History and Development of GTEM Cells

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INTRODUCTION

This article reviews the history, development and state of current research on GTEM cells, covering the period from 1984 to 1993. Modifications to the old GTEM cell are discussed. Fundamental, theoretical and experimental research efforts for practical, cost-effective EMI investigations are also addressed. In spite of the latest research in Europe, the U.S. and the Far East, there are still unresolved problems which prevent a full understanding of all parameters that might improve the field quality for immunity testing and emissions modeling.

BASIC DESIGN OF THE GTEM CELL

The GTEM cell is a radiated field measurement device which has a single input/output port (50 Ω) for immunity and emission purposes, including OATS correlation. The asymmetrical septum is designed to match the impedance of the flared/tapered, rectangular waveguide cross section. The inner conductor is terminated into a hybrid broadband load. For frequencies up to about 40 to 90 MHz, distributed resistors are used. Above this range, pyramidal foam absorbers are used. The overall field fidelity is presently better than ± 3 dB from 30 to 1000 MHz in the test area behind the large access door. The DUT fills 33% of the distance between the septum and ground or the vertical side wall; this rule of thumb was adopted based on earlier TEM cell research. Classic TEM cells [1] yield better than ± 1 dB, but are severely limited by frequency and size. Figures 1 through 4 show the GTEM cell cross section, the conventional TEM cell cross section and a three-dimensional view of the GTEM cell.

The GTEM concept is based on the classical TEM cell and anechoic chamber technology.

HISTORY OF THE GTEM CELL

The GTEM cell was developed during the period 1984 to 1991, mainly by a group of German and U.S. researchers working for a large multinational electrical power-oriented company based in Switzerland. By 1991, two GTEM patents were granted to and numerous scientific articles[2,3] were published by this internationally recognized team.

Table 1 outlines important milestones in the GTEM development. The first patent[4] defined the shape of the cell and detailed a lumped hybrid load of three single-power resistors. All calculations were done only electrostatically, assuming TEM-only wave propagations. The lumped load (Figure 3) resulted in some higher order modes. The measurement technique at that time was practically limited to time-domain reflectometry to trim the absorber load section (minimum deviation from 50 Ω) and small ground-based field sensors (E and H) to probe the field quality in the ceiling and bottom sections at various locations of the constructed GTEM cells between 1500 and 500 mm ground-to-septum height.

After almost endless, mainly experimental approaches, a second patent[5] described the fa-

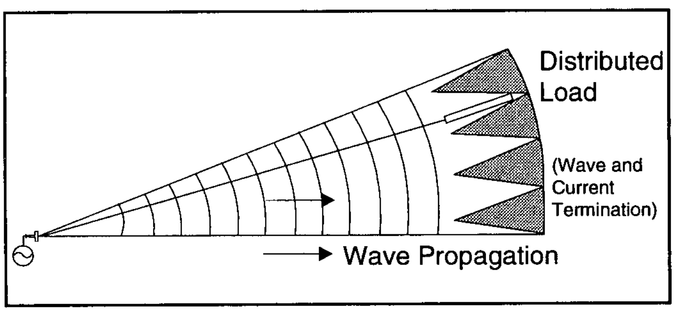

Figure 1. Cross Section of the Old GTEM Cell.

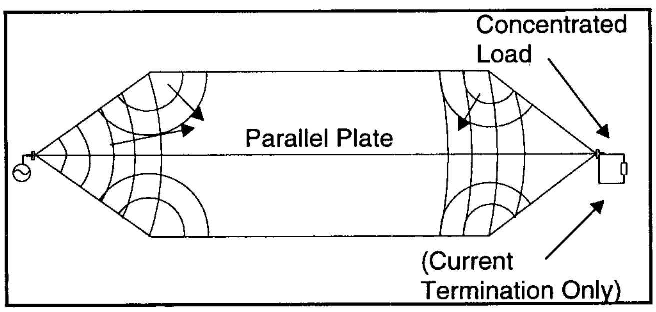

Figure 2. Cross Section of the Classical TEM Cell.

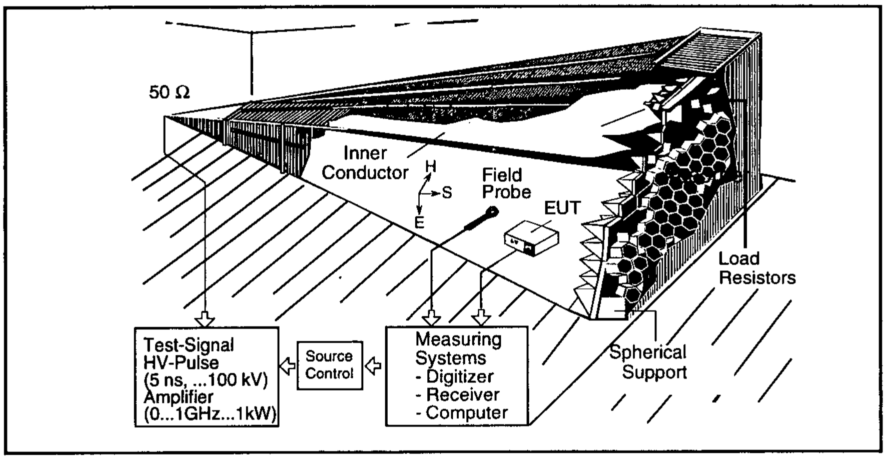

***Figure 3**. Three-dimensional View of a Big GTEM Cell with Lumped Load.*

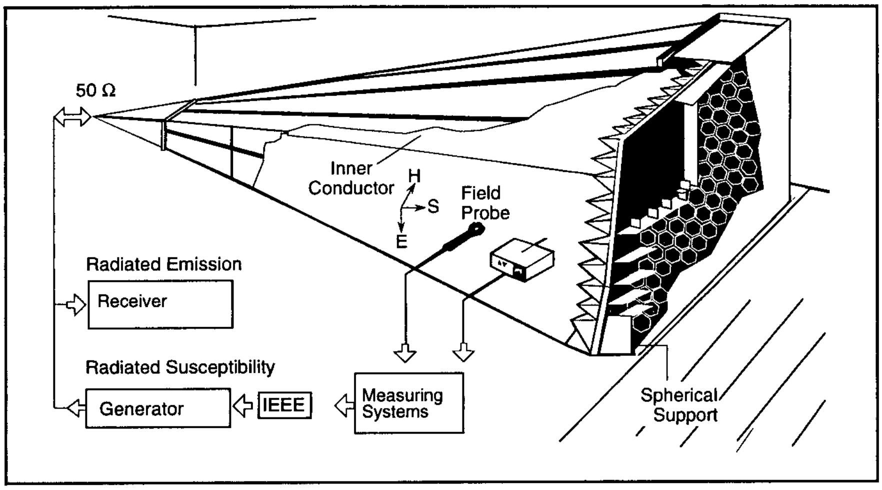

***Figure 4**. Three-dimensional View of a Big GTEM Cell with Distributed Load.*

YEAR	EVENT	UNSOLVED PROBLEM
1984 to 1986 Models Built: GTEM 1500 GTEM 1100 GTEM 750 GTEM 500	Hansen, Konigstein, and Giri research, design and build GTEM as NEMP simulator (100 kV)	1. Patent (1986) terminates septum into 3 lumped resistors, still causing higher order modes [4-7]
1986 to 1988 GTEM 1500 optimization 1987 exhibit of first semicommercial GTEM 500 at EMC Zurich Symposium.	Wilson joins BBC, successful first emission-OATS correlation for EMC applications and 1 kW CW immunity tests (1MHz-1 GHz) First prototype GTEM 1500 built for German NBS (PTB), weight 3500 kg	2. Patent (1988) uses distributed resistor load chains, trying to match spatial currents and local absorber impedance distribution .[8-9] In some modes, theoretical simulation models still too simple
1988 to 1991 GTEM 1500-Apollo built to optimize licensed production	Standardization efforts in VG, IEC and FCC. License production starts in U.S.A., UK, Germany and Japan	Competing ferrite technology in absorber chambers with good emission (±3 dB) correlation. GTEM still needs statistics, EUT rotation, many problems 1-18 GHz

***Table 1**. GTEM Development 1984 to 1991.*

vored design for what became a distributed resistor load (Figure 4). The introduction of about 20 to 30 single, isolated, 60-cm long resistor strings matching the absorber length and the dielectric constants of the foam pyramids resulted in much better field quality. In order to compensate for the capacitive absorber mismatch, a resistor profile was introduced. This profile expands in both longitudinal and lateral directions. The longitudinal profile has to account for the volumetric, dielectric effects of the absorber, while the lateral distribution is governed by the increase (by almost one order of magnitude) in RF currents at the edges of the septum.

The fundamental idea was derived from the simple transmission line equation, including losses. The characteristic input impedance Z of the GTEM cell is then given by the following equation:

$$Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \leq 50\ \Omega$$

One would obviously expect to compensate a capacitive mismatch with a corresponding inductor. However, this turned out to be impracticable on the resistor printed circuit boards (E_r = 4) due to uncontrolled crosstalk between the resistor strings and the appearance of certain radiating antenna effects in the absorber gap around the septum.

RECENT DEVELOPMENTS

From 1991 through 1994, a number of advances and modifications were achieved by researchers in Italy,[10,11] the U.S.,[12,13] Holland,[14] Germany,[15] Poland,[16] Switzerland,[17,18] Russia and China. A summary of important developments is given in Table 2. As research continues, almost 150 cells are in commercial use worldwide and this relatively

EVENT	UNSOLVED PROBLEM
Theory, simulation, EUT interaction	De Leo tried to use finite elements to predict modes; termination unrealistic
Modified concepts	WTEM, TrigaTEM and Triple TEM have not sufficiently proved clean fields
Design of gigantic GTEM cell 3500	Experimental data not available yet, too expensive vs. new ferrite absorber chambers (e.g. TDK)
Manipulator design	RCS, automation, EUT multi-rotations
Termination improvements	VSWR, radiation
Emission model improvements	<30 MHz, >1 GHz Too many assumptions and unknowns
Accuracy vs. TEM	Predictability
Baby cells	IC testing concepts
Standards	Slow acceptance
Field sensor development	x, y, z isotropy very bad, particularly above 1 GHz

Table 2. *Recent GTEM Developments.*

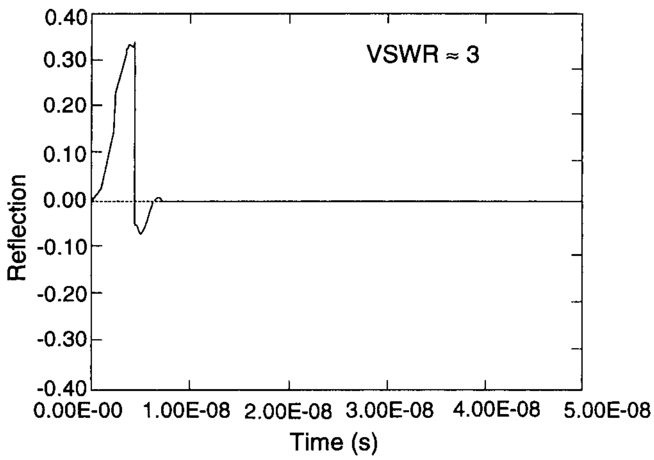

Figure 5. *GTEM 1500 Terminator Mismatch.*

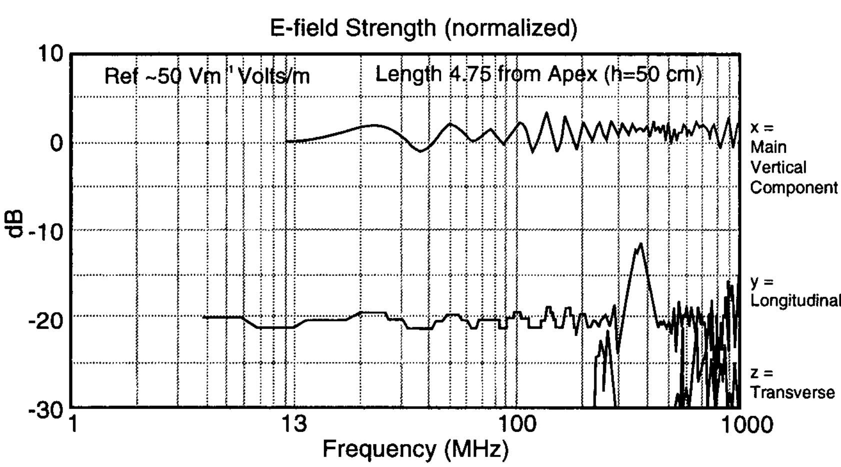

Figure 6. *Multimodeling Situation in GTEM 1500.*

new technology is slowly beginning to be included in EMC standards.

Advantages of a newly developed GTEM cell (16-m long) are the possible verification and potential expansion of the general GTEM concept, and the opportunity to answer questions posed on its fundamental functionality. But in terms of economics, this might soon turn out to be a white elephant. For example, using the old emission algorithm by adding near-field terms is scientifically interesting, but existing CISPR methods are more economical and faster.

FUTURE RESEARCH – REDUCING LIMITING FACTORS

Generally speaking, one could confidently state that modeling techniques and results are still very vague. The field mapping up to 18 GHz reveals serious unanswered questions about possible applications. The lack of good field probes presents limitations. An expansion up to 40 GHz (MIL-STD-461/462D) and a perfect low frequency correlation to 1-m test results, including frequencies much less than 30 MHz, seem to be very challenging goals. Also, the price for a GTEM must be reduced so it is competitive with a new small, fully anechoic ferrite room which sells for about \$200,000 without instrumentation. Unresolved problems and issues are outlined in Table 3. Nevertheless, the GTEM concept, a hybrid of the classical TEM cell and absorber-loaded anechoic chamber, is now used by various organizations.

One area which can be improved upon relates to GTEM cells with imperfect terminations (VSWR ≈ 3) and the corresponding perturbation caused in the three orthogonal electrical field components. Figure 5 shows a considerable mismatch of the GTEM termination in the

ORGANIZATION	REQUIREMENTS, APPLICATIONS	PRACTICAL ISSUES, PROBLEMS
R&D	Field sensor calibration, field quality in time and frequency domain	DC to 1(18) GHz, GTEM field quality less than TEM, lack of good sensor instruments (x, y, z sensitive). GTEM foam absorbers difficult to model with MOM and finite element codes
EMC Test Labs	Recognition by standards	New work proposal in IEC 77B (Switzerland), 9/93 started, immunity OK; further emission work needed
Production	Throughput, automation	Starting in large companies, cable manipulation, design
Military	"DC" to 40 GHz (dc to daylight?!)	Near-field problems, many rotation positions for EUT, correlation to MIL-STD-461/462D
Civil	Fast and accurate testing	Physically meaningful correlation to some non-optimal old EMC test procedures, emissions, EUT cell interactions, EUT size limitations, price
Summarizing	EM simulation	Improving termination area

Table 3. *Issues Confronting GTEM Cell Users.*

time domain. The corresponding mode generation in the test volume of the GTEM field quality degradation (x, y, z) is presented in Figure 6. It is important to note that a perturbation could exist in any part of the cell, based on the localized ability to support that particular mode. If modes are generated, then these modes will propagate. Based on reciprocity, this should also be true for emissions.

Susceptibility data is interesting, because it might reveal the key to future, extremely clean fields. The important lesson to be learned from this is that, in principle, modes can be generated in GTEM cells. They will then propagate, but only if there is either a considerable mismatch in the termination or an equivalent effect caused by an EUT, and largely exceeding the recommended 1/3 occupation rule for the distance between septum and ground.

CONCLUSIONS

The existing GTEM technology represents a major contribution toward improving EMC measurements. Like OATs and absorber chambers, it is an important test facility. Serious practitioners should, however, admit that there is still room for many new ideas and improvements in the coming years.

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