PO-GO/ECM for Bistatic RCS Modeling of Complex Objects over Rough Sea Surface

Y. Bennani[1] **and R. Talhi**[1,2]

[1]Department of EECS, University of Tours, Avenue Monge, Tours 37200, France
[2]CNRS/LPC2E, 3A Avenue de la Recherche Scientifique, Orleans Cedex 2 45071, France

Abstract— The work summarized in this paper fits well in the field of remote sensing of the marine environment. It shall include, firstly, the study of interaction of an electromagnetic wave with a sea surface in the presence of a complex target observed in bi-static configuration. On the other hand, the work is completed by the study and analysis of the influence on this electromagnetic (EM) interaction of various parameters related to both the target and also to the environment. The proposed model has been validated by comparing theoretical results to experimental measurements obtained in the anechoic chamber, and then it was applied to a marine scene by considering the sea surface and the target as a single complex object.

1. INTRODUCTION

The prediction of scattering from a complex target over sea surface is a subject of recent interest in the radar target recognition field [1]. The computation of the Radar Cross Section (RCS) of a complex target involves several kinds of scattering mechanisms, such as multiple scattering, specular reflection, diffraction by edges [9]. To take into account these effects we have used asymptotic methods [6]. These methods can be divided into two types. The first one called asymptotic methods of rays based on the asymptotic expression for the scattered field such as Geometrical Optic (GO) [6] completed by the Uniform Theory of Diffraction (UTD) [6]. The other family called asymptotic methods of currents that are based on the asymptotic expression of surface current distributed on the illuminated surface of the target, where the scattered field is calculated as the scattering of these currents. So, surface reflection is calculated by Physical Optics (PO) method and edge diffraction is computed by the Equivalent Currents Method (ECM) [7]. The aim of this paper deals with modelling of interaction between electromagnetic (EM) wave and the complex target over sea surface. The RCS is computed using a combination based on PO-GO [10] and ECM [7] approximations.

In order to introduce the influence of the sea surface on the electromagnetic response of the target in its environment, we opted for a representation of the scene (target + sea surface) by a set of triangular facets. Within this framework, the target discretized by a triangular mesh is generated using a CAD — Computer Aided Design — tool (CATIA, V5); as regards the sea surface, it is generated using the Elfouhaily sea spectrum [3] (and the Debye model [11] to take into account the dielectric parameters of seawater).

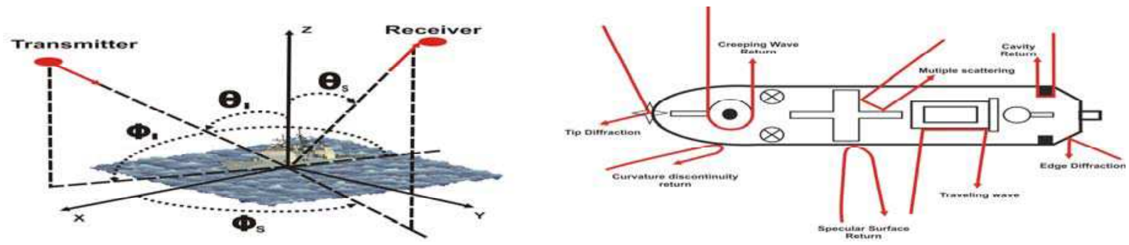
2. GEOMETRICAL MODELLING OF COMPLEX TARGETS

The first step in RCS computation [6] is to define the target in a global system coordinates as shown in Figure 1(a). We have chosen to represent the target by a collection of triangular facets, because they allow to obtain a good representation of complex targets and allow to achieve an accurate estimated contribution. When an EM wave intercepts a complex target, it gives rise to different scattering mechanisms.

Figure 1(b) illustrates some scattering mechanisms. In this paper, we consider different types of effects such as shadowing effects [5], direct scattering [6], multiple scattering [10], diffraction by edges [8]. The first step before computation of the RCS is to determine the real surface illuminated by the incident EM wave.

2.1. Shadowing Effect

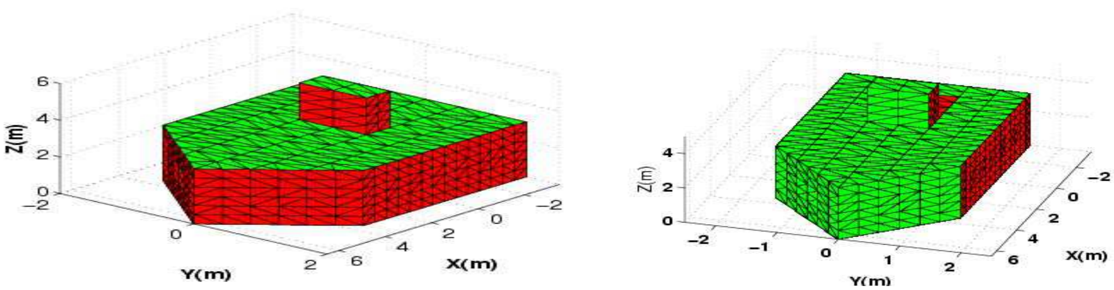
When an incident EM wave is intercepted by a target, a portion of its surface is illuminated and the rest remains dark. In addition, portions of the target can be hidden by other parts. As exposed above, it is assumed that the RCS takes into account only this visibility phenomenon. According to the propagation direction towards the target, the test of visibility is based on the algorithm of Trumbore et al. [5]. The main idea is to check if the ray passing through a predetermined point of the first facet intersects with the second facet. The visibility test is applied on a boat example



(a) Global system coordinates for marine scene (b) Scattering mechanisms for a marine target

Figure 1: Global system coordinate and scattering mechanisms.

for some radar viewpoints. Figures 2(a) and (b) show the visible facets with green colour for two positions of the radar ($\theta = \varphi = 0°$) and ($\theta = \varphi = 45°$). Another example is given in [4]. Now, as part of the illuminated target by the incident wave is determined, we apply PO approximation in order to calculate the contribution of direct scattering (specular reflection).



(a) Radar viewpoint (θ=φ=0 °) (b) Radar viewpoint (θ=φ=45 °)

Figure 2: The visibility test for a generic boat.

2.2. Direct Scattering (Physical Optics)

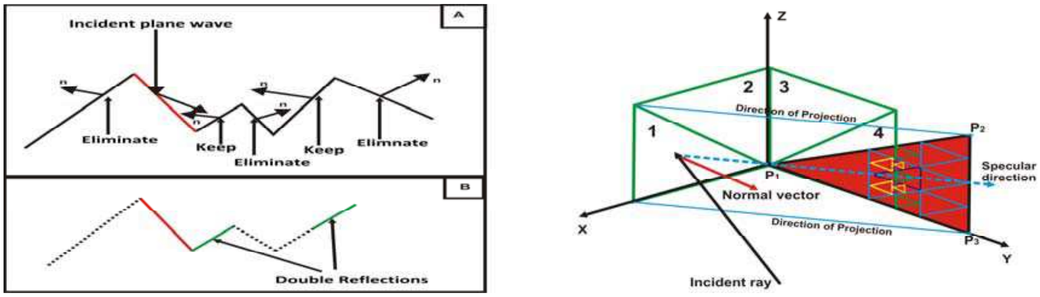
The specular reflection of each facet is obtained from PO method. The current is used in the radiation integrals to compute the scattered far field [6]. The simplified expression of the electrical scattered far field is given by the following equation:

$$\vec{E}_s = -\frac{jke^{-jkR}}{4\pi R} \int_S Z_0 \vec{k}_s \times \left[\vec{k}_s \times \vec{J}\right] - \left[\vec{k}_s \times \vec{M}\right] \, e^{-jk\,\vec{k}_s\,.\,\vec{r}} \, dS \tag{1}$$

where $\vec{J}$ and $\vec{M}$ represent respectively the electric and magnetic current on the surface, their expressions are $\vec{J} = \hat{n} \times (\vec{H}_i + \vec{H}_r)$ and $\vec{M} = -\hat{n} \times (\vec{E}_i + \vec{E}_r)$, where $\vec{E}_i$, $\vec{E}_r$ and $\vec{H}_i$, $\vec{H}_r$, represent respectively the electric and magnetic incident and reflected fields. This is valid for r in S_i, where S_i is the illuminated surface, k is the wave number, R is the distance between the illuminated surface and the receiver, $\vec{k}_s$ is the unit vector in the direction of the receiver, and Z_0 is the impedance of free space. For more accuracy of our model, we present in the next section, the multiple scattering contribution.

2.3. Multiple Scattering

Treatment of multiple scattering is not a trivial topic and requires careful implementation. Multiple interactions are approximated very well by GO approach [10]. The combination GO-PO technique is developed in [10], which uses the PO to calculate contribution at the last reflexion at the surface of the object. However, describing the complex target in terms of facets and edges reduces significantly the problem. The multiple scattering contributions are primarily expressed in terms of facet-facet. So, to take into account the contribution of double reflection [10] to the RCS of a complex target, we must find the facets candidates to the double reflection. To do so, we take the first facet intercepted by an incident EM wave and we select all facets oriented towards this facet as shown in Figure 3(a). The double reflection is expressed in terms of triangle-triangle.



(a) (b)

Figure 3: Multiple scattering contribution. (a) Detection of facets candidates for a double reflection contribution. (b) Real surface for double reflection contribution.

2.4. Diffraction by Edge (Equivalent Currents Method)

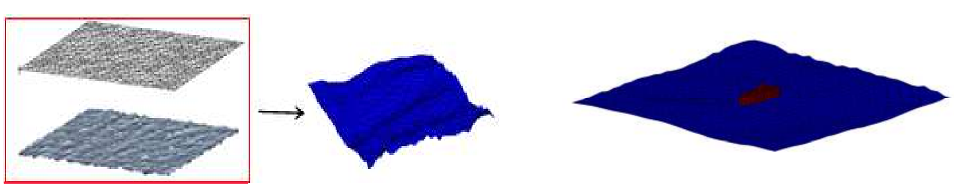
The ECM [8] is a technique involving integrals of radiation. The source of diffracted field is attributed to the fictitious equivalent currents, both electric and magnetic, which flowing along the edge. The expressions given by Michaeli [7, 8] are used to determine the diffracted far-field by an edge, and are based on the fringe currents existing on the edge. These currents are calculated assuming the straight edge locally around each point of the considered contour. The diffracted field is then calculated by linear integration of the equivalent currents on the contour L of the edge:

$$\vec{E}_d \approx jk \int_L \left[Z_0 \vec{I} \vec{k}_s \times \left(\vec{k}_s \times \vec{t} \right) + \vec{M} \vec{k}_s \times \vec{t} \right] \frac{e^{-j\vec{k}\,\vec{r}}}{4\pi r}\, dl \tag{2}$$

where $\vec{t}$ is the unit vector tangent to the edge, $\vec{I}$ and $\vec{M}$ are respectively the electric and the magnetic currents given in [6].

3. MARINE TARGET OVER SEA SURFACE

The purpose of this section is to study the RCS of a complex target located in a rough sea surface [2]. The complexity of the target and multiple interactions between the target and a rough surface, as shown in [2], make the model more difficult to handle. So, before computing RCS of marine target, we must characterize and generate 2D sea surface. The 2D sea surface has been generated using Elfouhaily spectrum [3]. Then we generated a surface mesh with triangular facets and we made a projection of this surface to obtain a sea surface meshing on triangular facets as shown in Figure 4(a). Finally, a target will be introduced over this sea surface to obtain a global complex target (Sea+Target); an example of sea surface and its corresponding discretized surface is given in Figure 4(b).



(a) Triangular representation of sea surface (b) Target over sea surface

Figure 4: Example of marine scenario.

3.1. Geometrical and Physical Characterization of Sea Surface

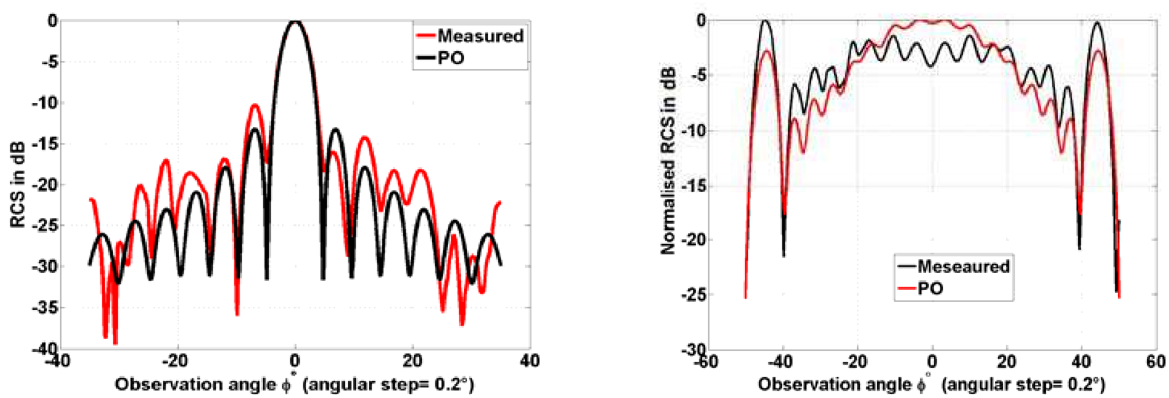
The scattering of EM waves by sea surface requires knowledge of the physical and geometrical characteristics of seawater [2]. The physical parameters that characterize the sea surface are the magnetic permeability and dielectric constant. The relative magnetic permeability is unitary because we assume that the sea surface is not magnetic. The dielectric constant is calculated from the Debye model [11] and depends on frequency f, temperature T and salinity S of seawater. The geometrical characterization of the sea surface can be done by the slopes distribution of rough surface. We chose in this work to characterize the surface by the Elfouhaily spectrum [3], established in 1997 from a synthesis of all works done since the 70 s. This model is semi-empirical and takes into account the fetch, speed and wind direction and the gravity and capillary waves.

4. NUMERICAL RESULTS AND VALIDATION

In order to validate our method, mono-static RCS of a Perfectly Conducting (PEC) plate is presented here. Then a PEC dihedral illustrates multiple scattering contributions. The model has been validated by measurement results only in the mono-static case. For the bi-static case, our results are also rather good compared to those published in the literature [2]. Another complex case as a box over a flat surface and a box target over sea surface are presented below in mono-static and bi-static configurations.

4.1. Rectangular Plate and Dihedral

Mono-static RCS of a square plate is calculated at $f = 10\,\mathrm{GHz}$ and compared with measurements (in anechoic chamber) results for a square conducting plate with dimensions $15\,\mathrm{cm} \times 15\,\mathrm{cm}$ in Figure 5(a), and a square perfectly conducting dihedral with the same dimensions is shown in Figure 5(b). Measurements and theoretical values provided by PO method are normalized to compare measurement results with the theoretical model. When the dihedral plate is normal to the axis of reception ($\pm 45°$), we find the main lobes of the RCS of a flat plate. Moreover, we observe that the level of the reflected signals of these lobes is more important than the multiple reflections occurring within the dihedral, while the theoretical model contradicts this finding.



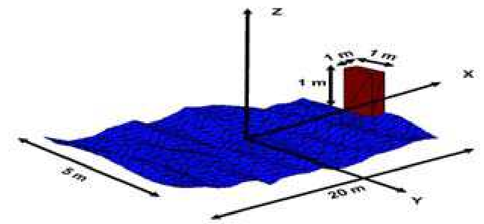
(a) (b)

Figure 5: Theory and measurements of normalized RCS for the square plate and dihedral. (a) Mono-static RCS of a square plate (PO and measurements). (b) Mono-static RCS of a square dihedral (GO-PO and measurements).

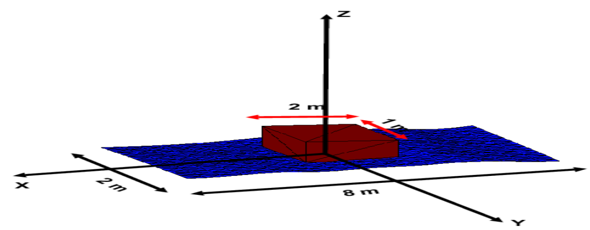
The computational time is not addressed in detail in this work, but as an example, for a dihedral of 5λ side, the mono-static RCS was calculated for a large number of facets (roughly 10^5) at a frequency of 10 GHz, and the cost time estimated with the method of moments is more than 3 hours against 1 minute with our model. All numerical calculations are carried out on a computer platform with a Microsoft Windows server 2003 operating system and Intel processor with a clock speed of 3 GHz, and a total memory of 4 GB.

4.2. Box Target over Plane Surface

As it is mentioned in [2], changes in the RCS of a complex target caused by a rough sea surface can be taken into account by studying the RCS of a target located in a flat surface. Indeed the surface of the sea at the local level in vicinity of the target tends to look like a flat plane [2]. Here, for monostatic RCS, we consider, a simple block of target of 1 m high by 1 m wide placed on positive x-axis extremity of rough sea surface of 5 m wide in y direction, and 20 m length in x direction as shown in Figure 6(a). Figure 6(b) illustrates another configuration for the computation of RCS in bistatic case. Mono-static and Bi-static RCS results are shown in Figures 7(a) and 7(b) respectively; as seen in these figures, the presence of target on the surface affects the scattered field, mostly in mono-static case for low elevation angles for which the scattering from sea clutter is small. These

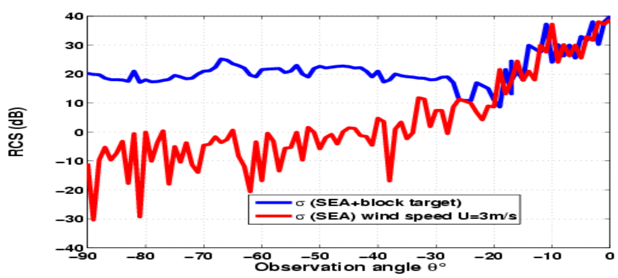


(a)

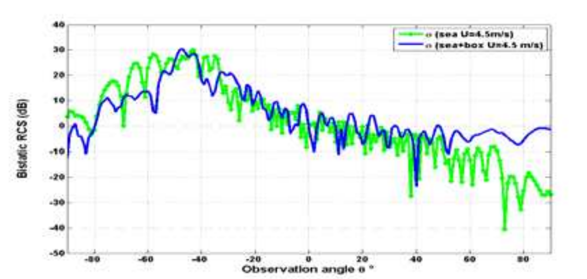


(b)

Figure 6: Geometrical configuration (box over sea surface).



(a)

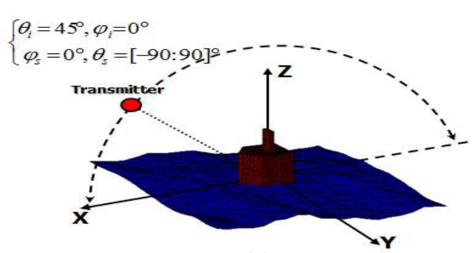


(b)

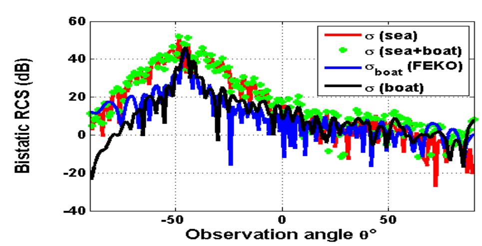
Figure 7: (a) Mono-static and (b) Bi-static RCS of PEC box over rough sea surface at $f = 1\,\text{GHz}$.

simulations show a good agreement when compared with those performed by R. J. Burkholder et al. [2].

A more complex scene is presented by a generic boat Figure 8(a), and consists of boat of 10 m length in x direction, 3 m wide in y direction, and 5 m height in z direction, centered on a rough sea surface of 50 m length in x direction and 50 m wide in y direction. The physical characteristics of sea are temperature $T = 20°\text{C}$, salinity $S = 35\,\text{ppt}$ (part per thousand), and wind speed $U = 5\,\text{m/s}$. Bi-static RCS results are shown in Figure 8(b). The black curve shows the RCS of the generic boat only obtained with our model, compared to the blue curve obtained using EM simulation (FEKO software) [13]. Finally, the curves with red and green colours show respectively, the RCS of sea surface alone and the RCS of the marine scene composed with the generic boat and sea surface. We find that the RCS of the sea surface is predominant, and this is due to the choice of the sea surface dimensions which are quite large compared to those of the boat.



(a)



(b)

Figure 8: Bi-static RCS of a PEC generic boat over 2D sea surface at $f = 10\,\text{GHz}$.

5. CONCLUSION

Combination of PO-GO and ECM methods for modelling the bi-static RCS of a complex target provides rather good results when compared with FEKO software (in bi-static configuration) and experimental measurements (in mono-static case), by taking into account the shadowing effects, double reflection and diffraction by edges. Total scattering, including multiple interactions between PEC target and rough sea surface, was computed using the PO-GO based approach where the Fresnel reflections coefficients are considered in the PO formulation to account for the dielectric aspect of sea surface. The computational time is not addressed in detail in this work, knowing that the choice of asymptotic methods is justified by their ease of application and by reducing the computational time. Therefore it would be necessary to optimize the model in order to reduce this time.

The presented model provides a good estimation of the RCS. However, it seems possible to improve it by taking into account more scattering mechanisms such as the triple reflections contribution, to make the model more reliable, and by including the diffraction by dielectric edges. Other phenomena could be incorporated in the computational process such as edge-edge interactions, edge-surface and creeping waves on the target. Moreover, other applications of our method could be the radar imagery in bi-static representation and 3-D imagery representation.

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