Radome Boresight

Introduction

This application note will describe efficient use of **WIPL-D Software** package and part of its **advanced features** for simulation of antenna arrays covered with large radomes.

Namely, antenna arrays are typically large EM structures and they are challenging for all **full-wave electromagnetic (EM)** solvers. The task is even more difficult for 3D solvers.

In practical realizations, such arrays are covered with **dielectric (usually plastic) covers or radomes**. Such a scenario makes EM simulation even more challenging.

In what follows, we will elaborate how to efficiently use **WIPL-D Pro 3D EM solver** for simulation of large waveguide slot array covered with A-sandwich radome. The radome consists of 3 layers (two are very thin with higher ε_r while the inner layer is thick and made with low ε_r material). Usual simulation methods include approximation techniques such as geometrical or physical optics (GO, PO), but due to **very efficient implementation of Method-of-Moments (MoM)** the simulation will be performed without such approximation. We will elaborate how to simplify the simulation without compromising accuracy. The ability to simulate such models in acceptable time from the engineering point of view is owed to usage of **graphical processing units (GPU)**. Simulation requirements heavily depend on array orientation and we will simulate three scenarios (elevation angles 90, 20 and 0 degrees), as illustrated in Figure 1. We will also elaborate how simulation times can be dramatically reduced if an inexpensive workstation with several GPU cards is used instead of single PC workstations.

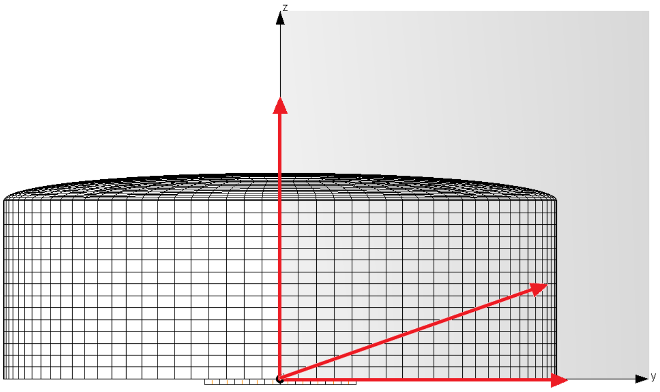

Figure 1. Three illumination angles of the radiating array

Simulation Description

The antenna array used as illuminator for this case is based on waveguide technology. It consists of 10 waveguides, each with 40 slots. We only model 10 x 20 slots array because all models can effectively apply symmetry to significantly speed up simulation. The array geometry is shown in Figs 2-3.

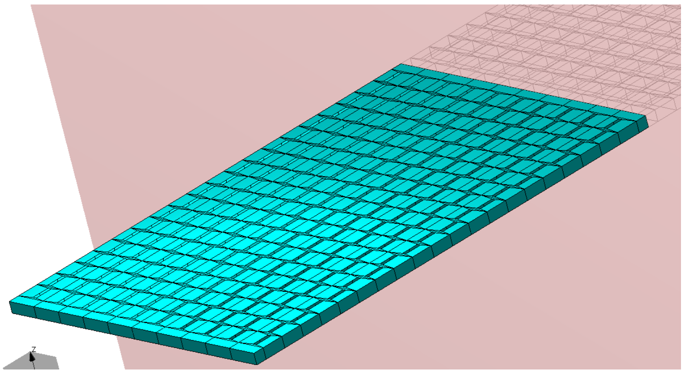

Figure 2. Waveguide array

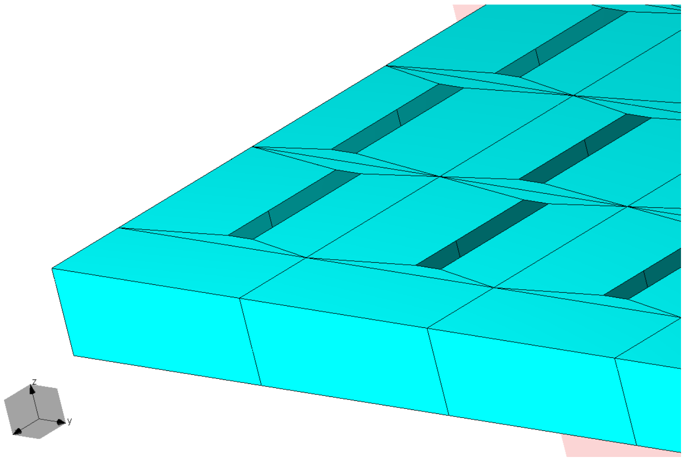

Figure 3. Array elements - slots

The radome used for this benchmark model consists of two components: a cylindrical surface tall enough to ensure that the array can be rotated inside it, and a splashed sphere used as top cover. They are both modeled as **WIPL-D Pro 3D EM solver built-in objects**.

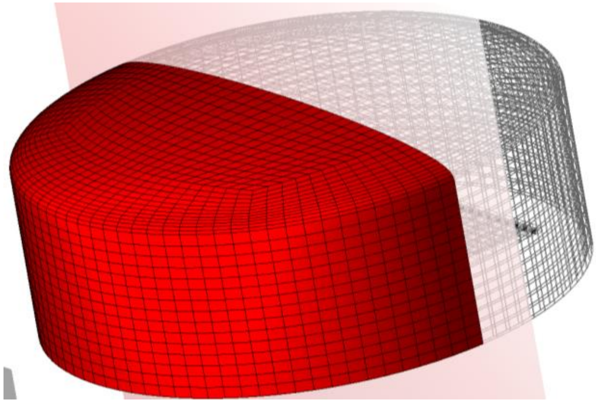

Figure 4. Shape of the radome

Radome is made as typical A-sandwich radome. It consists of 3 layers. Inner layer is approximately lambda/4 thick and it is made of low ε_r dielectric foam (ε_r = 1.05). Outside layers are very thin (lambda/20) and they are made of high ε_r material (ε_r = 4.4).

Design procedure was carried out at 34 GHz, although any given frequency can be used.

At the design frequency, waveguide array is approximately 26 x 8.5 wavelengths large (measured in air) and it can be considered as electrically large structure. Owing to the fact that WIPL-D Pro 3D EM solver uses unique **higher order basis functions** applied to very advanced MoM, number of unknowns is only 26,673 when the symmetry is applied. On an inexpensive desktop PC (comprising of novel technology quad core CPU, such as Intel i7-7700 @ 3.60 GHz, with 8 GB of RAM), equipped with low cost CUDA GPU card (such as Nvidia GeForce GTX 1080 Ti), this simulation lasts only 128 seconds. The radiation in two principle planes is shown in Figure 5 (xOz and yOz).

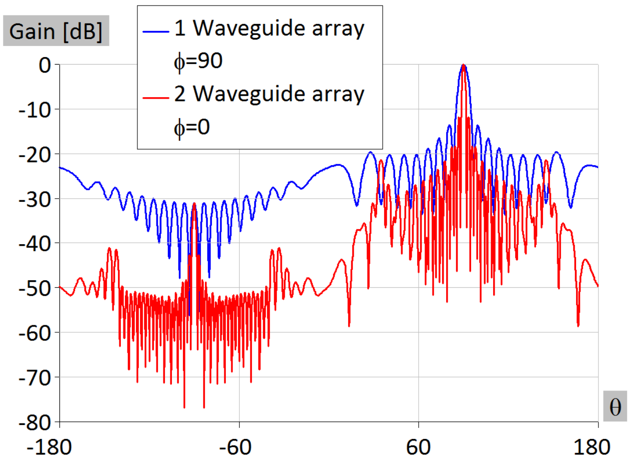

Figure 5. Free space array radiation

In WIPL-D, xOz plane corresponds to Phi = 0 degrees while xOy plane corresponds to Phi = 90 degrees. Theta is measured starting from z = 0 plane. So, Theta = 0 degrees corresponds to xOy plane while Theta = 90 degrees corresponds to +z axis.

Radome radius is around 16 wavelengths in air, while its height is 10 wavelengths. If we take into consideration that wavelength in dielectric is more than two times larger than in free space, it becomes clear that surface of the radome is electrically extremely large, especially since the 3-layer simulation requires 4 dielectric surfaces. Estimated number of unknowns is between 500,000 and 1,000,000 unknowns. Such a simulation is extremely challenging if carried out directly, without using additional hardware and prolonged simulation times. Thus, we will use **in-house developed techniques to successfully decrease number of unknowns** on radome parts which are less relevant for its EM functionality. That way, the number of unknowns will be kept small while **the accuracy will remain high**. Usage of such techniques is straight-forward and it was applied for number of EM simulation cases. It requires advanced previous knowledge about the use of WIPL-D Pro 3D EM solver.

Up-Frontal Direction

The first scenario we investigate is when waveguide array radiates towards +z direction. It is clear that the most of the radiated energy penetrates through top cover – splashed sphere surface of the radome. The side walls of radome are much less relevant. Thus, we can set current orders on plates that belong to cylindrical part to lowest values. Carefully performed tests showed that such reduction does not compromise the accuracy even at -50 dB side lobes (measured from maximum gain). At the next stage, we can carefully test reduction of number of unknowns on the top part. For this, we can use **WIPL-D built in smart reduction technique** named ***Shadow* reduction**. The effect of reduction is measured in percent (value between 0 and 100). We start from minimum reduction and we increase reduction (decrease number of unknowns) until the accuracy is lost. If we, for example, compare projects where reduction is set to 30 and 40 percent, there is no significant difference in radiation even for -60 dB levels.

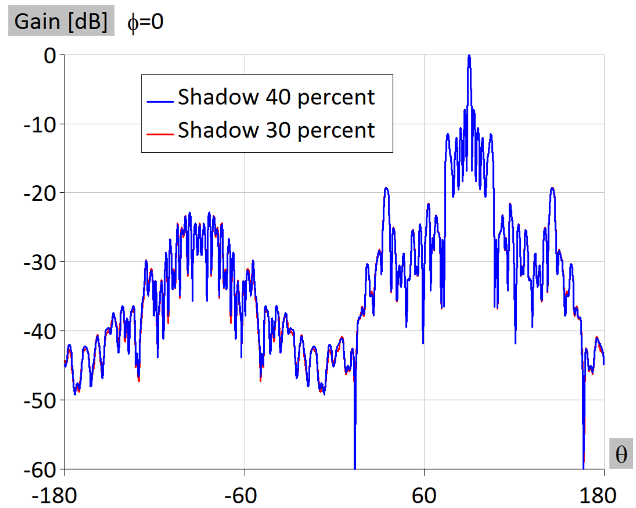

Figure 6. Convergence of results, level of shadow reduction

Note that model with 30% reduction requires over 240,000 unknowns while the 40% reduction yields less than 210,000 unknowns. Such a simulation can be performed on an inexpensive GPU workstation.

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.

The simulation lasts slightly under 1 hour (3,486 sec).

Note that only in this case the thickness of two high ε_r layers was intentionally increased to lambda/10. This caused the high degradation of the radome performance, but it was easier to determine convergence of results. In later cases, the thickness was halved which caused the radome to be very transparent.

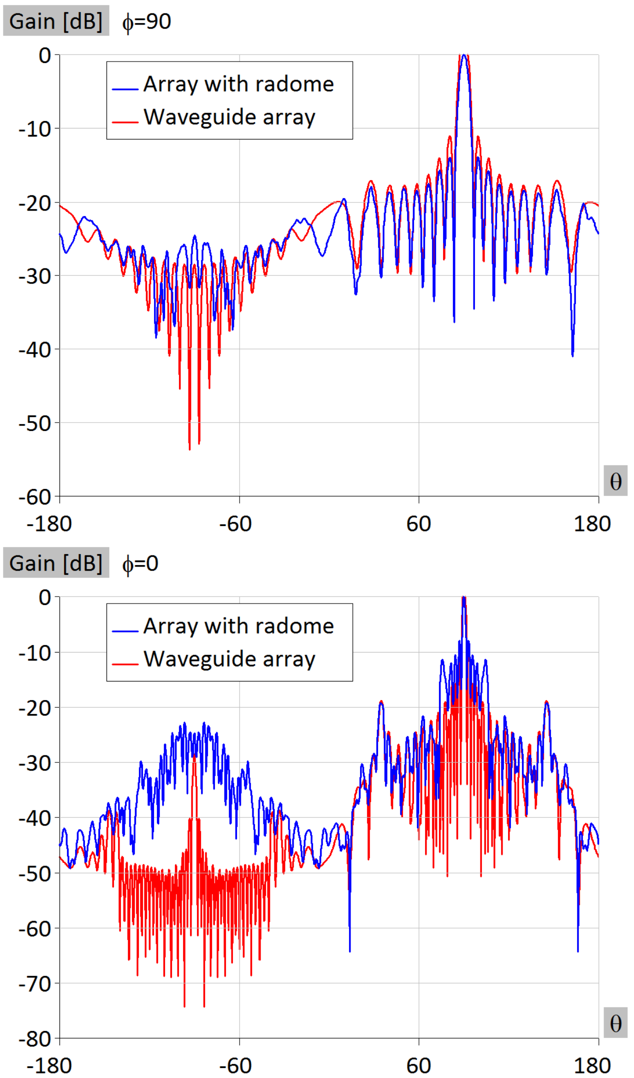

Figure 7. Influence of radome – upside orientation (intentionally decreased transparency as illustration)

Broadside Direction

In the following scenario, array is rotated for 90 degrees.

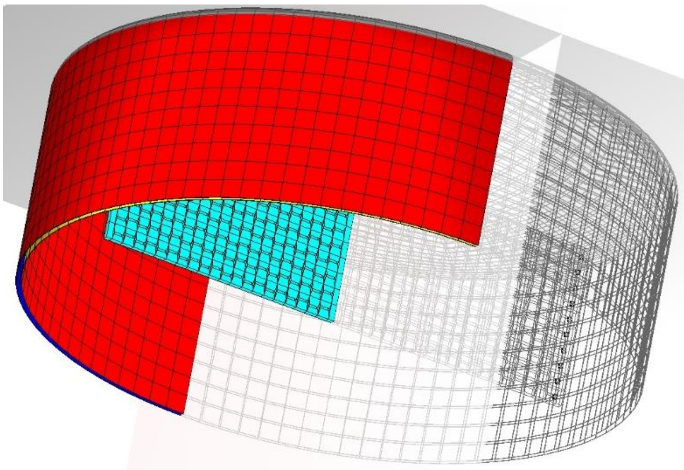

Figure 8. Waveguide array rotated for 90 degrees

The majority of radiated power is transmitted through the cylindrical part of the radome.

In this case, the majority of unknowns is needed on the side parts while the splashed sphere can be placed into a "deeper" shadow (70% reduction). Since the cylindrical part of the radome is much smaller in surface, number of unknowns here can be reduced to 110,000. The simulation time on the GPU workstation is only 796 seconds.

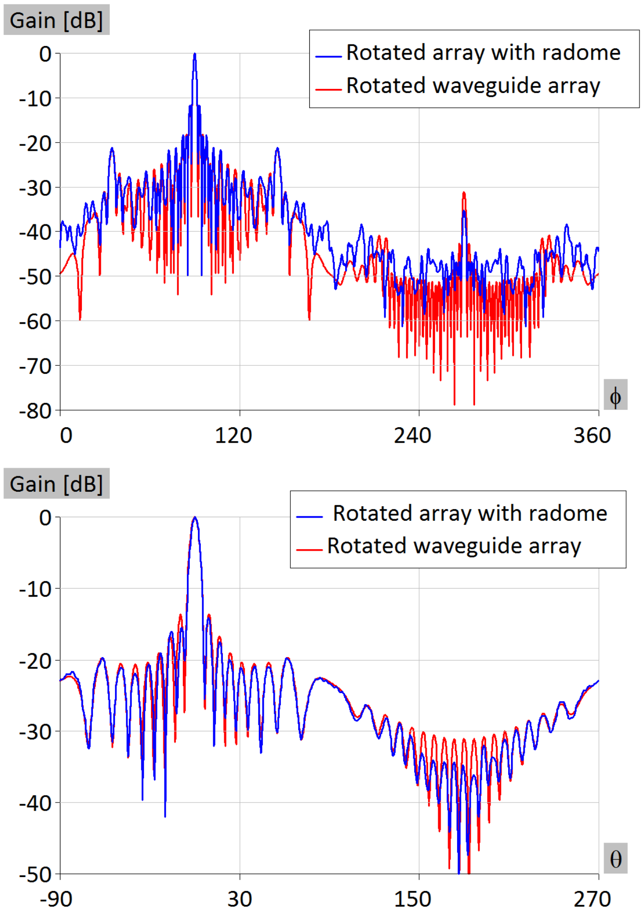

Figure 9. Influence of radome – broadside radiation

The radiation pattern is given in two most important planes, vertical and horizontal. Horizontal plane is xOy, while vertical plane is yOz where the main lobe is now located. The effect of radome presence is now much smaller as we use lambda/20 dielectric over the foam, which makes it almost fully transparent.

Broadside 20 Degrees Elevated Direction

In the final scenario, array is additionally rotated for 20 degrees so that majority of radiated power is transmitted through the common surface between cylindrical and splashed plate radome parts. In that sense, number of unknowns will be larger than for the broadside orientation (more of the splashed sphere cover is illuminated). Number of unknowns is very carefully determined to obtain the lowest possible value (by using built-in *Shadow* feature).

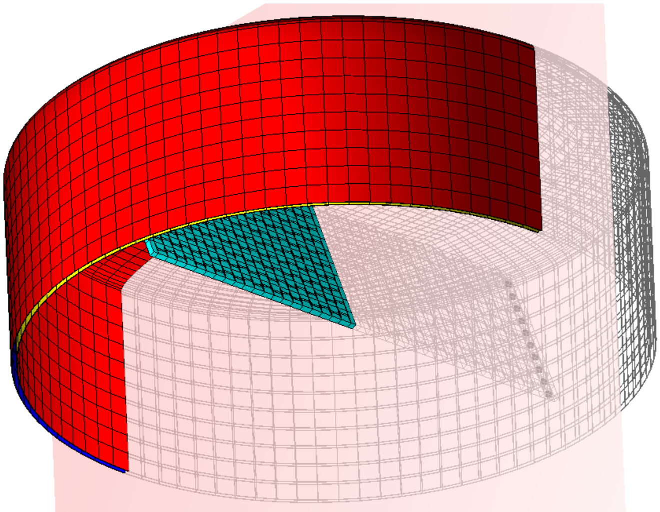

Figure 10 Waveguide array rotated for 90 degrees and elevated for 20 degrees

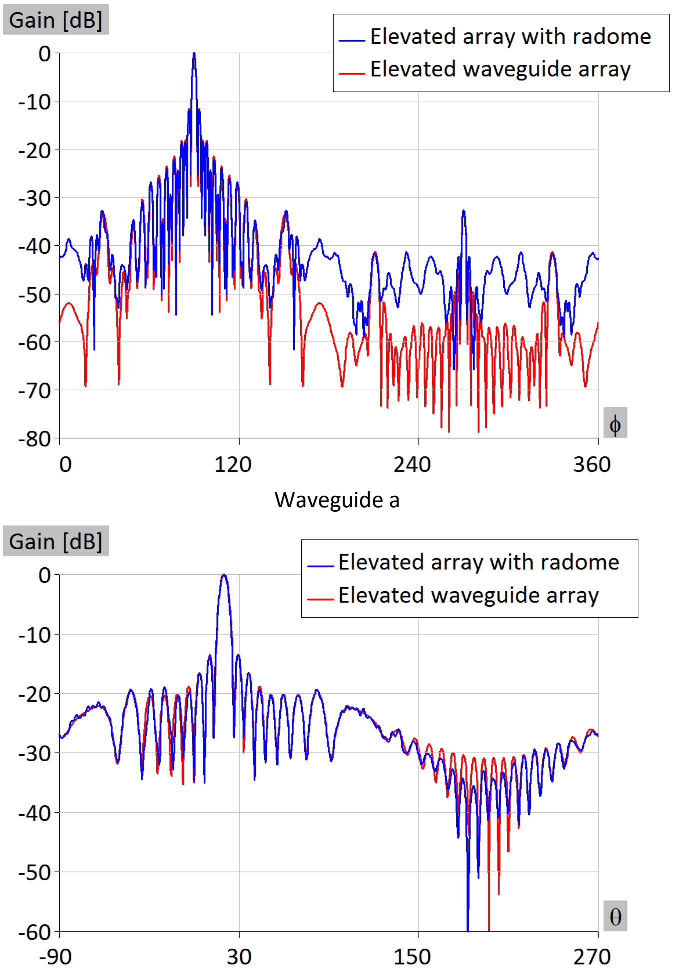

Figure 11 Influence of radome – broadside elevated radiation

Number of unknowns for this case is 140,000 (between 110,000 and 210,000, as reported in the two previous cases). The simulation time on the GPU workstation is only 1,116 seconds.

Conclusion

This application note demonstrates a comprehensive study of the radiation of large waveguide array through a highly transparent large radome in broad-side directions. Several effects lead to this highly advanced simulation: numerous WIPL-D features and the EM knowledge about functioning of the radomes.

The waveguide array itself is huge but **can be simulated on a standard desktop PC or laptop**. This is possible due to **efficient WIPL-D MoM implementation** based on usage of **higher order basis functions**, **quad mesh** with elements up to 2 lambdas. The simulation can be further improved by using widely available inexpensive CUDA enabled GPU cards and the **WIPL-D GPU solver.**

Finally, a larger 3-layer radome is added over the antenna. Such simulation is demanding even in the WIPL-D suite. However, with the knowledge about principles of radomes and set of WIPL-D features (such as *Shadow* reduction), GPU solver and inexpensive GPU workstation with 4 GPU cards, the simulation is possible and carried out in **reasonable engineering time**. The simulation lasts under 1 hour even for the most demanding case where the array illuminates entire top surface of the radome.

The three different scenarios are carefully carried out: up, broadside and elevated broadside radiation. The number of unknowns is carefully adjusted for each case.

Number of unknowns and total simulation time are given in the Table 1.

Table 1. Number of unknowns and total simulation time.

Model	Number of unknowns	Simulation time [seconds]
Waveguide array	26,673	128*
Up-frontal radiation	208,014	3,486
Broadside radiation	109,885	796
Elevated broadside radiation	139,889	1,116

* Simulated at regular desktop PC with single GPU card