Array Simulation and Beamforming for the Expanded GMRT

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Giant Metrewave Radio Telescope (GMRT)

- GMRT is one of the most sensitive telescopes for studying astrophysical phenomena at low radio frequencies (50 to 1450 MHz). GMRT is a national project of the Govt. of India
- Located 80 km north of Pune, 160 km east of Mumbai
- Array telescope consisting of 30 antennas of 45 m diameter – processing through a sensitive radio receiver and real-time digital signal processing backend

Panoramic View of the GMRT Array

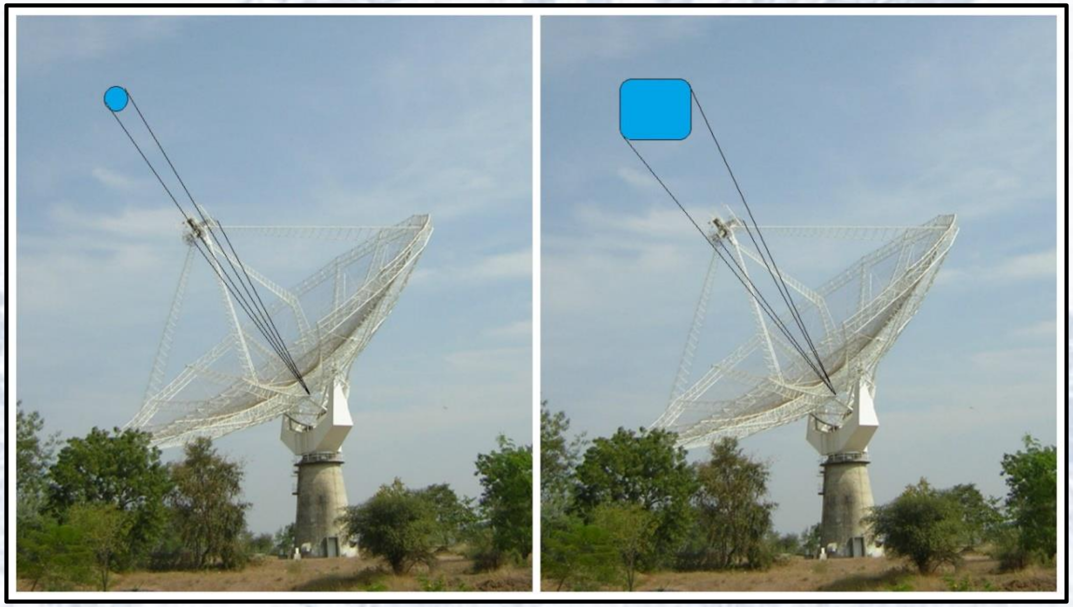
The Expanded GMRT (eGMRT)

- 30 new antennas at baselines less than 5 km. : need correlator and beamformer for 30 antennas

problem statement

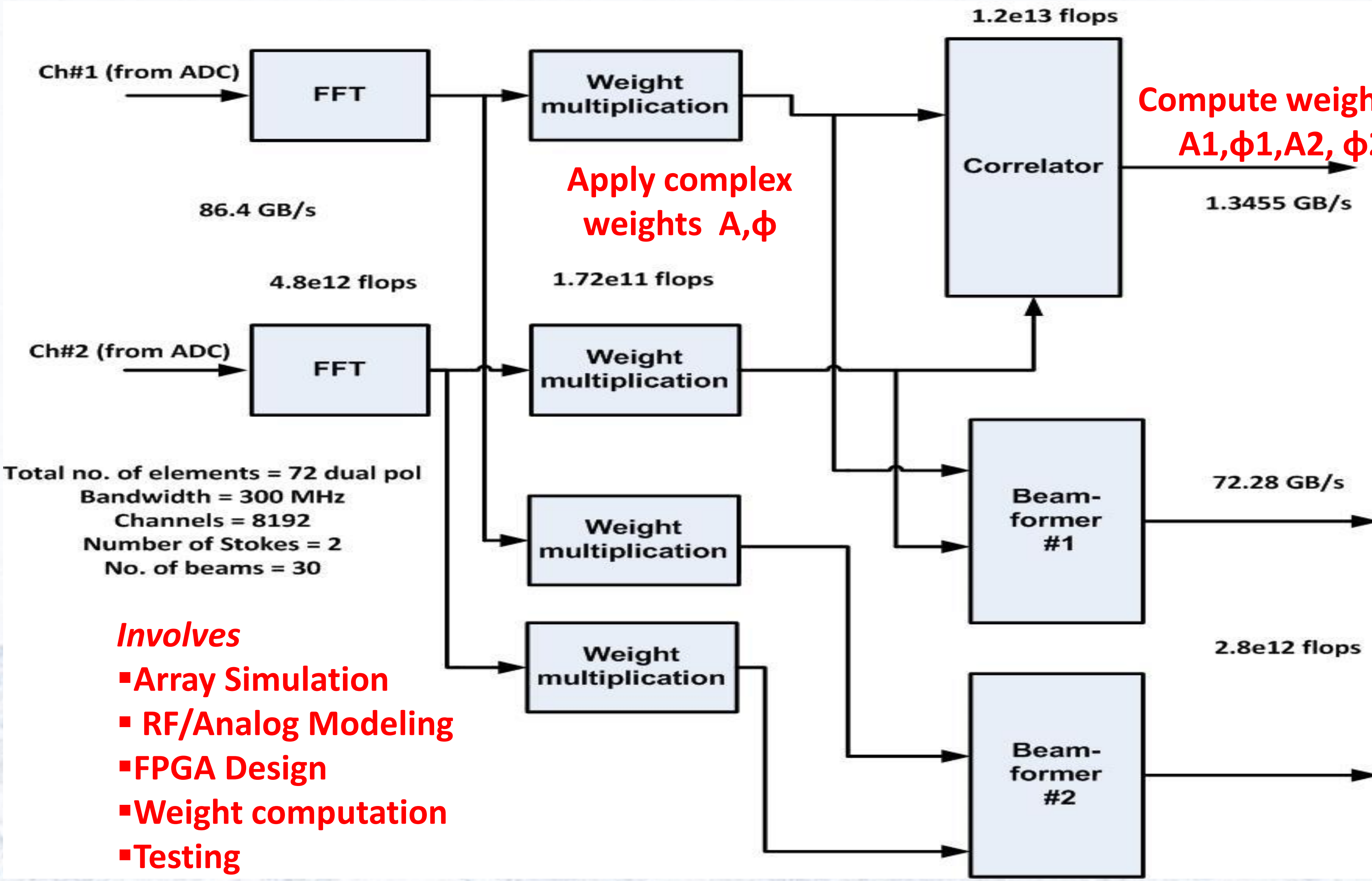
- Focal Plane Array (FPA) feeds with 30 beams on the sky : system-level simulation, design and test multi-beam beamformer, calibration
- 550-850 MHz RF, 300 MHz bandwidth, 16384 spectral channels, 30 beams – analog receiver and multi-beam digital beamformer

Refer: The Expanded GMRT Patra et al., MNRAS, 483, 2019



Artist's Impression: Increased Field-of-View with FPA at the focus (not to scale)

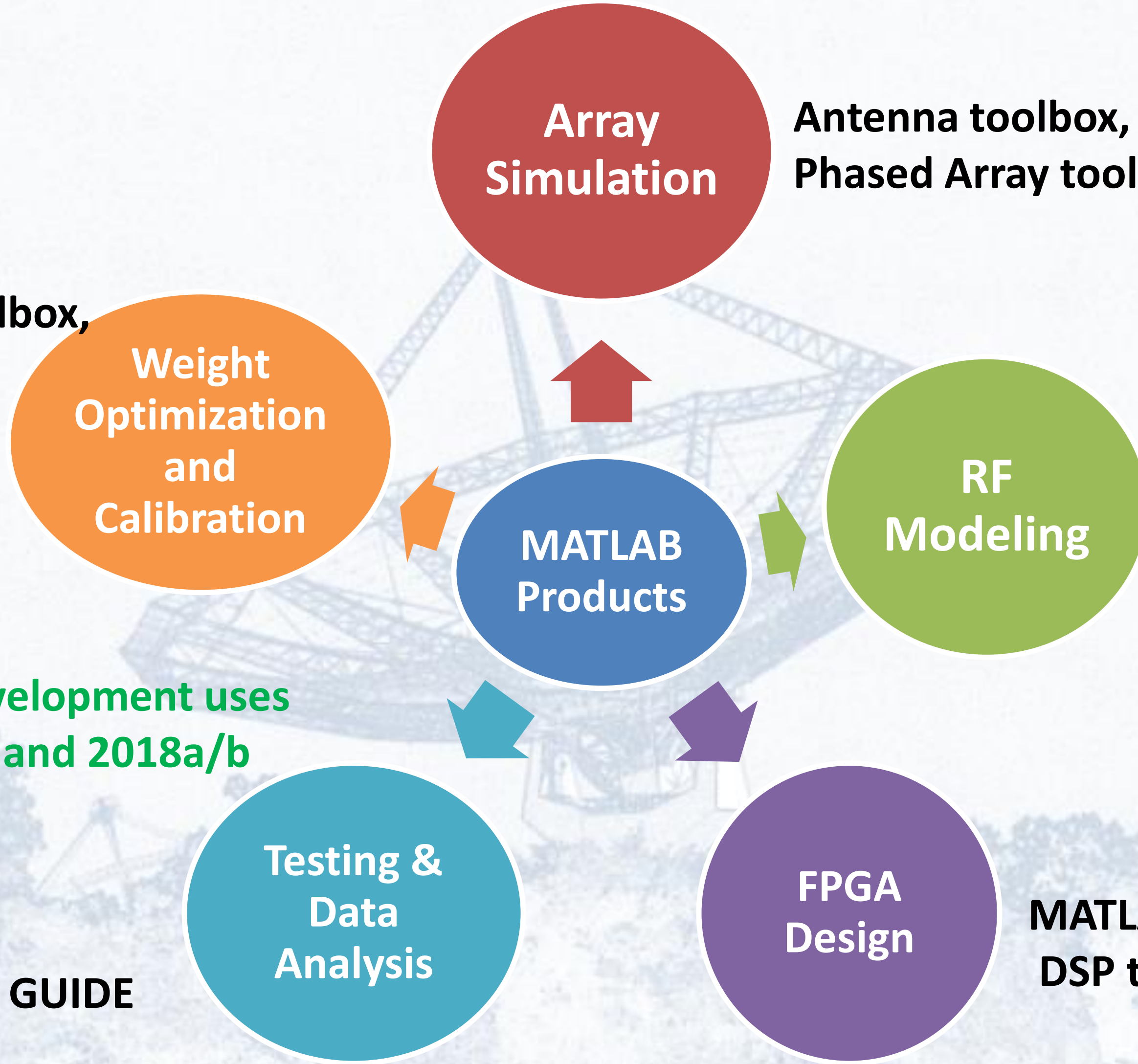
Block diagram: Basic FPA beamformer



Involves

- Array Simulation
- RF/Analog Modeling
- FPGA Design
- Weight computation
- Testing

Beamformer Development using MATLAB



Antenna toolbox, Phased Array toolbox

Optimization toolbox, Statistics toolbox

RF Blockset, RF Toolbox

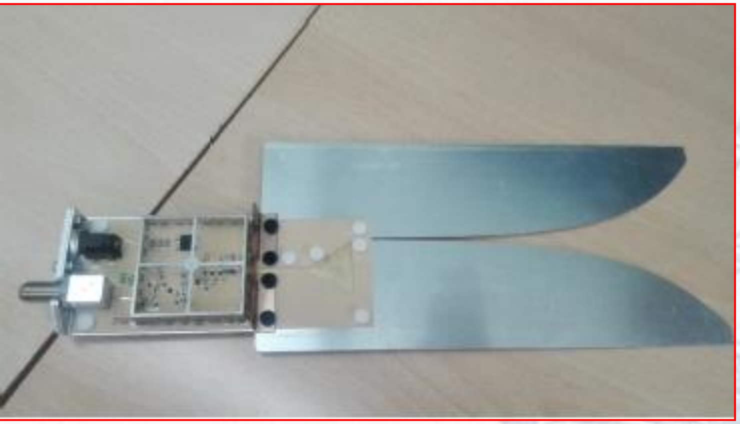
Most of the development uses MATLAB 2015b and 2018a/b

MATLAB, GUIDE

MATLAB, SIMULINK, DSP toolbox

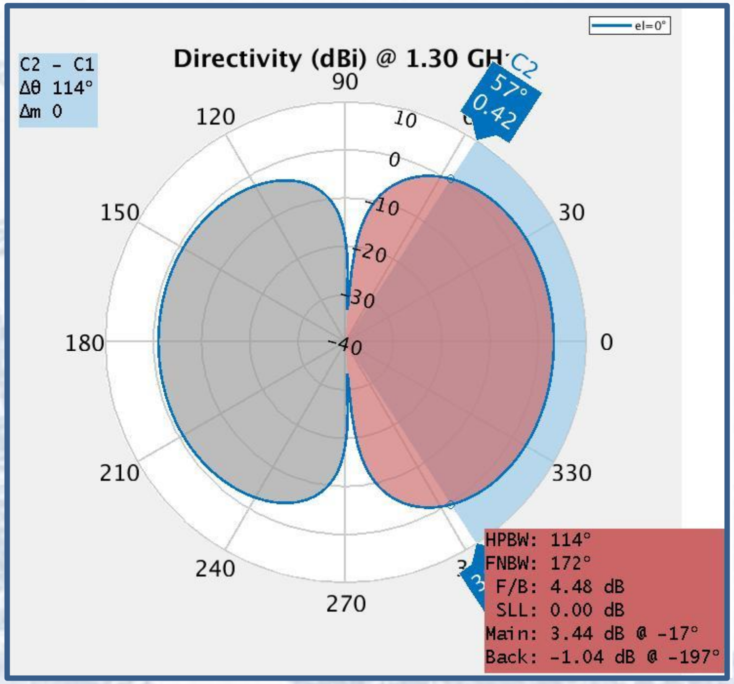
Involves a gamut of MATLAB products!

Simulating Vivaldi Element



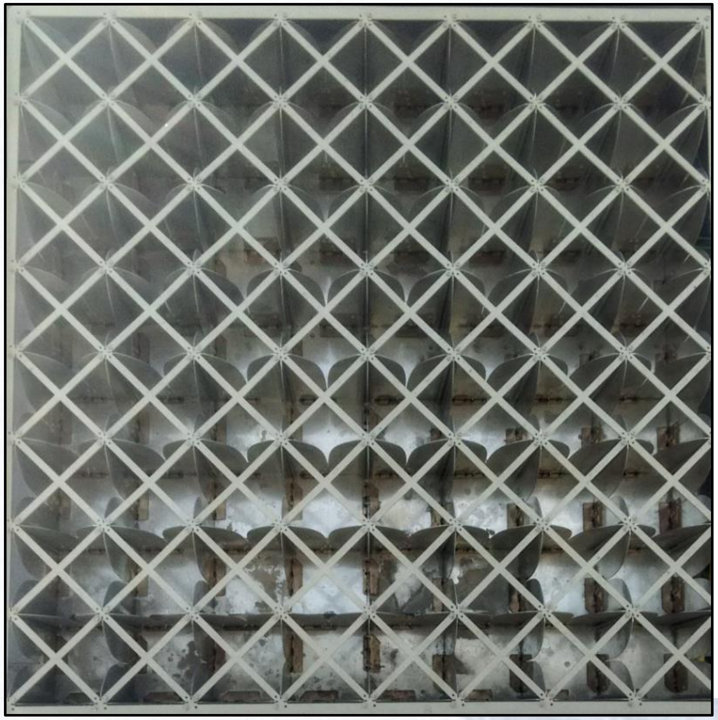
Vivaldi Antenna Element along with the Front-end Electronics

'TaperLength',179.92e-3 ,'ApertureWidth',83.94e-3 ,'SlotLineWidth',0.5e-3 ,'CavityDiameter',20e-3,'CavityToTaperSpacing',23.61e-3 ,'GroundPlaneLength',230.50e-3,'GroundPlaneWidth',100e-3,'FeedOffset',-65.0e-3 (all dimensions in m)



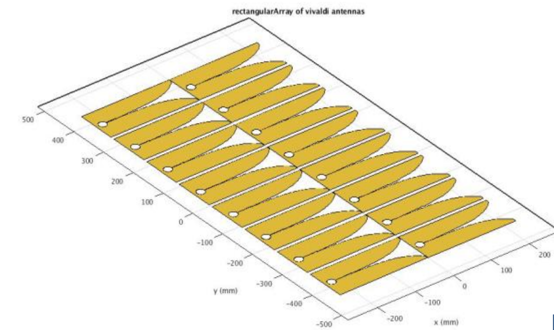
Element radiation pattern at 1.3 GHz simulated using Antenna Toolbox

Simulating Vivaldi Array

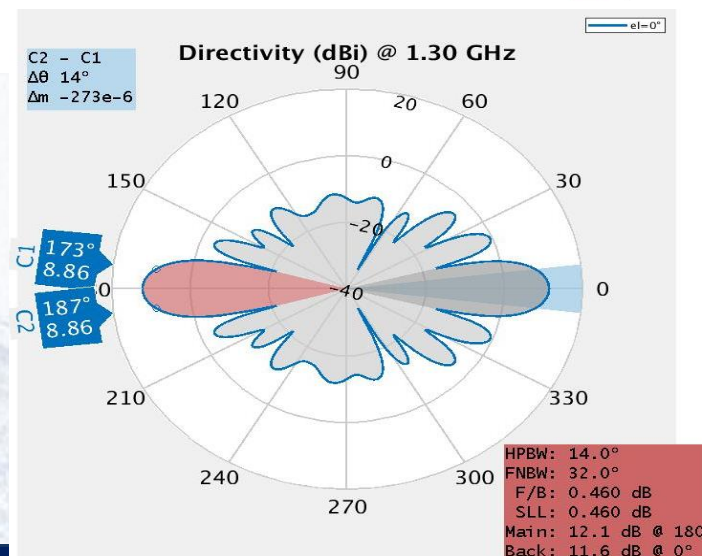


8x9 Vivaldi Array (from ASTRON) at GMRT

Two rows/columns (rectangular array) 8x2



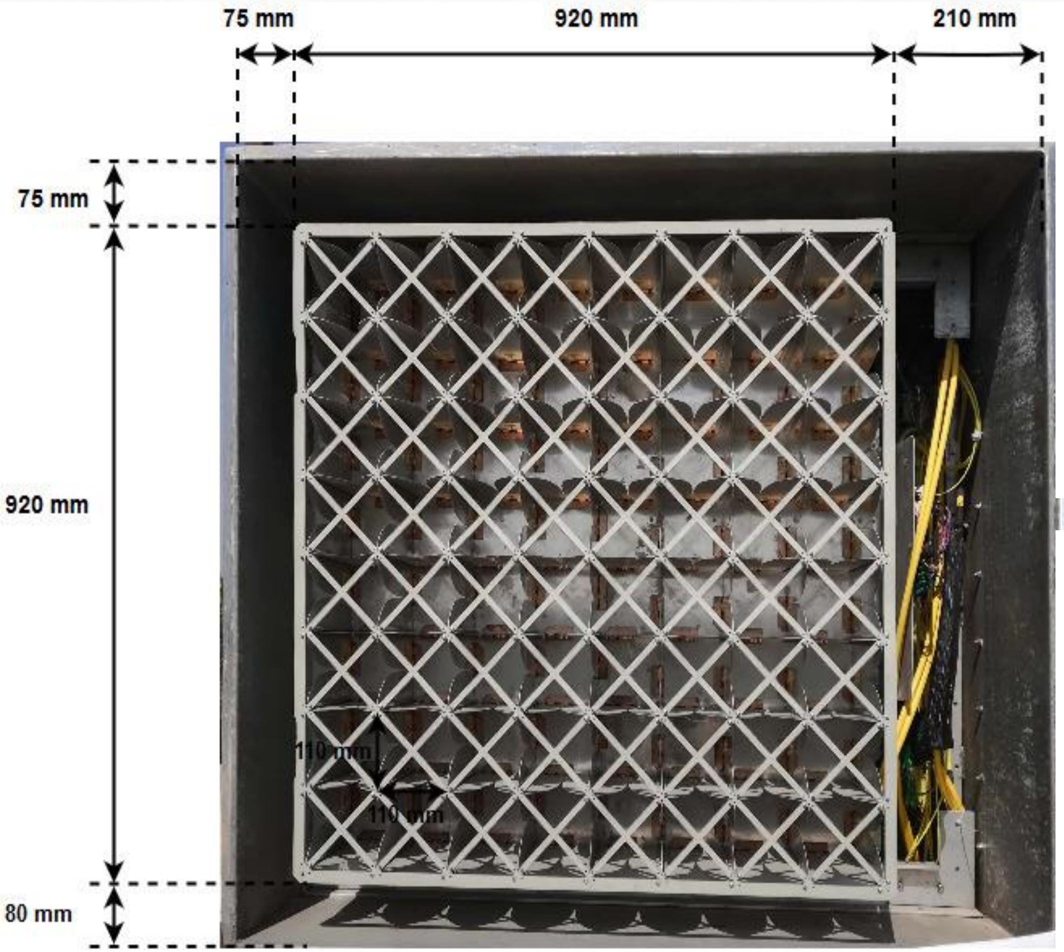
Radiation pattern



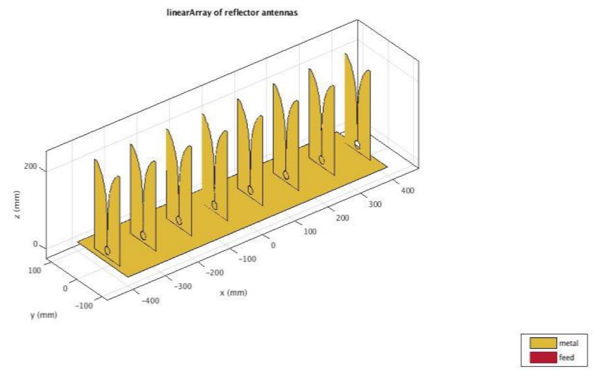
The spacing between the elements is ~λ/2 at 1.4 GHz – elements are mutually coupled

Current aim is to understand the antenna simulation at the system-level

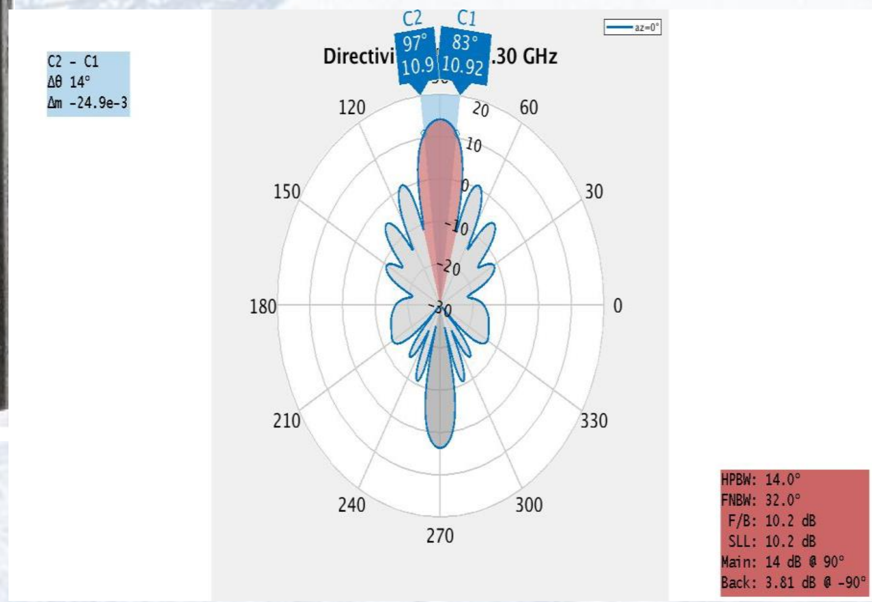
Simulating Vivaldi Array



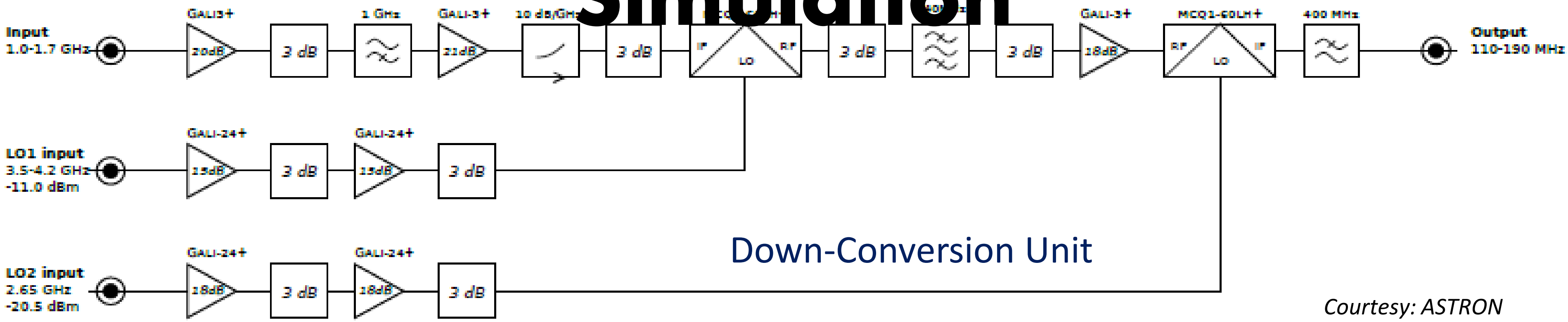
Actual Vivaldi array installation in an enclosure



Typical Simulation (8x1 with ground plane)

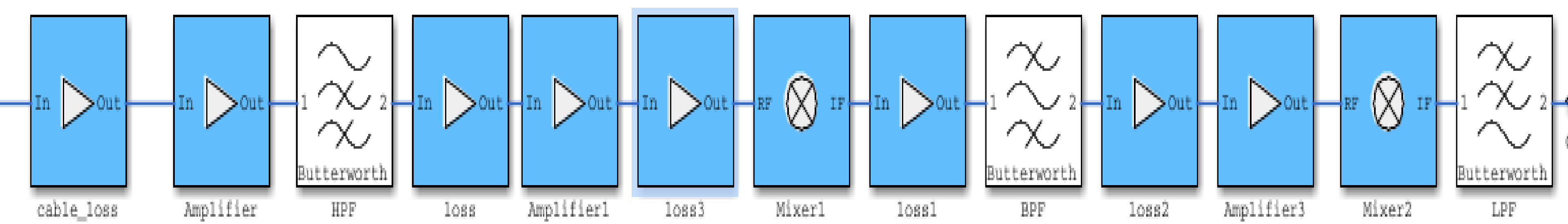


Down-Conversion Unit: Simulation



Down-Conversion Unit

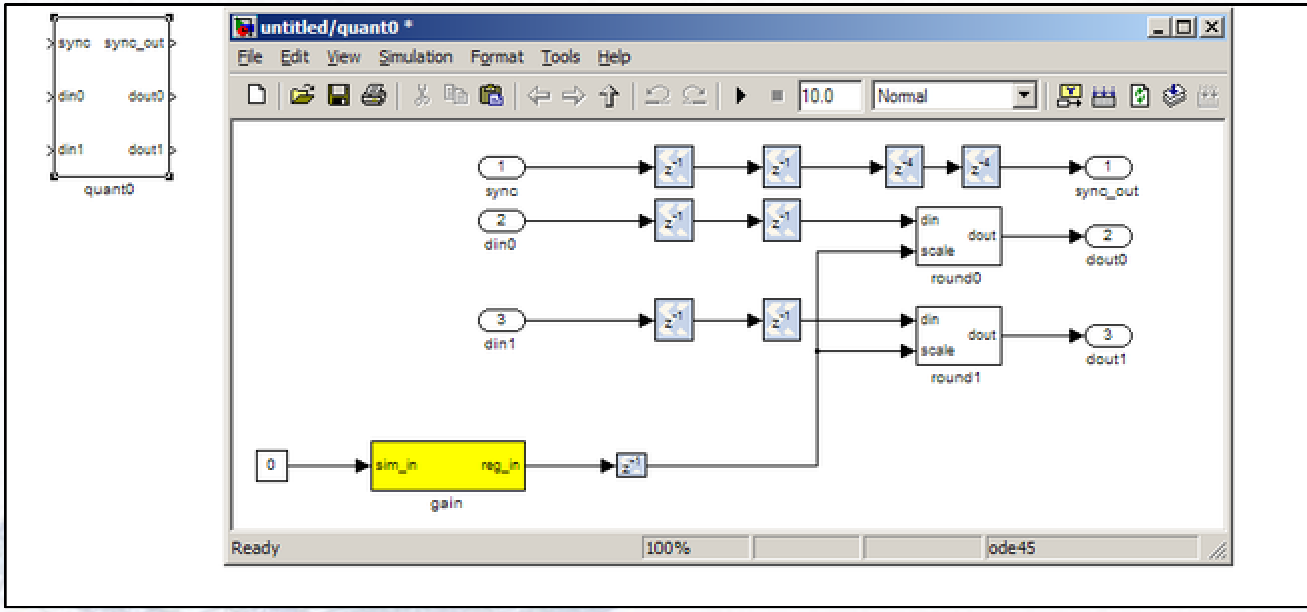
Courtesy: ASTRON



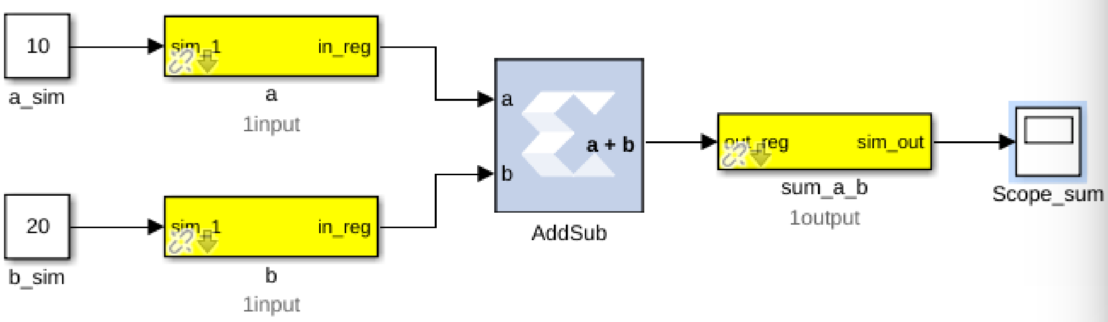
Simulation Model of DCU Block

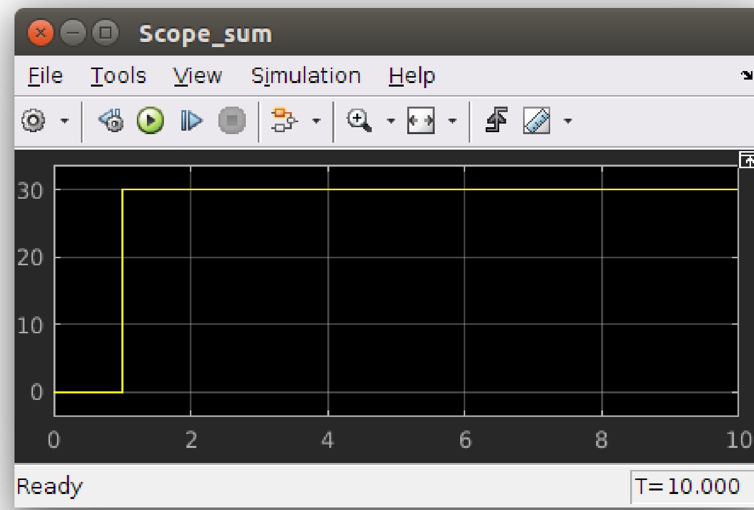
FPA Beamformer: FPGA Design

- ❑Model-based design approach
- ❑Helped in behavioral simulation ahead of implementation – leads to faster prototype development



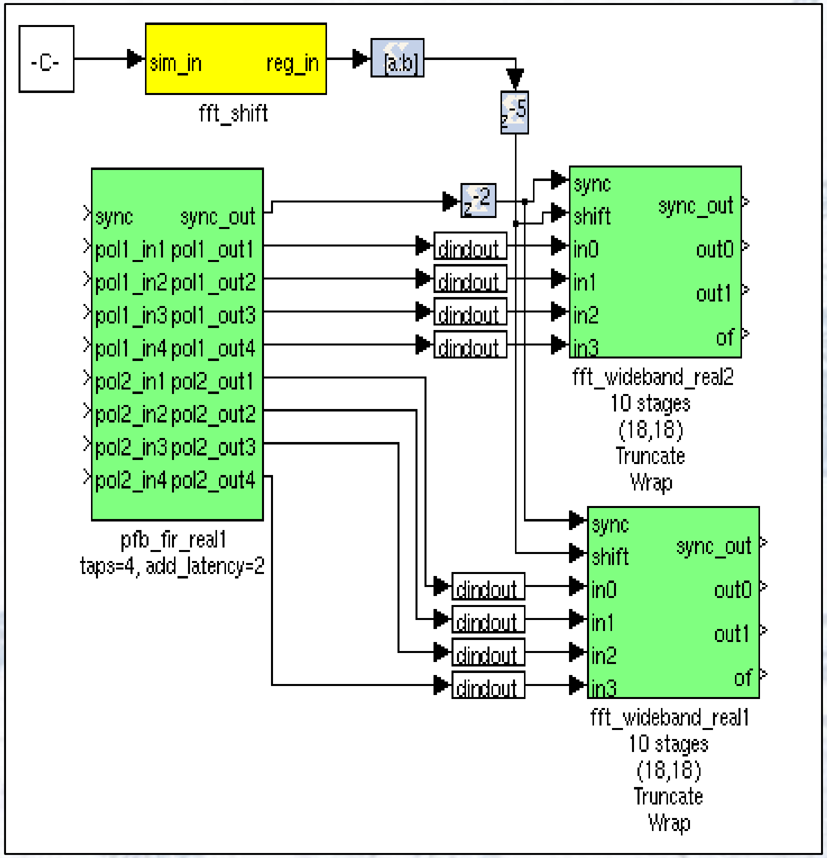
Snapshot of design

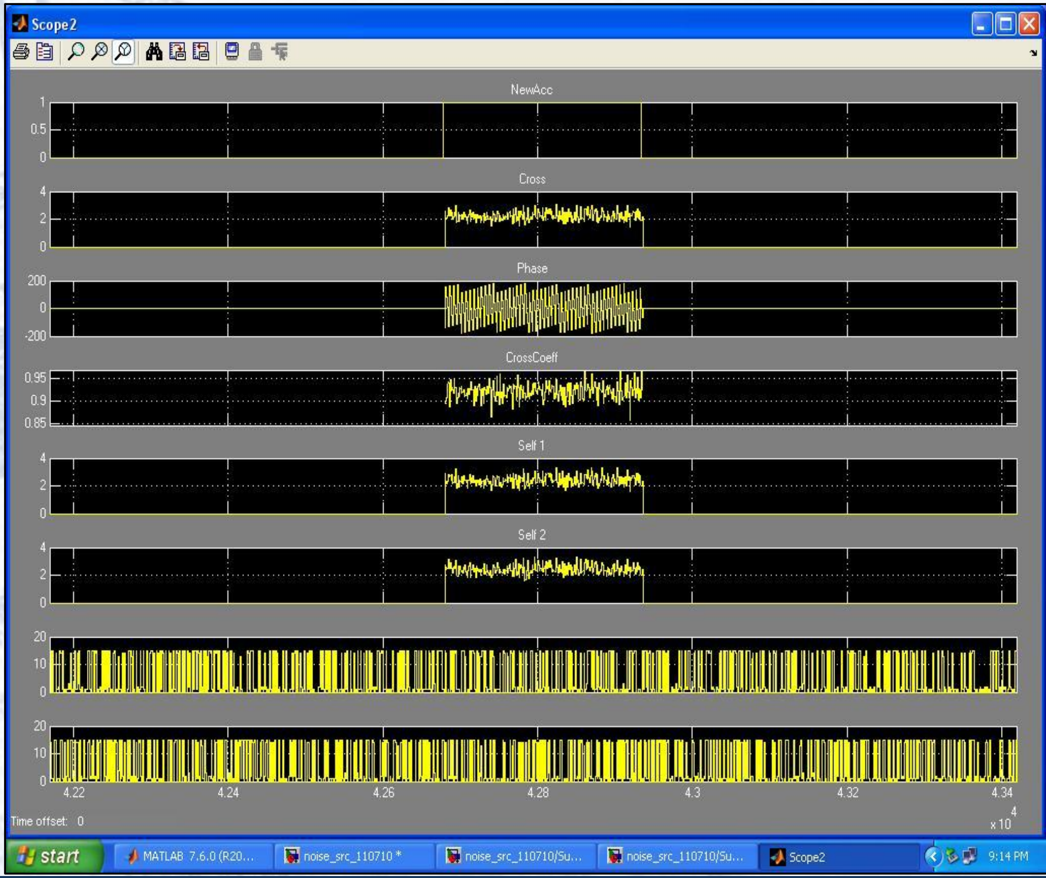




Behavioural Simulation

- ❑Uses CASPER tool-flow (https://casper.berkeley.edu/)
- ❑Ease of generating complex test scenario and test vectors

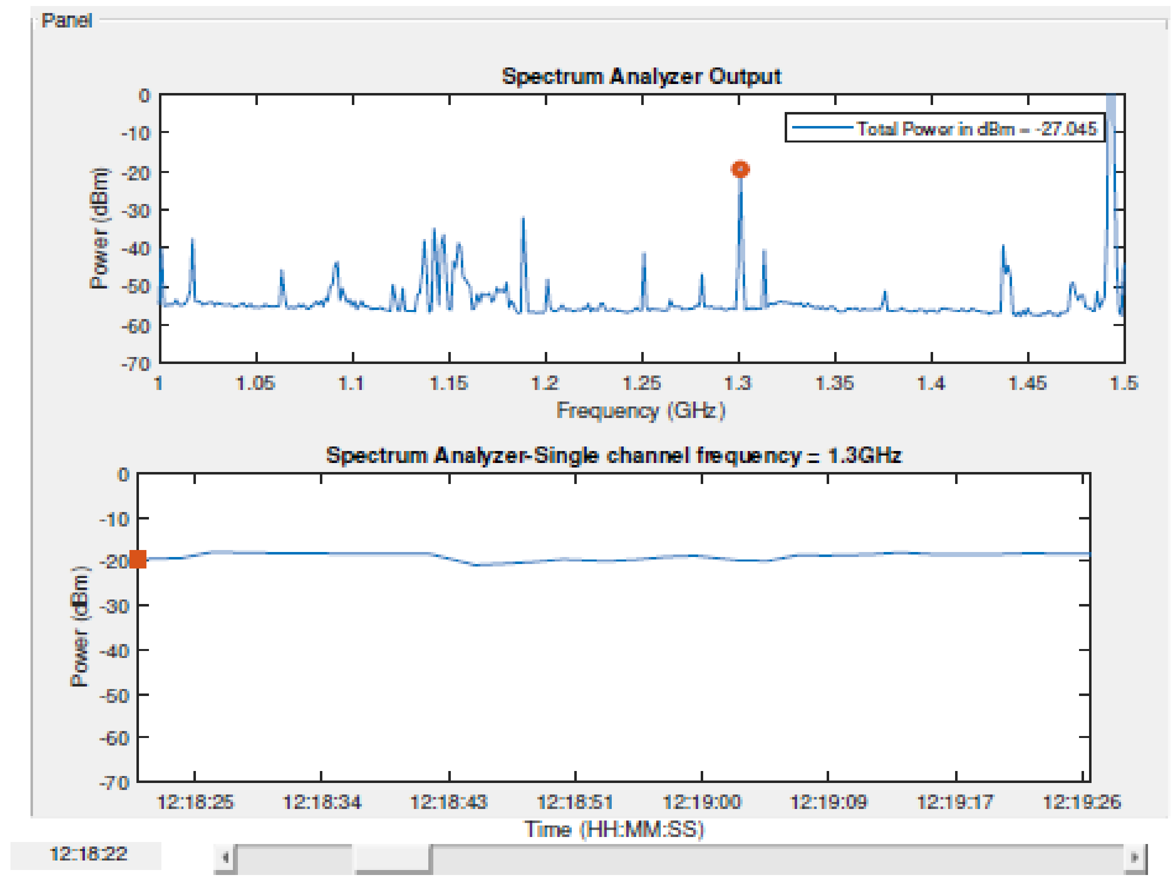




Monitoring and Diagnostic Tools

❑GUIDE (GUI Development Environment) used for monitoring and recording (.avi file) the spectrum to determine the gain stability of the system

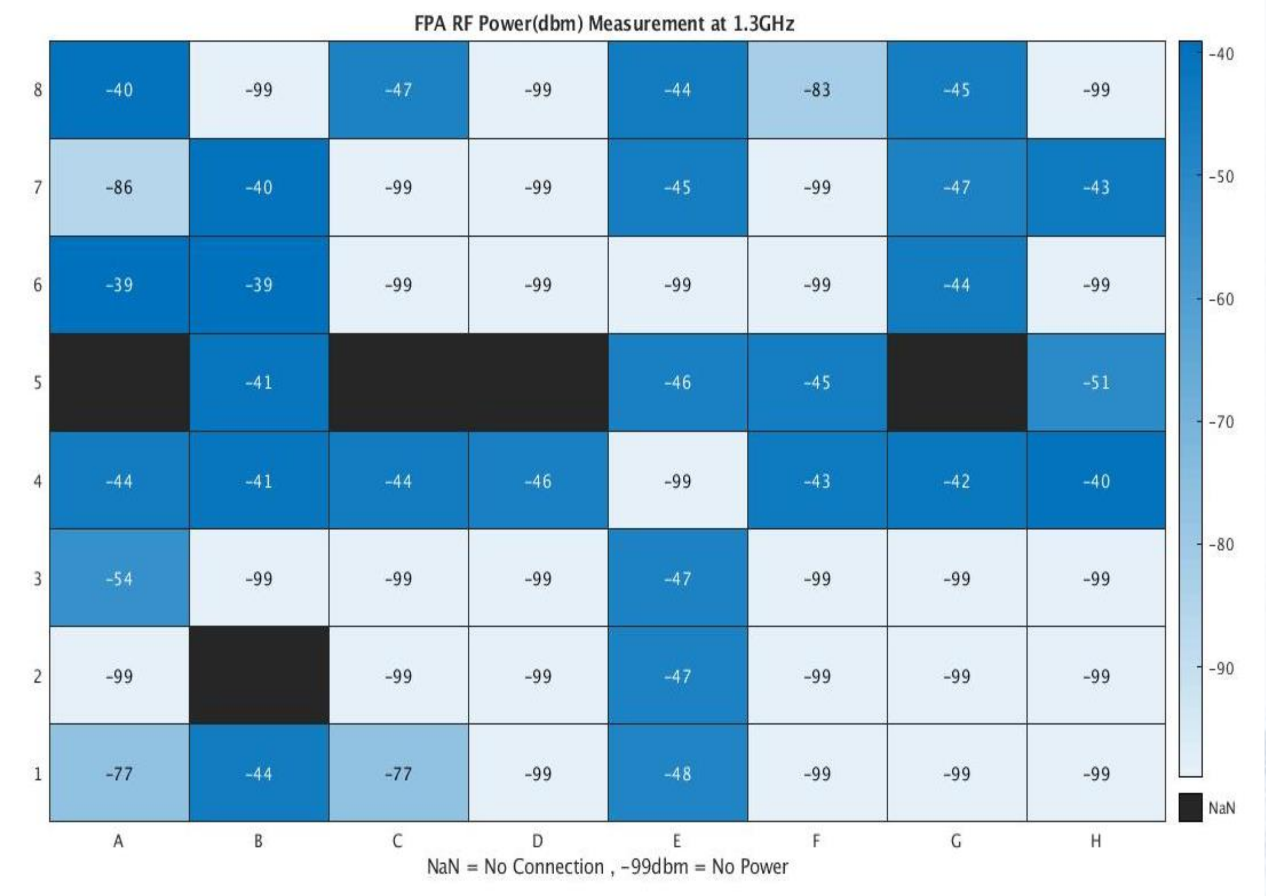
❑ Helps in visualizing time-varying external radio interference and its effects on the other signal quality



Snapshot of spectrum monitoring and recording GUI

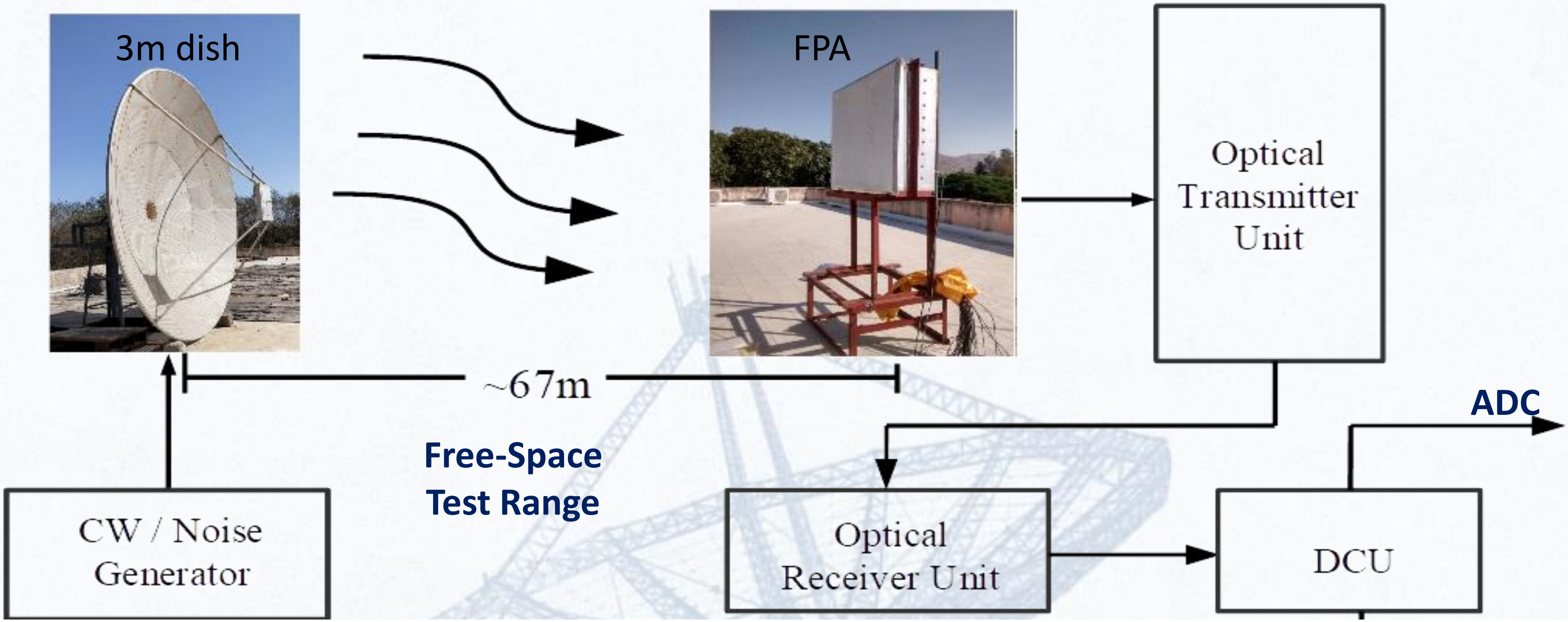
Monitoring and Diagnostic Tools

RF power measurement for choosing appropriate elements for the beamforming process

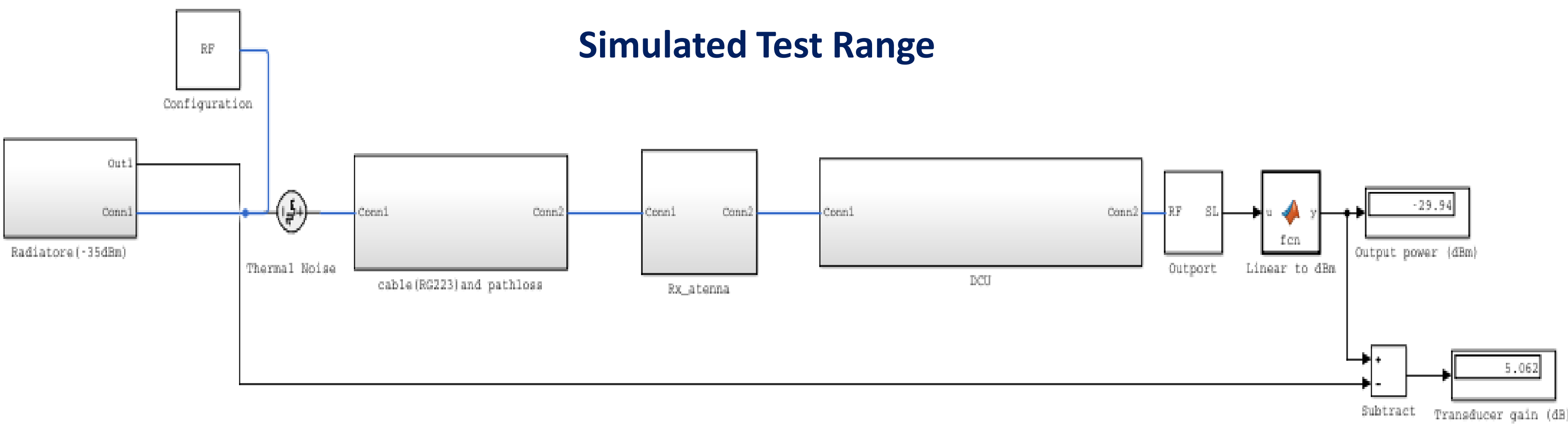


RF power of the array elements (free-space testing) –***heatmap*** function

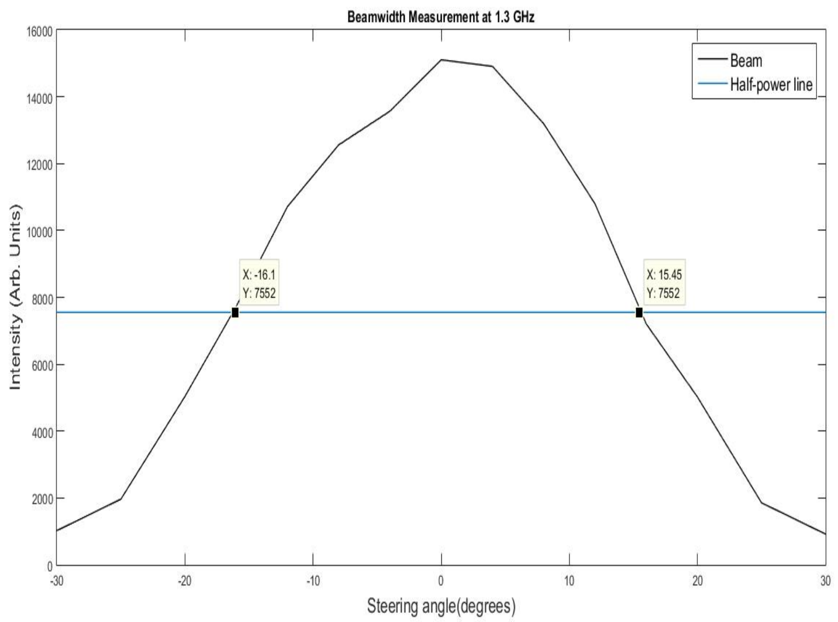
Free-Space Test Range



Simulated Test Range



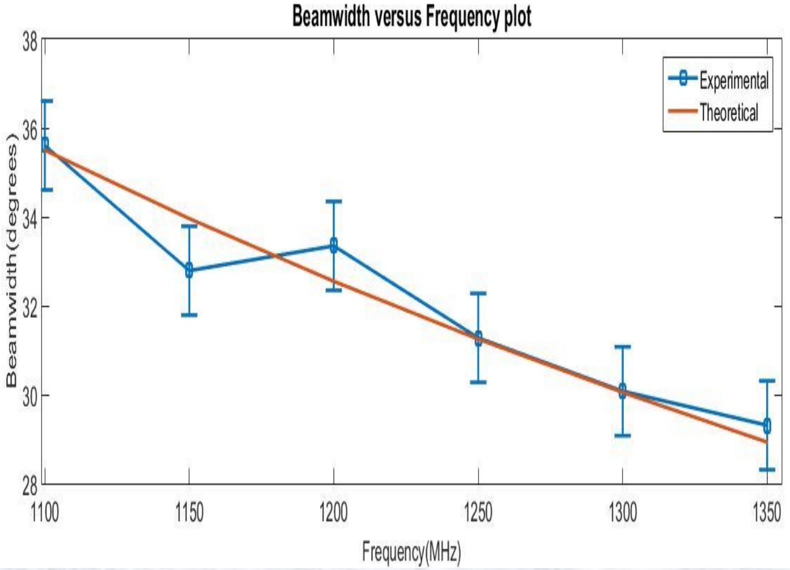
Test Results



❑Beamsteering across radiating antenna; good match between theoretical and measured beamwidth

❑Test carried out for a linear-array configuration (4-element array with 11 cm spacing)

❑Comparison between theoretical beamwidth and measured beamwidth as a function of frequency



Beam optimization and Calibration

Beamformer weights optimization (Max-SNR method):

[V,D] = eig(R_{on}-R_{off}, R_{off});
[tmp,idx] = max(abs(diag(D)));
w_maxsnr = V(:,idx);

R_{on} and R_{off} are the on-source and off-source Array Covariance Matrices (ACM)

Off- source (sky background)

Compute Off-source Array Covariance Matrix

Celestial Radio Source

Compute On-source Array Covariance Matrix

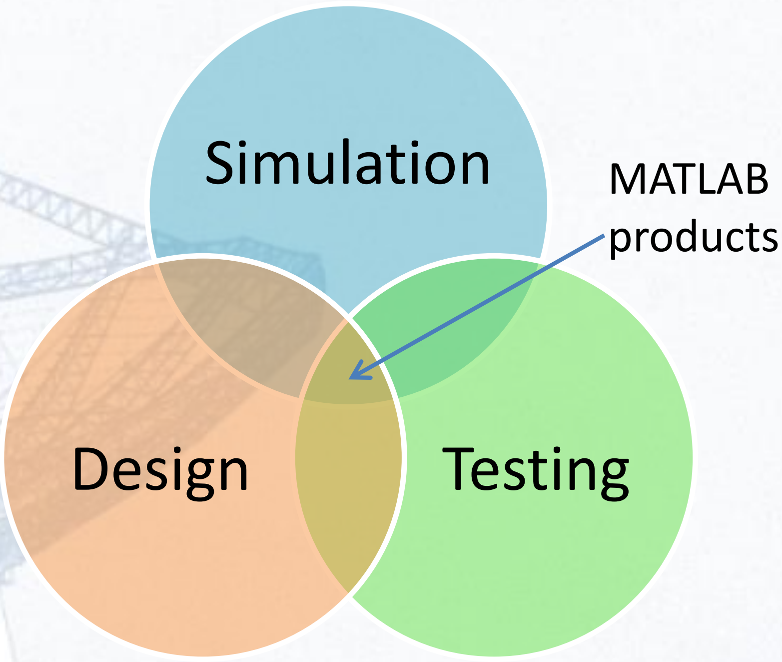
~5°

ACM values from correlator → Optimum Weight Calculation → Applying Weights to the beamformer

Summary

- ❑Current status of array simulation and beamformer development for the Expanded GMRT was described.
- ❑Simulation was carried out from the system-level modeling point-of-view (to understand the input to digital system)
- ❑Several MATLAB and products were used during the beamformer development and data analysis
- ❑Would like to learn about the upcoming features in MATLAB products

Beamformer Development



MATLAB and products form a common platform for the development

Acknowledgements

Team members (past and present) : Bela Dixit, Priya Hande, Aamer Shaikh, Rahul Argade, eGMRT beamformer development team

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The Expanded GMRT project team

GMRT Engineering Groups

The CASPER Collaboration

ASTRON, The Netherlands

Shashank Kulkarni, Mathworks (India)

Mathworks (India)


Thank You!