Low-Cost Near Field Pattern Measurement Technique for Aperture Array Characterization

Application to the SKA telescope

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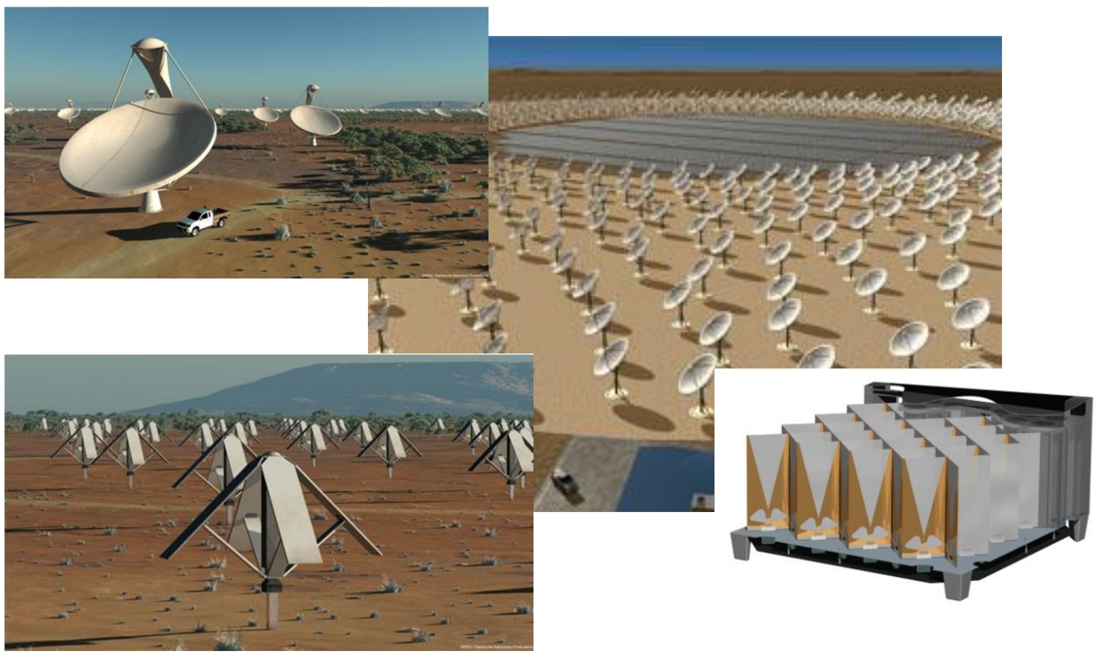
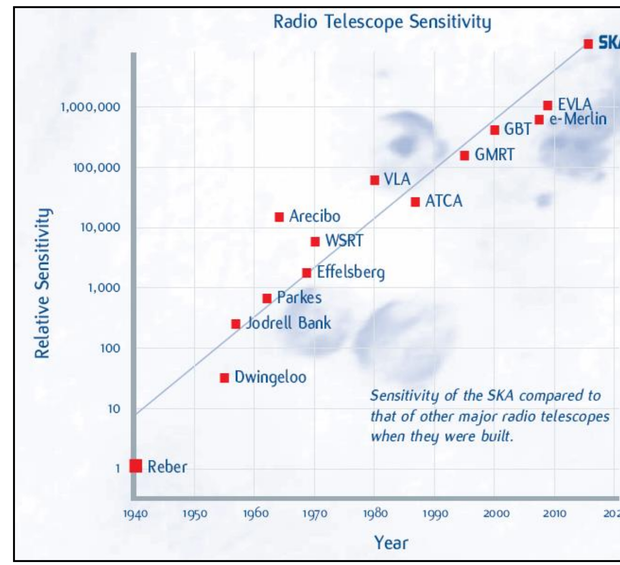
Overview

- Introduction – The SKA
- SKALA and the AAVS arrays (towards SKA-AAlow…)
- EM characterization of SKA arrays
- Near field pattern measurement
- Conclusions

Introduction: SKA, The Square Kilometer Array

- Frequency range from 50 MHz up to 20 GHz.*
- Great collecting area.
- 50 times more sensitivity & 100000 faster survey speed of today's best instruments.





The most powerful radio telescope of the world at low frequencies!
(see more at www.skatelescope.org)

Introduction: SKA-AAlow (I will update this a bit)

- Bandwidth: 70 MHz to 450 MHz **(sky noise dominates: sparse arrays)**
- Field of View: $\pm 45\,^{\circ}$
- Dual-polarisation
- 280 stations of ~80m diameter (SKA1)
- ~2,000 elements per station (SKA1)
- ~500,000 antennas for SKA1 and 3,000,000 for SKA2.
- Equating to an A/T of at least 1000 m^2/k (transients, 200 MHz up to 450 MHz) and 2000 m^2/k (EoR, up to 200 MHz)

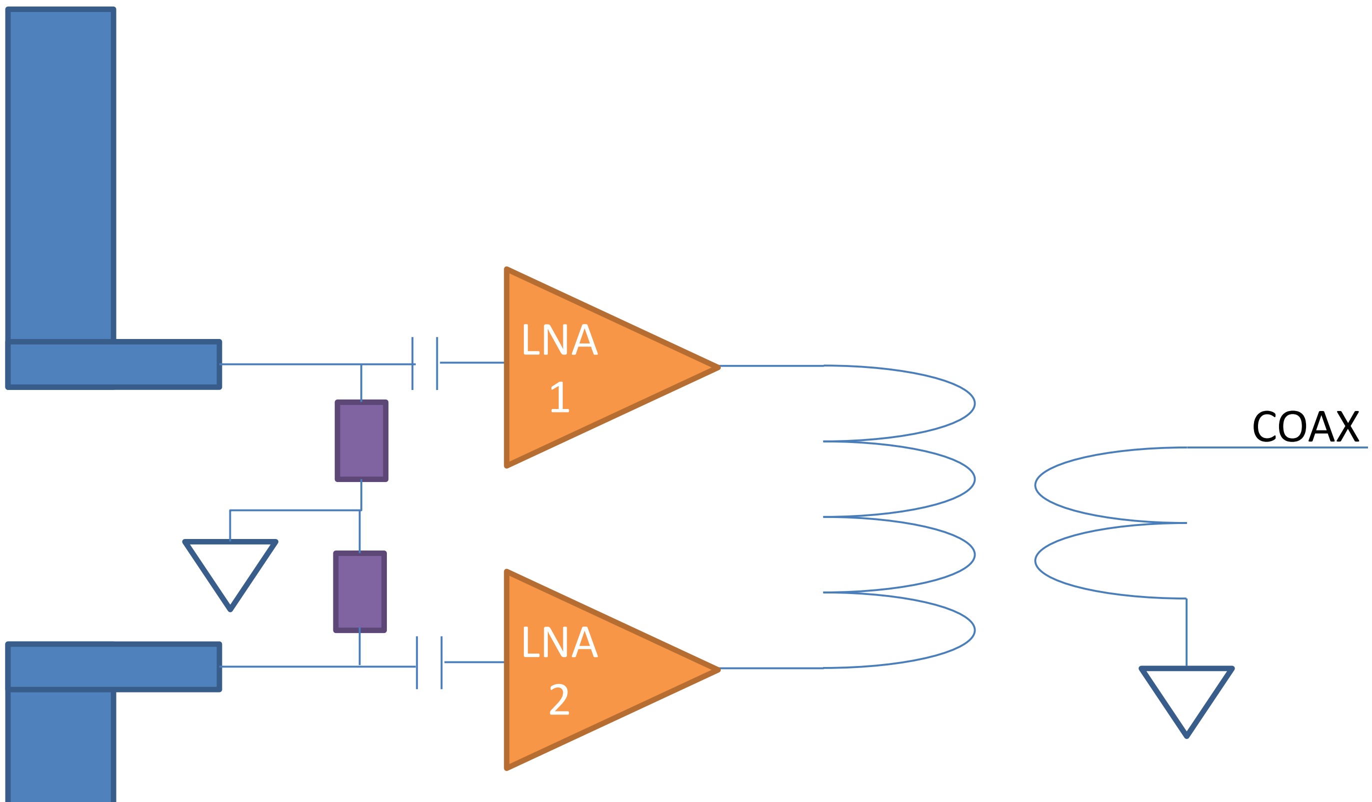
SKALA and the AAVS arrays

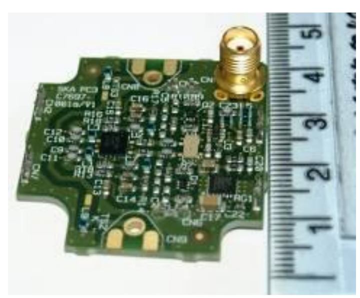
2 pseudo-differential LNAs

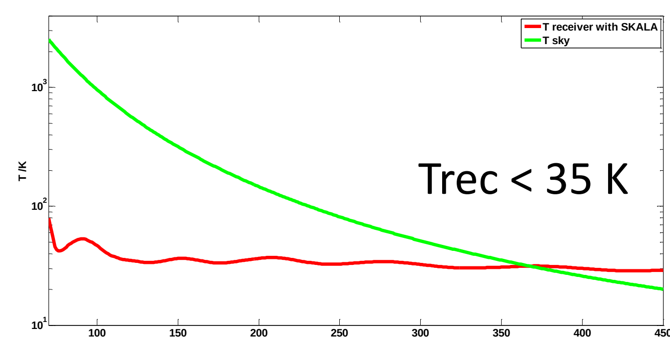
LPDA
Band: 70-450 MHz

- Flat impedance (low Trec)
- Stable patterns with max. A/T within FoV
  - Low ground noise
  - Optimized beam-width
- Low cost
- Small foot print for max. filling factor
- Good coupling efficiency in array environment

SKALA and the AAVS arrays







SKALA and the AAVS arrays

AAVS0 at Cambridge

*The array sits on top of a circular metallic ground mesh 15m in diameter (25mm x 25mm mesh pitch, 2.5mm wire diameter).

SKALA and the AAVS arrays

AAVS0.5 at MRO, Australia

*No ground plane

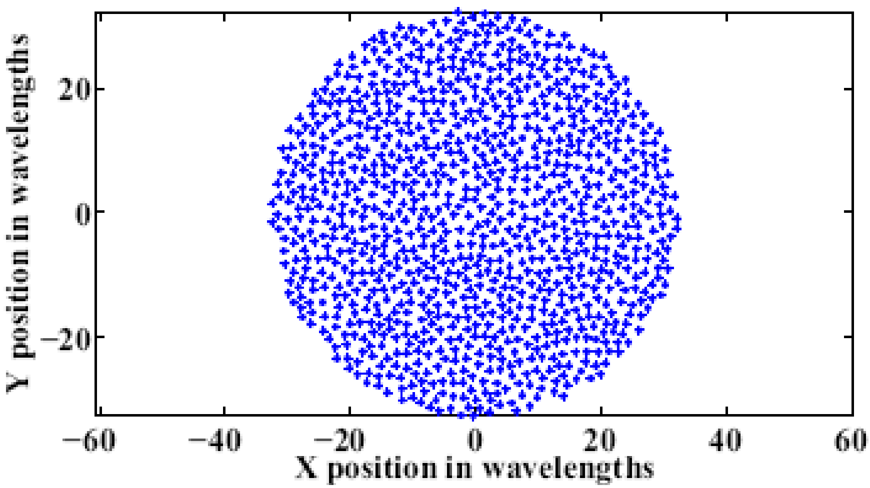
The tests

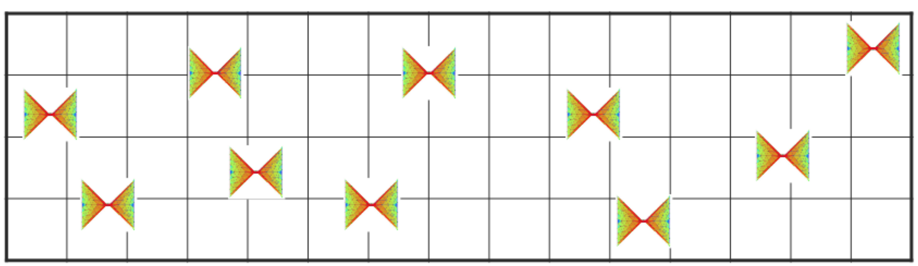
- AAVS, *Aperture Array Verification System*: 16 dual-polarised SKALA elements.
- Aim: Test realistic SKA AA-low front-end technology in an array environment.
  - Cross check with simulations: mutual coupling, embedded element pattern (EEP) and noise.
- Tests:
  - Mutual coupling.
  - EEP (**using near field probe**, micro-copter, 2 elements interferometer, etc.).
  - Noise: Hot/cold pointing of the array.
  - Further tests to check software, calibration strategies, cross-polarization, cross-talk, etc.

UNIBOARD processing

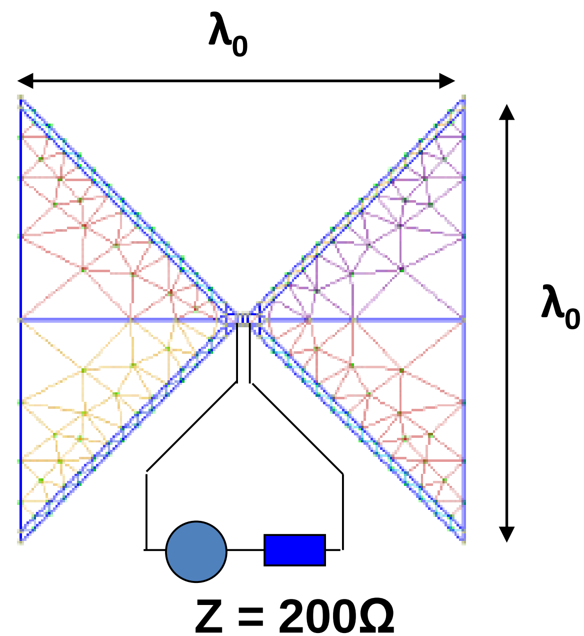
EM characterization of SKA arrays: Introduction

– Fast MoM/MBF method for EM simulations of large irregular arrays. It can solved SKA size stations in a laptop computer.**





- The computation of interactions between MBFs is carried out by interpolating exact data obtained on a simple grid.

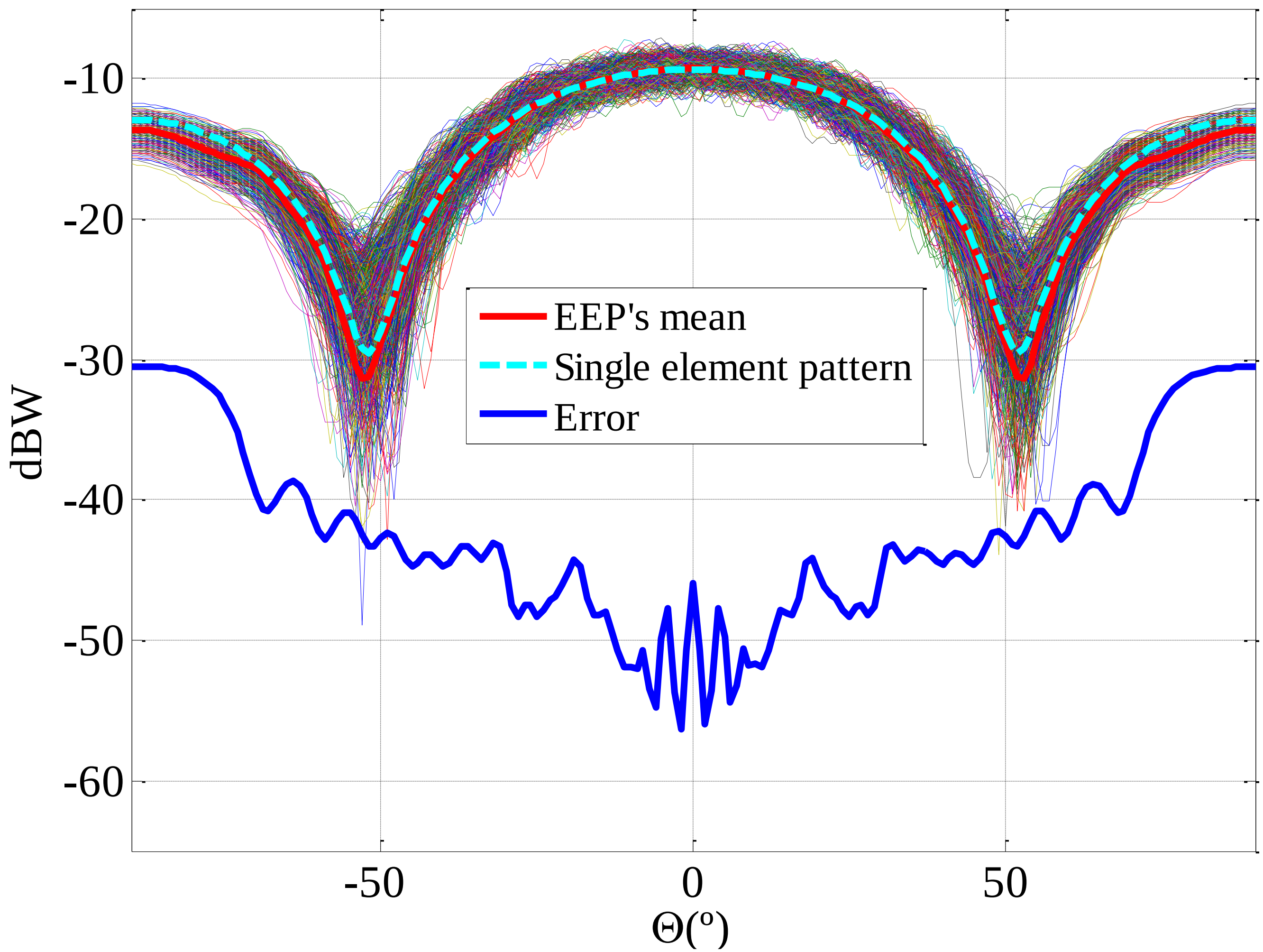


***Gonzalez-Ovejero*, D., and *Craeye*, C. (2008)

****Gonzalez-Ovejero*, D., and *Craeye*, C. (2011)

EM characterization of SKA arrays: Introduction

– Mutual coupling effects randomize out in quasi-random configurations.**

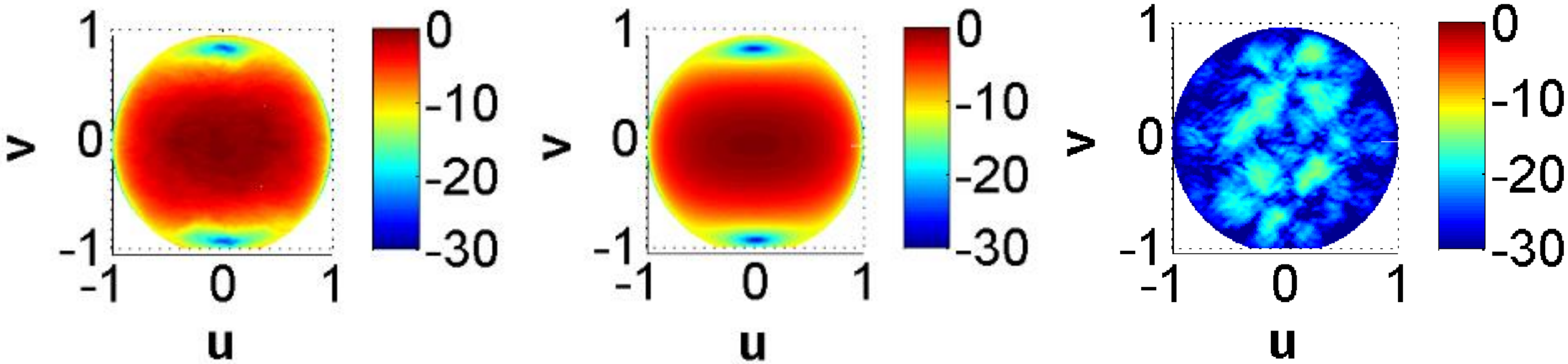


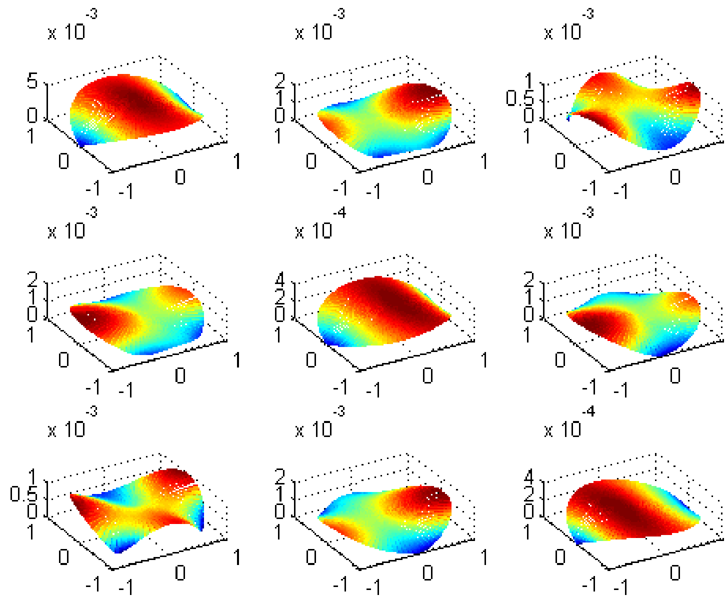
**Gonzalez-Ovejero*, D., *De Lera Acedo*, E., *Razavi-Ghods*, N., and *Craeye*, C. (2009)

**Gonzalez-Ovejero*, D., *De Lera Acedo*, E., *Razavi-Ghods*, N., *Garcia*, E., and *Craeye*, C. (2011)

EM characterization of SKA arrays: Introduction

– Accurate EM simulations can be useful for the telescope calibration.**





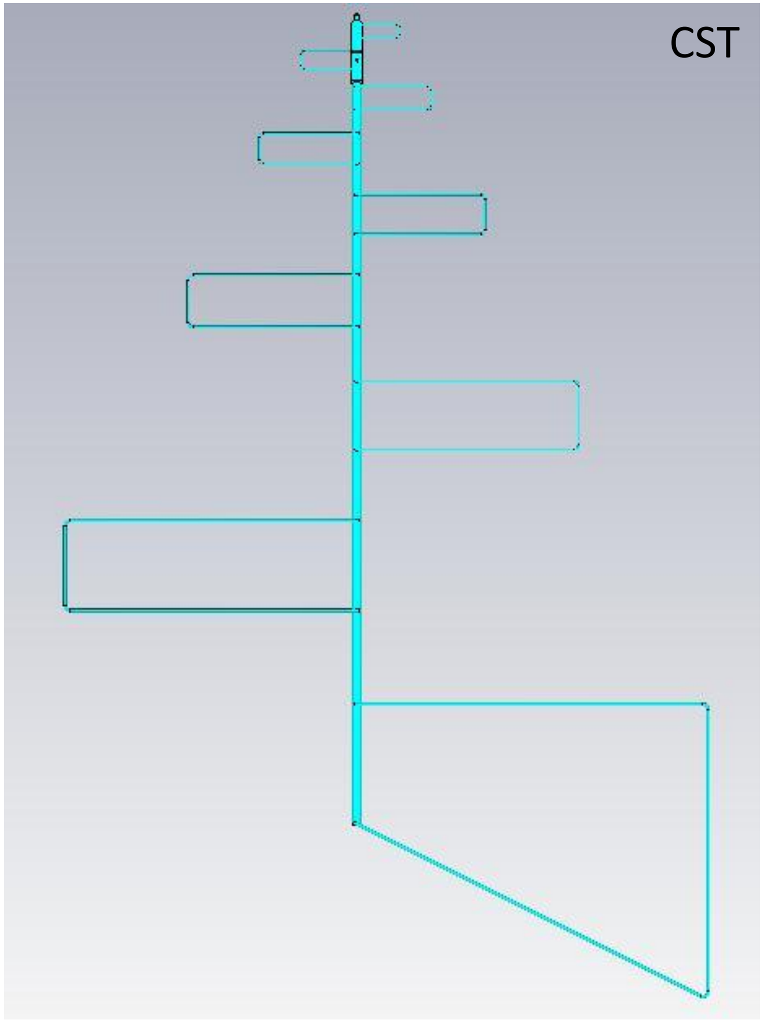
CBFs (MBFs) =
Basis functions
for the beam model

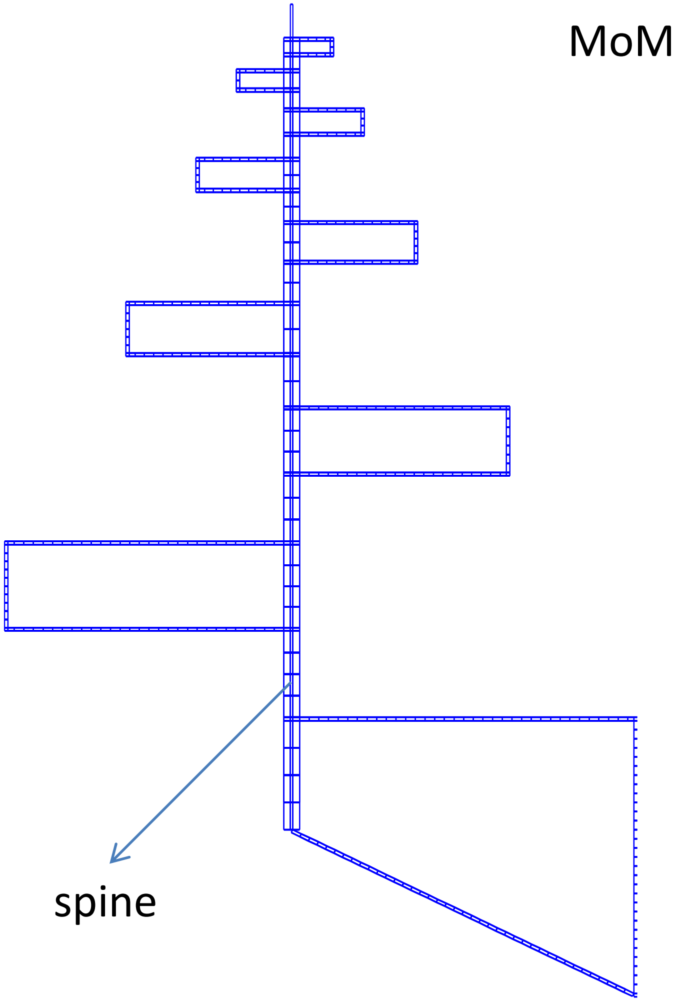
**De Lera Acedo*, E., *Razavi-Ghods*, N., *Gonzalez-Ovejero*, D., *Sarkis*, R., and *Craeye*, C. (2011)

** *Craeye*, C., *Gonzalez-Ovejero*, D., *Razavi-Ghods*, N., and *de Lera Acedo*, E. (2012)

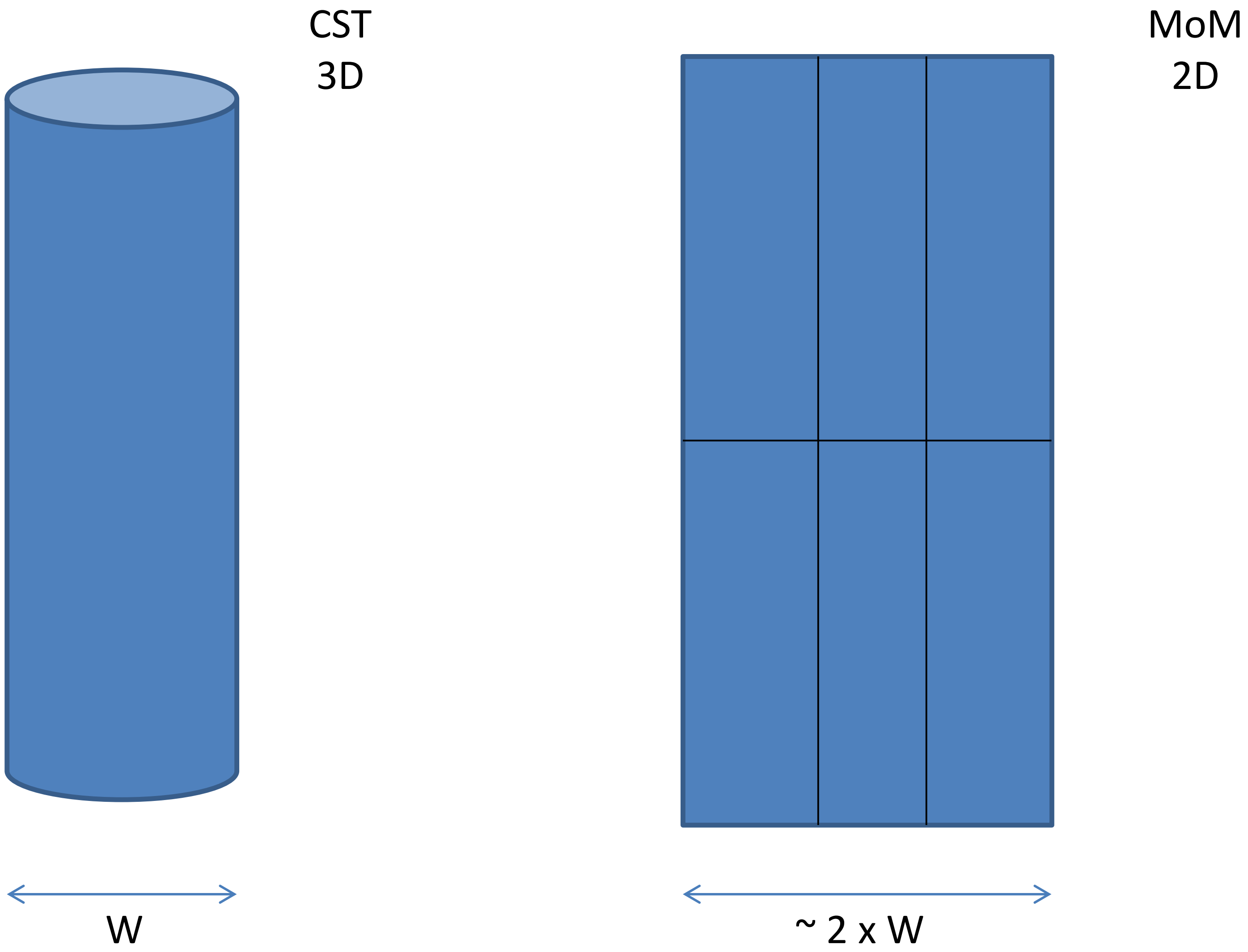
EM characterization of SKA arrays: Antenna model in simulations

Full antenna:
2642 Basis functions
22 MBFs

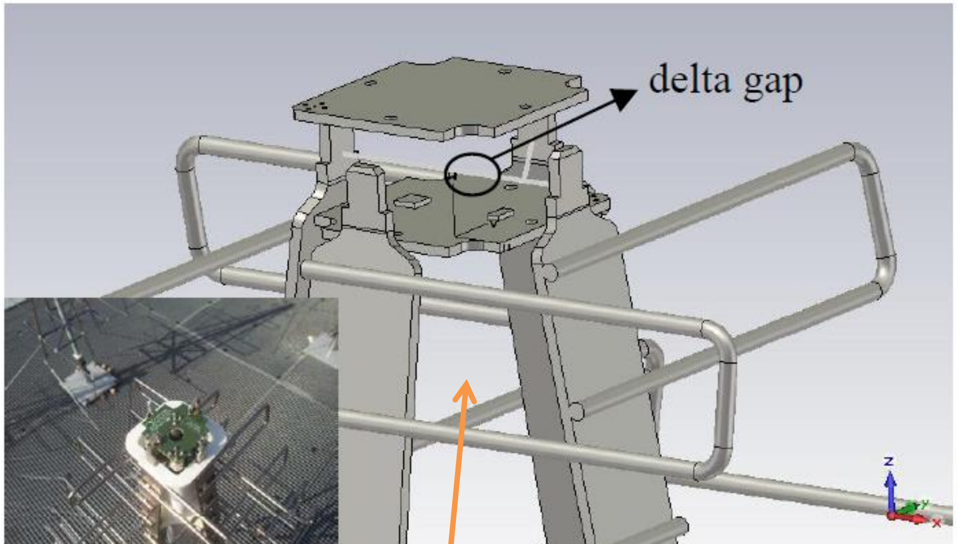


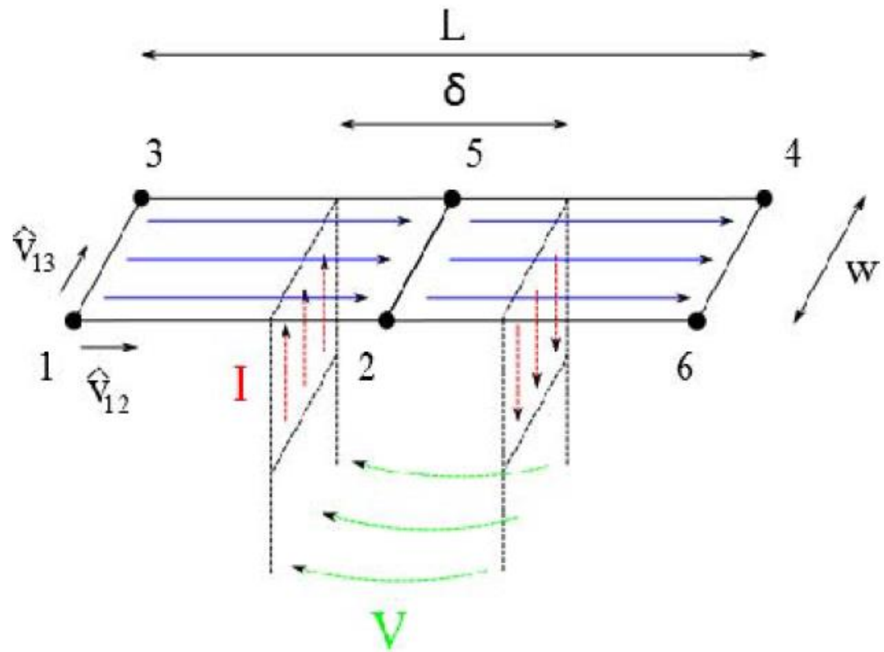


EM characterization of SKA arrays: Antenna model in simulations – Wires



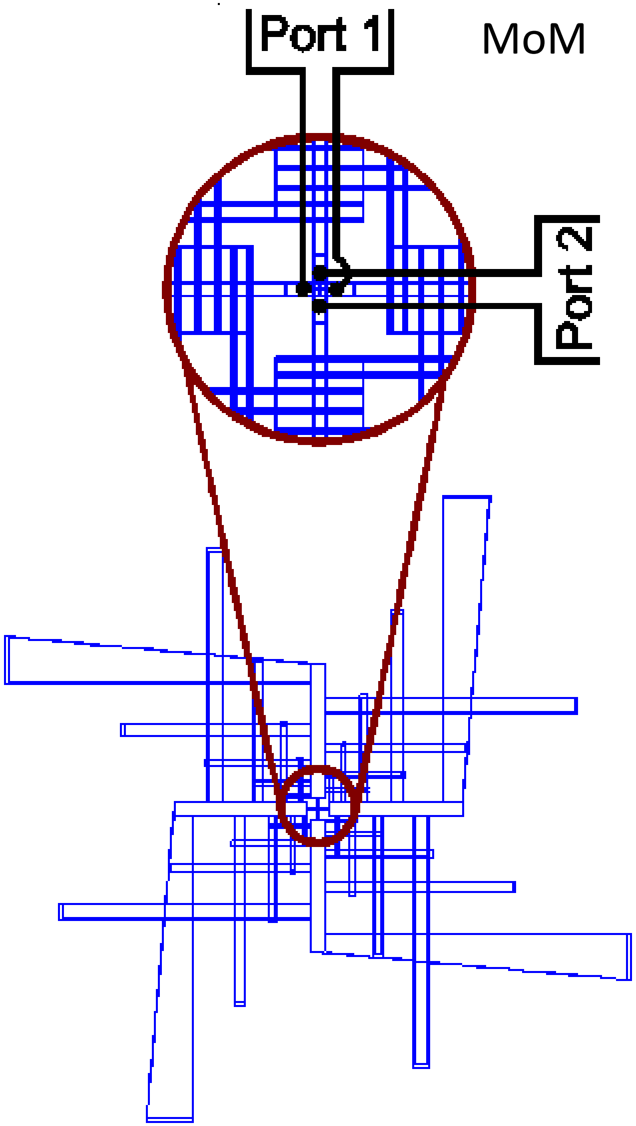
EM characterization of SKA arrays: Antenna model in simulations



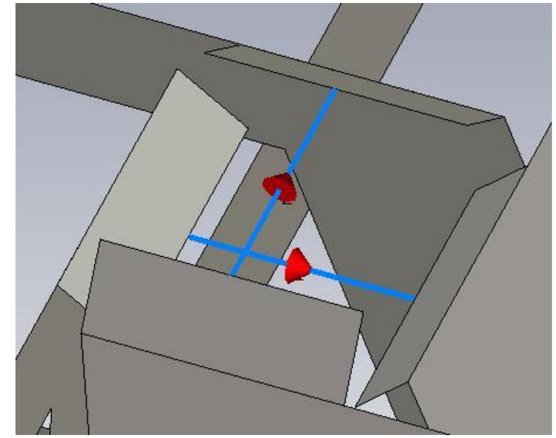


EM characterization of SKA arrays: Antenna model in simulations

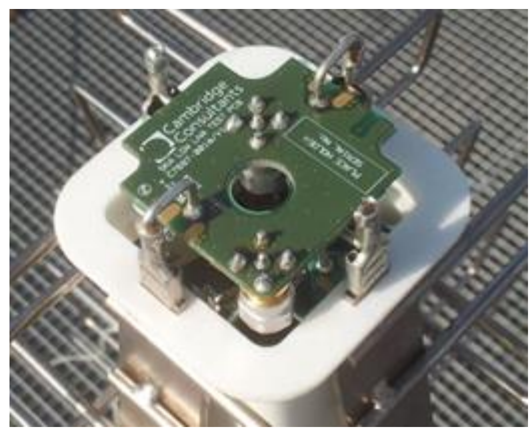
MoM

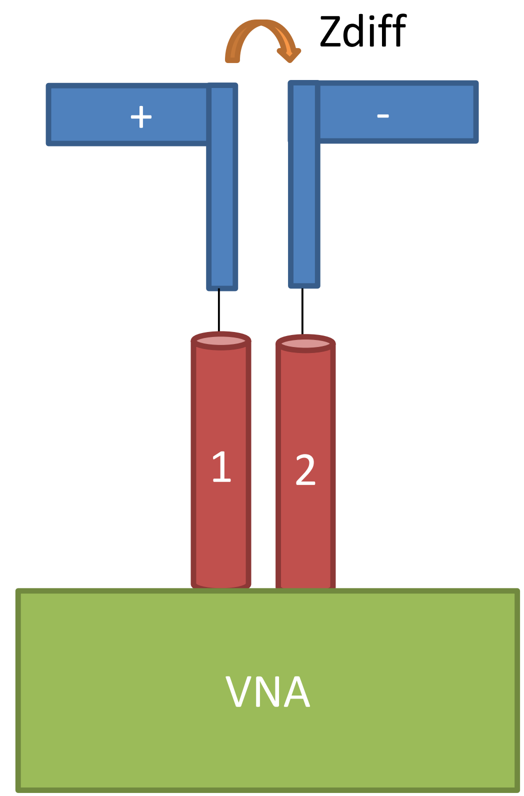


CST

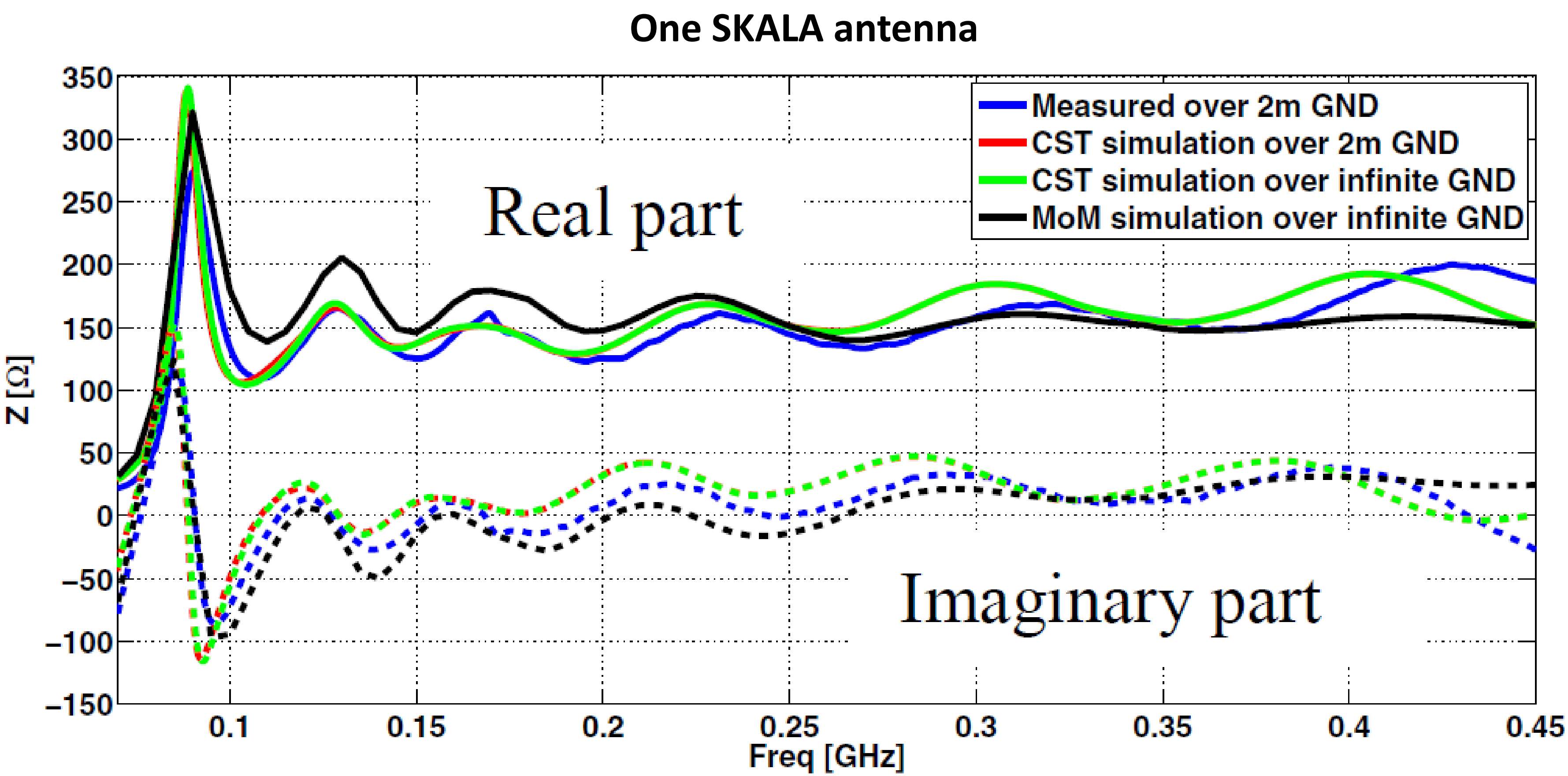


Measurements



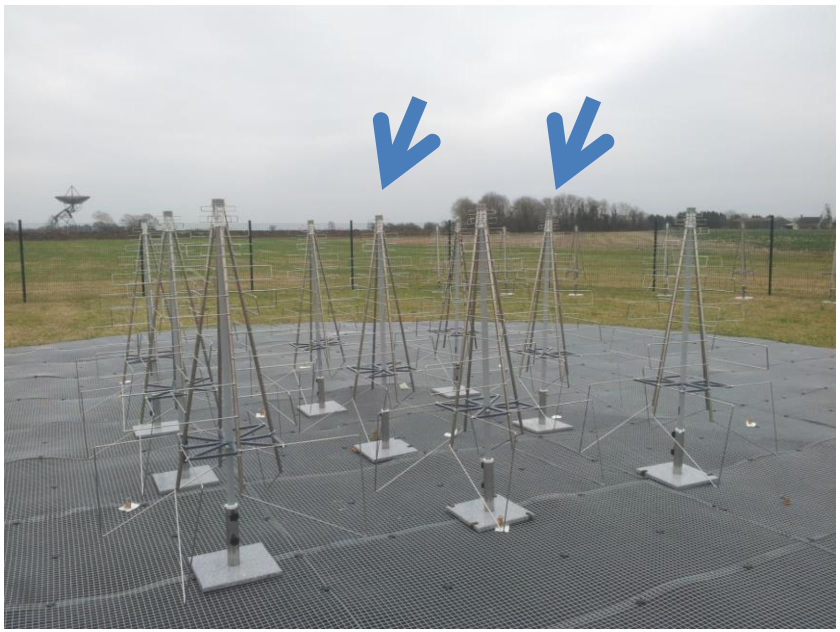


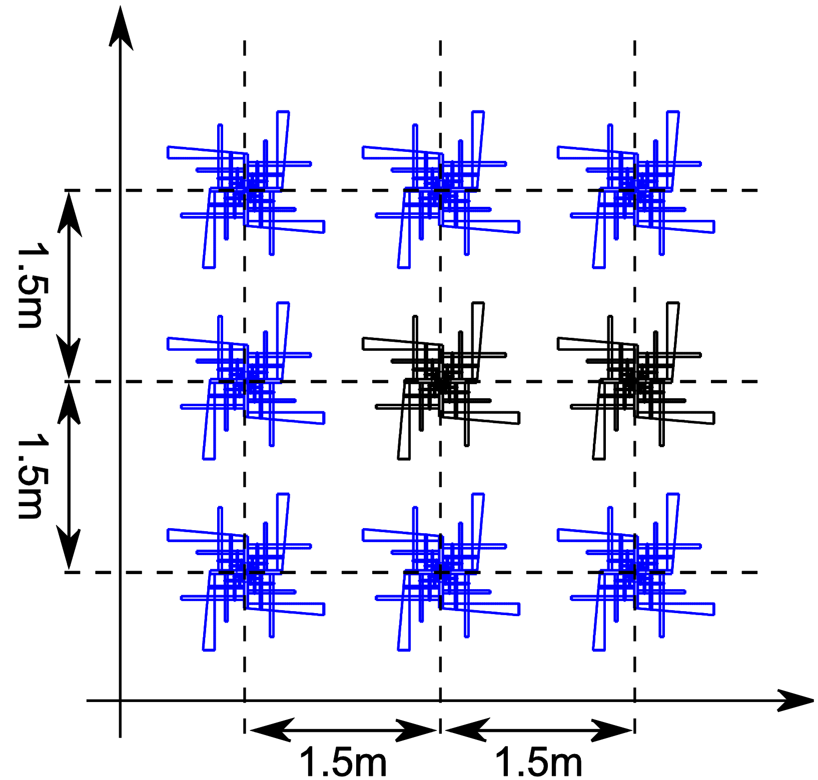
EM characterization of SKA arrays: Measured and simulated results



*Each arm of the antenna is measured with respect to ground and the differential impedance is then computed.

EM characterization of SKA arrays: Measured and simulated results





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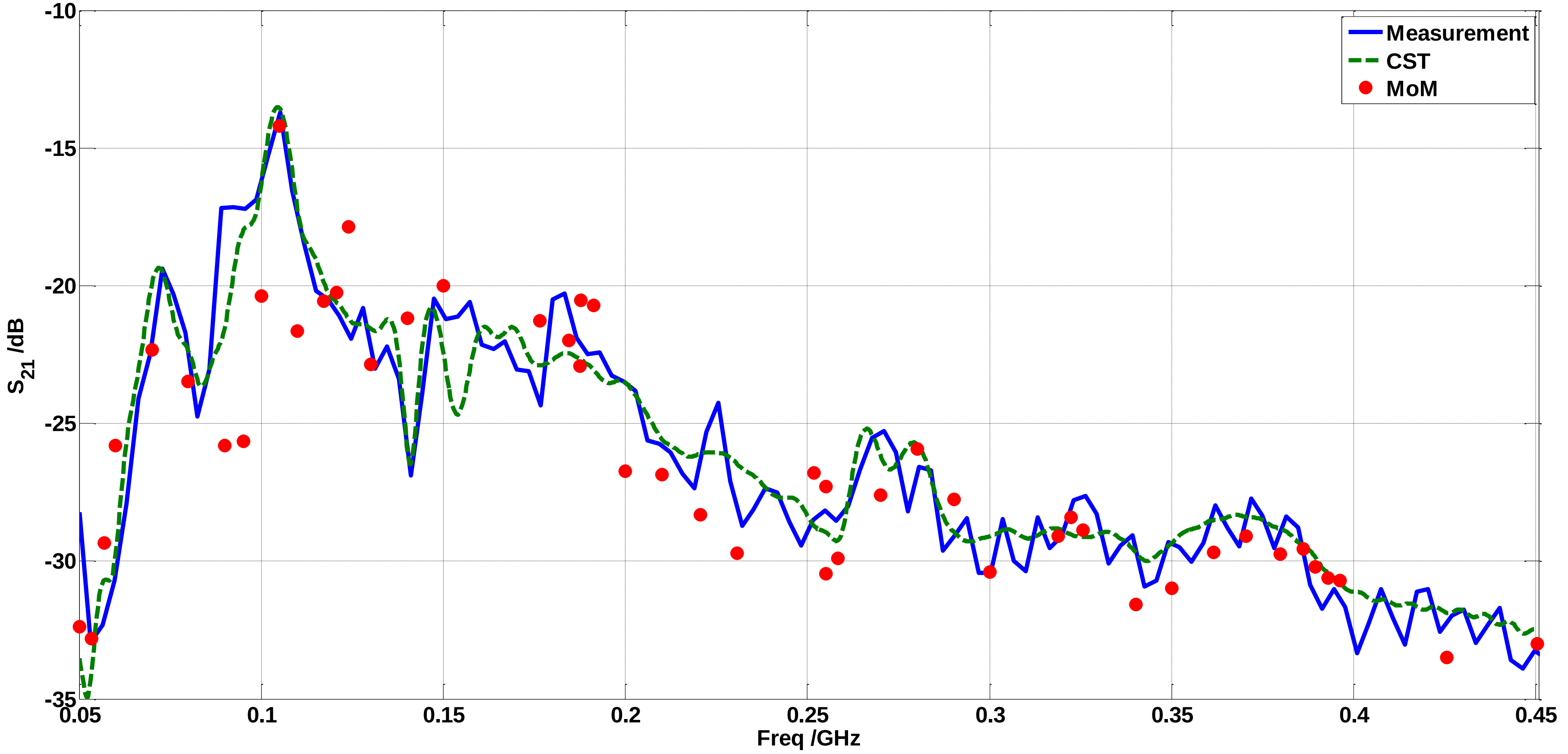
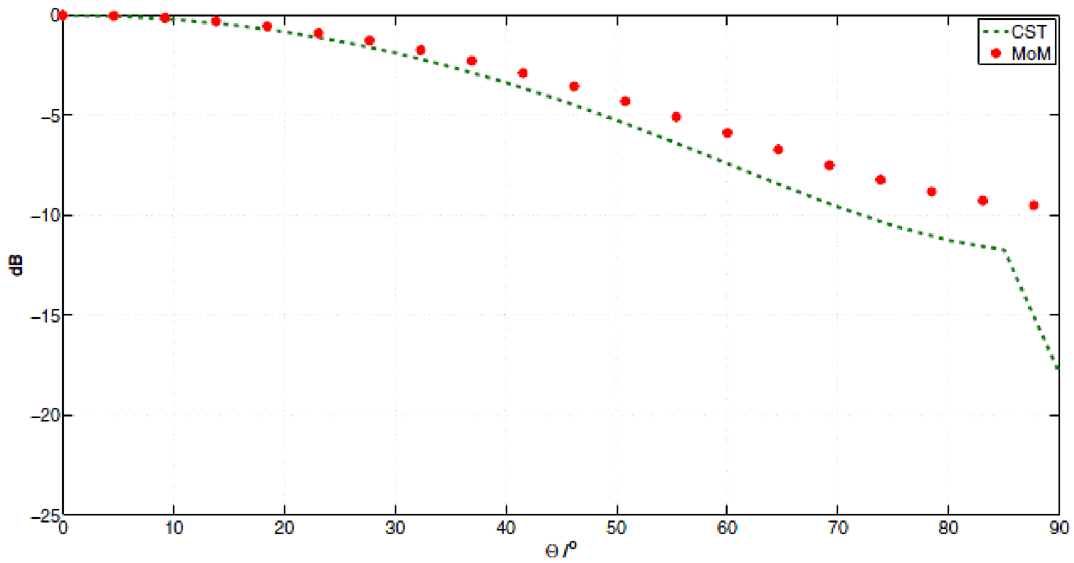
EM characterization of SKA arrays: Measured and simulated results

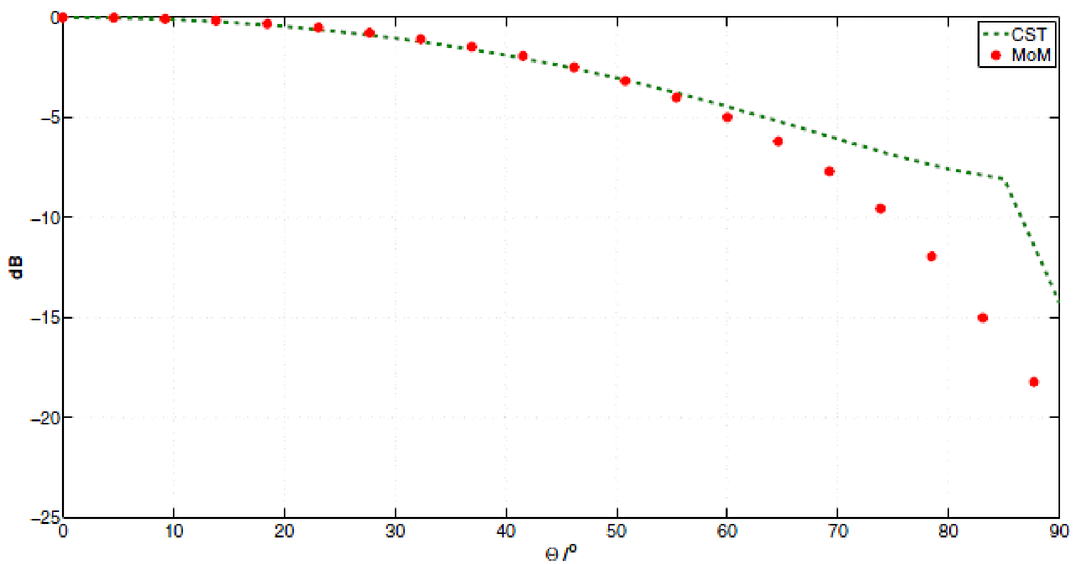


EM characterization of SKA arrays: Pattern simulation (add meas. with finite gnd?)



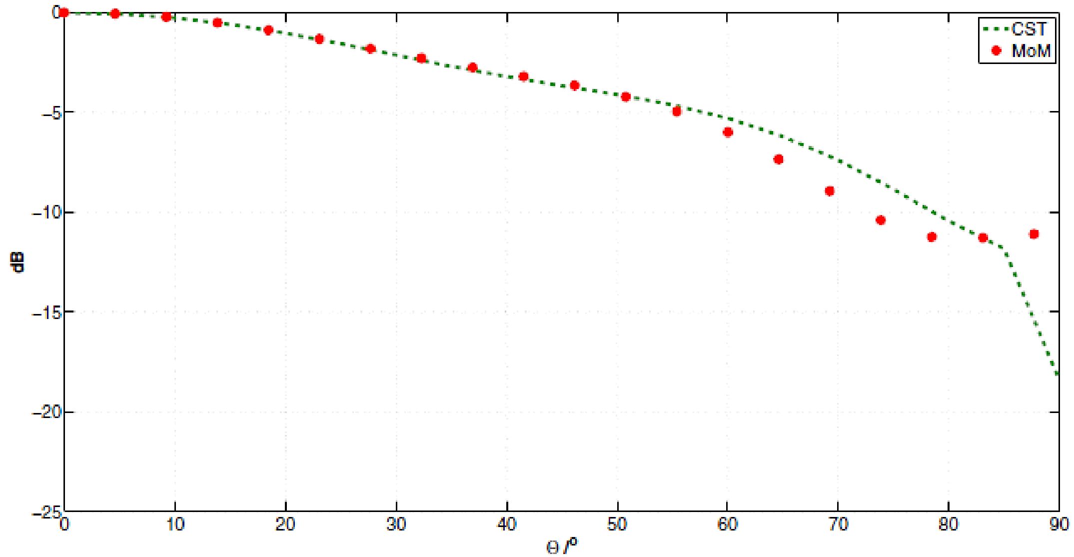
E-plane

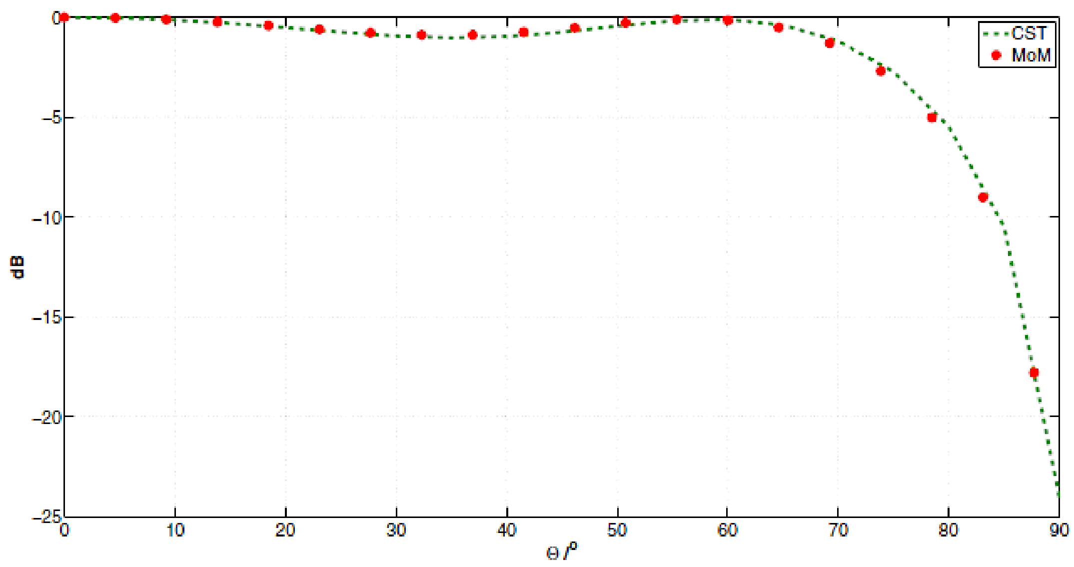
70 MHz



H-plane

EM characterization of SKA arrays: Pattern simulation (add meas. with finite gnd?)



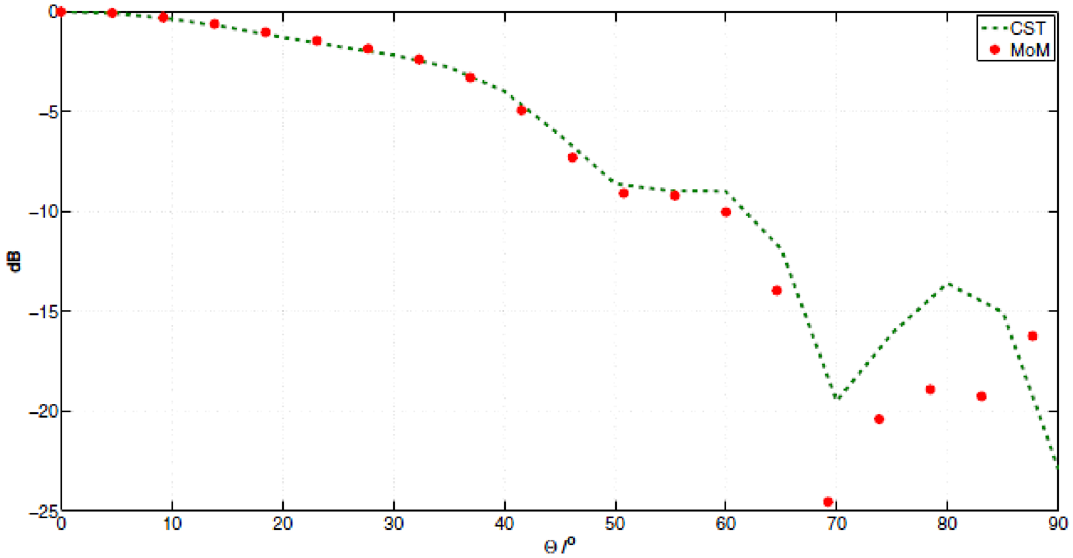


E-plane

150 MHz

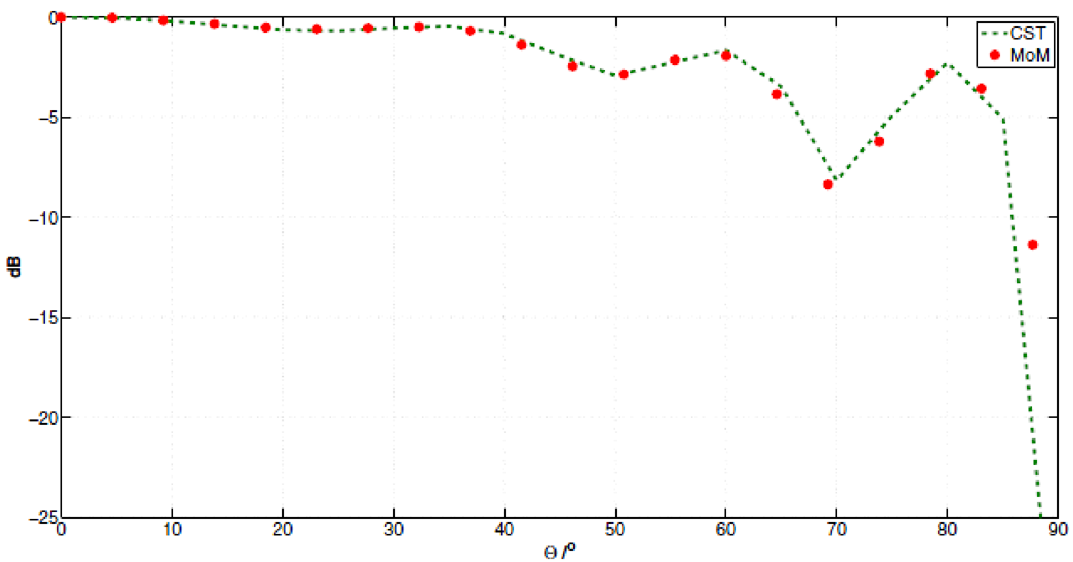
H-plane

EM characterization of SKA arrays: Pattern simulation (add meas. with finite gnd?)



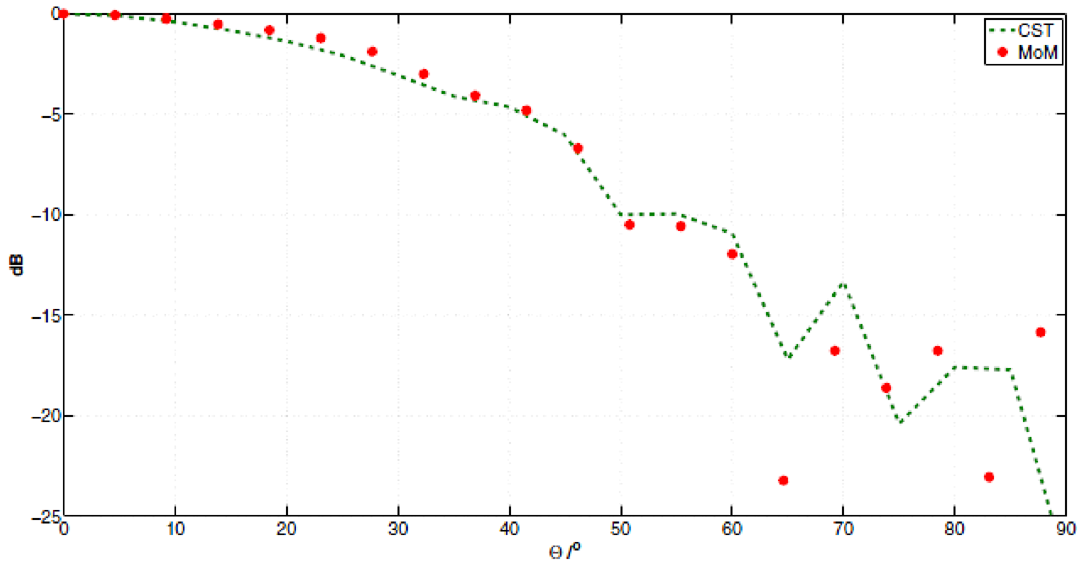
E-plane

300 MHz



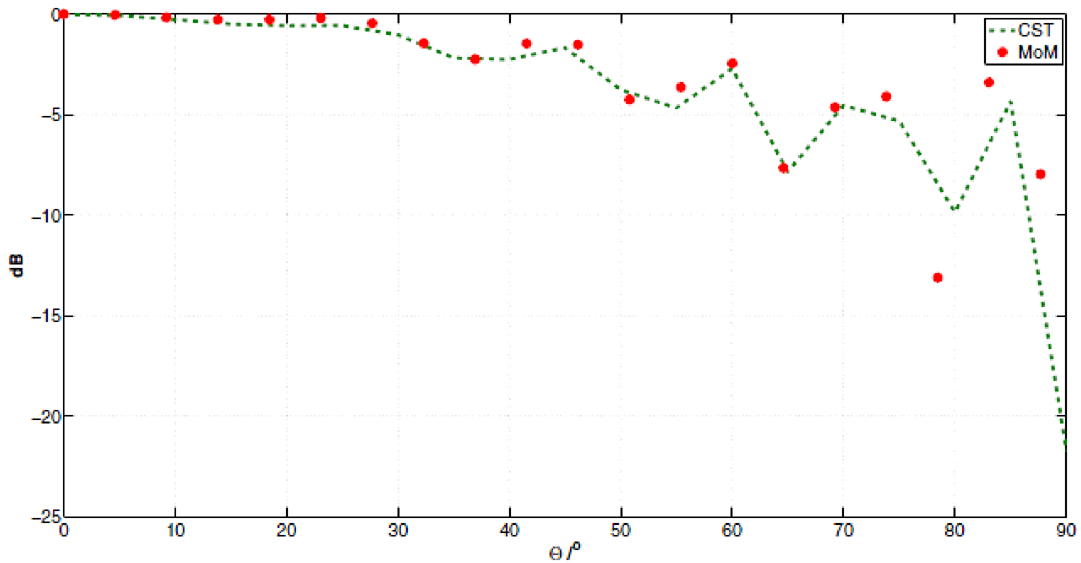
H-plane

EM characterization of SKA arrays: Pattern simulation (add meas. with finite gnd?)



E-plane

450 MHz

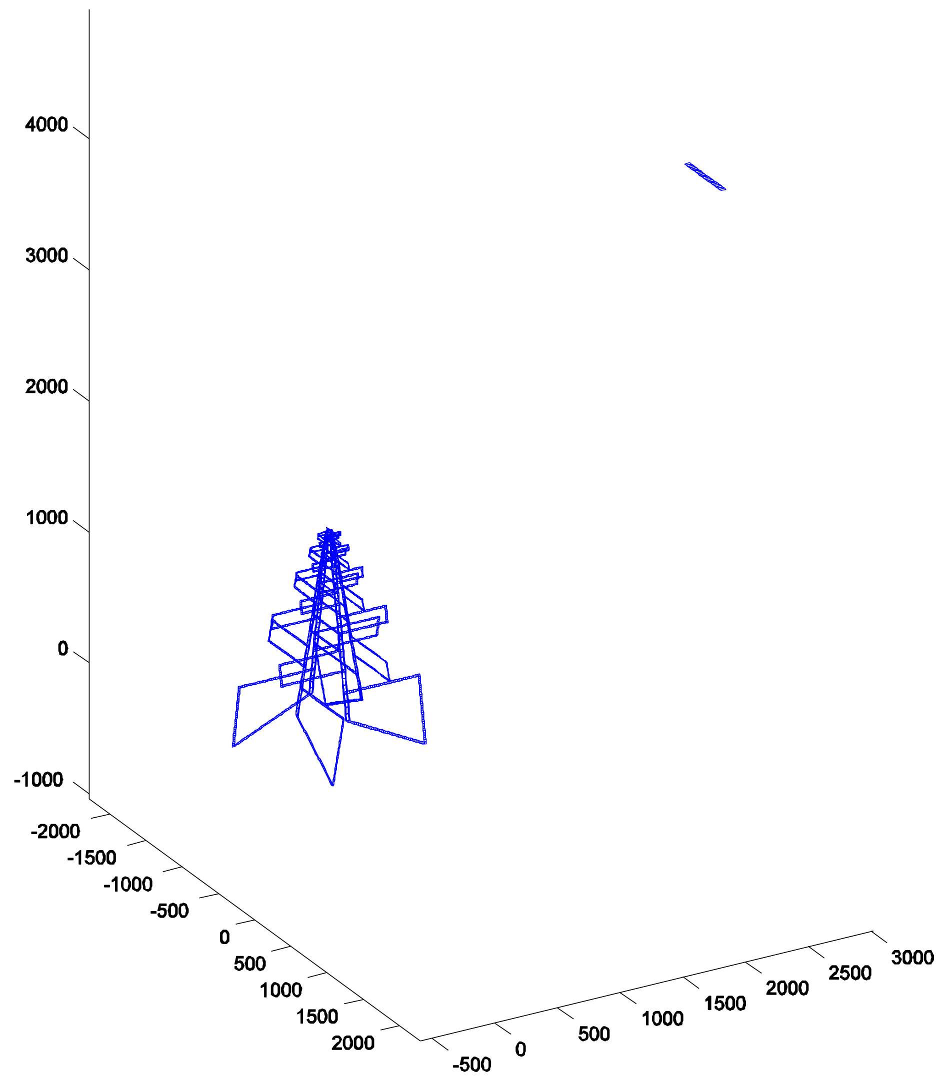


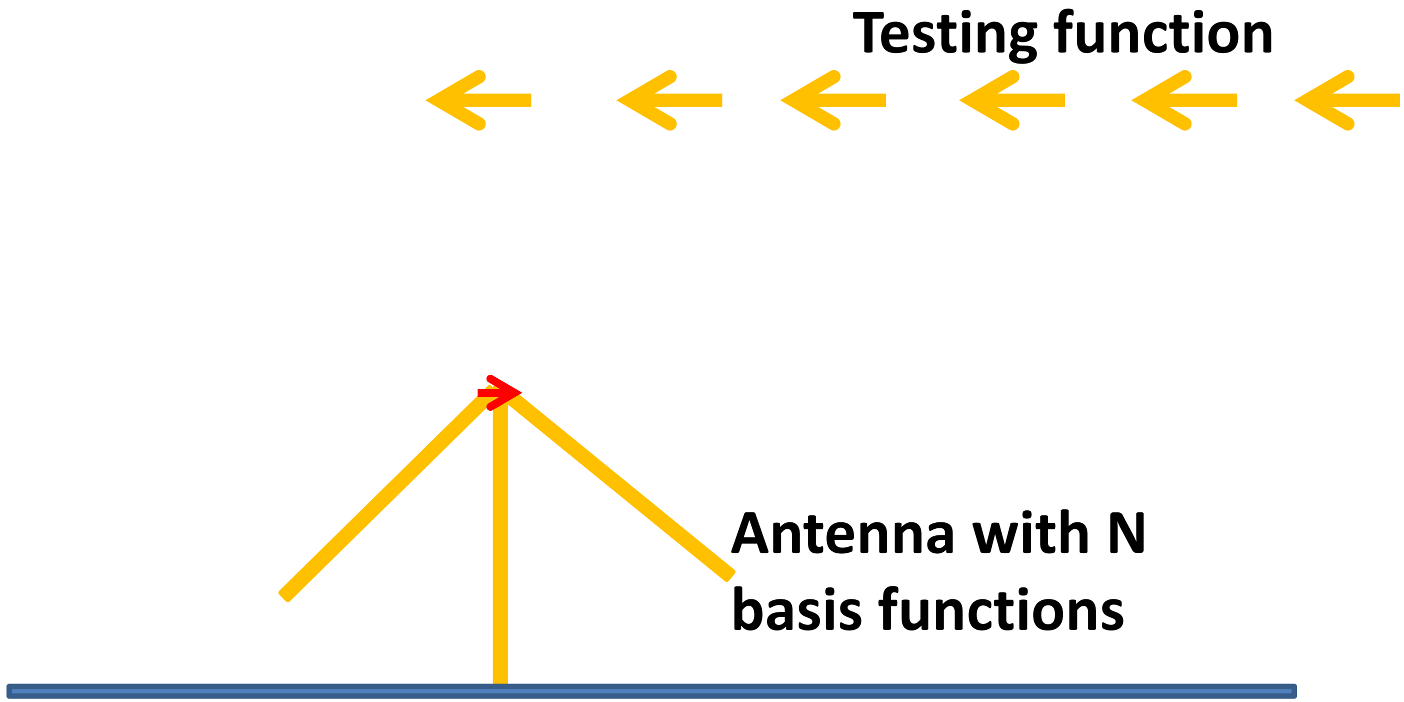
H-plane

Near field pattern measurement

- Measuring patterns for validation of EM simulation software can be tricky in aperture arrays at low frequencies (very large structures).
  - Solution: Near field pattern measurements and simulations.

Near field pattern measurement (single antenna)





MoM impedance matrix

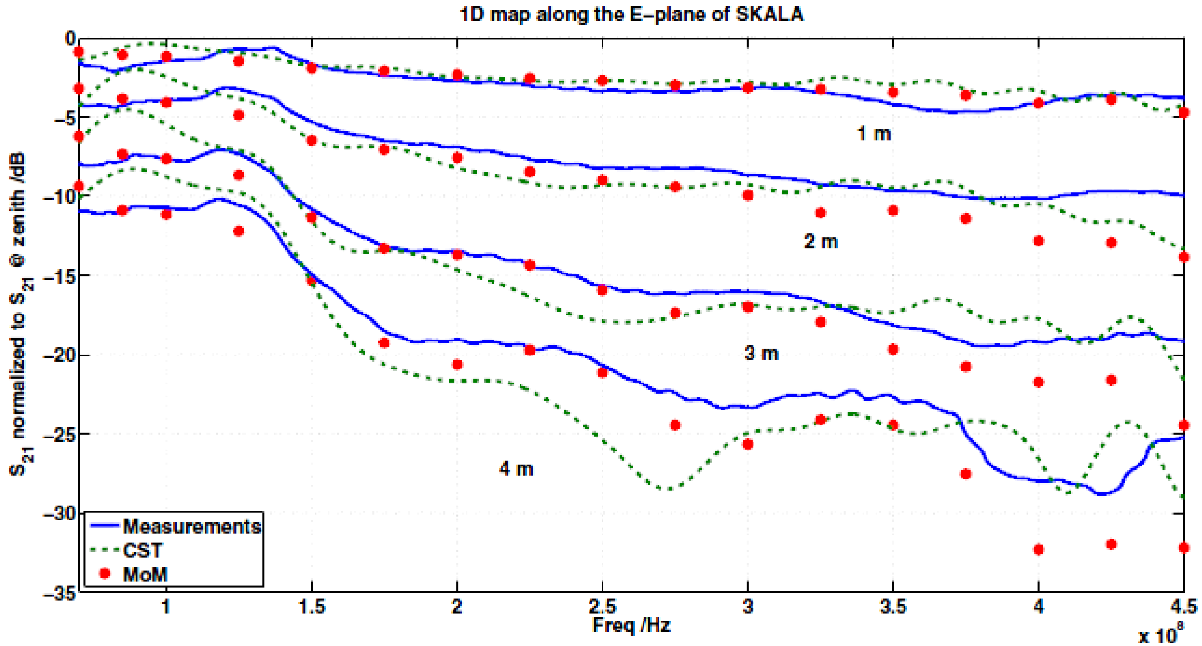
Testing vector

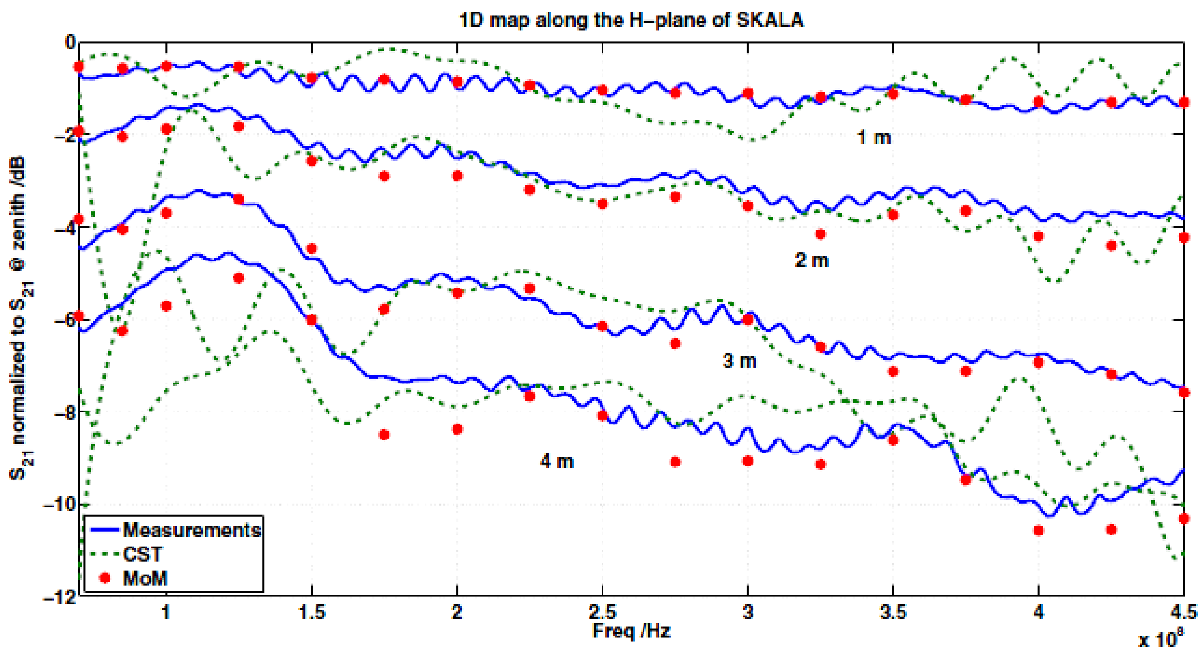
Excitation vector

$$R = [Z_{t1} \; \dots \quad \dots \; Z_{tN}] \begin{bmatrix} Z_{11} & \dots & Z_{1N} \\ \dots & & \\ Z_{N1} & \dots & Z_{NN} \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ -w \\ 0 \end{bmatrix}$$

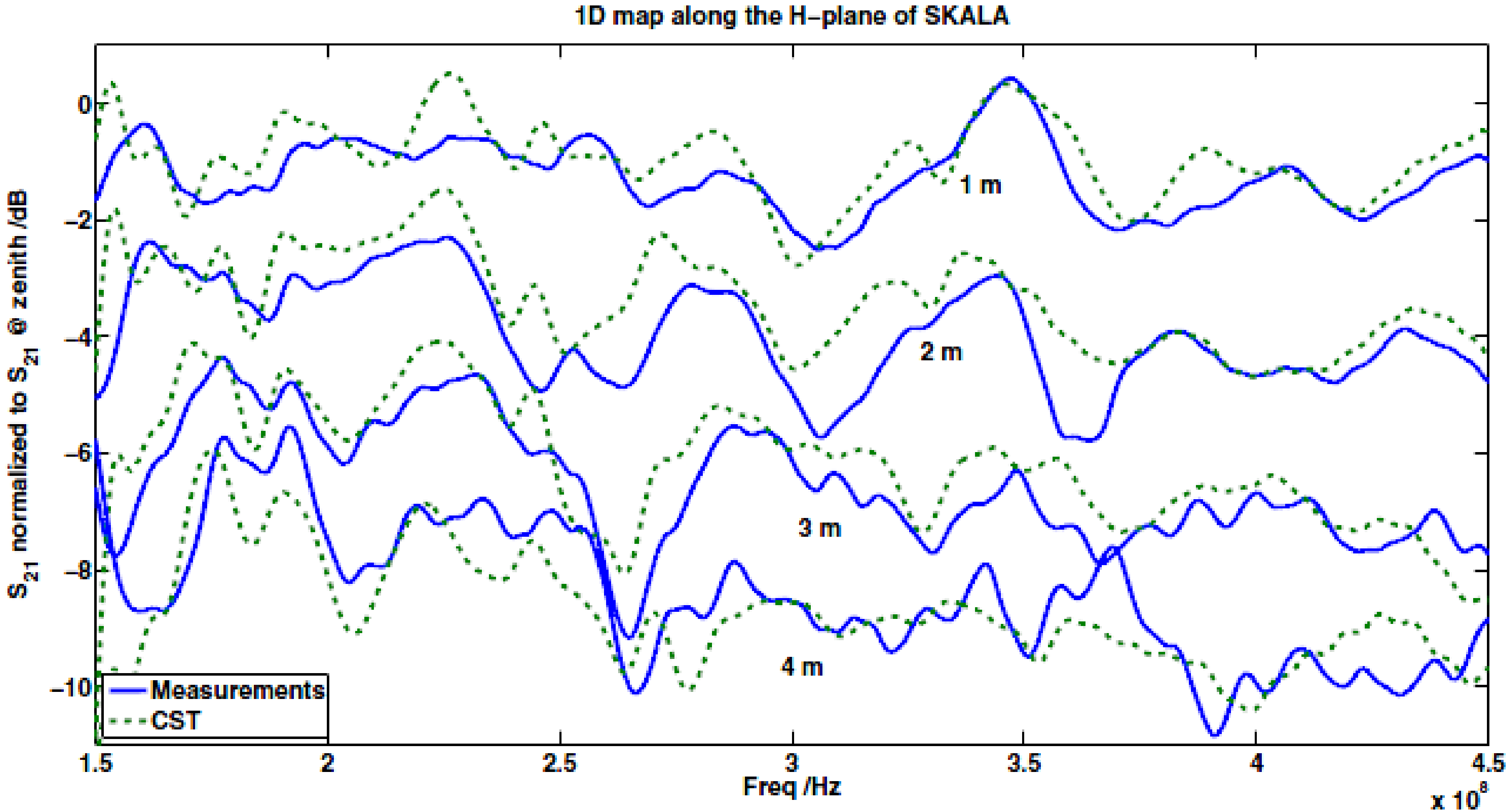
Received signal

Near field pattern measurement (single antenna)





Near field pattern measurement (embedded ant.)



Conclusions

- EM simulations very important for the SKA antenna array design and calibration.
- Accelerated MoM/MBF code capable of simulating full SKA stations.
- SKALA elements are now meshed for the code. Good agreement with CST simulations and measurements.
- A low cost near field pattern technique as described here can be useful for low frequency aperture array characterization on site.

Thank you for your attention!

SKA
SQUARE KILOMETRE ARRAY