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Research Paper

Some Studies on Shielding Effectiveness for Oblique EM Waves Incidence on Dual Shields

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Abstract *-Shielding effectiveness of various shields against angle of attack with conductors and conducting polymers using plane wave theory is carried out in this paper. The shielding efficiency of these new material combinations against EM waves is evaluated according to the angle of incidence of the dual shield. With recent advances in the synthesis of stable high-conductivity polymers, these lightweight, mechanically strong materials appear to be viable alternatives to metals for EMI shielding. A specific frequency analysis is performed ondual shield materials.*

Keywords– *shielding effectiveness, Electromagnetic Interference; Dual shields; angle of incidence.*

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I. INTRODUCTION

Electromagnetic Interference (EMI) refers to the interference or disruption of the operation of an electronic device caused by either electromagnetic conduction or radiation from an external source. This source could be either natural or artificial and is characterized by rapidly changing electrical currents. The resulting disturbance can interrupt, obstruct, degrade or limit the effective performance of the

device.To prevent the undesired coupling of radiated electromagnetic energy into equipment, shielding is used. The design and development of electromagnetic shields aim to minimize electromagnetic interference and improve circuit compatibility. Different types of electromagnetic shields have been proposed, including single, double and multi-layered conductors, as well as conductive polymers sandwiched between conductive layers. The focus of the design is on optimizing the performance of the shielding effectiveness.

Most of the difficult shielding problems occur in communication systems where many transmitters, receivers and other sensitive equipment must be located closely together, and weight is minimized. It is difficult to predict the shielding effectiveness of any enclosure, such as an equipment package or room filtration. Therefore, it is only necessary to treat problems of this kind theoretically. Several light-weight polymers, which are essentially non-conductive but are conductive upon doping, have been studied in recent years [1-5]. These materials have several potential applications, such as electromagnetic interference (EMI) shielding, microwave attenuators, gas sensors, display units, junction devices, etc. [3,5]. Properties such as conductivity variation over a wide temperature range, light weight and high mechanical strength of the polymers make them attractive in high frequency shielding applications. In previous investigations, thin films of two new polymer materials, namely polyacetylene and poly-p-phenylene-benzobis-thiazole (PBT), were doped with iodine either electrochemically or by ion implantation, and their conductivity was measured using a remove the disturbance of the cavity. technique [2]. Conductive polymers are useful as shielding materials in applications involving high data rate electronics (eg, supercomputers) and in weight-constrained aerospace applications.

The measured values of polyacetylene [2] are included in Table 1 for comparison. The conductivity of the material is given by$\sigma= 2\pi f_0\varepsilon_0\varepsilon''$where $f_0$is the resonant frequency of the cavity [3] andε_0 is the permittivity of the free space. The conductivity is found to increasewith the dopant levels, with the Polymer E (Table 1, Mnemonic E)doped electrochemically with 80% by weight of iodine, yielding thehighest conductivity. Therefore, it can be used in a wide frequency range.

Table 1 includes the measured values of polyacetylene [2] for comparison. The material's conductivity can be determined using the formula $\sigma= 2\pi f_0\varepsilon_0\varepsilon''$, where f_0 is the resonant frequency of the cavity [3], and ε_0 is the permittivity of free space. The conductivity of polyacetylene is observed to increase with higher dopant levels. In particular, Polymer E (Mnemonic E in Table 1) which was electrochemically doped with 80% by weight of iodine, exhibits the highest conductivity. This makes it suitable for use across a wide frequency range.

This work presents an extension of plane wave transmission line theory to analyze the shielding of various screens with conductors and conductive polymers. The article analyzes the screening of a plane wave by a double screen made of a polymer and materials such as inclined copper and aluminum. The analysis was carried out using the material polyacetylene, designated mnemonic E in Table 1. This material is referred to as polymer E.

II. SHIELDING THEORY

The theory of shielding is based on the transmission behavior through metals and the reflection from the surface of the metal, as depicted in Figure 1, since these two mechanisms, namely reflection loss and absorption loss, are responsible for a significant portion of the shielding effect.

Table 1: The complex dielectric constant ($\varepsilon r = \varepsilon' - \varepsilon''$) of conductive polymer films doped with various levels of iodine has been measured. The measurement frequency used was f0 = 9.375 GHz, which corresponds to the center frequency of the X-band.

Table 1: Representation of shielding mechanisms for plane-waves.

Mnemonic	Material	Doping	$\varepsilon_r=\varepsilon'-\varepsilon''$
A	PBT	Ion implantation to a fluence of 10^{16}ions/cm^2	3–j838
B	PBT	Ion implantation of a fluence of 10^{17} ions/cm^2	3–j1158
C	Polyacetylene Cis- $(CHI_{0.045})_x$	Electrochemical; 4.5% I_2 by weight	5–j607
D	Polyacetylene Trans-$(CHI_{0.045})_x$	Electrochemical; 4.5% $I_2$by weight	5–j909
E	Polyacetylene Cis- $(CHI_{0.8})_x$	Electrochemical; 80% I_2 by weight	5–j4.E5

A. *Angle of Incidence*

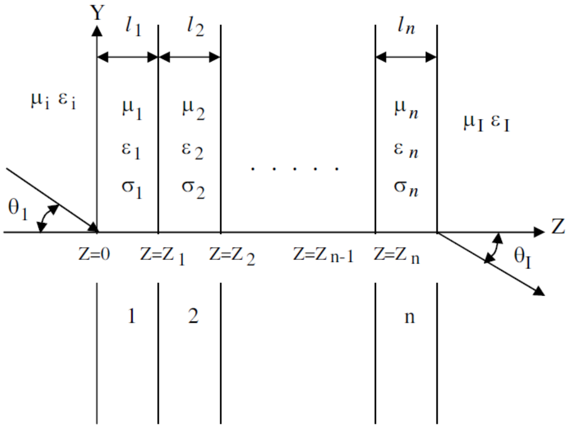

Figure2. When an electromagnetic (EM) wave is incident on a multilayered structure at an oblique angle θ_1, where n is the number of layers, the wave interacts with each layer in the structure.

Figure 2 depicts the reflection and transmission of electromagnetic waves for a single-layered dielectric material under a general incident angle. The dielectric is assumed to be homogeneous and isotropic, with electrical constants ε, μ, and σ. The direction of stratification is represented by the z-axis, while θ_1 represents the incident angle.

In the case of a single interface with thickness l, the incident electric and magnetic fields are denoted by E_i and H_i, respectively. Due to the impedance mismatch between the two media, there is a reflected electric field (E_r) and magnetic field (H_r), as well as transmitted electric (E_t) and magnetic (H_t) field strengths, as shown in Figure 1. For transverse electric waves, the electric field components E_y and E_z are both zero, while for transverse magnetic waves, the magnetic field components H_y and H_z are both zero.

$$\eta = \sqrt{\frac{j2\pi f\mu}{(\sigma \quad +2\pi jf\epsilon \quad)}} \qquad \ldots (1)$$

The shield material's impedance is determined by several factors, as stated in [6]. These include the permeability of the metal (μ), the permittivity of the material (ε), the metal's conductivity (σ), and the frequency of operation (f). Furthermore, the shield's impedance varies depending on the polarization, as outlined in[7].

$$Z_j = \begin{cases} \frac{\eta}{\cos\theta_j}\text{Transverse Electric Polarization} \\ \\ \eta\cos\theta_j \text{ Transverse Electric Polarization} \end{cases} \qquad (2)$$

Using Snell’s law, we obtain $cos\ \theta_2$as [7]

$$cos\ \theta_j = \left[1 - \left(\frac{k1}{kj}\right)^2 sin^2\theta_1\right]^{1/2} \ldots (3)$$

whereθ_2 is the angle of refraction in the shield, and the wave numberk_2 is

$$k_j = \omega\left[\mu_j\left(\epsilon_j + \left(\sigma_j/j\omega\right)\right)\right]^{1/2} \ldots (4)$$

B Dual Shield

The concept of a dual shield involves two shielding sheets separated by an air gap, as depicted in Figure 3. This technique is commonly employed to enhance shielding effectiveness. In this scenario, there are three layers present, including the air gap.,η_2=Z_w, α_2=0, γ_2=$\frac{j2\pi}{\lambda o}$, then

$$p = \frac{16\mathrm{Zw}^2\eta1\eta2}{(\mathrm{Zw}+\eta1)^2(\mathrm{Zw}+\eta2)^2}\ldots (5)$$

$$Z(l_2) = \eta_3\frac{\mathrm{Zw}\cosh\gamma3l3+\eta_3 sinh\gamma3l3}{\eta3\cosh\gamma3l3 + \mathrm{Zw}\sinh\gamma3l3}H(0)\ldots (6)$$

$$Z(l_1) = Z_w\frac{Z(l2)cos\beta ol2+jZ_w sinh\beta ol2}{Z_w cos\beta ol2 + jZ(l2)sinh\beta ol2}E(0)\ldots (7)$$

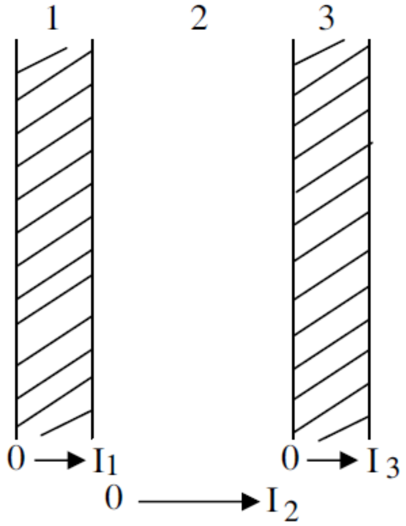

Figure 3. Dual Shield

$$q_1 = \frac{(\eta_1 - Z_w)[\eta 1 - Z(l1)]}{(\eta 1 + Z_w)[\eta 1 + Z(l1)]} \quad \text{---(8)}$$

$$q_2 = \frac{H_r}{H_i} = \frac{(Z_w - \eta 1)[Z_w - Z(l2)]}{(\eta 1 + Z_w)[Z_w + Z(l2)]} \ldots (9)$$

$$q_3 = \frac{(\eta 3 - Z_w)^2}{(\eta 3 + Z_w)^2} \quad \ldots (10)$$

The transmission coefficient across the interfaces is denoted by p, while q_1, q_2, and q_3 represent the reflection coefficients at the three interfaces. The impedances looking to the right of the $X=l_1$ and l_2 plane are represented by $Z(l_1)$ and $Z(l_2)$ respectively, and Z_w represents the impedance of the free space. The transmission coefficient across the double shield is given as

$$T=p[(1 - q1e^{-2\gamma 1l1})(1 - q2e^{-2j\beta ol2})(1 - q3\,e^{-\gamma 3l3})]^{-1} e^{-\gamma 1l1 - j\beta ol2 - \gamma 3l3} \quad \text{-- (11)}$$

And the shielding effectiveness is given by

$$S = -20 \log_{10}|T|. \quad \text{--(12)}$$

III. RESULTS

This paper examines the effectiveness of double shields made of copper, aluminum, and conductive polymer against both Transverse Electric and Transverse Magnetic waves at various angles of incidence. The shielding effectiveness is evaluated using Eq. (12) and the results are shown in Figures 4 to 7 for different polarization and angles of incidence. The total thickness of the double shields is either 10 mils or 40 mils.

The shielding effectiveness remains relatively constant with respect to the angle of incidence, with a variation of less than 2 dB for angles up to approximately 30 degrees, regardless of the polarization (perpendicular or parallel). Table 2 summarizes the total change in shielding effectiveness for angles of incidence ranging from 0 to 89 degrees.

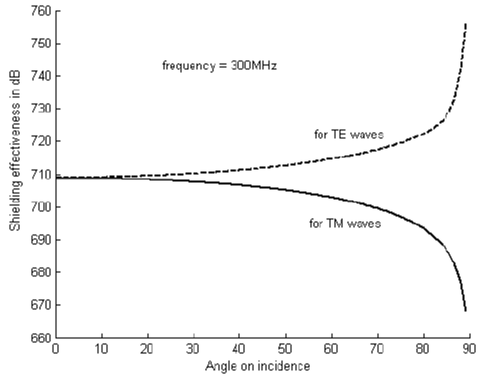

Figure 4: Variation of the shielding effectiveness with Angle of incidence of copper- free space - copperdouble shield with 5+10+5 mils thickness.

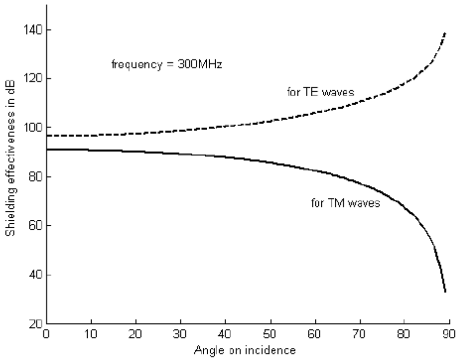

Figure 5: Variation of the shielding effectiveness with Angle of incidence of polymer E- free space – polymer Edouble shield with 5+10+5 mils thickness.

IV. CONCLUSIONS

The shielding effectiveness of double shields made of conductive polymer and copper is analyzed using transmission line theory. The shielding effectiveness is found to be higher for perpendicular polarization compared to parallel polarization. Furthermore, the shielding effectiveness increases with the angle of incidence for perpendicular polarization and decreases for parallel polarization.

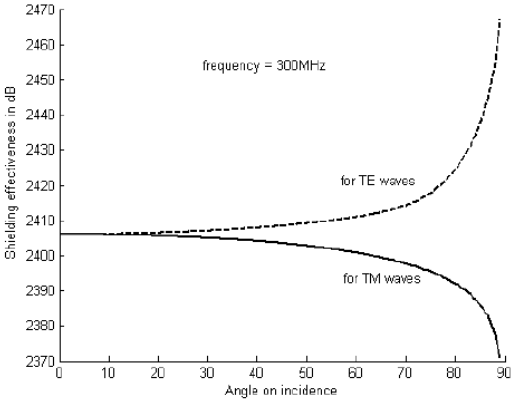

Figure 6: Variation of the shielding effectiveness with Angle of incidence of copper- free space - copper double shield with 20+10+20 mils thickness

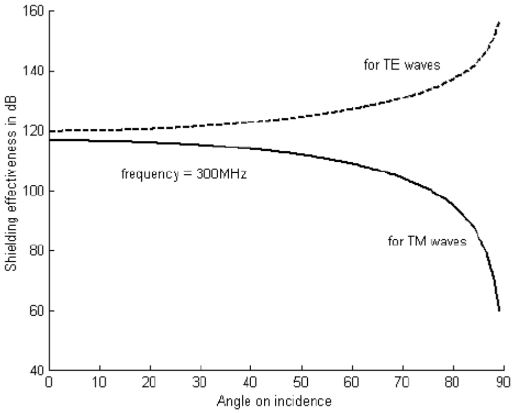

Figure 7: Variation of the shielding effectiveness with Angle of incidence of polymer E- free space – polymer E double shield with 20+10+20 mils thickness.

Conductive polymers can provide a lightweight and effective shielding alternative to metals, especially when considering their high conductivity-to-weight ratio. The analysis using transmission line theory can help in designing an electromagnetic shield to achieve the required shielding effectiveness against different angles of incidence of an electromagnetic wave.

From the comparison of the total variation in shielding effectiveness in dB for different polarizations for double shields made of different materials: copper and conductive polymer (polyE), with thicknesses of 10 mils and 40 mils.

For perpendicular polarization, the highest shielding effectiveness is achieved by the double shield made of copper with a total variation in shielding effectiveness of 50 dB for a thickness of 10 mils and 60 dB for a thickness of 40 mils. The double shield made of conductive polymer (polyE) has the lowest shielding effectiveness with a total variation of 42 dB for 10 mils and 40 dB for 40 mils.

For parallel polarization, the double shield made of copper still has the highest shielding effectiveness with a total variation of 41 dB for 10 mils and 36 dB for 40 mils. The conductive polymer double shield has the highest shielding effectiveness with a total variation of 60 dB for 10 mils and 58 dB for 40 mils.

Overall, copper dual shields perform better than the conductive polymer double shield, but the latter is a viable alternative to metals in lightweight shielding applications.

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