Application of GTEM Cells for IC EMC Testing

Ralf Heinrich*, Viki Müllerwiebus#, Andreas Lange*, Bernd Deutschmann#, Uwe Karsten*, Frank Klotz#

*Teseq GmbH, Landsberger Straße 255, 12623 Berlin, Germany

#Infineon Technologies AG, Am Campeon 1-12, 85579 Neubiberg, Germany

***Abstract*— A test object for investigation and comparison of different IC EMC test facilities (µTEM and GTEM cell) has been designed. The test board allows the characterization of the test facility directly at the position of the EUT. Based on this test object the DUT orientation and test facility requirements are investigated theoretically and experimentally. The comparison of µTEM cells and a GTEM cell showed a good agreement of the measurement results up to the frequency limitations of the µTEM cells.**

I. Introduction

The increasing use of wireless and high complexity devices running at high clock speeds requires a rising concern about EMC. The consideration of EMC aspects should ideally be done in an early stage of a product development. Later changes, e.g. additional shielding or filtering due to EMC requirements are typically more difficult to implement and may cause additional costs and delay of the development process. The knowledge of the EMC behaviour of IC's gives guidance for component selection and design considerations and can help to consider all relevant EMC aspects already during the development.

In order to characterize the EMC behaviour of integrated circuits emission measurements and immunity tests have to be performed on IC level. The methods doing this are typically different from the ones on device level, because they have to take into account the high complexity and the small size of the IC's. Therefore the test set-ups are specially adapted to IC testing. A typical test set-up is e.g. a µTEM cell as specified in IEC 61967 and IEC 62132 [1,2].

TEM cell is a transmission line with characteristic impedance of which is realized by gradually expanding the size of a coaxial transmission line [3]. In [4] the radiated RF emissions from a family of microprocessors using a 1GHz TEM cell with an IC under test on a standardized test board regarding the SAE standard [5] has been shown.

The desired frequency range for EMC testing on IC level is similar to the one on device level. Increasing clock speeds etc. require testing also at higher frequencies above 1 GHz. Some of the established methods, e.g. µTEM cells have an upper frequency limit.
An alternative method to overcome this drawback is the use of GTEM cells [6]. The conical shape of a GTEM cell reduces the occurrence of higher order modes which limit the application of TEM cells at higher frequencies. However, GTEM cells need a well matched termination being a part of the cell. The quality of this termination may limit its application. In [7] Malarić et. al. already showed the influence of absorbers and resistors regarding the GTEM-cell parameters such as SWR and return loss. Their investigations were based a self made GTEM-cell as well as on a GTEM-cell without resistors, absorbers, and with open and metal end. They showed that the influence of the absorber is more important, at especially the higher frequencies (above 500MHz) while resistors have more influence at the frequencies up to 400 MHz.

Theoretical and practical investigations regarding EUT positioning and orientation as well as requirements to the test facility were done and will be discussed in the paper.

II. Considerations of EUT orientation and test facility properties

A special test PCB was designed for the purpose of GTEM investigations and optimization. The test board can be clamped on a special opening in the wall of the cell. It consists of a 45 mm long strip line mounted in 1 mm distance above the PCB. At one side of the strip line a SMA connector is mounted and at the other side a 50 Ohm SMD resistor for termination. The test PCB has a dimension of 100x100 mm and is designed according to the requirements of the IEC 61967 and IEC 62132. Fig. 1 shows the test board.

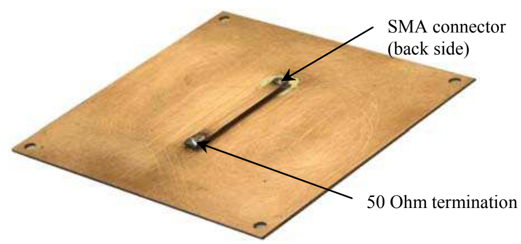

Fig. 1 Test board

The test PCB can be placed into four different orientations (O1=0°, O2=90°, O3=180°, O4=270°) as shown in fig. 2.

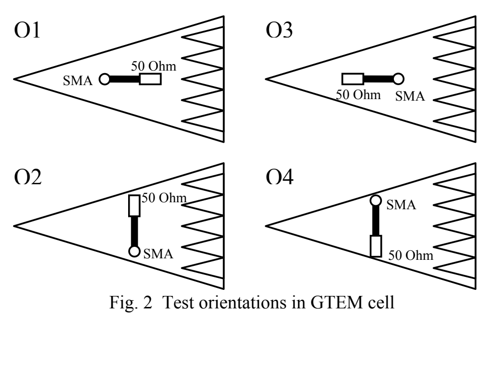

Fig. 2 Test orientations in GTEM cell

For the orientation O1 and O3 the strip line is in parallel to the septum, in orientation O2 and O4 at right angles to the direction of the septum. In O1 the SMA connector and in O3 the 50 Ohm load is located next to the feeding point of the GTEM cell.

Regarding therefore the placements parallel to the septum (Orientation O1 and O3), the DUT can be described by the theory of a coaxial directional coupler. The port of the GTEM cell at which the receiver is connected shall be neglected as a termination without reflection. Termination at feeding port of DUT is neglected to be without reflection, too. The other port of DUT represents a termination of a current path via the IC which is terminated with a reflection factor r. The absorber of the GTEM cell terminates a port with reflection factor r_1. The schematic of the setup is outlined in Figure 3.

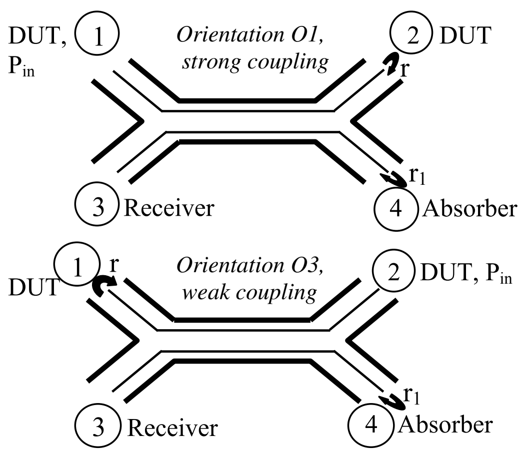

Fig. 3 DUT outlined as the related directional coupler setup

In case of orientation O1, the receiver is connected to the coupling port of the directional coupler. In case of orientation O3, the receiver is connected to the isolation port of the directional coupler. The power received was reflected by the DUT and coupling to the receiver after that. As magnitude of reflection coefficient of DUT is $|r| < 1$, orientation O1 is expected to result in higher levels of power than O3 (compare fig. 8).

In case of non ideal absorbers ($r_1 > 0$), an additional path is created. In case of orientation O1, power is reflected by the DUT, coupling to port of absorbers, reflected by non ideal absorbers and to receiver. Depending on frequency, destructive or constructive interference will appear. Therefore, non ideal absorbers will create a measurement error depending on frequency, oscillating between a minimum value and maximum value. In case of orientation O3, the additional path is created due to direct coupling to the absorbers and reflection of the absorbers to the receiver. In case of DUT showing a low reflection coefficient r, this path can dominate the regular path. Influence is increasing with increasing reflection coefficients r or r_1. Hence, high amplitudes of the oscillation in the measurement result are expected. In case of orientation O1, the additional path is weaker than the regular path due to the additional reflection by DUT and absorbers needed. Hence, lower amplitudes of oscillation are expected.

These will be stated in measurement results (compare figs. 7 and 8).

To avoid this oscillation and therewith a measurement error due to non ideal absorbers, a low reflection coefficient of TEM cells is mandatory.

Example: Let's assume a worst case of $|r| = 1$ (no specific radiation direction of the DUT). Let's further assume a matching of the GTEM absorbers of 20 dB. This would be equivalent to a reflection coefficient of $|r_1| = 0.1$ or +/-10% or +0.8 dB / -0.9 dB failure of the measurement result due to the reflections. This can be regarded as an acceptable compromise between desired measurement accuracy and achievable technical performance of the test environment.

If $|r| = 0$ it is necessary to differentiate between strong coupling and weak coupling direction. For strong coupling the influence of r_1 is negligible since no energy is coupled towards the absorbers. For weak coupling we get maximum influence of r_1. However, even for the worst case $|r_1| = 1$ the measured radiation would be less or equal the maximum radiation of the DUT. Therefore $|r| = 1$ remains the worst case.

Since the radiation direction of the DUT is a priory unknown it is necessary to measure different orientations of the DUT in order to ensure the determination of the maximum radiation.

III. Optimization of GTEM Return Loss

As discussed in section II the return loss of the GTEM cell shall be better than 20 dB in order to achieve less than 1 dB measurement error due to the test facility. Two different methods were used for optimization of the GTEM return loss, classical time and frequency domain measurements at the feeding port of the GTEM cell as well as the test PCB. The methodology of using the test PCB will be explained with experimental results of 2 GTEM cells, a poorly matched GTEM 1 (only RF absorbers, no resistive load) for comparison and cross check of the tests and a well matched GTEM 2 which was used for optimization.

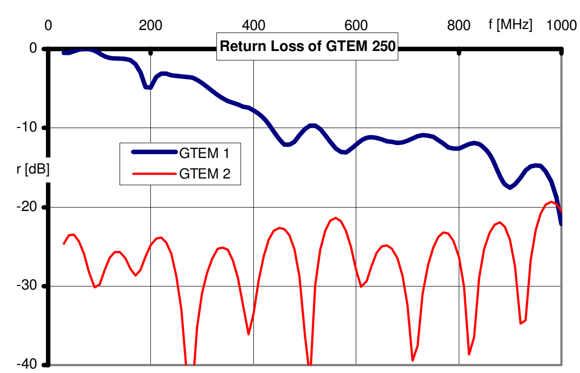

Fig. 4 Return loss of GTEM 1 and GTEM 2

Fig. 4 shows the return loss of both GTEM cells measured at the feeding port of the GTEM. The return loss of GTEM 1 is improving with rising frequency due to the work of RF absorbers, GTEM 2 has a return loss of better than 20 dB over the frequency range (after optimization). Fig. 5 shows the set-up for the return loss measurement using the test board. The results are shown in fig. 6.

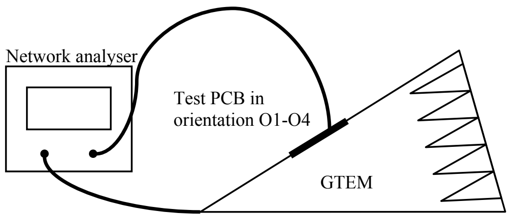

Fig. 5 Test setup for test PCB measurements

A network analyser was used for this measurement injecting a signal at the feeding port of the GTEM and measuring at the output of the test board. The return loss was calculated from the difference between orientation 1 and 3 of the test board which corresponds to the relation of reverse to forward power. The accuracy of this method is limited by the directivity of the test board directional coupler, especially for well matched cells. Unfortunately the directivity of our test PCB was not better than about 15-20 dB, therefore the measured return loss at the feeding port of the GTEM looks better than the one of the test PCB measurement.

This is a limitation of the test PCB measurement method. On the other hand this method allows measuring possible reflections directly at the position of the test object. In the higher frequency range the disturbing occurrence of higher order modes could be observed which may not be seen at the feeding point.

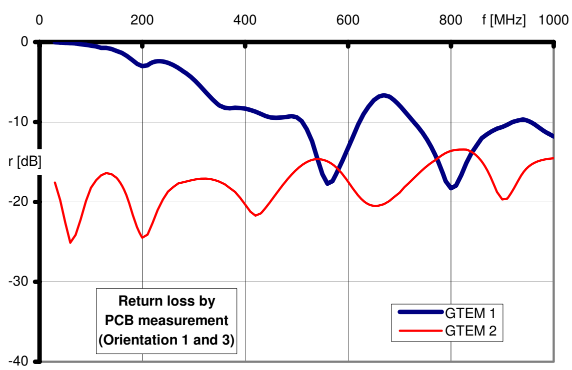

Fig. 6 Return loss of GTEM 1 and GTEM 2 obtained from test PCB measurements

Fig. 7 and 8 show the results of 4 orientations of the test PCB in GTEM 1 and 2. The well matched GTEM 2 shows a larger difference of the levels of orientation 1 and 3, hence a good return loss whereas GTEM 1 shows only a little difference improving to higher frequencies.

Similar observations can be derived from orientations 2 and 4. A smooth shape without any ripples and little difference between both orientations show a good symmetry and a well matched GTEM 2. GTEM 1 shows ripples due to the reflections at the poor cell termination.

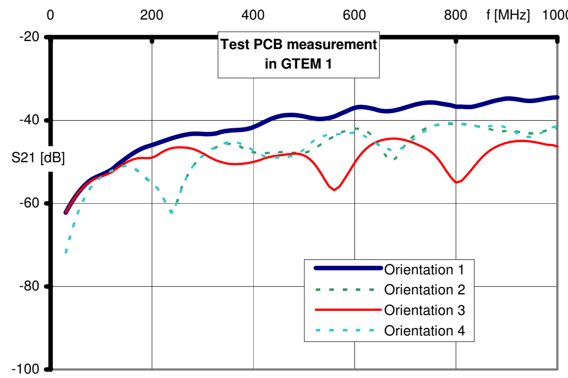

Fig. 7 Test PCB measuring results in GTEM 1

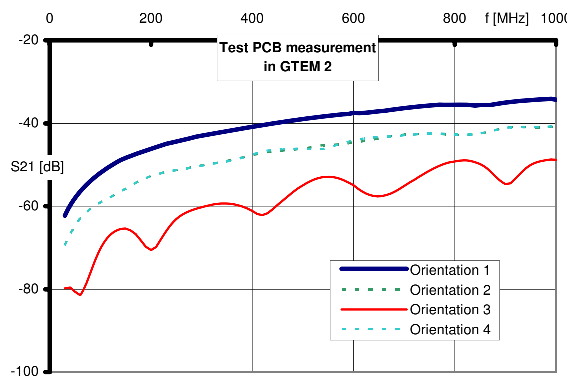

Fig. 8 Test PCB measuring results in GTEM 2

Depending on the size and properties of the directional coupler this method can be used for different frequency ranges. Fig. 9 shows the return loss of an optimized GTEM cell in the frequency range up to 18 GHz.

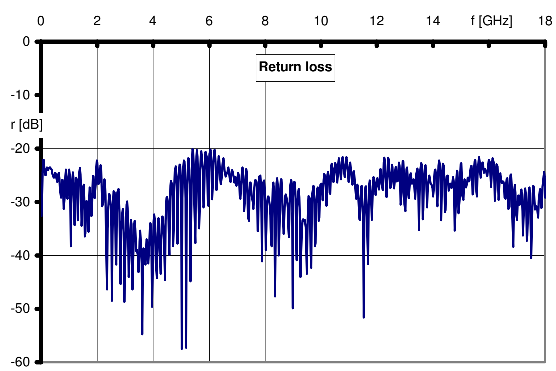

Fig. 9 Return loss of an optimized GTEM cell up to 18 GHz

IV. Application

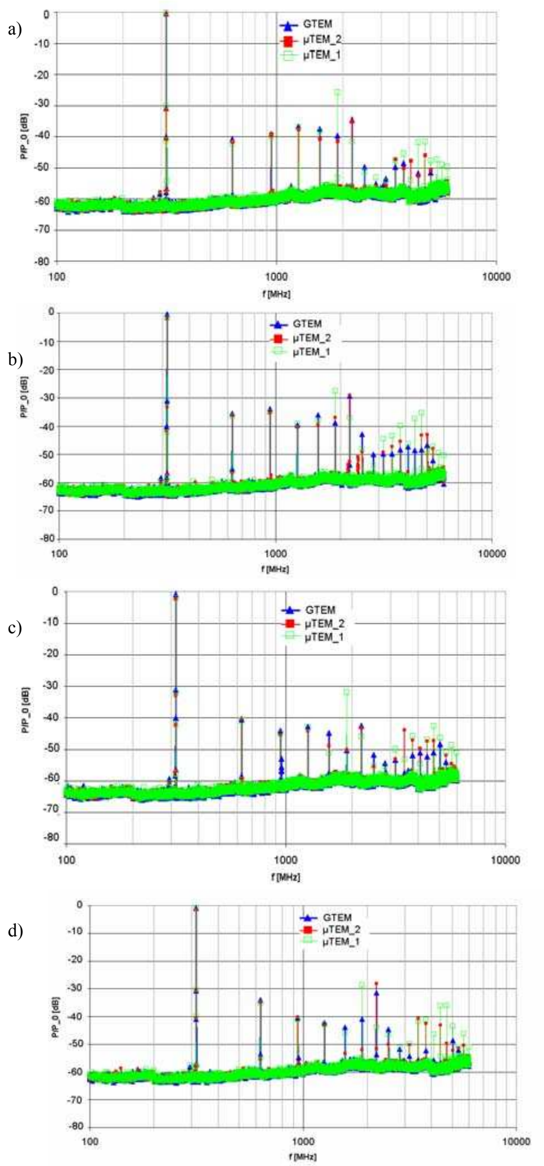

Fig. 10 Emission measurement results of a test IC, relative to maximum emission level. Three different cells were used. Optimized GTEM cell (blue, triangles), µTEM cell valid up 1.2 GHz (green, not filled squares) and µTEM cell valid up to 2 GHz (red, filled squares). Measurement results of four different orientations of the DUT (0°, 90°, 180°, 270°) are shown in a), b), c) and d).

For comparison of GTEM cell to µTEM cell, emission measurements were done to a test IC. Same µTEM cell board was used. Used GTEM cell is an optimized GTEM cell (compare fig. 9) and two µTEM cells. Cell µTEM_1 is supposed to be valid up to a frequency range of 1.2 GHz and has got a strong resonance at 1.9 GHz. Cell µTEM_2 is valid up to 2GHz. Measurements results are depicted in fig. 10, reflection coefficients of used cells are depicted in fig. 11 (uTEMs with load at output port).

Good agreement of all cells is achieved in the frequency range up to 1 GHz. As distance of septum to placement of IC is nearby the same in GTEM and µTEM cells, same power levels are received, as expected. Resonance at approx. 1.9 GHz of µTEM_1 results in highly increased results compared to the other cells, as expected. Remarkable is, that using µTEM_2 can result in lower power levels in case of rather low coupling than using GTEM in the frequency range of 1.5 GHz < f < 2 GHz, though cell should be valid up to 2 GHz.

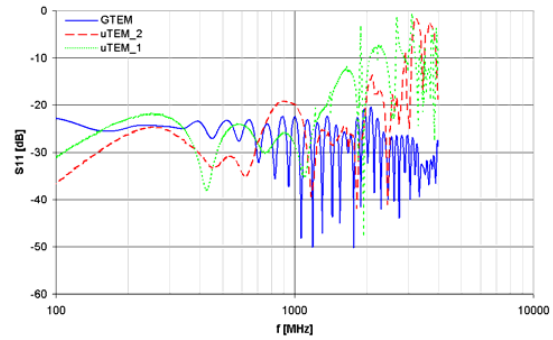

Fig. 11 Reflection coefficients of used cells, uTEM cells terminated with load

V. Conclusions

Based on a special test object the matching of a GTEM cell has been optimized up to 18 GHz in order to fulfil the theoretically investigated test facility requirements. The optimized GTEM cell could successfully be applied for IC EMC testing and showed a good agreement of the measurement results achieved in different µTEM cells. Thus the drawback of the frequency limitation of µTEM cells can be overcome using a GTEM cell.

References

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