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Shielding effectiveness of textile woven fabric with conductive weft in microwave frequency range

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Abstract
The article examines the shielding effectiveness of fabrics with conductive fibres in the microwave frequency range. Because of the limited size of the samples and high frequency range, the methods presented in literature could not be applied in this research. The method proposed, using a special measurement setup, demonstrated practicality for smaller textile samples. The results showed an angular dependence of shielding effectiveness, suggesting the need for perpendicular orientation of conductive fibres in fabrics to maximize shielding. This research provides knowledge on tailored solutions to mitigate electromagnetic interference in modern electronic technologies.

Keywords
woven fabrics, shielding effectiveness, conductive yarns, microwave frequency.

1. Introduction

The shielding effectiveness of textiles at microwave frequencies is a topic of increasing importance as electronic devices become more popular in modern society. As the use of wireless technologies and microwave-emitting devices increases, there is an increasing need for effective measures to mitigate the potential adverse effects of electromagnetic interference (EMI). Textile materials, due to their flexibility and versatility, represent a promising avenue for developing solutions to protect against electromagnetic interference in the microwave spectrum. The shielding effectiveness of textile materials can be measured with various standard methods and test setups e.g. the coaxial probe method or anechoic chamber method [1, 2]. However, they show several limitations that make them difficult to be applied to characterize the textile material that is presented in this paper.

The coaxial probe method is a widely used and recognized technique for measuring the shielding effectiveness of materials, including textiles [3, 4, 5]. Its advantages include wide applicability, simple configuration, effectiveness over a wide frequency range (especially lower frequencies), and the ability to provide quantitative results. This method involves placing the textile sample within a coaxial transmission line and aligning it with the electric field vector. This technique effectively measures the attenuation of electromagnetic waves, particularly those with linear polarization parallel to the conducting fibres in the material. However, it has limitations in providing a comprehensive characterization of the maximum shielding effectiveness. A significant disadvantage is the limited bandwidth, typically up to 1.5 GHz, which makes it less suitable for higher frequency textiles such as microwave ovens [6, 7]. This method may also have problems with highly anisotropic textile materials, and it is sensitive to the precise placement and orientation of the sample in the system. The radial distribution of the electric field in the coaxial waveguide may not accurately reflect the overall shielding behaviour of textiles, especially those with specific orientation relationships. The electric field in the coaxial waveguide has radial distribution (see Figure 1a) and the magnetic field lines are circular. This is the reason why it has limited applicability to highly anisotropic textile materials.

The anechoic chamber method is a technique utilized to assess the shielding effectiveness of textiles against electromagnetic waves, particularly in the context of anechoic (echo-free) environments [8]. This method is designed to minimize reflections and external interferences during measurements. An anechoic chamber is a specialized room constructed with radio-frequency (RF) absorbers on its walls to reduce reflections of electromagnetic waves. The goal is to create an environment that absorbs incident waves, preventing them from bouncing off surfaces and interfering with measurements. The anechoic chamber method, as outlined in [9], necessitates an even larger sample size (1 m × 1 m).

Another method of shielding effectiveness measurement - an adaptation of the MIL-STD-285 method at ITA PWr for attenuation measurement of thin materials- utilizes a shielded chamber in which the measured material fills the opening. This method also requires a relatively large sample of material (approx. 30 cm diameter) [1,2].

In the next paragraph, an analysis was conducted to assess the applicability of the measurement methods presented in characterizing the textile material discussed in this article.

2. Methods

The woven fabric presented in this paper has conductive weft and dielectric warp and couples effectively with electromagnetic wave of linear polarization, parallel to the conductive fibres. In Figure 1b the orientation of the sample relative to the electric field in coaxial probe is presented. This results in relatively high attenuation of the electromagnetic wave, which has an electric field vector parallel to the conducting fibres and poor attenuation of the electromagnetic wave with the electric field perpendicular to the conducting fibres. The sample placed in the coaxial probe is then only partially coupled with the electromagnetic wave, and the results of measurements obtained in this way do not characterize the maximum shielding effectiveness that could be achieved for linear polarization of the electromagnetic wave, parallel to the conducing fibres.

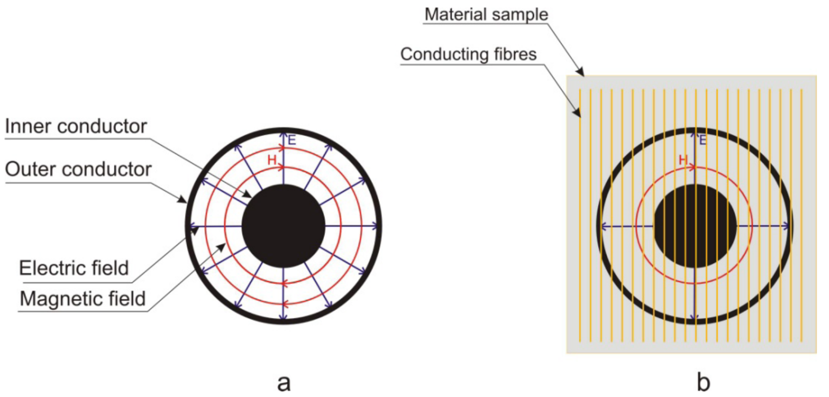

Fig.1. Coaxial probe for shielding effectiveness measurement: a - electric field and magnetic field in coaxial transmission line, b – material sample alignment

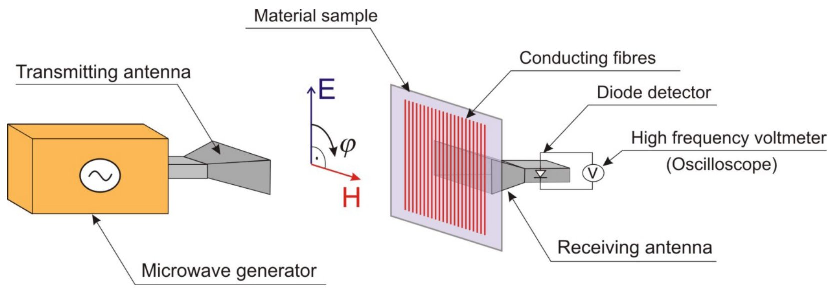

Fig. 2. Schematic of measurement setup

The other methods described above need a large sample size, as in the anechoic chamber method (1 m × 1 m) and an adaptation of the MIL-STD-285 method at ITA PWr (ca. 30 cm diameter). For this reason, we could not apply this method because our samples of textile materials had dimensions of 15 cm × 13 cm.

Given the limitations of the standard measurement methods presented, there was a need to explore alternative approaches, particularly tailored to the characteristics of the textile material discussed in this article.

To identify the shielding properties of a given textile material against a wave of linear polarization we used the measurement setup presented in Figure 2. It consist of a microwave generator type G4-109, which operates in the frequency range from 8.5 GHz to 12.1 GHz. It is connected with an X-band rectangular waveguide type WR-90 to a horn antenna with an aperture size equal to 77 mm × 54 mm and half power beam width is of 12 deg. The antenna transmits an electromagnetic wave to the receiving antenna (of the same type) that is covered with a sample of the material being measured. The size of the samples used (approx. 150 mm × 135 mm) was larger than that of the antenna aperture and covered it completely. The signal received by the antenna reaches the diode detector that is placed in the waveguide, and the voltage on the diode is measured with an oscilloscope (LeCroy 9354AM).

The practical realization of the measurement setup is presented in Figure 3. To decrease the reflection of the wave from the obstacles, microwave absorbers were used (Emerson & Cuming Eccosorb VHP-8-NRL). The distance *D* between the antennas was set to 110 cm. For the purpose of shielding effectiveness measurements we used a calibrated variable attenuator that is built into the generator to identify the attenuation of the samples (the transmit power was constant and equal to 10 dBm). When the sample of material was placed towards the receiving antenna, the attenuator was set to 0 dB and the voltage on the detector was measured. Then the sample was removed and the attenuator tuned to reach the same voltage level that was measured with the sample placed towards the antenna. The attenuation set on the attenuator to compensate the losses on the material gave the value of shielding effectiveness.

The measurement setup uses an electromagnetic wave that has linear, vertical polarization. To measure the shielding effectiveness for different orientation of the sample towards the electric field vector, we used a circular sample holder made of Styrofoam. It allows to rotate the sample, changing the angle *j* (defined in Figure 2) from 0 to 90 degrees.

3. Results

For the purpose of measurements of the shielding effectiveness of textile woven fabric with a conductive weft in the microwave frequency range, we used 4 types of material. Sample 1 was made with the weft made from steel fibres with carbon nano tubes (CNT) and graphene. Sample 2 has the weft made form steel fibres with CNT and silver, while sample 3 uses steel with CNT only. Sample 4 has the weft made of steel fibres with no additions.

The shielding effectiveness of the samples measured agains an electric field parallel to the conducting fibres *j* = 0°, is

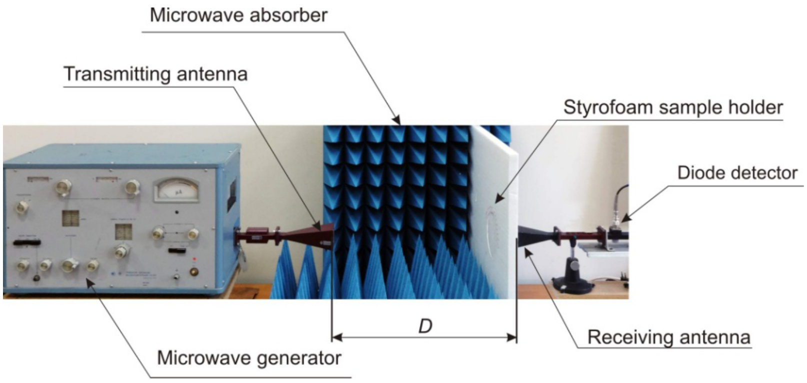

Fig. 3. Picture of measurement setup with sample holder and microwave absorbers (antenna distance D not to scale)

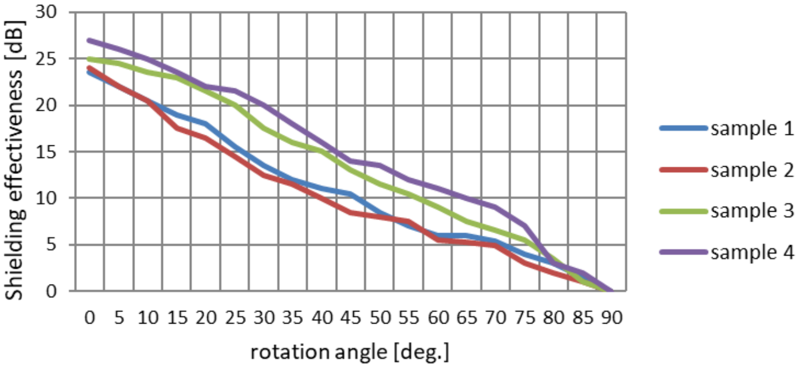

Fig. 4. Shielding effectiveness for different rotation angles

Sample	Shielding effectiveness at 8.5 GHz [dB]	Shielding effectiveness at 12 GHz [dB]
1. Steel + CNT +Graphene	23	16
2. Steel + CNT + Ag	24	17.5
3. Steel + CNT	25	17
4. Steel	27	19

Table 1. Shielding effectiveness of samples measured for an electric field parallel to the conducting fibres, j =0°

presented in Table 1. The measurements were performed for a frequency equal to 8.5 GHz and 12 GHz, which is the operational range of the microwave generator used in the experiment.

The shielding effectiveness of the sample was measured at 8.5 GHz for different rotation angles *j* between the electric field vector and conductive fibres. The results are presented in Figure 4.

4. Conclusions

This study aimed to characterize the shielding effectiveness of woven fabrics incorporating conductive fibres within the microwave frequency range. The research was motivated by the increasing demand for effective measures against electromagnetic interference (EMI) as electronic devices become more prevalent in modern society. Because of the limited size of the samples and high frequency range the methods presented in literature could not be applied in this research.

In response to these challenges, the authors introduced a novel method for identifying shielding effectiveness in the microwave frequency range, specifically tailored for the linear polarization of electromagnetic waves. The method proposed, utilizing a unique measurement setup with a microwave generator, X-band rectangular waveguide, horn antenna, and diode detector, proved to be practical and efficient for the characterization of textile materials with dimensions of 15 cm × 13 cm.

While acknowledging the limitations of the method applied, such as detuning of the receiving antenna due to the proximity of the material sample, the results obtained provided a valuable estimation of the material properties. The method demonstrated sensitivity sufficient for comparing the shielding properties of different samples, offering insights into the range of shielding effectiveness.

One noteworthy outcome of the investigation was the identification of the angular dependence of shielding effectiveness concerning the linear polarization of electromagnetic waves. The shielding effectiveness exhibited significant variations, ranging from approximately 24 dB to 0 when the sample was rotated by 90 degrees (see Figure 4). This observation underscores the importance of considering the orientation of woven fabrics in optimizing shielding properties.

In light of these findings, the study recommends the utilization of a packet of woven fabrics consisting of two layers with conducting fibres oriented perpendicularly. This strategic approach is proposed to maximize the shielding properties of the material, offering a potential solution for enhancing electromagnetic interference protection in the microwave frequency range.

In conclusion, this research contributes to the understanding of shielding effectiveness in woven fabrics with conductive fibres, offering a specialized method for microwave frequency range assessment. The study's findings have implications for the development of tailored solutions to address the challenges posed by electromagnetic interference in the evolving landscape of modern electronic technologies.

References

1. Németh-Erdődi, K., Tibor G., "Development of Measurement Method for Testing the Shielding Properties of Textiles and Analysis of Avialibity of the Measurment System." (2011). Óbuda University Bulletin, Vol. 2, No. 1, 2011
2. Więckowski, T. W., Janukiewicz, J. M. Methods for Evaluating the Shielding Effectiveness of Textiles. Fibres & Textiles in Eastern Europe, Vol. 14, No. 5 (59) 2006r., pp. 18-22.
3. ASTM D 4935-99, Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials, ASTM, June 1999
4. Safarova et al. (2015) "A new method and apparatus for evaluating the electromagnetic shielding effectiveness of textiles" Textile research journal (2015) doi:10.1177/0040517515581587
5. Savazzi et al. (2020) "Development of a Transmission-Based Open-Ended Coaxial-Probe Suitable for Axillary Lymph Node Dielectric Measurements" (2020) doi:10.23919/eucap48036.2020.9135778
6. Kim M.S., Kim H.K., Byun S.W., Jeong S.H., Hong Y.K., Joo J.S., Song K.T., Kim J.K., Lee C.J., Lee J.Y., PET fabric/polypyrrole composite with high electrical conductivity for EMI shielding, Synthetic Metals, Vol. 126, Issues 2–3, 2002,pp. 233-239, ISSN 0379-6779, https://doi.org/10.1016/S0379-6779(01)00562-8.
7. Rathour R, Krishnasamy J, Das A, Alagirusamy R. Water vapor transmission and electromagnetic shielding characteristics of stainless steel/viscose blended yarn woven fabrics. Journal of Industrial Textiles. 2023;53. doi:10.1177/15280837221149217
8. Ortlek HG, Alpyildiz T, Kilic G. Determination of electromagnetic shielding performance of hybrid yarn knitted fabrics with anechoic chamber method. Textile Research Journal. 2013;83(1):90-99. doi:10.1177/0040517512456758
9. N. Dvurechenskaya, P. R. Bajurko, R. J. Zieliński, Y. Yashchyshyn, Measurements of Shielding Effectiveness of Textile Materials Containing Metal by the Free-Space Transmission Technique with Data Processing in Time Domain, Metrology and Measurement Systems, vol. 21, nr 2, 2013, pp. 217-228