# Steering Array under 100 Lambda Radome via Field Generators

The paper presents efficient full wave analysis of electrically large radomes, which are based on advanced Method of Moments (MoM) techniques: 1) empowered with higher order basis functions (HOBFs) and CPU/GPU parallelization.

## Introduction

A radome is a protective enclosure for an antenna. The primary function of a radome is to protect an antenna system from environment. It is very important that radome is designed to have minimum impact on the electrical performance of the enclosed antenna.

A variety of different approaches have been employed to investigate the influence of radomes to antenna radiation pattern. In the case of electrically large radomes the techniques that are most often used are analytical and asymptotic techniques (such as PO, GO). However, in the number of cases the results obtained by these techniques are not enough accurate.

One possibility to obtain very accurate results is to use the method of moments (MoM) applied to surface integral equations (SIEs). However, MoM was not used very much in the past for that purpose, since too much memory and time resources were required. In particular, it was limiting factor in case of electrically very large radomes. By development of advanced MoM techniques and using various possibilities for parallelization, such an analysis became available even on a PC computer.

The goal of this paper is to propose the efficient full wave analysis of electrically very large radome illuminated by arbitrary field distribution using proper combination of advanced MoM and parallelization techniques.

## Numerical Examples

Let us consider two radomes illuminated by field generators array. Shape of the radomes is generalized sphere. Equation of generalized sphere is given by:

$$\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2 = 1 , \qquad (1)$$

where $a=50\lambda$, $b=12.5\lambda$ and $c=6.25\lambda$ are semi-axes along $x$, $y$ and $z$-coordinates. The first example consists of one thin layer, while second one consists of tree thin layers. Parameters are given in Tab. 1 and 2.

**Table 1. Parameters of the one-layer radome example**

| Layer | Thickness [mm] | Dielectric constant |
|---|---|---|
| #1 | 10 | 1.2 |

**Table 2. Parameters of three layers radome example**

| Layer | Thickness [mm] | Dielectric constant |
|---|---|---|
| #1 | 0.5 | 4 |
| #2 | 10 | 1.2 |
| #3 | 0.5 | 4 |

## Modeling

Modeling of generic shape radome is very easy and fast using WIPL-D Pro CAD tool. Set of various primitives and manipulations allows us to create wide spectra of arbitrary objects. Shell of the radomes is created using sphere primitive and applying scale and crop by plan manipulations, as shown on Fig 1.

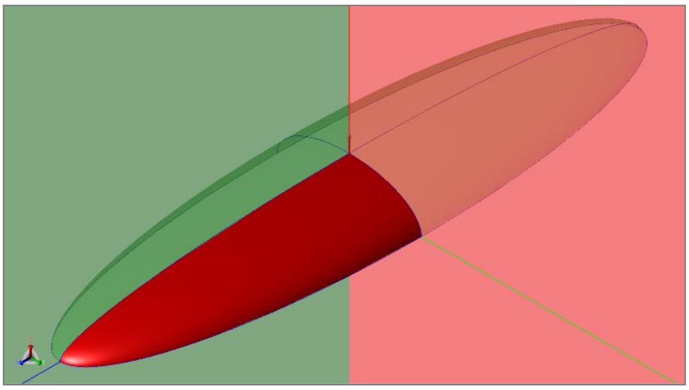


**Figure 1. Radome shell in WIPL-D Pro CAD.**

After modeling shell in WIPL-D Pro CAD tool, mesh is created, Fig. 2, and exported to WIPL-D Pro. The same WIPL-D Pro CAD model can be used for both of radomes.

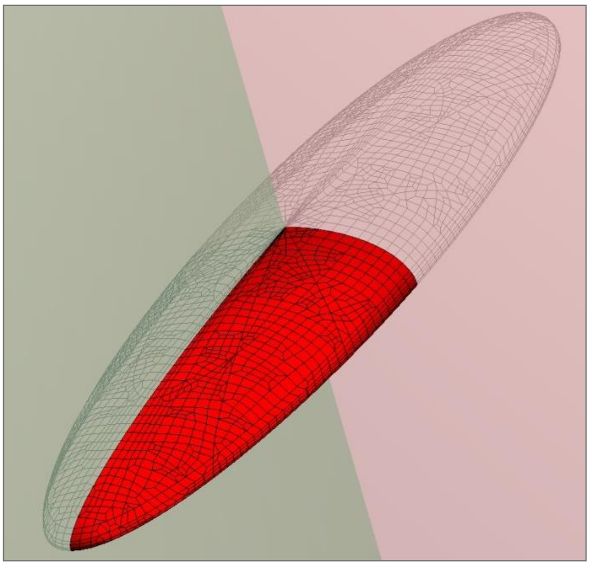


**Figure 2. Meshed radome shell presented in WIPL-D Pro**

Using WIPL-D Pro copy layer manipulation, adding multiple layers is done in a few seconds. The field generators array is set up. Field generators array and quarter of the one-layer radome model is shown in Fig. 3, while quarter of the tree layers model is shown in Fig. 4, as well as field generators arrays.

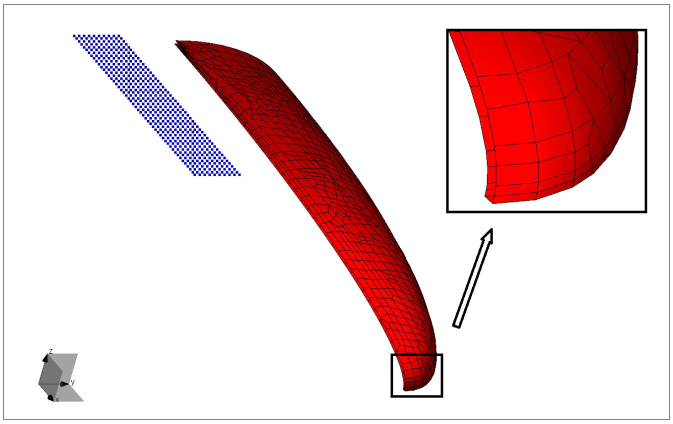


Figure 3. One-layer Radome in WIPL-D Pro

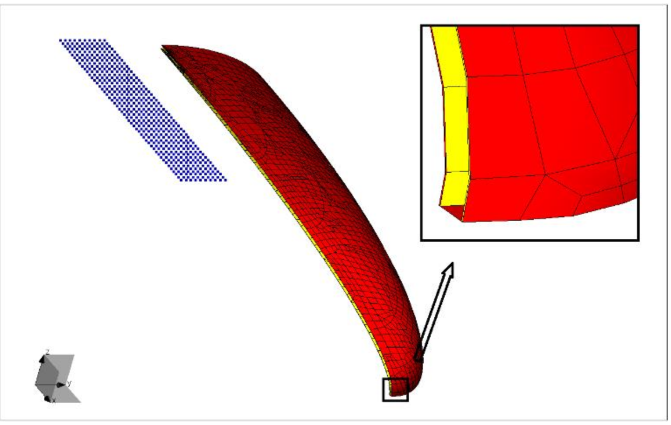
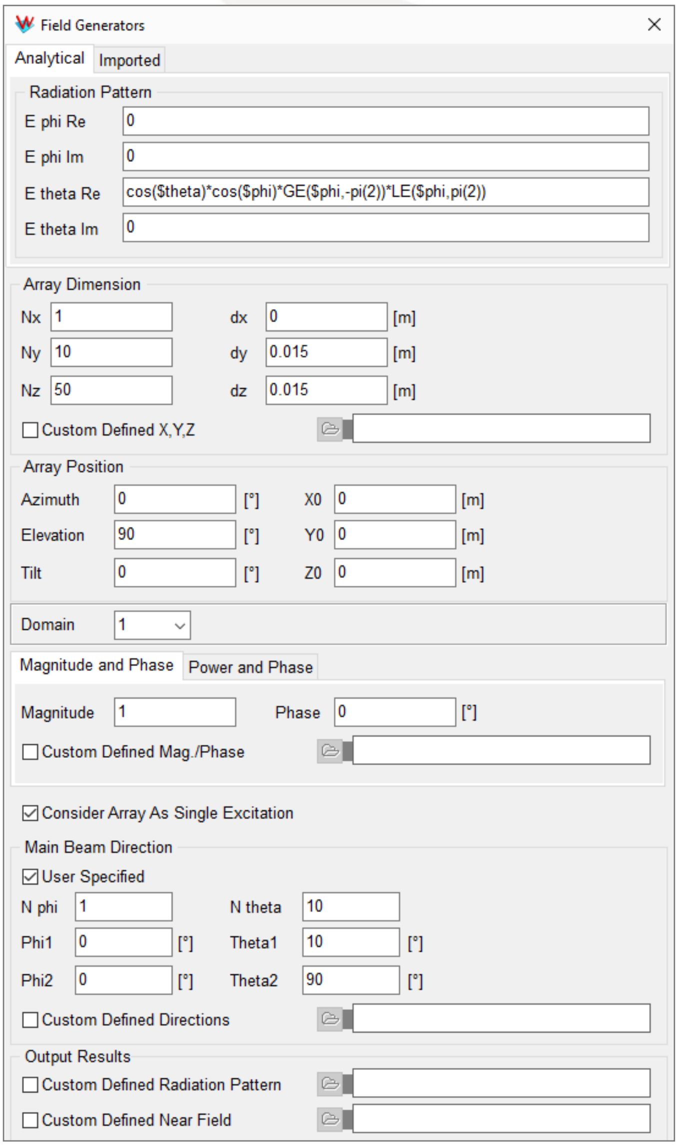


Figure 4. Three-layers Radome in WIPL-D Pro

**Field Generators array** can be defined in detail using Field Generators table, Fig. 5. At first, radiation pattern of basic element should be defined. It can be done analytically or it can be imported from another WIPL-D project or from another software. Fig. 6 illustrate analytically defined radiation pattern of single radiation element. Next, Array dimensions and array position should be defined, as number of elements, their mutual distance and its position.

WIPL-D Pro Field Generators feature enables Main Beam Steering, by checking Consider Array as Single Excitation dialog box and defining Main Beam Directions fields. Based on array dimensions, Main Beam Direction features calculates phase shifts between array elements in order to obtain desired radiation pattern.


Field Generators

Analytical | Imported

Radiation Pattern
E phi Re: 0
E phi Im: 0
E theta Re: cos($theta)*cos($phi)*GE($phi,-pi(2))*LE($phi,pi(2))
E theta Im: 0

Array Dimension
Nx: 1 dx: 0 [m]
Ny: 10 dy: 0.015 [m]
Nz: 50 dz: 0.015 [m]
☐ Custom Defined X,Y,Z

Array Position
Azimuth: 0 [°] X0: 0 [m]
Elevation: 90 [°] Y0: 0 [m]
Tilt: 0 [°] Z0: 0 [m]

Domain: 1

Magnitude and Phase | Power and Phase
Magnitude: 1 Phase: 0 [°]
☐ Custom Defined Mag./Phase

☑ Consider Array As Single Excitation

Main Beam Direction
☑ User Specified
N phi: 1 N theta: 10
Phi1: 0 [°] Theta1: 10 [°]
Phi2: 0 [°] Theta2: 90 [°]
☐ Custom Defined Directions

Output Results
☐ Custom Defined Radiation Pattern
☐ Custom Defined Near Field

Figure 5. Field Generators table

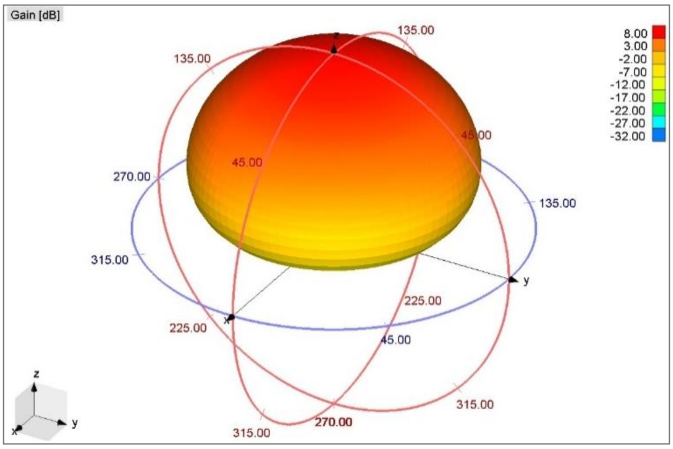


Figure 6. Radiation pattern of single radiation element

## Results and Simulation Times

The emphasize of this application note is not to reduce number of unknowns and simulation time for a single array orientation. The array is simulated at 10 GHz. The only reduction applied is that the referent frequency is taken as 8 GHz, which reduces number of unknowns greatly on the entire surface of the radome.

The array radiation is steered across the entire surface of the radome. Instead to run multiple problems and reduce number of unknowns for each case, we use field generators. The most demanding phase of MoM simulation is the matrix inversion (done as LU decomposition in WIPL-D). For the array steered into 10 directions, we run only single LU decomposition, which is the most expensive phase in terms of simulation time. After that, for each steering angle, the code only runs inexpensive forward-backward substitution. That way, instead to increase simulation time 10 times for 10 steering directions, the simulation time is doubled at most.

Simulation times are listed in Tab. 3. The workstation used is:

Intel(R) Xeon(R) Gold 5118 CPU @ 2.30 GHz (2 processors), 192 GB of RAM, 5 SSD hard drives in RAID-0 and 4 NVidia GeForce GTX 1080 Ti cards. The matrix inversion phases is speeded up by using the GPU solver.

Simulation times and size of problems are listed in Tab. 3. Fig. 5a-f illustrate influence of one-layer radome on radiation pattern for different beam steering angles. Subfigures a-c shows result with radome included, while subfigures d-f shows field generators array radiation pattern in free space.

Fig. 6a-f illustrate influence of three-layer radome to radiation pattern for different beam steering angles. Subfigures from a-c shows result with radome included, while subfigures d-f shows field generators array radiation pattern in free space.

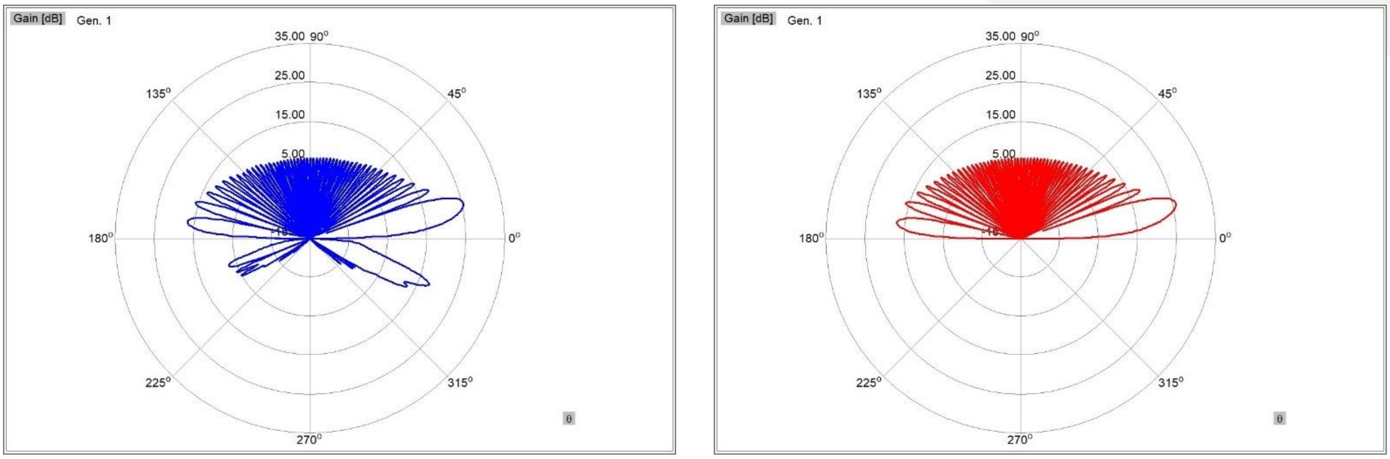
**Table 3. Simulation Times and number of unknowns**

| Number of layers | Number of Unknowns | Simulation Time [s] |
|---|---|---|
| 1 | 81,110 | 3464 |
| 3 | 286,592 | 23,830 |

## Conclusion

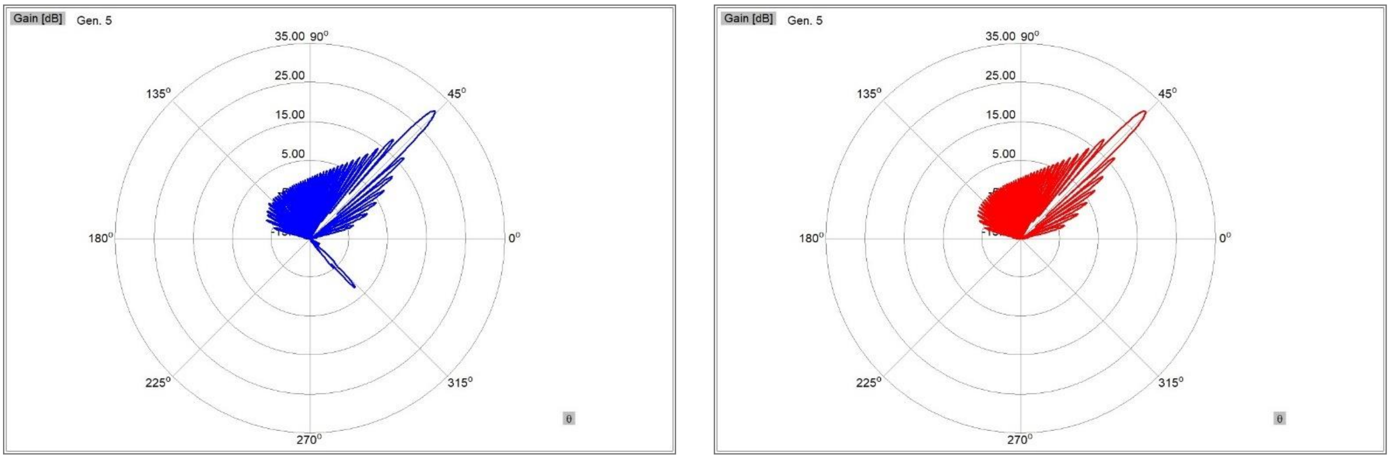
Using advanced MoM and parallelization techniques it is demonstrated that very large radomes, excited by field generator array, can be efficiently analyzed on GPU based configuration. The simulations time is not dramatically increased for practically an arbitrary number of beam steering angles. Thus, for radomes of quasi ellipsoidal shape, 100 λ long, the simulations are carried out in several hours, depending on the number of layers used.

Field generators combined with MoM allow that the most demanding MoM phase, the LU decomposition, is run only once for the arbitrary number of steering angles and the result for each angle is obtained by time inexpensive forward-backward substitution.



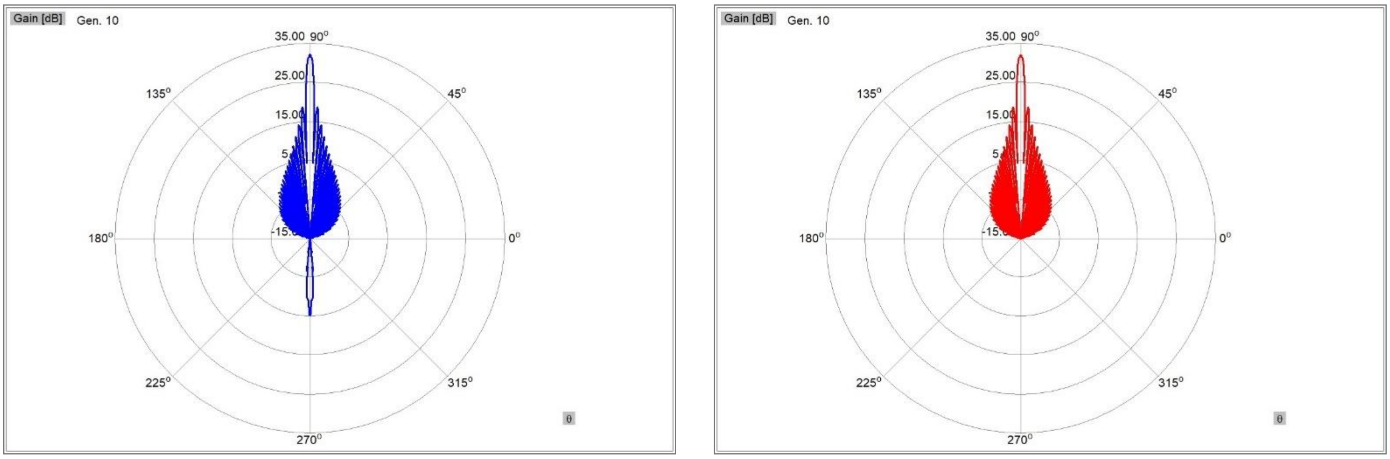
**(a) Radome influence on beam steering angle theta equal to 10 degree**

**(d) Beam steering angle theta equal to 10 degree**



**(b) Radome influence on beam steering angle theta equal to 45 degree**

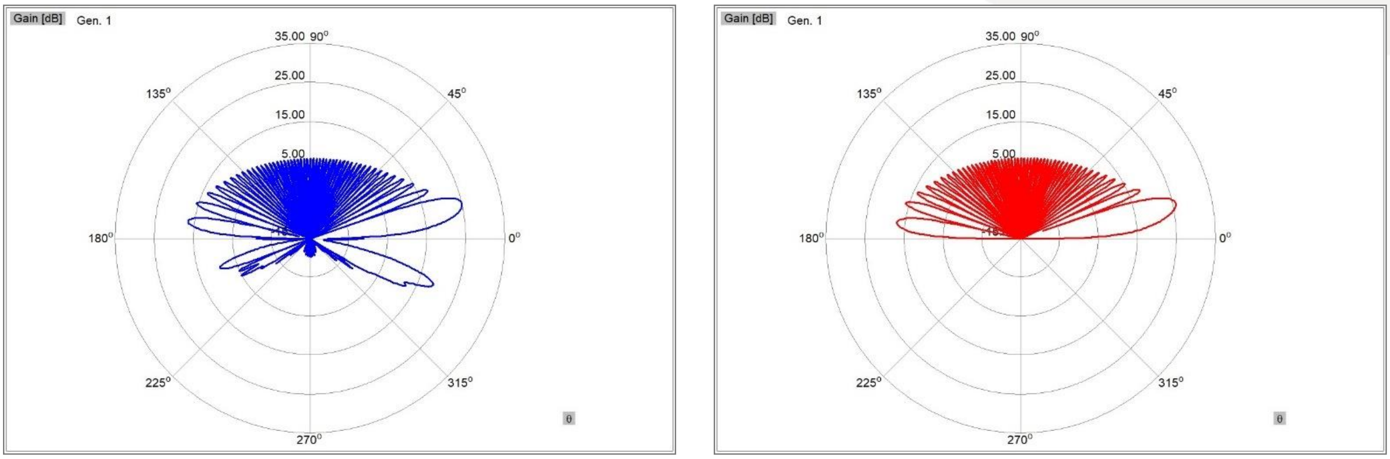
**(e) Beam steering angle theta equal to 45 degree**



**(c) Radome influence on beam steering angle theta equal to 90 degree**

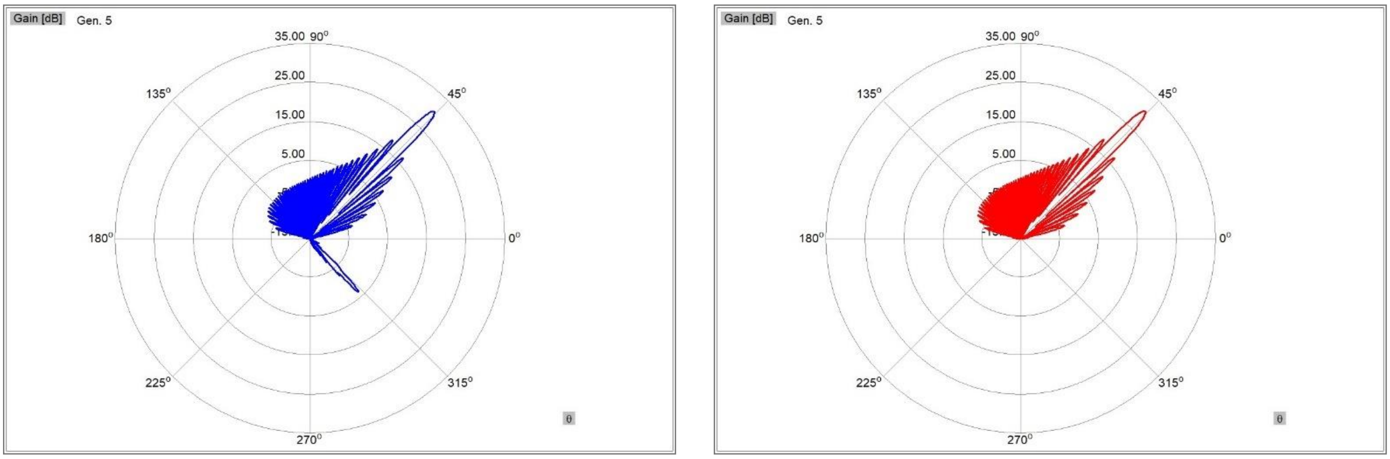
**(f) Beam steering angle theta equal to 90 degree**

**Figure 5. Influence of one-layer radome to field generators array radiation pattern**



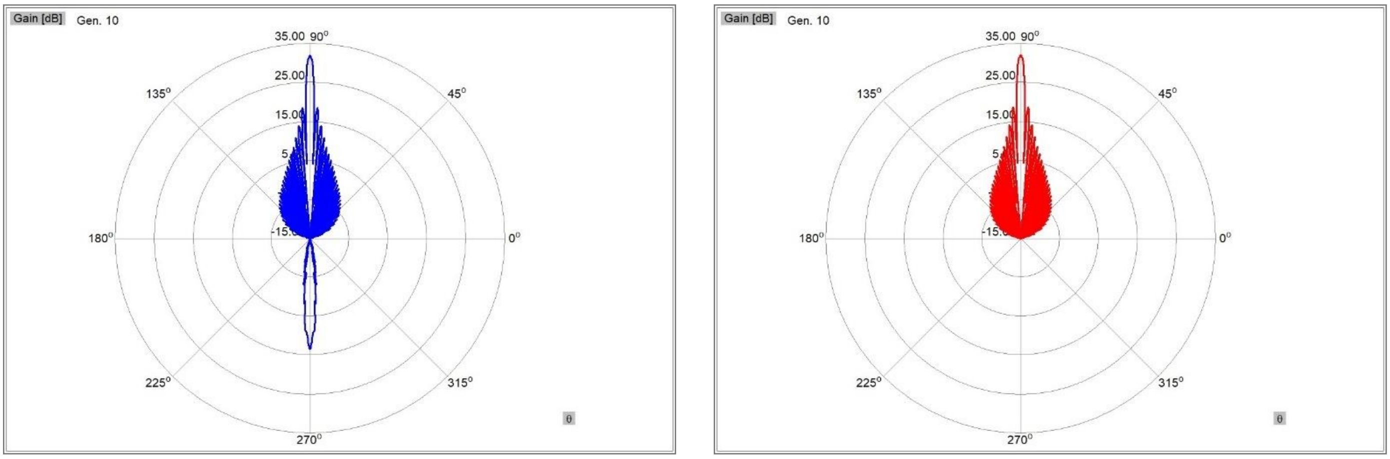
**(a) Radome influence on beam steering angle theta equal to 10 degree**

**(d) Beam steering angle theta equal to 10 degree**



**(b) Radome influence on beam steering angle theta equal to 45 degree**

**(e) Beam steering angle theta equal to 45 degree**



**(c) Radome influence on beam steering angle theta equal to 90 degree**

**(f) Beam steering angle theta equal to 90 degree**

**Figure 6. Influence of three layer radome to field generators array radiation pattern**