CHARACTERIZATION AND UNCERTAINTY ANALYSIS OF A SIMPLE TEXTILE MATERIAL FOR THEIR SHIELDING EFFECTIVENESS

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Abstract

A simple and comparatively economical but novel laboratory developed method has been proposed and applied to shield electromagnetic energy with the help of a textile material. An easily available textile material taken as a sample and with three different densities is characterized. Samples are measured for their shielding effectiveness with the help of Vector Network Analyzer 37247B and laboratory calibrated two X-band (8.2 -12.4 GHz) horn antennas. Free space measurement of different samples of textile material shows that electromagnetic energy can be shielded up to 16.2 dB with measurement uncertainty less than ±0.2 dB.

1. Introduction

In general, EMI (electromagnetic interference) is the disruption of operation of an electronic device when it is in the vicinity of an electromagnetic field (EM field) in the radio frequency (RF) spectrum that is caused by another electronic device. The origins of EMI are electrical, with the unwanted emissions being either conducted (voltages or currents) or radiated (electric or magnetic fields) [1]. Problems due to EMI can be minimized by ensuring that all electronic equipments are operating with a good electrical ground system. In addition, all cords and cables connecting the peripherals in an electronic system should be shielded to keep unwanted RF energy from entering or leaving.

Shielding effectiveness (SE) is a parameter used for shielding evaluation, which is defined as the ratio between the field strength, at a given distance from the source, without the shield interposed and the field strength with the shield interposed [2]. For SE applications materials with electromagnetic screening capabilities are generally used to attenuate the strength of electromagnetic fields in certain areas. Nowadays, instead of metallic shields, research on various types of textile materials with special ingredients for SE applications is being carried on. These textile materials should have good mechanical properties, like flexibility and lightweight. Far-field shielding efficiencies as high as 70 dB at 1 GHz has been obtained for polymer blends [3].

A VNA is a versatile measurement system, which comprises of two or four channel microwave receiver designed to process the magnitude and phase of transmitted and reflected waves of the network. It directly displays the transmission and reflection coefficients in terms of Scattering (S) parameter of passive and active networks for their complete characterization. The complex S-parameter (real and imaginary components) and corresponding uncertainties involved along with their correlation coefficients for the one and two port components in the frequency range of 2-18 GHz have been studied and reported [4]. The two port S-parameter measurement i.e. transmission measurement using VNA can be used to obtain the SE values. The difference in the transmission parameters with and without the screening sample is then the desired SE (in dB). Thus,

$$SE_{dB} = (S_{21\ dB} - S'_{21\ dB})$$

where $S_{21\ dB}$ is the transmission parameter without shield and $S'_{21\ dB}$ is transmission parameter with shield.

2. Measurement of Shielding Effectiveness

Various techniques can be applied to determine the SE of textile materials at microwave frequency [3]. The basic principle adopted here is the determination of the reflection or absorption properties of the material. For SE determination of textile materials, free space measurement set up using VNA Wiltron 37247B and two X-band horn antennas is established as shown in Fig.1. The horn antennas are designed and characterized at National Physical Laboratory, India using three-gain method. These horns have the largest aperture dimension of 12.08 cm and gain around 17 dB in the X-band [5].
In the present work, we have taken three samples namely 1, 2 and 3 of the same textile material but with average thickness of 150 \(\mu\)m, 155 \(\mu\)m and 160 \(\mu\)m respectively. The thickness has been measured using a calibrated Screw Gauge. Compactness of the samples has been indicated by the number of knots. The total number of knots is counted in the 5 cm \(\times\) 5 cm piece of sample 1, 2 and 3 are 37x34 knots, 37x36 knots and 37x41 knots respectively. This indicates that the sample 3 is the most compact or dense and sample 1 is least. The VNA has been calibrated by Thru-Reflect-Line (TRL) calibration technique using the two horn antennas (Ant.1 and Ant.2) \[6\]. A thru standard has been configured by placing two antennas in a distance of \(R \approx 97.44\) cm (2D^2/\(\lambda\) at center frequency 10 GHz, D is the largest dimension of the antenna aperture, \(\lambda\) operating wavelength). The reflection standard has been realized by placing an aluminum sheet of about 2 mm thickness at the focal point of the respective antenna. The line standard has been achieved by separating the antennas by a distance equal to free-space quarter wavelength at the center frequency. Thus two-port free space calibration is obtained by performing the TRL calibration using the realized free space standards as per Fig. 1. The calibration of VNA is verified by the VSWR measurement of the third X-band horn antenna, which is earlier, calibrated by the Tuned Reflectometer technique. The VSWR recorded in the X band frequency range is shown in Fig. 2. It is observed that even after taking care of precautions regarding antenna alignments and other radiation or interference effects, the \(S_{21}\) is less than 0.0 dB throughout the range after full two port calibration.

![VECTOR NETWORK ANALYZER WILTRON 37247B](image)

**Fig 1. Measurement set up**

![Fig 2. VSWR vs. Frequency](image)

**Fig 2. VSWR vs. Frequency**

After calibration the transmission parameters are measured in X-band without any shield in between two antennas, say set A. Now the textile samples are placed in the centre of the two antennas as shown in Fig. 1 and transmission coefficients are again measured respectively, say set B. The difference in the recorded transmission coefficients, set A and B, at each frequency point is the desired SE of the sample at that frequency from equation 1.

The uncertainty in measured SE value can be derived from the Friss formula

\[P_r = P_t G_1 G_2 \left( \frac{\lambda}{4\pi R} \right)^2\]  \hspace{1cm} (2)

where, \(R\) is the separation between two antennas and \(\lambda\) is the operating wavelength.

The three-antenna method has been established with the help of VNA and so the equation (2) is modified as

\[\frac{P_r}{P_t} = S_{21} = G_1 G_2 \left( \frac{\lambda}{4\pi R} \right)^2\]  \hspace{1cm} (3)

Knowing the measured values of the transmission parameter, \(S_{21}\) over the measurement range the product of the gains of the antennas is given as

\[G_1 G_2 = S_{21} \left( \frac{4\pi R}{\lambda} \right)^2\]  \hspace{1cm} (4)

or,

\[G_{1,db} + G_{2,db} = S_{21,db} + 20\log_{10} \frac{4\pi R}{\lambda}\]  \hspace{1cm} \hspace{1cm} (5)

Equation 5 can be re-written as,

\[S_{21,db} = G_{1,db} + G_{2,db} - 20\log_{10} \frac{4\pi R}{\lambda}\]  \hspace{1cm} \hspace{1cm} (6)

Equation 6 can be applied to evaluate the uncertainty in the measured SE value using free space method. To obtain the standard uncertainty in the measured value due to repeatability, 10 readings are taken and the associated...
uncertainty is calculated. Uncertainties associated with mismatch, multipath interference, proximity correction and polarization are obtained from the previous work [5] using ISO/IEC Guide 98:1995[7].

3. Results

The SE values of three samples are presented against the frequency range of interest in Fig.3. The least compact sample 1 produced SE in the range of 6-8 dB whereas the sample 2 and sample 3 with comparatively higher compactness have SE values in the range of 8-13 dB and 10-16.2 dB respectively. It is also observed that these SE values are nearly overlapping irrespective of their thicknesses in the measurement frequency range. The higher SE values are found with thickest material as the samples have 5 µm differences in their thickness. The SE properties of the three samples have been tabulated as in Fig. 4.

![Fig 3. SE values of the samples](image)

![Fig 4. Characteristics of the samples](image)

For the present case, based on the discussions given in section 2, the uncertainty budget associated with this work is prepared and given in Table 1.

<table>
<thead>
<tr>
<th>Sources of Uncertainty</th>
<th>Standard Uncertainty (dB)</th>
<th>Type/Probability Distribution</th>
<th>Coverage Factor</th>
<th>Uncertainty Component (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability</td>
<td>0.09</td>
<td>t/Type A</td>
<td>3.162</td>
<td>0.02846</td>
</tr>
<tr>
<td>VNA</td>
<td>0.04</td>
<td>N/Type B</td>
<td>2.000</td>
<td>0.02000</td>
</tr>
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<td>Mismatch</td>
<td>0.0424</td>
<td>U/Type B</td>
<td>1.414</td>
<td>0.02998</td>
</tr>
<tr>
<td>Multipath Interference</td>
<td>0.1</td>
<td>R/Type B</td>
<td>1.732</td>
<td>0.05774</td>
</tr>
<tr>
<td>Polarization</td>
<td>0.08</td>
<td>N/Type B</td>
<td>2.000</td>
<td>0.04000</td>
</tr>
<tr>
<td>Proximity Correction</td>
<td>0.09</td>
<td>N/Type B</td>
<td>2.000</td>
<td>0.04500</td>
</tr>
<tr>
<td>Screw Gauge Uncertainty</td>
<td>0.063</td>
<td>N/Type B</td>
<td>2.000</td>
<td>0.03125</td>
</tr>
<tr>
<td>Combined Uncertainty (dB)</td>
<td>0.1002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanded Uncertainty (dB)</td>
<td>0.2005 at coverage factor k=2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thus for the sample 3, SE value is given by 16.5 ± 0.20 dB at 10 GHz. Similar exercises has been performed for other samples in complete frequency range and SE values along with expanded uncertainties for samples 1, 2 and 3 are given in Fig.5a, Fig.5b, Fig.5c respectively.

4. Conclusions

SE values of materials mainly depend on its intrinsic properties, frequency range used and thickness. However the reliability of the measurement result depends on the method used, environmental conditions, accuracy of instruments. There is also a lack of generally accepted standardized methods for measuring shielding effectiveness.
So we are making efforts towards formulating the standardized methods and establishing its link to the SI units for more confidence on measured values. Hence the uncertainties are evaluated for the measurement results. The results showed that the textile material with high density will have higher SE and it may increase with thickness. Thus a simple material like utilized here can be modified to design special apron like garments for applications under the area of electromagnetic exposures. Practical examples are like while using microwave ovens and while taking RF and microwave measurements etc. Thus the results presented are useful while developing new textile materials for EM shielding or modifying currently existing materials in order to check their parameters and to compare them with other materials for evaluating the effect of the implemented modifications.

5. Acknowledgement

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6. References


