An Investigation of the Effect of Chassis Connections on Radiated EMI from PCBs

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***Abstract*— This paper investigates the effect of grounding posts when printed circuit boards are mounted near and parallel to a metal plate or chassis. Specifically, experimental data showing changes in radiated emission levels are explained by means of coupling phenomena between a power bus, a chassis cavity including grounding posts, and a cable connected to the power bus. This coupling is modeled using SPICE and the results are combined with an equivalent magnetic current source model to estimate the radiated emissions from various printed circuit board configurations. The calculated results are shown to be consistent with the corresponding experimental data.**

***Keywords*- power bus resonance; compact microstrip patch resonance; grounding posts; SPICE model; equivalent magnetic current source; radiated EMI from PCBs**

I. INTRODUCTION

Printed circuit boards (PCBs) are often mounted to a metallic enclosure or chassis. Standoffs are used to keep components or traces on the bottom side of the board from contacting the metal chassis. Sometimes metal standoffs and metal screws are used to make an electrical connection between the printed circuit board ground and the chassis. The metal parts used for this purpose are often called *grounding posts*.

It is empirically known to device designers that the radiated EMI is affected by the number and the location of the grounding posts when circuit boards are mounted vertical or parallel to a metal surface. For vertical mounting, it is possible for the chassis to be driven by signal or power currents on the board in much the same way that modules or daughter boards can be driven [1-3]. For parallel mounting, there are few investigations identifying the physical mechanisms and quantifying the radiated emissions. This paper provides a preliminary experimental investigation of this phenomenon and a numerical model based on the SPICE.

II. THEORY

When a PCB with power and ground planes is mounted near and parallel to a metal chassis and the PCB ground is electrically connected to the chassis by means of grounding posts, there are at least two types of resonances that may result in excessive radiated emissions from the board: *Power bus resonance* and *chassis cavity resonance* including grounding posts. When a PCB is mounted on a metal chassis with its power return plane on top, the direct coupling between a power bus and a chassis cavity through grounding posts affects the radiated emissions over a wide frequency range.

The coupling between a chassis cavity including grounding posts and a cable connected to a power bus also affects the radiated emissions. These phenomena are physically explained in the following ways.

A. Power Bus Resonance

For PCBs that have solid power planes, direct radiation from the power bus structure is one possible source of radiated emissions [4, 5]. A cavity formed by parallel copper planes in a board becomes resonant at certain frequencies and is capable of radiating efficiently at those frequencies. In this case, power bus noise is the source of the emissions and the power planes themselves are the antenna.

B. Chassis Cavity Resonance including Grounding Posts (Compact Microstrip Patch Resonance)

When a PCB is mounted to metal chassis with its power plane on top (as shown in the Fig 1.), the power return plane and the chassis form a cavity resonator including grounding posts, which can behave like a compact microstrip patch antenna [6]. Therefore, it is referred to as a compact microstrip patch (CMP) resonance in this paper. Notice that the first resonance is essentially an LC resonance with the capacitance between the PCB and chassis and the inductance of the grounding posts.

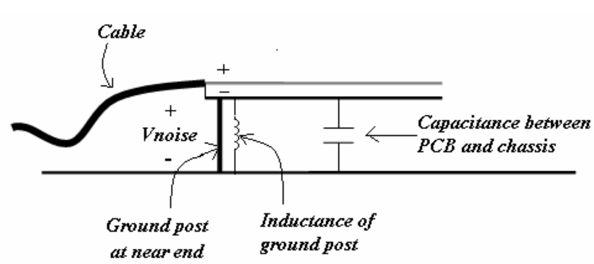

Figure 1. LC resonance in the cavity between PCB and chassis when ground post is employed at near end

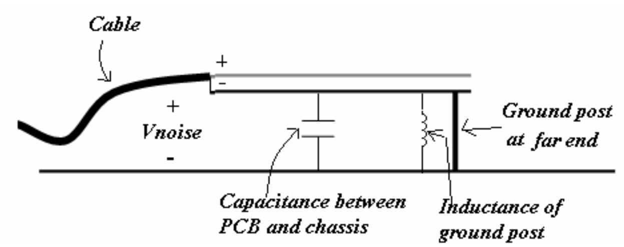

Figure 2. LC resonance in the cavity between PCB and chassis when ground post is employed at far end

When grounding is employed near a cable connection, the coupling from a CMP resonance to the cable is relatively small because the voltage between the cable and chassis, V_{noise}, is small. If grounding is employed further from the cable, as shown in Figure 2, the coupling to the cable is relatively high because V_{noise} is also high. Therefore, employing grounding posts near cable connections can help to reduce radiated emissions from a cable. On the other hand, employing grounding posts further from the cable can have unpredictable results on the radiated emissions because the value of V_{noise} near the cable attachment point is not controlled.

The resonant frequency of the CMP will shift depending on the size, number and location of grounding posts. In general, it will shift higher as more grounding posts are employed. The direct coupling between a power bus and a CMP at low frequencies is relatively small because the power return plane separates the two resonant structures. In this case, the fringing electromagnetic field is the main coupling source.

C. Direct Coupling from Power Bus to Chassis Cavity Through Grounding Posts

When a PCB is mounted on a metal chassis with its power return plane on top, the power bus is directly coupled to the chassis cavity over a wide frequency range. The radiated emissions may be increased or decreased by the coupling depending on whether the fields in the power bus cavity and the chassis cavity add or cancel at the edges. The radiated emissions from the system are mainly observed near the resonant frequencies of the power bus structure as well as the CMP structure resonances.

The same explanation as in Section B can be applied to describe the dependence of the CMP resonance on the size, number and location of grounding posts, as well as the coupling between the CMP and the cable.

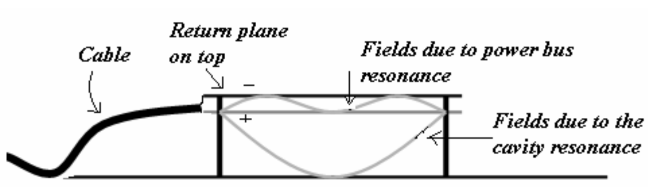

Figure 3. Resonance of the cavity between PCB and chassis.

III. MEASUREMENTS

A two-layer test board was built and radiated emission measurements were made with different chassis ground configurations. An HP8753D network analyzer was used to measure radiated emissions from the test board. The setup is illustrated schematically in Fig 4. Port 1 of the network analyzer was the driving source for the test board and the output of the receiving antenna was connected to Port 2. Two board orientations were measured. One orientation was the vertical electric field off the short edge of the board and the other was the vertical electrical field off the face of the board. These orientations were chosen because they represent the maximum field likely to be radiated due to PCB resonances or resonances associated with the plate or the cavity between the plate and the board. The maximum emissions at each frequency in either orientation are reported.

The dimensions of the test board were 12.5 cm x 10 cm and it was mounted on a 42.5 x 23.5-cm metal chassis using 1-cm or 2-cm posts as shown in Figure 5

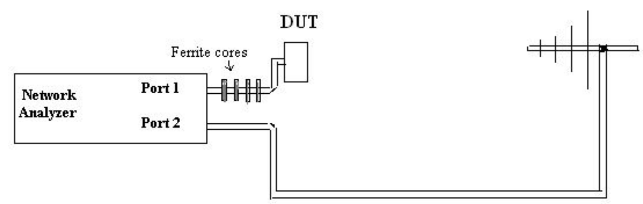

Figure 4. Experimental setup used to measure radiated emissions.

As indicated by the plot in Figure 6, the radiated emissions from this test board with no chassis exhibit peaks at 560 MHz, 1.1 GHz, 1.38GHz, and 1.7 GHz which correspond to the TM_{10}, TM_{20}, TM_{02}, and TM_{30} modes of the cavity formed by two copper planes filled with FR-4 material.

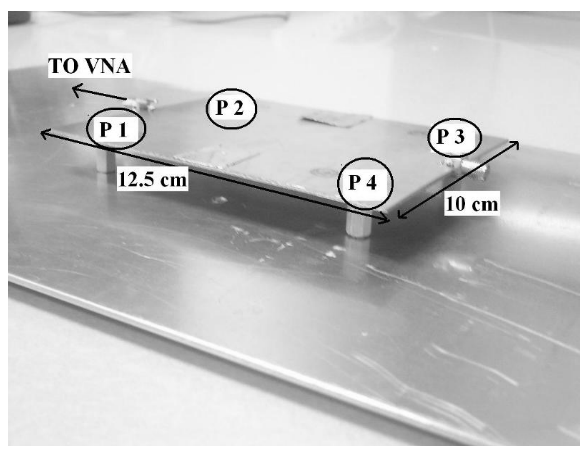

Figure 5. Test board, chassis and grounding post geometry.

When the test board was mounted to the metal plate using 1-cm or 2-cm nylon posts (i.e. the test board was not electrically connected to the plate), it was observed that the overall radiation was the same as the radiation from the board alone at the peak frequencies. The unconnected metal plate had little effect on the overall level of radiated emissions.

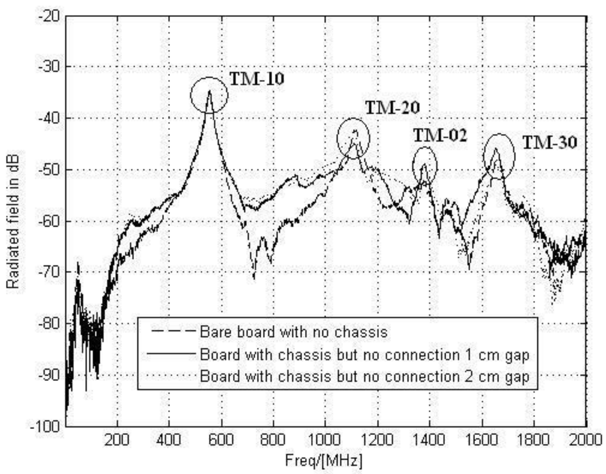

Figure 6. Radiated emissions from test board and from test board when mounted to a metal plate using non-metallic posts.

The printed circuit board was then connected to the metal plate by substituting metal grounding posts for one or more of the nylon posts making an electrical connection between one of the planes and the chassis. Figure 7 shows the radiated emissions from the test board when metal posts were used to connect the lower plane to the metal plate at two of the four points indicated in Figure 5. The peaks that correspond to the TM_{10} and TM_{20} power bus modes are not much affected by grounding at these points. However, grounding two points between the lower plane on the board and the metal plate resulted in two additional emission peaks as illustrated in Figure 7. These peaks occurred at about 1.5 GHz and 1.8 GHz. The resonant frequency and amplitude of the peaks changes with the location of the two ground posts. Grounding the two points near the cable connection (P1 and P2) had relatively little effect on the radiated emissions. Whereas grounding at the far end of the board (P3 and P4) increased radiated emissions at 1.5 GHz or 1.8 GHz. This suggests that the CMP resonances are excited by the fringing electromagnetic field from the test board at these frequencies (which correspond to the TM12 and TM22 power bus resonances, respectively) and the CMP resonances are then coupled to the cable described in the previous section.

Grounding all four points results in the curve shown in Figure 8. The peaks that correspond to the TM_{10} and TM_{20} modes in the PCB are relatively unaffected by grounding to the plate. However, this configuration still exhibits higher emissions around 1.5 GHz and 1.8 GHz.

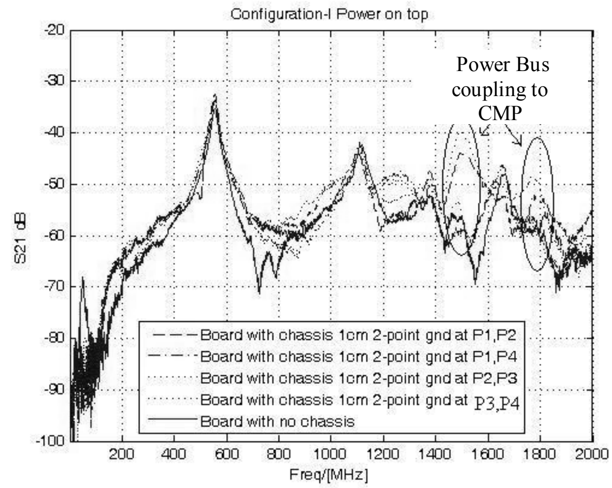

Figure 7. Radiation from the test board with 2-point grounding posts

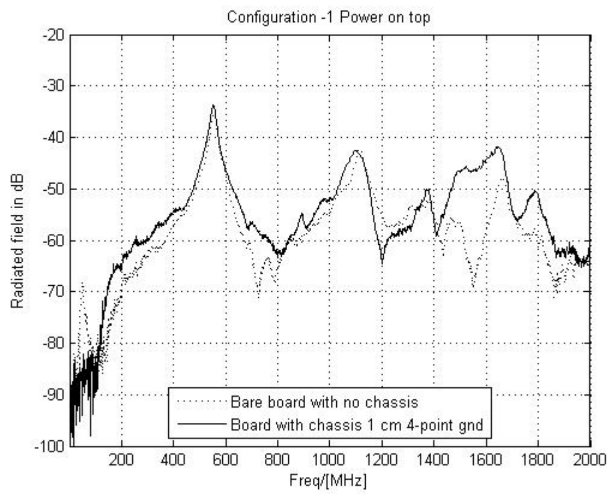

Figure 8. Comparison of radiated emissions from test board with no grounding and 4-point grounding

Next, measurements were made with the upper plane of the PCB grounded to the metal plate. In this case, the plane being driven is sandwiched between the ground plane and the chassis metal. Figure 9 shows the radiated emissions from the structure when it is grounded with two metal posts. In this case, the peak due to the first board resonance at 560 MHz is reduced by a few dB. However, the peak at the second harmonic is a few dB higher. Radiation from the power bus structure is enhanced or attenuated depending on whether fields in the CMP structure are in-phase or out-of-phase with the power bus fields at the connection points and at the edges.

Grounding the two points near the cable connection (P1 and P2) generates a new radiated emissions peak at 480 MHz; whereas grounding at the far end of the board (P3 and P4) increases radiated emissions at frequencies below 480MHz.

This suggests that the CMP resonances coupling to the cable are responsible for the radiated emissions, as described in Section II. Once again, 2-point grounding resulted in additional emission peaks at 1.5 GHz and 1.8 GHz just as it did when the lower plane was grounded at these points. The amplitude of the peaks changes depending on the distance between the posts and the connection. This can again be explained as a CMP resonance coupling to a cable.

Figure 10 shows that grounding all four points of the upper plane to the metal chassis reduced the radiated emissions at the first power bus resonance frequency by 16 dB. Emissions at the second peak are relatively unaffected and emissions around 1.5 GHz and 1.8 GHz are higher (as predicted by the calculations presented in the following section).

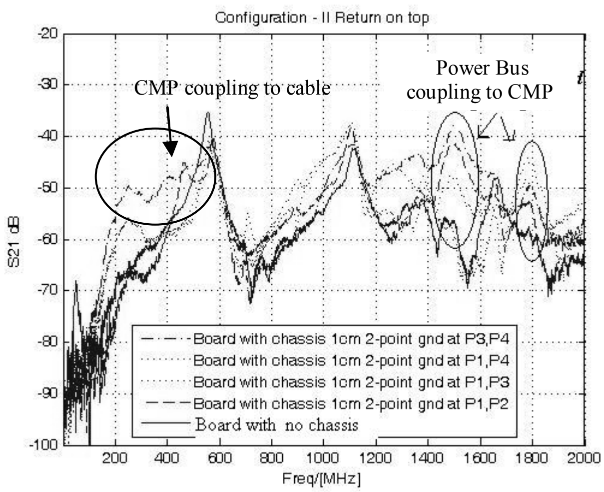

Figure 9. Radiation from the test board with 2-point grounding posts

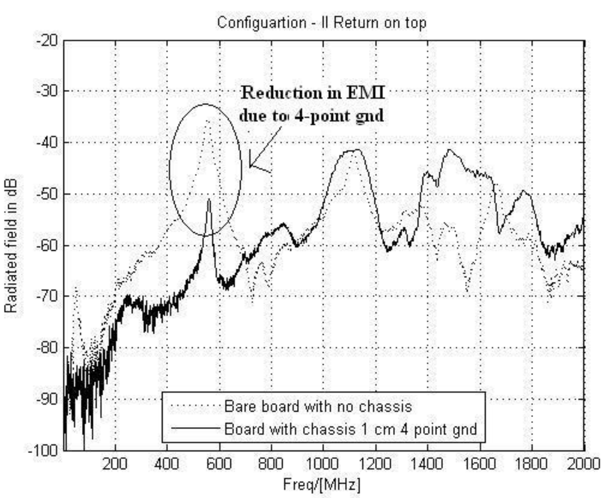

Figure 10. Comparison of radiated emissions from test board with no grounding and 4-point grounding

IV. CALCULATIONS

A SPICE model for multiple planes [7] was applied to the test board with the upper plane connected to the chassis with 4 grounding posts but without the cable. The SPICE model consists of 2 pairs of planar circuit models, one corresponding to the test board planes, and the other corresponding to the chassis cavity. The planar circuit models are connected to each other using a circuit model for grounding posts, which is based on a radial line/coaxial line junction model [7][8]. A shunt current source of 1 A with a shunt resistance of 50 Ω was located at the position corresponding to the connecting point of the network analyzer and the voltage distributions of the planar structures were calculated.

Next, the radiated electric field maximum at a distance of 3 m from the test board was calculated by applying equivalent magnetic current sources corresponding to the calculated voltages along the sides of the test board and chassis cavity structures. The radiated electric field maximum from the single test board was also calculated based on the SPICE model without the chassis cavity model [9]. Figure 11 shows the calculated results from the above models. It is seen from the figure that the calculated results are consistent with the experimental data of Figure 10 over a wide frequency band. The calculated resonances are shifted slightly higher compared to the experimental data at the upper frequencies because the frequency dependence of the dielectric material and the fringing fields are neglected [7]. Also, the SPICE model neglects the coupling due to the fringing electromagnetic field and the additional effects of an attached cable.

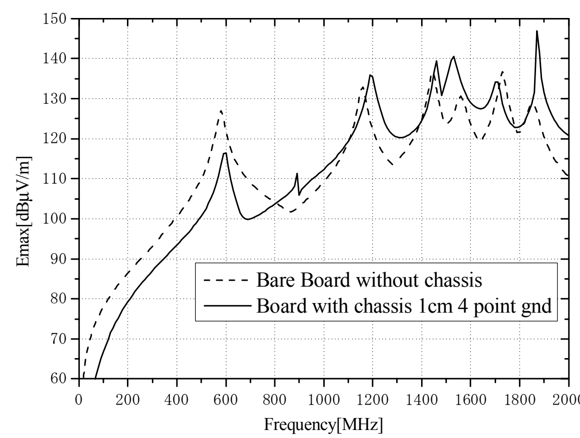

Figure 11. Comparison of radiated emissions from test board with no grounding and 4-point grounding posts(Calculated)

Similarly, the SPICE model for one pair of planes was also applied to the chassis cavity structure with 2 or 4 grounding posts and the radiated field was calculated by applying the equivalent magnetic current sources to the voltages along the sides of chassis cavity. A shunt current source of 1 A with a shunt resistance of 50 Ω was assumed at the position under the connection point of the network analyzer. Circuit models for the grounding posts were obtained from the radial line/coaxial line junction model where the coaxial line ports are shorted [7][8]. Figure 12 shows the calculated results from the above model with 2-point grounding (P1P2, P3P4), and 4-point grounding. The calculated electric field is increased at around 500 MHz (2-point grounding at P1P2, P3P4), which apparently corresponds to the first resonance mode of the CMP in Figure 9. Comparing Figure 12 with Figure 10 and Figure 11, it is evident that the first 4-point grounding resonance at around 900 MHz has little effect on the radiated emissions. The calculated results also show that the radiated emissions are increased at around 1.5 GHz (2-point grounding at P1P2) and 1.8 GHz (4-point grounding).

Notice that the radiated emission from the test board can be enhanced due to the coupling with the CMP structure, as described in Section III. For example, the increase in the radiated emissions at 1.5 GHz with 4-point grounding (Figures 8 and 10) can be explained as the radiated emissions due to coupling from the TM12 power bus resonance to the CMP structure resonance at the same frequency.

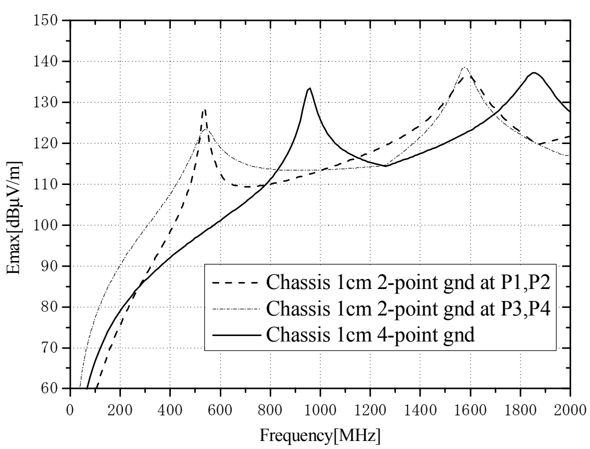

Figure 12. Comparison of radiated emissions from 2-point and 4-point grounding posts(Calculated)

V. CONCLUSIONS

The effect of printed circuit board-to-chassis connections on radiated emissions was experimentally investigated demonstrating that size, location and number of grounding posts can have a significant influence on radiated emission levels. These results were theoretically explained based on the coupling between a power bus and the chassis cavity including grounding posts and a cable. Moreover, a numerical method based on the SPICE model and the equivalent magnetic current source model was applied to calculate the radiated emissions. The calculated results showed good agreement with the experimental data. The investigations using experimental and numerical approaches presented in this paper represent a promising procedure to optimize the number and location of grounding posts before launching a device design.

REFERENCES

[1] K. Li, M. Tassoudji, S. Poh, M. Tsuk, R. Shin, and J. Kong, "FD-TD analysis of electromagnetic radiation from modules-on-backplane configurations," *IEEE Trans. on EMC*, vol. 37, no. 3, pp. 326-332, Aug. 1995.

[2] M. Valek, M. Leone, F. Schmiedl, "Analysis of the electromagnetic radiation behaviour of motherboard-subboard structures," *Proc. of the 2005 IEEE International symposium on EMC*, Chicago, IL, Aug. 2005, pp. 175-178 .

[3] M. Leone and V. Navratil, "On the electromagnetic rdiation of printed-circuit-board interconnections," *IEEE Trans. on EMC*, vol. 47, no. 2, pp. 219-226, May, 2005.

[4] M. Leone, "The radiation of a rectangular power-bus structure at multiple cavity-mode resonances," *IEEE Trans. Electromag. Compat.*, vol. 45, no. 3, Aug. 2003, pp. 486-492.

[5] H. Shim and T. Hubing, "A closed-form expression for estimating radiated emissions from the power planes in a populated printed circuit board," *IEEE Trans. Electromag. Compat.*, vol. 48, no. 1, Feb. 2006, pp. 74-81.

[6] Grish Kumar and K.P.Ray, "Partially shorted RMSAs," in Broadband Microstrip Antennas, p.209, Artech House, 2003.

[7] Naoki Kobayashi, Takashi Harada and Takahiro Yaguchi, "Analysis of multilayered power-distribution planes with via structures using SPICE," IEICE Technical Report, EMCJ2005-97, pp.25-30.

[8] A.G.Williamson,"Radial/coaxial-line junction: analysis and equivalent circuits," INT. J. Electronics, vo.58, No.1, 1985, pp.91-104.

[9] Manabu Kusumoto, Takashi Harada and Hiroshi Wabuka, "An analytical model for calculating EMI radiation from power-bus structures in PCBs," Proceedings of the 20th JIEP Annual Meeting, March, 2006, pp.137-138 (in Japanese).