board edges are 2.6 cm away from the edges. There are 12 global decoupling capacitors of 4.7 μ F each are placed between the SMA connectors. 23 groups of capacitors, consisting of one 1 μ F, one 0.1 μ F and two 0.01 μ F, placed around the 15 SMA connectors and in the centre of 4 SMA connectors. To provide insight of the cause of radiated emission from the test board, besides the usual far-field radiated emission measurement in the GTEM (Gigahertz Transverse Electromagnetic) cell, the near-field emission of test board also be measured with the EM scanner [3]. The purpose of the near-field EM scan is to capture the current distribution for specific frequency so that it

can be visualized for in-depth analysis. To excite the test board, a separate driver circuit clocked at 100 MHz is designed. It acts as a dynamic load to draw current from the test board when the driver circuit switches logic state. The driver circuit is fabricated on a very small PCB and is completely shielded in a small metal box. The only connection to the test board is through a SMA connector, where it connects the power and ground of the driver circuit to the power and ground planes of the test board. The external driver circuit draws a peak current of 280 mA during logic state switching. Three cases are studied as follows:

- Plane separation of 63 mils without capacitors,
- Plane separation of 63 mils with capacitors and,
- Plane separation of 40 mils with capacitors.

Figure 1: Two-Layer Board with SMA Connectors and Decoupling Capacitors

II. EM SCAN MEASUREMENT RESULTS

Fig. 2 shows the setup of the test board on the scanner module. A power supply is connected to a voltage regulator to provide stable +5V DC supply voltage. The power and ground planes of the test board are connected to +5V and 0V of the regulator output at the left lower corner of the test board. The driver circuit can be placed at any of the 15 SMA ports. For the results presented in this paper, it is placed at the excitation port shown in Fig. 2. Once the driver circuit is powered up

and clocked at 100 MHz, the scanner module scans the field across the whole test board from 30 MHz to 1.3 GHz.

Figure 2: Position of Test Board on the EMScan Scanner Module

The resonant frequencies of the test board can be determined using Equation (1). For the given board size, the length and width of the board are 25.6 cm and 15.3 cm, respectively. Table 1 lists all possible resonant frequencies of the test board with highest mode number stops at $m = n = 4$.

$$f_{(res)} = \frac{\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}}{2\pi\sqrt{\epsilon\mu}} \quad (1)$$

where a is the length of the board in m, b is the width of the board in m, m and n are integers associated with the resonant modes, $\epsilon = \epsilon_0\epsilon_r$, $\epsilon_0 = 8.85 \times 10^{-12}$ F/m, $\epsilon_r = 3.9$, $\mu = \mu_0\mu_r$, $\mu_0 = 4\pi \times 10^{-7}$ H/m, $\mu_r = 1$.

TABLE I
CALCULATED RESONANT FREQUENCIES (IN MHZ) OF THE BOARD

$m \backslash n$	0	1	2	3	4
0	N.A.	496.14	992.29	1488.43	1984.57
1	296.52	578.00	1035.64	1517.68	2006.60
2	593.05	773.22	1156.00	1602.23	2071.29
3	889.57	1018.57	1332.65	1734.00	2174.82
4	1186.09	1285.68	1546.43	1903.22	2312.00

Fig. 3 shows the result obtained from the EM scanner for the test board with plane separation of 63 mils without decoupling capacitors when it is excited by the external driver circuit positioned at the excitation port. As the external driver circuit is clocked at 100 MHz, harmonic emissions at multiples of 100 MHz (fundamental) are expected. However, not all of these harmonics have shown up in the near-field scan results.

Figure 3: Near Field Spectral Result when External Driver Circuit is Excited by the Test Board with 63 mil Plane Separation

Figure 4: Spatial Emission Plot of Bare-Board with Plane Separation of 63mils at (a) 300 MHz, (b) 1000 MHz, (c) 1100 MHz and (d) 1300 MHz when the Driver Circuit is Excited

To investigate each of these emissions, the spatial field distribution of the test board at each of these detected emission frequencies is plotted using the EM scanner. The spatial field distributions of the test board at 300 MHz, 1000 MHz, 1100 MHz and 1300 MHz are shown in Figs. 4(a), 4(b), 4 (c) and 4 (d), respectively; where the red box indicates the physical position of the test board on the scanner. For better visualization, the 3D spatial field distribution plots are given in Figs. 5 (a), 5(b), 5 (c) and 5 (d) for the respective frequencies. At 300 MHz, a half-wavelength standing wave at one of the board edges is clearly observed, which indicates a resonant mode at 296.52 MHz ($m = 1, n = 0$), closest to 300 MHz. Hence, a strong near-field emission at 300 MHz is detected from the board.

Figure 5: 3D Spatial Emission Plot of Bare Board with Plane Separation of 63mils at (a) 300MHz, (b) 1000MHz, (c) 1100MHz and (d) 1300MHz when Driver Circuit is Excited

Similar board resonance phenomenon at 1000 MHz, 1100 MHz and 1300 MHz, corresponding to modes $mn = 31, 22$

and 32 in Table 1, are also clearly observed in Figs. 5(b), 5(c) and 5 (d), respectively. Hence, the emissions at 300 MHz, 1000 MHz, 1100 MHz and 1300 MHz are due to the board resonances. The other near-field emissions detected by the EM scanner at 200 MHz, 800 MHz and 900 MHz are unlikely due to the board resonances as no visible spatial field resonant patterns are observed. These near-field emissions are likely emitted from the power delivery path from the regulator and the excitation port.

III. FAR FIELD MEASUREMENT

The shielded driver circuit is connected to the test board at the excitation port. The test board is powered by a 12V battery through a 5V voltage regulator. The far-field radiated emission of the test board is measured with a GTEM cell from 30 MHz to 1.3 GHz.

Figure 6: Far Field Measurement with the Driver Circuit Positioned at the Excitation Port of the Bare Board with Plane Separation of 63mils

In Fig. 6, the blue plot is the far-field emission of the driver circuit in the shielded box without the test board, while the red plot is the far-field emission of the test board together with the driver circuit placed at excitation port. It shows clearly that the emission from the driver circuit is much lower the emission contributed by the board. Unlike the near-field emission, Fig. 6 shows that far-field radiated emissions due to all harmonics of the clock oscillator frequency (100MHz) are detected.

Fig. 7 shows the far-field measurement for the same test board but with all the decoupling capacitors mounted. The red plot is the emission from the board with decoupling capacitors mounted on the board while the green plot is the emission from the bare board. It shows that the emission reduces significantly (6 to 22 dB) up till 700 MHz. Therefore, the decoupling capacitors are effective to suppress the radiated emission from the board up to about 700 MHz. Above 700 MHz, the decoupling capacitors are no longer effective due to their equivalent series inductances.

Figure 7: Far Field Measurement of the Driver Circuit Positioned at Excitation Port of the Board with Capacitors Mounted, Plane Separation of 63mils

Figure 8: Far Field Measurement of the Driver Circuit Positioned at Excitation Port of Board with Capacitors Mounted for Plane Separation of 63mils and 40mils

The second analysis focuses on the effect of the plane separation on radiated emission from the test board. Fig. 8 shows the emission from the board with capacitors mounted for 2 different plane separations, 40mils and 63mils. When the plane separation decreased from 63mils (red plot) to 40mils (black plot), there is a further reduction of 2-3dB in the emission throughout the whole frequency spectrum. Hence, with the presence of discrete decoupling capacitors and the thinning of plane separation do help to reduce radiated emissions from the board. However, the emissions from the board due to the board resonances at 300 MHz, 1000 MHz and 1100MHz are so significant that they still exceed the CISPR 22 Class B radiation limit, even with the decoupling capacitors and thinning of the plane separation.

IV. CONCLUSIONS

In this paper, it has been demonstrated that near-field emission measurement is very effective to detect the board resonances. However, those harmonics not detected by the near-field measurement will be detected in the far-field measurement. The usual decoupling technique has been demonstrated to be effective for emissions below 700 MHz. However, for emission higher than 700 MHz, reducing plane separation does help to reduce emission. However, the emission due to board resonances can be so significant that both decoupling techniques and thinning of board may not be sufficient to bring the emission below the regulatory EMI limit. Other cost-effective solutions are on-going currently to overcome such design challenge.

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