Electromagnetic Surface Wave Scattering with Microwaves

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Abstract— We present a microwave analog experiment for evanescent surface wave scattering by dielectric objects. The instrument provides the amplitude and the phase of the scattered fields in both the near- and far-field regions. We compare the experimental results against numerical simulations, which take into account particle-substrate interaction. This not only allows assessing the validity of the numerical methods but also offers a better understanding of surface wave scattering.

1. INTRODUCTION

Microwave-analog-to-light-scattering (MALS) is a powerful method to analyze electromagnetic scattering properties of systems, which are difficult to manipulate and hence to study in the optical domain. Furthermore, modern detection techniques give direct experimental access to the field value (amplitude and phase), which is much more difficult for optical frequencies. The linearity of Maxwell's equations is the physical principle underlying the method. It allows rescaling wavelength together with object size, keeping field distributions invariant. These properties make it suitable as a proof of concept tool (near-field optical microscopy, metamaterials, cloaking, Kerker conditions), but also as an experimental validation tool of numerical methods [1–3].

MALS has been applied extensively to the study of free space electromagnetic wave scattering by single particles [4] and complex aggregates [5]. In some cases it has also been applied to surface geometries [6]. On the other hand, the case of simple and complex-shaped objects deposited on a surface has received little attention despite numerous applications in nanoscience such as biological detection and surface contamination. To fill in this gap, we present a new device in which evanescent waves are generated on top of a dielectric substrate. This allows studying the behavior of the electromagnetic fields scattered by objects placed on the substrate, in both the near- and far-field regions. Over the past few years, numerical methods capable of handling correctly particle-surface interactions started to emerge [7–12]. These methods are, however, still in a process of development and require experimental validation. Our set-up offers ideal conditions to perform such tests.

After a presentation of the experimental set-up, we will provide some experimental and numerical results.

2. EXPERIMENTAL SET-UP

To measure electromagnetic surface wave scattering by macroscopic objects (object sizes between few millimeters to few centimeters), experiments were performed in an anechoic chamber of Institut Fresnel in Marseille using a device specially designed for this purpose called Surface Wave Scattering-Microwave Scanner (SWS-MS) (see Figure 1) [13]. It consists of a polyamide (PA6) semi-circular prism ($\varepsilon = 2.9 + i0.05$) and emitting and receiving antennas operating in the [4–8 GHz] frequency range. The set-up allows two types of illuminations: a propagating illumination (PI) and an evanescent illumination (EI). The PI consists in placing both emitter and receiver on top of the substrate. Hence, the object is excited with a propagating wave. For the EI, the emitter is placed against the cylinder wall and sends the beam through the prism with an angle of incidence θ_{inc} larger than the critical angle θ_{cri}, thus generating an evanescent wave at the air-prism interface. In this work we will focus on this EI configuration.

Evanescent waves are very sensitive to the presence of any object placed near the surface (at a distance of the order of the penetration depth) since it induces scattering of the evanescent wave, which can be detected in near- or far-field. In the latter case, the receiver is placed on an arm with translation and rotation capabilities. In the near-field region, the electric field is measured using a probe.

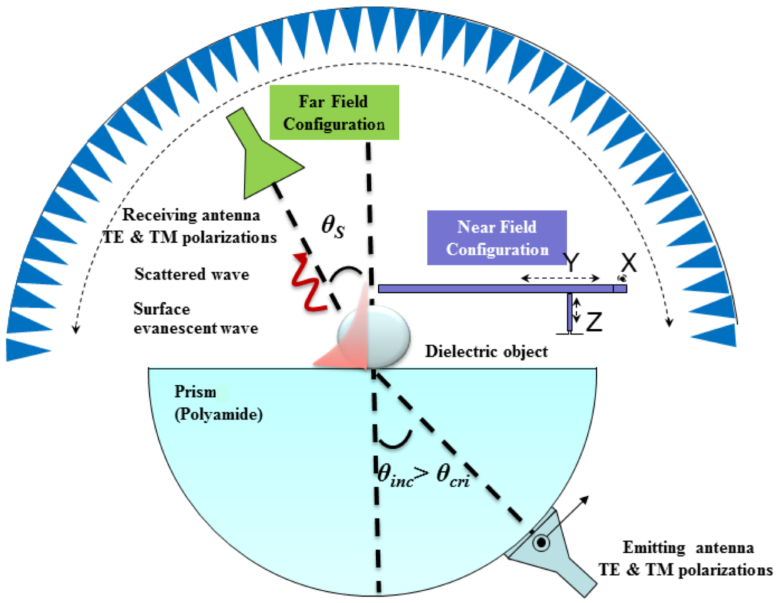

Figure 1: SWS-MS device. The emitting antenna produces a beam with an angle of incidence θ_{inc} and generates an evanescent wave at the top surface of the semicircular prism. Objects placed on or near the interface scatter the evanescent field and create propagating modes that can be detected in both the far- and near-field.

3. RESULTS

We report scattering measurements for two types of spheres: the first one is a quasi-lossless sphere (PA6), with a permittivity of $2.9 + i0.05$ (refractive index of $1.7 + i0.02$) and a diameter of 30 mm ($\lambda/1.92$), and the second is an absorbing sphere, with a permittivity of $1.4 + i0.3$ (refractive index of $1.19 + i0.13$) and a diameter of 69 mm ($\lambda/0.87$).

The first sphere is placed on the top surface of the prism and illuminated by a TE polarized plane wave at a frequency of 5.2 GHz, with an incident angle for the EI illumination of $\theta_{inc} = 36°$.

The results show the measured electric fields amplitude scattered by the particle located on the substrate. The amplitude is plotted in logarithmic scale as a function of the scattering angle θ_S (Figure 2(a)). The measurements are used to assess numerical simulations, carried out by two open source codes based on the Discrete Dipole Approximation taking into account particle-surface interaction: DDA-SI [14] and ADDA [9]. For both DDA-SI and ADDA calculations, the sphere was modeled using 512 cubical sub-volumes. To compare with a different numerical approach we also

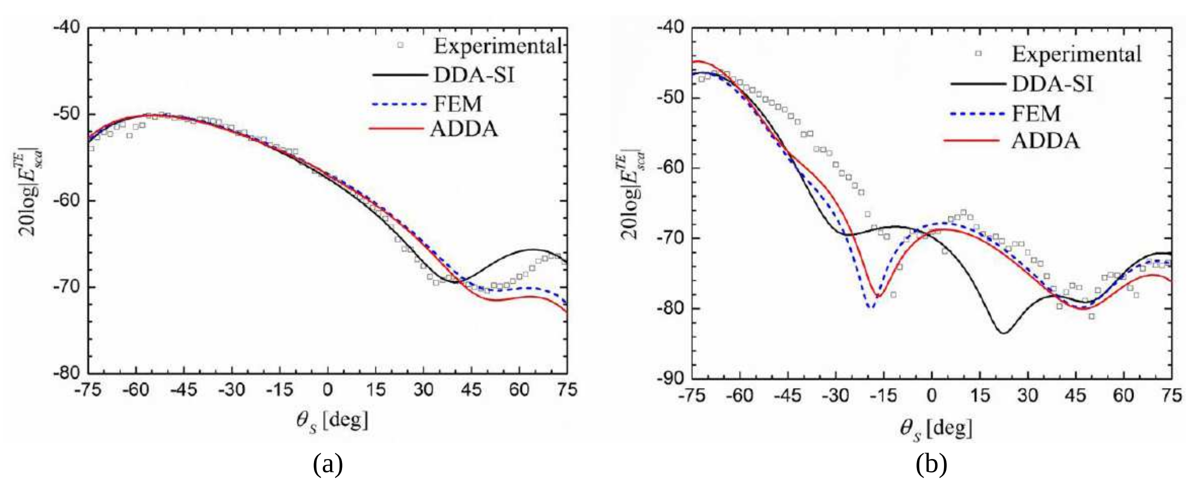

Figure 2: TE-polarized electric field scattered in the far zone by (a) quasi-lossless sphere illuminated at a frequency of 5.2 GHz, (b) absorbing sphere illuminated at a frequency of 5 GHz.

used a "home implementation" of the Finite Element Method (FEM) using an adaptive triangular mesh with adequate high mesh density.

Despite slight differences in the positions of the minima, measurements and simulations by ADDA and FEM are generally in good agreement. This agreement is excellent between 0° and −75°, but important differences appear in the range [0°–75°] for the three methods, especially for DDA-SI. Part of the observed differences is likely to be due to spurious reflections at the interfaces and due to the fact that the beam is slightly diverging. Both phenomena introduce propagating modes in the evanescent wave. In the future, we will use new antennas with better collimation to avoid the generation of non-evanescent modes.

In Figure 2(b), the large absorbing sphere is illuminated by an evanescent wave generated by a TE-polarized plane wave at an angle of incidence of 36° with a frequency of 5 GHz. Here, the sphere was modeled using 1472 cubical sub-volumes. Compared to the quasi-lossless sphere, the differences between numerical predictions and experimental results are more pronounced. We observe again that FEM and ADDA reproduce the experiments better than DDA-SI. This indicates that DDA-SI suffers from numerical inaccuracies more apparent in the case of higher losses. We think that the most probable cause for these problems is the numerical evaluation of the Sommerfeld integrals.

4. CONCLUSION

We have presented experimental results and numerical simulations for far-field scattering of evanescent waves by two types of dielectric spheres. The experimental results are found to be in reasonable agreement with the numerical simulations obtained with the FEM and ADDA including surface interactions. Our set-up offers the possibility to researchers to evaluate the accuracy of their codes. Experimental work is ongoing to demonstrate the set-up capabilities for both near- and far-field in terms of detection sensitivity, object size resolution and object separation resolution.

ACKNOWLEDGMENT

The authors are indebted to Institut Carnot Ingénierie@Lyon (I@L) and Institut Carnot STAR for their support and funding of the project SPLM.

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