MID-FREQUENCY APERTURE ARRAY

# Mid-Frequency Aperture Arrays
# Status and Plans

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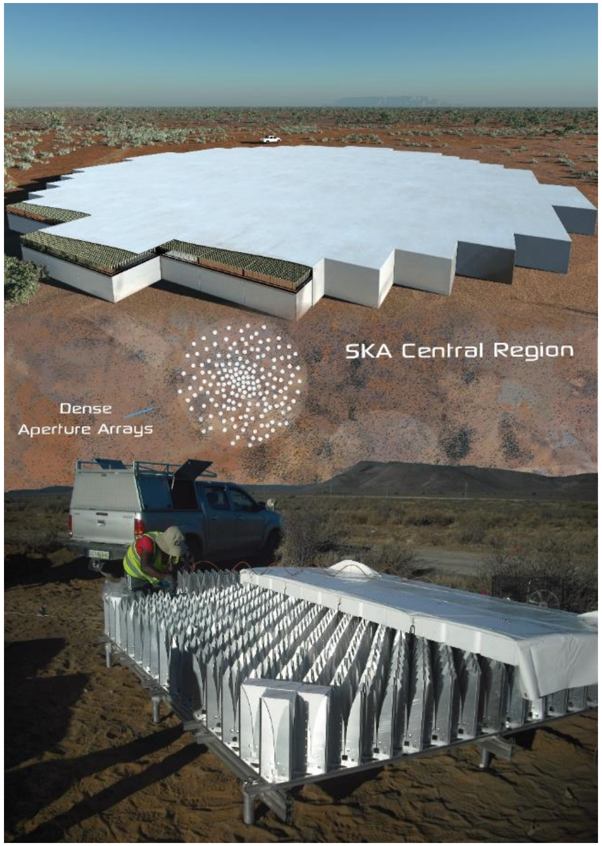
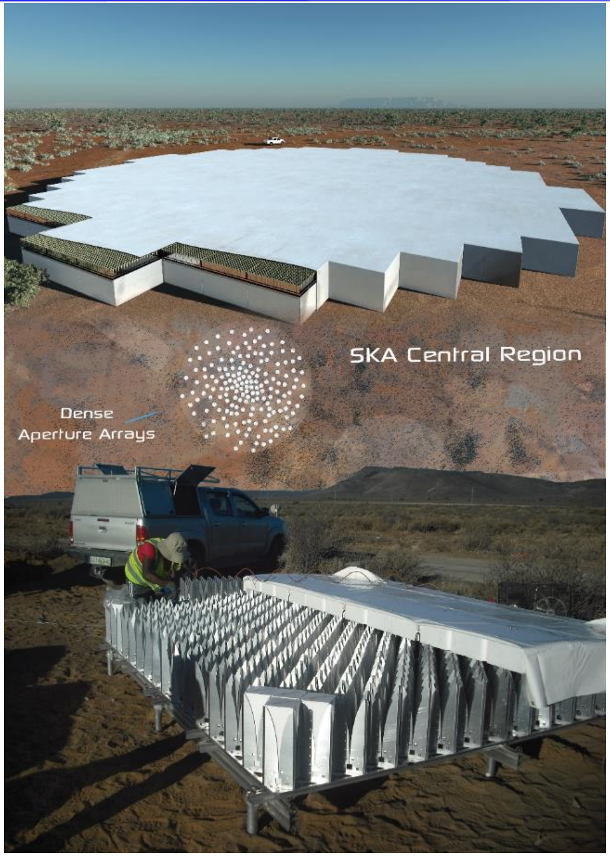
# MFAA has

- A very large field of view, and the opportunity of transient buffering
- A fast response time and pointing
- Multiple beams, concurrent observations
- A very high survey speed capability
- High sensitivity < 1.45 GHz
- No moving parts
- No vacuum, helium, cryogenics
- Relatively low post-processing costs (large stations)



# MFAA Rationale

- Billion galaxy survey, i.e. high sensitivity and survey speed from 1450 MHz down to z ~3
- Very wide field-of-view transient observations, incl. buffering
- Timing of very many pulsars (10,000+)




Can only be done with an SKA-AAMID telescope

# MFAA will drive science discoveries

- Transients
  - J.P. Macquart: “There is no substitute for Field of View,
    twice the beams = twice the science”.
  - FRB’s, RRAT’s, and many others.
- Pulsars
  - Bulk pulsar timing, high cadence long-term timing, vast improvement of on-source time, surveys
- HI
  - Deep survey, fast wide wide survey, regular re-observation
  - Local HI, Billion Galaxy Survey, Intensity Mapping
- Cosmic Magnetism

# Consortium partners

***Full members***

| | |
|---|---|
| – ASTRON | *System design, prototyping, management* |
| – China: KLAASA | *Receiver, antenna: 3x3 $m^2$ array* |
| – Observatoire de Paris (Nancay) | *Front-end MMIC's* |
| – Stellenbosch University | *Antenna research* |
| – University of Bordeaux | *ADC* |
| – University of Cambridge | *System design* |
| – University of Manchester | *Front-end design* |

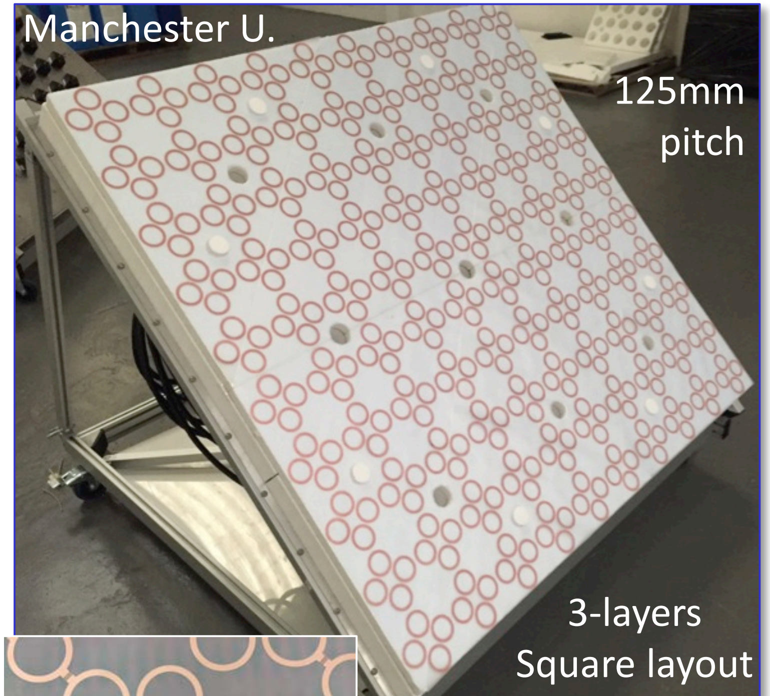
***Associate members***

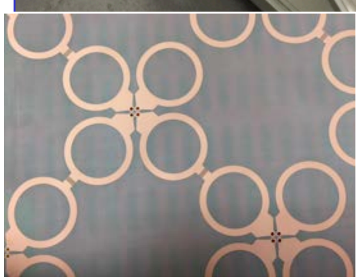
| | |
|---|---|
| – ENGAGE SKA (Portugal) | *Renewable energy* |
| – SKA South Africa | *Site support* |
| – University of Malta | *Fractal ORA* |
| – University of Mauritius | *Front-end research* |

# MFAA Key challenges

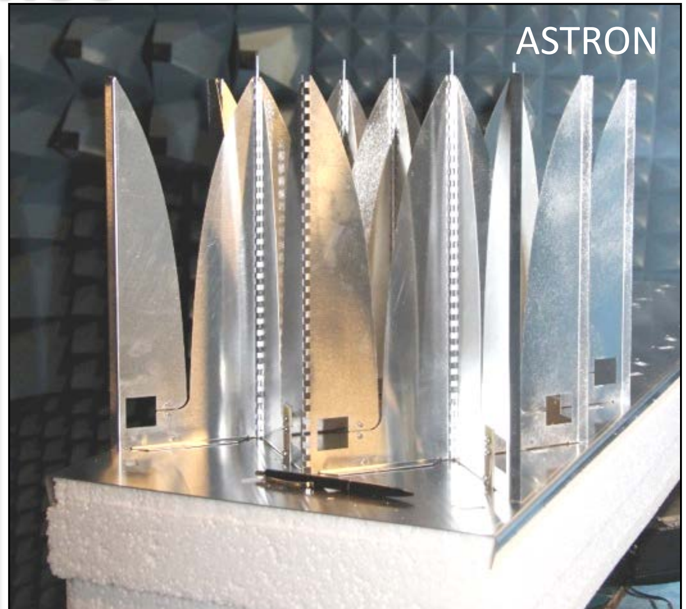
- Reducing power consumption
  - Integration
  - System optimization
- Reducing costs
  - Hardware: Design for Mass production, integration
  - Computing: Novel architectures and algorithms, integration
- Calibration down to thermal noise needs accurate beam and sky models to calibrate sources in near and far sidelobes
  - Algorithm development
  - Learn from other AA instruments (LOFAR, MWA, SKA1-Low)

# Antennas - Dense



Planar - ORA



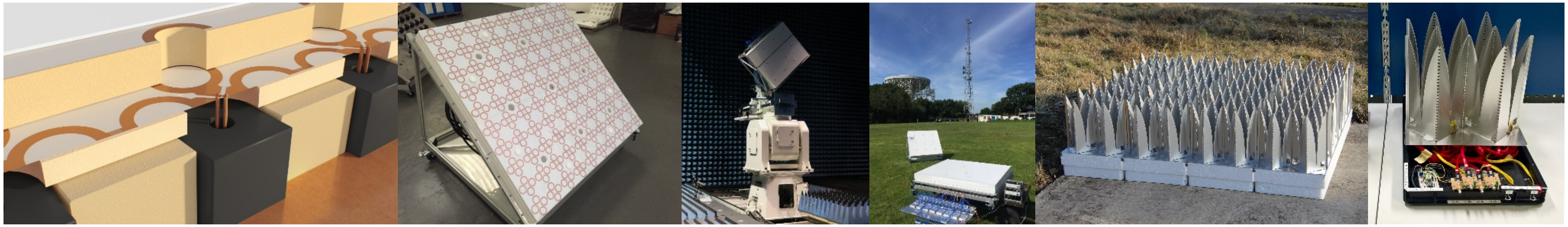

Vivaldi elements


- Regular layout
- Spacing λ/2 @ ~max. frequency

# Antennas - Sparse


- Log-periodic antenna
- Random layout
- Spacing λ/2 @ **low** frequency

**Same concept as LFAA!**



# Front-End Design for Mid-Frequency Aperture Array

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**The University of Manchester**
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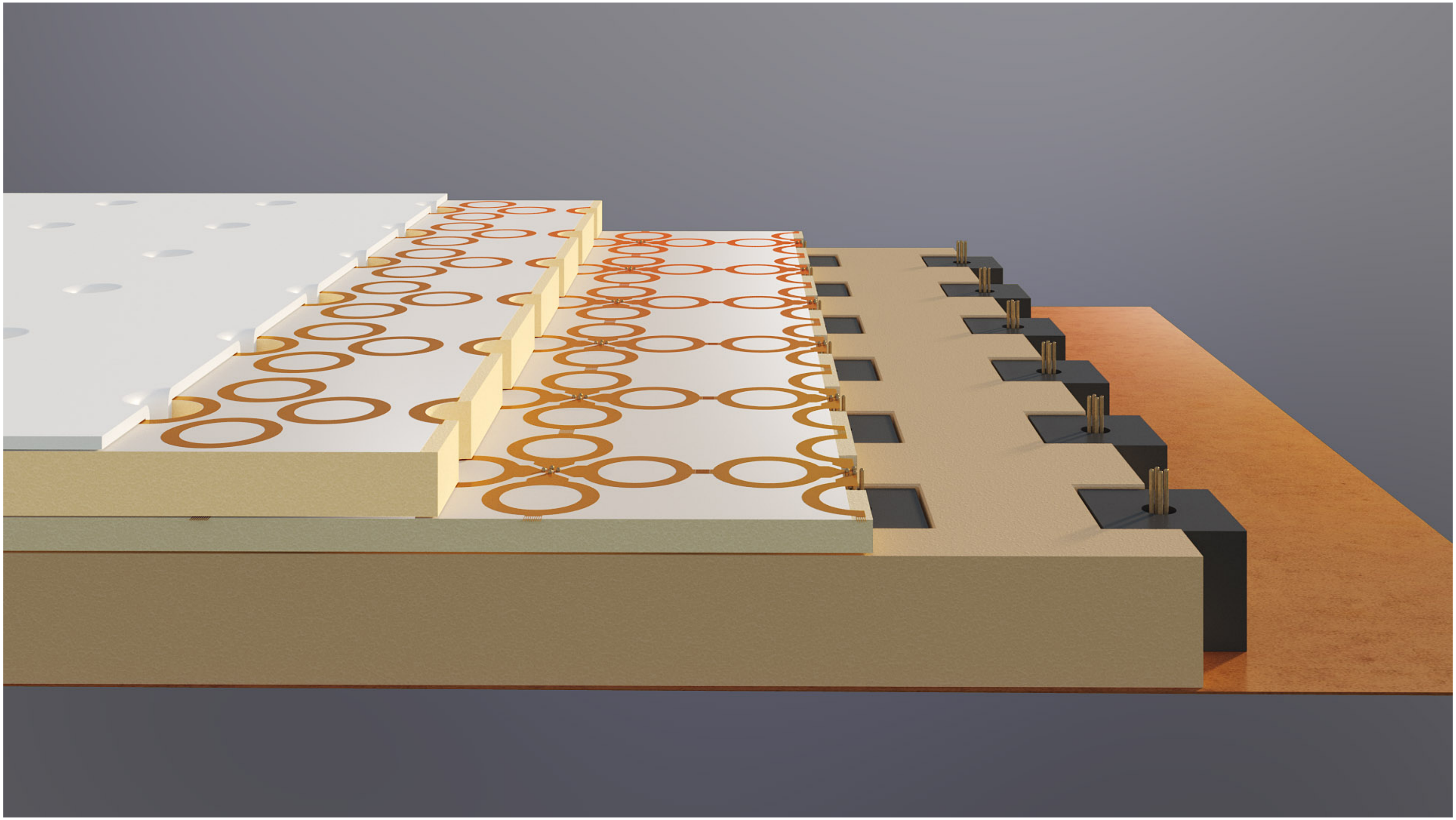
**Severin Barth, S. Bosse, S. Rakotozafy Harison**
**Obs. de Paris, Nancay**

**Rui Cao**
**KLAASA, CETC-38**

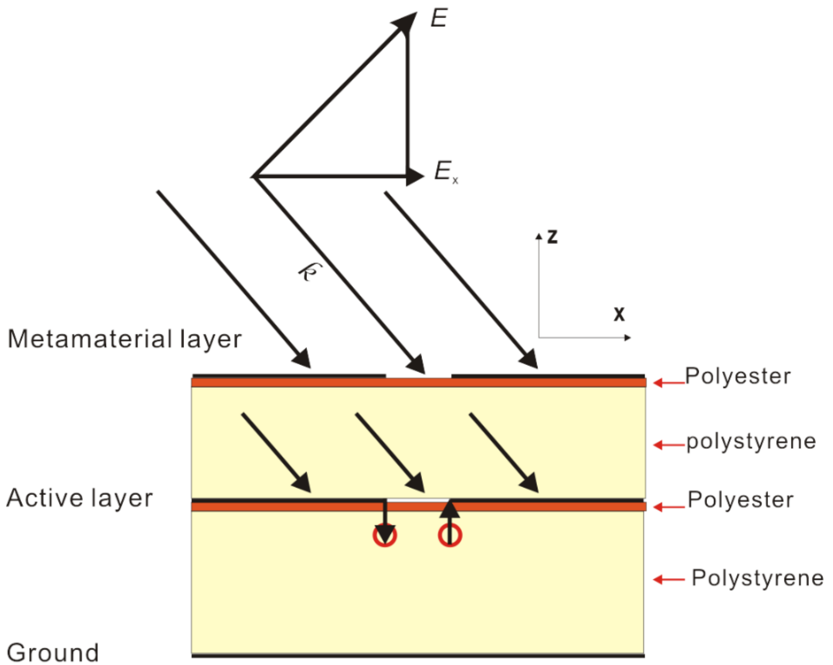
**Pieter Bentham, David Prinsloo**
**ASTRON, the Netherlands**

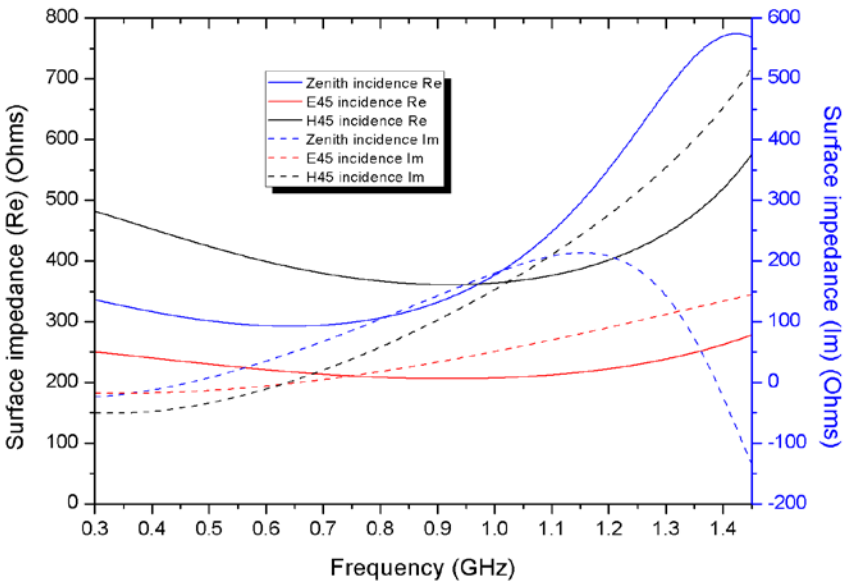
# Review of Crossed Octagonal Ring Antenna (C-ORA) Design

# The Layered Structure



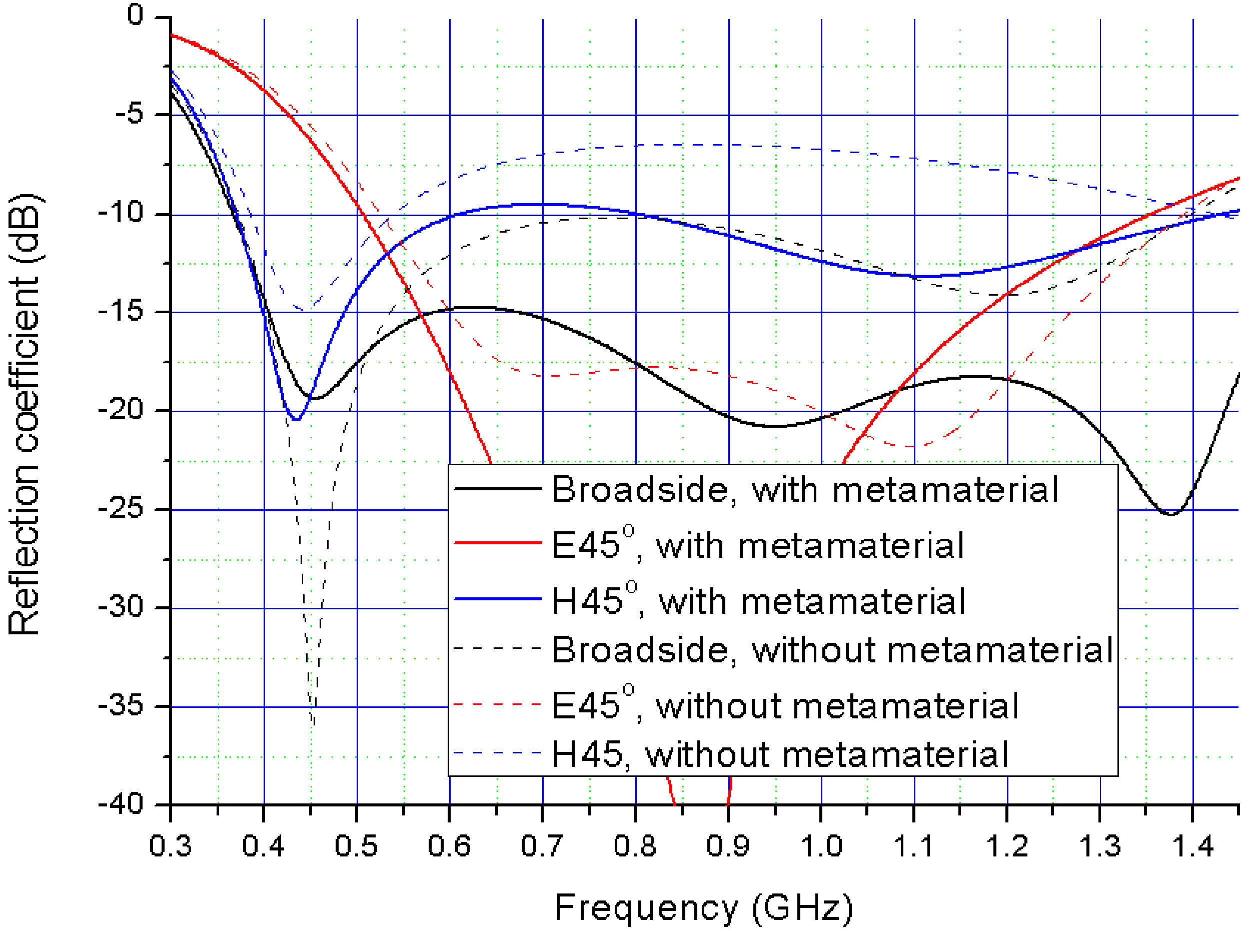
# Surface Impedance of the Passive Layer for the incoming waves from different angles



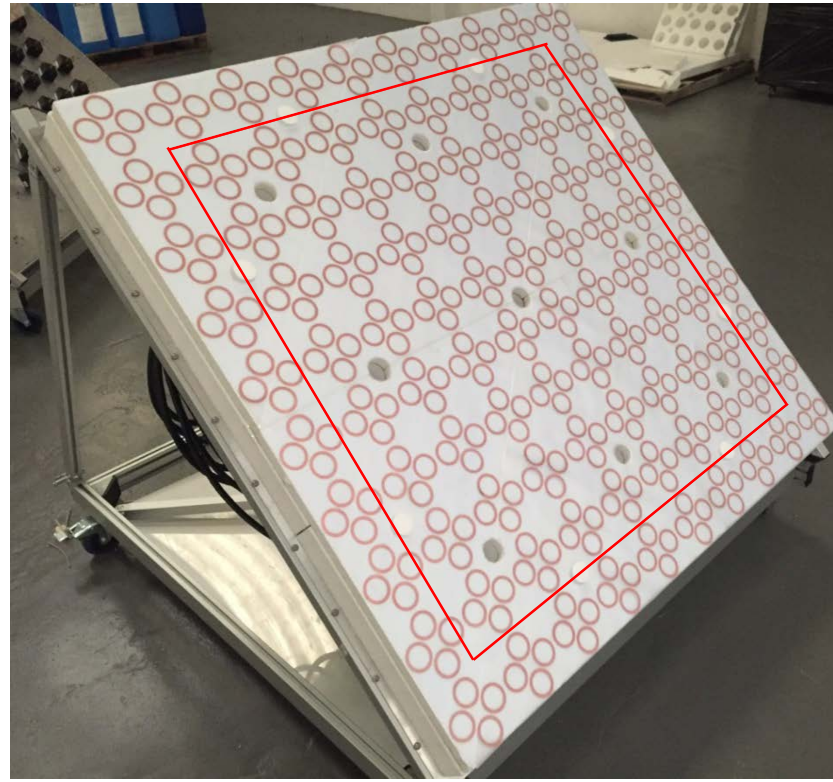

The incident wave exhibits different impedance values to the antenna element polarised direction when scanned.

# Metamaterial performance in C-ORA

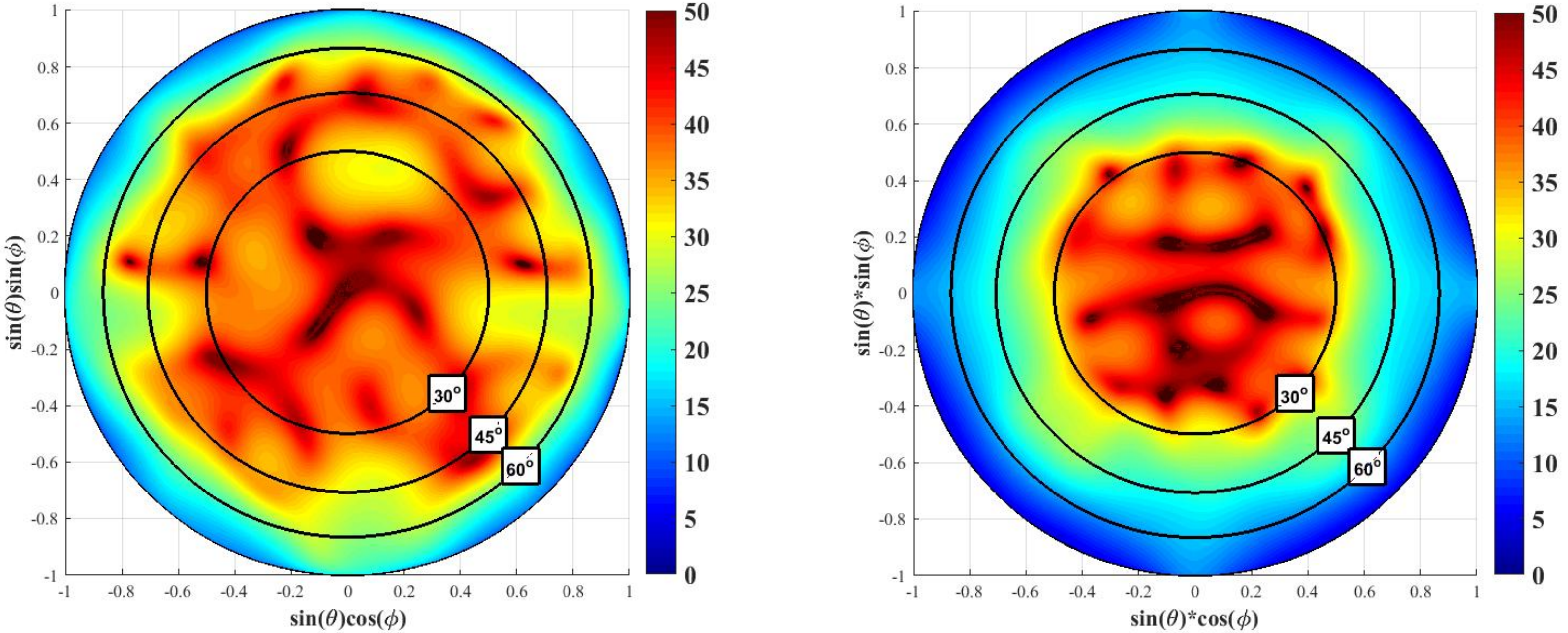


# The 1 $m^2$ ORA prototype facts

- 10x10 elements(1.25m x 1.25m)
- Dual-polarised for each element
- Frequency 400MHz to 1450MHz
- Element separation: 125mm
- Low profile (array thickness <10cm)
- 64 (8x8) central elements excited (within the red box)
- 36 edge elements terminated with the matched load
- 128 LNAs integrated (64 for each polarisation)



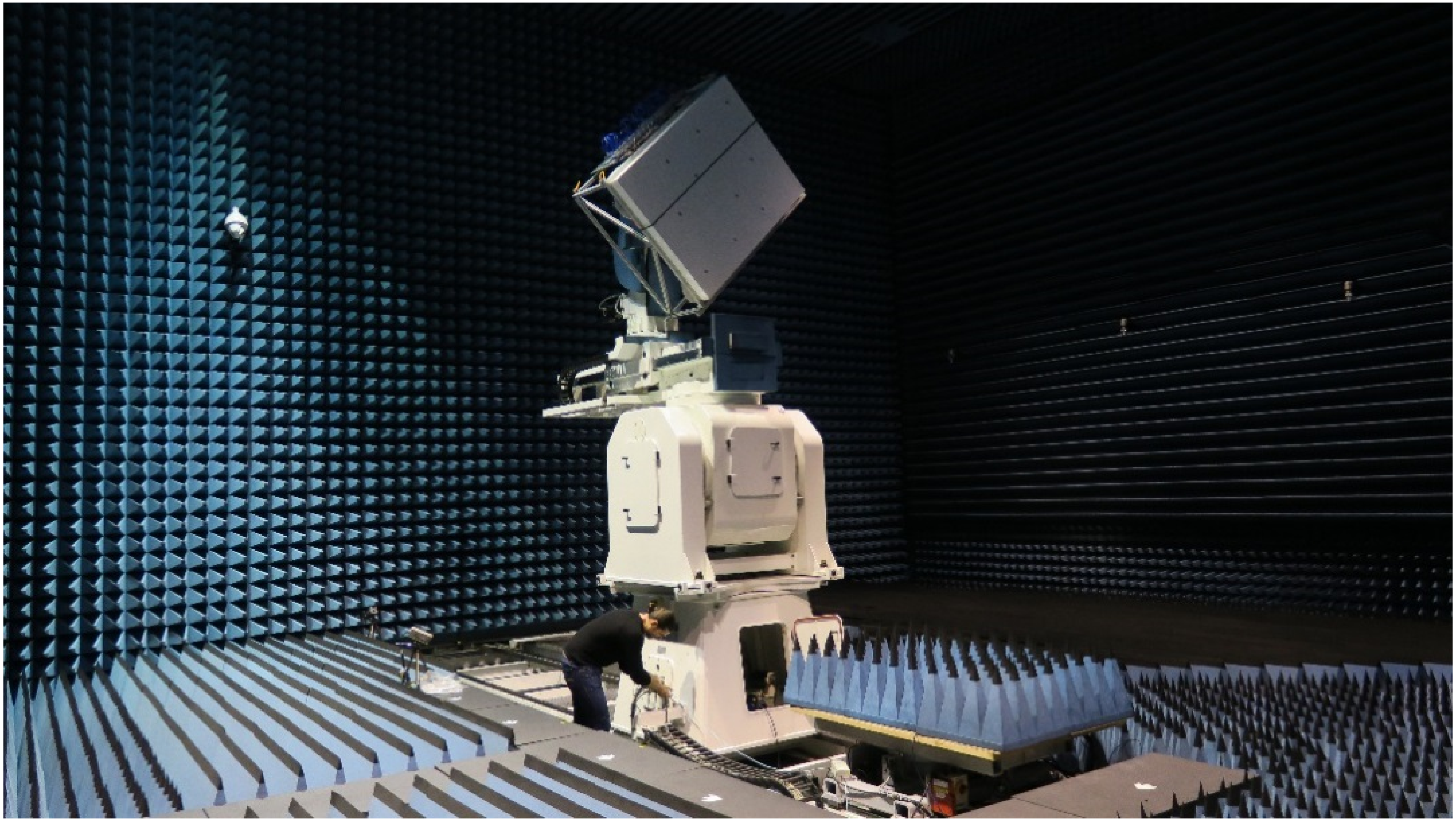
# The IXR (Intrinsic Cross-Polarisation)



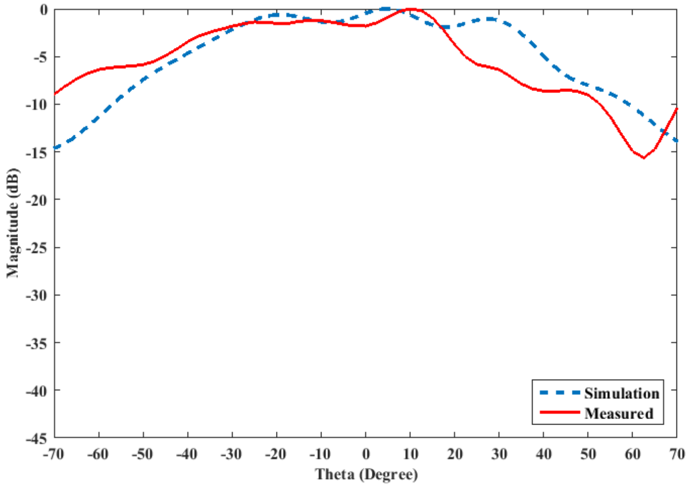

900MHz

1200MHz

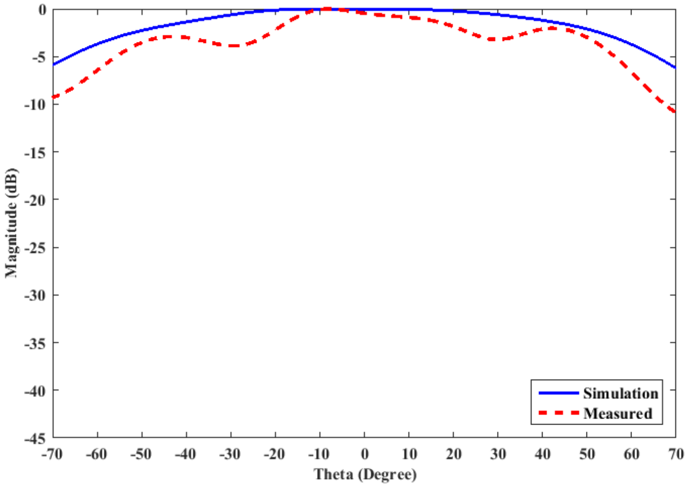
# Radiation pattern measurement



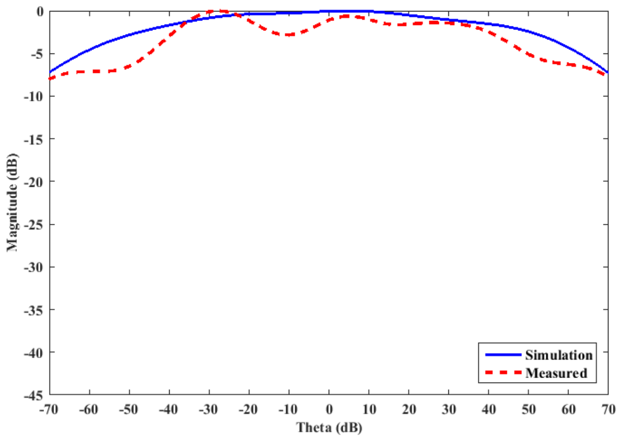
# Measured immersed element patterns



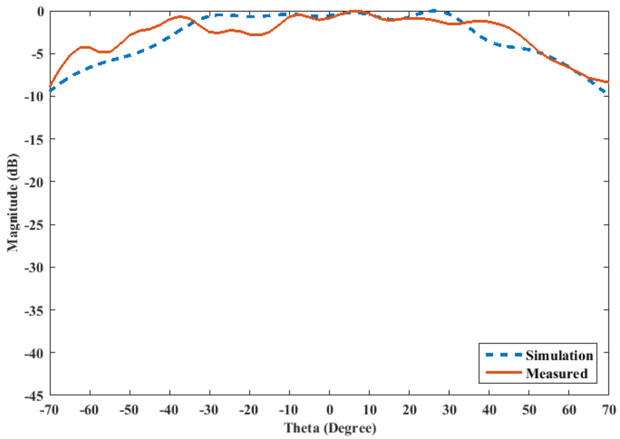

900MHz, E-plane




1400MHz, E-plane

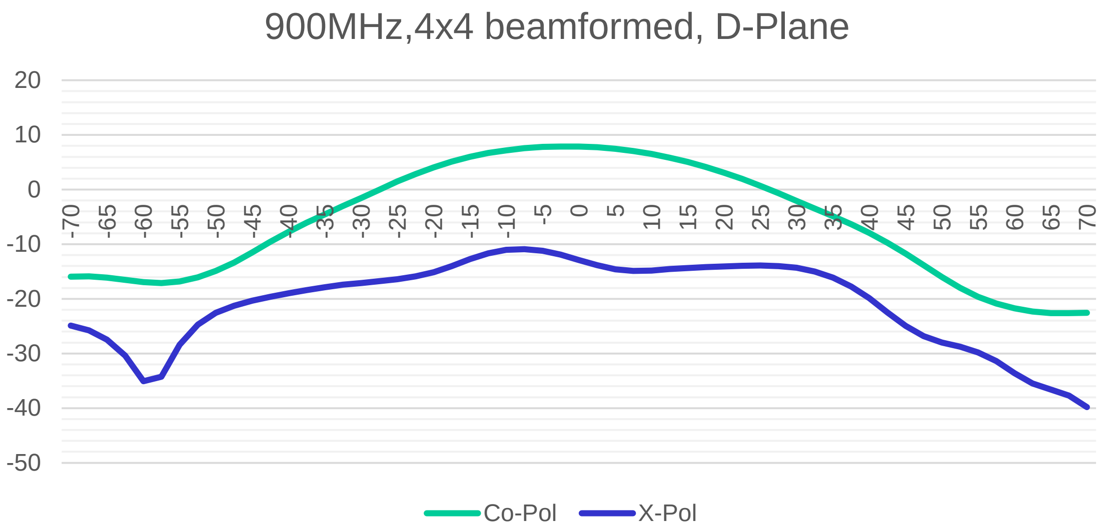


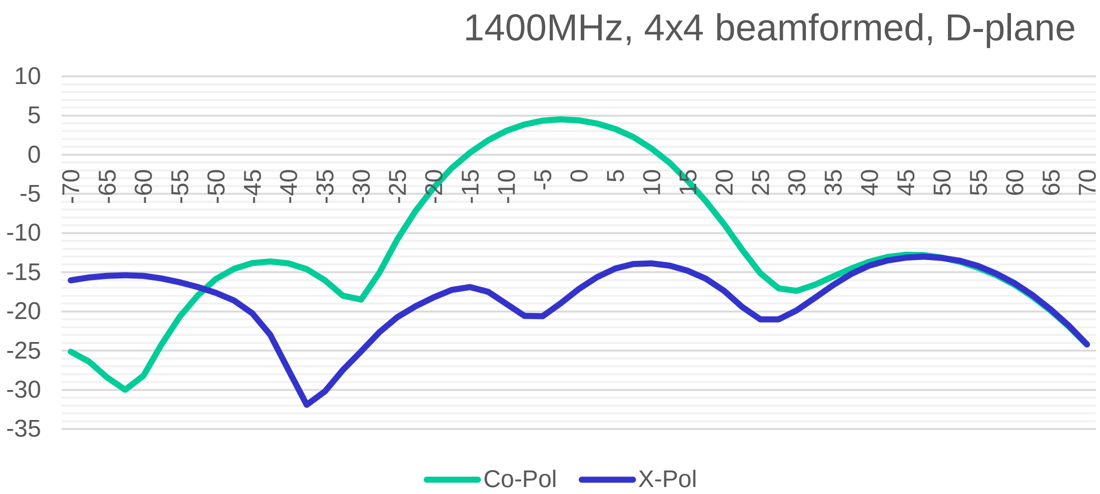

900MHz, H-plane



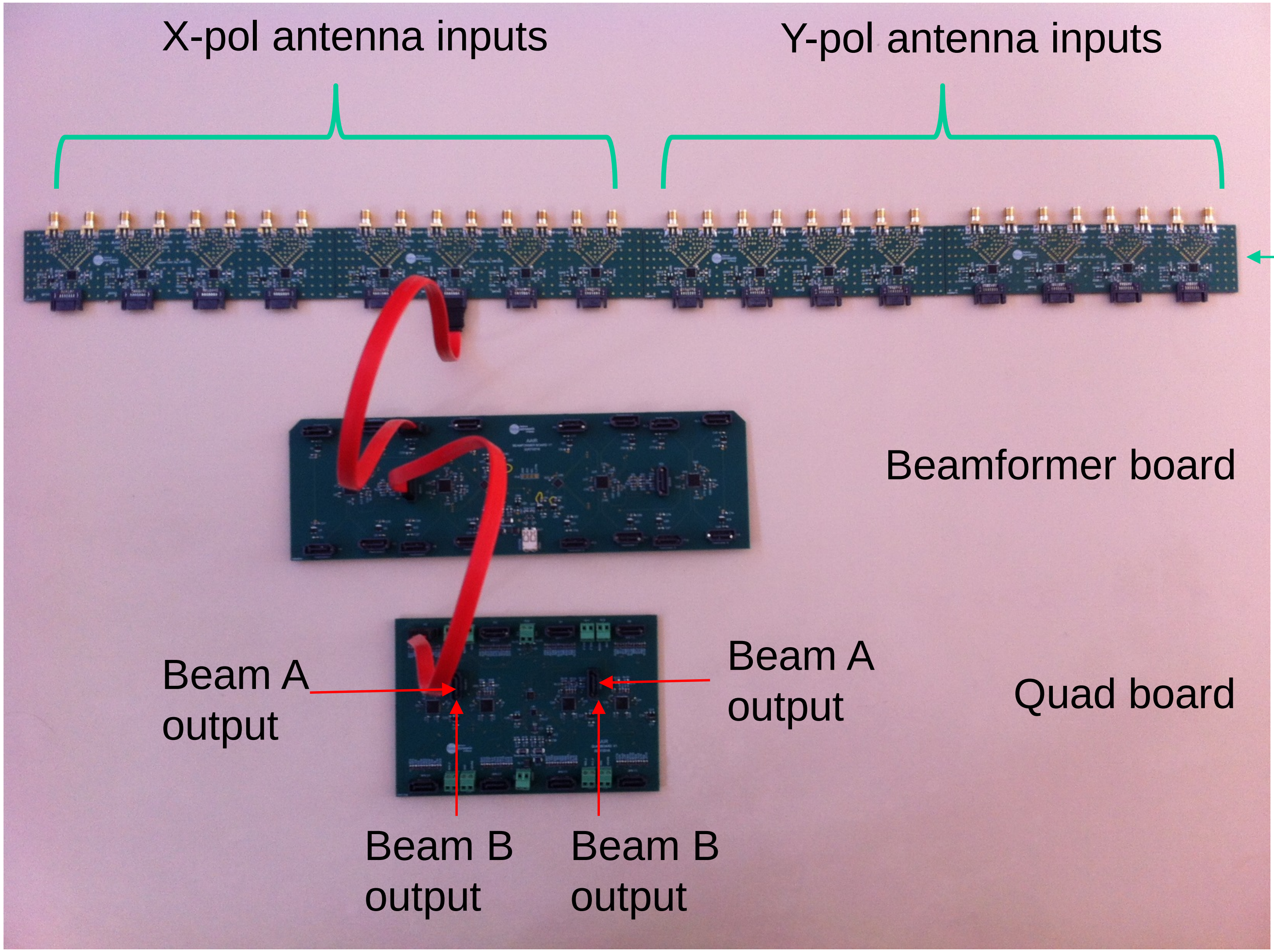

1400MHz, H-plane

# The 4x4 beamformed patterns, measured

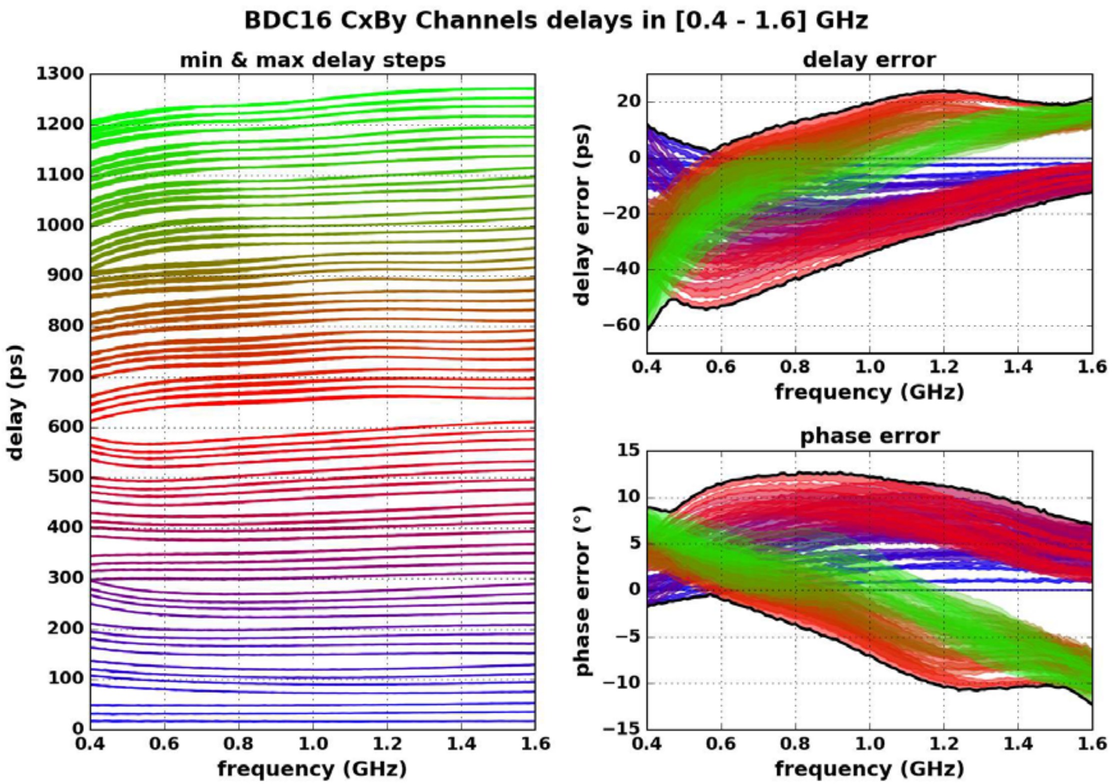


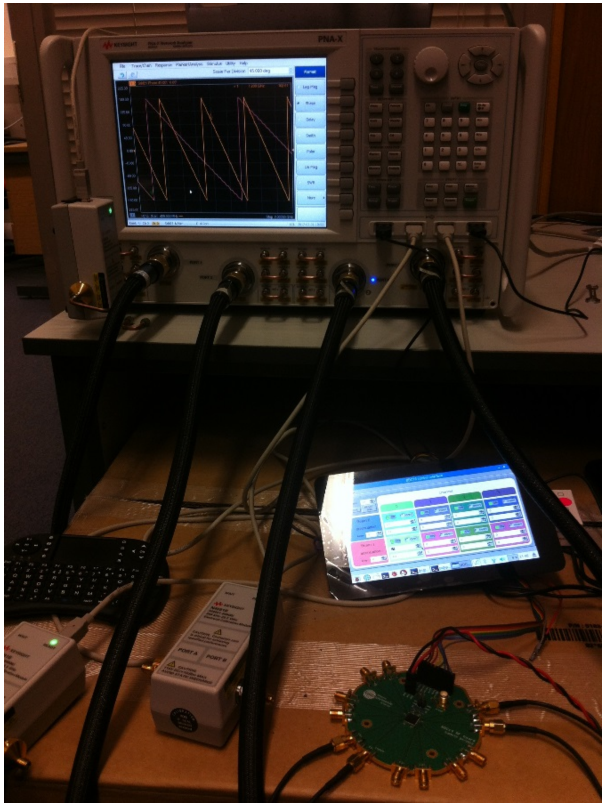



# Time delay based beamformer solution for dual polarisation with two beams



# Beamformer board performance

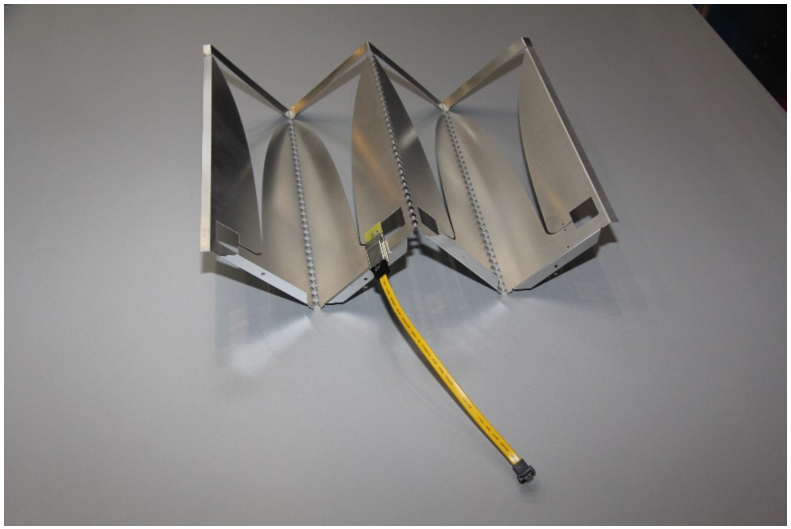


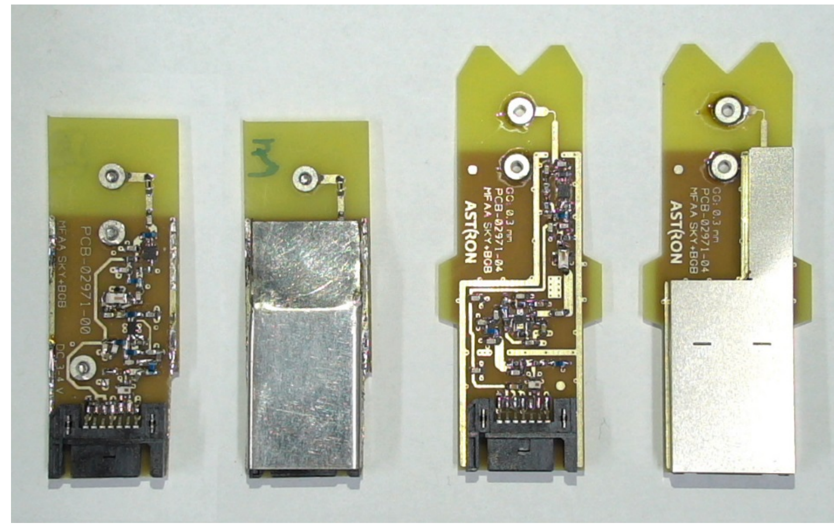



# Single-Ended Front-End Development
# ASTRON

# Vivaldi Tile for MFAA

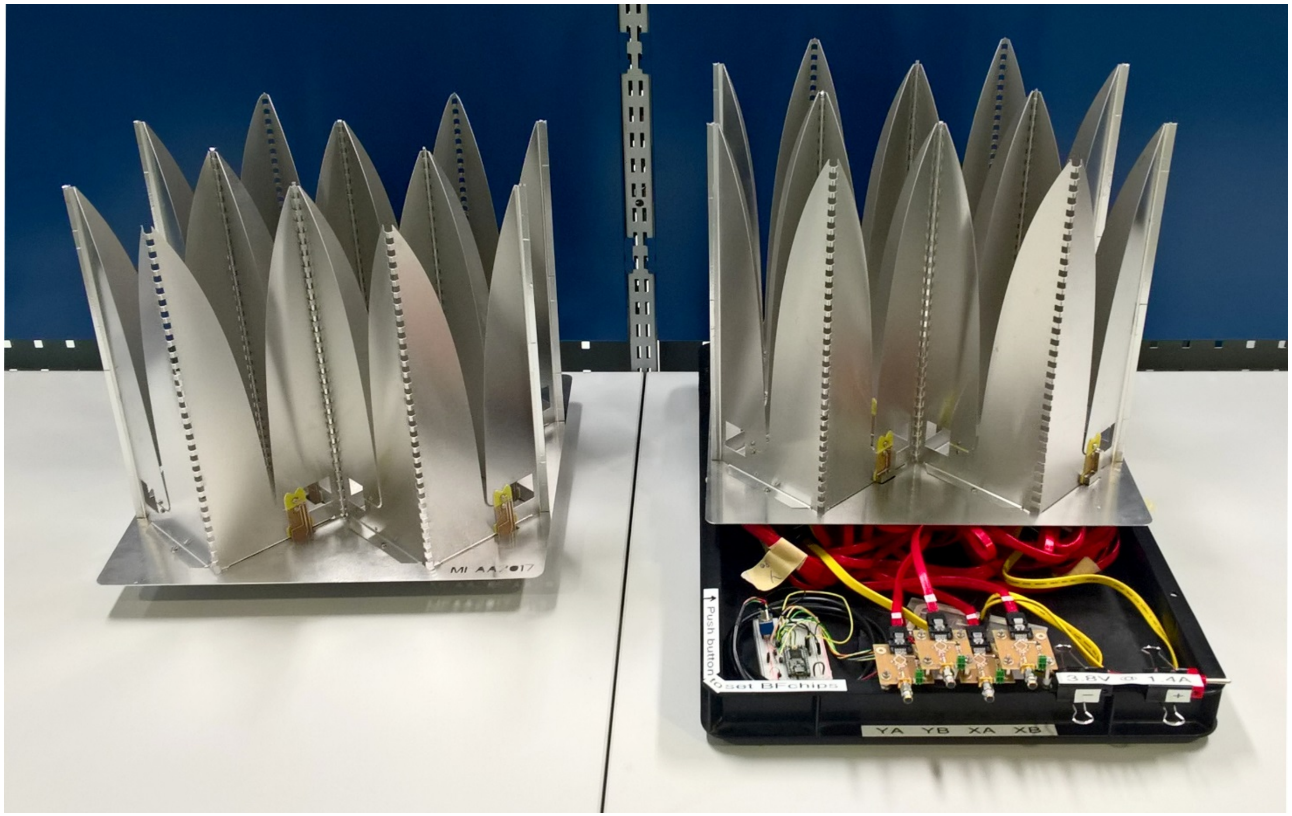
# Active array with low noise solution





LNAs are integrated at the feeding points,
SATA interface to the beamformer board

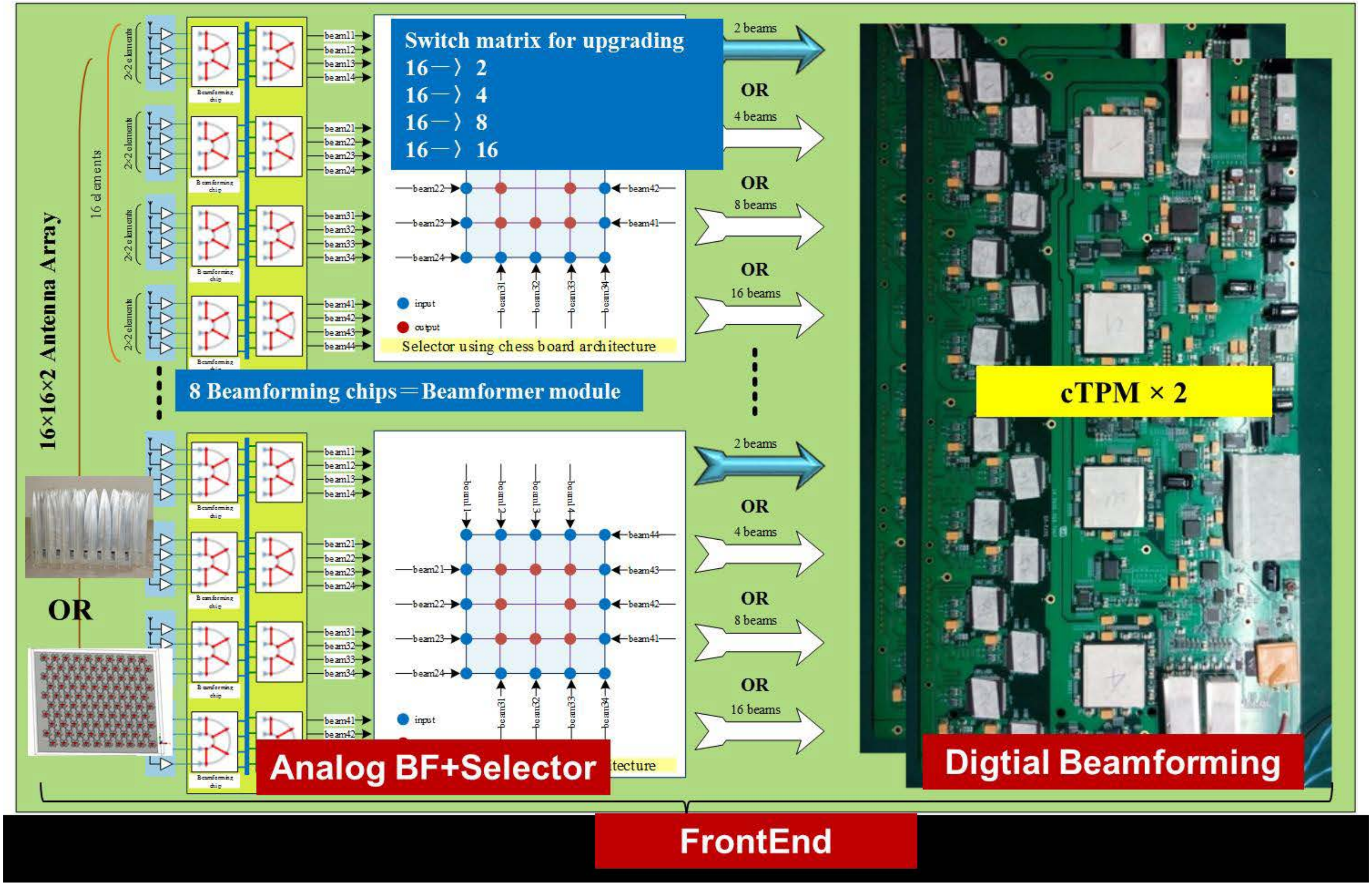
# Dual polarisation two beams beamformer



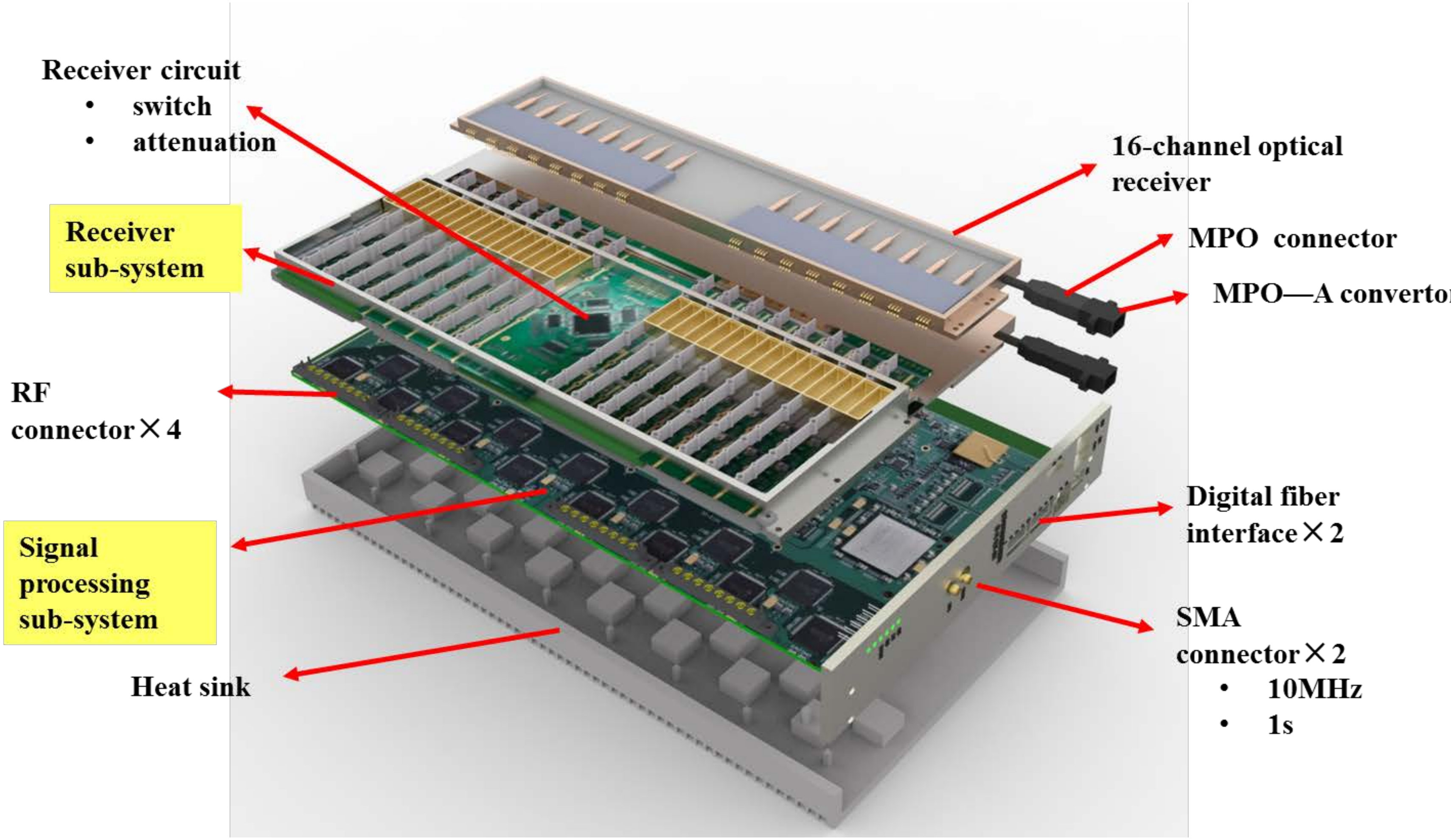

8 elements beamformer PCB for dual polarisations
2 beams for X polarisations
2 beams for Y polarisations

# Single-Ended Front-End Development KLAASA

# Architecture

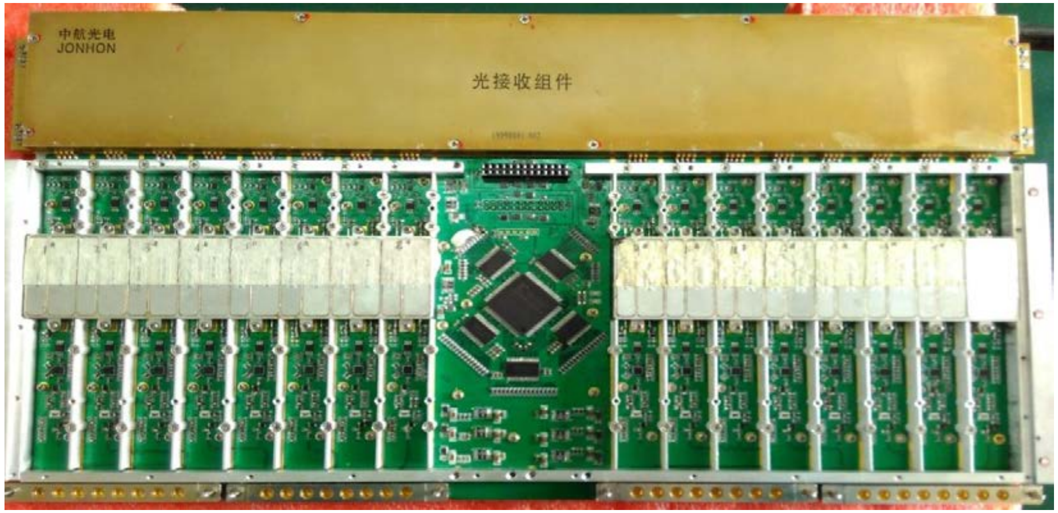


# CTPM with three layered structure



# Prototyping

KLAASA has completed the test of V1.0 For LFAA

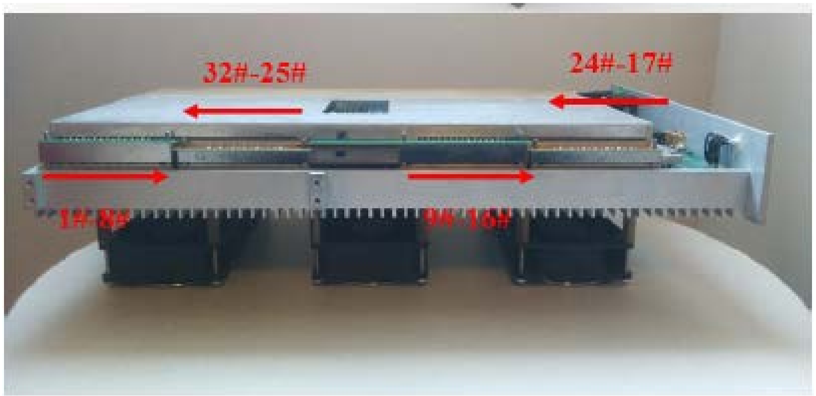



32 channels with optical receivers


32 AD channels Processing

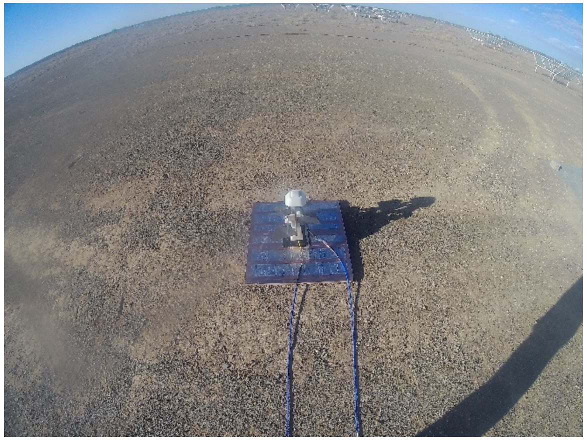
# CTPM for MFAA

| | |
|---|---|
| Frequency | 500MHz-1500MHz |
| Rx Channels | 32 |
| Band width | 400MHz(700MHz-1100MHz) |
| Amplitude Flatness | ≤±1.5dB (Rx) |
| Band Suppression | ≥ 40dB (Rx) |
| Attenuator | 4bit, 1dB step |
| Power supply | DC -48V |
| Digital Output | 40Gb/s |
| Adjacent frequency channel suppression | 60dB |
| Power consumption | ≤ 120W |
| Size | ≤ 233.35mm×430mm×50mm |




# University of Cambridge

- Mechanical design in collaboration with Cambridge Consultants Ltd.
  - Prototype on the South African SKA site
  - Taking RFI measurements
- Working towards 128 element demonstrator at the Mullard Radio Astronomy Observatory at Lords Bridge, Cambridge



# University of Stellenbosch

# Basic Beamforming on a Dense Dipole Array

**Investigate manners to reduce computational requirements during beamforming**

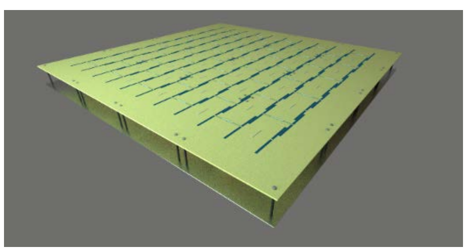
- Reduce the number of bits available during phase quantization.
- Maintain a high pointing accuracy.
- Optimization done on array factor performance.

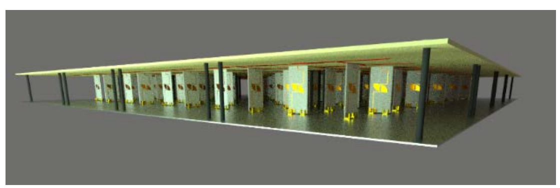
**Array factor performance characterised by:**

- Effects on the visible region.
- Pointing accuracy in the visible region.
- Power lost in side lobes and grating lobes.

**Beamforming application on a Dense Dipole Array**

- Measure embedded element patterns.
- Compare simulated patterns with measured patterns.
- Implement simple beamforming with array factor multiplication.
    - Simulated pattern multiplication vs measured pattern multiplication.





Figures 3 and 4: CG Renders of the Dense Dipole Array under investigation

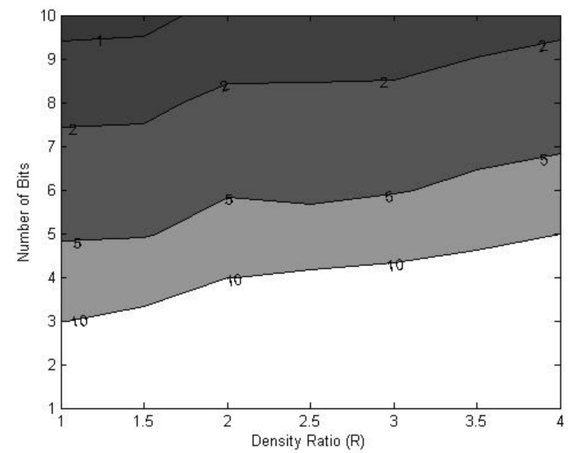



Figure 1: Pointing error with a very basic beamforming algorithm

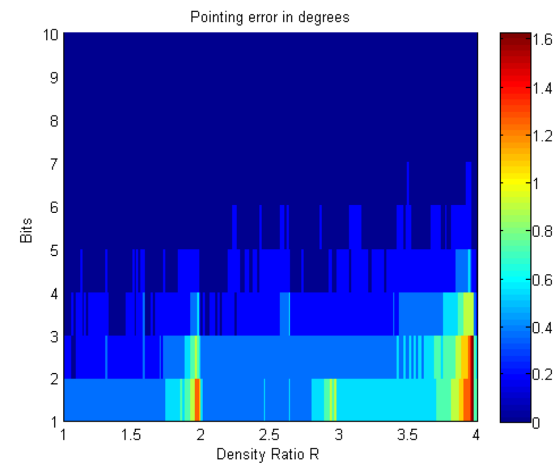
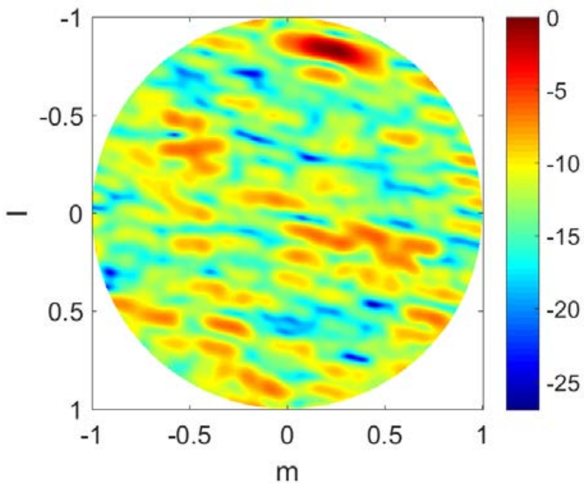


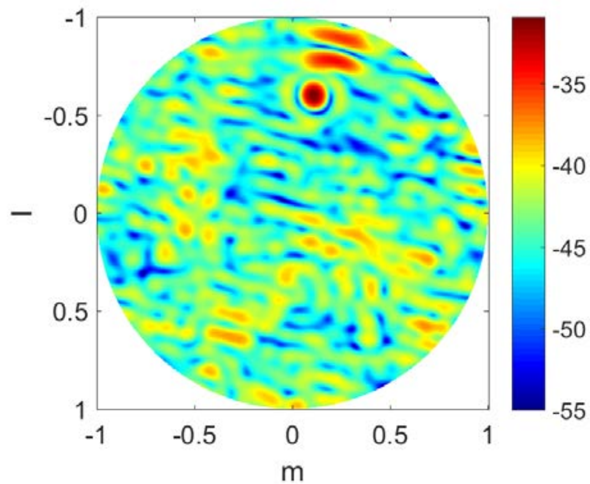

Figure 2: Pointing accuracy with an improved beamforming algorithm

# RFI mitigation using spatial filtering

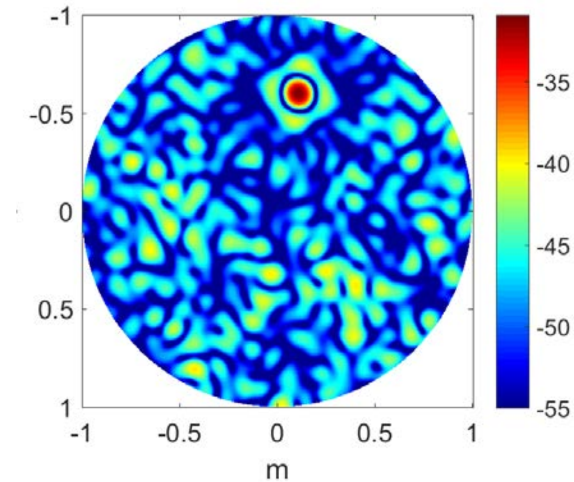
- PhD student: Jan-Willem W. Steeb. Supervisors: Prof Davidson and Wijnholds
- Results below for a LOFAR station with a UAV source.




a) Full skymap with RFI source visible in top right corner in dB (the RFI source is the 0 dB point).



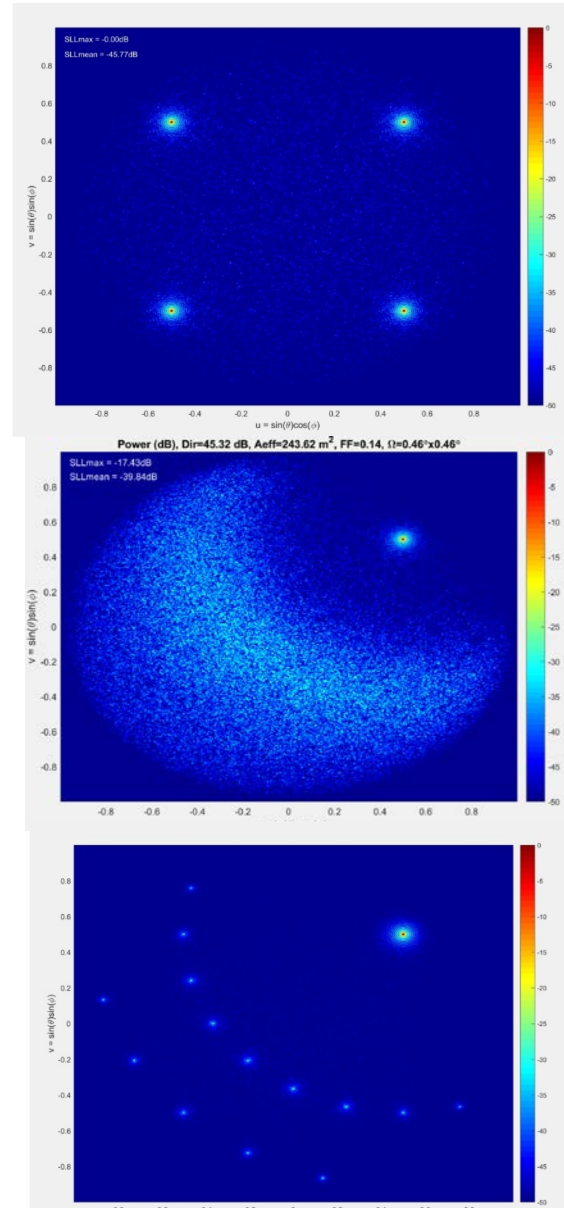

(b) Full skymap with RFI source removed using orthogonal projection with bias correction in dB. The cosmic source (Cassiopeia A) appears as a point source and two smeared RFI sources are also present.




(c) Full skymap with RFI source removed using the adapted orthogonal projection with bias correction in dB. The secondary RFI sources are removed and only the cosmic source is present.

- PhD topic of Jan Geralt Bij de Vaate
- Investigating options beside dense-regular MFAA array.
- Sparse regular brings grating lobes (top); sparse random (middle) tends to cancel; station rotation can potentially suppress grating lobes.

EUCAP 2017, bij de Vaate and Davidson



# Environmental prototypes

- Environmental proto-types in the Karoo, South Africa
- Goal: Identify the “fuzzy” environmental design drivers
  - Dust, soil variation, erosion, vegetation, bugs, rodents, wildlife, birds, water, puddles, floods
- Next step: install functional antennas/receivers (Vivaldi and Log-per)

# Educational MFAA Tiles

- Education and building-up experience is critically important
- Planning to install "educational" tiles
  - UCT
  - Stellenbosch University
  - …

The MFAA courier

# Concluding remarks

- Mid-Frequency Aperture Arrays is an enabling technology for SKA2 (survey) radio astronomy around 1 GHz

- Lots of exciting R&D !

- Reduction of costs and power consumption is key!