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Analysis of Shielding Effectiveness of Perforated Shields with Multiple Rectangular Apertures

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Abstract: Shielding is a widely used technique to make any electronic device compatible to Electro Magnetic Interference (EMI). In this present work an efficient method is introduced for analyzing and calculating shielding effectiveness of perforated shields. The phenomenon of electromagnetic interference is presented for metallic shields. The properties and shielding effectiveness of a special class of polymers called 'conducting polymers' are also presented here. The selection of the type of shielding material depends on the frequency of operation. In this work perforated shields with normal incidence of Electromagnetic (EM) waves, are analyzed using Transmission Line theory for rectangular multiple apertures. This analysis is presented to keep the design problems under scope for designing EMI systems.

Keywords: Electromagnetic Interference, Shielding effectiveness, Perforated shields, Rectangular Apertures

I. INTRODUCTION

Electromagnetic Interference is the degradation in performance of any electronic device due to an electrical disturbance caused by an external source. Compatibility refers to the proper functioning of the electrical device (system) under EMI and not be a source of it. Shielding is a technique in which either the source of EMI or victim is enclosed with a shielding material so that it doesn't cause EMI and not get affected to it. Generally perfect enclosing with a shield is practically not possible. A shield contains apertures for air inlets, electrical contacts etc. In such cases the practical shielding effectiveness of the shield differs greatly for the measured value, neglecting apertures. In this work, an efficient and accurate method is presented for analyzing and calculating the shielding effectiveness of shields with apertures. This analysis also represents the properties of a class of polymers called 'conducting polymers', pertaining to their shielding effectiveness.

II. MECHANISM OF SHIELDING

Mechanism of shielding works on two basic principles: reflection and absorption. Reflection occurs when there exists a large mismatch between characteristic impedance of the incident wave to the impedance of the shielding material. This phenomenon exists for near electrical fields. At near electric fields, E-field strength is more compared to electric field, and so the wave impedance η is high. Generally, impedance of the shield is low. Therefore, most of the incident interfering wave gets reflected due to mismatch in impedances.

Absorption phenomenon is used when the reflection loss is not considerably high. When a wave travels through a conducting material, it is attenuated. The amount of attenuation depends on the conductivity of the conductor. Skin depth is the distance into the shield at which the field strength decreases to $1/e$ of the field that is incident on it. So, the shield should be at least 4 skin depths of thickness.

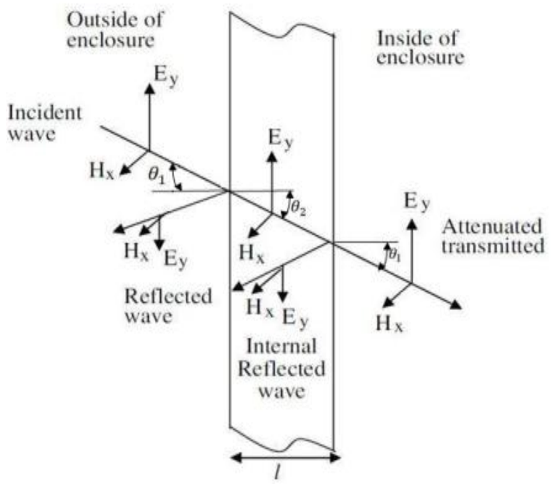

Fig. 1: Representation of shielding mechanisms for plane-waves

III. CONDUCTING POLYMERS

Conducting polymers are intrinsically non-conducting, but are made conducting upon doping with a particular dopant (Ex: Iodine). These have potential applications in EMI shielding, as microwave absorbers, gas sensors etc. The properties like conductivity variation over a wide temperature range, high mechanical strength made them good shielding materials at high frequencies. Two polymers Polyacetylene and poly-p-phenylene-benzobis-thiazole (PBT) are presented in this paper, and their conductivities according to the level of doping. Conductivity is found to increase with doping level. The measured values of relative complex permittivity ($\varepsilon_r = \varepsilon' - \varepsilon''$) of the two conducting polymers with their doping level have been presented in table 1. Conductivity is give

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by $\sigma = 2\pi f_0 \varepsilon_0 \varepsilon''$ where f_0 is the resonant frequency of the cavity at which the values are measured, which is 9.375 GHz, ε_0 is the permittivity of the free space.

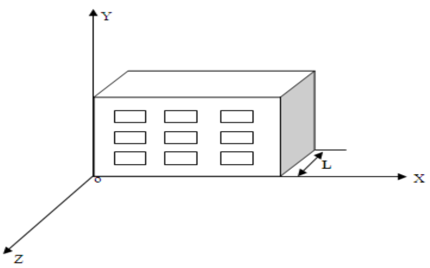
Mnemonic	Material	Doping	$\varepsilon_r=\varepsilon'-\varepsilon''$
A	PBT	Ion implantation to a fluence of 10^{16} ions/cm^2	3–j838
B	PBT	Ion implantation of a fluence of 10^{17} ions/cm^2	3−j1158
C	Polyacetylene Cis- $(CHI_{0.045})_x$	Electrochemical; 4.5% I_2 by weight	5−j607
D	Polyacetylene Trans-$(CHI_{0.045})_x$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

Table 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 the X-band.

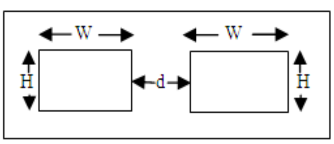
The materials are represented with pneumonic from A to E. Polyacetylene with iodine doped to 80%, represented with E is been used for analysis in this paper. Conductive polymers are useful as shielding materials in applications involving high data-rate electronics (e.g., supercomputers) and in aerospace applications where weight is a constraint.

IV. RECTANGULAR WAVEGUIDE AND APERTURE ANALYSIS

Waveguides can be constructed to carry waves over a wide portion of the electromagnetic spectrum, but are especially useful in the microwave and optical frequency ranges. Depending on the frequency, they can be constructed by either conductive or dielectric materials. Because rectangular waveguide have a much larger band width over which only a single mode can propagate, standards exist for rectangular waveguides but not for circular waveguides [8, 11].



(a) Multiple Aperture Consideration



(b) Horizontal Aperture Measurements
Fig. 2. Rectangular Aperture

A perforated shield with horizontal multiple apertures is considered as in Fig. 2 with L as the thickness of the aperture (mm), 'W' as the width of the aperture(mm), 'H' as height of the aperture (mm) and 'd' as distance between the apertures (mm).

A. *Aperture attenuation Loss (A in dB)*

The A factor represents attenuation (at frequencies below cutoff) as the wave passes through an aperture. For rectangular openings W is the dimension perpendicular to the incident field.

The Effectiveness of a shield as being the ratio of the magnitude of electric (magnetic) field that is incident on the barrier to the magnitude of the electric (magnetic) field that is transmitted through barrier

Attenuation in material is given by

$$A = 20\, log e^{-aL} \qquad \text{--- (1)}$$

The Wave will be attenuated when $\omega^2\mu\varepsilon < (f_c)^2$ and attenuation

$$\therefore \alpha = \pm\omega\sqrt{\mu\varepsilon}\sqrt{\left(\frac{f_c}{f}\right)^2 - 1} \qquad \text{--- (2)}$$

this means that if the operating frequency is below the cutoff frequency, the wave will decay exponentially with respect to a factor of $-\alpha$ and there will be no wave propagation because the propagation constant is a real quantity.

The cutoff wavelength and frequency for the TE_{10} mode [7]

$$\lambda_c = 2W \qquad f_c = \frac{v}{\lambda_c} = \frac{v}{2W}$$

$$\text{Then } \alpha = \omega \times \frac{1}{v} \times \sqrt{\left(\frac{f_c}{f}\right)^2} - 1 = \frac{2\pi f_c}{v0} = \frac{\pi}{W}$$

$$\therefore A = 20\log e^{\left(\frac{\pi}{W}\right)L} = 27.3\,\frac{L}{W}\,\text{dB} \qquad \text{--- (3)}$$

where L is aperture length and W is aperture width.

B. *Aperture Reflection Losses (R in decibels)*

The Reflection losses are an interaction between the impedance of an incident wave and the waveguide. Hence, the resulting charts for electric (E), magnetic (H), and plane wave (P) fields are incident upon rectangular apertures.

Wave impedance in wave guide (TE Mode)

$$Z = \frac{\eta_0}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \qquad \text{--- (4)}$$

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}\ , f_c = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\frac{m^2}{a^2}+\frac{n^2}{b^2}}$$

for TE_{10} dominant mode

$$f_c = \frac{1}{2\sqrt{\mu\epsilon}}\frac{1}{W} \qquad a = W \qquad f_c \ll f$$

The aperture characteristic impedance is then given by

$$Z_a = \sqrt{\frac{\mu}{\epsilon}} \times \frac{1}{\sqrt{1-\left(\frac{1}{4\mu\epsilon W^2}\times\frac{1}{f^2}\right)}}$$

$$= \mu 2Wf = \frac{\mu 2\pi Wf}{\pi} = \frac{j\omega\mu_0 W}{\pi}$$

Hence the Rectangular aperture Characteristic Impedance is [7]

$$Z_a = \frac{j\omega\mu_0 W}{\pi} \qquad \text{---- (5)}$$

The Wave impedance for Magnetic and Electric Fields

$$Z_{wH} = j\omega\mu_0 r \quad \text{if } r < \frac{\lambda}{2\pi} \qquad \text{--- (6)}$$

$$Z_{wE} = j.\frac{1}{\omega\varepsilon_0}.r = \frac{j}{\omega\varepsilon_0} r \qquad \text{--- (7)}$$

$K = \frac{Z_a}{Z_w}$ = the ratio of the Aperture characteristic impedance to the impedance of the incident wave [7].

$$K = \frac{\omega}{\pi r} \qquad \text{Magnetic incident field} \qquad \text{--- (8)}$$

$$K = 4\pi\mu_0\varepsilon_0 f^2 Wr \quad \text{Electric incident field} \qquad \text{--- (9)}$$

C. Correction factor for Aperture reflection Losses (B in decibels)

B is a correction factor to reflection losses when A is less than 10 db. In other aspects it is similar to R.

By definition total shielding effectiveness [6]

$$S = -20\log_{10}|T|$$

Where the correction term due to successive to successive re-reflection is defined as

$$B = 20\log_{10}\left|1 - \frac{(k-1)^2}{(k+1)^2} e^{-2\gamma l}\right| \qquad \text{--- (10)}$$

D. Correction factor for opening per unit square (C_1)

It can be used for all perforated shields. The amount of power transferred through a perforated shield is a function of the number of openings, And applicable when test antennas are far from the shield in comparison to distance between hold in the shield [7].

$$C_1 = -10\log(a.n) \qquad \text{--- (11)}$$

Where 'a' is the hole area and 'n' is number of holes for exposed area.

E. Correction factor for conductor penetration at low frequencies (C_2)

It can be used for all screen-type perforated shields. This factor assumes that the waveguide depth for screens [7].

$$C_2 = -20\log_{10}\left[1 + \frac{35}{(\pi f d^2 \sigma\mu)^{1.15}}\right] \qquad \text{--- (12)}$$

Where'd' is the conductor width between holes

F. Correction factor for coupling between closely spaced, shallow holes (C_3)

Shielding effectiveness has been found to increase when holes area closely spaced and the opening depth is small compared to hole size [7].

$$C_3 = 20\log_{10}\left[\frac{1}{\tan h\left(\frac{A}{8.686}\right)}\right] \qquad \text{--- (13)}$$

The total Shielding effectiveness

$$\therefore SE = A + R + B + C_1 + C_2 + C_3 \text{ in db} \qquad \text{--- (14)}$$

V. ANALYSIS AND RESULTS

The results and analysis of shielding effectiveness is carried out for various perforated shields with materials, like Aluminum, Copper and conductive Polymers. The Shielding effectiveness variation with frequency of all three types of perforated shields for single and multiple apertures is observed by considering aperture area of (W*H) as 40*20 mm, thickness of material 'L' as 1mm, distance between apertures 'd' as 0.005m and source to shield distance 'r' as 1m. The variation of the Shielding effectiveness as a function of frequency for Aluminum, Copper and Conductive Polymer shields for Electric field is depicted in Figures 5.1 to 5.3. The shielding effectiveness reduced to minimum level when the signal frequency is equal to the cut-off frequency (f_c =1.19 GHz) of an aperture. Beyond the cut-off frequency again the

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shielding effectiveness will increase to the maximum level with frequency.

Fig 5.4 to 5.6 will represent shielding effectiveness of perforated shields for Magnetic fields. The shielding effectiveness is increased up to 105 dB with frequency at lower range for all the materials, and remained constant for high frequency range.

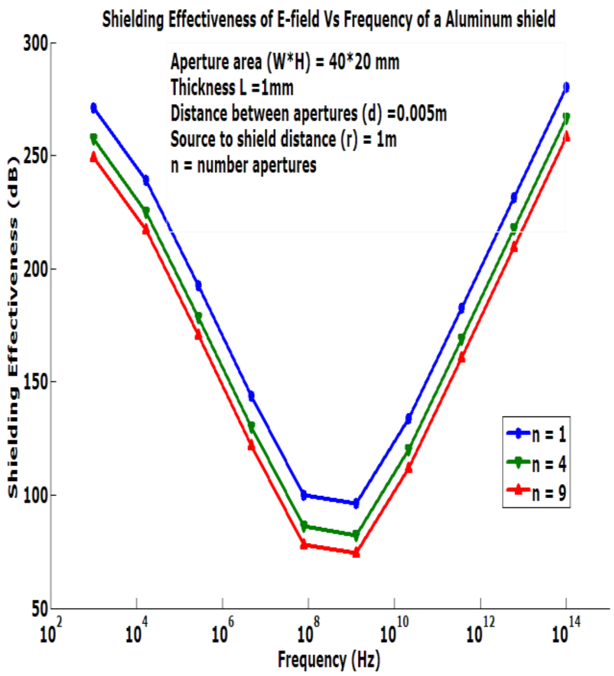

Fig 5.1: The variation of the Shielding effectiveness as a function of frequency for Aluminum perforated shield with multiple apertures (n) for Electric field.

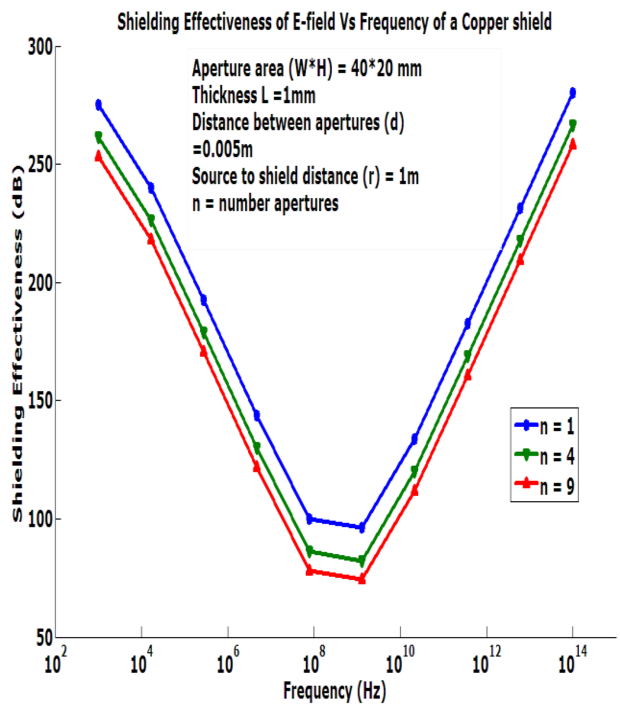

Fig 5.2: The variation of the Shielding effectiveness as a function of frequency for Copper perforated shield with multiple apertures(n) for Electric field.

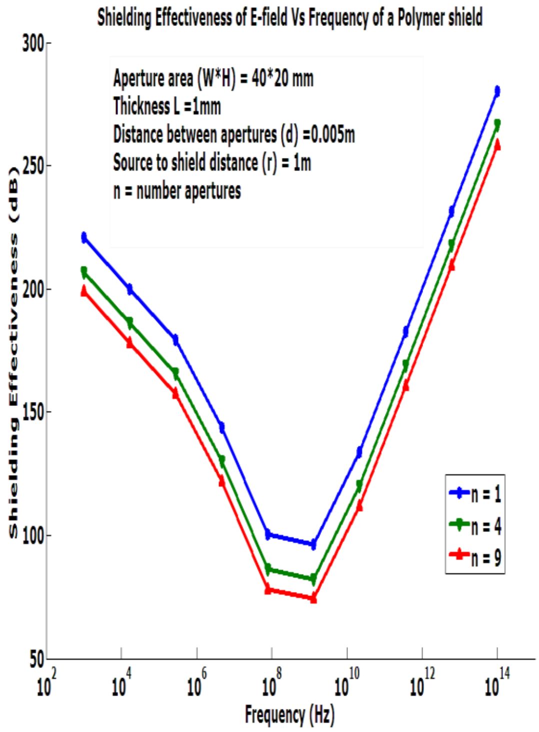

Fig 5.3: The variation of the Shielding effectiveness as a function of frequency for Polymer-E perforated shield with multiple apertures (n) for Electric field.

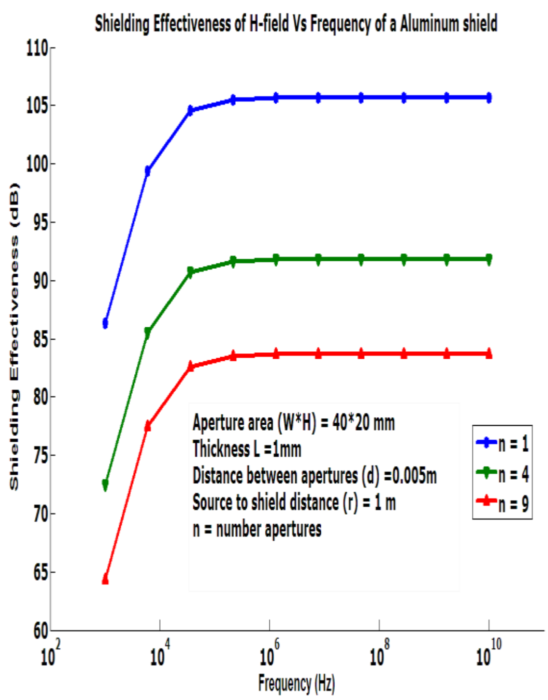

Fig 5.4: The variation of the Shielding effectiveness as a function of frequency for Aluminum perforated shield with multiple apertures (n) for Magnetic field.

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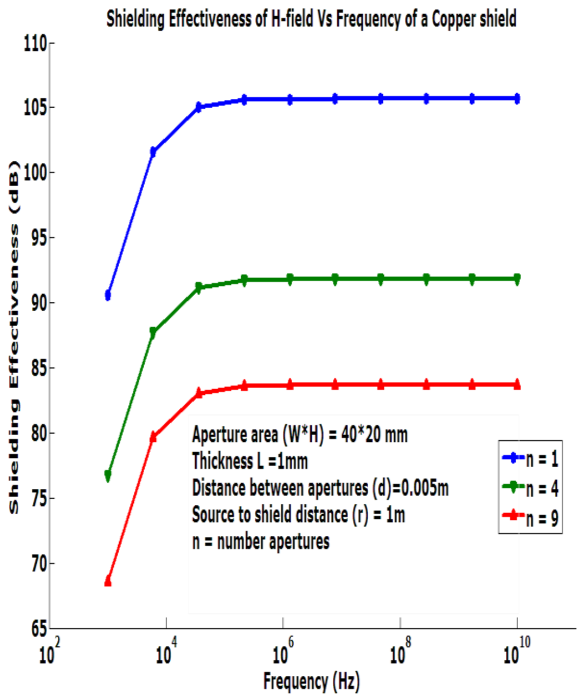

Fig 5.5: The variation of the Shielding effectiveness as a function of frequency for Copper perforated shield with multiple apertures (n) for Magnetic field.

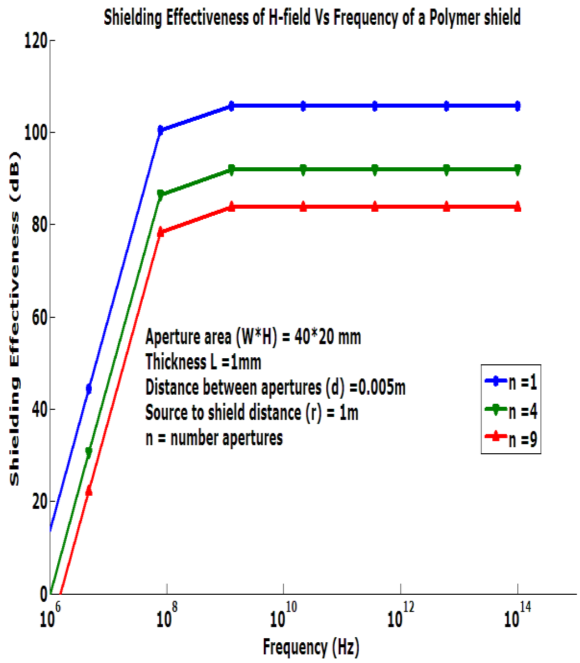

Fig 5.6: The variation of the Shielding effectiveness as a function of frequency for Polymer –E perforated shield with multiple apertures (n) for Magnetic field.

VI. CONCLUSIONS

In this analysis, the shielding effectiveness of single perforated shields constructed with conductive polymer, metals such as copper and aluminum is evaluated using transmission line or wave impedance theory. The better Shielding effectiveness will be obtained for minimum number of apertures, both for Electric and Magnetic fields. A conductive polymer has a very high conductivity to weight ratio and thus, it can yield same shielding effectiveness performance as that of a conductor with less weight at high and low frequency ranges

In the above results, Copper and Aluminum materials exhibit better shielding effectiveness because of their high conductivity. Polymer-E provides good shielding effectiveness with same frequency considerations. This analysis is to place the design problems within the scope of ability of all who are engaged in EMI systems design.

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