Polarization studies of Vivaldi aperture arrays for the Square Kilometre Array

Michel Arts (ASTRON)
Benedetta Fiorelli (ASTRON)
Overview

- Dense Aperture Arrays
- Intrinsic Cross Polarization Ratio (IXR)
- Scan volume ratio
- Description of array element and array configuration
- Results
- Conclusions
- Bonus:
  - IXR of Hertzian dipoles
  - IXR of different dipole configurations (both single element and array)
Dense Aperture Arrays (AA-mid, MFAA)

- Possible option for SKA2-mid in the 1-2 GHz frequency range.
- Vivaldi arrays are a possible option for this.

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Artist’s impression of SKA2-mid dense aperture array (© SKA Organisation/Swinburne Astronomy Productions)
Intrinsic Cross Polarization Ratio (IXR)

- A possible figure of merit for polarization purity.
- IEEE X-pol definitions are dependent on choice of coordinate system.
- The intrinsic cross polarization ratio is not dependent on choice of coordinate system.
Intrinsic Cross Polarization Ratio (IXR)

Jones matrix:

\[
\begin{bmatrix}
V_1 \\
V_2
\end{bmatrix} =
\begin{bmatrix}
J_{1p} & J_{1q} \\
J_{2p} & J_{2q}
\end{bmatrix}
\begin{bmatrix}
E_p \\
E_q
\end{bmatrix}
\]

Choose transformation matrices $A$ and $B$ such that

\[
\begin{bmatrix}
V'_1 \\
V'_2
\end{bmatrix} =
\begin{bmatrix}
1 & d \\
d & 1
\end{bmatrix}
\begin{bmatrix}
E'_p \\
E'_q
\end{bmatrix}
\]

$A$ and $B$ should be unitary (conservation of energy).

\[
\text{IXR} = \frac{1}{d^2}
\]
Scan Volume Ratio

- Scan volume ratio: ratio of the scan volume for which the IXR is greater than or equal to the minimum required IXR and the total scan volume.
- Scan volume: solid angle containing all scan angles within a certain scan range.
- Scan range: all scan angles for which $\theta<\theta_{\text{max}}$ and arbitrary $\varphi$ ($\theta$ is the angle with respect to zenith, $\varphi$ is the azimuth angle).
- IXR of a beam: the IXR of a beam at the scan angle.
Array Element and Array Configurations

Feed board is not taken into account in simulations
Array Element and Array Configurations

Number of elements per m$^2$:
- 128 for rectangular and rotated array.
- 104.4 for W-shape array.
Results (scan volume ratio for rectangular array)

Scan volume ratio for different array sizes (not loaded)

Scan volume ratio for 144-element array
Results (scan volume ratio for rotated array)

Scan volume ratio for different array sizes (not loaded)

Scan volume ratio for 144-element array
Results (scan volume for W-shape array)

Scan volume ratio for different array sizes (not loaded)

Scan volume ratio for 144-element array
Results (scan volume ratio, convergence for large arrays)

- **Rectangular array**
  - Solid: 220 elements
  - Dashed: 264 elements

- **Rotated array**
  - Solid: 196 elements
  - Dashed: 256 elements

- **W-shape array**
  - Solid: 196 elements
  - Dashed: 256 elements
Results (scan volume for 144-element and large arrays)

- Rectangular array: 264 elements
- Rotated array: 256 elements
- W-shape array: 256 elements
Results (impact of reducing the minimum IXR from 25 to 20 dB)

Unloaded 144-element array

Loaded 144-element array

Blue line: $\text{IXR}_{\text{min}} = 25 \text{ dB}$

Red line: $\text{IXR}_{\text{min}} = 20 \text{ dB}$
Conclusions

- For a large array (appr. 200 elements) the scan volume ratio as a function of array size is converged.
- Loading the arrays with 100 Ω resistors increases the scan volume ratio.
- The scan volume ratio of a 264 element rectangular array and a 256 element rotated array are the same for a scan range of 45°.
- The scan volume ratio of a 256 element W-shape array is less than for a 256 element rotated array for a scan range of 45 degrees.
Conclusions (continued)

- If the minimum required IXR is reduced to 20 dB the scan volume ratio of a 144 element array is 1 between 0.3 and 1.3 GHz for the rectangular and rotated array.

- For a 144 element W-shape array the scan volume ratio is 1 between 0.4 and 1.2 GHz if the minimum required IXR is reduced to 20 dB.
Future work

- Include the effect of the LNA in simulations (including noise and noise coupling).
- Which parameter should be used for antenna design.
Why investigate Hertzian dipoles?

Three orthogonal Hertzian dipoles (tripole) directly probe the x-, y-, and z-components of the electric field.

The IXR of two orthogonal Hertzian dipoles is the IXR due to the projection of the electric field on a plane.
Two orthogonal co-located Hertzian dipoles:

\[ IXR = \left( \frac{1 + |\cos \theta|}{1 - |\cos \theta|} \right)^2 \]

Same result for two orthogonal Hertzian dipoles above ground plane
IXR of Hertzian dipoles with(out) groundplane

IXR for a Hertzian ‘tripole’ (three orthogonal co-located dipoles) is infinite.

IXR of a Hertzian ‘tripole’ located $\lambda/4$ above perfect infinite ground plane.

Note the different array factors for the z-oriented dipole and the x- and y-oriented dipoles.
IXR of dipoles (single element)

Dipole length: 14 mm
Wire diameter: 1 mm
$f_{\text{res}}$: 1 GHz

Results comparable with Hertzian dipole
IXR of dipoles (single elements)
IXR of dipoles (single elements)

Results are worse due to asymmetric structure
IXR of dipoles (single elements)
IXR of dipoles (single elements)

Note that IXR of three orthogonal Hertzian dipoles is infinite.
IXR of dipoles (arrays)

Size of unit cell: 15 mm x 15 mm
IXR of dipoles (arrays)

IXR w.r.t. single element improves along the principal axes.

Unloaded

Loaded with 75 Ω
IXR of dipoles (arrays)

Better performance than single element. Array creates symmetry.
IXR of dipoles (arrays)

IXR performance is worse than single element.

Unloaded

Loaded with 75 Ω
IXR of dipoles (arrays)
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