EM Simulations in Automotive Industry

Electromagnetic (EM) simulations have become an indispensable part of the modern automotive industry design process as several general electronics, radar, and communication systems are operating in the modern car environment. Several of these systems are presented in this paper to demonstrate scenarios typical to the automotive industry and how such scenarios can be successfully analyzed using WIPL-D EM simulation software suite.

The first scenario deals with a **77 GHz anti-collision radar mounted on a car bumper**. The second scenario presents **EM obstacle detection** at the same operating frequency. The third scenario describes **a radar antenna** operating at 24 GHz and 40 GHz **mounted on a car bumper**. Finally, the last scenario explains the specifics of **vehicle-to-vehicle communication** at 5.9 GHz.

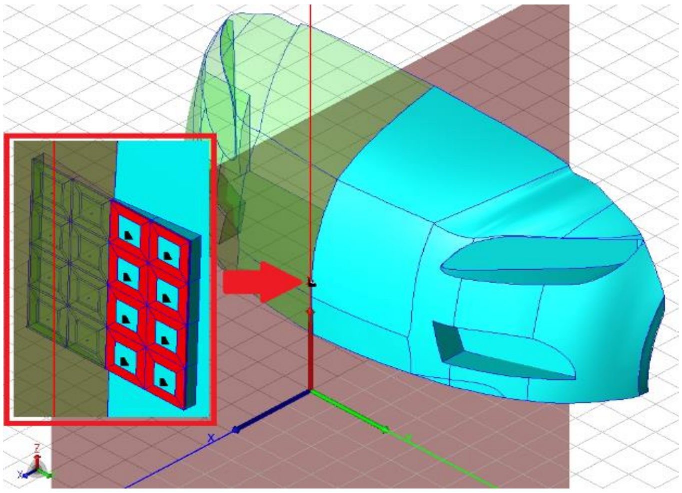


Figure 1. Anti-collision radar antenna mounted on the car's bumper – WIPL-D Pro CAD

The selected scenarios represent very important topics in the modern car industry. For example, the prediction of radiation pattern and/or near field distribution of anti-collision (collision avoidance) system should be a design validation parameter for both, car chassis designers and radar designers. The cars of the future will include an ability to communicate and exchange data for safety or comfort, in the final instance leading to driverless operation. Therefore, various aspects of vehicle-to-vehicle communication should be examined including EM simulation of the physical layer properties.

WIPL-D Company continuously improves and develops a variety of tools to facilitate various simulation approaches and ease each design phase. Specifically, in relation to the automotive industry, a CAD tool named **WIPL-D Pro CAD** can be used not only to import realistic geometries of various car parts and details but also to easily model various EM devices such as antennas and perform the concurrent design of such devices operating in a realistic automotive environment.

In addition to CPU-only computations, the **GPU Solver** tool enables EM simulations on fast GPU cards to perform demanding EM simulations on **affordable workstations** comprising a regular PC with one or several graphic cards. In addition, full Method-of-Moment (MoM) solutions can be also obtained using **GPU Cluster Solver**.

A tool named Domain Decomposition Solver (DDS) can be used to solve extremely large electrical structures. Structures that would otherwise be impossible to solve using WIPL-D MoM solver and structures that would require impractically long simulation time to solve using the MoM solver can be solved efficiently using DDS. The solver analyses electrically very large structures by subdividing the boundary problem into smaller sub-domain problems, solving the subdomain problems, and combining the solutions.

Antenna placement scenarios:

Simulation of antennas placed on large platforms is computationally very demanding even for modern PCs. WIPL-D method (**quadrilateral mesh elements**, rather than triangles; **higher-order basis functions (HOBFs)** on quadrilaterals, rather than polynomials of the first order) requires about 30 unknowns per wavelength squared for metallic structures. Even so, extremely large structures are very demanding in terms of computer resources. Besides the basic properties of the solution method ensuring numerical efficiency and various symmetry options, WIPL-D software suite includes several options for smart and sophisticated approximations.

The ***Antenna placement reduction*** is a special technique for reducing the number of unknown coefficients (the "unknowns") on model parts that are far away from the antenna as such elements do not significantly contribute to the results. In addition, the number of unknowns can be reduced on model parts that are not directly illuminated by the antenna using another feature called ***shadow*** reduction.

This approach leads to a noticeable reduction of simulation time and memory resources so that electrically very large problems can be solved with a small loss of accuracy.

1. Anti-Collision Radar on Car Bumper

The model of the car bumper was imported into WIPL-D Pro CAD and the anti-collision radar antenna was added to emulate a real-world antenna placement scenario. Due to the symmetry of the antenna and the bumper, only half of the scenario was modeled and the appropriate symmetry options were applied. This reduces the simulation requirements, hence the simulation time. Figure 1 shows a realistic front of a car chassis with a bumper and the position of the antenna (a 4x4 patch array) on the bumper. The bumper was modeled using PEC material.

The meshed model of the bumper with the antenna array is shown in Figure 2.

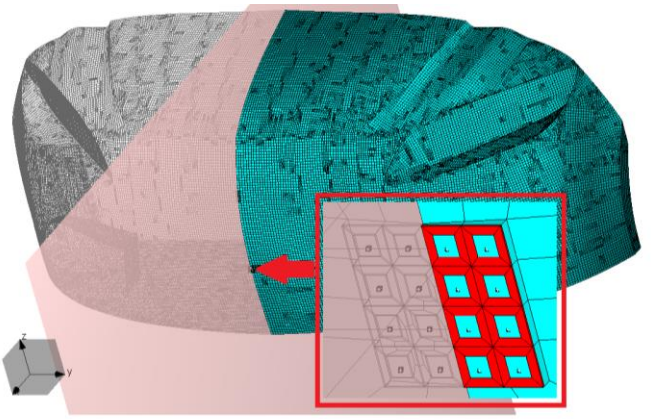


Figure 2. Anti-collision radar antenna mounted on the bumper – WIPL-D Pro

The model of the radar antenna on the bumper was simulated at 77 GHz by using Domain Decomposition Solver (DDS). Two scenarios were observed, with and without smart reduction applied (Antenna placement reduction set to 70%). The first scenario (without reduction) includes 3 simulations (DDS iterations), while the second scenario includes 2 iterations. Simulations were performed with groups whose size was equal to 3,000 unknowns (Figure 3).

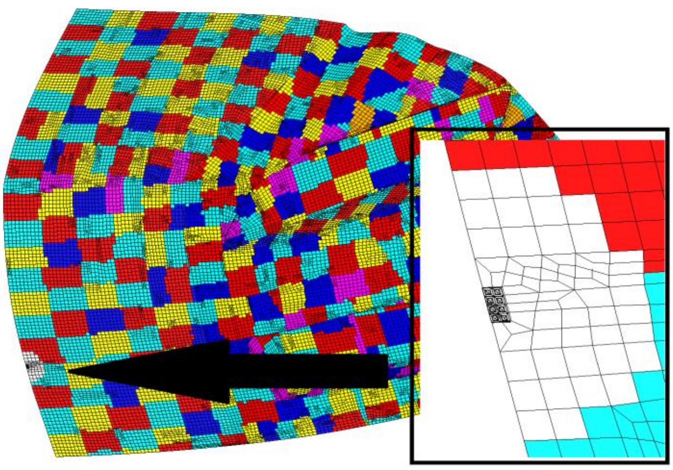


Figure 3. Antenna and the groups – DDS preview

The calculated radiation pattern of the antenna in $\theta = 0$ plane[1] is shown in Figure 4. The simulation time and the number of unknowns per iteration are shown in Table 1. The computer used for these simulations is Intel® Xeon™ CPU E5-2660 v2 @2.20 GHz, 2 processors with 256 GB RAM. The results obtained in the two scenarios have a matching solution, so the *Antenna placement reduction* technique can be efficiently used for this type of simulation.

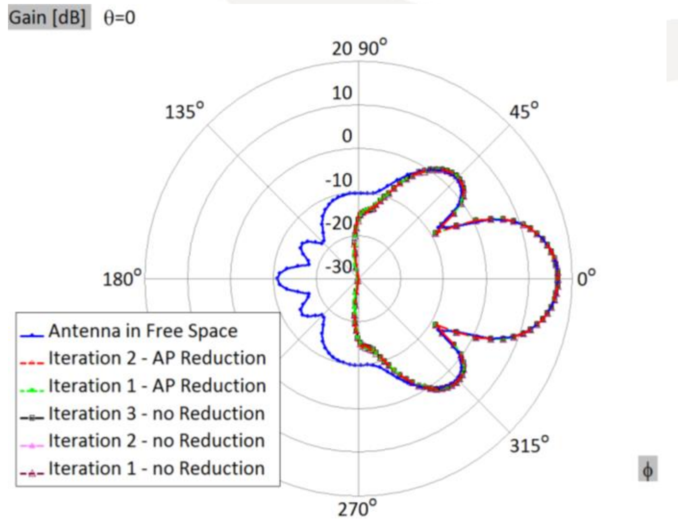


Figure 4. Radiation patterns of the anti-collision radar antenna in free space and anti-collision radar antenna mounted on the car front bumper

Table 1. Iteration, simulation time and number of unknowns

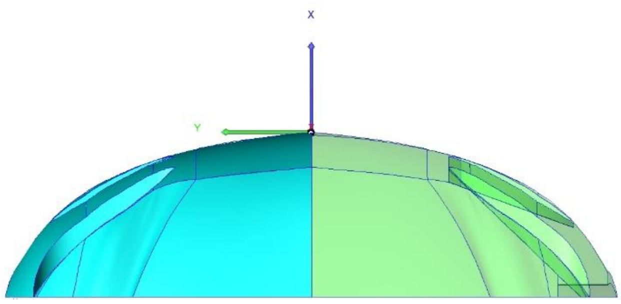
Model	Iteration	Simulation time [minutes]	Number of unknowns
Without Reduction	1st	41 (0th + 1st)	~2.5 million
Without Reduction	2nd	12	
Without Reduction	3rd	11	
70% Antenna Placement Reduction	1st	30 (0th + 1st)	~1 million
70% Antenna Placement Reduction	2nd	20	

2. Obstacle Detection with 77 GHz Automotive Radar

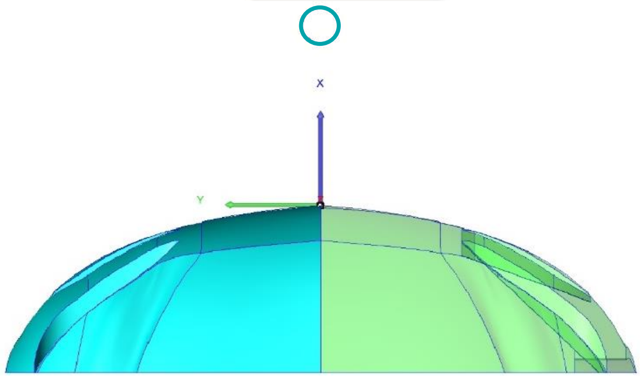
In the first part of this paper, it is shown that DDS in combination with the symmetry option and the antenna placement reduction technique can be efficiently used for a 77-GHz anti-collision radar antenna on a car bumper. This scenario was further modified to demonstrate obstacle detections (for example traffic barrier pole) with the aforementioned radar system. In total, 4 scenarios were investigated:

- **Scenario 1**: the automotive radar antenna (a 4x4 patch array) mounted on a car bumper (Figures 2 and 5a),
- **Scenario 2**: modified Scenario 1 - a metallic hollow pole is placed in front of the car bumper (Figure 5b),
- **Scenario 3**: modified Scenario 1 – car bummer is modified with sidewalls (Figure 5c) and
- **Scenario 4**: modified Scenario 3 - a metallic hollow pole is placed in front of the car bumper (Figure 5d).

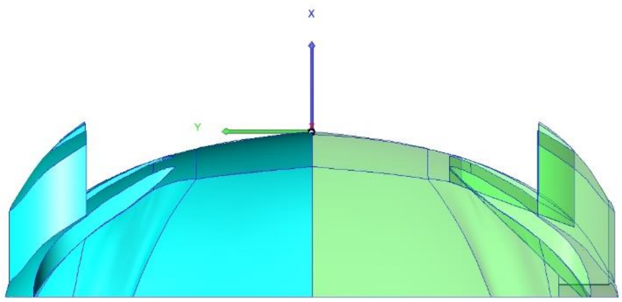
[1] In WIPL-D, this is z=0 plane.



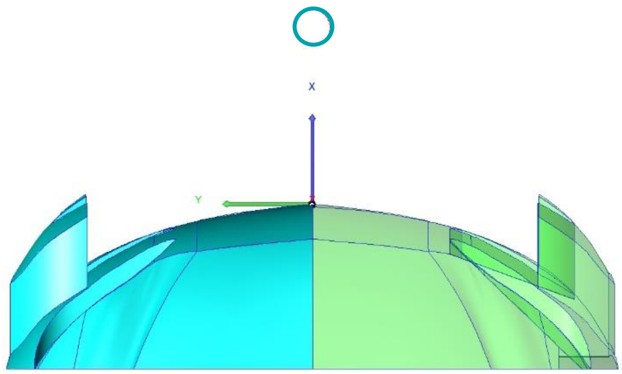
a) Scenario 1: the automotive radar antenna (a 4x4 patch array) mounted on a car bumper



b) Scenario 2 (modified Scenario 1) - a metallic hollow pole is placed in front of the car bumper



c) Scenario 3 (modified Scenario 1) – car bummer is modified with sidewalls



d) Scenario 4 (modified Scenario 3) - a metallic hollow pole is placed in front of the car bumper with sidewalls

Figure 5: Different obstacle detections scenarios - bird's-eye view

There are a few techniques to decrease the number of unknowns in complex and large projects. Modeling only the front part of the car instead of the full model is sufficient for obtaining high-accuracy results as the rest of the car shell does not significantly influence the radar antenna operation. The model is symmetrical, so only half of the model is made and the appropriate symmetry options are set. Special reduction techniques (antenna placement reduction and shadow) are further used. To illustrate the size of the problem the final mesh of the structure with applied aforementioned reduction methods for scenario 4 (the most complex, hence the most EM-simulation-demanding scenario) is shown in Figure 6.

The next step was to determine the required number of iterations in DDS, so the convergence study was performed for the 4th scenario. The results for the 0th, 1^{st,} and 2nd iterations were compared (Figure 7) and it is concluded that iteration 1 provides sufficiently high accuracy.

All 4 scenarios were simulated at 77 GHz. The influence of the ground is neglected. The radiation patterns are calculated in one principal plane, for each scenario. Fitted radiation patterns are presented in Figure 8. Near field distributions for scenarios 2 and 4 are presented in Figures 9-10.

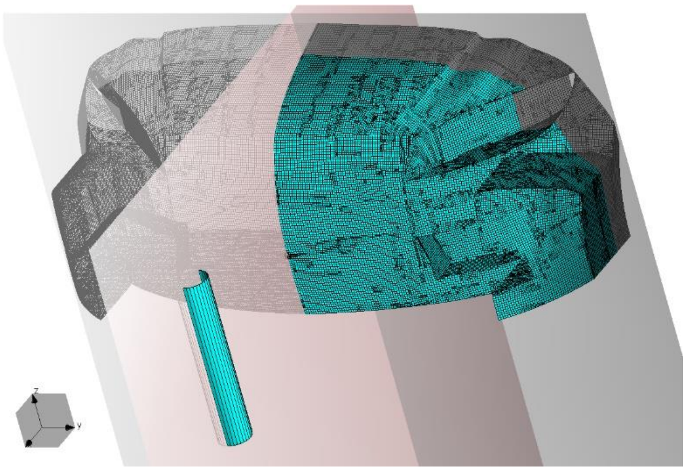


Figure 6. Scenario 4 with applied reduction techniques – meshed model at 77 GHz

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. Simulation times necessary for carrying out four simulation scenarios are displayed in Table 2.

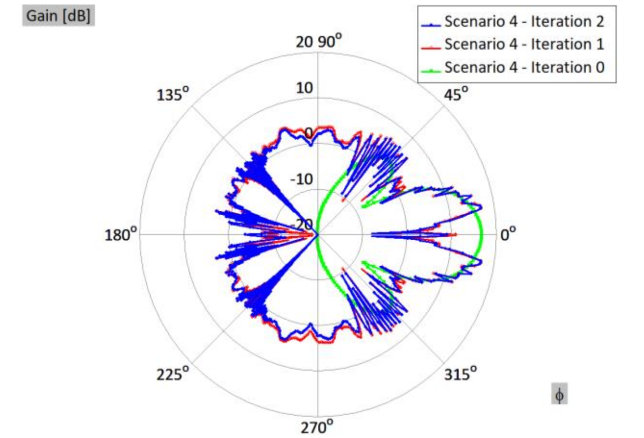


Figure 7. Convergence study in the Scenario 4 – iterations

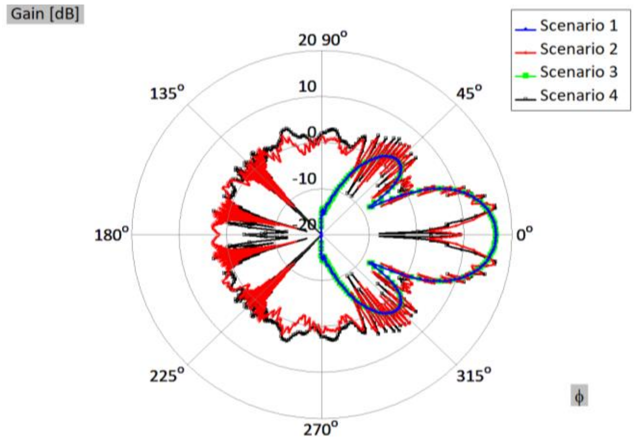


Figure 8. Radiation patterns

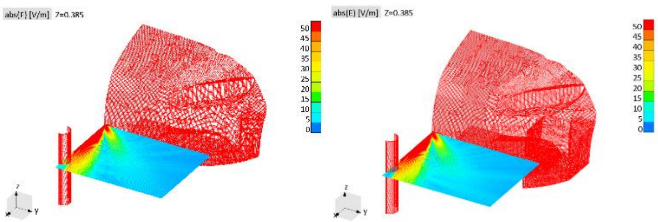


Figure 9. Near field distributions: Scenario 2 [left] and Scenario 4 [right]

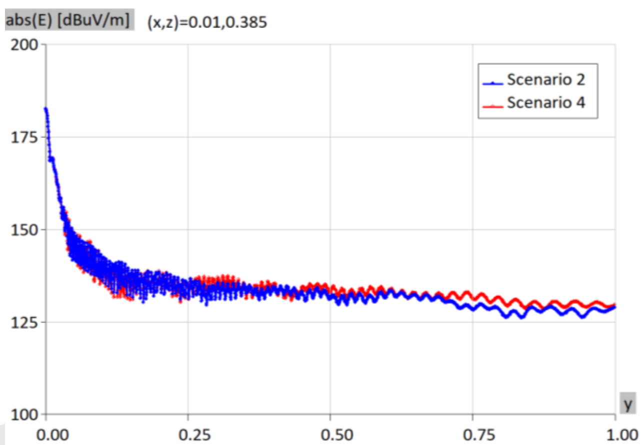


Figure 10. Near field distributions: Scenario 2 and Scenario 4 – comparison (the influence of the bumper modification is recognized for higher y coordinates)

Table 2. Iterations, number of unknowns, and simulation times for simulated scenarios

Model	DDS Iterations	Unknowns	Simulation time [min]
Scenario 1	$0^{th} + 1^{st}$	0.86 M	36
Scenario 2	$0^{th} + 1^{st}$	0.94 M	33
Scenario 3	$0^{th} + 1^{st}$	1.02 M	52
Scenario 4	$0^{th} + 1^{st}$	1.10 M	47

3. Full-Wave EM Simulation at 24 and 40 GHz

WIPL-D software can solve electrically large structures even with an intrinsic MoM solver. Full-wave EM simulations were done for a scenario containing a car with a mounted dipole antenna at 24 GHz and 40 GHz. Figure 11 shows the car shell and magnified area where the half-wavelength long dipole is placed at λ/4 distance in front of the front bumper. Figure 12 shows the final mesh of the structure at 40 GHz with 2λ x 2λ (0.015m x 0.015m) mesh elements.

The *Antenna placement* and *Shadow* reduction were applied for both operating frequencies.

The EM simulations were performed on the following hardware platform: Intel® Xeon® Gold 5118 CPU @ 2.30 GHz (2 processors) with 192 GB RAM and four NVIDIA GeForce GTX 1080 Ti GPU cards.

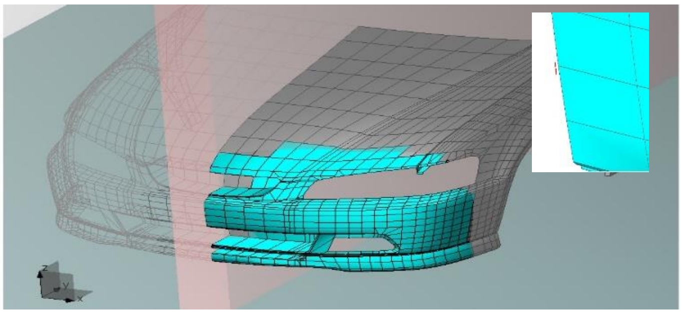


Figure 11. Realistic car front shell with shadow reduction applied and dipole antenna in front of the bumper

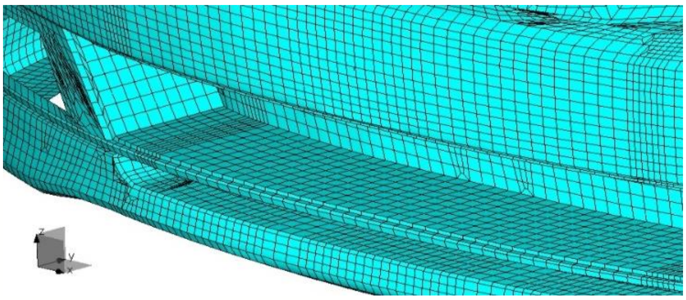


Figure 12. Final mesh at 40 GHz

The reduced number of unknowns along with simulation times for both frequencies (24 GHz and 40 GHz) are listed in Table 3.

Table 3. The number of unknowns and simulation times for both cases (24 GHz and 40 GHz)

Frequency	Number of unknowns	Simulation time
24 GHz	119,000	1,107 sec
40 GHz	295,000	12,644 sec

The radiation pattern for the case of 24 GHz is shown in Figure 13. To compare the results for 2 different operation frequencies, a magnified area with small elevation angles (between zero and 10 degrees) is presented in Figure. 14. As expected, the number of minimums in the radiation pattern is approximately 2 times larger at 40 GHz than at 24 GHz.

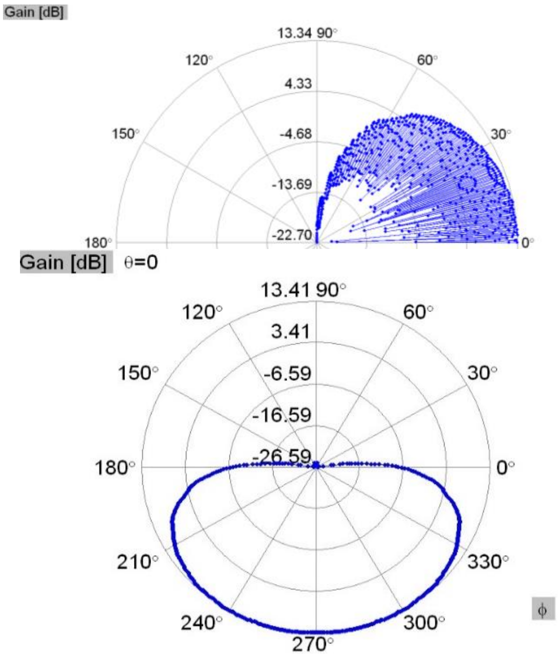


Figure 13. Radiation pattern in two principal planes at 24 GHz

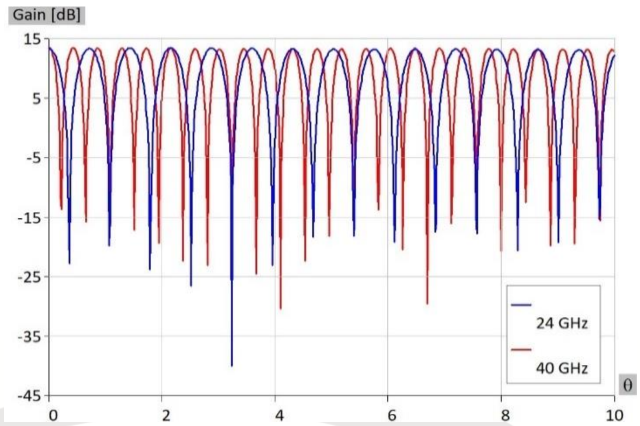


Figure 14. Comparison of radiation patterns for small elevation angles for 2 operating frequencies

4. Vehicle to Vehicle Communication

A typical EM challenge in a vehicle-to-vehicle communication case is the design of an optimal antenna and determining the antenna's appropriate position on or inside a car shell. One of the operating frequencies for this type of application is 5.9 GHz. At this frequency, antennas should be physically small and arranged so that they integrate smoothly with a car shell design. However, at 5.9 GHz (~0.05 m wavelength), a car represents an electrically large object. In the following example, we demonstrate placing 3 short monopole antennas on a generic car model and an advanced scenario where we analyze radiation properties between antennas mounted on two vehicles. The full simulation scenario with two cars is presented in Figure 15, while the locations of the antennas are explained in Figure 16.

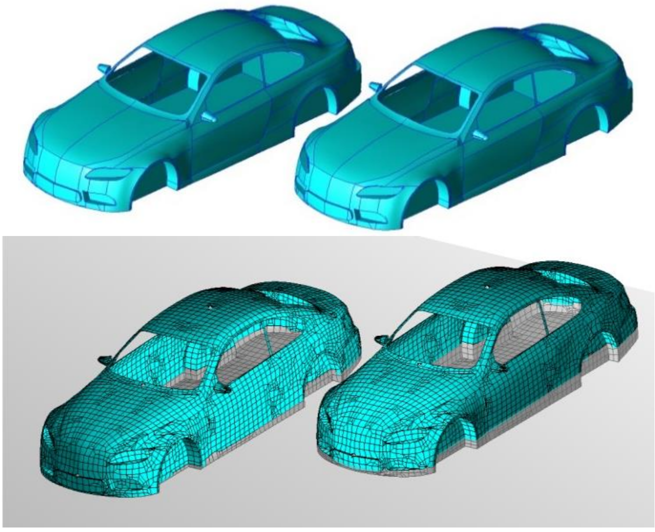


Figure 15. Vehicle to vehicle scenario – CAD model and meshed model

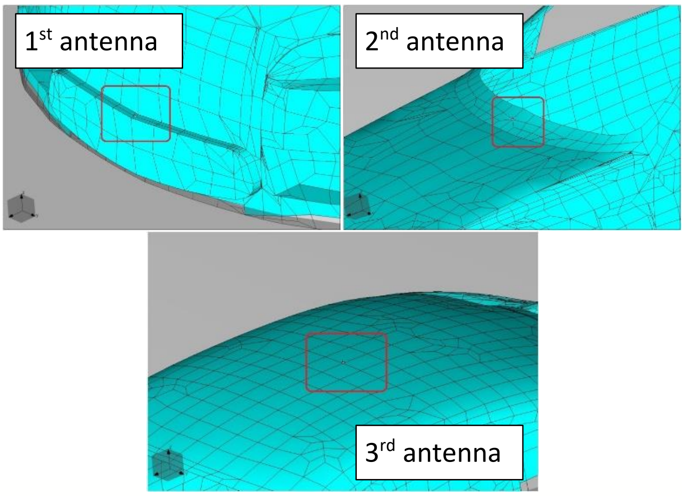


Figure 16. Antennas' locations

Simulations were performed on a desktop computer, Intel® Xeon® CPU E5-2650 v4 @2.20 GHz, 2 processors, 256 GB RAM, and 4 GPUs Nvidia GeForce GTX 1080 Ti. Matrix inversion was performed on GPU cards.

The first simulation includes a single car model with 3 antennas installed. The return loss of the antennas and coupling between the antennas is shown in Figures 17-18. The symmetry option was applied and the problem required **90,000 unknowns**. **Simulation time per frequency is around 24 minutes.** The radiation pattern at 5.9 GHz of the third antenna (the antenna mounted on the roof) is shown in Figure 19.

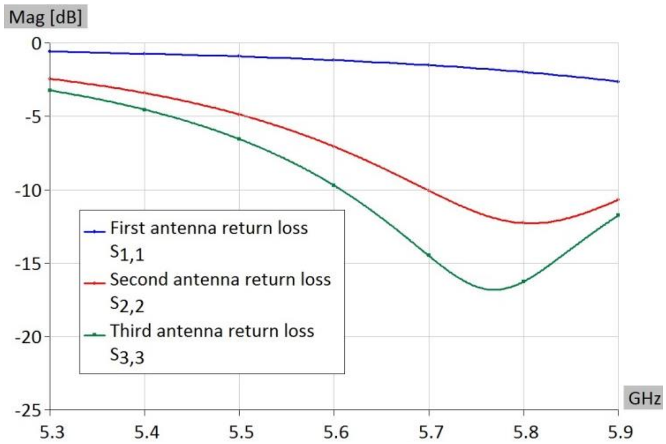


Figure 17. Three antennas on the car - return loss

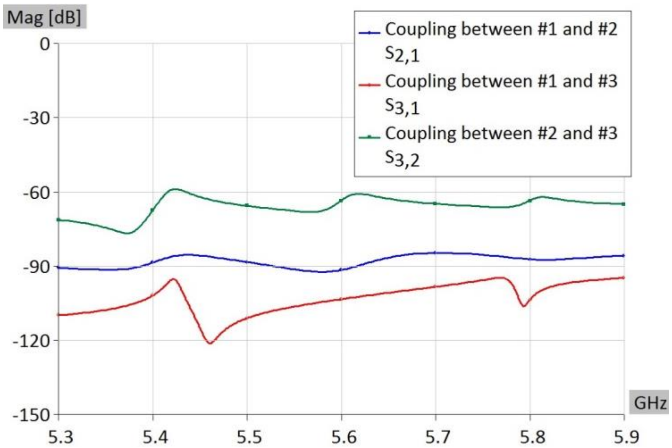


Figure 18. Three antennas on the car - coupling

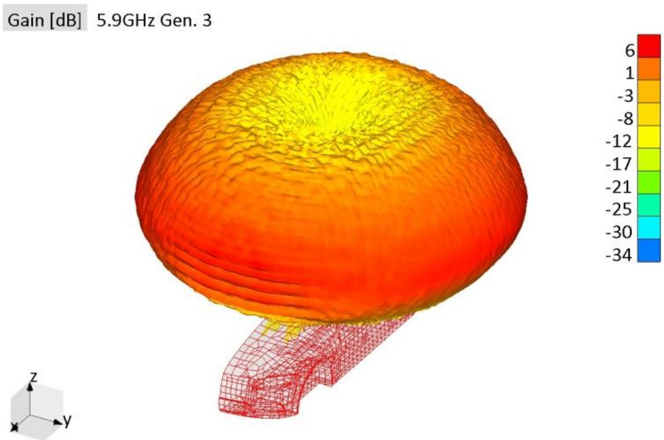


Figure 19. Antenna at the roof of the car - radiation pattern

The second scenario includes 2 vehicles and 6 antennas in total. No symmetry can be applied so the total **number of unknowns is 364,262**. Simulation time on the previously described desktop is **4.6 hours**. The number of unknowns was reduced by putting the bottom of the cars and parts insignificant for EM simulation in the **shadow region**, where the number of unknowns is significantly reduced (Figure 15, bottom). The number of unknowns was also reduced via **antenna placement reduction**. As the last step to minimize the number of unknowns, the parts of the model were selected manually (backside of the car, the interior side of vehicle doors, etc.) and reduction was set specifically on the selected parts. The results are shown in Figures 20 -21.

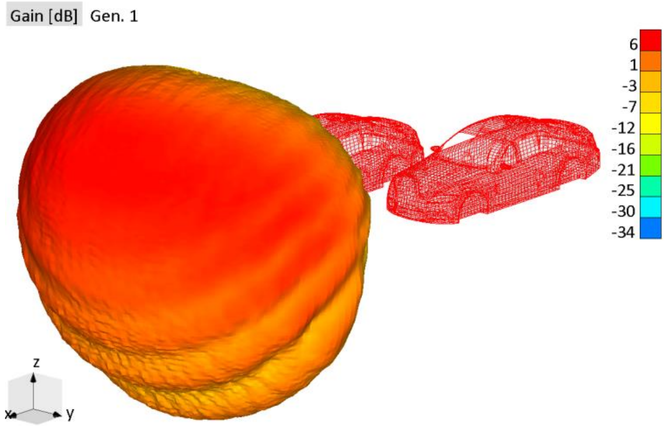


Figure 20. 2-car scenario – 1st antenna radiation pattern

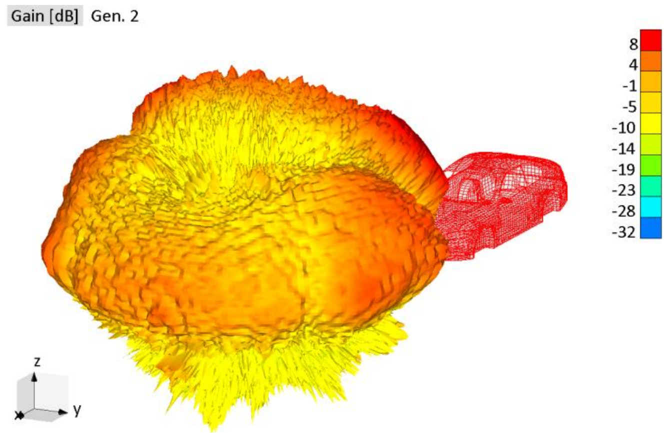


Figure 21. 2-car scenario – 2nd antenna radiation pattern

Similar simulations were performed on the aforementioned desktop machine using DDS. In this case, the first DDS iteration was sufficient for obtaining an accurate result. The obtained radiation patterns are presented in Figures 22-23, while DDS simulation times are shown in Table 4.

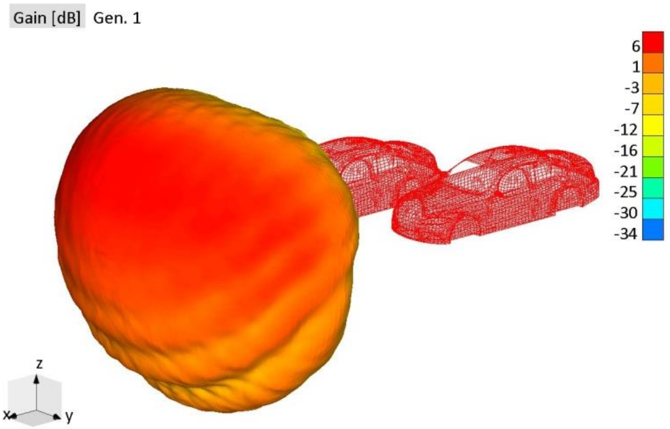


Figure 22. 2-car scenario – 1st antenna radiation pattern – DDS simulation

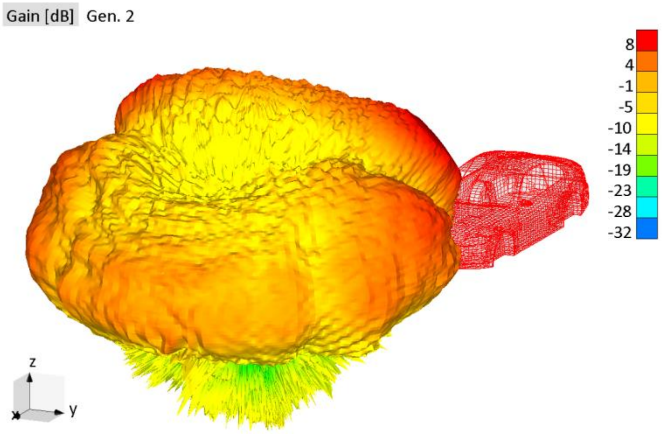


Figure 23. 2-car scenario – 2nd antenna radiation pattern – DDS simulation

Table 4. Iterations and simulation time in DDS

Model	Iteration	Simulation time [minutes]
2-car scenario	1^{st}	30 (0^{th} + 1^{st})
2-car scenario	2^{nd}	19.6

Conclusion

This whitepaper shows how electromagnetic simulations can be applied to various scenarios in the automotive industry. It was highlighted that the rapid increase of requirements for efficient EM simulations in automotive applications could be addressed successfully by applying several sophisticated techniques.

The scenarios encompassed 77 GHz anti-collision radar mounted on a car bumper, an EM obstacle detection also at 77 GHz, a radar antenna mounted on a car bumper operating at 24 GHz and 40 GHz, and vehicle-to-vehicle communication at 5.9 GHz.

As a result of applying quad mesh with higher-order basis functions (HOBFs), customized in-house quad mesher optimized for HOBFs, methods for efficient reduction of the number of unknowns without compromising accuracy, and relatively fast simulations are achieved on affordable GPU/CPU platforms. In other words, all simulation times are relatively short and achieved with affordable hardware.