Optimization of the TEM-cell for a New Type of Climatic Chamber

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***Abstract* — A problem of design of a special chamber for joint environmental and electromagnetic testing is considered. Particularly, design of a TEM-cell for this chamber is addressed. The need of design methodology to create a series of these chambers is shown. Numerical electromagnetic modeling and optimization is proposed as a base of this methodology. An algorithm of the proposed optimization process is presented. The first optimization results for TEM-cell are given. The maximum value of $|S_{11}|$, being around -20 dB for frequencies up to 2 GHz, is obtained.**

***Index Terms* — TEM-cell, climatic chamber, optimization, testing, electromagnetic analysis, quasistatic analysis.**

I. INTRODUCTION

Continuous penetration of electronics in our society's life is a fact caused by a great usefulness of the electronics for humanity. It is especially important that the electronics helps man to withstand harsh environmental conditions, particularly in regions with extra low temperature and/or high humidity. In these cases, various high power and very sensitive electronics units are usually placed densely and this often causes the aggravation of electromagnetic compatibility (EMC) problem. Thus, to warrant reliable operation of the electronics, the joint (electromagnetic, temperature, humidity) effects must be taken into account during design process. In turn, the testing in conditions being as close to real exploitation as possible is necessary to ensure a real achievement of the desirable characteristics.

Representative results of the importance of such testing have been published recently [1]. In this article, the idea of relevance of joint tests of climatic and electromagnetic effects of electronic equipment used in harsh environments has been proposed, research data proving practicability of such tests have been collected and possible mechanisms of natural and artificial electromagnetic interference in the northern latitudes have been considered.

As a next step, a special chamber for joint environmental and electromagnetic testing of electronic components has been proposed [2]. This chamber design has been described as one of the new results obtained in the TUSUR University [3].

Note, that we came to the idea of the chamber based on our considerations from harsh environment for electronics, but there is also another somewhat unexpected application of the chamber as an environmental shielded TEM chamber for biomedical testing. In [4], a problem of microwave exposure of biological systems has been considered and an urgent need to reveal mechanisms of thermal and nonthermal biological effects of radiation has been emphasized. For this objective, a concept of joint control of shielding, temperature and humidity for object under exposure has been proposed. In order to implement this concept, the use of an environmental shielded TEM chamber for biomedical testing has been suggested.

Summing up, we can state that the TEM-cell is the key element for any applications of the camera. It is remarkable that the studies on TEM-cell modeling, began with a classical paper [5], are continuously going on (in papers [6]–[8], for example), despite advanced industrial production of TEM cells. It can be assumed that one of the main reasons for this is the steadily growing variety of objects under test (OUTs). Meanwhile, getting back to the joint electromagnetic and climatic tests, we must note that their specificity brings additional requirements to the TEM-cell, especially for biomedical applications. Unfortunately, these requirements, when they are satisfied, necessarily cause various inhomogeneities in the TEM-cell design and worsen its electromagnetic characteristics, while the diversity and specificity of the tested objects even more aggravate the situation.

To solve this serious problem, we need a design technique that can find the resources to get the best electromagnetic characteristics of the TEM-cell with arbitrary inhomogeneities caused by design specificity of each new version of the TEM-cell. One of the possible solutions for this problem is the proper use of numerical electromagnetic modeling and optimization. Indeed, introducing new changes in the camber we consider an increase in the number of optimized parameters which increases the likelihood of the electromagnetic characteristics improving due to the correction of new inhomogeneities via the mutual choice of optimal parameter values. Maximum use of the results of several studies, briefly described in [9], is supposed to be rational for the implementation of the technique. However, the most general final formulation of the method requires careful consideration. Nevertheless, as a first step to its realization, it is useful to run a numerical electromagnetic simulation and TEM-cell optimization, even for its simple design. Analysis of the process and results of the optimization will be the basis for the establishment of the final technology.

The purpose of this work is to present preliminary results of numerical electromagnetic simulation and optimization of a TEM-cell for a new type of a climatic chamber.

II. CALCULATION OF THE GEOMETRICAL PARAMETERS

Traditionally, a TEM-cell is constructed from the central conductor and three volumetric parts with rectangular cross section. The two parts have the linear expansion of the cross section, shaped as a pyramidal horn, and the third part is a cube with regular cross section along the length of the cell. Line characteristic impedance should be the same along the cell length as it defines an uniform distribution of the electromagnetic field in the homogeneous irregular line and, consequently, minimizes the magnitude of the reflection coefficient $|S_{11}|$. Thus the problem is reduced to the definition of the optimal geometric parameters of the TEM-cell using the minimization criterion for the maximum value of the frequency dependence $|S_{11}|$. Fig.1 shows the algorithm used for the search of optimal geometric parameters which is detailed in the following.

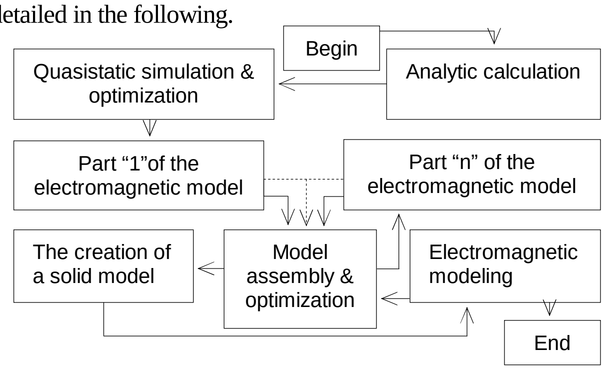


Fig. 1. An algorithm for the TEM-cell parameters calculation.

A. Analytical calculation

According to the method we obtained, an approximate analytical evaluation of geometric parameters of the cross (in the near end and the middle) (Fig. 2) and the longitudinal (Fig. 3) cross-sections of the TEM-cell with wave resistance 50Ω for three different OUTs are 20, 140, 280 mm [5]–[7], [10].

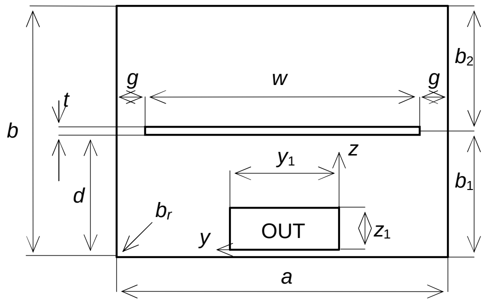


Fig. 2. Cross section of the TEM-cell.

TEM-cell lengths (Fig. 3) were calculated using an approximate formula from [6].

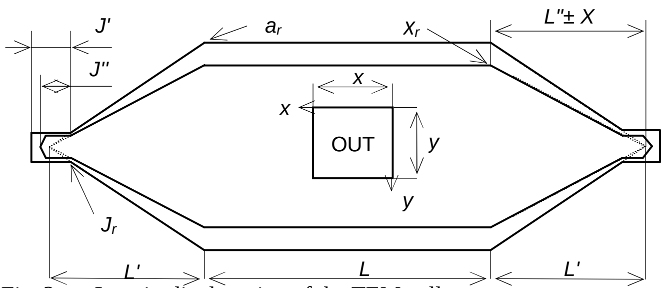


Fig. 3. Longitudinal section of the TEM-cell.

The value of the capacity per unit of length for the analytical calculation is approximate as it is analytically derived from the Taylor series. To adjust the analytical values, we use the quasistatic simulation which is faster and has less computational cost than the electromagnetic one.

B. Quasistatic analysis

In the TALGAT program geometrical parameters of the TEM cell are optimized using the module of quasistatic simulation for Z=50Ω. Analytically derived values are considered as initial data. We take into account the sizes of OUT and the different thicknesses of the main conductor t = 1, 2 mm. Z values, received in modeling, confirm the calculated value of 50Ω. The calculation error for the cell with the height of 140 mm and 280 mm is less than 0.86 %, while the error increased to 4.2% for the height of 20 mm and t=2 mm. The error increase can be explained by the fact that the cell height for different OUTs differs by a factor of 14, while their thickness is constant for all sizes making a significant impact on the calculation of the cell's per unit length capacity.

C. Electromagnetic analysis

According to optimized geometrical parameters of the cross sections, three-dimensional electromagnetic models of the middle and pyramidal parts of the TEM-cell for OUT of 20 mm (Fig. 4) have been built separately in the CST MWS program. Electromagnetic modeling and parametric optimization of the middle part of the TEM-cell have been conducted. The aim of the optimization was the minimization of the maximum value of the $|S_{11}|$ frequency dependence for Z=50Ω.

It was assumed that pyramidal TEM-cell parts may have not traditionally linear aperture. According to this assumption, the model with the hyperbolic aperture has been developed and its structural optimization has been carried out. After the optimization, the transition structure got the line aperture in the basis, and at the same time, transition there were roundings with bends of a linear part at the beginning and at the end of the cell (Fig. 4a). Due to it, the maximum value of the VSWR decreased from 1.12 to 1.06 compared to the completely linear aperture without bends.

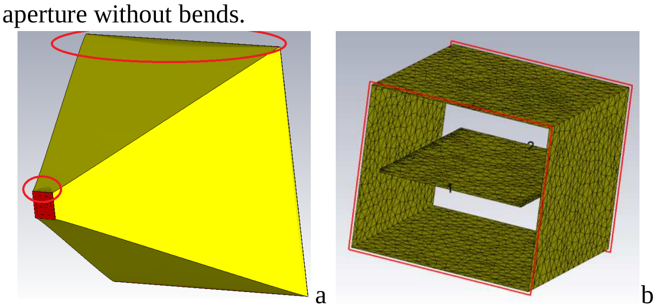
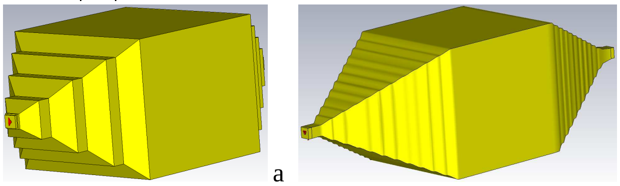


Fig. 4. Three-dimensional electromagnetic models of the linear aperture with a bend (a) and the middle part (b)

Models of TEM-cells with different shapes of the aperture of the pyramidal transition (linear, step and wave, Fig. 5) were built according to the parameters obtained during optimization of separate electromagnetic models. Then, optimization (of the main parameters) of three TEM-cells, which are different from the others in the aperture shape of the pyramidal part, was carried out according to the algorithm presented in Fig. 6. Transition elements were optimized in the number and shape of the elements on the basis of minimization of the maximum value of $|S_{11}|$.



a b

Fig. 5. Geometrical models with step (a) and wave transitions (b).

The values obtained during modeling and separate optimization of the linear and pyramidal parts were taken as initial parameters. In the algorithm (Fig. 6), optimization parameters of geometrical values of the cross-section in the middle of TEM-cell have no stroke (*e.g. b*, *w*, *etc.*), parameters in the beginning and the end of the line have a stroke (*e.g. b'*, *w'*, *etc.*), the same parameters but for the central conductor are marked with two strokes (*e.g. b''*, *w''*, *etc.*). Spherical radii marked with *r* (*e.g.* b_r, J_r, *etc.*) occur due to the bending of metal of Solid Model in one of the parts of TEM-cell. The algorithm has cycles, which can contain 3 steps: main (–), additional (- - -) and intermediate (– · –). A current step or the higher step is the most important.

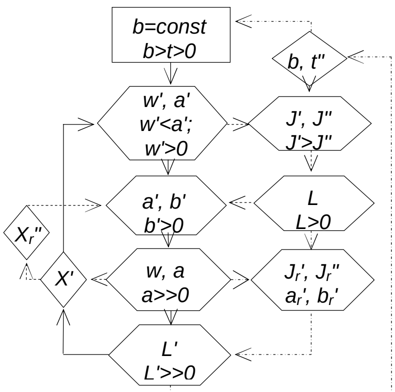
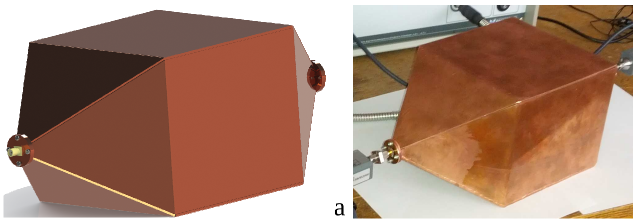


Fig. 6. The algorithm of the TEM-cell optimization.

The algorithm presented in Fig. 6 functions as follows. Constant *b* is set, it should be positive and be bigger than metal thickness *t* of the central conductor ($b>t>0$), it also should be more than three times bigger than the maximum height of the examined object ($b>3$ OUT). Then we optimize parameters of aperture shape of the pyramidal part *a*' and width of the line *w*' in the beginning and the end of a line. These parameters were the first chosen from the parameters of convergence in the input and output of the TEM-cell, for the defined height *b*' of the pyramidal part aperture. Optimization can be carried out, if width of the central conductor *w*' is less than aperture of the pyramidal part *a*' and its value is not negative. When we have found the optimal *a*' и *w*', we go to the next transition element, where height *b*' and width *a*' of the pyramidal parts in the beginning and the end of the cell (cross-section of the cell narrowing) are optimized to the width of the line in the beginning *w*'. Then we find the optimal values of width of the central conductor *w* and width of the square part of the TEM-cell *a*. Cross-sections optimized, length of the pyramidal parts *L*' is optimized, which determines angle of the pyramidal part aperture and position of the central conductor *X*' against the angle formed in the place of connection of pyramidal and square parts of the cell. The first cycle can be finished or repeated until the values give the needed result. After the first cycle or some cycles we can add additional and supplementary steps. We give the priority to the step higher in the hierarchy. Additional and supplementary steps done, we optimize lengths of narrowing of pyramidal parts *J*' and central conductor *J*'', and length of the square part of the TEM-cell *L* and circling radii. The last step is optimization of initial height of the square part *b* of the TEM-cell and metal thickness *t*'' of the TEM-cell. The algorithm has circles for all steps and can be repeated from the main to the additional and then to the supplementary steps.

D. Solid model and electromagnetic analysis

According to the obtained optimal parameters of the electromagnetic model built in the CST MWS, a solid model was constructed from the lossy cooper sheet material, using CAD (Fig. 7a). During the construction we took into account characteristics of real bench and welding tools (accuracy of the hydroabrasive cut, angle, and characteristics of the bending machine), and changes of metal edges in the result of its strain and stress. Then model was imported from the CAD to the CST MWS, where electromagnetic modeling of the solid model was carried out. Using solid model, drafts for the machines were made, the construction was welded (Fig. 7b).



a b

Fig. 7. Solid model (a) and real construction (b) of TEM-cell.

Fig. 8 shows frequency dependencies $|S_{11}|$ for models, which were constructed without considering real curves, cuts and welding, computed by the finite integral technique in the frequency domain and by the method of finite differences in the time domain, accounting or SM. A measured frequency dependence $|S_{11}|$ of the real TEM-cell constructed using CAD drafts is given. As we can see, dependences converge; there is better convergence, if the details are accurately accounted.

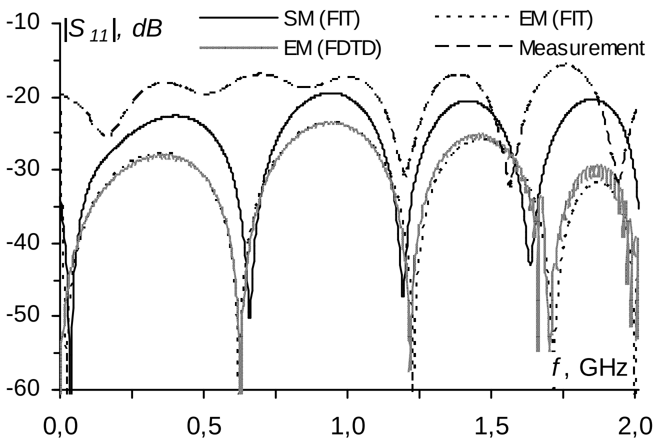


Fig. 8. Measured and computed using FIT and FDTD methods frequency dependencies $|S_{11}|$ for solid (SM) and electromagnetic (EM) models of TEM-cell.

VI. Conclusion

According to the presented technology, preliminary parameters optimization was carried out using the presented optimization algorithm for different sizes of TEM-cell and any examining objects inside it.

This technology provides optimization of a structure and geometrical parameters of a TEM-cell. The presented methodology can be used to evaluate the frequency dependence $|S_{11}|$ of the particular implementation of the solid state model with various practical modifications of the initial TEM-cell model.

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