UCLA Engineering

Electrical Engineering

Synthesis and Analysis of Low Profile, Metal Only Stepped Parabolic Reflector Antenna using FEKO

Antenna Research, Analysis, and Measurement Laboratory

http://www.antlab.ee.ucla.edu/

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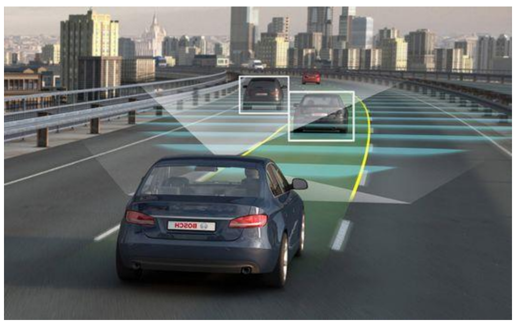
The Need for Low Profile High Gain Antennas

High gain reflector antennas are desirable for many applications that require high data rate and resolution

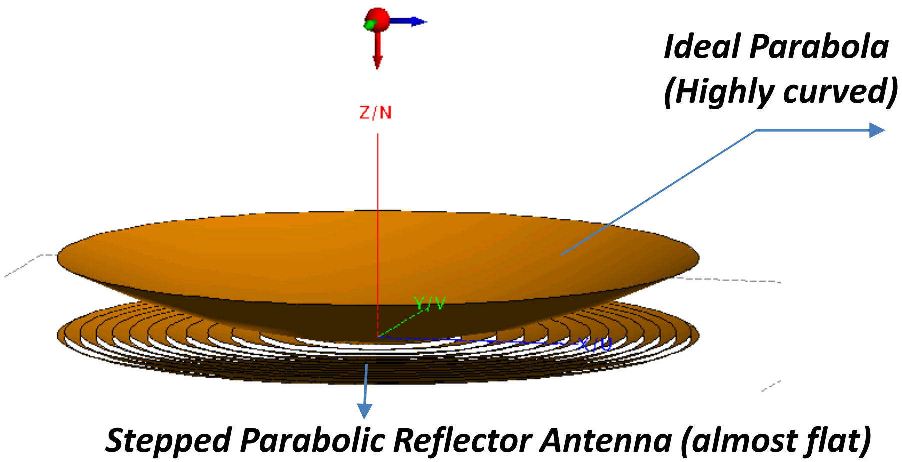


Tight volume constraints present engineers with a major integration challenge when meeting gain requirements of advanced systems.

This is especially true for emerging technologies like CubeSats , automotive radar sensors , or potentially even 5G mmWave networks

Y. Rahmat-Samii, V. Manohar and J.M. Kovitz*,* "For Satellites, Think Small, Dream Big: A review of recent antenna developments for CubeSats," *IEEE Antennas and Propagation Magazine,* vol. 59, no. 2, pp. 22-30, February 2017

Low Profile High Gain Antennas: Needs and Challenges



While conventional parabolic reflectors offer high efficiencies, the volume occupied by the reflector poses significant mechanical constraints for packaging and/or deployment

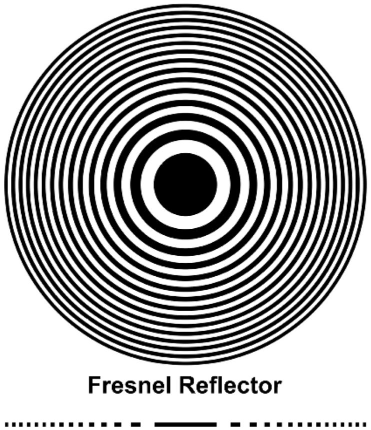
The development of high gain antennas that can conform to a flat surface is an area of continued research

This work looks to develop and characterize a high efficiency, metal only low profile antenna that can conform to a flat surface

Computational Challenges:

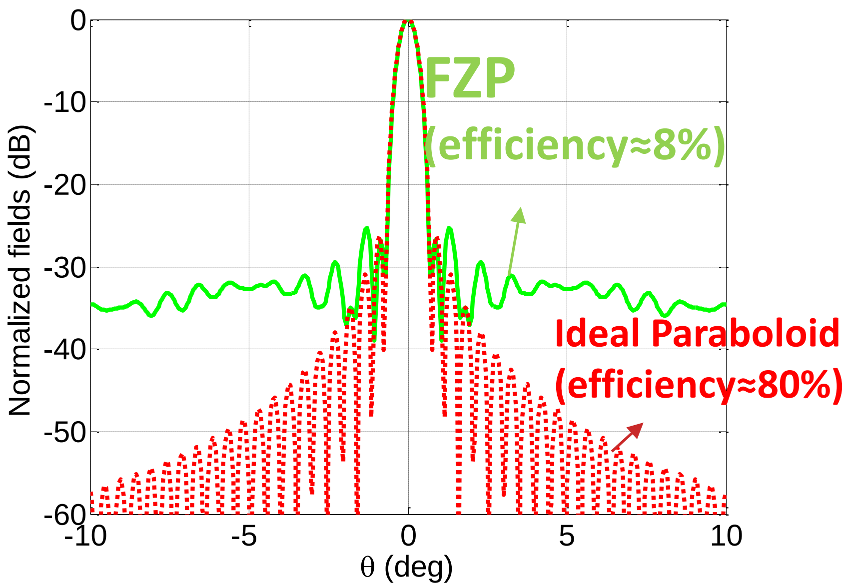
1. Setting up the structure can be time consuming, since each section is unique.
2. The structure consists of multiple rings whose dimensions can get electrically small, necessitating complex meshing strategies
3. Since frequency performance is an important consideration, multiple simulations are required. Run times must thus be reasonable

The Big Question:



Easy to fabricate and simulate

Bidirectional Radiation
High sidelobe envelope



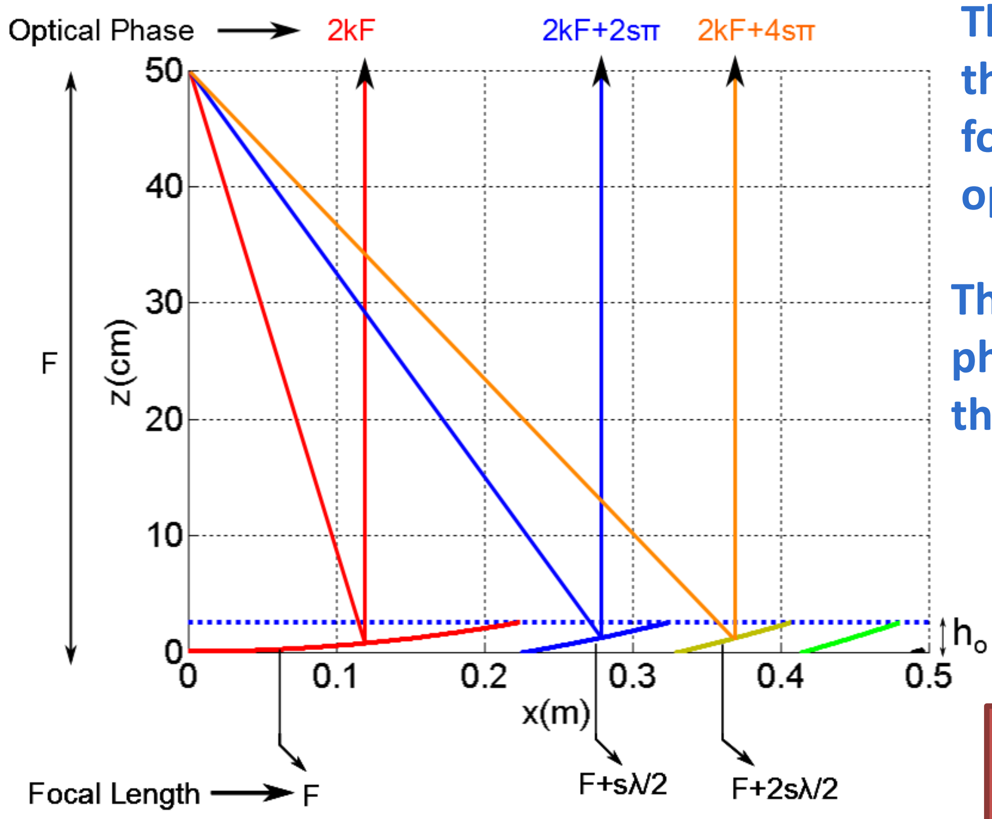
Fresnel Zone Plate Antennas (FZP) were amongst the first ‘flat’ reflectors to be investigated by the community

A typical Fresnel Zone Plate Antenna consists of a series of transmitting and reflecting rings, such that the fields interefere constructively at boresight

Big Question:
Is it possible to develop a low profile METAL ONLY, reflector that can maintain the simplicity of FZPs while providing high efficiencies?

B. Khayatian and Y. Rahmat-Samii, "A novel antenna concept for future solar sails: application of Fresnel antennas," in IEEE Antennas and Propagation Magazine, vol. 46, no. 2, pp. 50-63, April 2004

Stepped Parabolic Reflector: Basic Principles



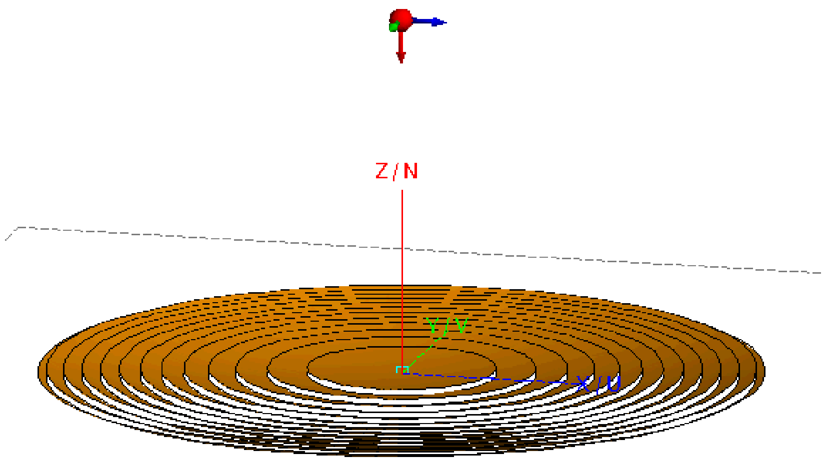
The total ray path for a ray emerging from the focus for a parabolic reflector to the focal plane is 2F with a corresponding optical phase of 2kF (k=2π/λ)

Thus, it is possible to achieve uniform phase from a family of parabolic sections if the following condition is satisfied:

$$2kF_n = 2kF + 2(n-1)s\pi, \text{ or}$$
$$F_n = F + (n-1)s\lambda/2$$

Thus, for a given profile height of h_0, multiple parabolic sections can be used to construct a high efficiency aperture

Generating a Symmetric Stepped Parabolic Reflector



The equation to generate the nth section of symmetric stepped reflector antenna can be given as:

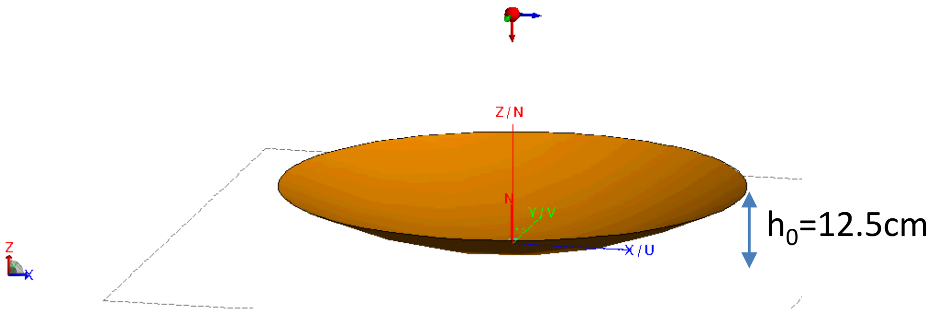
$$z_n = \frac{\rho_n^2}{4\left(F + \frac{(n-1)s\lambda}{2}\right)} - \frac{(n-1)s\lambda}{2}$$

Where $a_{n-1} \leq \rho_n \leq a_n$

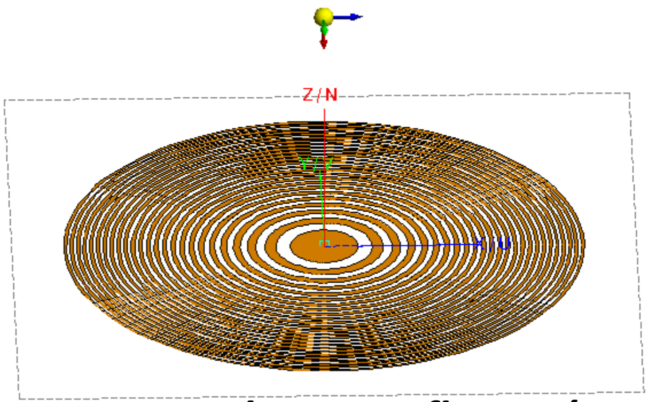
$$a_n = 2\sqrt{\left(h_0 + \frac{(n-1)s\lambda}{2}\right)\left(F + \frac{(n-1)s\lambda}{2}\right)}$$

(between the (n-1)th and nth section boundaries)

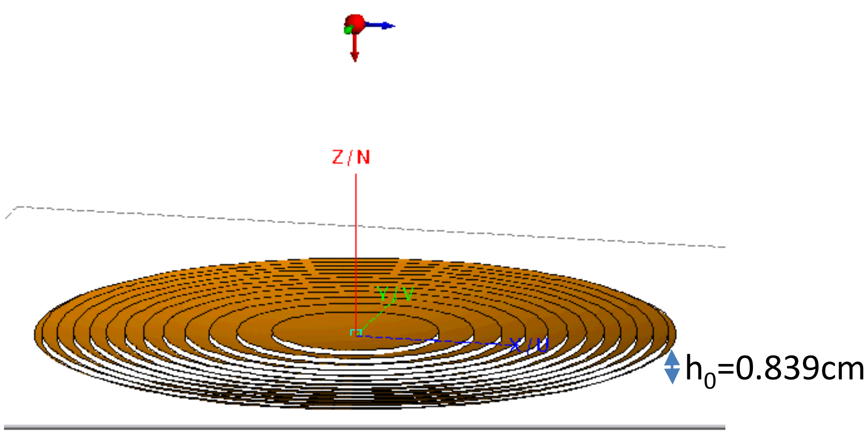
Cases Simulated



Ideal Parabolic Reflector
(Diameter=1m, F/D=0.5)



Fresnel Zone Reflector (FZP)
(Diameter=1m, F/D=0.5)
Number of rings: 26

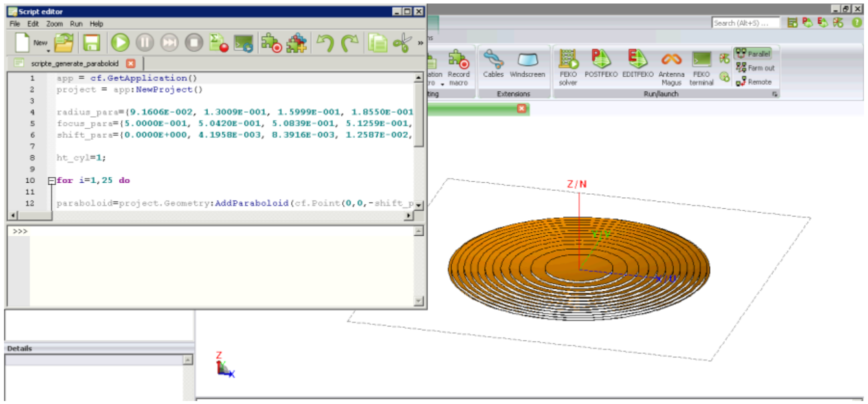


Stepped Parabolic Reflector

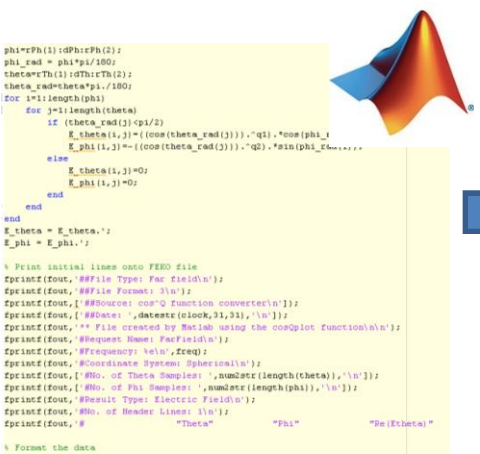
Profile Height: 1λ (0.839 cm)
Diameter=1m, F/D=0.5, s=2
Number of rings: 13

Frequency: 35.75 GHz, Solver: PO (FEKO)

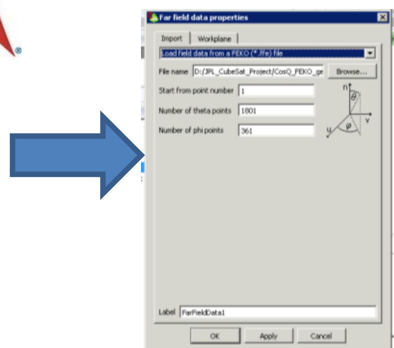
Simulation Setups in FEKO

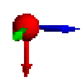


The power of analytical equations along with scripting in FEKO was used to create a symmetric stepped parabolic reflector



MATLAB script to generate FFE file

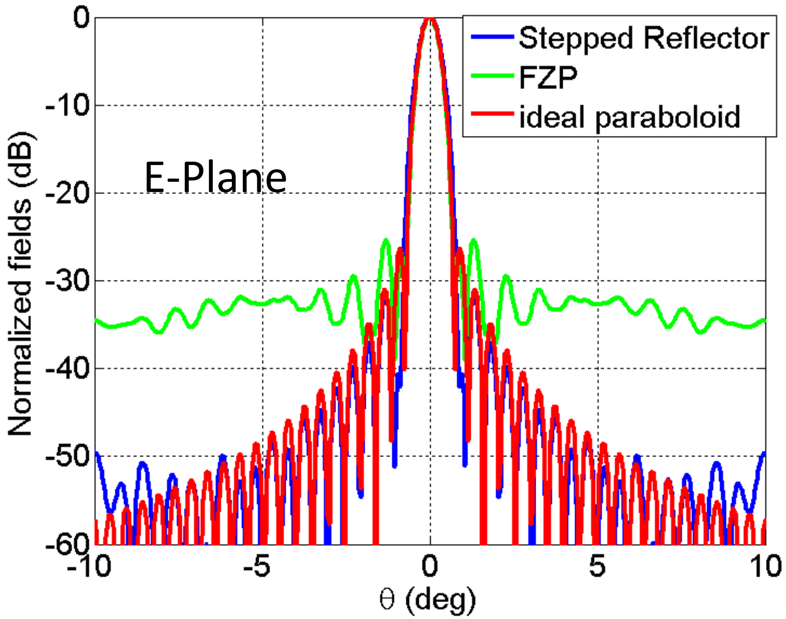


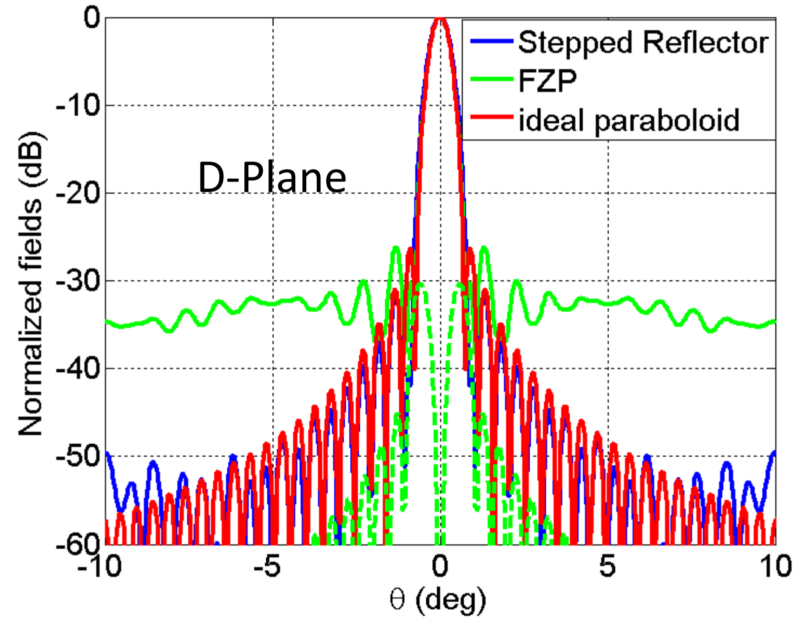


The feed for analysis was the cosine-Q feed, which was imported through a discrete far field source

The cosine-Q feed was setup to provide a 10 dB tapered aperture illumination to maximize aperture efficiency

Far Field Result Comparison





Freq: 35.75 GHz

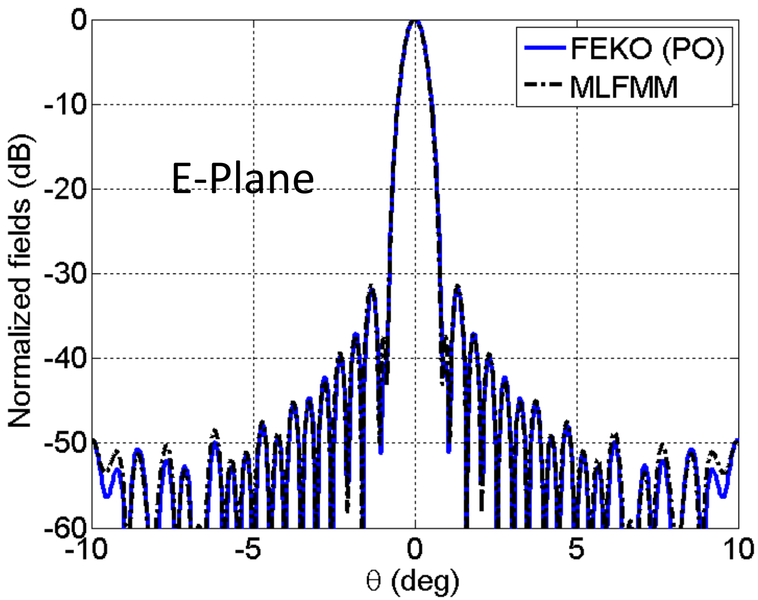
	Ideal Paraboloid	Stepped Reflector	FZP
Directivity	50.57 dB	49.54 dB	40.41 dB
Efficiency	81.35%	64.18%	7.84%

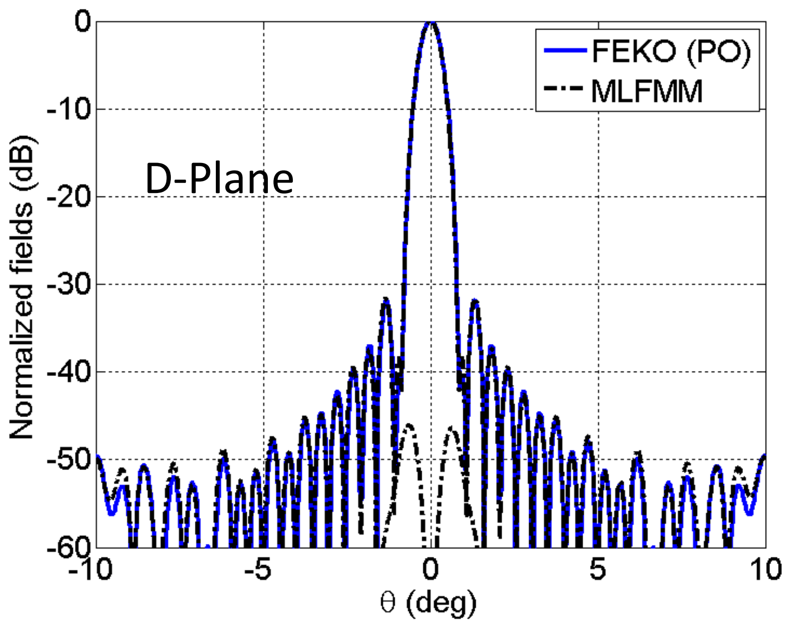
The stepped reflector configuration provides a much higher efficiency than conventional FZPs, but retains the simplicity of parabolic reflectors

Comparisons with CST (MLFMM solver)

As a check, the results of FEKO (PO results) were compared with CST (MLFMM solver)

To do this, the FEKO model was exported as a CAD step file, and then imported into the other solver



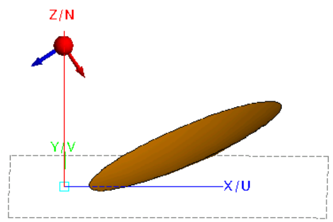


FEKO (PO) directivity: 49.54 dB
CST (MLFMM) directivity: 49.95 dB

The comparisons between FEKO (PO) and MLFMM solver were very encouraging

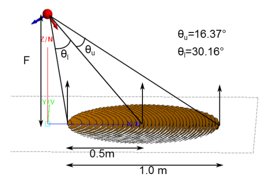
Offset Stepped Parabolic Reflectors

For many practical applications, an offset configuration is desired since it avoids feed blockage



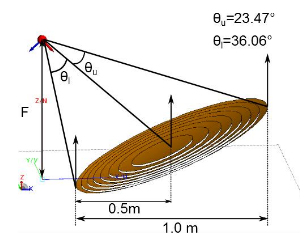
In this work, two novel methods to develop offset stepped reflector is introduced

Intersect the symmetric configuration with a cylinder at a desired offset height



(Horizontal Flat Offset Stepped Reflector ***(HFOSR)****)*

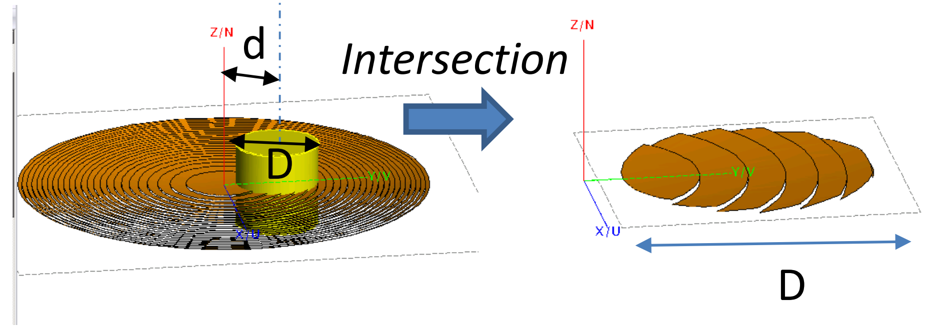
Generate the offset stepped reflector on a plane tangential to the first section



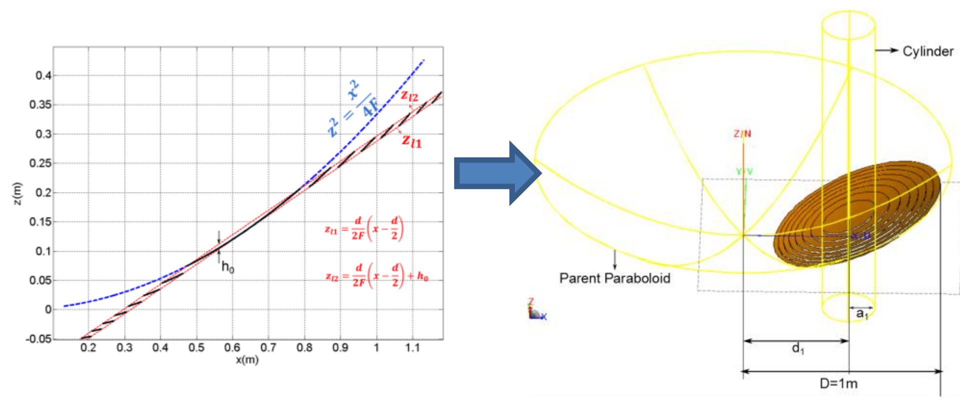
(Inclined Flat Offset Stepped Reflector ***(IFOSR)****)*

Generation of HFOSR and IFOSR Surfaces

The HFOSR is generated by creating a symmetric parabolic stepped reflector and intersecting it with a cylinder at the desired offset height (d)

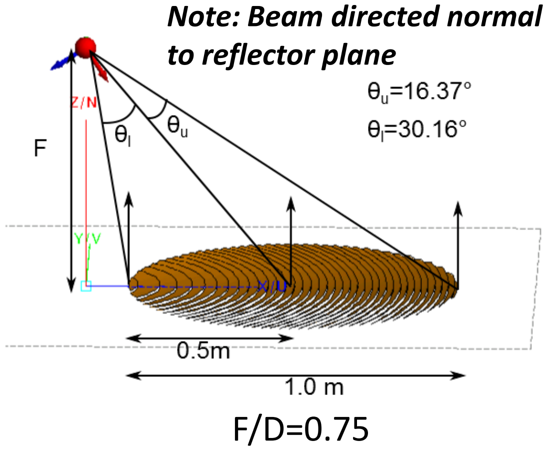


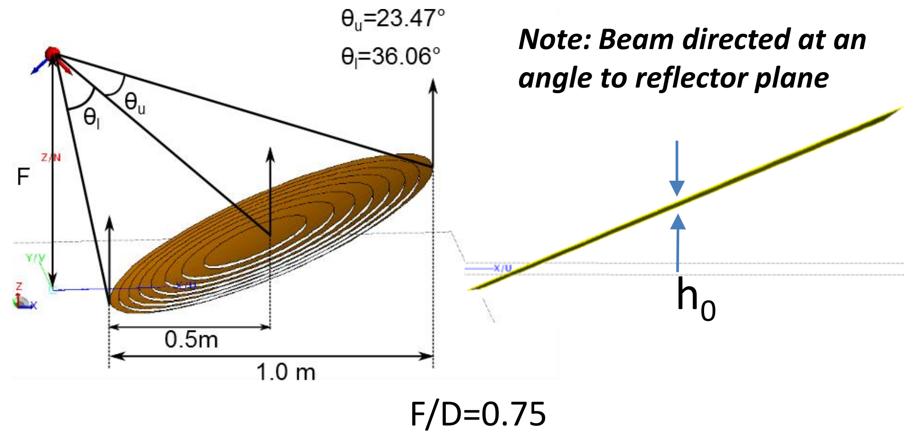
The HFOSR is generated by creating a symmetric parabolic stepped reflector and intersecting it with a cylinder at the desired offset



FEKO allows incorporating these complex structures into CADFEKO with great ease due to its advanced scripting capabilities

Detailed Geometry of the Simulated Configuration





Horizontal Flat Offset Stepped Reflector (HFOSR)

Number of rings: 37, s=2

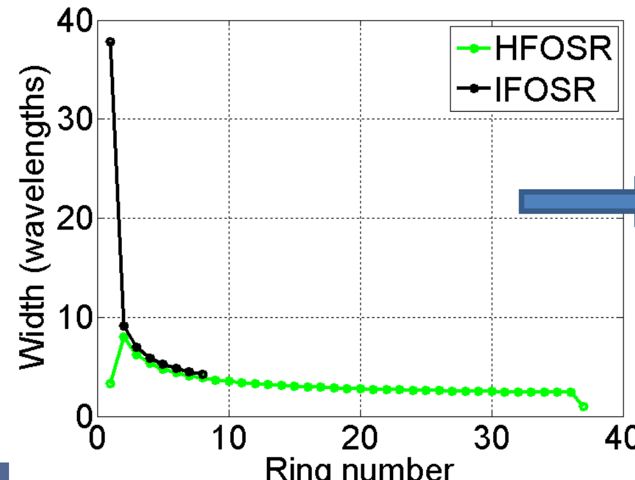
Profile height (h_0) = 0.839 cm (1λ at 35.75 GHz)

Inclined Flat Offset Stepped Reflector (IFOSR)

Number of rings: 8,), s=2

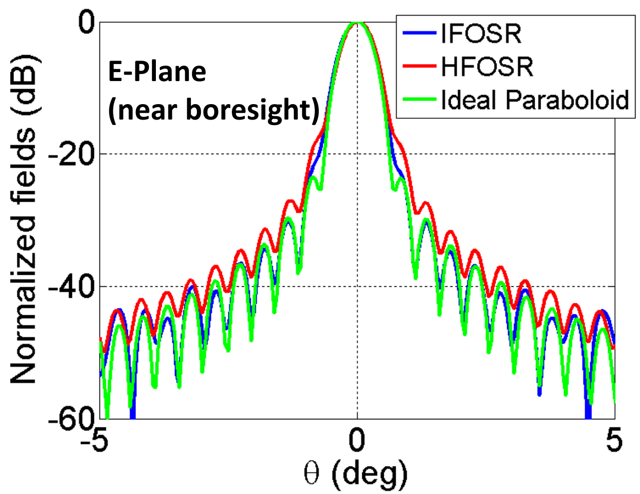
Profile height (h_0) = 0.839 cm (1λ at 35.75 GHz)

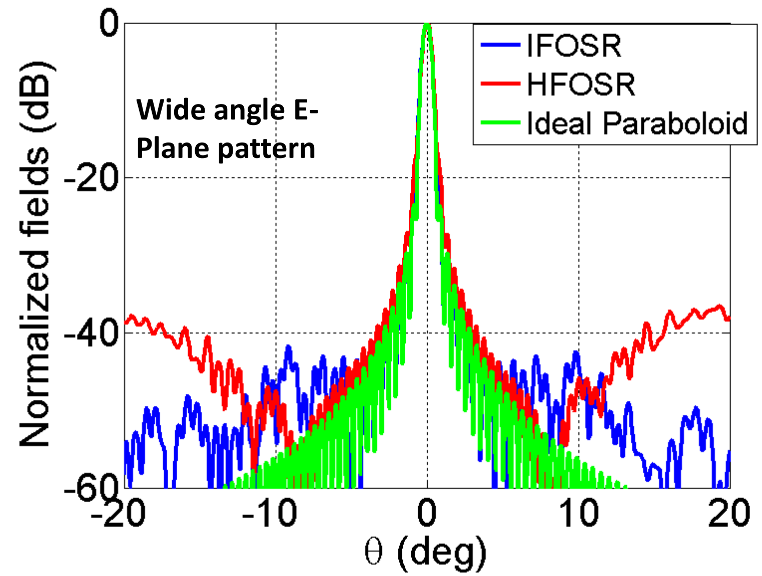
Frequency: 35.75 GHz,
Solver: PO (FEKO)

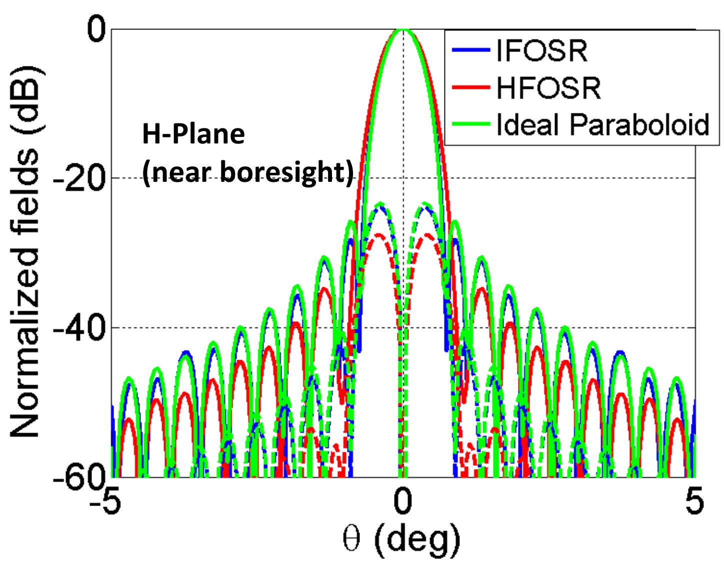


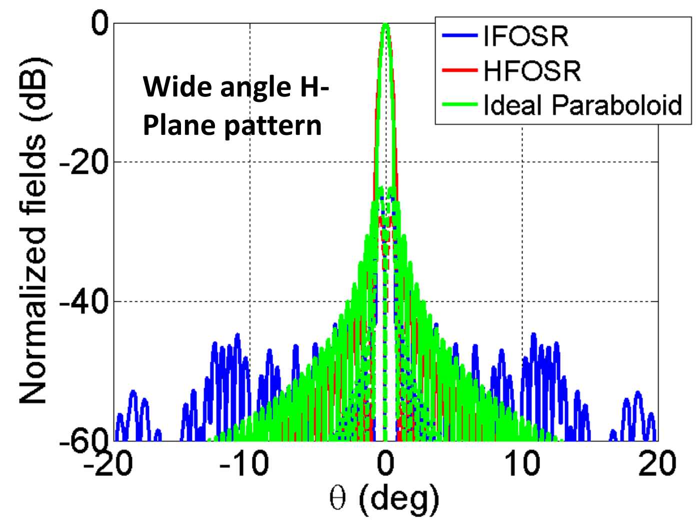
Individual ring widths in the projected aperture

Far Field Results





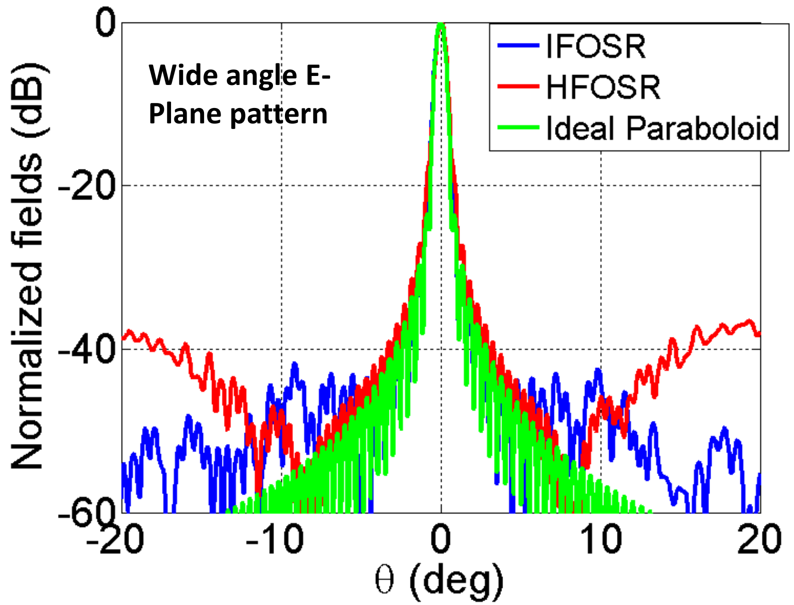




(E-plane is the plane of offset)

Freq: 35.75GHz

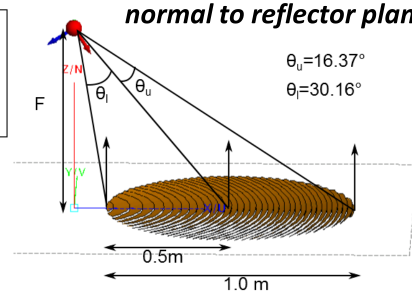
Interpretation of Results



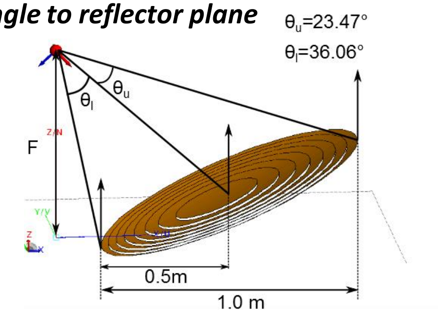
Freq: 35.75GHz

	Directivity	Efficiency
IFOSR	49.92 dB	70.04%
HFOSR	48.95 dB	56.02%
Ideal Paraboloid	50.45 dB	79.21%

Note: Beam directed normal to reflector plane



Note: Beam directed at an angle to reflector plane



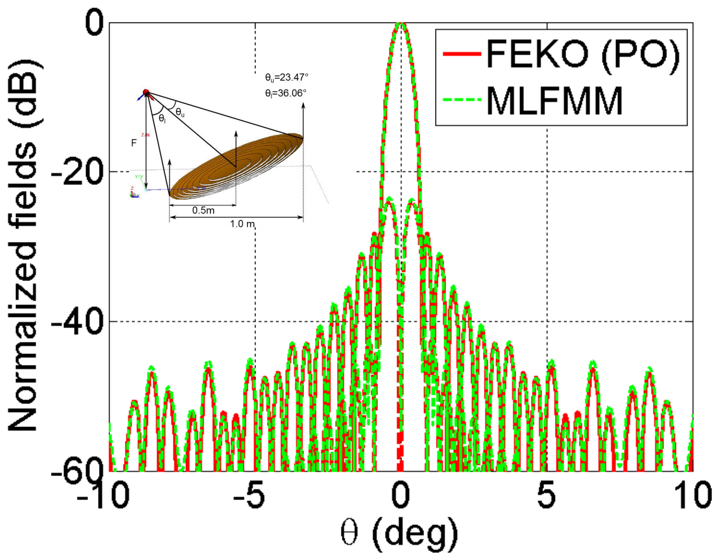
The HFOSR suffers from lower efficiency. This is expected since:

1. The asymmetry in the structure makes it difficult to balance the spillover and taper, reducing aperture efficiency
2. The HFOSR behaves similar to a uniformly excited broadside array. Since the average width is greater than a wavelength, one sees grating lobes.
3. The angular position of grating lobes can be estimated by simple array theory as $\sin^{-1}\frac{\lambda}{avg\ width} \approx 18^\circ$, which matches simulations

Comparisons with CST (MLFMM solver)

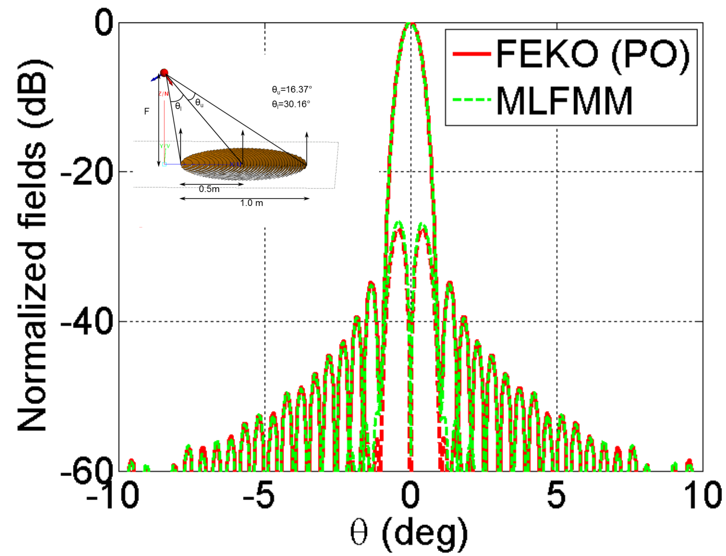
The results for the offset geometry was also validated using CST (MLFMM solver)

To do this, the FEKO model was exported as a CAD step file, and then imported into the other solver



Comparisons for IFOSR

FEKO (PO) directivity: 49.92 dB
MLFMM directivity: 50.10 dB

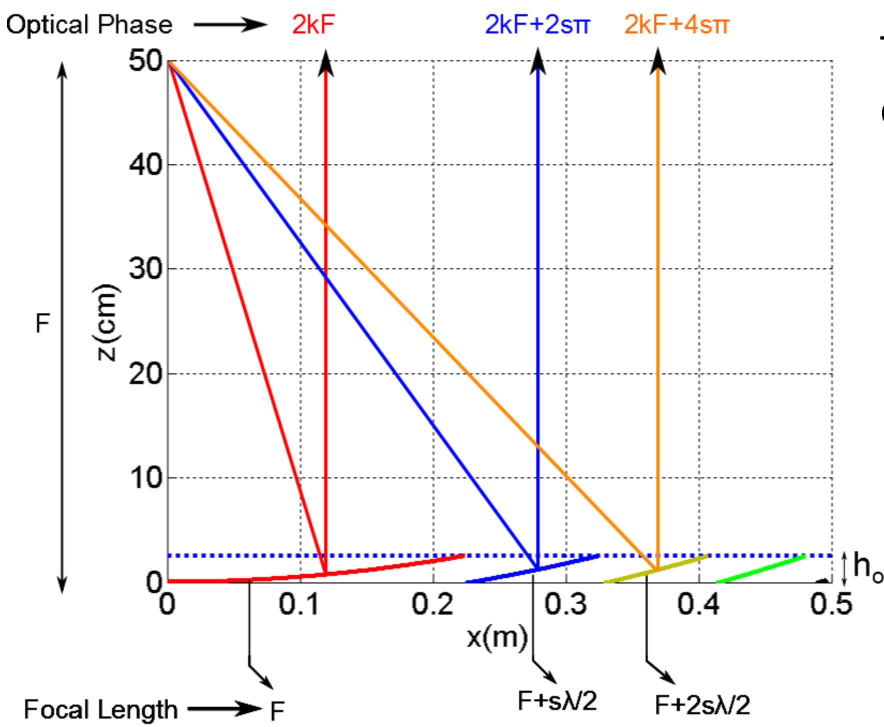


Comparisons for HFOSR

FEKO (PO) directivity: 48.95 dB
MLFMM directivity: 49.43 dB

Frequency Response

The frequency response for a structure whose dimensions are wavelength dependent is an important consideration



The phase difference between the edge and center can be expressed as:

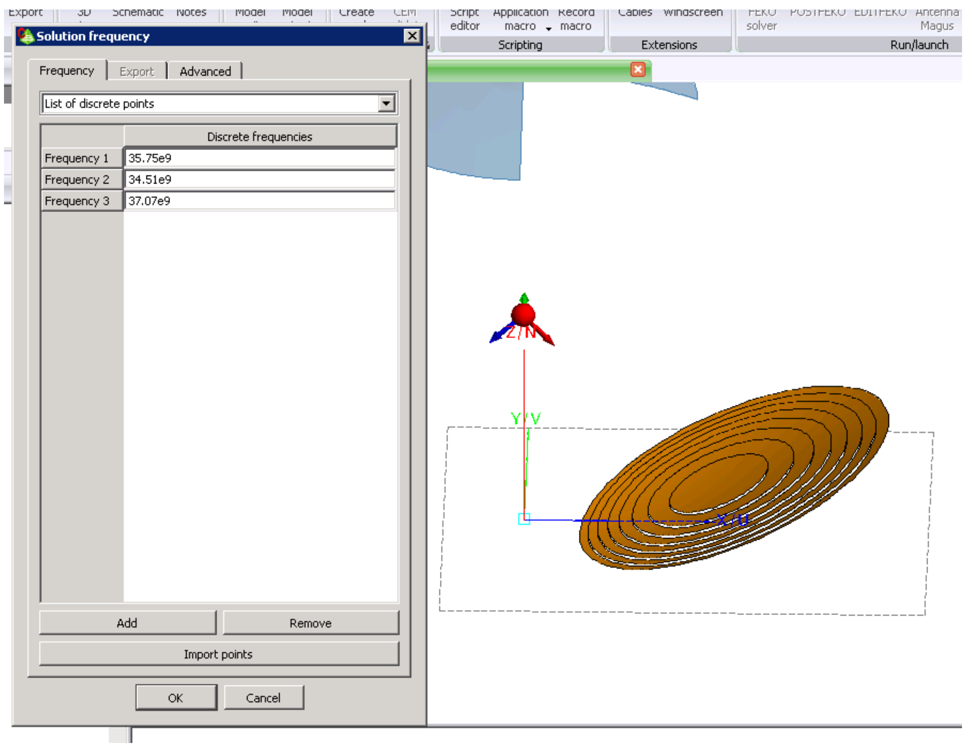
$$\delta = \frac{2\pi}{\lambda}(2F_{N-1} - 2F_0) - \frac{2\pi}{\lambda_0}(2F_{N-1} - 2F_0)$$

Where λ_0 is the central wavelength (giving $\delta = 0$) and N is the number of rings

In order to get the upper and lower bounds for the frequency, the value of δ can be set to $\pm\pi$, to give:

$$f_{l,h} = \frac{f_0}{1 \pm \frac{1}{4N'}}, N' = s(N-1)$$

Discrete Frequency Simulations in FEKO



In order to assess the frequency performance of the stepped reflector structure, the far field patterns were evaluated at multiple frequencies

After evaluation, the FFE file (containing far fields for all the frequencies) were exported.

The IFOSR and the HFOSR geometry have very different geometrical characteristics, and thus, different performance is expected

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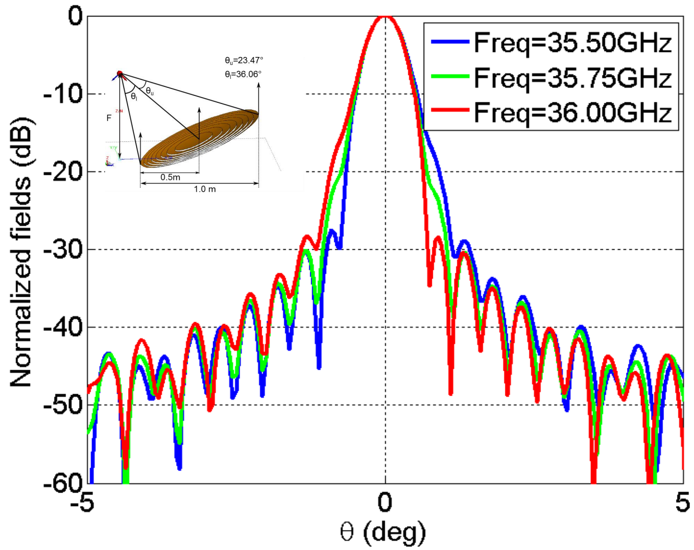
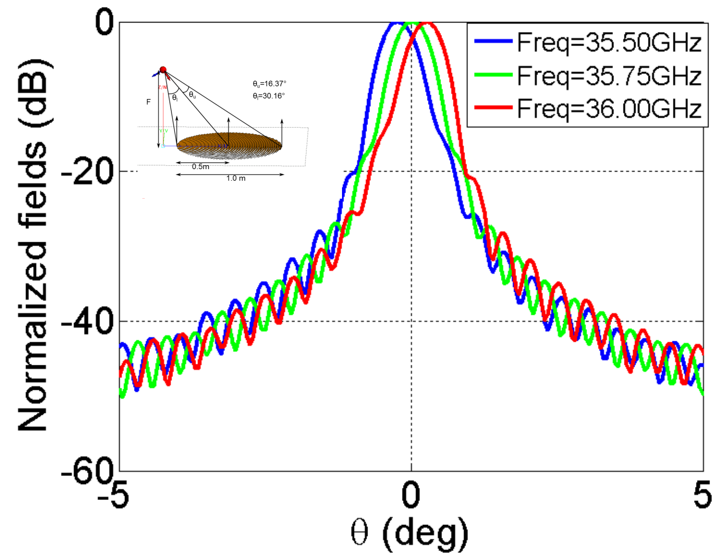
Frequency Performance of offset Reflectors





IFOSR

Frequency	Max. Gain	Scan Angle
35.50 GHz	49.73 dB	0
35.75 GHz	49.91 dB	0
36.00 GHz	49.78 dB	0

HFOSR

Frequency	Max. Gain	Scan Angle
35.50 GHz	48.83 dB	-0.20°
35.75 GHz	48.95 dB	0
36.00 GHz	48.92 dB	+0.25°

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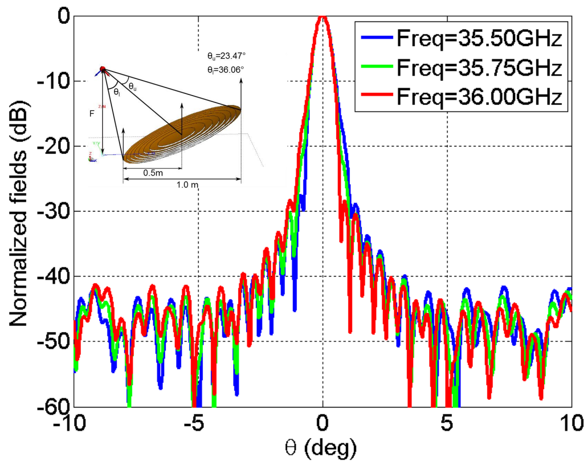
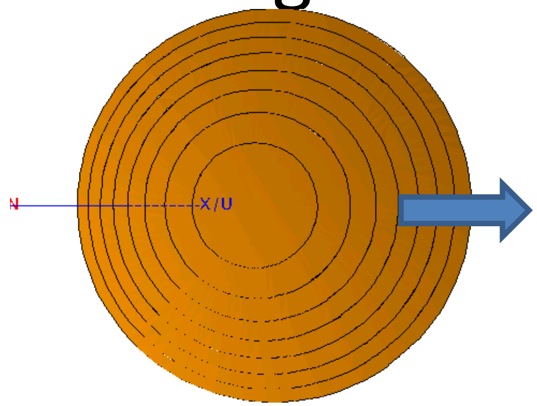
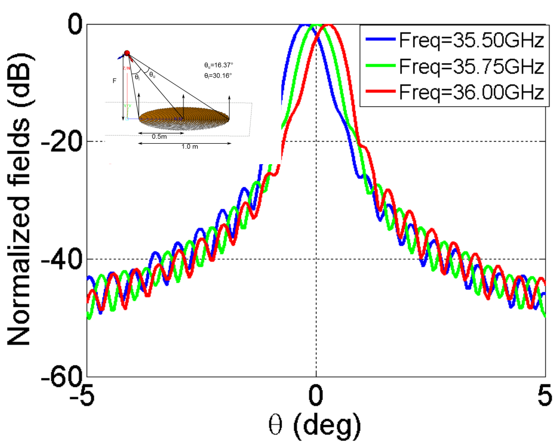
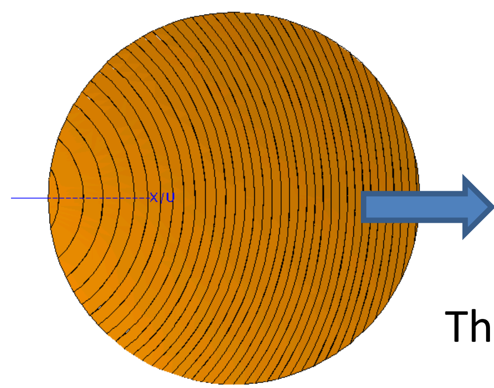
Frequency Performance of offset Reflectors: Insights





The IFOSR aperture consists of complete circular rings, causing the beam to be directed along boresight as frequency changes





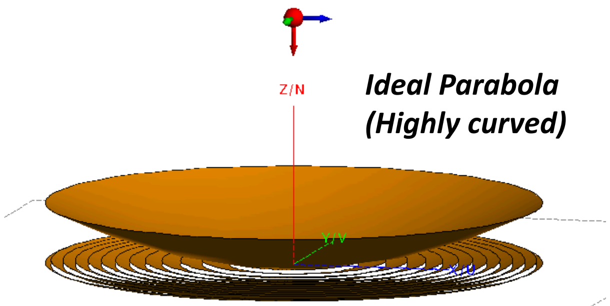
The HFOSR aperture consists of incomplete arcs, causing a phase gradient as the frequency changes, causing the beam to scan

The extent of scan can be analytically estimated using array theory as:

$$\sin\theta_{0,l} = \frac{1}{\beta_l W}\frac{\pi}{N-1},$$

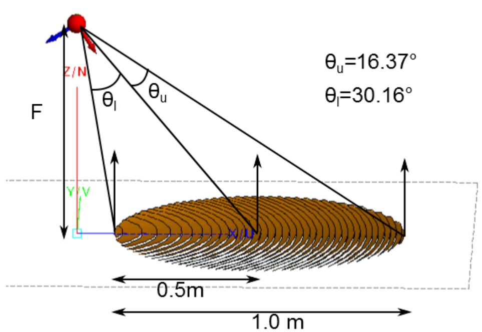
Where $\beta_l = \frac{2\pi f_l}{c}$

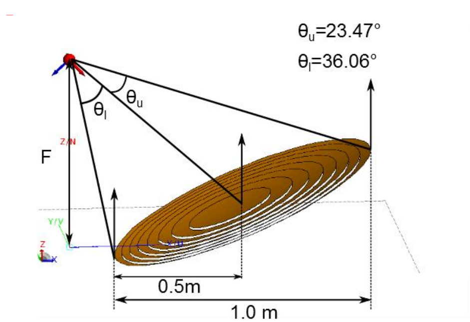
Conclusions



Ideal Parabola (Highly curved)

Stepped Parabolic Reflector Antenna (almost flat)





The stepped parabolic reflector configuration is a challenging structure to analyze and could be seamlessly solved with FEKO

The extensive scripting features of FEKO allowed efficient generation of structures with large number of rings

The structure could also be solved efficiently for various frequencies using FEKO's PO engine

All results were double checked using closed form expressions and other commercial solvers