Shared aperture reflector antenna

Final Presentation
7th November 2013
ESTEC

UNIVERSITÀ
DI SIENA
1240

TICRA

Shared Aperture Project Overview

Prime contractor: TICRA, Copenhagen

Sub-Contractor: The University of Siena

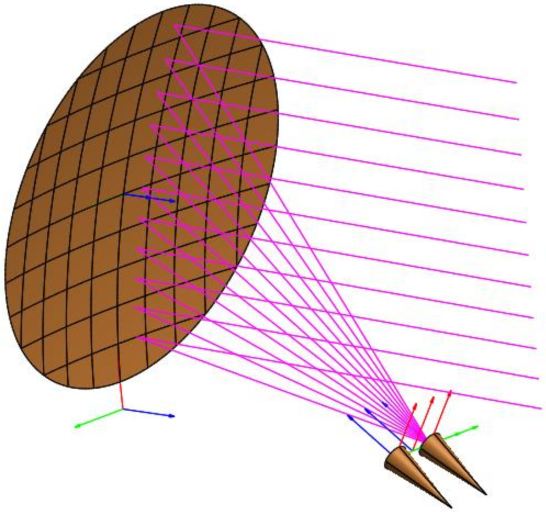
Project duration: 12 months

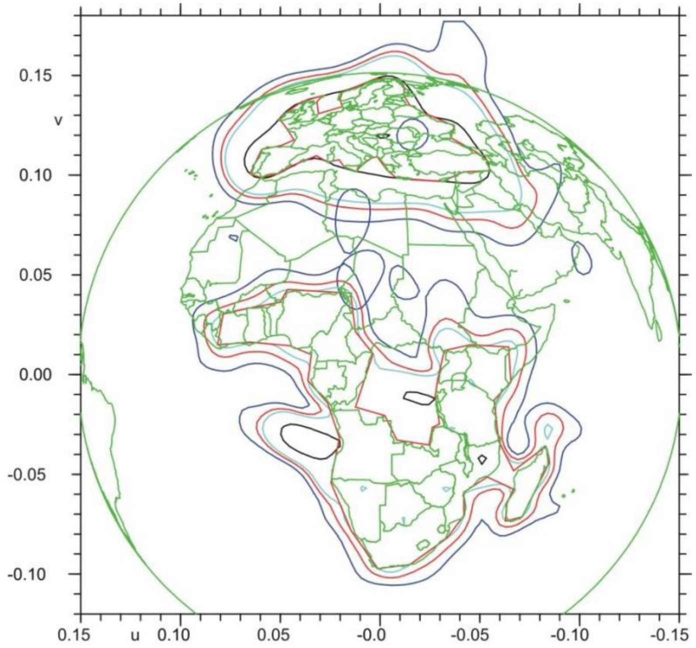
Project Goal

Generate more than one contoured beam from a single aperture.

Reduce loss compared to traditional shaped reflectors.

Combine surface shaping and metasurface materials.





General Approach

Traditional shaped reflectors:

Very efficient for one feed and one contoured beam.
Performance degradation if several beams are optimized.

Planar reflectarray:

Performance similar to the shaped reflector for one beam.
Severe degradation for multiple contoured beams.

Metasurface shaped reflector:

Metasurface: Very small metallic elements ($\lambda/10$) on substrate with high dielectric constant ($\varepsilon=9$).
Continuous equivalent current (J,M) distribution assumed.

Requirements

More than one contoured beam from one aperture.

One or two frequency bands.

Cx-polar level comparable to shaped metallic reflector.

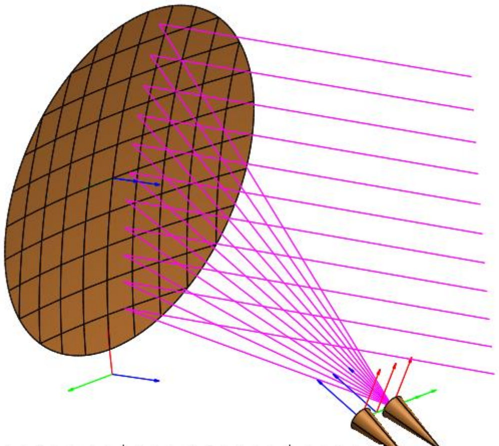
Loss due to multiple beams < 0.5 dB, compared to separate metallic shaped reflectors.

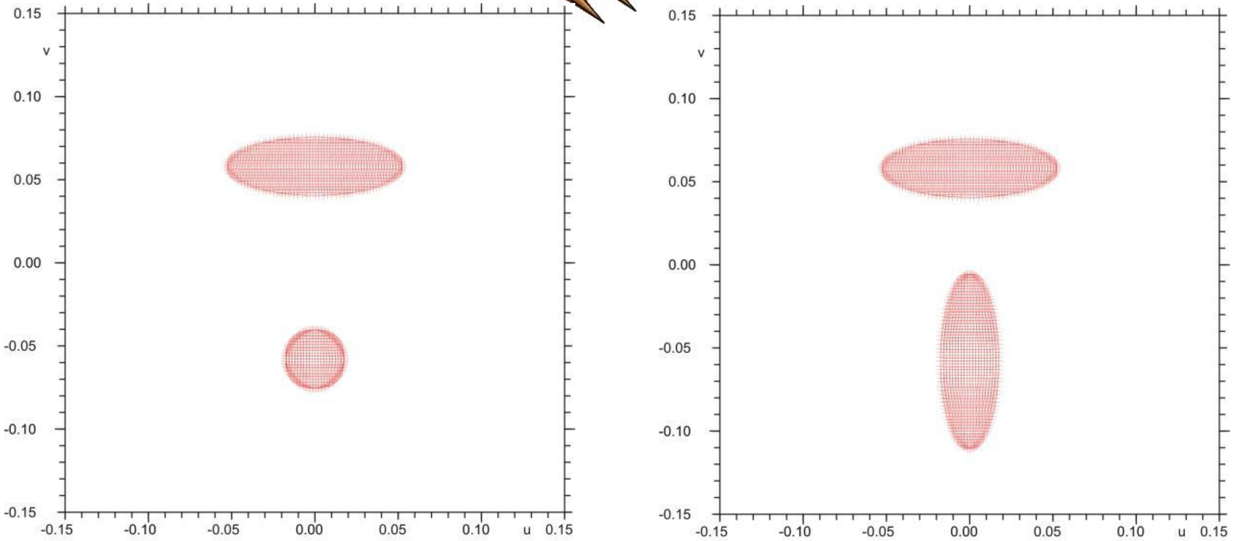
Metasurface material compatible with space environment.

Benchmark Solution

Metallic shaped reflector

2 feeds, 2 elliptical coverages.
Ellipse sizes from 1°x 1° to 1°x 5°.
Scan: ±3.3° and ±6.6°
Frequencies: 10.7 and 14.5 GHz.
Comparison to two separate reflectors.





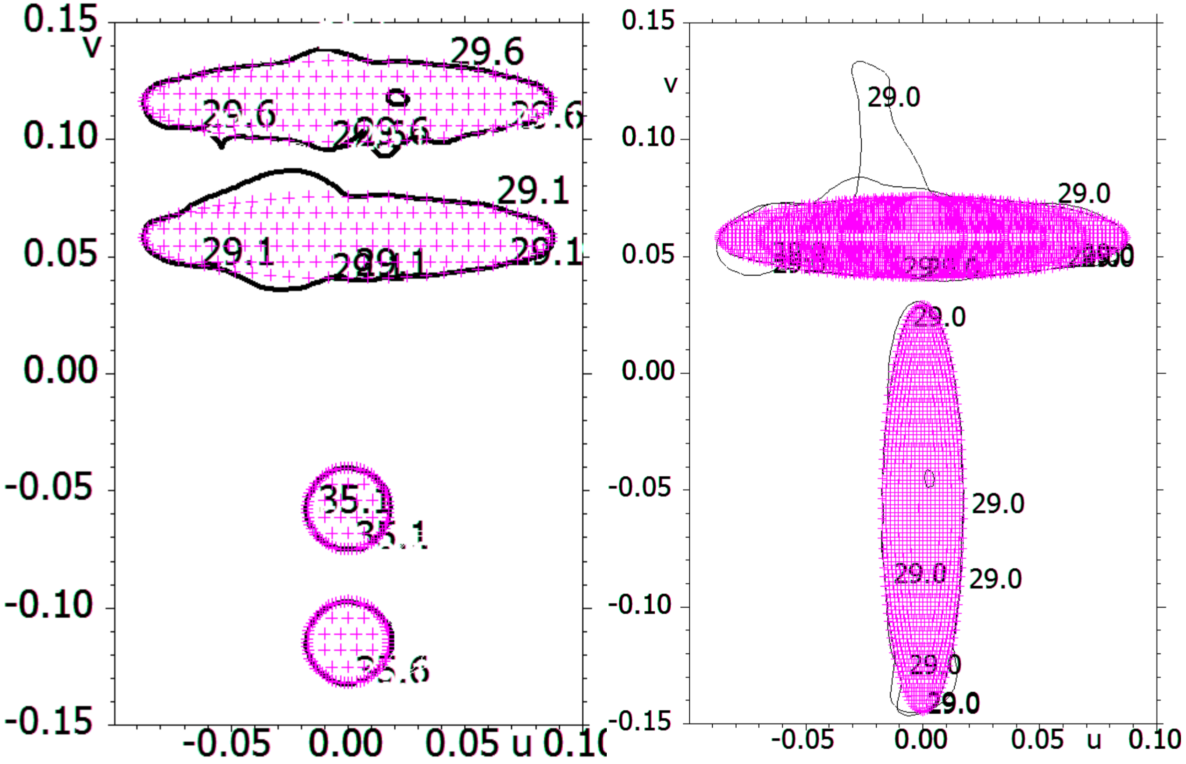
Benchmark Solution

Metallic shaped reflector

Two beams from one reflector.

Comparison to two separate metallic reflector.

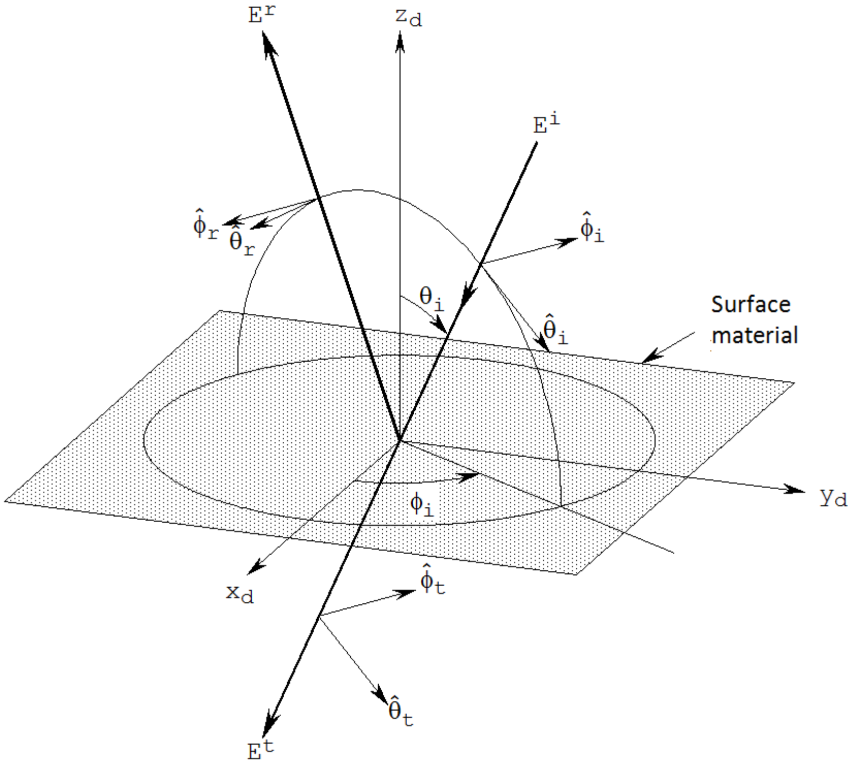
Penalty varies from 0.4 dB to 1.7 dB in minimum coverage gain.



S-Matrix Database

The S-matrix relates the reflected to the incident field.

$$\begin{pmatrix} E^r_\theta \\ E^r_\phi \end{pmatrix} = \begin{pmatrix} S_{\theta\theta} & S_{\theta\phi} \\ S_{\phi\theta} & S_{\phi\phi} \end{pmatrix} \begin{pmatrix} E^i_\theta \\ E^i_\phi \end{pmatrix}$$



S-Matrix Database

The S-matrix has been tabulated by UNISI as a function of:

Frequency :	10.7 and 14.5 GHz
Patch diameter:	50 values
Slot-length/width:	15 values
θ-angle:	5 values
ϕ-angle:	72 values

Intermediate values obtained by:

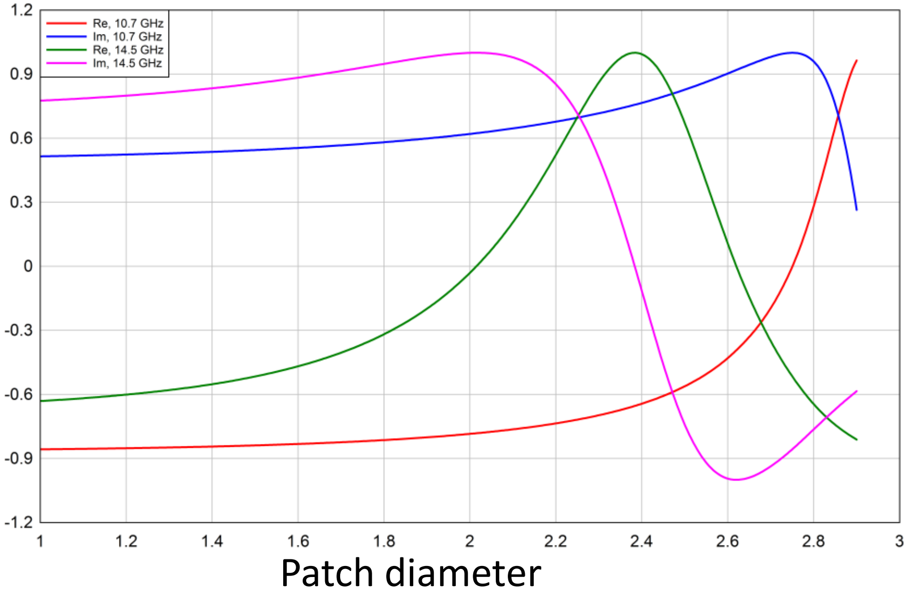
- Cubic Lagrange interpolation in geometrical variables and in θ.
- Trigonometric interpolation in ϕ.

S-Matrix Database

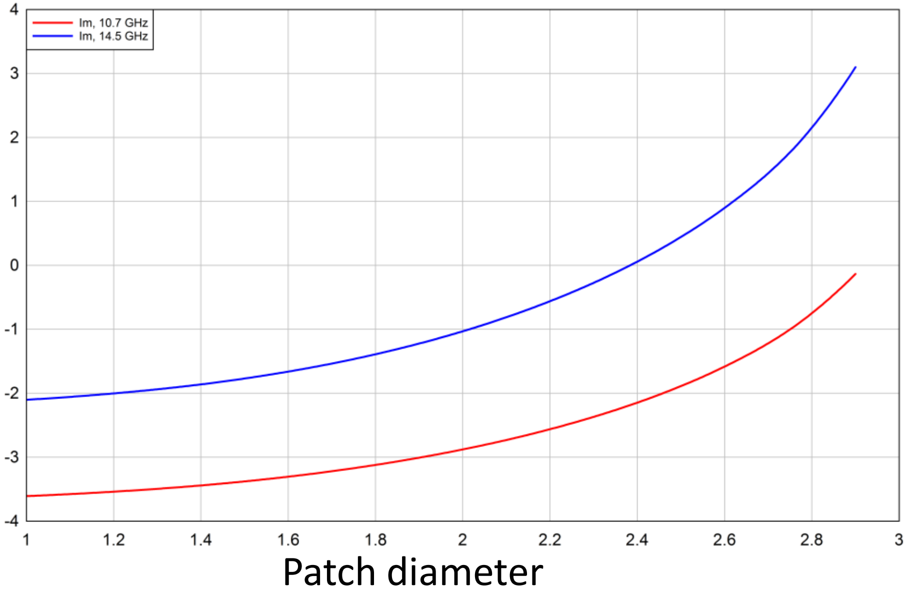
Interpolation in Y-matrix (Admittance matrix) much easier than in S-matrix.

Conversion: $\boldsymbol{Y} = (\boldsymbol{U} - \boldsymbol{S})(\boldsymbol{U} + \boldsymbol{S})^{-1}$, $\boldsymbol{S} = (\boldsymbol{U} - \boldsymbol{Y})(\boldsymbol{U} + \boldsymbol{Y})^{-1}$

S_{11}



Y_{11}



S-Matrix Database

The S-matrix is a function of 4 variables: $\mathbf{S}(a,b,\theta,\phi)$

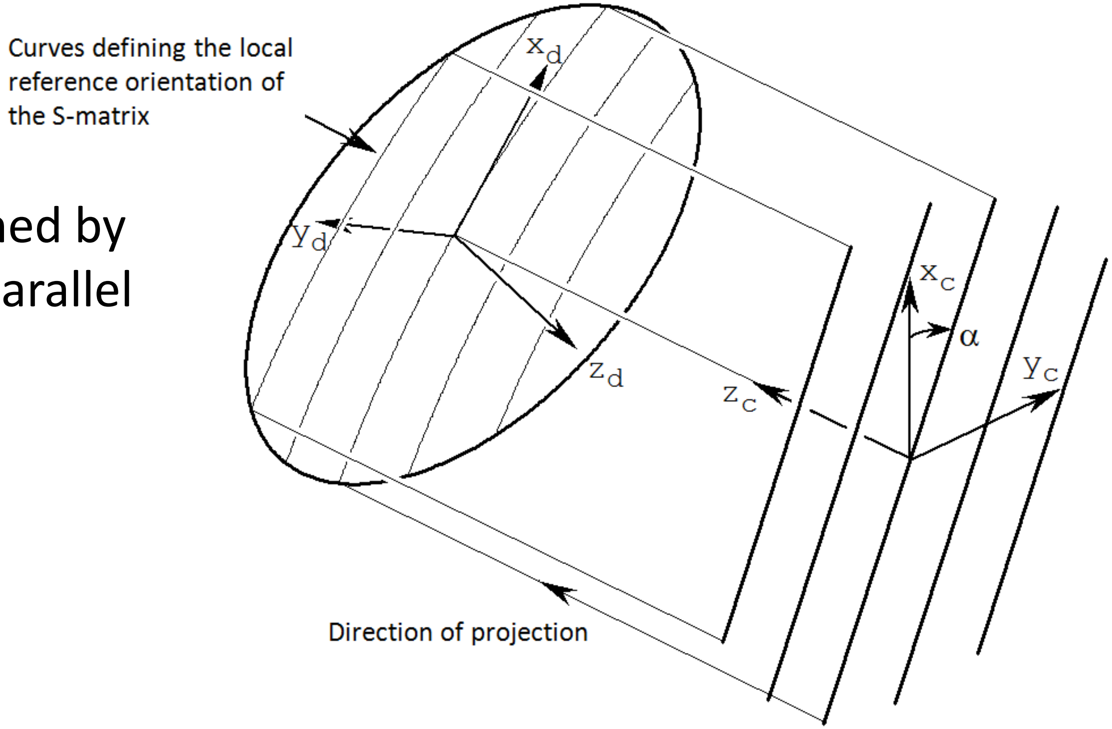
a: patch diameter
b: slot-length/diameter

From the Lagrange and trigonometric interpolation derivatives are computed analytically: $d\mathbf{S}/da$, $d\mathbf{S}/db$, $d\mathbf{S}/d\theta$, $d\mathbf{S}/d\phi$.

Derivatives needed in optimization.

Reference direction on curved surface

Patch orientation defined by projection of a set of parallel lines onto the surface



Curves defining the local reference orientation of the S-matrix

Direction of projection

Reflector Currents PO approximation

A continuous metasurface distribution is assumed.

Equivalent currents (**J**, **M**) are computed from the S-matrix database.

Standard integration of the currents are performed to obtain the far field.

Fast optimization due to analytic calculation of derivatives of the far field with respect to the metasurface geometrical parameters.

$d\mathbf{E}_{\text{far-field}}/da$, $d\mathbf{E}_{\text{far-field}}/db$, $d\mathbf{E}_{\text{far-field}}/d\theta$, $d\mathbf{E}_{\text{far-field}}/d\phi$

Analytic derivatives with respect to surface shape variables is standard in the POS software.

Optimization Variables

Surface shape spline expansion: $z(x,y)=\sum_s c_s B_s(x,y)$

Patch size variable: $a(x,y)=\sum_r d_r B_r(x,y)$

Problems with discontinuities, use instead complex representation.

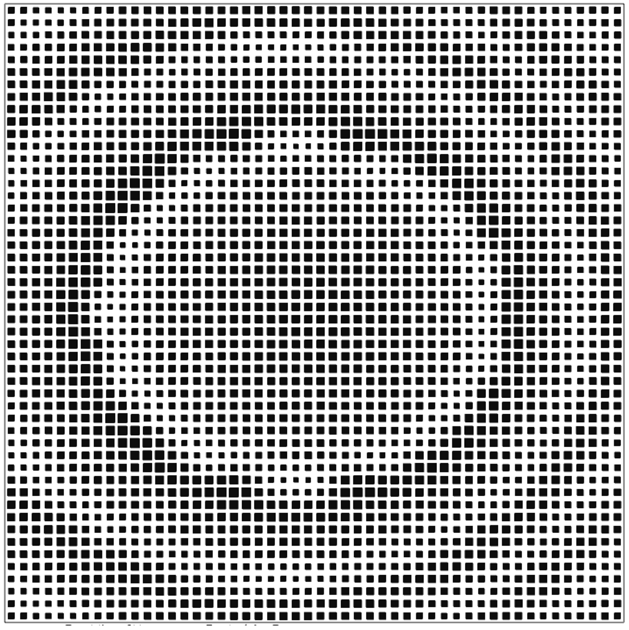
Complex expansion coefficients γ_r : $F(x,y)=\sum_r \gamma_r B_r(x,y)$

$a(x,y)=\arg(F(x,y)), \qquad a(x,y)\in\left]-\pi;\pi\right]$

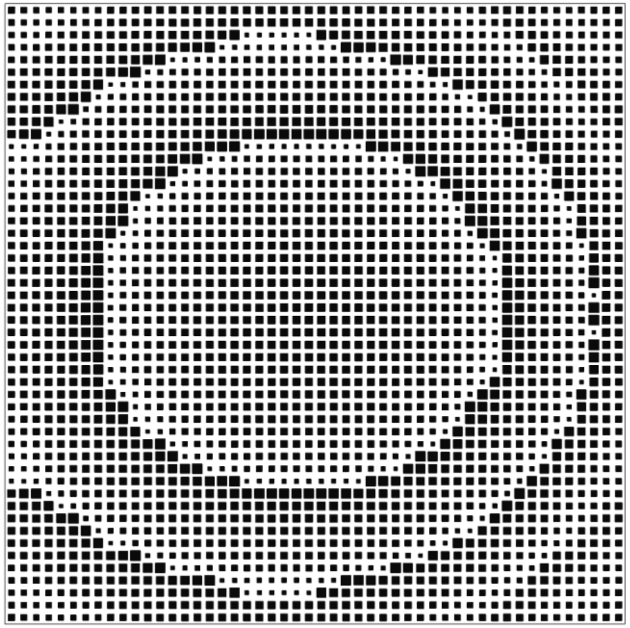
Linear transformation used to bring $a(x,y)$ into an appropriate interval.

Optimization Variables

Direct spline expansion optimization

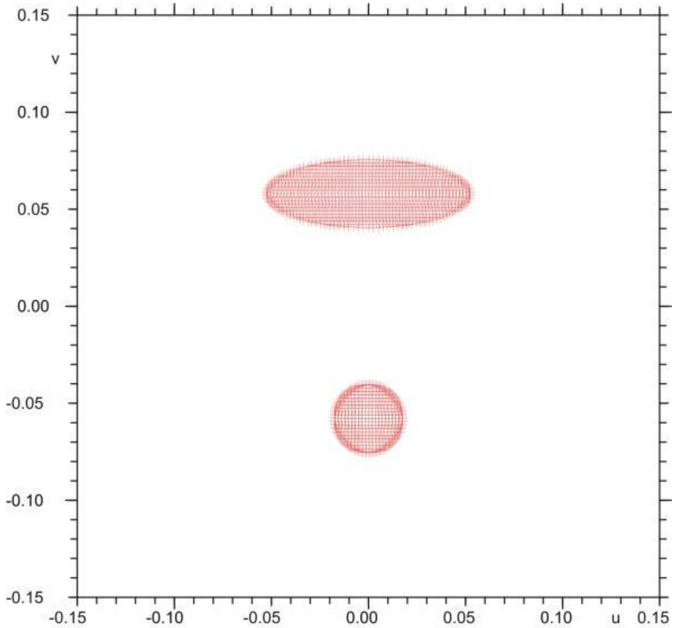


Complex spline expansion optimization

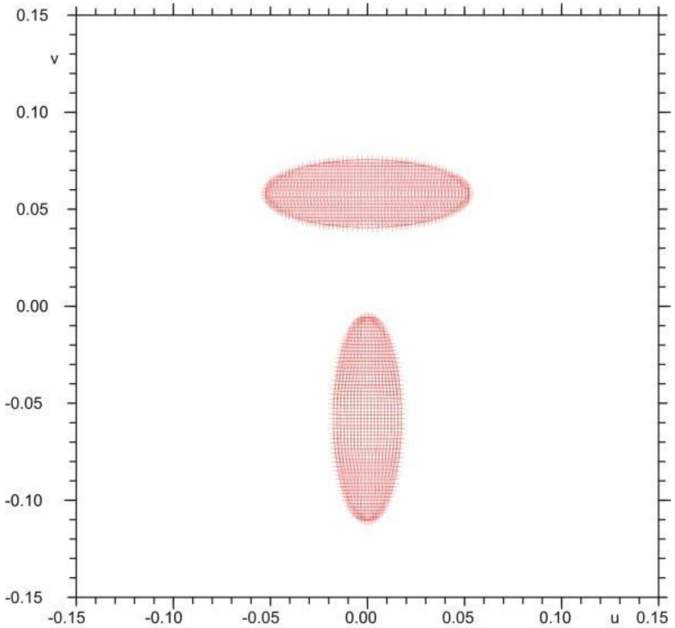


Combined Metasurface and surface shaping

Comparison with benchmark cases



1°x 1° + 1°x 3°



1°x 3° + 3°x 1°

Combined Metasurface and surface shaping

Penalty of using one shaped reflector instead of two.
The penalty can be reduced by combining metasurface and surface shaping.

One frequency, two beams:

No improvement. Metasurface and surface shaping provides identical degrees of freedom.

Two frequencies, two beams, different frequency for each beam:

Penalty typically reduced from 1.5 dB to 0.5 dB.

Two frequencies, two beams, two frequencies for each beam:

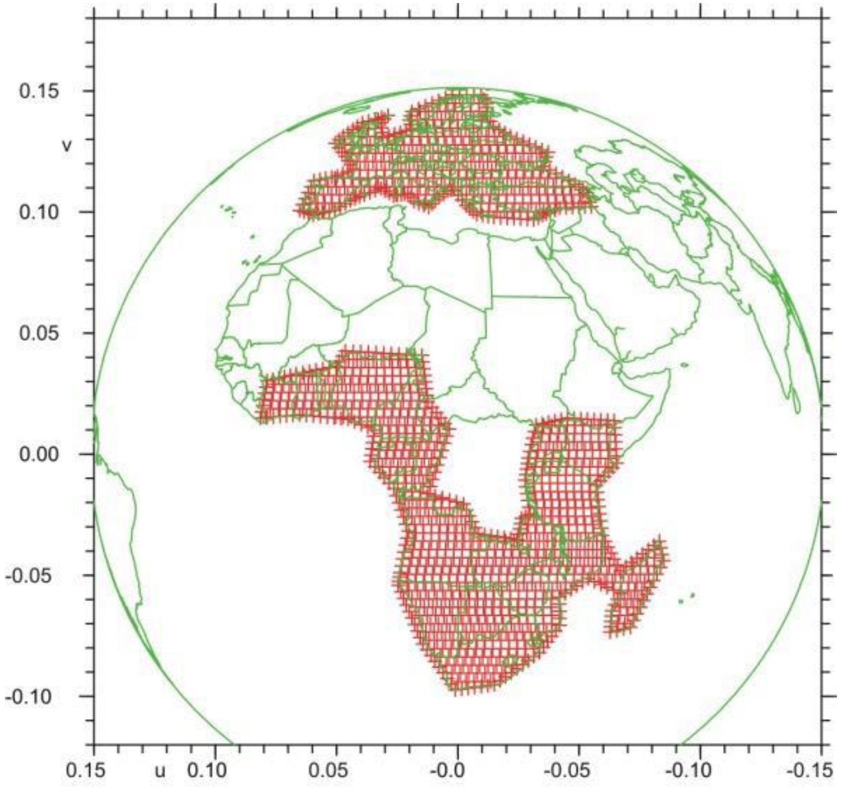
Penalty typically reduced from 2 dB to 1.6 dB.

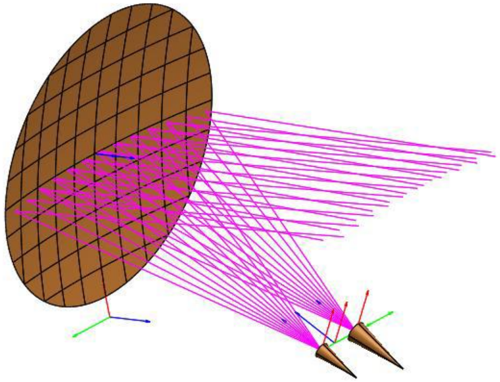
Two frequencies, one beam:

Penalty typically reduced from 1.5 dB to 0.8 dB.

Applicational example

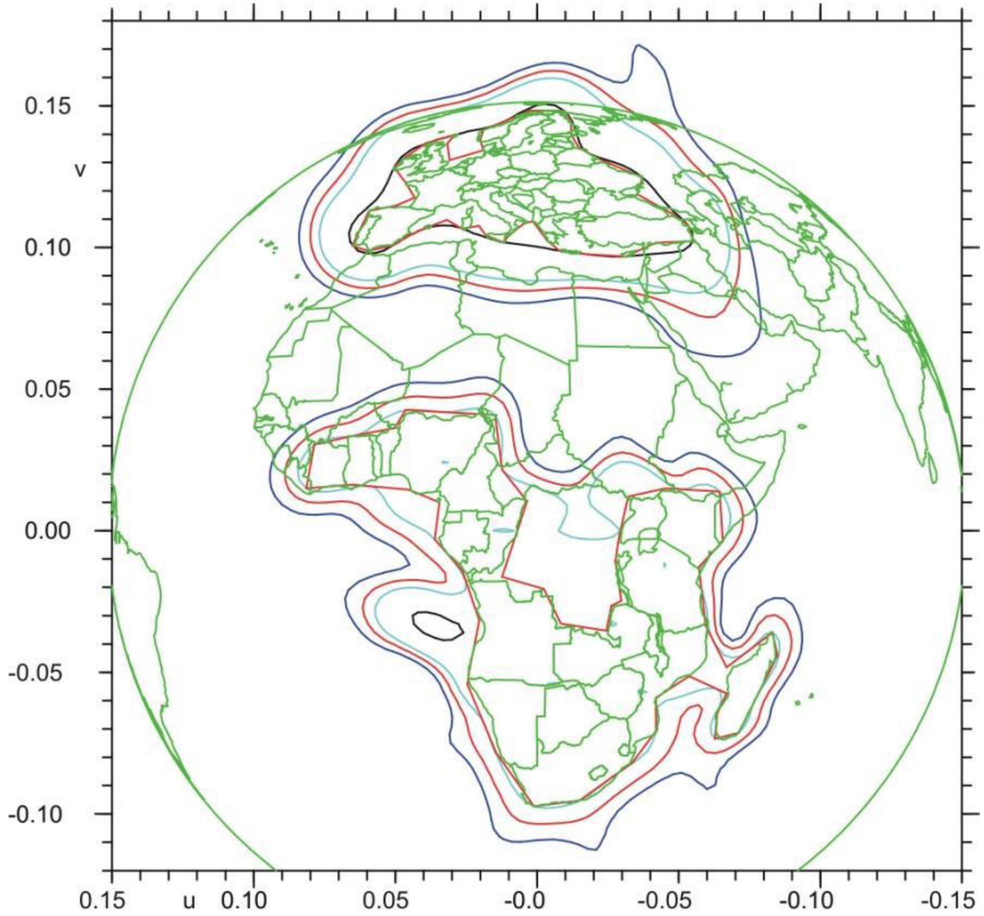
European and African contoured beam generated by one reflector.





Diameter: 1400 mm
Focal length: 1400 mm
10.7 GHz and 14.5 GHz

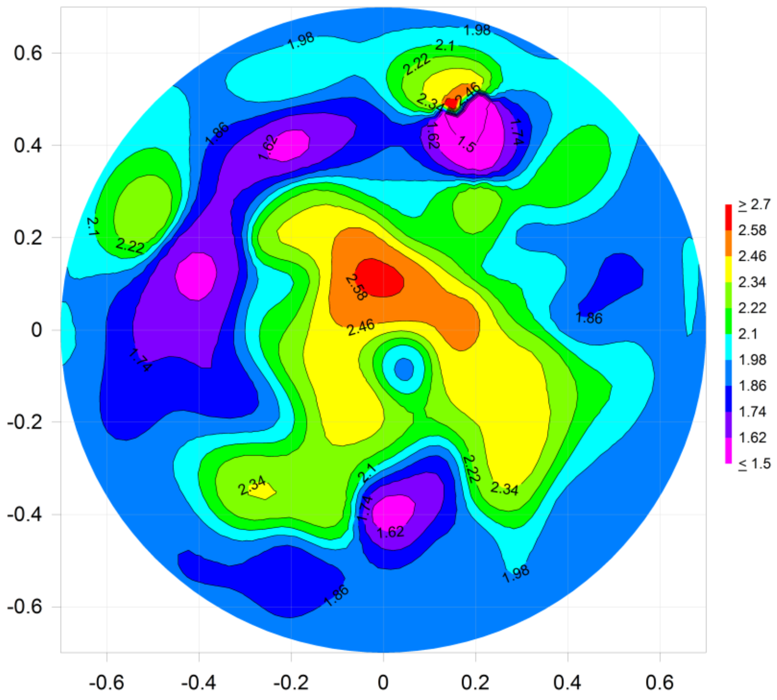
Applicational example



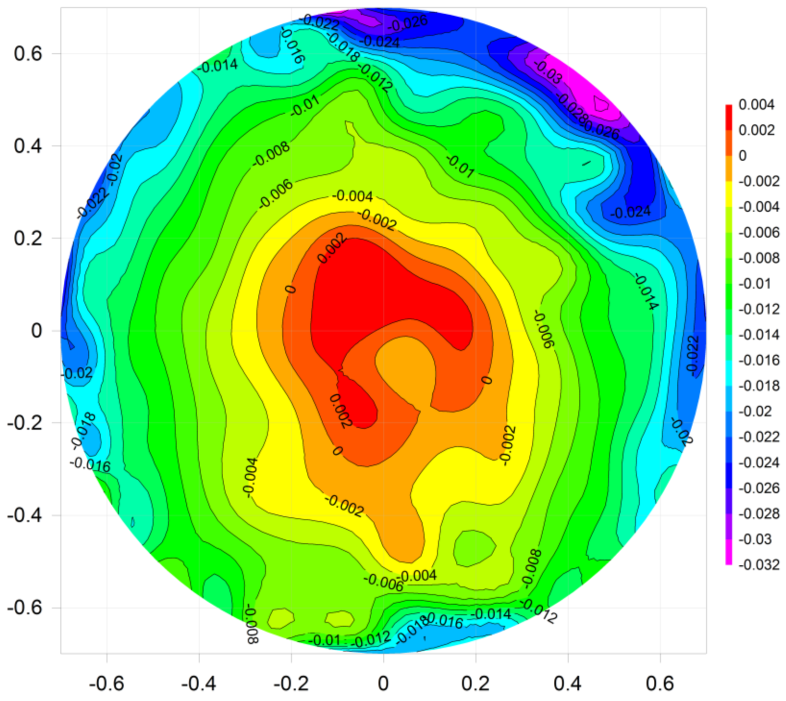
Europe: 14.5 GHz, min. cov. directivity 31.09 dBi

Africa: 10.7 GHz, min. cov. directivity 27.02 dBi

Applicational example



Element size distribution (mm) on reflector.



Surface shaping (m). Initial paraboloid subtracted.

Result Summary

The metasurface reflector appears to be a natural further development of the shaped reflector.

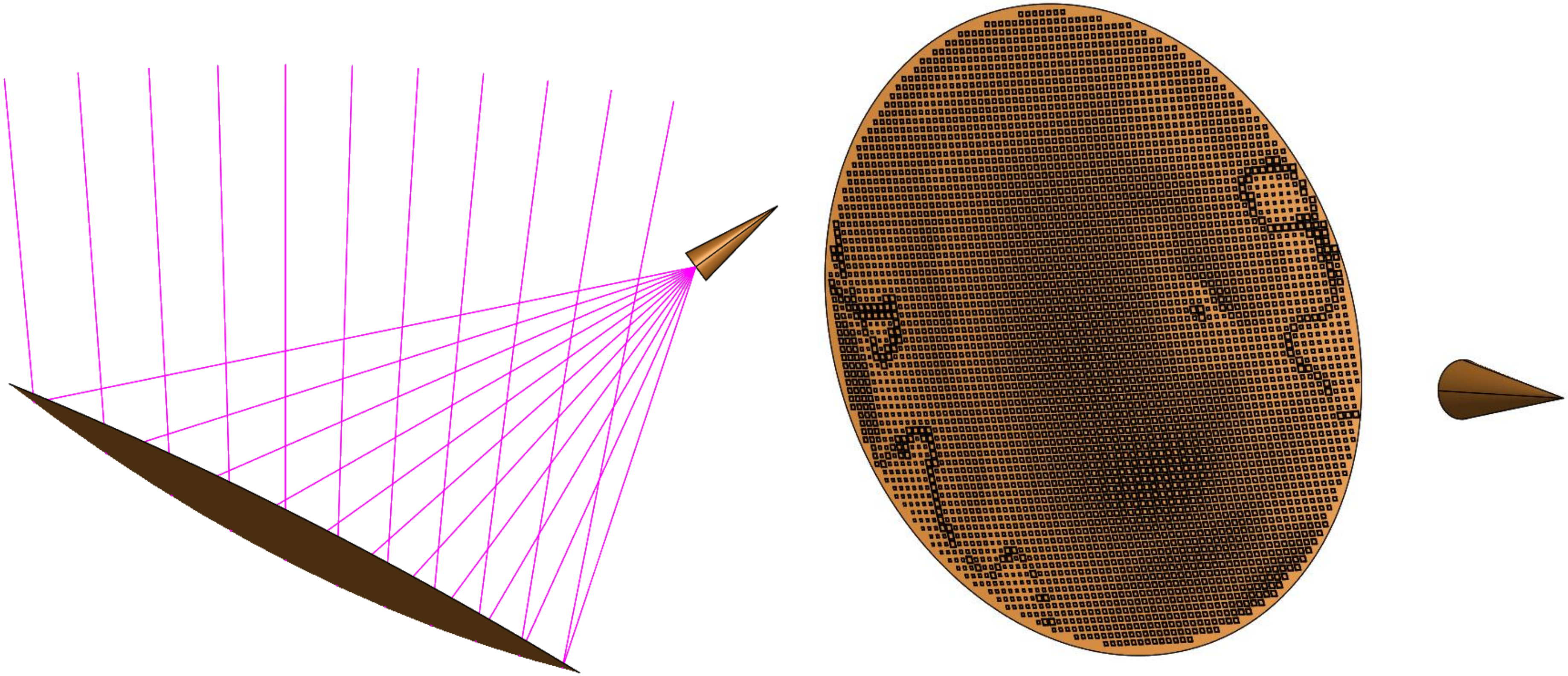
Penalty of generating two beams from one reflector can be reduced to 0.6-0.7 dB.

Improvement due to metasurface: 0.6-1.0 dB.

Further research needed in:

- Patch design for large bandwidth.
- Optimization methods, due to discontinuities and the large number of variables.

Curved reflectarray for Rx-Tx bands

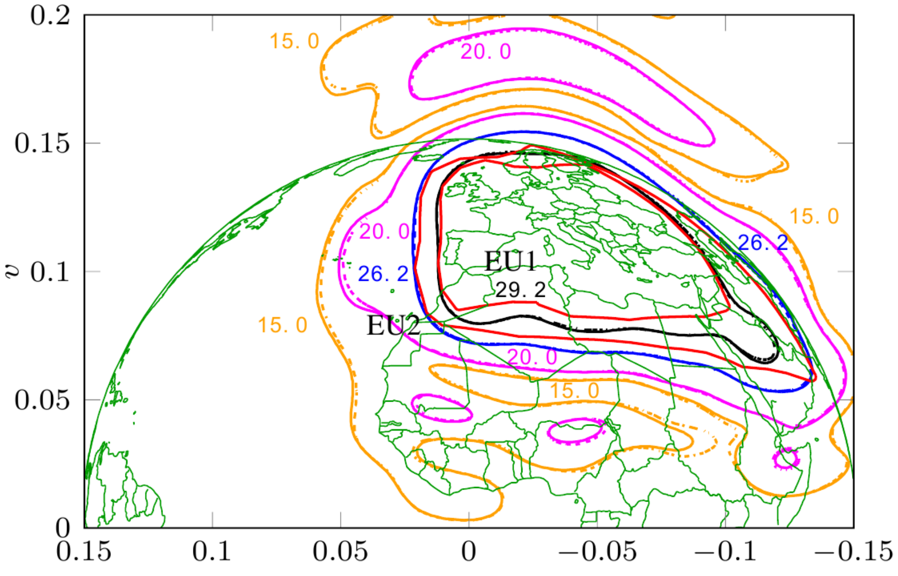


Comparison with MLFMM

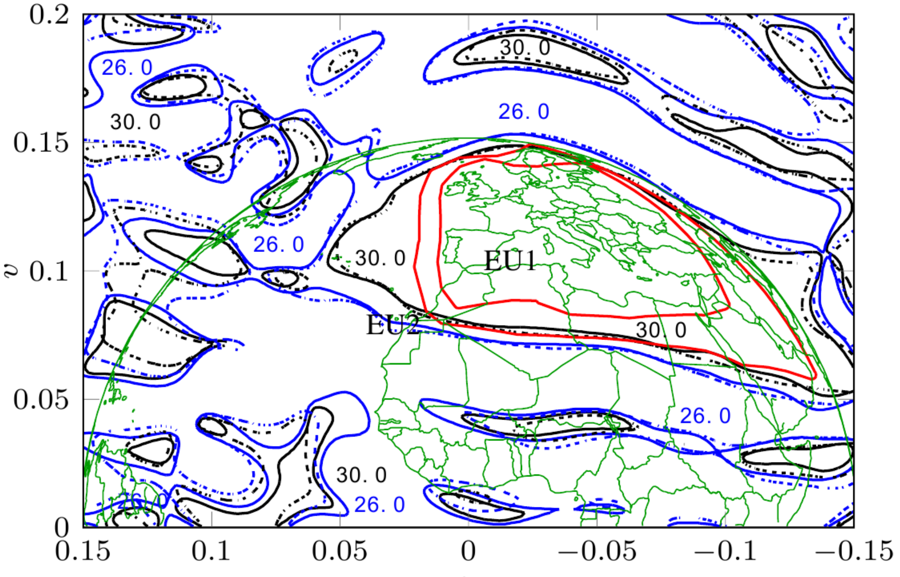
Very good agreement between Periodic MoM-PO and full-wave MLFMM.

The periodic MoM-PO approach is expected to be perfectly applicable for optimization of curved metasurface reflectors.

Limitations may appear for large angles of incidence and high surface curvature.



Co-polar



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