(1979-2014)

In the memory of
Julien Perruisseau-Carrier

Fast Construction of the MoM Matrix for Reflectarrays through a Smart Tabulation

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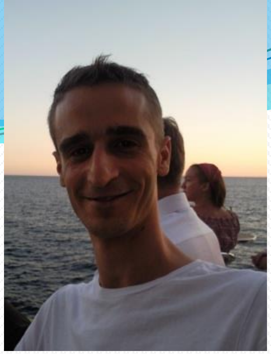
Outline

- Collaborations of METU team with Julien:
  - Tunable RF MEMS components
  - Dual Frequency Circularly Polarized Beam Steering Reflectarray
  - COST (European Cooperation in Science and Technology) actions
- Fast and efficient analysis method for the design of reflectarrays of variable size elements
  - Characteristic mode concept
  - Matrix reduction using CMs
  - Fast calculation of MoM matrix entries



How we met - AMICOM

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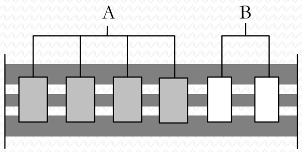
Project: **AMICOM**: European Network of Excellence on RF MEMS and RF Microsystems, European Union FP6 network of excellence
Role: Various technical collaborations, including the design and realization of MEMS-variable CRLH-TLs and MEMS-reconfigurable reflectarray cells.

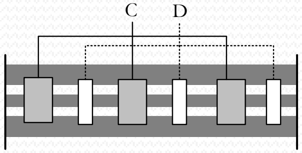
Collaboration with EPFL (Prof. Anja Skrivervik & Julien Perruisseau, PhD canditate):

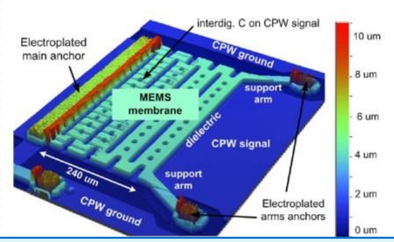
- fabrication of EPFL's devices by METU
- collaboration on EM modelling tools and reflectarrays
- Julien’s visit to METU: Oct 18-November 12, 2004

Cascaded DMTLs



Interlaced Bits





J. Perruisseau-Carrier, K. Topalli, and T. Akin, “Low-loss Ku-band Artificial Transmission Line with MEMS Tuning Capability,” *IEEE Microwave and Wireless Components Letters*, vol. 19, no. 6, pp. 377-379, June 2009.

AMICOM MEMSWAVE Workshop, Laussane 2005

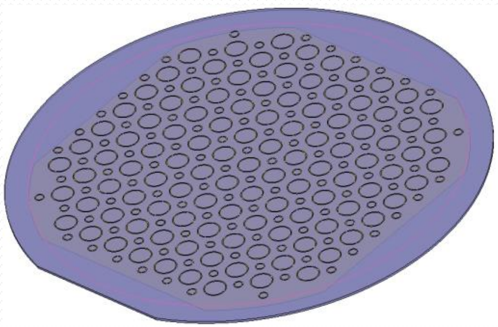
COST Actions on Antennas

COST ASSIST IC0603: Antenna Systems and Sensors for Information Society Technologies.

Funding: European Union, 2007-2011

Role of Julien : Leader of the Focus Area 'Reconfigurable & Multibeam Antennas'.

Short Term Scientific Mission: Caner Güçlü from METU visited Julien Perruisseau-Carrier from CTTC, 26 October to 7 November 2009



C. Guclu, J. Perruisseau-Carrier, O. Aydın Civi, "Proof of Concept of a Dual-band Circularly-polarized RF MEMS Beam-Switching Reflectarray, IEEE Transactions on Antennas and Propagation, vol.60, no.11, pp. 5451 - 5455, 2012.

COST VISTA IC1102 Versatile, Integrated, and Signal-aware Technologies for Antennas, European Union, 2012- present

Role of Julien : Leader of the WG2 – HOW? Enabling technologies

- set up the *Technology Platforms* to enhance the exchanges among the participants
- organized several sessions in COST VISTA workshops and EuCAPs

Reflectarrays

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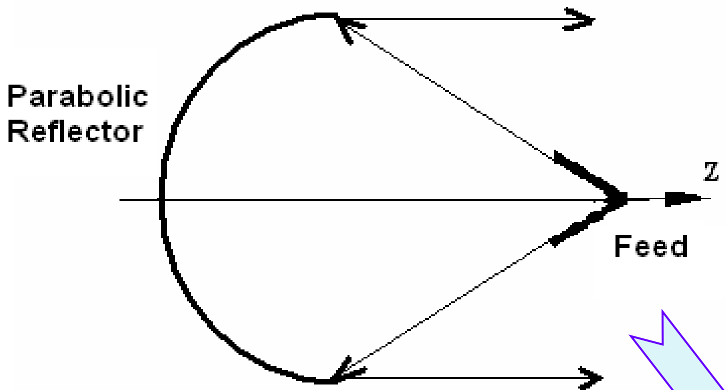
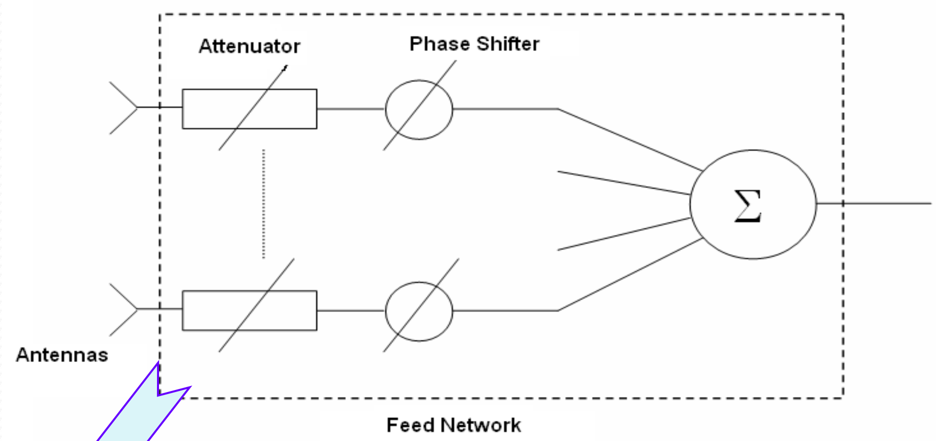
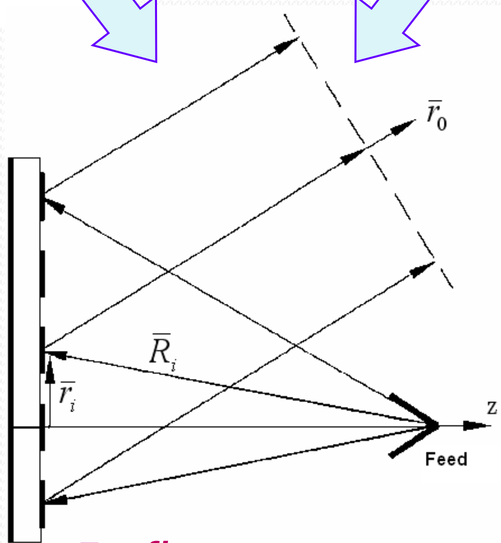


Reflector antenna



Phased array antenna



Reflectarray

Some reflectarray elements:

- *patches of varying size*
- *rotated patches*
- *patches with variable length stubs*
- *rotated split rings*

- *Reflectarrays can be flat or slightly curved printed structures*
- *Reflecting surface consists of many elements with no power division network*
- *By changing phase of each element, beam can be steered*

Background Information

Common design approach

- Choose type of array elements
- Obtain phase design curve: variation of phase of reflected field w.r.t element dimension/rotation by using infinite array approach

- Given a desired pattern (Scanned and/or shaped beam)
- Perform phase only pattern synthesis to find the phase distribution across the array aperture

- Determine element sizes/angles by using phase design curves to achieve the required phase distribution.

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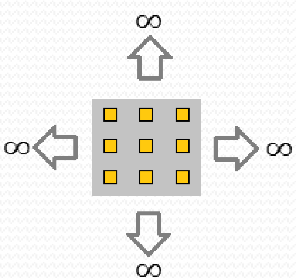
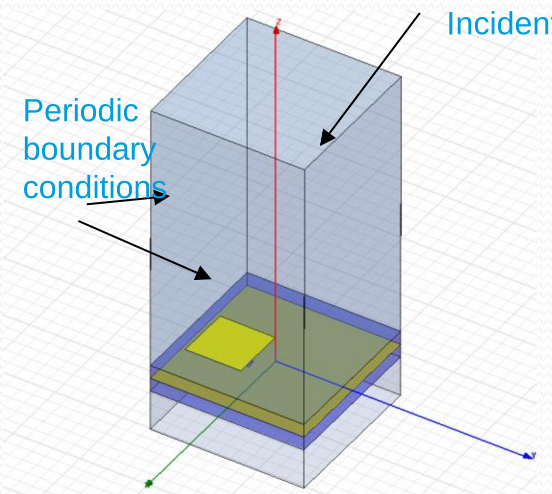
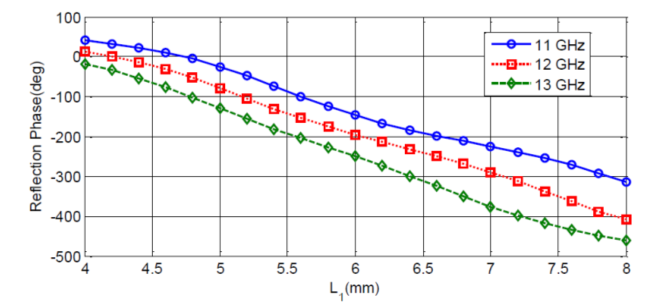
Common Design Approach of a Reflectarray

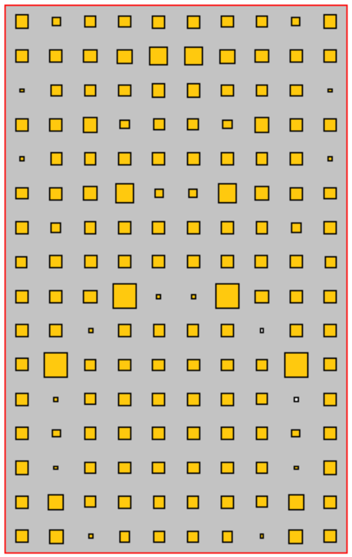
- Infinite array approach (local periodicity approach): Using Floquet Theorem, the analysis is reduced to only one periodic cell
  - Widely accepted for analysis and design
  - Mutual coupling is approximately taken into account
  - Accuracy is lost on regions of abrupt dimension change





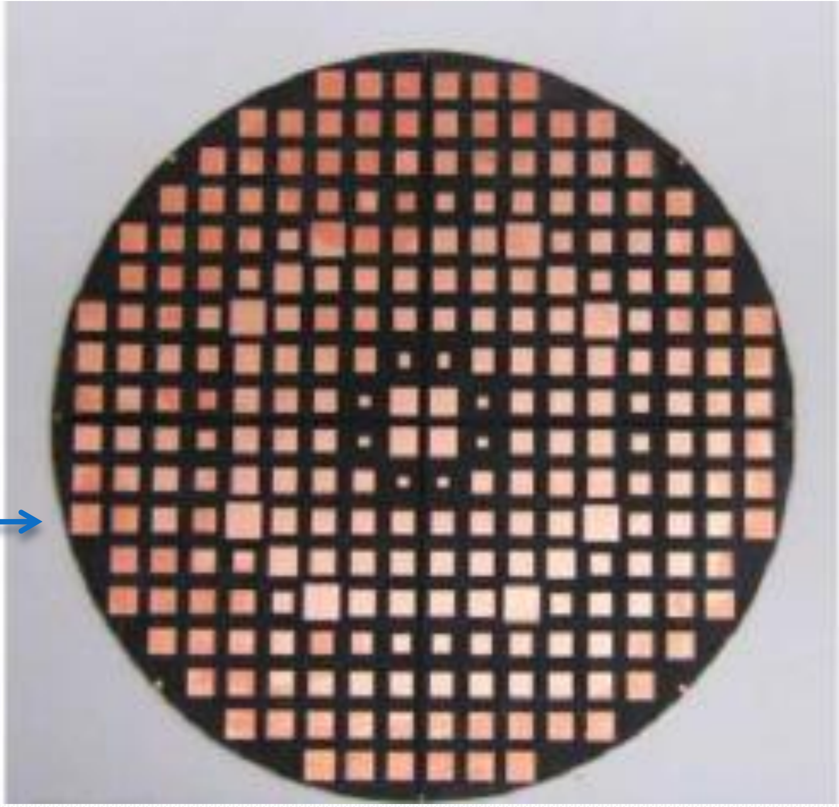
Schematic of unit cell





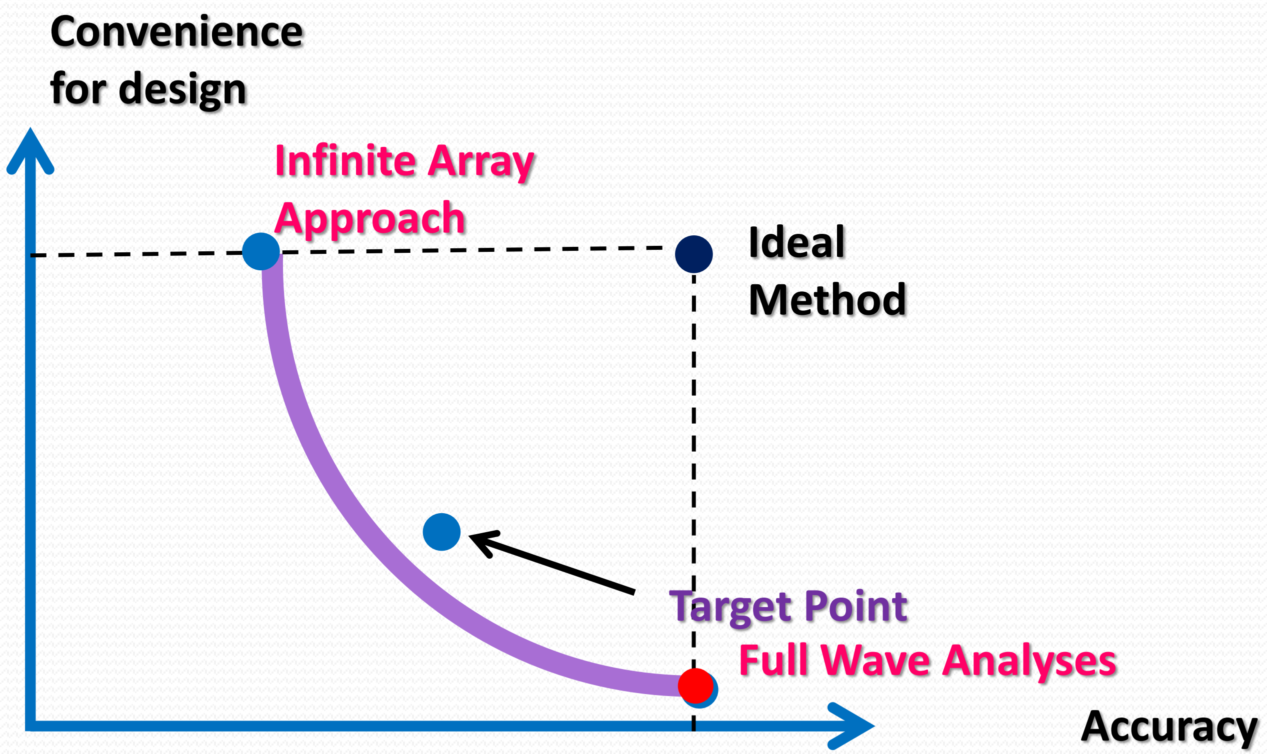
Reflectarrays with variable size patches

Considerable variation in size of adjacent elements



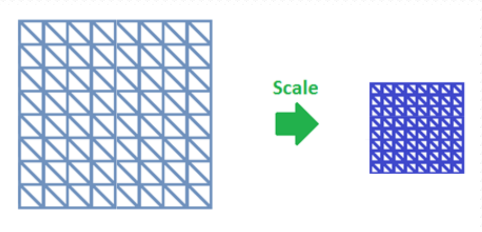
H. Rajagopalan, S. Xu, and Y. Rahmat-Samii, "Experimental demonstration of reflectarrays acting as conic section subreflectors in a dual reflector system," *IEEE Trans. Antennas Propag.*, vol. 61, no. 11, pp. 5475–5484, Nov. 2013.

Aim of this study



Fast and efficient analysis method

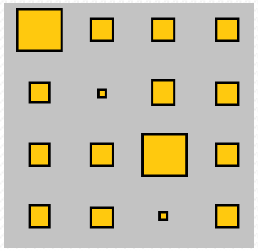
- Reduction of the MoM matrix equation size significantly using characteristic modes as macro basis functions
- Reusability of characteristic modes



  - dominant characteristic mode of the resonant patch can be used for all differently sized patches on the array
- Construction of reduced impedance matrix in a very efficient way

E. Erçil, L. Alatan, Ö. Aydin Civi, «Efficient Analysis of Reflectarrays Through the Use of Characteristic Modes», 9th EuCAP, April 2015

Reduced MoM matrix for array solution



N basis functions on each patch, P patches

$$[Z]_{PNxPN}\,\alpha = V \quad\Rightarrow\quad \tilde{Z}\beta = \tilde{V}$$

$$Z = \begin{bmatrix} [Z_{11}]_{NxN} & [Z_{12}]_{NxN} & . & [Z_{1P}]_{NxN} \\ . & [Z_{22}]_{NxN} & . & . \\ . & . & . & . \\ . & . & . & [Z_{PP}]_{NxN} \end{bmatrix}_{PNxPN}$$

$$\tilde{Z} = I^H Z I$$

$$\alpha = I\beta$$

$$\tilde{V} = I^H V$$

$$I_p = \lfloor \overline{J_1} \quad \overline{J_2} \quad \rfloor_{NxN}$$

NxM

$$I = \begin{bmatrix} [I_1]_{NxN} & 0 & . & 0 \\ 0 & [I_2]_{NxN} & . & 0 \\ . & . & . & . \\ 0 & . & . & [I_P]_{NxN} \end{bmatrix}_{PNxPN}$$

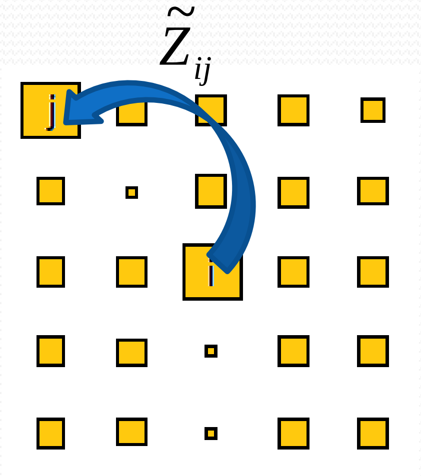
- **When I_0 is NxM instead of NxN where M<N $\tilde{Z}$ is PMxPM.**
- **Number of unknowns is reduced to PM from PN**
- **If I_0 is Nx1, i.e. only a single CM is used, $\tilde{Z}$ is PxP**

$$\tilde{Z}_{ij} = J_1^T Z^{ij} J_1$$

Construction of reduced matrix

• It is required to compute the full impedance matrix Z in order to find the reduced matrix $\tilde{Z}$

$$Z_{\mathrm{PN}\times\mathrm{PN}} \longrightarrow \tilde{Z}_{P\times P}$$



•The terms in $\tilde{Z}$ are computed as: $\tilde{Z}_{ij} = J_1^T Z^{ij} J_1$

• Is it possible to find a fast way of computing $\tilde{Z}_{ij}$?

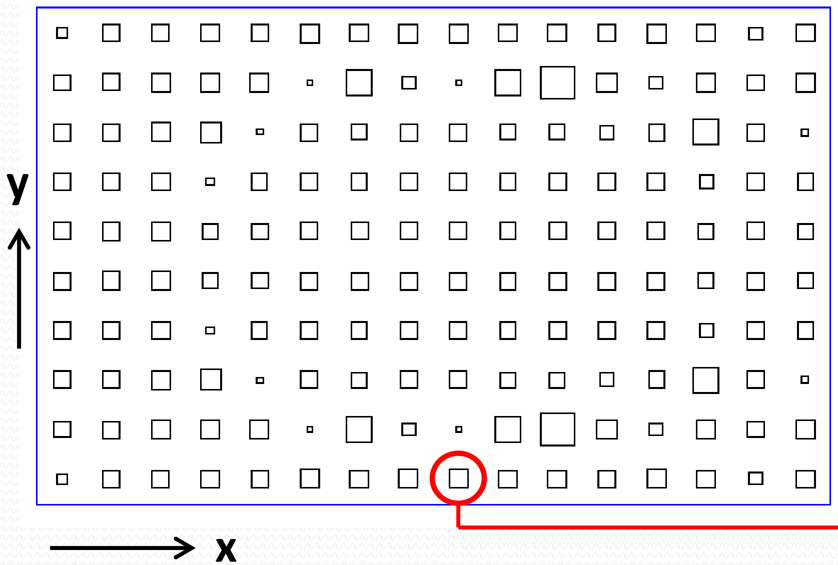
• Tabulate for all possible displacement types and possible size couples.

➢Too many possible cases even for a medium sized array. ☹

•Ignore distant interactions and consider only near interactions.

➢ **We have observed that we need to take all interactions.**

Why take all interactions?



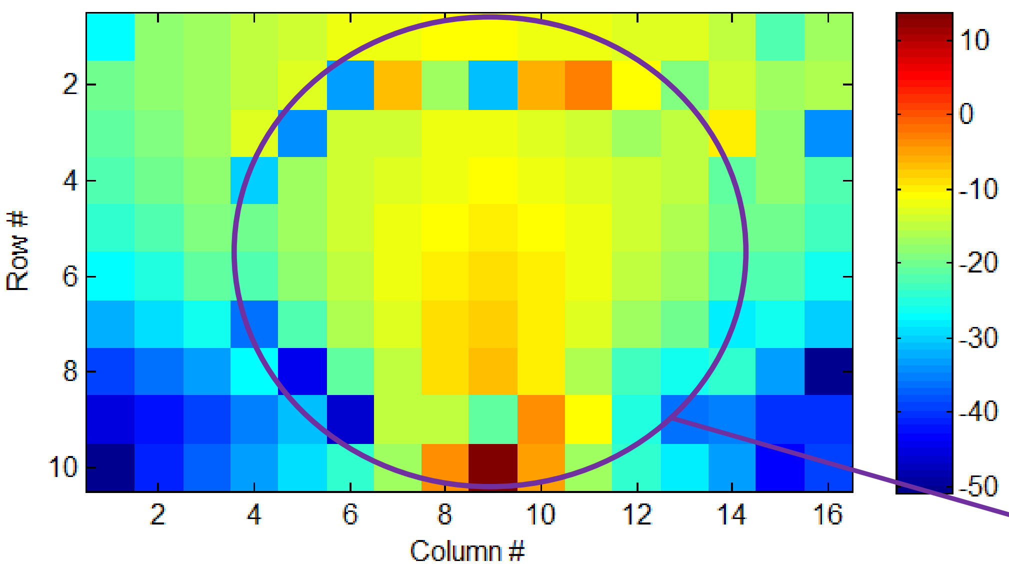
$\tilde{Z}_{160x160}$

90th element

Interactions with all elements

$\tilde{Z}_{90,1:160}$

Arrange 160 entries w.r.t corresponding physical positions



Strong E plane coupling!

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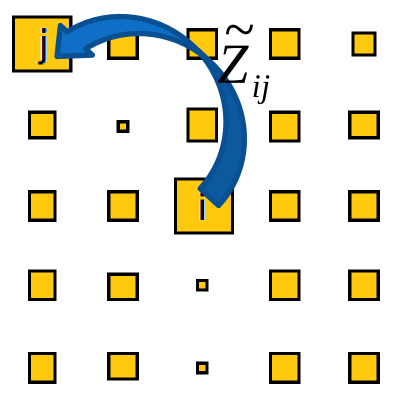
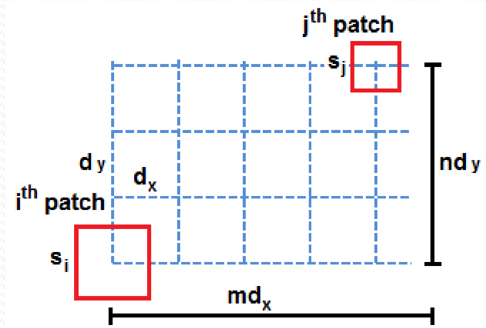
How to compute all interactions ?

- We investigated if a «rule» exists



$$\tilde{Z}_{ij} = J_1^T Z^{ij} J_1 = f\left(d_x, d_y, s_i, s_j\right)$$



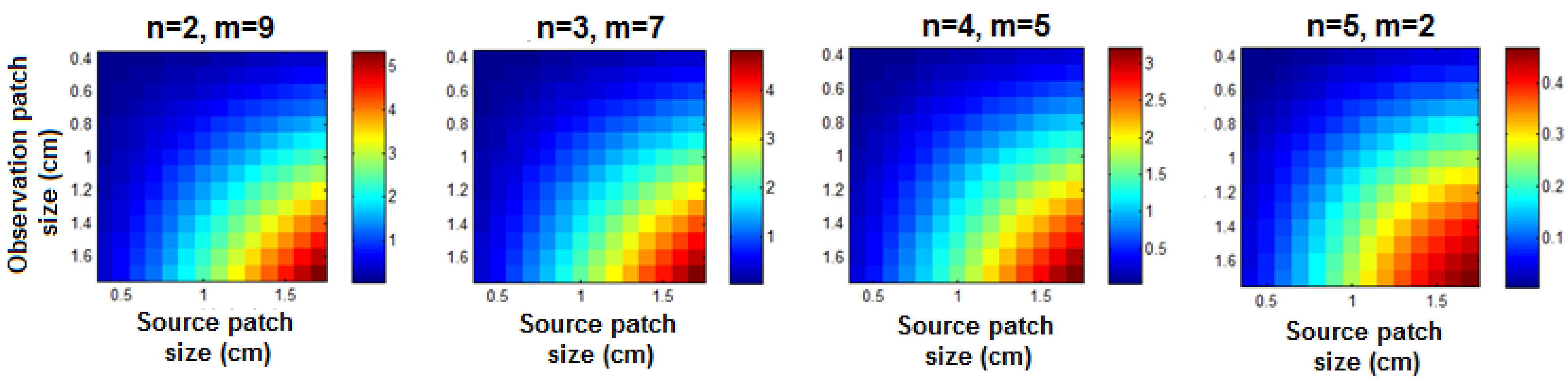
- It was observed that when the patches i & j are sufficiently distant apart, $\tilde{Z}_{ij}$ can be characterized as a separable function of displacement vector and sizes.

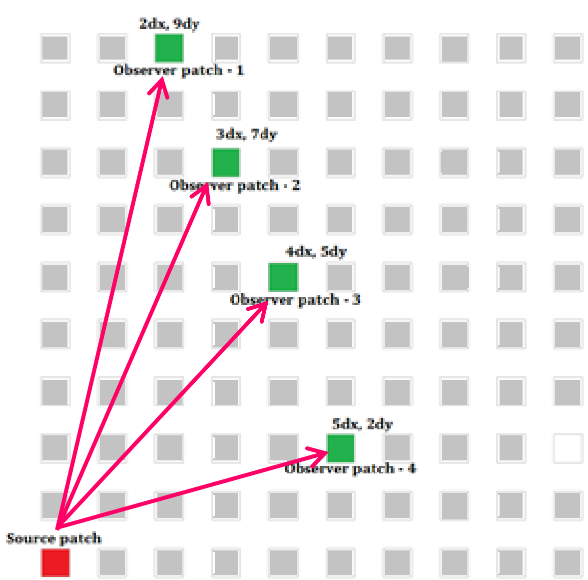
$$\tilde{Z}_{ij} = J_1^T Z^{ij} J_1 = f\left(d_x, d_y, s_i, s_j\right) \approx g(d_x, d_y) h(s_i, s_j)$$

$N_x x N_y x N_{size} x N_{size}$ $\quad$ $N_x x N_y + N_{size} x N_{size}$

Separability $h(s_i, s_j)$

Amplitude of $J_1^T Z^{ij} J_1$



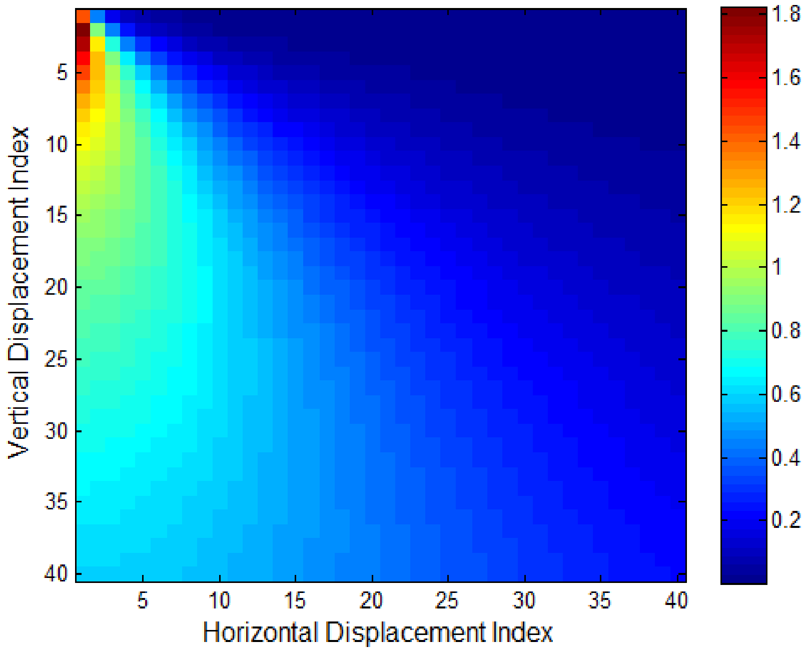


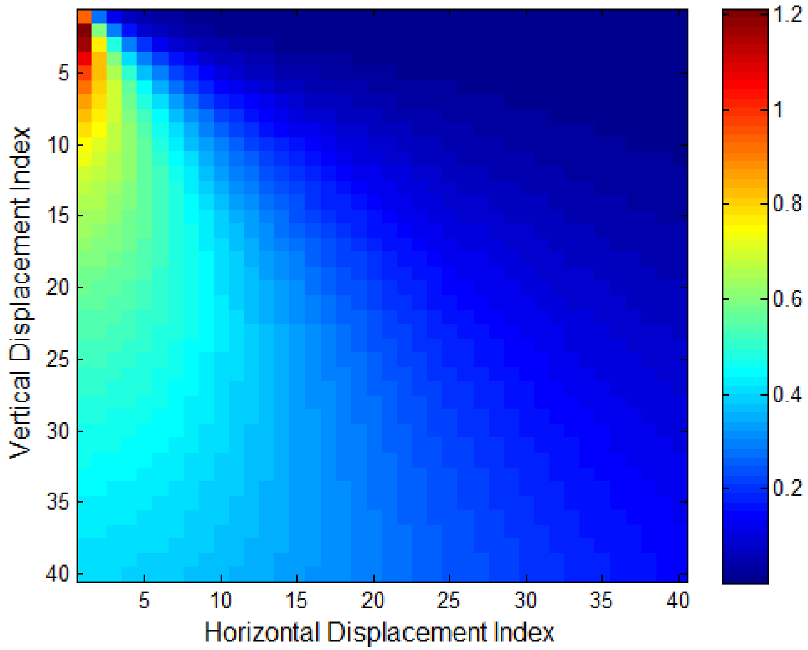
f's at different (d_x,d_y) are almost same within a scaling constant!

Separability $g(d_x, d_y)$

Amplitude of $J_1^T Z^{ij} J_1$

s_1=10 mm, s_2=10 mm **s_1=14 mm, s_2=6 mm**

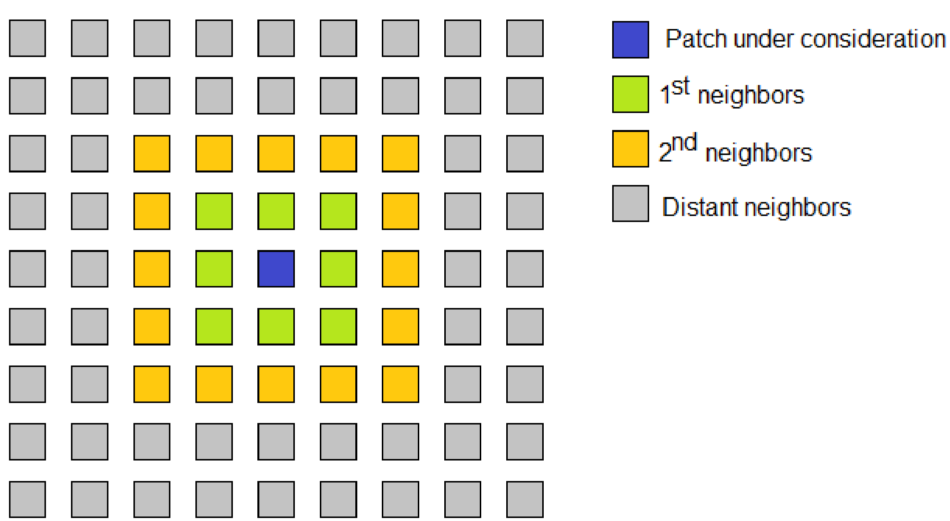




f's at different (s_i,s_j) are almost same within a scaling constant!

Exceptions of separability

- Near neighborhoods do not obey the rule.
- But they are of manageble count.
- For near neighborhoods, full characterization is applied.
- For other elements look up table is formed.
- Once characterizations are completed, far field of any reflectarray with the same substrate properties & periodicity can be found **without ever solving the MoM problem**!



Computational Load

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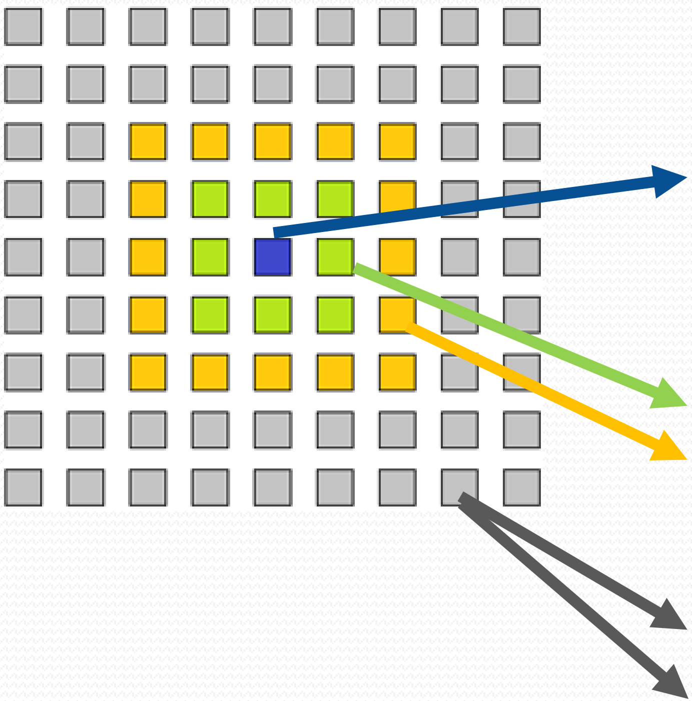
For a 1000 element array



	Number of repetitions	Time to compute $\bar{\bar{Z}}^{ij}$	Total time
Function f (self terms)	121	7.5 s.	908 s
Function f (close neighborhoods)	8×11×12/2	0.5 s.	265 s
Function g	11×12/2=66	0.5 s	33 s
Function h	~1000	0.5 s	500 s
Total time	1706 s ~ 28 min		

If it wasn't for separability, it would take 1000 x 66 x 0.5 =33000 seconds to have the same information.

Once the tabulation is done it takes 0.38 seconds to fill and invert the matrix $\tilde{Z}$ for a 1000 element array.

Intel Core i5 2500, 3.3 GHz Clock Speed, 64 Bit OS, MATLAB

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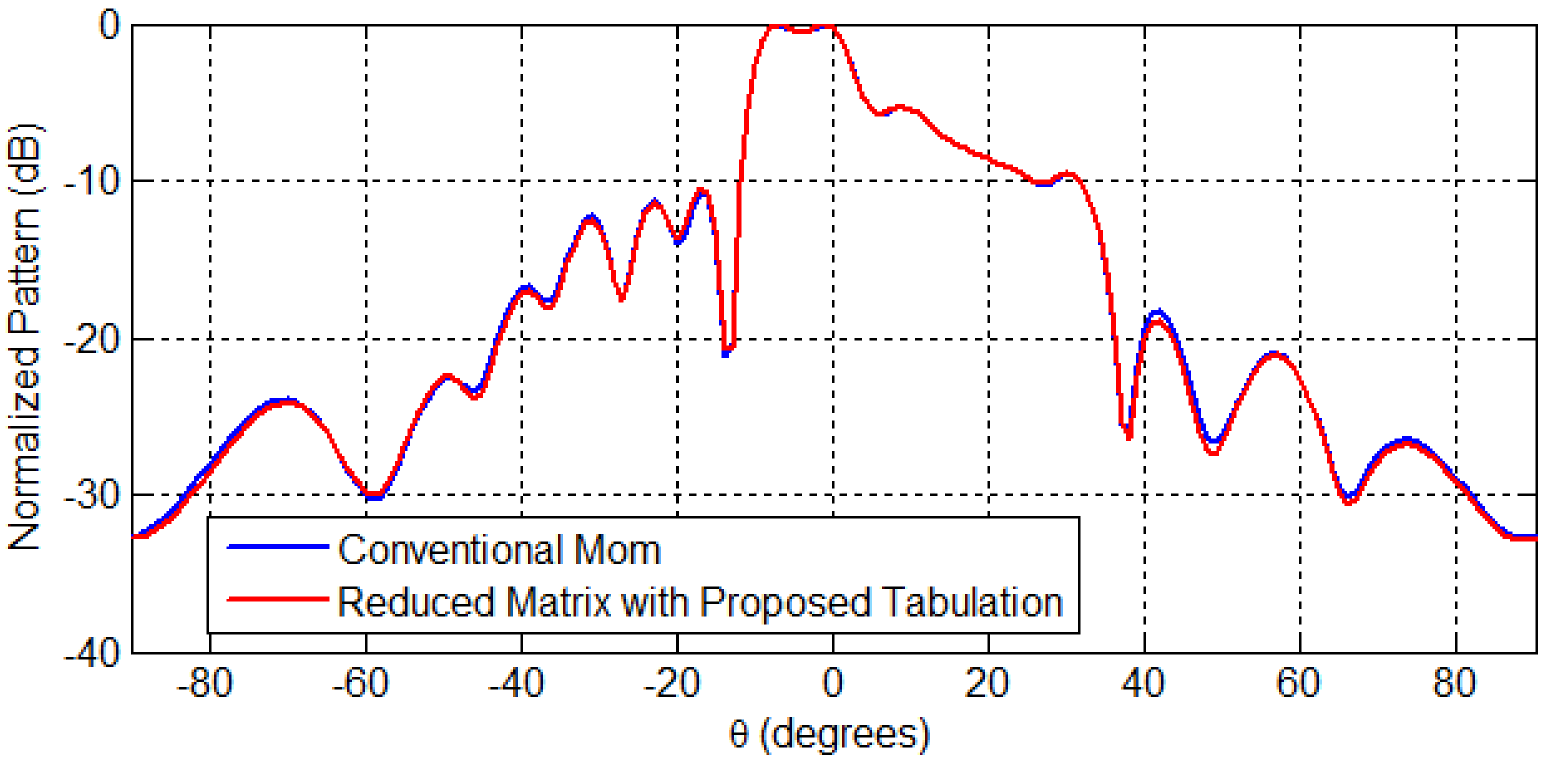

Normalized Pattern (dB)
0
-10
-20
-30
-40
-80
-60
-40
-20
0
20
40
60
80
θ (degrees)
Conventional Mom
Reduced Matrix with Proposed Tabulation

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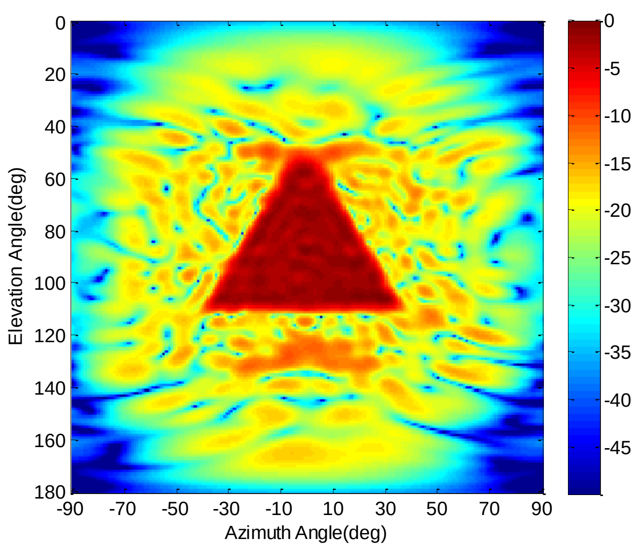
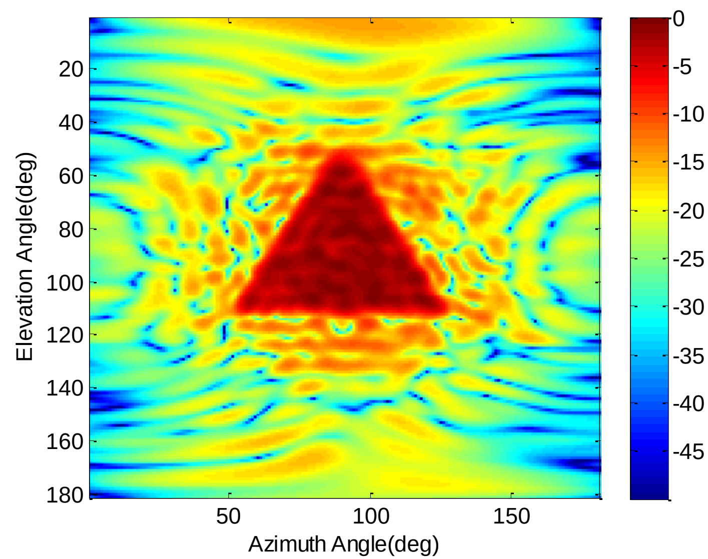
New design paradigm

- Do not obtain phase design curve !
- Do the tabulations.
- Start with all same patches.
- Optimize for desired pattern properties (Steepest descent is appropriate)
    - EXAMPLE: 400 element array, 0.6λ spacing. Frequency :10 GHz

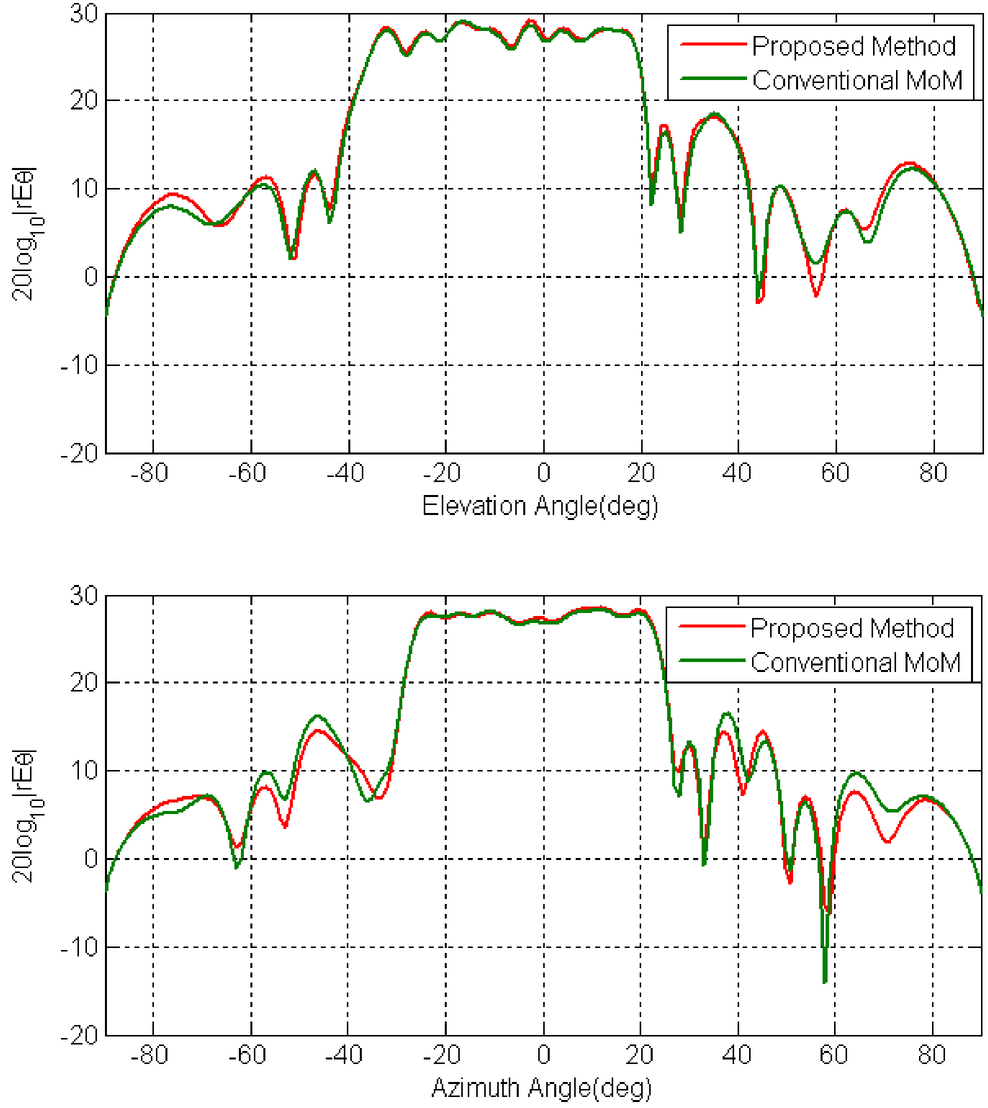


MoM, Reduced Matrix
(Analysis time:28min+ 0.38 sec each solution)



HFSS result (2 hours)

New design paradigm



Conclusions and Future Work

- An accurate and efficient method is proposed to analyze large reflectarrays with varying element size.

    ➢ Future work will be

- studying feasibility of the method for various element shapes,
- studying feasibility of the method for multilayer reflectarray configurations.

We miss Julien!