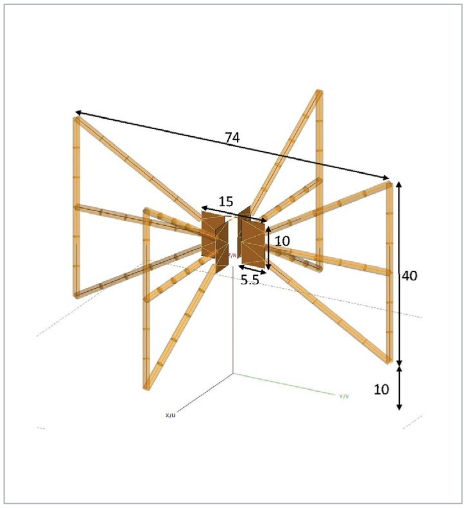
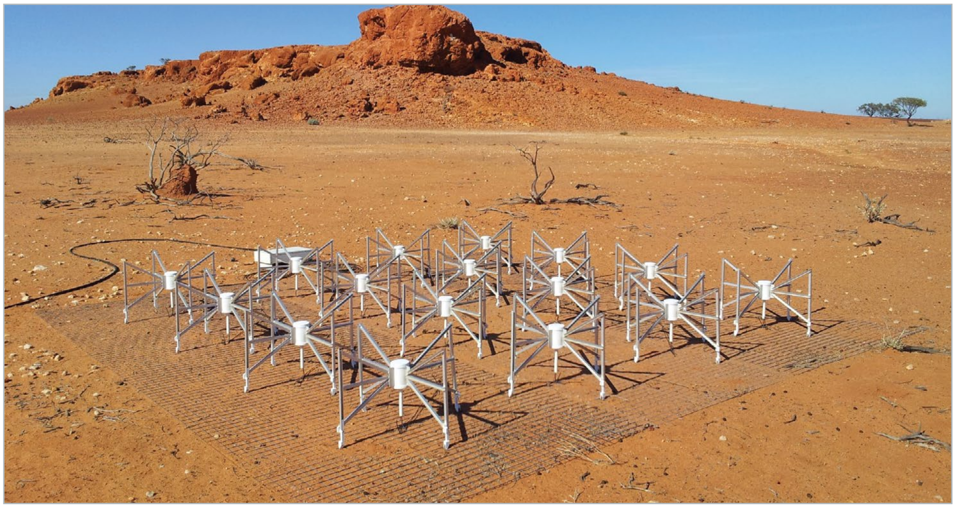
Characterizing the Murchison Widefield Array Beam Pattern





ICRAR
International
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Radio
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Key Highlights

Industry
Aerospace, Radio Science

Challenge
Characterize radio telescope beam pattern

Altair Solution
FEKO

Benefits
- Huge time savings from automation of configurations
- Spherical modal coefficients
- Efficient solvers to represent geometry, LNA impedance and soil

Customer Profile

A precursor to the Square Kilometer Array (SKA), the Murchison Widefield Array (MWA) radio telescope was constructed in the Murchison Radio-astronomy Observatory in Western Australia [www.mwatelescope.org/science]. The MWA comprises of 128 tiles, each an array consisting of 16 uniformly distributed antenna elements (4×4 configuration, 1.1 m apart) as shown in Figure 1.

The work presented in this case study focuses on an electronically steered phased array, where steering is achieved by introducing phase delays to each element in the array. Phased array antennas have direction dependent primary beams. In order to correctly calibrate and image the data collected by the radio telescope, it is imperative that the beam pattern is known accurately.

Previously, the simulation of the beam pattern was conducted using analytical models, but in this study a rigorous approach was applied where the full array geometry was simulated using FEKO, Altair's electromagnetic simulation tool. The goal of the project was to characterize the beam pattern of the MWA and to demonstrate that this approach was more accurate than the analytical approach.

The challenges

Characterizing the beam pattern of the array could be achieved using measurement, but it is time consuming and requires specialized equipment. In this regard, a simulation based approach is the most practical method. The beam pattern is a function of each of the

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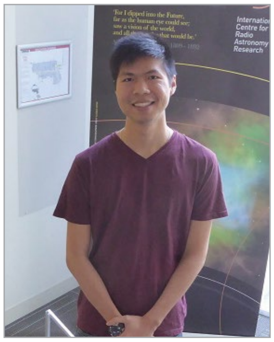
ICRAR Success Story



> **“FEKO was vital in overcoming the challenges as it has all the right tools for the job”**

Daniel Ung,
ICRAR/Curtin University, Perth, Australia

16 array elements as well as the operational frequency of the system. In order to model the pattern, each of the array elements must be excited independently, and at different frequencies within the operation band. By using pattern multiplication, the full array beam pattern can then be modelled at an arbitrary steering direction.

Figure 2 shows the MWA single dipole element geometry, which is oriented such that 2 aluminum arms face North-South (Y-polarization) and the remaining 2 arms face East-West (X-polarization). All 4 arms are attached to the central hub, which houses the low noise amplifier (LNA). The MWA beamformer generates the required phase delays to point the array to point in a specific direction.

The Solution

FEKO was vital in overcoming the challenges of this case study. Due to the sheer number of different configurations that were to be analyzed (218 frequency points, 16 array elements, 2 polarizations, nearly 7000 configurations!), FEKO’s automatization played a key role in enabling the different configurations to be set up automatically, saving a huge amount of time. FEKO’s spherical mode far-field representation was also required to reconstruct the array beam pattern with adjustable resolution in azimuth and zenith angle. Finally, FEKO’s Method of Moments (MoM) solver was used, which is known

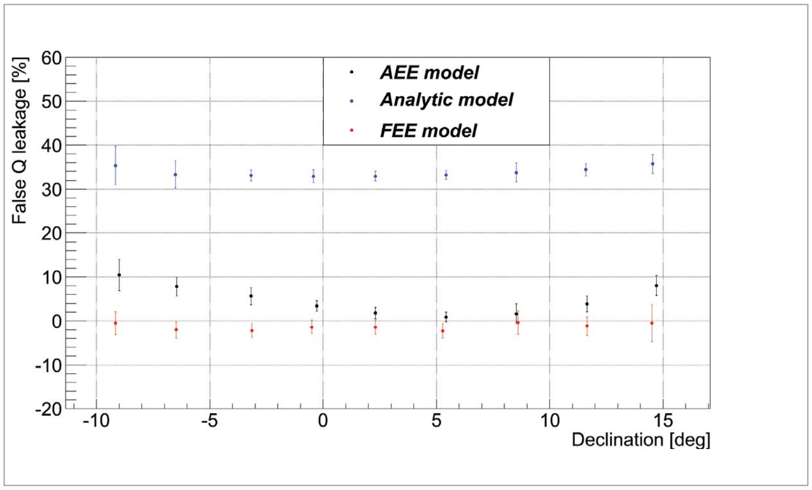


Figure 6: Average Q-leakage results where AEE is the beam generated by average embedded element pattern (singular averaged pattern for all elements). The FEE is the full embedded element pattern presented in this study.

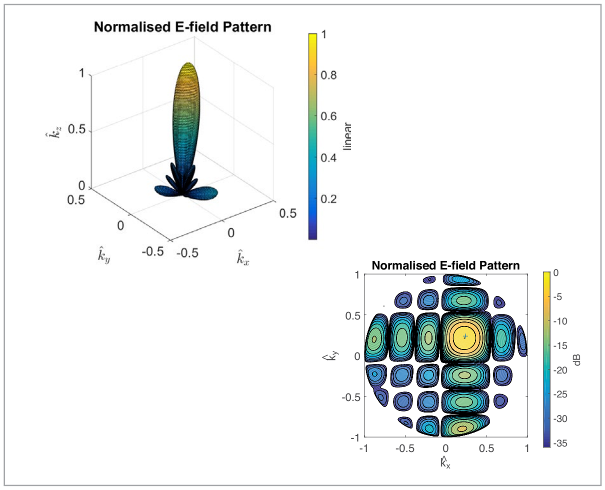


Figure 5: 3D electric field pattern of the MWA tile (left) at Azimuth = 45◦ and Zenith = 19.6◦ at 216.32 MHz and corresponding contour plot (right).

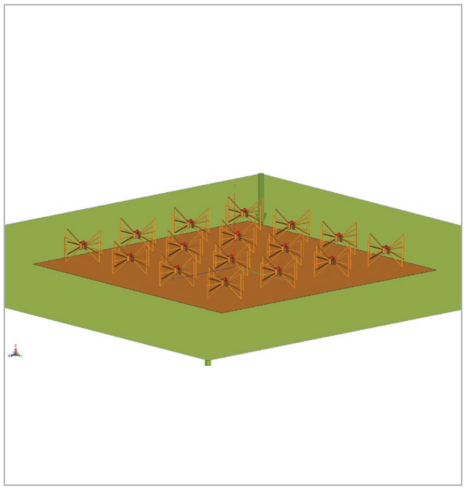


Figure 4: FEKO model of the full array including ground plane and soil layer.

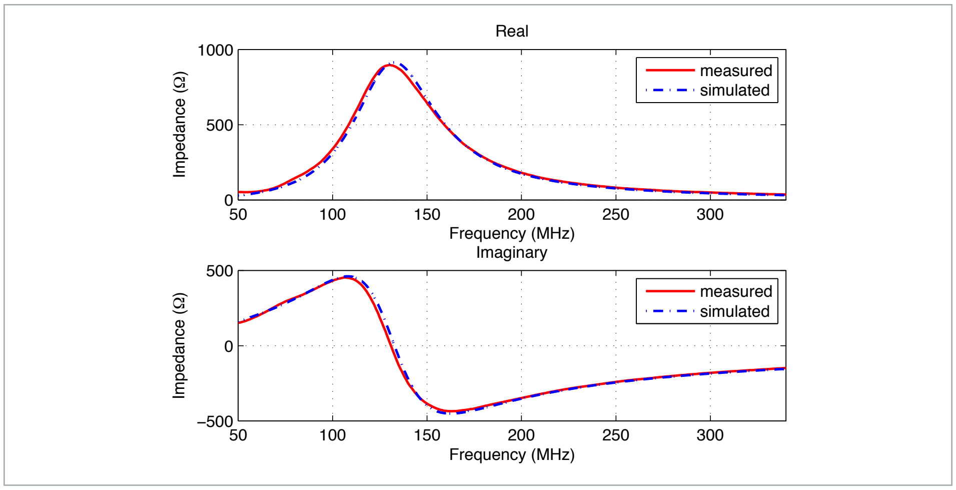


Figure 3: Comparison between measured LNA impedance and simulated RLC lumped circuit that was implemented in FEKO

to be both accurate and highly efficient to solve problems with these attributes (e.g. type of geometry, LNA impedance and soil representation). This meant that, despite the very large number of configurations, simulation time could be kept within acceptable limits.

The array was modelled over a 5x5m solid ground plane. Each LNA was represented by a lumped RLC circuit (Figure 3), which is attached to the feed port of each array element. The ground under the array was modelled using FEKO's planar multilayer substrate model, with typical permittivity and conductivity for soil with 2% moisture content. The FEKO model is shown in Figure 4.

It is necessary to include the geometry of all non-active array elements in the simulation as mutual coupling between the elements influences the patterns.

Each element in the array is simulated for both polarizations and the corresponding radiation patterns are then calculated. This process is repeated throughout the MWA operational band 49.92 - 327.68 MHz, at increments of 1.28 MHz (218 frequency points). From the results, the spherical modal coefficients can be extracted and used to generate the full array pattern at arbitrary steering directions, resolution and operating frequency. This is done by performing a linear weighted sum of all the 16 radiation patterns. Figure 5 shows an example of a reconstructed pattern.

The Q-leakage test which measures the fractional linear polarisation was used to test the validity of the model presented in this study. Based on observation facts, most astronomical radio sources have little or no linear polarisation however, the instrument will introduce artefacts which shows up in the Q-leakage test.

If the primary beam has been modelled correctly, it can be used to account for the artefacts and thus, most of the observed astronomical radio sources should have no measurable linear polarisation (~0% Q-leakage).

Figure 6 shows a comparison for average Q-leakage using beam models generated by different techniques. The observation was performed on the 6th March 2014 at a pointing of Azimuth = 0° and Zenith = 28.3° at 216.32 MHz. The full embedded element (FEE) model in this study shows vast improvements in the accuracy compared to the analytical approach. It also shows improvement over the average embedded element pattern method which serves as a precursor to this approach. In conclusion, the accuracy and applicability of the approach was demonstrated. This work lays the foundation for the EM simulations that will be used for the SKA low telescope.

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