FEM Modeling of Gigahertz TEM Cells for Susceptibility Analysis of RFID Products

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Abstract— **This paper presents a novel simulation methodology to model the coupling between a GTEM cell and an RF-ID antenna. This model can further be used in a simulation test bench to verify the susceptibility of contactless RFID cards to RF interference from mobile phone transmissions. In this test bench the immunity test signals are injected into the contactless smart card under design within a model of a GTEM cell. A GTEM cell is used for this purpose because it is the only real-life test environment that allows exposing the DUT with a localized plane wave from 13.56 MHz up to multi-GHz frequencies. Our proposed methodology has been well verified by comparing simulations with measurements.**

Keywords—Gigahertz transverse electromagnetic (GTEM) cell, numerical simulation, Finite Element Methods (FEM), Electromagnetic Compatibility (EMC), RFID.

I. Introduction

Contactless payment/banking card transactions can be protected against nearly all kinds of fraud by the use of a so-called crypto tunnel. Such a crypto tunnel is an encapsulation of the data transfer over different public (wireless) networks from the CPU of a contactless smart card directly to the credit card provider. Such a crypto tunnel is required if e.g. a GSM/GPRS enabled Point-of-Sale terminal or a Near Field Communication (NFC) enabled phone is used as a terminal of a continuous cell phone connection. During the entire smart card transaction the RFID circuit is exposed to the wireless connection, which can interfere with the smart card. Therefore credit card providers and banks demand proper Electromagnetic Interference (EMI) susceptibility testing from the smart card industry with a special focus on the frequency bands of mobile devices.

Until now such tests have been performed with real-life contactless readers based on the transformer principle operating at 13.56 MHz [1] and a simple dipole antenna has been used to emit the interference signal. The disadvantage of such a configuration is to setup a proper simulation environment due to the complexity caused by the fact that the field distribution is strongly dependent on the distance from the antenna. In contrast, the simplest simulation setup is a homogenous plane wave that is incident on the contactless smart card, as it is available in FDTD (Finite-Difference Time-Domain) 3D EM simulators. The practical implementation of such a test bench is not possible, because a true plane wave does not exist. Therefore the best approximation of a true homogenous plane wave is the TEM (transverse electromagnetic) wave within a GTEM (gigahertz transverse electromagnetic) cell, because it locally corresponds to a plane wave from DC to several GHz. Besides the fact that it is difficult to generate the approximation of a plane wave over such a wide band within an anechoic chamber even with several antennas, most anechoic chambers are not really anechoic anymore below 30 MHz. In comparison, such a GTEM cell is a low cost and well established test environment in Electromagnetic Compatibility (EMC) testing and described in various EMC standards [2].

In this paper a simulation methodology is proposed, based on well-verified measurements, that calculates the scattering (S-)parameters between the feed port of a GTEM cell and the feed port of a prototype Proximity Integrated Circuit Card (PICC) coil antenna (see Fig. 1). This S-parameter model can be further used in a test bench to verify the EMI susceptibility of an RFID proximity integrated circuit. This simulation method enables either the IC or antenna designer to verify, at an early stage, the susceptibility of RFID products to any electromagnetic interferer (such as EMI from a GSM signal). The S-parameter model from the simulation can be validated using S-parameters obtained from measurements.

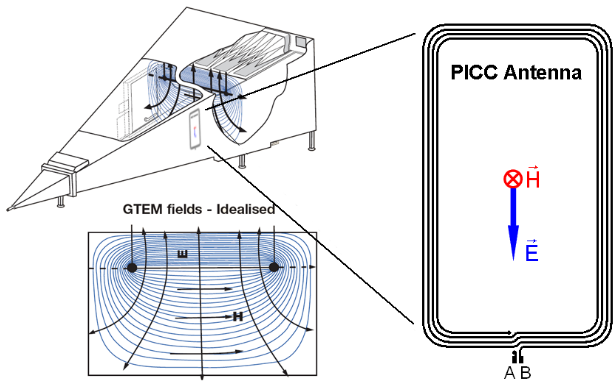

Figure 1. Orientation of the PICC Antenna inside the GTEM Cell, including the fields.

This paper is organized as follows: in section II the individual components of the test bench are described; section III shows how the simulation setup is used in real-life to test contactless chip-card prototypes against EMI; in section IV the simulation setup is described; finally, in section V the measurement setup is described that is used to validate the simulation methodology and the comparison between measurements and simulations is given.

II. Description of Test Bench Components

A. GTEM cell

The GTEM cell is a well-known device used for EMC tests [3]. The GTEM cell has a coaxial structure where the outer conductor is constructed with a tapered section and the inner conductor, also called septum, is constructed from a tapered plate. The septum is connected to the inner core of the coaxial connector of the GTEM cell through a so called coax to waveguide element. The GTEM cell is a single port device with 50 Ohm characteristic impedance, which enables low levels of reflections. Reflections are reduced by construction of the backside of the GTEM cell. Low frequencies are absorbed by a 50 Ohm resistive network which is present between the end of the septum and the back wall of the GTEM cell. Higher frequencies are absorbed by polyurethane pyramid absorbers which are present at the back end of the GTEM cell.

B. RFID Antenna

To validate the GTEM modeling a reference PICC coil antenna according to the ISO/IEC 10373-6:2011 standard [4] is used. In order to measure the S-parameters, the feed point is slightly adjusted in such a way that SMA connectors are properly integrated. The card with SMA connectors is then mounted on an aluminum plate with SMA dimension contact holes and outer dimensions that fit on the mounting door of the GTEM cell. In this way the SMA connectors are accessible from the outside of the GTEM cell while the antenna is located in the open area of the GTEM cell. A 3-port S-parameter measurement is done with 2 ports on the PICC coil antenna and 1 port on the GTEM cell. The reference for all ports is connected to the outer conductor of the GTEM cell and grounded. The 2 ports of the PICC coil are post-processed into a single port with a commercially available Analog Design tool. In the next sections the PICC coil antenna will be called antenna and the PICC IC will be called IC.

III. Real-Life Configuration of the Test Setup

The real-life configuration of the described simulation setup is derived from the test setup that is described in the IEC 62132-2 standard [2] The test setup of the GTEM cell as depicted in Fig. 2 (according to [2]) is used to apply the electric *E* and magnetic *H* field to the antenna. Unlike the method used in [2], the IC under test is not placed inside the GTEM cell, but only the antenna is positioned inside the GTEM cell (see Fig. 2). Fig. 1 shows the electromagnetic field inside the GTEM cell and how the antenna is placed in the EM field.

The IC under test is placed outside the GTEM cell on the back side of the so-called EMC test board (see Fig. 2). On the front side of the EMC test board, a ground plane is placed to electrically continue the inside of the GTEM cell housing and to shield the IC under test. The only connection between the IC under test and the antenna is through a number of vias. In this setup the IC under test is indirectly connected to the GTEM port through the antenna. Therefore with this test the influence of the GSM disturbance to the IC under test can be measured. The usage of a typical PICC antenna guarantees that the impedance at the input of the IC under test is the same as the conditions in a typical application.

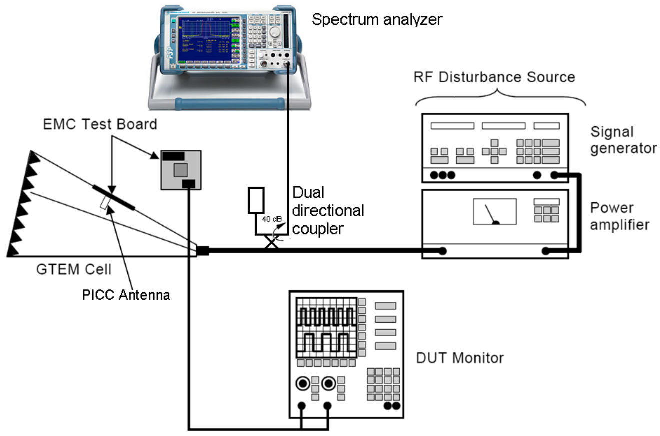

Figure 2. GTEM Cell Test Setup according to IEC 62132-2

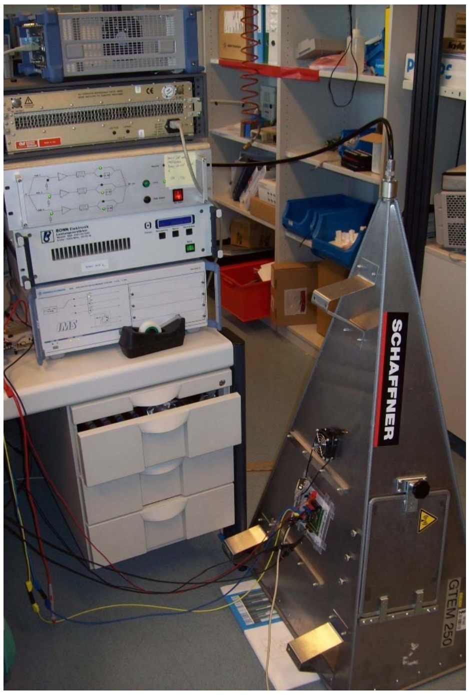

Figure 3. Photo of the Measurement Setup

IV. Simulation Setup

3D-EM simulations are done with a commercially available tool, Agilent EMPro version 2011.11 [5]. A single lumped element port is defined between the 2 connections of the PICC coil (point A and B in Fig. 1) and a waveguide port is defined at the GTEM coax side. The coax to wave guide element is not included in the simulation model because the reflections of the GTEM cell and therefore this element are not relevant (as long as the reflections are lower than the specification of the GTEM cell).

In several publications the FDTD method is used for modeling of the GTEM cell [6]. In this paper the Finite Element Method (FEM) is used to model the GTEM cell. This method is preferred because in the antenna model there are very thin layers used which would explode the number of elements when using the FDTD method. The advantages of FEM are that it can increase the mesh density where more details are required and where the field strengths become very strong, leading to a high accuracy of the simulation. Also FEM allows dealing with multiple ports more efficiently in comparison to FDTD.

A. GTEM modeling

The physical modeling of the back side termination of a GTEM cell is in general a complicated task [7]-[9]. In this paper, a very simple yet effective way to model the 50 Ohm termination of the back side is proposed. This is done by defining an absorbing boundary condition in the vertical plane of the GTEM cell as shown in Fig. 4. This is a simplification of the real situation, which effectively reduces the reflections from the backside of the GTEM cell. The fields in the GTEM cell are predominately TEM and can be decomposed into normally incident plane waves (both consist purely of transverse E and H fields). Therefore the TEM fields should be largely absorbed by the absorbing boundary condition. Also trying to represent the back side by a 50 Ohm waveguide port does not work, since higher order modes which are generated introduce reflections from the back end of the GTEM cell.

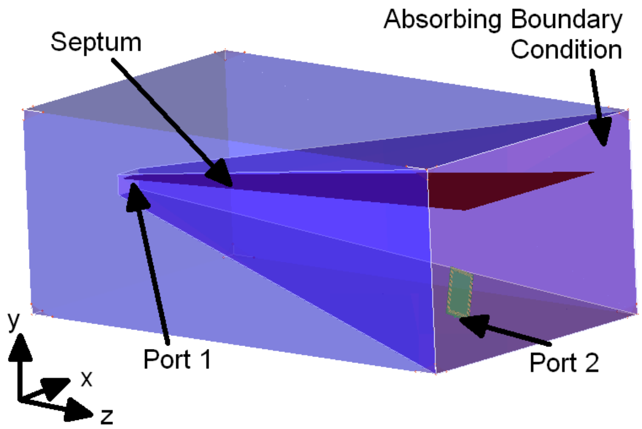

Figure 4. Graphical representation of FEM modeling of combined GTEM and PICC coil antenna.

Furthermore, an absorbing boundary condition in the z-direction is defined at the front side (GTEM port side). The outer conductor is defined by a solid block of Perfectly Electrical Conducting (PEC) material extended to the outer dimensions (x-, y-directions) of the model.

B. Combined GTEM & PICC coil antenna modeling

The model of the GTEM as described in sub-section A is combined with a model of an RFID antenna similar to the one shown in Fig. 5. The two feed points of the RFID antenna are made from a thin metal layer of 40 um and therefore the antenna port can be defined as a lumped element port. The GTEM port is defined as a waveguide port. The tapered geometry of the GTEM cell makes it impossible to define a waveguide port in a Cartesian coordinate system, for both the GTEM and the PICC port.

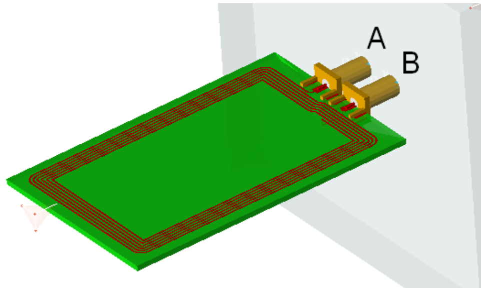

Figure 5. Graphical representation of 3D EM model of PICC coil antenna with SMA connectors

V. COMPARISON OF MEASUREMENT AND SIMULATION

The measurement results are obtained from 3-port S-parameter measurements where 2 ports are required (due to shielding purposes) for the antenna and 1 port for the GTEM cell port. All ports have the grounded outer conductor of the GTEM cell as a reference.

The two ports of the antenna (see Fig. 6) can be post-processed with a commercially available analog simulation environment into a single differential port, where the PICC port is defined as port 2 in the simulation and the GTEM cell port is defined as port 1. After post-processing the measurement results can be directly compared with the simulation results. The reflection and transmission coefficients are given as a function of frequency in Figs. 7-9.

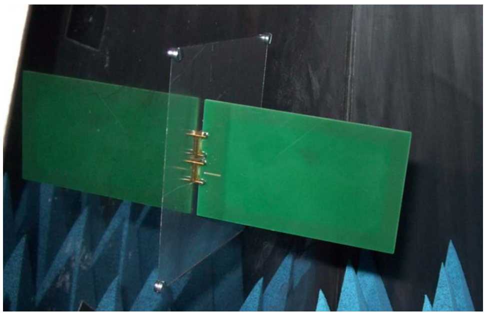

Figure 6. Orientation of PICC Antenna inside the GTEM Cell

In Fig. 7 it can be seen that the simulation result of the reflection coefficient of the GTEM port (S_{11}) is for almost all frequencies much lower than the measurement result. Also, the reflections are much lower than the specification (-20 dB to -30 dB in the frequency range of interest) of the unloaded GTEM cell. This shows that the absorbing property of the absorbing boundary condition defined in the back plane of the GTEM model is effective.

From the graphs, it can be concluded that the results for the transmission coefficient (S_{21}) show a very good match below 1 GHz and some deviation above 1 GHz. The reflection coefficient of the antenna (S_{22}) shows a very good match for the full frequency range under observation. Some minor deviations for the exact location of the resonance frequencies can be observed which are considered to be caused by small imperfections in the details of the simulation model.

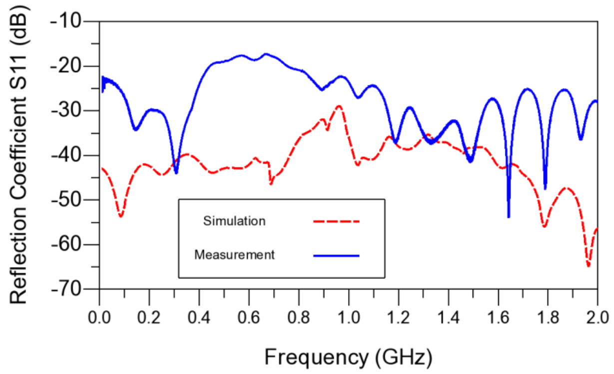

Figure 7. Measurement and simulation of reflection coefficient of the GTEM port.

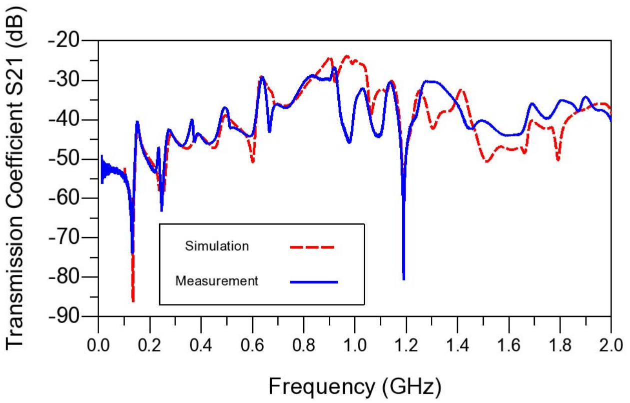

Figure 8. Measurement and simulation of transmission coeffecient between GTEM and PICC coil antenna ports.

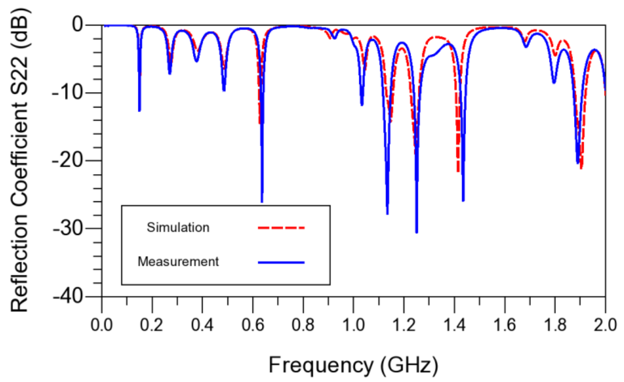

Figure 9. Measurement and simulation of refelection coefficient of the PICC coil antenna port

Additionally, the electric field inside the GTEM is measured with an isotropic field probe while inserting an RF signal at the GTEM port with an input power of 44 dBm at 900 MHz. The electric field strength is found to be around 110 V/m. The 3D-EM simulation shows for equivalent settings an electric field strength of approximately 106 V/m, which is considered to be in agreement with the measurement given the accuracy of this type of measurements.

VI. CONCLUSION

An effective way to model the 50 Ohm termination of a GTEM cell is proposed. The method is validated by inserting a Class 1 PICC antenna in a GTEM cell. Special feedthroughs are constructed to enable measurement of S-parameters. Reflections of the GTEM port are well below the specification of the GTEM cell, which shows that the absorbing property of the boundary condition is effective for the applied frequency range. Measurement and simulation of the transmission between the GTEM port and the PICC antenna port are in agreement. Also measurement and simulation of the reflection of the PICC antenna is in agreement.

The proposed methodology has been well verified through simulation and measurement. It can be used by the PICC antenna design engineer to validate his new design prior to manufacturing of the first prototypes.

Also, the S-parameter model obtained from simulation can be used in an analog simulation test bench to verify the EMI susceptibility of proximity integrated circuits in the common mobile radio bands.

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