Shielding Effectiveness of Laminated Shields

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Abstract. *Shielding prevents coupling of undesired radiated electromagnetic energy into equipment otherwise susceptible to it. In view of this, some studies on shielding effectiveness of laminated shields with conductors and conductive polymers using plane-wave theory are carried out in this paper. The plane wave shielding effectiveness of new combination of these materials is evaluated as a function of frequency and thickness of material. Conductivity of the polymers, measured in previous investigations by the cavity perturbation technique, is used to compute the overall reflection and transmission coefficients of single and multiple layers of the polymers. With recent advances in synthesizing stable highly conductive polymers these light-weight mechanically strong materials appear to be viable alternatives to metals for EM1 shielding.*

Keywords

Laminated shield, shielding effectiveness, frequency, conductive polymer.

1. Introduction

Some of the most difficult shielding problems occur in mobile systems in which many transmitters, receivers, and other sensitive equipment must be mounted closely together, and weight is minimized. Increased electronic requirements of future vehicles for integration of more electronic functions within one compact enclosure accentuate these problems. Predicting the shielding effectiveness of any enclosure such as equipment package or screening the room is difficult. Therefore any theoretical treatment for problems of this nature is necessarily approximate only. A number of light-weight polymers, intrinsically nonconductive but made conductive upon doping, have been studied in recent years [1-3]. These materials have several potential applications, such as electromagnetic interference (EMI) shielding, microwave absorbers, gas sensors, display units, junction devices, etc. [4], [5]. Doping a pristine polymer with p-type or n-type impurities increases its conductivity by several orders of magnitude over a wide temperature range. The properties like conductivity variation over 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 polymeric materials, namely polyacetylene and poly-p-phenylene-benzobis-thiazole (PBT), have been doped with iodine either electrochemically or by ion implantation, and their conductivity measured using the cavity perturbation technique [2], [3]. Conductive polymers are useful as shielding materials in applications involving high data-rate electronics (e.g., supercomputers), and in aerospace applications, where weight is a constraint. In this paper, an extension of plane-wave transmission line theory of shielding analysis of laminated shields with conductive polymers is presented.

The measured values of polyacetylene [1], [2] are also included in Tab. 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] and ε_0 is the permittivity of free space. The conductivity is found to increase with the dopant levels, with the Polymer E (Tab. 1, Mnemonic E) doped electrochemically with 80% by weight of iodine, yielding the highest conductivity. A comparison to the dc conductivity, measured by the four-probe method, indicates that the microwave conductivity at room temperature (300 K) is within a small percentage of the dc result. Therefore it can be used over a wide frequency range.

We study in this paper, the plane wave shielding behavior of laminated shields constructed with this polymer and materials like copper and aluminum as a function of frequency. The well-known formulation of reflection and transmission by a planar multilayer is applied to compute the shielding effectiveness S of the polymers [6-8]. In this paper the analysis is done using the material polyacetylene, mentioned with mnemonic E in Tab. 1. This material is represented in this paper as Polymer E.

2. Shielding Effectiveness

The electric field and magnetic field are related by the wave impedance, which is defined by the ratio of tangential component of E-field and H-field [6], [7]. For predominantly E-field, the wave impedance is very large and for predominantly H-field, the wave impedance is very small. Quantitative values of E-field and H-field impedances can be expressed by considering the sources as a small electric dipole or a small magnetic loop, respectively. In the near field region r of the source ($r << \lambda_0/2\pi$), the wave impedances for the predominantly E and H fields can be approximated, respectively, by the following expressions [6]

$$Z_E = \frac{Z_0\lambda_0}{2\pi r} >> Z_0, \quad Z_H = \frac{Z_0 2\pi r}{\lambda_0} << Z_0. \tag{1}$$

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 - j I I58
C	Polyacetylene cis-($CHI_{0.045})_x$	Electrochemical; 4.5% I2 by weight	5 - j607
D	Polyacetylene Trans-$(CHI_{0.045})_x$	Electrochemical; 4.5% I2 by weight	5 - j909
E	Polyacetylene cis-$(CHI_{0.8})$x	Electrochemical; 80% I2 by weight	5 - j4.E5

Tab. 1. Measured complex dielectric constant $\varepsilon_r = \varepsilon' - \varepsilon''$ of Conductive Polymer Films Doped with Iodine various levels. The frequency of measurement is f_0 = 9.375 GHz, i.e. the centre frequency of X-band.

At sufficiently large distance $r > D^2/2\lambda_0$ or $r > \lambda_0/2\pi$ from the source, the electromagnetic waves become plane-waves with wave impedance equal to the characteristic impedance (Z_0), where D is the size of the source. The impedance of shield material is [7]

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma}} = (1+j)\sqrt{\frac{\pi\mu f}{\sigma}} \tag{2}$$

where μ is the permeability of the metal, and σ the conductivity of the metal.

When two mismatched must be considered as in a planar sheet, the net transmission coefficient is the product of the transmission coefficients across the two boundaries [8].

$$p = p_E = p_H = p_E(0).p_E(1) = p_H(0).p_H(1) = \frac{4Z(l)\eta}{(\eta + Z(l))^2} \tag{3}$$

When successive re-reflections are considered, the transmission coefficients across the sheet are

$$T_H = \frac{H(l)}{H_i} = \frac{H(l)H(0)}{H(0)H_i}, \quad T_E = \frac{E(1)}{E_i} = \frac{Z(i)H(l)}{Z_w H_i} = \frac{Z(l)}{Z_w}T_H \tag{4}$$

where $E(0)$, $H(0)$, and $E(1)$, $H(1)$ are the actual values at interfaces 0 and l, respectively, with reflection taken into account; E_i, H_i are the field strengths of incident wave and Z_w is the impedance of the incident wave. The transmission coefficients of electric and magnetic fields are given by $T_E = T_H = T$ and it is expressed as

$$T = p(1 - qe^{-2\gamma l})^{-1}e^{-\gamma l} \tag{5}$$

where q is the reflection coefficient. By definition, the total shielding effectiveness is

$$\begin{aligned} S &= 20\log_{10}|T| \\ &= 20\log_{10}\left|\frac{(1-qe^{-2\gamma l})e^{-\gamma l}}{p}\right| \\ &= 20\log_{10}|e^{-\gamma l}| + 20\log_{10}|p| + 20\log_{10}|1-qe^{-2\gamma l}| \\ &= A + R + C \end{aligned} \tag{6}$$

where A, R, C are the absorption loss, reflection loss and the correction term due to successive re-reflection and this expression is the complete formula for shielding effectiveness of a single shield.

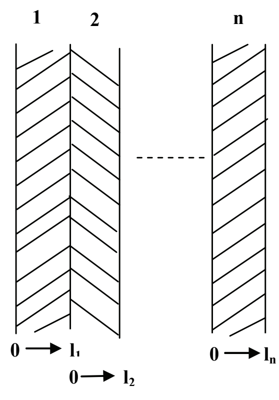

Fig. 1. Multilamina shielding.

To develop the theory for any number of multiple sheets or laminations of a single sheet, illustrated by Fig. 1, the approach beginning with (4) may be extended. Let the constants of a typical sheet be η_m, γ_m, l_m; let the impedance looking to the right of each section be $Z\,(l_m)$; let Z_w be the characteristic impedance of the incident wave. Then the transmission coefficient for E or H field is

$$T = p[(1 - q_1 e^{-2\gamma_1 l_1})(1 - q_2 e^{-2\gamma_2 l_2}). \\ ....(1 - q_n e^{-2\gamma_n l_n})]^{-1} \times e^{-\gamma_1 l_1 - \gamma_2 l_2 \;\dots\; -\gamma_n l_n} \tag{7}$$

where

$$p = \frac{2\eta_0 . 2\eta_1 .... 2\eta_n}{(Z_w + \eta_1)(\eta_1 + \eta_2).....(\eta_n + Z_w)}, \tag{8}$$

$$q_m = \frac{(\eta_m - \eta_{m-1})[\eta_m - Z(l_m)]}{(\eta_m + \eta_{m-1})[\eta_m + Z(l_m)]}. \tag{9}$$

3. Results

In this paper laminated shields are considered as the combination of three layers constructed using conductive polymer i.e. polyacetylene with mnemonic E listed in Tab. 1 and conducting materials like copper and aluminum. The computed results were achieved using MATLAB 6.5.

The shielding effectiveness of laminated shield is calculated against frequency using (6). The frequency dependence of the shielding effectiveness S computed for laminated shields constructed with thin sheets of the polymer with mnemonic E listed in Tab. 1 and conducting materials like copper and aluminum. These laminated shields considered as the combinations of copper-polymerE-copper, polymerE-copper-polymerE, aluminum-polymerE-aluminum and polymerE-aluminum-polymerE with the thickness of 1 mm and 10 mil. The frequency dependence of shielding effectiveness of all four types of laminated shields with total thickness of 1 mm and 10 mils are represented in Figs. 2 and 3. In this analysis, the important consideration is that each laminated shield is constructed with equal thicknesses of polymer E and metal.

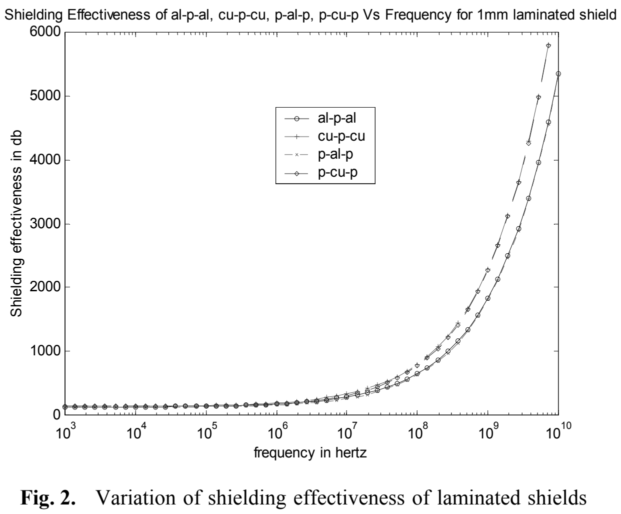

Fig. 2. Variation of shielding effectiveness of laminated shields of al-polymerE-al, cu-polymerE-cu, polymerE-al-polymerE and polymerE-cu-polymerE with thickness 1 mm.

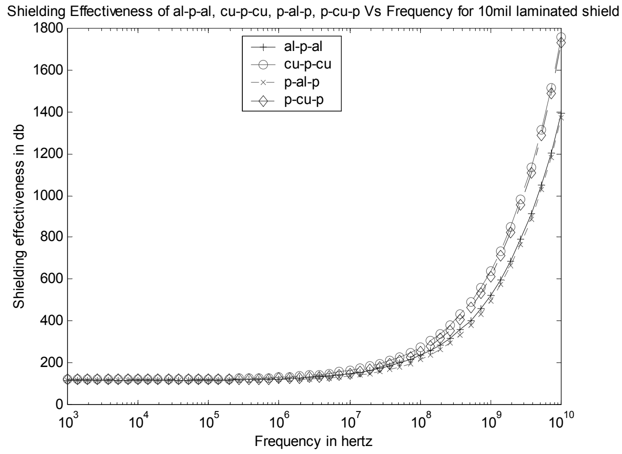

Fig. 3. Variation of shielding effectiveness of laminated shields of al-polymerE-al, cu-polymerE-cu, polymerE-al-polymerE and polymerE-cu-polymerE with thickness 10 mil.

The behavior of the shielding effectiveness for all four types of single shields with total thickness of 1 mm and 10 mils are depicted in Figs. 4 and 5.

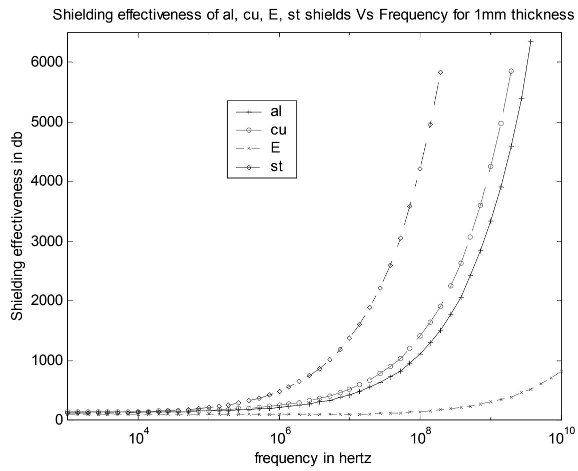

Fig. 4. Variation of shielding effectiveness of single shield of Al, Cu, polymer E and steel with thickness 1 mm.

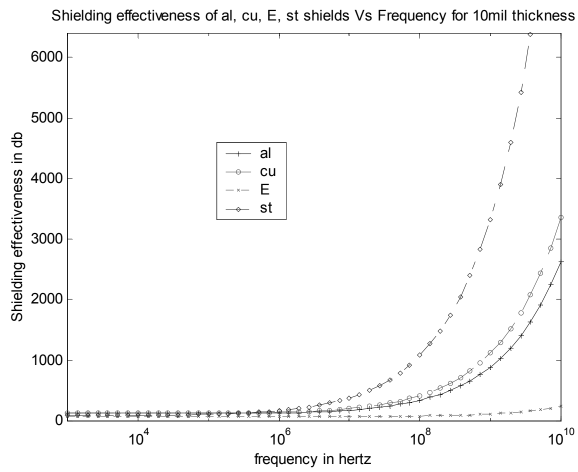

Fig. 5. Variation of shielding effectiveness of a single shield of Al, Cu, polymer E and steel with thickness 10 mil.

4. Conclusions

In this paper, we evaluated the shielding effectiveness of laminated shields constructed with conductive polymer, metals like copper, aluminum and steel using transmission line theory. The conductivity of the polymer is measured by the cavity perturbation technique [3]. The computed results of the transmitted field as a function of frequency for different combinations of materials indicate that the laminated shields perform well as EM1 shields over a substantial frequency band.

All four laminated shields exhibit very less shielding effectiveness (approximately 100 dB) up to 1MHz and after 1 MHz there is a drastic increase in shielding effectiveness according to the thickness of the shield. At very high frequencies the shielding effectiveness of laminated shields is approximately equal to infinity (for 1 mm thickness).

The shielding effectiveness will approach infinity at very high frequency in the case of single shield with 1mm thickness. The single shield of same thickness i.e. 1 mm, constructed with polymer E (conductive polymer with increased conductivity) will exhibit lower shielding effectiveness (approximately one sixth) with that of laminated shield.

When we compare metals with polyacetylene on a basis of the conductivity/weight ratio CW, it can be seen that laminated shields constructed with the combination of conductive polymers and metals like copper and aluminum have already reached the same level as many metals. Therefore, laminated shields with conductive polymers appear to be a viable alternative to metals in lightweight shielding applications.

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