CHARACTERIZATION OF ELECTRIC FIELD DISTRIBUTION IN A GTEM CELL

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For my wife Khairaty Binti Badron,

My sons,

Muhammad Farhan and Muhammad Zakwan,

My daughter,

Amirah Farzana.

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ABSTRACT

Two of the most important measurements related to electromagnetic compatibility (EMC) are radiated emission and radiated immunity. These measurements must be performed in a facility which provides reliability and reproducibility. The Gigahertz Transverse Electromagnetic Mode (GTEM) cell is one of the facilities for EMC measurement due to its well defined electric and magnetic field distribution in addition to being cost effective. The research undertaken in this project is to determine the field distribution in the GTEM by using Finite Difference Time Domain (FDTD). The results from the modeling are then compared with actual measurements and any differences will be noted and explained. The field strength inside a GTEM cell is a function of the input power as well as location along the longitudinal axis or septum height. Radiated immunity measurements require field uniformity (+6 dB according to IEC 61000-4-3 standard) which depends on the design aspects of the GTEM such as size, material and absorbing condition. The capability of the GTEM cell to provide the uniform field can be tested theoretically and experimentally. FDTD is a numerical method that can be used to predict the electric field distribution in a GTEM cell. The electric field distribution for frequencies at 100 MHz, 200 MHz, and 400 MHz were calculated using the EZ-FDTD software. In this report, theoretical study on the field strength and distribution in a GTEM cell is described. It is followed by making measurements of the field based on the radiated immunity test setup. It is found that at septum height 63 cm for frequency 100 MHz, the measured and simulated results are very close. This is the location recommended by the manufacturer for the placement of equipment under test (EUT) in radiated emission and radiated immunity test. The difference varies from 0.01 dB to 4.91 dB. The difference between modeling and actual measurement can be attributed to the input field distribution, inhomogeneous characteristics of the septum and existence of standing wave. In the future, it is recommended that other numerical methods such as Finite Element Method (FEM) and Transmission Lines Method (TLM) be used and more accurate model and absorbing boundary condition parameters be implemented.

ABSTRAK

Dua daripada pengukuran paling penting berhubung keserasian elektromagnet (EMC) adalah pancaran radiasi dan ketahanan radiasi. Pengukuran ini mestilah dilakukan di dalam kemudahan yang menyediakan kebolehharapan dan kebolehulangan. Sel Mod Elektromagnet Melintang Gigahertz (GTEM) adalah satu daripada kemudahan untuk pengukuran EMC hasil daripada medan elektrik dan medan magnetnya yang tertakrif dengan baik disamping kosnya yang efektif. Penyelidikan yang dijalankan di dalam projek ini adalah untuk menentukan taburan medan di dalam GTEM menggunakan Bezaan Terhingga Domain Masa (FDTD). Keputusan daripada permodelan kemudian dibandingkan dengan pengukuran sebenar dan sebarang perbezaan diantaranya akan dicatat dan dihuraikan. Kekuatan medan di dalam sel GTEM adalah fungsi bagi kuasa masukan dan juga lokasi sepanjang paksi membujur atau ketinggian septum (pengalir dalam). Pengukuran ketahanan radiasi memerlukan keseragaman medan (+ 6 dB menurut piawaian IEC 61000-4-3) yang bersandar kepada aspek rekabentuk sel GTEM seperti saiz, bahan dan keadaan serapan. Kemampuan sel GTEM menyediakan medan yang seragam boleh diuji secara teori dan ujikaji. FDTD adalah satu kaedah berangka yang boleh digunakan untuk meramal taburan medan elektrik di dalam sel GTEM. Taburan medan elektrik pada frekuensi 100 MHz, 200 MHz dan 400 MHz telah dikira menggunakan perisian EZ-FDTD. Di dalam laporan ini, kajian teori ke atas kekuatan medan dan taburannya di dalam sel GTEM diterangkan. Ianya diikuti dengan melakukan pengukuran medan berdasarkan pengujian ketahanan radiasi. Didapati bahawa pada ketinggian septum 63 cm untuk frekuensi 100 MHz, keputusan pengukuran dan simulasi adalah paling hampir. Lokasi ini adalah yang dicadangkan oleh pengeluar untuk perletakan peralatan dibawah ujian (EUT) dalam ujian pancaran radiasi dan ketahanan radiasi. Perbezaan berubah dari 0.01 dB hingga 4.91 dB. Perbezaan diantara permodelan dan pengukuran sebenar boleh disifatkan kepada masukan taburan medan, ciri-ciri ketakhomogenan bagi septum dan kewujudan gelombang pegun. Di masa hadapan, adalah dicadangkan kaedah berangka yang lain seperti Kaedah Elemen Terhingga (FEM) dan Kaedah Penghantaran Talian (TLM) digunakan dan model dan parameter keadaan serapan sempadan yang lebih tepat dilaksanakan.

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GLOSSARY OF ABBREVIATIONS

ABC	Absorbing Boundary Conditions
CW	Continuous Wave
DC	Direct Current
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMS	Electromagnetic Susceptibility
EUT	Equipment Under Test
FDTD	Finite Difference Time Domain
FEM	Finite Element Method
GPIB	General Purpose Interface Bus
GTEM	Gigahertz Transverse Electromagnetic Mode
OATS	Open Area Test Site
PEC	Perfect Electric Conductor
PML	Perfectly Matched Layer
RAM	Radio Frequency Absorbing Material
RF	Radio Frequency
TEM	Transverse Electromagnetic Mode
TLM	Transmission Lines Method

LIST OF SYMBOLS

B	Magnetic flux density (T or Wb/m^2)
C	Capacitance (F)
c	Speed of light in free space (m/s)
D	Electric flux density (C/m^2)
E	Electric field strength (V/m)
f	Frequency (Hz)
H	Magnetic field strength (A/m)
h	Distance between center conductor and outer floor conductor (m)
J	Current density (A/m^2)
n	Number of step
P	Input power (W)
ρ_v	Volume charge density (C/m^3)
t	Time (s)
V	Input voltage (V)
V_{inner}	Voltage at center conductor (V)
V_{outer}	Voltage at outer conductor (V)
v	Phase velocity (m/s)
Z	Characteristic impedance (Ω)
Δt	Time step (s)
$\Delta x, \Delta y, \Delta z$	Space increment or cell size (m)
σ	Conductivity of material (S/m)
ε_o	Permittivity of free space (F/m)
ε	Permittivity of material (F/m)

μ	Permeability of material (H/m)
Γ	Amount of reflection
η	Intrinsic impedance (Ω)
λ	Wavelength (m)

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CHAPTER I

INTRODUCTION

1.1 Introduction to Project

The measurement method for radiated emission and radiated susceptibility requires a method, which is reliable and reproducible. This is important to ensure the measurements fulfill the electromagnetic compatibility (EMC) standard. The Gigahertz Transverse Electromagnetic Mode (GTEM) cell as a new measurement facility in electromagnetic compatibility need to be evaluated especially its electric field distributions.

It is important to determine the field strength and distribution in a GTEM cell for EMC and calibration measurements. The field strength inside a GTEM Cell is a function of the input power as well as location along the longitudinal axis or septum height. Immunity measurements require field uniformity (+6 dB according to IEC 61000-4-3 standard) over certain test area and calibration can only be carried out if the precise field strength at a particular location is known.

Finite Difference Time Domain (FDTD) is a numerical method that can be used to predict the electric field distribution in a GTEM cell. FDTD is a tool to calculate the electric field in a defined test volume in a GTEM cell. The electric field distribution at certain frequency was calculated using EZ-FDTD software based on FDTD method.

In this report, theoretical study on the field strength and distribution in a GTEM cell is described. It is followed by making measurements of the field. The results from both works will be compared and the differences will be noted and explained. The differences of the theoretical and measurements denotes the sources of field problems and recommended solution will be mentioned.

1.2 Objectives

i) To perform numerical modeling of field strength in GTEM cell using Finite Difference Time Domain, (FDTD).

ii) To conduct measurements of field strength in GTEM cell based on immunity measurement setup.

iii) To analyze, compare, and conclude the results obtained from the modeling and measurements.

1.3 Scopes of Work

i) Measurement and calculation of electric field distribution was done at frequency 100MHz, 200MHz and 400MHz.

ii) Simulation model using three-dimensional FDTD method.

iii) Measurement GTEM facility is GTEM 750 model by Schaffner.

iv) Electric field distribution for an unloaded GTEM cell.

v) Measurement and calculation was done at three different planes where septum height, h was 54cm, 63cm, and 70cm.

1.4 Importance of Project

i) To determine the capability of a GTEM cell as a measurement facility in electromagnetic compatibility.

ii) To provide an input to GTEM manufacturer to improve their GTEM cell.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Electromagnetic Compatibility is the ability of a device or equipment or a system to function satisfactorily in its electromagnetic environment without at the same time introducing intolerable electromagnetic disturbances to any other device or equipment in that environment.

The requirements of electromagnetic compatibility (EMC) test are becoming increasingly important for electrical and electronic products.
There are two types of EMC test.

i. Emission (interference) test, which includes conducted and radiated test.
ii. Susceptibility (immunity) test, which includes conducted and radiated test.

Figure 2.1 shows an EMC structure to give an overview of electromagnetic compatibility.

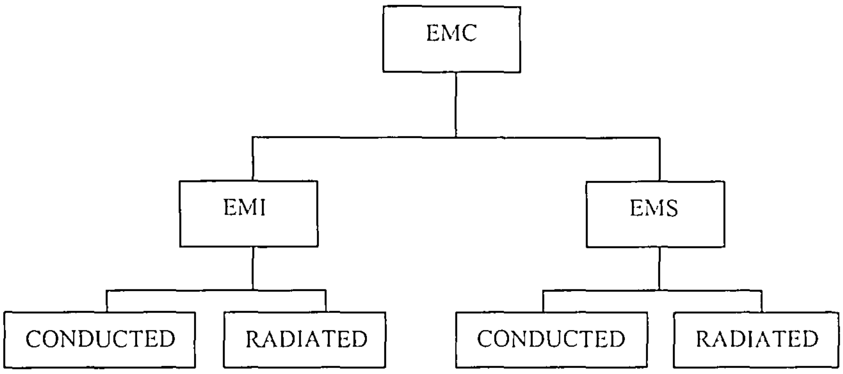

Figure 2.1: EMC Structure

2.2 EMC Measurement Facilities

In last twenty years, extensive research has been performed regarding the improvement of the instrumentation for the electromagnetic compatibility measurements [1]. The susceptibility (immunity) test and emission test require reproducible measuring methods, which are mentioned below.

2.2.1 Open Area Test Site (OATS)

Most regulatory authorities specify open area test sites for the radiated emission testing of domestic and commercial electronic equipment. An open area test site is characterized by a large ground screen and the absence of other conducting surfaces surrounding the equipment under test (EUT). Antennas are used to generate and to measure the fields [2]. The open field site can only be used for emission testing. The testing for immunity testing would require the radiation of substantial amounts of radio frequency energy into the environment with inevitable interference to other services. The lack of isolation from ambient noise highlights its disadvantages. The major advantage of OATS is its perceived accuracy and its repeatability when compared with semi-anechoic chamber.

2.2.2 Anechoic Room

Anechoic rooms have been used for electromagnetic compatibility measurement in an electromagnetic isolated environment according to international standards. Electromagnetic fields are established and measured by means of antennas. All surfaces of full anechoic rooms are covered with RF absorbers to simulate free space environment. For semi-anechoic chamber all the surface are constructed with RF pyramidal absorbers except for ground surface.
Anechoic chamber are less effective at lower frequencies. Particular care shall be taken to ensure the uniformity of the generated field at lower frequencies.

2.2.3 TEM Cell

Transverse Electromagnetic Mode (TEM cell) was described by M.L. Crawford in 1974 [2]. It is an expanded planar transmission line operated in the TEM mode to simulate a free space plane wave for susceptibility testing. The empty TEM cell should be matched to the load and generator impedances by means of appropriate tapered transitions to avoid standing wave in longitudinal direction.
The frequency range of TEM cell is restricted by its vertical dimensions. At frequencies equal to or higher than the frequency at which the height, h equals $\lambda/2$, higher order modes can occur which give rise to reflections and therefore yields non-uniform field distributions. Therefore the frequency range of a TEM cell with h = 0.75m is restricted to frequencies up to 200MHz. Figure 2.2 shows a typical TEM cell.

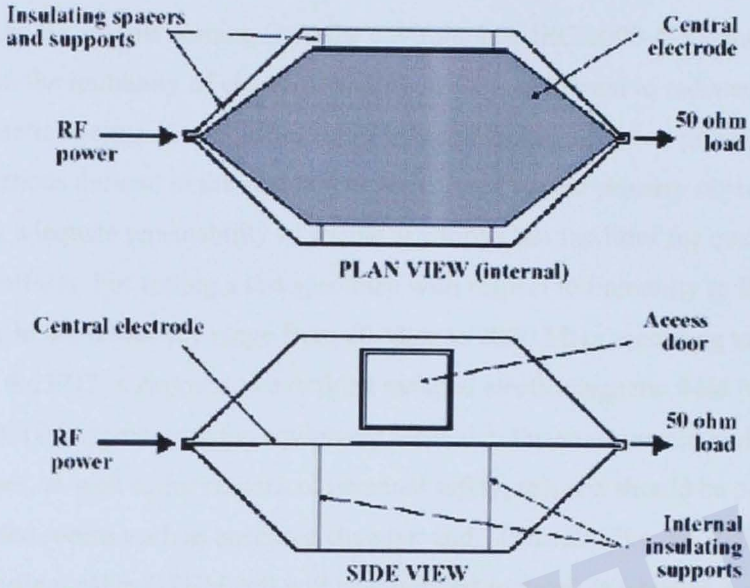

Figure 2.2 : Typical TEM cell. [2]

2.2.4 GTEM Cell

GTEM cell is a pyramidal tapered coaxial line from a coaxial feeding point, having an air dielectric and characteristic impedance of Z = 50 Ω. The GTEM cell which is the hybrid of TEM cell and anechoic chamber can be used for both radiated susceptibility and emission and is well suited for time domain as well as continuous wave, CW. The chamber has very high broadband characteristics, with a usable frequency range from DC to several GHz [3]. Further discussion will be discussed in detail in the next topic.

2.3 Radiated Immunity Overview

The radiated immunity in EMC is a measure of how immune or susceptible a product to the RF signals coming from the environment. IEC 1000-4-3 standard is applicable to the immunity of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures. The test methods defined in the standard are structured for the primary objective of establishing adequate repeatability of results at various test facilities for qualitative analysis of effects. For testing a test specimen with respect to immunity to RF interference in the frequency range from 80 MHz to 2000 MHz according to IEC 61000-4-3, the EUT is exposed to a defined radiated electromagnetic field [4]. In order to avoid interference on the equipment located in the environment and on the radio services, as well as for reasons of personal safety, this test should be performed in RF shielded rooms such as anechoic chamber and TEM cell. The radiated immunity system using GTEM cell will be described in detail in Chapter 3.

2.4 GTEM Cell Concept

D. Hansen and D. Konigstein introduced the GTEM cell in 1987 and they got patent on their GTEM design [2]. GTEM overcame many limitations of previous TEM cell. The GTEM cell is an extension of 50Ω coaxial transmission lines, which is flared to create a useable test volume between the inner and outer conductors with predictable, repeatable characteristics. The GTEM is terminated with a broadband load, which matches the impedance of the source across the useable frequency range of the cell. It has two terminating loads, one for lower frequencies and another for higher frequencies. The lower frequency one is current load connected directly to the end of septum plate to the cell wall, and for higher frequencies distributed wave termination in the form of RF Absorbing material (RAM) [5]. Figure 2.3 illustrates the GTEM cell structures.

REFERENCES

1. Malaric, K., Bartolic, J., and Modlic, B. (2001). "Instrumentation for Electromagnetic Compatibility Measurements." *Measurement Science Review*. 1. 5-8.

2. Icheln, Clemens. (1995). "The Construction and Application of a GTEM Cell." Helsinki University of Technology: Master's Thesis.

3. Garbe, H., and Hansen, D. (1990). "The GTEM cell concept; applications of this new EMC test environment to radiated emission and susceptibility measurements." *Seventh International Conference on Electromagnetic Compatibility*. 152 –156.

4. International Electrotechnical Commission IEC. (1998). "Electromagnetic Compatibility (EMC) Part 4: Testing and Measurement Techniques – Section 3: Radiated, Radio Frequency Electromagnetic Field Immunity Test." Geneva, Switzerland: IEC 61000-4-3.

5. Pande, D.C. and Bhatt, P.K. (1997). "Characterization of a gigahertz transverse electromagnetic cell (GTEM cell)." *Proceedings of the International Conference on Electromagnetic Interference and Compatibility*. 31-38.

6. Ghosh, S., Singhley, R., Shastry, S.V.K. and Chakrabarty, A. (1999). "Design and Characterisation of GTEM cell." *Proceedings of the International Conference on Electromagnetic Interference and Compatibility*. 274-279.

7. Malaric, K., Bartolic, J., and Modlic, B. (2000). "Absorber and resistor contribution in the GTEM-cell." *IEEE International Symposium on Electromagnetic Compatibility*. **2**. 891-896.

8. Sadiku, Matthew N.O. (2001). "Numerical Techniques in Electromagnetics." 2nd. ed. New York: CRC Press. 177-184.

9. Taflove, A. and Hagness, S.C. (2000). "Computational Electrodynamics: The Finite Difference Time-Domain Method." 2nd. ed. Boston: Artech House, Inc. 160,285.

10. Sullivan D.M. (2000). "Electromagnetic Simulation Using the FDTD Method." New York: IEEE Press. 8, 52.

11. Radasky, W.A., Smith, K.S., Hansen, D., and Ristau, D. (1996). "Calculations and measurements of fast EM pulses in the GTEM cell." *IEEE International Symposium on Electromagnetic Compatibility*. 52-57.

12. Harrington, T.E., Zhong Chen, and Foegelle, M.D. (1999). "GTEM radiated emissions correlation testing and FDTD modeling." *IEEE International Symposium on Electromagnetic Compatibility*. **2**. 770-775.

13. Malaric, K., Sarolic, A., Roje, V., Bartolic, J., and Modlic, B. (2001). "Measured distribution of electric field in GTEM-cell." *IEEE International Symposium on Electromagnetic Compatibility*. **1**. 139-141.

14. Ishigami, S., Harima, K., and Yamanaka, Y. (2001). "Estimation of E-field distribution in a loaded GTEM cell." *IEEE International Symposium on Electromagnetic Compatibility*. 1. 129 -134.

15. EMS Plus (2002). "EZ-EMC and EZ-FDTD Tutorial 1." http://www.ems-plus.com/ezfdtd.html.

16. Schaffner (1995). "Manual: Specification and Operating Instructions for MEB GTEM Cells." Switzerland: Schaffner EMC Systems. 4.

17. Taflove, A. (1998). "Advances in Computational Electrodynamics: The Finite Difference Time-Domain Method." 2nd. ed. Norwood: Artech House, Inc. 3.

18. Harrington, T.E. (1997). "GTEM Fields FDTD Modeling." *IEEE International Symposium on Electromagnetic Compatibility*. 614-619.

19. De Leo, R., Rozzi, T., Svara, C., and Zappelli, L. (1991). "Rigorous analysis of the GTEM cell." *IEEE Transactions on Microwave Theory and Techniques*. **39**. 488-500.

20. Hansen, D., Ristau, D., Radasky, W.A., and Smith, K.S. (1996). "Sources of problems in the GTEM field structure and recommended solutions." *IEEE International Symposium on Electromagnetic Compatibility*. **1**. 48-51.