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# Usability of a Modified Method for Testing Emissivity to Assess the Real Shielding Properties of Textiles

## Abstract

The usability of a modified method for testing the effectiveness of multi-layer textile shields against electromagnetic radiation (EMR) was examined within the frequency range of 30 MHz to 6900 MHz. The textile-polymeric materials under investigation were spread out on the side surface of a foamed polystyrene cylinder tightly enclosing an EMR source placed in its interior. Tests were carried out on several foamed polystyrene structures with various geometric dimensions that could affect the test results obtained. The tests were performed in an anechoic chamber to provide predictable and reproducible measurement conditions. In order to verify the method proposed and the measurement results obtained, the coefficient of transmission was tested with the use of a waveguide applicator, which made it possible to assess the shielding properties of the multi-layer textile material under testing. Owing to the specific measuring system at our disposal, measurements were performed with the use of the waveguide method within the frequency range of 900 MHz to 6900 MHz.

**Key words:** emissivity measurement, shielding effectiveness, multi-layer textiles, textile-polymeric shields.

sional structures. Depending on the application, their function can be either to attenuate any harmful radiation or to protect, e.g. electronic equipment sensitive to interferences caused by such radiation, which can be done by tightly surrounding the harmful radiation source or the equipment to be protected by a shielding material, e.g. textile or textile-polymeric with a mostly three-dimensional structure in the form of a rectangular prism. However, such a system creates a completely different electromagnetic medium in comparison with the flat initial material used for its construction. The shielding properties of such a structure depend, besides its geometric dimensions, on various passes, technological holes or orifices, leakages for ventilation, ducts, etc. Theoretical evaluation of the shielding effectiveness of such a real 3D shield structure is very difficult and possible only in the simplest cases, and the results obtained should always be treated as approximate values. Therefore there is a need for the development of an experimental method for the determination of the electromagnetic shielding effectiveness of 3D textile systems. A proposal of such a measurement method limited to the far-field zone is presented in this study. The limitation of considerations to the far-field environment results from practical reasons and is connected with the range of electromagnetic field frequency taken into account (e.g. for a frequency of 100 MHz, the far-field already appears within a distance of about 0.5 m). As the frequency increases, the near-field occurs even closer to the potential field

source; thus in practice there is a low probability of being within its area [1].

The experiment results obtained should be compared with those for shielding effectiveness obtained by other methods, e.g. by the waveguide method, for component elements of the same shield.

## ■ Emissivity measurement

The measurement of electromagnetic emissivity is one of the basic measurements concerning electromagnetic compatibility [2 – 6], which means the capability of a given electric or electronic device to properly operate in a specified electromagnetic environment with no emission of disturbances from an electromagnetic field interfering with the correct operation of other equipment within this environment [7]. Emissivity tests allow one to check whether the given device or electric system interferes with the operation of other equipment [6]. They are generally performed on an open testing ground or in an anechoic chamber and consist in measuring the emissions from electric or electronic devices operating under normal work conditions. The measuring element consists of a broadband receiving antenna that makes it possible to detect harmful electromagnetic fields within a wide frequency range.

## ■ Measurement method

According to Standard EN500147, the shielding effectiveness (SE) of an EM shield is defined as a logarithmic ratio of

## ■ Introduction

The measurement of the electromagnetic shielding effectiveness of textile and textile-polymeric materials using the method of waveguide applicator is very often performed in practice, and the results obtained are treated as reference for other measurements. This is due to the fact that this method makes it possible to independently determine the values of coefficients of the EMR transmission and reflection of shield materials, requiring flat textile samples with relatively small dimensions. However, in reality, most of the shields used for protection against EMR are in the form of three-dimen-

the field intensity  $E_0$ , determined under conditions without any shielding material between the receiving and transmitting antennas, to the intensity value  $E_1$  obtained in the presence of a shielding material. The shielding effectiveness determined in this way concerns the far-field zone (within a distance  $R > \lambda/2\pi$  from the emission source, where  $\lambda$  – wavelength) and is determined by the following formula:

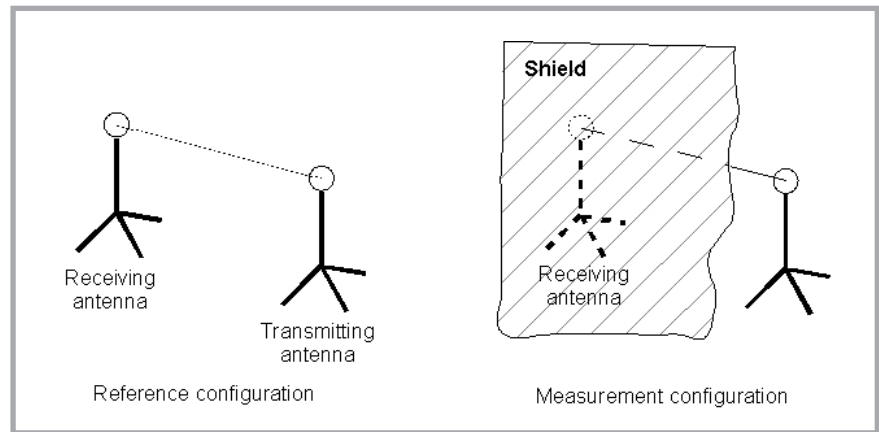
$$ES = 20 \log(E_0/E_1) \quad (1)$$

Formula (1) leads directly to two measurement configurations, shown in **Figure 1**, for experimental determination of the shielding effectiveness coefficient.

The first measurement, later called the reference measurement, leads to the determination of the electric field intensity as a function of the frequency,  $E_0$ , in a situation where there is no shielding material between the transmitting and receiving antennas. The second measurement leads to the determination of the electric field intensity,  $E_1$ , as a function of the frequency, when a shield is present between the transmitting and receiving antennas. Both measurements should be performed in an electromagnetic environment with reflectionless characteristics, preferably in an open testing ground or in an anechoic or semi-anechoic chamber. Considering the fact that Standard EN500147 outlines insufficiently detailed conditions concerning the measuring system, especially the dimensions and configuration of the shield placed between the transmitting and receiving antennas, there is a need for the development of a modified method for measuring shielding effectiveness with the use of the emissivity measurement method.

### Modification and implementation of the measuring method proposed

The shielding properties of three-dimensional structures made from single- and multi-layer textile materials were tested by the modified method for the determination of the emissivity of electric and electronic devices developed using the emissivity test assumptions and test procedures contained in Standards EN 55011 and EN 500147 [8, 9]. An isotropic spherical generator, type KSQ1000, used for the calibration of anechoic or semi-anechoic chambers, was used as an EMR source. The use of such a signal source conditions the range of frequencies tested (from 30 MHz to 1 GHz) and is beneficial due to its small dimensions

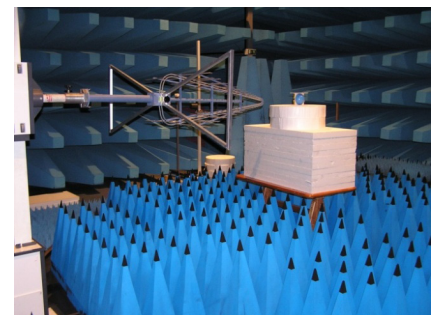


**Figure 1.** Measurement systems for electromagnetic shields.

and isotropic character. The radiation receiver consisted of an ultra-logarithmic measuring antenna, type HL 562. Prior to performing proper measurements, it was necessary to determine a so-called reference curve for the measurement system shown in **Figure 2**. Then the value of the intensity of the electric field generated by the isotropic spherical generator, placed 1.50 m above the floor, was measured within a frequency range of 30 MHz to 1 GHz (with a 5 MHz step up to 200 MHz and a 10 MHz step over 200 MHz). In the case of this measurement, there was no barrier (textile) element between the field transmitter and receiver. In consequence, maximal attainable values of the electric field intensity were obtained for the measurement system corresponding to  $E_0$  in formula (1).

Afterwards, in the same measurement system, the isotropic spherical generator was tightly encased with a spatial structure of the shielding woven or knitted fabric tested, which was spread out on the side surface of the foamed polystyrene cylinder, with a diameter of 0.50 m and a height of 0.70 or 0.50 m. The cylinder height was adjusted to the size of the sample spread out on its perimeter and bases. A structure of this type can simulate a simple shielding enclosure with an equal distance between the textile shield and isotropic signal source, in which the structure material – foamed polystyrene makes no significant changes to the spatial distribution of the electromagnetic field. The measurements resulted in the characteristic of the electric field intensity,  $E_1$ , as a function of the frequency within a range of 30 MHz to 1 GHz. Measurements of the field intensity were performed for several angular positions of the cylinder in relation to the axis of rotation passing through the centers of its

bases. Owing to the object's symmetry in relation to this axis, the characteristics obtained did not depart from themselves, and an average characteristic was determined. If the casing had had channels, ventilation holes or other structural disorders, it would have been necessary to determine the electromagnetic field intensity within a full spatial angle, i.e. for a complete cylinder revolution around its axis with the accepted angle step. This characteristic ( $E_1$ ), compared with the reference curve previously obtained ( $E_0$ ), represents the shielding effectiveness of the single- or multi-layer shielding textile material under investigation. For control purposes, a noise curve of the reflection-



**Figure 2.** Isotropic spherical generator placed in a foamed PS cylinder.



**Figure 3.** Isotropic spherical generator enclosed with a sample of woven/knitted fabric spread out on a foamed PS cylinder.

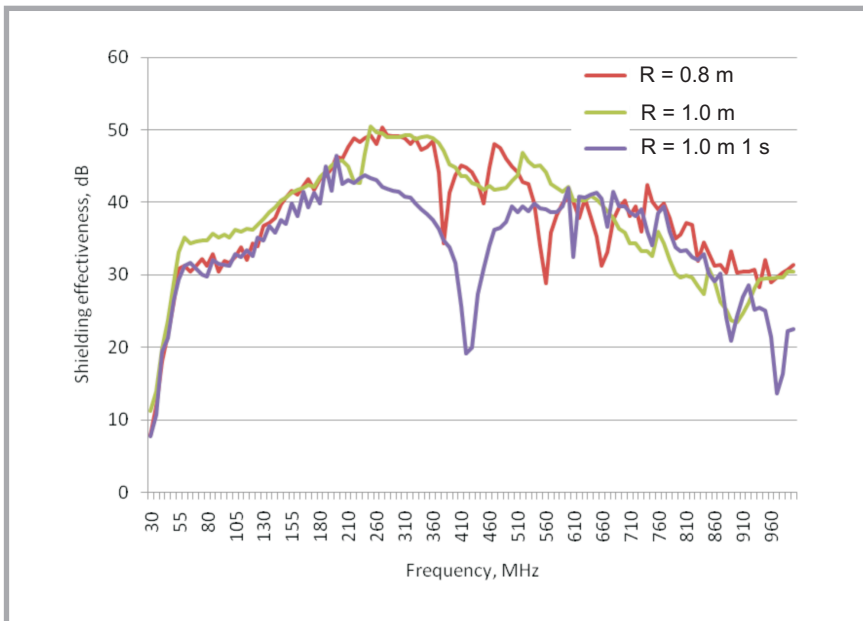


Figure 4. Shielding effectiveness of the knitted fabric system (Material 4).

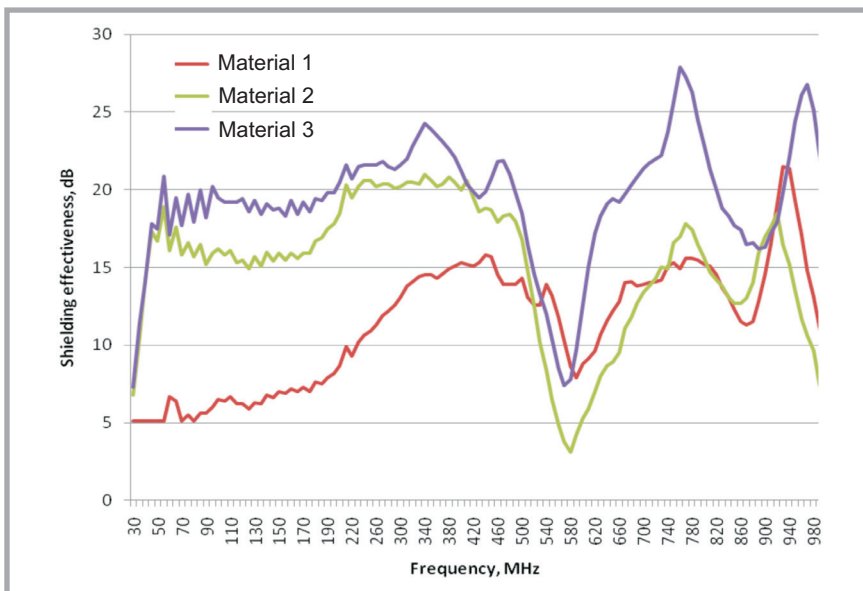


Figure 5. Shielding effectiveness of multi-layer woven systems (Materials 1, 2 and 3).

less chamber (with the signal source turned off) was determined. To accept the measurement as reliable for each frequency tested, the course of this curve should always take place below the electric field characteristic obtained for the shielding sample -  $E_1$ . The measurement of maximal values of the electric field intensity in the system described was performed by the “maxpeak” method.

The “maxpeak” method makes it possible to determine the maximum value of electric field intensity for a given frequency as a function of the height of the receiving antenna. In order to find the maximum value of field intensity, the

position (height) of the receiving antenna installed on a vertical measurement mast is changed during the performance of the measurements. In the case of the tests performed, this height could be controlled within the range of 1.25 m to 2.25 m with a 0.25 m step.

### Materials

Tests were carried out on four examples of developed materials [10], being different in respect of their anticipated application (elements of protective clothing, technical applications, camouflage elements, etc.), as well as in respect of

their fabric structure and content of components with various EMR reflection and absorption properties.

The materials were made by harness weaving or the course knitting technique.

- Material 1 (Woven fabric) is a cotton type garment fabric with a surface weight of 117 g/m<sup>2</sup> and plain weave. Both warp and weft consist of 20 tex cotton yarn with a 10% addition of silver-coated polyamide staple fibres.
- Material 2 (Woven fabric) is a cotton type garment fabric with a surface weight of 75 g/m<sup>2</sup>, plain weave and various finishes (color, print, etc.). This fabric contains conductive fibres only in the weft thread system. The weft threads consist of cotton fibres with a 10% addition of silver-coated polyamide fibres. The warp thread system consists of 100% 16 tex cotton yarns. The content of conductive fibres (silver-coated PA fibres) in the fabrics is 5.4% by wt.
- Material 3 (Woven fabric) is a technical fabric with a surface weight of 110 g/m<sup>2</sup> and plain weave woven from polyester yarn of 167 dtex continuous filaments and yarn of 40 tex polyester staple fibres. In the warp and weft thread system, threads of staple polyester fibre yarns with a 20% addition of steel fibres were spaced at strictly specified distances (a “rib-stop” structure).
- Material 4 (Knitted fabric) is a fabric for technical applications. It is a two-layer weft-knitted fabric with a surface weight of 252 g/m<sup>2</sup>, in which one layer is made of staple 80/20 PES/ steel fibres yarns of Nm 50/2, while the second layer consists of silver-coated continuous PA filaments. The content of steel fibres in this knitted fabric is 15.2% by wt. and that of silver coated PA filaments amounts to 4.3% by wt.

### Results

Figure 4 shows the shielding effectiveness curves of the shielding system based on knitted fabric (Material 4). The runs marked with R = 0.8 m and R = 1.0 m were determined by the „quasi-peak” method with a measurement time of 5 ms, for two different distances between the receiving antenna and the side surface of the shield: 0.80 m and 1.00 m. The run marked with R = 1 m 1 s was determined by the „maxpeak” method with a measurement time of 1 s for the

distance between the receiving antenna and the side surface of the shield, equal to 1.00 m. The measurement principles of the 'maxpeak' and 'quasipeak' methods are very similar. The essential difference results from the lower sensitivity of the „quasipeak” method to random impulse disturbances occurring during testing. On the one hand, this results in a higher probability of eliminating unrepeatable erroneous measurements, but on the other, the actual measurements with extreme values are decreased; hence the name „quasipeak”, as shown in *Figure 4*.

The three curves in *Figure 4*, presenting the shielding effectiveness of the knitted fabric system, show good compatibility, although they are obtained by different measurement methods. The considerable deterioration in shielding properties at a frequency of about 410 MHz is connected with the supporting structure geometry (a cylinder with a diameter of 50 cm and a height of 70 cm), on which the shield is spread out, and the formation of the cavity resonator. Based on the curves shown in *Figure 4*, in further tests the “quasipeak” method was used with a measurement time of 5 ms, which provides good accuracy and a relatively short measurement time.

*Figure 5* shows the results of the shielding effectiveness of three various multi-layer shielding systems made of woven component materials (Materials 1, 2 and 3). The tests were performed with the use of the measurement system presented and the “quasipeak” method with a measurement time of 5 ms.

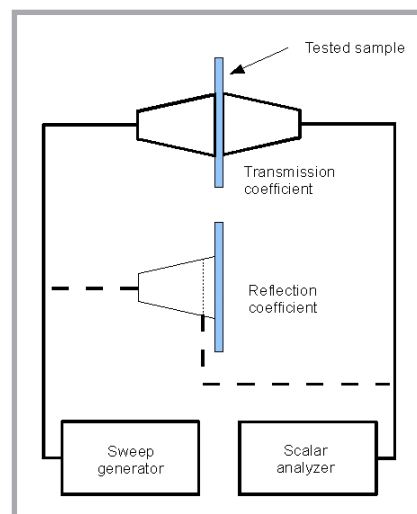
In *Figure 5* one can see the similarity between the runs of shielding effectiveness within the same frequency range, which differ only in the absolute value of shield attenuation. The deterioration in shielding properties within the frequency range at about 560 MHz results from the geometrical structure of the shielding system with different dimensions from those in the tests shown in *Figure 4* (the woven fabric was spread out on the surface of a cylinder with a diameter of 0.50 m and height of 0.50 m).

### Verification of the results obtained and the measurement method used

To verify the method proposed and the measurement results obtained, it is nec-

essary to compare the shielding effectiveness runs obtained with the values determined by means of other measurement methods for the same samples of shielding textile-polymeric materials. It was proposed to use a method exploiting a wave-guide applicator [11–13] as a reference method. The measurement principle of this method is shown in *Figure 6*.

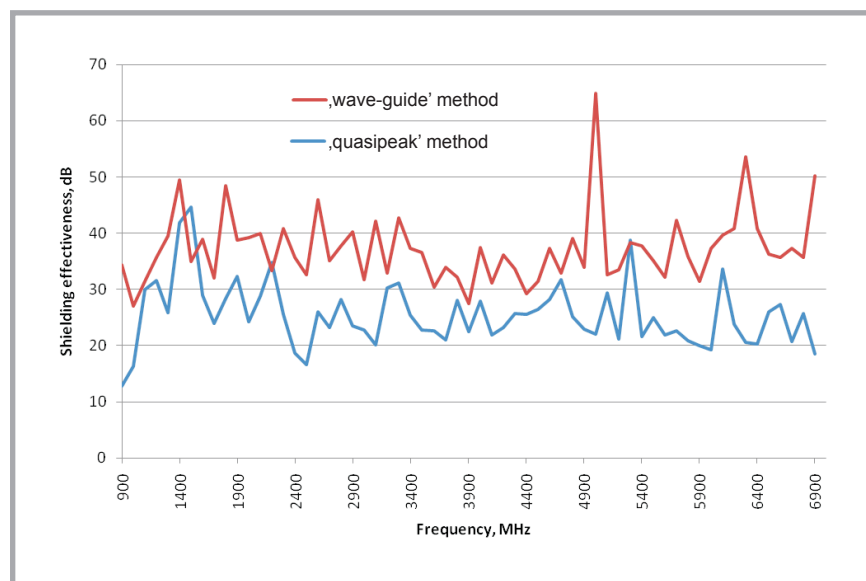
The measurement system shown in *Figure 6* makes it possible to obtain independent values of EM transmission and reflection coefficients of the material under investigation. This system was used to determine the coefficient of EM wave transmission of the material tested. The reciprocal of the transmission coefficient was compared with the shielding effectiveness obtained by means of the modified method of emissivity testing, determined in the system shown in *Figure 2*. Owing to the specific measurement system (mainly the waveguide applicator) at our disposal, verifying measurements were performed within a wider and shifted frequency range in comparison with previous considerations, i.e. from 900 MHz to 6900 MHz. The diagram given in *Figure 7* shows a comparison of shielding effectiveness values (the reciprocal of transmission coefficient) obtained with the use of the waveguide method [11], in which the shielding effectiveness was obtained by means of the modified method of emissivity measurement for the two-layer knitted fabric system (Material 4). The two diagrams of shielding effectiveness in *Figure 7* show consistency in their character of changes



*Figure 6.* Scheme of the waveguide method for the assessment of the shielding properties of textile or textile-polymeric materials.

as a function of the frequency. They differ only in the absolute value by about 10 dB in favor of the coefficient obtained by the wave-guide method, which is due to the fact that this method makes it possible to test flat samples of shielding materials with small dimensions, and consequently it does not take into account joints and bends in the shielding material, being the casing of the transmitter under investigation. Furthermore, the difference is also caused by the inaccuracy of the two methods used, but its real value is difficult to evaluate at this stage of the project development.

Comparing the results of shielding effectiveness obtained for Material 4 using the



*Figure 7.* Shielding effectiveness of the two-layer knitted fabric system (Material 4) measured by different measurement methods

modified method of emissivity measurement in different frequency ranges (**Figures 4** and **7**), one can observe similar results in the common frequency sub-range e.g. from 900 MHz-1000 MHz, which gives a basis for the assumption that the results obtained for the modified method of emissivity in the range from 30 MHz to 1 GHz are proper and valid.

If one takes into account the real conditions of a specific shield (seams, joints, technological holes, bends etc.) and examines it with the use of the modified method of emissivity measurement, it is then possible to determine the shielding effectiveness of a real 3D shield. It should be emphasised that big holes in the shield could significantly reduce the shielding effectiveness, especially at frequencies higher than 1GHz. In such cases, special conductive nets should be used to cover such openings and gain EMF immunity. The shielding effectiveness of casing made from textile-polymeric material is worse than that of the material used for constructing the casing, as confirmed by the diagram shown in **Figure 7**.

By continuing the project, the authors intend to measure the shielding effectiveness of different textile 3D enclosures by replacing the metal shields used nowadays. In particular the plans include comparing the SE of different types of metal boxes for everyday electronic devices with those obtained for 3D textile and textile-polymeric types of the same shape.

## ■ Conclusions

1. The modified method for emissivity measurement, developed with the use of testing procedures contained in Standards EN55011 and EN50147, makes it possible to test the shielding effectiveness of textile and textile-polymeric shielding materials that could be used for making equipment shielding casings, masking or camouflage shields, protective clothing etc.
2. Testing the structures of 3D shields is required because of their different geometrical dimensions, great heterogeneity and joining elements.
3. While interpreting the results of shielding effectiveness measurements (**Figures 4** and **5**), one should take into account the geometrical dimen-

sions of shielded objects since they can cause local increases or decreases in the values of EM field intensity, resulting from the formation of cavity resonators.

4. To prove the deterioration or improvement in the shielding effectiveness of shields, in which cavity resonators were found, one should repeat measurements of the different geometric dimensions of the shielding object more than for those previously tested.
5. The shielding effectiveness of flat samples of shield components is much better than that of the real 3D shield system with specific dimensions, containing joints, bends and other heterogeneity (**Figure 7**).
6. The method of emissivity testing developed creates real opportunities to assess the actual shielding properties of textile materials, including effective multi-layer systems. The results obtained refer to the accepted frequency range and EM field intensities resulting from apparatus limitations.
7. Further development of the test method established in this study depends on the possible use of transmitting antennas generating electromagnetic fields with higher intensity values, operating within a wider frequency range.

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