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Electromagnetic Scattering for Dielectrically Coated Conducting Bodies of Translation by using Physics Optics method PO.

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In this research we study the problem of electromagnetic scattering of conducting bodies of translation (BoT) coated with dielectric material using the theory of physical optics as a numerical method. Using mathematical equations and programming language (Fortran Power Station 90) were calculated surface electric and magnetic currents and the scattered fields from such bodies. By using surfer program the body under study was draw , and then calculate its radar cross section (RCS).It will be noticed that increasing the coating layer lead to reduces the radar cross section.

1.Introduction.

When a perfectly conducting body is illuminated by an electromagnetic field, electric currents are induced on the surface of the body. These currents act as new sources and create an electromagnetic field radiated outward from the body. This field, called the scattered field, depends on the frequency and the polarization of the incident field. The scattered field is also related to the physical dimensions and shape of the illuminated body. According to the ratio between the wavelength of the incident field and the scattering body size, at least three scattering regimes can be defined. These are: Low-frequency scattering, resonant scattering and high frequency scattering. Radar Cross Section (RCS), which is the fictitious area of

the target, characterizes the spatial distribution of the power of the scattered field . In this research , RCS calculation of arbitrary shaped targets in high frequency regime is considered, in other words, the incident wavelength is much smaller than the length of the scattering body($\lambda << L$). Among high frequency scattering techniques, Physical Optics (PO) and Geometric Optics (GO) are the easiest to implement. GO is based on the classical ray-tracing of incident, reflected and transmitted rays. PO is based on the integration of induced currents predicted by GO. The PO surface integral approach in [1] gives the correct result around specular direction. However, PO may fail at wide angles from the specular direction. This failure can be eliminated by insertion of the effect of diffraction. The phenomenon of diffraction was first introduced by Young, who described the source of this field as an interaction between all incremental elements of the edge. Young advocated that interaction of different edge elements with each other and with the GO field produces the observed interference pattern for the total field. The following are the well-known edge diffraction techniques: Keller's Geometrical Theory of Diffraction (GTD), Ufimtsev's Physical Theory of Diffraction (PTD) [2], [3]. Additionally, Uniform Geometrical Theory of Diffraction (UTD) of The Ohio State University and Uniform Asymptotic Theory (UAT) of University of Illinois are improved versions of Keller's GTD and described in [4] and [5]. Additionally, diffraction from corners can be included by corner diffraction coefficients formulated for GTD in [4].The electromagnetic scattering problem from bodies with perfect electric conductor surface was considered by many numerical methods as Method of Moments(MoM) with Galerkin technique .The methods developed for calculating problem of electromagnetic scattering from dielectric coated bodies as well as many of the results obtained and presented herein are useful not only in determining the charge in echo area of the satellite because of the plasma shell.

Exact boundary value solutions have been obtained for bistatic scattering by conducting cylinder and concentric dielectric coated conducting cylinder in both E-plane and H-plane .These exact boundaries are of value both in determining the effects of a dielectric upon the scattering properties of conducting cylinder and in determining the validity of the various approximations which are considered[6].

2.Theory background.

In this paper Physical Optics (PO) is applied to impenetrable objects modeled as an impedance surface boundary conditions .A conducting body with material coating can be approximated as impedance sheet , under the assumption of thin coating with respect to the radius of curvature and free space wavelength. The surface of targets also should be impenetrable . If the scattering object has an impedance surface induced magnetic currents will be included in addition to the induced electric currents . Scattered field from an impedance surfaces is derived and results are tested for some targets[7].

By a detailed study of the scattering of the dielectric clad cylinder , the regions for which the approximations are valid may be determined and applied with confidence to similar problems for which no exact solutions are available. It should be noted at this point thata previous se of computations for the analogous problem of the dielectric coated cylinder indicated that no such approximations could be made. Tang [8]computed the echo area of dielectric clad cylinder for relative dielectric constants of 2.54 and 6 0. These cases yield results which are difficult to interpret in terms of the approximations suggested above.

When the coating of the body is thin relative to the radius of curvature of the surface and the free space wave length , the surface of the target can be approximated to an impedance sheet having an impedance of Z as in equation(2). If the thin sheet is primarily conductive, the sheet impedance will be resistive . A thin lossless dielectric sheet will have a purely reactive sheet impedance. The formulation in this paper is suitable for dielectric materials.

When the radius of curvature of the body is electrically large and the coating thickness is much smaller than the radius of the curvature, the boundary condition is well defined. The following boundary condition relates the scattered field from a body to the surface impedance Z [9]

$$-\hat{n}\times\hat{n}\times\overline{E}=\eta_{\circ}Z\hat{n}\times\overline{H} \qquad \ldots\ldots(1)$$

Additionally, the magnitude of the refractive index N , and its imaginary part should be large. Under these assumptions the surface impedance can be stated as

$$Z=j\eta\tan(Nk_{\circ}d) \qquad \text{where } k_{\circ}=\frac{2\pi}{\lambda_{\circ}} \qquad \ldots..(2)$$

Here $\eta=\eta_{\circ}\sqrt{\frac{\mu_r}{\varepsilon_r}}$ **is the intrinsic of the material ,** $k_{\circ}$ **and** $\lambda_{\circ}$ **are propagation constant and chrematistic impedance of the free space and (d) is the thickness of the coating layer. Fig. 1 illustrates the geometry of the problem for bistatic scattering case.**

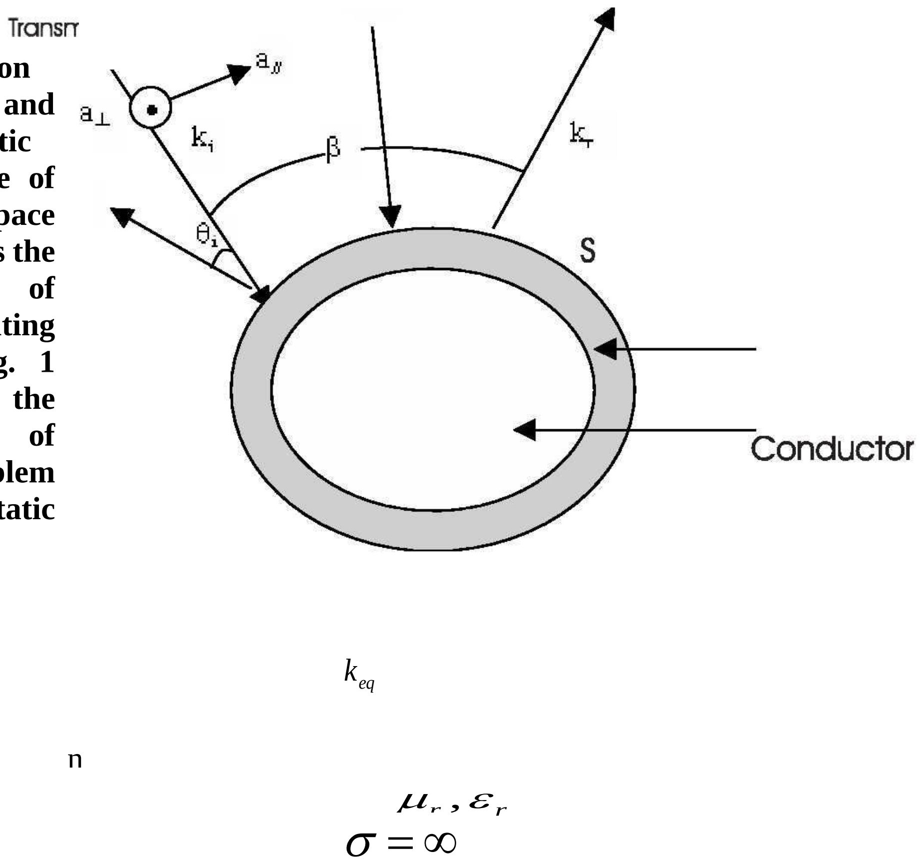
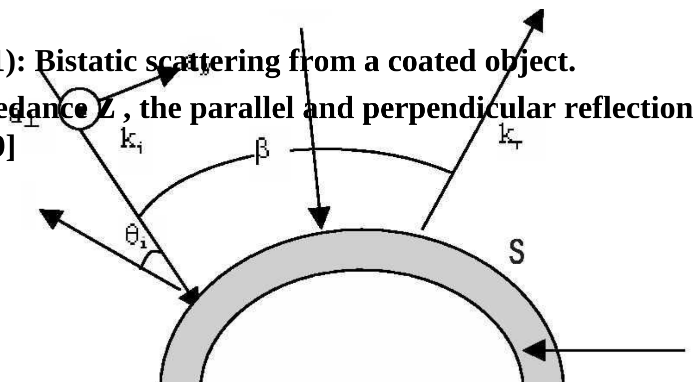


Figure (1): Bistatic scattering from a coated object.

Using the surface impedance Z , the parallel and perpendicular reflection coefficients are given as [9]



$$R_{//} = \frac{\frac{z}{\eta_\circ} - \cos\theta_i}{\frac{z}{\eta_\circ} + \cos\theta_i} \quad .....(3)$$

$$R_{\perp} = \frac{\frac{z}{\eta_\circ} - \sec\theta_i}{\frac{z}{\eta_\circ} + \sec\theta_i} \quad ....(4)$$

Over an illuminated body, it is assumed that both electric and magnetic surface currents are induced. The Physical Optics approximation for the electric surface current on a body with reflection coefficient matrix R is

$$\bar{J} = \hat{n} \times \bar{H}_t \quad \textbf{. ......(5)}$$

where $\bar{H}_t$ **stands for the magnetic field vector and** $\hat{n}$ **is the unit normal vector of the surface positioned outward . Using the impedance boundary condition in equation (1), the magnetic surface current is found to be**

$$\bar{M} = \bar{E} \times \hat{n} = -Z\hat{n} \times \bar{J} \quad \textbf{........(6)}$$

The total field is can be Written in terms of incident field as

$$\bar{H}_t = \hat{n} \times (1 - \bar{\bar{R}})\bar{H}_i \quad \textbf{........(7)}$$

The total H-field is given as [9]

$$\bar{H}_t = \begin{bmatrix} (1-R_{//})\bar{H}_i & parallel & polarization \\ (1-R_{\perp})\bar{H}_i & vertical & polarization \end{bmatrix} \quad \textbf{......(8)}$$

where the matrix R is

$$\bar{\bar{R}} = \begin{bmatrix} R_{//} & 0 \\ 0 & R_{\perp} \end{bmatrix} \quad \textbf{......(9)}$$

$$\bar{H}_t = (1 - R_{//})(\bar{H}_i \cdot \hat{a}_{//})\hat{a}_{//} + (1 - R_{\perp})(\bar{H}_i \cdot \hat{a}_{\perp})\hat{a}_{\perp} \quad \textbf{....(10)}$$

where $\hat{a}_{//}$ **is the unit vector along the plane of incidence and** $\hat{a}_{\perp}$ **is the unit vector perpendicular to the plane of incidence.**

The scattering from a triangular plate with the surface impedance Z will be considered. The triangular plate lies on X-Y plane. The geometry of problem is illustrated in fig.(2) . For a scattered plate lying on the X-Y plane, the plane of incidence is parallel to $\hat{a}_\theta$ **and perpendicular to** $\hat{a}_\phi$ **, when the incident wave is a plane wave. Hence, equation (10) is simplified to**

$$\bar{H}_t = (1 - R_{//})H_\theta^i\, \hat{a}_\theta + (1 - R_{\perp})H_\phi^i \hat{a}_\phi \quad \textbf{.......(11)}$$

The scattered E-field can be calculated using the following radiation integral

$$\bar{E}^s = \frac{j\omega\mu}{4\pi} \iint \left(\frac{\bar{R} \times \bar{R} \times \bar{J}}{R} e^{-jk\bar{R}} + \frac{\hat{k}_r \times \bar{M}}{R} e^{-jk\bar{R}} \right) da \quad \textbf{.....(12)}$$

Where $da = dx_l' dy_l'$

The following vector algebra will be used :

$$\bar{R} \times \bar{R} \times \bar{J} = \bar{R}(\bar{R} \cdot \bar{J}\ ) - \bar{J}(\bar{R} \cdot \bar{R}) = -\bar{J} \quad ....(13)$$

Incident wave

Y

X

…re (2): Triangular impedance plate orientation.

Since the surface cu a_θ **is perpendicular to** $\overline{R}$ **, then** $(\overline{R}\cdot\overline{J}=0)$ **and** $(\overline{R}\cdot\overline{R}=1)$**.** **Hence, the equation (13) reduced to** $(-\overline{J})$**. Therefore, equation (12) can be written as :**

$$\overline{E}^{s} = -\frac{j\omega\mu}{4\pi r}e^{-jkr}\iint(\overline{J}-\widehat{k}_r\times\overline{M})e^{-j\widehat{k}_r r^{/}}da$$

$$= -\frac{j\omega\mu}{4\pi r}e^{-jkr}\iint((\widehat{n}\times\overline{H}_t)-\widehat{k}_r\times(-Z\widehat{n}\times\overline{J}))e^{-j\widehat{k}_r r^{/}}da$$

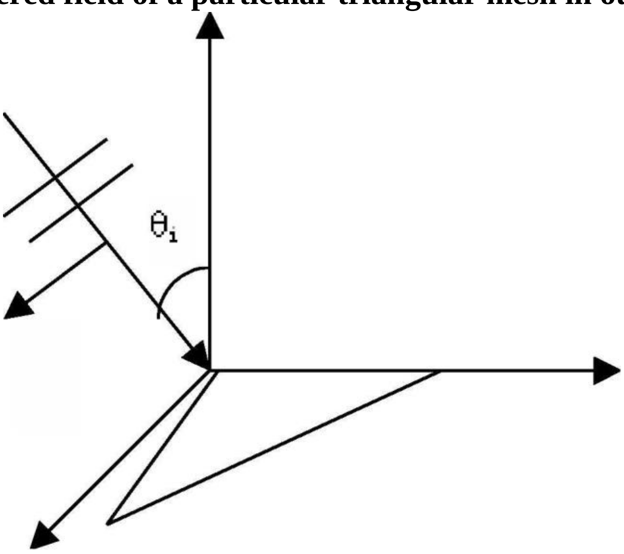
$$= -\frac{j\omega\mu}{4\pi r}e^{-jkr}\iint((\widehat{n}\times\overline{H}_t)-\widehat{k}_r\times(-Z\widehat{n}\times\widehat{n}\times\overline{H}_t))e^{-j\widehat{k}_r r^{/}}da \qquad \text{….(14)}$$

Using $\overline{H}_i = \dfrac{\widehat{k}_i\times\overline{E}_i}{\eta_\circ}$ **we get,**

$$H_\phi^i = -\frac{E_\theta^i}{\eta_\circ} \qquad \text{……..(15)}$$

$$H_\theta^i = -\frac{E_\phi^i}{\eta_\circ} \qquad \text{…….(16)}$$

Using equation (11) and the relationships (15)(16) in equation (14),the two components for the scattered field of a particular triangular mesh in our model are found to be [9]



$$E_\theta^s = \frac{-jke^{-jkr}}{4\pi r}\iint(E_\theta^i(1-R_{//})(\cos\theta\cos(\phi-\phi_i)-Z)+E_\phi^i(1-R_\perp)\cos\theta\cos\theta_i\sin(\phi-\phi_i))e^{-kr}da$$

……..(17)

$$E_\phi^s = \frac{-jke^{-jkr}}{4\pi r}\iint(-E_\theta^i(1-R_{//})\sin(\phi-\phi_i)+E_\phi^i(1-R_\perp)(\cos\theta_i\cos(\phi-\phi_i)+Z(\sin\theta\sin\theta_i-1)))e^{-kr}da$$

…..(18)

Where unit normal is taken as, $\hat{n}=\hat{z}$. The equations (17) and (18) can be written in matrix form as[9]

$$\begin{bmatrix} E_\theta^s(r,\theta,\phi) \\ E_\phi^s(r,\theta,\phi)\end{bmatrix} = \begin{bmatrix} F_{11}+Z & F_{12} \\ F_{21} & F_{22}+Z(\sin\theta\sin\theta_i-1)\end{bmatrix}\begin{bmatrix}(1-R_{//}) & 0 \\ 0 & (1-R_\perp)\end{bmatrix}\begin{bmatrix}E_\theta^i \\ E_\phi^i\end{bmatrix}\frac{2I_0}{\eta}\frac{j\omega\mu}{4\pi r}e^{-jkr}$$

……(19)

Where

$$F_{11} = -\cos\theta_s\cos(\phi_s-\phi_i)$$
$$F_{12} = -\cos\theta_s\cos\theta_i\sin(\phi_s-\phi_i)$$

……….(20)

$$F_{21} = \sin(\phi_s-\phi_i)$$
$$F_{22} = -\cos\theta_i\cos(\phi_s-\phi_i)$$

Radar cross section(RCS) is compute of the target for the horizontal and vertical polarizations from formulas in equations (21) and (22) respectively.

$$\sigma_{\theta\theta} = \lim_{r\to\infty}\frac{4\pi r^2}{\lambda^2}\frac{\left|\bar{E}_\theta^s\right|^2}{\left|\bar{E}_\theta^i\right|^2}$$ ……..(21)

$$\sigma_{\phi\phi} = \lim_{r\to\infty}\frac{4\pi r^2}{\lambda^2}\frac{\left|\bar{E}_\phi^s\right|^2}{\left|\bar{E}_\phi^i\right|^2}$$ ……….(22)

Where (θ_i,ϕ_i) are the spherical coordinates of the source and . The phase factor along the surface of the plate is taken into account by the integral I_0. The integral I_0 is given as

$$I_0 = \int_{x_l'=a}^{b}\int_{y_l'=\alpha(x_l')}^{\beta(x_l')} e^{j(ux_l'+\upsilon y_l')}dx_l'dy_l'$$ ………(23)

where the terms u and υ are

$$u = k(\sin\theta_i\cos\phi_i+\sin\theta_s\cos\phi_s)$$

………(24)

$$\upsilon = k(\sin\theta_i\sin\phi_i+\sin\theta_s\sin\phi_s)$$

From the figures (3) and (4), can be written ,

$$
\begin{aligned}
y_l &= -\frac{e_1}{|e_3|} \\
z_l &= \frac{e_1 \times (-e_3)}{|e_1 \times e_3|} \\
x_l &= y_l \times z_l \\
\alpha(x_l) &= \alpha_0 + \alpha_1 x_l \\
\beta(x_l) &= \beta_0 + \beta_1 x_l
\end{aligned}
\qquad \text{........(25)}
$$

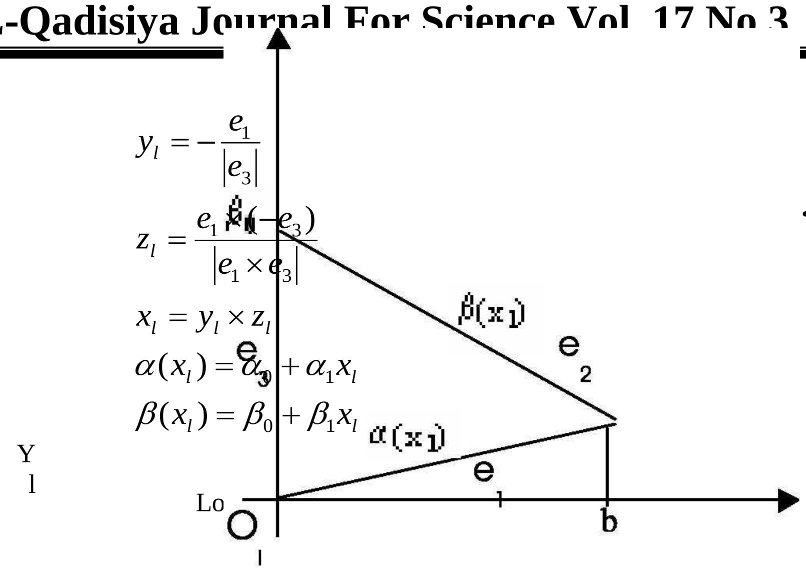


Figure (3): Local coordinates of a triangle residing in glabal coordinates.

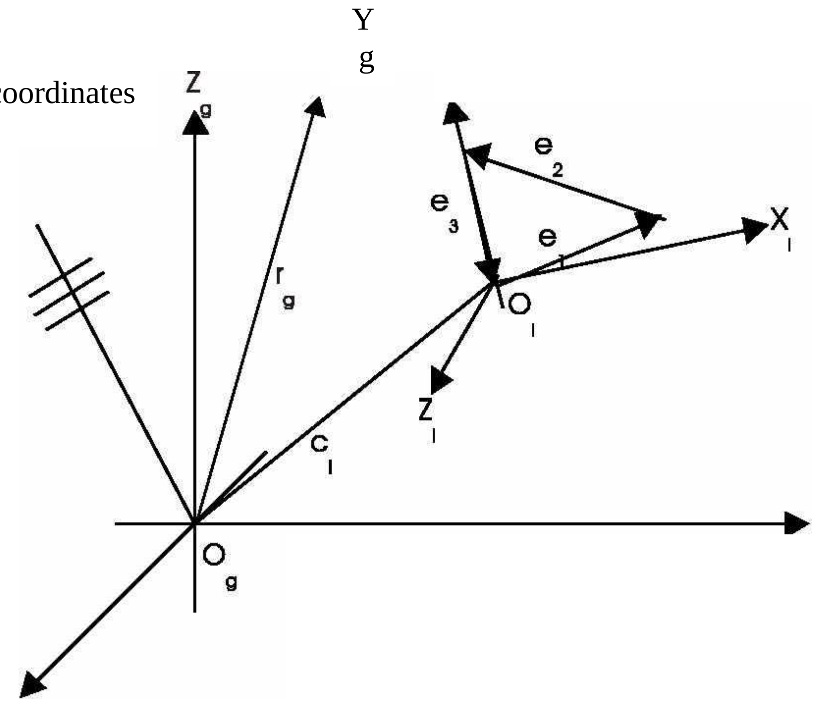


Figure (4): The local triangle in coordinates.

Since e_1 edge starts from the origin of the local coordinate system, α_0 should be equal to zero. The parameters in equation (25) are given as

$$\alpha_0 = 0$$
$$\alpha_1 = \frac{e_{1y}}{e_{1x}}(e_{1x} \neq 0)$$
$$\beta_0 = |e_3| \qquad \text{.......(26)}$$
$$\beta_1 = -\frac{e_{2y}}{e_{2x}}$$

Using the above expressions, I_0 integral can be analytically calculated by via Gaussian quadrature integration routine . The result is found to be[9]

$$I_0 = \frac{1}{j\upsilon}(e^{j\upsilon\beta_0}\frac{e^{jb(u+\upsilon\beta_1)} - e^{ja(u+\upsilon\beta_1)}}{j(u+\upsilon\beta_1)} - e^{j\upsilon\alpha_0}\frac{e^{jb(u+\upsilon\alpha_1)} - e^{ja(u+\upsilon\alpha_1)}}{j(u+\upsilon\alpha_1)} \qquad \text{......(27)}$$

3.Results and discussion:

The body's geometry is important approach for calculating the radar cross section because of it's given an accuracy describing for the body of translation (BoT). Fig.(5) is depicted the conducting cylinder with dielectric coating. The sketch is obtained by Fortran Power Station and surfer programs .Its divided into meshes by moments of method (MoM) .

Figure (6) depicted the bistatic radar cross section for cylinder having a length of $2.76cm$, a diameter of $0.432cm$,(ka=1.4) and uncoated dielectric or air-dielectric (d=0,$\varepsilon_r = 1$,) for both $\theta\theta$ (horizontal) polarization or E-plane (fig.6.b) and $\phi\phi$ (vertical) polarization or H-pane (fig.6.a) .It should be noted here the result is have good convergence compared with the previous research[10]. We computing the bistatic radar cross section with thickness of dielectric((Rogers RT/Duroid5870) (d=0,1cm,$\varepsilon_r = 2.23$) ,see figure (7) . This approximation may be expected to yield reasonable results when the component of scattering by the Rogers RT/Duroid5870-dielectric is smaller compared to that scattered by the conducting cylinder with air-dielectric .We noted that the value of the radar cross section is decrease and the presence of dielectric, fig.(7) giving the results for $\theta\theta$ (horizontal) polarization or (E-plane), and the results for $\phi\phi$ (vertical) polarization or (H-pane). By increasing thickness of insulating coating ,that the bistatic radar cross section is decrease more because of dielectric layer . Fig.(8) depicted the results for coated conducting cylinder case for $\theta\theta$ (horizontal) polarization or (E-plane) and the results for $\phi\phi$ (vertical) polarization or (H-pane) also with Fr4-dielectric (d=0,4cm ,$\varepsilon_r = 4.4$).When we choose the(poly-2.5-dichlorostyren) as a dielectric layer , the computed normalized backscatter cross sections results that are lower than the results of the early cases. Fig.(9) depicted reduced RSC with thickness of dielectric (d=0,8cm $\varepsilon_r = 7.3$).

From the results shown in Figs.7-9, they are observed that the RCS decreases by comparing with the perfectly conducting case (thickness of dielectric

(d=0.0,Z=0, $\varepsilon_r = 1$) because of the dielectric layer . The results are different for different polarization .The wavelength can be as long as about 10cm, hence the targets are not likely to be more than two or three wavelengths in size .This is edge of the high frequency RCS region. The errors in the PO approximation are worse for small cylinders than for large ones. The error being on the order of 2.5 to 3.5 dB for (ka=1.4) for E-Polarization. It in the PO approximation decreases to 0.15 or less for (ka=9.7)

These results are important for designers of aircraft, where those seeking to reduce the radar cross section of the aircraft and the missiles as much as possible in order to avoid radar detection and thus the success of the mission of military operations. Aircraft's engineers trying to make the plane look like a small bird on the radar screen and this is known as stealth technology.

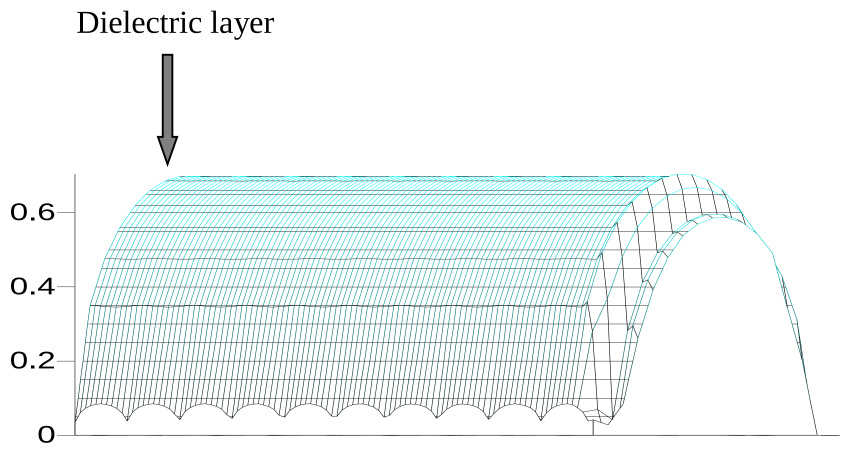
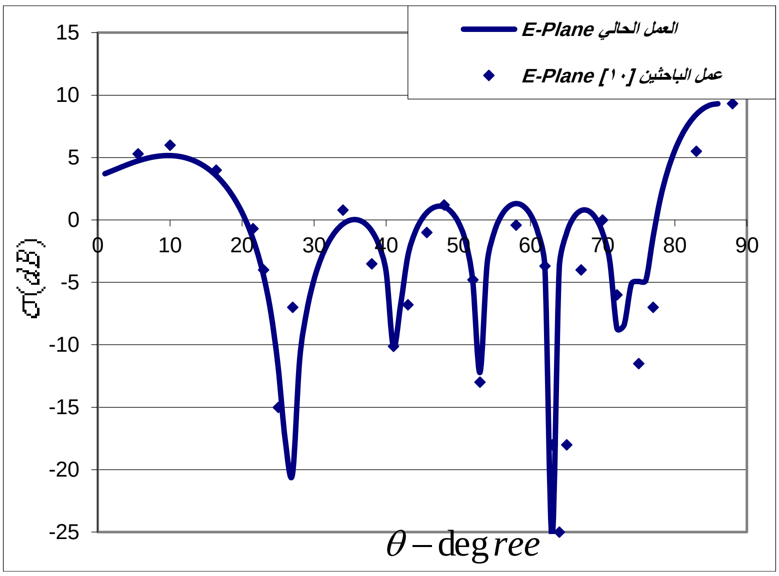
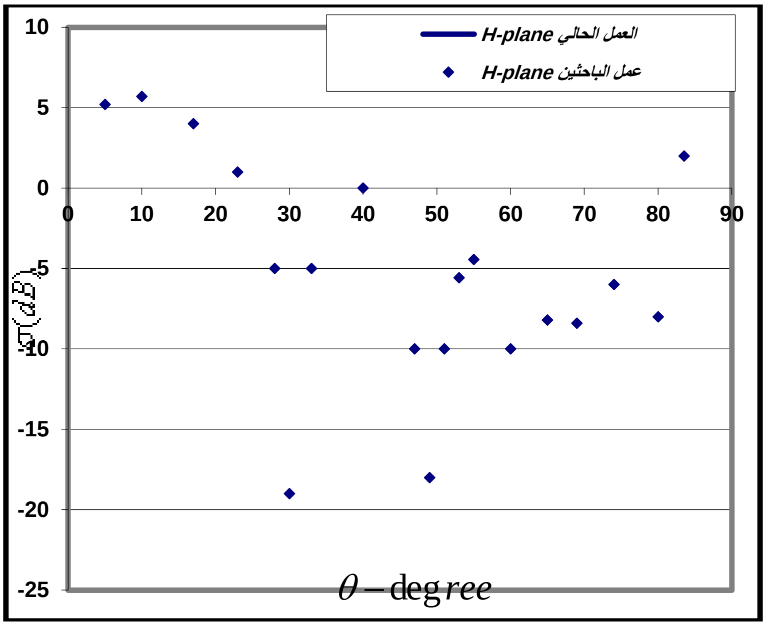


Figure (5): Distribution of meshes for Cylinder with dielectric layer by MOM.



(a)



(b)

Figure (6): Computed normalized backscatter cross sections for cylinder(d=0,Z=0) .a- $\phi\phi$ polarization. b- $\theta\theta$ polarization.

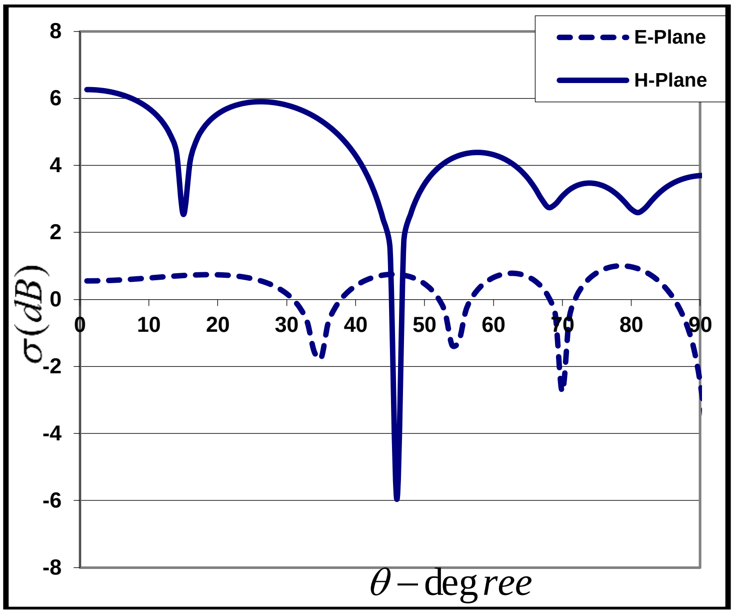


Fig.(7). Computed normalized backscatter cross sections for coated conducting cylinder (thickness of dielectric(d)=0.1cm,)

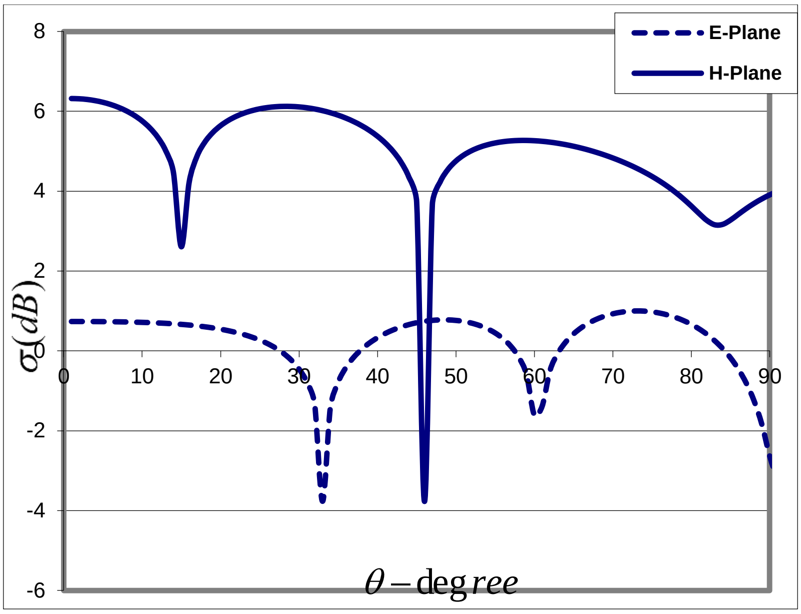


Fig.(8). Computed normalized backscatter cross sections for coated conducting cylinder (thickness of dielectric(d)=0.4cm,)

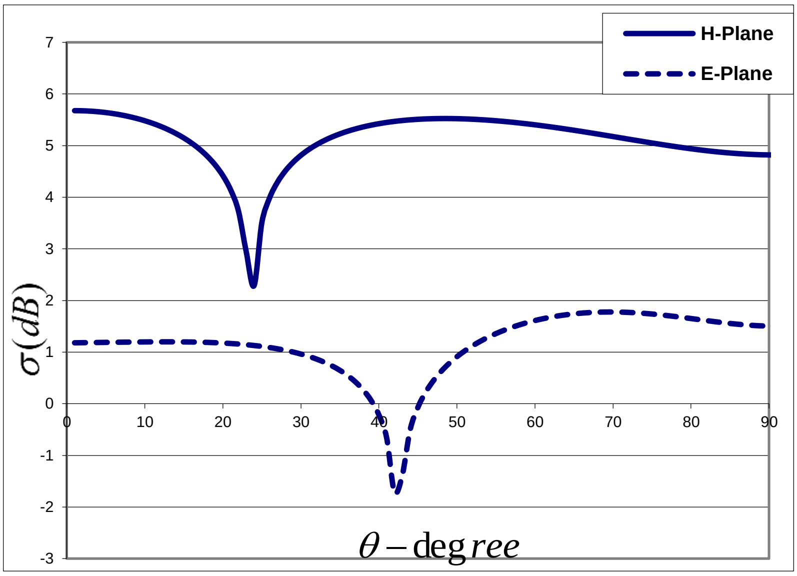


Fig.(9). Computed normalized backscatter cross sections for coated conducting cylinder (thickness of dielectric(d)=0.8cm) .

4.Conclusions.

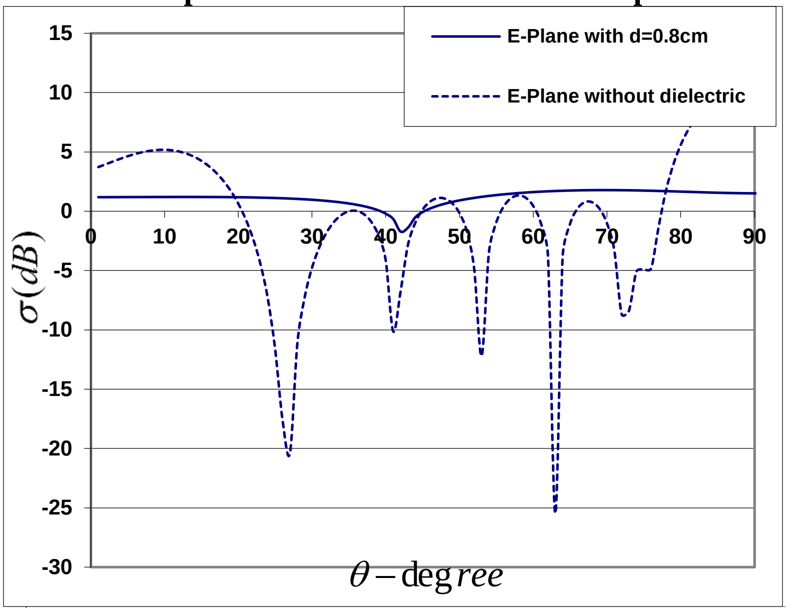
1-Physical Optics (PO) is used to calculate RCS of targets with arbitrary shapes, with perfectly conducting or impedance surfaces. A computer program has been written in Fortran for the computations.
2-The targets are modeled in triangular meshes by MoM for easier computations. The program includes a mesh generator algorithm for basic shapes.

3- A conducting body with material coating can be approximated as impedance sheet under the assumption of thin coating with respect to the radius of\ curvature and impenetrable surface.

4- PO is one of the high frequency techniques. For high frequency Radar Cross Section(RCS) computations, PO gives faster results for large targets. PO approximates the induced surface currents.

5. Applying the PO for targets that have impedance surface yields RCS results that are lower than the results of perfectly conducting surfaces ,see to Fig.(10)

6- RCS of conducting targets can be decreased by material coating. Although the scattered field is polarization independent for perfect conductors, the results for horizontal and vertical polarizations are different for impedance surfaces.



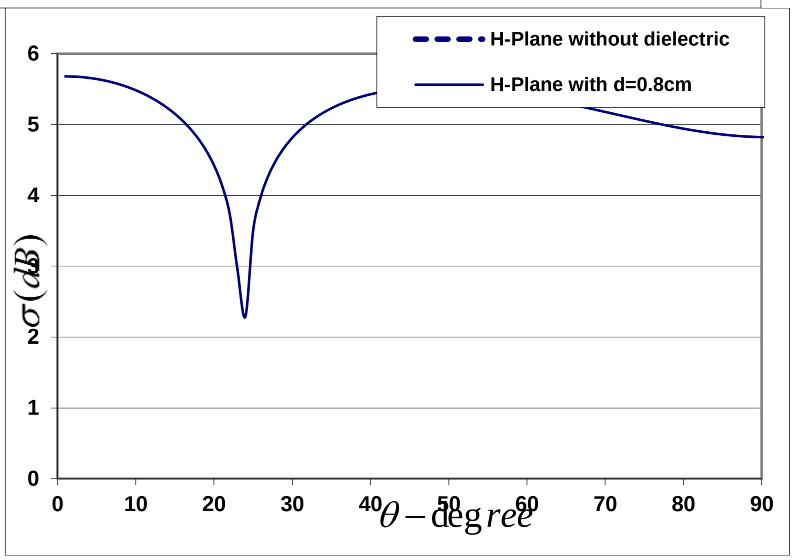


Fig.(10): RCS Comparing for the conducting cylinder and the conducting cylinder with dielectric coating.

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الاستطارة الكهرومغناطيسية للأجسام الموصلة المتولدة انتقاليا والمطلية بمادة عازلة باستخدام طريقة البصريات الفيزيائية.

نبيل عباس عريبي. قسم الفيزياء. كلية التربية . جامعة القادسية.

الخلاصة.

تم في هذا البحث دراسة مسالة الاستطارة الكهرومغناطيسية للأجسام الموصلة والمتولدة انتقاليا والمطلية بمادة عازلة باستخدام نظرية البصريات الفيزيائية باعتبارها طريقة عددية لحل مثل هذه المسائل . باستخدام المعادلات الرياضية والبرمجة بلغة Fortran Power Station 90 تم حساب التيارات السطحية (الكهربائية والمغناطيسية) والمجالات المستطيرة لتلك الأجسام . باستخدام برنامج Surfer تم رسم الجسم قيد الدراسة ومن ثم حساب مساحة المقطع الراداري له. سنلاحظ أن زيادة سمك الطلاء العازل تقلل من مساحة المقطع الراداري.