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Determination of reflection loss, absorption loss, internal reflection and shielding effectiveness of a double electromagnetic shield of conductive polymer

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Abstract
In this paper, a new approach is proposed by using the transfer matrix method to modelling the double electromagnetic shield. A development of calculation will be presented to calculate the reflection loss, the absorption loss, the internal reflection and the shielding effectiveness of this kind of shield. An analysis of these four quantities of electromagnetic double shield of a conductive polymer (polyacetylene cis-$(CHI_{0.8})_x$) associated to a classic conductor (Aluminum) will be carried out in function of the electromagnetic wave frequency at normal and oblique incidences for the two combinations: conductive polymer – aluminium and aluminium – conductive polymer.

Keywords: Conductive polymer, Reflection loss, Absorption loss, Internal reflection**,** Shielding effectiveness.

Introduction
The extensive development of electronic systems and telecommunications has led to major concerns regarding electromagnetic pollution [1]. Although electric equipments make our life more convenient, the electromagnetic radiation restricted the continuable development of our society because of their pollution to environment, harm to human being and can produce interference, malfunction, and irreversible damage in parts of electronic equipment [2]. Thus, EMI shielding effectiveness is needed to protect electronics instrument from electromagnetic interference (EMI) which is emitted by computer circuit, radio transmitters, cellular phones, electric motors and overhead power lines [3]. Motivated by environmental questions and by a wide variety of applications, the quest for materials with high efficiency for mitigating electromagnetic interference (EMI) pollution has become a mainstream field of research [1]. As a result, the shield tends to be electrically conducting [4]. The shielding materials must possess good electrical conductivity and dielectric constant. Metals are well suited for many EMI shielding applications. However, metals have their own shortcomings such as heavy weight, susceptibility to corrosion, wear and physical rigidity [5]. The development of electromagnetic interference (EMI) shielding materials has attracted great interest in exploitation of materials with superior shielding properties in a wide frequency range, low density, and excellent mechanical and electrical propertie [6]. The conductive polymers have been considered for EMI shielding applications because of their design flexibility, ease of processing, lightweight and improved durability compared to conventional materials in the market like metallic shields and coatings [7, 8].Today there are over 25 conductive polymer systems [9]. The early work on conductive polymers was triggered by the observation that the conductivity of polyacetylene, a polymer that is normally only semi-conducting at best, increases by 10 million-fold when polyacetylene is oxidized using iodine vapour [10, 11]. The underlying phenomenon was named ‘‘doping’’ and is essential for the conductivity of polymers, as only through this process do they gain their high conductivity [12, 13]. In previous investigations, thin films of polyacetylene, have been doped with iodine either electrochemically or by ion implantation [14, 15], and their conductivity is measured using the cavity perturbation technique [16], it given by $\sigma = 2\pi f_0 \varepsilon_0 \varepsilon''$, where $f_0 = 8{,}9\,GHz$ is the resonant frequency of the

cavity, $\varepsilon_0 = 8{,}85410^{-12}\, F.m^{-1}$ is the permittivity of free space and $\varepsilon^{"}$ is imaginary party of the complex dielectric constant measured of the polyacetylene doped electrochemically with 80% by weight of iodine [16], given by: $\varepsilon_r^* = \varepsilon^{'} - i\varepsilon^{"} = 5 - i4.10^5$.
The aim of this article is modulate and simulate the double electromagnetic shield constructed with polyacetylene doped and aluminum with using the transfer matrix method. The development of calculation has allowed us to have the reflection loss, the absorption loss, the internal reflection and the shielding effectiveness of this shield. These four quantities will be analyzed as a function of frequencyat normal and oblique incidences for the two combinations: Conductive polymer – Aluminium and Aluminium – Conductive polymer.

2. Reflection loss, absorption loss, internal reflection and shielding effectiveness of double electromagnetic shield

An incident electromagnetic wave through a material undergoes different processes: reflection, absorption, internal reflection and transmission (figure1a). The electromagnetic shielding effectiveness (SE) of a material is defined in decibel (dB) by [17, 18]:

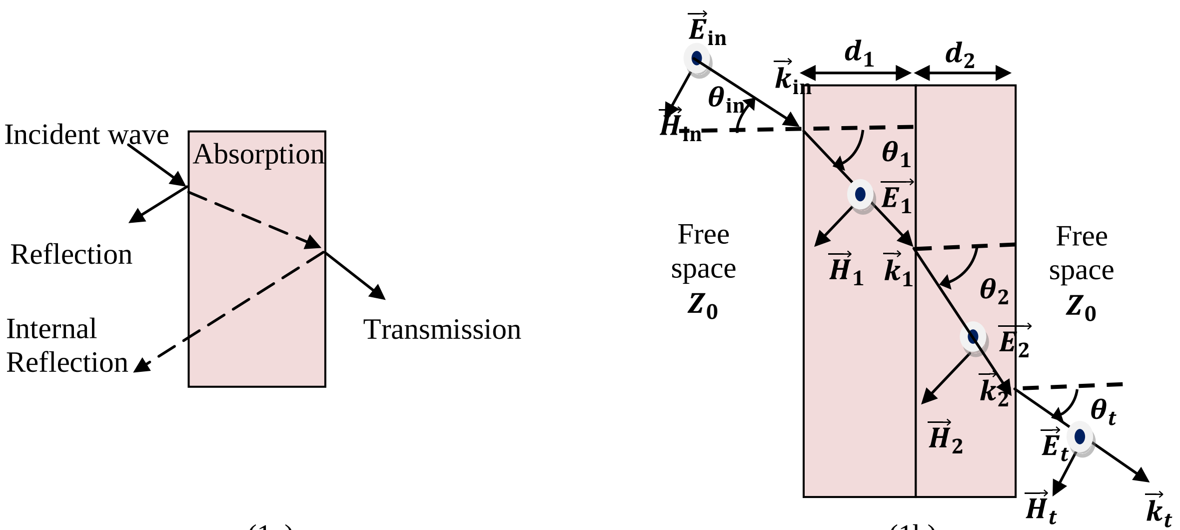
$$SE = -20\log|T| = -20\log\left|\frac{E_t}{E_{in}}\right| \tag{1}$$

where E_{in} and E_t are the incident and transmitted field.

The shielding effectiveness can be broken into the sum of three terms, such as [17]:

$$SE(dB) = R(dB) + A(dB) + M(dB) \tag{2}$$

where $R(dB)$ represents the reflection loss, $A(dB)$ represents the absorption loss and $M(dB)$ represents the additional effects of multiple re-reflections.
The reflection and the transmission of EM in two layers for any angle of incidence are show in figure (1b). We consider that each layer is homogeneous and isotropic, with constitutive parameters: the permittivity ε_j, the permeability μ_j, the conductivity σ_j and the thickness d_j. For transverse electric wave [19], the electric and the magnetic field components are $E_{in} = E_y$, $E_{in} = H_x$ and for transverse magnetic wave field the magnetic field components are $E_{in} = E_x$, $E_{in} = H_y$.



(1a) (1b)

Figure 1: (1a) The general processes of an incident electromagnetic wave through a material.

(1b) Representation of double electromagnetic shield.

The intrinsic impedance of j[th] layer is given by [17]:

$$\eta_j = \sqrt{\frac{\mu_j}{\varepsilon_j + \frac{\sigma_j}{i\omega}}} \tag{3}$$

The impedance of the shield is varied according to the polarization as follows [16]:

$$Z_j = \begin{cases} \dfrac{\eta_j}{\cos\theta_j} & \text{TE polarization} \\ \eta_j \cos\theta_j & \text{TM polarization} \end{cases} \tag{4}$$

The angle of refraction θ_j, can be calculated using the Snell's law [20]:

$$\cos\theta_j = \sqrt{1 - \left(\frac{k_{in}}{k_j}\sin\theta_{in}\right)^2} \tag{5}$$

where k_j is the wave number given by:

$$k_j = \frac{\omega\mu_j}{\eta_j}\cos\theta_j \tag{6}$$

For each layer, we associate a matrix which gives the electric field E_{j-1} [21] according to the electric field E_j.

$$\begin{bmatrix} E_{j-1} \\ H_{j-1} \end{bmatrix} = M_{j-1}\begin{bmatrix} E_j \\ H_j \end{bmatrix} \quad (j = 1,2) \tag{7}$$

where M_{j-1} is given by:

$$M_{j-1} = \begin{bmatrix} \cosh(ik_{j-1}d_{j-1}) & -Z_{j-1}\sinh(ik_{j-1}d_{j-1}) \\ -\dfrac{1}{Z_{j-1}}\sinh(ik_{j-1}d_{j-1}) & \cosh(ik_{j-1}d_{j-1}) \end{bmatrix} \tag{8}$$

According to K. Naishadham [19, 22], the shielding effectiveness for two layers which are in contact with two semi-infinite air media is given as:

$$SE = 20\log\left|\frac{1}{T}\right| = 20\log\left|\frac{(M_{11}Z_0 - M_{12}) + Z_0(M_{22} - Z_0M_{21})}{2Z_0}\right| \tag{9}$$

where

$$\begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} = \underbrace{\begin{bmatrix} M_{11}^1 & M_{12}^1 \\ M_{21}^1 & M_{22}^1 \end{bmatrix}}_{\text{First layer matrix}} \underbrace{\begin{bmatrix} M_{11}^2 & M_{12}^2 \\ M_{21}^2 & M_{22}^2 \end{bmatrix}}_{\text{Second layer matrix}} \tag{10}$$

The development of calculation has enabled us to write the relation (9) in another form:

$$\begin{aligned} SE = {} & 20\log\left|4M_{11}^1M_{11}^2\right| + 20\log\left|\left[\frac{(Z_1+Z_0)(Z_1+Z_2)}{4Z_1Z_0}\right]\left[\frac{(Z_2+Z_1)(Z_2+Z_0)}{4Z_2Z_1}\right]\right| \\ & + 20\log\left|\left[1 - \frac{e^{-ik_1d_1}}{M_{11}^1}\left(\frac{Z_1^2 + Z_2Z_0}{(Z_1+Z_0)(Z_1+Z_2)}\right)\right]\left[1 - \frac{e^{-ik_2d_2}}{M_{11}^2}\left(\frac{Z_2^2 + Z_0Z_1}{(Z_2+Z_1)(Z_2+Z_0)}\right)\right]\right| \end{aligned} \tag{11}$$

In identification with the relation (2), we can write respectively, the reflection loss, the absorption loss and the additional effects of multiple re-reflections:

$$R(dB) = 20\log\left[\left[\frac{(Z_1+Z_0)(Z_1+Z_2)}{4Z_1Z_0}\right]\left[\frac{(Z_2+Z_1)(Z_2+Z_0)}{4Z_2Z_1}\right]\right] \tag{12}$$

$$A(dB) = 20\log\left|4M_{11}^1 M_{11}^2\right| \tag{13}$$

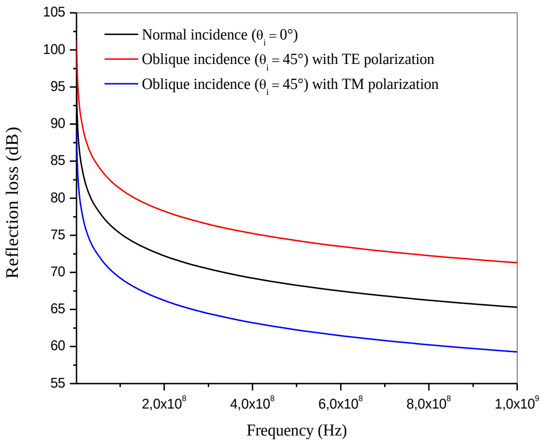
$$M(dB) = 20\log\left[\left[1-\frac{e^{-ik_1d_1}}{M_{11}^1}\left(\frac{Z_1^2+Z_2Z_0}{(Z_1+Z_0)(Z_1+Z_2)}\right)\right]\left[1-\frac{e^{-ik_2d_2}}{M_{11}^2}\left(\frac{Z_2^2+Z_0Z_1}{(Z_2+Z_1)(Z_2+Z_0)}\right)\right]\right] \tag{14}$$

3. Results and discussion

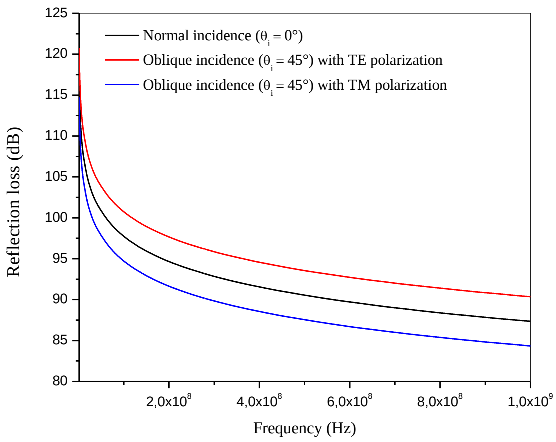
In this paper, the effect of the frequency and the polarization of the electromagnetic incidence wave on the reflection loss, the absorption loss, the internal reflection and the shielding effectiveness are analyzed for double electromagnetic shield composed of Polyacetylene cis-$(CHI_{0.8})_x$ and Aluminum. This study was carried out for two possible combinations: Polyacetylene cis-$(CHI_{0.8})_x$ – Aluminum and Aluminum – Polyacetylene cis-$(CHI_{0.8})_x$.

Figures 2 depict, the frequency dependencies of the reflection loss of the two kinds of combinations: (a) (Polyacetylene cis-$(CHI_{0.8})_x$ – Aluminum) and (b) (Aluminum – Polyacetylene cis-$(CHI_{0.8})_x$) using, the equation (12). The reflection loss, for the two combinations of shield at normal and oblique incidence, is decreasing with frequency. For the transverse electrical polarization, the reflection loss is greater than for magnetic polarization. We also can see that the reflection obtained by the combination (b) is better than (a) due the position occupied by the good conductor (Aluminum), which is excellent for the reflection.

The absorption loss, the internal reflection and the shielding effectiveness of (a) (Polyacetylene cis-$(CHI_{0.8})_x$ – Aluminum) and (b) (Aluminum – Polyacetylene cis-$(CHI_{0.8})_x$) with using, respectively, the equations (13), (14) and (9) are plotted, respectively, in the figures 3, 4 and 5 as a function of frequency at normal and oblique incidence. The shape of these three quantities is the same for the two combinations of shield. Unlike the absorption loss and the shielding effectiveness that increases with frequency, the internal reflection vanishes for large frequencies. It can be also see that the absorption loss and the internal reflection are independent of the angle and the polarization of incidence wave, but the better shielding effectiveness can be obtained with the transverse electrical polarization than magnetic polarization.

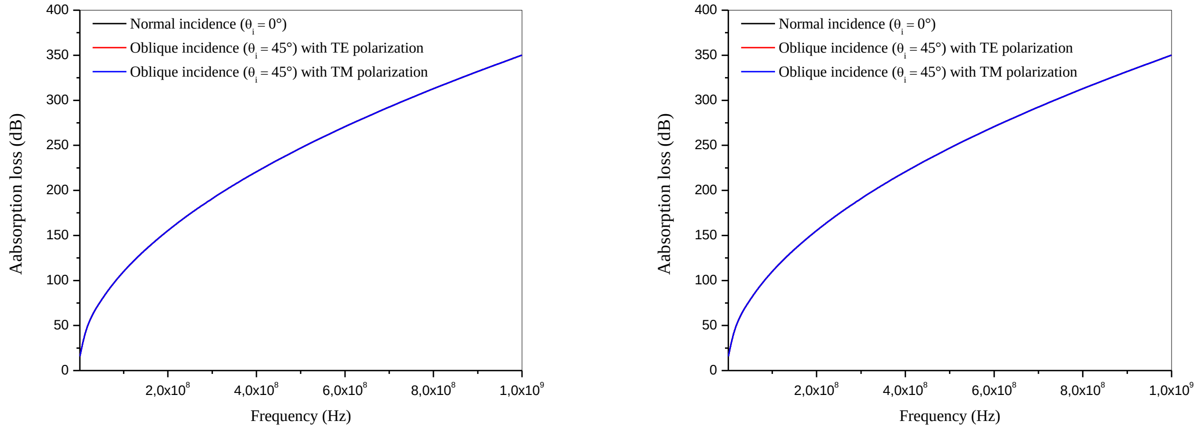


(a)



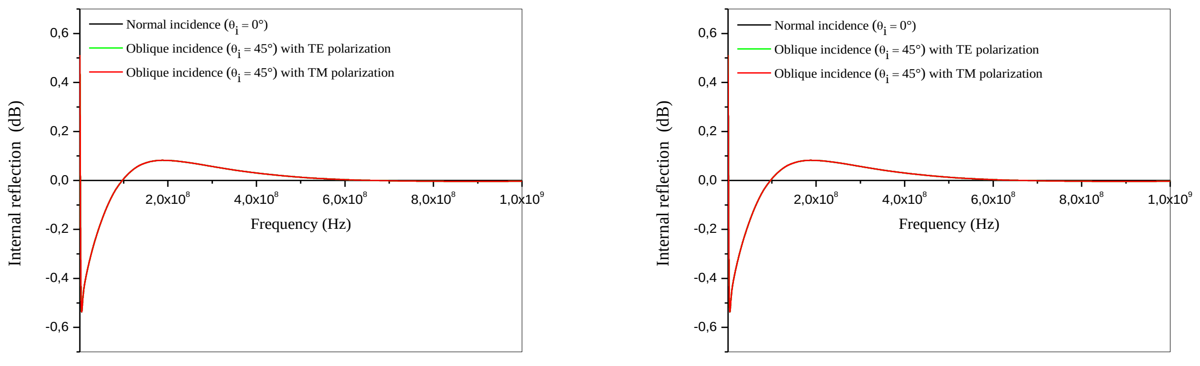
(b)

Figure 3: The variation of the reflection loss as a function of frequency of (a) Polyacetylene cis-$(CHI_{0.8})_x$ – Aluminum and (b) Aluminum–Polyacetylene cis-$(CHI_{0.8})_x$, with 0,1 mm thickness of Polyacetylene cis-$(CHI_{0.8})_x$ and 0,1 mm of Aluminum.



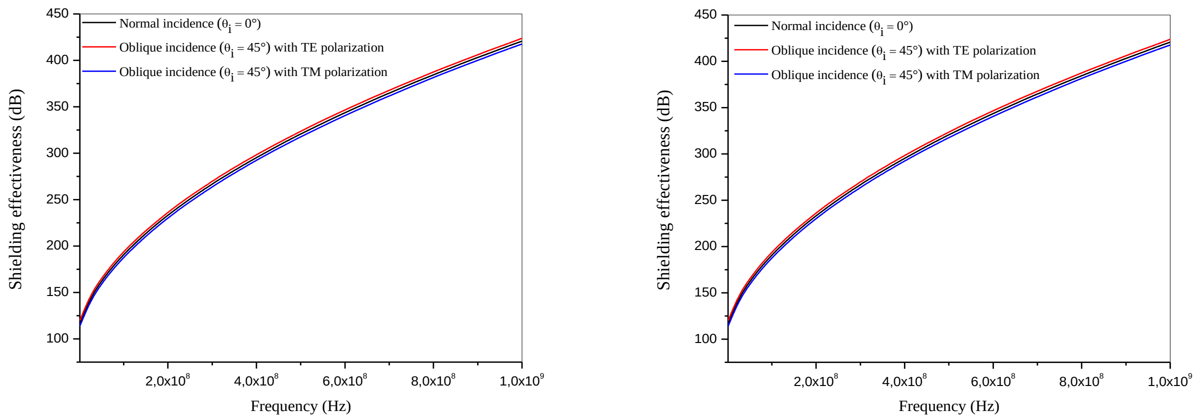
(a) (b)

Figure 4: Dependence of the absorption loss on frequency of (a) Polyacetylene cis-$(CHI_{0.8})_x$ – Aluminum and (b) Aluminum – Polyacetylene cis-$(CHI_{0.8})_x$, with 0,1 mm thickness of Polyacetylene cis-$(CHI_{0.8})_x$ and 0,1 mm of Aluminum.



(a) (b)

Figure 5: The variation of the internal reflection as a function of frequency of (a) Polyacetylene cis-$(CHI_{0.8})_x$–Aluminum and (b) Aluminum–Polyacetylene cis-$(CHI_{0.8})_x$, with 0,1 mm thickness of Polyacetylene cis-$(CHI_{0.8})_x$ and 0,1 mm of Aluminum.



(a) (b)

Figure 6: The variation of the effectiveness shielding as a function of frequency of (a) Polyacetylene cis-$(CHI_{0.8})_x$ – Aluminum and (b) Aluminum – Polyacetylene cis-$(CHI_{0.8})_x$, with 0,1 mm thickness of Polyacetylene cis-$(CHI_{0.8})_x$ and 0,1 mm of Aluminum.

Conclusion

In the present study, the reflection loss, the absorption loss, the internal reflection and the shielding effectiveness of the double electromagnetic shield of a conductive polymer (polyacetylene cis-$(CHI_{0.8})_x$) associated to aluminum are analysed using a new approach based on the transfer matrix method. This analysis shows that increase of frequency decreasing reflection loss and increasing absorption loss and shielding effectiveness. The internal reflection can be neglected with increase of frequency. The absorption loss, the internal reflection and the shielding effectiveness are independent of the layer combination but the reflection loss can be infected by the position of layer. Sure effect, better reflection is obtained when we put the classic conductor in the first position with respect to the propagation direction of the wave.

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