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IMPROVED ACCURACY OF GTEM CELL/SAC-CORRELATED MEASUREMENT OF IC-RADIATED ELECTRIC FIELDS BY A CORRECTION FACTOR

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ABSTRACT

Gigahertz Transverse Electromagnetic (GTEM) cell has been a popular test facility for evaluating integrated circuit (IC)-radiated emission. Since it is single-port test device, GTEM measurement cannot distinguish electric field component from magnetic field component. Rather, both fields are captured as a global quantity. It is therefore speculated that radiated emission measured using GTEM cell is less precise comparing with near-field probe scanning technique. Nonetheless, GTEM cell is cost-effective in providing sufficiently good ambient shielding to conduct field measurement at broad frequency range. Meanwhile, GTEM measurement typically is associated with semi-anechoic chamber (SAC) measurement. This study attempted to improve the correlation between GTEM and SAC through a correction factor. A specific circuitry pattern was constructed to replicate the wide-ranging IC interconnections and used for evaluation in GTEM cell and SAC. The horizontal and vertical electric fields based on GTEM measurement were preprocessed by MATLAB code to obtain the correction factor. Subsequently, the correction factor was employed to fine-tune any deviation arose from correlating the IC-radiated electric fields of GTEM cell to SAC. The results demonstrated a strong correlation coefficient upon regulation of GTEM fields with a correction factor, thereby offering a high-accuracy GTEM cell measurement strategy.

Keywords: GTEM cell, radiated electric field, integrated circuit, correction factor.

INTRODUCTION

Given the merits of smaller size and lower development cost, modern electronic appliances utilize ICs extensively for signal processing applications. Today, the advanced process integration technology and the introduction of new packaging technology at chip scale allow production of incredibly dense ICs with higher number of I/Os that can operate at extraordinary frequencies. Consequently, these ICs are likely to constitute significant noise sources that give rise to electromagnetic interference (EMI) in electronic devices (Pencek ; David, 2006). Such undesired electromagnetic noise may degrade the performance of an electronic device and cause it to malfunction. Indeed, EMI at component level has drawn increasing attention in the light of growing demand for low emission and high immunity device, especially when concern of safety is involved, such as in automotive and consumer electronic applications (Mittra, 2008).

The Society of Automotive Engineers introduced the standard SAE J1752-3 (Standard 2003) for measuring electromagnetic emission from an IC in 1995. In the following year, the International Electrotechnical Commission published the standard IEC 61967-2 (Standard 2005) for similar purpose. Both standards stipulate that the evaluation of IC's electromagnetic radiation must be performed by clamping the IC test printed circuit board (PCB) onto a wall port cut in the top or bottom of a TEM or wideband GTEM cell. The evaluation frequencies range from 150 kHz to 1 GHz. Hitherto, these standards remain widely accepted by industries and academic researchers.

As IC operates in concert with supporting components, the evaluation procedure of clamping the IC test board onto the cell wall enables separation of IC radiation from its board environment. However, this setup limits the rotation of test board in two dimensions across its vertical axis. By convention, the measurement of radiated emission is dependent on horizontal and vertical polarization fields. By clamping the IC test board onto the wall port, this measurement approach takes into consideration only the horizontal polarization field while neglecting the equally significant vertical polarization field (K.L. Chua, 2014). Hence, an alternative measurement methodology which incorporates both horizontal and vertical polarization fields is desirable. By conducting emission test inside GTEM cell, any unpredictable fabrication defect can be avoided. Moreover, the test device may rotate freely in three orthogonal dimensions for comprehensive data acquisition.

Additionally, the study of IC's electromagnetic behavior provides crucial information for component selection and design consideration at the early product development stage. It facilitates shortened product development process as well as prevents undue shielding or filtering cost prior to electromagnetic compatibility (EMC) compliance test.

With the foregoing concerns in mind, this paper describes an effort to minimize the measurement deviation

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between GTEM cell and SAC by a correction factor. To establish the correction factor, we developed a simple circuitry pattern representative of a standard IC. The same pattern was exploited for electric field measurement in either GTEM cell or SAC. The correction factor was expressed as a ratio of SAC-based field measurement to GTEM cell-based field estimation, featuring deviation adjustment of IC-radiated electric fields in GTEM cell. The corrected results demonstrated a promising correlation between GTEM cell and SAC measurements.

The concept of IC-Radiated field measurement in GTEM cell

GTEM cell is an enclosed and tapered transmission line terminating with a broadband radio frequency (RF) load. The cell structure allows a frequency response extended beyond 1 GHz. The testing volume of the cell is typically defined below the inner transmission line or septum plate. For evaluating emission of an IC in the cell, the IC test board must be placed within the testing volume. The electromagnetic fields contributed by the IC will couple with the septum plate to induce voltage and current waves that propagate along the septum plate, and eventually measured by a spectrum analyzer attached to the input port.

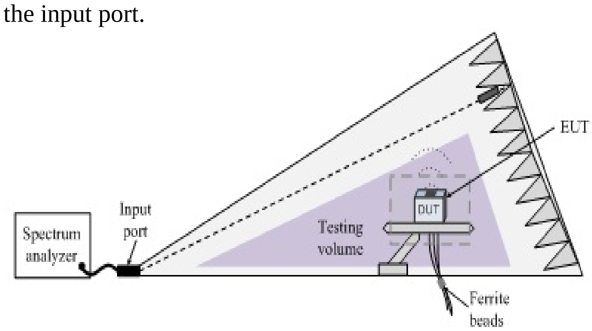

Figure-1. Evaluation setup for IC-radiated emission.

Figure-1 shows the setup for measuring IC-radiated emission in GTEM cell. The major concern of this setup is that the undesired disturbance generated by IC-supporting components and interfacing cables can adversely affect the measurement accuracy. In accordance with the study conducted previously (K.L. Chua 2014), we effectively tackled this issue by applying several EMC measurement strategies such as shielding, grounding and suppression using ferromagnetic material. Figure-2 illustrates the actual setup of IC test board in GTEM cell. Our experiment proved that these approaches are efficient in ensuring reliable IC emission measurement in GTEM cell. While the results presented in paper (K.L. Chua 2014) indicated relatively good correlation between GTEM cell and SAC measurements, occasional inconsistencies in the correlation had nonetheless been observed. For enhancing agreement of the correlation values, this paper proposes a further improvement by integrating a correction factor.

Figure-2. Strategies for minimizing interference of unwanted noises.

Representation of IC with A Spiral-Like pattern

Generally, every IC contains numerous wire routes for interconnecting the active elements. In fact, the routing of each IC is unique and can hardly be reproduced in another IC. Since routing is built to interconnect the active elements distributed randomly across an IC, we developed a spiral pattern (in a square) to represent a real IC. Figure-3(a) reveals the circuit diagram from which a spiral pattern is derived. To get around the use of interfacing cable, the circuit was designed to be powered by a rechargeable battery. In addition, a crystal was attached to the circuit to generate a sinusoidal signal of 50 MHz that travelling along the spiral pattern. As seen in Figure-3 (a), the right most trace, highlighted in red color, is the section to be manipulated to create a spiral pattern. Figure-3 (b) and (c) present the actual PCB configuration of this circuitry. Whereas PCB top comprises only the spiral pattern, all components are mounted onto the bottom of PCB. Notably, a large ground plane is formed at the bottom, upon which the spiral pattern is laid.

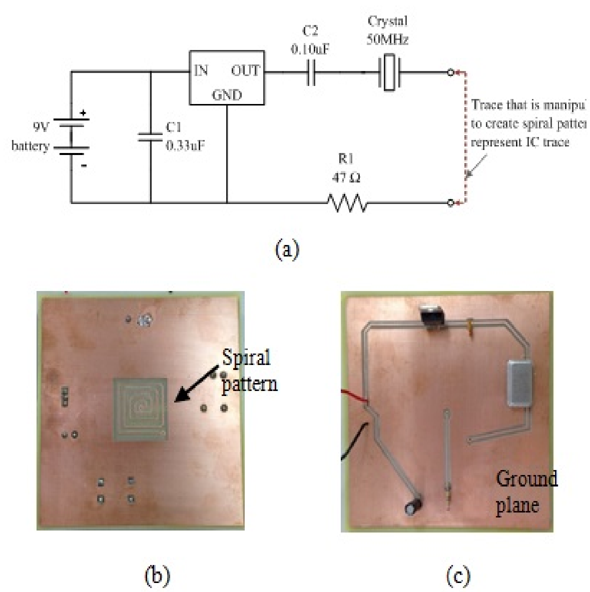

Figure-3. Proposed circuitry representative of standard IC for deriving a correction factor. (a) Schematic diagram of test circuitry, (b) Top view, (c) Bottom view.

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Evaluation of Spiral-Like equivalent circuit

The same evaluation procedure, as described earlier in Section II, was applied to the spiral-like equivalent circuit and Schaffner GTEM 750 was used for measurement. In general, GTEM cell-based measurement cannot differentiate between electric field and magnetic field. Both fields are picked up by spectrum analyzer as a global value in terms of voltage. In this case, analytical equations are required to extract an equivalent dipole moment that characterizes the spiral pattern. This equivalent moment is deemed an analogous radiation source applicable for estimation of horizontal and vertical electric fields at a distance from the source. In paper (Chua 2013), we expounded the techniques to estimate IC-radiated horizontal and vertical electric fields in GTEM cell. To determine the correlation between GTEM cell and SAC results, the radiated electric fields emanating from the equivalent circuit was likewise evaluated in SAC using biconical antenna placed at 3 m from the circuit board. Despite SAC is a shielded room which provides an alternative method for measuring radiated electric fields, it is more commonly employed for evaluating radiated electric fields at far distances. Figure-4 depicts the setup for measurement of radiated electric fields in SAC.

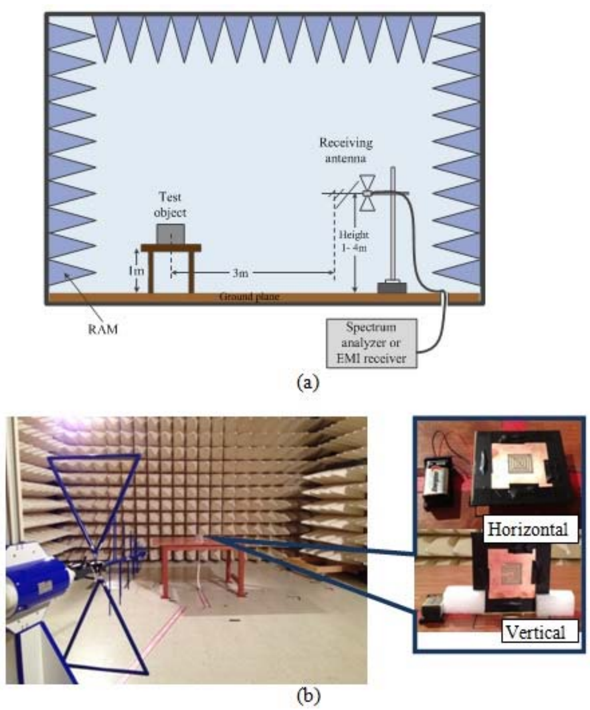

Figure-4. Radiated electric field test in SAC.(a) SAC measurement parameters, (b) Actual setup for equivalent SAC measurement.

The correction factor proposed for deviation adjustment of the correlation between GTEM cell and SAC is defined as a ratio of SAC-based measured field to GTEM cell-based estimated field, as given by equation (1). Note that these fields stem from the spiral-like equivalent circuit.

$$Correction\ factor, CF = \frac{SAC\ measured\ field}{GTEM\ estimated\ field} \quad (1)$$

Having determined the correction factor, the IC-radiated electric fields can subsequently be estimated by equation (2). The intervention of a correction factor is expected to eliminate any unforeseen factor that could affect the precision in correlating GTEM-based estimated fields to SAC-based measured fields.

$$New\ GTEM\ estimated\ field = CF \times GTEM\ estimated\ field\ for\ IC \quad (2)$$

To assess how well these equations relate to real-life applications, we selected field-programmable gate array (FPGA) chip as a test IC to repeat the measurement of radiated electric fields in GTEM cell and SAC. The FPGA chip was mounted onto a standard 10 cm x 10 cm test board designed according to IEC 61967-1. To prevent any interference that may arise from the supporting components during measurement, the entire FPGA test board was shielded with metallic enclosure, except the part exposed through a window. The design also included a toggle flip-flop (TFF) circuit to be configured into the FPGA chip and triggered by an external sinusoidal clock frequency of 50 MHz.

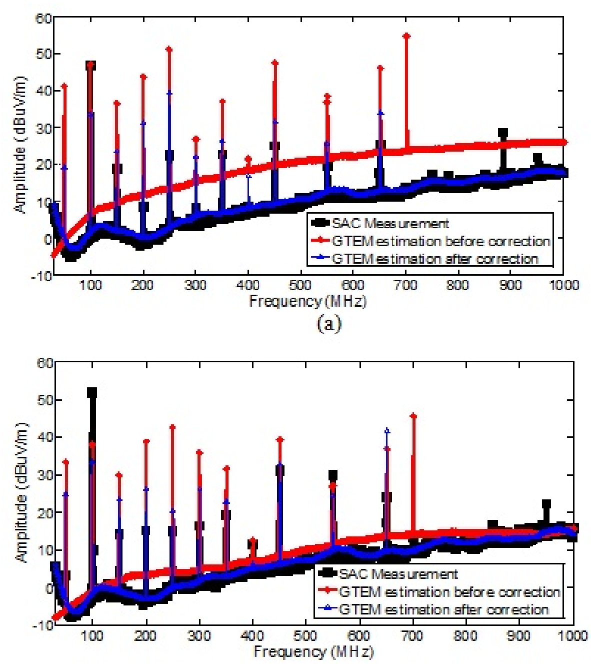

Figure-5. Comparison of GTEM cell's estimated IC-radiated electric fields before and after deviation adjustment by correction factor in reference to SAC measurement. (a) Horizontal component of radiated electric field,(b) Vertical component of radiated electric field.

Figure-5 presents the horizontal and vertical fields of GTEM cell-based estimated electric fields, as validated by the direct measurement in SAC. It is evident that the deviation in correlating GTEM cell measurement to SAC measurement was eliminated upon introduction of the proposed correction factor. The correlation coefficient of peak values for the predicted and measured fields is presented in Table-1. Before correction, the GTEM predicted fields exhibit a moderate and positive relationship against the SAC measured fields. This suggests that the similarity between the two fields is low. A strong correlation is attained after improving the predicted fields using the correction factor. The result indicates the difference between the fields have decreased, thus the predicted fields are closer to SAC measured field.

Table-1. Correlation coefficient of predicted and measured fields.

Components	Before correction	After correction
Vertical	0.2609	0.5568
Horizontal	0.4269	0.6135

CONCLUSIONS

This paper has presented a correction factor that can be applied to fine-tune the difference in correlating GTEM cell measurement to SAC measurement of IC-radiated emission. The correction factor was derived using a spiral-like circuitry which serves as universal representation of the complex interconnected traces on a real IC. A relatively good correlation between GTEM cell and SAC measurements of IC-radiated electric fields has been demonstrated. Positively, this lays a foundation for further investigation to explore and examine other factors that may enable improvement of peak amplitudes between measurement and prediction results.

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