Multi-Mode Antennas for Hemispherical Field-of-View Coverage

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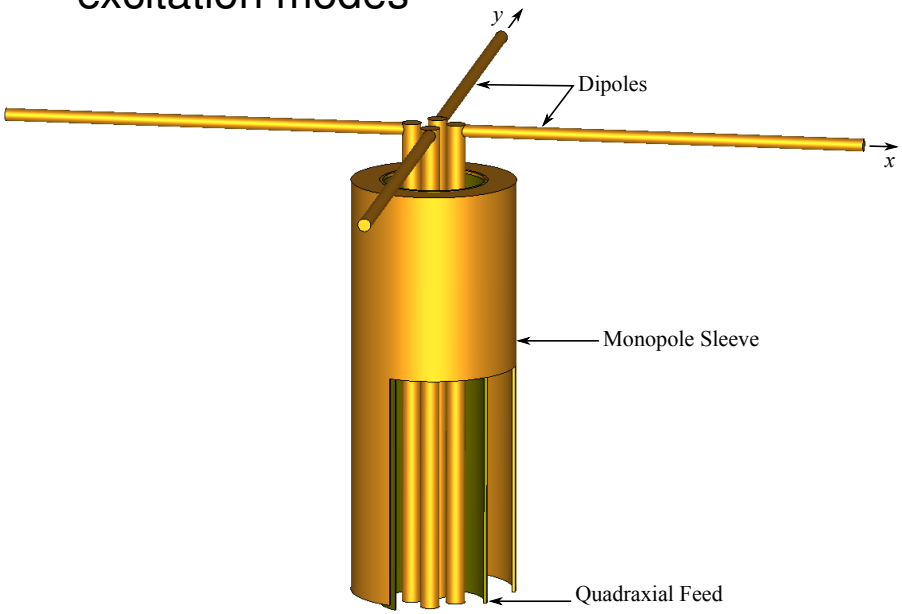
Outline

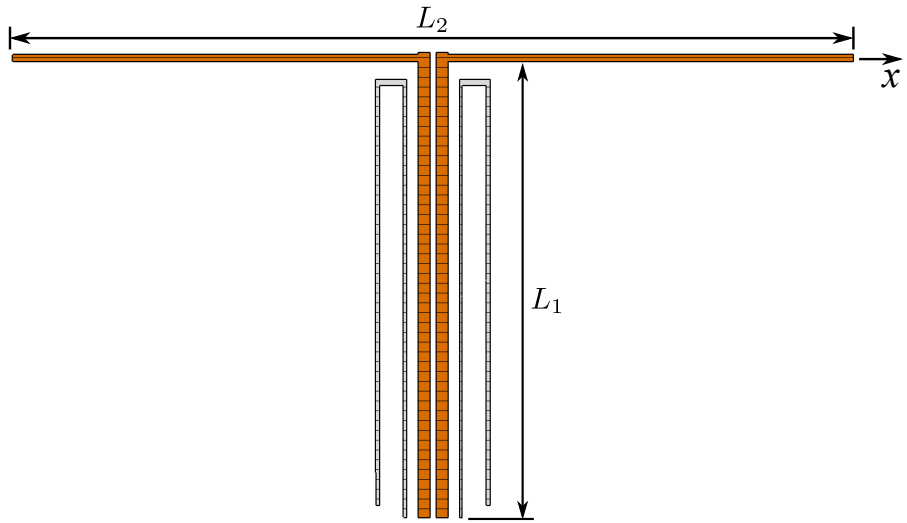
Motivation

To develop antenna elements that achieve near-hemispherical field-of-view coverage by utilizing multiple orthogonal excitation modes present within multi-conductor antenna feeds

Cylindrical Quad-Mode Antenna

- Cylindrical quad-mode antenna integrates and co-locates two perpendicularly oriented cylindrical dipole elements with a cylindrical monopole element [1]
- Antenna excited through a quadraxial transmission line supporting four orthogonal excitation modes



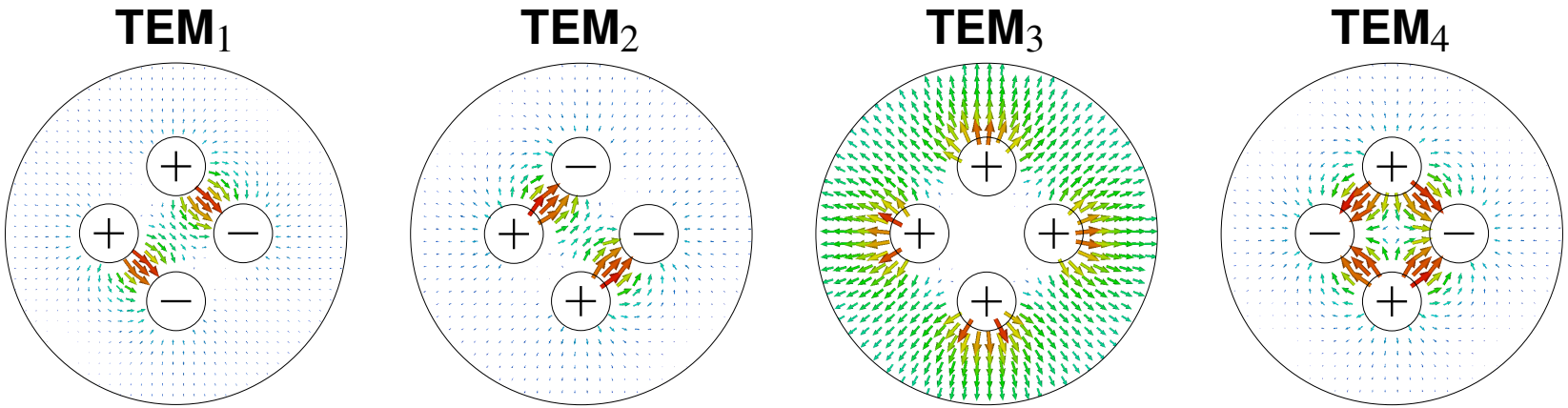


- Each inner conductor connected to one of the dipole arms
- Cylindrical monopole element realized by extending the ground shield of the feed and folding it back over itself

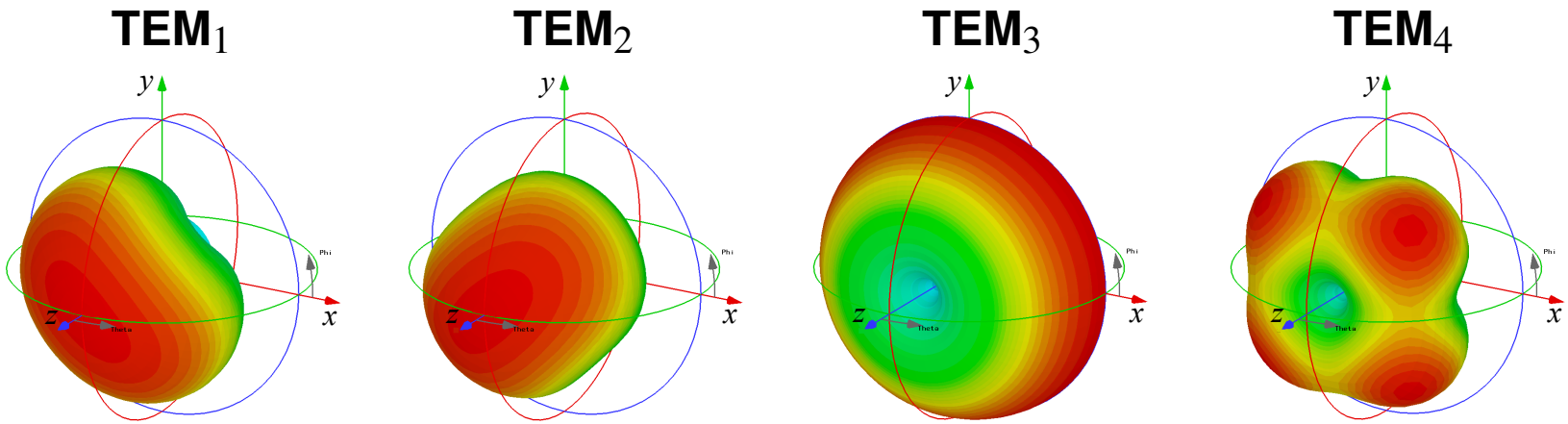
[1] D. Prinsloo, *et al.*, "A quad-mode antenna for accurate polarimetric measurements over an ultra-wide field-of-view," in 8th European Conf. on Antennas and Propag. (EuCAP), April 2014, pp. 3794-3797.

Quad-Mode Antenna Excitation Modes

Port electric field distributions

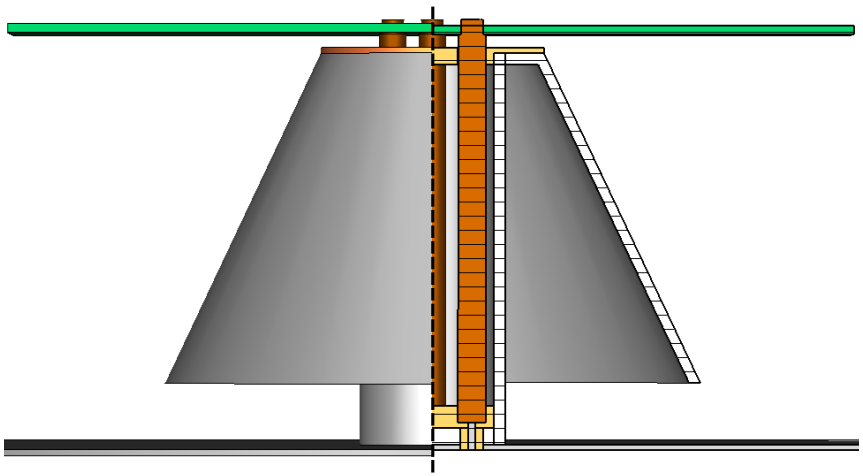


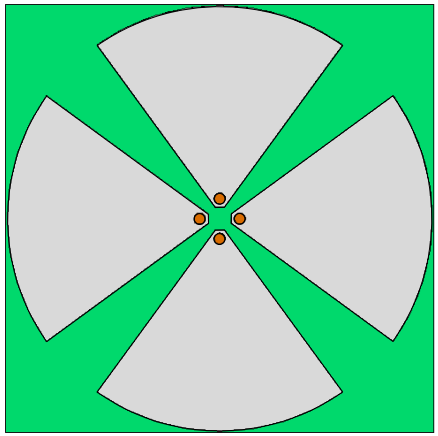
Radiated far-field distributions



Conical Quad-Mode Antenna

- Conical quad-mode antenna integrates [1]
  - two perpendicularly oriented bow-tie dipole antennas with
  - a conical monopole element excited through
  - a quadraxial transmission line supporting four orthogonal excitation modes



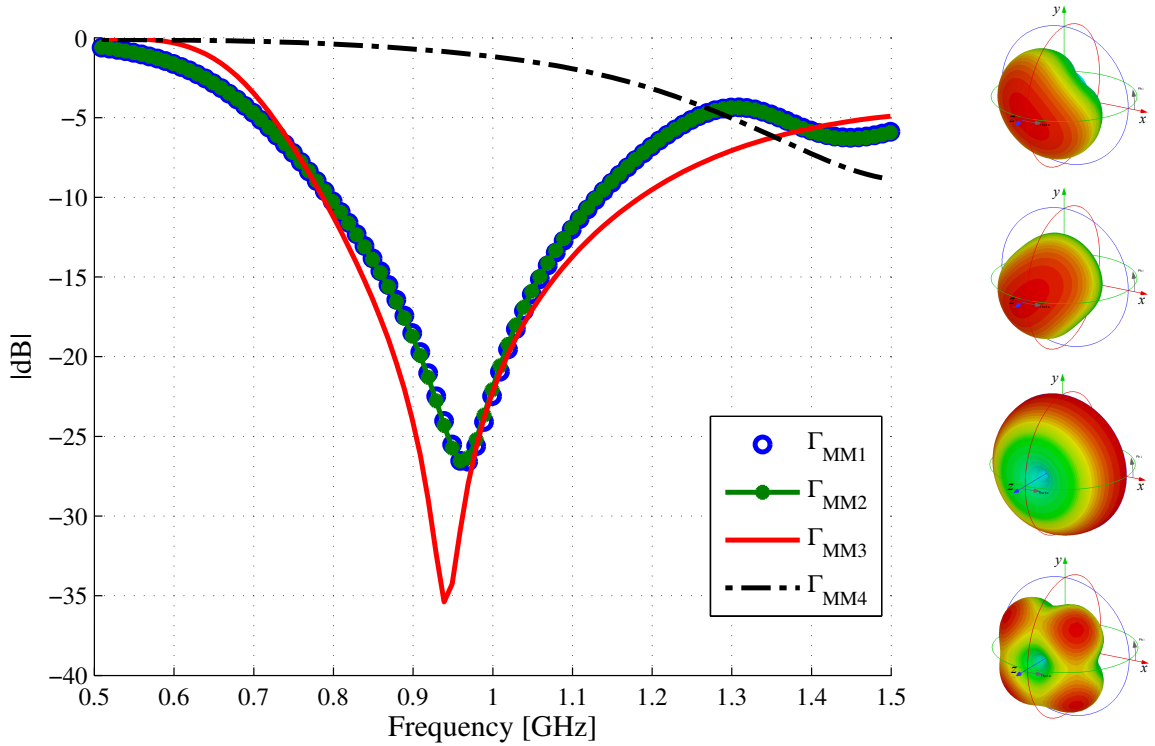


- Bow-tie dipoles printed on FR-4 substrate with each arm connected to one of the four inner conductors of the quadraxial transmission line
- Conical monopole element connected to the ground shield of the quadraxial feed

[1] D.S. Prinsloo, P. Meyer, R. Maaskant, and M.V. Ivashina, "Quad-mode antenna for wide-scan sparse arrays," *2015 Int. Symp. Antennas Propag.*, Jul. 2015, accepted for publication.

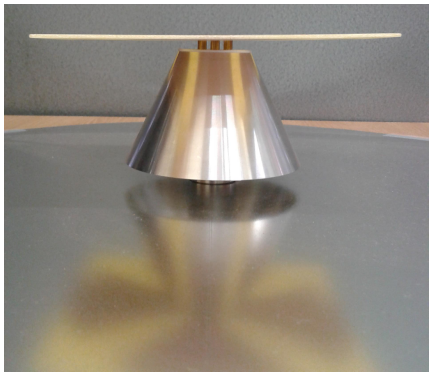
TEM Input Reflection Coefficients

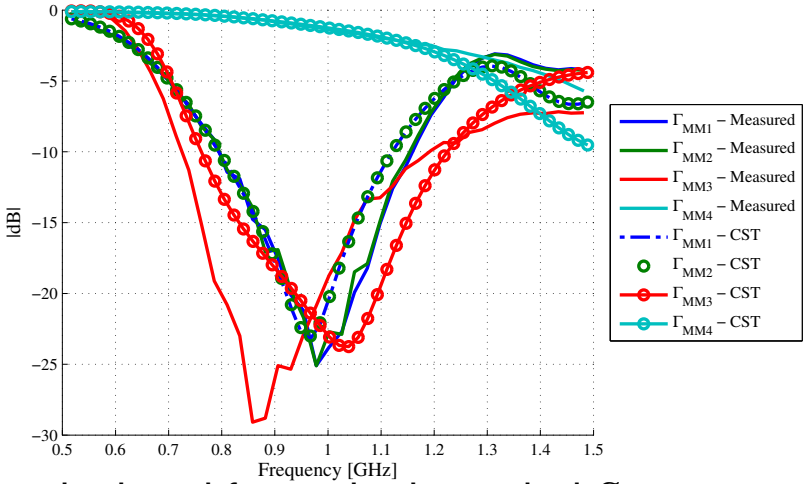
- Using multi-pin port excitations, the input reflection coefficients of the four TEM modes are simulated in CST.

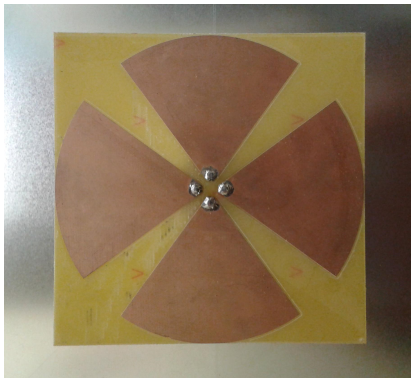


- Modes MM_1 – MM_3 -10 dB bandwidth approximately 30 percent

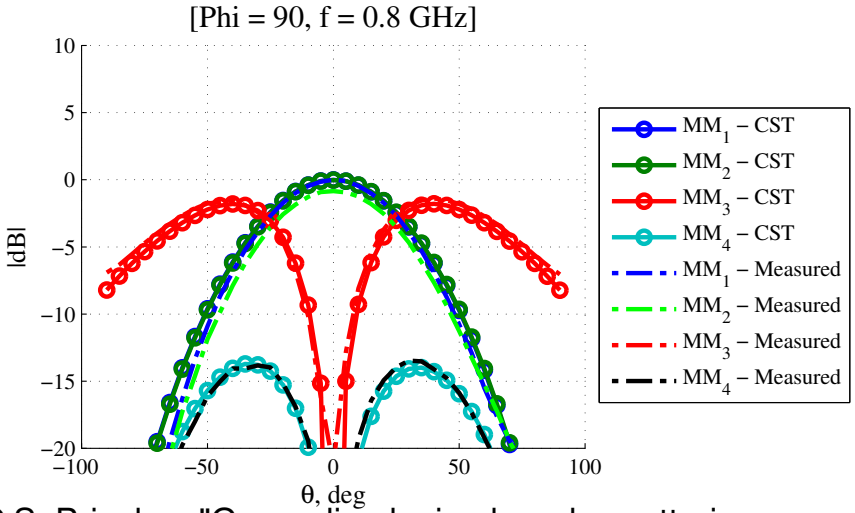
Measured Response

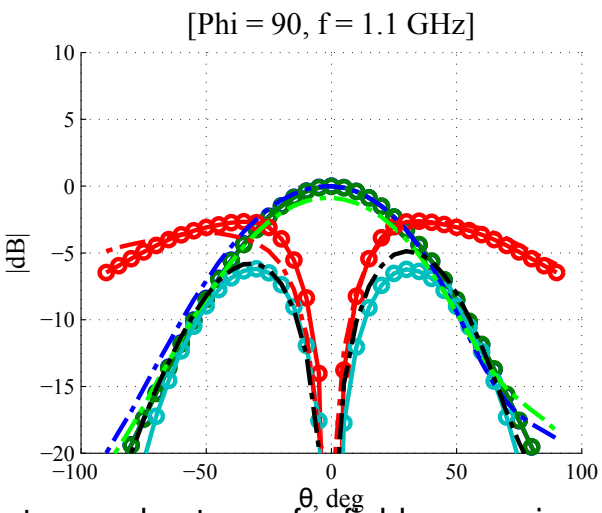






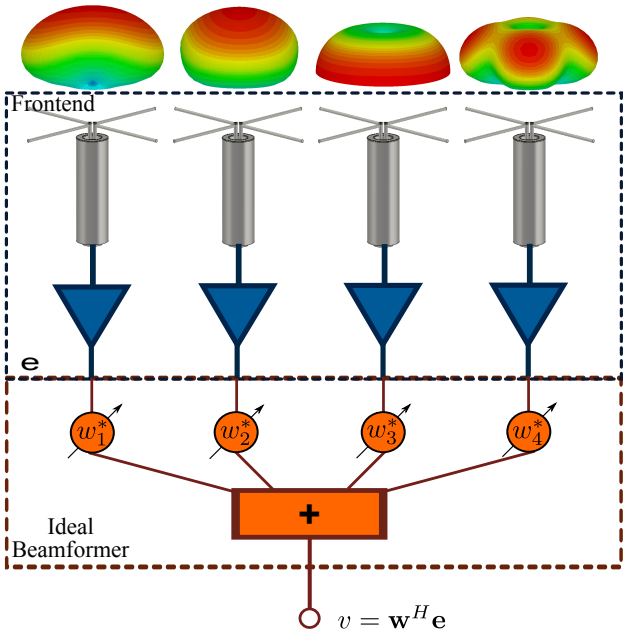
- Multi-mode response calculated from single-ended S-parameters and radiated far-field pattern measurements [1]





[1] P. Meyer, D.S. Prinsloo, "Generalized mixed-mode scattering parameters and antenna far-field conversions," *IEEE Trans. Antennas Propag.*, submitted for publication.

Quad-Mode Receiver Model



- Quad-mode antenna modelled as a four element array
- Each excitation mode represented by an array element
- Receiver model assumes identical and isolated SE Low-Noise Amplifiers (LNAs) connected to each of the four inner conductors of the quadraxial feed
- SE LNA noise model: $T_{\text{min}} = 37$ K, $R_{\text{n}} = 3\,\Omega$, $\Gamma_{\text{opt}} = \Gamma_{\text{MM1}}$

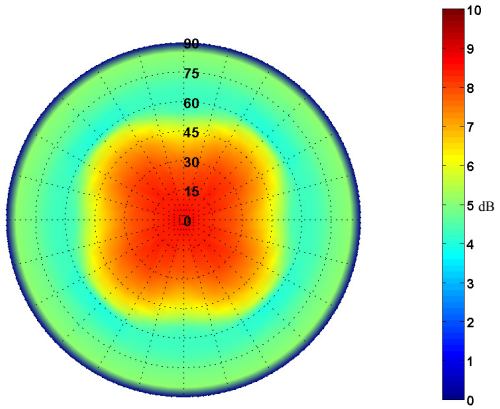
TEM Receiver Noise Model

Receiver noise matched to passive input impedance of mode MM_1

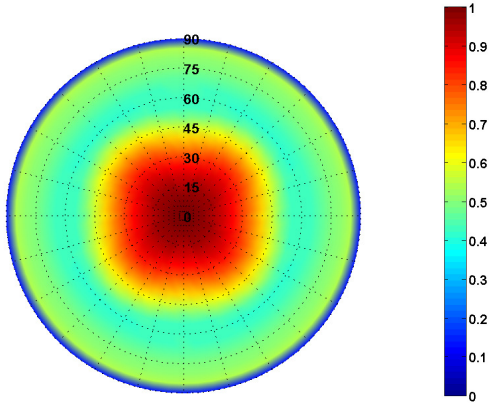
Max-SNR Beamformer: Gain and SNR

$f = 0.8$ **GHz**

Gain

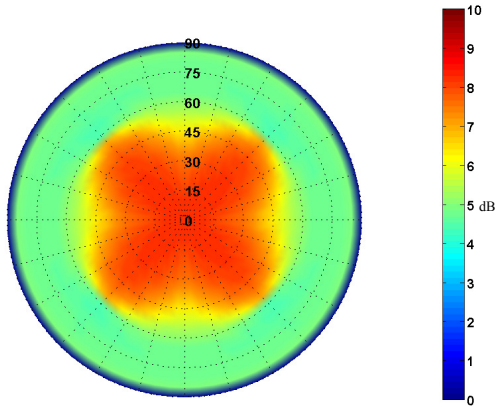


SNR

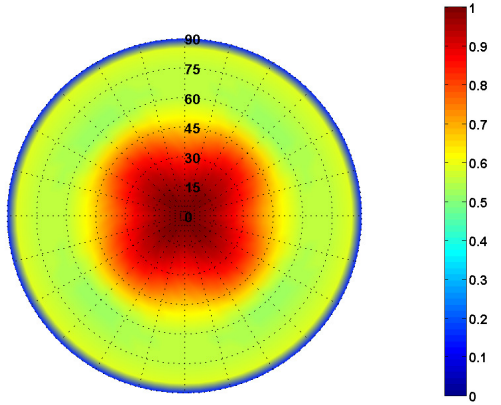


$f = 1.1$ **GHz**

Gain



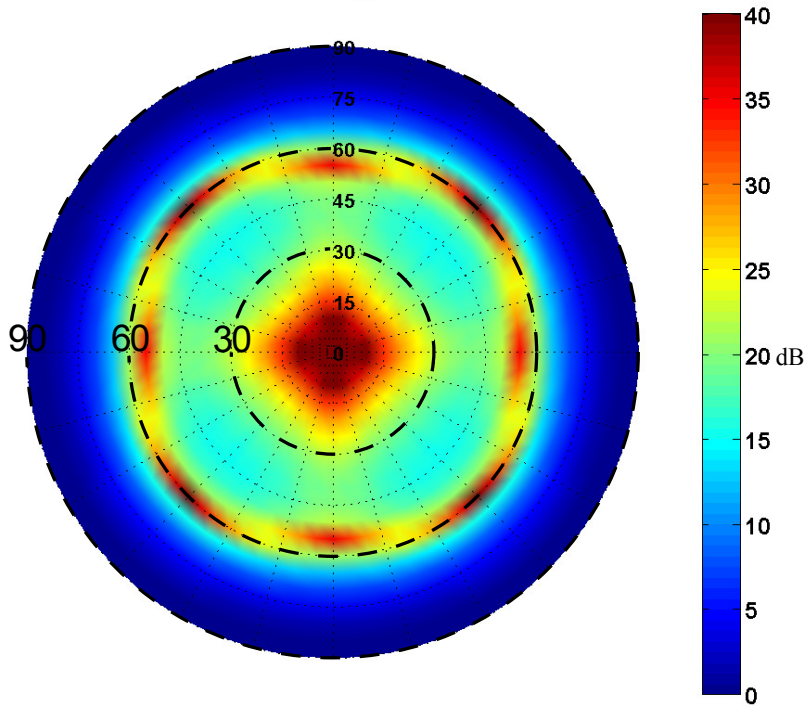
SNR



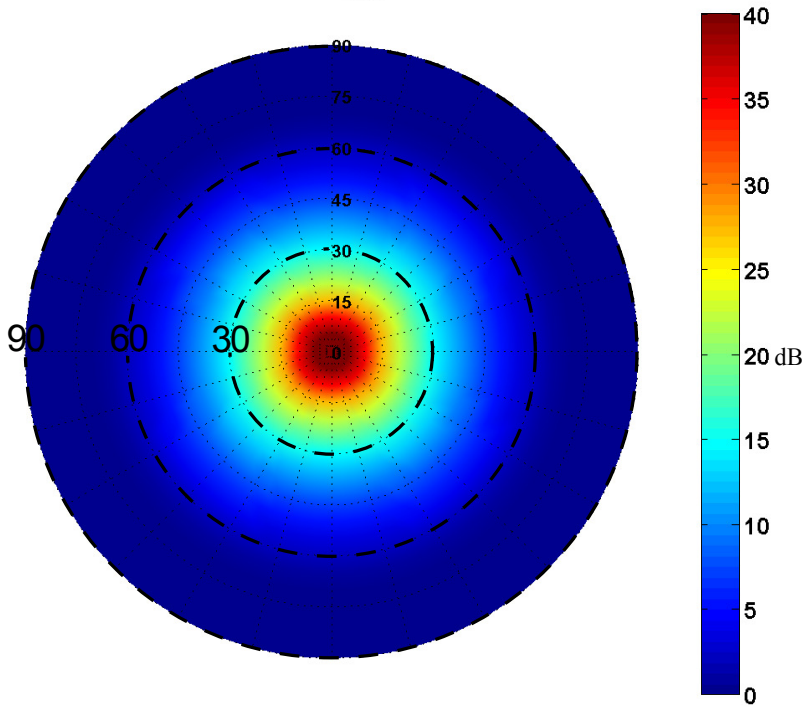
- Variation in gain and sensitivity 3dB – 4dB over the hemispherical FoV coverage

Max-SNR Beamformer: IXR [1]

Quad-Mode Antenna $f = 0.9$ GHz



Dual-Polarised Dipoles $f = 0.9$ GHz

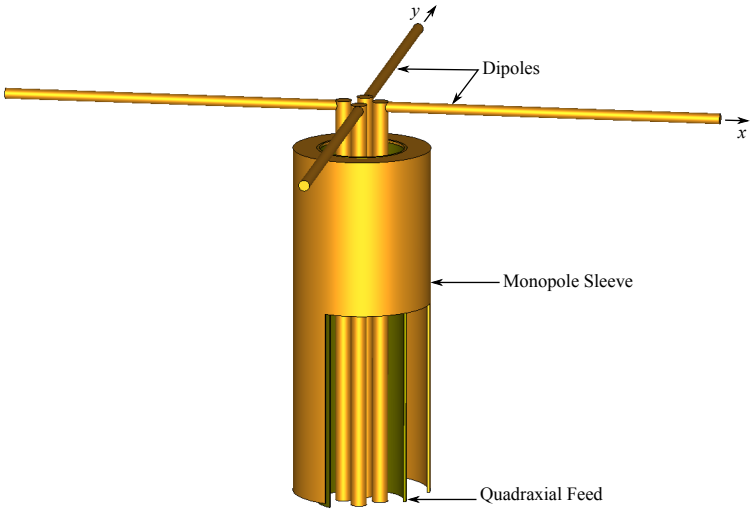


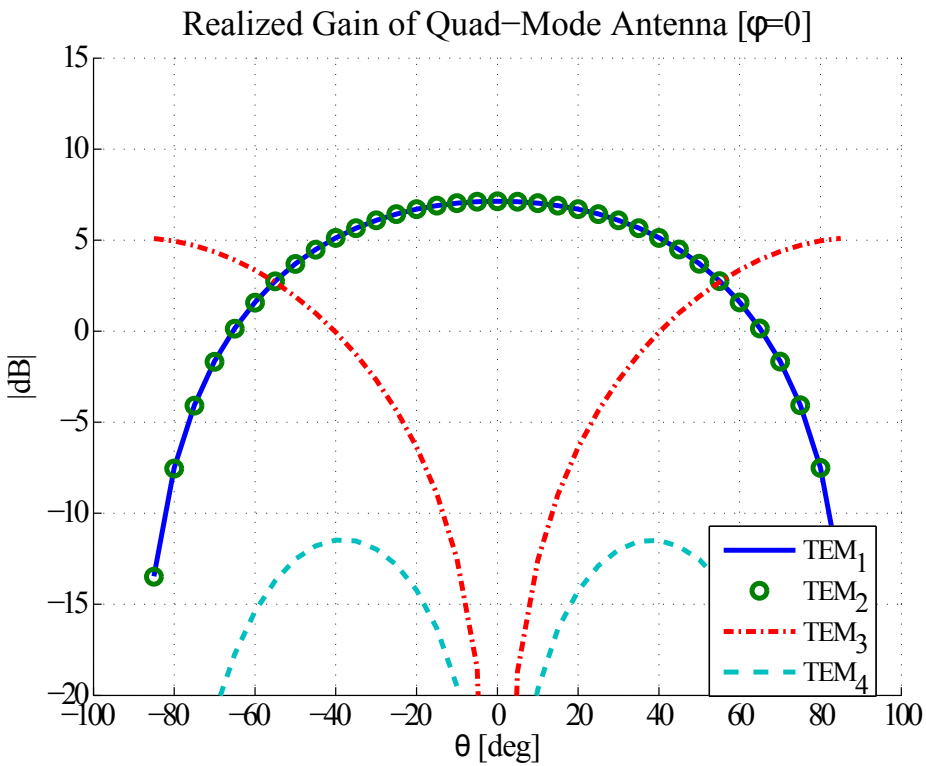
- Quad-mode antenna nearly quadruples polarimetric performance with respect to FoV coverage – IXR values above 15dB achieved up to 60° from zenith

[1] T. Carozzi and G. Woan, "A fundamental figure of merit for radio polarimeters," *IEEE Trans. Antennas Propag.*, vol. 59, no. 6, pp. 2058–2065, June 2011.

Single Quad-Mode Antenna

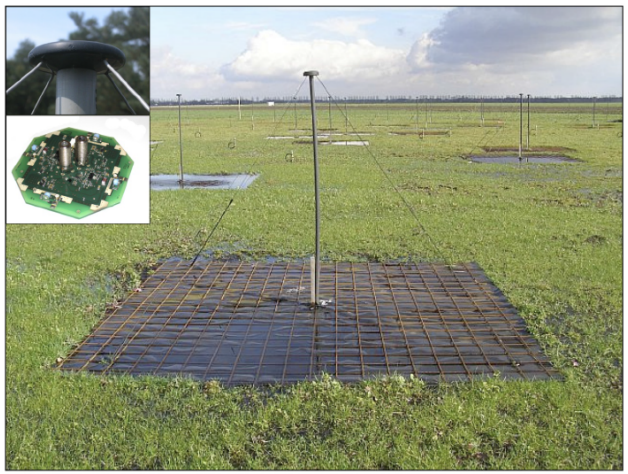
Quad-mode antenna designed for a center frequency of 55 MHz



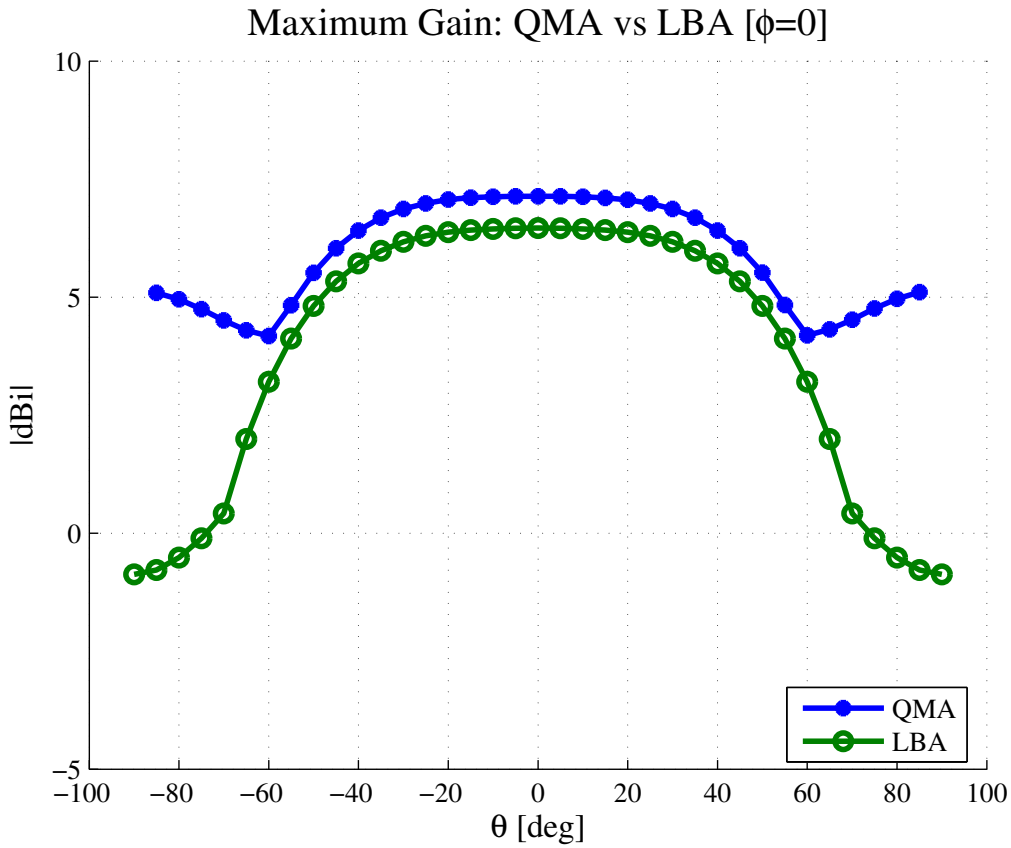


Maximizing the Gain (QMA vs LBA)

Gain maximized at each scan angle by applying conjugate field matching [1]



http://www.lofar.org



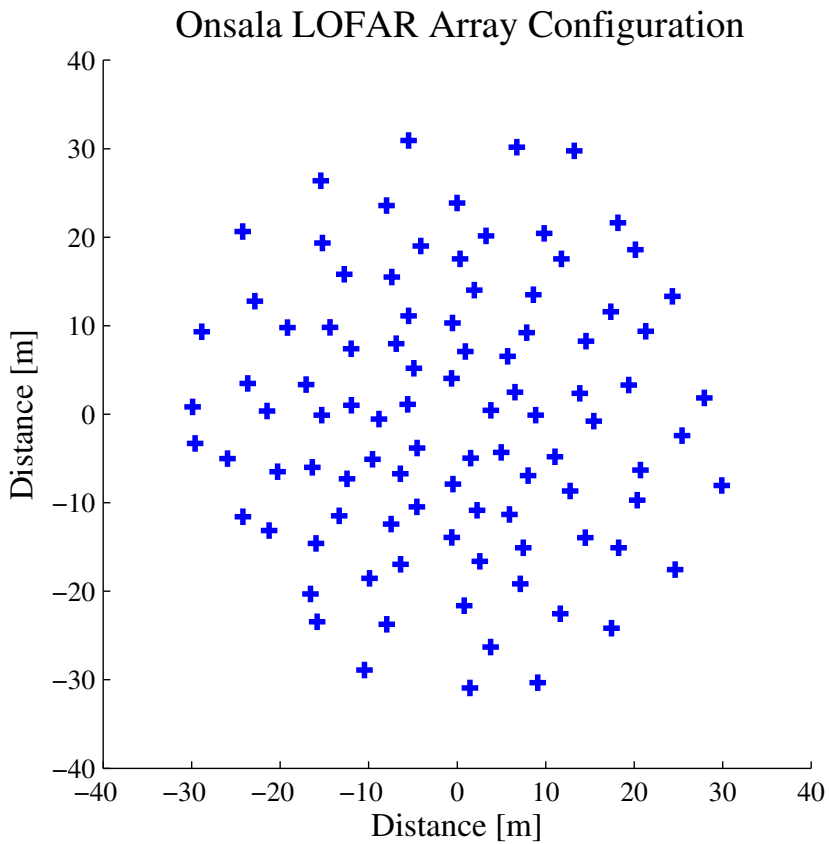
Quad-mode antenna achieves a gain variation below 3dB over the scan range from -90° to 90°

[1] M. Ivashina *et al.*, "An optimal beamforming strategy for wide-field surveys with phased-array-fed reflector antennas," IEEE Trans. Antennas Propag., vol. 59, no. 6, pp. 1864-1875, June 2011.

Onsala LOFAR Station Layout

LBA station comprises 96 elements placed within a circular area with 60m diameter

- Embedded element patterns of LBA and QMA solved over infinite ground plane using CAESAR [1]
- 192 excitations for LBA array
- 384 excitations for QMA array



[1] R. Maaskant *et al.*, "Fast analysis of large antenna arrays using the characteristic basis function method and the adaptive cross approximation algorithm," IEEE Trans. Antennas Propag., vol. 56, no. 11, pp. 3440-3451, Nov. 2008.

Maximized Gain over Hemispherical FoV

Using conjugate field matching the gain of both the LBA and QMA arrays can be maximized at each scan angle [1]

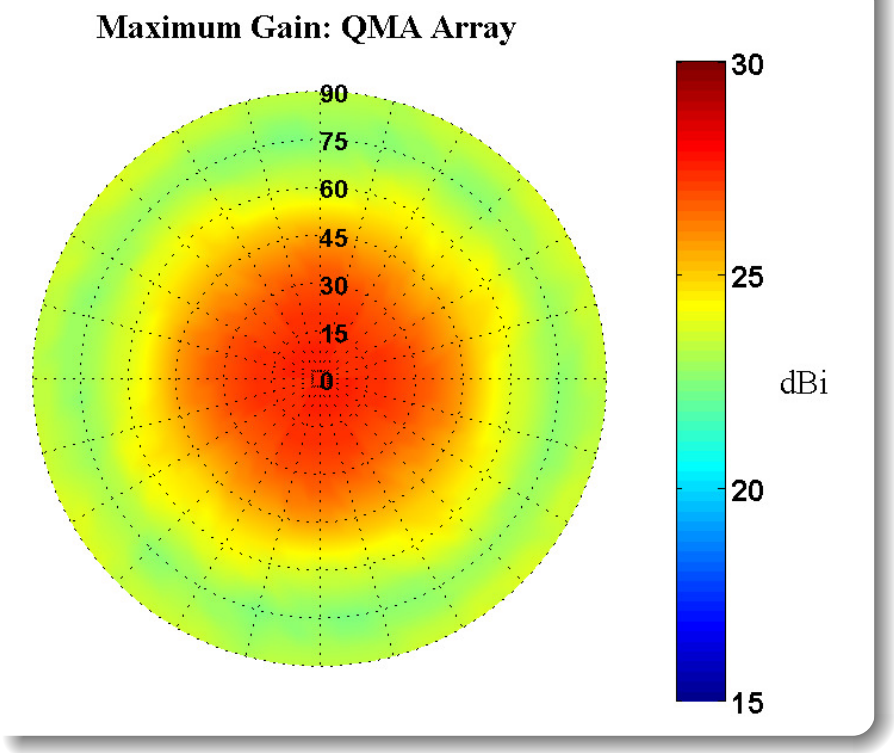
$$G(\theta,\phi) = \frac{2\pi}{\eta}\left[\frac{\left|\sum_{m=1}^{N} w_m f_m(\theta,\phi)\right|^2}{\mathbf{w}^H\left[\mathbf{I}-\mathbf{S}^H\mathbf{S}\right]\mathbf{w}}\right]$$

- LBA Array: N = 192
- QMA Array: N = 384

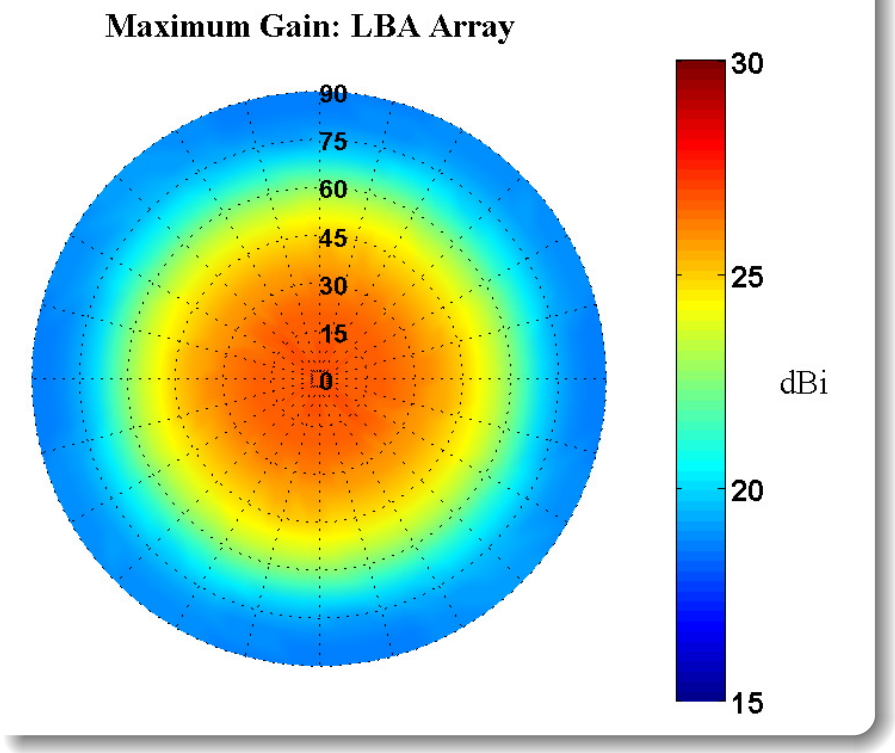
[1] D.S. Prinsloo, P. Meyer, R. Maaskant, and M.V. Ivashina, "Irregular quad-mode antenna array: Field-of-View comparison with the Swedish LOFAR station," in *9th European Conf. on Antennas and Propag. (EuCAP)*, Lisbon, April 2015.

Maximized Gain over Hemispherical FoV

QMA Array



LBA Array



- Quad-mode antenna array shows 5dB increase in gain toward the horizon
- A 2dB increase in gain variation is observed in the array environment

Conclusion

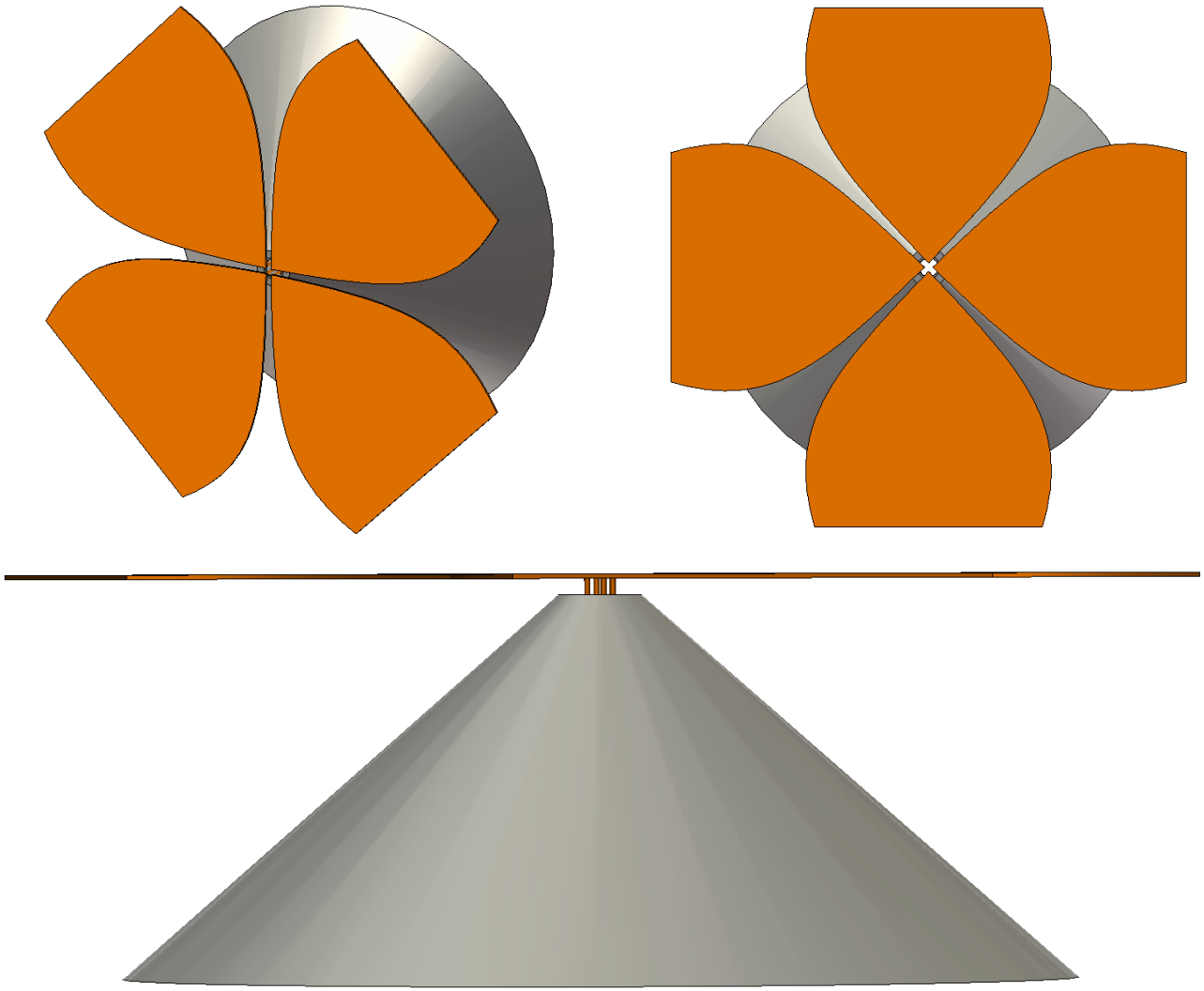
Conclusions

- Single element multi-mode antenna designs illustrate improved FoV coverage with respect to gain, sensitivity and polarimeteric performance
- Preliminary investigation of an irregular sparse array of quad-mode antennas show promising results

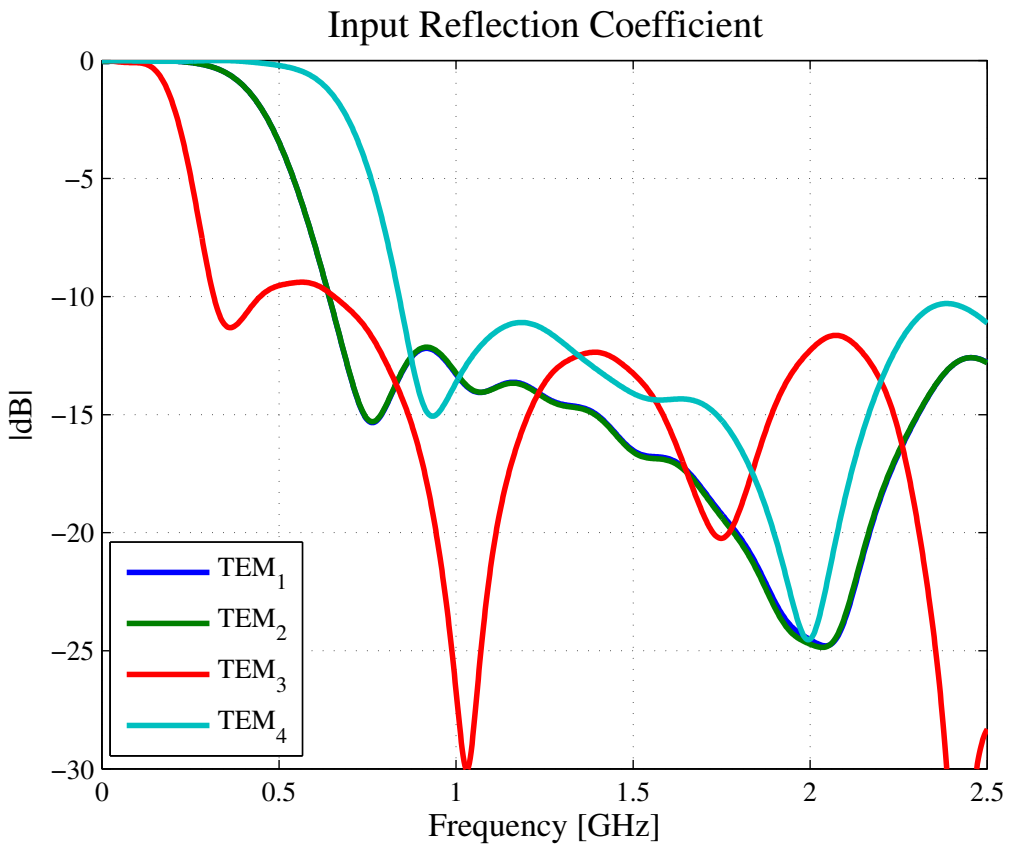
On-going work

- Wide-band quad-mode antenna with integrated slot antennas – improve match of fourth excitation mode
- Investigate feasibility of an irregular sparse MFAA of quad-mode antennas

Quad-Mode Antenna with Integrated Tapered-Slot Antenna elements



Quad-Mode Antenna with Integrated Tapered-Slot Antenna elements



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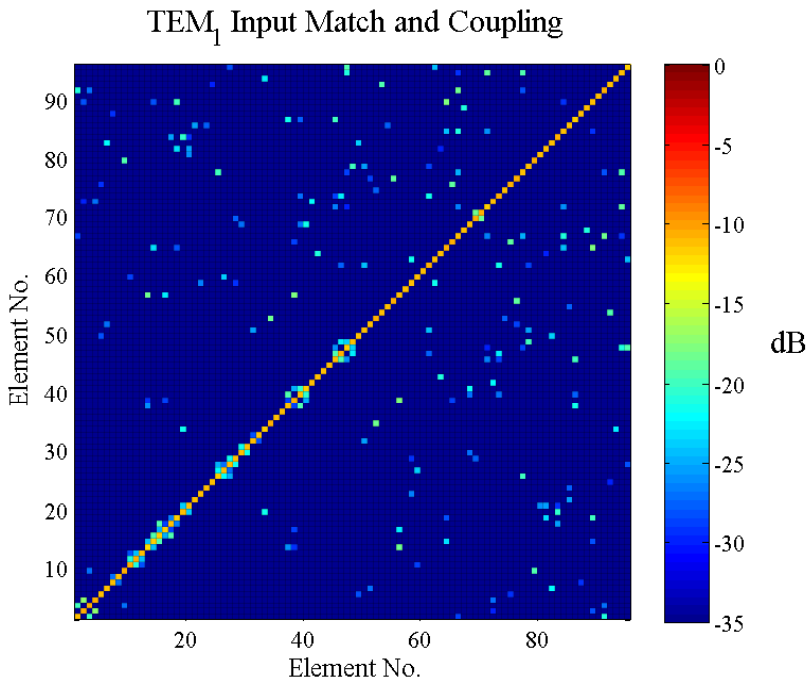
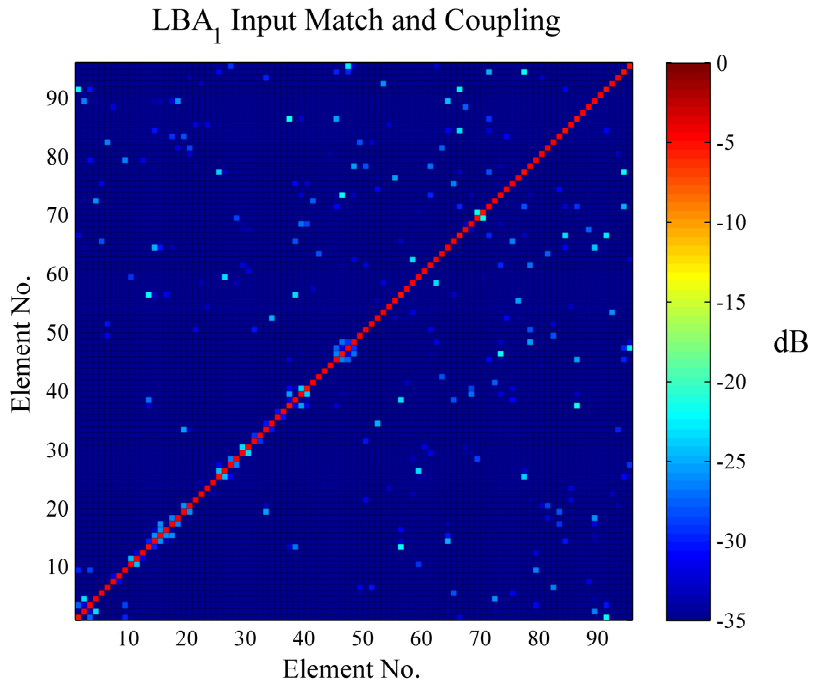
QMA Array Mutual Coupling

QMA array mutual coupling of excitation mode TEM_1 compared to mutual coupling of LBA array

QMA Array



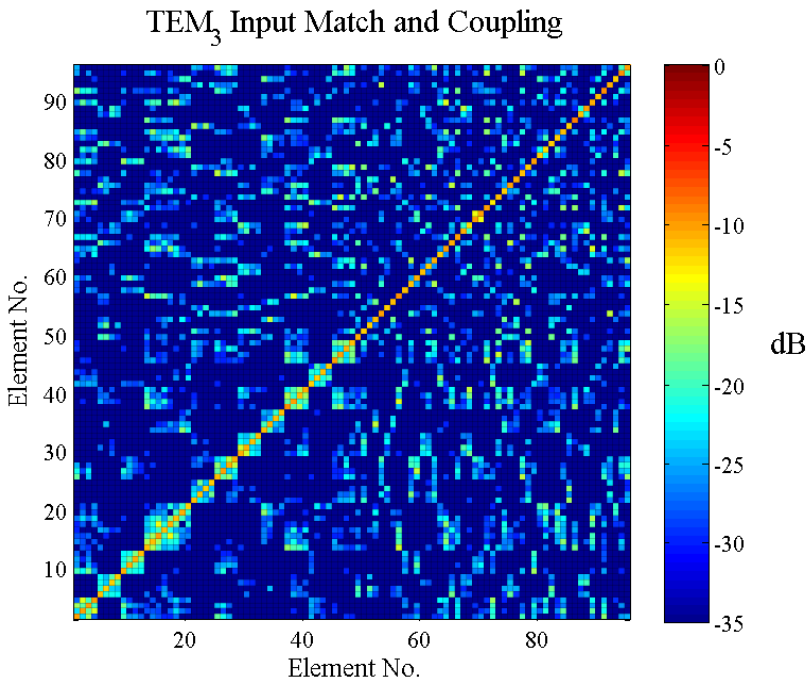
LBA Array



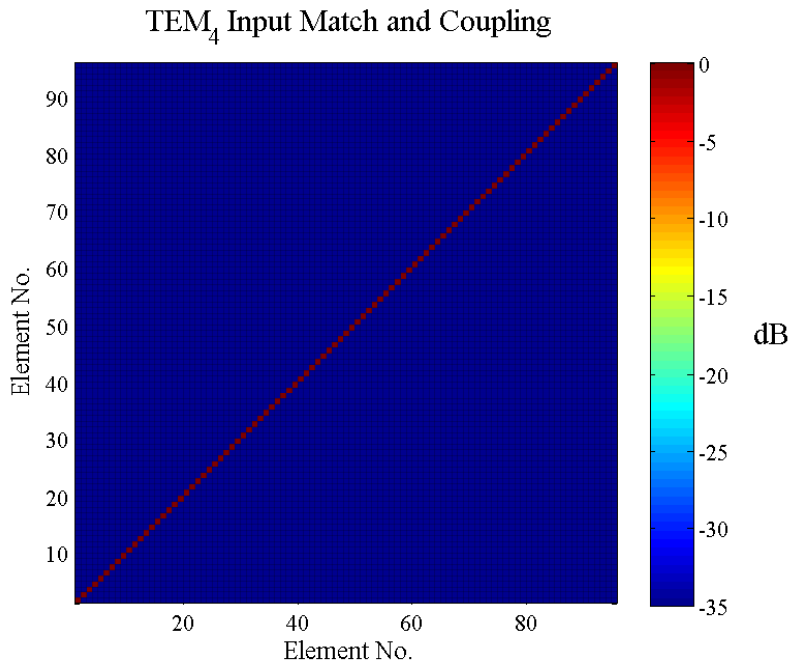
QMA Array Mutual Coupling

QMA array mutual coupling of excitation modes TEM_3 and TEM_4

QMA Array



QMA Array



Mutual coupling of each excitation mode below -15dB for all 96 elements