Obstacle Detection with 77 GHz Automotive Radar

EM simulations have a significant role in automotive industry. However, in recent years, the challenges of EM simulations have been more and more demanding. One of typical applications in automotive radar industry would be usage of an EM simulator to accurately predict radiation pattern of automotive radar antenna mounted on the front part of a car. Also, near field distribution in front of the car shell (usually in presence of obstacles) could be investigated. In these scenarios, frequencies of interest are usually very high (typically, above 10 GHz). Thus, electrical dimensions of the cars measured in wavelengths are extremely large. WIPL-D software, a Method-of-Moments (MoM) based solver allows successful simulations of models at such frequencies.

MoM Efficiency

WIPL-D uses **quadrilateral mesh elements**, rather than triangles. This **decreases the required EM problem size**, which is measured in unknown coefficients (the “unknowns”) required to determine current distribution on the model (“EM solution”). In addition, WIPL-D Pro 3D EM solver uses **higher order basis functions (HOBFs)** on quadrilaterals, rather than polynomials of the first order. This allows utilizing quadrilaterals of larger size (up to 2 wavelengths for polynomial order 7), which compared to low order EM simulators, **reduces number of unknown coefficients** between 3 and 10 times.

Electrically Large EM Simulations

WIPL-D Pro software suite allows usage of special reduction techniques designed to perform significant reduction of unknown coefficients (thus, also performing reduction of simulation time and memory resources) while preserving acceptable accuracy of the output results. That way, the electrically very large problems can be solved approximately, with very small loss of accuracy. Number of unknown coefficients on model parts which are far away from the antenna can be **reduced** since such elements do not significantly contribute to radiation pattern. The feature providing this form of reduction is called ***antenna placement reduction***. In addition, number of unknowns can be reduced on model parts which are not directly illuminated by the antenna by using feature called ***shadow*** reduction.

Furthermore, WIPL-D **CAD tool** becomes a part of the WIPL-D software suit. The WIPL-D CAD tool allows easy import of CAD files, fast meshing of various structures, easy modeling and positioning of devices in conjunction to complex CAD geometries... In addition, comparing to CPU computations, WIPL-D **GPU simulation module** extends the range of utilized frequencies where the EM model can be designed and simulated for acceptable simulation time.

Finally, for electrically very large models, which are beyond the scope of all reductions and behind the scope of GPU solver, a WIPL-D user can apply **Domain Decomposition Solver (DDS)** - a tool which was created for simulating structures which would otherwise be impossible to be simulated using WIPL-D MoM based solver. Or, simulating the structures using WIPL-D MoM solver would require very long simulation time. The basic idea behind DDS is that the original model is decomposed into a number of groups. A group is composed of a number of neighboring plates and wires. Each group represents a subproject. In the 0^{th} iteration, subprojects are simulated independently and the coupling between them is not taken into account. Solutions of all subprojects are used as macro-basis functions whose weighting coefficients are determined from the condition that mean-square value of the residuum of the original project is minimized. The residuum of the final solution in the 1^{st} iteration can be used as the excitation in the 2^{nd} iteration, and so on. The entire iterative procedure finishes when the total residuum falls below the predefined threshold.

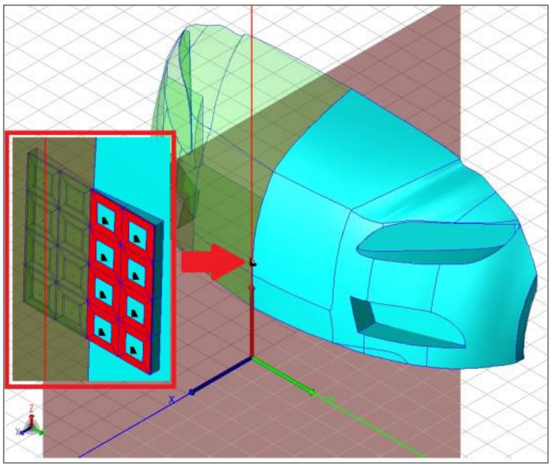

Figure 1. An example of electrically large structure - the anti-collision radar antenna and the car shell.

The motivation for writing this application note is to show DDS (WIPL-D) capabilities in simulating electrically large structures (Fig. 1). The usage of WIPL-D reduction features and DDS will be presented. Four automotive radar scenarios will be investigated:

- *Scenario 1* represents the automotive radar antenna mounted on a car bumper (Fig. 1, Fig. 2).
- *Scenario 2* represents a modification of the first scenario. Comparing to the *Scenario 1* the difference exists in added metallic hollow pole in front of the bumper (Fig. 3, Fig. 7).
- *Scenario 3* represents the automotive radar antenna mounted on the modified car bumper (Figure 4).
- *Scenario 4* represents a modification of the third scenario. Comparing to the *Scenario 3* the difference exists in added metallic hollow pole in front of the bumper (Figs. 5-6).

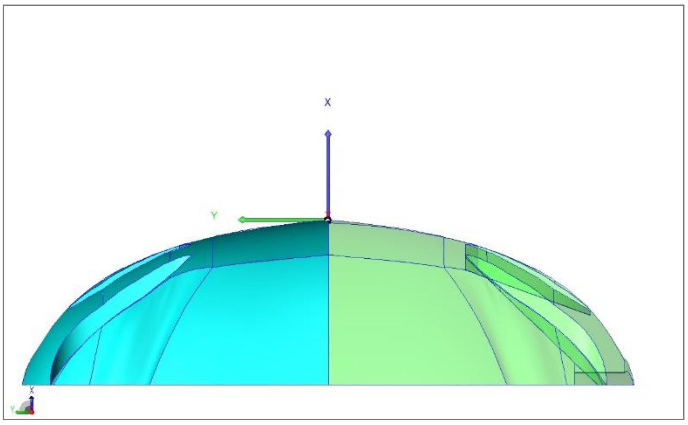

Figure 2. Scenario 1.

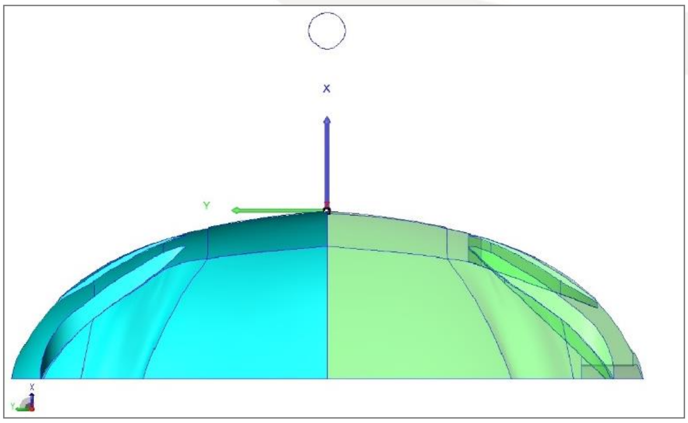

Figure 3. Scenario 2.

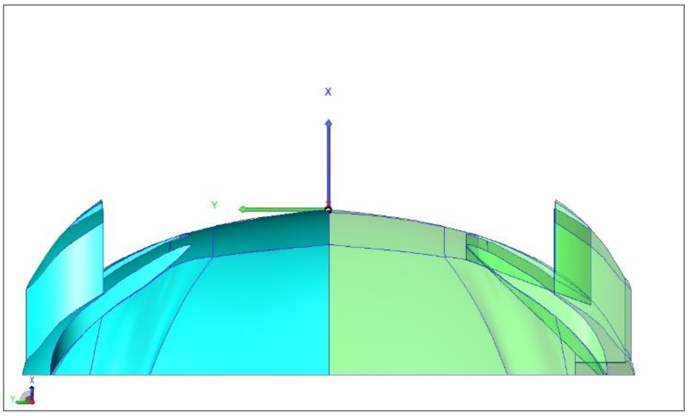

Figure 4. Scenario 3.

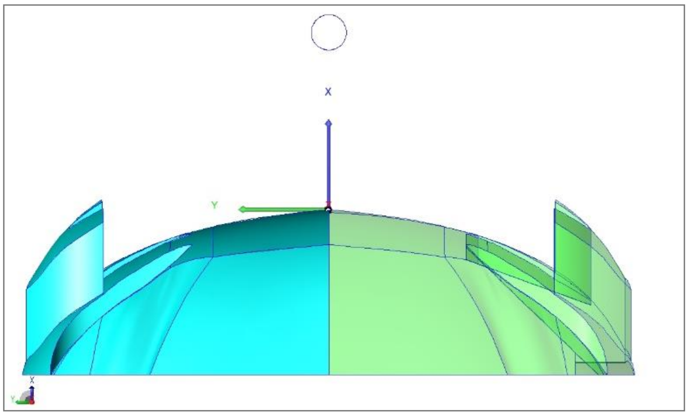

Figure 5. Scenario 4.

In order to enable better insight to the simulated scenarios, 4 figures illustrating front part of the car are displayed (Figures 2-5). The figures represent bird's eye view of the front part of the car (with added hollow metallic pole - Figure 3 and Figure 5; with modified bumper - Figure 4 and Figure 5).

All figures are obtained after exporting models as picture from WIPL-D Pro CAD. Hollow metallic poles are presented here (Fig. 3, Fig. 5) due to the demonstration, only. During preparing the models for run, they are added after process of meshing, within WIPL-D Pro; they are not part of WIPL-D Pro CAD projects.

All automotive anti-collision radars mounted onto a car front will be investigated at 77 GHz. Influence of the ground will be neglected. Near field distributions and radiation patterns results will be presented.

WIPL-D Models

Realistic model of the front part of a car shell with magnified anti-collision radar antenna are displayed in Figure 1. It represents CAD model of the first scenario. The simulated model of the anti-collision radar mounted on the front part of the car shell was created after:

- using WIPL-D Pro CAD,
- converting the model to WIPL-D Pro native format and applying *antenna placement reduction* and *shadow*
- and finally, converting to the format used by DDS.

The anti-collision radar is modeled by 4x4 patch array which is mounted on the front part of the car shell (Figure 1). The influence of the whole car to the radar antenna operation characteristics is approximated well with introducing the front part of the car shell, only. The simulated model is symmetrical. Thus, a symmetry plane was applied so that number of unknowns is halved and simulation time is reduced.

To illustrate the size of the problem, final mesh of the structure with applied *antenna placement reduction* and *shadow* reduction in the fourth scenario (the most complex scenario) is shown in Figure 6. The mesh elements are maximum 2 wavelengths large (Figure 6). In addition, DDS groups for the second scenario are shown in Figure 7.

Simulations and Results

The EM simulations were performed on the platform: Intel® Xeon® CPU E5-2660 v4 @2.20 GHz, 2 processors with 256 GB RAM. The models were simulated with applied reductions. According to the results presented in the other WIPL-D automotive application notes, it is assumed that applied reductions do not disturb radiation pattern results. Simulation times necessary for carrying out four simulation scenarios are displayed in Table 1.

After the convergence study, it was concluded that iteration 1 enables us good accuracy. In order to support this claim, fitted results obtained after three iterations (in the fourth scenario) are displayed in the Figure 8. Iterations 1 and 2 produce similar results (Figure 8). Thus, iteration 1 is selected as accurate enough.

The radiation patterns are calculated in one principal plane, for each of four scenarios. Fitted radiation patterns are presented in the Figure 9. Near field distributions are presented in Figure 10 and Figure 11.

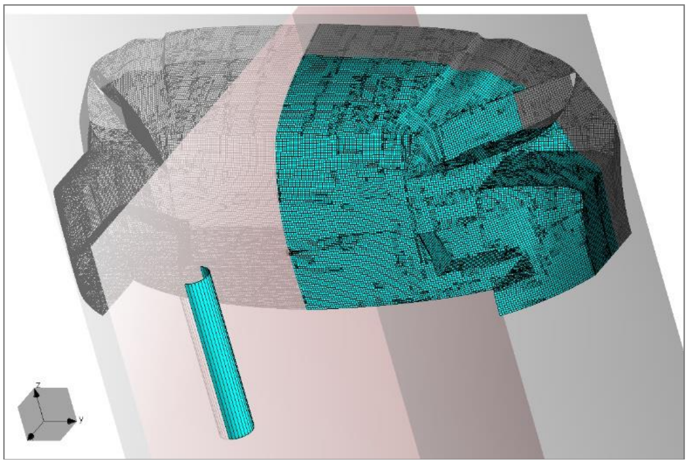

Figure 6. Mesh at 77 GHz – the fourth (the most complex) scenario. Applying the *shadow* reduction can be noticed.

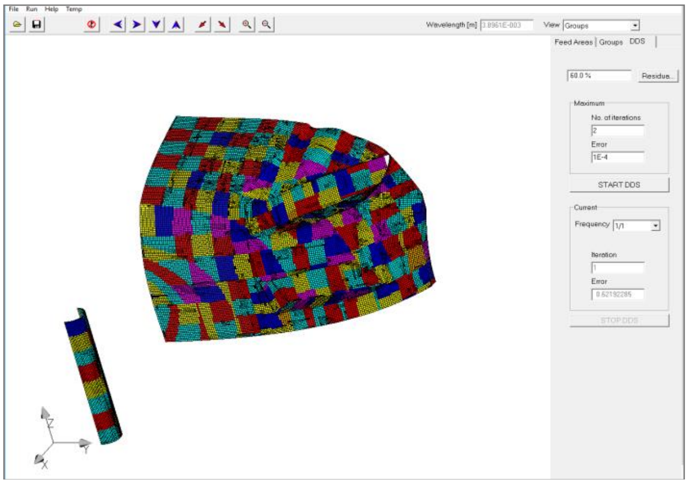

Figure 7. DDS groups – the second scenario.

Table 1. Iterations, number of unknowns and simulation times for simulated scenarios

Model	Iterations	Unknowns	Simulation time [min]
The first scenario	$0^{th} + 1^{st}$	0.86 M	36
The second scenario	$0^{th} + 1^{st}$	0.94 M	33
The third scenario	$0^{th} + 1^{st}$	1.02 M	52
The fourth scenario	$0^{th} + 1^{st}$	1.10 M	47

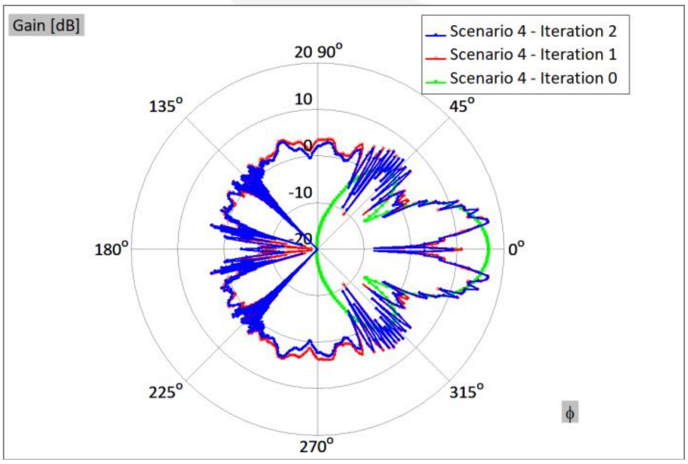

Figure 8. Convergence study – iterations.

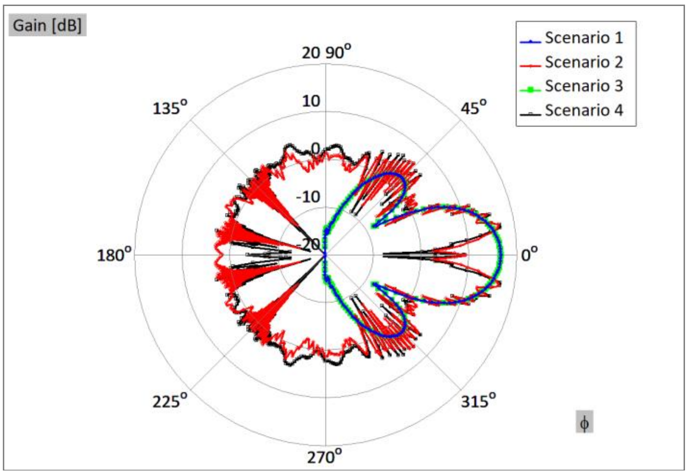

Figure 9. Radiation patterns.

Conclusion

Four scenarios of mounting model of anti-collision radar antenna on a car bumper were investigated. Radiation pattern results and near field distributions were observed. With simulation frequency equal to 77 GHz and ordinary bumper dimensions, all the scenarios are considered to be electrically large. Anyway, all of the simulations were performed relatively fast on an affordable desktop workstation. Furthermore, all performed simulations led us to some conclusions about usage of WIPL-D features\tools and about obtained results.

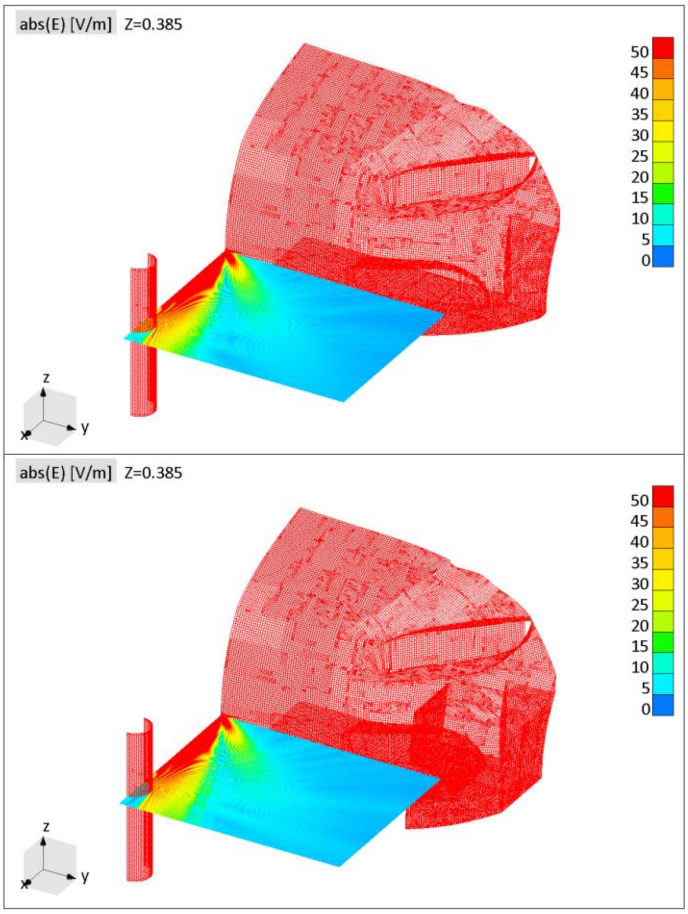

Figure 10. Near field distributions for scenario 2 [up] and scenario 4 [down].

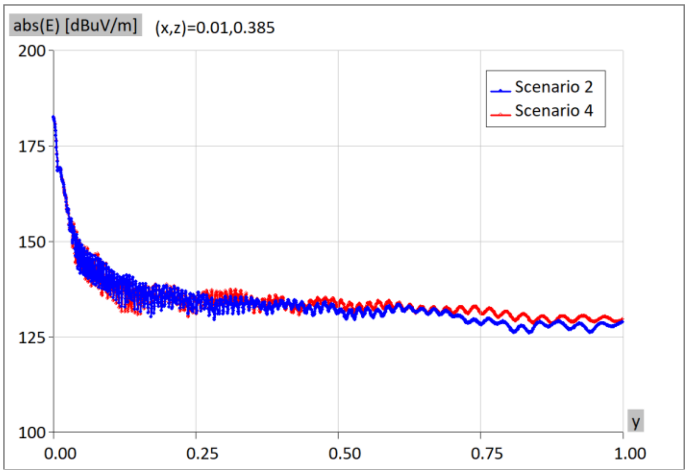

Figure 11. Near field distributions for scenario 2 and scenario 4 – the influence of the bumper modification is recognized for higher y values.

The usage of WIPL-D features and tools was successfully applied. The process of manipulating CAD model, manipulating WIPL-D Pro native format model and, finally, manipulating and running DDS model was straightforward.

In these scenarios, iteration 1 was sufficient for obtaining adequate results (Figure 8). Furthermore, modification of the bumper does not influence output results significantly (Figure 9).

On the other side, Figure 9 displays that small difference between radiation patterns calculated in *Scenario 2* and *Scenario 4*. The difference exists due to presence of bumper modifications. Precise insight to bumper modification influence cannot be achieved by observing only Figure 10. The deep insight to the bumper modification influence on the near field can be achieved by observing, for example, results presented in Figure 11. Finally, the influence of presence of the hollow, metallic pole is clearly displayed in the Figure 9.