

## Evaluation of the Radiated Emission of a Printed Circuit Board Attached with Cables

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**Abstract**—An electronic product has to comply with a myriad of EMC requirements before it can be marketed globally. Radiated Emission is one of the EMC requirements which constantly poses a challenge to many circuit designer due to the ever increasing speed of PCB clocks. Consequently, in the product it is essential to investigate, identify, model and predict the PCB radiated emission before compliance test is performed for cost and time saving. In this paper, a simple double layer PCB board is fabricated to investigate the PCB radiated emission. Three PCB configurations are investigated for the level of emissions and to correlate with the common-mode currents. These configurations are PCB without attached cables, with one attached cable and with two attached cables. The radiated emission from each configuration is measured in a semi-anechoic chamber at open circuit and 50 ohm loads. It can be shown that the cables are the major sources of radiated emission due to the common-mode currents flowing through it.

**Keywords**—Radiated emission; Printed Circuit Boards; Differential Mode Current; Common Mode Current

### I. INTRODUCTION

Manufacturing high speed electronic products with cost effective and compliance to Electromagnetic Compatibility (EMC) requirements is a huge challenge for design engineers. Printed Circuit Board (PCB) is known to be the main source of the radiated emission [1]. This radiated emission is prominent at higher frequencies due to ever increasing clock speed of the PCB. Therefore, it is essential to investigate, identify, model and predict the PCB radiated emission to ensure cost and time saving for EMC compliance.

The radiated emission of PCB originates from two sources; Differential Mode (DM) current and Common Mode (CM) current. The differential mode current is the wanted (functional) current that is responsible of differential mode radiation while the common mode current is the unwanted current (displacement current) that flow between the circuit and its environment. The common mode current is typically much less than the differential mode current but significantly contributes to the total radiated emission [2].

The common mode radiation can be enhanced by attaching cables to the PCB ground plane. The common mode current induced on the attached cables is the main source for the unintentional radiated emission [3] and will be discussed in section II.

In this paper, a simple double layer PCB is built to evaluate the radiated emission due to cables attached to the PCB ground plane.

The PCB radiated emissions are measured in a Semi Anechoic Chamber (SAC) with three PCB configurations namely PCB without attached cables, PCB with one attached cable and PCB with two attached cables. Each configuration is demonstrated with open circuit and 50 ohm load. Section III provides the equivalent circuits of the PCBs boards. The measurement results are shown in section IV.

### II. DIFFERENTIAL MODE AND COMMON MODE RADIATIONS

The Differential Mode (DM) current is the functional current that may convey data or signal of interest whereas the common mode current is unwanted current which poses trouble for EMC compliance requirements [4].

Both the signal and ground traces in PCB can be modeled as current loop radiation source. The maximum electric field due to DM current is given as [2]

$$|E_D|_{\max} = 1.316 \times 10^{-14} \frac{|I_D| f^2 l s}{r} \quad (1)$$

where  $f$  is frequency,  $l$  is the length of the trace,  $r$  is the point of observation of the electric field and  $s$  is the distance between the signal trace and return trace.  $I_D$  denotes the amplitude of the signal current.

The maximum electric field due to CM current of the PCB with two parallel traces can be written as [2]

$$|E_C|_{\max} = 1.257 \times 10^{-6} |I_C| \frac{f l}{r} \quad (2)$$

where  $|E_C|_{\max}$  is the maximum common mode electric field,  $I_C$  is the common mode current,  $f$  is the frequency and  $l$  is the signal trace length.

Common mode current is generated due to lack of DM cancellation that occurs due to the imbalance between two signal paths. However, the CM current may also be created as a result of ground bounce and power plane fluctuation. Most of the RF current flows along signal trace on the PCB return on the ground plane directly beneath the signal trace.

However, a small amount of the ground trace current also return via indirect path causing the PCB and attached cables to produce common mode radiation similar to antenna [4].

The partial inductance of a ground plane is a parameter which indirectly determines the level of CM radiation [5]. Due to this inductance, there is a voltage drop which provides a noise source that can drive common mode current on the external structure.

#### A. Voltage Driven CM Mechanism

Generally, voltage driven sources can drive object referenced to the ground against other objects whose potential are related to the signal voltage as shown in Fig. 1. The voltage driven radiation can be enhanced significantly if these traces are coupled to larger objects.

#### B. Current Driven CM Mechanism

In this mechanism, common mode currents can be induced on attached cables due to the drop voltages on the ground plane as shown in Fig. 2. The induced common mode current is directly proportional to the signal current. Connecting two cables to the opposite sides of the PCB board can drive these cables like dipole antenna. In this configuration, the current driven mechanism has been observed to be a dominant source of radiated emission.

### III. DESCRIPTION OF PCB BOARD UNDER TEST

A simple double layer PCB board under test is built, and the radiated emissions are measured in a SAC. The PCB board schematic layout is illustrated in Fig. 3. The 5cm x 20.7cm PCB is fabricated with 1-mm wide and 14.5 cm long trace at the center of the board. The top layer is employed for signal trace while the bottom layer is used for the ground trace separated by 1.6 mm of FR4 dielectric material. The signal trace is driven by 25-MHz oscillator and powered by 5 volt battery as shown in Fig. 4. Both the clock oscillator and battery are located at the bottom side of the PCB.

The attached cables are one meter long and connected to the load or on each side of the board as shown in Fig. 4. The output pin of the oscillator is connected to one end of the trace and the other end of the trace is configured with open and 50-ohm load. The board is placed on a 0.8- meter height wooden table in a SAC and rotated to detect the maximum emission. The receiving antenna is horizontally polarized (in the plane of the board) and is placed three meter away of the PCB.

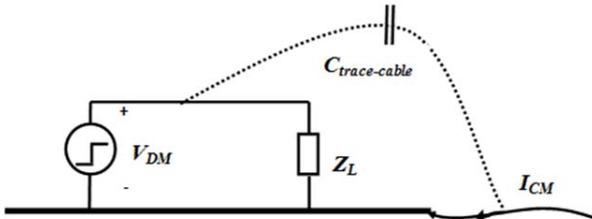


Figure 1. Test board configuration based voltage driven mechanism

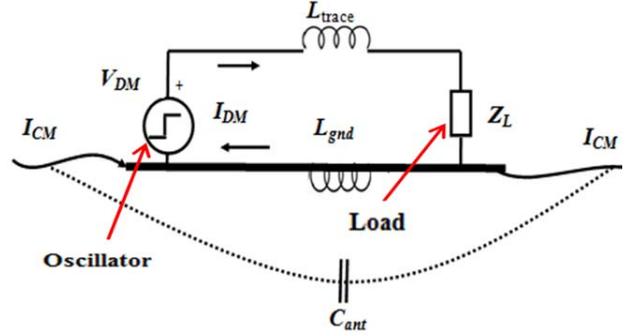


Figure 2. Test board configuration based current driven mechanism

### IV. MODELING OF THE PCB EQUIVALENT CIRCUIT

The equivalent circuit of the PCB without attached cables is shown in Fig. 5. The differential mode current flows from source to load and then return back to the source.

The DM current and CM current can be written as [2]

$$I_{DM} = \frac{I_1 - I_2}{2} \quad (3)$$

$$I_{CM} = \frac{I_1 + I_2}{2} \quad (4)$$

The second case is PCB with one cable attached to ground trace at node 1 as shown in Fig. 6. In this case, some current flows through the attached cable which is called common mode current resulting in increased emission. The cable seems to behave as monopole antenna and is illustrated in the equivalent circuit in Fig. 6.

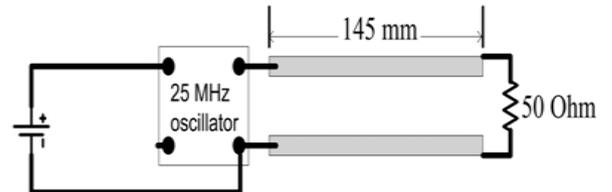


Figure 3. The schematic layout of the PCB test board



Figure 4. PCB board under test in SAC

Adding two cables to the return current path poses more challenges to the circuit. The equivalent circuit is illustrated in Fig. 7. The forwarded current is decomposed at node 1 into two branches. Some of the forwarded current returns to the source across direct path via the ground trace but the other portion flows down the cable attached at node 1. The current that flows down the attached cable drives the cable as antenna. In Fig. 7, the signal and ground trace are

represented by their inductances whereas the attached cables are modeled as an inductance with serial resistance connected to the circuit ground.

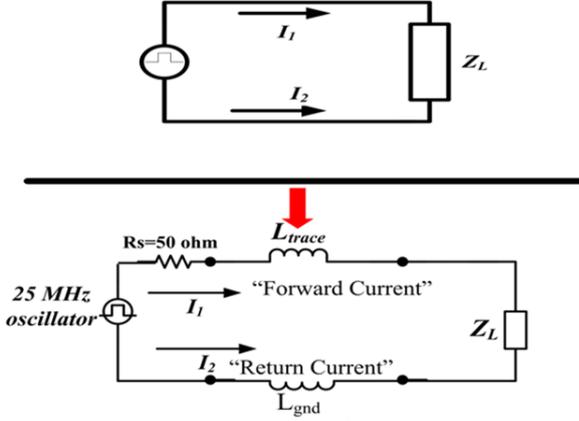


Figure 5. The equivalent circuit of PCB without attached cables

## V. EXPERIMENTAL RESULTS

### A. PCB without attached cables

In this configuration, the radiated emission of the PCB board is measured for a matched and open circuit load. RE for open circuit load is mainly due to CM currents. In the case of open circuit, the differential mode current is much less contributor to the total radiated emission than in case of 50 ohm load. However, the differential mode voltage can couple to larger nearby objects that may act as efficient antenna. Even though the circuit is open and no efficient antenna existed, there is a common mode radiation produced from the PCB without attached cables.

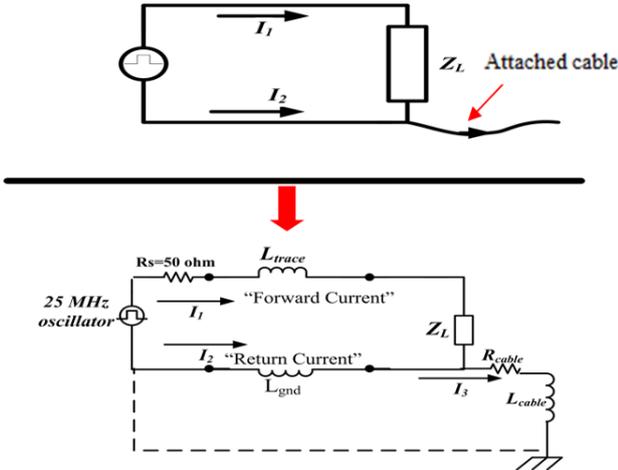


Figure 6. The equivalent circuit of PCB with one attached cable.

Based on (3) & (4), the common mode current on the attached cables can be obtained as follow:

$$I_1 = I_{CM} - I_{DM} \quad (5)$$

$$I_2 = I_{CM} + I_{DM} \quad (6)$$

$$I_3 = I_1 + I_2 = 2I_{CM} \quad (7)$$

Fig. 8 illustrates the total radiated emission of PCB without attached cables. The RE of PCB in matched load is generally higher than in open circuit load. A maximum difference of about 15dBuV/m is detected at 175MHz. Voltage driven mechanism is the dominant in the open circuit case while in the matched case, the RE was raised due to both current and voltage driven mechanisms

### B. PCB with one attached cable

In this configuration, one cable is connected to the ground trace of the PCB. This attached cable has enhanced the total radiated emission noticeably. The induced common mode voltage drives this attached cable to act as antenna. The cable provides another path for the forwarded current to return to the source. In Fig. 9 the total radiated emission is shown for both open and match circuit.

In open circuit, the RE is enhanced much more comparing with PCB without attached cables due to the electric field coupling between the signal trace and the attached cable. The maximum PCB REs due to the attached cables are obtained at frequencies 75, 150, 175, 225 MHz where the cable length is a multiple of half wavelength of interest. RE for open circuit load is predominantly due to CM current which can be seen to be always less than for matched load. This is understandable because for matched load the emission due to DM current adds to the CM emission.

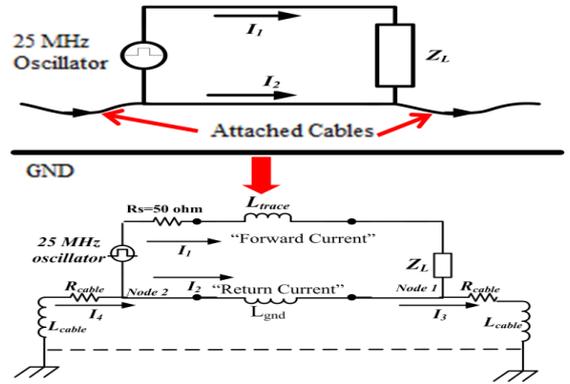


Figure 7. The equivalent circuit of PCB with two attached cables.

### C. PCB with two attached cables

In this configuration, the PCB board under test is demonstrated to measure the radiated emission within two cases, open and 50 ohm load. Two cables are attached to the PCB ground trace. One cable of 1-meter long is attached to the source end of the PCB while the other cable of 1-meter long is connected to the load end of the PCB. The PCB RE as shown in Fig. 10 indicates that in case of matched circuit is higher than in case of open circuit.

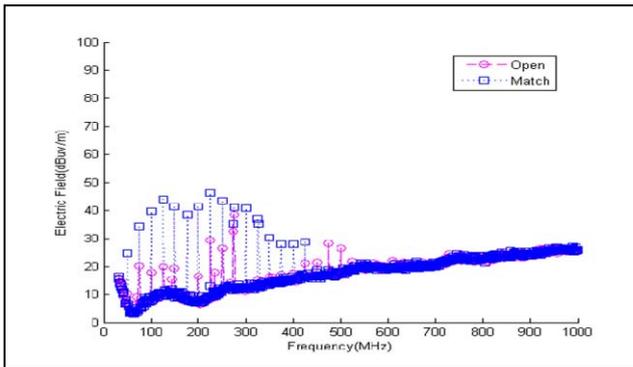


Figure 8. RE of PCB without attached cables.

However, in the two cases the RE has increased in comparing with PCB with one attached cable. Moreover the radiated emission above 500 MHz has increased by 35dBuV/m while in the other two configurations the RE is about 20dBuV/m because the second attached cable is near the source and easier electric coupling can be obtained between the source and the attached cable. Generally, attaching two cables have enhanced the radiated emissions for both open and matched circuit by 10dBuV/m above the RE of PCB with one attached cable as shown in Fig. 10.

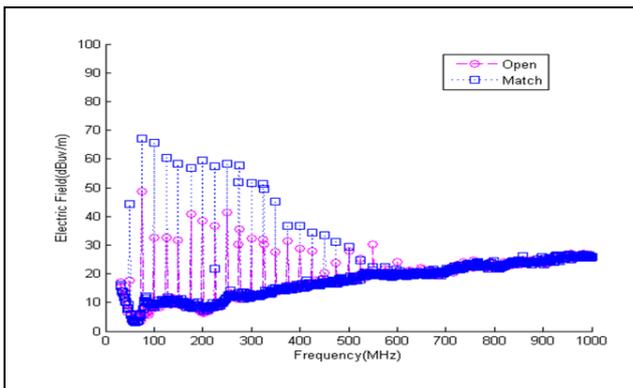


Figure 9. RE of PCB with one attached cable.

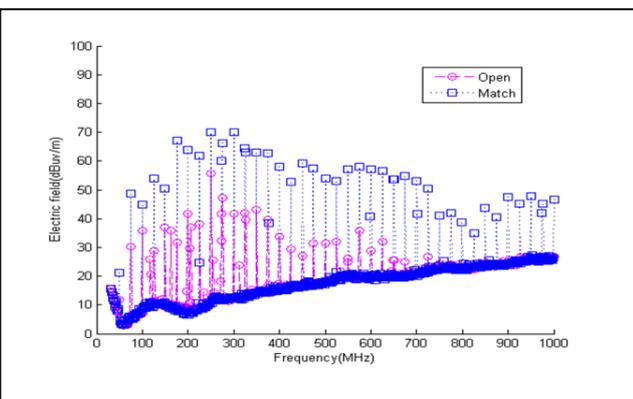


Figure 10. RE of PCB with two attached cables

## VI. EXPERT SYSTEM PREDICTION OF PCB RADIATED EMISSION

Common mode radiation is identified as a significant contributor of the total radiated emission. Consequently, the prediction of common mode radiation is helpful for assisting circuit designer to ensure compliance to EMC. The work reported in this paper will be useful in developing reliable PCB RE expert system in the future.

## VII. CONCLUSION

In this paper, the total radiated emissions due to differential and common mode currents on a simple PCB circuit were modeled and measured. The common mode radiation is identified as the main contributor of the total radiated emission. The common mode radiation is enhanced noticeably when the PCB is attached with cables connected to the ground trace. The results are evidence to show the difficulty in complying with EMC radiated emission requirements for high speed circuits with numerous cables attachment.

## ACKNOWLEDGMENT

The authors would like to acknowledge the support given by the Center for Electromagnetic Compatibility, Universiti Tun Hussein Onn Malaysia (UTHM) in performing the measurements.

## REFERENCES

- [1] H. W. Shim and T. H. Hubing, "Model for estimating radiated emissions from a printed circuit board with attached cables driven by voltage driven sources," *IEEE Transactions on Electromagnetic Compatibility*, vol. 47, pp. 899–907, 2005.
- [2] C. R. Paul, *Introduction to Electromagnetic Compatibility*, 2<sup>nd</sup> ed. New Jersey: Wiley interscience, 2006, p. 1016.
- [3] S. Deng, T. Hubing, and D. Beetner, "Estimating Maximum Radiated Emission From Printed Circuit Boards With an Attached Cable," *IEEE Transactions on Electromagnetic Compatibility*, vol. 50, no. 1, pp. 215–218, 2008.
- [4] M. I. Montrose, *Printed Circuit Board Design Techniques for EMC Compliance — A Handbook for Designers*, Second Edition, New York: Wiley interscience, 2000, pp. 1–340.
- [5] S. Caniggia and F. Maradei, *Signal Integrity and Radiated Emission of High-Speed Digital Systems*, 1<sup>st</sup> ed. Chichester, UK: John Wiley & Sons, Ltd, 2008, pp. 1–555.