Material Analysis and Application
for Radio Frequency Electromagnetic Wave Shielding

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Our environment is full of radio frequency (RF) electromagnetic radiation due to rapid progress of wireless communication technologies, which have many applications, such as base stations of mobile communication networks and wireless internet antennas. In the context of Electromagnetic Compatibility (EMC) discipline, the word shield is used to describe any sort of metal sheet or material capable of reflecting, refracting or absorbing electromagnetic radiation (EMR), which is custom manufactured for the target electronic device casing, in a way to intervene any radiation passing to and from the device. Examining of electromagnetic shielding effectiveness (SE) is an important part of not only ensuring electromagnetic compatibility and of protecting electrical and electronic equipment but also protection of human beings against electromagnetic energy exposure as well. In this study, after a brief introduction and review on electromagnetic shielding, material selection and their applications for an indoor environment protection against electromagnetic radiation are explained. Potential electromagnetic shielding values of fabrics found in the market have been analyzed and compared by considering various criteria and requirements. Experimental results show that around 20 dB shielding effectiveness values can be obtained using test fabrics for a typical indoor environment.

1. Introduction

With continuous development of mobile communication, our environment is full of radio frequency (RF) electromagnetic radiation due to rapid progress of wireless communication technologies, which has many applications such as base stations of mobile communication networks and wireless internet antennas. Electronic devices both radiate and are affected by electromagnetic interference (EMI).

In Electromagnetic Compatibility (EMC) discipline, electromagnetic shielding concept is used to describe any sort of metal sheet or material capable of reflecting, refracting or absorbing electromagnetic radiation, which is custom manufactured for the target electronic device casing, in a way to intervene any radiation passing to and from the device. There are numerous studies in the literature on electromagnetic shielding effectiveness and some of them related to our motivation can be found in [1–13].

It is vital to protect devices from disruptive electromagnetic signals to guarantee their functionality in stable operation conditions. Also design criteria for EMC are not only important for the desired functionality, stability and performance; but also the device must meet legal requirements of almost all countries in the world before it can be sold [14, 15]. In addition to device interaction, it has been reported that in residential areas which have continuous exposure to electromagnetic fields, these cause bio-interactions and can lead to health problems in humans [16].

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In this study, after this introduction, in the second section the electromagnetic shielding concept is discussed. In the third section material selection and applications for an indoor environment, protection against electromagnetic radiation are explained and the results for curtain and fabrics tested for shielding effectiveness are provided. Finally, the paper ends with the conclusions section.

2. Electromagnetic shielding phenomenon

Shielding effectiveness is the ratio of impinging to the residual energy. When an electromagnetic wave passes through a shield, absorption and reflection take place. Residual energy is part of the remaining energy that is neither reflected nor absorbed by the shield but is emerging from the shield.

EMC problems can be classified into three parts: source of EMI, coupling path and victim system. EMI source has to be removed to solve EMC problem. Protecting the devices from the incoming EMI is essential to maintain their functionality and integrity, as well as controlling their EMI emission level is required to achieve product acceptance in complying with electromagnetic compatibility standards imposed by governmental agencies [14]. Conductive coatings, metal cabinets, foil laminates and conductive polymer composites (CPCs) are the means of EMI shielding. Metal-based shields, as the most widely used EMI protectors [2], suffer from drawbacks of being heavy, prone to corrosion, and expensive to process.

Shielding effectiveness (SE) is the ratio of the field before and after attenuation of electric and magnetic field and can be expressed as [1, 5]

$$\text{SE}[\text{dB}] = 20 \log \left| \frac{E_\text{i}}{E_\text{t}} \right|,$$
$$\text{SE}[\text{dB}] = 20 \log \left| \frac{H_\text{i}}{H_\text{t}} \right|. \tag{1}$$

Here numerator and denominator terms refer to the transmitted and incident waves, respectively. Shielding effectiveness is a function of frequency and it is measured in dB. The attenuation of an electromagnetic wave in a shielding structure occurs by mainly three mechanisms as shown in Fig. 1.
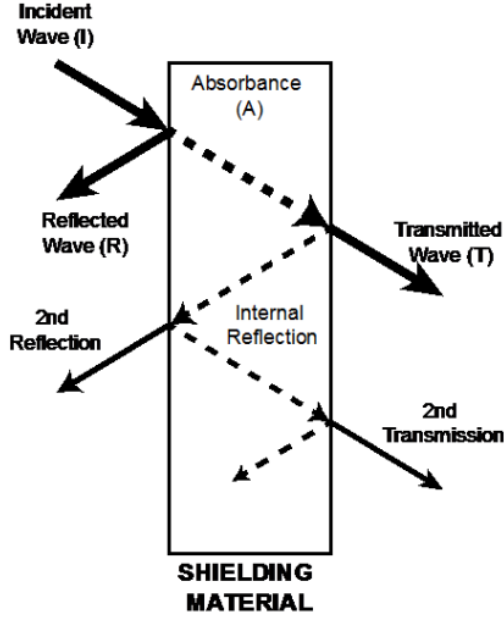

Fig. 1. Shielding mechanism and attenuation of an electromagnetic wave by a shielding structure.

Electromagnetic waves consist of two essential components, a magnetic field H and an electric field E. Assuming a uniform plane wave characteristic of E and H, that varies only along x direction, the Maxwell's curl equations are expressed as [17]

$$\frac{\text{d}E}{\text{d}x} = -j\omega\mu H \quad \text{and} \quad \frac{\text{d}H}{\text{d}x} = -(\sigma + j\omega\varepsilon)H, \tag{2}$$

where σ is the conductivity of the material in S/m and ω is angular frequency in rad/s, equal to $\omega = 2\pi f$ (f in Hz). μ and ε are the permeability and the permittivity of the material, which are expressed as

$$\mu = \mu_0 \mu_r, \tag{3}$$
$$\varepsilon = \varepsilon_0 \varepsilon_r. \tag{4}$$

Here μ_0, μ_r are permeabilities and ε_0, ε_r are the permittivities of free space and material, respectively. All homogenous materials are characterized by a quantity known as the intrinsic impedance

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}. \tag{5}$$

The propagation constant in the media is given as

$$\gamma = (\alpha + j\beta) = \sqrt{j\omega\mu(\alpha + j\omega\varepsilon)}, \tag{6}$$

where α is attenuation constant and β is phase constant. Equation (6) can be rearranged and simplified by considering $\sigma/\omega\varepsilon \gg 1$ and $\sigma/\omega\varepsilon \ll 1$ for a good conductor and for a dielectric plane respectively. The impedance of a homogeneous barrier of thickness t is defined as

$$Z = \eta \frac{Z(t)\cosh(\gamma t) + \eta\sinh(\gamma t)}{\eta\cosh(\gamma t) + Z(t)\sinh(\gamma t)}. \tag{7}$$

$$H(t) = \frac{\eta}{\eta\cosh(\gamma t) + Z(t)\sinh(\gamma t)} H(0),$$
$$E(t) = \frac{Z(t)}{Z(t)\cosh(\gamma t) + \eta\sinh(\gamma t)} E(0). \tag{8}$$

The transmission coefficients across the plane can be written as [17]

$$T_H = \frac{H(t)}{H_\text{i}} = \frac{H(t)}{H(0)} \frac{H(0)}{H_\text{i}}$$

$$\text{and } T_E = \frac{E(t)}{E_\text{i}} = \frac{Z(t)}{Z_\omega} \frac{H(t)}{H_\text{i}} = \frac{Z(t)}{Z_\omega} T_H. \tag{9}$$

$$\frac{H(t)}{H_\text{i}} = \frac{2Z_\omega}{Z_\omega + Z(0)} \quad \text{and} \quad \frac{E(t)}{E_\text{i}} = \frac{2Z(0)}{Z_\omega + Z(0)}. \tag{10}$$

$$p = p_H = \frac{4k}{(k+1)^2} \quad \text{and} \quad q = q_H = \frac{(k-1)^2}{(k+1)^2}, \tag{11}$$

where $Z(0)$ is the impedance at interface 0. $E(0)$, $E(t)$, $H(0)$ and $H(t)$ are actual values at interfaces $x = 0$ and $x = t$. By plugging (10) into (9); $Z(t) = Z_w$ and taking $k = Z_\omega/\eta$ it is obtained as

$$T_H = T_E = T = p\left(1 - qe^{-2\gamma t}\right)e^{-\gamma t}. \tag{12}$$

From (12) the total shielding effectiveness is express as

$$\text{SE} = 20\log_{10}|T| = 20\log_{10}\left|p\left(1 - qe^{-2\gamma t}\right)e^{-\gamma t}\right|. \tag{13}$$

$$\text{SE}[\text{dB}] = \underbrace{20\log_{10}|p|}_{SE_R} + \underbrace{20\log_{10}\left|e^{-\gamma t}\right|}_{SE_A}$$

$$+ \underbrace{20\log_{10}\left|\left(1 - qe^{-2\gamma t}\right)\right|}_{SE_M}. \tag{14}$$

Thus shielding effectiveness is the sum of the three components, absorption (A), reflection (R) and multiple reflections (M) and it can be expressed in logarithmic scale as [5, 17]

$$\text{SE}[\text{dB}] = SE_R + SE_A + SE_M. \tag{15}$$

Also more practically the shielding effectiveness, as the ratio of electromagnetic field, is measured with and without tested material, which separates the source from the receiver. It is expressed as follows,

$$\text{SE}[\text{dB}] = 20\log\left(\frac{E_M F_\text{i}}{E_M F_\text{t}}\right), \tag{16}$$

where F_i is the electromagnetic field received from source without shielding, F_t electromagnetic field received from source after shielding.

3. Experimental procedure and results

Various screening materials and shielding fabrics with SE from 20 dB to over 100 dB are available on the market today [17, 18]. These cover a diverse price spectrum, material composition variety and promise various shielding

efficiency levels. Some materials it is difficult to handle and/or they are expensive. On the other hand, certain materials such as commercial shielding fabrics and curtains are good alternatives for personal use in indoor environment and they are relatively cheap. The shielding effectiveness comparison of Aaronia X-Dream (Fabric A) [18] and Swiss Shield Naturell (Fabric B) [19] with respect to frequency is depicted in Fig. 2.
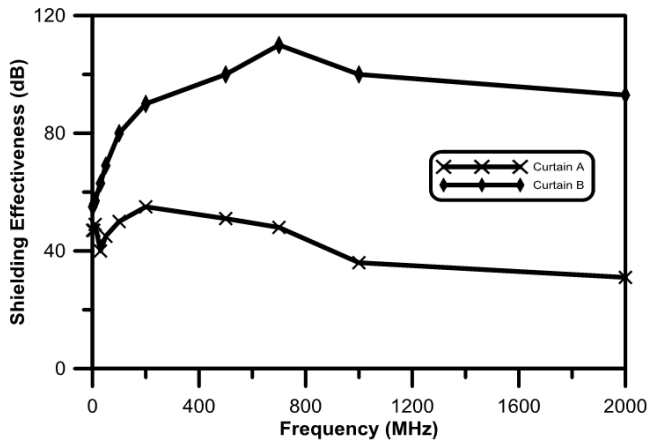

Fig. 2. Shielding performance comparison of two shielding fabrics.
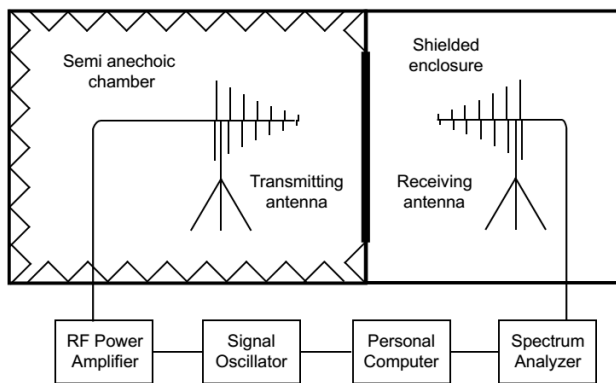

Fig. 3. Schematic diagram of the measurement setup.

For our measurements we have used a semi-anechoic chamber and a shielded room next to it. The test sample is placed in a rectangular aperture with dimensions of 1×2 m^2 in common wall of the chamber with shielded room. During measurements, it is aimed to observe practical shielding effectiveness of the test fabrics around GSM frequencies in a typical indoor environment such as a home or an office room. Aaronia X-Dream (Fabric A) and Swiss Shield Naturell (Fabric B) were used as test fabrics. These fabrics have been folded and applied to the aperture as blind fabric and tulle curtain, respectively. Considering a realistic examination for the intended use area and mounting type, the top edge of the curtain is fixed, the other three sides have been released. Schematic diagram of the measurement setup is shown in Fig. 3.
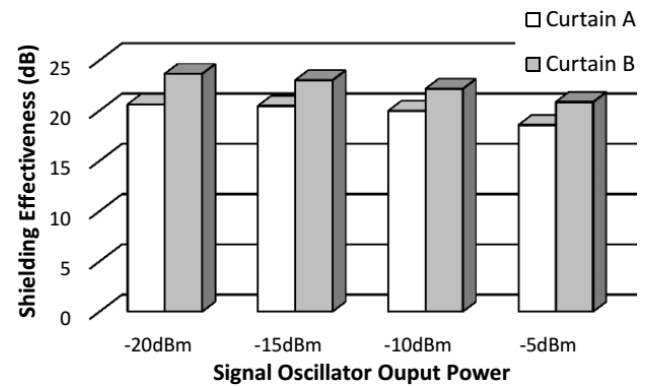

Fig. 4. Measurement results.

Four different output power levels have been applied from the signal oscillator output to amplifier at 900 MHz frequency. Values are selected as -20 dBm, -15 dBm, -10 dBm and -5 dBm for low to very high exposure levels, corresponding to radiation levels of a typical GSM antenna. Measured signal levels of the electric field were in the range between 1 V/m and 50 V/m, corresponding to minimum and maximum output power values, respectively. Shielding effectiveness values obtained from the measurements are shown in Fig. 4.

4. Conclusions

In this study, shielding effectiveness for various commercial curtain and fabrics has been examined and results have been compared. As the test signal, four output power levels have been applied at frequency of 900 MHz. Shielding effectiveness of two fabrics [18, 19] were measured for a typical indoor application. Shielding effectiveness levels of around 20 dB have been reached in the measurements.

Shielding materials suffer from various weaknesses due to their physical nature. For example, metal-based shielding materials suffer from weak corrosion endurance, high weight and sometimes from entirely conductive characteristics. They also cannot be used as alternative shielding materials for such indoor application as covering windows. New materials, especially various high engineered shielding fabrics and composites are the proper and remarkable candidates for shielding applications, especially due to their lightweight, easy formability, non-corrosive nature and adjustability in providing the desired shielding rates. Experimental results show that shielding effectiveness rates obtained for fabrics tested are at acceptable levels for the protection of indoor environments from radiated electromagnetic energy.

Acknowledgments

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