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# Antenna Array Modeling in the Netherlands

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## Outline

- infinite arrays: extension of classical approach
  - acceleration of MoM matrix fill
  - integration of FSS and phased array antennas
- finite arrays:
  - eigenvalue analysis
  - embedding approach (only applied to EBG structures, not in this presentation)

# Infinite Arrays: Classical Approach

- at interfaces:
  - modal expansion (global expansion functions)
  - EFIE or MFIE (local expansion functions)
- Green's functions: spectral (Floquet) analysis $\Rightarrow$ transmission-line equations
- handle layered medium in Green's function
- numerical solution: method of moments (MoM)
  problem: matrix fill
- scattering operator for composite structures

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# Acceleration of MoM Matrix Fill

Bart Morsink, October 17, 2005
with Gertjan van Werkhoven,
sponsored by Thales Nederland

# General form of MoM matrix elements:

$$A_{v,r} = \sum_{j,\alpha} G^{(\alpha)}(k_j)\,\gamma_{v,r}^{(\alpha)}(\vec{k}_j)$$

where

$\vec{k}_j = \vec{k}_j^{inc} + \vec{R}_j$ with $\vec{R}_j$ a reciprocal lattice vector

$G^{(\alpha)}(k_t)$ = solution of 1D transmission-line equation

$$\gamma_{v,r}^{(\alpha)}(\vec{k}_t) = \begin{cases} [\,j\vec{k}_t \cdot \vec{g}_r^{\,*}(\vec{k}_t)][\,j\vec{k}_t \cdot \vec{g}_r(\vec{k}_t)] & \text{if } \alpha = 1 \\ \vec{g}_r^{\,*}(\vec{k}_t) \cdot \vec{g}_r(\vec{k}_t) & \text{if } \alpha = 2 \end{cases}$$

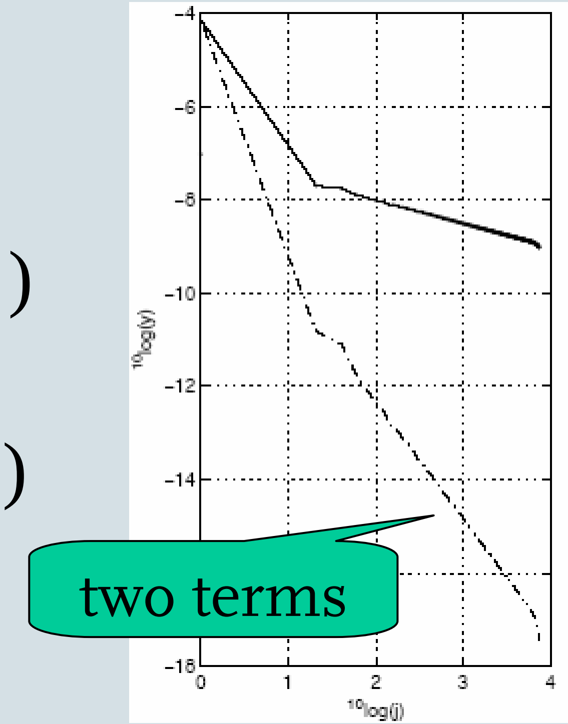
## Asymptotic expansion:

$$\hat{G}^{(\alpha)}(k_t) = c_1^{(\alpha)} k_t^{-1} + c_2^{(\alpha)} k_t^{-3} + c_3^{(\alpha)} k_t^{-5} + \ldots$$

## Kummer transformation:

$$A_{v,r} = \sum_{j,\alpha} [G^{(\alpha)}(k_j) - \hat{G}^{(\alpha)}(k_j)]\, \gamma_{v,r}^{(\alpha)}(\vec{k}_j)$$

$$+ \sum_{j,\alpha} \hat{G}^{(\alpha)}(k_j)\, \gamma_{v,r}^{(\alpha)}(\vec{k}_j)$$



# Asymptotic series: Ewald's transformation

$$\frac{1}{k_t^n} = \frac{2\lambda}{\Gamma(n/2)} \int_0^\infty \tau^{\lambda-1} \exp(-k_t^2 \tau^{2\lambda}) \,\mathrm{d}\tau$$

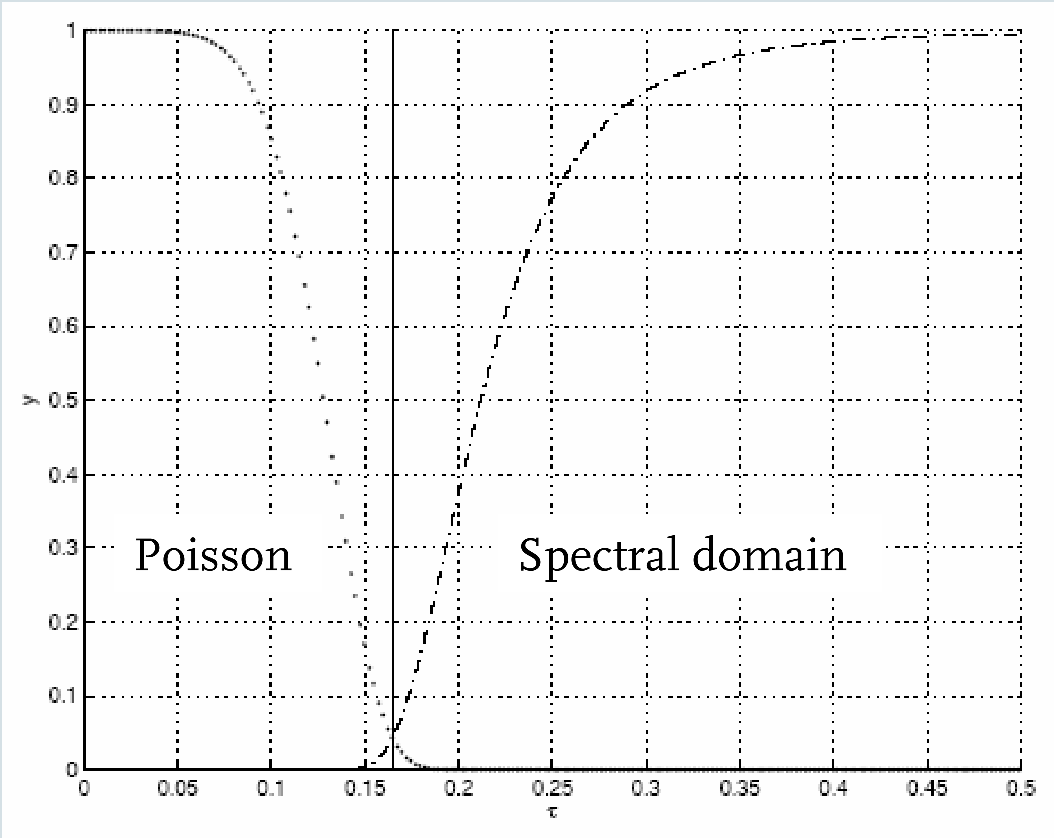
results in

$$\hat{A}^{(\alpha)}(k_t) = \frac{2\lambda}{\sqrt{\pi}} \int_0^\infty \tau^{\lambda-1} \sum_j (c_1^{(\alpha)} + 2\tau^{2\lambda} c_2^{(\alpha)}) \exp(-k_{t;j}^2 \tau^{2\lambda}) \,\gamma_{v,r}^{(\alpha\alpha)}(\vec{k}_j) \,\mathrm{d}\tau$$

Large argument: exponential convergence

Small argument: Poisson summation

# Transition point: leading-order term



Success depends on the determination of

$$\gamma_{v,r}^{(\alpha)}(\vec{\rho},\tau) = F^{-1}\{\exp(-k_t^2\tau^{2\lambda})\,\hat{\gamma}_{v,r}^{(\alpha)}(\vec{k}_t)\}$$

Can be identified as solution of heat equation

Example: rooftop function

- product of pulse and triangular function
- regularized function also as product

Recent development: RWG functions

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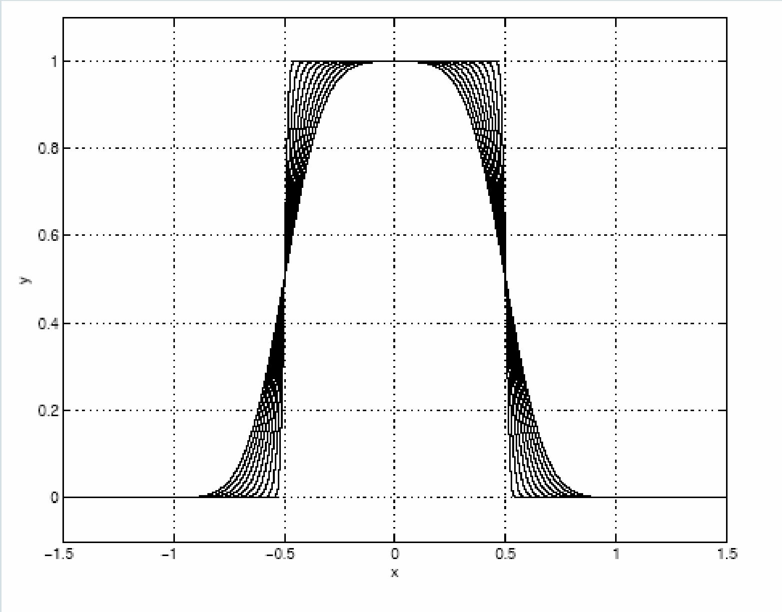
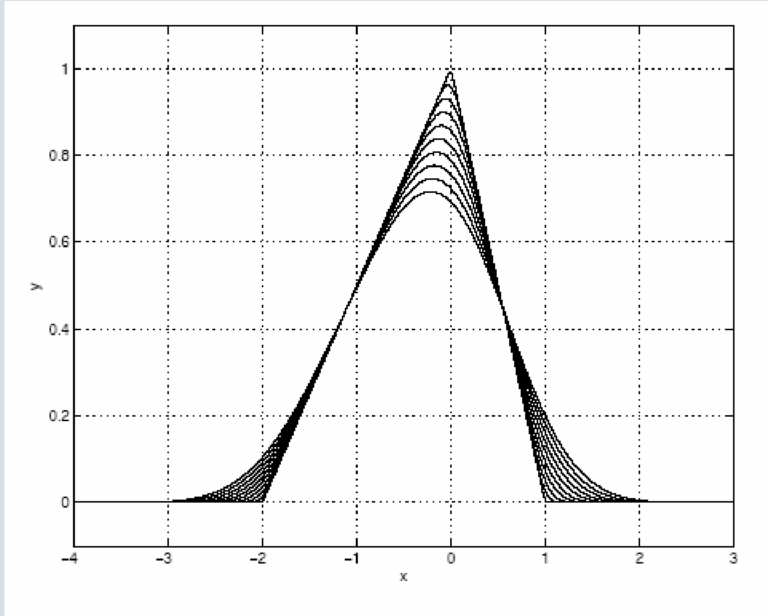
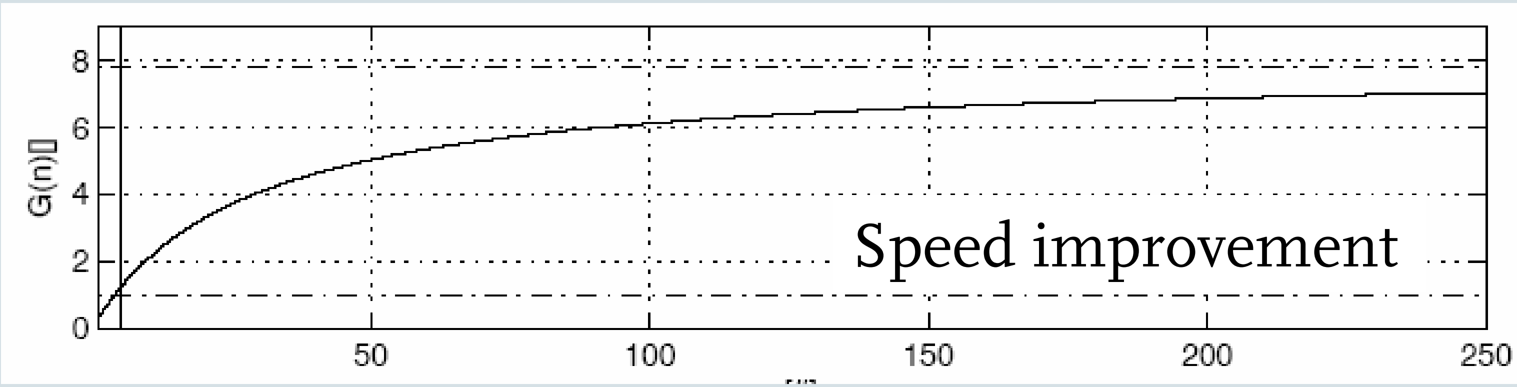
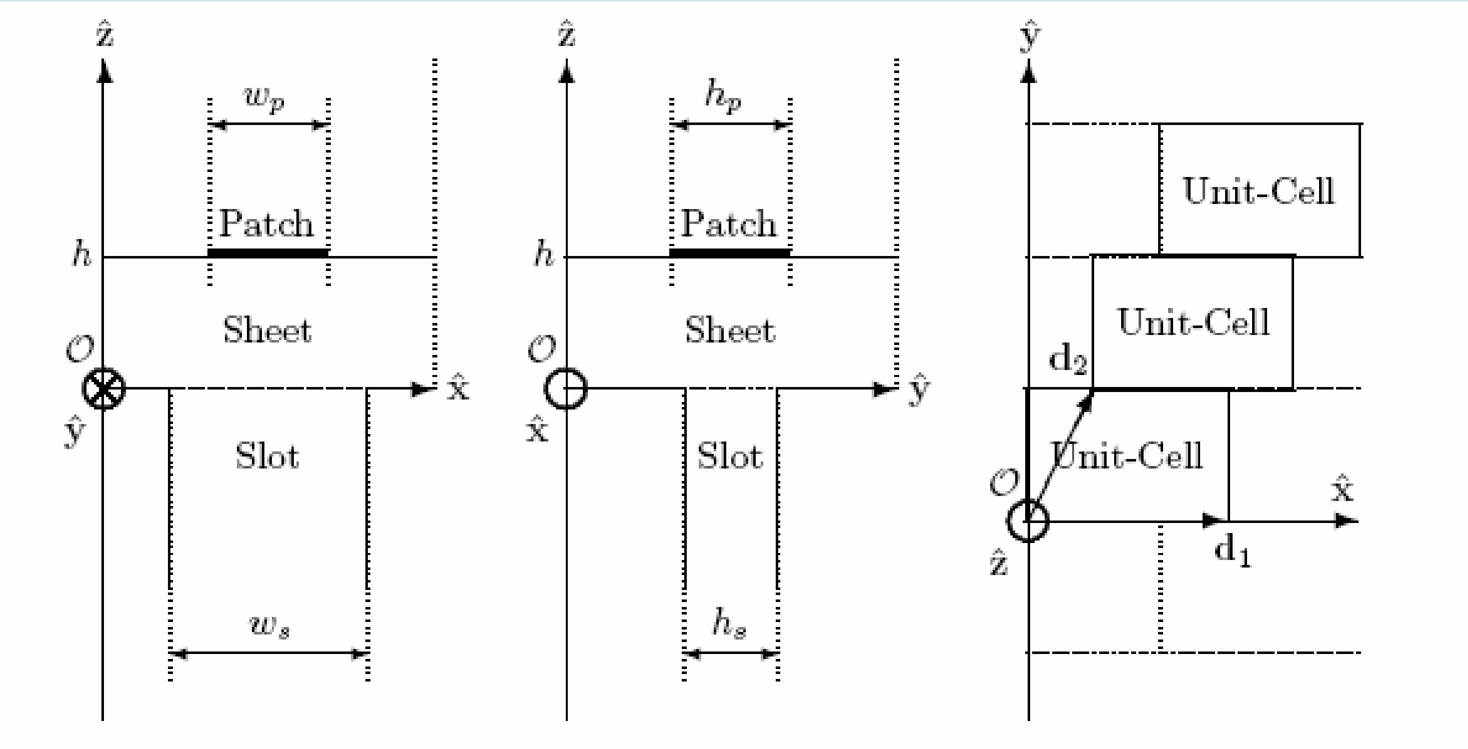


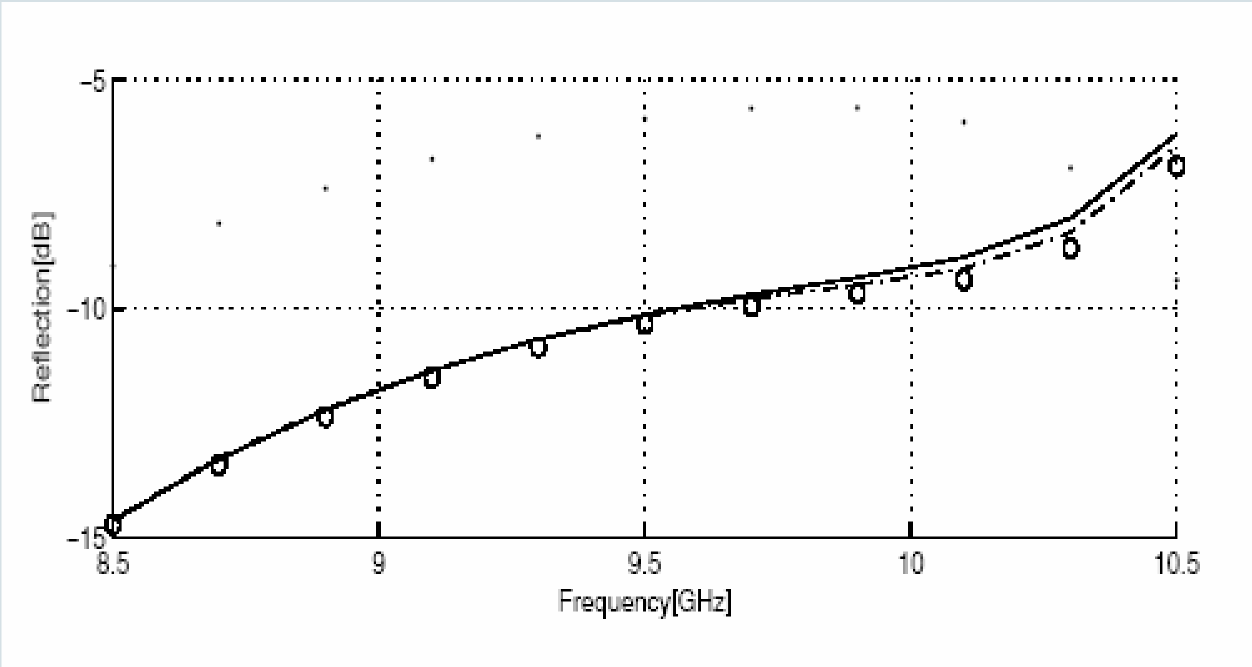



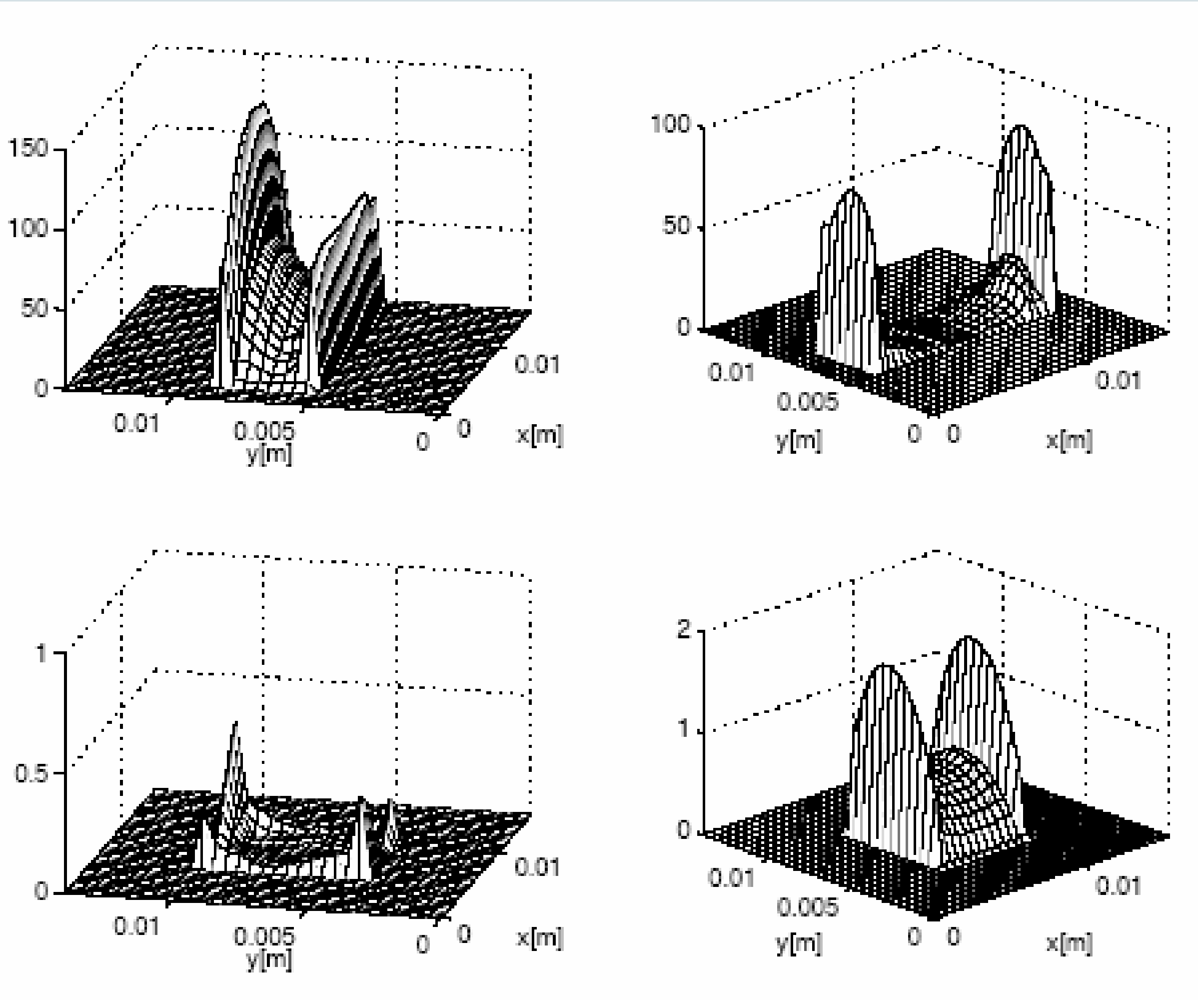
# Example: open-ended waveguide with patch




Side view *x* Side view *y* Top view

# Power reflection coefficient






$M_x$ and $M_y$ on aperture

$J_x$ and $J_y$ on patch

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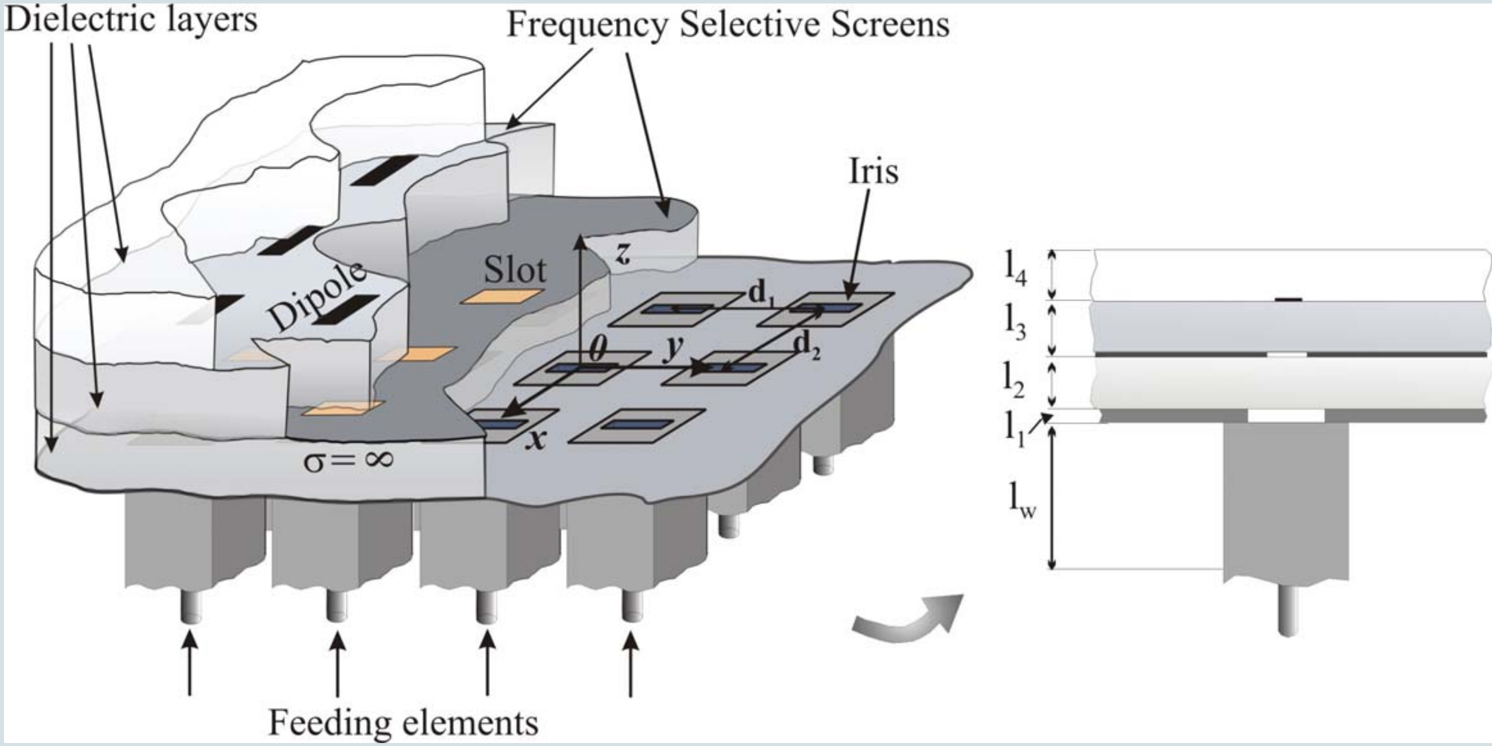
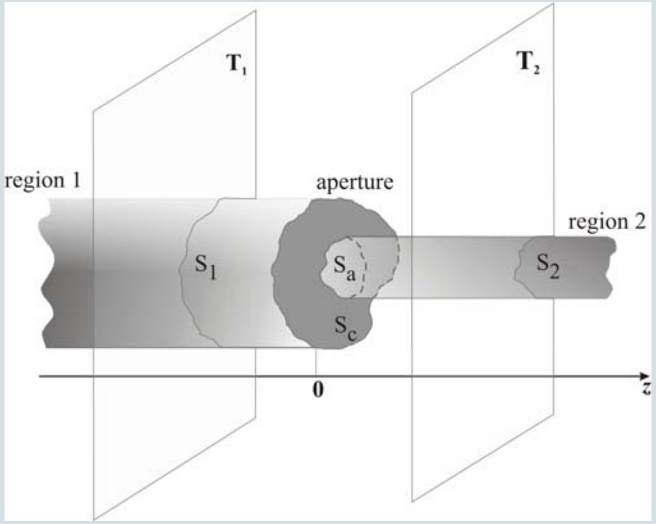
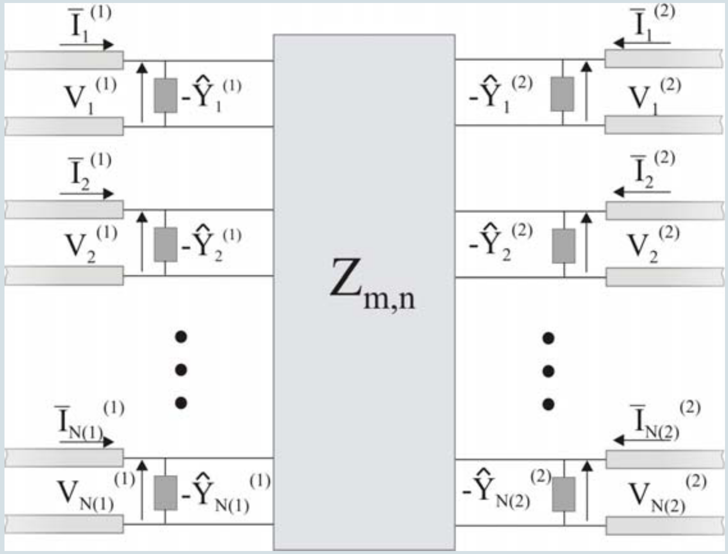
# Integration of Waveguide Array and FSS

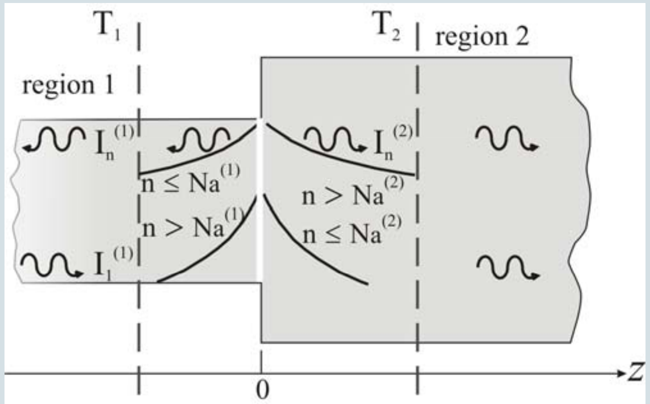
Stefania Monni, June 27, 2005
with Giampiero Gerini and
Andrea Neto, TNO FEL

# Structure to be analyzed/designed





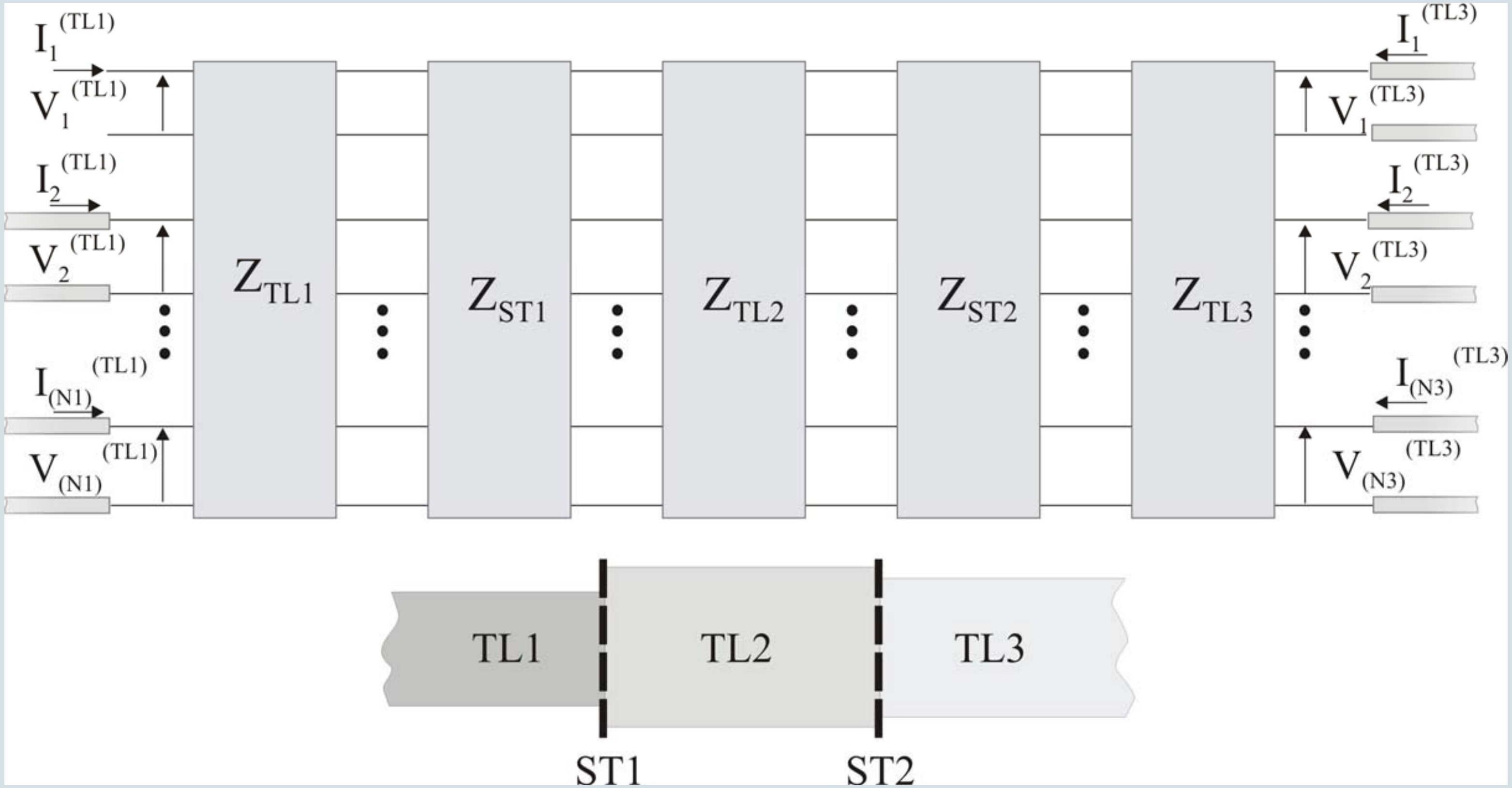



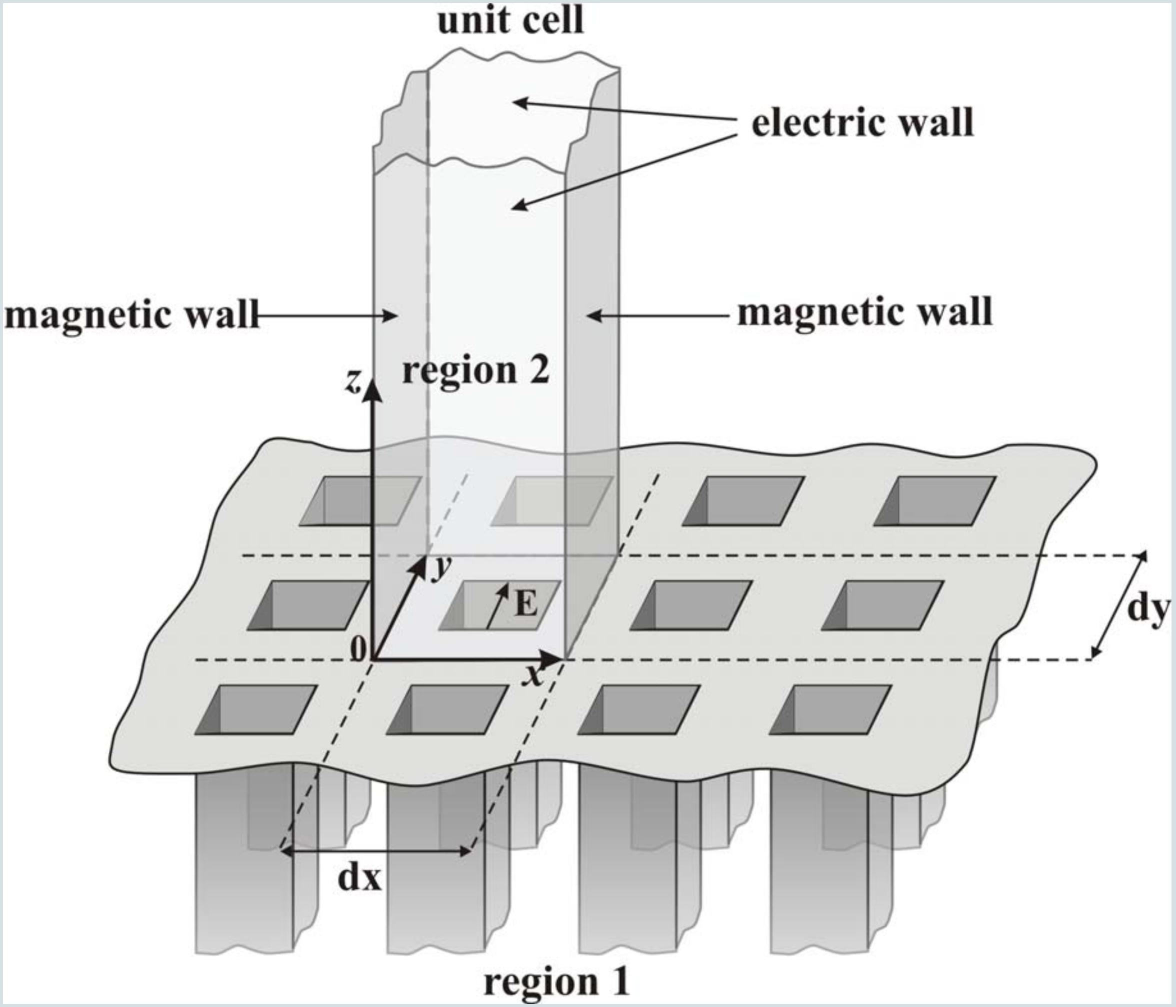




Procedure:

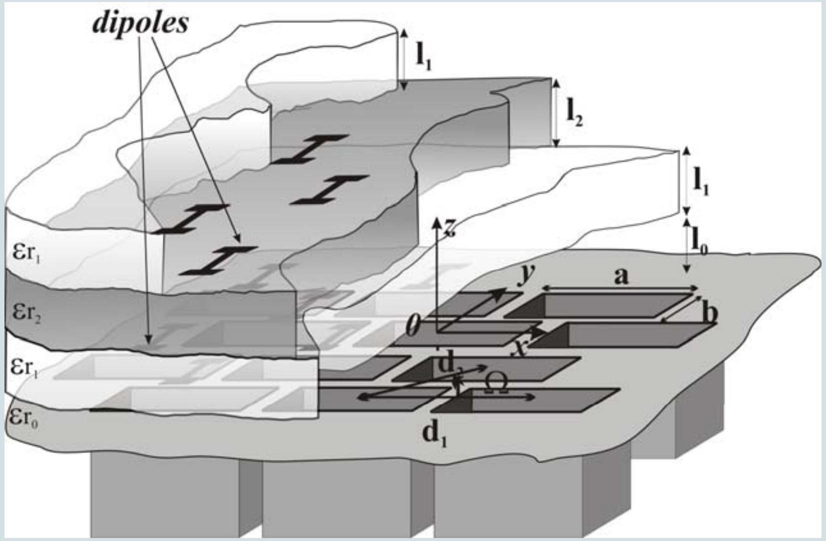
- identify accessible modes
- boundary conditions at $z=0$
- identify multimode network

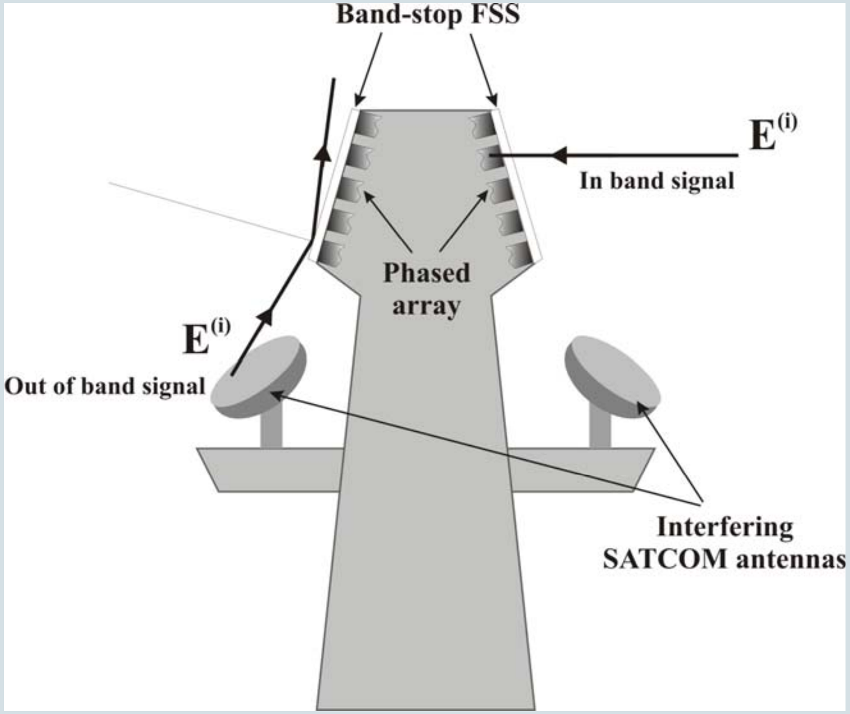
# Multiple sections

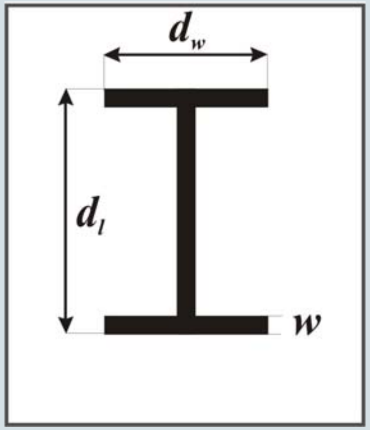




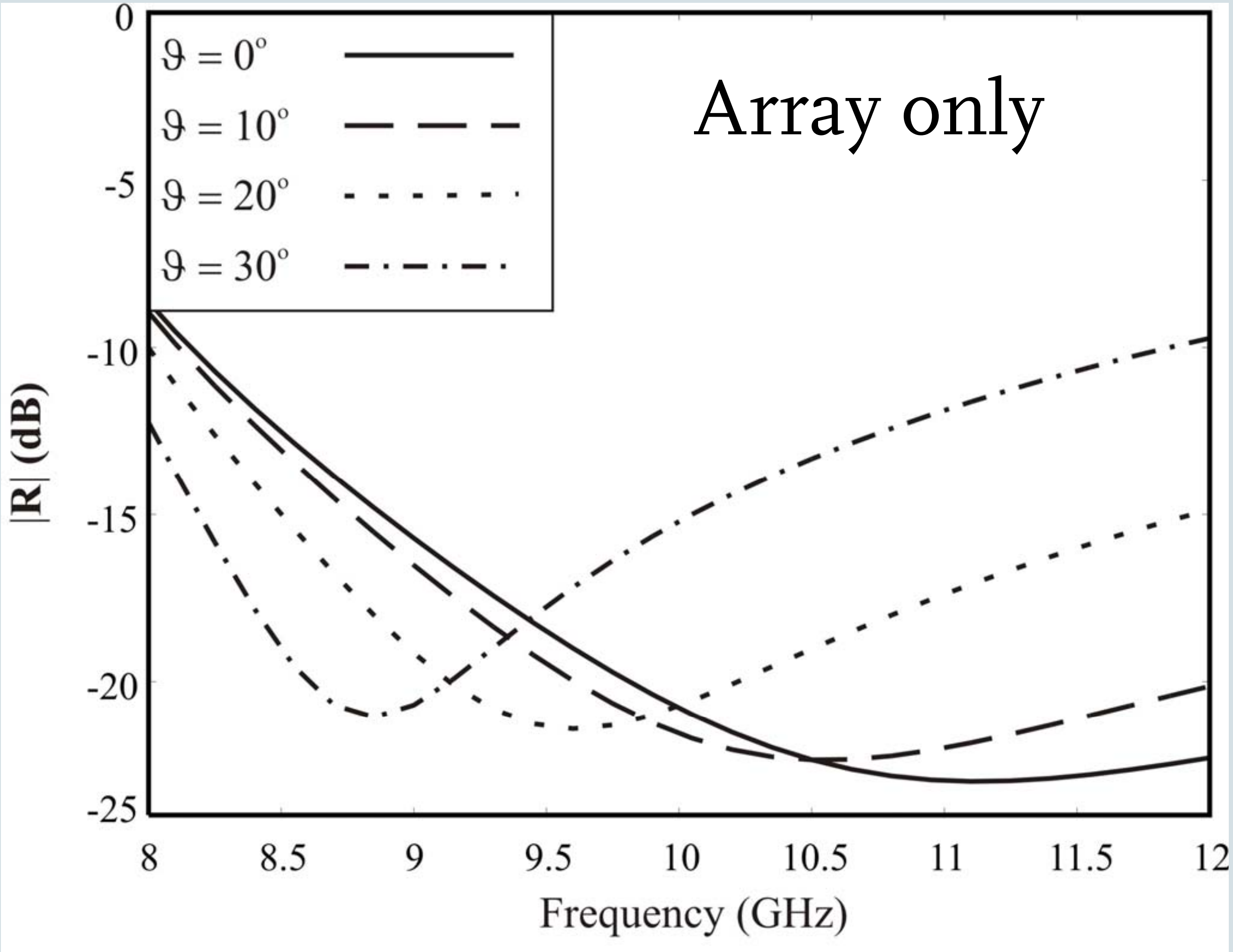

# Boundary conditions for infinite half space



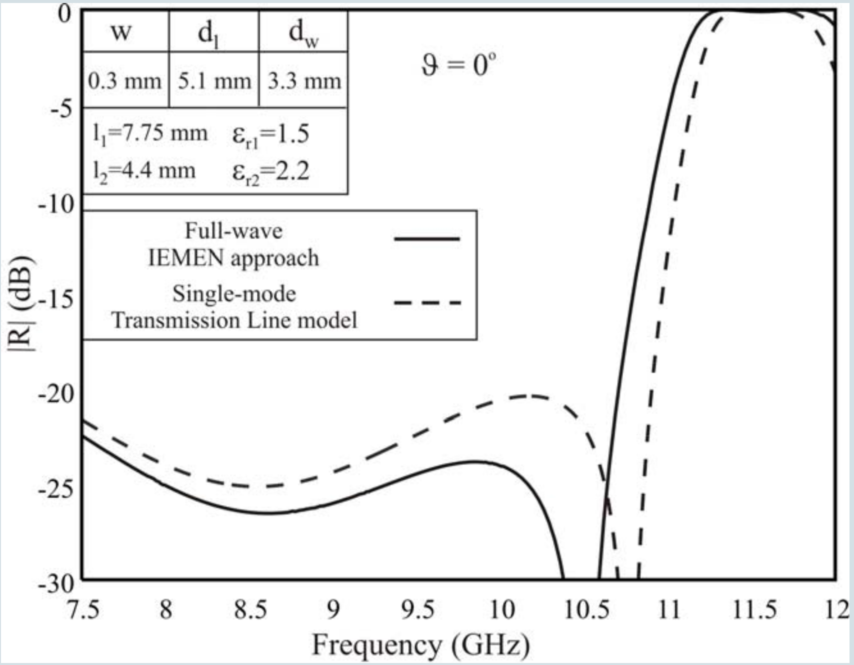



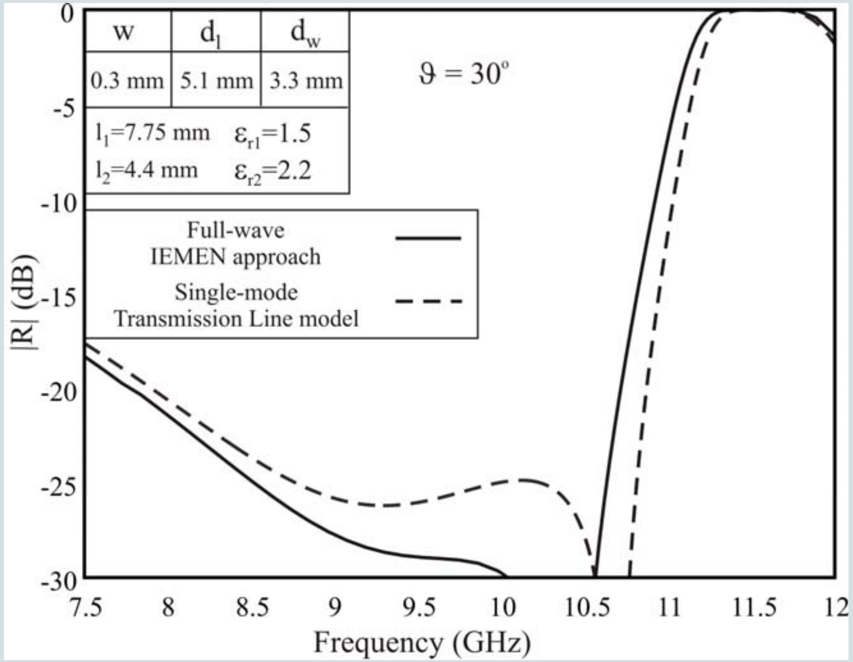




Example for synthesis: interference between MFR array and satellite communication antenna

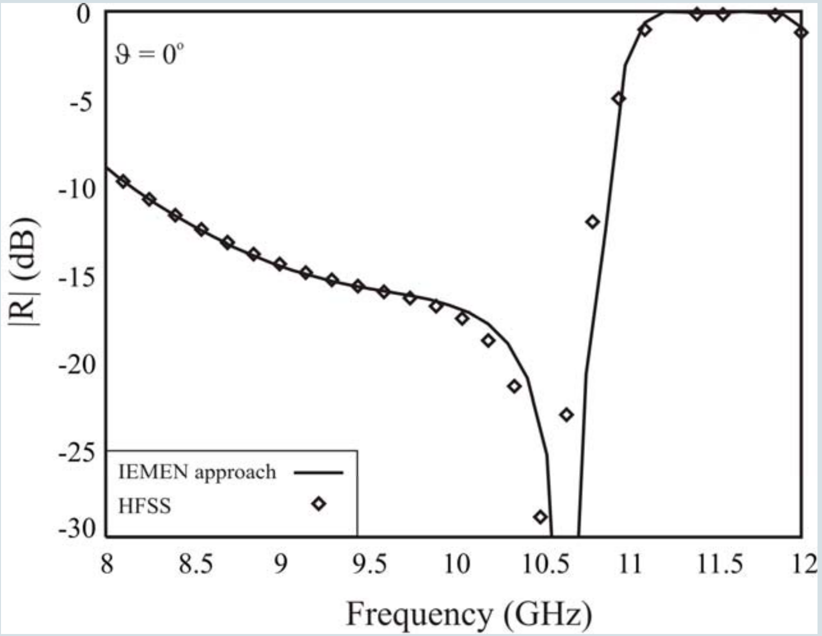


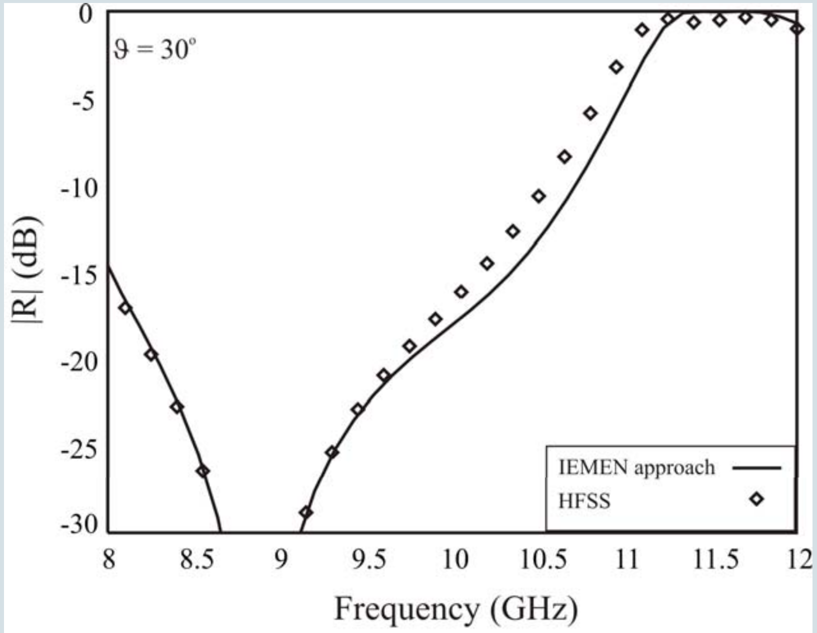
0
-5
-10
-15
-20
-25
|R| (dB)
8
8.5
9
9.5
10
10.5
11
11.5
12
Frequency (GHz)
ϑ = 0°
ϑ = 10°
ϑ = 20°
ϑ = 30°
Array only




# Single-mode design and full-wave model






# IEMEN method and HFSS

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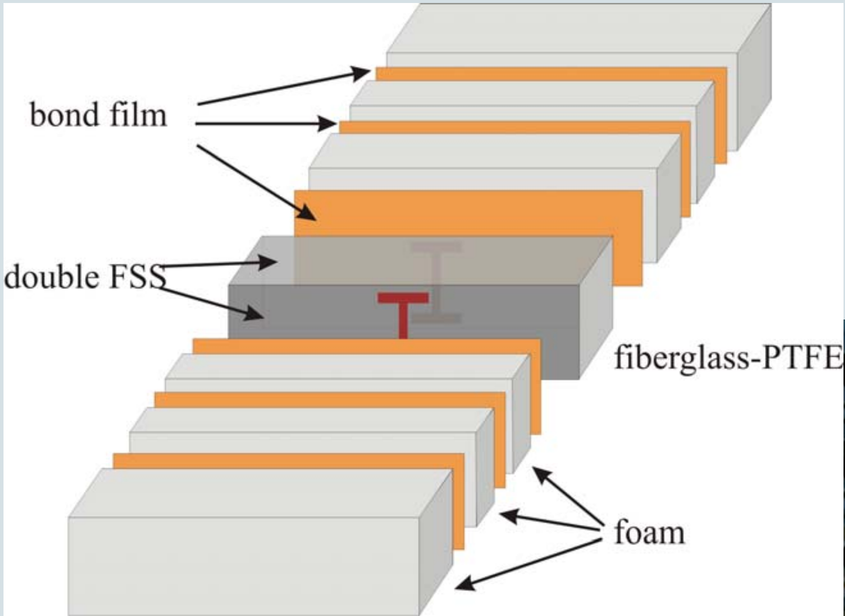
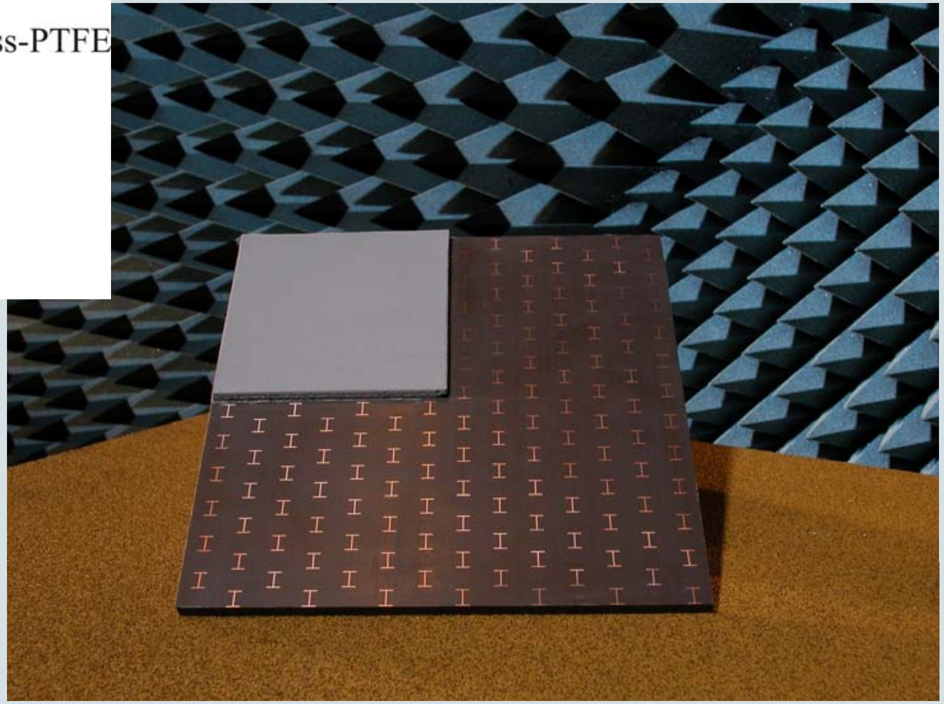
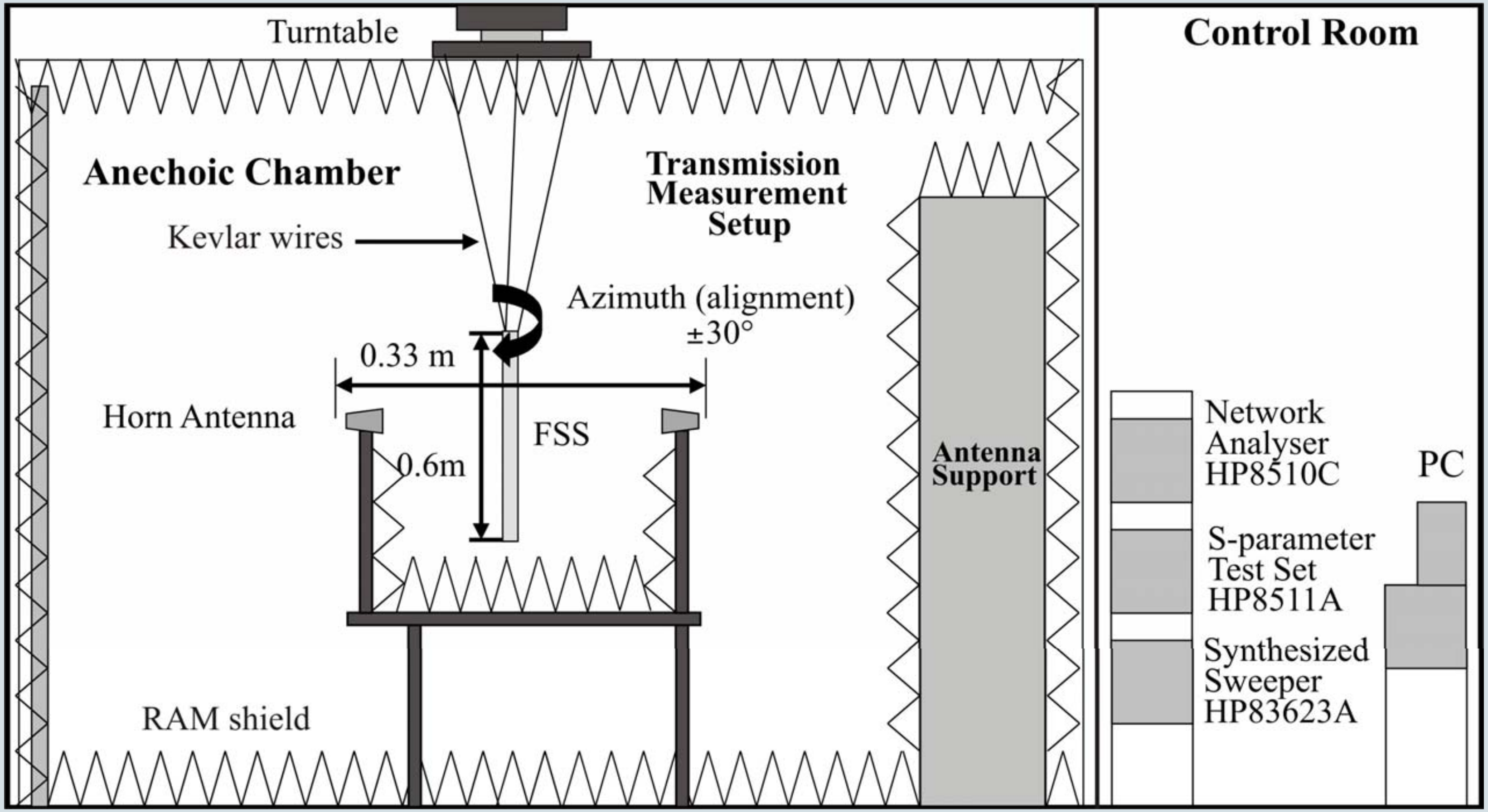
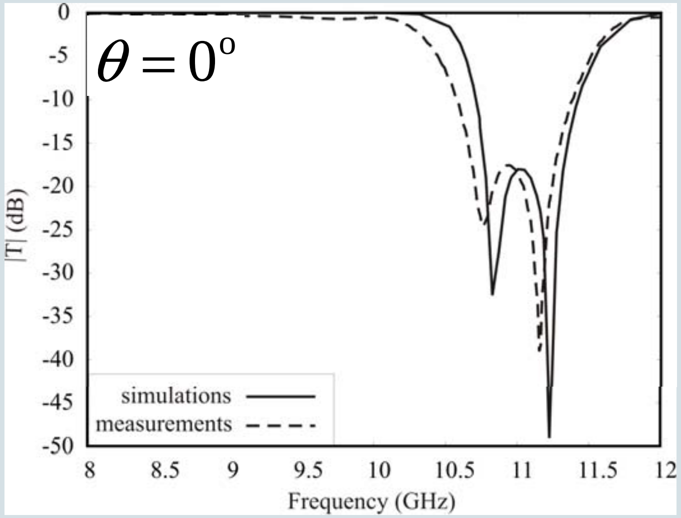


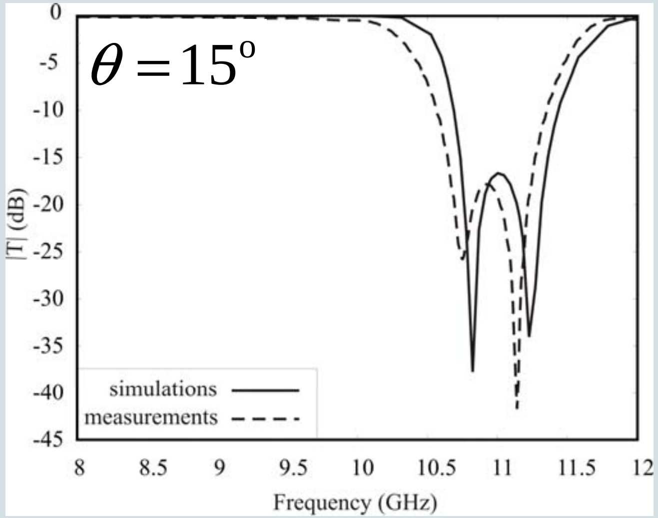



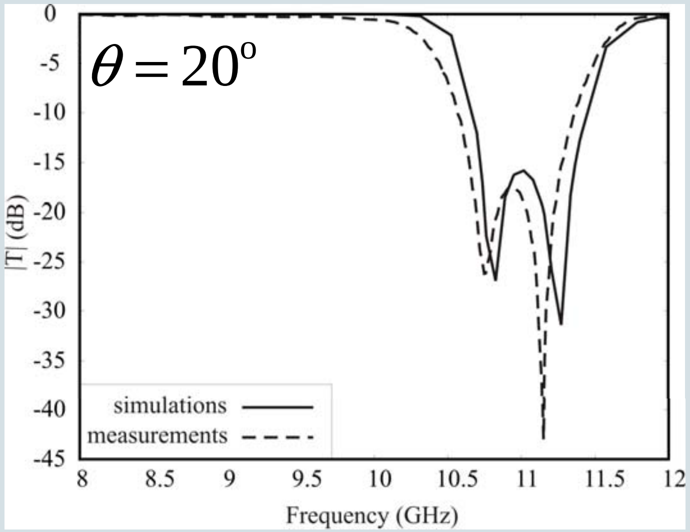
# Realization

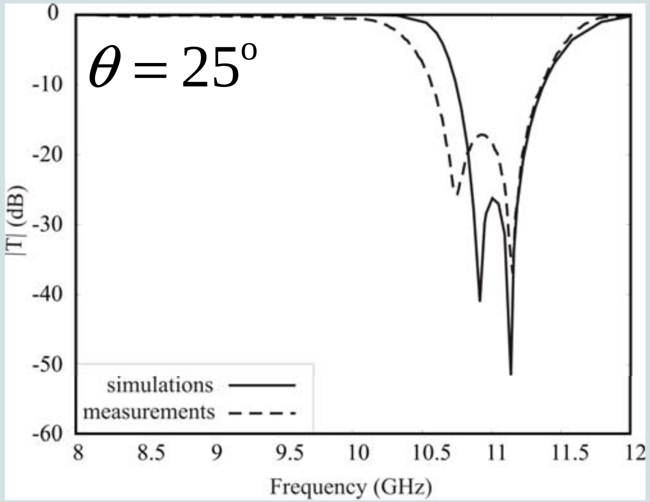
Transmission measurement


Turntable
Control Room
Anechoic Chamber
Transmission Measurement Setup
Kevlar wires
Azimuth (alignment) ±30°
0.33 m
Horn Antenna
FSS
0.6m
Antenna Support
Network Analyser HP8510C
PC
S-parameter Test Set HP8511A
Synthesized Sweeper HP83623A
RAM shield


$\theta = 0^{o}$
|T| (dB)
Frequency (GHz)
simulations
measurements


$\theta = 15^{o}$
|T| (dB)
Frequency (GHz)
simulations
measurements


$\theta = 20^{o}$
|T| (dB)
Frequency (GHz)
simulations
measurements

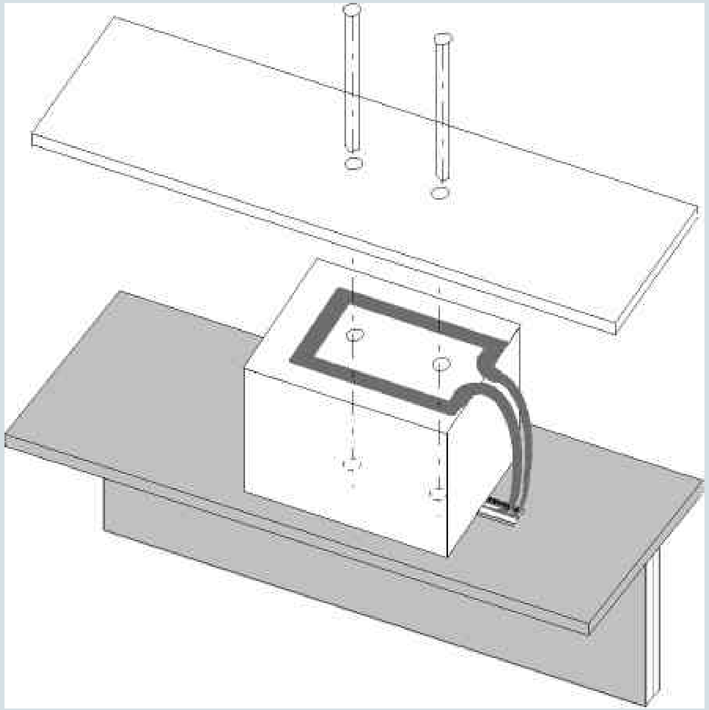

$\theta = 25^{o}$
|T| (dB)
Frequency (GHz)
simulations
measurements

# Finite Antenna Arrays: Eigencurrent Approach

Dave Bekers, December 13, 2004

with Stef van Eijndhoven, Fons van der Ven en Peter Paul Borsboom

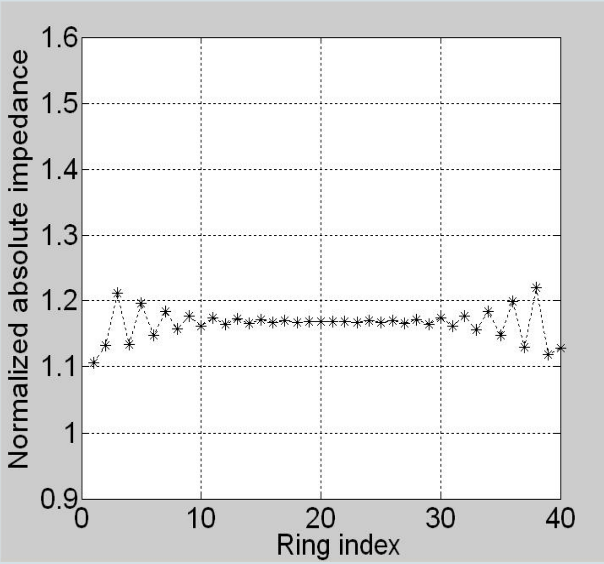
Sponsored by Thales Nederland



Phased array radar systems:
1000 elements in an array

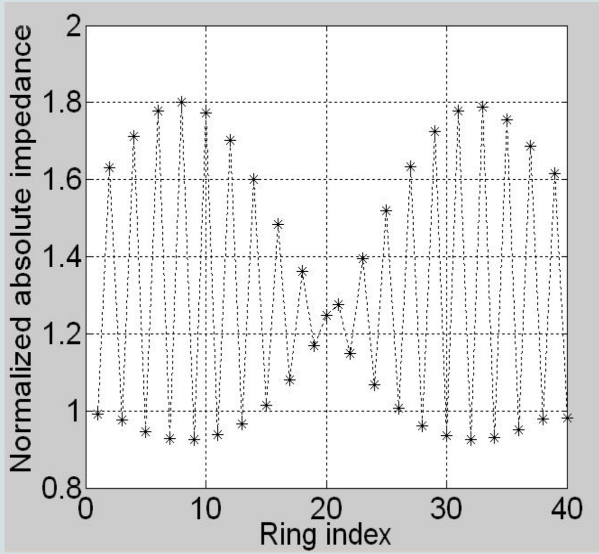
**Desired in arrays:**

Small variation of impedance

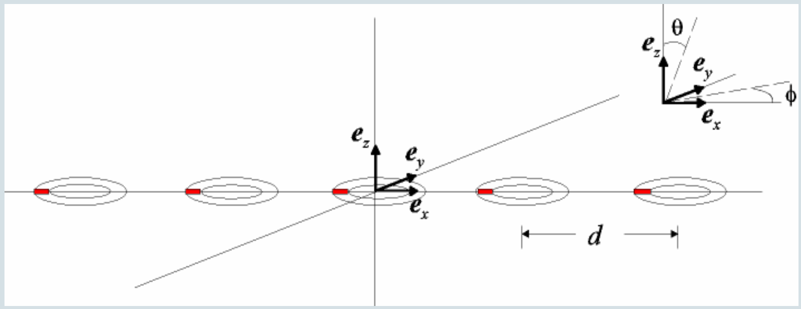



**Not desired in arrays:**

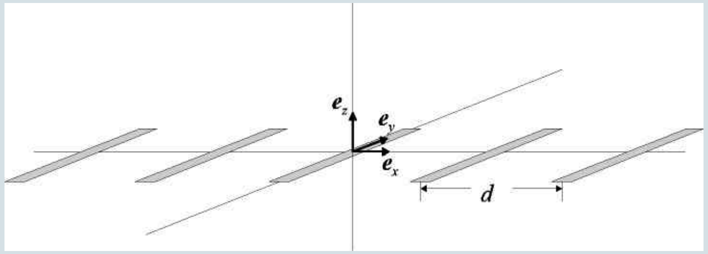
Large variation of impedance

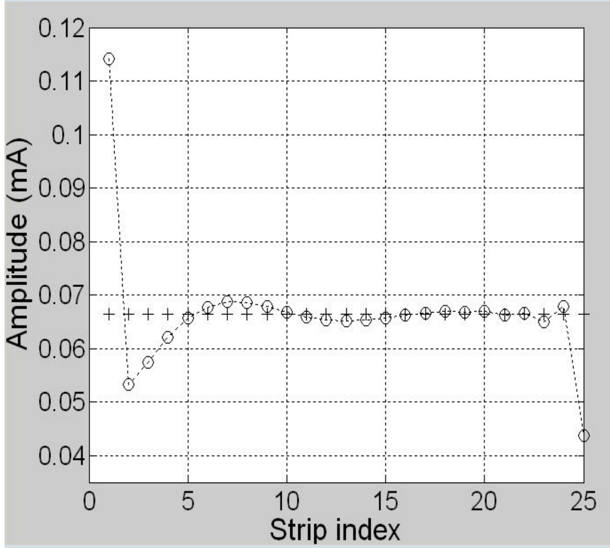


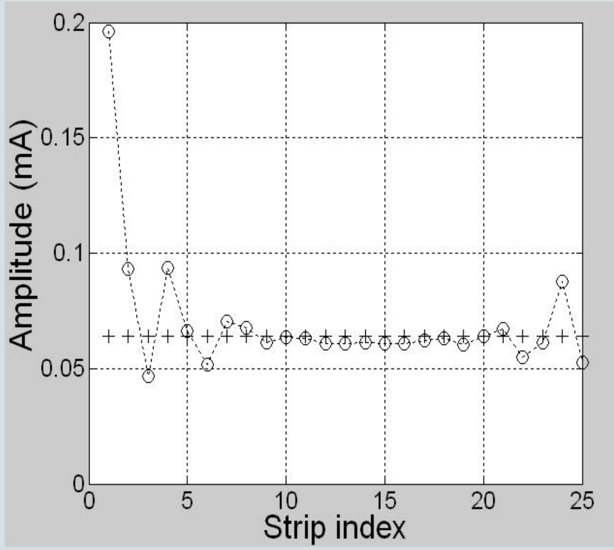

Line array of 40 rings

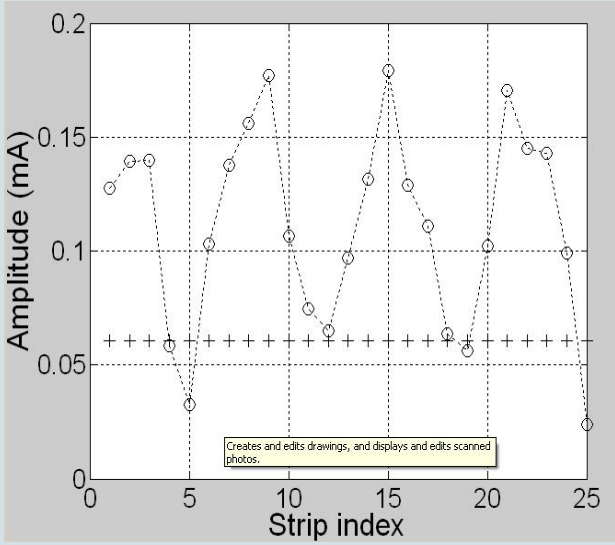


Line array of 25 strips




**Decreasing frequency**

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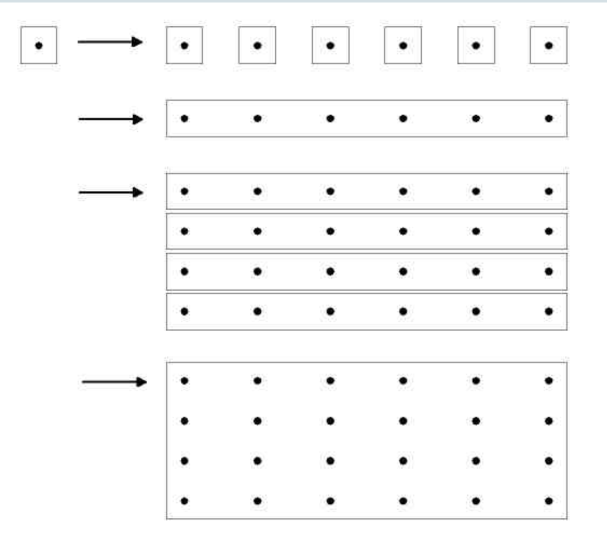
# General Idea

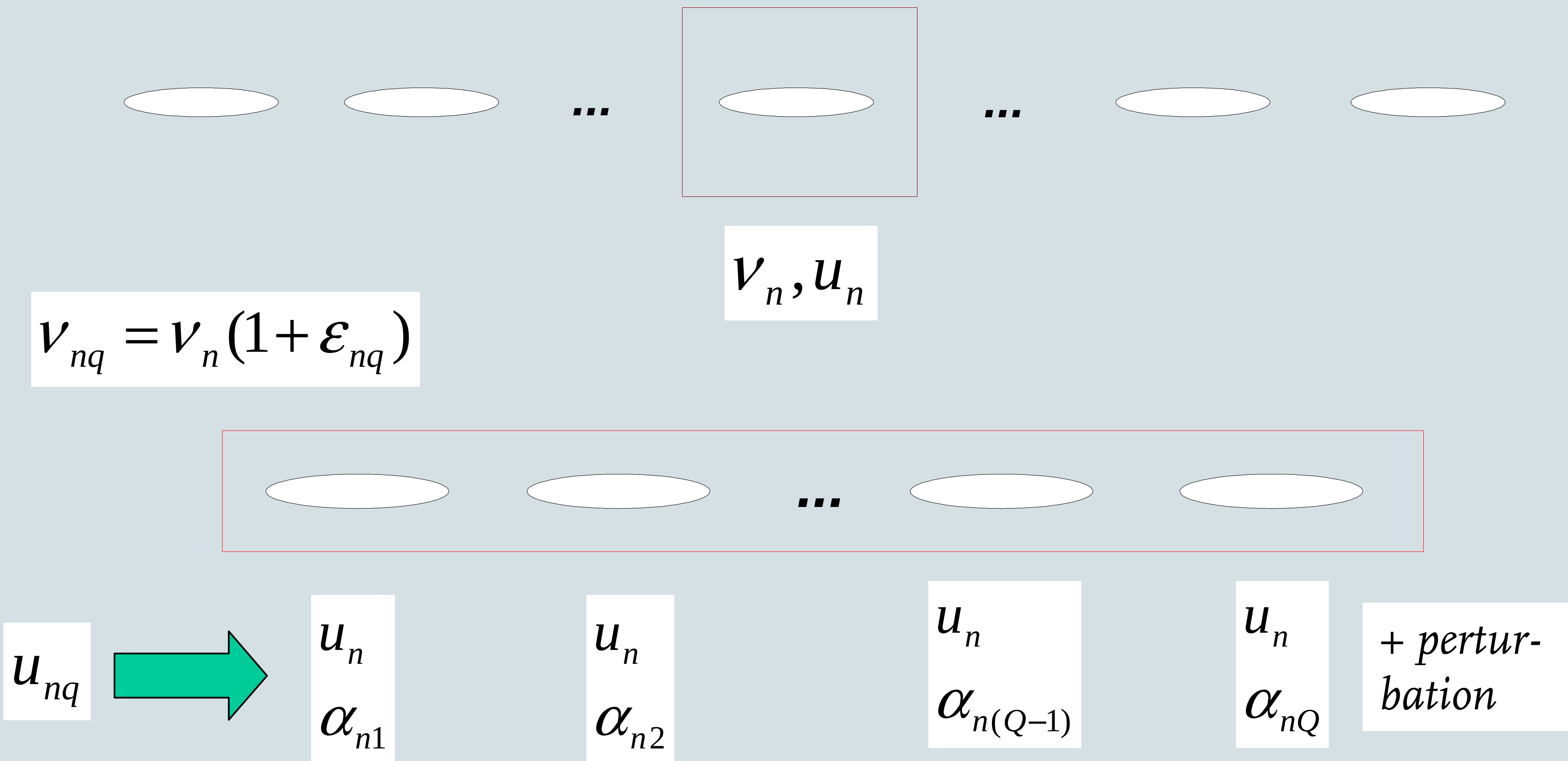
- Characteristics of arrays and their elements is reflected in their "eigenstates"
- Modularity: hierarchy of "subarrays"



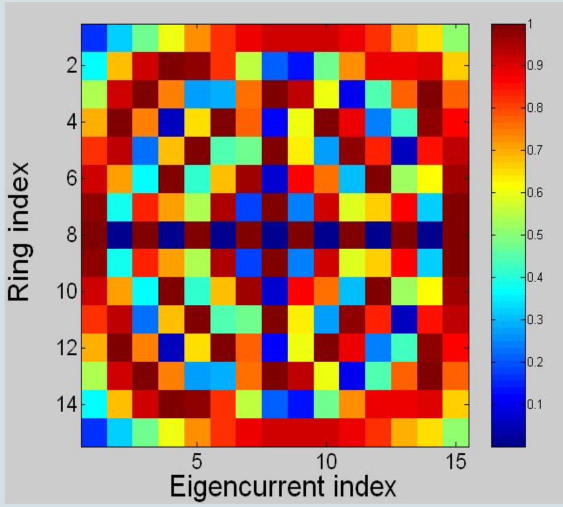
"Brute force" method: 40 elements, 30 piecewise functions per element ⇒ matrix size 1200×1200

New approach: 30 piecewise functions on element ⇒ matrix size 30×30
40 elements, 2 coupling eigencurrents ⇒ matrix size 80×80

# General Idea

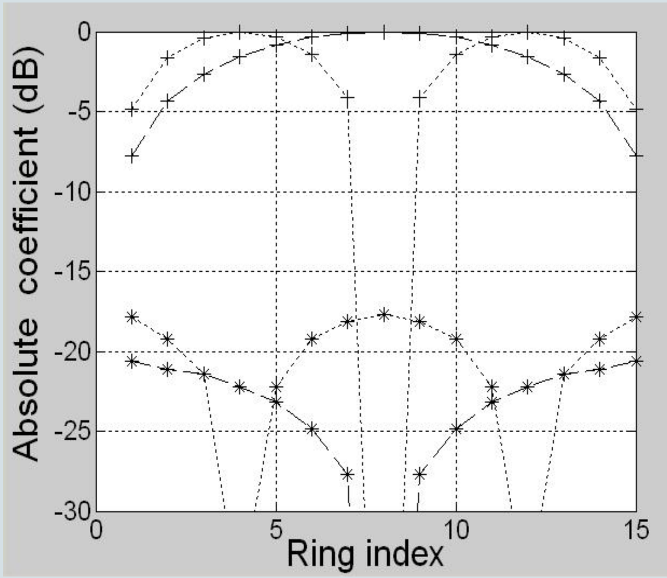


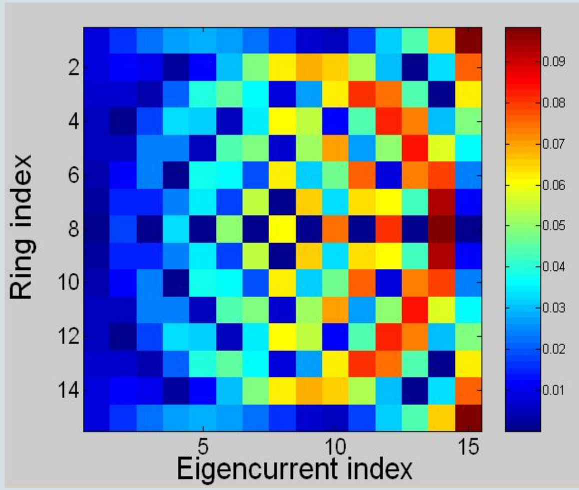
# Line array of 15 rings with 2 groups of eigencurrents




First group:
dominant coefficients

First 2 eigencurrents

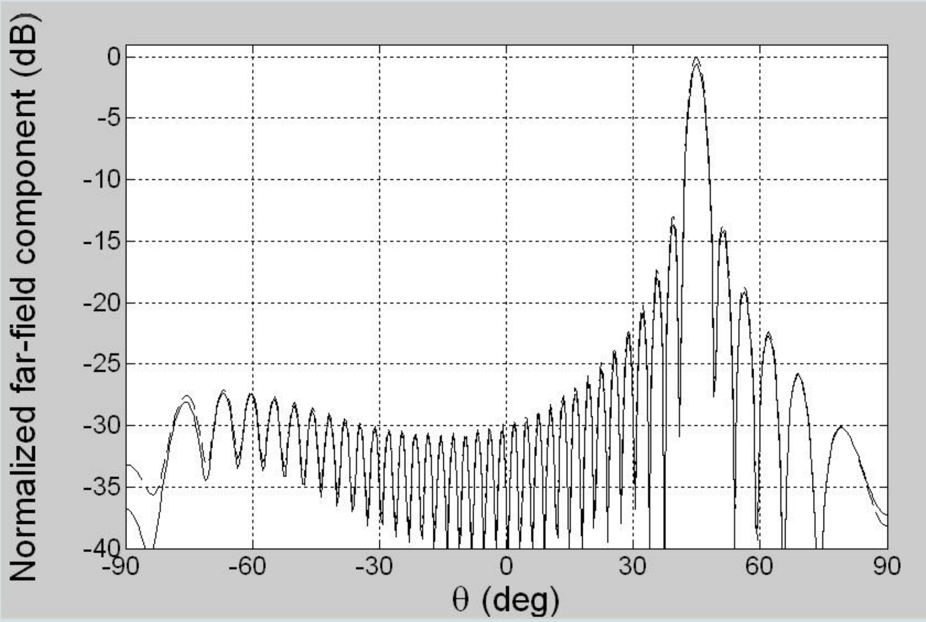


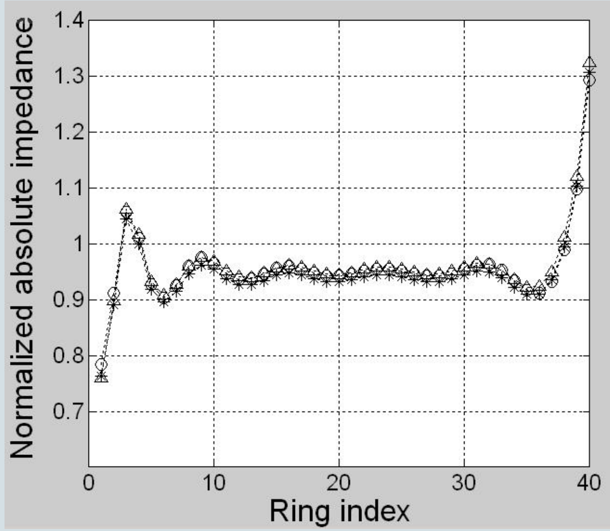



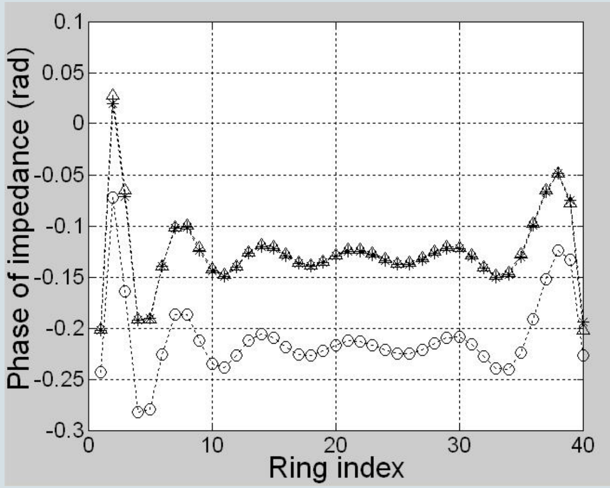

Second group:
`perturbation'

# Results

Line array of 40 rings, scan at 45°, far field and normalized impedance

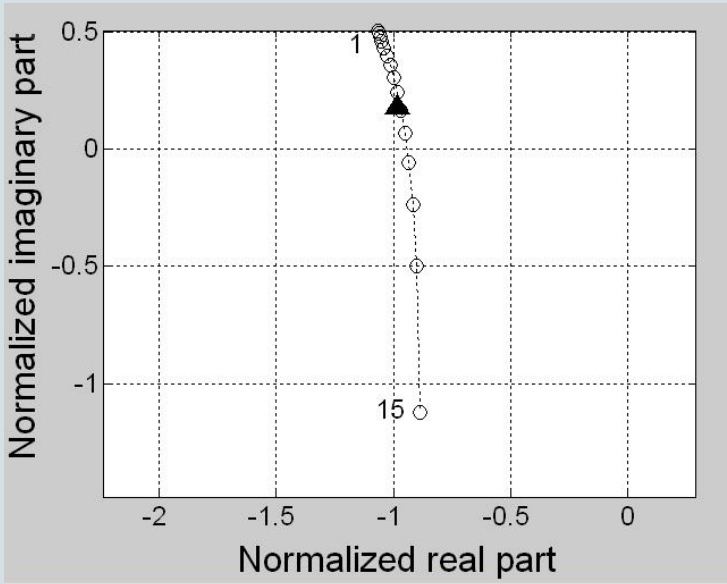


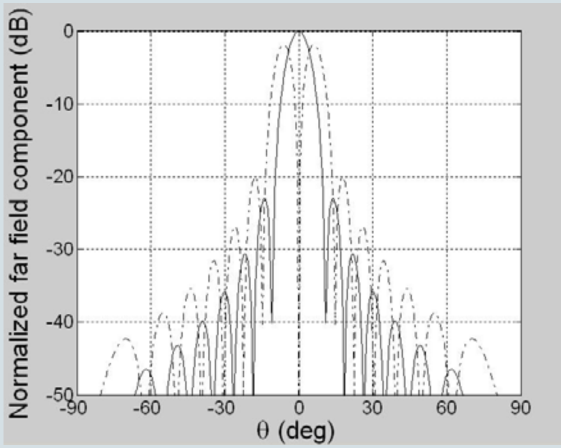



# Eigencurrents: only computational ?

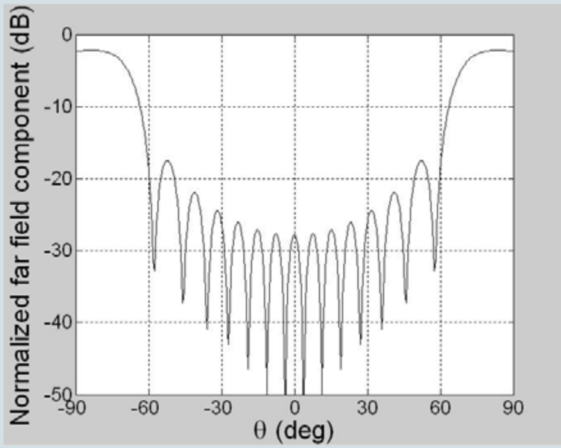
Line array of 15 rings




Eigenvalues




1st and 2nd eigencurrent

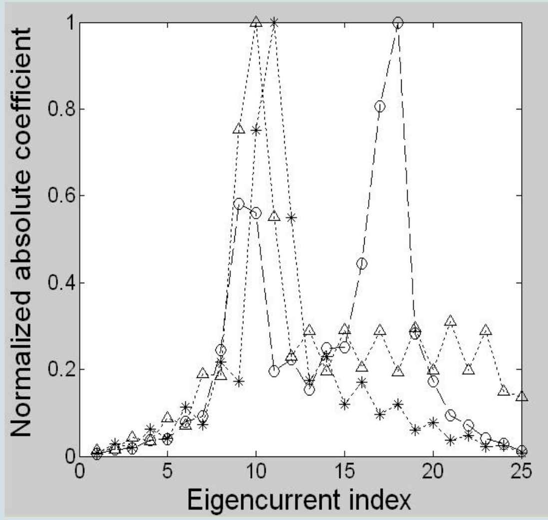


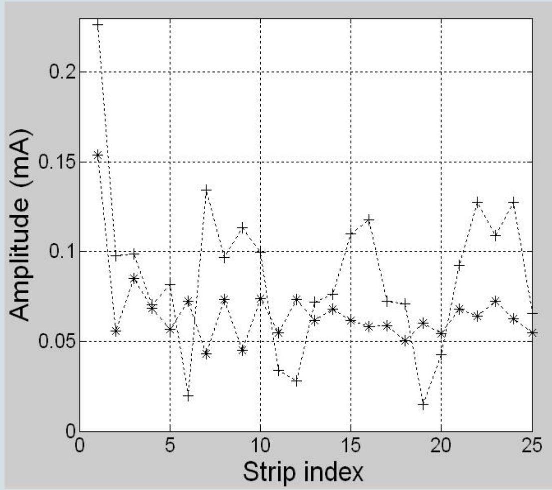

15th eigen-current

# Impedance variations

Line array of 25 strips

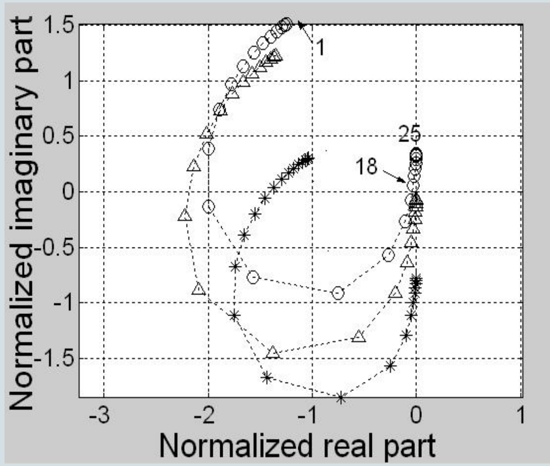
Expansion coeffcients 1st group

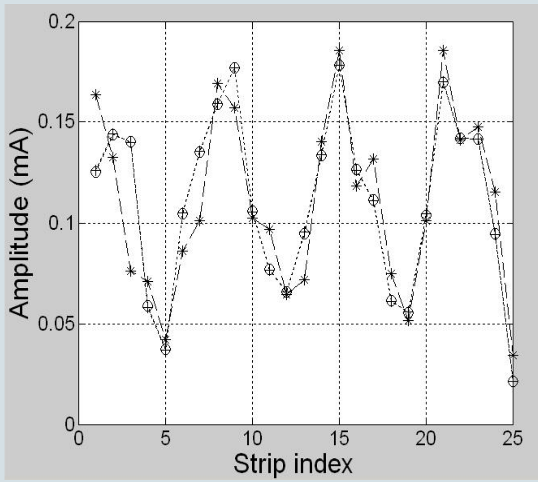



First 14 and first 17 eigencurrents

Eigenvalues




First 18 eigencurrents and all eigencurrents