LOW-ORDER BEAM MODELS FOR APERTURE ARRAYS

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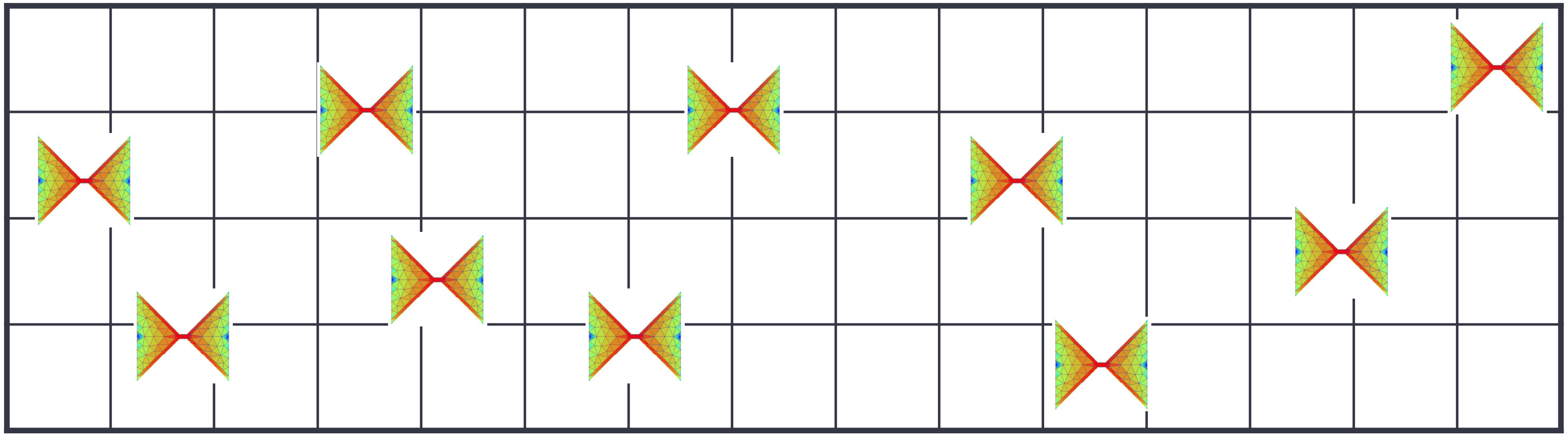
Overview

- MoM-MBF simulations of large irregular arrays
  - We have a powerful simulation tool!
- Mutual coupling in irregular arrays
  - What have we learnt from that tool?
- Representation of mutual coupling effects
  - Initial ideas to model the MC effects
- Low-order models for station beams
  - Where are we right now?
- Conclusions
  - And where do we go from now…?

MoM-MBF simulation of large irregular arrays

- Based on **Method of Moments + MBFs** (CBFs) and the interpolation technique presented in **[1]**, where the computation of interactions between MBFs is carried out by **interpolating exact data obtained on a simple grid**.



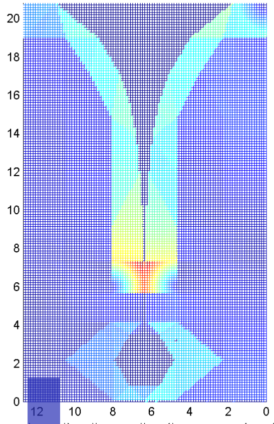
[1] D. Gonzalez-Ovejero and C. Craeye, "Fast computation of Macro Basis Functions interactions in non-uniform arrays," in *Proc. IEEE AP-S Soc. Int. Symp.*, San Diego, CA, Jul. 2008.

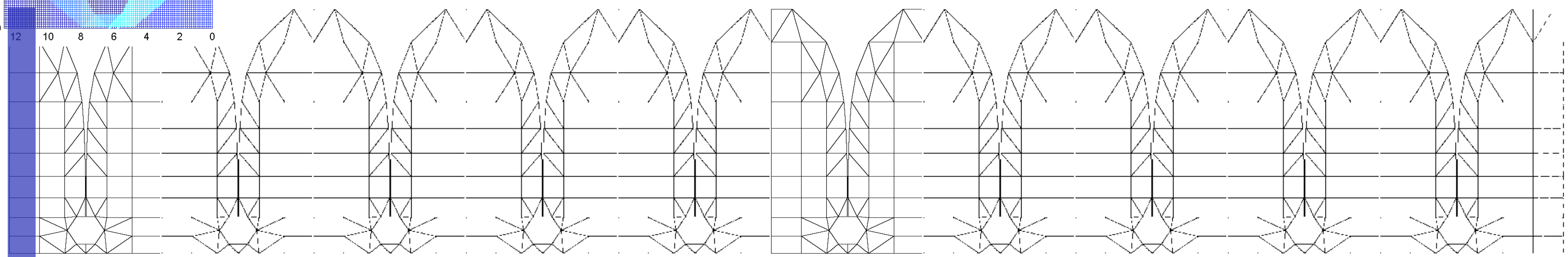
Multiple-mode approach

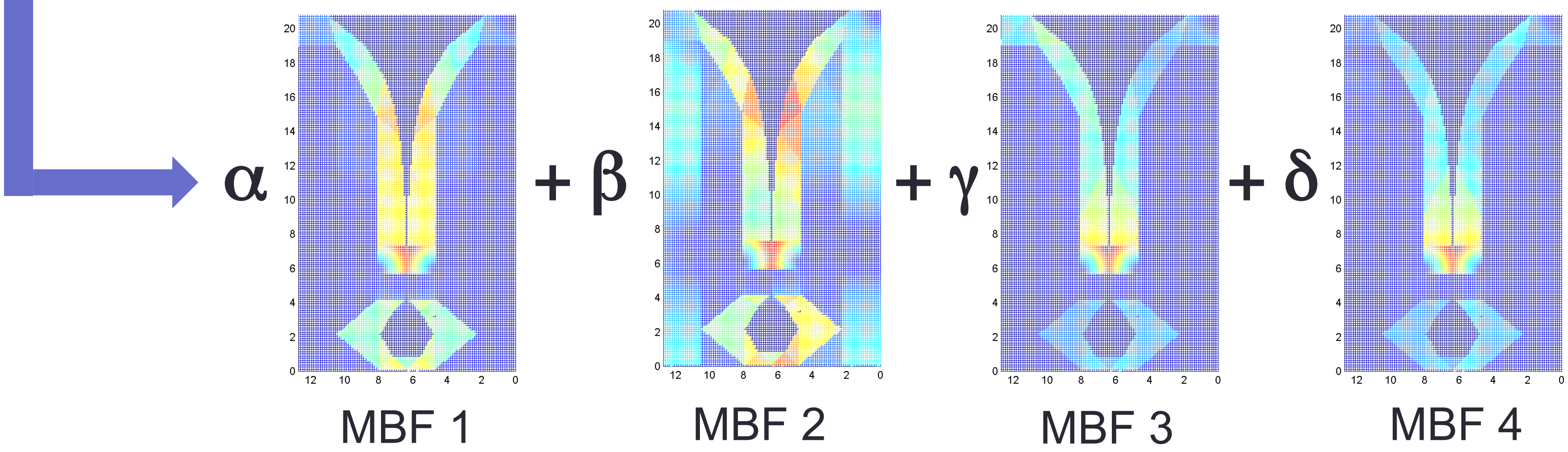
Macro Basis Functions

(Suter & Mosig, MOTL, 2000,

cf. also Vecchi, Mittra, Isernia, Maaskant,…)

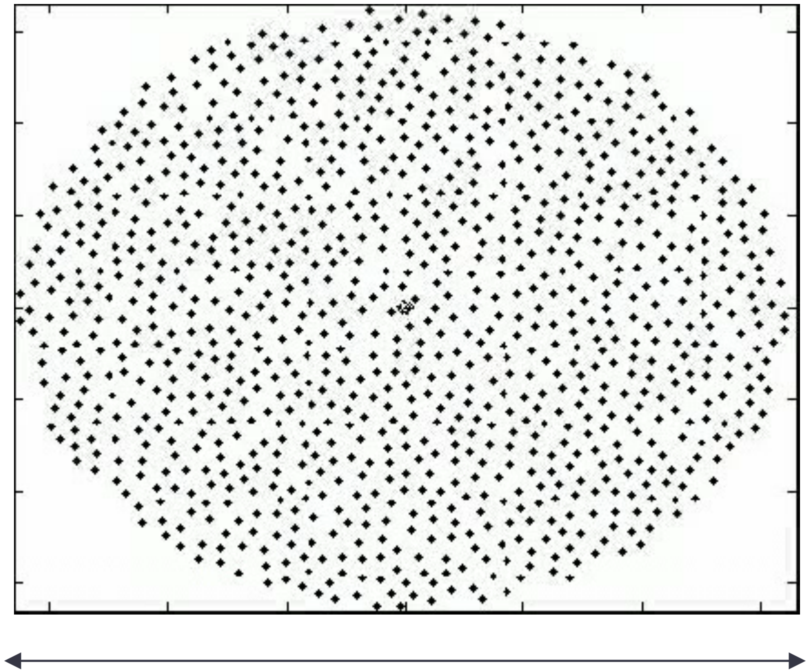






Radius of Influence

A so-called "radius of influence" (RI) is defined for every antenna in the array.



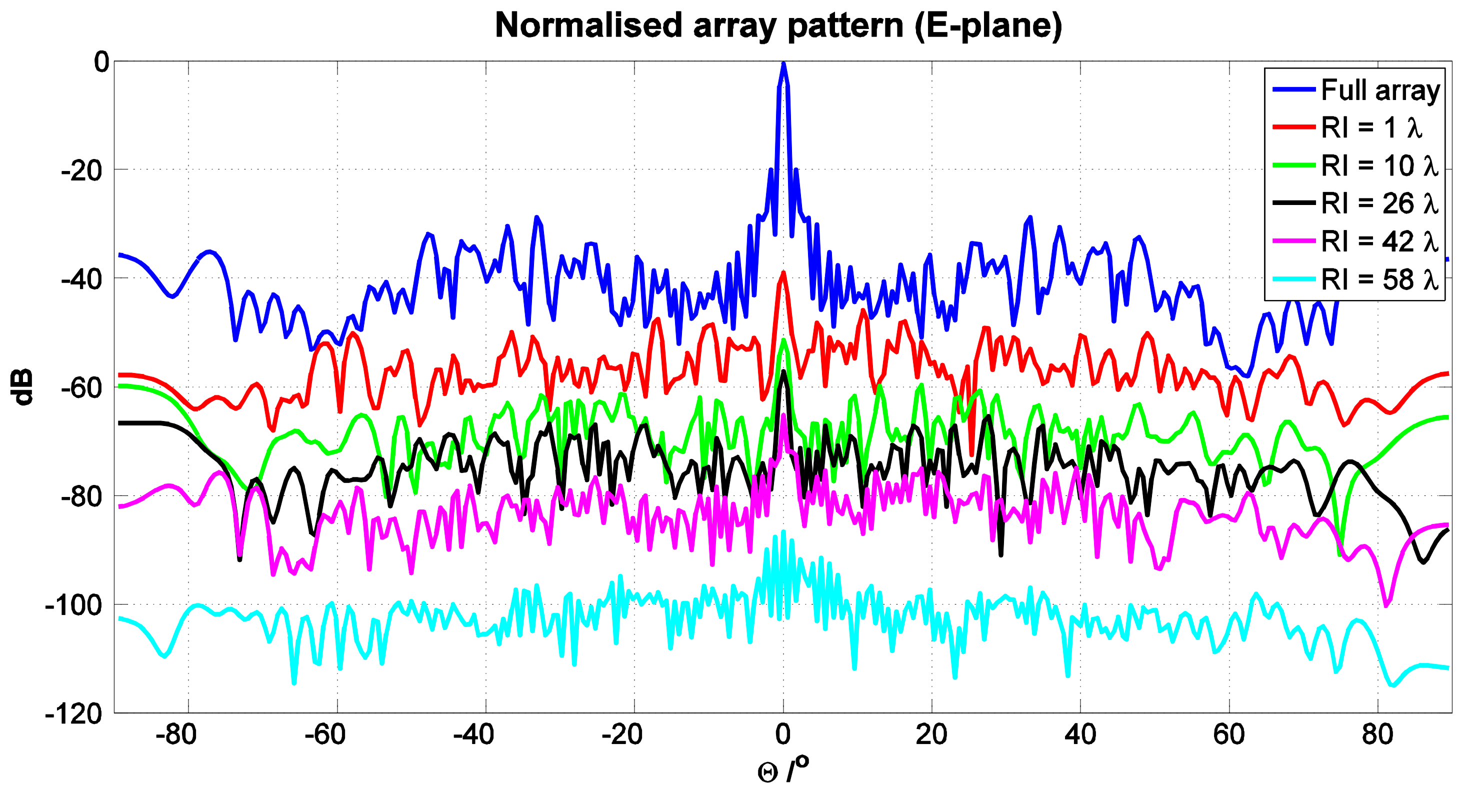
60λ

The interactions between MBFs are computed only within that region reducing drastically the number of unknowns.

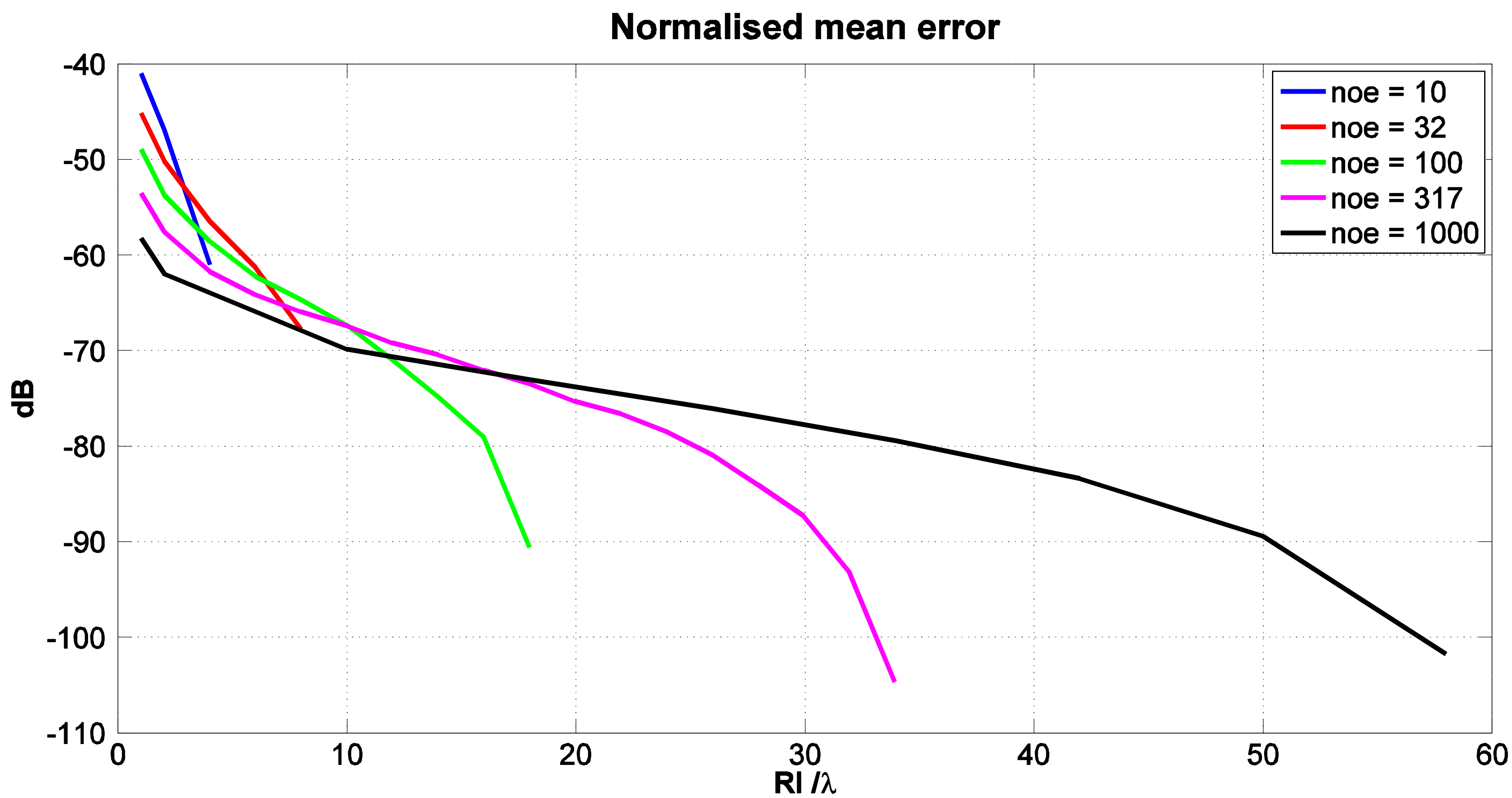
The system is solved for the whole array but now we have a sparse matrix.

$$e_i(\theta,\phi) = 10\log_{10}\left(\frac{\left|\vec{E}^{h}_{full}(\theta,\phi) - \vec{E}^{h}_{i}(\theta,\phi)\right|^2 + \left|\vec{E}^{v}_{full}(\theta,\phi) - \vec{E}^{v}_{i}(\theta,\phi)\right|^2}{\max\left(\left|\vec{E}^{h}_{full}(\theta,\phi)\right|^2 + \left|\vec{E}^{v}_{full}(\theta,\phi)\right|^2\right)}\right)$$

1000 elements

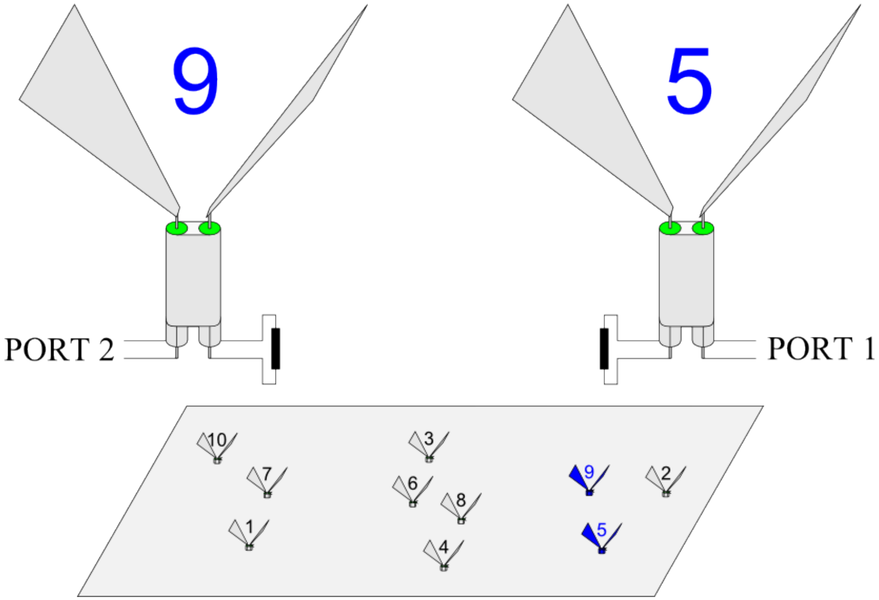


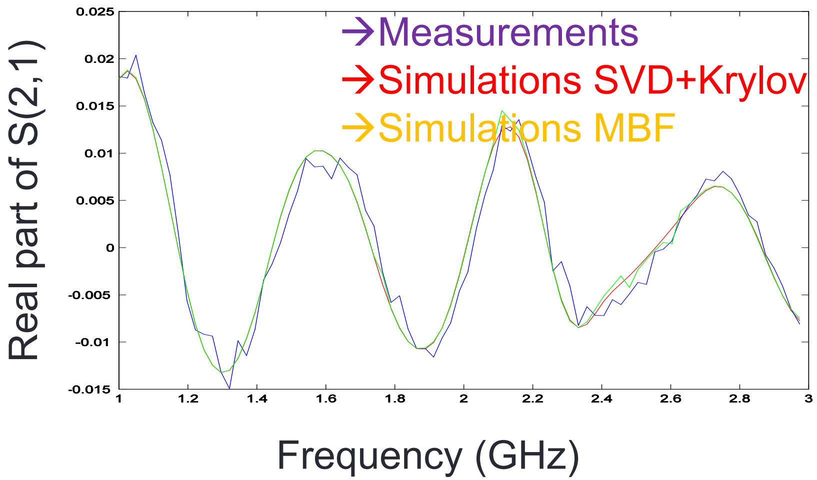
Edge effect

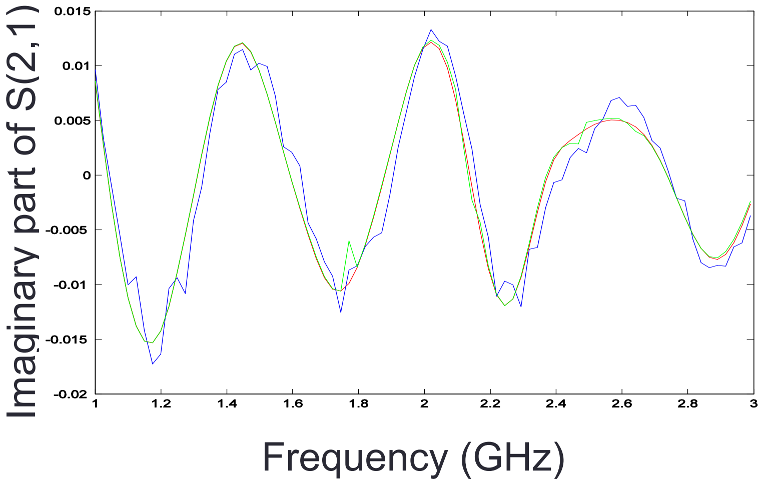


Normalised mean error
-40
-50
-60
-70
-80
-90
-100
-110
dB
0
10
20
30
40
50
60
Rl /λ
noe = 10
noe = 32
noe = 100
noe = 317
noe = 1000

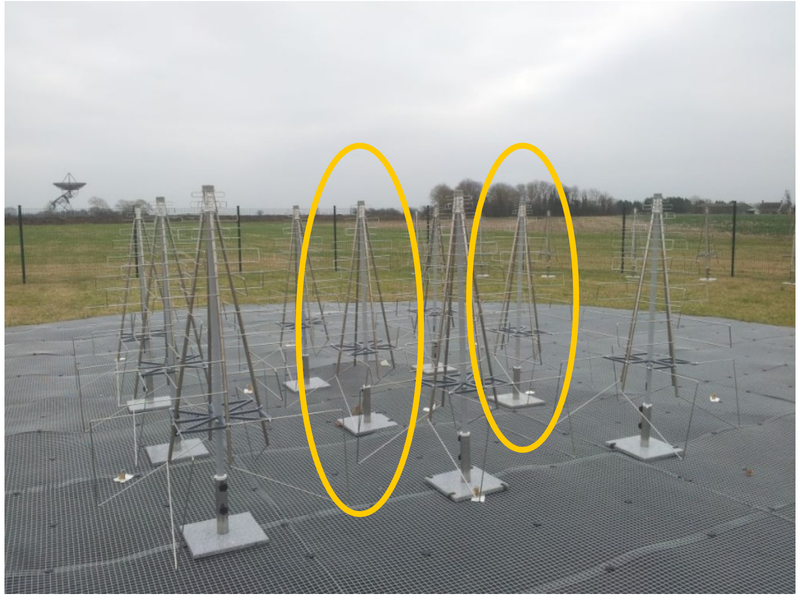
Validation

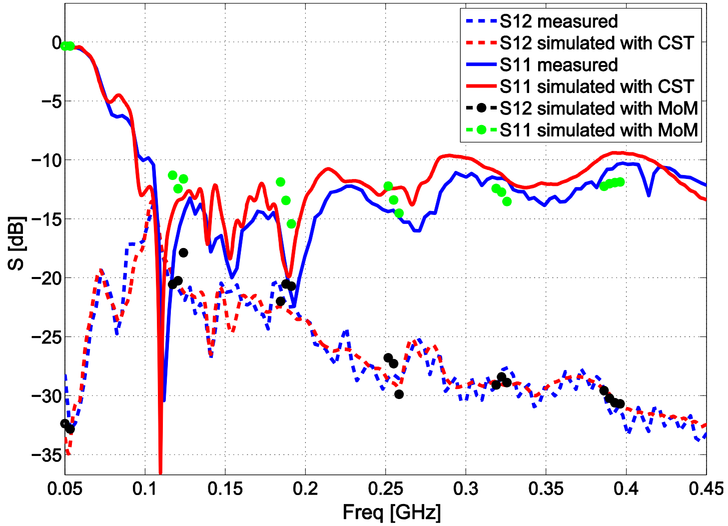

9
5
PORT 2
PORT 1
10
7
1
3
6
8
4
9
5
2


→Measurements
→Simulations SVD+Krylov
→Simulations MBF
Real part of S(2,1)
Frequency (GHz)


Imaginary part of S(2,1)
Frequency (GHz)

Validation AAVS0 array

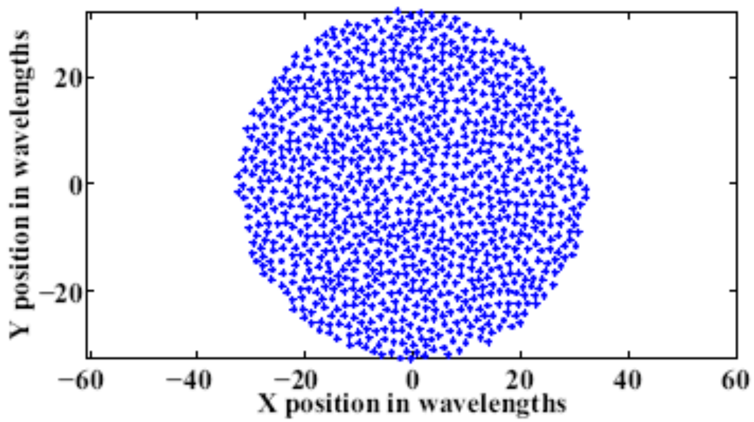


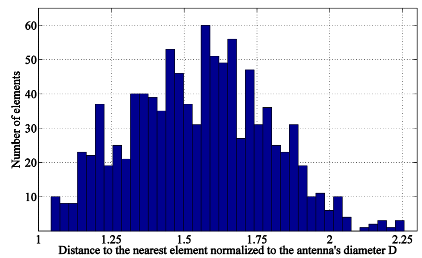


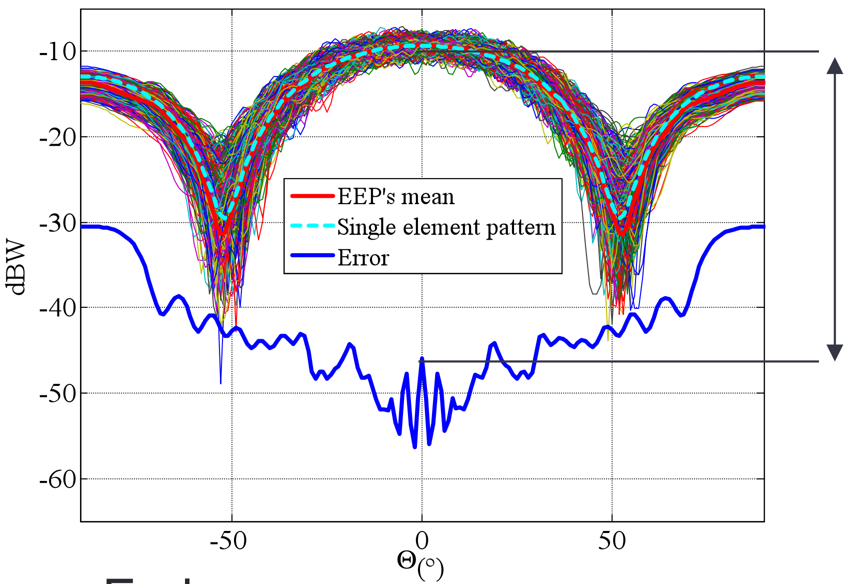
Mutual coupling in irregular arrays

$$e = 10\log_{10}\left(\left|\vec{E}_{mean}(\theta,\phi) - \vec{E}_{single}(\theta,\phi)\right|^2\right)$$

Random configuration

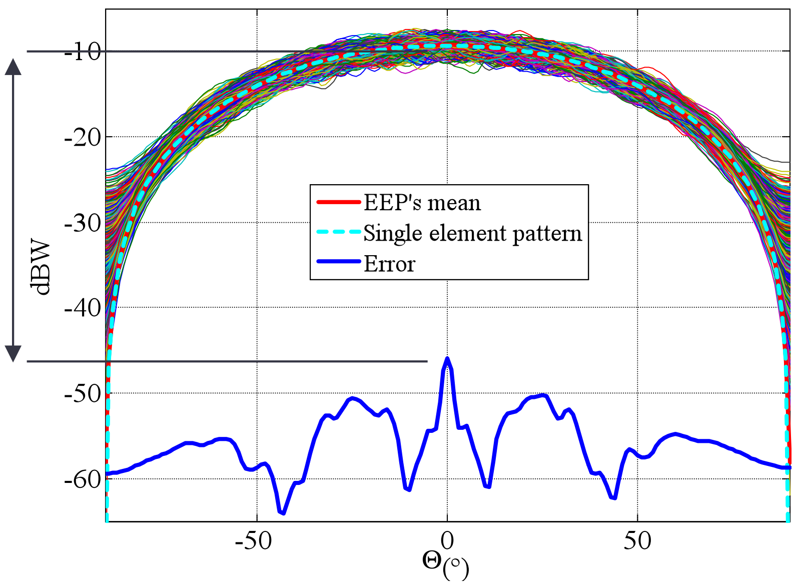






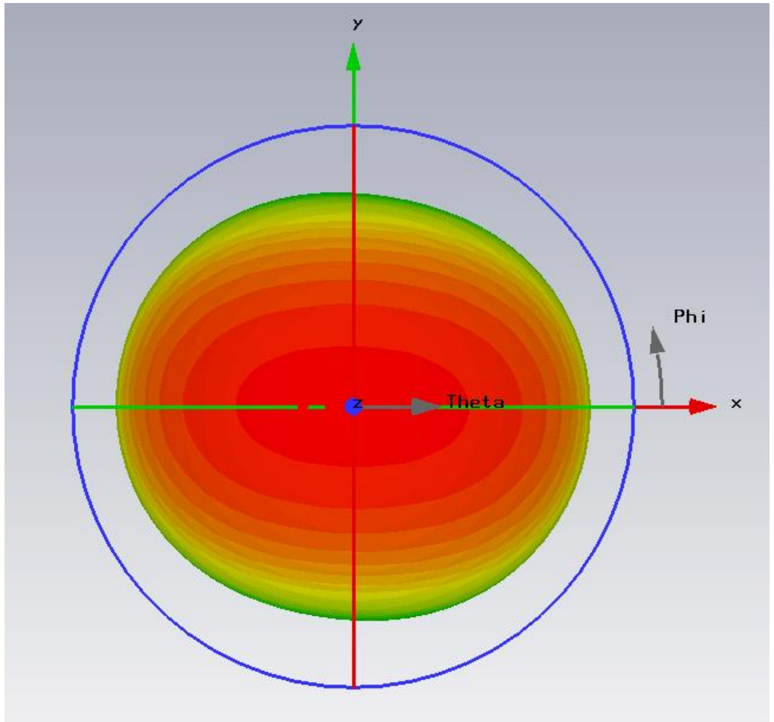
E-plane

~ 35 dB

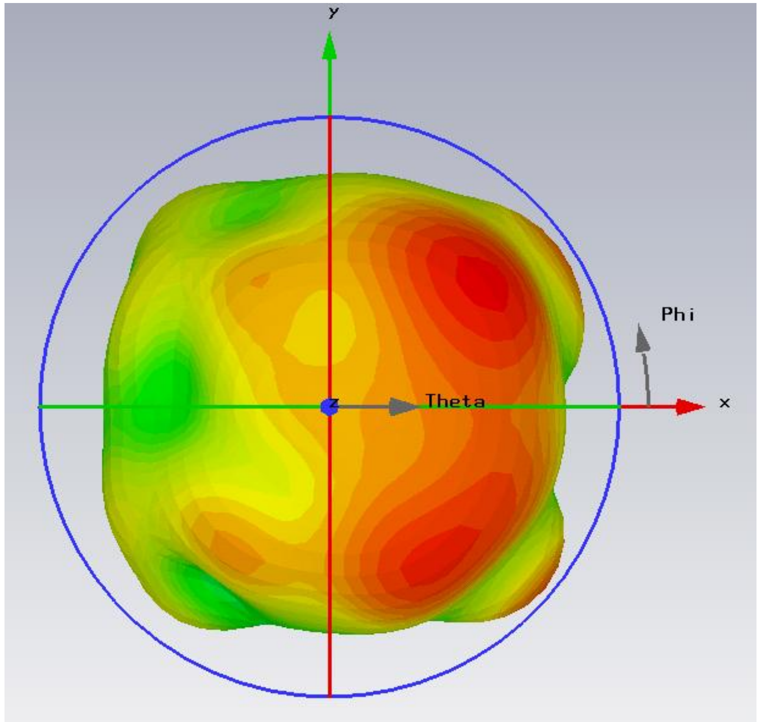


H-plane

Station_Beam = Array_Factor x Average_EEP

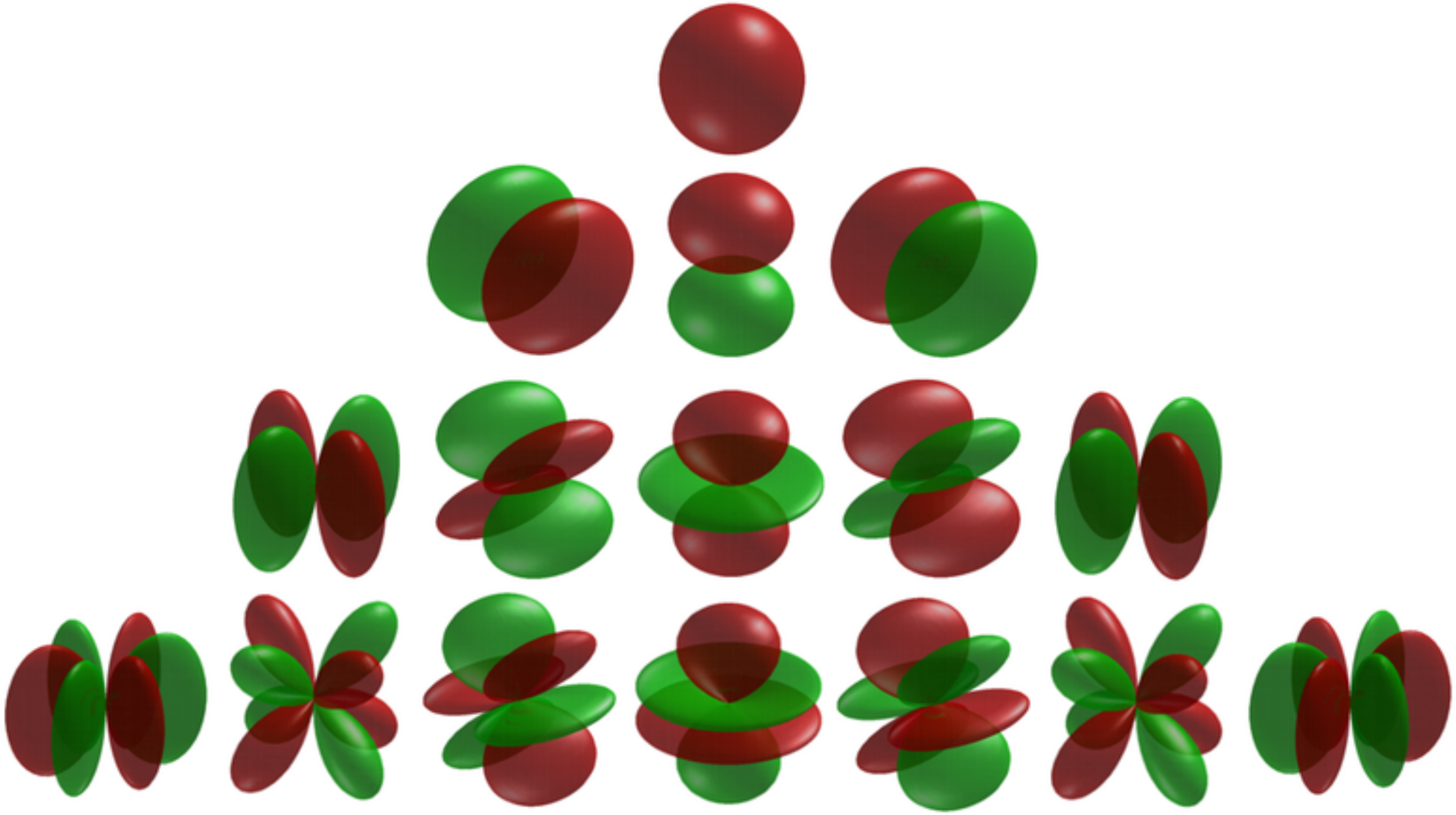


Average Embedded Element Pattern

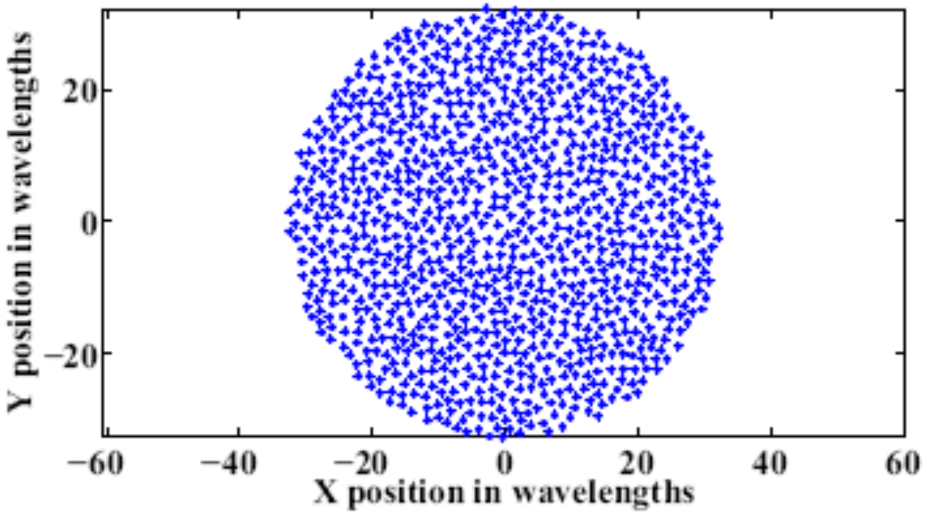


Pattern of a given element

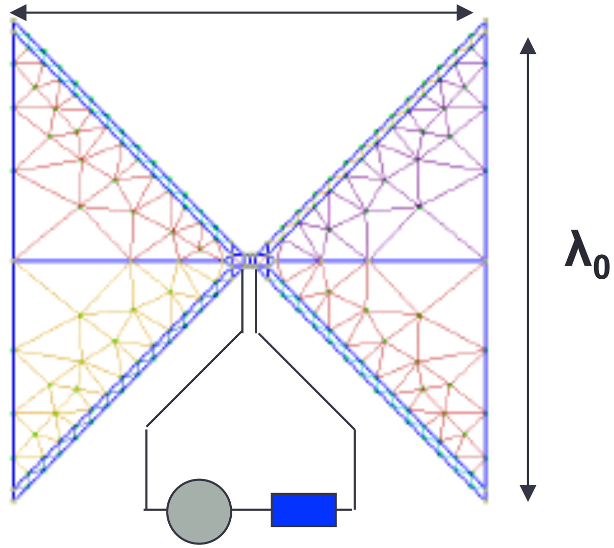
Representation of mutual coupling effects



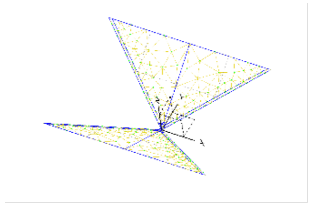
Spherical Harmonics

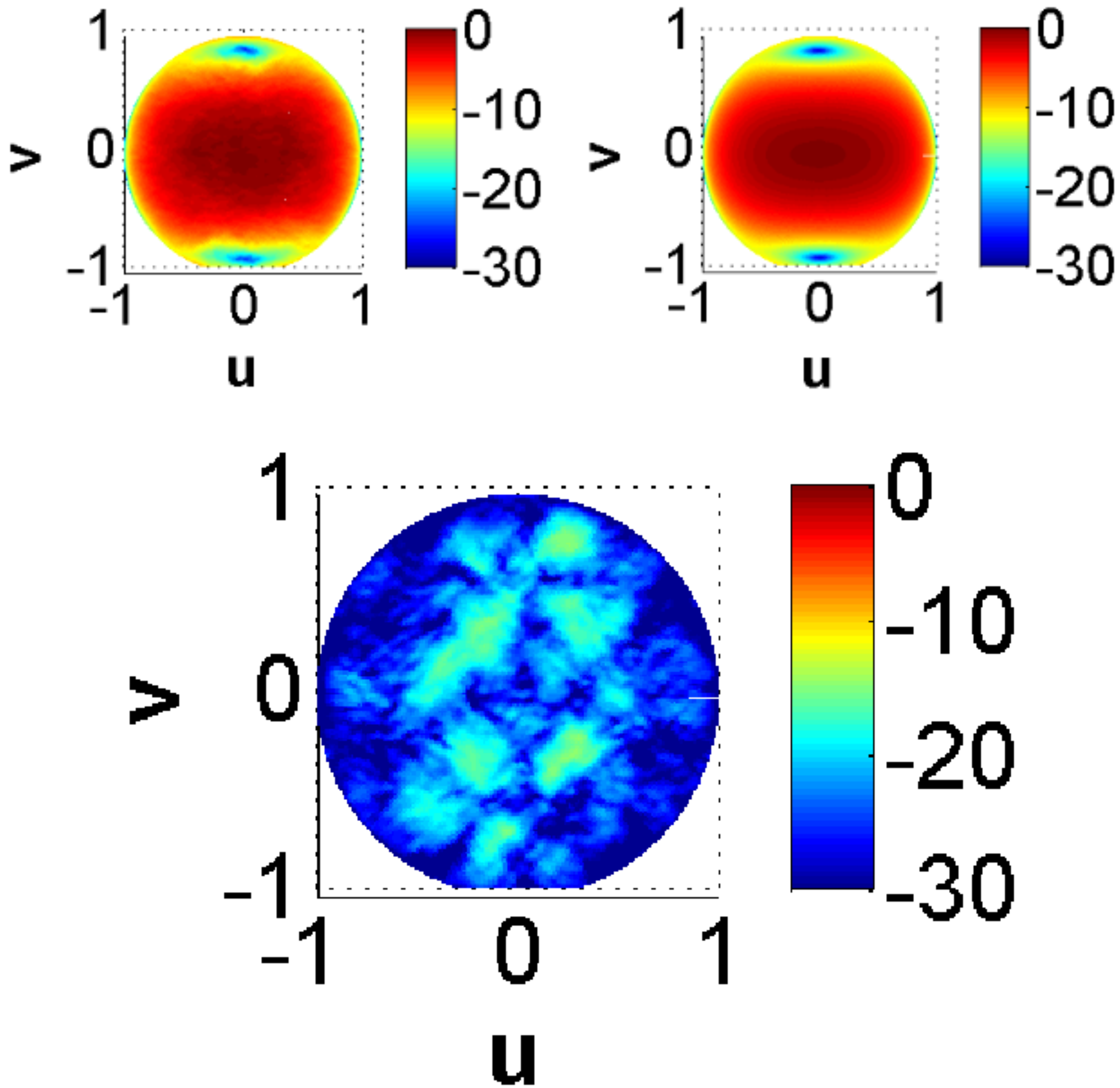


- Array radius = $30\lambda_0$.
- Number of elements = 1000.



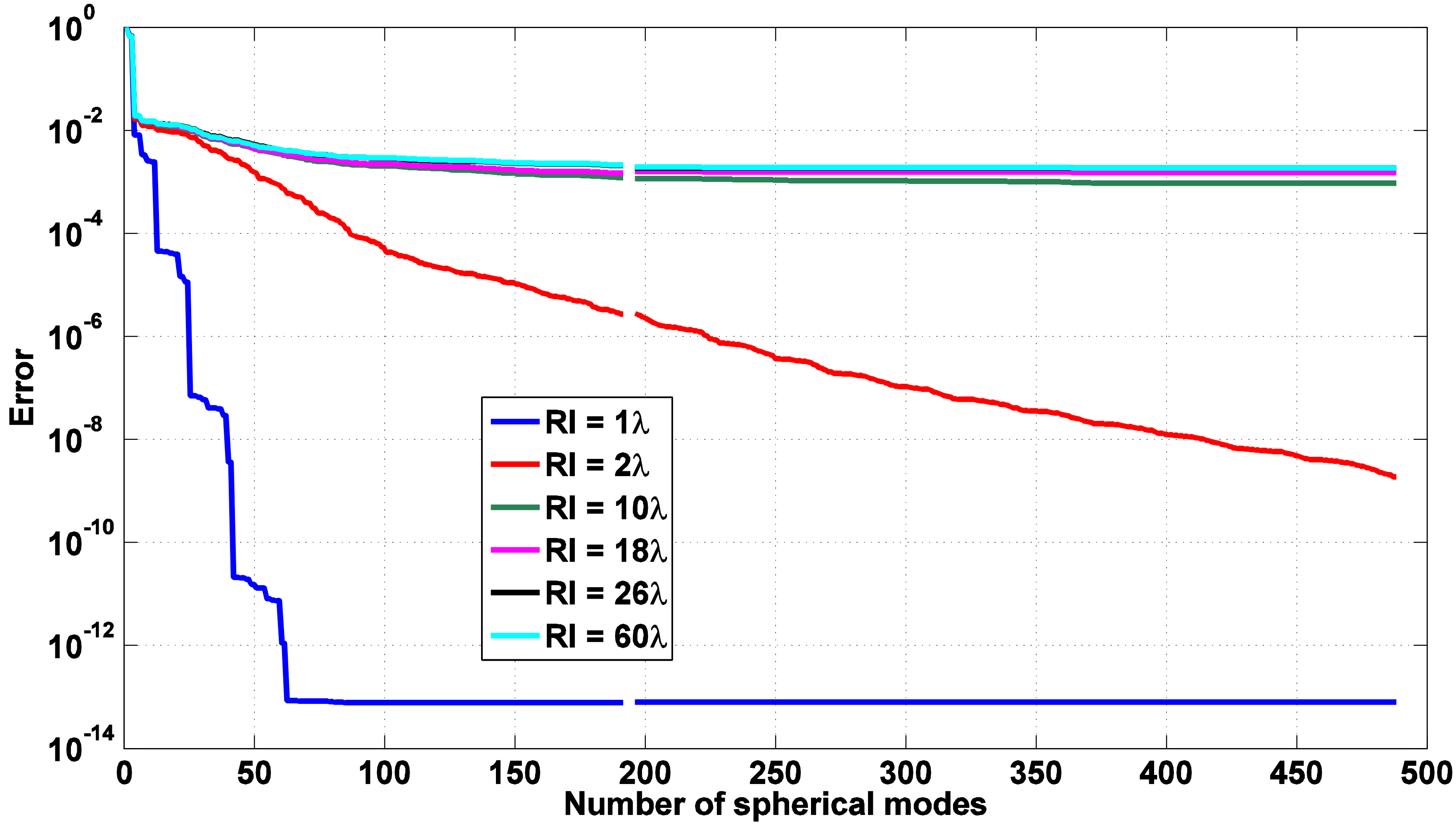
- Distance to ground plane = $\lambda_0/4$.
- No dielectric.



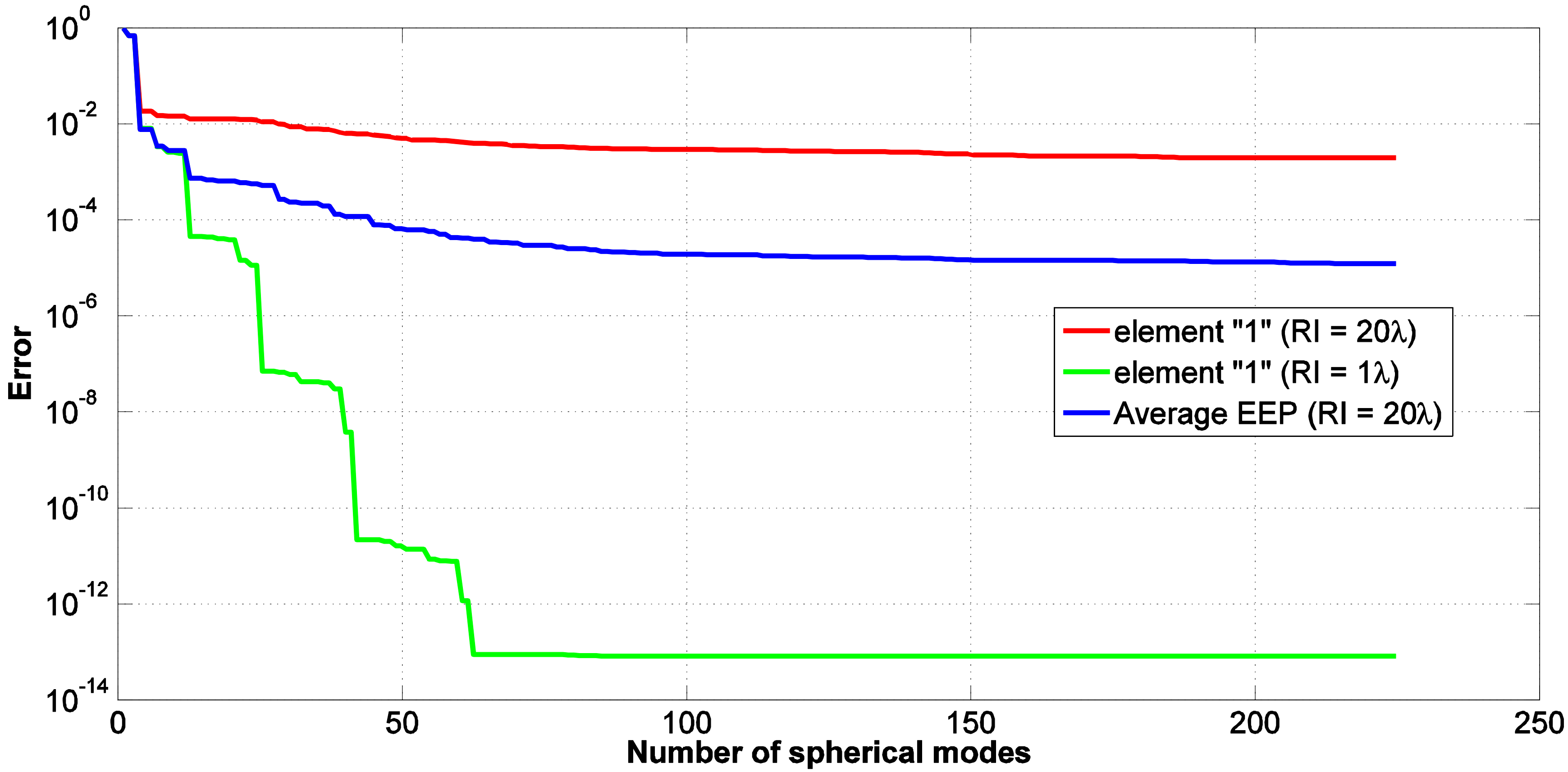


1
0
-1
v
-1
0
1
u
0
-10
-20
-30

Convergence



Average Embedded Element Pattern



Low-order models for station beams

Goal: pattern representation for all modes of operation at station level.

Too many antennas vs. number of calibration sources

➡ **Calibrate the main beam and first few sidelobes**

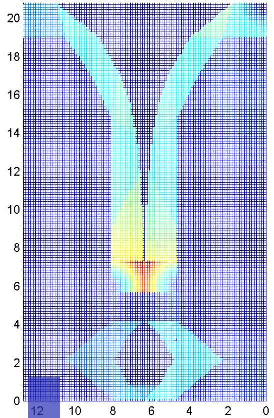
➡ **Compact** representation of patterns, inspired from radiation from apertures, including effects of mutual coupling:
Pattern ≠ AF X element pattern !

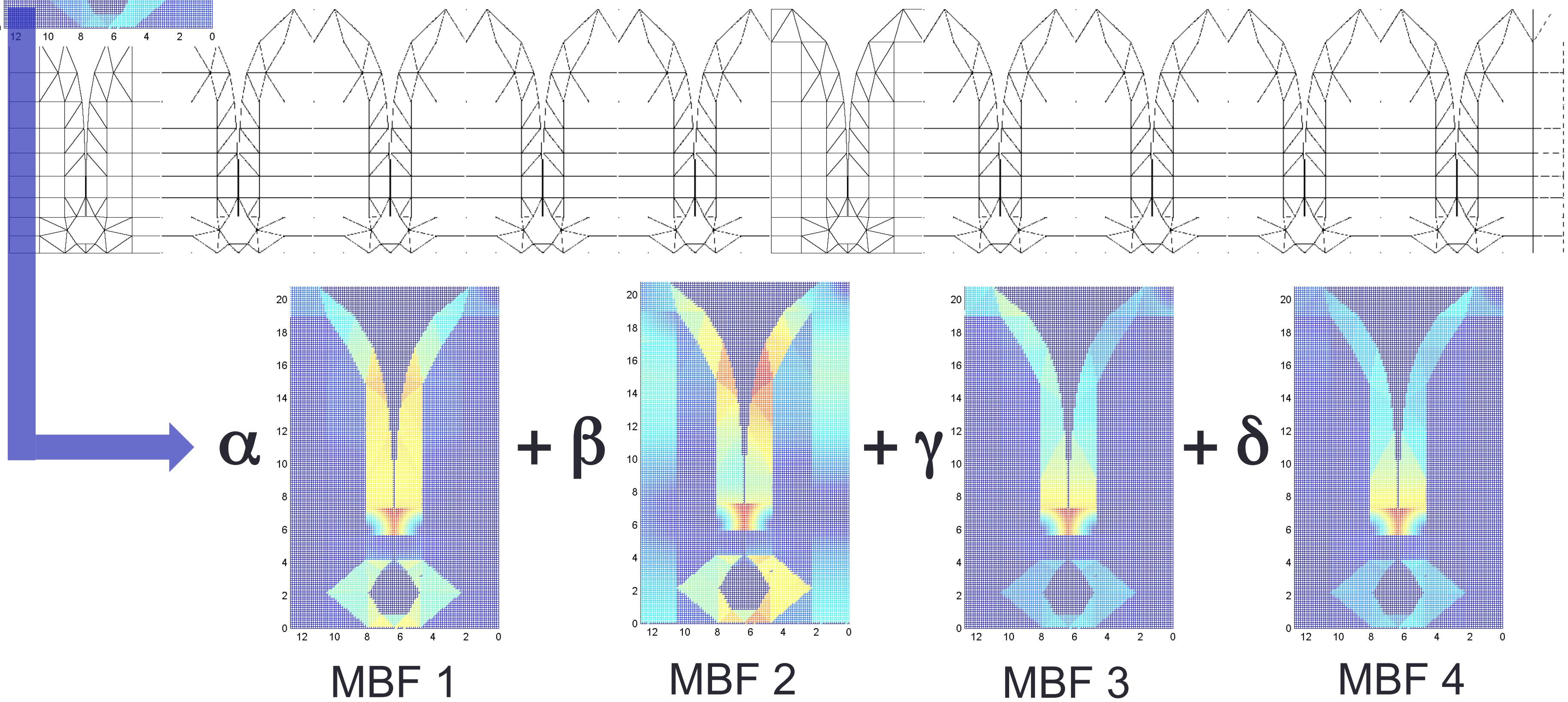
Multiple-mode approach

Macro Basis Functions

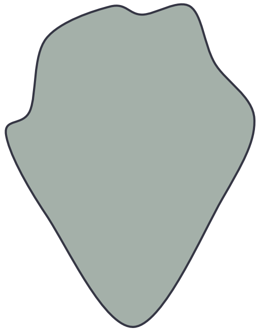
(Suter & Mosig, MOTL, 2000,

cf. also Vecchi, Mittra, Isernia, Maaskant,…)





Array factorisation



Index of excited element

$$\vec{J}_{ns} \simeq \sum_{p=1}^{P} C_{nsp} \, \vec{J}_p^{\circ}$$

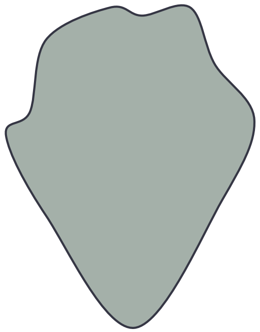
	Antenna index		
MBF 1	C_{111}	C_{211}	C_{311}
MBF 2	C_{112}	C_{212}	C_{312}
⋮			

Coefficients for **IDENTICAL** current distribution

$$\vec{F}_s \simeq \sum_{p=1}^{P} \sum_{s=1}^{N} A_s \sum_{n=1}^{N} C_{nsp} \, e^{j\,k\,\hat{u}.\vec{r}_n} \, \vec{F}_p^{\circ}$$

Array factorisation

$$\vec{J}_{ns} \simeq \sum_{p=1}^{P} C_{nsp}\ \vec{J}_p^{\circ}$$



	Antenna index		
MBF 1	C_{111}	C_{211}	C_{311}
MBF 2	C_{112}	C_{212}	C_{322}
⋮			

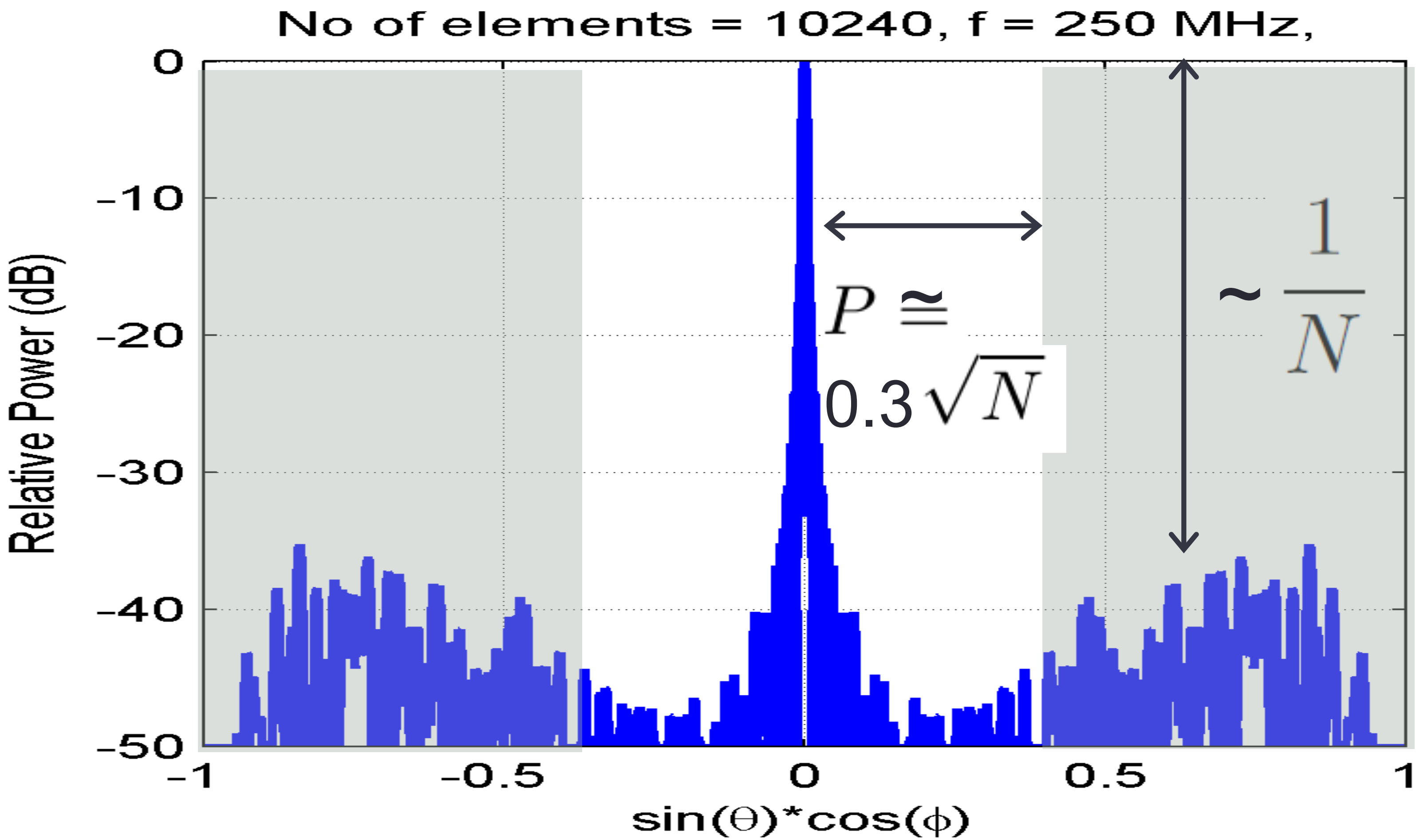
→ Coefficients for **IDENTICAL** current distribution

$$\vec{F}_s \simeq \sum_{p=1}^{P} \underbrace{\sum_{n=1}^{N} \Bigg(\overbrace{\sum_{s=1}^{N} A_s\, C_{nsp}}^{A'_p} \Bigg) e^{j\,k\,\hat{u}.\vec{r}_n}}_{AF_p}\ \vec{F}_p^{\circ}$$

A'_p

→ ***AF_p***

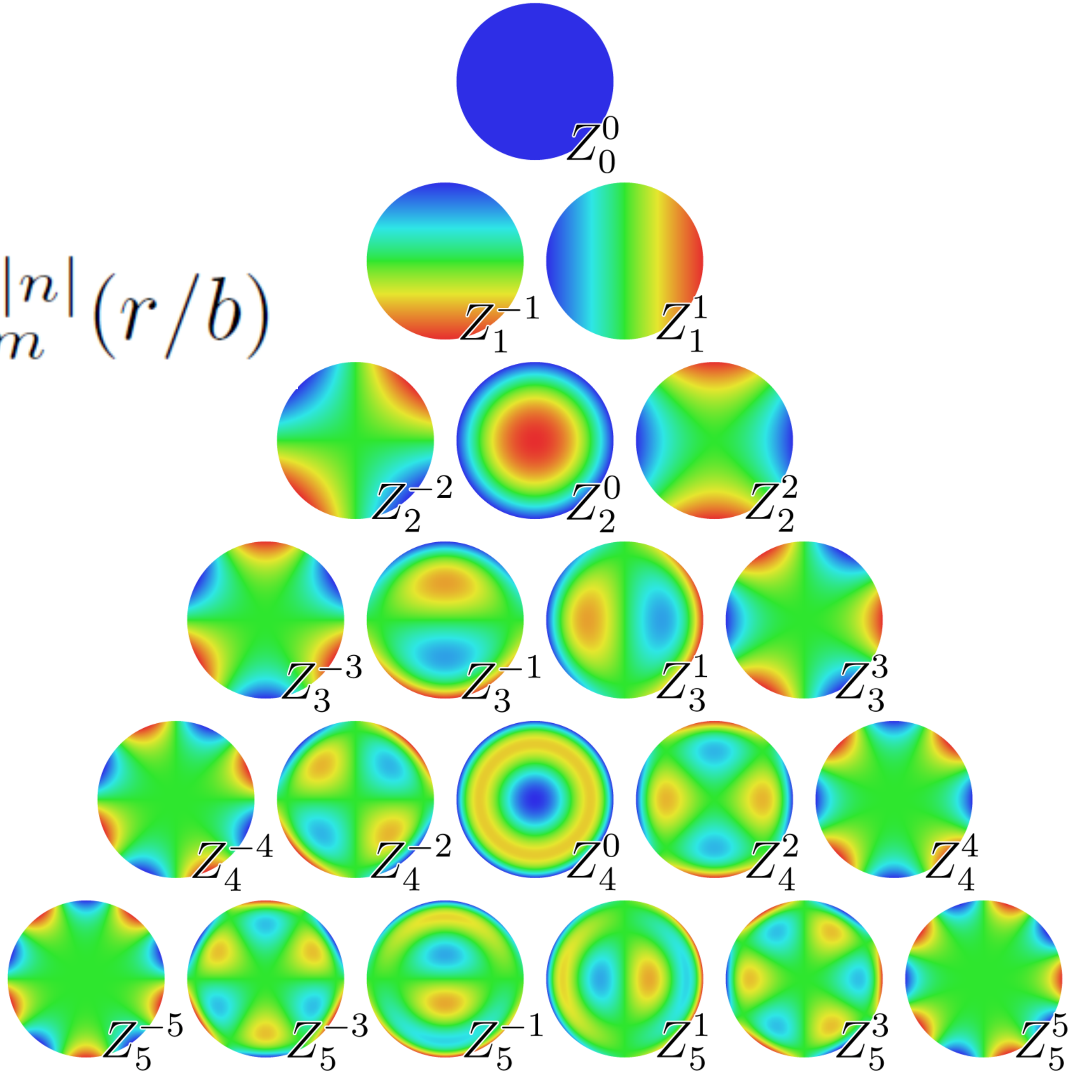
Array factor



Continuous aperture regime

Zernike functions

$$e^{j\,n\,\alpha}\;F_m^{|n|}(r/b)$$



Picture from Wikipedia

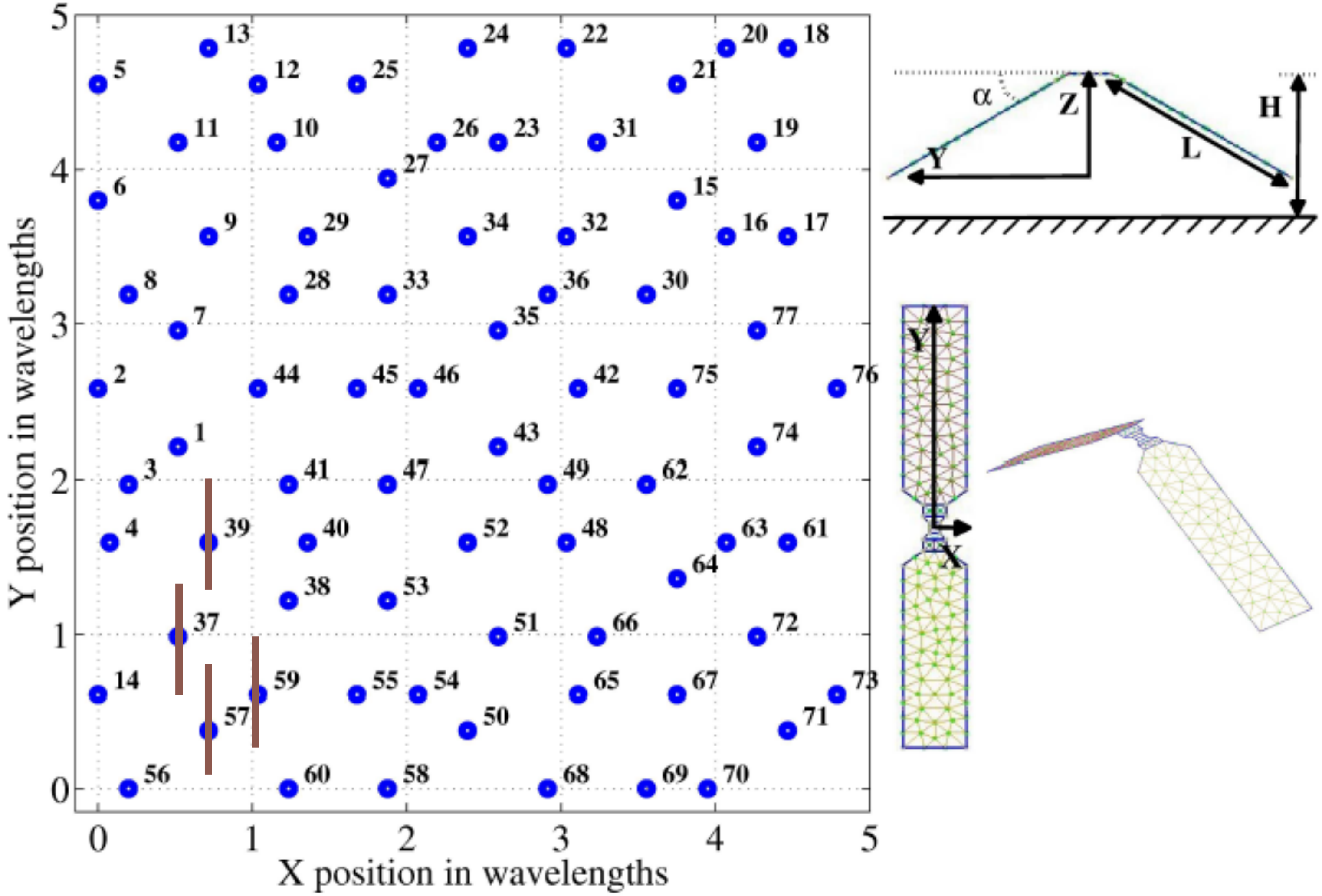
Zernike-Bessel decomposition

$$AF(\theta,\phi) = 2 \sum_{n=-N}^{N} \sum_{m=0}^{M} (|n| + 2m + 1)\, B_{mn}\, j^{n}\, e^{j\,n\,\phi}$$
$$(-1)^{s}\, \frac{J_{|n|+2m+1}(k\,b\,\sin\theta)}{k\,b\,\sin\theta}$$

$$B_{mn} = \sum_{i} A'_{i}\, F_{m}^{|n|}(r/b)\, e^{-j\,n\,\alpha_i}$$

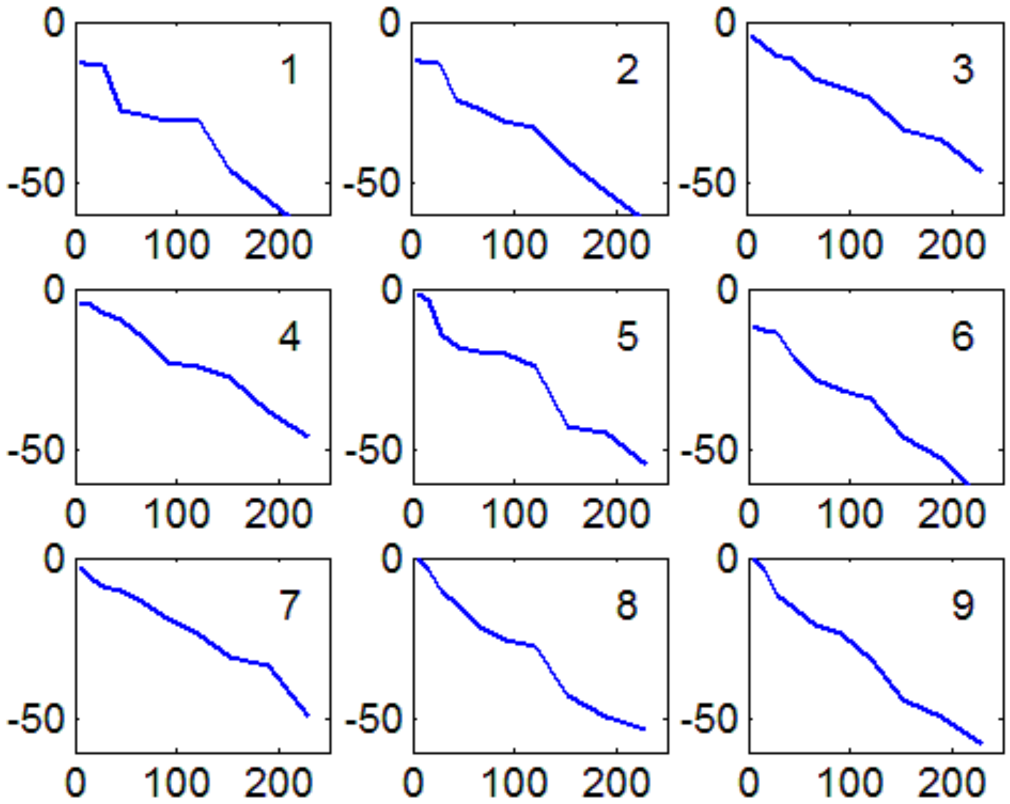
Similar to theory of ~circular apertures:
Y. Rahmat-Samii and V. Galindo-Israel, “Shaped reflector antenna analysis using the Jacobi-Bessel series,” IEEE Trans. Antennas Propagat., Vol. 28, no.4, pp. 425-435, Jul. 1980.

Array of wideband dipoles



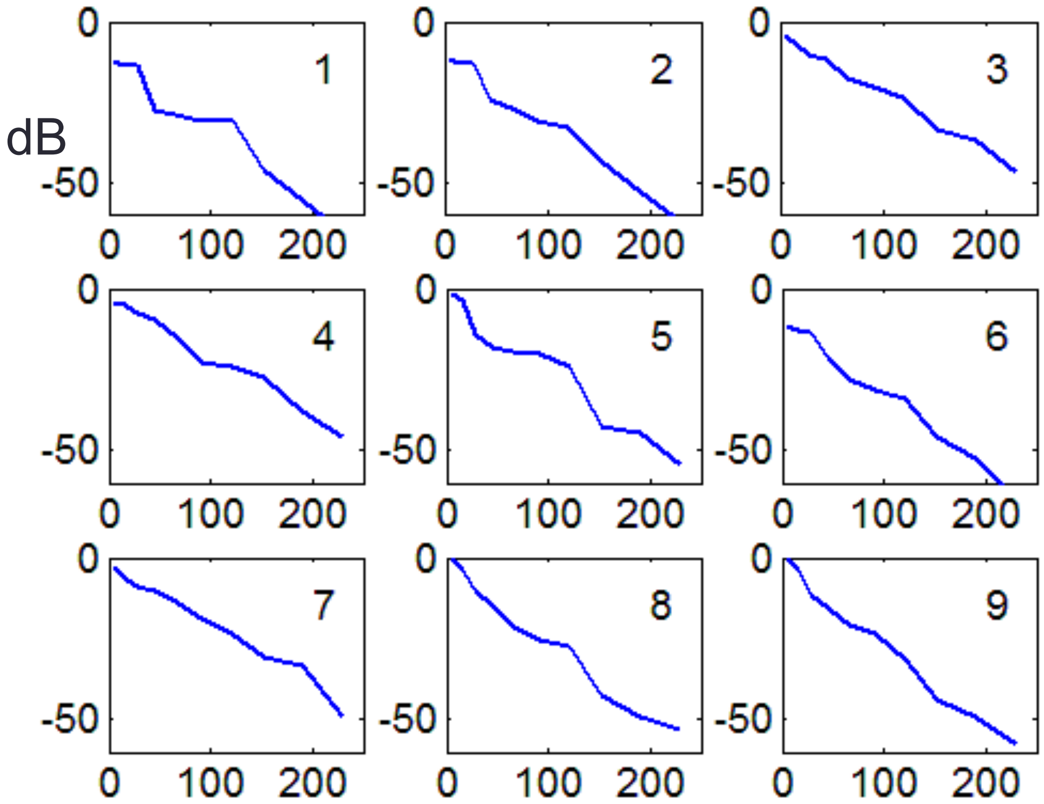
Modeled with 9 MBFs

AF convergence



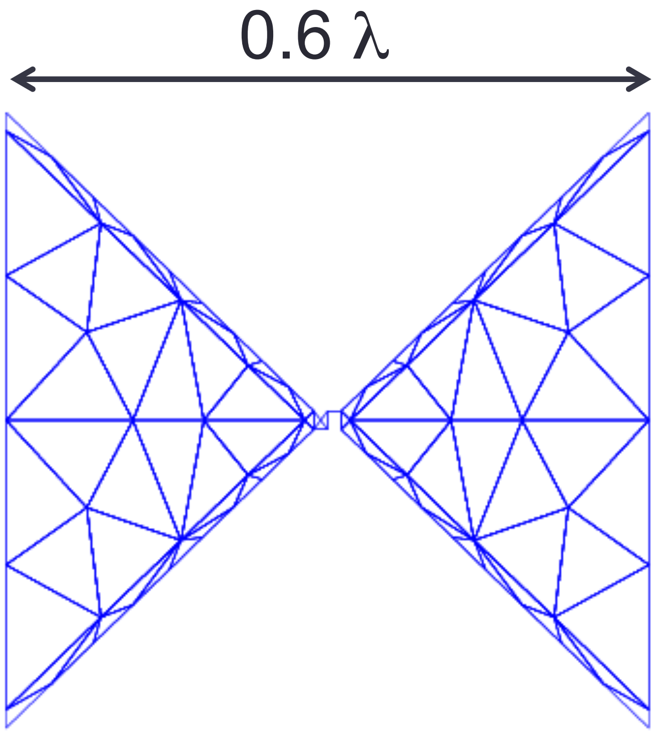
Main beam + 1st sidelobe

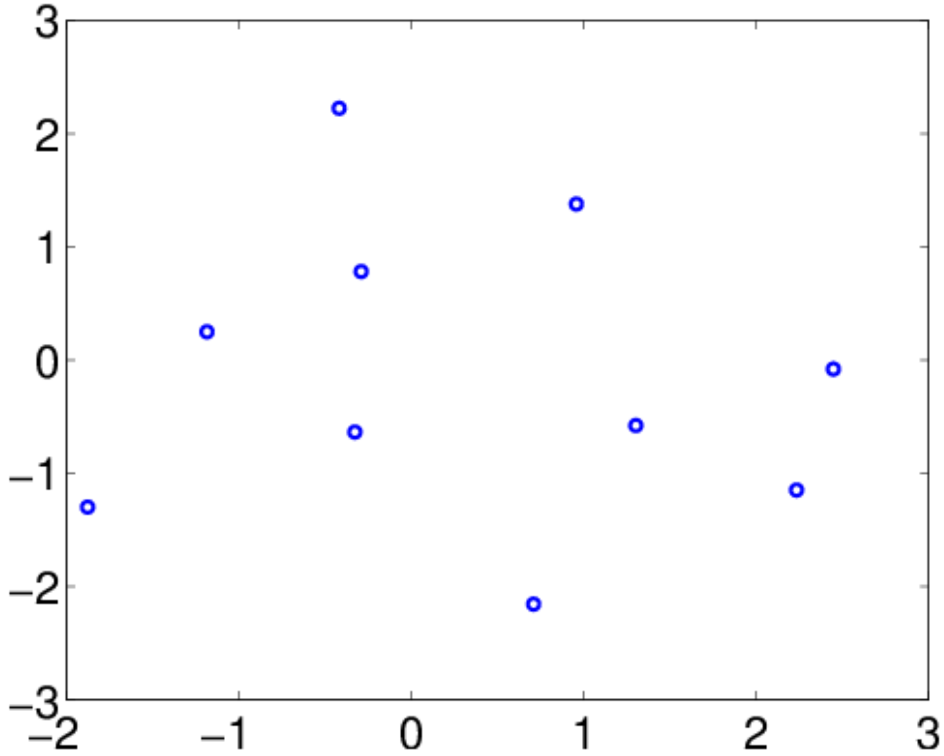
Reduce number of terms ?



9 is still too many:
Exploit similarity between MBF patterns

Small array of over-moded elements

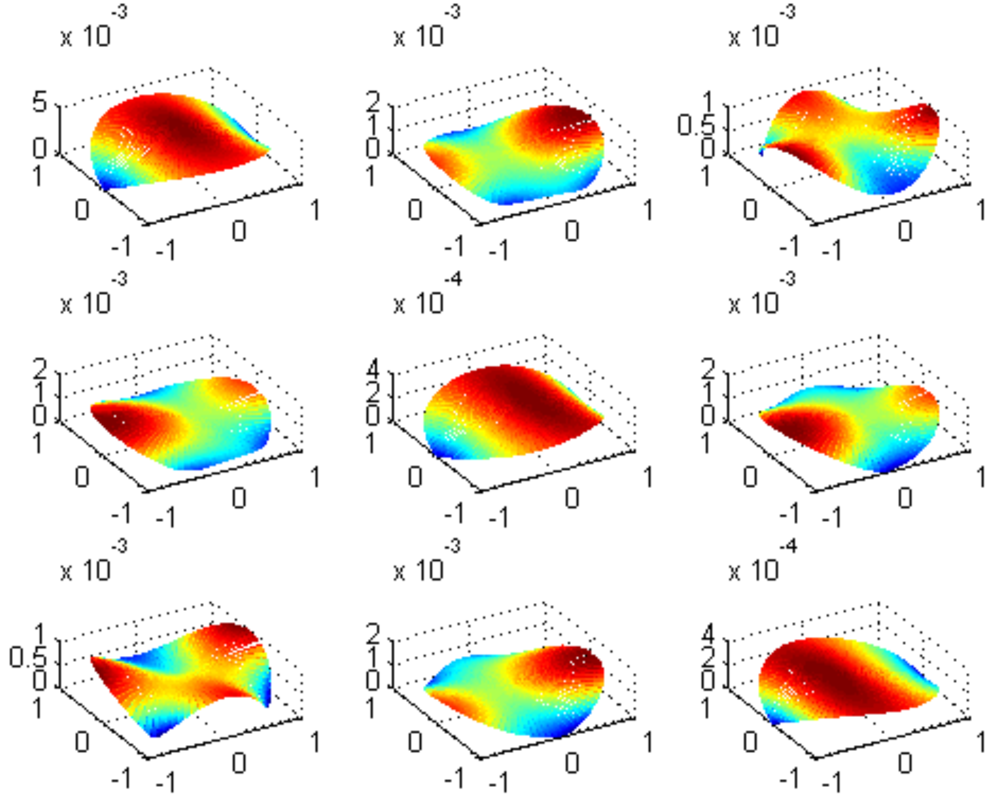




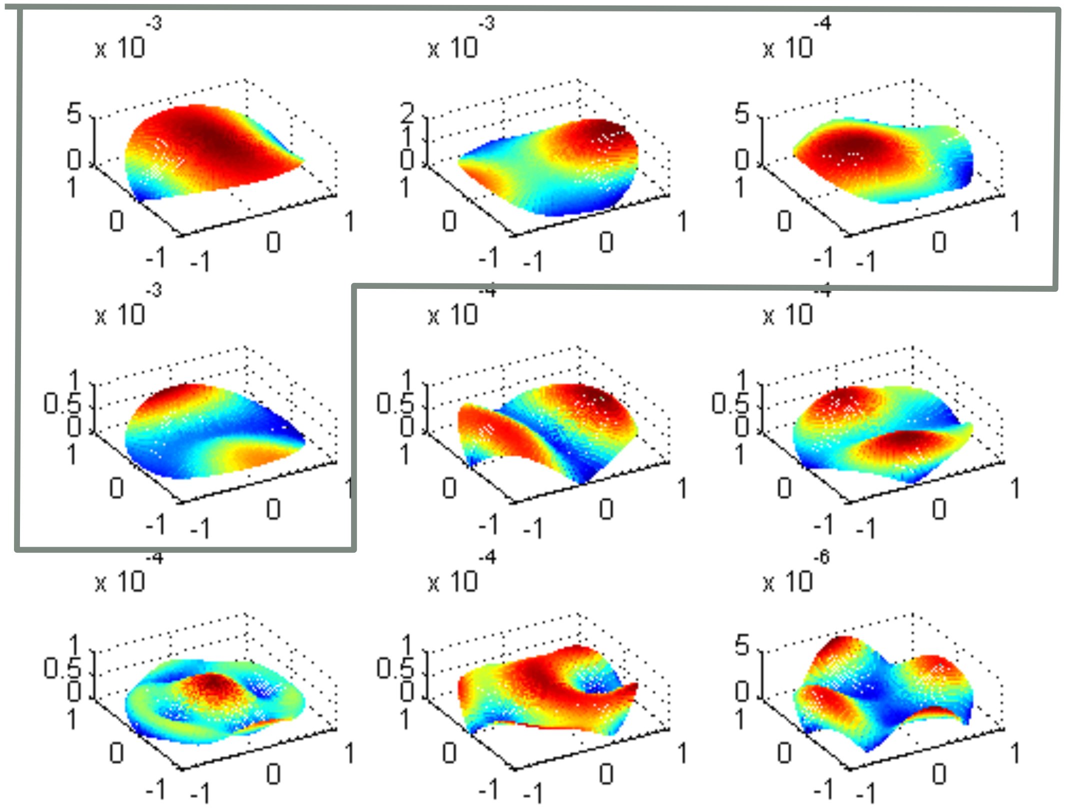
Positions in wavelengths

Elements are almost touching !

MBF patterns



Orthogonalized patterns



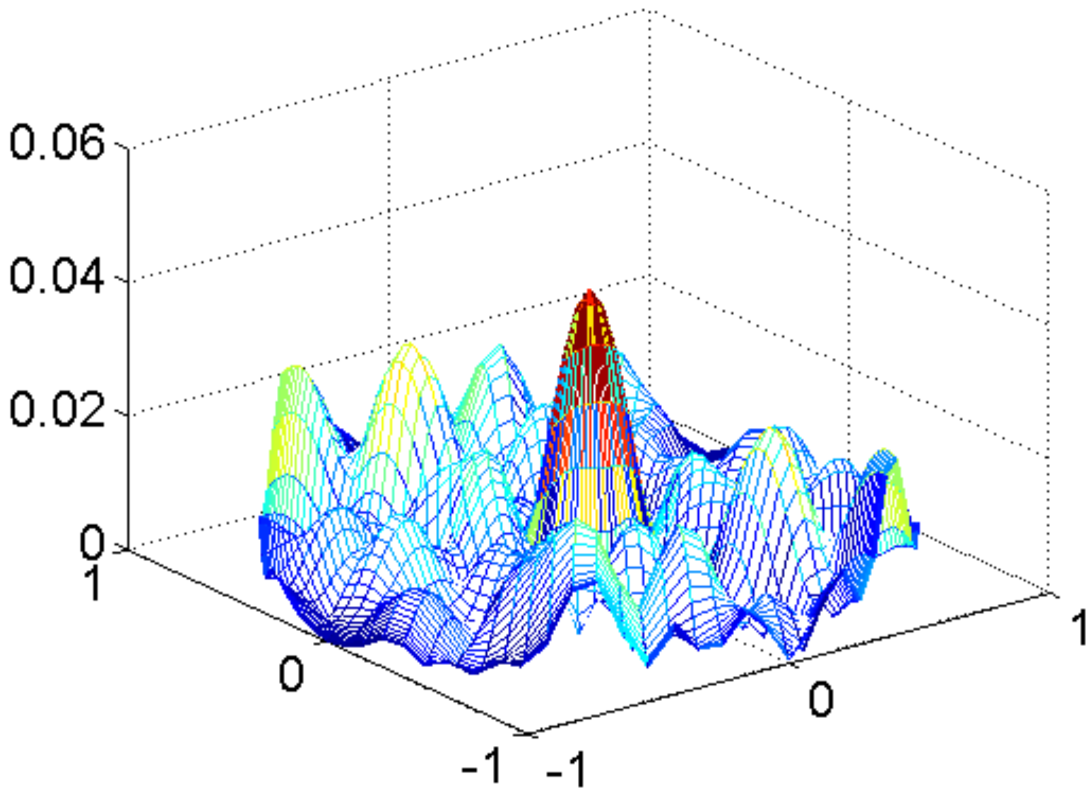
Pattern orthogonalized through Gram-Smidth procedure, 1st pattern is that of primary.

$$\vec{F}_p^{\circ} \simeq \sum_{q=1}^{Q<P} \alpha_{p,q} \; \vec{F}_q^{\circ,\mathrm{orth}}$$

$$\sum_{p}^{P} AF_p \, \vec{F}_p^{\circ} \simeq \sum_{q}^{Q<P} \left(\sum_{p}^{P} \alpha_{p,q} \; AF_p \right) \vec{F}_q^{\circ,\mathrm{orth}}$$

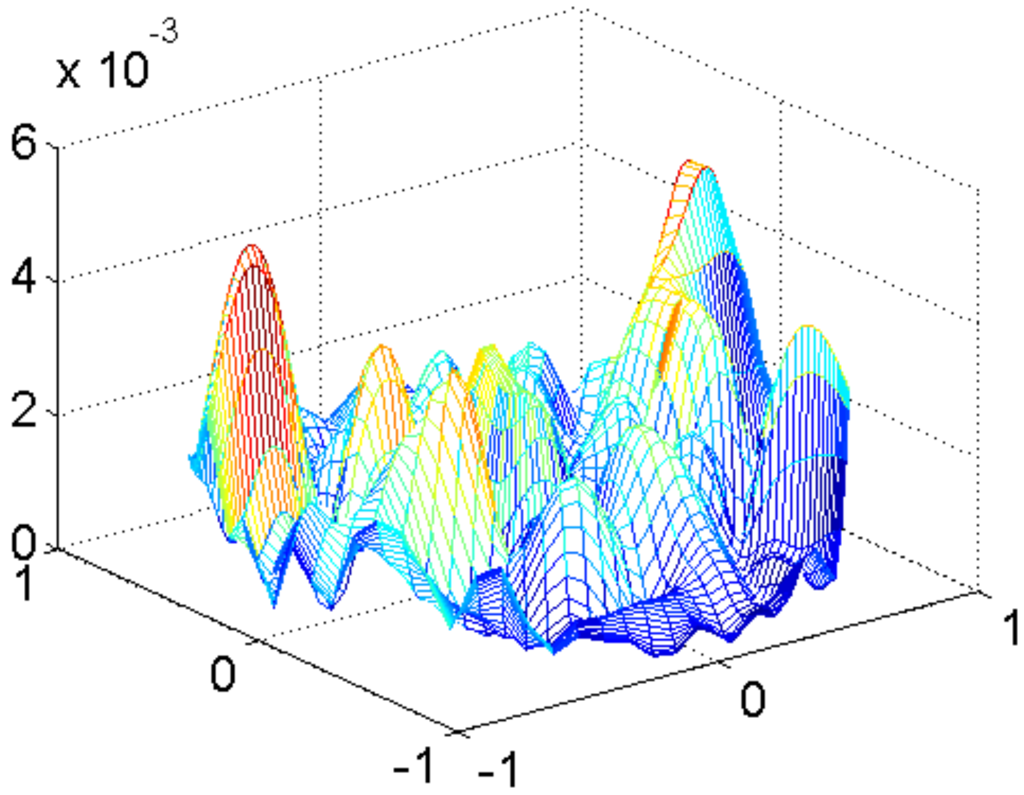
Project on Q=1, 2, 3, 4 patterns at most

Array pattern



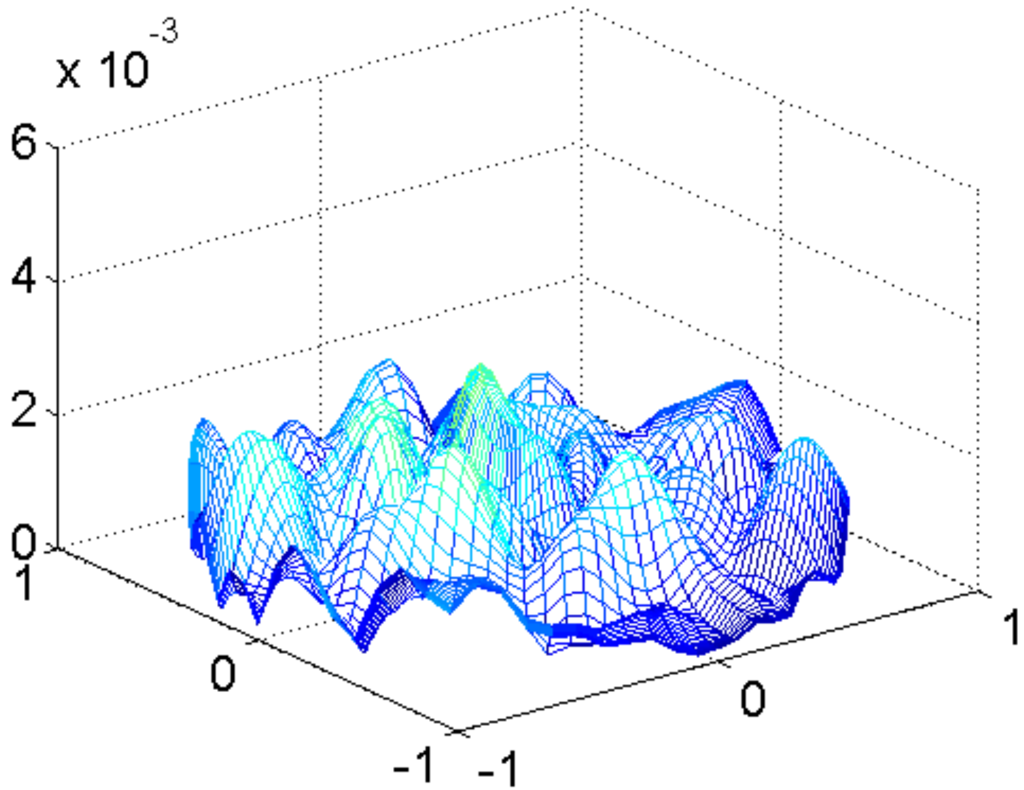
Array pattern |F|

Error after pattern projection



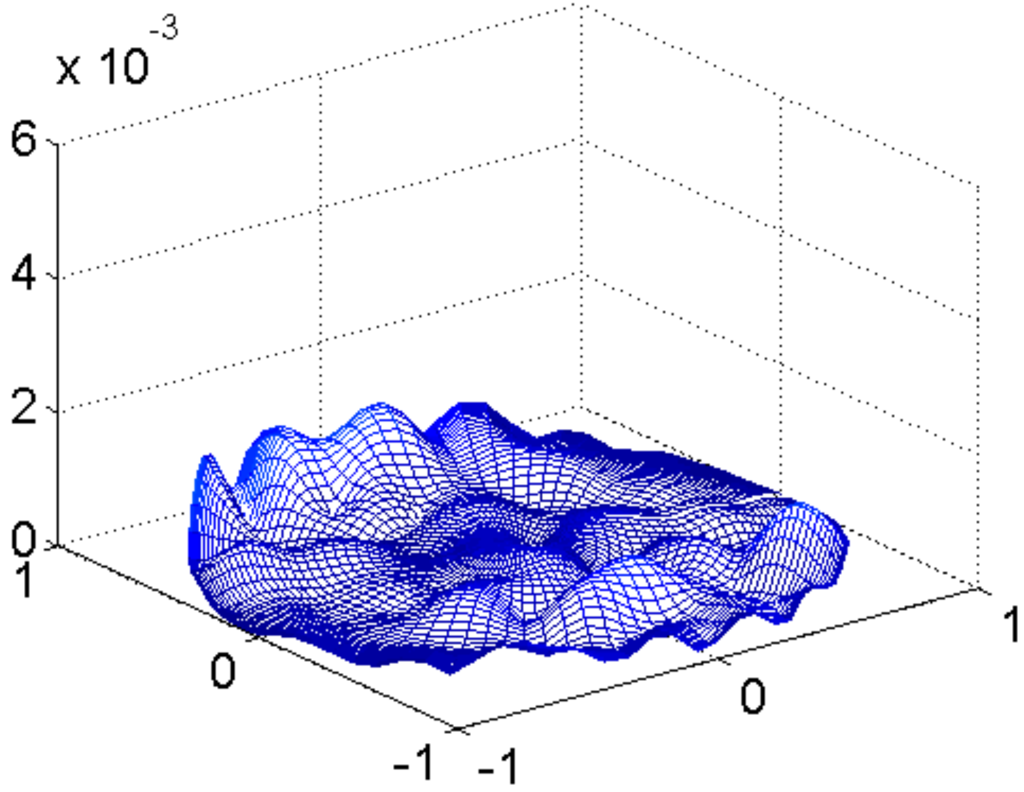
Error pattern $|F-F_{approx}|$ for Q=1

Error after pattern projection



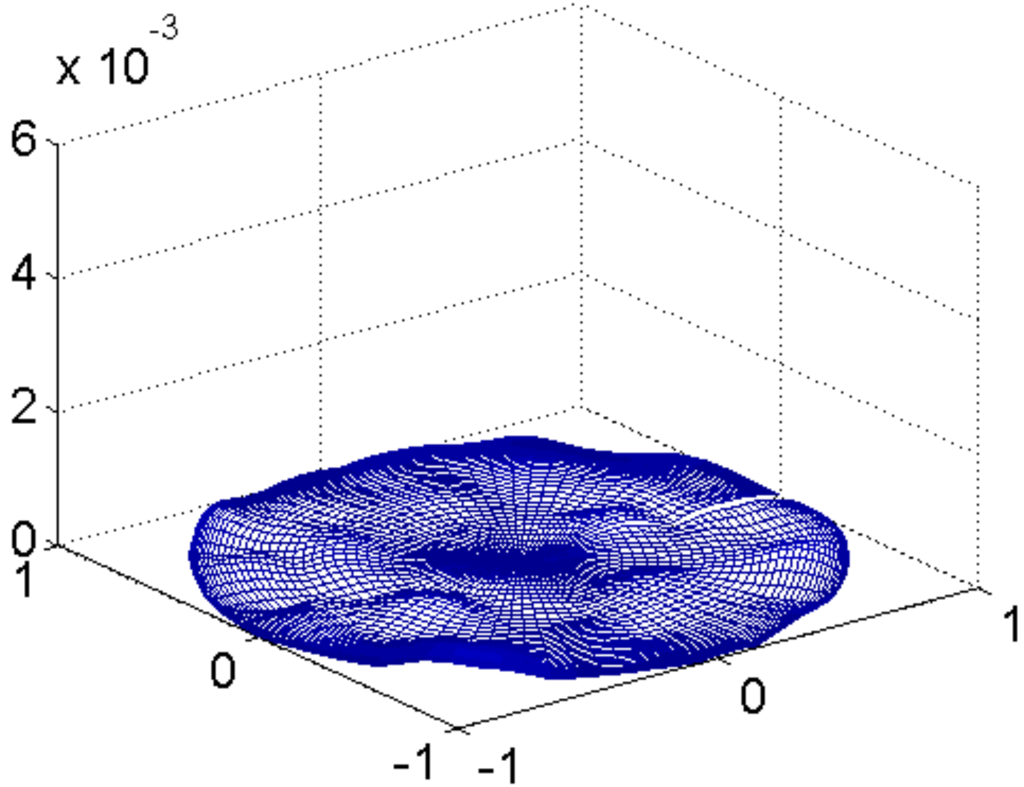
Error pattern $|F-F_{approx}|$ for Q=2

Error after pattern projection



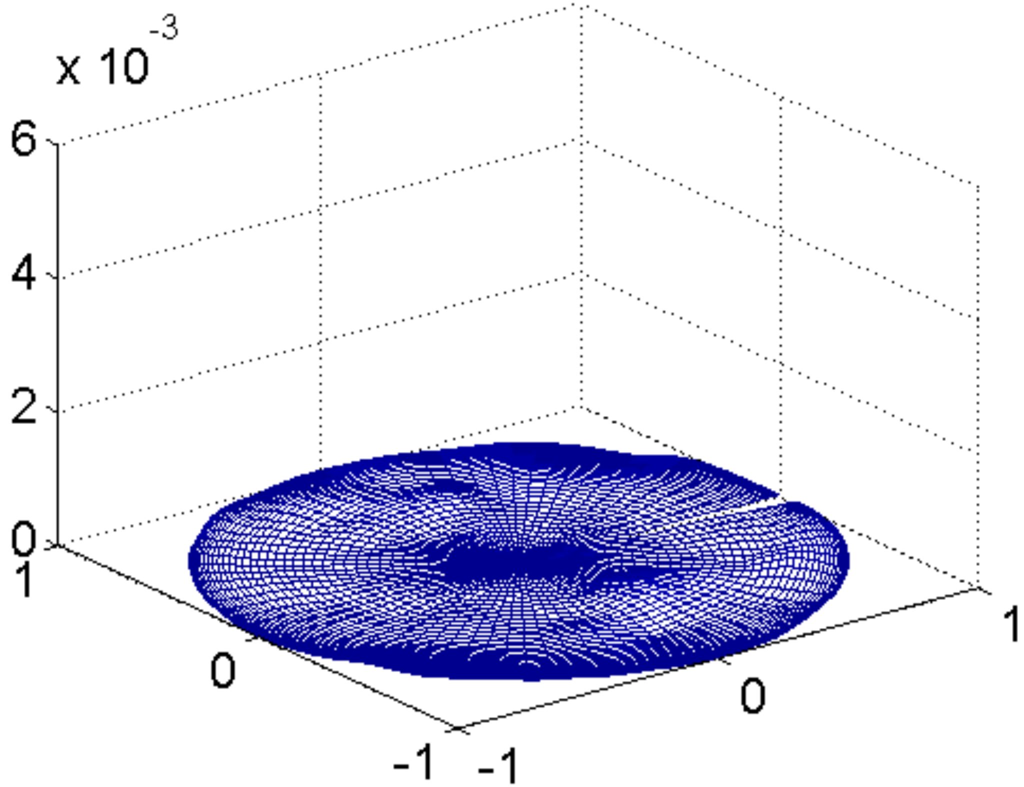
Error pattern $|F-F_{approx}|$ for Q=3

Error after pattern projection



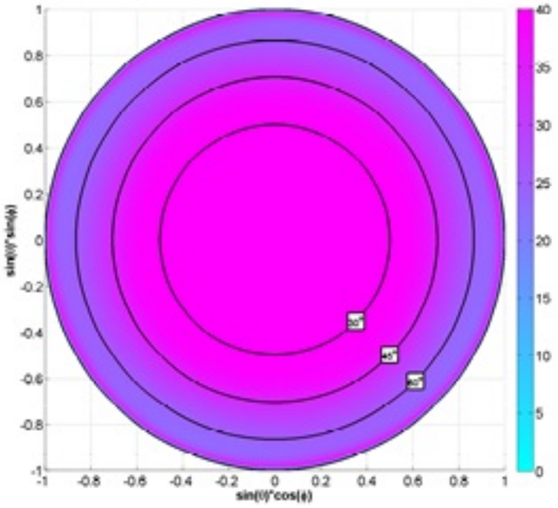
Error pattern $|F-F_{approx}|$ for Q=4

Error after pattern projection

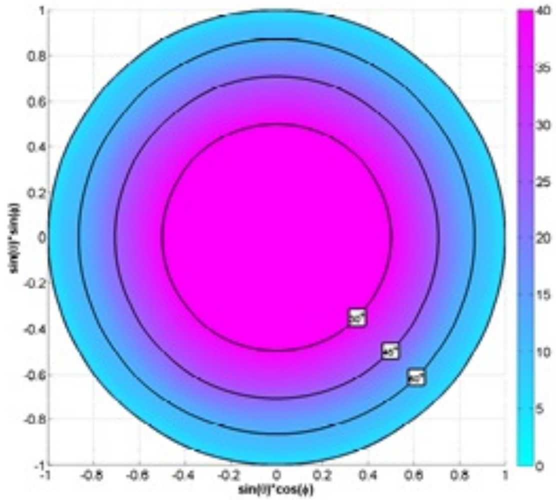


Error pattern $|F-F_{approx}|$ for Q=5

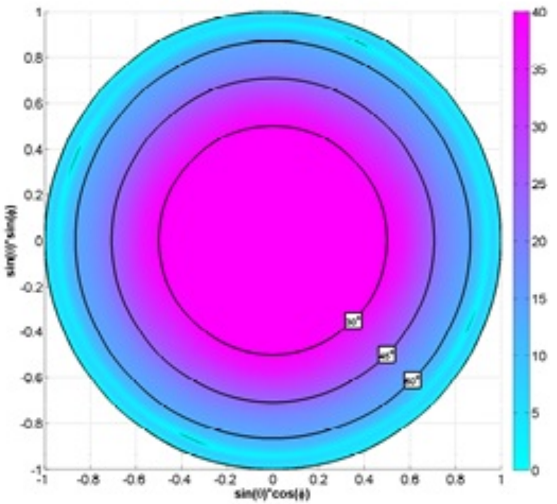
Before the end… *IXR* for SKALA element



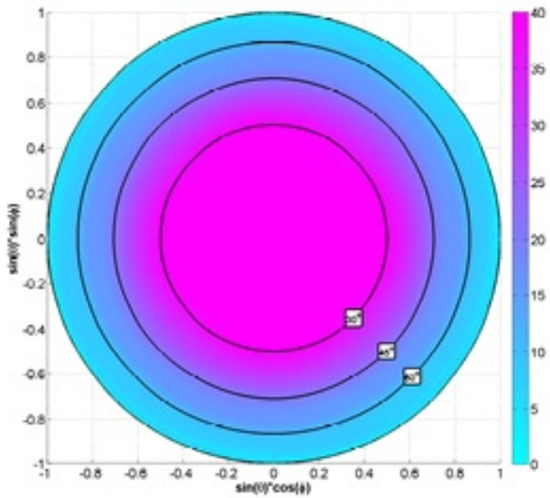
100 MHz



200 MHz



300 MHz



400 MHz

$$IXR_J = \left(\frac{\kappa(J)+1}{\kappa(J)-1}\right)^2$$

Conclusions

- Great tool available. Many lessons learnt about aperture array beams: average EEP, edge effect, etc.
- MBFs => Finite series of pattern multiplications
- Representation of array factors with functions used for ~circular apertures. Fast convergence.
- Further reduction through projection of MBF patterns on a few patterns. Fast convergence.
- Better selection of subset of orthogonal patterns: Average EEP?
- Need to link all this to the efforts of others…
- Science/calibration requirements must get to the lab/workshop sooner rather than later (IXR, etc.)

Thank you!

- Questions?