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Development of an improved coaxial cell for measuring the shielding effectiveness of materials

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Abstract. The article presents the results of the development of a coaxial cell for measuring shielding effectiveness of composite materials. The basis for the design of the cell was a model of a coaxial transmission line with air filling, which was obtained using full wave analysis and parametric optimization and is characterized by a maximum reflection coefficient $|S_{11}|$ less than -20 dB in the frequency range up to 10 GHz. Based on the results of modeling and optimization, an improved design of the cell for SE measuring is presented, which differs from standardized cells in a simplified assembly with the material located inside and providing measurements also in the low-frequency region.

1. Introduction

An increase in the integrated-circuit density and operating frequencies of modern radio-electronic facilities leads to an exacerbation of the problem of electromagnetic compatibility (EMC) [1]. Placement of equipment in an electromagnetic shield is used to protect blocks and units of radio-electronic equipment from external and internal electromagnetic effects [2]. For this task, polymer composites are investigated and actively developed, characterized by a low mass compared to metals and a wide range of shielding frequencies [3].

Measurement of the shielding effectiveness (SE) of a material is a mandatory procedure at the stage of its production, and for this, devices based on a transmission line in the form of a coaxial waveguide with an internal cylindrical conductor are used. This method has been widely used due to the simplicity of the measurement procedure and processing of results. At the same time, the improvement of measuring devices for studying the shielding properties of materials in a wider frequency range remains relevant.

The aim of this work is to develop an improved coaxial cell for measuring the shielding efficiency of composite materials in the frequency range up to 10 GHz.

2. Measurement procedure in coaxial cells

The construction of the coaxial cell is a segment of the transmission line in the form of two coaxial conical conductors isolated from each other. The principle of the SE measuring in a coaxial cell is to measure losses during the propagation of electromagnetic waves along the cell with a sample of the material with a thickness t_o placed inside. Due to the difference in the characteristic impedance of the medium Z_0 and the material sample Z_m, the incident wave is reflected from the surface of the material, which is characterized by the power P_i. This leads to the formation of a reflected wave with a power

P_r, absorption of a power P_a, and transmission of a wave with a power P_t through a shield, as shown in Figure 1 [4].

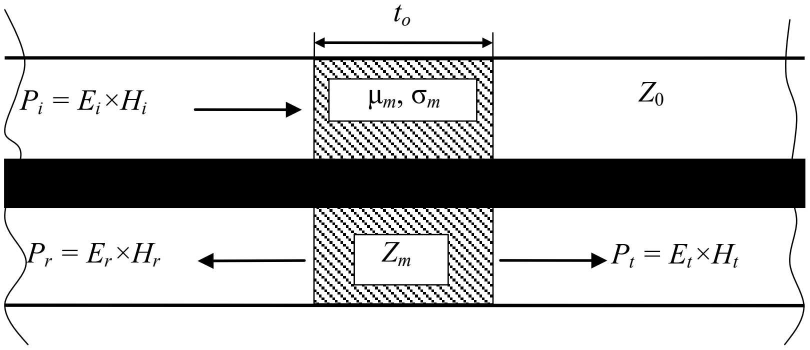


Figure 1. Electromagnetic wave propagation in a coaxial cell with a sample of the material located inside.

According to ASTM ES7 [5], the cell is an inextricable segment of the transmission line, and a sample of the material in the form of a disk is placed in the air gap between the conductors. In this case, the SE can be calculated as:

$$\mathrm{SE} = 20\lg\left|\frac{1}{S_{21}}\right| \tag{1}$$

where S_{21} is the transmission coefficient of the cell with a sample of material placed inside.

According to ASTM D4935 [6], a sample of material is round in shape without holes and placed in the gap between the divided symmetric sections of a cell, connected by screws from a dielectric material. When measured in the coaxial cell with a discontinuous central conductor, the SE is defined as:

$$\mathrm{SE} = 20\lg\left|\frac{S_{21u}}{S_{21l}}\right| \tag{2}$$

where S_{21u} is the transmission coefficient of the cell with a reference sample, S_{21l} is the transmission coefficient with a sample of material.

3. Development and analysis of the model

The characteristic impedance in the cross-section of the coaxial line can be calculated by the expression [7]:

$$Z = \frac{\eta_0}{2\pi\sqrt{\varepsilon_r}}\ln\left(\frac{r_2}{r_1}\right) \tag{3}$$

where η_0 is the characteristic impedance of free space, ε_r is the dielectric constant of the medium, r_1 is the radius of the active conductor, r_2 is the radius of the outer conductor.

The cutoff frequency of the cell is defined by the resonance frequency of TE_{11} mode:

$$f_c = \frac{c}{\pi(r_1 + r_2)} \tag{4}$$

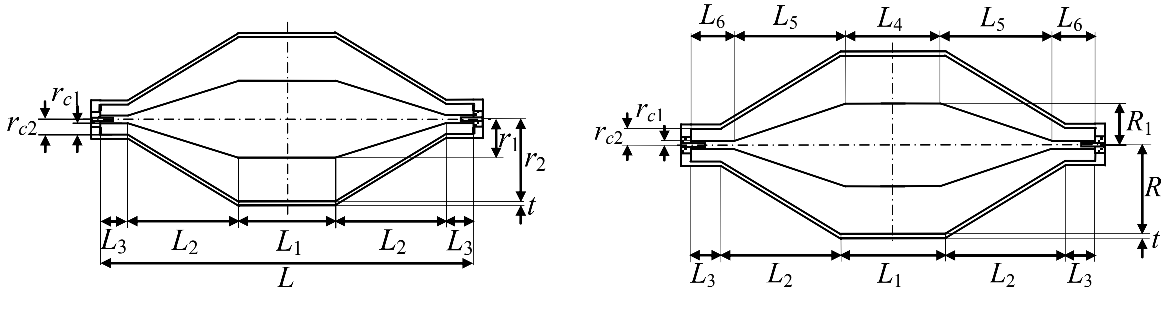
where c is the speed of light in free space.

According to expressions (3) and (4), the radii of the conductors in the regular part were calculated for $Z = 50$ Ohm and $f_c = 3$ GHz: $r_1 = 9.64$ mm, $r_2 = 22.00$ mm. Based on the calculated dimensions, construction and quasistatic analysis of the cross-sectional model in the TALGAT system [8] was performed. The values of the geometric parameters were corrected to match the required characteristic impedance: r_1 = 10.00 mm, r_2 = 21.44 mm.

The development and full wave analysis of models of coaxial cells with various forms of matching transitions in the frequency range up to 10 GHz were performed to match the calculated regular part with SMA connectors. The dimensions of the models were calculated using parametric optimization in order to minimize the maximum value of frequency dependence of the reflection coefficient $|S_{11}|$.

A model of a coaxial cell with linear matching transitions was considered. Matching of the regular part with the connectors is ensured by a linear decrease in the radii of the conductors to r_{c1} = 1.30 mm and r_{c2} = 2.95 mm (Z = 50 Ohm), as shown in Figure 2a.

A model with linear shifted matching transitions was considered, which differs from the previous model in different lengths of the central and outer conductors in the regular part and in the junction area of the SMA connectors (Figure 2b).



a b

Figure 2. Geometrical parameters of the coaxial cells with linear (a) and linear shifted (b) matching transitions.

A cell model with exponential matching transitions was developed, in which the radius of the outer conductor varies in the longitudinal direction along a curve passing through 5 points corresponding to the dimensions in Figure 3a. The radius of the center conductor decreases in the longitudinal direction along the curve described by 4 points, as shown in Figure 3b.

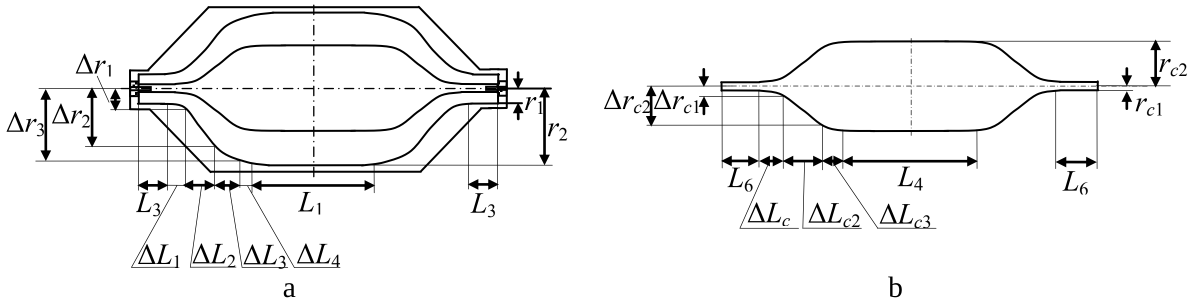


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Figure 3. Geometric parameters of the outer (a) and central (b) conductors of the coaxial cell with the exponential matching transitions.

An analysis of the calculated frequency dependences of the S-parameters of models with optimized geometric parameters revealed that the value of the frequency dependence $|S_{11}|$ for a model of a coaxial cell with a linear matching junction does not exceed -11 dB. At the same time, at frequencies exceeding the resonance frequency of the TE_{11} mode, a satisfactory matching of the cell with the impedance 50 Ohm is observed, which indicates the possibility of using the calculated dimensions for further development of the prototype with a range of operating frequencies up to 10 GHz (Figure 4a).

A model with linear shifted matching transitions is characterized by a satisfactory level of matching in the studied frequency range: values of $|S_{11}|$ are less than -15 dB, except for an increase to -12.6 dB at a frequency of 5.09 GHz and to -10.5 dB at 8.74 GHz (Figure 4b).

It can be seen that the model with exponential transitions is characterized by the maximum value $|S_{11}|$ no more than -20 dB, which ensures the best matching of the considered models (Figure 4c).

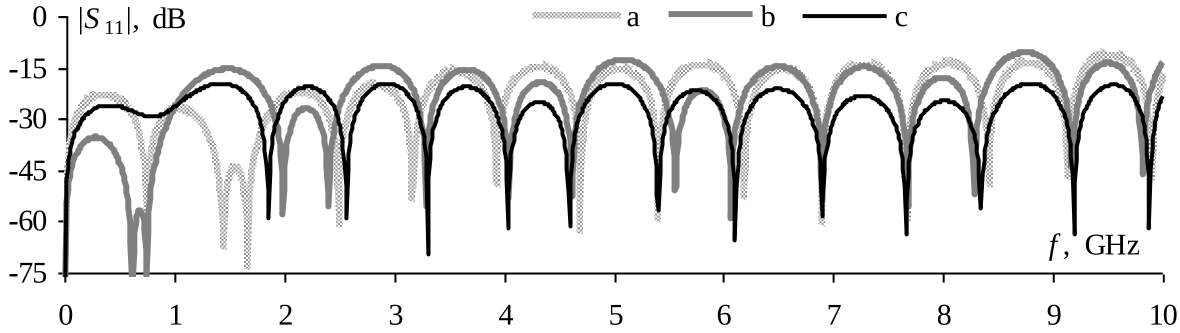


Figure 4. Frequency dependencies $|S_{11}|$ models of coaxial cells with linear (a), linear shifted (b) and exponential (c) matching transitions.

4. Analysis of options for assembling the cell's construction

Based on the cell model with exponential transitions, solid models were developed according to the requirements of standards [5] and [6] (Figure 5).

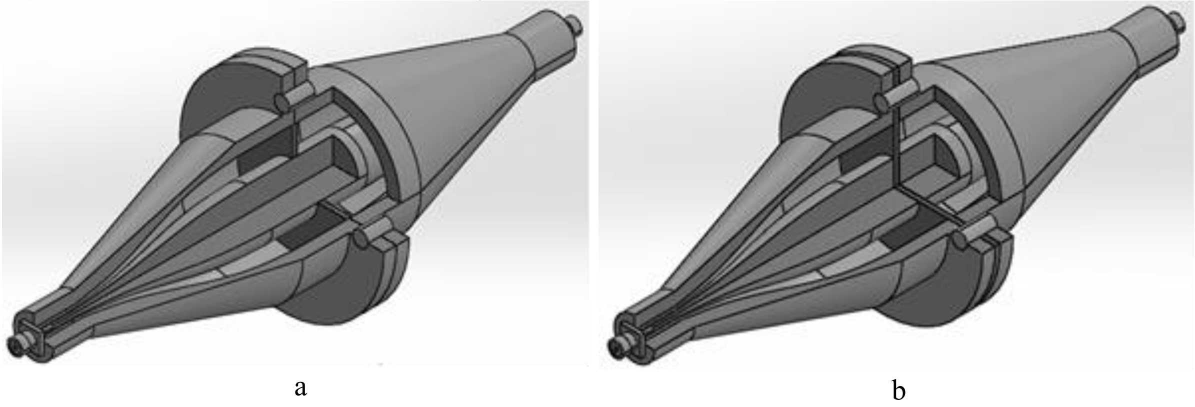


Figure 5. Isometric views of coaxial cells solid models designed to standards [5] (a) and [6] (b).

An improved coaxial cell was developed, the outer conductor of which is in the form of two symmetrical structural elements connected by a threaded connection. The central conductor of the cell is divided into two halves, at the end of one of which a groove of a cylindrical shape is made, into which a cylindrical protrusion of the second half of the conductor is installed (Figure 6a).

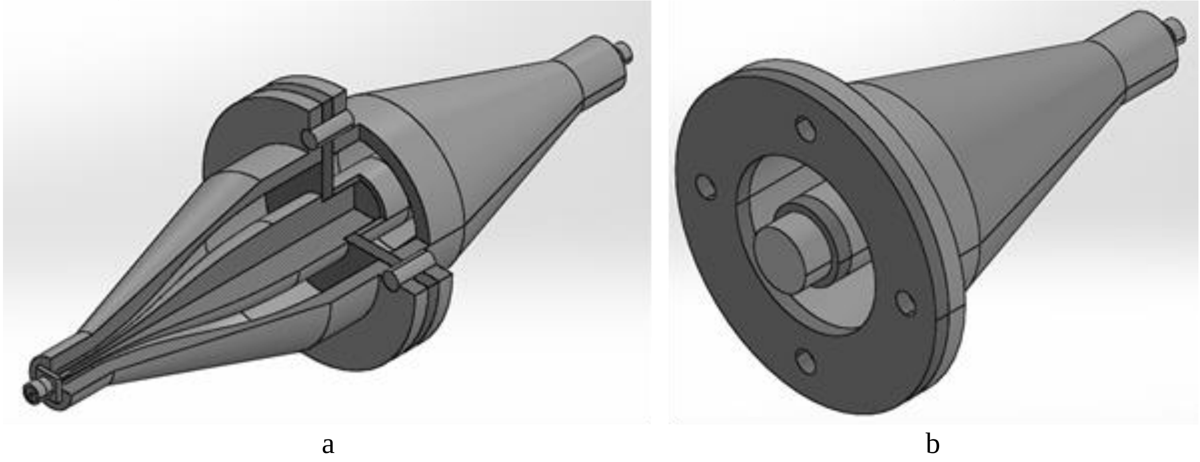
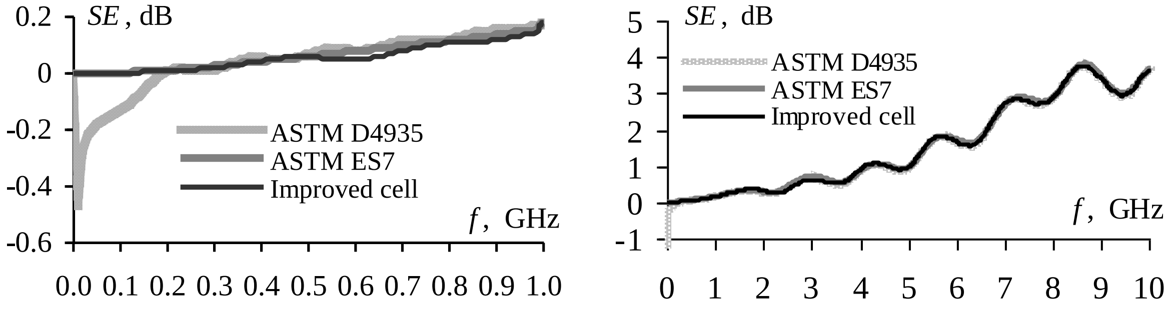


Figure 6. Isometric view of the improved coaxial cell (a) and the shape of the reference sample (b).

The SE analysis requires the measurement of a reference sample, which is located in the gaps of the cylindrical protrusion of the central and outer conductors, as shown in Figure 6b.

A computational experiment was performed to measure the SE of the composite material using the developed cell models to assess the effect of various options for connecting structural elements on the measurement results. To create a material sample during modeling, we used the measured frequency dependences of the relative dielectric and magnetic permeabilities of a composite shielding material based on Z-type hexaferrite, a description of the properties of which is given in [9].

Based on the *S*-parameters of chambers with a sample located inside and expressions (1)-(2), the frequency dependences of the SE of a sample of composite material 1 mm thick were calculated. From the obtained frequency dependences, it can be seen that the results obtained using the model according to the standard [6] differ from the results for other models at frequencies up to 0.2 GHz and are incorrect (Figure 7a). At the same time, there is a convergence of the frequency dependences of the SE obtained using the improved and standardized [5] cell models, which indicates the correctness of the results obtained using the improved design (Figure 7b).



a b

Figure 7. Frequency dependences of the SE of the material in the ranges up to 1 GHz (a) and up to 10 GHz (b) calculated using the developed cell models.

It should be noted that the improved design of the cell ensures uniformity of filling the space between the conductors with the measured material, however, an additional measurement of the control sample is required. At the same time, when assembling without material, the design is a closed regular coaxial transmission line, which allows it to be used also for measurements according to the requirements of the standard [5].

5. Conclusion

The article presents the results of the development of a coaxial cell for measuring the shielding effectiveness of materials. Based on full wave modeling and parametric optimization, a model of a coaxial line is developed that provides the maximum value $|S_{11}|$ less than -20 dB in the frequency range up to 10 GHz. Standardized models of coaxial cells have been developed and based on them the improved model has been proposed. A computational experiment was performed to measure the SE of a composite shielding material, which showed the correctness of the results obtained using an improved design.

Acknowledgement

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References

[1] Paul C R 2006 *Introduction to Electromagnetic Compatibility* (New Jersey: John Wiley & Sons, Inc.)

[2] Schelkunoff S A 1963 *Electromagnetic fields* (New York, Blaisdell Pub. Co)
[3] Piersanti S *et al* 2017 *IEEE Transactions on Electromagnetic Compatibility* **60(1)** 188-95
[4] Wilson P F *et al* 1998 *IEEE Transactions on Electromagnetic Compatibility* **30(3)** 239-50
[5] *ASTM ES7 Test method for electromagnetic shielding effectiveness of planar materials*, ASTM, Philadelphia, PA, 1983
[6] *ASTM D4935 Standard test method for measuring the electromagnetic shielding effectiveness of planar materials*, ASTM, Philadelphia, PA, 2018
[7] Fusco V F 1986 *Microwave Circuits: Computer Aided Analysis and Design* (Dunfermline: Better World Books Ltd)
[8] Kuksenko S P *et al* 2015 *Doklady TUSUR* **36(2)** 109-13
[9] Kuleshov G E *et al* 2013 *Polzunovsky vestnik* **3** 45-50