

Using Electric and Magnetic “Moments” to Characterize IC Coupling to Cables and Enclosures

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Abstract — The electric field coupling from ICs to cables or enclosures is proportional to the source voltage, source frequency and the self capacitance of the IC structure. The product of these three values is a quantity that effectively represents the strength of an electric field source independent of the structure(s) that it may couple to. Magnetic field coupling from the small circulating currents generated by ICs and their packages is proportional to the source current, source frequency and the effective mutual inductance associated with the coupling path. The product of these quantities is also a scalar value and represents an IC’s ability to couple to cables and enclosures through a magnetic field. These electric and magnetic “moments” can be used to characterize an IC’s ability to couple noise to its external environment. These moments depend on local geometric parameters such as the circuit board dimensions, IC package structure, presence of heatsinks, etc., but they are independent of system parameters such as cable and enclosure geometries. Measurements of ICs in a TEM cell with a hybrid can be used to determine these electric and magnetic moments. These moments can then be used to estimate the maximum radiated emissions from the ICs in a given environment.

1. INTRODUCTION

IEC 61967-2 [1] describes a procedure for evaluating the electromagnetic compatibility of integrated circuits (ICs). This procedure calls for the IC to be mounted on a 10-cm x 10-cm printed circuit board with the IC being evaluated on one side and other components needed to exercise the IC on the other side. The board is mounted in the wall of a small TEM (or GTEM) cell with the IC facing in. The voltage measured on one end of the cell is used to evaluate the performance of the IC from 150 kHz to 1 GHz.

Recent publications [2, 3] have demonstrated that connecting both ends of a TEM cell to a hybrid as shown in Fig. 1 allows the electric field coupling to be isolated from the magnetic field coupling. The sum of the voltages at the outputs of the hybrid A and B is proportional to the electric field coupling, since the electric field coupling at both terminations is in phase. Magnetic field coupling, which is 180 degrees out of phase at the two terminations, does not significantly affect the sum. The difference in the outputs of the hybrid is a voltage that indicates the strength of the magnetic field coupling, since the in-phase electric field coupling tends to be canceled while the out-of-phase magnetic field coupling is enhanced.

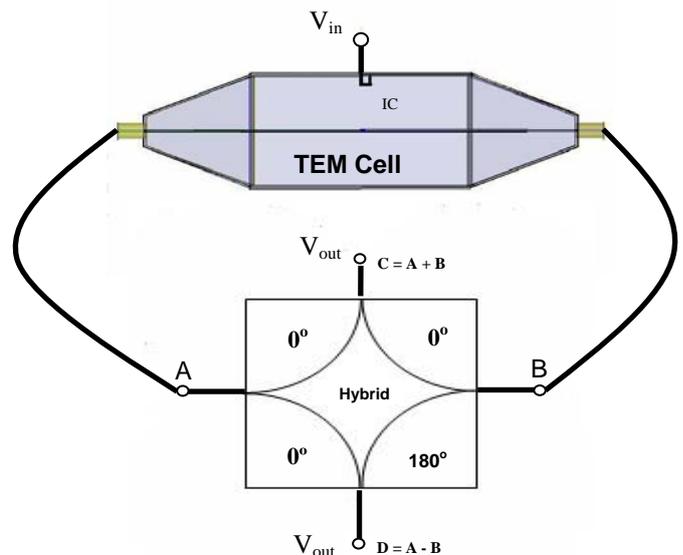


Fig. 1. TEM cell with hybrid.

2. ELECTRIC FIELD COUPLING

A previous study of electric field coupling to cables from small sources such as printed circuit board traces and ICs showed that the amount of coupling was directly proportional to the source voltage, the source frequency and the self capacitance of the source [4]. The self capacitance is a measure of the electric flux emanating from the IC (in its intended environment) that is not captured by the circuit board ground plane or other nearby structures. It is a quantity that can be determined using static field modeling techniques or (for simple structures) estimated from closed-form expressions [5]. Each of these quantities (voltage, frequency and self capacitance) is localized to the source geometry and doesn’t depend on objects or structures distant from the source. In [4], these quantities are used to develop an equivalent common-mode voltage source that replaces the more complicated trace or IC geometry and drives cables attached to a printed circuit board directly. This process allows the complicated geometries on a printed circuit board to be replaced by much simpler structures in a full-wave system model.

The product of the source voltage, source angular frequency and self capacitance fully characterize a small source's ability to couple to distant objects through an electric field. In this paper, the product of these three quantities (which has units of current) will be referred to as the "electric moment" of the source. For example, the electric moment of an object that had a 1-volt potential relative to a circuit-board ground plane, an angular frequency of 628 rad/sec (i.e. 100 MHz), and a self capacitance of 15 fF would be 9.4 μ A. In a system with one circuit board and attached cables, this would basically represent the maximum sum of all common-mode currents that could be induced on the cables [4]. In an equivalent model of the source, any value of source voltage and self capacitance that had this same product would yield an equivalent result. In other words, it's not necessary to know values for the voltage and self capacitance independently in order to estimate the electric field coupling to distant objects.

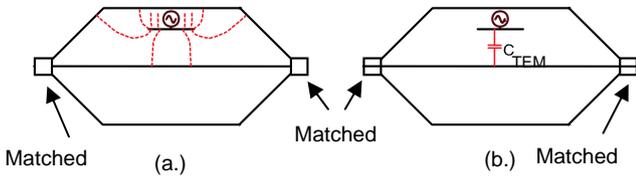


Fig. 2. Electric field coupling between an IC and a TEM cell.

Fig. 2 illustrates electric field coupling between a small IC and the septum in a simple TEM-cell test set-up. A voltage difference between the IC and the wall of the TEM cell produces lines of electric flux that emanate from the patch. Most of these flux lines terminate on the wall of the TEM cell; however a small portion of the flux lines terminate on the septum of the TEM cell. These flux lines produce a current in the septum that flows through the 50-ohm terminations at each end of the cell. In the hybrid TEM cell set-up (Fig. 1), a spectrum analyzer records the sum of the voltages induced at each end. The measured voltage is proportional to the average voltage on the IC and is directly related to the ability of this IC to couple electric fields to moderately distant objects. It is convenient to represent the electric field coupling between the IC and the septum as a mutual capacitance, C_{TEM} , as indicated in Fig. 2. For a given TEM cell, the value of C_{TEM} is related to the geometry and the position of the IC.

A recent study showed that the measured value of C_{TEM} is directly related to the self capacitance of the mounted IC [6]. In fact, given the dimensions of the TEM cell and the dimensions of the circuit board, it is possible to calculate the self capacitance directly from measured values of C_{TEM} .

If the voltage on the IC is known, then measurements of the TEM cell voltage at the output of the hybrid can be used to obtain the value of C_{TEM} . Fig. 3 shows an equivalent circuit modeling the IC coupling through C_{TEM}

to the matched terminations of the TEM cell. The value of C_{TEM} can be determined from the formula,

$$|V_{IC}| = \frac{1 + 25\omega C_{TEM}}{25\omega C_{TEM}} |V_{measured}| \quad (1)$$

where V_{IC} is the open-circuit voltage on the trace and $V_{measured}$ is the voltage from the hybrid TEM cell measurement.

Of course, in most cases, the value of V_{IC} is also unknown; however the product of V_{IC} and C_{TEM} can be obtained by noting that the impedance of the capacitive coupling is much greater than 25 ohms at all frequencies of interest. Therefore,

$$|V_{IC}| \approx \frac{|V_{measured}|}{25\omega C_{TEM}} \quad (2)$$

and the electric moment can be expressed as,

$$|V_{IC}| \omega C_{TEM} \approx \frac{|V_{measured}|}{25} \quad (3)$$

Therefore measurements made in a hybrid TEM cell configuration can be used to determine the electric moment of the IC source. This value can then be used to estimate the maximum radiated emissions due to electric field coupling from ICs to the cables and/or enclosures that act as the "antennas" for these emissions.

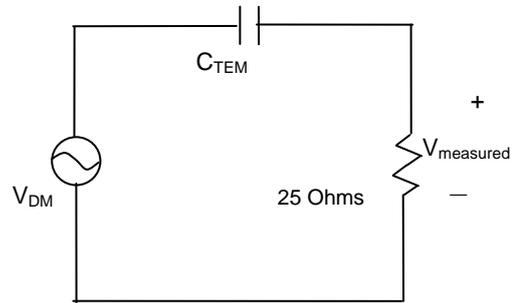


Fig. 3. Equivalent circuit showing TEM cell loading of the effective source structure.

3. MAGNETIC FIELD COUPLING

Fig. 4 illustrates magnetic field coupling in a TEM cell. Current flowing in an electrically small loop generates a magnetic field. Some of the magnetic field lines wrap around the bottom side of the septum inducing a voltage between the septum and the wall of the cell. This voltage appears across both terminations with opposite phase. This coupling can be represented by a mutual inductance, M_{TEM} , between the source loop and the septum-cell loop as indicated in the figure. The voltage measured by the hybrid and TEM cell in Fig. 1 is equal to the product of the current in the loop, the angular frequency and this mutual inductance.

The mutual inductance between the current loop and the TEM cell is related to the amount of magnetic flux that wraps around the printed circuit board when it is not mounted in the TEM cell. This value can be used to determine the maximum amount of magnetic field coupling that occurs between an IC mounted on a printed circuit board and attached cables or enclosures.

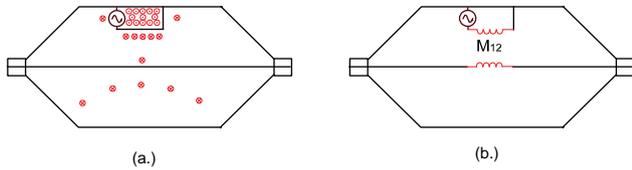


Fig. 4. Magnetic field coupling between a small loop and a TEM cell.

Of course a single TEM cell measurement doesn't provide both the current and the mutual inductance independently. As in the case of electric-field coupling, the hybrid TEM cell measurement yields the product of these quantities.

$$|V_{measured}| = |I_{IC}| \omega M_{TEM} \quad (4)$$

This product and the relationship between M_{TEM} and the flux wrapping the printed circuit board can be used to determine a "magnetic moment" for the IC. Since the magnetic field coupling to the septum is a function of the board orientation, the magnetic moment will also be a function of board orientation. However, it is relatively easy to determine the maximum possible coupling from the measurement of two perpendicular board orientations. In this way a single value for the maximum magnetic moment can be obtained.

4. EXAMPLE

To illustrate how hybrid TEM cell measurements can be used to estimate peak radiated emissions, the radiated emissions from a test board with a metal heatsink were measured in a semi-anechoic chamber and compared to results derived from hybrid TEM cell measurements [6]. The test set-up is shown in Fig. 5. The signal driving the heatsink was delivered through a cable attached to the back side of the board. The heatsink was 33 mm by 31 mm by 14 mm, and was 22 mm above the board. The board was 10 cm by 10 cm. The peak voltage between the heatsink and the test board was 0.224 V. A receiving antenna was located 3 m away.

The radiated emissions were measured and also calculated using a full-wave electromagnetic field solver [7]. The measured and simulated open-field radiated emissions are plotted in Fig. 6. The dotted green line in Fig. 6 indicates the calculated radiated emissions from a simplified model of the source that consisted of an "electric moment" source driving the board relative to the cable. This source model eliminates the geometric complexity of the original full-wave simulation and

replaces the entire heatsink and coaxial feed geometry with a single, ideal source.

Despite the simplicity of the model, the peak radiated emissions are accurately determined. Nulls in the radiated emissions are not as accurately determined because our equivalent source was placed at the edge of the board rather than the center and the null frequencies are sensitive to the exact source location relative to the board and cable. Nevertheless, when estimating unintentional radiated emissions, it is generally much more important to accurately predict peak amplitudes.

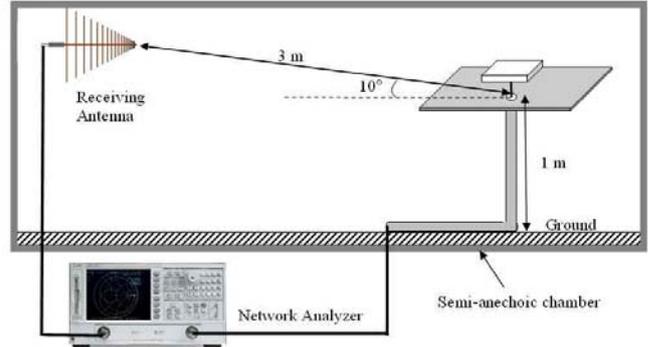


Fig. 5. Setup for radiated emissions measurement.

More details related to this example are provided in [6] and the basic theory is reported in [4]. The point of this exercise is to demonstrate that the "electric moment", which is readily obtained from hybrid TEM cell measurements, can be used to estimate the maximum radiated emissions due to electric field coupling to cables attached to an IC-circuit-board structure.

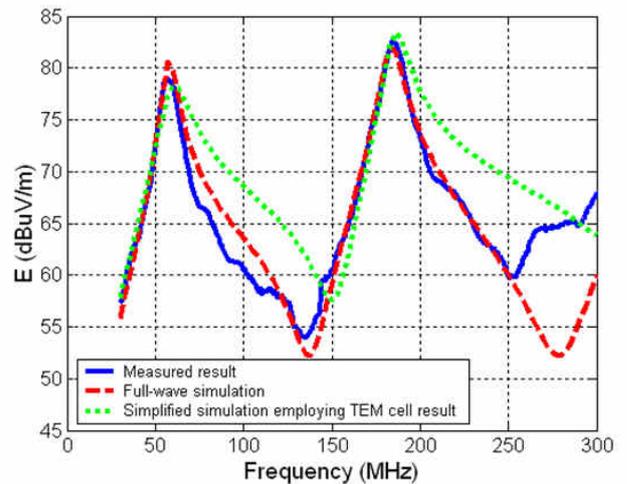


Fig. 6. Comparison of the radiated emissions from a measurement, a full-wave simulation of the complete setup, and the corresponding simplified simulation using an electric moment source.

Similar validation exercises are being performed to demonstrate the use of the “magnetic moment” for calculating the maximum radiated emissions due to magnetic field coupling. The results obtained so far indicate that magnetic moments can be used in the same way that electric moments are used to estimate the maximum radiated emissions from systems with circuit boards, cables and enclosures.

5. CONCLUSIONS

Measurements of an integrated circuit in a hybrid TEM cell configuration can be used to obtain values for the “electric moment” and “magnetic moment” associated with an IC as it is configured on a given circuit board. These moments have at least two purposes. First, the values of the electric and magnetic moments by themselves are a useful indication of the “quality” of a given IC-package design. ICs with smaller moments are less likely to couple to other parts of a system resulting in unintentional radiated emissions. Second, electric and magnetic moments can be used in full-wave electromagnetic models of a system, replacing complex IC-package geometries with simple equivalent sources. This greatly reduces the amount of computational resources required to model systems that utilize these ICs.

6. REFERENCES

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