Efficient simulation of finite wideband arrays for focal plane applications

From large to small, and back

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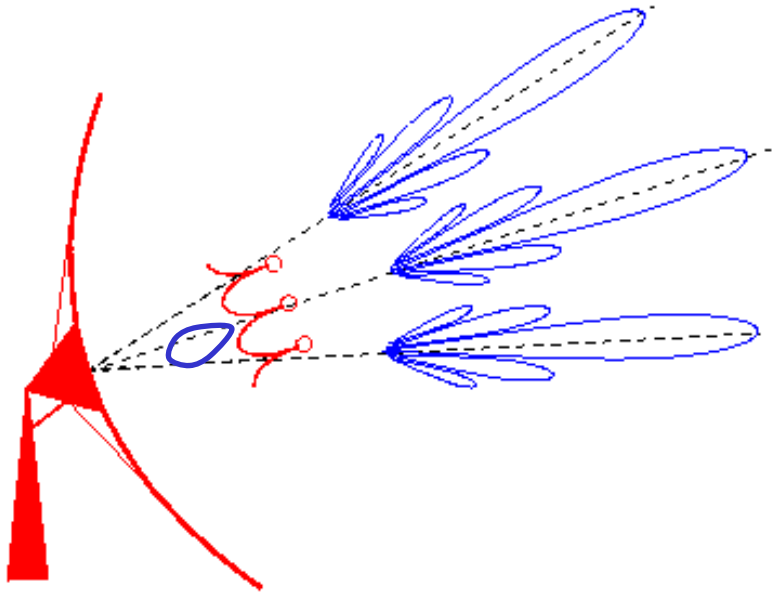
Outline

Update w.r.t. presentation at May 2004 PFA workshop:

- Further **validation** of the finite-by-infinite array approach.
- Full-wave simulation of wideband line feeds in **cylindrical reflector**.
- **Ongoing extensions:** antennas containing finite dielectric material + Fast Multipoles approach + addition on thermal noise from lossy antennas.

PFA's: fundamental quantities needed



- Element patterns in array conditions*: the patterns are defined in a way automatically involving the matching issue.
- Coupling coefficients (for noise computations, essentially).

* Will also include the effect of the reflector for the cylindrical reflector case.

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Goals in the field of astronomy

- **Continue progress** in the field of numerical simulations, along the lines adopted since Jan. 2000. Frequency domain approach. (i) infinite arrays+corrections and (ii) wave phenomenology inside the array.
- Let the **application** involve us in **new fundamental questions** in EE.
- Consider astronomy as an application which can **attract students** in fundamental disciplines of electrical engineering.
- **Contribute** to a field where the challenge-to-ressources ratio is huge. Obtain **leverage** from other research projects.
- **Cooperate** with many groups over the world.
- Have **fun**…

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UCL ANTENNA GROUP (C. Craeye):

• **Ph.D. students:** X. Dardenne, P. Druyts, B. Hubert, R. Mateos, L.Aberbour, X. Radu, Th. Gilles.

• **05-06 Master's students:** S. Mutha, B. Matthyssen, B. Pagost, D. Dancila.

Other names at UCL in microwaves and numerical techniques: A. Vander Vorst, B. Stockbroeckx, I. Huynen, J-P. Raskin, J-F. Remacle, P. Sobieski, I. Vandenbosch.

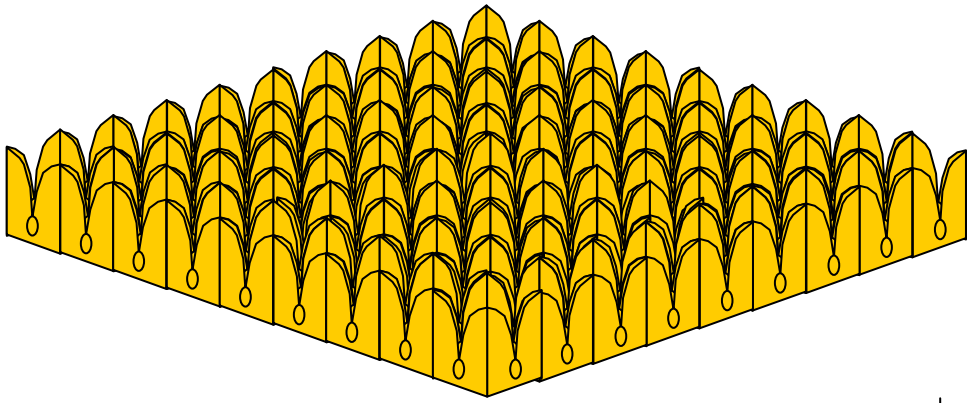
Courses taught: antennas, electromagnetics, transmission lines.

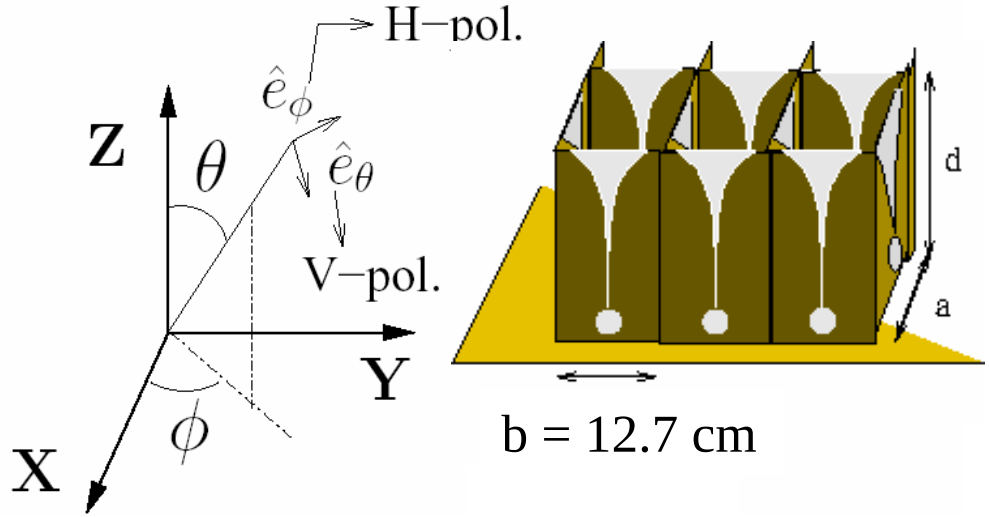
Funding sources: FNRS, Région Wallonne, ESA, Marie-Curie, Belgian Military Academy.

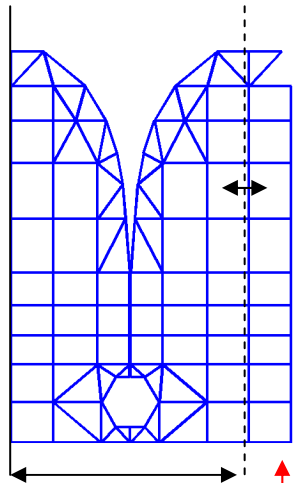
International cooperation: COST284 on antennas, COST297 on HAP's, Metamorphose NoE, Siena, UMass, HUT, DRAO…

meta morphose

Reference geometry



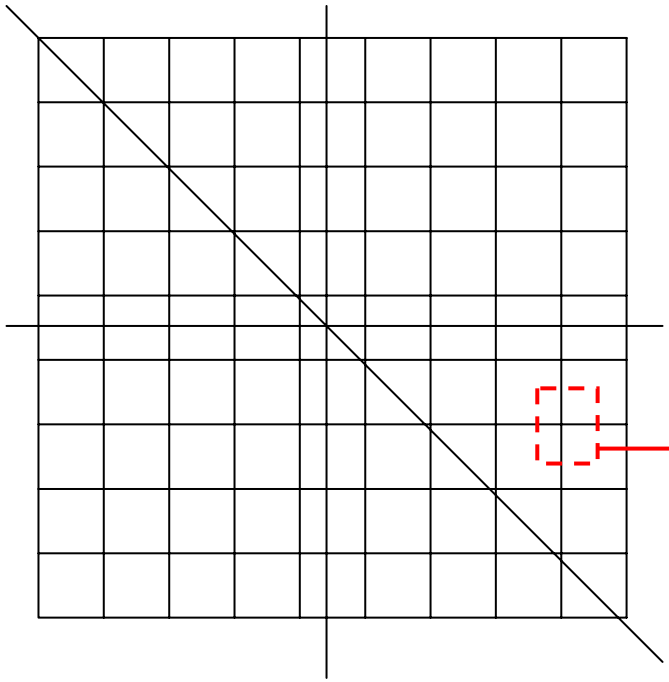




Not exactly a **periodic** structure, because of **connections** between antennas !!!

From small to large

Exploit the symmetry of the array



8X9X2 array
(180 antennas)
seen from top

Array ≠ repetition of this cell !!

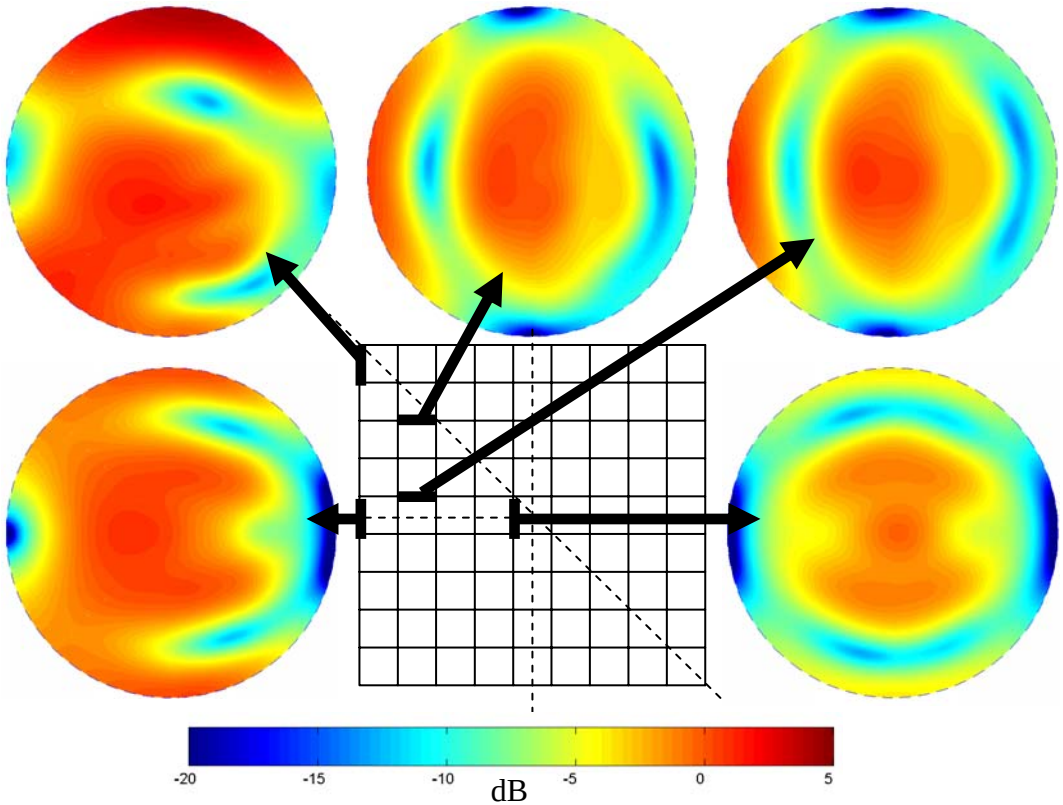
Save a factor of 16 in both RAM memory and inversion time by exploiting symmetry AND obtain all the patterns at each run.

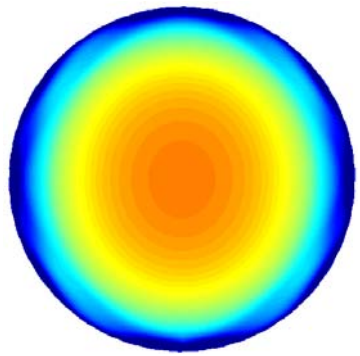
NB: special attention given to basis functions and sources crossing the planes of symmetry.

Finite-array simulations

180 elements

Element patterns at 440 MHz





Infinite-array pattern

Fine for small arrays: **data available on request**

[14] Brisken W., Craeye C., « Focal-plane array beam-forming and spill-over cancellation using Vivaldi anten-nas, » *EVLA memo 69*, Jan 04. www.aoc.nrao.edu/evla/memolist.shtml

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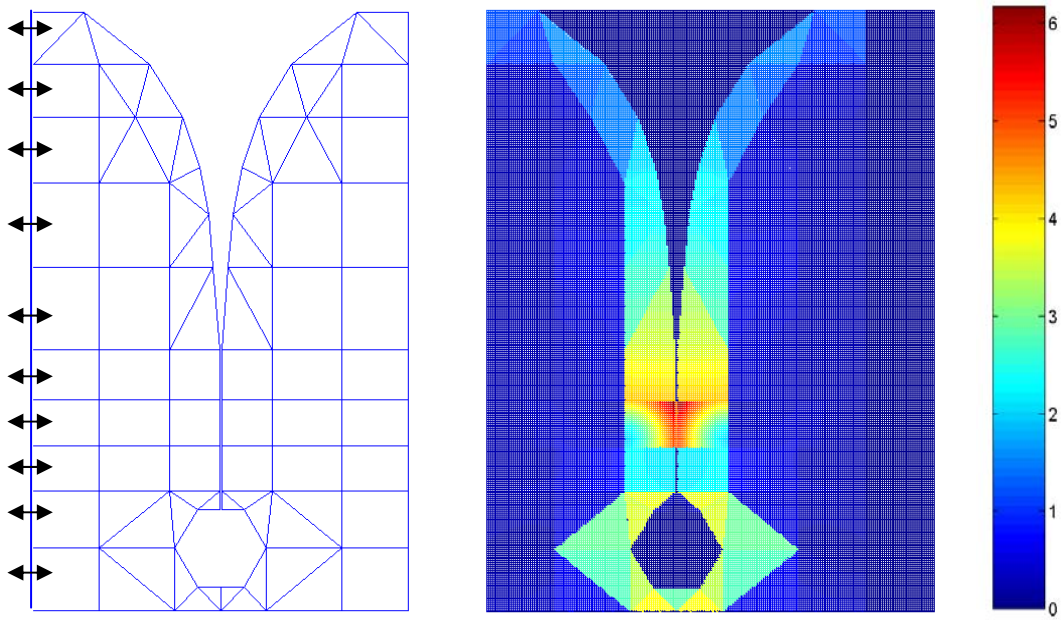
From large to small

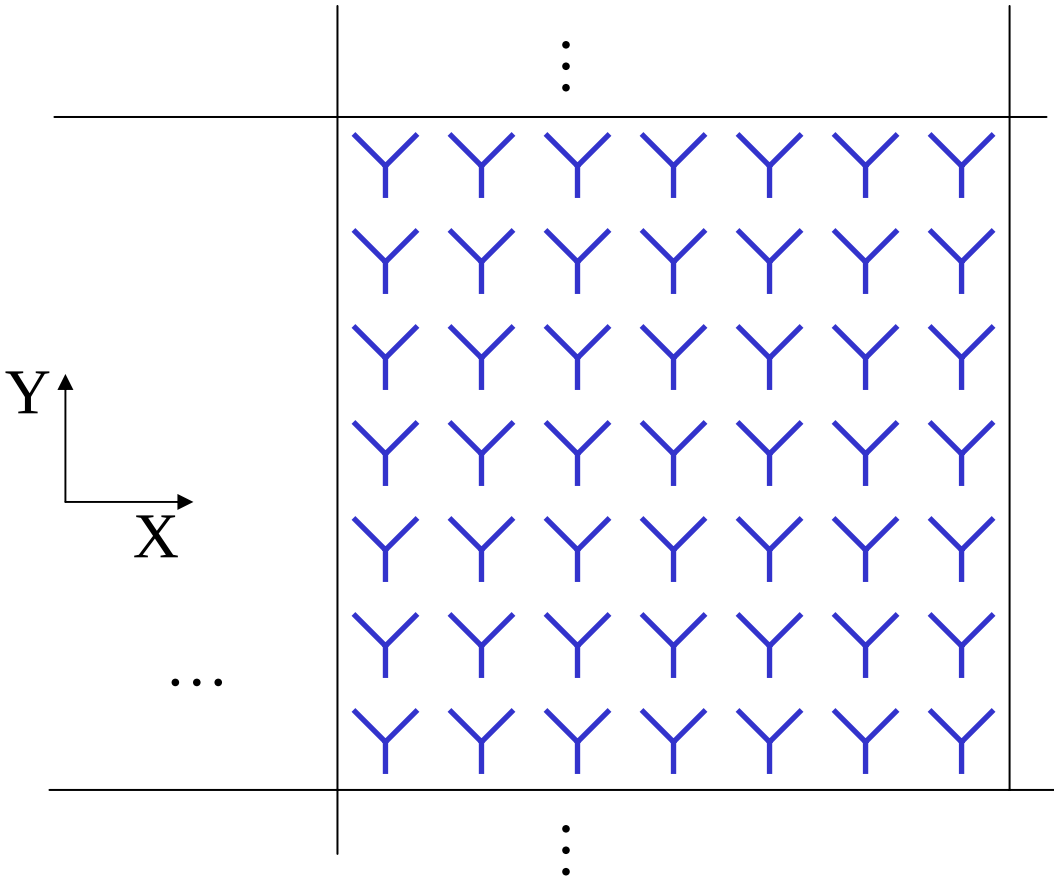
The infinite-array solution computed with the help of the Method of Moments



Mesh of the antenna surface and current distribution at 1 GHz.

From large to small

Finite-by-infinite array approach



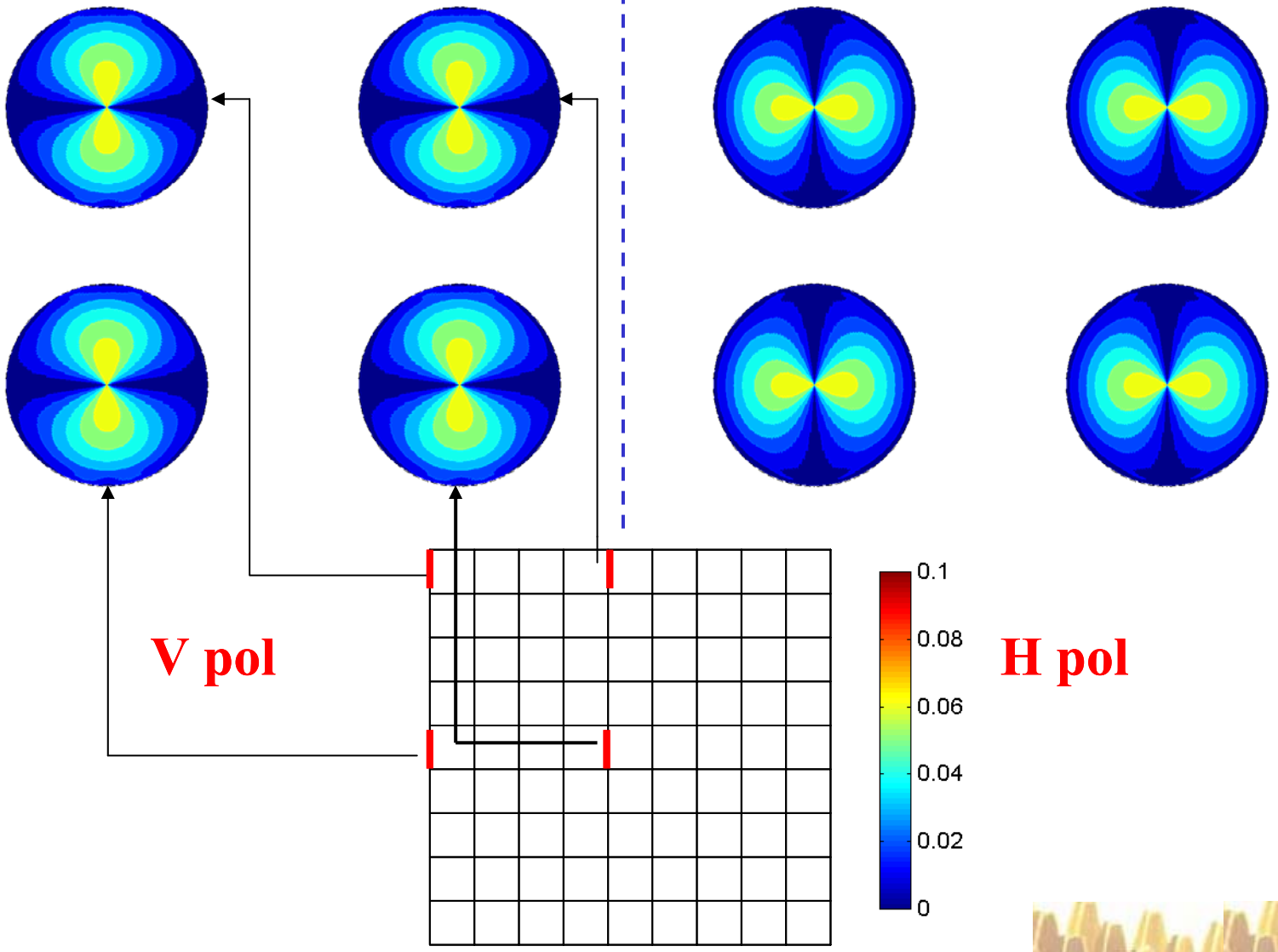
Can also be applied to hexagonal arrays (Maci et al.)

Correct for array truncation in the two principal directions

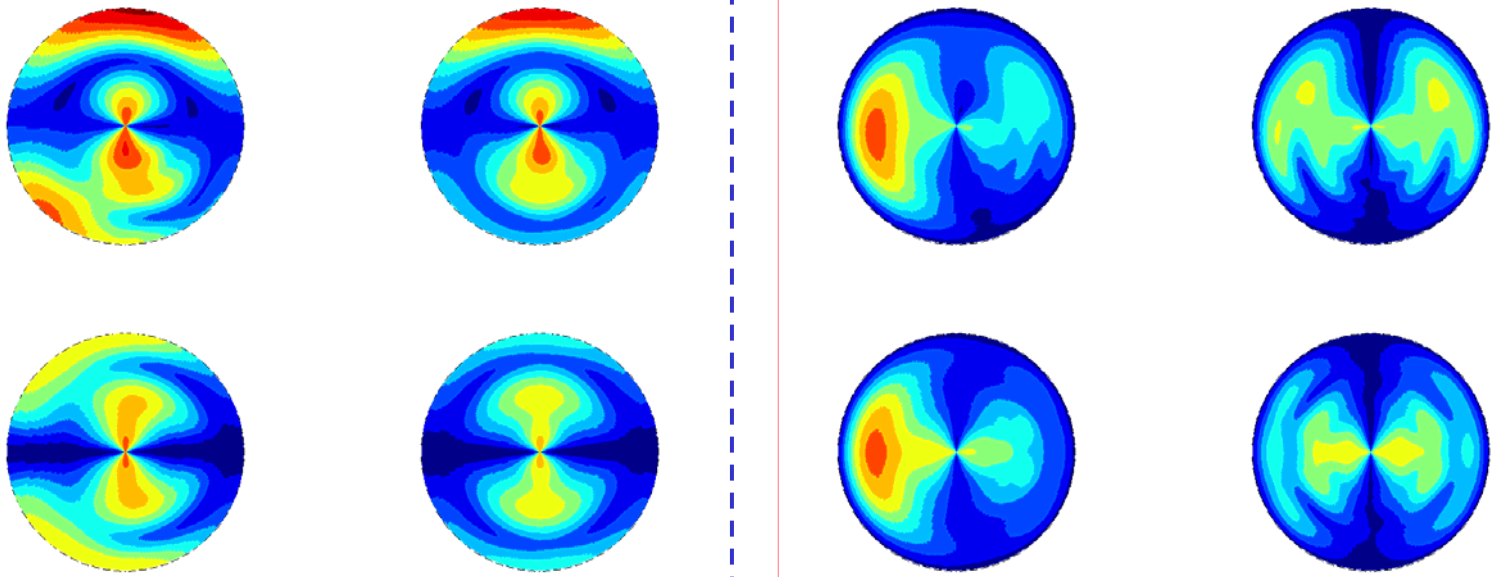
…

5 min

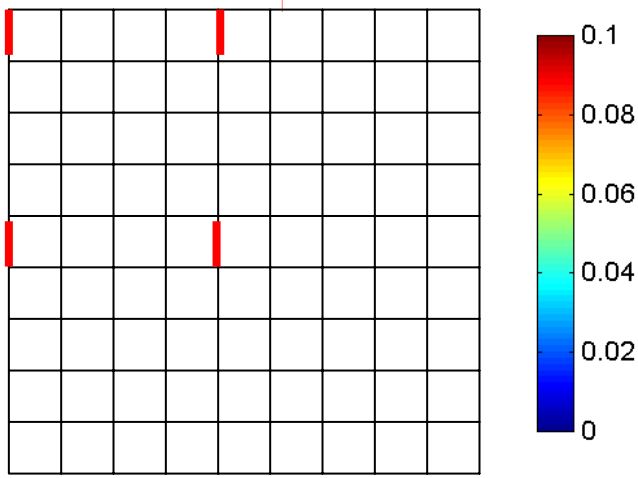
Element patterns at 500 MHz : infinite array



Element patterns at 500 MHz : exact

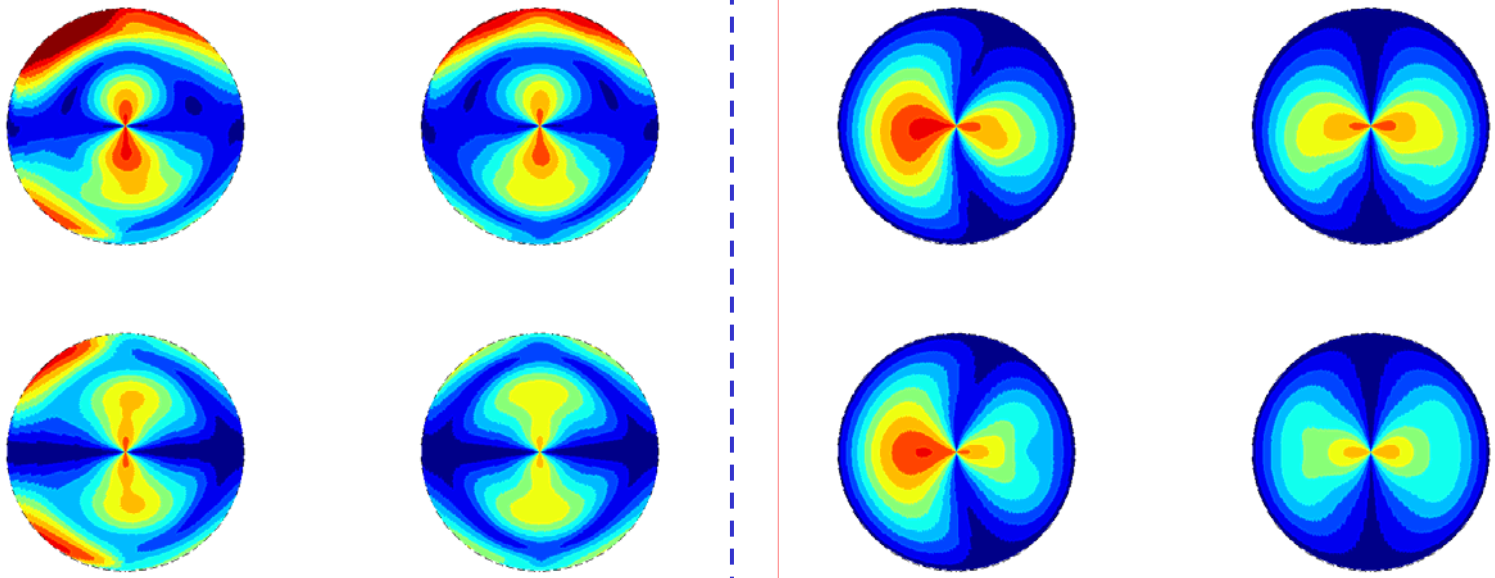


V pol

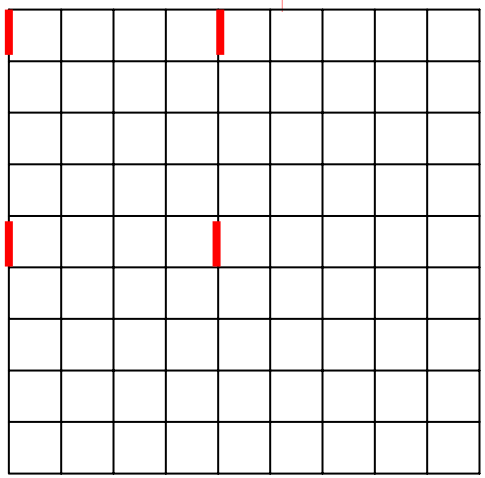


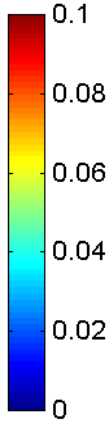
H pol

Element patterns at 500 MHz : finite-by-infinite



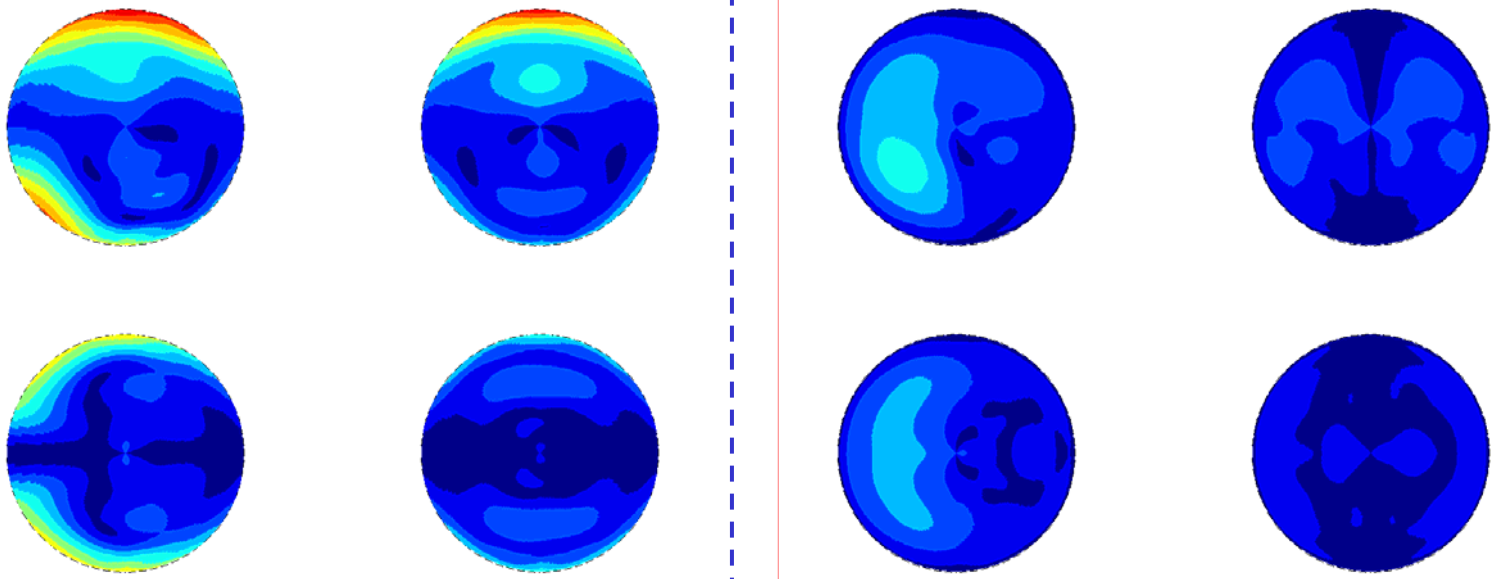
V pol



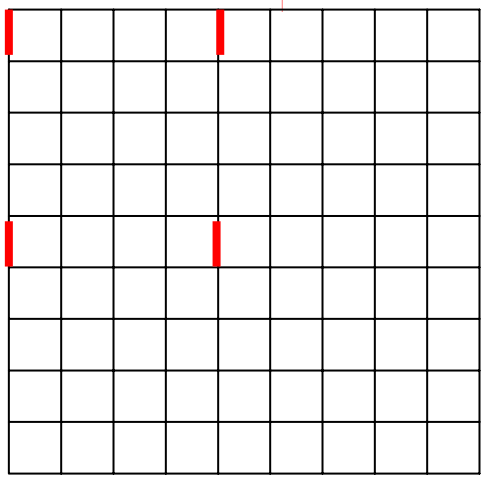


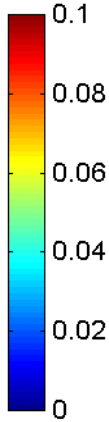
H pol

Element patterns at 500 MHz : error from infinite-array



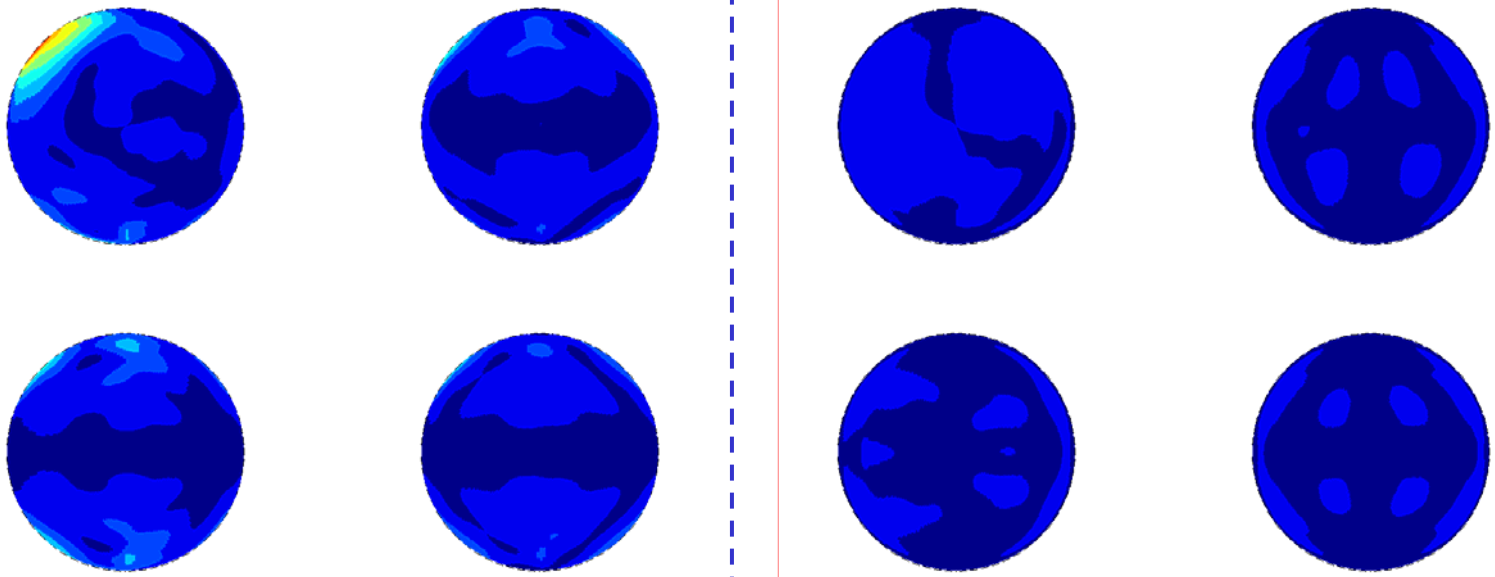
V pol



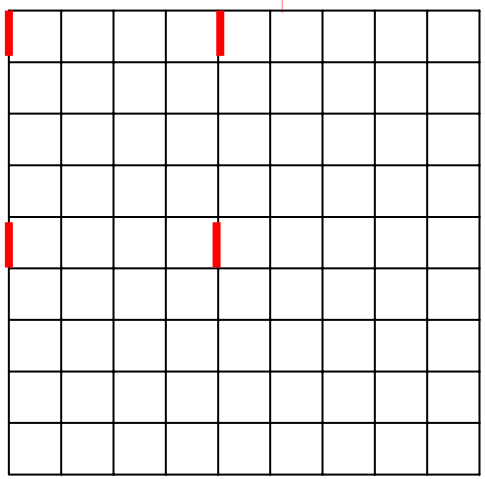


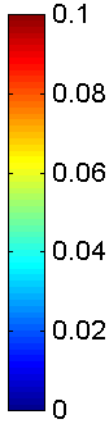
H pol

Element patterns at 500 MHz : Error from finite-by-infinite



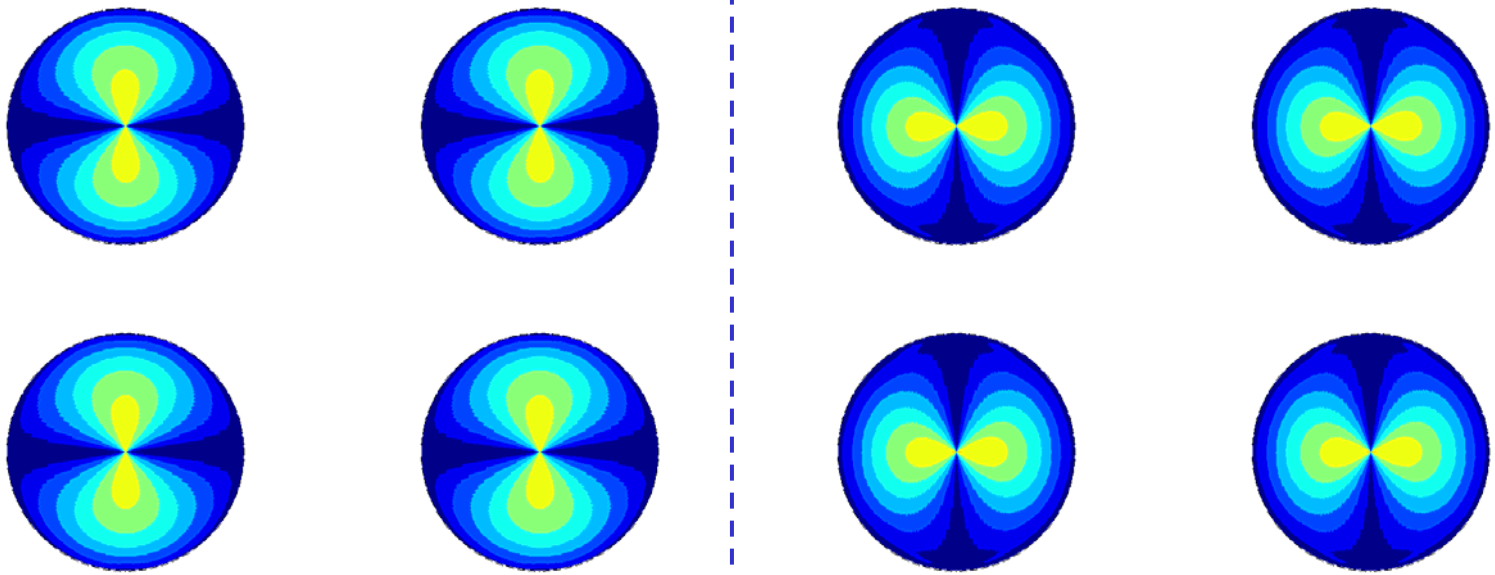
V pol



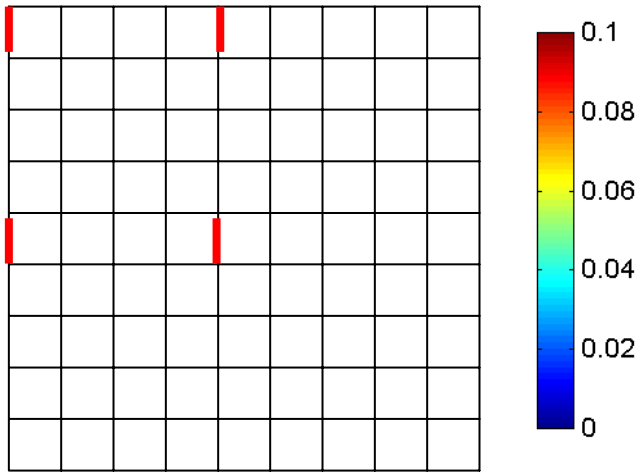


H pol

Element patterns at 1 GHz : infinite array

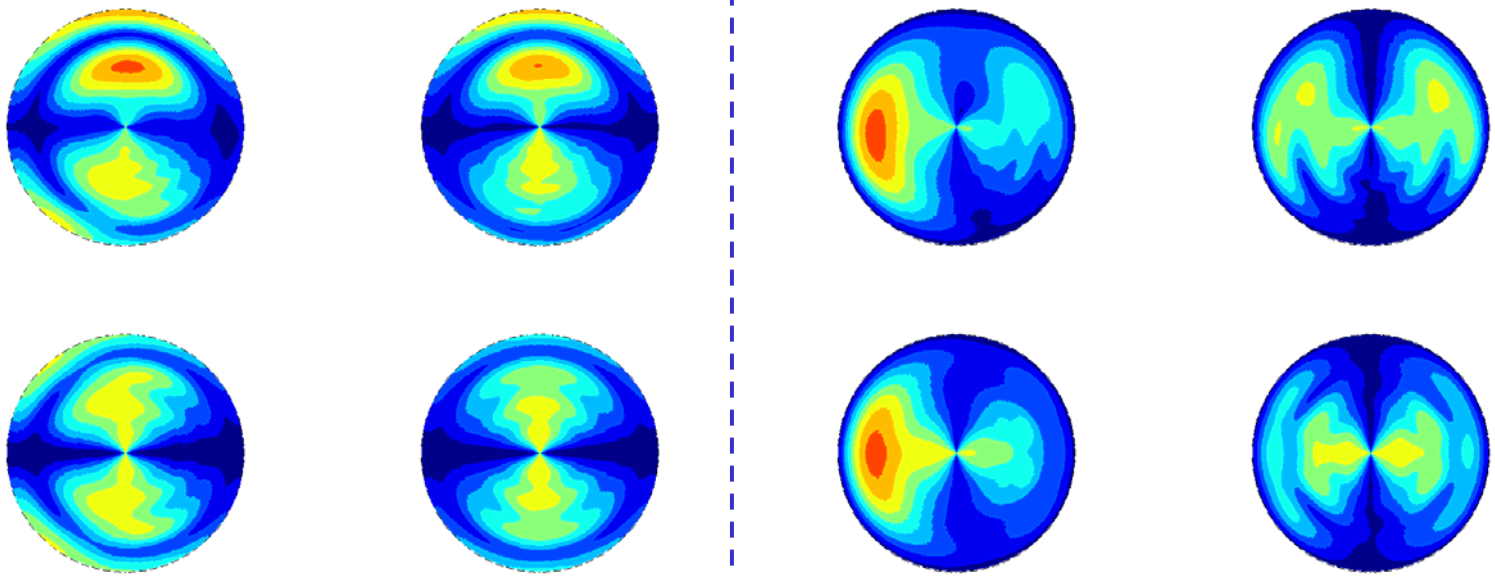


V pol

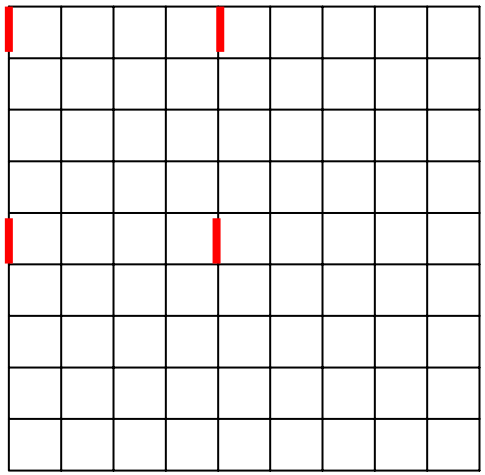


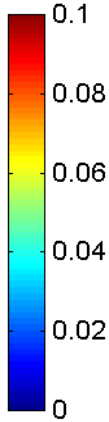
H pol

Element patterns at 1 GHz : exact



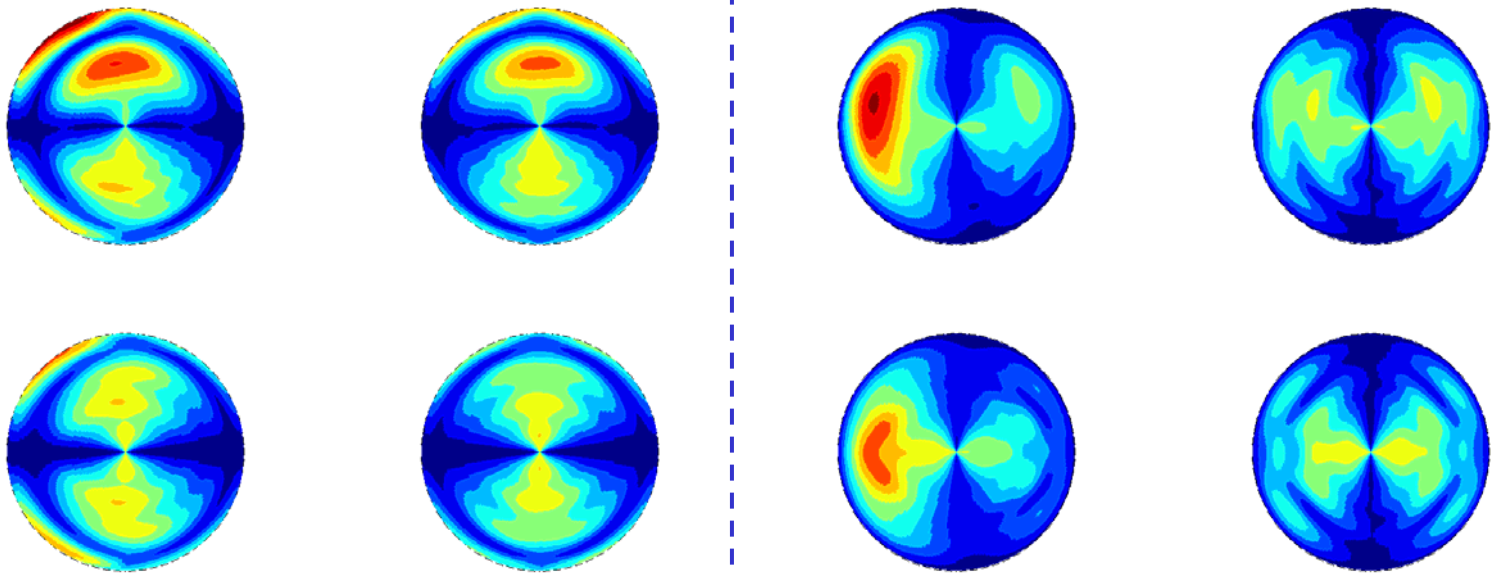
V pol



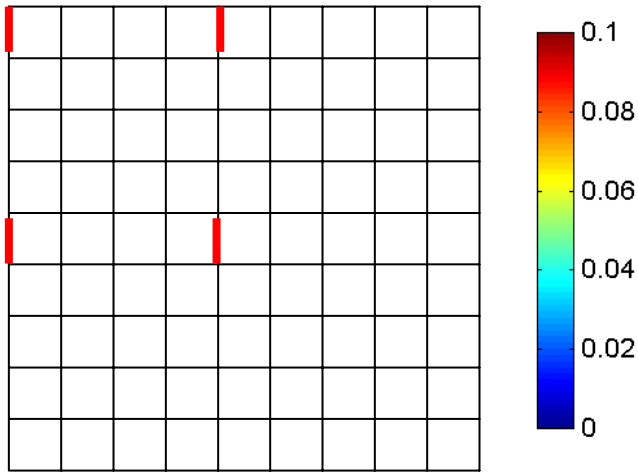


H pol

Element patterns at 1 GHz : finite-by-infinite

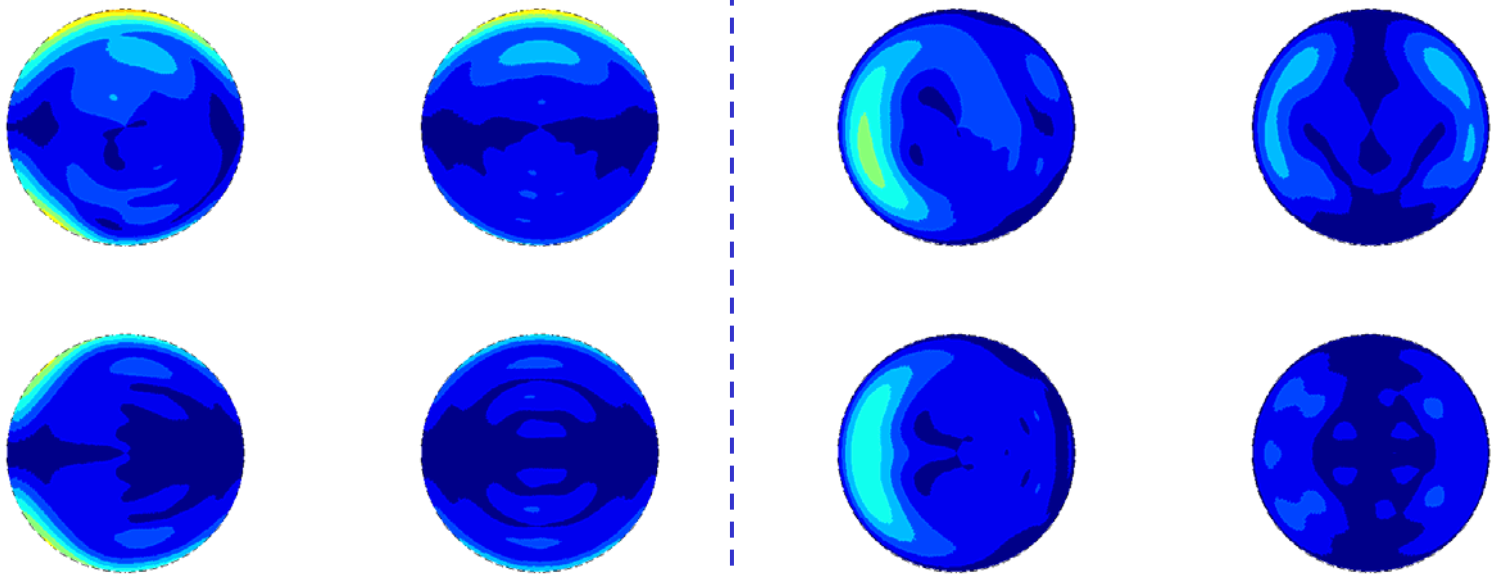


V pol

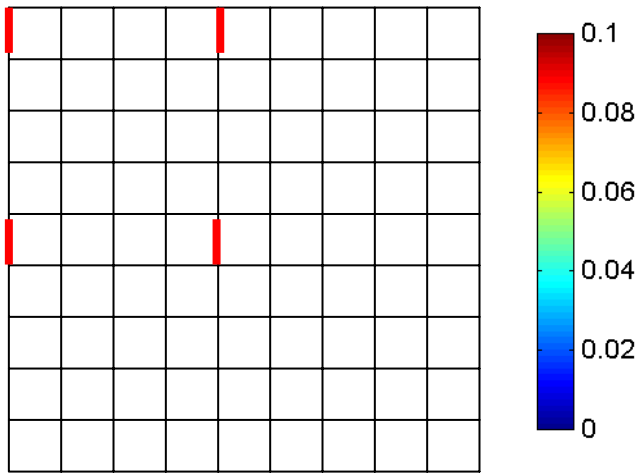


H pol

Element patterns at 1 GHz : error from infinite-array

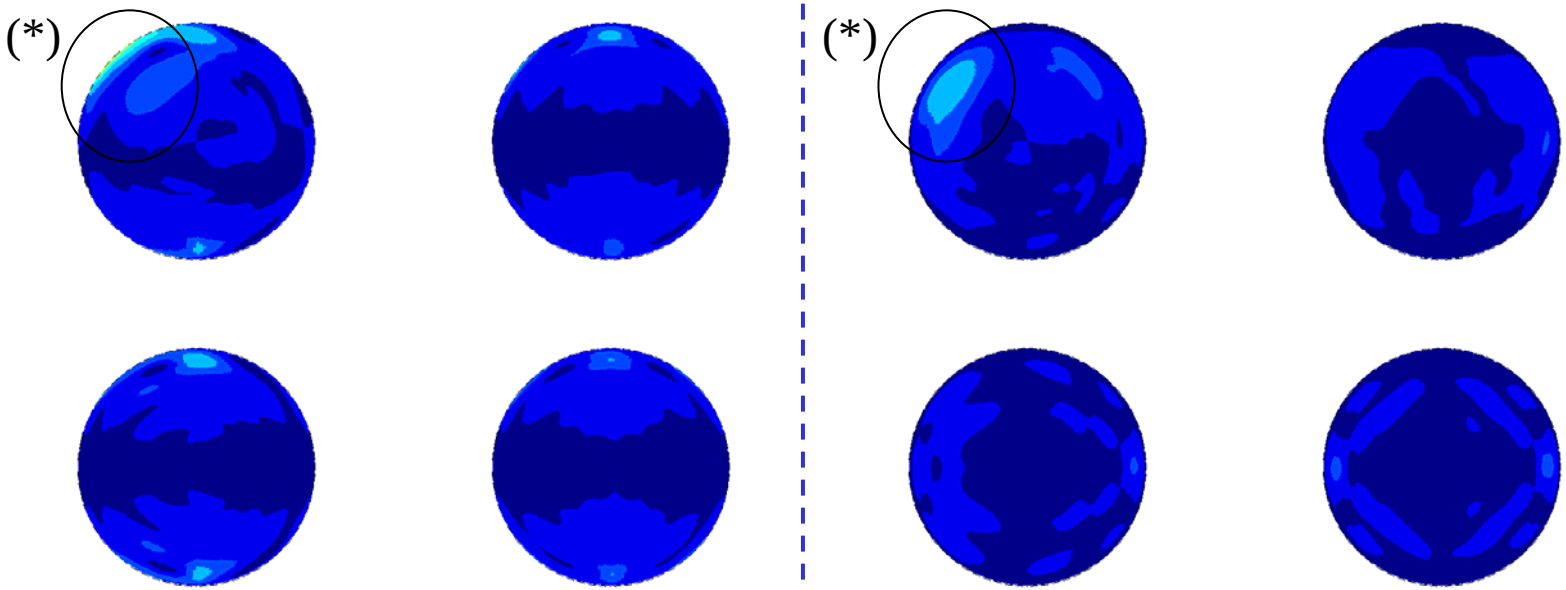


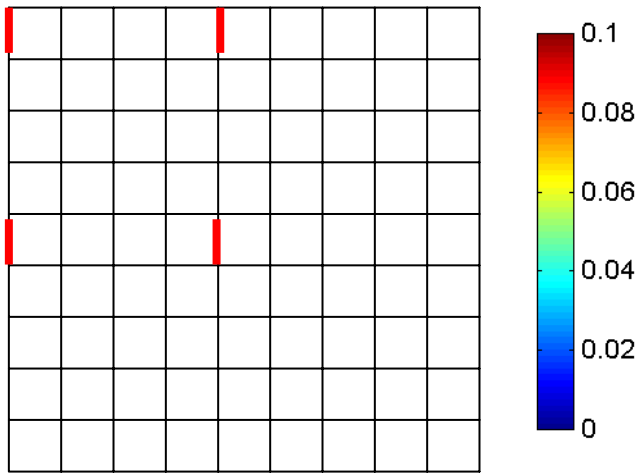
V pol



H pol

Element patterns at 1 GHz : Error from finite-by-infinite





V pol

H pol

(*) larger errors in corners corrected with special procedure

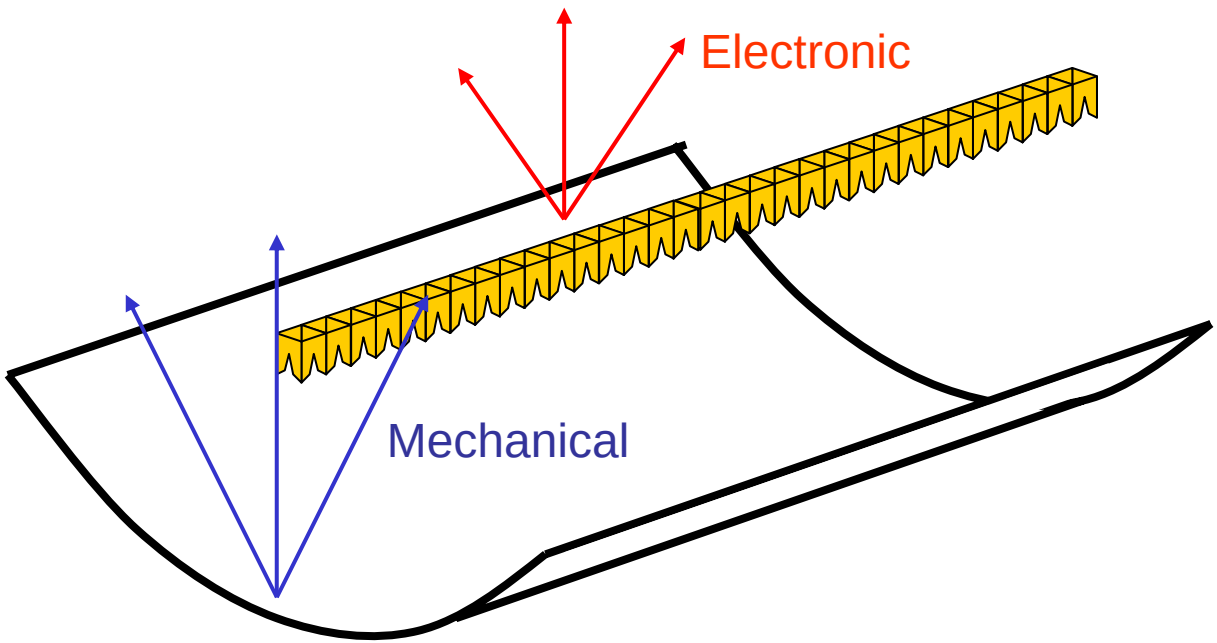
12 min

Cylindrical reflectors

Mix of mechanical and electronic scanning.

Trade-off between cost/complexity and adaptive capabilities

Possibility to cool the whole focal line ?

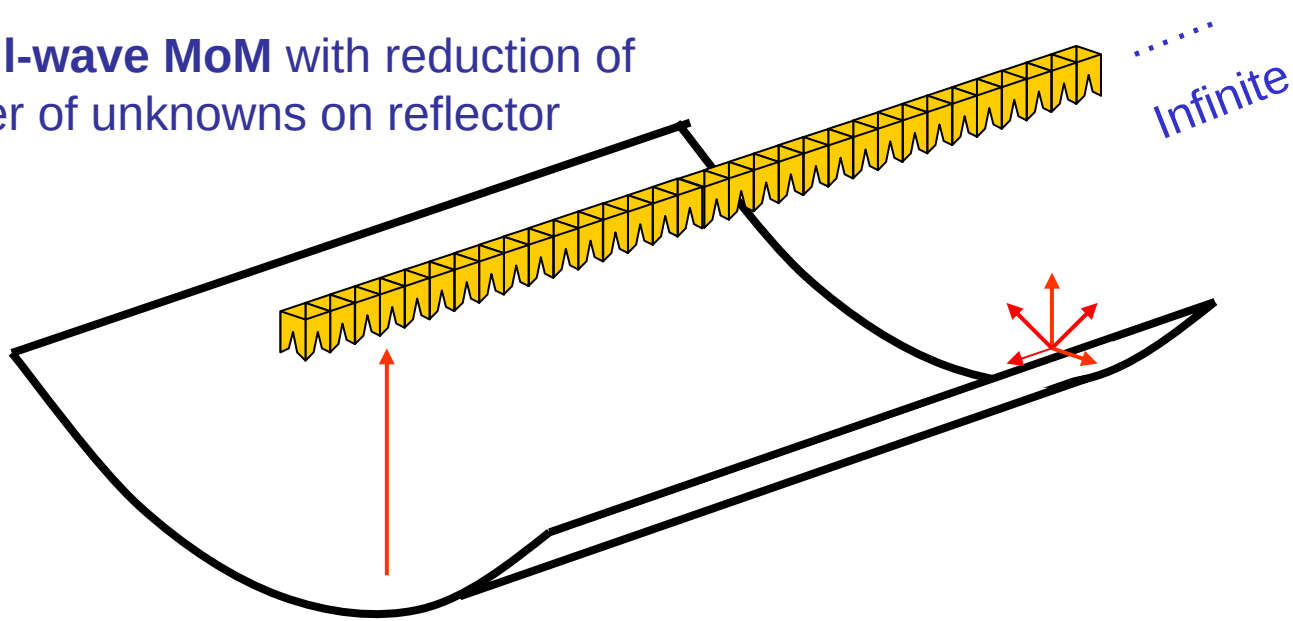


Array-reflector interaction

(a) primary element patterns of antennas in the array,
(b) secondary pattern obtained after reflection.

Step (b): physical optics + diffraction by edges + blockage
=> not so easy !

=> **Full-wave MoM** with reduction of number of unknowns on reflector

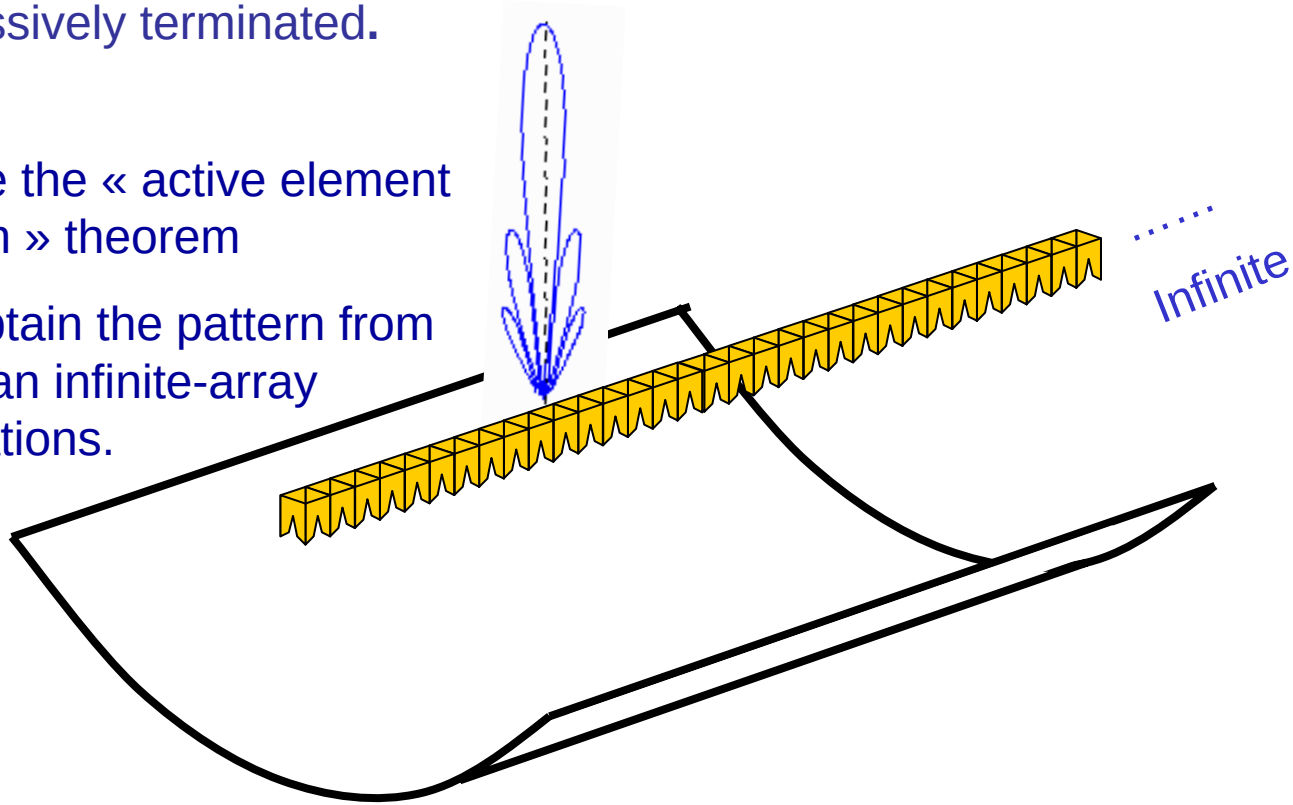


Element patterns

Compute the « **embedded element pattern** », i.e. the **secondary** pattern when one element is excited, the other ones are passively terminated**.**

⇒ Use the « active element pattern » theorem

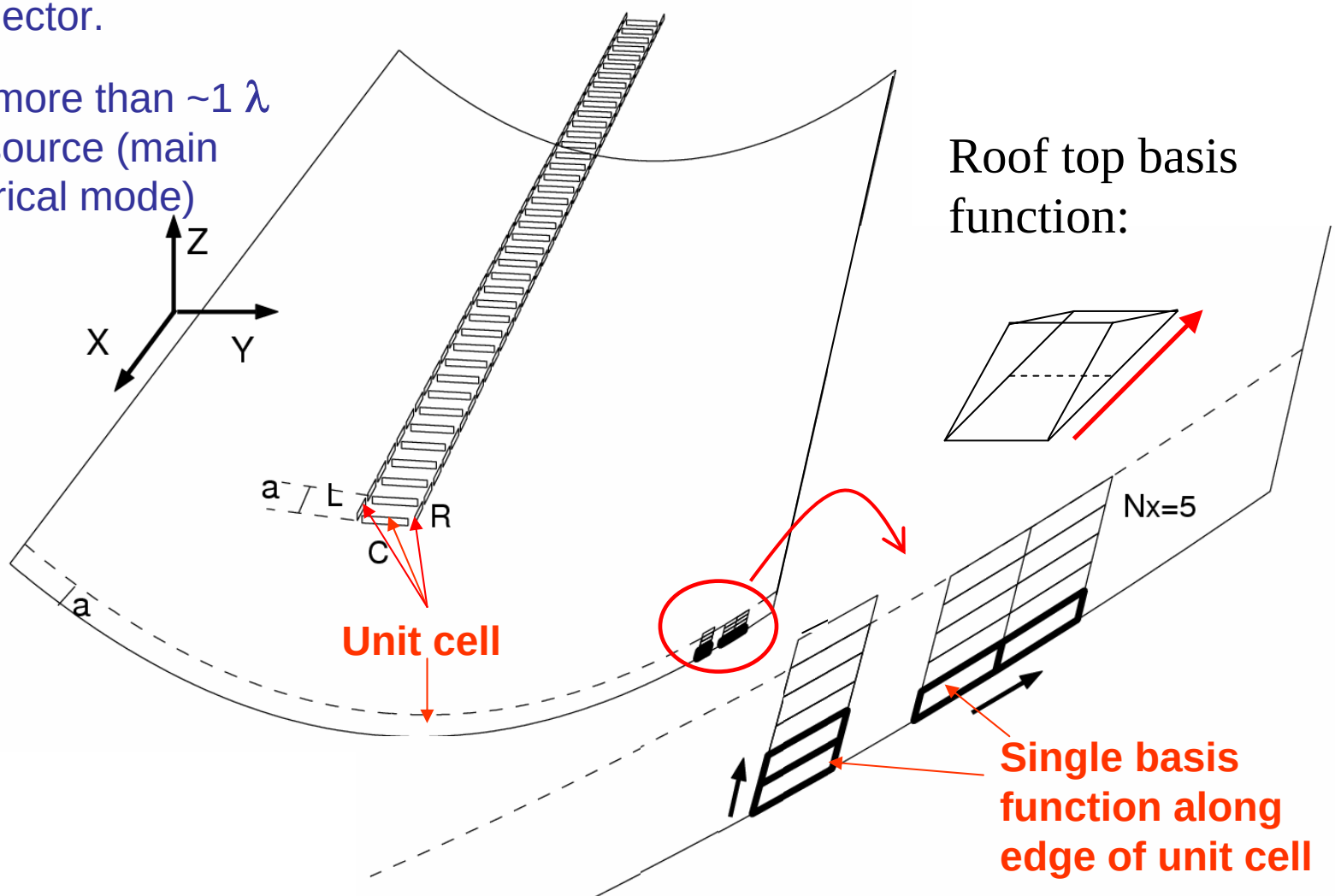
i.e. obtain the pattern from full-scan infinite-array simulations.



Reduction of unknowns

Hypothesis: linear phase progression of currents on reflector.

OK if more than ~1 λ from source (main cylindrical mode)



MoM system of equations

$$\begin{array}{c|cc} & \text{array} & \text{reflector} \\ \hline \text{array} & \underline{\underline{Z}}_{ss} & \underline{\underline{Z}}'_{rs} \\ \text{reflector} & \underline{\underline{Z}}_{sr} & \underline{\underline{Z}}'_{rr} \end{array} \begin{bmatrix} \underline{x}_s \\ \underline{x}_r \end{bmatrix} = \begin{bmatrix} \underline{v}_s \\ \underline{0} \end{bmatrix}$$

Currents on array

Excitation

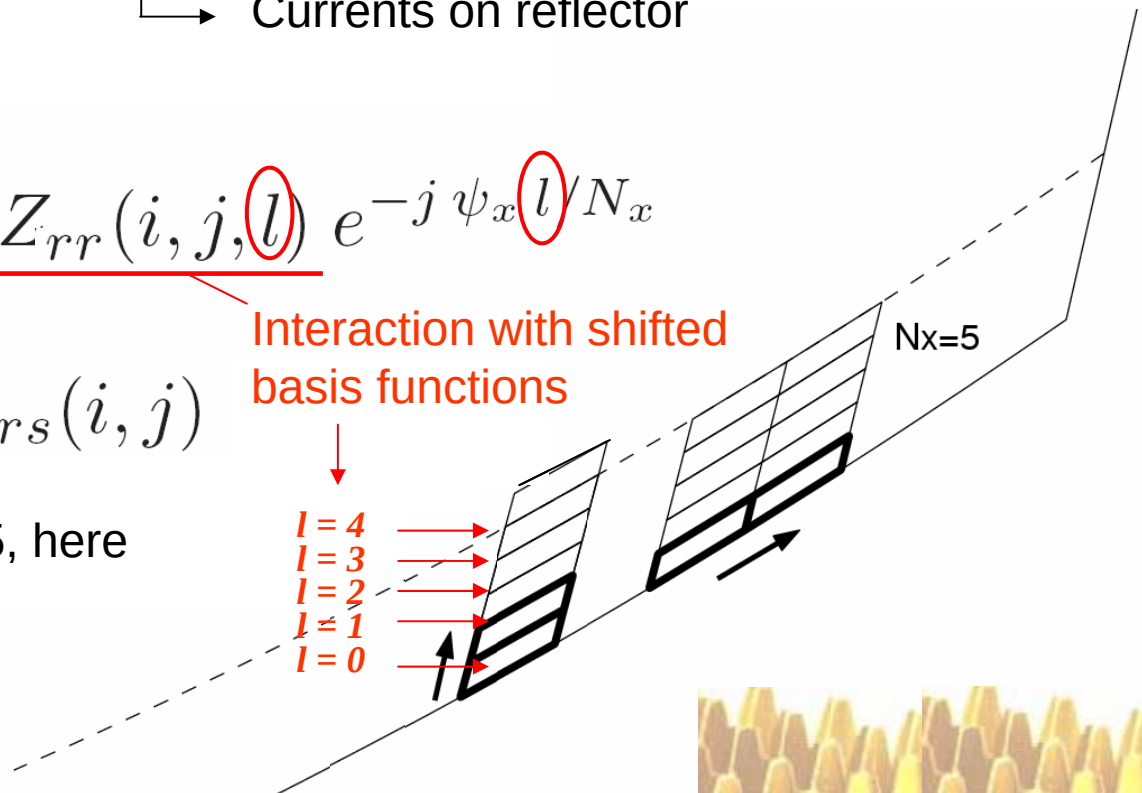
Currents on reflector

$$Z'_{rr}(i,j) = \sum_{l=0}^{N_x-1} Z_{rr}(i,j,l)\, e^{-j\,\psi_x\, l/N_x}$$

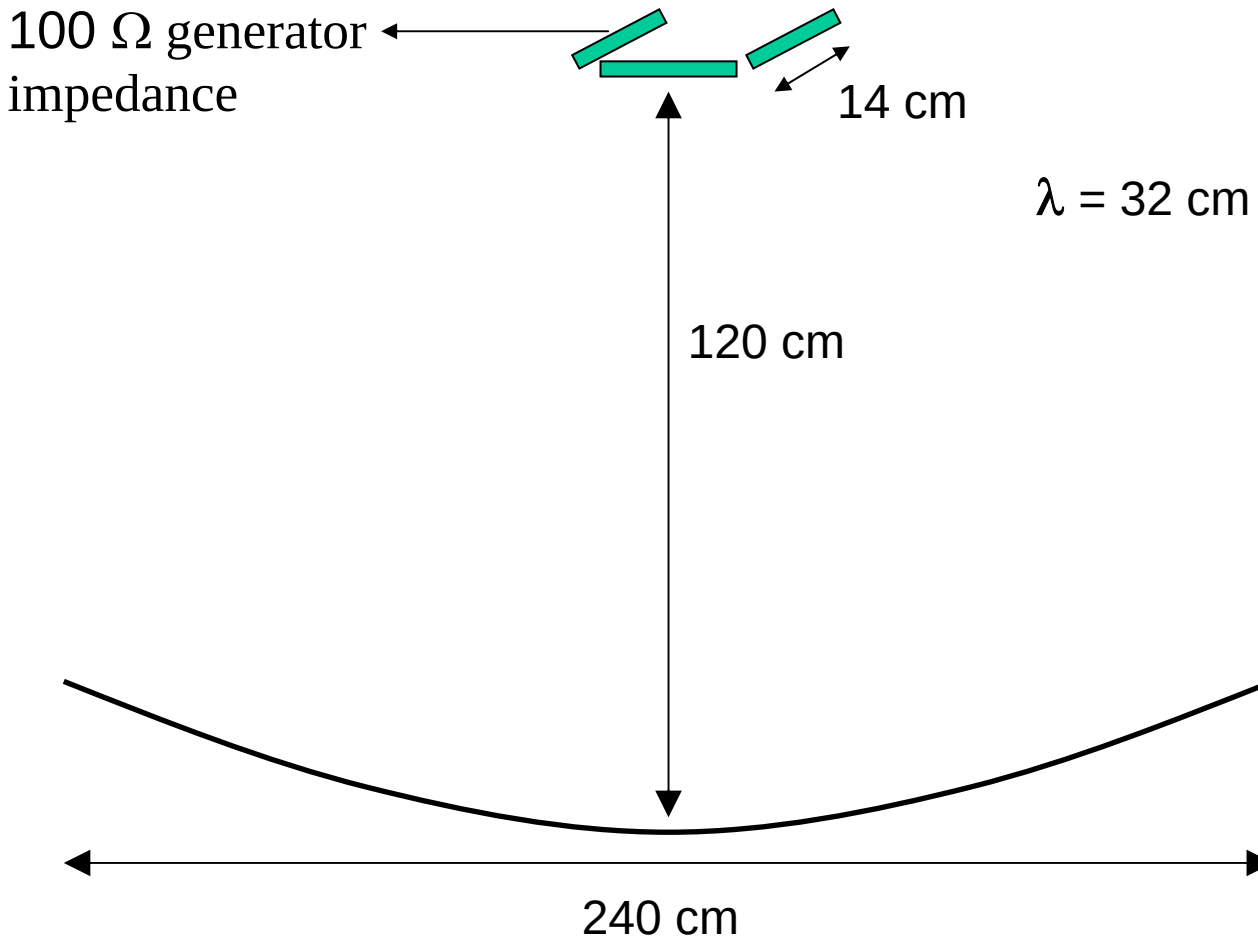
$$Z'_{rs}(i,j) = N_x\, Z_{rs}(i,j)$$

5, here

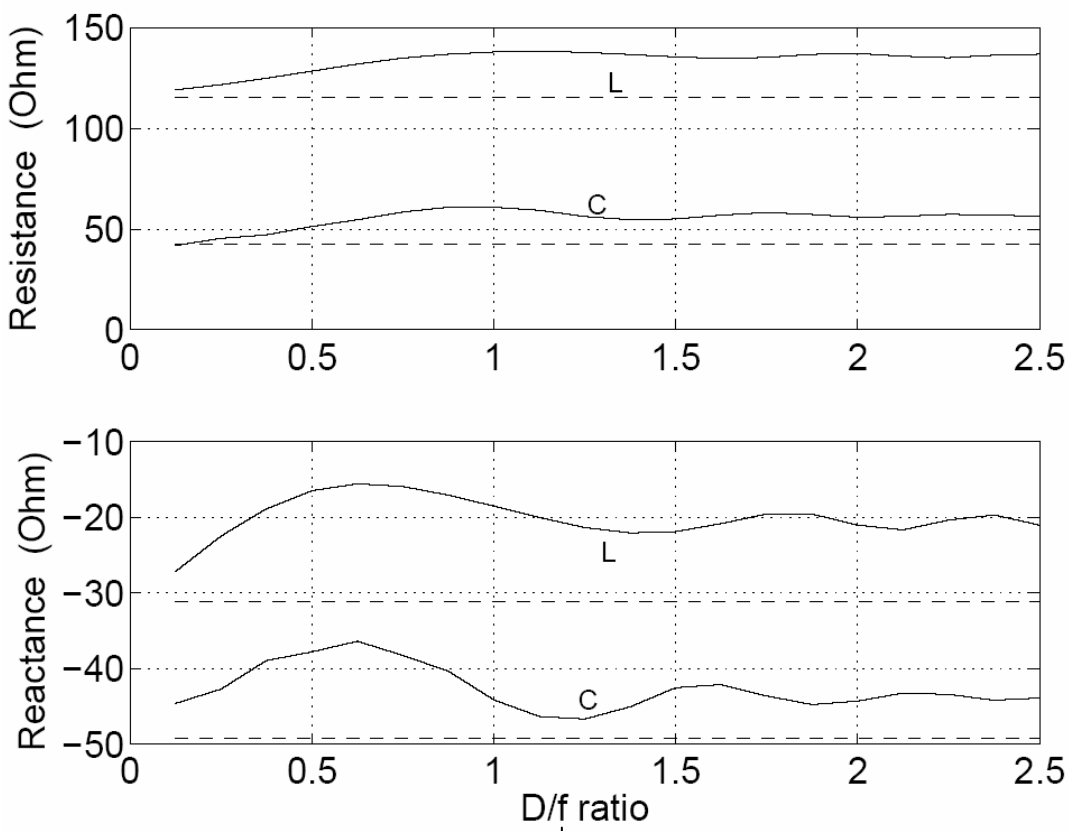
Interaction with shifted basis functions



Simulated configuration



Effect of reflector on impedance



f kept constant

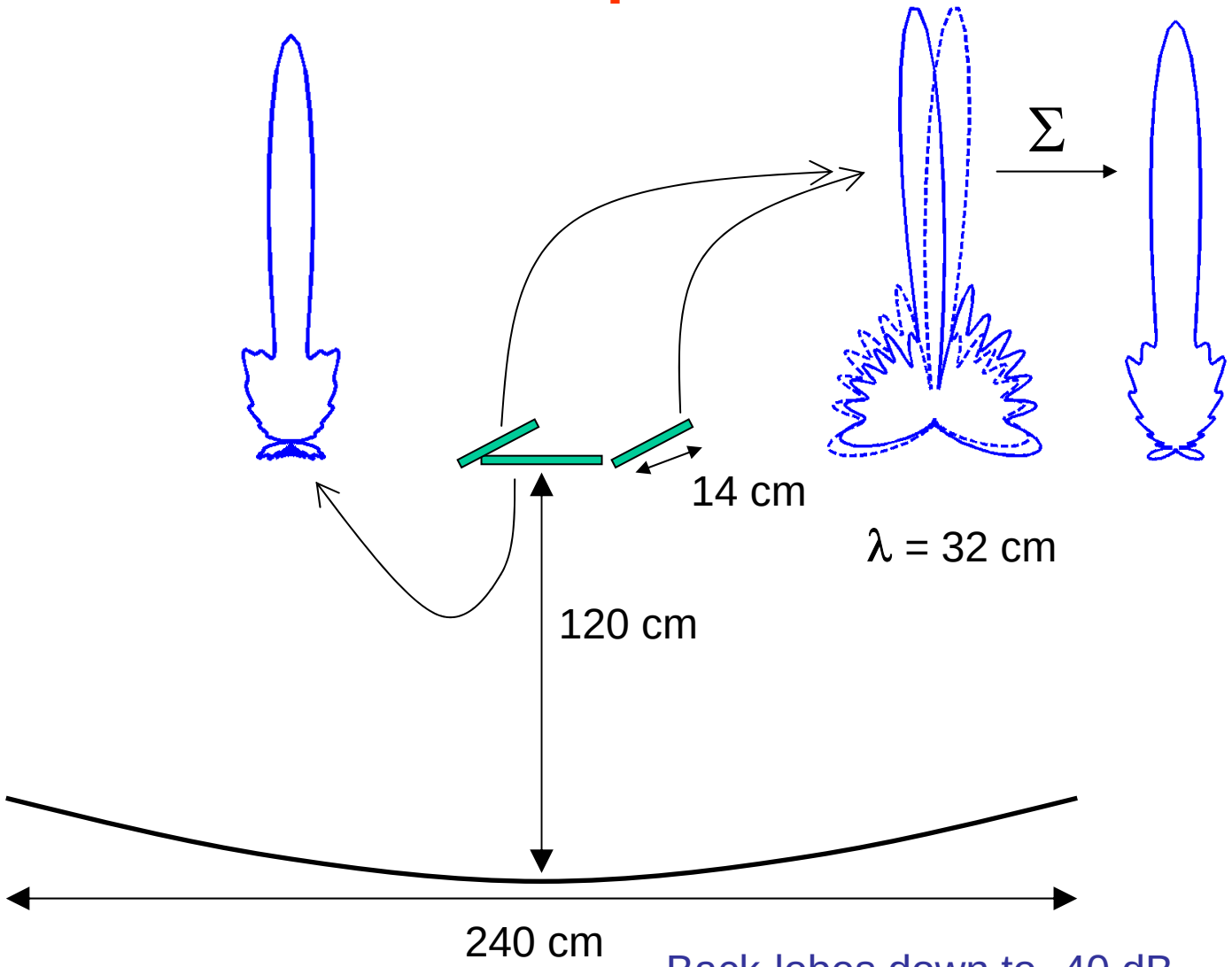
D increased

Power fed to input impedance =

radiated power + dissipated in other ports

Vérified within 0.1 to 1 %

Element patterns



Back-lobes down to -40 dB

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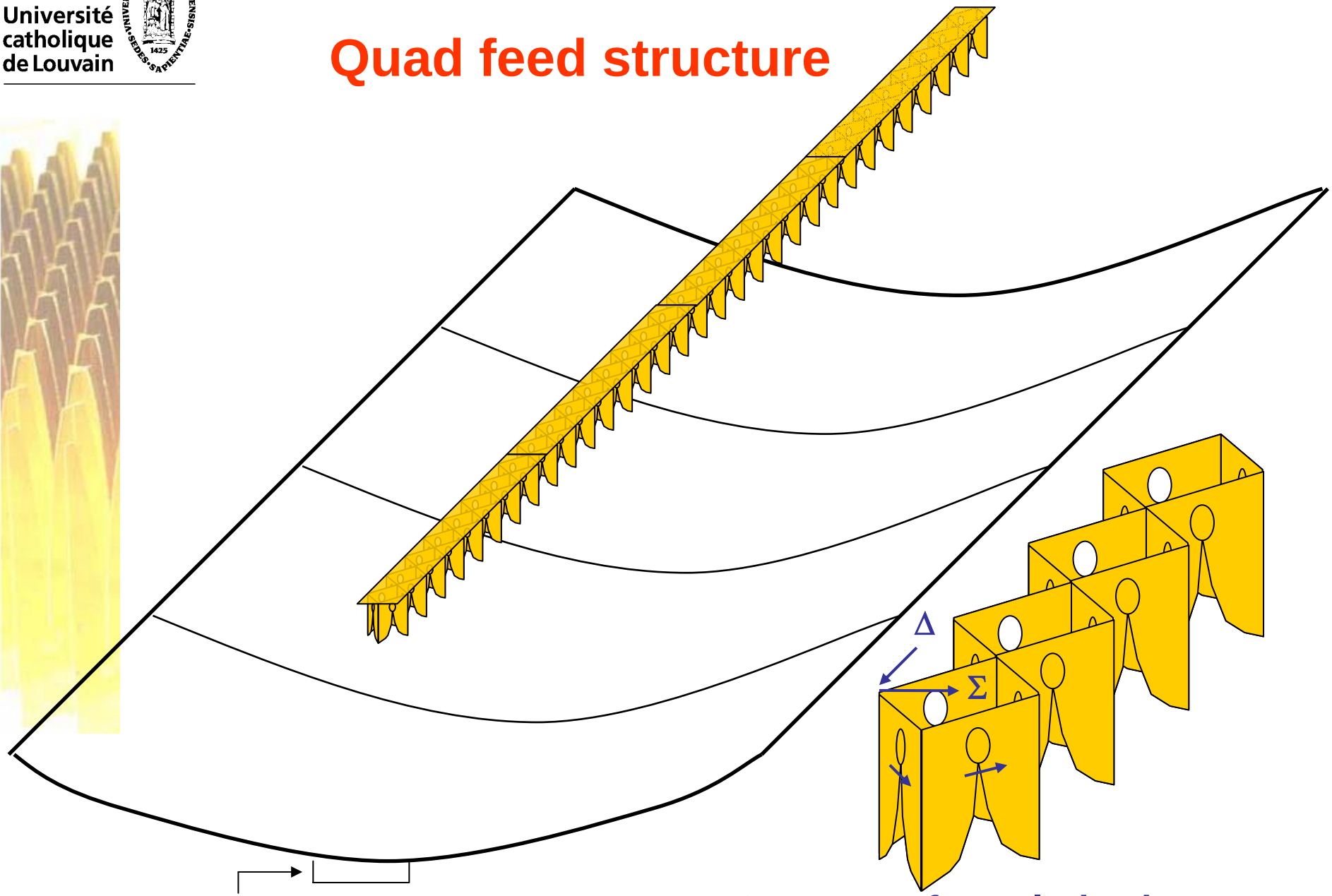
Element pattern for center element

Quad feed structure



NB: vertex plate easily analyzed

Σ – Δ strategy for polarization

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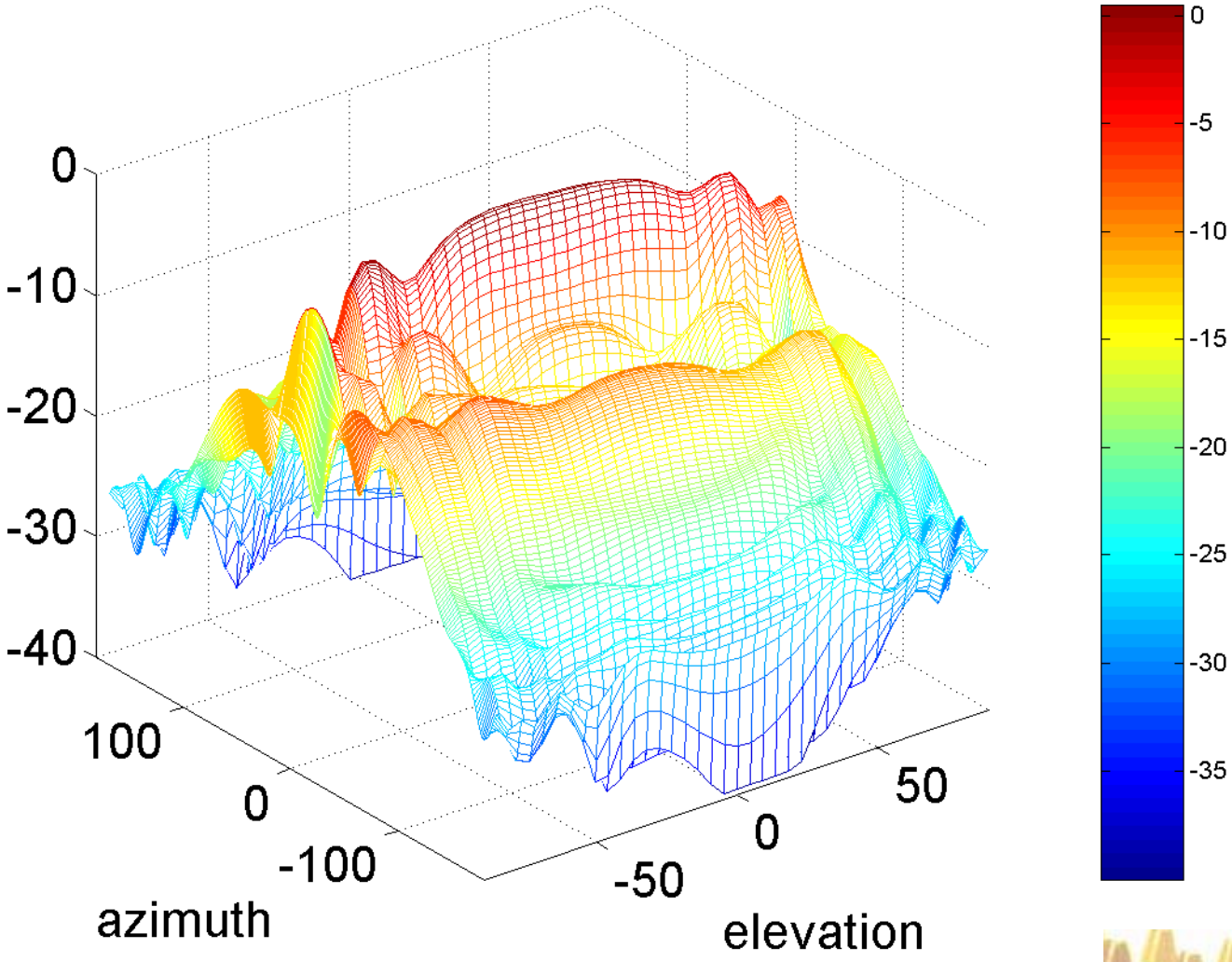
Element pattern of quad feed



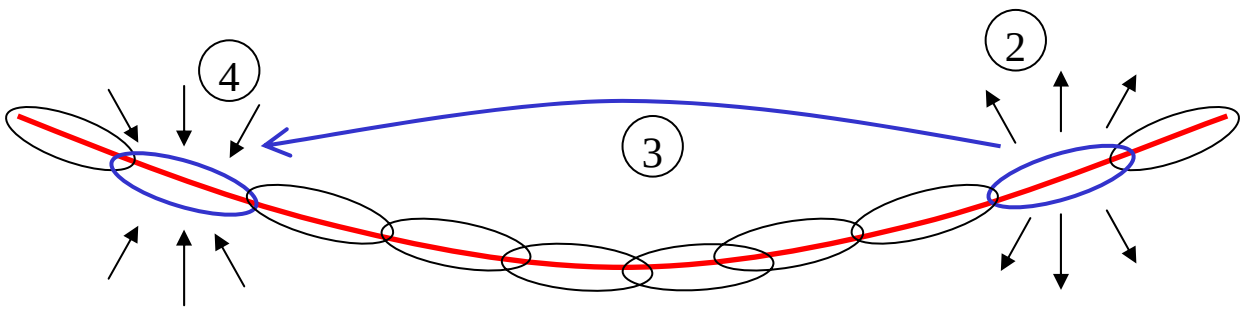
22 min

Ongoing developments (1/3)

- Accelation of iterative solution with the help of **Fast Multipoles** (completed for single-level multipoles).

1. Grouping basis functions with unknowns
2. Define wave going out of transmitting groups
3. Perform a translation operation
4. Define wave coming into receiving groups

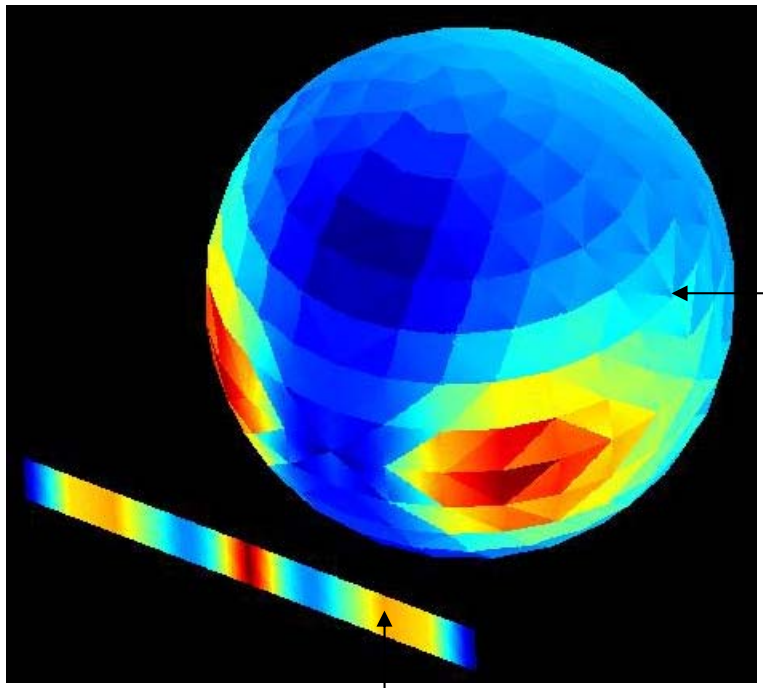
(Cf. Rohklin, Michielssen …)



Tool: addition theorem of Bessel functions

Ongoing developments (2/3)

• Introduction of dielectric material (Th. Gilles and X. Dardenne).



Solve interior and exterior problems (homogeneous media) while ensuring continuity of E_{tan} and H_{tan}.

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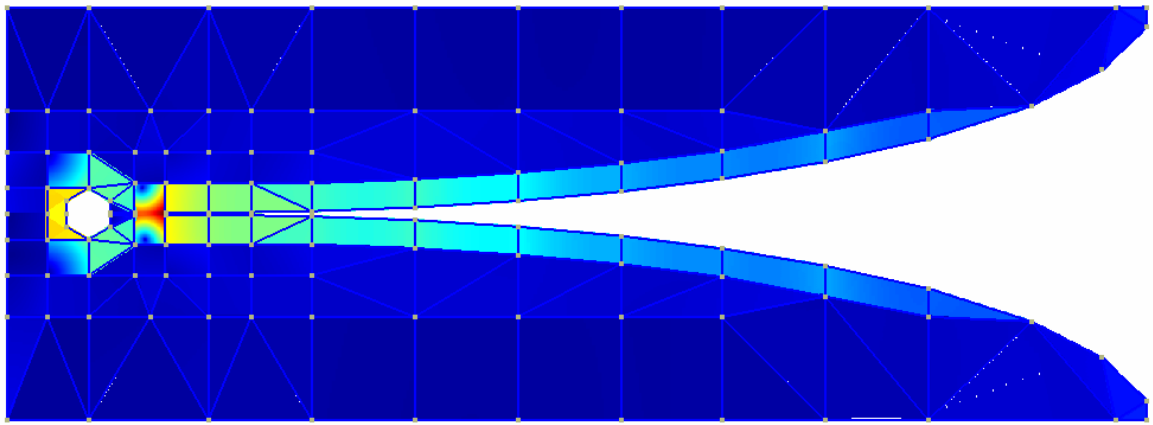
Ongoing developments (3/3)

- Simulations for LAR demonstrator (B. Pagost).



- Effect of spatial **correlation of thermal noise** in arrays (in press).
- Fast PO for reflectors: O(DN log N) complexity (with W. Brisken)
- Wave phenomenology in finite and finite-by-infinite arrays (with A. Boryssenko and D. Schaubert)

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Further prospects

- Complete the work on **finite dielectric material**.
- Continue to develop **new corrections** for array truncation.
- Develop further **acceleration** techniques.
- Investigate **other kinds of elements and configurations**.

Publications in the field of finite wideband arrays

Journal papers

Published or accepted

[1] Craeye C., Smolders A.B., Schaubert D.H., Tijhuis A.G., An efficient scheme for the computation of the Green's function of a two-dimensional semi-infinite array, *IEEE Transactions on Antennas and Propagation*, vol. 51, pp. 766-771, April 2003.

[2] Craeye C., Arts M., Modulated oscillations appearing in the scan impedance of a finite phased array, *IEEE Transactions on Antennas and Propagation*, vol.51, pp. 2504-2506, September 2003.

[3] Craeye C., Tijhuis A.G., Schaubert D.H., An efficient MoM formulation for finite-by-infinite arrays of two-dimensional antennas arranged in a three-dimensional structure, accepted for publication in *IEEE Transactions on Antennas and Propagation*, March 2003, January 2004.

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