

## RCS Convergence Study on Electrically Large Corner Reflector in WIPL-D Software

A corner reflector is well-known structure used in numerous applications where emulation of a large Radar Cross Section (RCS) is required from a reasonably sized object. In this application note we present the analysis of an **electrically large corner reflector** to illustrate the process of simulation results convergence study in WIPL-D software. By following the changes in RCS related to PEC corner reflector from several, carefully selected simulations, the convergence can be established and high reliability of the calculated results confirmed. The simulations differ in some kernel parameters settings which are thoughtfully explained in the text. The changes in reflector RCS obtained after the simulations can be easily compared for the sake of convergence analysis using WIPL Graph module in polar or Cartesian coordinate systems.

**WIPL-D Pro CAD** and **WIPL-D Pro** are used for modelling and simulations. It will be shown that WIPL-D Software, a full wave 3D EM **Method-of-Moments (MoM)** based solver, applying **Surface Integral Equations (SIEs)** and **Higher Order Basis Functions (HOBFs)** can be used effectively to simulate the corner reflector scenario in reasonable time using more or less standard computer workstation configuration. The models will be simulated at 10 GHz – a frequency which is important for some military radars.

### Corner Reflector Models in WIPL-D Pro CAD and WIPL-D Pro

The model of the corner reflector was created easily and intuitively using solid modeling features of WIPL-D Pro CAD. To reduce the computational burden, **one symmetry plane was applied**, as indicated in Figure 1.

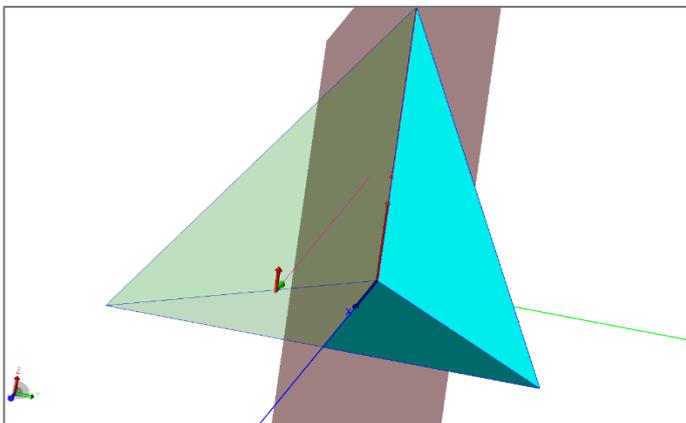


Figure 1. WIPL-D Pro CAD model of the corner reflector.

The CAD model was then meshed and converted to a WIPL-D native format, a process that is called “meshing”. As the result of meshing the solid model is converted in a number of

quads, as presented in Figure 2. The meshing was performed with *Maximum Patch Size*, a kernel setting which limits the maximum size of the quads, set to **1.83 lambdas**. **A particular value represents recommended numerical kernel setting for electrically large PEC scatterers.**

The physical dimensions of the reflector in meters and the electrical dimensions in wavelengths are shown in Figure 2. The electrical length of the edge which is 1.95 m long is 65 lambdas. The corner reflector was simulated at **10 GHz** in **monostatic RCS** operation mode. Radiation patterns are shown in principal plane  $y=0$  for theta angle defined as  $0^\circ < \theta < 90^\circ$ . In WIPL-D coordinate system, elevation angle of  $\theta = 90$  degrees points toward value  $+\text{inf}$  of  $z$  axis.

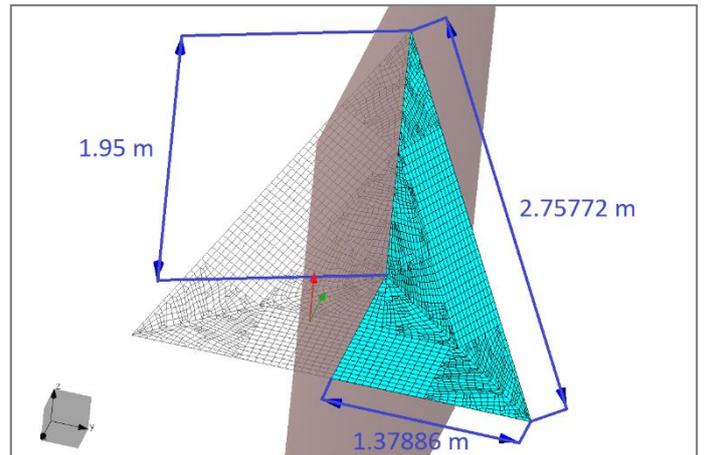


Figure 2. Meshed model of the corner reflector displayed in WIPL-D Pro. The dimensions of the reflector are also shown.

All simulations are performed on the computer platform presented in the Table 1. The GPU card is used for matrix inversion. The other operations are performed on CPU.

Table 1. Computer used in the simulations.

Hardware	Description
CPU	Intel® Core™ i7-7700 CPU @ 3.60 GHz
RAM	64 GB
GPU	One card: NVIDIA GeForce GTX 1080

Numerical kernel parameters which will be increased in order to achieve the most stable results are *Integral accuracy* and *Reference frequency*.

### Numerical Kernel Parameter *Integral Accuracy*

The first parameter to be changed in order to achieve stable results is *Integral accuracy*.

During WIPL-D computation, the evaluation of many integrals is performed, which is mainly related with accurate calculation of MoM matrix elements. WIPL-D Software **automatically determines the orders of numerical integration required**, so that satisfactory results are obtained requiring minimum of simulation time. However, it is recommended to check if increasing the order of integration affects the output results. If an increasing integration order (through *Integral accuracy* parameter) does not change results significantly, the results are considered stable. Thus, the *Integral accuracy* parameter (further, IA) is increased and obtained results are compared in such manner that:

- the results from projects where IA is set to a default value *normal*, and IA is set to *enhanced 1* are compared (Figure 3). As the results are noticeably different, it is concluded that the results do not agree as desired, and that the process of convergence study thorough increasing IA parameter should be continued.

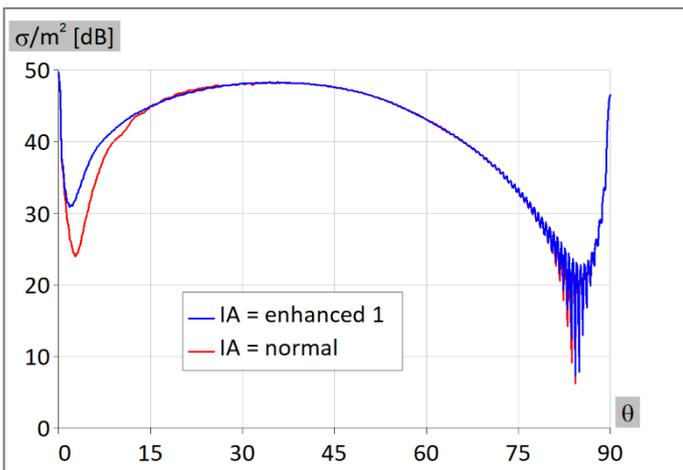


Figure 3. RCS obtained for IA set to *enhanced 1* and *normal*.

- the results between projects where IA is set to *enhanced 2* and *enhanced 1* are compared (Figure 4). As the agreement between the results is very good, it is concluded that the accuracy of the computation is high and that the convergence regarding the parameter IA has been reached.

**The results requiring lower simulation time should be selected.** In this case, it means that the calculations should proceed with IA set to *enhanced 1*. Generally speaking, the convergence is **relative** as It can vary depending on a particular application. For example, for the example described above, one can perhaps select to proceed with IA set to *normal* if the results for the particular applications of the reflector are sufficiently accurate.

For electrically large PEC objects, especially if reduction is applied, **the rule of thumb** is to study the convergence with IA initially set to *enhanced 2* as lower IA values (*normal* and *enhanced 1*) usually fail to provide satisfactory results.

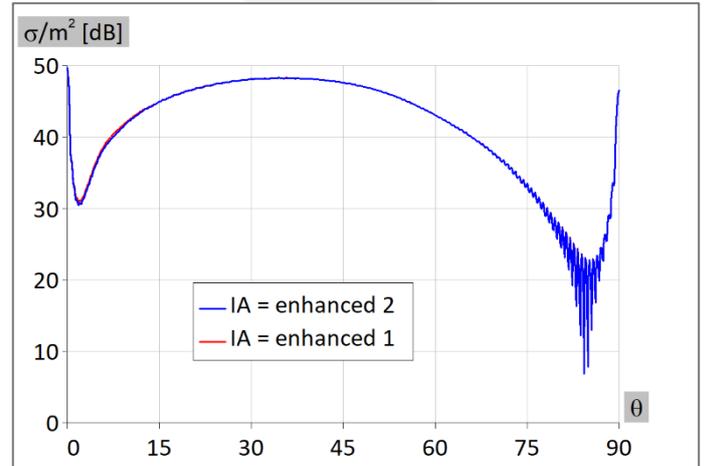


Figure 4. RCS obtained for IA set to *enhanced 2* and *enhanced 1*.

Furthermore, in general, the process of increasing IA parameter can proceed even higher, or it can be stopped on the lower IA. However, here, the results between *enhanced 2* and *enhanced 1* converged. In the other words, the results obtained after applying *enhanced 2* and *enhanced 1* are satisfactory the same and thus, it is considered that the result with lower numerical kernel requirement (here, *enhanced 1*) converged. Number of unknowns and total simulation times for the model with changed *Integral accuracy* are shown in Table 2. It should be noticed that number of unknowns remained the same in each of four mentioned cases and that simulation time is increased with increasing IA parameter. RCS obtained for IA set to *enhanced 2*, *enhanced 1*, and *normal* are also shown and compared using polar coordinate system (Figure 5).

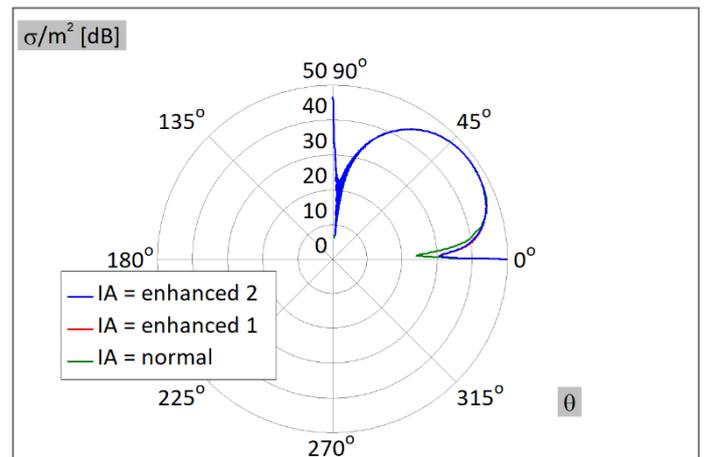


Figure 5. RCS obtained in polar coordinate system for IA set to *enhanced 2*, *enhanced 1*, and *normal*.

Table 2. Number of unknowns and total simulation time.

Integral accuracy	Number of unknowns	Total simulation time [sec]
<i>normal</i>	91,568	1,596
<i>enhanced 1</i>	91,568	1,638
<i>enhanced 2</i>	91,568	1,729

## Numerical Kernel Parameter Reference Frequency

The second parameter to be changed in order to achieve stable solution is *Reference frequency*. The program automatically determines which orders of current expansions should be used on entities (here, plate entities) in the model by analyzing the electrical size of each entity at the reference frequency. By increasing the *Reference frequency*, the entities in the model become electrically larger so program assigns to them higher orders of current expansion. The wavelength will be also calculated according to increased *Reference frequency*. This means, for example, that the plate entities can be subdivided and that the CAD model of the structure will be meshed again. Thus, the *Reference frequency* parameter is increased and obtained results are compared so that:

- the results between projects where the IA parameter is set to *enhanced 1* are compared, **the first one where *Reference frequency* has a default value** (in WIPL-D, it is stop frequency) and **the second one where *Reference frequency* is increased** by 10%. The results are illustrated in Figure 6. The value of 10% represents recommended increment step for electrically large PEC scatterers. As the results are in good agreement, the process of convergence study through increasing *Reference frequency* can be concluded.

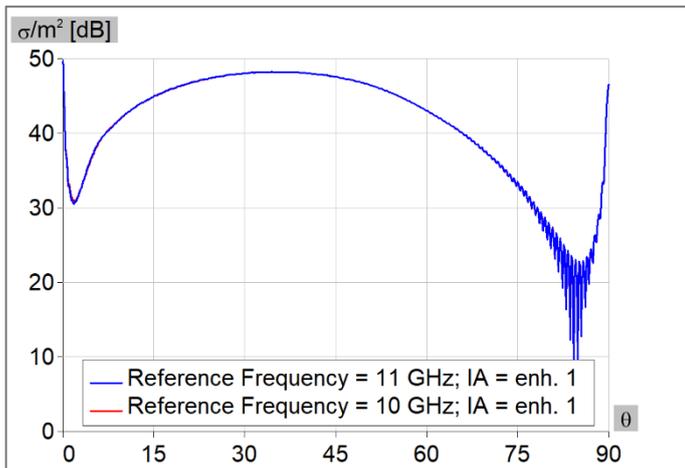


Figure 6. RCS obtained for *Reference frequency* set to 10 GHz and for 11 GHz (10% greater frequency).

The highly accurate computations can proceed with lower *Reference frequency* parameter as **the results requiring less demanding computation resources should be selected**. In this case, this is the result obtained with *Reference frequency* set to 10 GHz.

**In a general case where sufficiently good agreement between the simulations is not achieved after the first iteration, the process of increasing *Reference frequency* parameter can proceed.** For electrically large objects, the increment between *Reference frequencies* should be 10%. In this particular case, this means that the subsequent *Reference frequencies* should be

12 GHz, 13 GHz, 14 GHz, etc., resulting in increased number of unknowns, as listed in Table 3.

RCS obtained for *Reference frequency* set to 11 GHz and 10 GHz are also shown and compared using polar coordinate system (Figure 7).

Table 3. Number of unknowns and total simulation time.

Reference frequency	Number of unknowns	Total simulation time [sec]
10 GHz	91,568	1,596
11 GHz	106,543	2,615

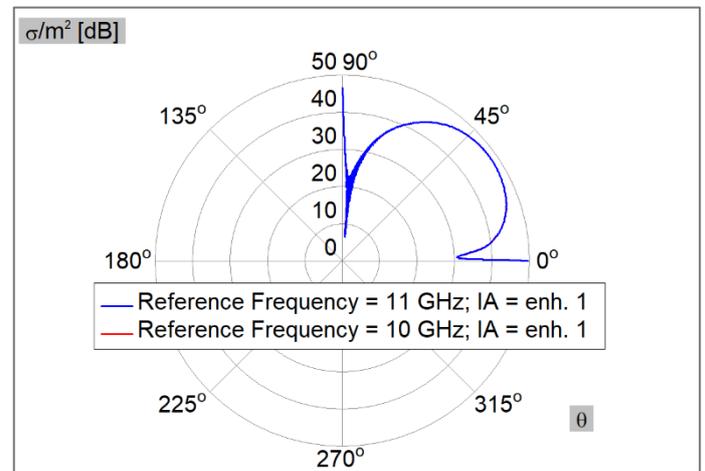


Figure 7. RCS obtained in polar coordinate system for *Reference frequency* set to 10 GHz and for 11 GHz (10% greater frequency).

## Conclusion

The application note explains the process of convergence study for a relatively large PEC scatterer when WIPL-D Software is used for simulations. The scatterer has been chosen to be a corner reflector as it represents a realistic, widely used structure. Two numerical kernel parameters were changed in order to achieve stability of the RCS, the order of numerical integration introduced through *Integral accuracy* parameter, and the order of current expansion (reflecting in the number of unknowns) controlled by *Reference frequency* parameter.

The comparison of the results was performed by visual inspection of the RCS from both, Cartesian and polar plots. All of the simulations were performed with high numerical efficiency as a moderate computer configuration has been used. This is very important considering electrical size of the simulated object. For this particular case simulation parameters ensuring highly accurate results do not differ much from the default numerical kernel settings.