A novel implementation of a microwave analog to light-scattering measurement setup

R. Vaillon*[,1], J.-M. Geffrin[2], O. Merchiers[1], C. Eyraud[2], P. Sabouroux[2], and B. Lacroix[1]

[1]*Université de Lyon, CNRS, INSA-Lyon, UCBL, CETHIL, UMR5008, F-69621, Villeurbanne, France.*
[2]*Institut Fresnel, Aix-Marseille Univ., Ecole Centrale Marseille, CNRS, Domaine Univ. St-Jérôme, 13397 Marseille, France.*

We report on a novel implementation of the well-known and established method to test approximate light-scattering codes using the so-called microwave analogy principles for fully controlled complex-shaped particles. The set-up allows making broadband ([2-20] GHz) 3D measurements of the full amplitude scattering matrix (amplitude and phase of the elements). An insight into the most relevant results obtained to date for a 74 sphere aggregate is provided.

INTRODUCTION

The Scale Invariance Rule (SIR) states that a dimensionless amplitude scattering matrix can be defined for an arbitrary fixed particle embedded in an infinite, homogeneous, linear, isotropic, and non-absorbing medium[1]. This represents the underlying condition to carry out microwave analog to light-scattering experiments which involve the simultaneous scaling of particle size and wavelength by the same factor, keeping the size parameter constant, and using materials that have the same complex refractive index in the microwave region as in the optical domain. Application of this method has been successfully proven to provide reliable experimental data for the assessment of light-scattering codes (see details and a review by B.Å.S. Gustafson[2], with a particular emphasis on the University of Florida's set-up).

Still some improvements could be envisaged at several levels: the use of larger wavelengths to make the building of fully controlled complex-shaped particles even easier; the realization of 3D measurements, viz. when the emitter and the receiver displacement courses are not necessarily in the same plane; the determination of both amplitude and phase of all elements of the amplitude scattering matrix for a non-spherical particle. In the following, a novel implementation of a microwave analog to light-scattering measurement setup is presented which accounts for these possible extensions. The next section is dedicated to a short description of the microwave scattering facility as well as of the procedure to build a fully controlled aggregate of few centimeters in size. Then, the methodology to perform a proper assessment of scattering codes is summarized, followed by the delivery of sample results.

* Corresponding author: Rodolphe Vaillon (Rodolphe.Vaillon@insa-lyon.fr)

EXPERIMENTAL METHODS AND SET-UPS

The microwave scattering facility

The main features of the experimental set-up developed by members of the Institut Fresnel in the anechoic chamber of the 'Centre Commun de Ressources Microondes'[3] are the following (see Fig. 1): broadband measurements (2 to 20 GHz, i.e. λ_0 = 1.5 to 15 cm); the course of the receiver antenna in the azimuthal plane is of 260°; possible location of the emitter antenna out of the azimuthal plane with a 180° vertical excursion (3D measurements); analysis of all polarization cases by rotating the linearly polarized antennas; drift compensation[4] and noise characterization and reduction to permit cross-polarization scattering measurements for centimeter-sized targets; and investigation of target orientation from axial rotations around the vertical axis (see [5-6] for details).

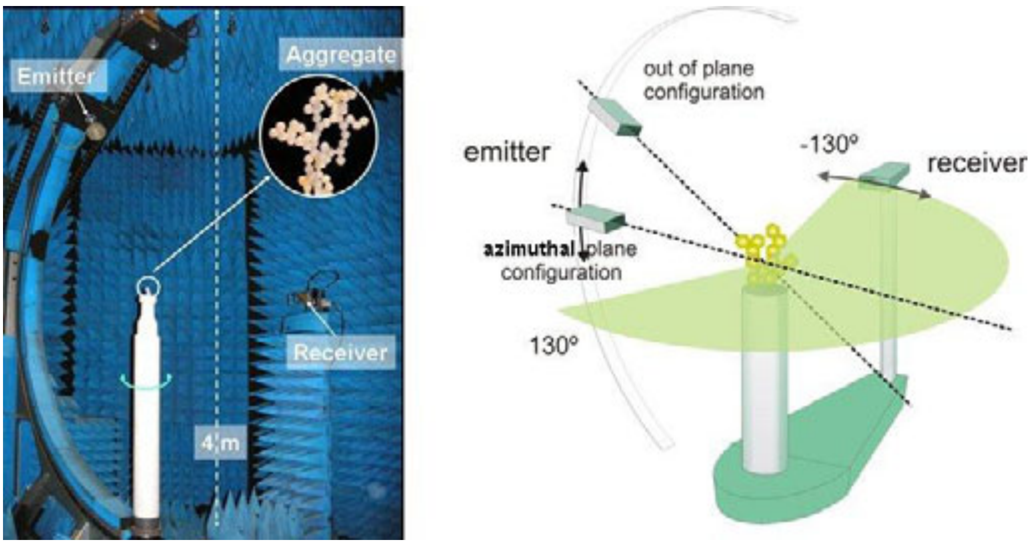

Figure 1. Picture of the facility (left) and azimuthal ("in plane configuration") and "out of plane configuration" for the location of the emitter antenna (right).

Building of a fully controlled aggregate

The tested fractal aggregate depicted on Fig. 1 is the analog of a micrometric particle composed of 74 spherical monomers with tens of nanometers in diameter. It was obtained by realization of the following steps (see Fig. 2): computational generation of the position of each individual sphere from pre-specified fractal parameters (fractal dimension 1.7, prefactor 2); building of the analog aggregate by using a micro-milling machine as three-dimensional positioning system and by glueing each sphere (5 mm in diameter) one after the other; positioning of the resulting aggregate onto a polystyrene support (transparent to microwaves) which itself is put at the top of the pole in the microwave facility. Permittivity in the microwave range of the material constituting the spheres (polyacetal) was determined by using the 'Epsimu' laboratory facility[7]. Some other encouraging tests have also been made using stereo-photolithography to design the targets offering thus new possibilities.

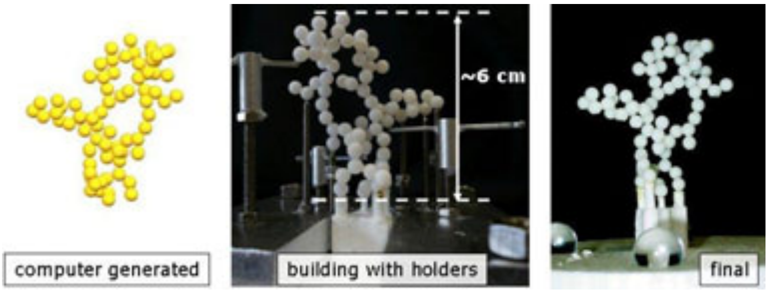

Figure 2. Steps for the preparation of the analog 74-sphere fractal aggregate.

ASSESSMENT OF LIGHT SCATTERING CODES: METHODOLOGY, DATABASE AND SAMPLE RESULTS

The aforementioned setups allow the building of a database containing the measurements of all amplitude-scattering-matrix elements (amplitude and phase) for this aggregate. To make the comparison with light-scattering codes easy and fully coherent, several pre-processing operations have to be performed[6]: a calibration method must be applied to both measured and simulated data to ensure that the exact same normalization technique is employed (amplitude of the incident field equal to unity and phase null at the centre of the target). As the convention used in the experimental set-up for the polarization components is not the common Bohren and Huffman one (referring to the scattering plane), all experimental data were converted into the usual frame to define incident and scattered polarization orientations. Thus, direct comparison with simulated data is made fully possible as well as it is ensured that off-diagonal (S3 and S4) elements contain solely cross-polarization information.

The resulting database is freely and publicly accessible at the web page http://www.fresnel.fr/3Ddirect/database.php, where downloads of the coordinates of the aggregate's spheres, the experimental results and the simulations obtained with Mackowski's T-matrix code are made possible after a registration process. Sample results are provided in Fig. 3. One can observe the high quality of measurement data, particularly for the cross-polarization term S_4, where amplitude minima are satisfactorily resolved. Simulations compare very well with the experiments, both in amplitude and phase of the elements. Additional experimental results and comparisons with other numerical methods can be found in [6].

CONCLUSION

The novel implementation of a microwave analog to light-scattering measurement setup introduced in this paper allows 3D measurements of the full amplitude scattering matrix for fully controlled targets, so as to constitute databases for the assessment of approximate light-scattering codes and also for inversion purposes. We believe that this facility can still be improved to perform full 3D measurements around the object and with application to particles even more complex in geometry and composition.

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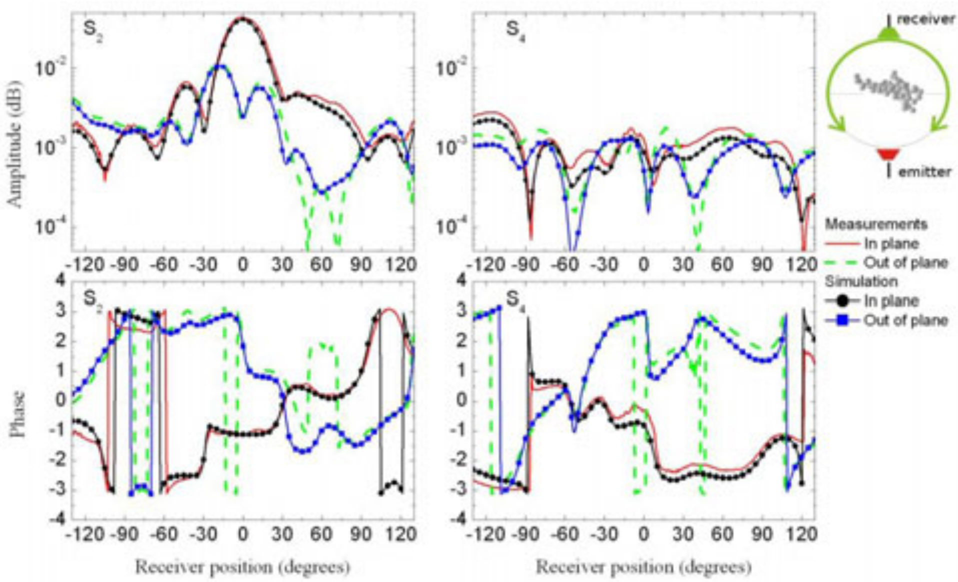

Figure 3. Measurements and Mackowski's T-Matrix simulations of the amplitude and phase of S_2 and S_4 at 18 GHz. The out of plane configuration corresponds to a position of the emitter at 60° from the vertical axis.

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