

Large Multilayer Radomes

Introduction

In realistic antenna placement problems, most of the outdoor mounted antennas are covered with radomes. These structures most often protect the antenna from physical damages and various environment conditions. Typically, the radome should affect antenna performances as little as possible. The antennas are mostly designed without radomes, and the influence of the radome is investigated only at the final stages, without including it during the designing process. Radome volume and surface can be even order of magnitude larger than the antenna itself. Thus, the typical phases of simulation scenarios for radomes are:

- Design of the antenna in free space,
- Design of the radomes which influence the antenna performances as little as possible and
- Simulate the antenna with radome to confirm that antenna maintains its characteristics under the radome.

The WIPL-D team has significant experience in simulation of antennas with radomes. Since radomes are often electrically large in volume and surface, Method of Moments (MoM) codes (such as WIPL-D Pro) are very suitable for radome simulations. In addition, WIPL-D state-of-the-art MoM implementation offers some unique advantages for simulation of electrically large structures. Namely, WIPL-D kernel uses quadrilateral mesh of structures, compared to more commonly used triangles. This significantly reduces the simulation requirements, but more important, the advantage is the use of Higher Order Basis Functions (HOBFs). They enable the usage of larger mesh elements, up to 2 wavelengths. In case of radome simulations, the radome surface is usually smoothly curved or flat which is ideal for very large mesh elements supported in WIPL-D Pro. Hence, there are 3-10 times less unknown coefficients in MoM matrix compared to the low order triangular mesh based MoM matrix.

However, all of the aforementioned would not be enough for radomes with multiple layers whose dimensions are measured in hundreds of wavelengths since these scenarios are very demanding when it comes to the required number of unknowns. The basic quality of radome surfaces is that they affect antenna performances very little. This property is used to significantly reduce the simulation requirements. WIPL-D software suite offers several techniques to reduce number of unknowns on parts of the model. Combining these techniques along with extensive experience in radome simulations which WIPL-D support team has gathered through years, we can greatly reduce the number of unknowns on large radome surfaces. The current distribution on such surfaces changes very smoothly, so instead of using higher orders of polynomial degrees representing those currents (orders 5,6,7) we can use much lower orders (2,3,4) and preserve the accuracy.

For simulation of electrically large structures, WIPL-D recommends usage of inexpensive GPU platforms. A regular desktop PC can be turned into GPU platform by adding 1-3 GPU cards. On the other hand, for largest problems we offer Domain Decomposition Solver (DDS), which works very efficiently on desktop computers with multiple threads.

Smaller 3-layer Radome

In this application note, we describe the radome simulations by using the example of reflector antenna below a large multilayer radome. The simulation frequency is **30 GHz**. Reflector antenna is relatively small **Cassegrain reflector** shown in the Figure 1.

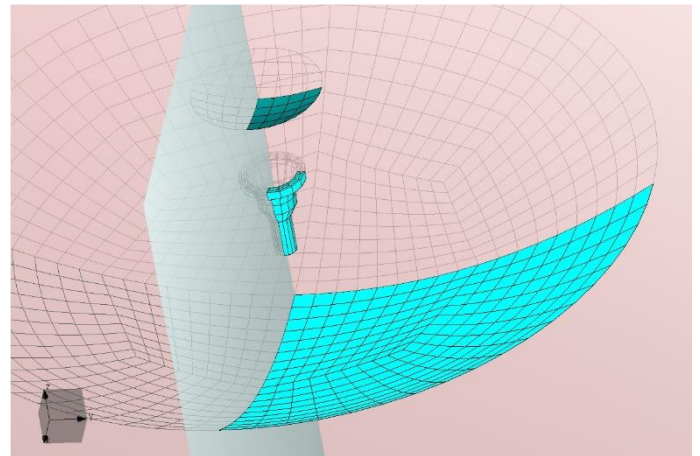


Figure 1. Cassegrain reflector antenna

The antenna's diameter is 300 mm, and the entire simulation requires only 4,000 unknown coefficients. On any modern desktop or laptop, the simulation lasts only a couple of seconds.

In order to demonstrate the techniques to reduce the number of unknowns on radomes, we will cover the antenna with the modest-size radome. Such a simulation is in the reach of full wave MoM simulation.

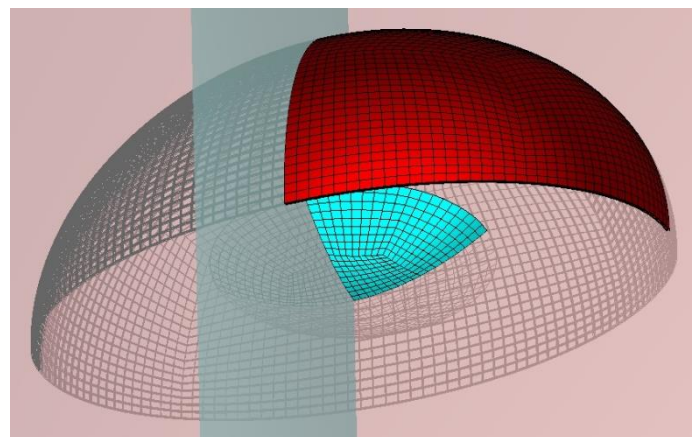


Figure 2. Reflector antenna covered with elliptical radome

For simplicity, the radome that is used is **elliptical**. Its height is 300 mm, while the half axes of base eclipse are 200 and 350 mm. The radome has **3 dielectric layers**. The thicknesses of layers are 1.4, 1.1 and 1.1 mm, while permittivity for each layer is respectively 2.5, 2.4 and 2.32. The radome is made as WIPL-D Pro Sphere object with 40 segments, which means that its' patches are 1.5-2 wavelength large. The polynomial orders for current distribution representation are between 4 and 6. Such a simulation (the antenna plus 4 dielectric surfaces) requires over 400,000 unknowns. With the affordable hardware resources, this is a practical limit for MoM simulations. On a desktop PC with 3-4 inexpensive GPU cards, simulations with up to 500,000 unknowns run in under 1 day.

However, previous experience shows that the orders of currents on radome surfaces can be reduced to 2 and 3 (from 4, 5 and 6). A very simple way to achieve this is to set referent frequency in the project to 12 GHz. The referent frequency for the feeder should be kept at 30 GHz. It carries insignificant number of unknowns, so no reduction is needed. This reduces number of unknowns down to **150,000 unknowns**, which is much more practical EM simulation.

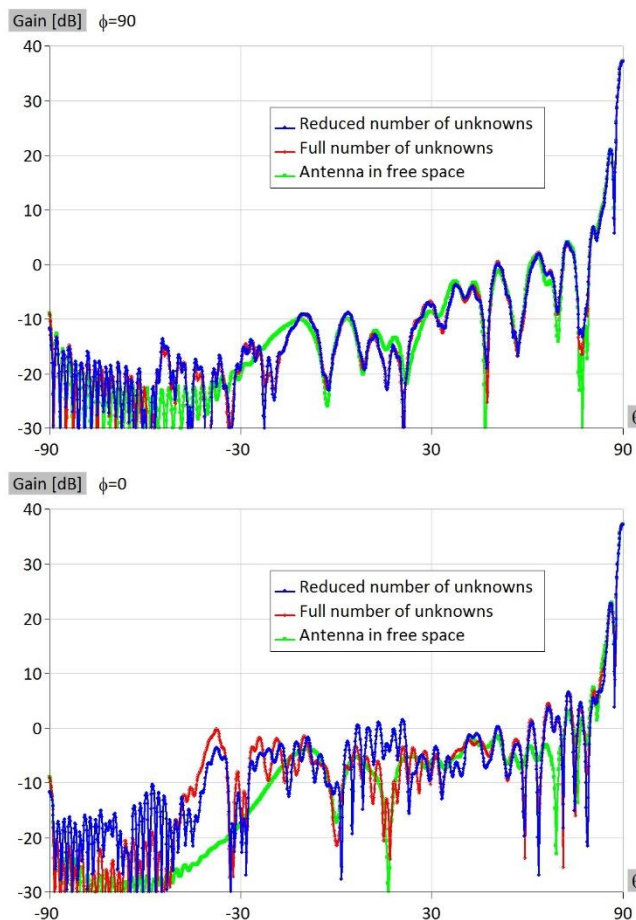


Figure 3 Efficiency of reduction

The agreement of the obtained results in case where no reduction is used and the case where reduction is implemented through lower reference frequency is excellent

The next step in radome simulations is to use WIPL-D product specialized for electrically large structures: Domain Decomposition Solver (DDS). and perform the same simulations as with full MoM. The required hardware resources and simulation time are reduced several times, while the accuracy of the obtained results is preserved. This will be rather important later, for simulation of larger radome with more layers. The DDS tool is an iterative solver, so we present the results for several iterations in order to demonstrate the convergence.

Since the final radome is symmetrical in single symmetry plane, DDS simulations were carried out on the half of the model which requires **300,000 unknowns** (with the reduction applied).

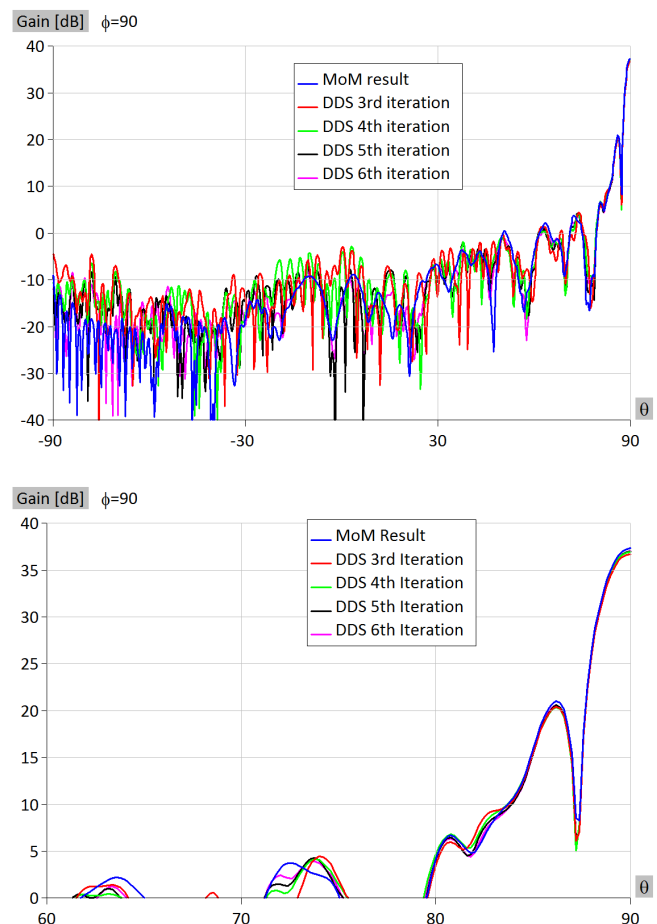


Figure 4. Convergence of DDS results

Based on the results shown in Figure 4, we can conclude that DDS results with more iterations quickly approach to the full wave MoM results.

The same workstation was used for DDS and MoM simulations: 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 assume matrix fill-in on CPU, while the GPU cards are used for matrix inversion.

For the DDS simulations, multi-thread CPU parallelization was utilized. MoM simulation (reduced case, lower reference frequency) with 150,000 unknowns was run in 28 minutes, while

the full simulation (422,777 unknowns) lasted much longer, around 405 minutes. Simulation times for DDS simulation per iteration are shown in Table 1 (model has 300,000 unknowns).

Table 1. Simulation times for DDS (3-layer radome).

Number of iteration	t [min]
0	3.1
1	9.0
2	13.4
3	15.7
4	13.11
5	13.29
Total	67.6

Large 7-layer Radome

The most challenging task is the simulation of the 7-layer radome of greater size. Total radome thickness is equal to 8 mm, where all 7 layers have the same thickness. Radome permittivity increases starting from 2.0 to respectively: 2.08, 2.16, 2.24, 2.32, 2.4 and 2.5. Radome covering the antenna is shown in Figure 5.

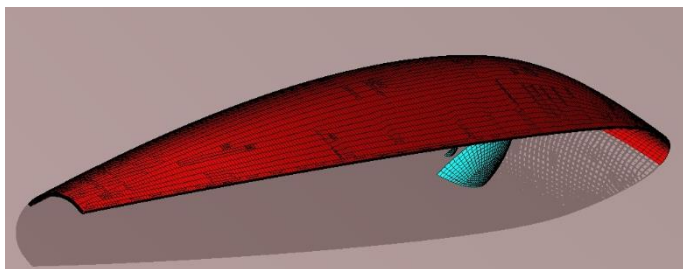


Figure 5. Antenna under 7-layer large radome

Now, only the simulation with DDS is acceptable in terms of reasonable simulation time and hardware resources.

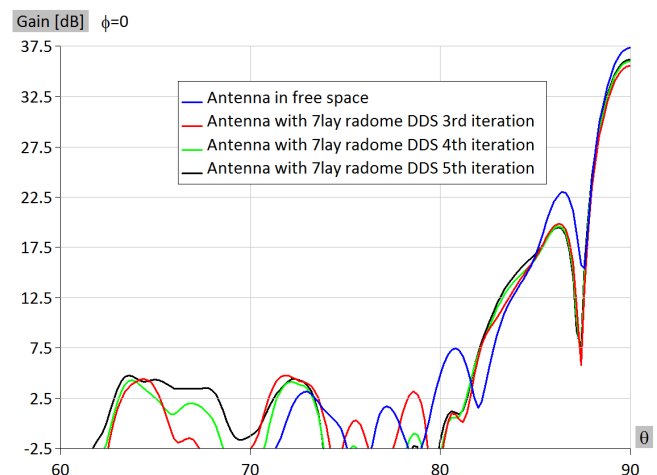
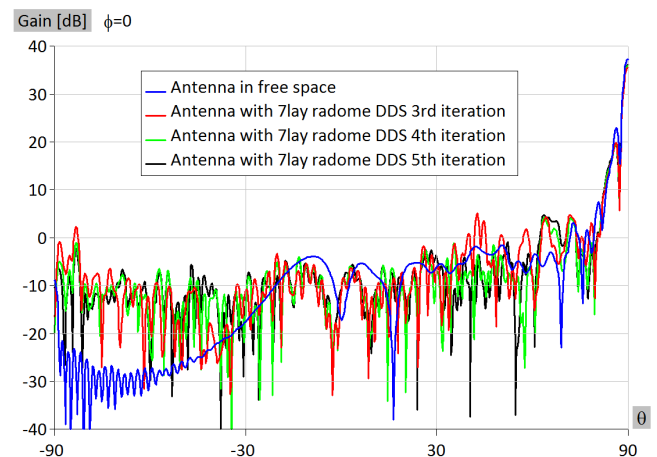
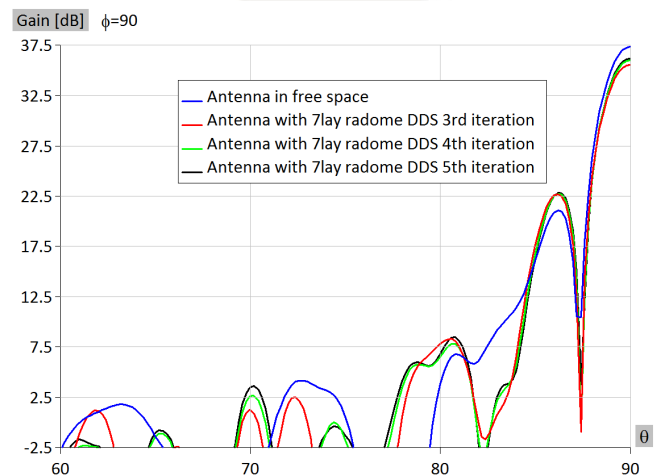
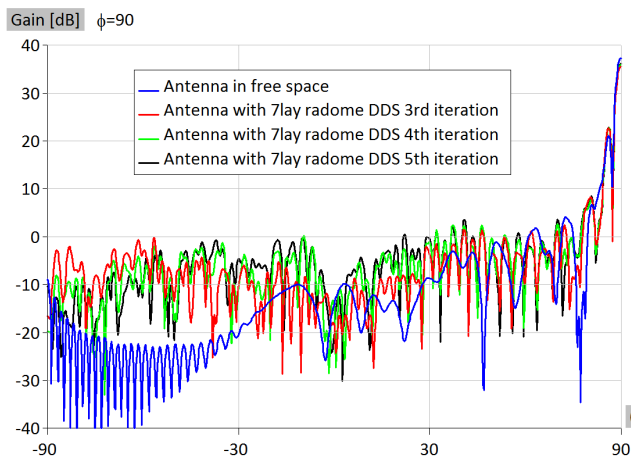


Figure 6. DDS simulation of 7-layer radome

The simulations were carried out on the following workstation:

Intel® Xeon® Gold 5118 CPU @ 2.30 GHz (2 processors, 24 cores in total) with 192 GB RAM.

DDS model for the **7-layer large radome** scenario requires **2,364,447 unknowns**.

Simulation times for the DDS iterations along with the total time for DDS analysis are shown in Table 2.

Table 2. Simulation times for DDS (7-layer radome).

<i>Number of iteration</i>	<i>t [min]</i>
0	49.3
1	34.1
2	50.8
3	68.1
4	92.7
5	116.9
Total	411.9

Conclusions

In this application note we have first demonstrated that number of unknowns can be significantly reduced for radome simulations by using WIPL-D built-in techniques. The process was done without impacting the accuracy of the results. Typical reduction in terms of number of unknowns is several times (for the smaller 3-layer radome the reduction is above 3 times).

Next, we have demonstrated the efficient utilization of DDS for radome simulations. Starting from the 4th iteration, DDS result showed fine accuracy compared to the full-wave MoM solution. The comparison was done for a smaller 3-layer radome which basically represents the limits of MoM solution (for the reasonable simulation time).

Based on this, we proceed to the simulation of much larger, numerically more demanding model of the 7-layer radome. DDS allows such a simulation for reasonable simulation time on moderate CPU-based platform. The tool fully exploits CPU multi-threading capabilities. The final simulation that was performed requires over 2 million unknowns. While it is still beyond the reach of full wave MoM, it can be very efficiently solved by DDS.