5G毫米波大型天線結構數值分析與模擬

Phase-Only Synthesis of Convex Metallic Reflectarray Antennas for Multi-beam Radiations via Steepest Descent Method

Jake W. Liu, NTU, Jul 17 th, 2019

National Taiwan University

Outline

- Introduction
- Structure of Reflecting Elements
- Formalism of the Reflectarray Radiation
- Phase-Only Synthesis Via SDM
- Numerical Results
- Conclusion

Introduction

- In mmWave applications, narrow beamwidth is required to compensate the power loss of electromagnetic (EM) waves in propagation, which causes the reduction of the coverage area.
- The objective is to use single set of antenna to radiate multiple beams for the multi-sector coverage.
- There are two ways to accomplish multi-sector coverage
  - ➢ Beam switching
  - ➢ Multi-beam

Introduction

What is a reflectarray antenna?

- Reflectarray is an antenna consisting of either a flat or a slightly curved reflecting surface and an (or a set of) illuminating feed antenna(s).

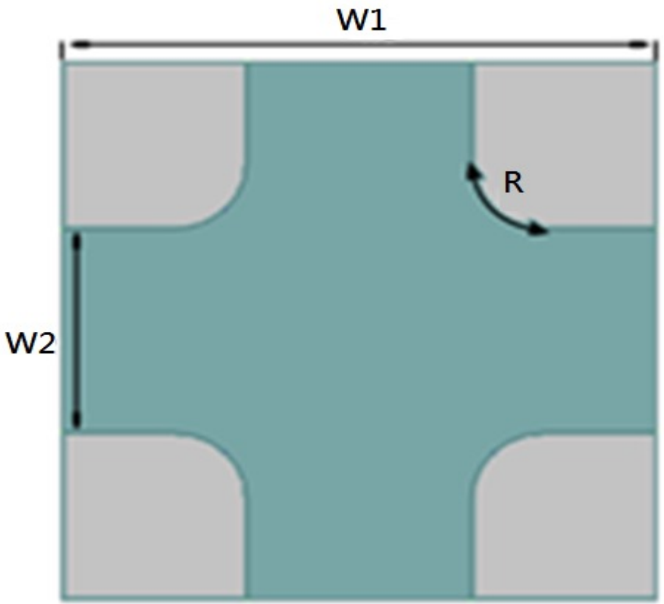
- Each reflecting elements on the surface phased to synthesize the radiation pattern.

Introduction

- The design of metallic reflectarray antennas for the multi-beam radiations is presented.
- metallic reflecting elements consists of several advantages, such as high-energy efficiency, miniaturized sizes, compact structures, broad bandwidth of radiations.
- The synthesis procedure o the phase for each metallic reflecting element is based on the concept steepest descent method (SDM) for the compromised multi-beam radiations.

Structure of Reflecting Elements

$$\Phi = kh_2(\cos\theta_i + \cos\theta)$$



Formalism of the Reflectarray Radiation

The radiation of reflectarray antenna can be modeled by

$$E_{co}^{s}\left(\overline{r}\right)=\sum_{n=0}^{N-1}e^{j\Phi_n}\left[F\left(\hat{r}_{f\cdot n}\right)\frac{e^{-jk\ell_n}}{\ell_n}\right]\left[G_n\left(\hat{r}\right)e^{jk\hat{r}\cdot\overline{r}'_n}\right]\frac{e^{-jkr}}{r}$$

and the feed's radiation pattern can be modelled by a cosine taper with a power *q* as

$$F\left(\widehat{r}_f\right)=Ae^{j\Phi_f}\left(\cos\theta_f\right)^q$$

It is desired to make the overlapping of beams orthogonal or uniformly distributed for an optimum coverage.

$$E_{co}^{s}\left(\overline{r}_m\right)=\sum_{n=0}^{N-1}e^{j\Phi_n}E_{nm}\approx E_d\left(\overline{r}_m\right)$$

Phase-Only Synthesis Via SDM

The procedure starts with defining the cost function by

$$\Omega = \sum_{m=1}^{M} \sum_{p=1}^{P} f_{mp} \left| G_{mp} - G_{mp}^{d} \right|^{2}$$

and the phases are found along the derivative of the cost function, which can be expressed as a closed form by

$$\frac{\partial \Omega}{\partial \Phi_{n}} = 2 \sum_{m=1}^{M} \sum_{p=1}^{P} \left[f_{mp} \frac{\partial G_{mp}}{\partial \Phi_{n}} \left(G_{mp} - G_{mp}^{d} \right) \right]$$

Phase-Only Synthesis Via SDM

The directivity is defined by

$$G_{pq} = 4\pi r^2 \frac{\left|(\bar{E}_p^s(\bar{r}_q)\cdot\hat{v}_q^p)\right|^2}{2Z_0 P_r^p}$$

Thus, the derivative of the directivity is given by

$$\frac{\partial G_{pq}}{\partial \Phi_n} = \frac{4\pi r^2}{Z_0 P_r}\mathrm{Re}\left[(\bar{E}_p^s(\bar{r}_q)\cdot\hat{v}_q^p)(\frac{\partial \bar{E}_p^s(\bar{r}_q)}{\partial \Phi_n}\cdot\hat{v}_q^p)^*\right]$$

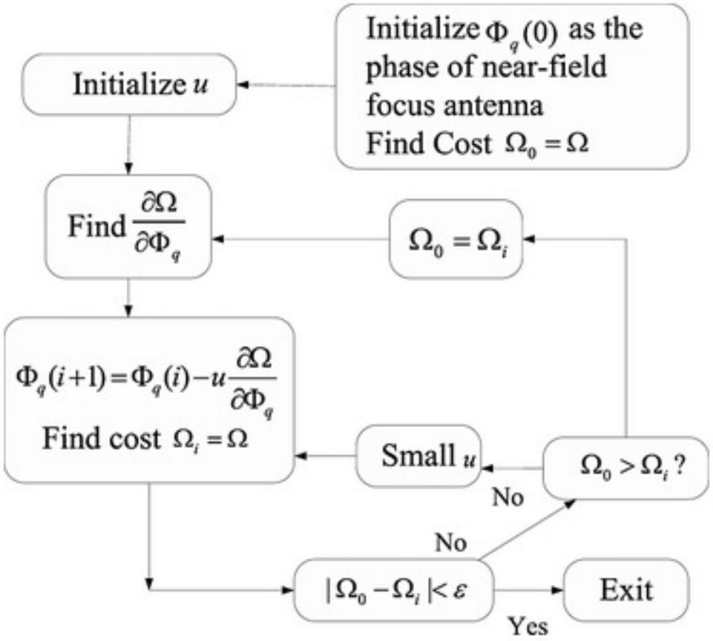
$$\frac{\partial \bar{E}_p^s(\bar{r}_q)}{\partial \Phi_n} = je^{j\Phi_n}\bar{E}_n^p(\bar{r}_q)$$

Phase-Only Synthesis Via SDM

The minimum of the cost function is searched along the derivatives of the cost function with respect to

$$\left[\Phi_n(i+1)\right] = \left[\Phi_n(i)\right] + \left[\Delta\Phi_n(\mathrm{i})\right];$$

$$\left[\Delta\Phi_n\right] = -\mu \left[\frac{\partial\Omega}{\partial\Phi_n}\right]_{[\Phi_n]=[\Phi_n(i)]}$$



Phase-Only Synthesis Via SDM

- The advantage of this modelling is that the derivatives of G_{mp} can be found as a closed form.
- In the procedure of simulation, the computation of gains does not need to repeat as each time of computation only an element's contribution is changed, which can be simply replaced in the gain computation without the need to re-compute the others.

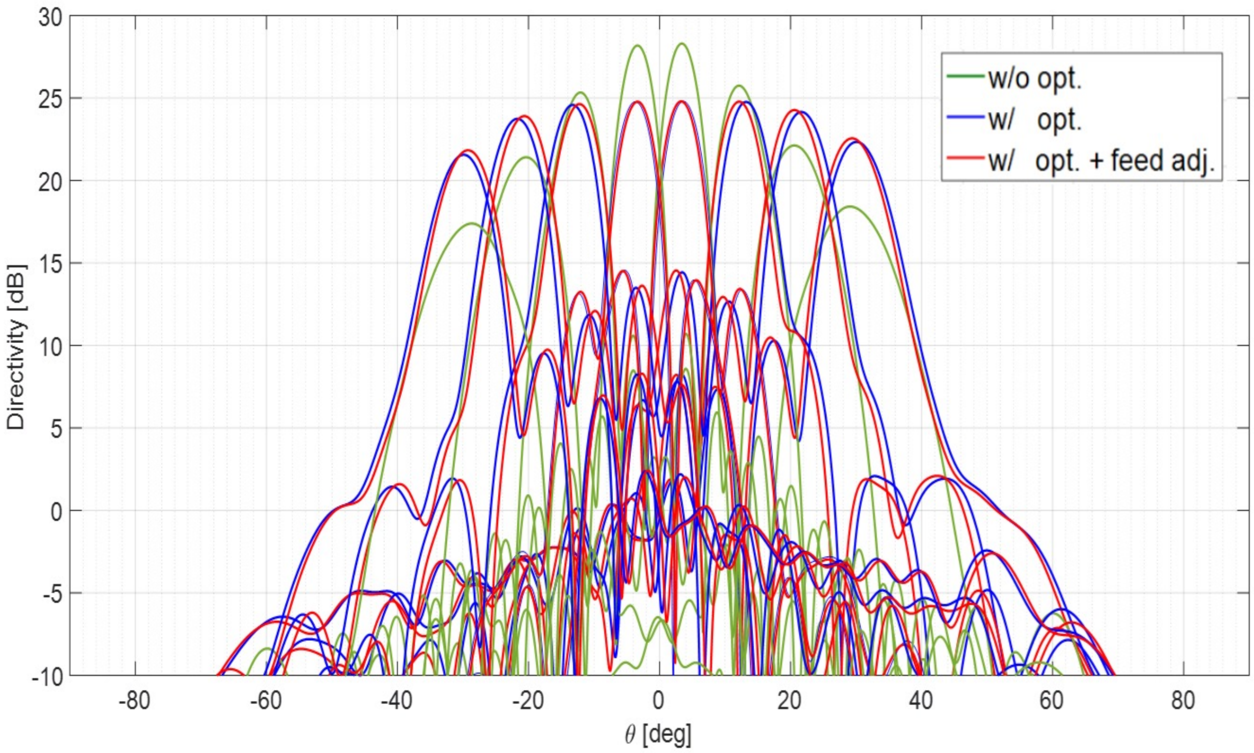
Numerical Results

Case I: 8 feeding antennas with 24*25 elements

Case II: 8 feeding antennas with 30*20 elements

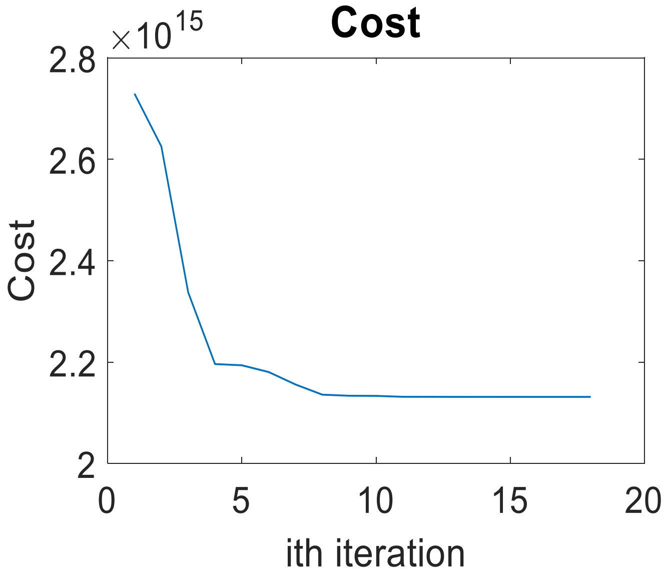
Case III: Case II with special design For Sidelobe reduction

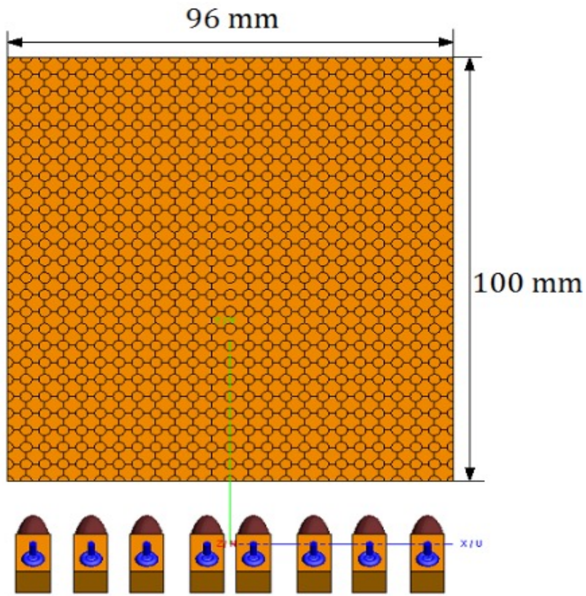
Case I: 8 feeding antennas with 24*25 elements

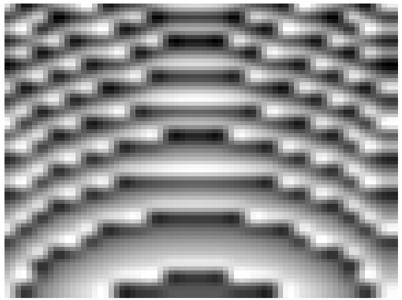


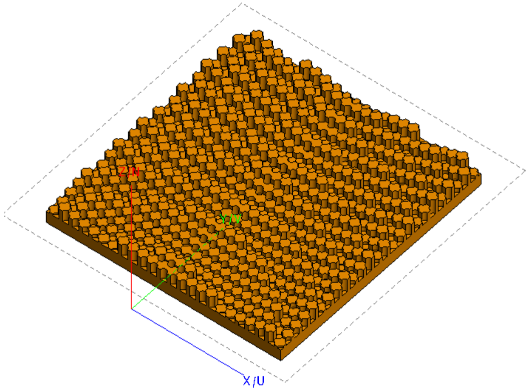
The peak value of the main beam from the first feed increased about 4.3709 dBi

Simulation in FEKO

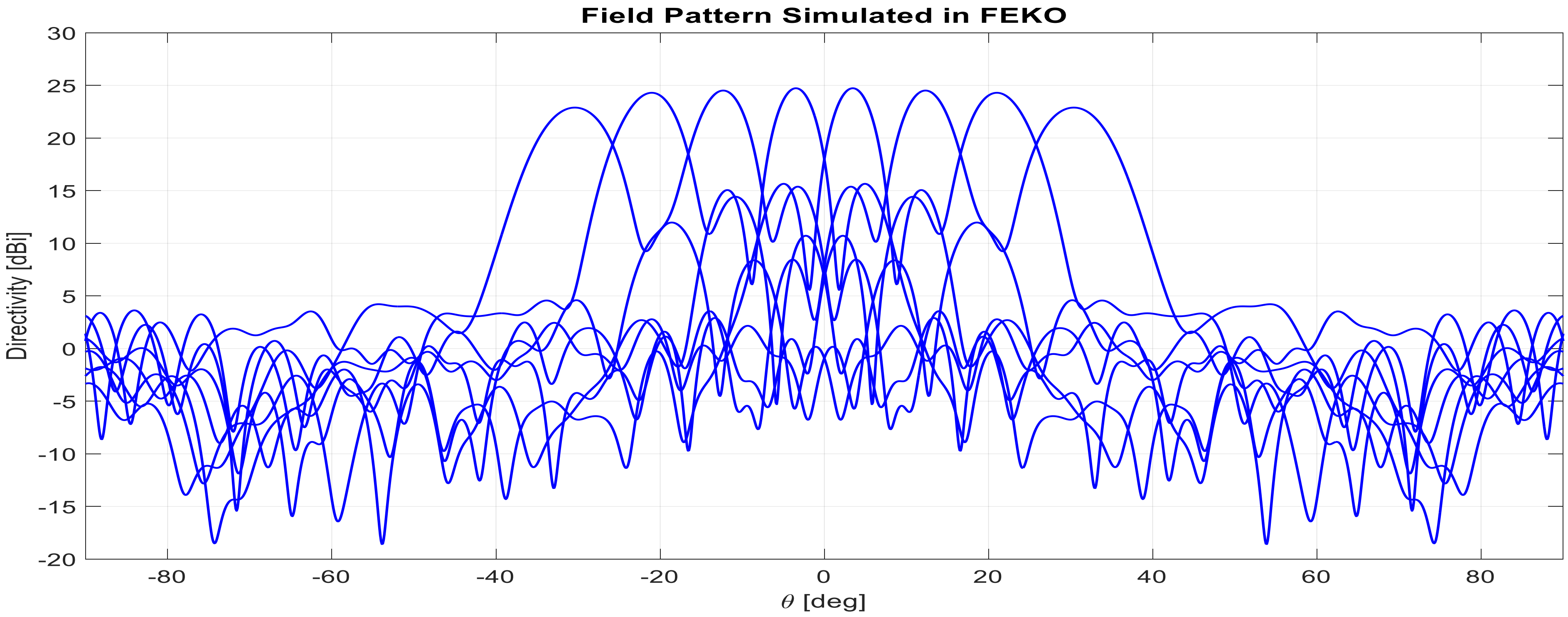


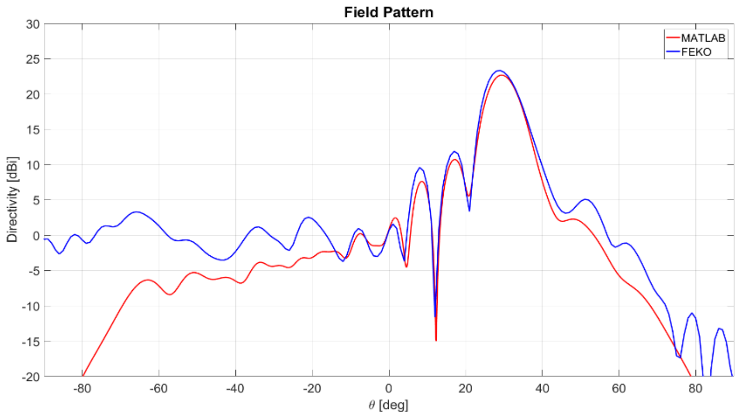


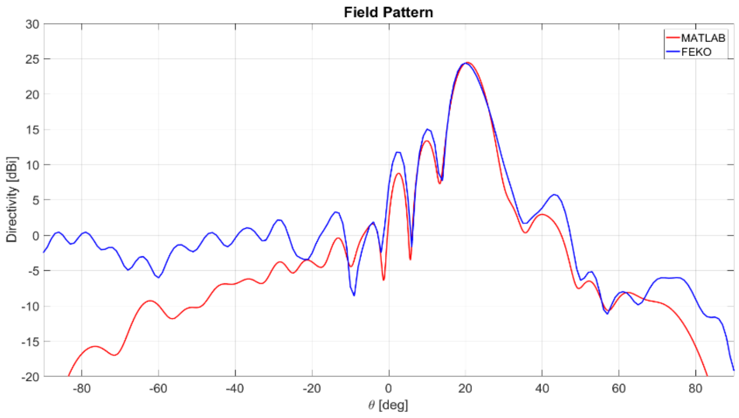


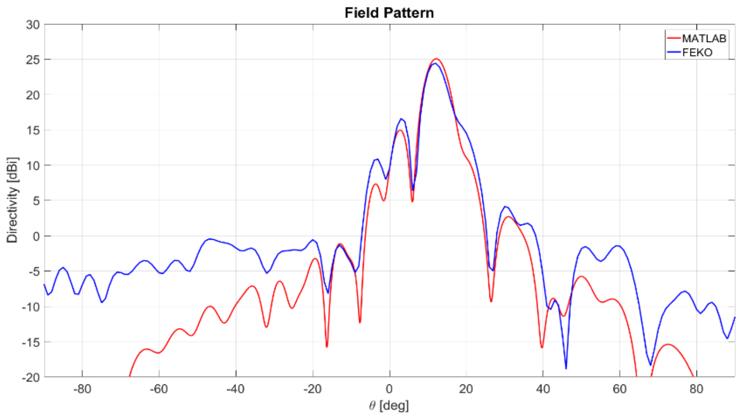


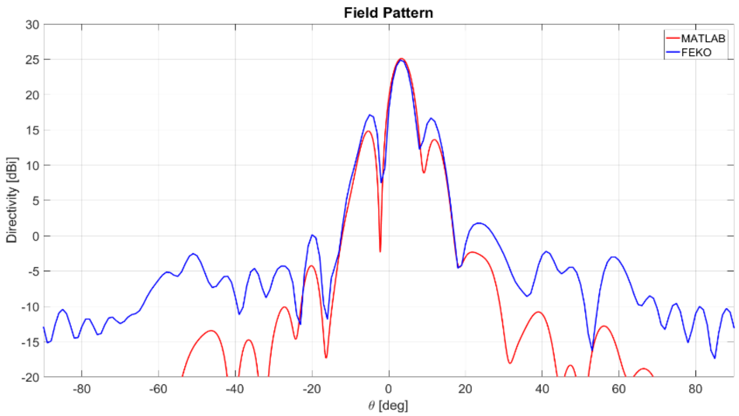
Simulation in FEKO



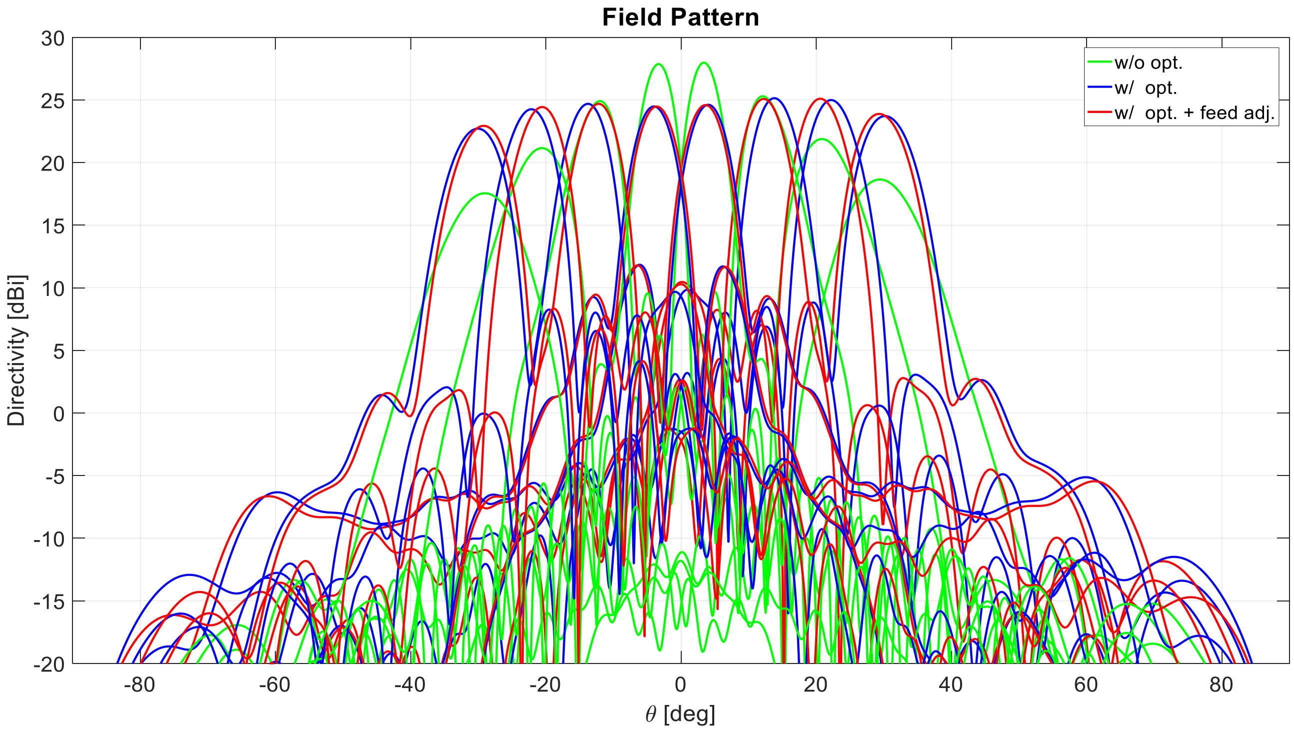

Field Pattern
MATLAB
FEKO
Directivity [dBi]
θ [deg]


Field Pattern
MATLAB
FEKO
Directivity [dBi]
θ [deg]

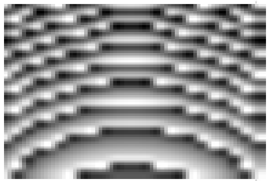

Field Pattern
MATLAB
FEKO
Directivity [dBi]
θ [deg]

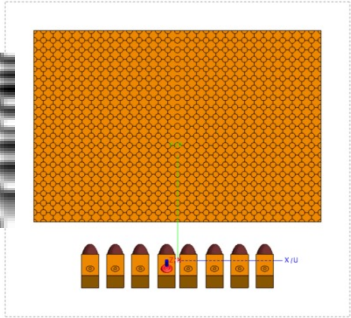

Field Pattern
MATLAB
FEKO
Directivity [dBi]
θ [deg]

Case II: 8 feeding antennas with 30*20 elements

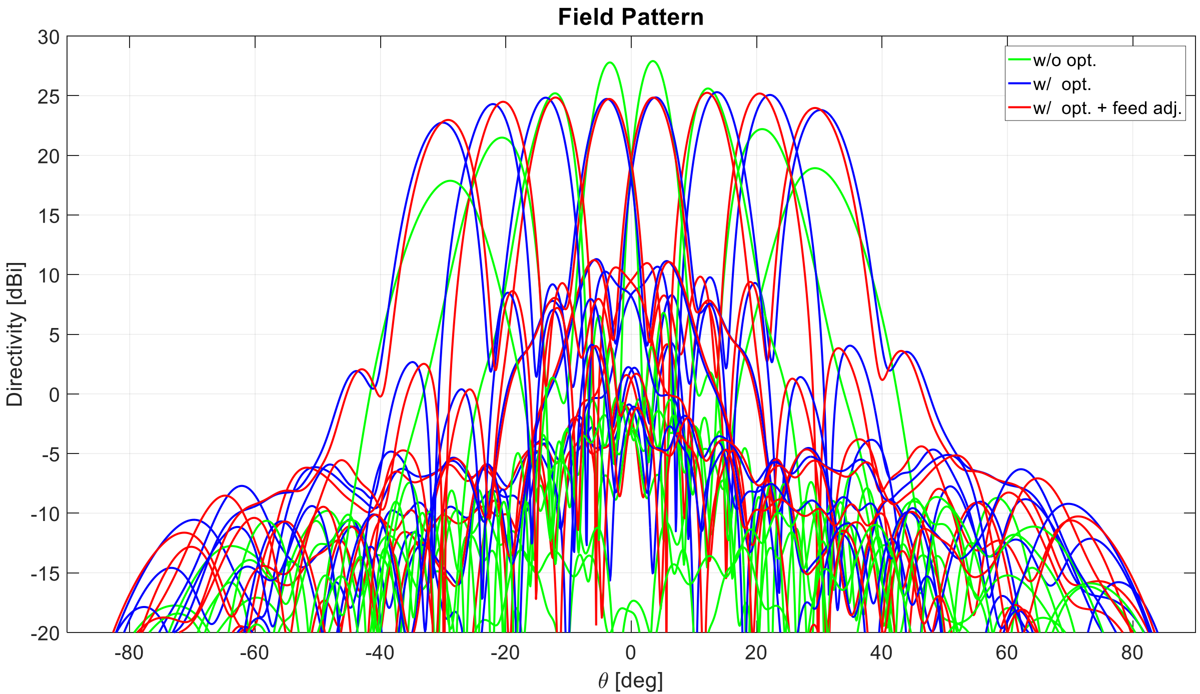


A more uniform coverage is achieved by rearranging the elements' arrangement.

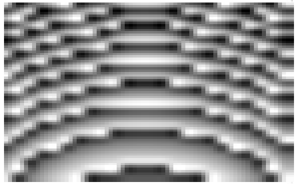


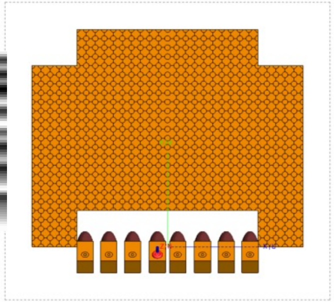


Case III: Case II with special design for sidelobe reduction

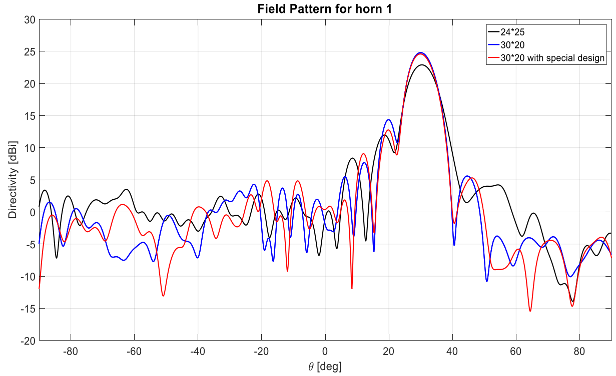


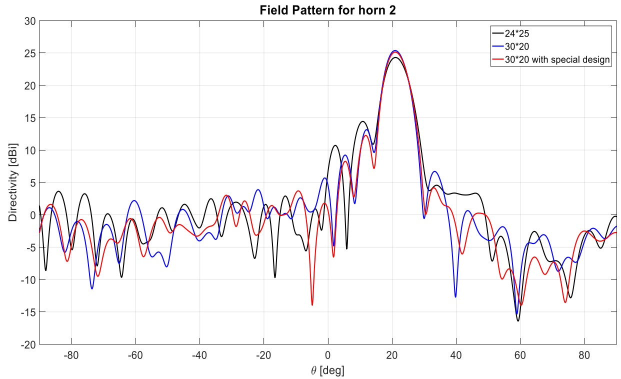
The sidelobe is reduced especially for the midst feed without loosing the main beam value of each feed.

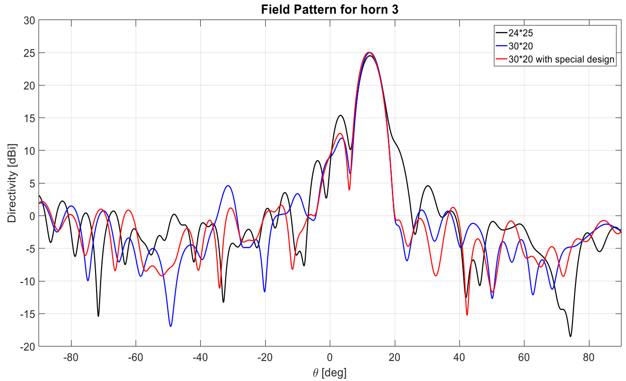


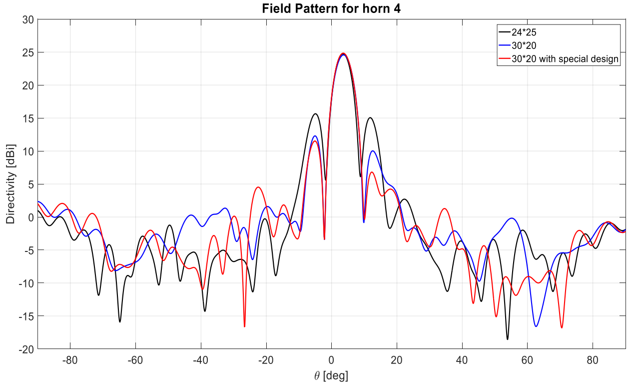


Comparison of the three cases in FEKO









Conclusion

- A simple approach to design a metallic reflectarray antenna is presented. Promising results have been obtained without the need of using sophisticated commercial codes.
- The comparison with full-wave simulation is also given, and precise results have been obtained.

Thank you for your time and attention