Design and Fabrication of a Large GTEM Cell for Electromagnetic Compatibility Testing

Blas Vega
Paraguay Space Agency
Asunción, Paraguay

Alejandro Reckziegel, Manuel Aquino, Luis Bernal, Primo Cano, Diego H. Stalder
Engineering Faculty
Asunción National University
San Lorenzo, Paraguay

Juan Carlos Cabral, Hyun Ho Shin
Polytechnic Faculty
Asunción National University
Asunción, Paraguay
Corresponding Authors: bvega@aep.gov.py and dstalder@ing.una.py

Abstract

One mandatory requirement for validating new electronic devices and machines is electromagnetic compatibility (EMC) tests because any new design can emit or receive unwanted electrical interference, affecting the operation of other systems or devices in their environment. This requirement becomes critical in the case of real-time control systems, electromedical devices, and outer space operations. The Gigahertz Transverse Electromagnetic Cell (GTEM) is a tool for performing preliminary electromagnetic compatibility tests on new products. It generates a standardized and uniform electromagnetic field in a shielded environment, integrating pyramidal electromagnetic absorbers with large bandwidth. Compared to other environments, such as an anechoic chamber, its reduced dimensions and cost make it a suitable test laboratory environment for EMC measurements. This article describes the steps to design and build a Radio frequency isolated chamber (GTEM) with dimensions 4 m long, 2.2 m wide, and 1.5 m high. A literature review of the recommendations is summarized. The design of the mechanical parts and construction techniques are described to generate a construction guide for future interested parties. Its critical dimension was analyzed with simulations using finite elements method to match the characteristic impedance of the exciter impedance and guarantee to minimize reflections.

Keywords
Gigahertz Transverse Electromagnetic Mode Cell (GTEM), Electromagnetic Compatibility (EMC), Radio Frequency (RF) absorbers, Return loss S11, Impedance Matching.

1. Introduction
A GTEM cell is a chamber that acts like a coaxial transmission line whose dimensions gradually increases until it ends in a flat base. It has a pyramidal form, more like a wedge from a sphere with a solid angle. This is to generate a flat and uniform electromagnetic field wave inside the cell in order to perform electromagnetic compatibility and immunity tests. GTEM cells are reciprocal devices that can detect or receive from a source or establish an EM field for testing. This cell contains the EM field inside the transmission line and avoids the radiated energy into the surrounding space that may interfere with other equipment.

Instead of a circular, centered copper conductor, it has a rectangular section and a flat wide conductor with tapered ends with a series of matching loads in parallel resistors to get a characteristic impedance of 50 Ω. To absorb the high-frequency electromagnetic field, 700 mm height polyurethane foam pyramidal microwave absorbers are used to match the impedance of the source.

The first mention of an electromagnetic compatibility cell (TEM cell) was given in 1974 (Crawford 1974) which had a closed chamber with two ends with a centered flat conductor. Since then, the shape, dimensions, openings, etc. have been optimized for better broadband efficiency (Bozzetti et. al. 2007). In 1987, a frequency extended cell above 1 GHz was introduced (GTEM cell) (Konigstein and Hansen 1987) that overcomes the limitations of older designs. Based on a TEM-cell anechoic-chamber hybrid concept, an expanded transmission line terminated with a broadband hybrid load. Due to this, it can be used for radiation susceptibility and radiation emission from dc up to 1 GHz or higher.

A susceptibility test examines the effects of unwanted electromagnetic waves on the equipment under test (EUT). On the other hand, an emission test examines the unwanted EM field of the EUT, like the levels of the emissions in different angles of the EUT as suggested in standards such as IEC or CISPR.

1.1 History and Motivation

There is enough documentation and bibliography regarding the mathematical analysis for the design. In (Clemens 1995) and (Ghosh et. al. 1999), the authors study the theory, design, and construction of a GTEM cell. In (Clemens and Weiland 2001) shows the Finite Integration Technique (FIT) as a discretization method for computing numerical simulations in this field. In (Pasakawee and Sittakul 2017) shows the use of ferrite tiles with foam to enhance absorption above 100MHz. In (Budania et al. 2020) shows an interesting comparison between the reflection parameters in the transition from the N-Type connector and the septum, similar to what is shown in (Junru et. al. 2011). Kotwal et. al. (2019) shows a simulation work using Finite Difference Time Domain (FDTD) with the help of proprietary software. Stander and Sanditia (2013) list a handful of methods to effectively stimulate this cell and illustrate how critical components are mounted on the cell, but as the authors said, there are a few articles that deal with the same degree of detail in the construction of the cell.

As there are many practical challenges in the construction of a large GTEM cell (Sahraei and Aliakbarian 2020), one of them being the budget, this paper shows a simulation and the implementation of some low-cost methods, such as welding, cutting, and assembly in general, and then indicates the preliminary results obtained from this configuration. Also indicates some possible solutions and modifications that will be carried out in the future to obtain better results in terms of the cell's reflection coefficient and insulation.

1.2 Objectives

The aim of this work is to present more information about the design and focus on the construction of a GTEM cell which allows testing the EMC properties of relatively small equipment such as small satellites subsystems, and small health monitors, according to the international standards of EMC measurements.

At universities and institutions from developing countries focused on R&D, there may be a need to produce commercial electronics like medical devices, broadcast and transceivers devices, (Boriraksantikul et. al. 2009), (Heuvelman et. al. 2012), (Iftode and Miclaus 2012), (Moraitis et. al. 2014), (Morales et. al. 2022). The Paraguay Space Agency seeks to develop electronic telecommunications devices for satellite subsystems. As these devices will be used in nanosatellites, they should comply with international standards, e.g., MIL-STD 461F. Other equipment may be subjected to compliance with IEC, CISPR, etc.
The cell designed and built in this work will be used for the research and development of many electronic devices, for the University and the Paraguay Space Agency. Thshowre the dimensions should be big enough to accommodate structures of the cubesat standard and test a large variety of equipment but small enough to fit inside our laboratory.

2. Design and Fabrication

2.1. Requirements of the GTEM

The experiments that will be carried out and the equipment to be developed are not that large. In some cases, it is expected to test electronic boards, so the dimensions of the chamber should allow the testing of equipment of approximately 200x300x600 mm. Also allow the use of accessories, wiring and the possibility of maneuvering inside the cell.

Another important requirement is the easy building processes. Researchers and students from the engineering faculty are in charge of the cell assembly process. That's the reason why there should be no complex parts in order to keep the budget low and not to need highly specialized personnel to build the cell.

Most of the materials used for construction are commercially available in the country, but not the activated carbon foam and graphite plates suggested in (Pasakawee and Sittakul 2017). Due to this, the design needs to keep free space between the absorber foam and the flat base, so in the future, the graphite plates can be installed behind the absorbent foam.

2.2. Design

In this section the main elements and dimensions of the GTEM are introduced. Figure 1 shows the main structure, the septum (in red), and the pyramidal absorbers with their real dimensions, the base of 50x50 cm and height of 70cm. To accommodate the desired EUT dimensions and according to suggestions in (Icheln 1995), the main structure has dimensions of 4 m long, 2.2 m wide, and 1.5 m high which is comparable with commercial e.g. GTEM750.

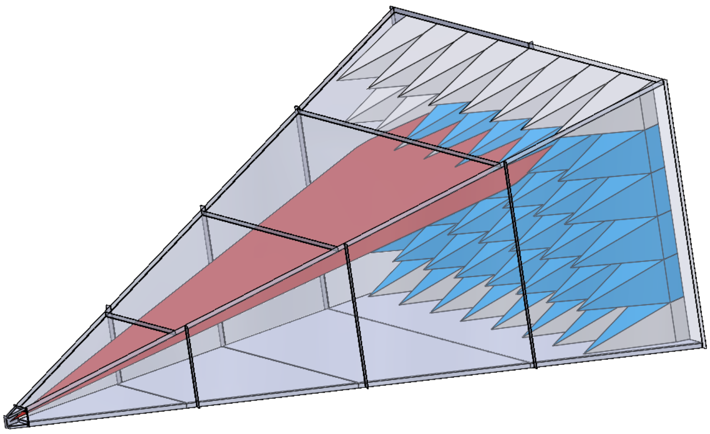
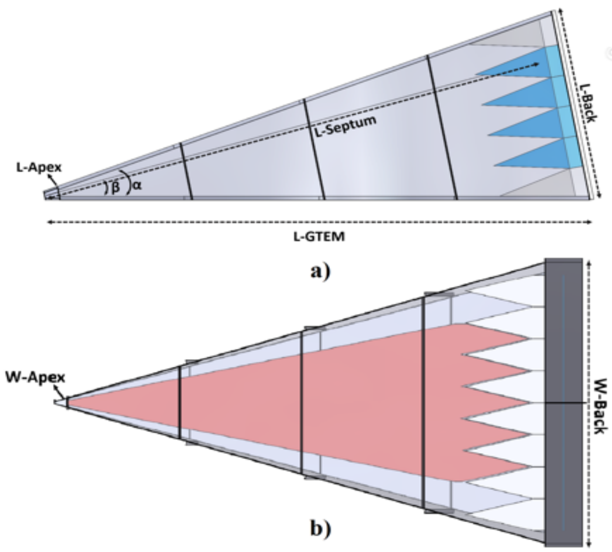


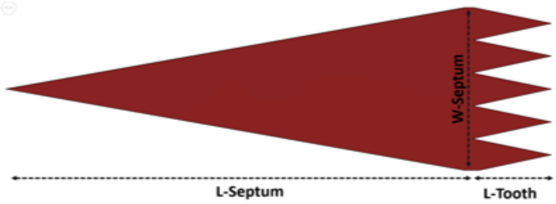
Figure 1. Isometric View of the GTEM, the septum, and the pyramid absorbers.

Figure 2 shows the lateral and top views of the GTEM where the angle **β** and **ω** are the most important structural parameters obtained from the literature and verified with our simulations. The structure also has a door of 78x 78cm. The parameters of α and β are 21,22° and 16,5° respectively.



a)

b)



c)

Parameters	cm
L-Apex	9
W-Apex	9
L-GTEM	407
L-Back	155
W-Back	225
L-Septum	522
W-Septum	124
L-Tooth	55

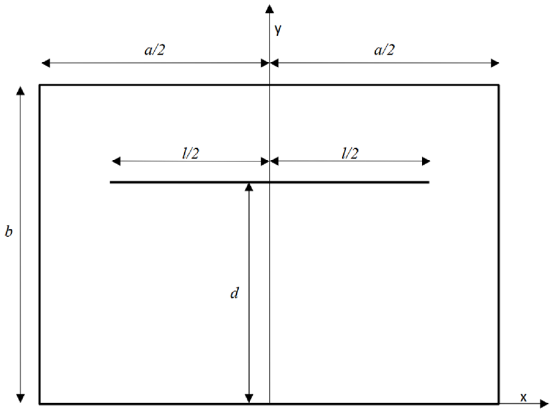
d)

Figure 2. View of the design and its main dimensions

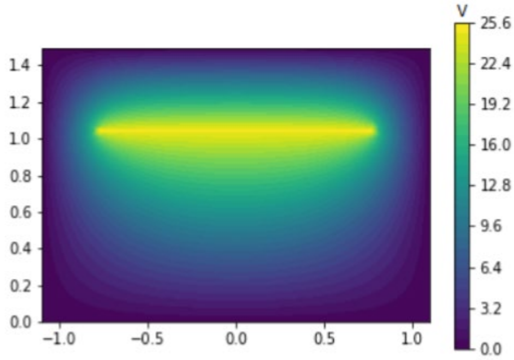
2.3. Numerical Simulation

In this section, the computation of the characteristic impedance of the constructed GTEM cell is presented using the simulation obtained from FEniCSx software. FEniCSx is an open-source platform for solving partial differential equations based on finite element method (Logg et al., 2012).

The Poisson equation for the electric potential field $\Phi(x, y)$, expressed as $\nabla^2\Phi = 0$ in a computational domain corresponding to a two-dimensional cross-section of the constructed GTEM cell (Figure 3(a)), is solved using FEniCSx. The dimensions shown in the Figure are a = 2.19 m, b = 1.49 m, l = 1.53 m, and d = 1.04 m. Homogeneous conditions $\Phi|_b = 0$ in the boundary of the domain, and a constant value of $\Phi|_c = 25$ V on the centerline conductor, are imposed. The computational domain is discretized into meshes with triangular elements, and the weak form of the Poisson equation is represented by second-order interpolation polynomials as basis and weighting functions. The resulting linear system is solved using UMFPACK (Logg et al., 2012). Grid-independence tests were performed, and Figure 3(b) shows the color-map of the potential field obtained from the simulation.



(a)



(b)

Figure 3: (a) Computational domain of a two-dimensional cross-section of the constructed GTEM cell; (b) color-map of the potential field obtained from the simulation.

From the potential field obtained from the simulation in FEniCSx, the electric field $\vec{E}$ is computed by $\nabla\Phi = \vec{E}$. Then, the transverse magnetic field is calculated using the following expression:

$$\vec{H} = \frac{1}{\sqrt{Z_{TEM}}}\hat{k} \times \vec{E},$$

where $Z_{TEM} = 377\ \Omega$ is the impedance of free space, and the unit-vector $\hat{k}$ points to the direction of z (orthogonal to the xy-plane). Finally, the characteristic impedance is computed by applying the Ohm's Law as follows:

$$Z_0 = \frac{V^2}{P_{max}},$$

where $V = 25$ V is the centerline potential, P_{max} is the maximum power that flows through the GTEM, and it is calculated by the flux of Poynting vector $\vec{S}$ across the 2d computational domain: $P_{max} = \int_{\Omega} \vec{S} \cdot \hat{k}\, dS$; the Poynting vector is defined as: $\vec{S} = \vec{E} \times \vec{H}$. The value of the characteristic impedance obtained was $Z_0 = 50\ \Omega$.

2.4. Mechanical Assembly

The construction began by acquiring galvanized steel plates for the exterior structure to isolate RF noise and aluminum plates 5052-H34, both 2mm thick and 10 mm plywood for septum support. This thickness was chosen so that the exterior structure can support its weight with sufficient rigidity.

The cuts of the galvanized steel plates were made by laser for their practicality, accuracy, and speed, using the CAD model, Figure 4 (a). The cut of the aluminum plate, being larger, was done manually. As seen in other investigations, aluminum rivets were used to assemble the steel plates.

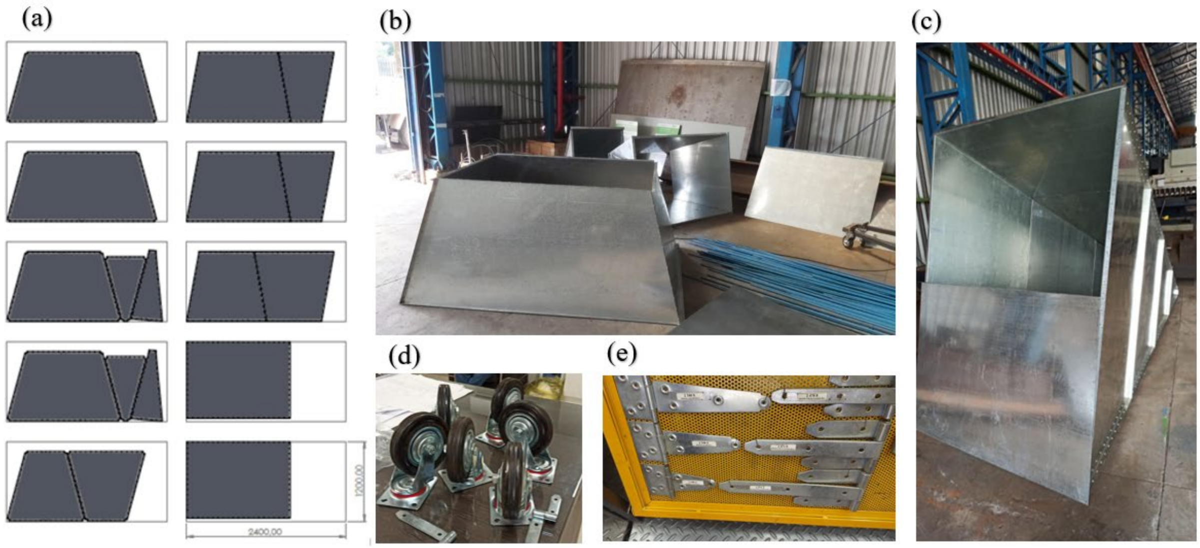


Figure 4. Structure fabrication process.

For the base that supports the entire structure, 50 mm of 2 mm thickness square pipes were used, welded in a triangular shape with six wheels that hold 150 kg. each see Figure 4 (b).

Figure 5 (a-f) presents the apex, which was tig welded but secured to the chamber with rivets as well. To support the weight of the septum, which is an integral aluminum plate, plywood was used to provide greater rigidity. Both plates are glued together to prevent slippage Figure 6 (a-f). This plate is supported by wood placed vertically and glued to the metal structure with silicone glue.

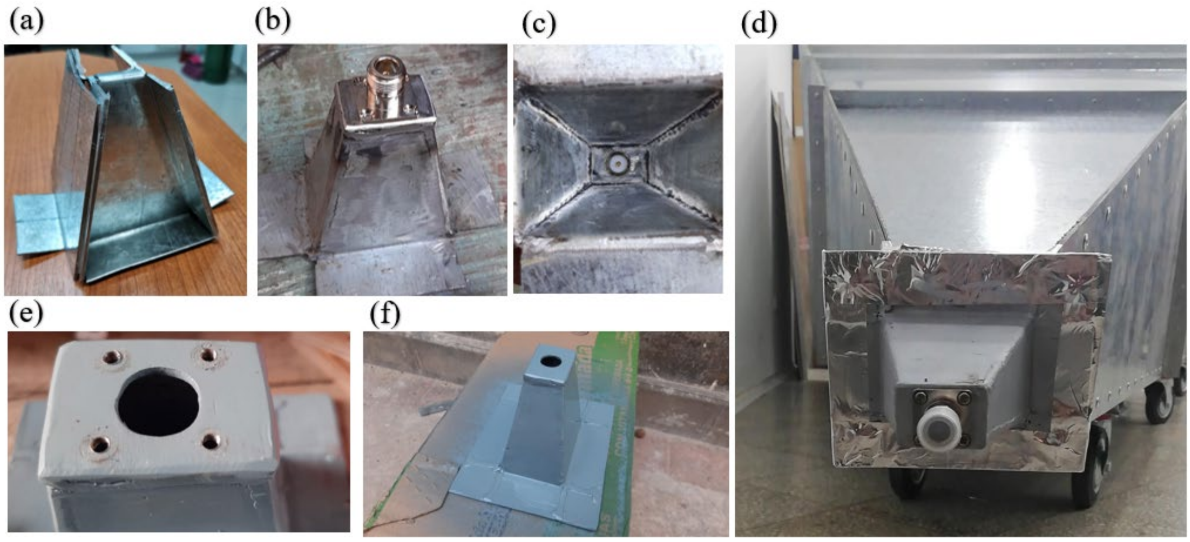


Figure 5. The Apex fabrication and assembly.

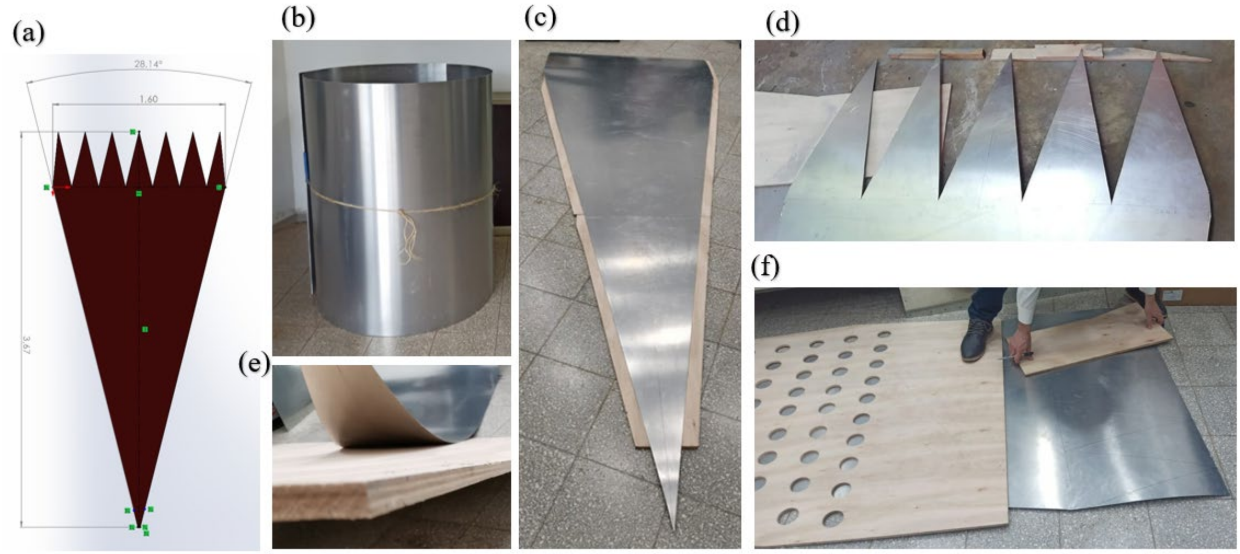


Figure 6. The septum fabrication and its problems

The N-type connector to the septum was made by soldering a copper wire to the aluminum and the copper wire to the connector (see Figure 7). As this connector must be secured to the apex, the connector is welded to the septum. To this, the apex was first riveted to the structure, leaving a large part of the septum retracted, allowing the connector to be welded to the septum plate. Once the welds have been made, the septum was positioned by moving it forward a few centimeters until the connector is aligned with the apex as well.

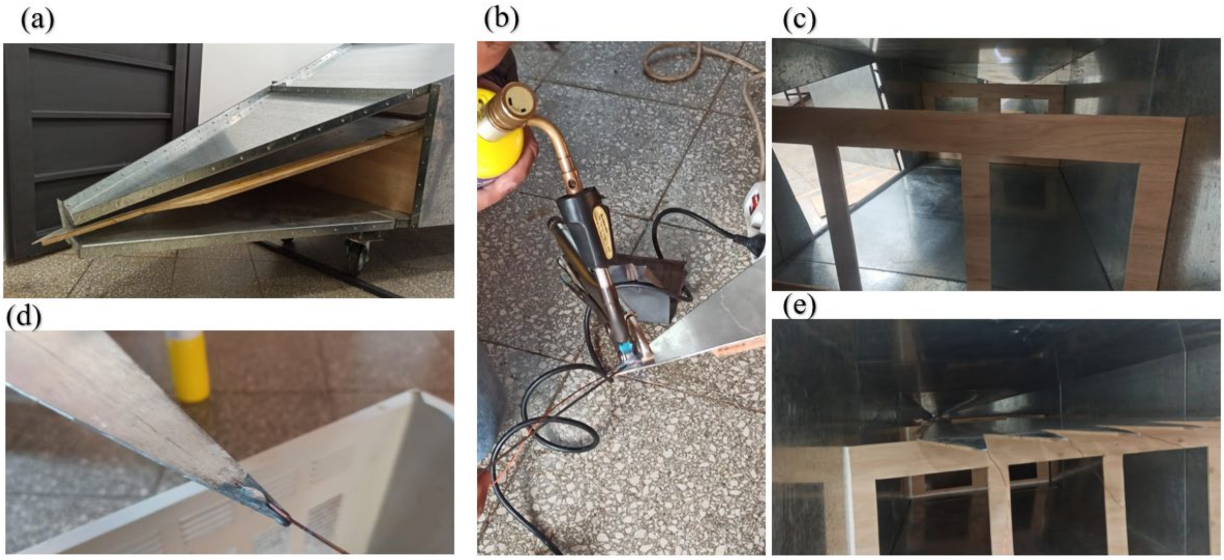


Figure 7. The septum assembly

To absorb high-frequency waves, it is necessary to use electromagnetic absorbers to cover the GTEM cell's back wall to prevent the reflection of waves from the back wall of the cell. Usually, in a GTEM cell, pyramidal or hybrid absorbers are used to prevent the reflection of waves in the frequency band. In this work, we have EMCPioneer SA-700 pyramidal RF absorbers with dimensions of 50x50x70cm. Figure 8 (a-d) shows the RF absorbers mounting process.

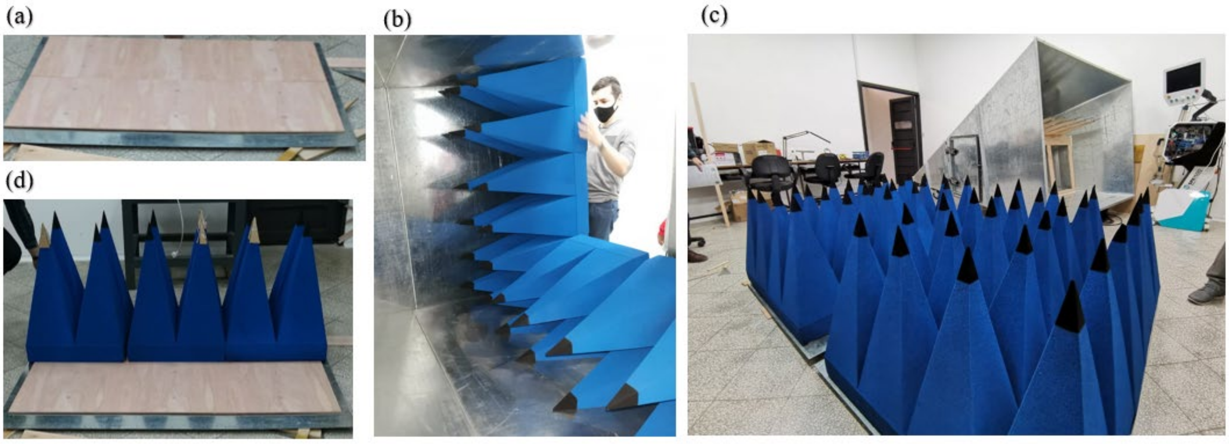


Figure 8. Final assembly with RF absorbent.

3. Results and Experimental Measurements

The GTEM's DC termination, as well as the performance of the mounted absorber, are tested with the use of a Vector Network Analyzer (NanoVNA). Figure 9 presents the measured **Voltage Standing Wave Ratio** (VSWR) and S11 the return loss from 50Mhz to 900Mhz, respectively. The VSWR and S11 are almost flat along the tested spectrum, which is a good characteristic. However, the VSWR values are higher than 2 and the S11 is larger than -10dB, which indicates that the impedance matching, and the shielding of the door can be improved.

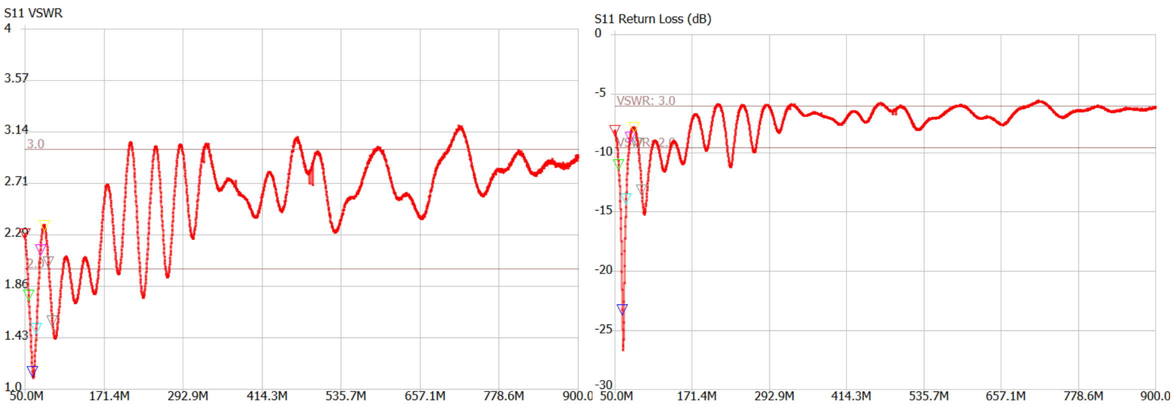


Figure 9. The Voltage Standing Wave Ratio and The Return Loss

Remains to be done the verification of its field uniformity which is the most important factor in a GTEM cell. For this test, the GTEM cell should be excited with a Vector Signal Generator, and the Electric field is measured with a probe set inside the GTEM.

4. Conclusion

In this paper, we describe the design and fabrication of a GTEM cell for EMC testing small EUT. The design and fabrication pose several multi-disciplinary engineering challenges. In order to simplify the full-wave simulation of the cell, a 2d simulation with open-source finite element software has been presented to match the impedance of 50 Ohms. All the fabrications process and assumptions were detailed and described to share the knowledge with other researchers from developing countries who are developing new products. Preliminary measurements indicate the fabricated GTEM presents good characteristics for the EMC test of small size (230x300x700 mm) according to (Icheln 1995) criteria. However, a detailed characterization remains to be reported in future works.

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Biographies

Blas Vega, 1989, graduated in Electronics Engineering in 2017, from the Polytechnic Faculty (FP-UNA) of the National University of Asunción, Paraguay. He worked in industrial instrumentation and in 2017 he started a master's degree in Satellite Instruments from the Higher Training Unit dependent on the National Commission for Space Activities (CONAE) and the National Technological University (UTN) from Argentina. Since 2020 he works as Director of Research Projects at the Paraguay Space Agency, where he currently develops scientific projects. His research interests involve telecommunications in delay tolerant networks, STEAM education, and satellite electromagnetic compatibility testing.

Diego H. Stalder, received the BS degree in Electronic Engineering (2010) from the Engineering Faculty of National University of Asunción (FIUNA), the Master (2013) and the PhD degree (2017) in Applied Computing from the National Institute for Space Research, Brazil. Since 2019, is a full-time researcher at FIUNA, Paraguay. His research interests include time series analysis, deep learning models, biometric signal processing, and instrumentation.

Alejandro Reckziegel is an electronics student at the Engineering Faculty of the Asuncion National University (FIUNA). His research interests include radio telescopes and simulation models.

Luis Bernal, received his degree in Electronic Engineering in 2016, at the Faculty of Engineering of the National University of Asuncion (FIUNA), Paraguay. He is a researcher since 2017 within the Laboratory of Mechanics and Energy of FIUNA, in the line of air quality, in charge of the monitoring network of particulate matter. Since 2020 he works at the Laboratory of Medical Equipment Testing of FIUNA, his research interests include Biomedical development, specifically in the analysis of ECG signals.

Hyun Ho Shin, received the BS degree in Electromechanical Engineering from National University of Asunción (Paraguay), the Master of Science from State University of Rio de Janeiro (Brazil) and the PhD degree in Scientific Computing from National University of Asunción (Paraguay) with doctoral stay at Technology University of Delft (Netherlands). Lecturer and researcher at National University of Asunción (Paraguay), and his research interests include applied mathematics, modeling and simulation of fluid dynamics, incompressible flow, multiphase flow, and different industrial/engineering applications.

Juan Carlos Cabral, received the BS degree in Electromechanical Engineering (2009) from National University of Asuncion (Paraguay), the MSc. (2014) and the DSc. degree (2019) in Computer Science from National University of Asunción (Paraguay). He participated in the Postgraduate Scholarship Program of the Itaipu Binational Technological Park (2011), the Incentive Program for the training of CONACYT research professors (2015), and the CONACYT Program for Scientists and Technologists (2017) for a research stay at the Federal University of Rio de Janeiro (Brazil). He is currently a Research and Professor at the National University of Asuncion (Paraguay). His published articles are mainly on numerical linear algebra and control theory topics.

Primo Cano Coscia, received the BS degree in Electromechanical Engineering from the Engineering Faculty of National University of Asuncion (FIUNA) (Paraguay), the Master of Science from the Polytechnic University of Catalonia (Spain). Has also a Specialization Course in Oil and Gas Marketing by the Technological Institute of Buenos Aires. (Argentina). Since 2001, Professor of Thermal Machines and Thermotechnics in the Faculty of Engineering (FIUNA), and since 2.015 professor of reciprocating Engines in the Aeronautical Engineering Career at the FPUNA. Was president of the company Primo Cano Martínez SA, dedicated to the exploration and exploitation of natural gas in the Chaco, carrying out, among other things, the transformation of diesel engines for dual diesel-gas operation, assembly of the natural gas compression system, maintenance and assembly of a gas turbine to drive an electric generator. Director of the company 9 de JUNIO SA, dedicated to the drilling of water wells for industries, irrigation and rural settlements.

Manuel Aquino, received his degree in Mechatronic Engineering in 2020, at the Faculty of Engineering of the National University of Asuncion (FIUNA), Paraguay. Since 2021, Professor of Mechanical Drawing and since 2022, Assistant Professor of Hydraulic and Pneumatic Systems in the Faculty of Engineering (FIUNA). Since 2021 he works at the Laboratory of Mechanics and Energy of FIUNA, his research interests include automation, gas turbine engines, Biomedical development, and engineering applications.