Array Simulation and Beamforming for the Expanded GMRT

Kaushal D. Buch
GMRT, NCRA-TIFR, Pune
kdbuch@gmrt.ncra.tifr.res.in
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

Apply complex weights \( A, \phi \)

Compute weights \( A_1, \phi_1, A_2, \phi_2 \)
Beamformer Development using MATLAB

Involves a gamut of MATLAB products!

MATLAB, GUIDE

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

Optimization toolbox, Statistics toolbox

Weight Optimization and Calibration

Array Simulation

Antenna toolbox, Phased Array toolbox

RF Modeling

RF Blockset, RF Toolbox

MATLAB Products

Testing & Data Analysis

FPGA Design

MATLAB, SIMULINK, DSP toolbox

Kaushal Buch

MATLAB EXPO 2019, Pune
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

The spacing between the elements is $\sim\lambda/2$ 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

Simulation Model of DCU Block

Courtesy: ASTRON

Kaushal Buch
MATLAB EXPO 2019, Pune
FPA Beamformer: FPGA Design

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

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

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

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

Compute On-source Array Covariance Matrix

Compute Off-source Array Covariance Matrix

~5°

Celestial Radio Source

Kaushal Buch

MATLAB EXPO 2019, Pune 16
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.

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

Short-term interns – Ritwik Sarkar, Aditi Patade

The Expanded GMRT project team

GMRT Engineering Groups

The CASPER Collaboration

ASTRON, The Netherlands

Shashank Kulkarni, Mathworks (India)

Mathworks (India)