Microstrip Patch Array Printed on Cylinder

The aim of this application note is to demonstrate efficient modeling and simulation of an antenna array by using WIPL-D software (WIPL-D Pro, WIPL-D Microwave and WIPL-D Optimizer). The result of interest is radiation pattern of the array.

Modeling

The first step is modeling of the structure in WIPL-D Pro. There are a few procedures for modeling of this structure:

- by using WIPL-D Pro 3D EM Solver (defining symbols, nodes, making plates, feeding areas)
- by using WIPL-D Pro 3D EM Solver (defining symbols, grids, making plates, feeding areas)
- by using WIPL-D Pro CAD (defining symbols, solid objects, Boolean operations, automatic mesh)
- by using WIPL-D Pro CAD for importing .dxf, .x_t, .stp, .sat, .iges, …

The first procedure is explained in this paper. Using this approach enables achieving optimal mesh and minimum simulation time.

The first step is modeling a single patch antenna. After that, the array will be created by copying the antenna element. A patch (antenna element) was fed using a probe.

Using the first procedure means that symbols, nodes, plates, wire, junctions and generator should be defined. Symbols will be used for representing dimensions of the model. Actually, the symbols are used for defining nodes. That way, by changing symbols, the model can be easily changed preserving originally defined mesh. Table of symbols (a part of it) is shown in Figure 1.

Symbols

	Symbol	
1	20	lambda=20; wavelenght
+2	32	N=32; Number of segments
3	0.6	Hsub=0.6; Thickness of substrate
4	6.6	L=6.6; Patch length
5	8	W=8; Patch width
6	0	Xfeed=0; X-coordinate of the probe
7	-2	Yfeed=-2; Y-coordinate of the probe
8	0.1	Rwire=0.1; Radius of the probe

Figure 1. Table of symbols (partially)

The model of the single patch antenna is shown in Figure 2. In WIPL-D Pro, a generator can be attached to the wire only. A node where electrical contact between wire and plate appears is marked in the Figure 2. The electrical contact between wire and plate is obtained by using Junction – a special WIPL-D Pro entity.

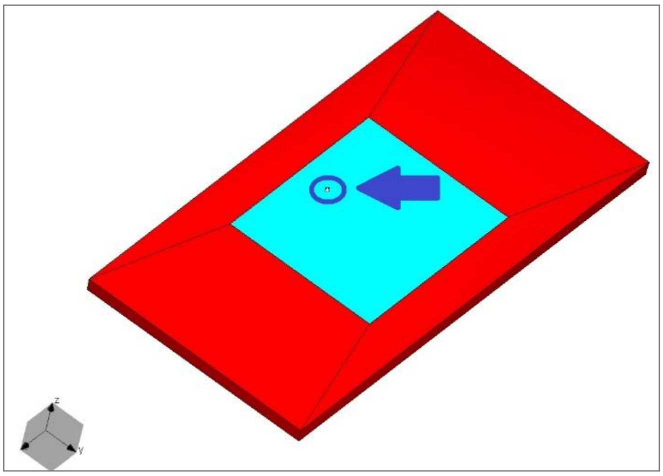

Figure 2. Model of the single patch antenna

After optimizing characteristics of this antenna, our aim is to create an antenna array. Creating antenna array will be performed mainly through WIPL-D Pro Manipulations.

Table of Manipulations is shown in the Figure 3. Manipulation Group is shown in Figure 3. In this Group we created a group of entities consisting of plates and a wire.

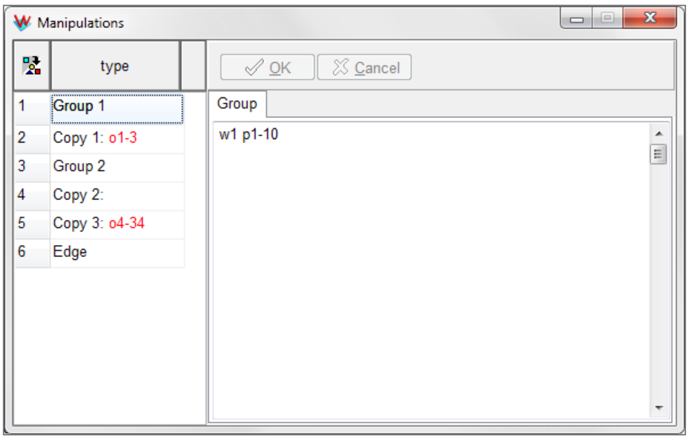

Figure 3. Group manipulation

The following step consists of making copies of the previously created group. Three copies were created. Copy manipulation is shown in the Figure 4. It can be noticed that symbol Lant is used in this Copy manipulation. The symbol represents length of the antenna element. It is equal to half of the wavelength calculated at 15 GHz.

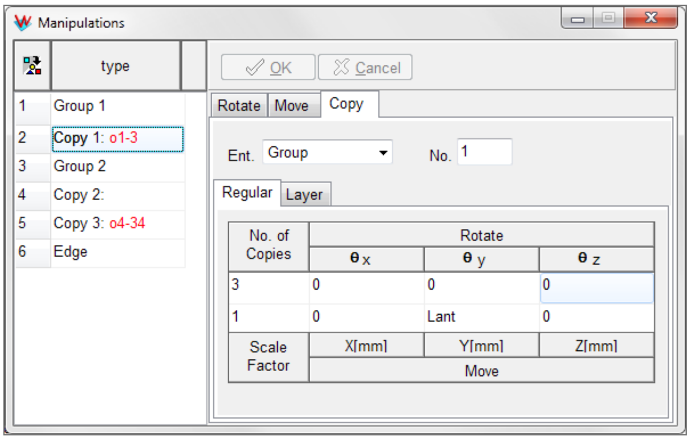

Figure 4. The first Copy manipulation

This means that four patches are modeled, so far (Figure 5).

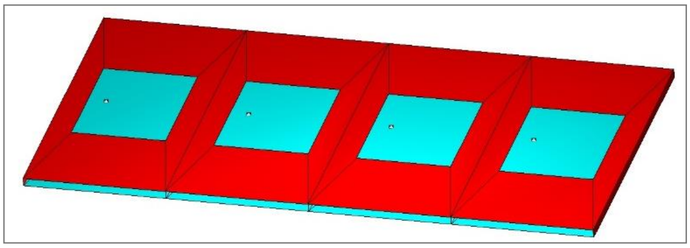

Figure 5.Array consisting of 4 antenna elements

In order to create the desired array, next modelling step will be rotation of this model around x-axis and around z-axis and its translation along x-axis. These array manipulations require appropriate grouping of entities and using a Copy manipulation with number of copies set to zero (Figure 6).

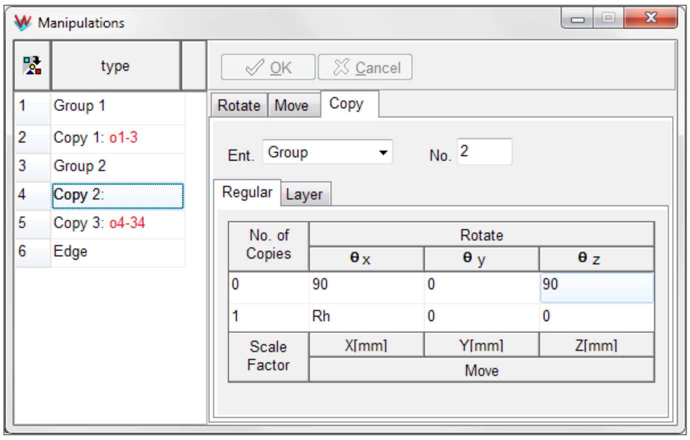

Figure 6. Copy manipulation – positioning four elements antenna array

The next modelling step is copying (multiplying) four elements array which is shown in the Figure 5. Copy manipulation used for this modelling step is shown in the Figure 7, while the final model of antenna array is shown in the Figure 8.

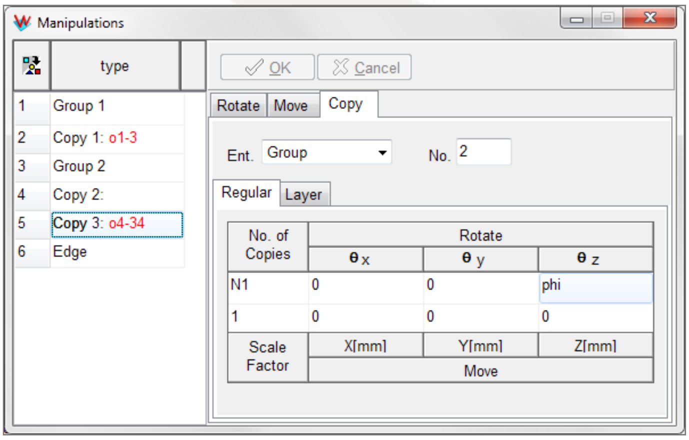

Figure 7. The second Copy manipulation

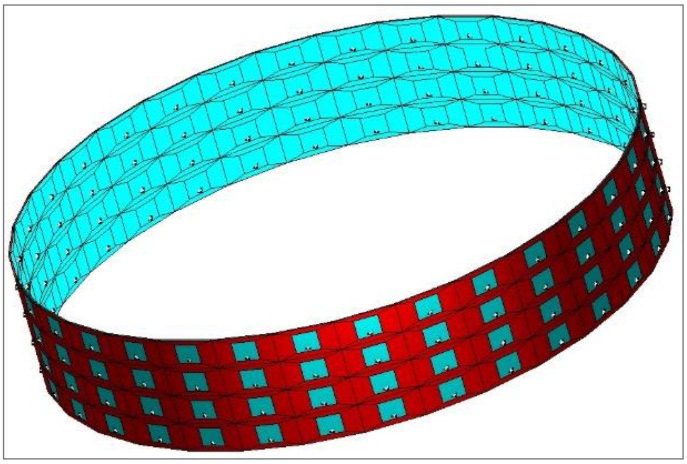

Figure 8. Model of the array

The last step is defining manipulation Edge. Manipulation Edge (often called Edging) represents involving automatic meshing along edges where the edge effect is a critical parameter for an accurate analysis of a model. Using of the edge manipulation is shown in the Figure 9.

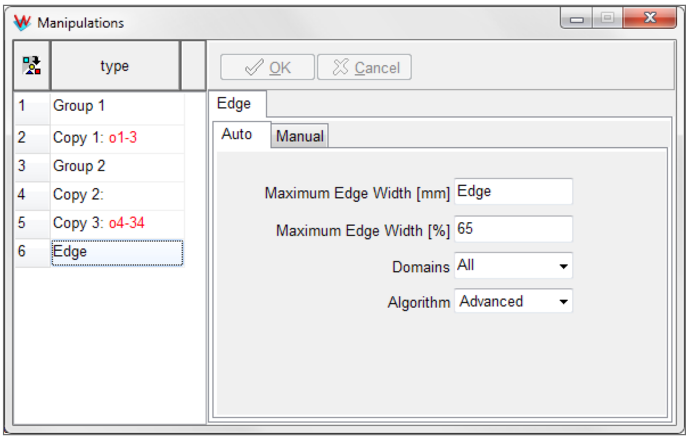

Figure 9. Edge manipulation

Effect of applying Edge manipulation on the model of array is shown in the Figure 10.

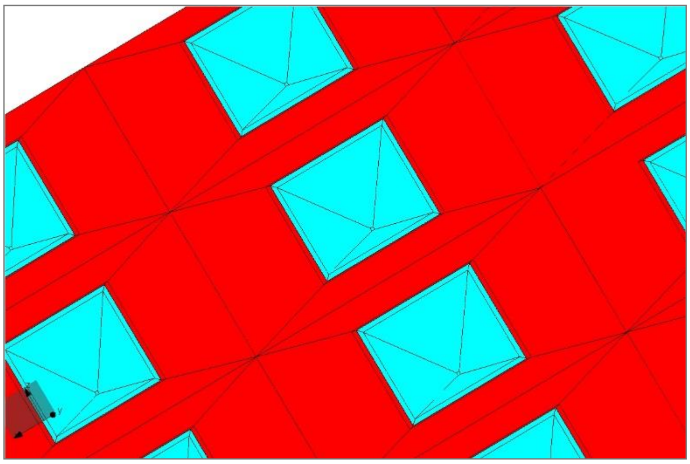

Figure 10. Effect of applying Edging. Additional meshing appears in the vicinity of edges.

Simulation Results

Single patch antenna representing an element of the array should be optimized first. By manually changing dimensions of the antenna, this optimization is performed in a few steps. S11 parameter is observed from 10 GHz to 20 GHz (Figure 11). It reaches minimum at 15 GHz (Figure 11).

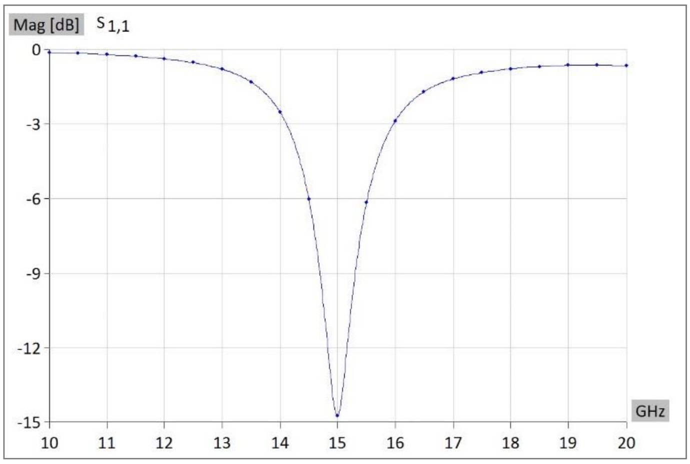

Figure 11. S11 parameters of single patch antenna

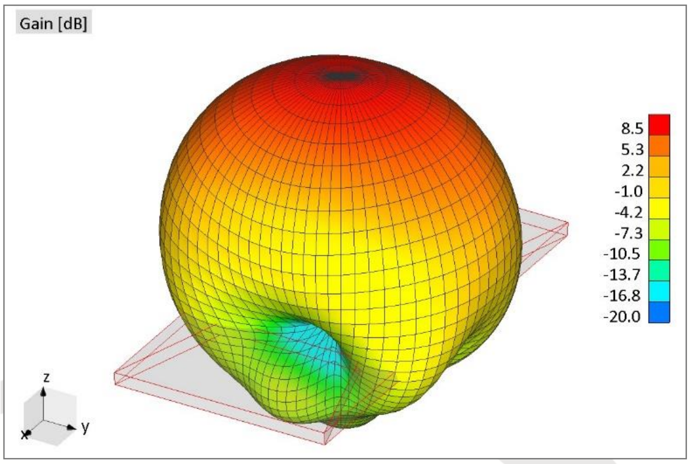

Figure 12. Radiation pattern – single antenna

Radiation pattern at 15 GHz is presented in Figure 12.

Only quarter of the antenna array is fed. Thus, it is required to simulated only a quarter of the array. Assumption is that the rest of the array doesn't influence significantly on the quality of the results. Also, by applying this approach, simulation time is decreased significantly. Model of a quarter of the array is shown in the Figure 13.

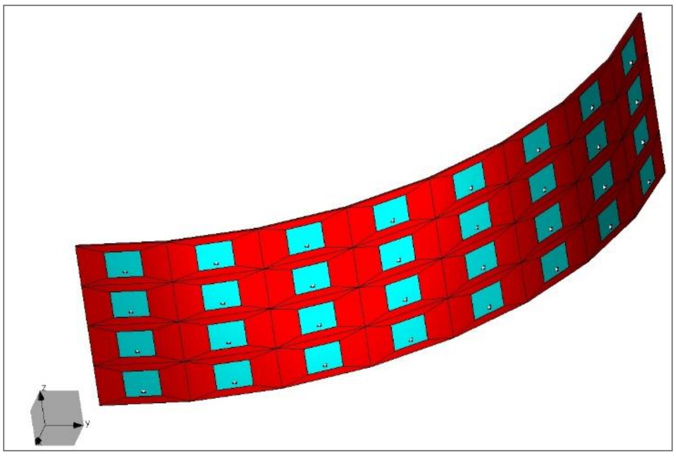

Figure 13. Quarter of the array

The model of quarter of the array is imported into WIPL-D Microwave. In WIPL-D Microwave, obtained circuit is fed using voltage generators. The circuit in WIPL-D Microwave is shown in the Figure 14.

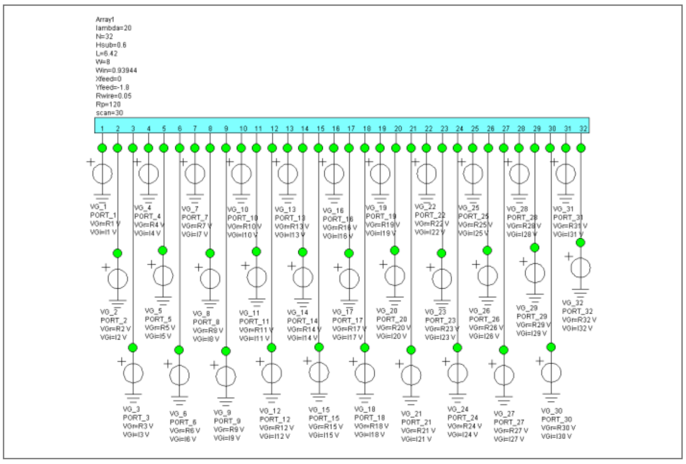

Figure 14. Circuit in WIPL-D Microwave.

All generators in the imported model are set to 1+j0 [V]. Operation mode is set to One generator at time. As consequence of such simulation settings, radiation pattern is obtained for each generator while all the other generators are short circuited.

WIPL-D Microwave Pro can modify radiation patterns according to voltages set in WIPL-D Microwave itself, considering that all generators operate. It is called "smart simulation" in WIPL-D Microwave Pro.

There are two methods for obtaining phase differences of generators in WIPL-D Microwave: by using formulas or by using WIPL-D Optimizer.

If the formulas are used and direction of the main beam is set to theta = 0 Degrees and phi = 45 Degrees, calculated radiation pattern is shown in the Figure 15.

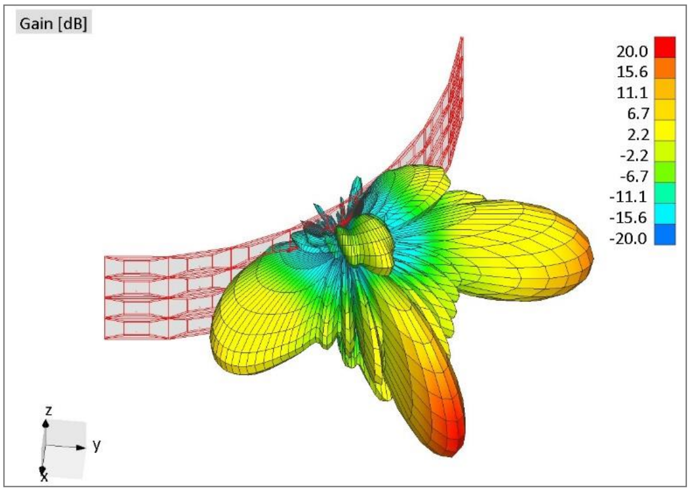

Figure 15. 3D radiation pattern of quarter of the array. Main beam direction is defined for theta = 0 Degrees and phi = 45 Degrees.

Theta = 0 Degrees cuts of radiation patterns obtained using models where phase shifts were calculated manually (using formulas) and optimized (using WIPL-D Optimizer) are shown in Figure 16. Gain in main beam direction should be maximized (theta = 0 Degrees, phi = 45 Degrees).

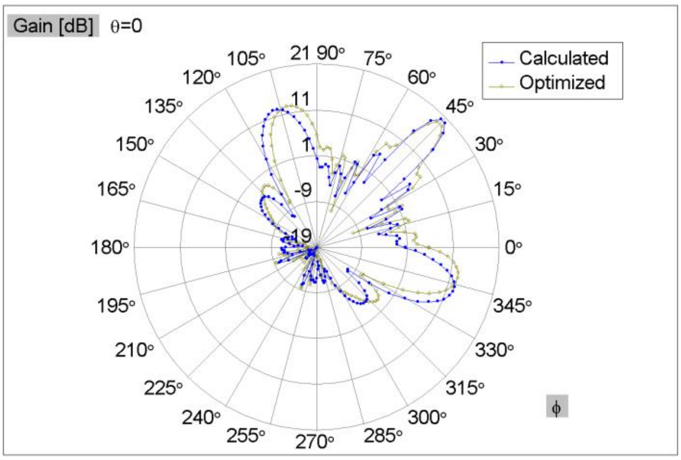

Figure 16. Overlaid theta-cuts. Manually calculated phase shifts and optimized phase shifts

Figure 17 and Figure 18 show us theta cuts of radiation patterns, where the main beam directions are set for theta = 0 Degrees and phi = 30 Degrees and theta = 0 Degrees and phi = 15 Degrees, respectively. Mentioned figures present results using models where phases of the generators are calculated using formulas.

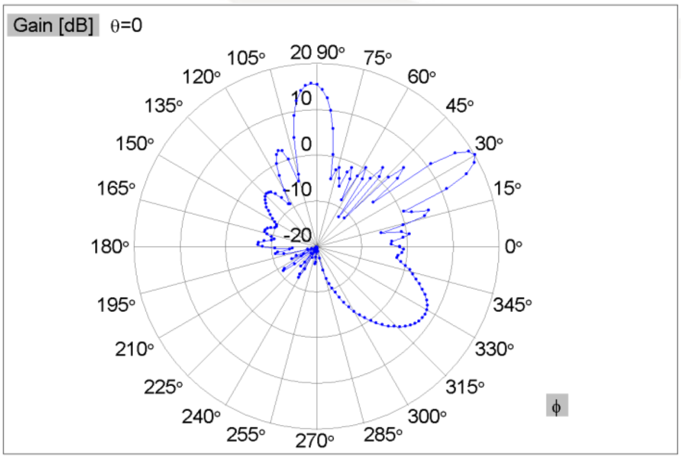

Figure 17. Theta-cut of the radiation pattern. Theta = 0 Degrees and phi = 30 Degrees is main beam direction

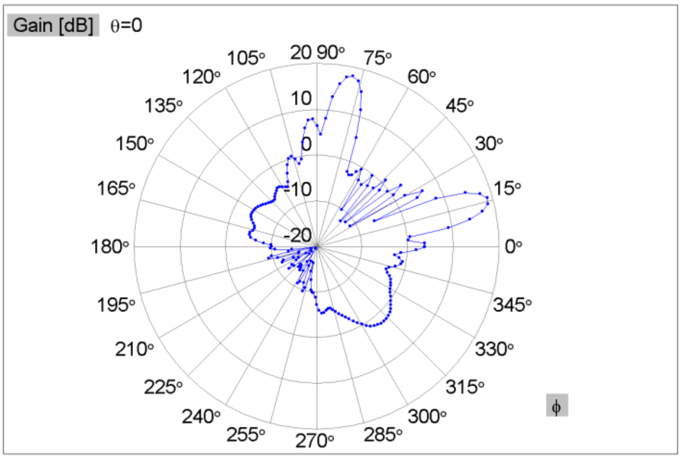

Figure 18. Theta-cut of the radiation pattern. Theta = 0 Degrees and phi = 15 Degrees is main beam direction

Observing Figure 17 and Figure 18, one can see that main beams standing out clearly. However, it can be also seen that level of side lobes is significant.

Thus, it is necessary for phases of the generators to be optimized, in order to minimize side lobes of the radiation pattern. In the Figure 19 a theta-cut of radiation pattern is shown. The antenna is with main beam direction defined for angles theta = 0 Degrees and phi = 30 Degrees. The optimization was performed in such manner that side lobes are less than 10 dB.

Difference between side lobes shown in Figure 18 and Figure 19 is clearly seen.

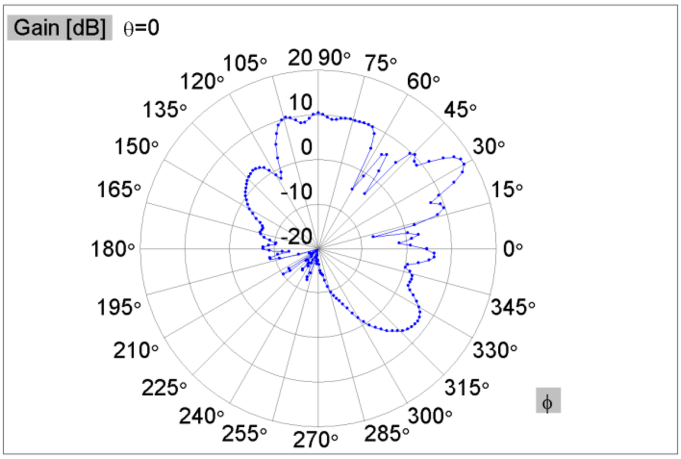

Figure 19. Theta-cut of the radiation pattern

3D radiation pattern where direction of the main beam appears for theta = -30 Degrees and phi = 30 Degrees is shown in Figure 20.

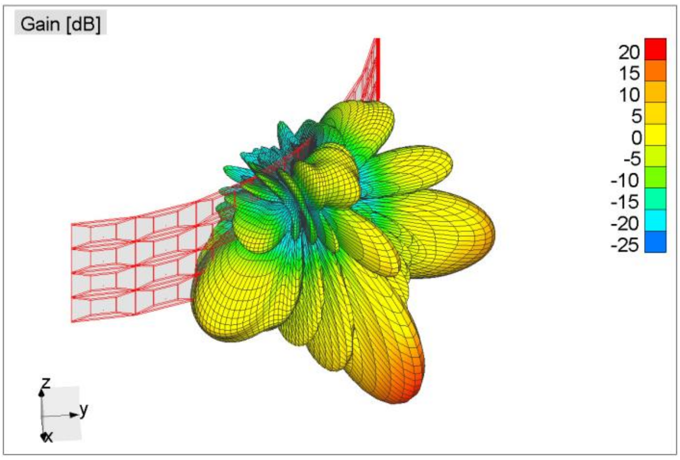

Figure 20. 3D radiation pattern of quarter of the array. Main beam direction appears for theta = -30 Degrees and phi = 30 Degrees

Theta = -30 Degrees cut of the radiation pattern shown in Figure 20 is shown in the Figure 21.

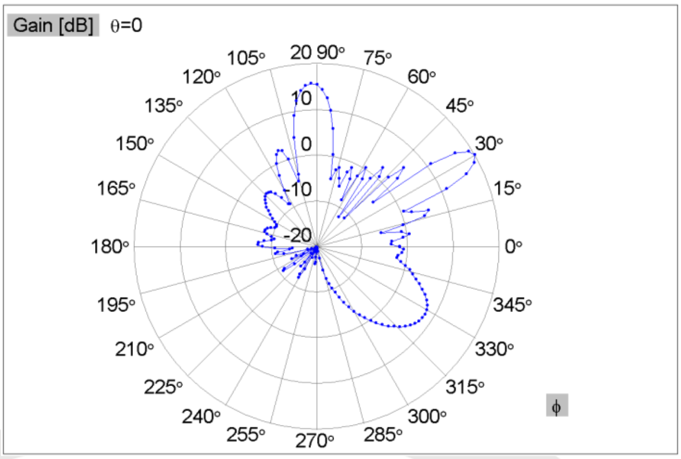

Figure 21. Theta-cut of the radiation pattern

The overlaid results for the theta cut of radiation pattern for full model of the array and for quarter of the array are presented in Figure 22.

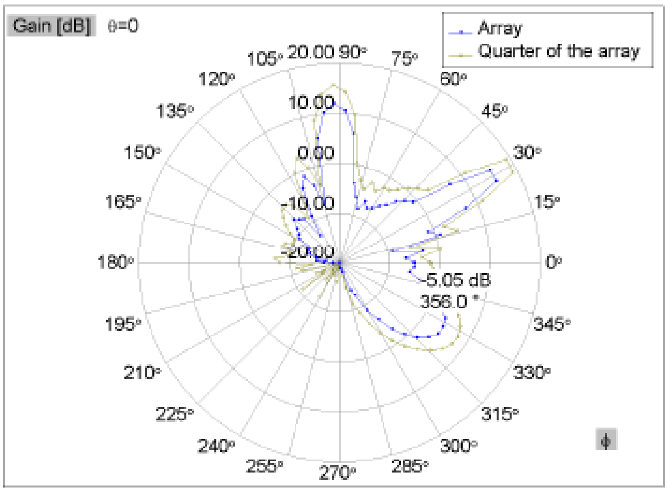

Figure 22. Overlaid theta-cuts. Radiation pattern obtained using full model of the array and quarter model of the array.

Observing Figure 22, one can see that the shapes of the radiation patterns are the same for the full model and for model of a quarter of the array.

All the simulations were carried out on regular desktop PC Intel® Core™ i7 CPU 7700@ 3.60 GHz. In order to speed up the most demanding stage of the MoM simulation (for electrically moderate and large models) the matrix inversion, WIPL-D GPU Solver was used. The PC was enhanced with inexpensive low-end Nvidia GPU card GTX1080. Simulation times and numbers of unknowns are presented in Table 1.

In all cases, the matrix fill-in was done on CPU. CPU time assumes that the matrix inversion is also done on CPU, while the mark GPU indicates that matrix inversion was done on GPU card.

Table 1. Simulation time and number of unknowns for simulated models

Model	*Number of unknowns*	*Simulation time CPU [sec]*	*Simulation time GPU [sec]*
Single patch antenna	550	0.5	-
Quarter of the array	13444	43	29
Array	52736	1,315	285

After 3D EM models are simulated, these are imported into the WIPL-D Microwave (as explained earlier). 3D EM models are simulated only once. The rest of microwave circuit is simulated during the optimization, while the results obtained using 3D EM simulation were used only once. This is, so called, co-simulation. Every co-simulation run lasts less than 2 seconds. This means that, for example, after the quarter of the array is simulated (simulation lasts about 100 seconds), each optimizer run lasts for about 2 seconds.