Large Patch Array behind Car Bumper

The goal of this application note is to **demonstrate superior capabilities of WIPL-D software when it is used to simulate very large antenna arrays**. In particular, an array of microstrip patch antennas with more than 150 array elements will be presented here. Frequency range of interest is 70-80 GHz, with special focus on performance around 77 GHz.

Model Description

The model of the array has been provided in a form of a **CAD file**. In WIPL-D Pro CAD tool import of various model geometry is supported, so the particular antenna array model has been imported and subsequently meshed. After importing the model, **dielectric domains** have been set up as required. At this stage the model looks like it is presented in Figure 1.

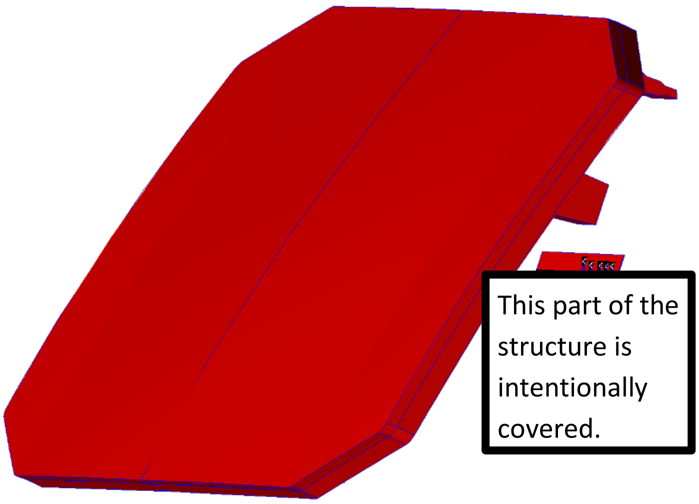

Figure 1. Model after import into WIPL-D Pro CAD

The array is proprietary so the detailed representation of the array cannot be disclosed. This is the reason why the figure presents a view of a covered array structure. The principle of array operation can be grasp Figure 2. The pattern consists of more than 15 rows of printed patches connected with microstrip lines and forming a so-called **travelling wave array**. There are different forms of rows and the design is not symmetrical. The number of patches within a raw varies along the array and can be approximated to be ten patches per row. Overall, the array consists of **more than 150 microstrip patches**.

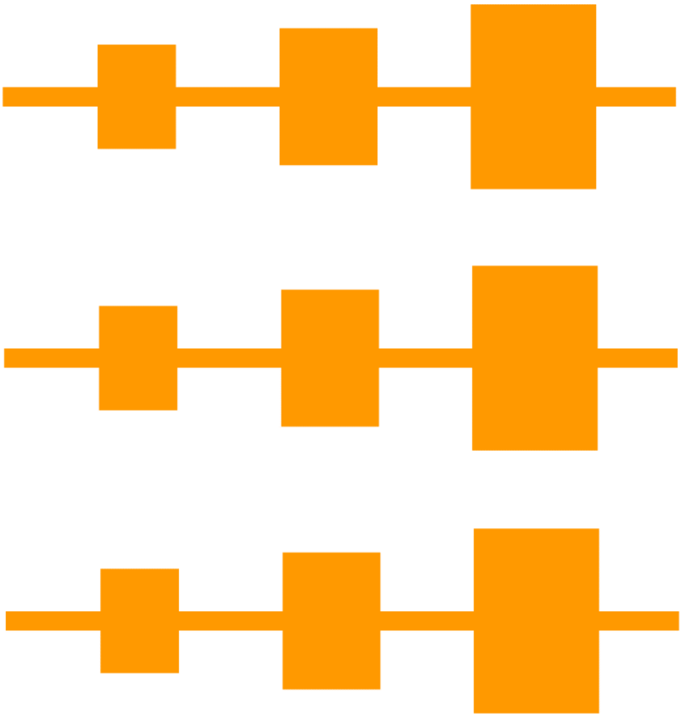

Figure 2. The printed pattern array concept

The model of the array is placed **behind large metallic structure (so called grill) which is immersed into dielectric**. Such structure is **a part of car bumper**. The array is printed in microstrip technology so it has a finite size ground plane covering the entire “hidden” side of the substrate.

WIPL-D Simulation Suite

WIPL-D software suite includes unique features which enable calculation of electrically extremely large structures. **It makes simulation of models measuring even hundreds of wavelengths possible on inexpensive desktop PCs.**

One of the most important **advantages of WIPL-D kernel is the fact it uses quadrilateral mesh**, unlike majority of other EM software which uses triangular meshing elements. Using an all-quad mesh instead of a triangular one brings the benefit of halving the number of unknowns for the problem of the same size. In case of a direct, LU-decomposition type linear system solver this means **decreasing the memory requirements 4 times, and speeding-up simulation 8 times**!

In addition to quad mesh elements, WIPL-D uses **higher order basis functions (HOBFs), up to 8th order**. This enables mesh elements to be very large, up to 2 wavelengths by 2 wavelengths. To mesh a model for best numerical efficiency, WIPL-D uses **very large mesh elements over flat or smooth model parts and small mesh elements over the tiny and/or curved model parts.** For relatively smooth or flat surfaces, a mesh element can be as large as 10 wavelengths by 10 wavelengths since **Ultra HOBFs of order up to 32nd have been developed recently.**

WIPL-D Pro CAD advanced mesher performs automated subdivision of CAD geometry into a set of quadrilateral meshing elements. Meshed geometry of the model is well-connected providing accurate representation of the original model while exploiting all of the benefits of HOBFs.

Additional features can be used to decrease a number of unknowns even further and relax the computational burden while keeping the high accuracy unaffected. For a symmetrical structure the model used for simulation can contain only a half of the original typically halving a number of unknowns. Furthermore, **several methods of automatic or user-defined reduction of number of unknowns are available**. These include decreasing a number of unknowns in **shadow** regions of a structure, reductions related to **antenna placement** problems, **unused entities**, **reduction of referent frequency for parts of the model** etc. As a result, when compared with other EM software packages, with WIPL-D a number of unknowns **can be 3-10 smaller**. Finally, WIPL-D offers very **efficient CPU and GPU parallelized simulation on inexpensive hardware platforms**.

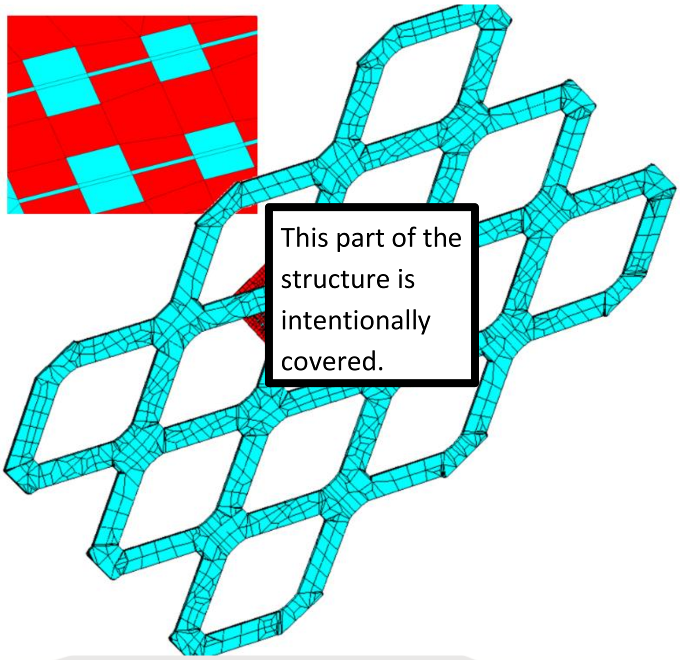

Figure 3. WIPL-D Pro CAD mesh

Simulation Requirements

In order to estimate required number of unknowns, WIPL-D offers a rather simplified formula where number of elements in a patch array is multiplied by 500 unknowns. This estimation applies when patch is placed above infinite PEC plane. When the ground conductor has finite dimensions, a number of unknowns per patch is increased to approximately 1,000 per patch. In a general case, the exact number of unknowns depends on several factors:

- The way the patches are fed
- Size of ground conductor
- The complexity of patch shape
- Symmetry.

In this example, a number of unknowns cannot be reduced by invoking the symmetry. In order to illustrate simulation times expected in general for an electrically large structure, we can use the following **approximation - a structure requiring 100,000 unknowns can be simulated at a single frequency point under 1h on the desktop PC with modern quad core CPU and CUDA enabled inexpensive GPU cards** (say Nvidia GeForce GTX 1080 Ti).

For this patch array without a bumper, the required number of unknowns (after performing detailed convergence test and without any sort of reduction) is 124,562. The automatic edging of metal and substrate is turned on for the improved accuracy. This is for the model of the substrate with the printed array above finite size ground conductor (without grill and the dielectric into which it is immersed).

From the previous two paragraphs, one can conclude that simulation of previously described array does not require a server PC, as simulation times for a standard PC with GPU are acceptable. However, as all of the following simulations will be carried out using a server, the formerly described array will be simulated using the same hardware to allow comparison of the simulation times. The server hardware comprises PC with 24 cores and 4 Nvidia GTX 1080 Ti GPU cards. **The exact configuration is as follows**:

Intel® Xeon® Gold 5118 CPU @ 2.30 GHz (2 processors) with 192 GB RAM and four NVIDIA GeForce GTX 1080 Ti GPU cards. The GPU cards are used for matrix inversion. The other operations are performed on CPU.

The next mid-step, prior to running the final model, is running **the array behind a metallic grill**. In this case, since the number of unknowns is relatively low, no reductions are applied. Since there are no dielectric parts added, number of unknowns is increased to 191,828 only, despite the large size of the grill.

The metallic grill is shown in Figure 4.

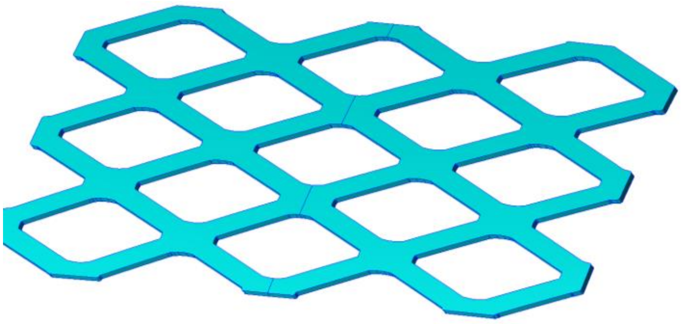

Figure 4. Metallic grill covering the array

The final step is **to immerse in the grill into dielectric radome** i.e. bumper cover.

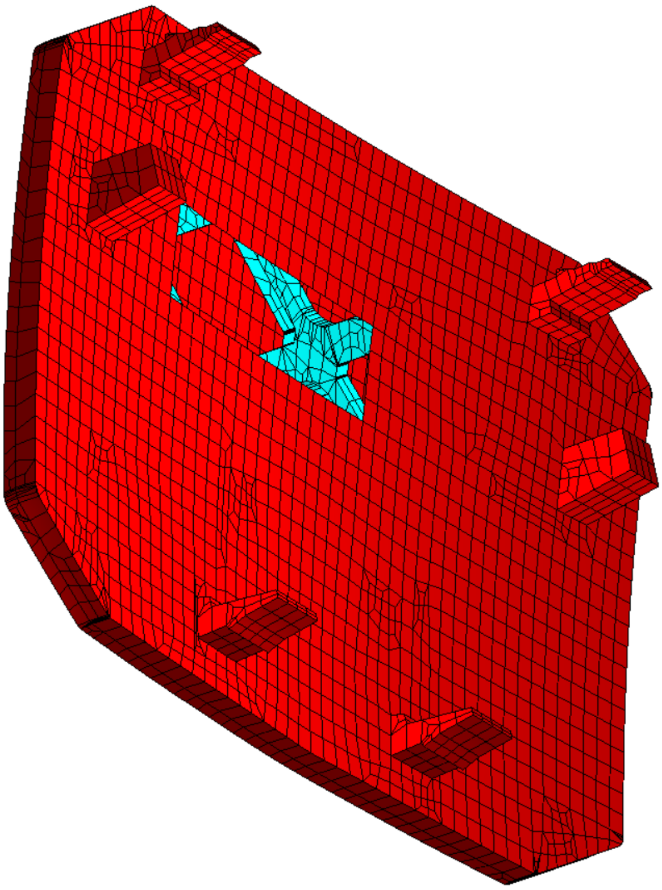

Figure 5. Grill immersed into radome (part of radome intentionally deleted to show interior)

Here, for the first time, number of unknowns has to be reduced for the efficient solution. The most comfortable way is to select entire bumper cover and **set local setting**. The type should be referent frequency, which should be set to only 32 GHz, instead of simulation frequency 77 GHz. The required setting to obtain accurate simulation is to increase *Integral Accuracy* parameter to Enhanced 2. It slows down the matrix fill, but does not increase a number of unknowns. **The final number of unknowns is 291,253. Without the reduction, the number of unknowns would be 790,029.**

The compared radiation patterns for all of the three cases considered so far are shown in Figure 6.

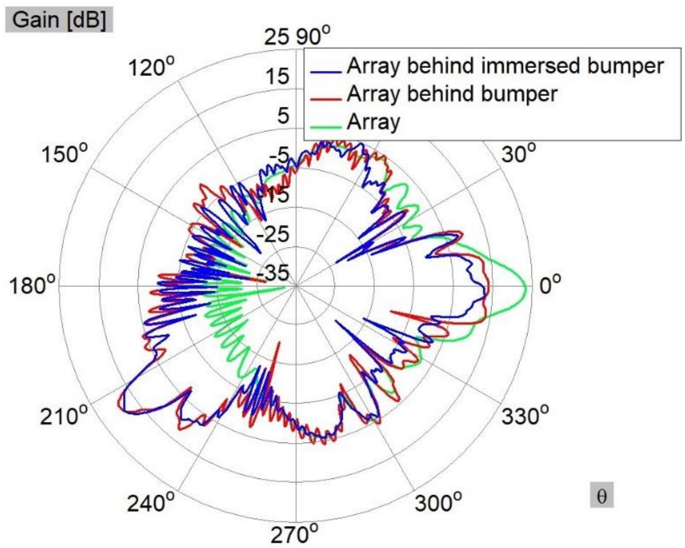

Figure 6. Radiation pattern at 77 GHz

The number of unknowns and simulation times are shown in Table 1.

Table 1. Number of unknowns and total simulation time

Model	Number of unknowns	Simulation time [minutes]
Printed Array	124,562	19
Array behind Grill	191,828	51
Array behind Immersed Grill	291,253 (reduced from 790,029)	153

DDS Solution

In addition to the traditionally accurate MoM solver, WIPL-D suite includes **Domain Decomposition Solver (DDS)**. The tool is intended for high frequency problems. MoM poorly scales with frequency, which is the only drawback of the method. The DDS focuses to the **iterative solution**. The 0th iteration solves the feeding array (in our case entire array) with MoM. The following iterations involve more and more unknowns into the solution until convergent result is achieved. The code basically performs matrix fill complexity in each iteration, it scales with frequency an order of magnitude better.

In our case, a fully convergent result is obtained after iteration #4 and beyond (the total of 15 iterations were examined). All other iterations have useful results, but due to a low complexity of the problem, we show results for iterations with full accuracy, and compare them to MoM solution in Figure 7. As one can conclude, **the differences between the solutions are negligible**.

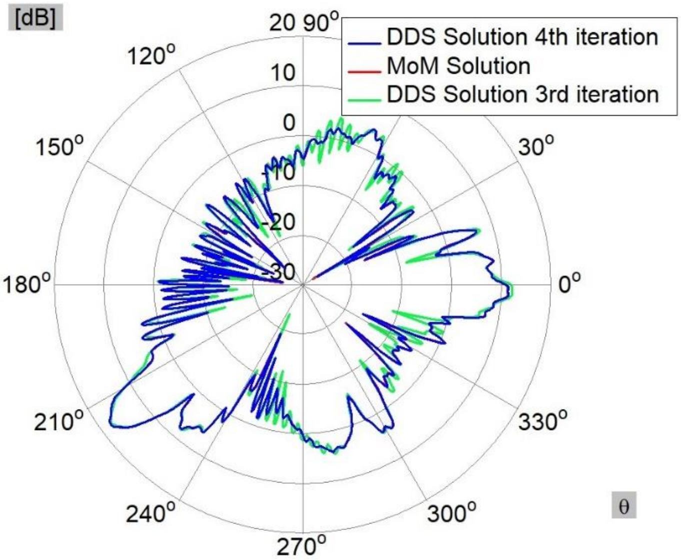

Figure 7. Reduction of number of unknowns

Table 2. DDS simulation times

Iteration	Simulation time [minutes]
0^{th}	43
1^{st}	40
2^{nd}	43
3^{rd}	44
4^{th}	44

The DDS simulation times are given in Table 2. The full efficiency of the method is a bit blurred. Namely, the array itself has 120,000 unknowns. As such, the computational burden remains unchanged for each of the iterations. From that point of view, with only around 300,000 unknowns (120,000 in the feeding zone), this can be considered as electrically very small problem for the DDS.

Conclusion

The application note demonstrates **excellent performance of WIPL-D suite for simulation of very large arrays of microstrip patch antennas**. The microstrip with finite ground plane array has over 150 elements. Simulation frequency of interest is 70-80 GHz (specifically 77 GHz).

The model of the array is placed behind large metallic grill, which is then immersed into dielectric (plastic). This **mimics the realistic situation** where antenna array is covered by a car bumper.

A rather simplified formula estimates number of elements in patch array as number of elements multiplied by 500. This estimation applies when patch is placed above infinite PEC plane, and increases to 1000 when the ground is finite. Here, the number of unknowns is approximately 124,000, without any number of unknowns reduction applied. With the grill added, and again without reductions, the number raises to 190,000.

Finally, reduction of referent frequency, which should be set to only 32 GHz, is used for the plastic to which the grill is immersed. This yields in 290,000 unknowns.

All simulations are carried out on **inexpensive server comprising of multiple core CPU and 4 low range Nvidia GTX GPU cards**. The **simulation times are couple of hours at most**.

Domain Decomposition Solver (DDS) is intended for high frequency problems, since MoM poorly scales with frequency. This is an **iterative solution**. In our case, a fully convergent result is obtained after iteration #4 and beyond (the total of 15 iterations were examined). Previous iterations also **show excellent accuracy, with each iteration being of approximately the same duration (under an hour)**.