Holographic performance verification of a Focal Plane Array Prototype

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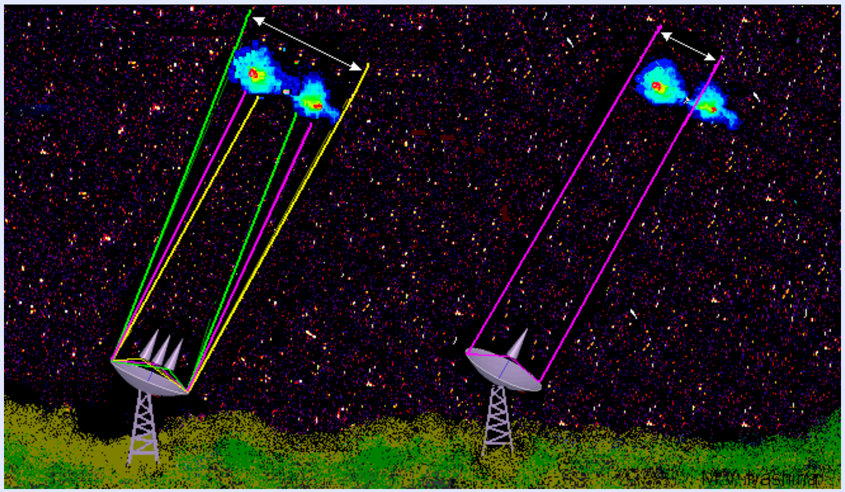

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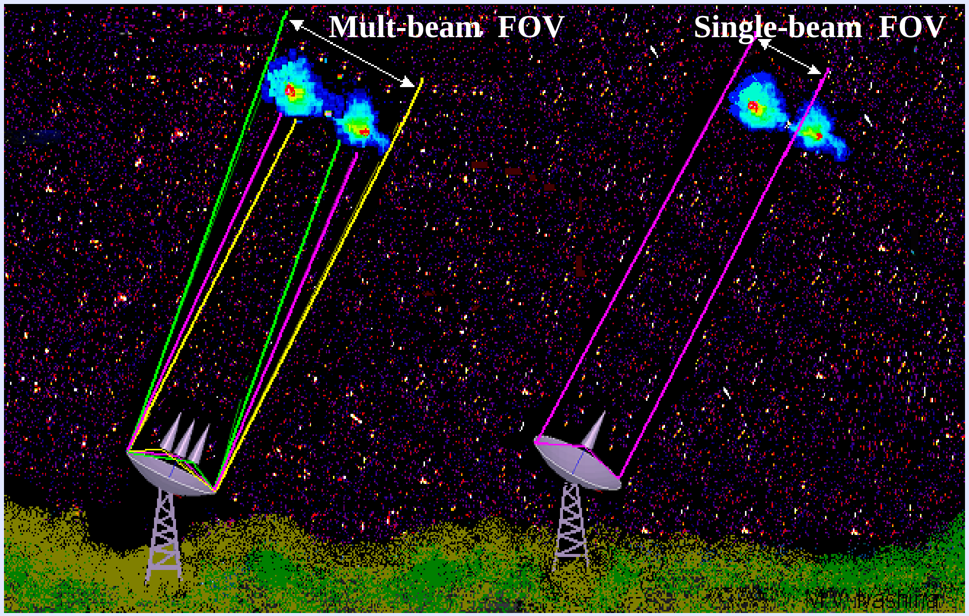
Outline

- Introduction.
- Design approach and performance criterion.
- An example of the FPA prototype for a Westerbork Telescope
- Conclusions and future activities

Introduction – performance requirements



- ✓ **High sensitivity** (Aeff/Tsys)
- ✓ **Wide Field Of View (FOV):** 2x(4-5BW) for F/D=0.3-0.6.
- ✓ **Smooth FOV**

  <3dB overlapping point of the beams/oversampling.
- ✓ **Broad frequency band:**

  2-3 octaves.

Introduction – design trade-off

- Challenge for a designer:
  - Multi-beaming $\Rightarrow$ large size $\Rightarrow$ the blockage $\uparrow$ $\Rightarrow$ an overall efficiency $\downarrow$.
  - Larger FPA $\Rightarrow$ the efficiency $\uparrow$ $\Rightarrow$ the complexity in a non-linear manner $\uparrow$ $\Rightarrow$ noise temperature $\uparrow$.

- Here we address the design of an FPA in order to optimize the performance (Aeff/Tsys) for a minimum cost.

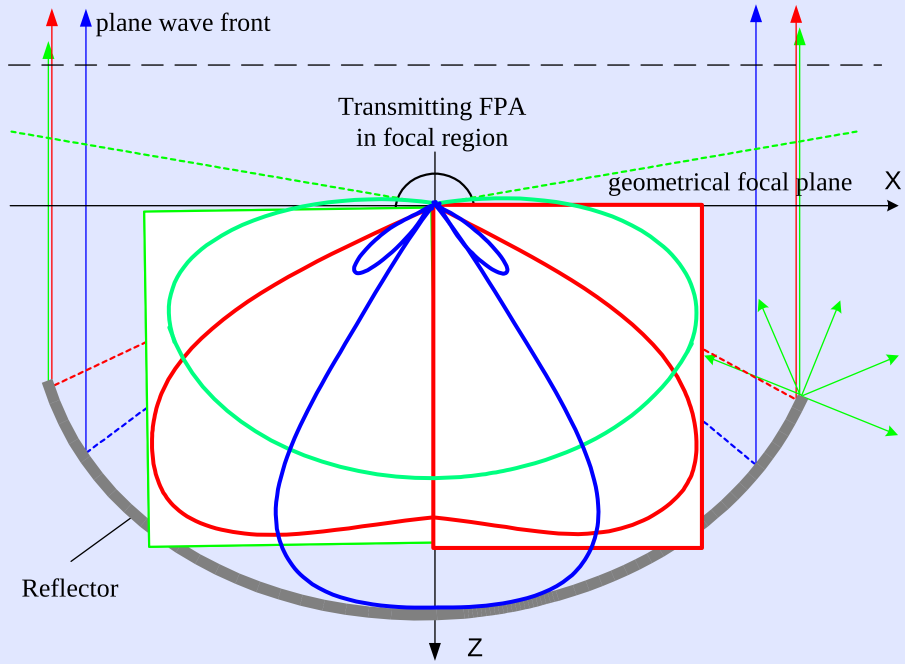
Design approach

- Focal Field (FF) modeling of the reflector.
- Sampling of the FF with the array elements.
- Experimental modeling of the mutual coupling effects in the dense array.
- Optimization of the FPA system for the maximum Aeff/Tsys (performance criterion).

Performance criterion: A_{eff} / T_{sys}

Aeff=Aph* η_A, η_A is the aperture efficiency

and Tsys is the system temperature.



Definitions:

$$\eta_A = \eta_{sp}\, \eta_T\, \eta_{Ph}\, \eta_{Pol}\, \eta_b$$

$$Tsys = T_A + T_{LNA} + T_{BF} + \ldots$$

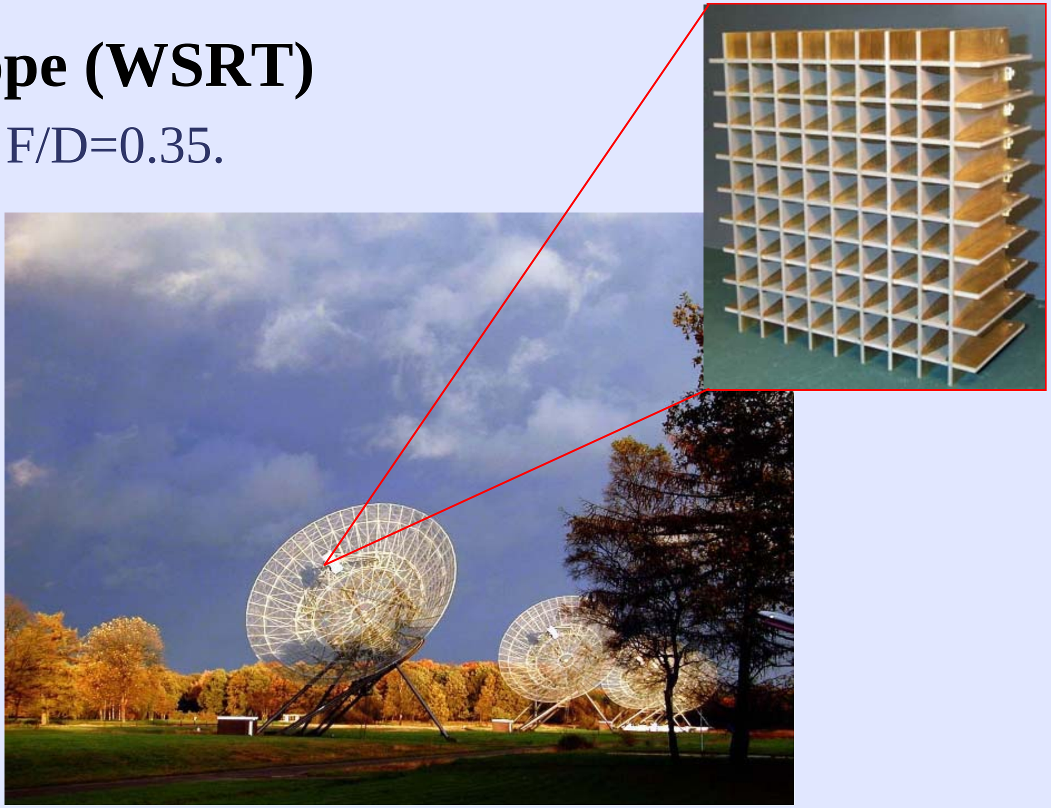
- Very high η_{sp}, low T_A (blue);
- Very high taper efficiency (green), high T_A.
- The optimal secant squared pattern (red).

An example of the FPA prototype

- **Westerbork Radio Telescope (WSRT)**
  Reflector Antenna D=25 m; F/D=0.35.

- FPA synthesis with
  a 8x9x2 Vivaldi Array

- Specification:
  - 2-5GHz
  - 2 Beams
  - Analog Beamformer
  - Uncooled



Focal Field modeling of the reflector

- Capabilities and limitations of the multi-beaming operation for the specified F/D.
- The results will be presented here for the sub-array sampling the field from 1 direction.

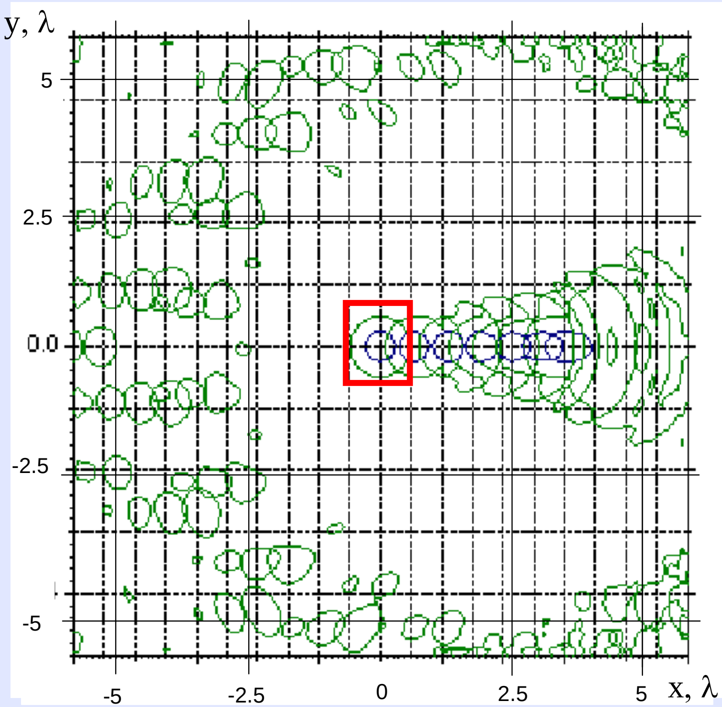


Fig. 1 - FFD for different plane wave incidence situations for the WSRT {–3dB (blue) , –12 dB (green)}.

Design approach

- ~~Focal Field (FF) modeling of a reflector.~~
- Sampling of the FF with the array elements.
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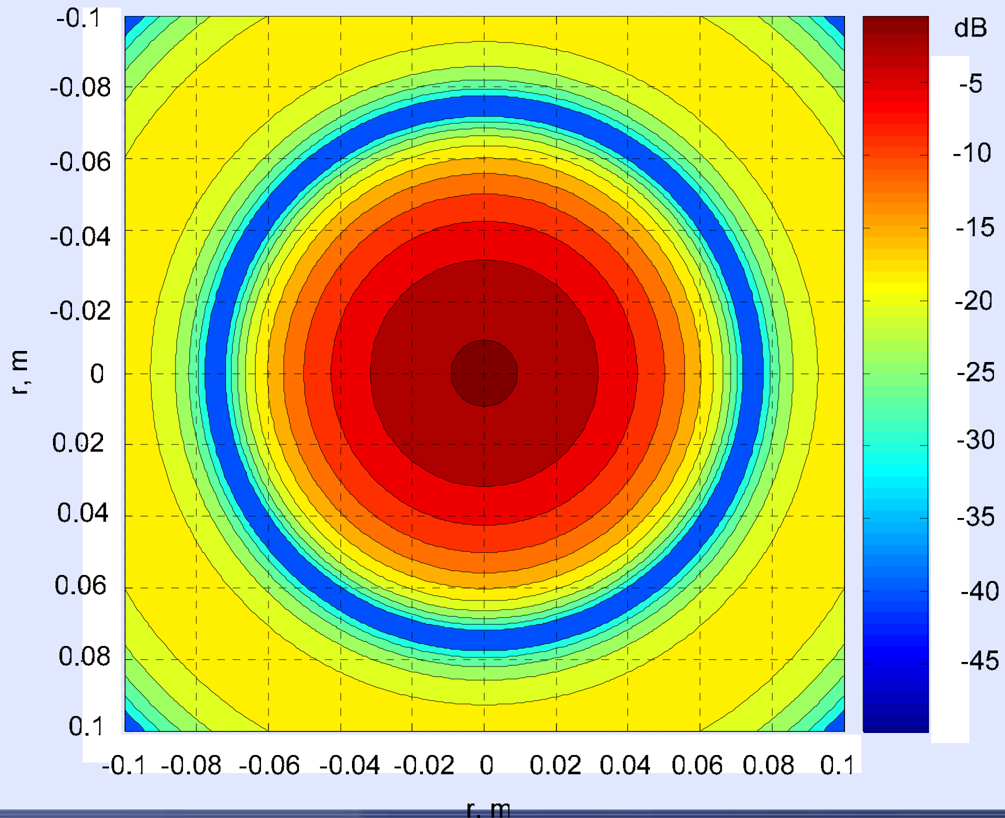
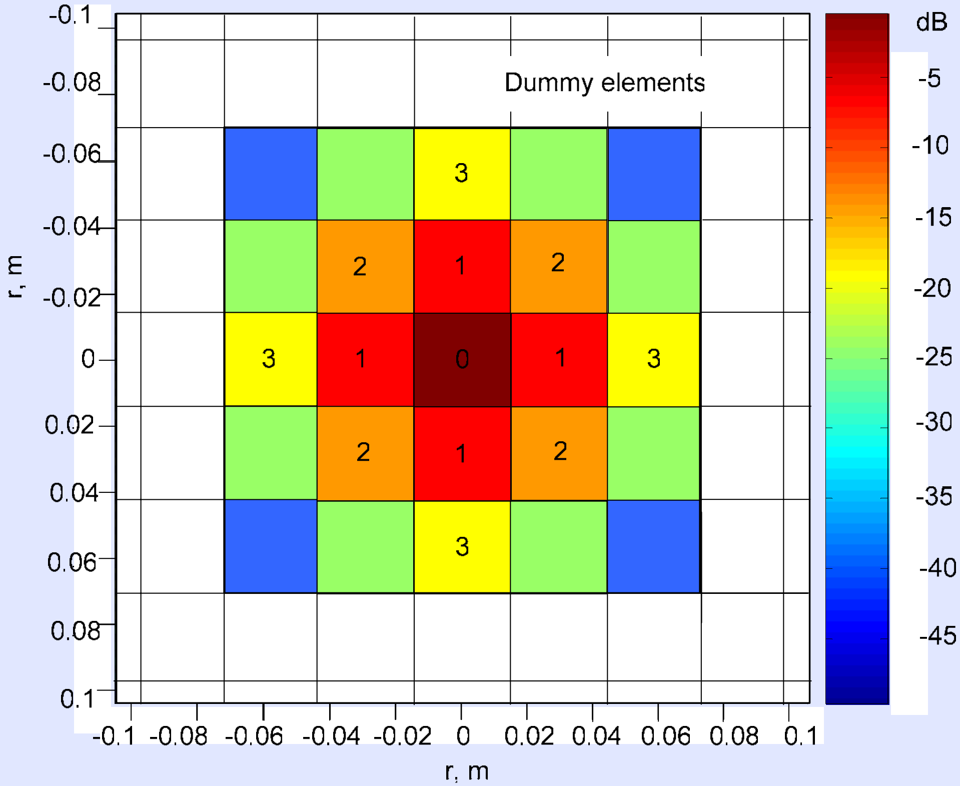
- Optimization of the FPA system.

Sampling of the FFD with the Vivaldi array using Conjugate Field Matching (CFM) method.

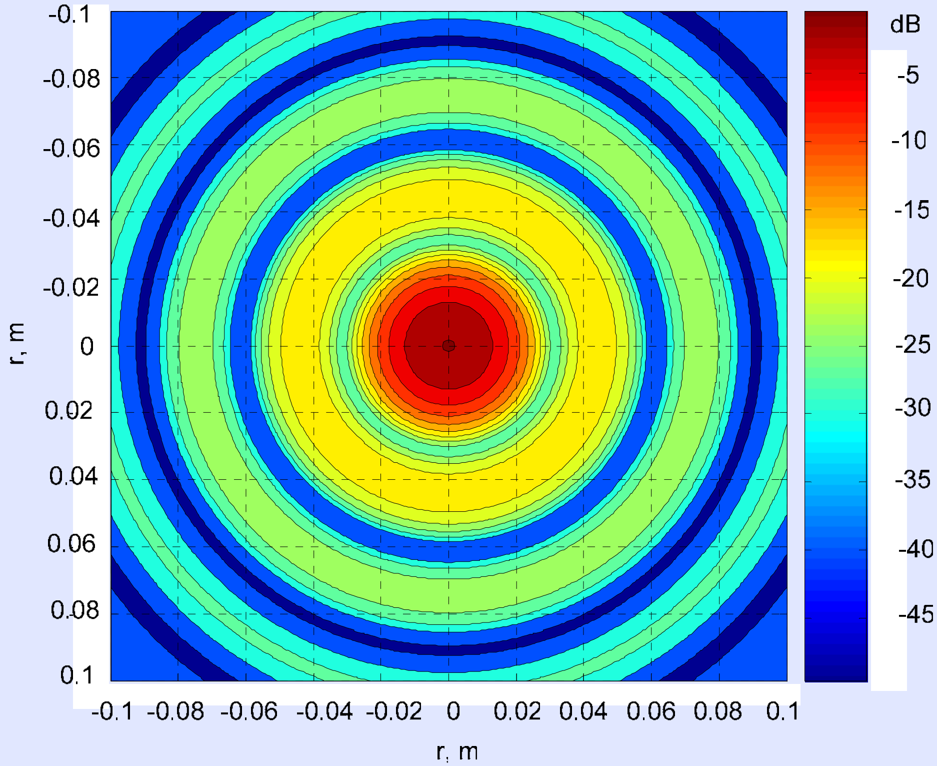
F=2.3GHz

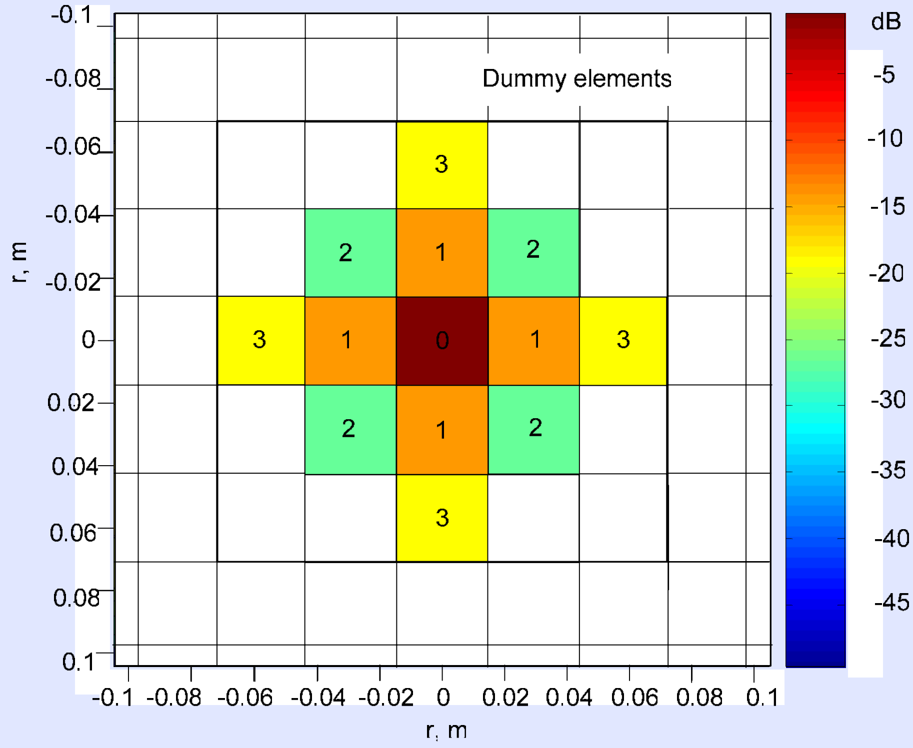




Sampling of the FFD with the Vivaldi array using Conjugate Field Matching (CFM) method.

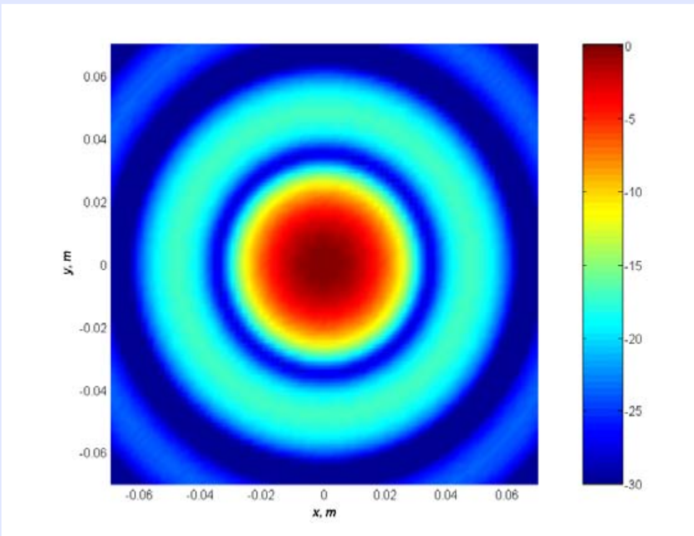
F=5.5GHz.



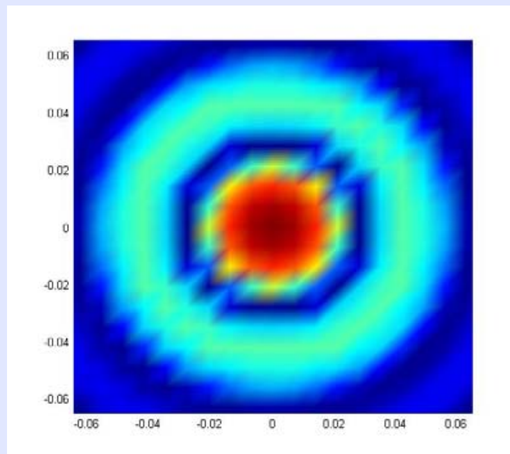


Weighting coefficients for the rings using the CFM method (?)

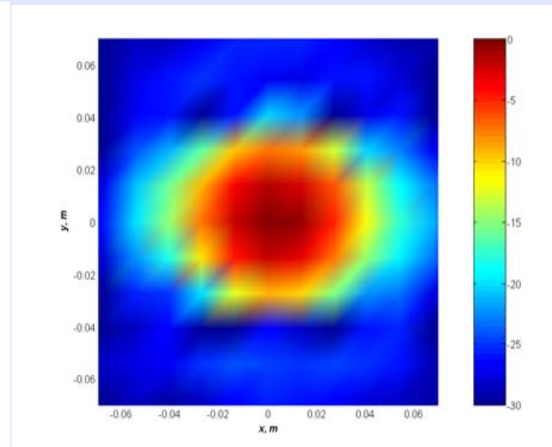
Focal Field (GRASP)



An example of the focal field sampling with 25 elements of the 0.5λ-spaced grid which are excited according to the CFM method



array without mutual coupling



array with mutual coupling

Results of the sampling using CFM

- Initial design parameters: minimal size of the array, # elements and their arrangement.
  - For our case, from 25 elements (6 rings) to 9/13 elements (2/3 rings) of the 8x9x2 Vivaldi array are used to design the FPA at the frequency band of 2.3 GHz – 5.5 GHz.
- In the method, mutual coupling effects are neglected because the assumption is made that the elements are sampling the array aperture field only locally.
- Then, no weights for the rings are determined.

Design approach

- ~~Focal Field (FF) modeling of a reflector.~~
- ~~Sampling of the FF with the array elements.~~
- Experimental modeling of the mutual coupling effects in the dense array.
- Optimization of the FPA system.

Experimental Modeling of the Mutual Coupling Effects in the dense array.

In the aperture of the FPA (Method 1)

- Determining the correction factor by comparing the modelled aperture patterns to the measured aperture patterns obtained from NF tests.

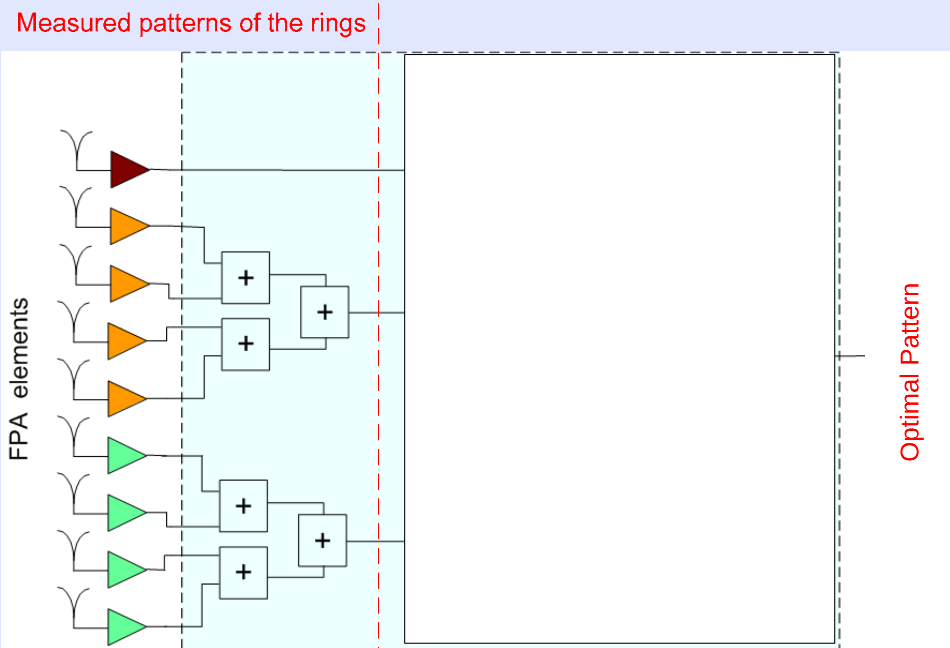
- The minimum deviation was used as a criterion for this procedure.

Experimental Modeling of the Mutual Coupling Effects in the dense array

In the far-field of the FPA (Method 2)

- Measuring the far-field patterns of the rings in the array environment (NF).
- Combining the measured patterns into the total pattern of the FPA for a certain specified set of the excitation coefficients for the rings (MatLab).
- Calculating the Aeff/Tsys from the total pattern.
- The optimization routing is searching for the maximum Aeff/Tsys for the given range of the settings.

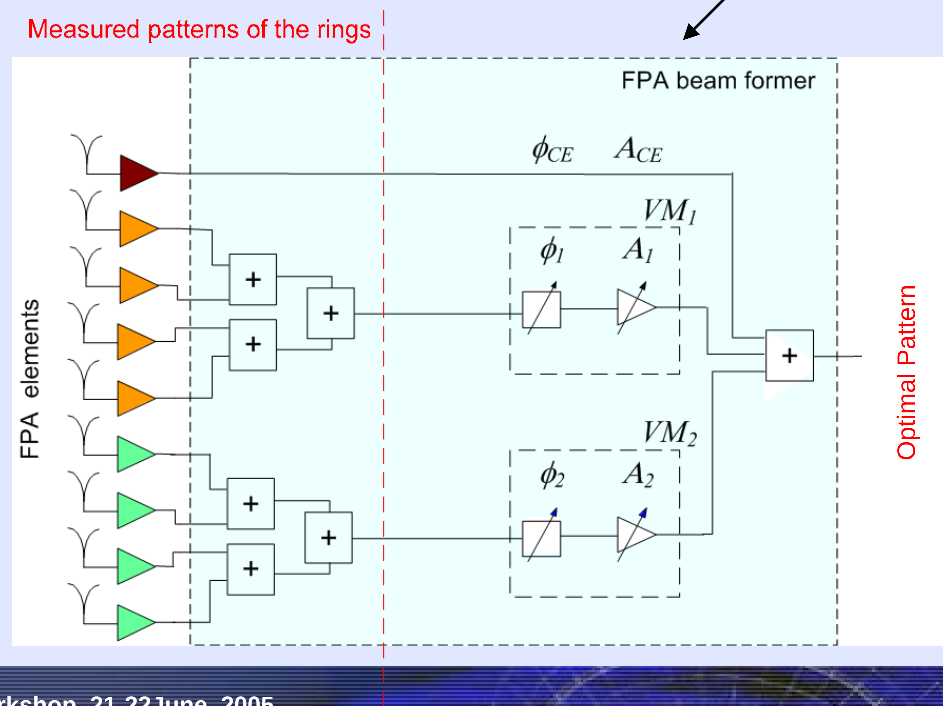
Experimental Modeling of the Mutual Coupling Effects in the dense array



The MatLab model

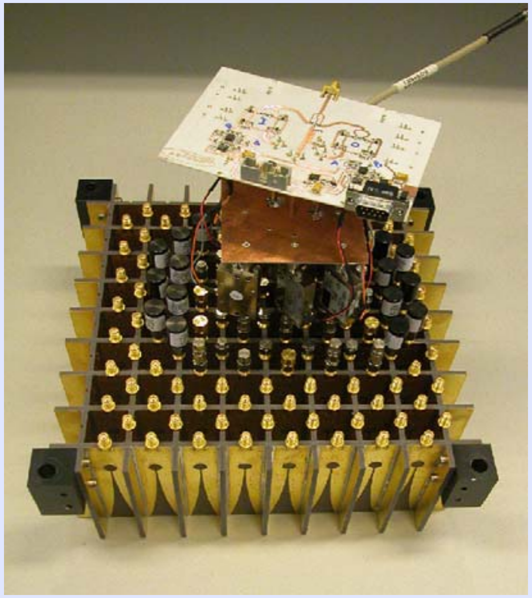
with the measured patterns of the rings and an ideal beamformer

The FPA with the practical beamformer

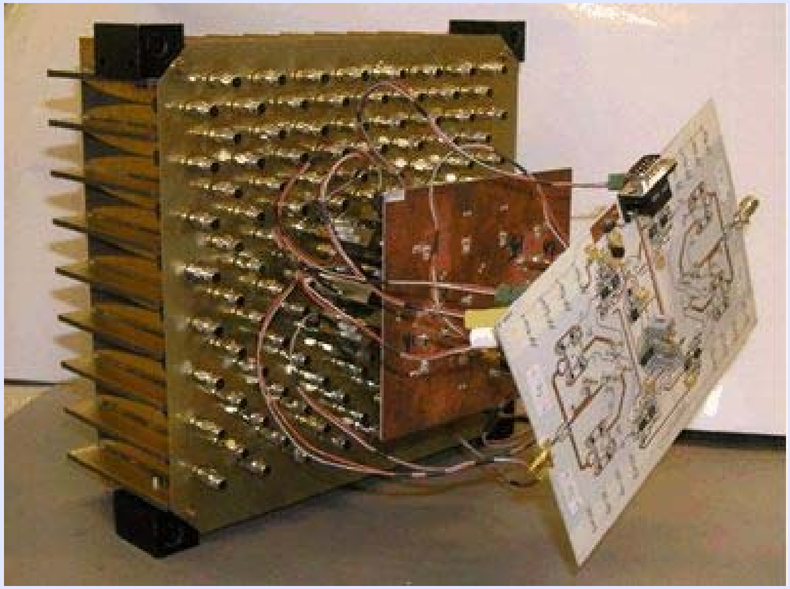


Examples of the beamformer designs.
F = 4.0 GHz - 5.5 GHz

2-rings and 1 polarization per beam

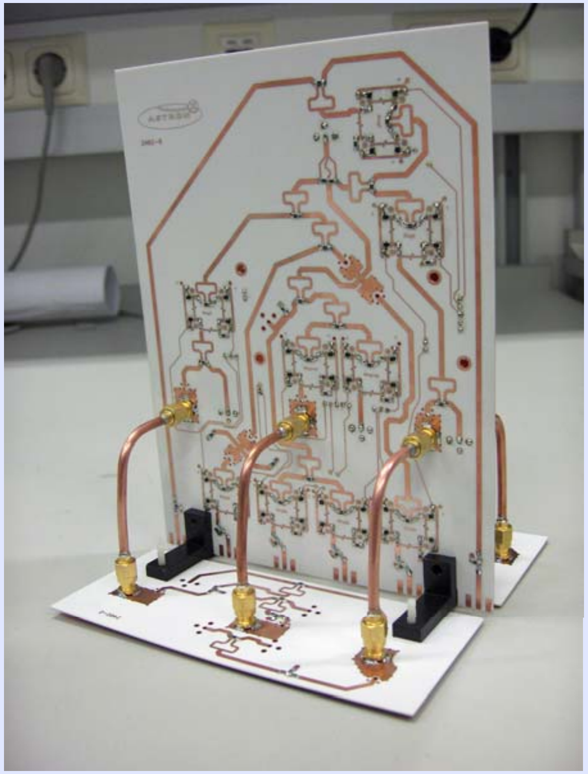


1 beam



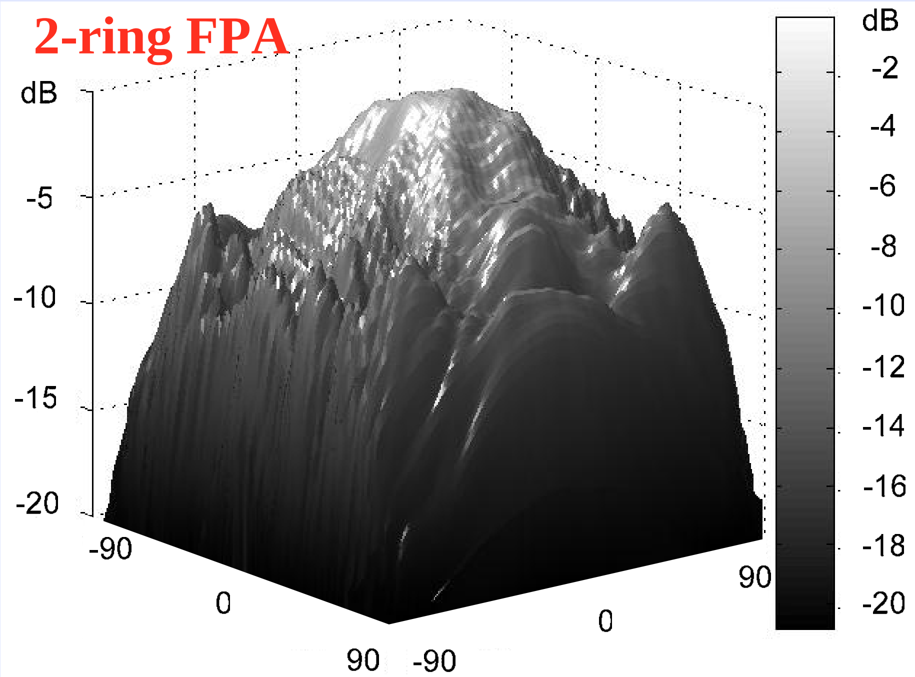
2 beams

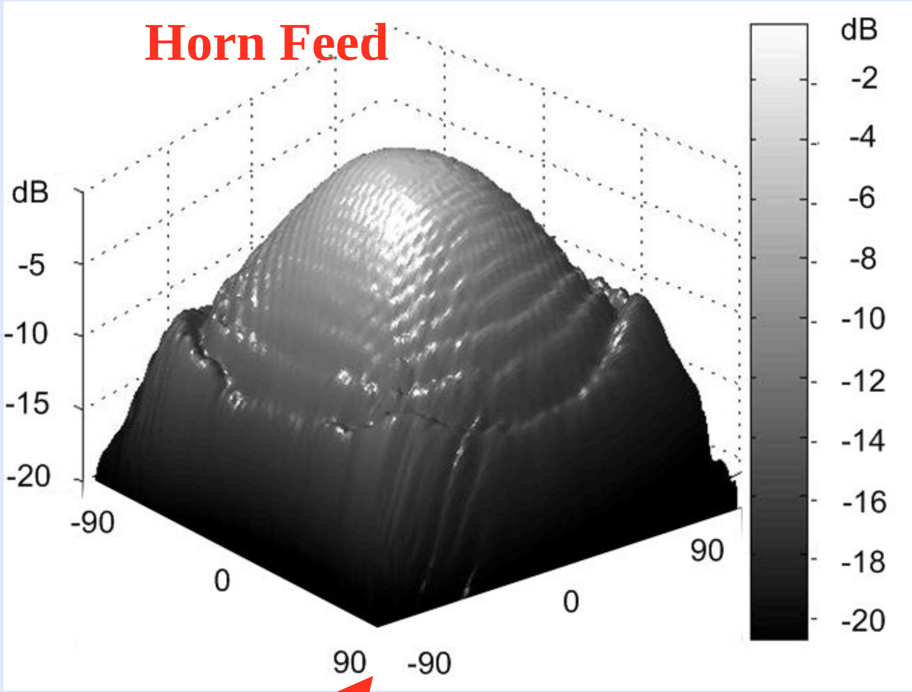
Beamformer design for 2.3 GHz - 4.0 GHz 2 polarizations



1 beam

Optimization Results: Measured far-field patterns of the FPA

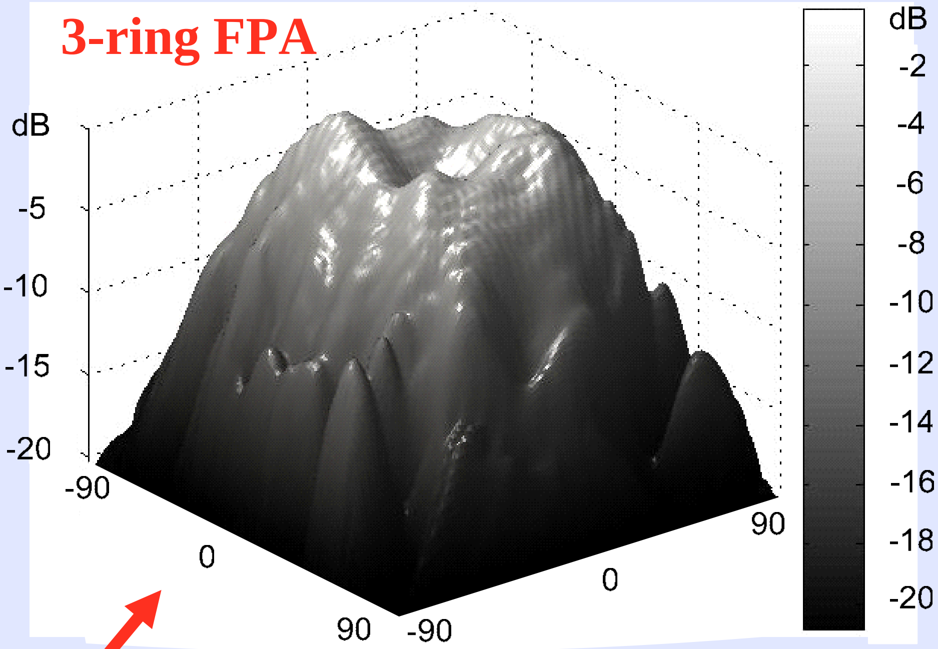


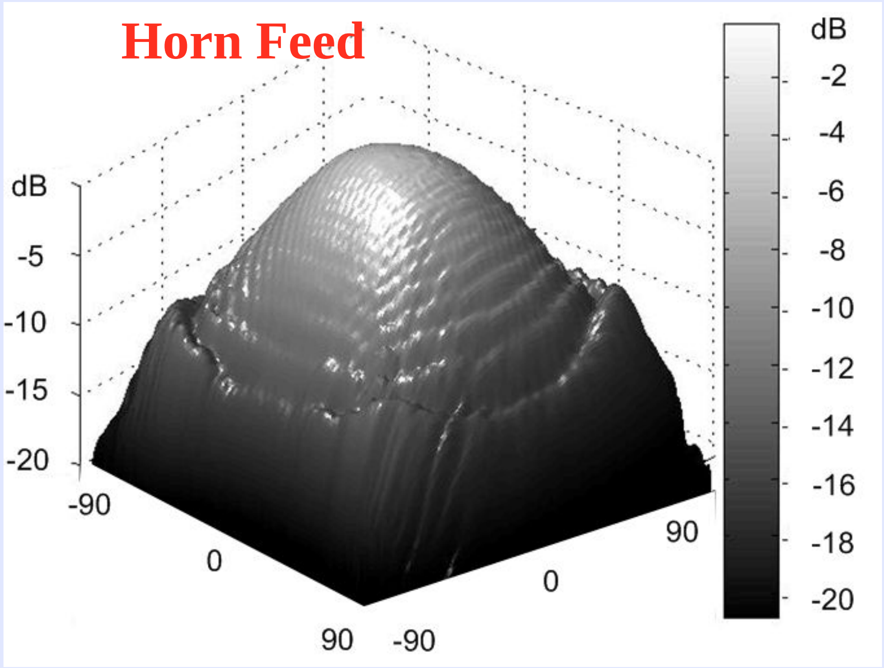


is a cosine shape

Optimization Results: Measured far-field patterns

is a cosine shape

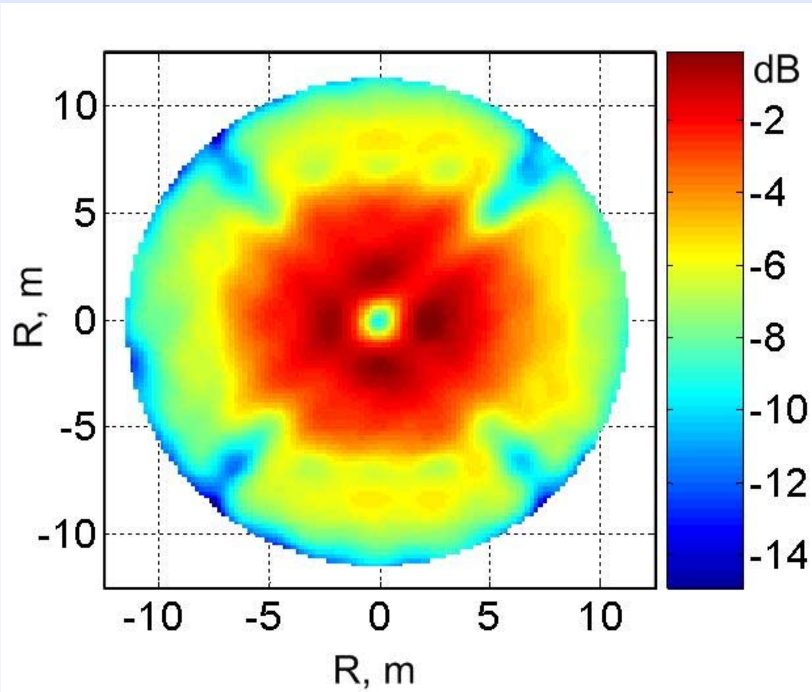




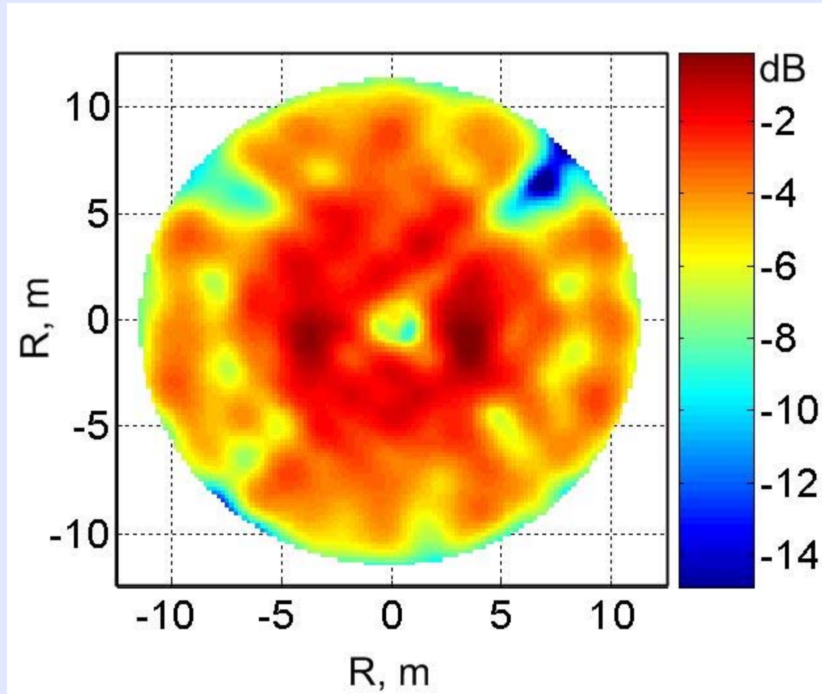
is close to the ideal secant squared shape!

Results: Holographic measurements at WSRT (amplitude distribution):

6-cm Horn Feed

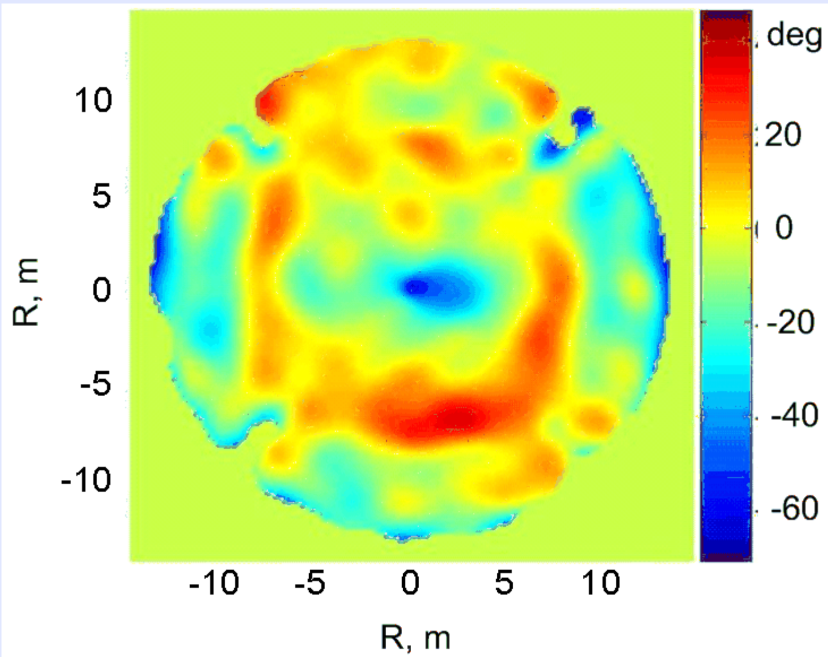


2-ring FPA

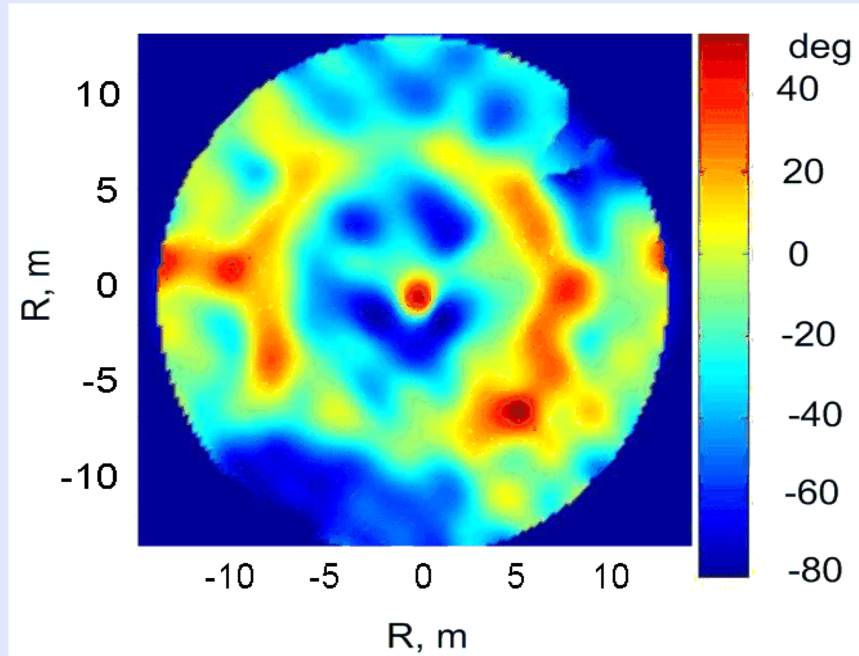


Results: Holographic measurements at WSRT (phase distribution):

6-cm Horn Feed



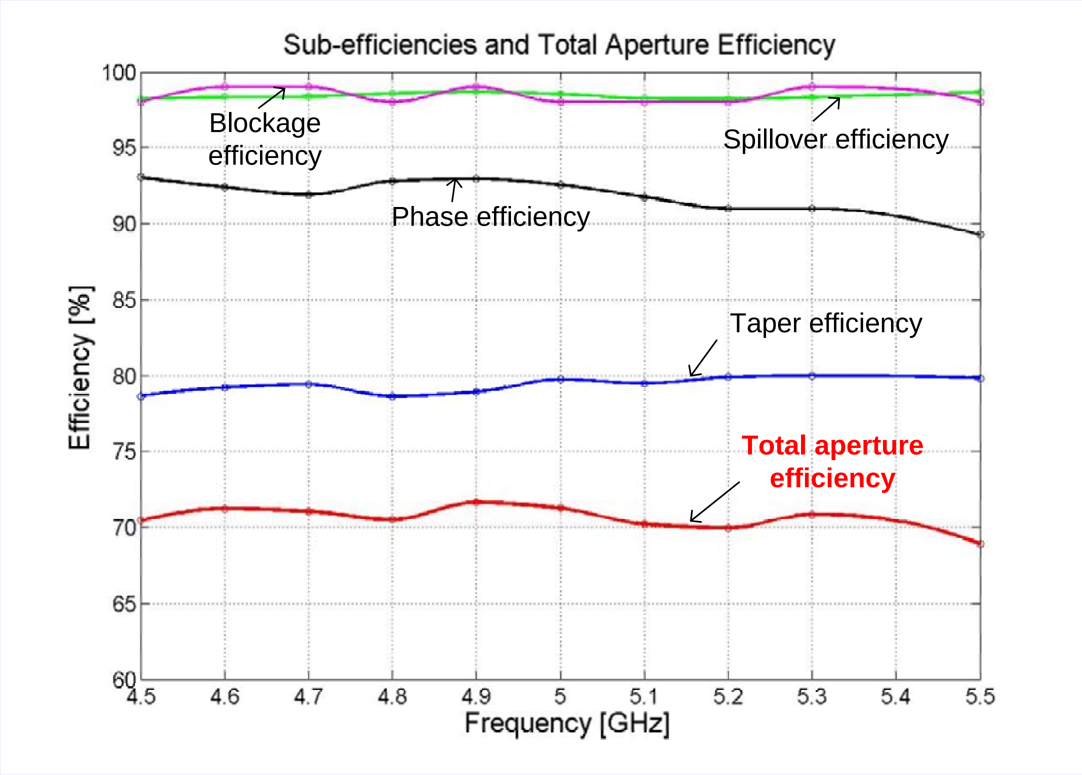
2-ring FPA



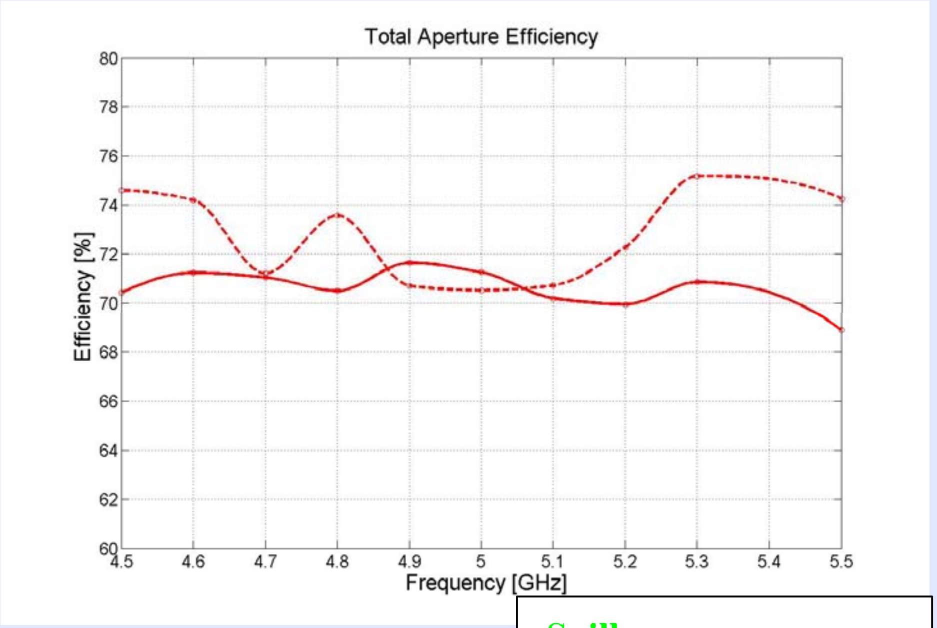
Optimization Results: Calculated Aperture Efficiency for the 13el. FPA

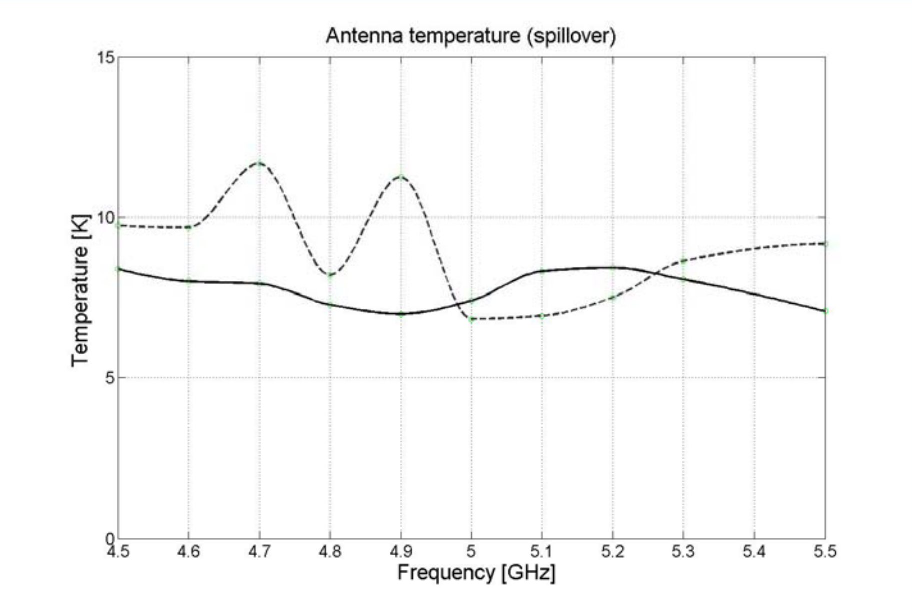
Horn Feed at 5GHz

Taper efficiency, %	74
Spillover efficiency, %	95
Phase efficiency, %	98
Blockage efficiency, %	96
Total efficiency, %	**66**



Optimization Results: Calculated Aperture Efficiency and Ta for the FPA





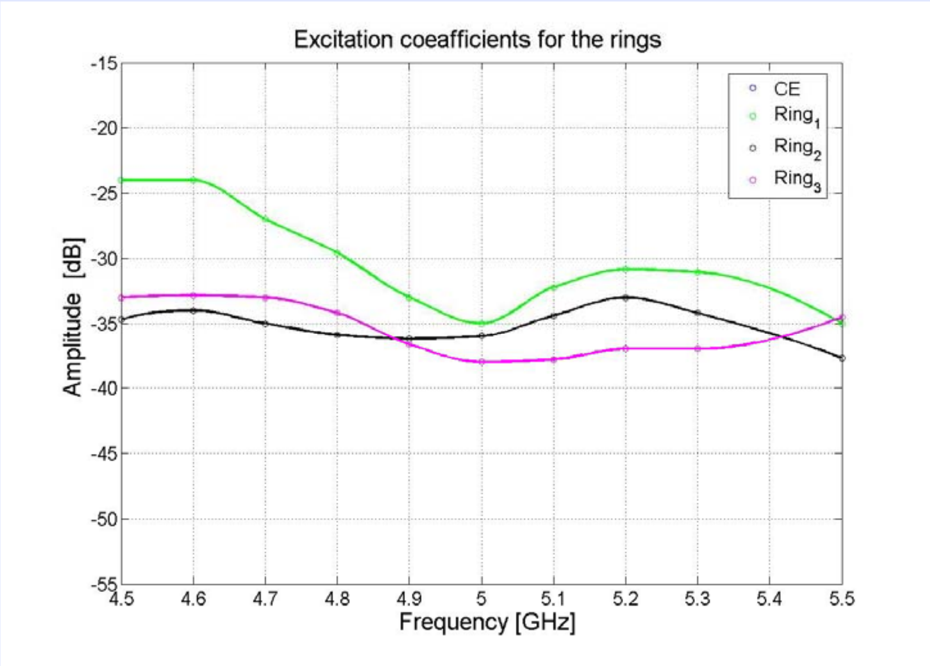
Horn Feed at 5GHz →

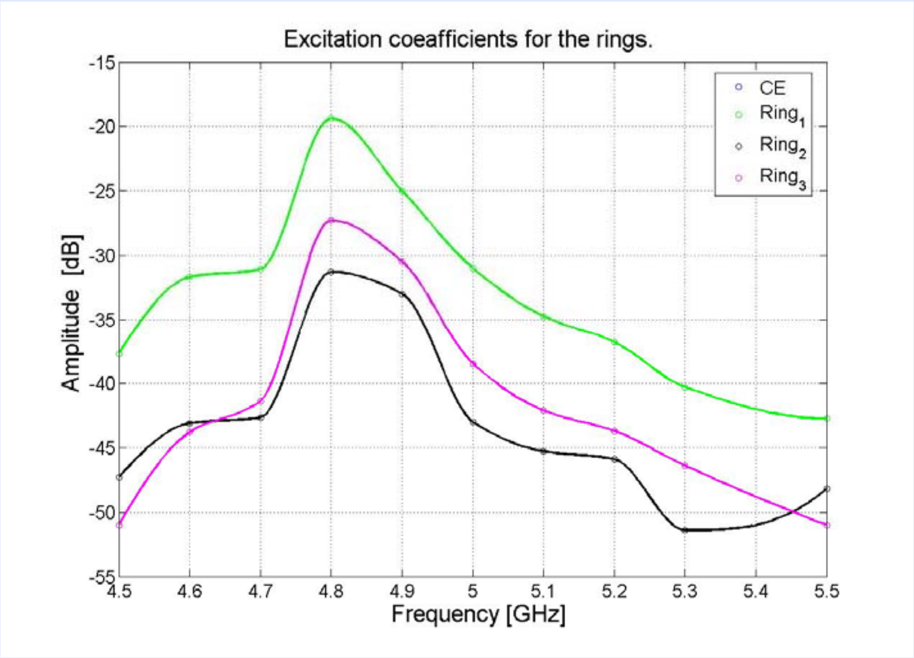
Spillover efficiency, %	95
Antenna temperature, K	19

Unloaded dummy elements (dash)

Loaded dummy elements (solid)

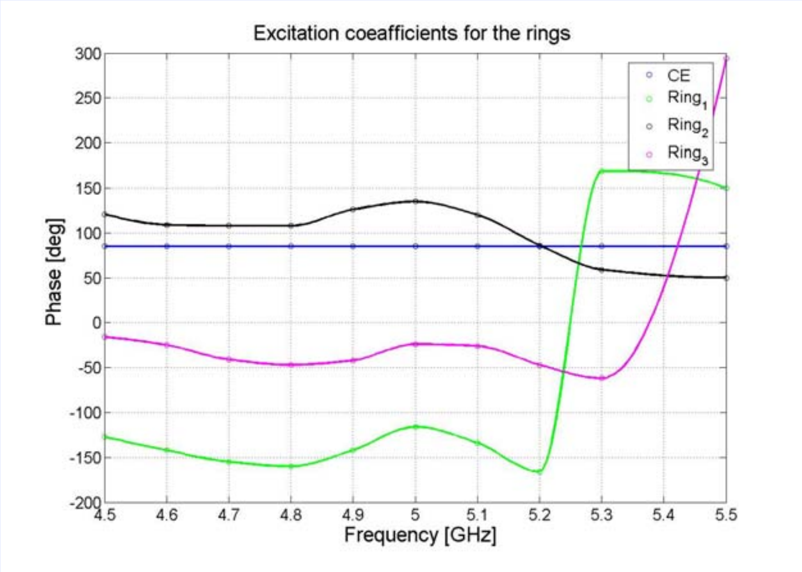
Optimization Results: Weighting coefficients for the 13el. FPA

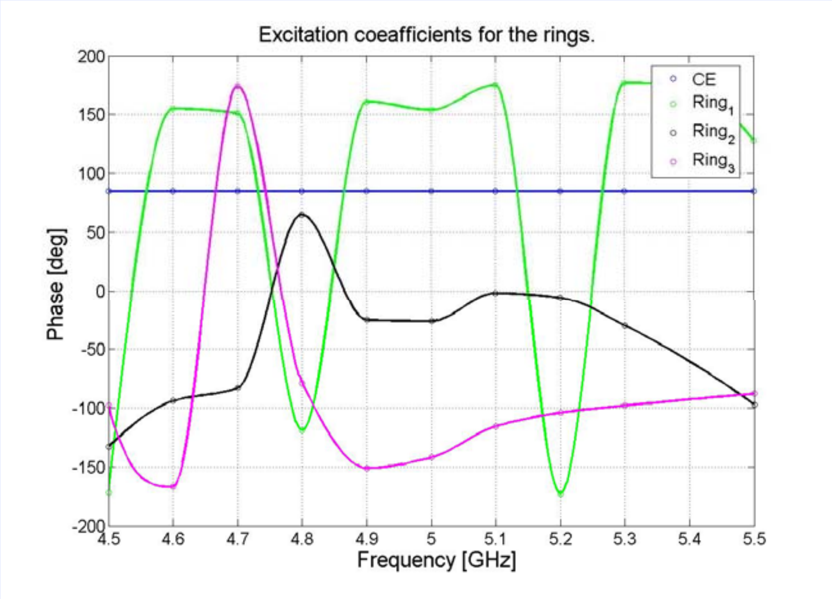




Loaded dummy elements (solid) **Unloaded dummy elements (dash)**

Optimization Results: Weighting coefficients for the 13el. FPA





Loaded dummy elements (solid) **Unloaded dummy elements (dash)**

Array efficiency (reflections, power dissipation in the loads)– correction for the calculated Aperture Efficiency for the FPA

$$\eta_A = \eta_{sp}\,\eta_T\,\eta_{Ph}\,\eta_{Pol}\,\eta_b$$

Conclusions

- The FPA was designed using CFM method to determine initial design parameters of the array (size, number and arrangements of clusters/rings,)
- Additional technique was developed to take into account MCEs in the array and to optimize the excitation coefficients of the rings for the maximum sensitivity (Aeff/Tsys) of the telescope.
- The technique was implemented in the modeled parameters using the measured far-field patters of the rings.
- The developed Vivaldi FPA was verified for the WSRT reflector antenna (F/D=0.35).
- For the antenna, up to 70% aperture efficiency is achievable over a wide frequency range, while the fraction of the system noise temperature which is related to the antenna design is a few K.