

Efficient simulation of finite wideband arrays for focal plane applications

From large to small, and back

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de Louvain**

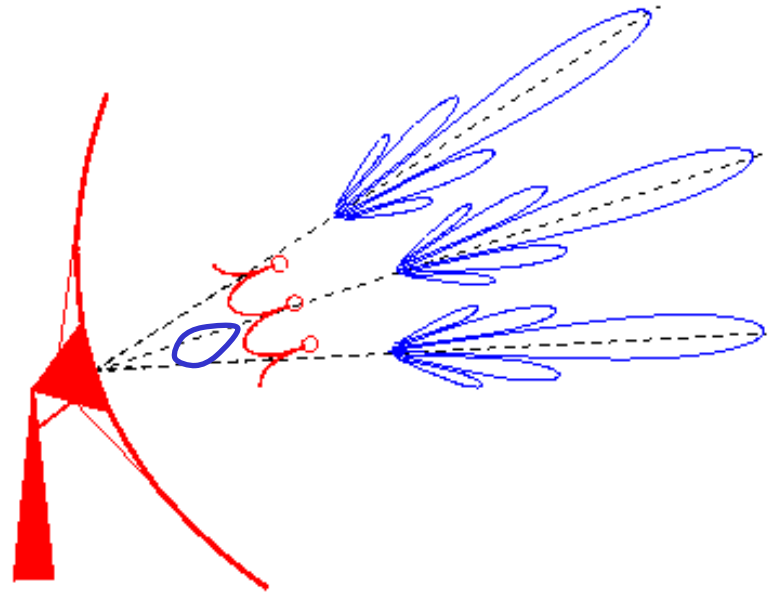


Outline

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.



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-resources ratio is huge. Obtain **leverage** from other research projects.
 - **Cooperate** with many groups over the world.
 - Have **fun...**
- 

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.

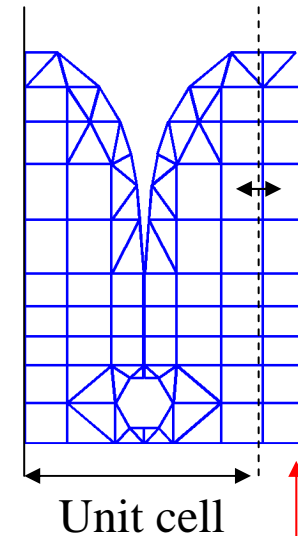
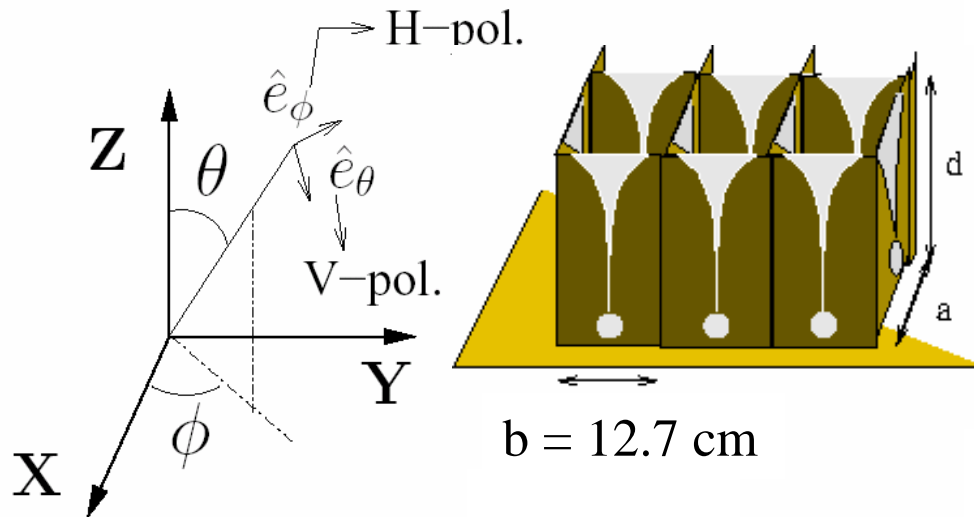
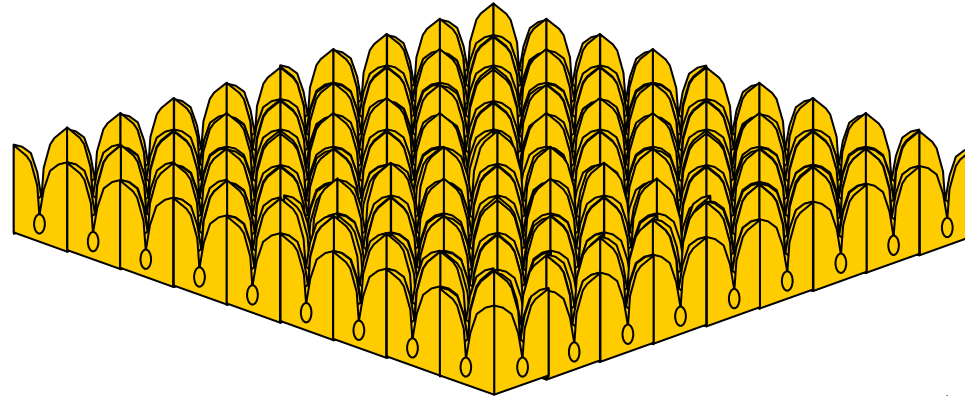
Courses taught: antennas, electromagnetics, transmission lines.

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...



Reference geometry

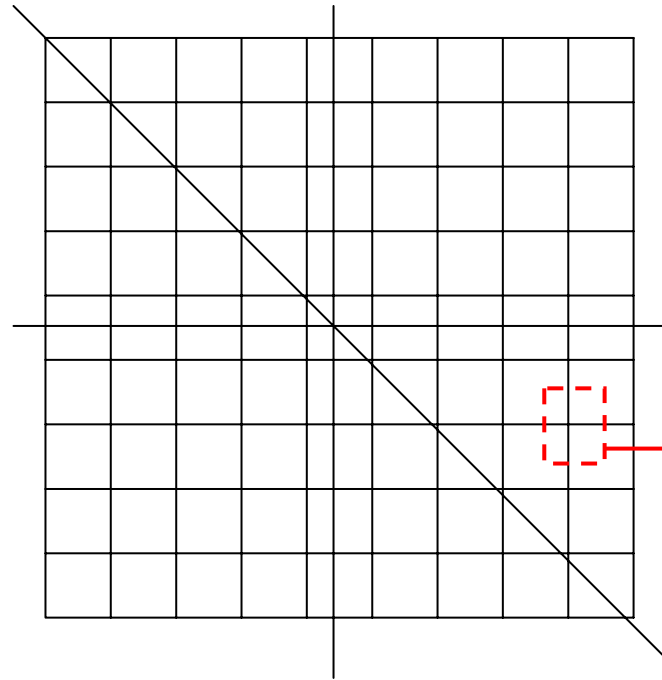


Not exactly a periodic structure, because of connections between antennas !!!



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.

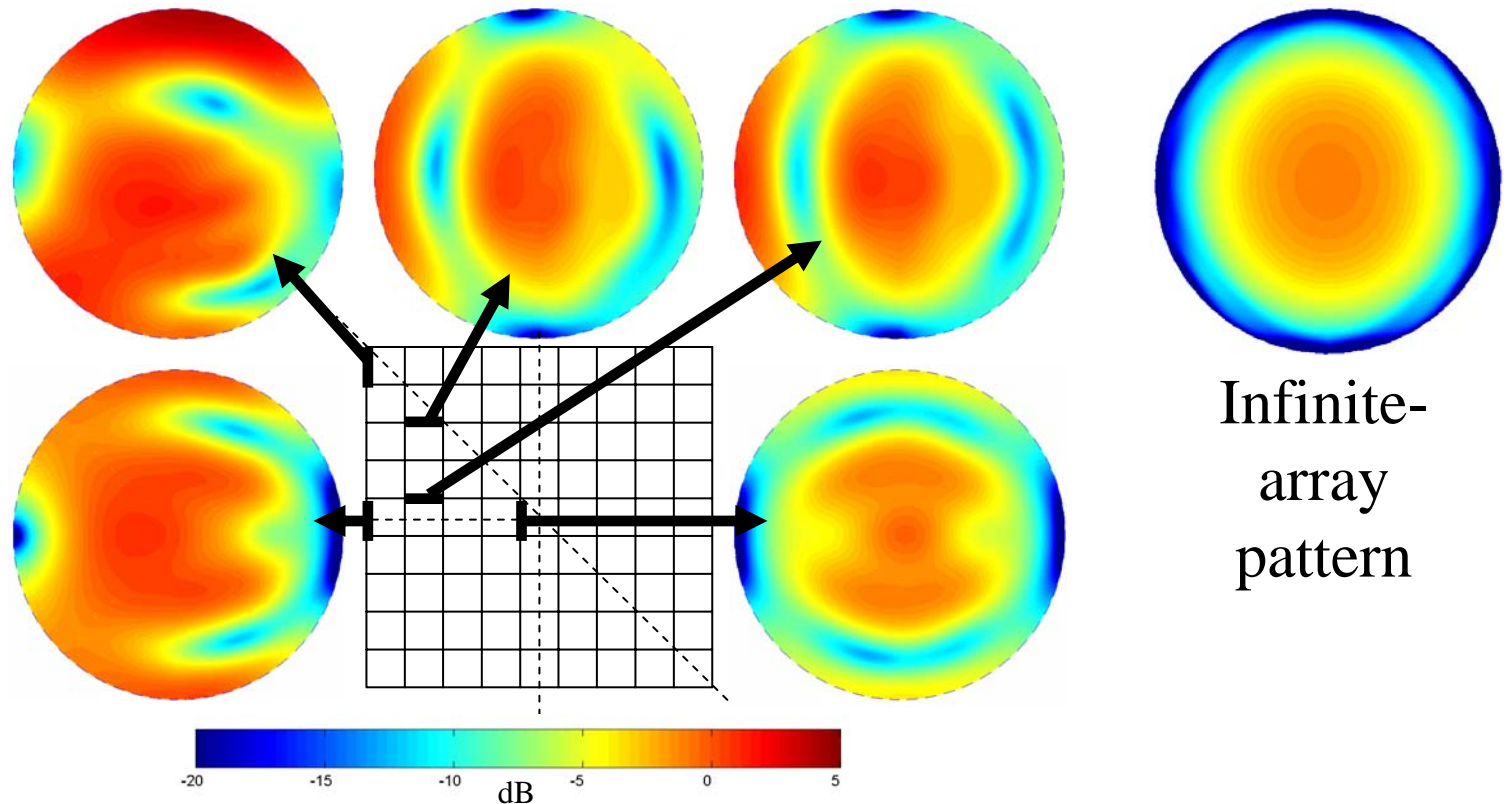
NB: special attention given to basis functions and sources
crossing the planes of symmetry.



Finite-array simulations

180 elements

Element patterns at 440 MHz



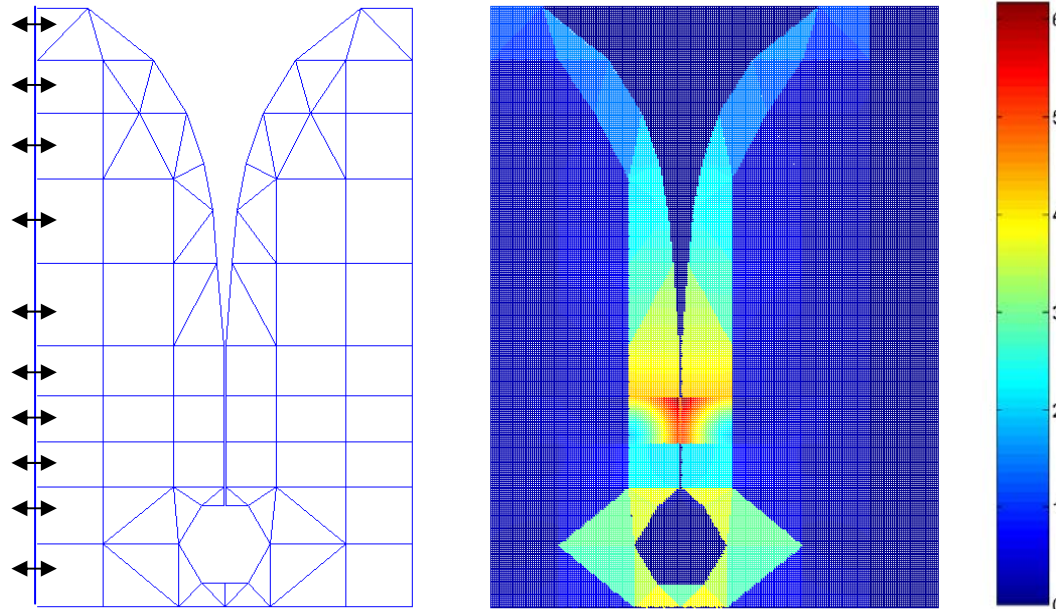
Fine for small arrays: data available on request

[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



From large to small

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

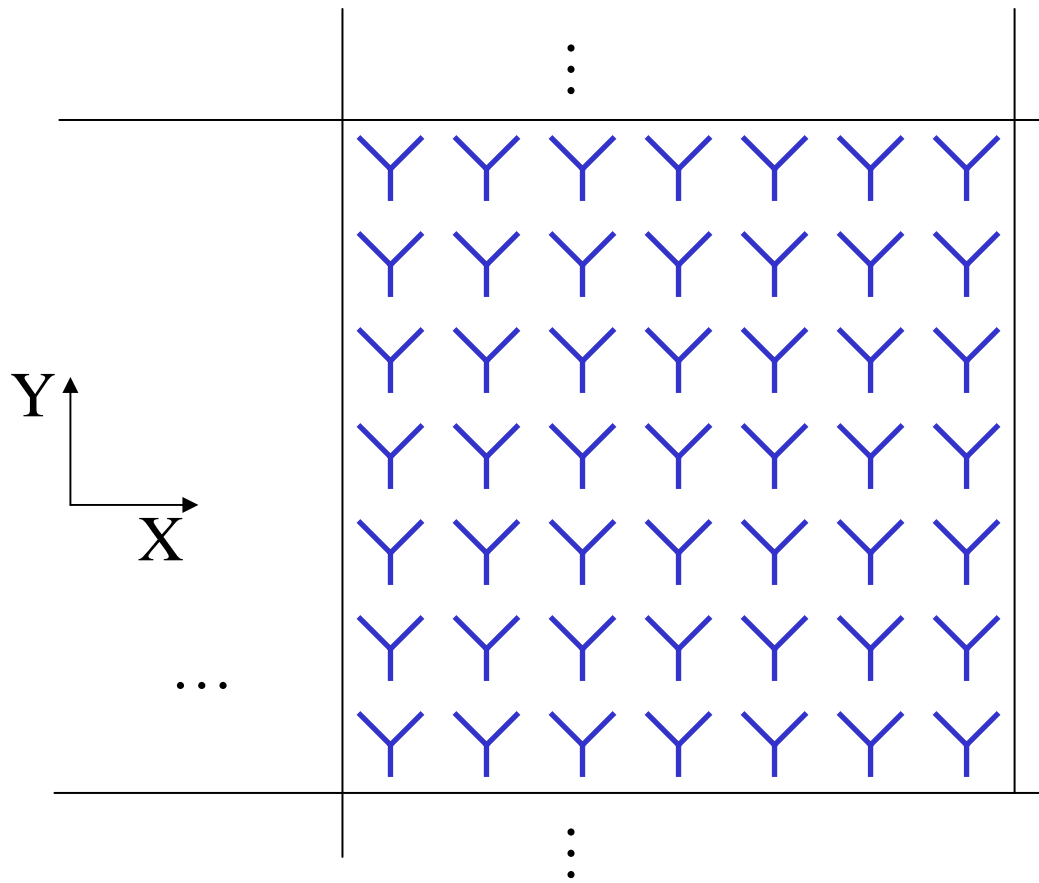


Mesh of the antenna surface and current distribution at 1 GHz.



From large to small

Finite-by-infinite array approach



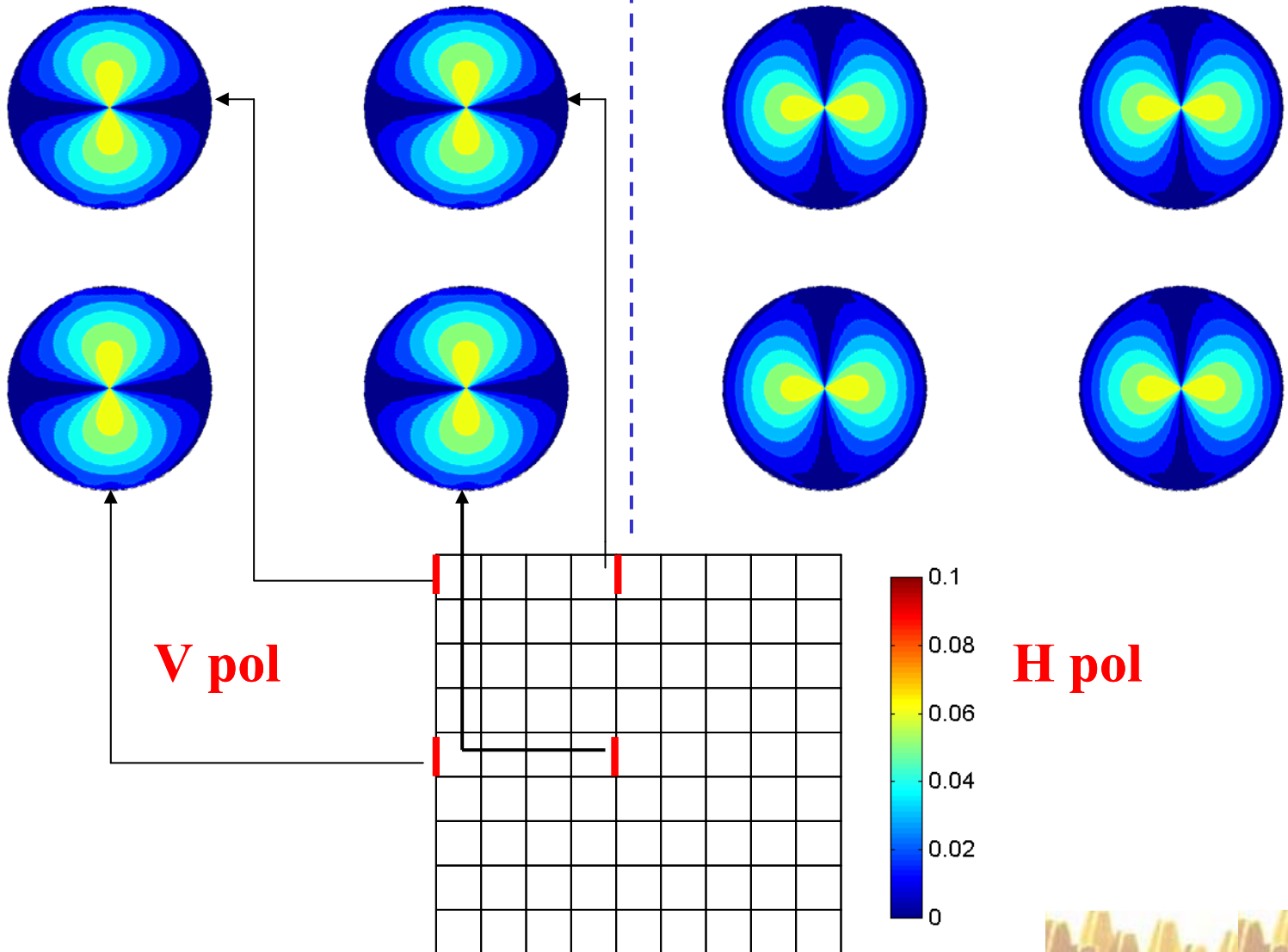
Can also
be applied to
hexagonal arrays
(Maci et al.)

Correct for array
truncation in the
two principal
directions

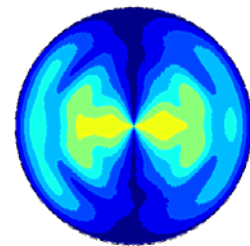
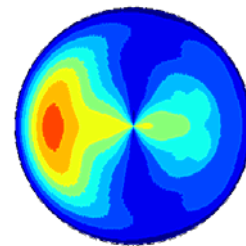
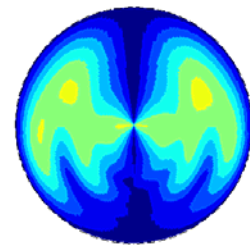
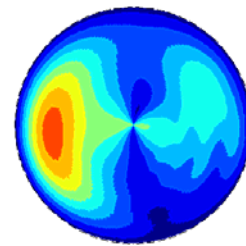
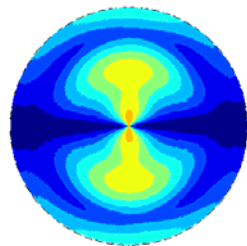
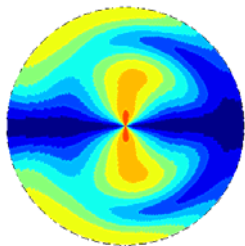
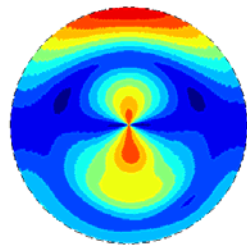
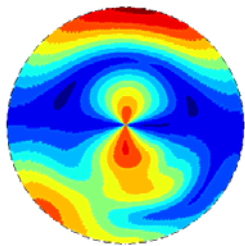
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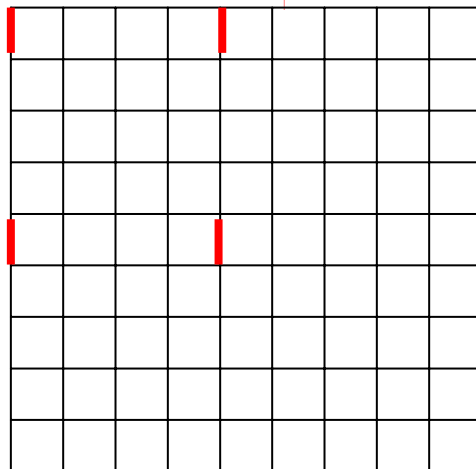
Element patterns at 500 MHz : infinite array



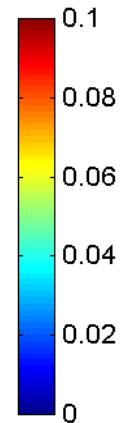
Element patterns at 500 MHz : exact



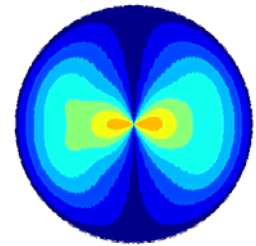
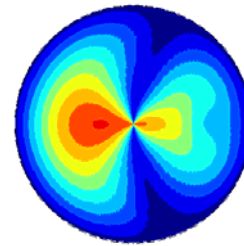
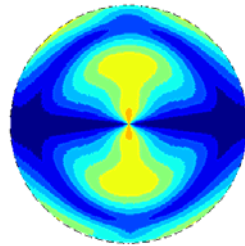
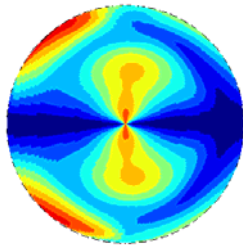
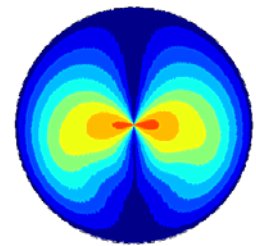
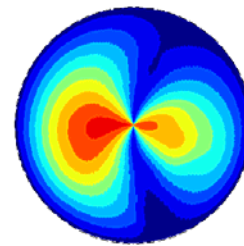
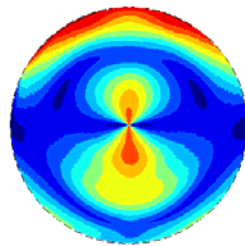
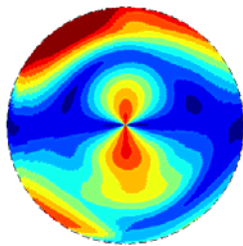
V pol



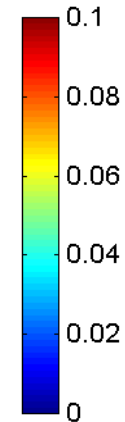
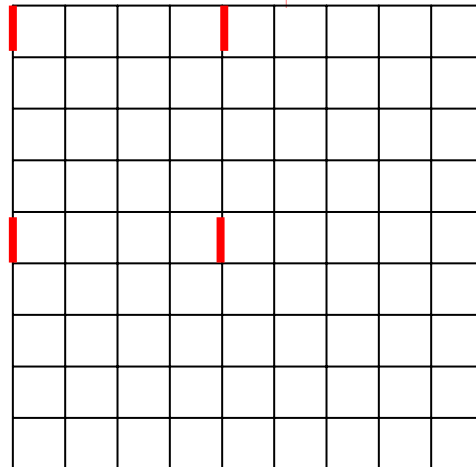
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Element patterns at 500 MHz : finite-by-infinite



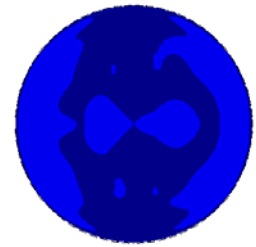
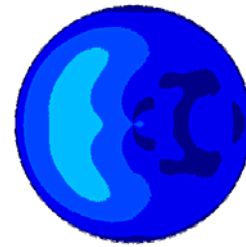
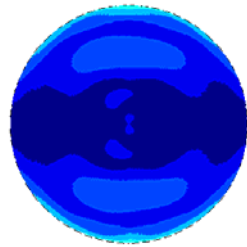
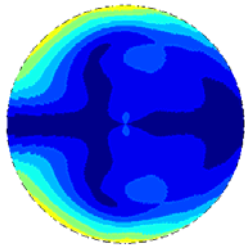
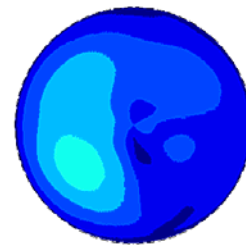
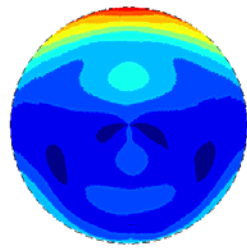
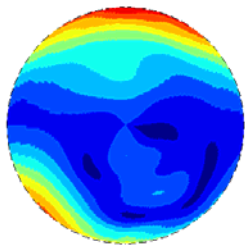
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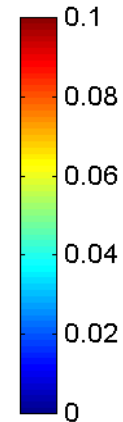
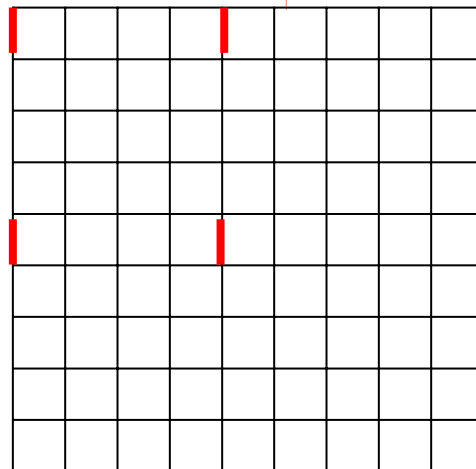
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Element patterns at 500 MHz : error from infinite-array



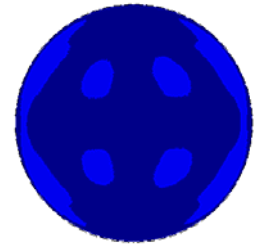
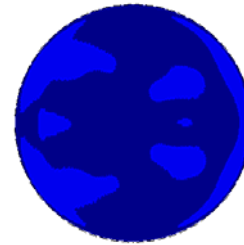
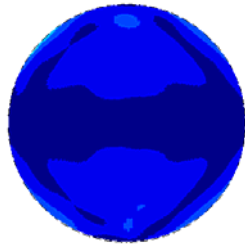
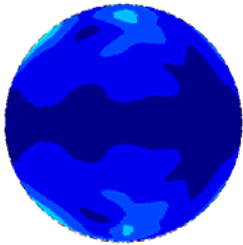
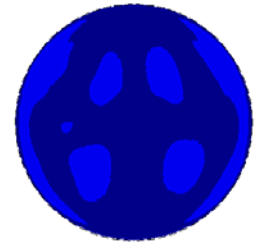
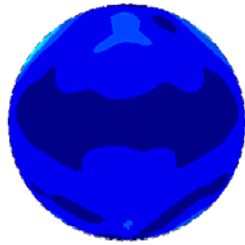
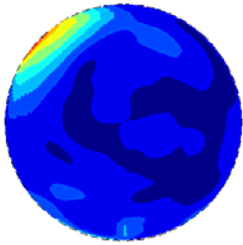
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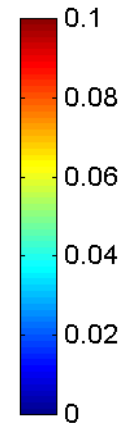
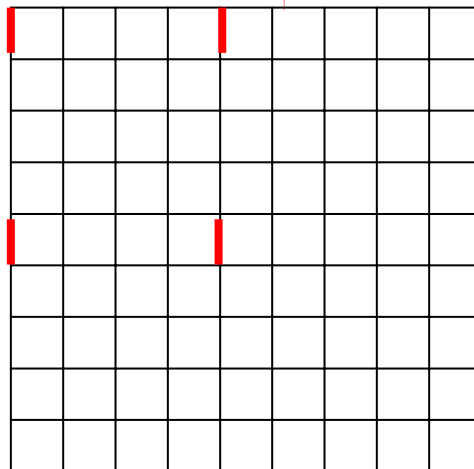
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Element patterns at 500 MHz : Error from finite-by-infinite



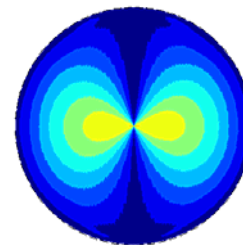
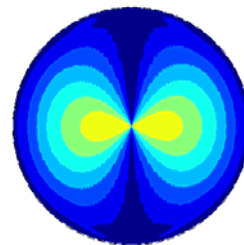
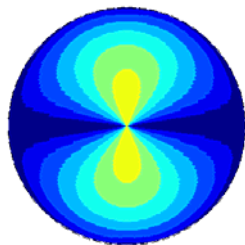
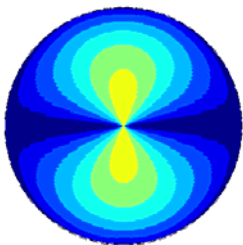
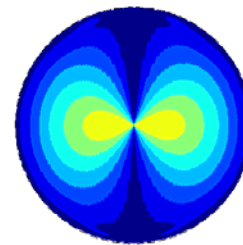
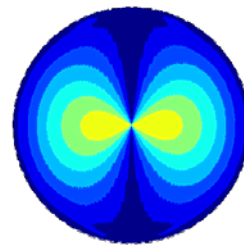
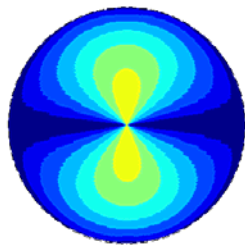
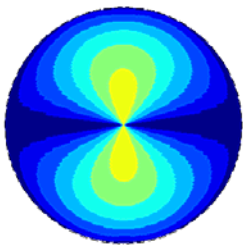
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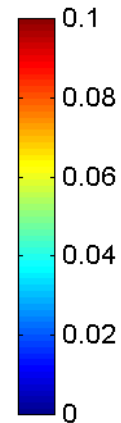
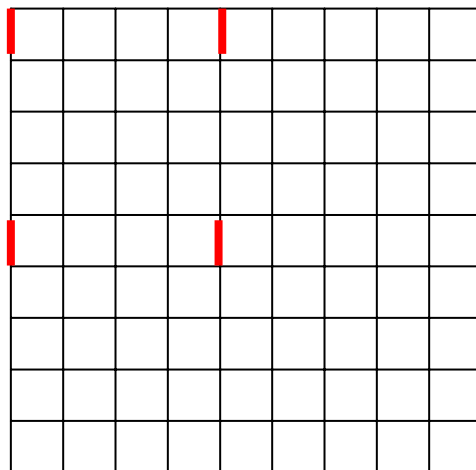
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Element patterns at 1 GHz : infinite array



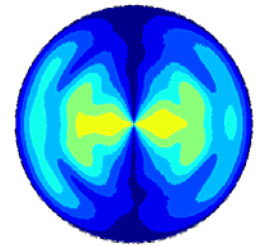
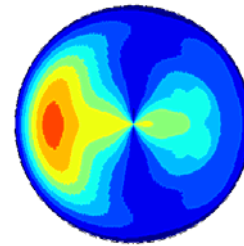
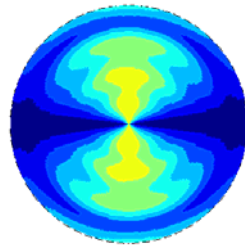
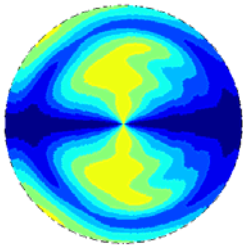
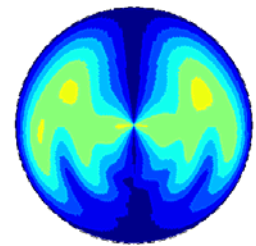
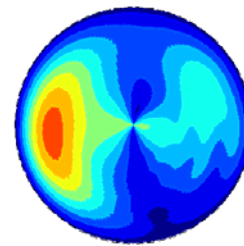
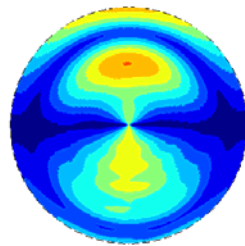
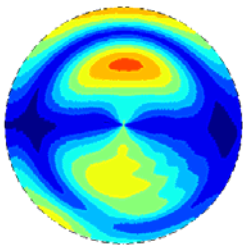
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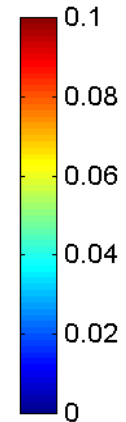
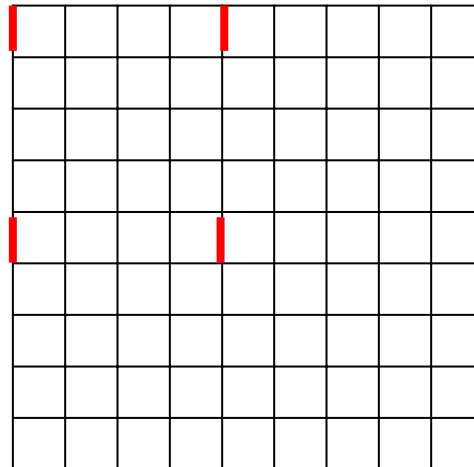
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Element patterns at 1 GHz : exact



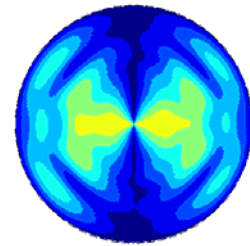
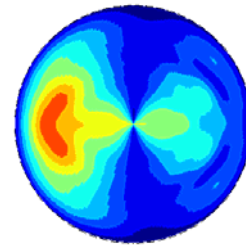
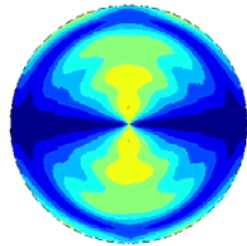
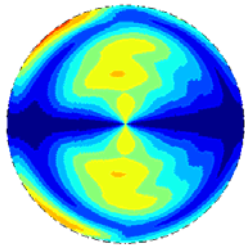
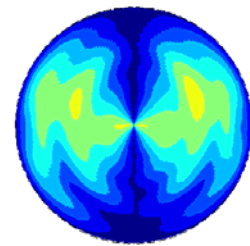
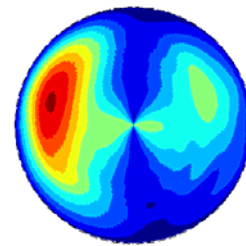
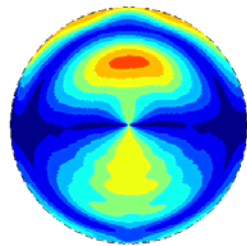
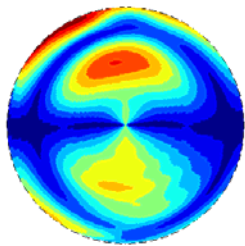
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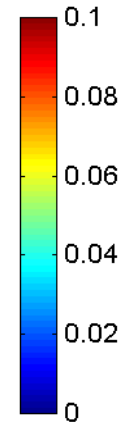
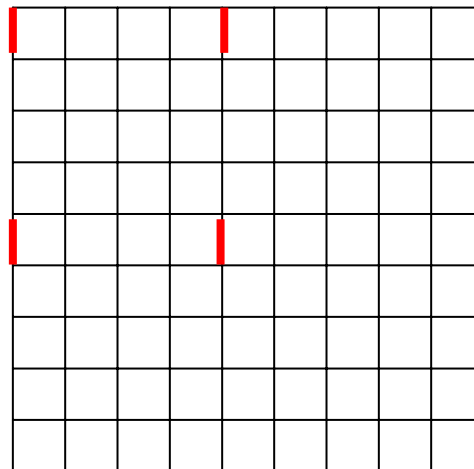


Element patterns at 1 GHz : finite-by-infinite

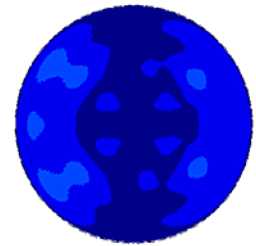
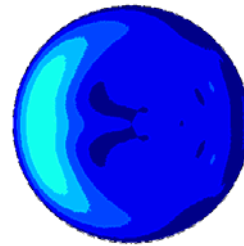
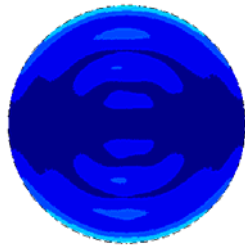
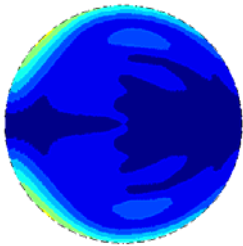
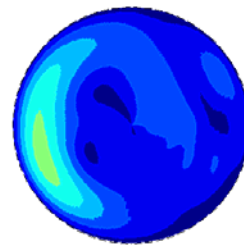
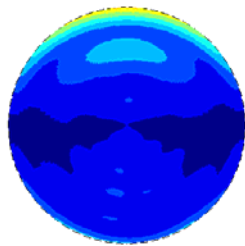
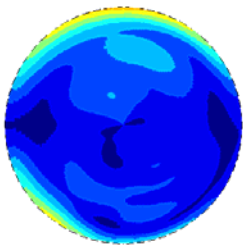


V pol

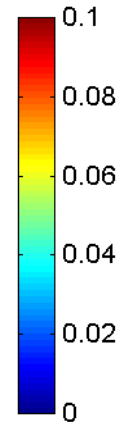
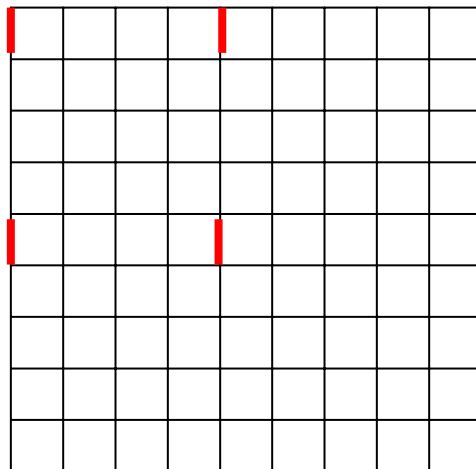
H pol



Element patterns at 1 GHz : error from infinite-array



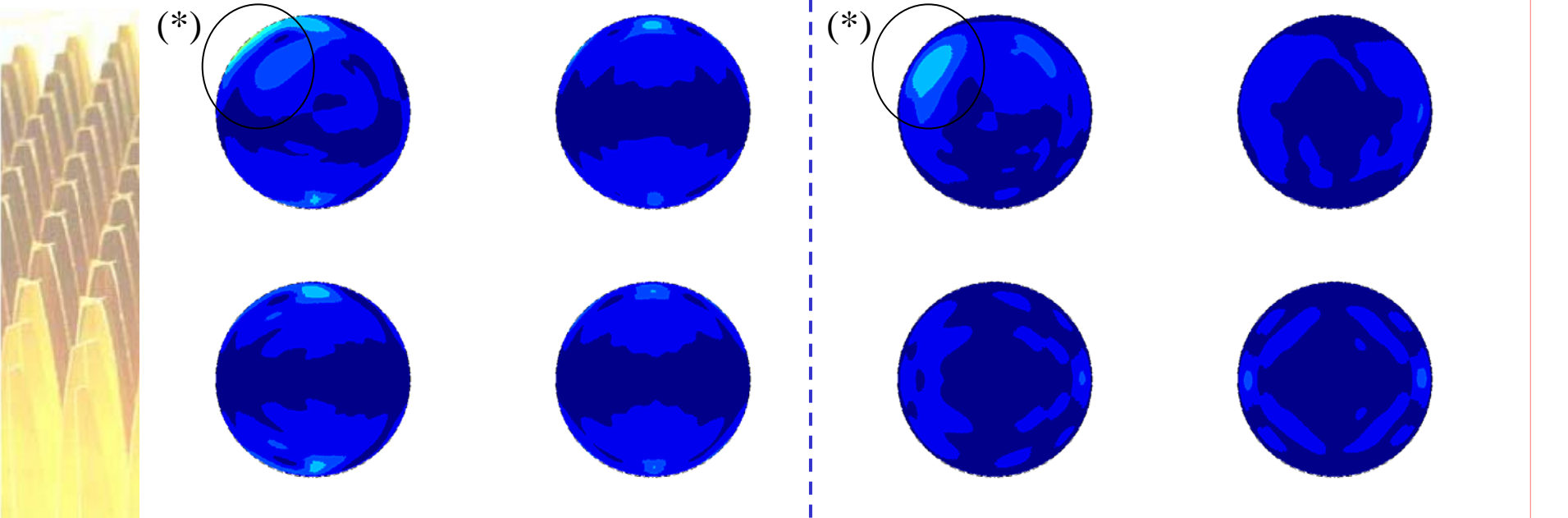
V pol



H pol



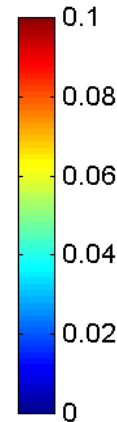
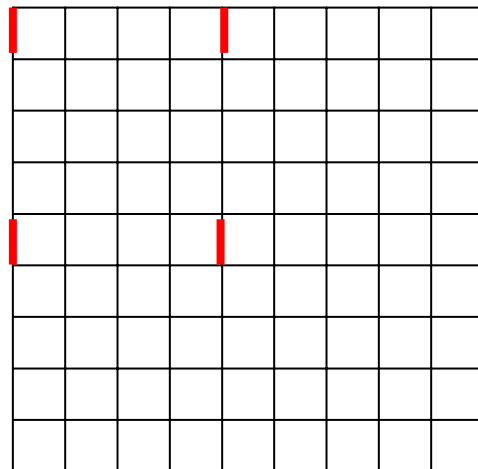
Element patterns at 1 GHz : Error from finite-by-infinite



V pol

**(*) larger errors in
 corners corrected with
 special procedure**

12 min



H pol

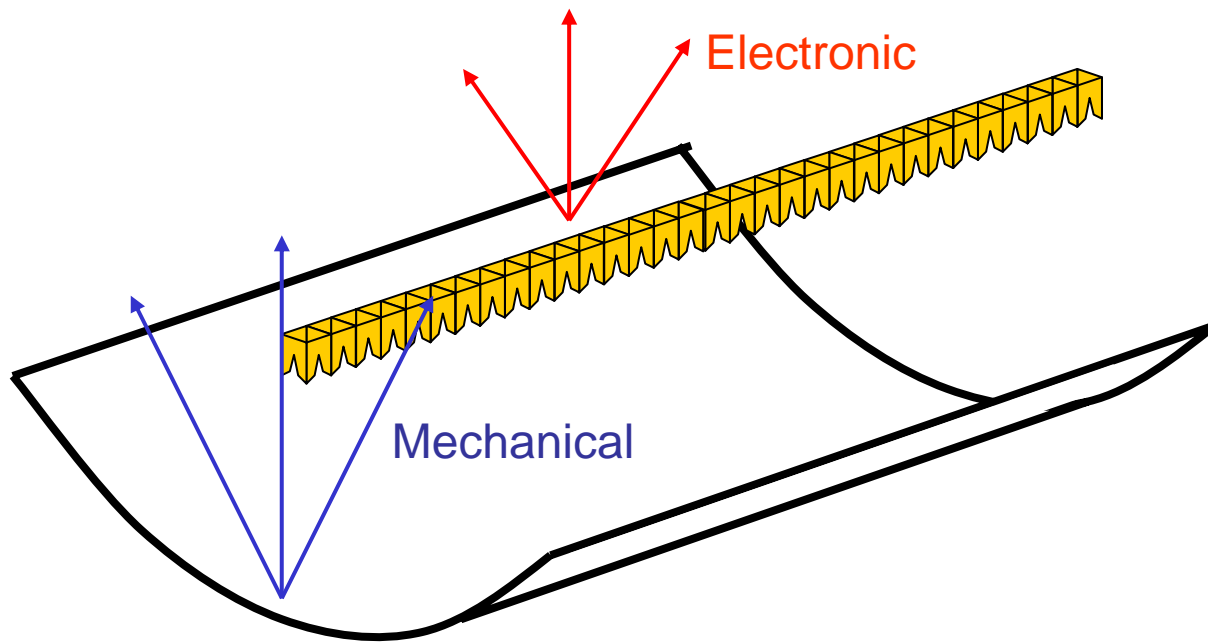


Cylindrical reflectors

Mix of mechanical and electronic scanning.

Trade-off between cost/complexity and adaptive capabilities

Possibility to cool the whole focal line ?

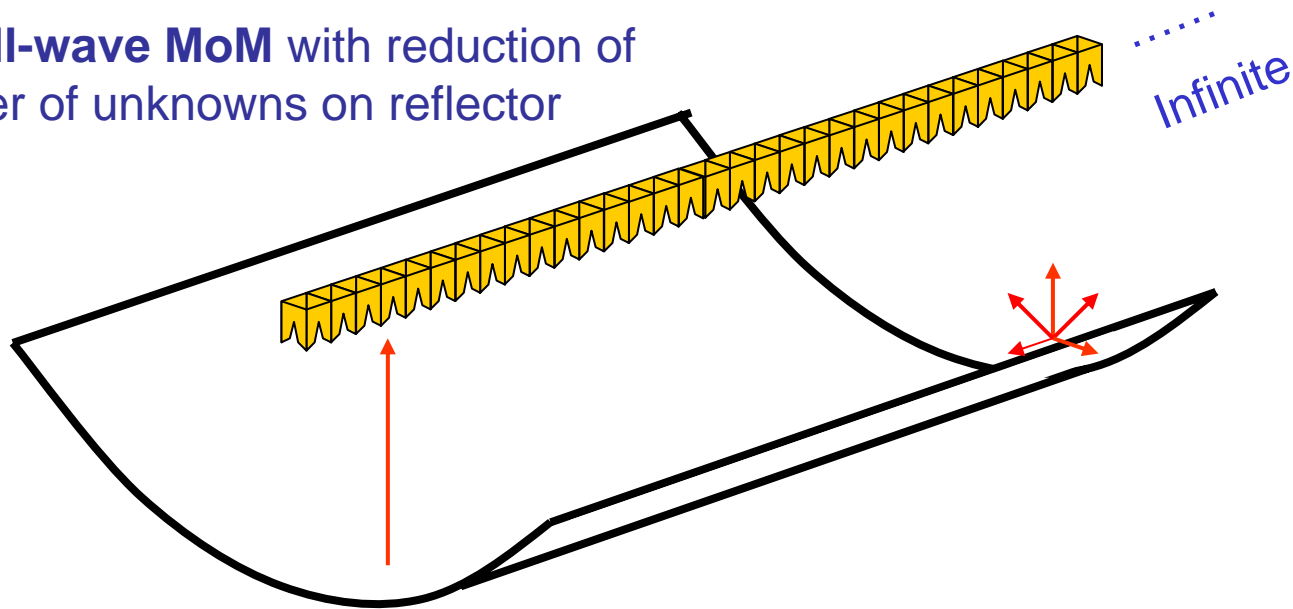


Array-reflector interaction

- (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

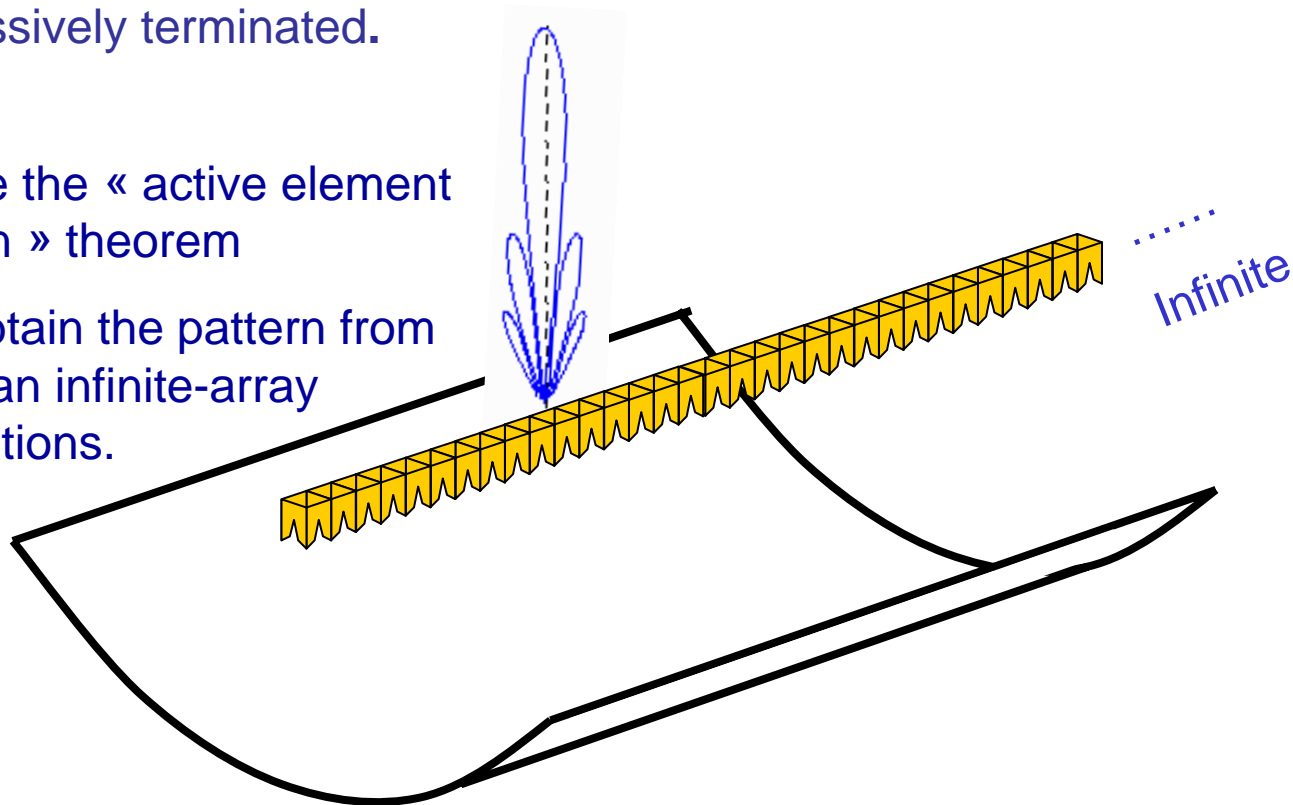


Element patterns

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

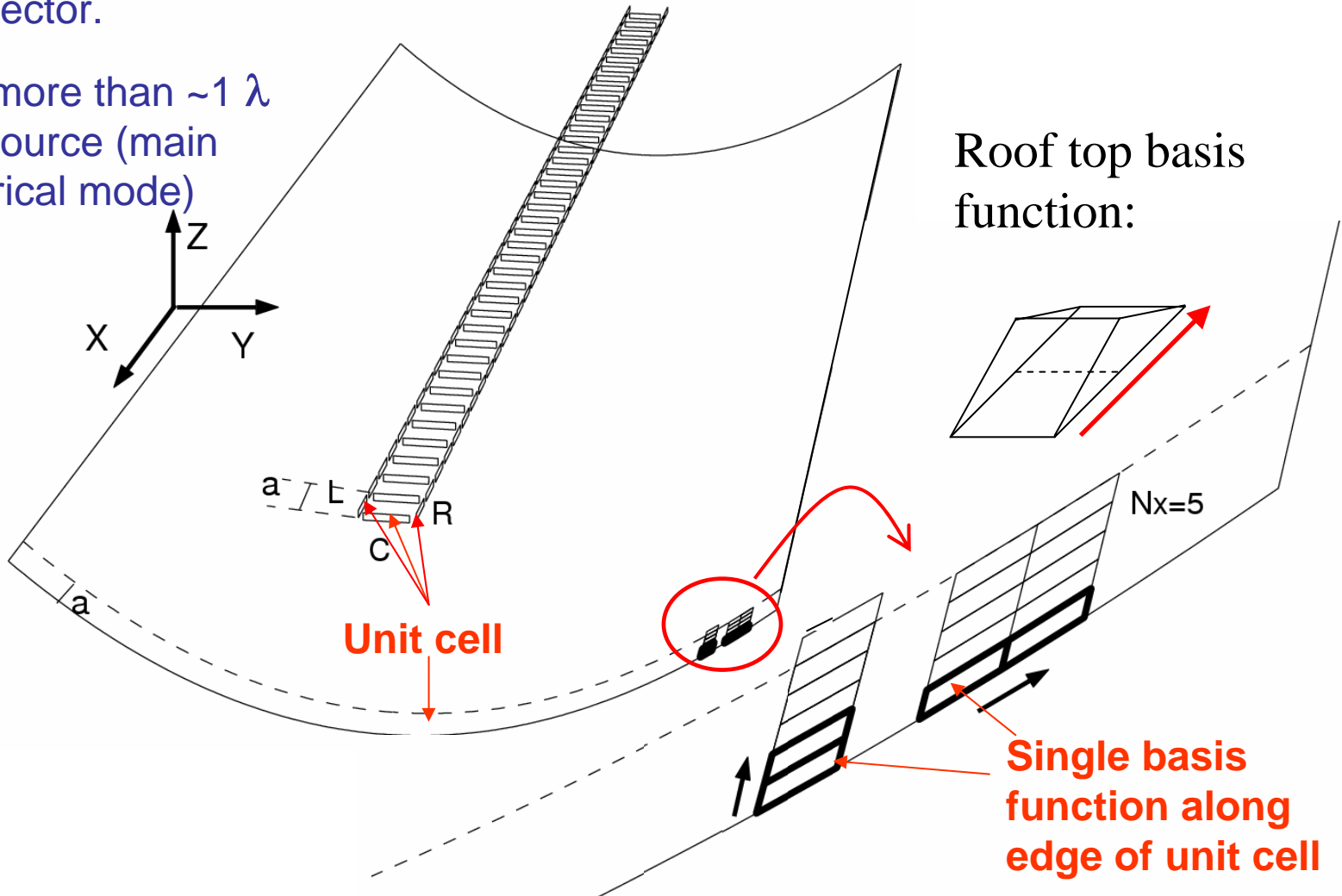
i.e. obtain the pattern from full-scan infinite-array simulations.




Reduction of unknowns

Hypothesis: linear phase progression of currents on reflector.

OK if more than $\sim 1 \lambda$ from source (main cylindrical mode)



MoM system of equations



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

Currents on array (pointing to \underline{x}_s)
 Currents on reflector (pointing to \underline{x}_r)

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

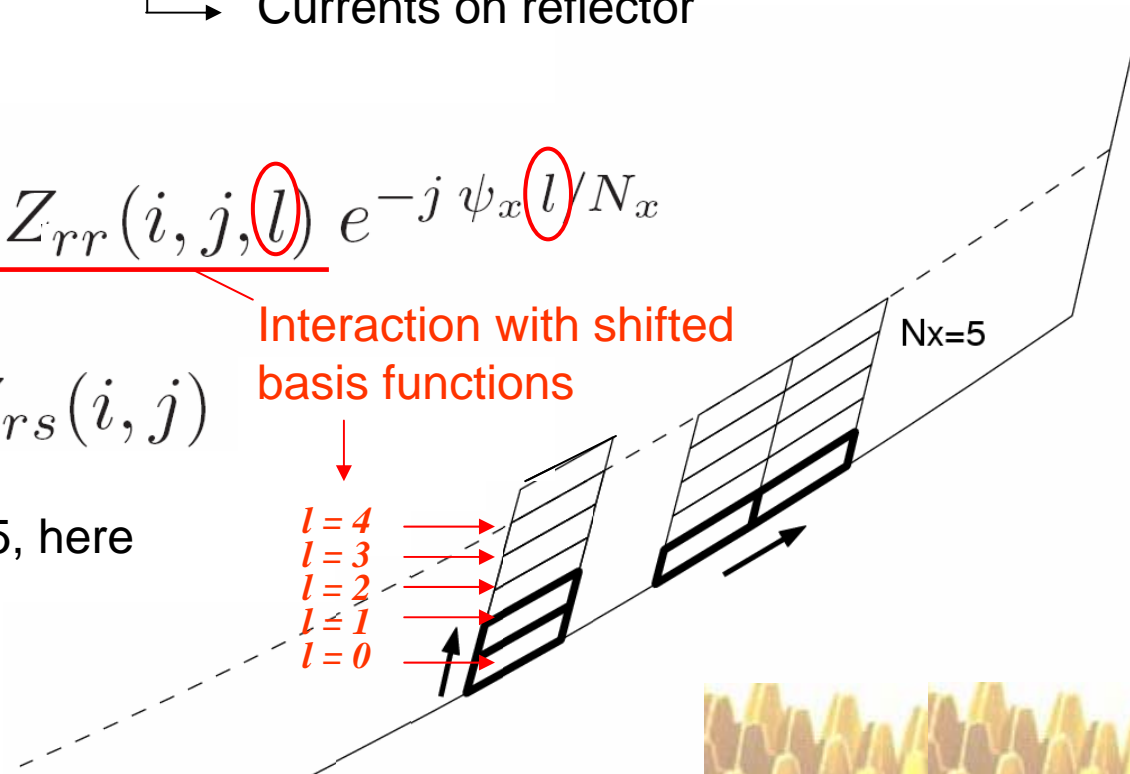
$$Z'_{rs}(i, j) = N_x Z_{rs}(i, j)$$

5, here

Interaction with shifted basis functions

- $l=4$
- $l=3$
- $l=2$
- $l=1$
- $l=0$

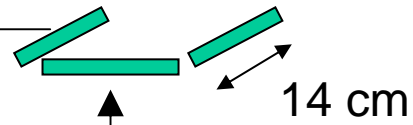
$N_x=5$



Simulated configuration

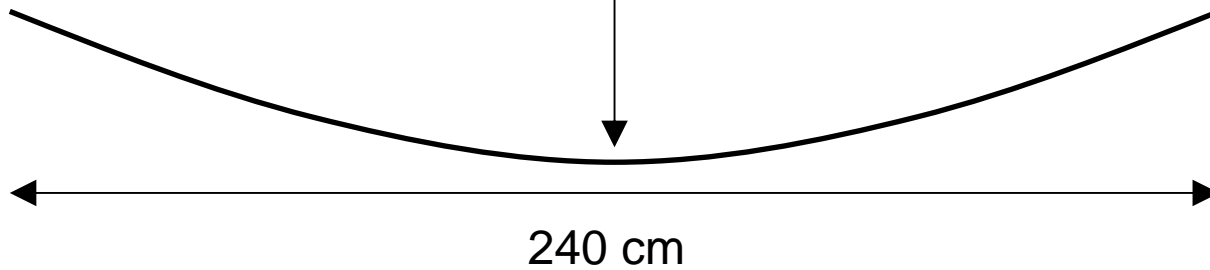


100 Ω generator impedance

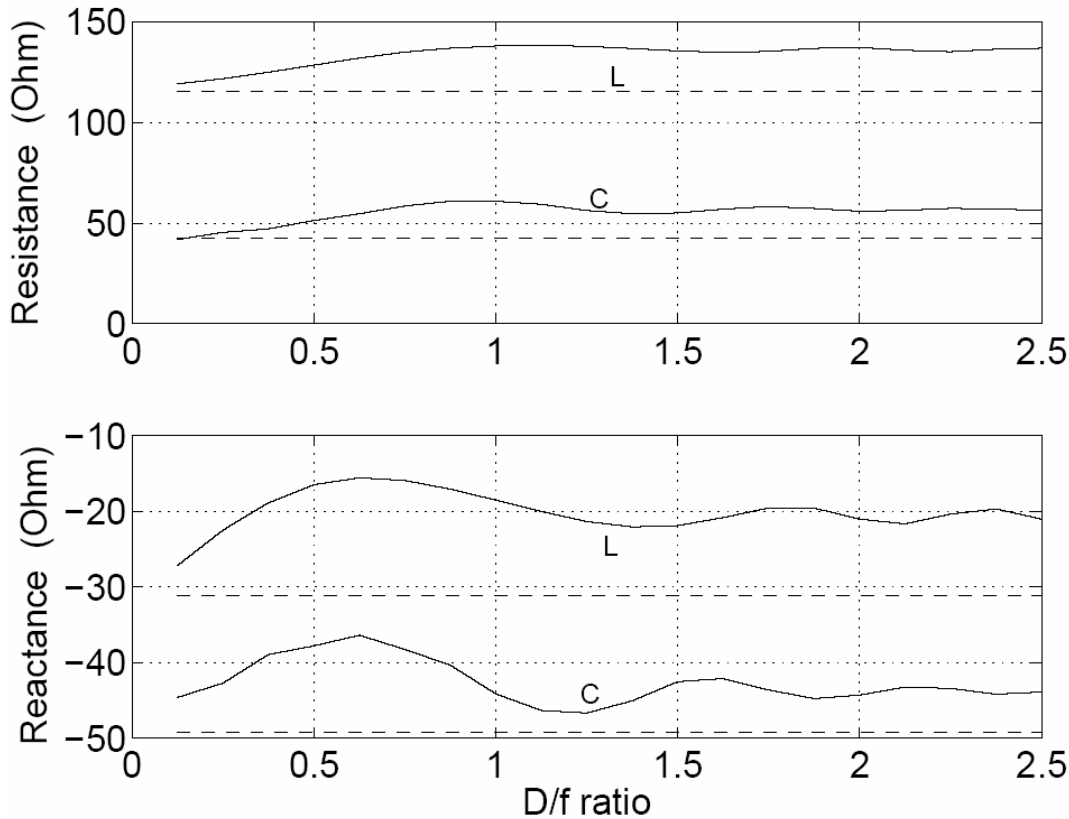


$\lambda = 32$ cm

120 cm



Effect of reflector on impedance



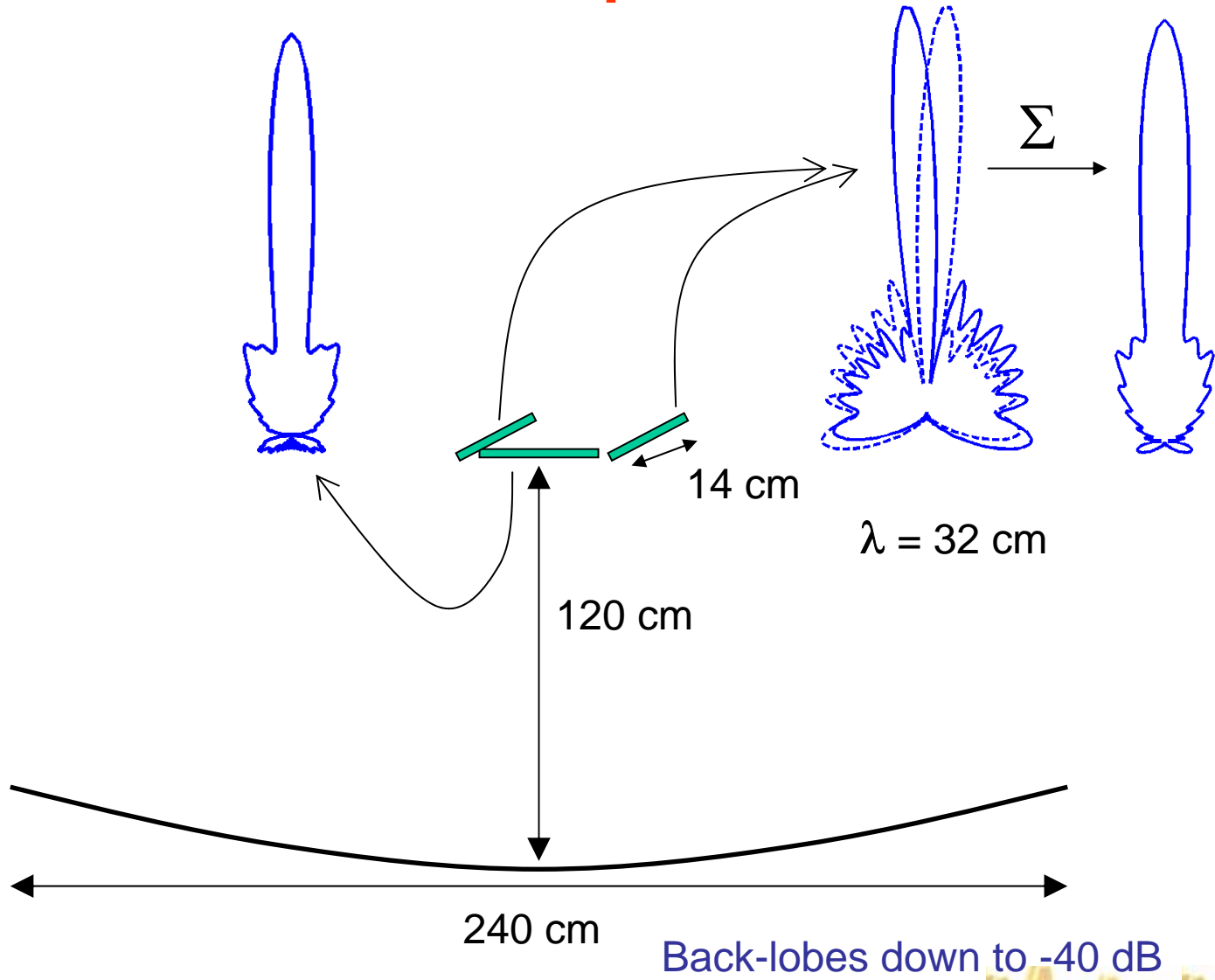
Power fed to input
 impedance =
 radiated power
 + dissipated in other
 ports

Vérifié within
 0.1 to 1 %

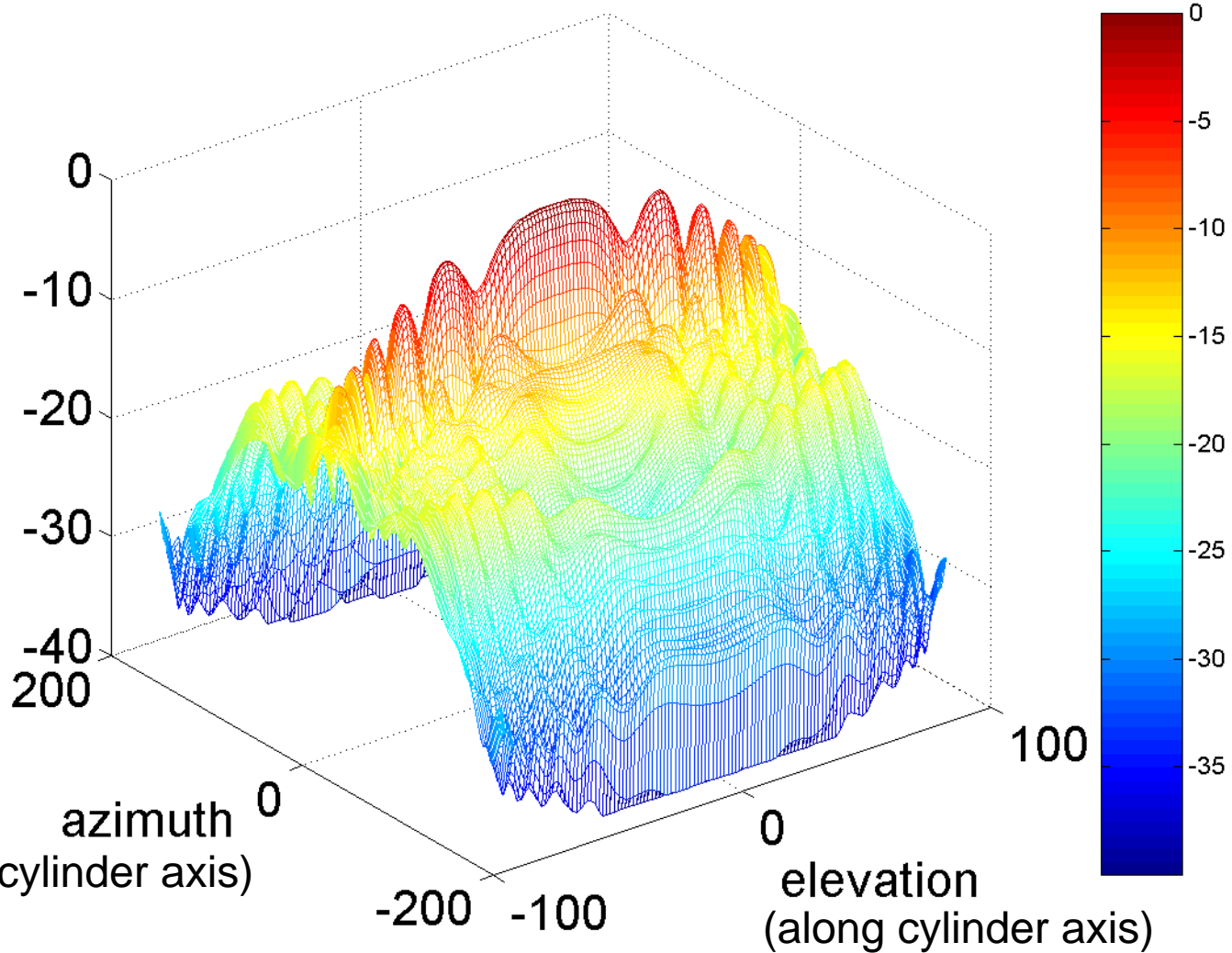
$\left. \begin{array}{l} \text{f kept constant} \\ \text{D increased} \end{array} \right\}$



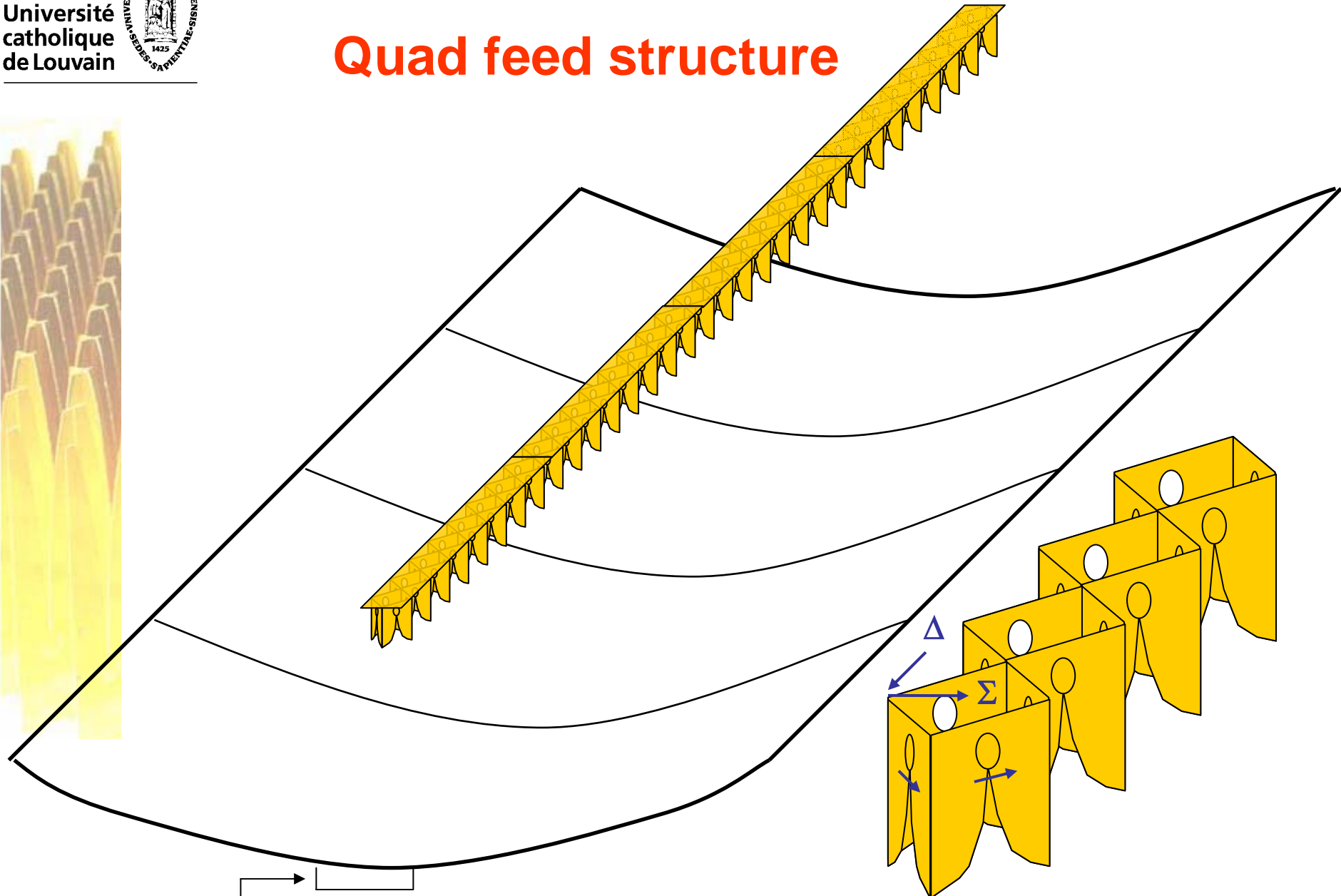
Element patterns



Element pattern for center element



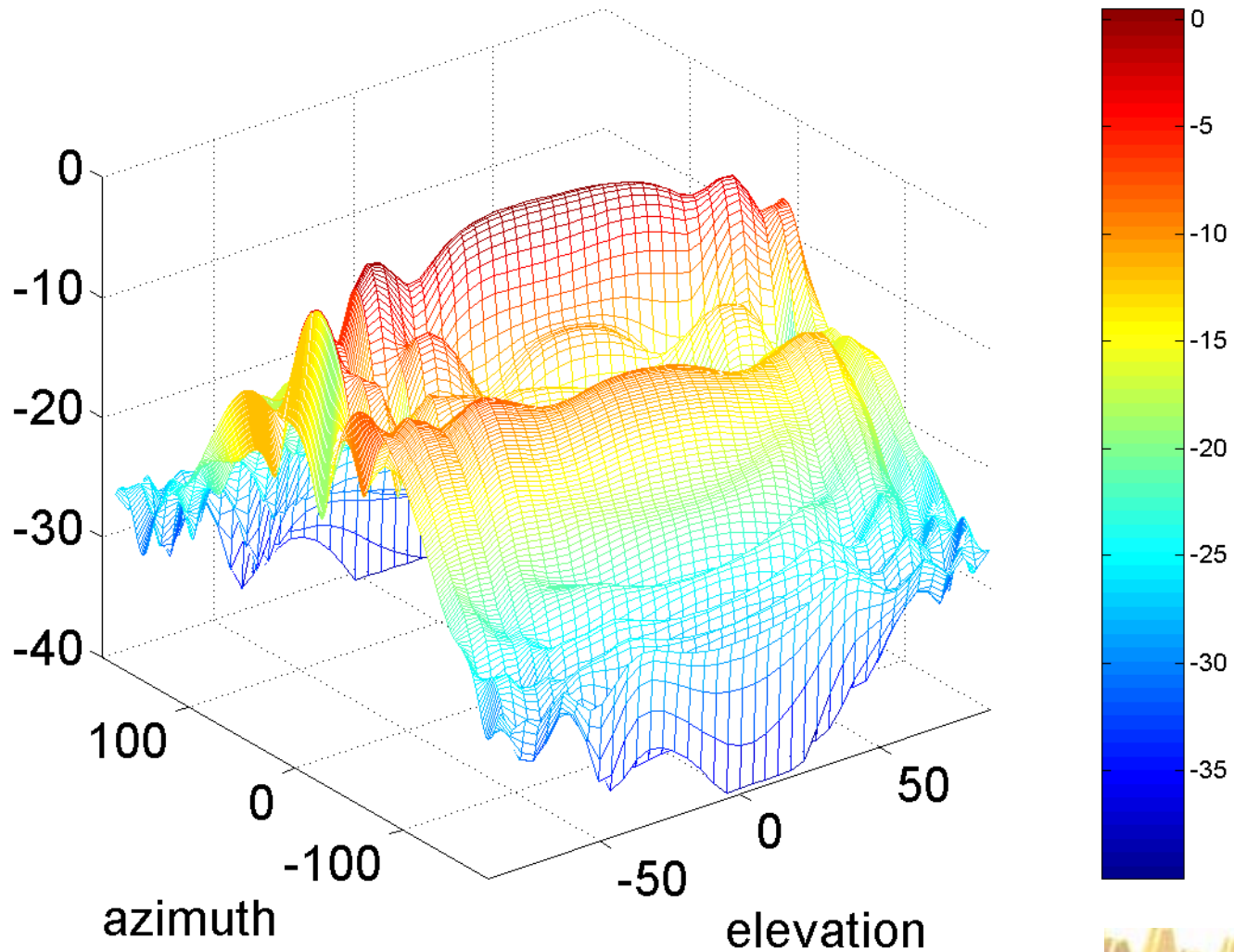
Quad feed structure



NB: vertex plate easily analyzed

$\Sigma - \Delta$ strategy for polarization

Element pattern of quad feed



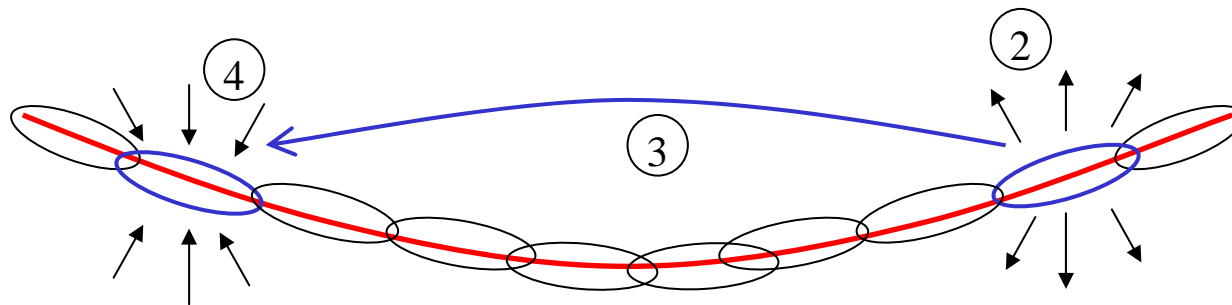
22 min



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 ...)

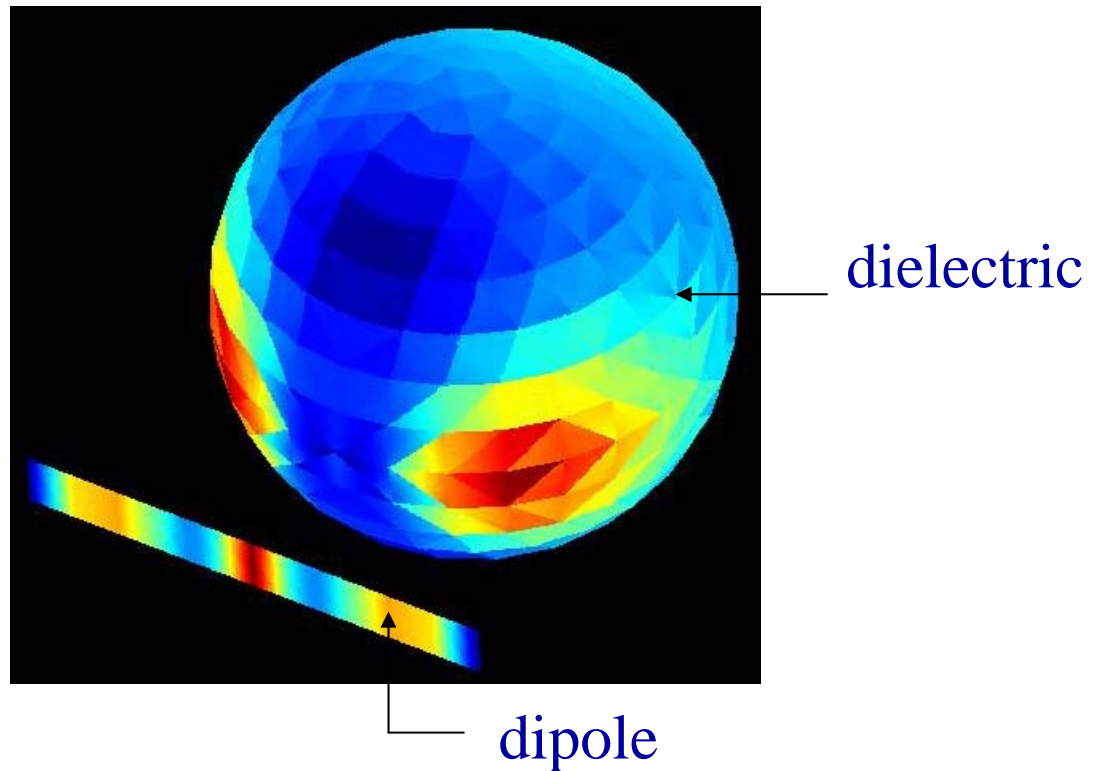


Tool: addition theorem of Bessel functions



Ongoing developments (2/3)

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

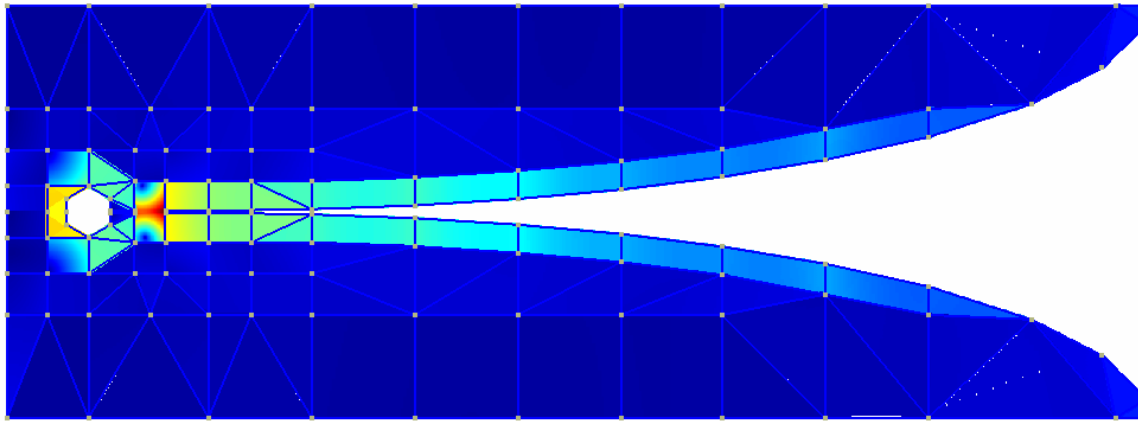


Solve interior and exterior problems (homogeneous media) while ensuring continuity of E_{tan} and H_{tan} .



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. Briskin)
- Wave phenomenology in finite and finite-by-infinite arrays (with A. Boryssenko and D. Schaubert)

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.
- [4] Craeye C., Arts M., On the receiving cross-section of an antenna in infinite linear and planar arrays, accepted for publication in *Radio Science*, April 2004.
- [5] Craeye C., Parvais B., Dardenne X., Signal-to-noise patterns in infinite and finite receiving antenna arrays, *IEEE Transaction on Antennas and Propagation*, December 2004.
- [6] Craeye C., Introducing spatial correlation in the thermal noise model of receiving arrays, Accepted for publication in *IEEE Transactions on Antennas and Propagation*, June 2005.

Submitted

- [7] Craeye C. and Dardenne X., Element pattern analysis of wideband arrays with the help of a finite-by-infinite array approach, Submitted to *IEEE Transactions on Antennas and Propagation*, Feb. 2005.



Conference papers

- [1] Craeye C., Smolders A.B., Tijhuis A.G., Schaubert D.H., Computation of finite array effects in the framework of the Square Kilometer Array project, *Proc. of the IEE conference on Antennas and Propagation*, Manchester, pp. 298-301, April 2001.
- [2] Craeye C., bij de Vaate J.G., Effects of array truncation on the depth of deterministic nulls obtained with a broadband phased array, *Proc. of the 2002 IEEE Antennas and Propagation Society Symposium*, pp. 232-235, San Antonio, Texas, June 2002.
- [3] Craeye C., Arts M.J., Bregman J.B., Truncation effects in tapered-slot antenna arrays for radio-astronomy applications, *Proc. of the 2002 URSI Symposium, Maastricht, The Netherlands*, August 2002.
- [4] Craeye C., Boryssenko A.O., Schaubert D.H., Analysis of infinite and finite arrays of tapered-slot antennas for SKA, *Proc. of the 2002 European Microwave Conference*, pp. 1003-1006, Milano, September 2002 (invited).
- [5] Craeye C., Decomposition of a finite-by-infinite array using two semi-infinite arrays, *Proc. of Journées Int. de Nice sur les Antennes*, pp351-354, Nice, Nov. 2002.
- [6] Craeye C., Boryssenko A.O., Schaubert D.H., Computation of truncation effects in broadband tapered-slot phased arrays using efficient frequency-domain and time-domain approaches, *Proc. of the 12th IEE Int. Conf. On Antennas and Propagation*, pp. 445-448, Exeter, March 2003 (invited).
- [7] Dardenne X., Craeye C., Simulation of the radiation characteristics of 3D quasi self-complementary arrays, *Proc. of the 3d COST284 meeting on Innovative antennas*, Budapest 6-8 April 2003.
- [8] Dardenne X. and Craeye C, Simulation of the effects of a ground plane on the radiation characteristics of self-complementary arrays, *Proc. of the 2003 IEEE Antennas and Propagation Society Symposium*, Columbus, Ohio, June 2002.



Conference papers (Ctd.)

[9] Boryssenko O.A., Schaubert D.H., Craeye C., A wave-based model for mutual coupling and truncation in finite tapered-slot phased arrays, *Proc. of the 2003 IEEE Antennas and Propagation Society Symposium*, Columbus, Ohio, June 2003 (invited).

[10] Craeye C., Fast computation and extrapolation of the effects of array truncation in broadband antenna arrays, *Proc. of the 2003 IEEE Antennas and Propagation Society Symposium*, Columbus, Ohio, June 2003 (invited).

[11] Craeye C., Dardenne X., Efficient computation of the polarization characteristics of infinite and finite arrays of tapered-slot antennas, *Proc. of the 2003 IEEE Symposium on Phased Array Systems and Technology*, Boston, October 2003.

[12] Schaubert D., Boryssenko A., van Ardenne A., Bij de Vaate J-G., Craeye C., The Square Kilometer Array (SKA) Antenna, *Proc. of the Phased Array Systems and Technology Symposium*, pp. 351-358, October 2003 (invited).

[13] Dardenne X., Craeye C., Analysis of infinite and finite broadband low-profile arrays, *Proc. of the 26th ESA Antenna Technology Workshop on Satellite Antenna Modelling and Design Tools*, pp. 167-174, Noordwijk, November 2003.

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

[15] Craeye C., Truncation analysis of dual-polarized broadband arrays, *Proc. of PIERS 2004 Symposium*, Pisa, March 2004 (invited).

[16] Craeye C., On the radiation characteristics of finite dual-polarized arrays of tapered-slot antennas, *Proc. of the 2004 IEEE Symp. on Antennas and Propagation*, Monterey, CA, June 2004.



Conference papers (Ctd.)

- [17] Craeye C., Brisken W., Dardenne X., Simulated radiation characteristics of wideband focal plane arrays and their impact on the system gain-to-temperature ratio, *Proc. of the JINA 2004 Conference*, Nice, Nov. 2004.
- [18] Gilles Th., Piette M., Craeye C., Controlling the local and global accuracy while minimizing computing time and memory in the case of PMCHW applied to solved the plane wave excitation of complex dielectric bodies, accepted for publication at PIERS 2005 in China.
- [19] Dardenne X. and Craeye C., ASM based method for the study of periodic metamaterials excited by a slotted waveguide, submitted for publication at IEEE Symposium on Antennas and Propagation, Jan. 2005.
- [20] Craeye C., Full-wave simulations of focal-line wideband arrays combined with cylindrical reflectors, Proc. of IEEE Symposium on Antennas and Propagation, Jan. 2005.
- [21] Craeye C., Toward full-wave simulations of cylindrical reflectors illuminated by focal-line phased arrays, Proc. the ANTEM 2005 conference, Saint-Malo, June 2005.
- [22] Craeye C., On the effective area of antennas in phased-arrays used as focal-line feeds in cylindrical reflectors, Proc. of the COST284 meeting on antennas, Chexbres, March 2005, Switzerland.

