ELIMINATION OF UNWANTED ELECTRO-MAGNETIC NOISE IN A GTEM CELL FOR IC EMISSION MEASUREMENTS

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ABSTRACT

The IEC 61967 standards suggest an integrated circuits (ICs) electromagnetic emission measurement technique by mounting IC test board on TEM/GTEM cell wall. It appears that the method has limited device under test (DUT) rotation in horizontal position and neglected vertical polarization while rotating in horizontal position. In general, the electromagnetic emission of a device at an observation point is contributed by both the horizontal and vertical polarizations. The limitation can be overcome by conducting the emission test in Gigahertz Transverse Electromagnetic Mode (GTEM). However, supporting components on the board and interface cable are the major concerns which may contribute unwanted noise to interfere with the measurement. In this paper, we present an effort to tackle these crucial matters in the setup in order to quantify IC electromagnetic emission in GTEM cell with application of basic electromagnetic compatibility (EMC) measurement approaches such as shielding, grounding and suppression using ferromagnetic material. The results show strong evidence on the effectiveness of the technique proposed to ensure reliable IC emission measurement in GTEM cell.

***KEYWORDS**: Electromagnetic emission; Integrated circuit; GTEM cell*

1.0 INTRODUCTION

In the trend towards faster clock speed and higher integration densities, ICs have become significant noise sources that cause electromagnetic emission. Thus, the demands on electromagnetic emission characterization of ICs are growing. The exploration of the IC electromagnetic behavior provides important information for component selection and design concerns in an early product

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development. Consequently, shorter time is needed in the process to develop any electronic system.

Diverse effort in previous studies have introduced TEM/GTEM cell measurement method (Standard EMC 61967-2, 2005) and near field measurement technique (Deutschmann, 2005) and (Weng, 2011) to evaluate electromagnetic emission of ICs. The near field technique is an attractive approach that has an advantage to characterize IC electromagnetic emission in close vicinity. The method assumed that the measured emission is contributed by the IC itself if an infinite perfect ground plane is established around the IC test board. This is to ensure that IC is the only radiator and at the same time the reliability of the measurement is attained. However, ambient electromagnetic disturbance may be considered as a major interference in the near field method. To prevent error due to the ambient noise, the near field system generally has to be setup in shielded room, which is often considered too expensive and not affordable by most of EMC test laboratories.

TEM/GTEM cell is an enclosed metallic structure which provides a well isolation between inner and outer environments of the cell. As the cell is properly closed, its inner side would neither contribute to nor suffer from any external interference. The cell cost is also relatively cheaper than building a shielding room. Another weakness of the near field method is that the sensitivity of the field probe must compromise with spatial resolution and dynamic range. A narrow band probe is merely suitable for testing in a specific frequency range, therefore various set of probes are needed for the emission test in different frequency ranges. In contrast, TEM/GTEM cell has a septum which behaves as receiving antenna over a wide band frequency. In addition, a GTEM cell can operate over wider range of frequencies than TEM cell.

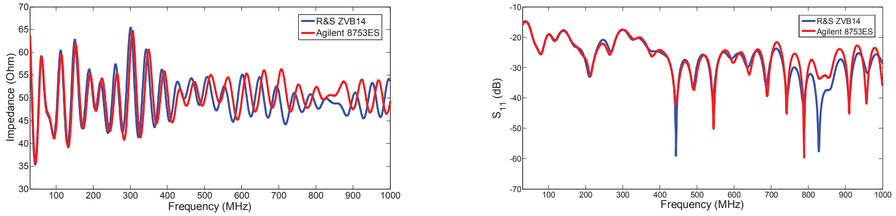
In this paper, the focus is given on the measurement technique to characterize radiated electromagnetic emission of a field programmable gate array (FPGA) chip in a GTEM cell. The chip was configured with toggle flip-flop (TFF) pattern and exercised at a 100 MHz clock signal. Several techniques are utilized in the setup to avoid interference of unwanted electromagnetic noise. The techniques employed are shielding the FPGA board in a metallic cavity, grounding the cavity with low impedance ground strap and suppressing common mode current emission of interface cable using ferrite beads. The results presented in the study provide useful alternative to IC emission test methods based on IEC 61967.

2.0 CHARACTERIZATION OF GTEM CELL

Prior to perform any electromagnetic emission measurement of the ICs, the performance of the GTEM cell is important to be checked and validated. This can ensure the measured data achieve a reasonable level of accuracy.

GTEM cell is considered as a rectangular transmission line which operates in TEM mode. The cell characteristic impedance Z_0 along the septum length is expected to be 50±2 Ω. This parameter must be checked because impedance mismatching can lead to multiple reflections and eventually affect the reliability and accuracy of the collected data. When a network analyzer is connected to the cell port, it is possible to evaluate the overall cell input impedance against frequency range of interest. Figure 1(a) shows the input impedance over a frequency range from 30 MHz up to 1 GHz. It is seen that the input impedance varies about 50 Ω over the frequency range.

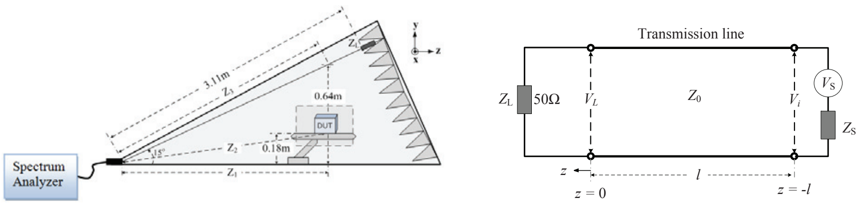
The reflection properties at the GTEM cell is characterized by measuring return loss of the cell when it is empty. As can be seen in Figure 1(b), the return loss is well below 20 dB over the frequency spectrum. According to the standard IEC 61967-2, the return loss ought to be below 14 dB which is also equivalent to a VSWR value of 1.5.



(a) (b)

Figure 1. Parameters of GTEM cell, (a) cell impedance vs frequency, and (b) cell return loss

Basically, a GTEM cell comprises of a tapered section with a single port, 50 Ω characteristic impedance and a broadband termination. A spectrum analyzer is utilized to measure the output voltage due to electromagnetic emission of any device under test (DUT) in the cell as shown in Figure 2(a). The equivalent circuit is shown in Figure 2(b).



(a) (b)

Figure 2. (a) GTEM emission measurement setup, (b) Equivalent circuit

Voltage reflection coefficient Γ at a load is defined as the ratio of the amplitude of the reflected and incident voltages (Ulaby, 2010). Assuming the GTEM cell as lossless transmission line, the voltage reflection coefficient can be obtained as

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1} \tag{1}$$

where V_0^+ is an incident wave travelling towards the load, V_0^- represents the reflected wave travelling towards the source, Z_L is load impedance, Z_0 is characteristic impedance, and z_L is normalized load impedance Z_L/Z_0. The resultant voltage $|\tilde{V}(z)|$ at the load is given by

$$\begin{aligned} |\tilde{V}(z)| &= \left|V_0^+\left(e^{-j\beta z} + \Gamma e^{j\beta z}\right)\right| \\ &= |V_0^+|[1 + |\Gamma|^2 + 2|\Gamma|\cos(2\beta z + \theta_r)]^{1/2} \end{aligned} \tag{2}$$

where $\beta = \frac{2\pi f}{c}$ is the phase constant, c is speed of light in free space, $\Gamma = |\Gamma| e^{j\theta_r}$ is reflection coefficient, and θ_r is its phase angle. The voltage at source $\tilde{V}_i$ is determined with

$$|\tilde{V}_i| = V_0^+\left(e^{j\beta l} + \Gamma e^{-j\beta l}\right) \tag{3}$$

3.0 TEST DEVICE PREPARATION

The DUT chosen for the emission test is a FPGA chip which is mounted on a printed circuit board (PCB) with a ground plane. All necessary components, other than the chip, are soldered on the opposite side of the PCB.

It is challenging to characterize electromagnetic emission of an IC inside the GTEM cell. This is because all supporting components and interface cables on the PCB may generate unwanted energy that would also be measured unintentionally. Consequently, the measured emission is a combination field contributed by both the IC and the disturbances. However, it is believed that the interference can be minimized if precautions are taken into account during the measurement setup.

Shielding is a simple and effective technique that has widely been used to isolate an environment from electromagnetic interference. So the PCB is firstly housed inside a metallic cavity with the IC exposed via an opening window. Since the metallic cavity is a perfect shield, it can isolate the unwanted energy inside the cavity from being emitted. This ensures the FPGA chip is the only source to contribute towards electromagnetic emission in the measurement.

In general, the performance of a metallic shield depends on its conductivity, permeability, thickness and operating frequency. According to Paul (2006), if the shield thickness is greater than the skin depth of the material at the frequency of incident field, the shielding effectiveness is dominated by absorption loss. The skin depth, δ of a material is given by

$$\delta = 1/\sqrt{\pi f \sigma \mu'} \tag{4}$$

with f is frequency of the incident field, σ is shield conductivity and μ' is shield permeability. Aluminium is a cheap and versatile conductor with an adequate absorption for shielding. Its conductivity, σ is 3.8×10^7 *S/m*, relative permeability, μ_r is 1.00002. When aluminium is selected as the shield material to build the cavity, the skin depth at the lowest frequency of interest (30 MHz) is approximated to be 0.026 mm. Since the shield thickness is 0.2 mm, it can be assumed that the cavity is working as a perfect barrier to isolate emitted electromagnetic wave from penetrating the shield.

Although the conductor can behave as a good shield, however, at the same time, it might be a perfect radiator if the cavity resonant frequency f_r agrees with fundamental frequency and harmonics of electromagnetic energy inside the cavity. In this particular case, resonance may amplify the energy inside the cavity and consequently propagate it out of the cavity. The resonance frequency of the cavity can be determined by

$$f_r = \frac{1}{2\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2} \tag{5}$$

where $\frac{1}{\sqrt{\mu\varepsilon}}$ is phase velocity of the uniform plane wave in the lossless dielectric medium (σ=0, μ, ε) filling the cavity, *m*, *n* and *p* correspond to the number of half-wave variations of the field in respective *x*-, *y*- and *z*-direction. The lowest resonant frequency of the cavity is approximated 1.7 GHz and it is greater than the highest frequency of interest. Thus, as long as the operating frequency and its harmonics stay below this resonance frequency, the cavity will sustain a free oscillation.

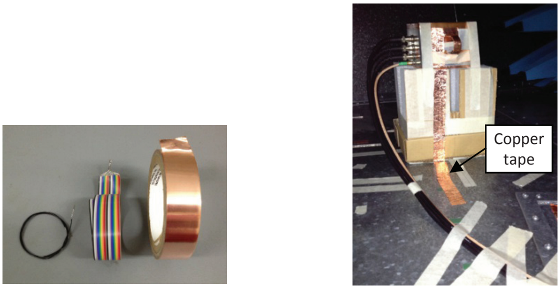
4.0 MEASUREMENTS AND PRECAUTIONS

4.1 Ambient Noise

It is important to perform ambient noise measurement inside the GTEM cell to ensure that there are no external electromagnetic leakages due to imperfect shielding of the cell. When the IC is not powered, the spectrum analyzer should only measure voltages due to noise floor of the cell and measuring equipment. Occurrence of voltage peak over the desired frequency spectrum should be identified and eliminated.

As mentioned previously, the cavity may be a good radiator if it is not properly grounded. When the IC is energized, the electromagnetic fields emitted will coupled to the cell septum. However part of the electromagnetic field will also be coupled to the cavity resulting in induction current which will produce secondary emission.

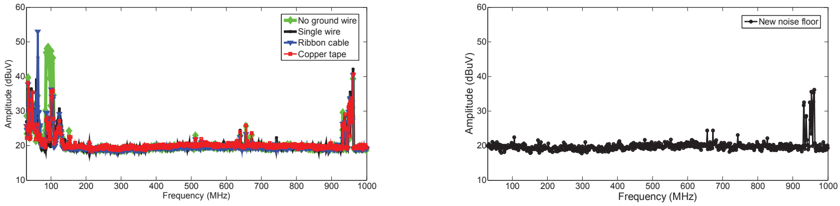
In this case, proper grounding is extremely important for diverting the induced current away from the cavity. The inner side of the cavity is grounded to PCB using gasket and the outer side is tied to GTEM cell body using ground strap. The ground strap has to be chosen to provide low impedance between connecting points to aviod unwanted potential difference. Figure 3(a) shows the wire, ribbon cable and copper tape that are used for grounding purposes. Figure 3(b) is the setup inside the GTEM cell with attachment of copper tape between the cavity and GTEM cell ground plane clearly shown.



(a) (b)

Figure 3. Minimizing enclosure effect with different types of ground straps, (a) selected ground strap, (b) setup of the measurement

Figure 4(a) presents the ambient noise inside the GTEM cell when the FPGA chip is not powered. It can be observed that leakages from external sources manage to enter the GTEM cell via the power and signal cables. These leakages must be removed to ensure correct measurement of electromagnetic emission due to FPGA chip. Various techniques were employed to remove the leakages and it was found that usage of copper tape located near all interconnection points (Figure 5) are effective in removing some of them. In addition ferrite beads connected to the cable could further improve the cleanliness of the noise floor. Figure 4(b) shows the new noise floor after implementing the techniques to reduce external leakages.



(a) (b)

Figure 4. Ambient noise (a) grounding cavity with different ground straps and (b) after implementing all techniques

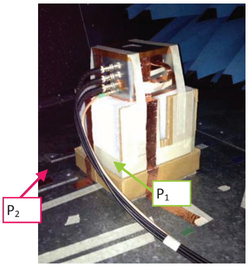


Figure 5. Placement of copper straps in different grounding locations

4.2 Double Shielded Cables

The previous result still shows the existence of electromagnetic leakage at about 900 MHz even after efforts had been taken to eliminate it with shielding, grounding and suppression using ferrite. Since these peaks appear across GSM mobile phone frequencies, it is suspected that these peaks originate from nearby base station. The cable connecting the GTEM cell to spectrum analyzer is able to pick up GSM signal. The condition can be improved using double shielded cable as shown in Figure 6.

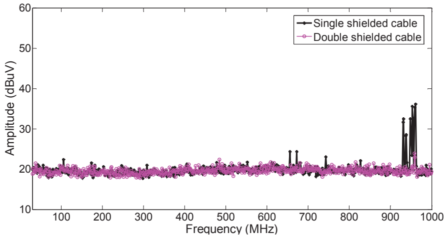


Figure 6. Removing GSM signal using double shielded cable

4.3 Electromagnetic Emission Measurement

After obtaining a clean noise floor, the FPGA chip was configured with a toggle flip-flop (TFF) logic circuit and exercised with an external sinusoidal clock signal. The clock frequency is 100 MHz and the output signal of the TFF pattern is 50 Mhz. Figure 7 shows the radiated emission is decomposition of fundamental clock frequency plus fundamental and harmonics of the output signal. The data can now be used for further applications because the effects of unwanted ambient noise have been eliminated using the techniques described earlier in this paper.

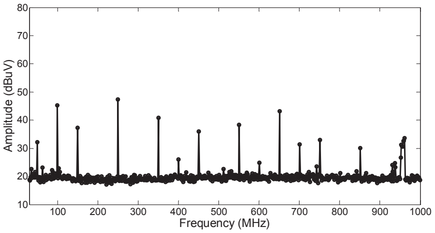


Figure 7. Measured radiated emission of the FPGA chip

5.0 CONCLUSION

In this paper, we have suggested techniques to eliminate electromagnetic noise from interfering the measurement of electromagnetic emission due to ICs in a GTEM cell. The combined usage of grounding near interconnection points using low impedance ground strap, shielding the IC test board using metallic cavity, and cable shielding using ferrite beads successfully removed the unwanted noise in the emission measurement. This work provides a preliminary input in an effort to perform IC emission measurement inside a GTEM cell as opposed to mounting it on the GTEM wall based on IEC 61967.

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