IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 10, Issue 6, Ver. II (Nov - Dec .2015), PP 36-39
www.iosrjournals.org

Shielding Effect Analysis of Em Waves for Oblique Incidence in Double Shields

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Abstract: *Shielding effectiveness analysis of double shields with conductors using plane-wave theory are carried out as a function of angle of incidence. The plane wave shielding effectiveness of new combination of these materials is evaluated for the double shields. Stable highly conductive materials , with characteristics of light-weight, mechanically strong materials are considered for shielding the EMI. The analysis is done at a particular frequency for double shields of aluminum and copper polymers.*

Keywords: *Shielding effectiveness; double shields, Oblique incidence, Electromagnetic Interference; EMI*

I. Introduction

The source of EMI may be artificial or natural, Conducted or radiated, that carries rapidly changing electrical currents. The interference may limit the effective performance of the device by either interruption or obstruction or degradation. Shielding protects the equipment by preventing the coupling of undesired radiated electro-magnetic energy. Electromagnetic shields are designed and developed to minimize the electromagnetic interference and to improve compatibility of the circuits (EMC). Various types of electromagnetic shields like single, double and multi layered conductors sandwiched between conductive layers etc. are proposed whose design concentrates on optimizing performance on shielding effectiveness.

In mobile communication applications many transmitters, receivers, and other sensitive equipment are mounted closely and shielding against EMI is a difficult problem in such applications. 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.

An extension of plane-wave transmission line theory of shielding analysis of different shields with conductors is presented in this paper. The plane wave shielding behavior of the double shield constructed with materials like copper and aluminum for oblique incidence is analyzed in the work.

II. Angle Of Incidence

The reflection and transmission of the electromagnetic waves for single layered dielectric is considered for a general incident angle as shown in Figure 2.

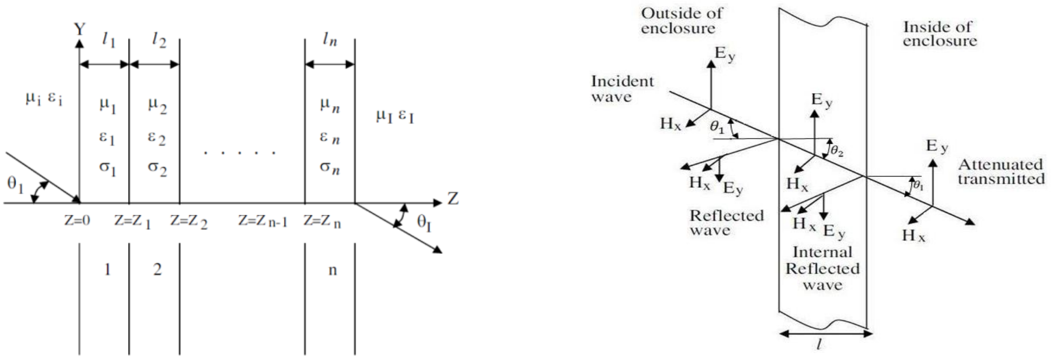

Figure 2. Oblique incidence of an EM wave on multi-almina, n is the number of layers, and θ_1 is the incident angle.

The *z*-axis is the direction of stratification. θ_1 denotes the incident angle. Considering for the single interface of thickness *l*, E_i, H_i be the incident electric and magnetic fields, E_r, H_r be the reflected electric and magnetic fields due to the impedance mismatch between the two media and E_t, H_t be the transmitted electric and magnetic fields strengths respectively as shown in the figure 1. Electric field components $Ey = Ez = 0$ for Transverse electric wave, and magnetic field components $Hy = Hz = 0$ for Transverse Magnetic wave respectively.

The impedance of the shield material is [6] given by

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

where, μ is the permeability of the metal, ϵ is the permittivity of the material, σ is the conductivity of the metal and f is the frequency of operation. The impedance of the shield is varied according to the polarization as follows [7]

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

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

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

where θ_2 is the angle of refraction in the shield, and the wave number k_2 is

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

A. Double Shield

A double shield is developed by considering two sheets separated by an air gap as shown in Figure 3. Generally, double shields are used to improve the shielding effectiveness. Considering the importance of two shielding sheets separated by an air space, n=3, $\eta_2=Z_w$, $\alpha_2=0$, $\gamma_2=\frac{j2\pi}{\lambda o}$, then

$$p = \frac{16Zw^2\eta 1\,\eta 2}{(Zw+\eta 1)^2(Zw+\eta 2)^2} \qquad \text{… (5)}$$

$$Z(l_2) = \eta_3\frac{Zw\cosh\gamma 3l3 + \eta_3\sinh\gamma 3l3}{\eta 3\cosh\gamma 3l3 + Zw\sinh\gamma 3l3}H(0) \qquad \text{… (6)}$$

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

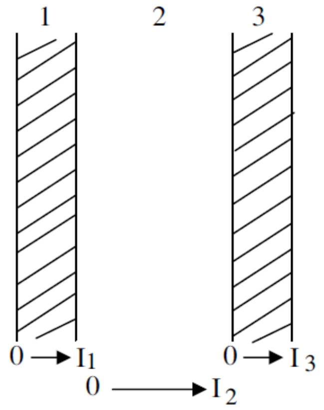

Figure 3. Double Shield

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

$$q_2 = \frac{H_r}{H_i} = \frac{(Z_W - \eta 1)[Z_W - Z(l2)]}{(\eta 1 + Z_W)[Z_W + Z(l2)]} \qquad \text{… (9)}$$

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

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

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

And the shielding effectiveness is given by

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

III. Results And Discussion

Using equations [1-12], shielding effectiveness for laminated conducting sheets is evaluated for copper, and aluminum materials of double shield. The angle of incidence of both Transverse Electric waves (TE) and Transverse Magnetic (TM) waves are considered for evaluating the shielding effectiveness. The shielding effectiveness is calculated against angle of incidence using Eq.(12). The variation of shielding effectiveness as a function of incident angle total thickness of (5+10+5) mils and (20+40+20) mils of aluminum and copper materials are presented in Fig. 4 & 5.

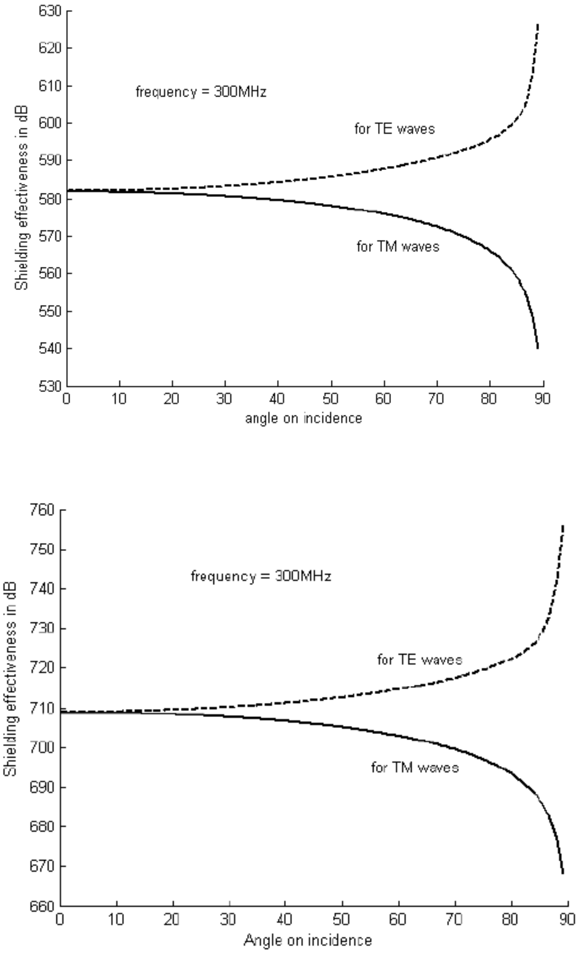

Figure 4: Variation of the shielding effectiveness with incident angle for – 1) Aluminum-free space-aluminum double shield and- 2) copper- free space - copper double shield with 5+10+5 mils thickness.

It is observed from the results that the shielding effectiveness is almost independent of the angle of incidence (less than 2 dB change) for angles from normal incidence upto about 30° in both cases of perpendicular and parallel polarizations.

IV. Conclusions

The shielding effectiveness of double shields constructed with conductive metals such as copper and aluminum is evaluated using transmission line theory. Better shielding is possible for Perpendicular polarization than for parallel polarization. Shielding effectiveness increases with the angle of incidence for perpendicular polarization and decreases for parallel polarization. From the above analysis an electromagnetic shield can easily be designed to achieve required shielding effectiveness against angle of incidence of an electromagnetic wave.

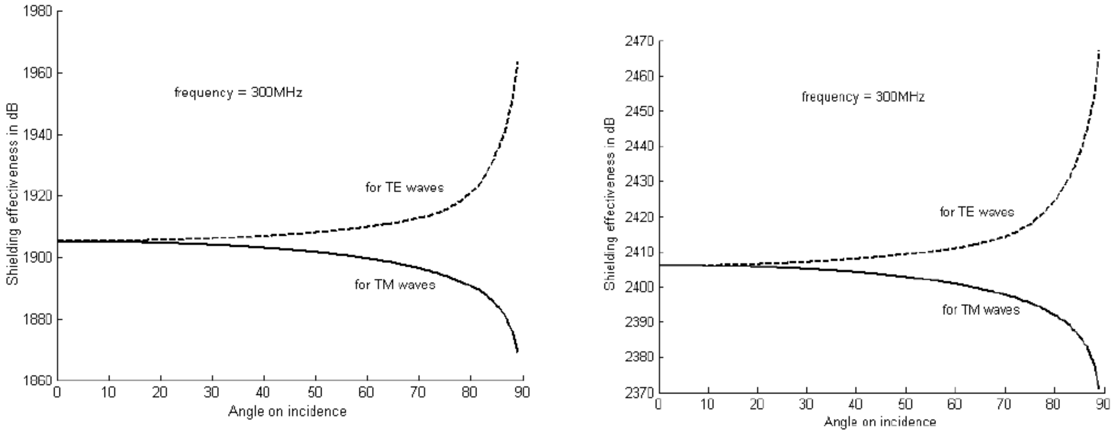

Figure 6: Variation of the shielding effectiveness with incident angle for – 1) Aluminum-free space-aluminum double shield and- 2) copper- free space - copper double shield with 20+10+20 mils thickness

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