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Shielding Effectiveness Study of Two Fabrics with Microwave Properties Before and After High Power Irradiation

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Abstract – **Over the past decade several applications for fabrics with electromagnetic properties have emerged, most of them relating to garments, including jackets with built-in antennas and workwear with increased radar visibility. Beside these have surfaced two protective applications, namely to protect transports of confidential equipment from discovery and identification; and to protect sensitive apparatus from damage by high power electromagnetic irradiation e.g. in field operations. In this paper results are presented from measurement of shielding effectiveness before and after high power radiation for two types of fabrics under consideration for the latter applications. Shielding effectiveness measurements have been conducted between 1 and 18 GHz while the high power irradiation was given with 28 kV/m at 1300 MHz.**

1 INTRODUCTION

Conductive fabrics have a wide range of applications. The fabric may have reflecting properties and thus act as a reflector of signals, or it may have absorbing properties and thus attenuate the signal passing through the material [1]. Electromagnetic interference (EMI) shields [2], [3], antennas [4], and wearable monitoring devices [5] are some examples of products that can be found on the market.

By integrating a reflective fabric in garments the radar cross section (RCS) increases and hence the radar visibility [6]. Areas where an increased RCS is desired are professional clothing for road workers and fishermen and rescue suits for people working in the off-shore industry. A study of microwave properties of two kinds of fabric, in the shipborne radar frequency range, 2-18 GHz, has been conducted in [1].

When transporting confidential goods a common problem is the rugged heavy duty packaging required preventing the goods from identification and damage. Civilian as well as military radars exhibit high electromagnetic field strengths while scanning. Another rising issue is High Power Microwave (HPM) radiators, a kind of electromagnetic radiation weapon designed to disrupt or destroy electronic equipment. Here a significant improvement can be achieved by replacing metal containers with light-weight, easy-to-use fabric-based packaging materials that maintains the shielding while facilitating handling.

Another application is to protect medical equipment from electromagnetic radiation, especially when using this type of equipment in the field; e.g. military field hospitals in base camps where high power transmitters are abundant. This protection may be achieved preparing equipment specific covers of EMI shielding fabric or as specially sewn tent sections lined with the same EMI shielding fabric. As a side effect this lining will help avoiding compromising emanations from equipment localized inside the compartment.

To be eligible, it is essential that these fabrics are robust, inexpensive, light-weight, easy to handle, and last but not least important; these materials must withstand HPM irradiation without structural breakdown, something that has been observed e.g. in coated window glass [7].

Little is known about what happens when conductive fabrics are exposed to strong electromagnetic fields. This is examined in the present work by comparing shielding effectiveness (SE) measurement results for two types of fabric, both in two different qualities. A comparison of SE before and after subjecting the samples to HPM irradiation is presented.

2 METHODS

Two different methods to determine the shielding properties of the fabrics were employed. The first method was a traditional comparative measurement with a plane wave under normal incidence in a semi-anechoic chamber (SAC). In the second method a nested reverberation chamber (RC) was used to measure the isotropic transmission cross section of the test object with a mode stirred incident field [7], [8] thus achieving a result representing all incident angles.

The samples were tested in the SAC with a plane wave at normal incidence to get a qualifying reference for the subsequent tests using the RC.

2.1 Semi-anechoic Chamber

The plane wave shielding effectiveness is determined from a traditional comparative measurement, “hatch on/hatch off”, measured at

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normal incidence using two polarizations. The plane wave shielding effectiveness of the test aperture, $\mathrm{SE}_{\mathrm{apert,pw}}$, is given by:

$$SE_{\mathrm{apert,pw}} = \frac{P_{trans,ref}}{P_{trans,apert}} \qquad (1)$$

where $P_{\mathrm{trans,ref}}$ denotes the power received in the reference case and $P_{\mathrm{trans,apert}}$ denotes the power received when the fabric sample is mounted on the test panel.

The transmitting and receiving antennas were positioned at a 300 mm distance from the sample on the respective side. The size of the test aperture was 300 by 300 mm.

2.2 Mode Stirred Reverberation Chamber

Inside the RC a smaller cavity (nicknamed 'Akilles') (size 1.53 x 0.93 x 0.69 m^3) is nested via a square aperture sized 300 mm by 300 mm, Fig. 1. Mode stirrers are located inside both chamber and cavity to generate different field patterns by altering the boundary conditions.

Shielding properties of the fabric samples were measured at isotropic conditions in the RC. An isotropic environment yields an average value of the transmission of plane waves, incident on the test sample (ideally) from all directions and with (ideally) all polarizations. In this case the shielding properties are expressed in terms of the isotropic transmission cross section, $\langle\sigma_a\rangle$, of the fabric (where the brackets indicate that the cross section has been measured at isotropic conditions). At plane wave conditions the transmission cross section, σ_a, of an aperture has the following definition: [8]

$$P_{trans} = \sigma_a(\theta,\phi,p)\cdot S_{inc}(\theta,\phi,p). \qquad (2)$$

In (2) P_{trans} is the power transmitted through the aperture. The parameters θ and ϕ denote the angle of incidence of the plane wave and p its polarization. S_{inc} is the power density of the incident field.

In an isotropic environment one gets:

$$\mathrm{P}_{\mathrm{trans}} = \langle\sigma_{\mathrm{a}}\rangle\cdot \mathrm{S}_{\mathrm{sc,Rev}} \qquad (3)$$

where $\langle\sigma_a\rangle$ is achieved by averaging σ_a over all angles and polarizations and $S_{sc,Rev}$ is the so called scalar power density in the reverberation chamber. The concept of scalar power density was introduced by Hill [9].

The measured field inside the cavity can thus be considered uncorrelated with respect to different positions of the mode stirrer and hence the ⟨SE⟩ measured using an average of the measured field for all positions, per frequency, as described above.

The transmission cross section consists of an absolute result, given in square meters, of the shielding properties of the structure. As is shown in *e.g.* [8] the outcome of a measurement of σ_a (or $\langle\sigma_a\rangle$ in case of an isotropic external environment) can be used to calculate the average shielding effectiveness $\langle SE\rangle$ of an overmoded cavity (denoted by index *cav*) backing the aperture by:

$$\langle SE\rangle = \frac{S_{inc}}{S_{sc,cav}} = \frac{2\pi\cdot V}{\sigma_a\cdot\lambda\cdot Q}. \qquad (4)$$

In (4) V is the cavity volume, λ the wavelength and Q the cavity quality factor. $S_{sc,cav}$ is the scalar power density of the field inside the cavity. The average, denoted by the brackets, is taken over uncorrelated field points over the entire internal volume of the cavity.

2.3 High Power Microwave Irradiation

The high power irradiation was conducted at the FMV Microwave Test Facility (MTF) located at Saab in Linköping, Sweden, see Fig. 2.

At the facility the samples were subjected to the field strength 28 kV/m at 1300 MHz with 5 µs pulses having a pulse repetition frequency of 390 Hz during 10 seconds.

3 RESULTS

The four fabrics tested, were two woven fabrics with steel weft and two non-woven fabrics with

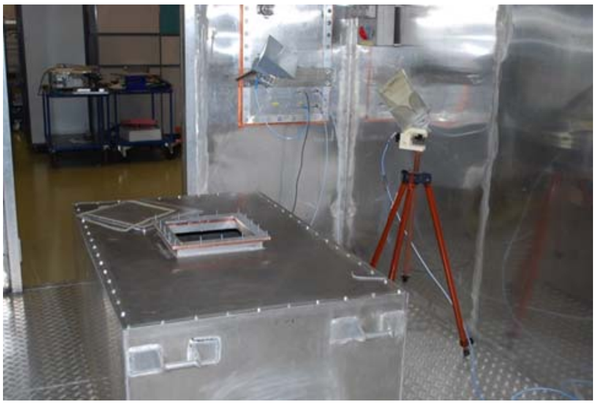

Fig. 1. The nested cavity (a.k.a. Akilles) inside the mode-stirred reverberation chamber.

Fig. 2. The Swedish microwave test facility, MTF at Saab, Linköping, Sweden.

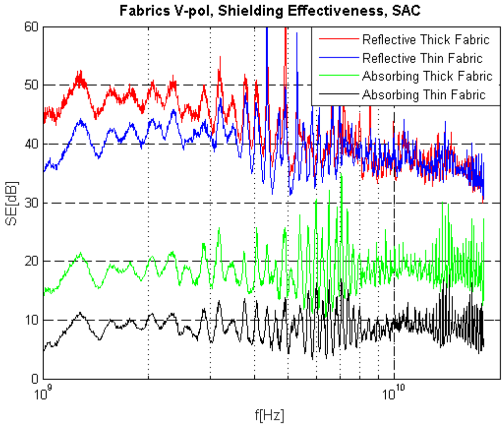

Fig. 3. SE measurement results from the semi-anechoic chamber with vertical polarization.

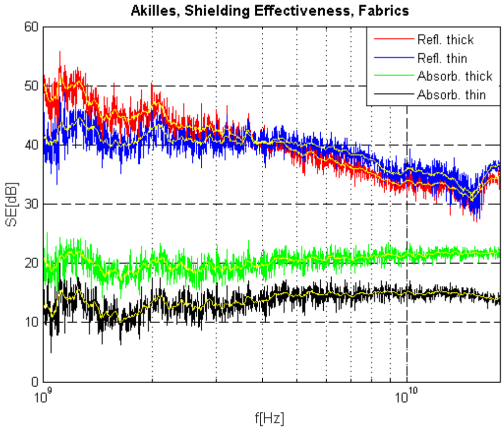

Fig. 4. $\langle SE\rangle$ measurement results, from the nested reverberation chamber. $\langle SE\rangle = A/(4\cdot\langle\sigma_a\rangle)$, [7].

polypyrrole (Ppy) fibers. The woven fabrics have in an earlier measurement shown highly reflective properties [1] while the non-woven showed mainly absorbing characteristics.

When comparing the SAC measurements in Fig. 3 with the results from the RC measurements in Fig. 4 it is clear that the RC measurement replicates the SAC measurement very well. The main exception is that the normal incidence in the SAC shows high frequency dependent variations that are “averaged” out in the RC which shows a much smother behavior.

Another observation is that the reflective fabrics have a substantially higher (20-40 dB) SE than the absorbing fabrics independent of fabric thickness. From these two measurements we can conclude that mode stirred camber measurements are reliable in the characterization of SE.

When studying Fig. 5 and Fig. 6 it is apparent that HPM-irradiation does not negatively affect the fabrics; neither the woven, reflective, nor the non-woven, absorbing type.

4 CONCLUSIONS

Four fabrics were tested, two from Kings Metal and two from EEONYX, both in one thick and one thin quality.

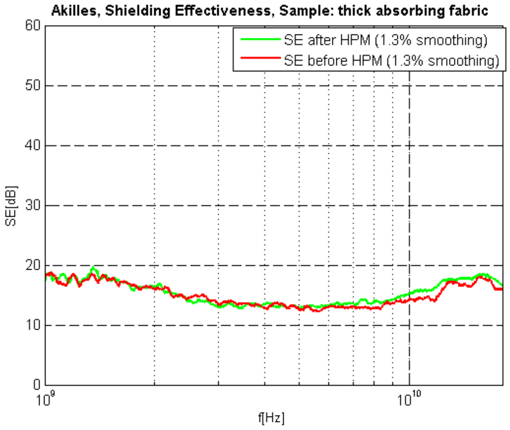

Fig. 5. Thick EEONYX fabric. There is no noticeable change in shielding effectiveness before and after the HPM irradiation.

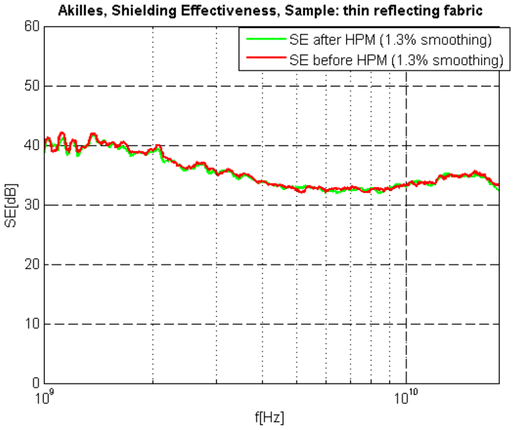

Fig. 6. Thin King's Metal fabric. There is no noticeable change in shielding effectiveness before and after the HPM irradiation.

The fabrics from Kings Metal are woven with steel weft and polyethylene warp in the proportions 40/60 and 30/70 respectively. These fabrics have earlier proven to reflect the signal well [1].

The fabrics from EEONYX of non-woven design with fibers of Ppy have in the same previous measurements shown absorbing characteristics.

Both materials proved to be unaffected by HPM irradiation which is a prerequisite to function in the proposed applications to replace heavy-weight sheet metal containers or to protect sensitive electronic equipment in field applications.

References

[1] T. Ödman, M. Lindén and C. Larsson, ”Reflection/Transmission study of two fabrics with microwave properties,” in *Studies in health technology and informatics*, Vienna, Austria, 2014.

[2] S. Kim, S. Jang, S. Byun, J. Lee, J. Joo, S. Jeong and K. Park, ”Electrical properties and EMI shielding characteristics of polypyrrole–nylon 6 composite fabrics,” *J. Appl. Polym. Sci.,* vol. 87, nr 12, pp. 1969-1974, 21 March 2003.

[3] S. Maity, K. Singha, P. Debnath and M. Singha, ”Textiles in Electromagnetic Radiation Protection,” *Journal of Safety Engineering,* vol. 2, nr 2, pp. 11-19, 2013.

[4] K. Karlsson and J. Carlson, ”Wideband Characterization of Fabrics For Textile Antennas,” in *Antennas and Propagation (EUCAP), 2012 6th European Conference on*, Prague, Czech Republic, 2012.

[5] D. de Rossi, F. Carpi, F. Lorussi, A. Mazzoldi, R. Paradiso, E. P. Scilingo and A. Tognetti, ”Electroactive Fabrics and Wearable Biomonitoring Devices,” *AUTEX Research Journal,* vol. 3, nr 4, pp. 180-185, December 2003.

[6] N. Yamada, Y. Tanaka and K. Nishikawa, ”Radar Cross Section for Pedestrian in 76 GHz Band,” in *Microwave Conference, 2005 European*, Paris, France, 2005.

[7] P. Ängskog, M. Bäckström and B. Vallhagen, ”High Power Microwave Effects on Coated Window Panes,” in *ASIAEM-2015*, Jeju, Republic of Korea, 2015.

[8] M. Bäckström , T. Nilsson and B. Vallhagen, ”Guideline for HPM protection and verification based on the method of power balance,” in *Electromagnetic Compatibility (EMC Europe), 2014 International Symposium on*, Göteborg, 2014.

[9] D. A. Hill, M. T. Ma, A. R. Ondrejka, B. F. Riddle, M. L. Crawford and R. T. Johnk, "Aperture Excitation of Electrically Large, Lossy Cavities," *IEEE Trans. Electromagn. Compat.,* vol. 36, no. 3, pp. 169-178, August 1994.