RCS of Electrically Large PEC Spheres

One of the standard applications for demonstrating accuracy of electromagnetic (EM) codes in radar cross section (RCS) analysis is simulation of perfect electric conductor (PEC) spheres. This application note demonstrates calculations of bistatic RCS of electrically large PEC spheres at 15 GHz using **WIPL-D** software. WIPL-D Pro is a full wave 3D EM **Method-of-Moments (MoM)** based solver which uses **HOBFs (higher order basis functions)**. The solver environment will be used both, for modelling and simulation of the spheres. The results of WIPL-D simulations will be compared with results obtained by using Mie series. Lorentz-Mie series is the standard benchmark result used in case of accuracy demonstration and it is based on analytical solution for canonical geometries.

WIPL-D and MoM Efficiency

In WIPL-D, equivalent surface currents of the composite metal-dielectric structure are accurately modeled using polynomial approximation. Galerkin testing method is applied to **Surface Integral Equations** (SIEs). Compared to some other volume-discretization based computational methods, with WIPL-D **volume discretization is not required** and the artificial boundaries like **radiation boxes or perfectly matched layers are not required**. All of these features contribute to the high accuracy and efficiency of the computations and make the method especially suitable for open-space problems.

WIPL-D software uses **quadrilateral mesh elements** rather than triangles. Furthermore, **sophisticated higher order basis functions (HOBFs)** rather than polynomials of the first order are used to approximate the current distribution on the quads, allowing the quadrilateral mesh elements to take relatively large sizes (up to 2 wavelengths for polynomial order 7). In addition, the parallelized computations using of WIPL-D **GPU simulation module** usually significantly decrease the simulation time.

PEC Sphere Models

Four models of PEC spheres were created and simulated using WIPL-D Pro. The radius of the spheres was 50 wavelengths. The, spheres of such a radius can be considered as electrically large objects. The spheres are illuminated using EM plane wave. The direction of incidence of the plane wave is defined as theta = -90 Degrees (Figure 1). In WIPL-D coordinate system, this means that the EM wave arrives from z = -Inf (Figure 1). The EM wave illuminating the sphere is linearly polarized. E-plane is determined for phi = 0 Degrees, while H-plane is determined for phi = 90 Degrees.

In order to decrease simulation time and number of unknowns, the models of spheres were simulated using three symmetry planes (Figure 1). This feature is available in WIPL-D Pro and in the particular simulation setup, it helps to **reduce the number of unknowns** about 8 times. Since simulation time is correlated to number of unknowns as O(~N^3), the total simulation time is dramatically reduced.

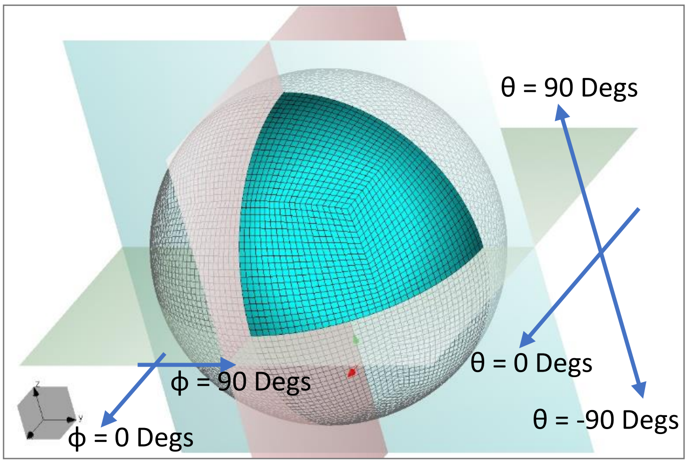

Figure 1. Sphere with three symmetry planes. Illuminating EM plane wave travels from z = -Inf toward z = +Inf.

The simulated spheres had the same radius, but were modeled using different number of segments per quarter of circumference (further: number of segments). Number of segments is WIPL-D parameter determining number of bilinear surfaces (patches) used to approximate the spherical geometry. For example, detail of the sphere with radius of 50 wavelengths and 202 segments per quarter of circumference is shown in Figure 2. Also, approximate size of a segment is shown in Figure 2. For the four models simulated, a number of segments was varied and the obtained results are compared.

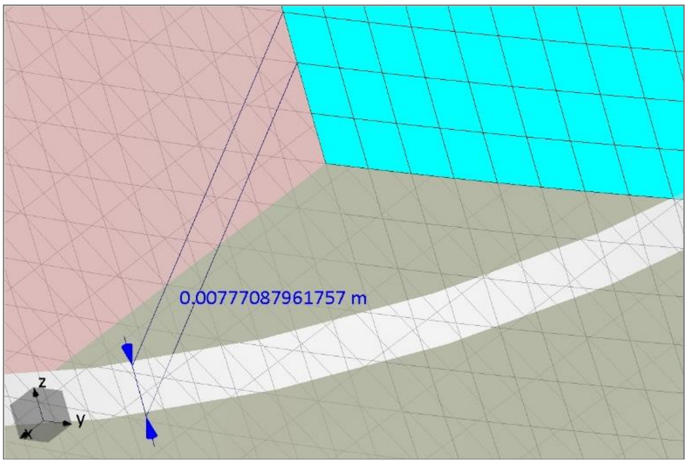

Figure 2. Size of a segment in meters (approximately 0.389 wavelengths). Sphere with 202 segments per quarter of circumference

Number of segments and approximate size of a segment for each sphere compared to wavelength are presented in the Table 1.

Table 1. Number of segments and approximate size of a sphere segment.

Number of segments	Approximate size of a segment	Number of segments	Approximate size of a segment
226	0.347 λ	190	0.413 λ
202	0.389 λ	180	0.436 λ

Results

WIPL-D results are compared with results obtained using Mie series. In order to compare WIPL-D results with Mie series result, RCS is observed over theta angle. RCS results of spheres are shown in two planes: E-plane (phi = 0 Degrees) and H-plane (phi = 90 Degrees). The comparisons of the results are displayed in Figures 3-8.

Simulations

Computer used for these simulations is Intel® Xeon® Gold 5118 CPU @ 2.30 GHz (2 processors) with 192 GB RAM and four NVIDIA GeForce GTX 1080 Ti GPU cards. The simulations were performed on the computer, using five-disc drives (five INTEL SSDSC2KB019T7) in RAID-0 mode. The GPU cards are used for matrix inversion. The other operations are performed on CPU.

Number of segments, approximate size of a single sphere segment, number of elements, number of patches per 1/8 of the sphere, number of unknowns, occupied computer memory, and simulation time for the simulated spheres are presented in the Table 2 and Table 3.

Conclusion

In this paper we demonstrated how scattering from electrically large spheres has been successfully obtained using WIPL-D Pro software, a full wave 3D EM MoM based solver. The calculated **results were compared with analytically obtained Mie series. The agreement between WIPL-D models and Mie series result is excellent.** Values for RCS, in terms of main and side lobes, are almost identical. The only difference is obtained for forward radiation (theta = -90 Degrees). The more accurate results are achieved when a number of patches (and accordingly, number of unknowns) increases. However, this results in significant increase of hardware requirements and simulation time. Therefore, a trade-off between high accuracy of the results and the available computational resources has to be made.

Finally, it should be noticed that the accuracy of the simulation can be controlled by changing a number of segments within the built-in WIPL-D object as it directly influences the size of the patches and a number of unknowns. For example, this application note illustrates that excellent accuracy for scattering from a PEC sphere with radius of 50 wavelengths can be obtained when using the size of a segment is set to approximately 0.35 wavelengths.

Table 2. Number of segments, approximate size of a segment, number of elements, number of patches per 1/8.

Number of segments	Approximate size of a segment	Number of elements	Number of patches per 1/8 of the sphere
226	0.347 λ	306,456	38,307
202	0.389 λ	244,824	30,603
190	0.413 λ	216,600	27,075
180	0.436 λ	194,400	24,300

Table 3. Number of segments, approximate size of a segment, number of unknowns, computer memory required and simulation time

Number of segments	Approximate size of a segment	Number of unknowns	Memory [GB]	Total simulation time [hours]
226	0.347 λ	306,682	701	7.9
202	0.389 λ	245,026	447	4.8
190	0.413 λ	216,790	350	3.6
180	0.436 λ	194,580	282	2.8

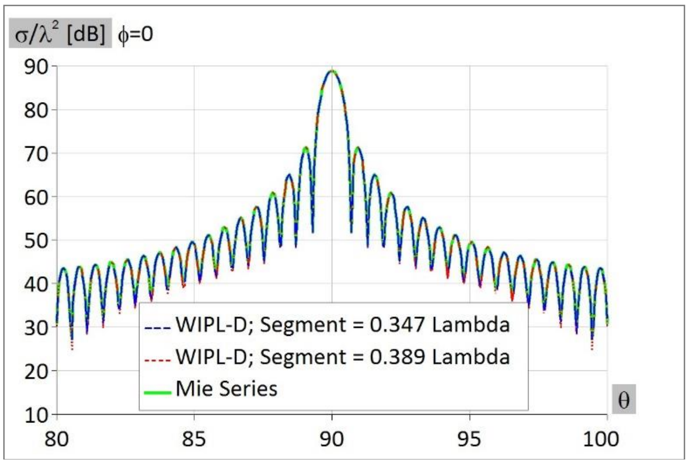

Figure 3. RCS around theta = 90 Degrees in E-plane (phi = 0 Degrees).

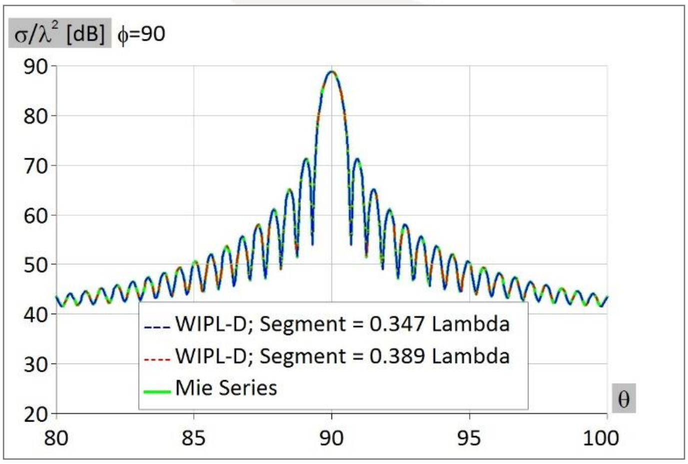

Figure 4. RCS around theta = 90 Degrees in H-plane (phi = 90 Degrees).

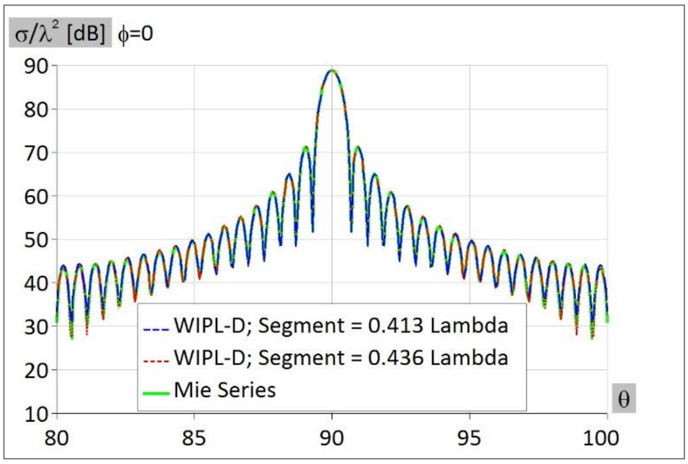

Figure 5. RCS around theta = 90 Degrees in E-plane (phi = 0 Degrees).

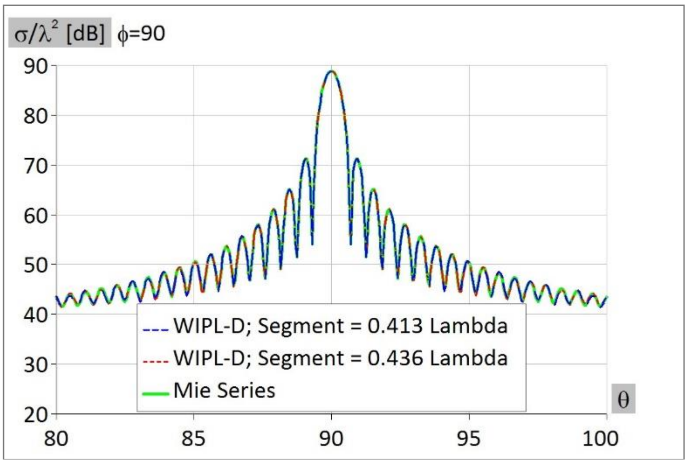

Figure 6. RCS around theta = 90 Degrees in H-plane (phi = 90 Degrees).

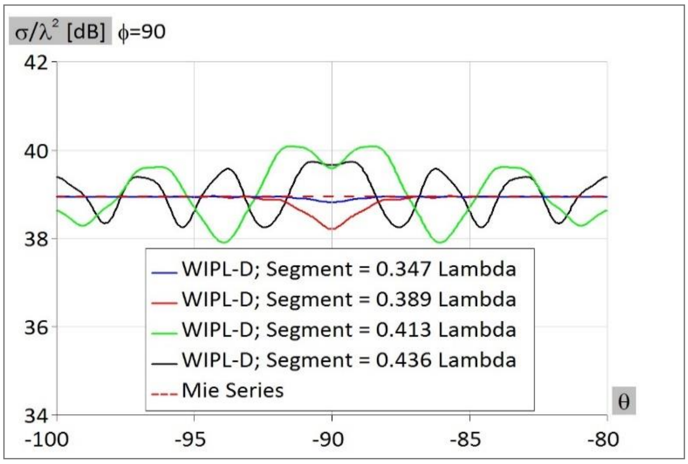

Figure 7. RCS around theta = -90 Degrees in E-plane (phi = 0 Degrees).

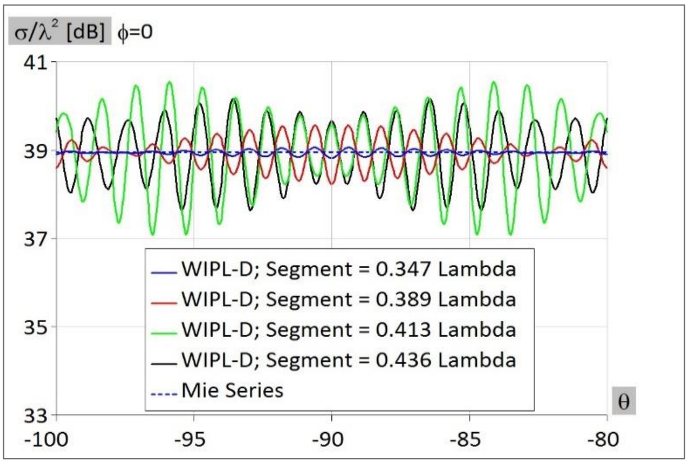

Figure 8. RCS around theta = -90 Degrees in H-plane (phi = 90 Degrees).