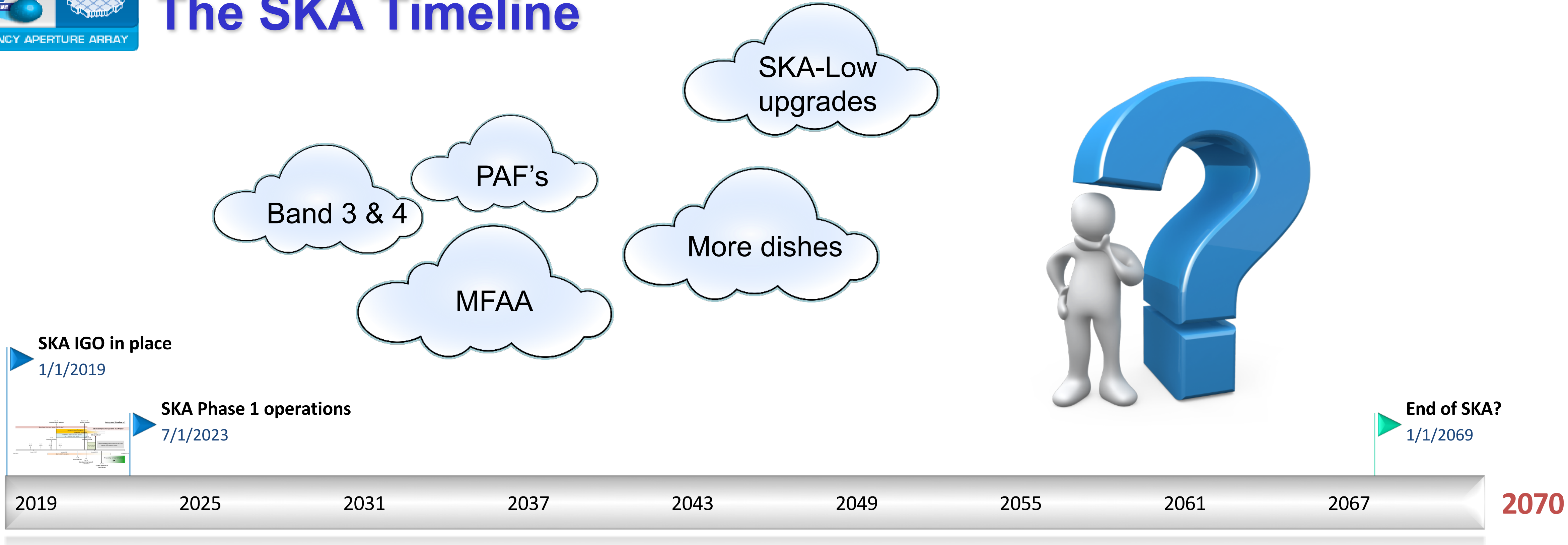
Mid-Frequency Aperture Arrays Update

Wim van Cappellen, Consortium Lead

The SKA Timeline



- The SKA is set-up to support a 50 year lifetime to offer world's biggest radio telescope in an international partnership
- Continuous upgrades and expansions, enabling new capabilities, are essential for the future of the SKA!

AIP Meeting

- Dwingeloo, 8 – 9 June, 2017

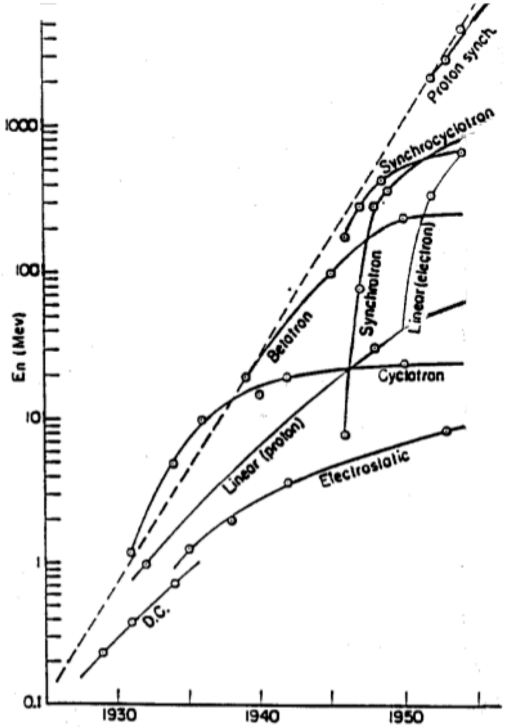
- Science
- AIP/SODP organisation
- Engineering

- http://www.astron.nl/ska-aip2017/

- Summary presentation
  - Thursday 15 June
  - 12.00 – 13.00h

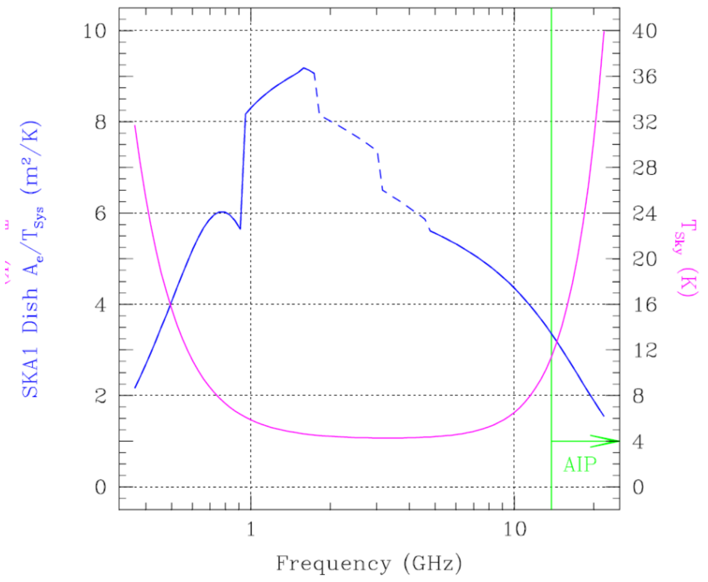
SKA 2 is about exponential growth

- Target:
  - Sensitivity > 10,000 m^2/K
  - Survey Speed > 1.4e10 $deg^2 m^4/K^2$



Following SKA-TEL-SKO-0000645 (Braun, 2016)

- To meet SKA2 target at 800 MHz:
  - Sensitivity spec
    - SPF 1,666 dishes
    - PAF 2,666 dishes
  - Survey speed spec
    - SPF 16,320 dishes
    - PAF 5,445 dishes



- Based on SKA1 costing, 1 billion euro buys us only 0.1% to 0.24% of the survey speed target.

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
- Lots of flexibility

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 MFAA based telescope

Consortium partners

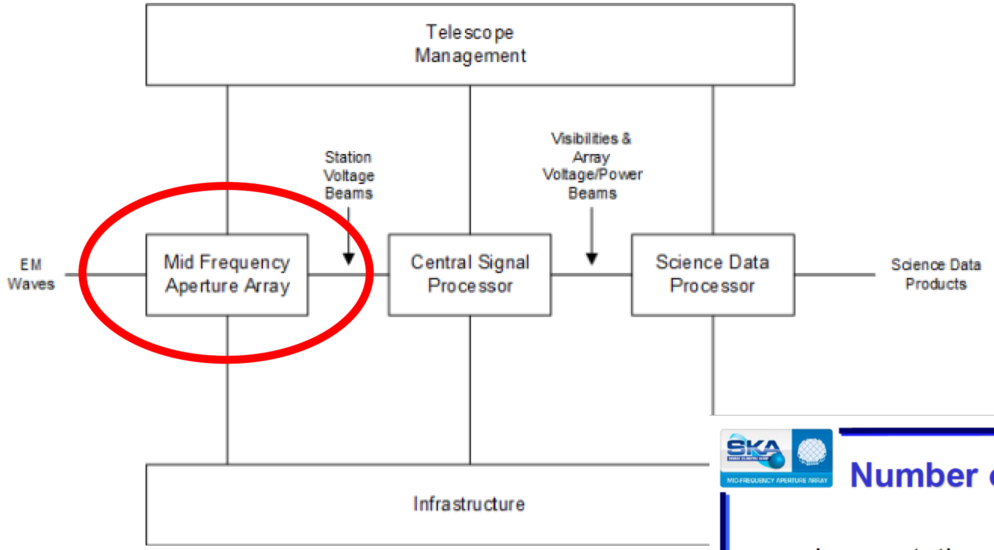
Full members

– 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

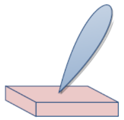
– ENGAGE SKA (Portugal)	*Renewable energy*
– SKA South Africa	*Site support*
– University of Malta	*Fractal ORA*
– University of Mauritius	*Front-end research*

Telescope system optimisation

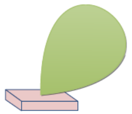


Number of MFAA Stations Trade-off

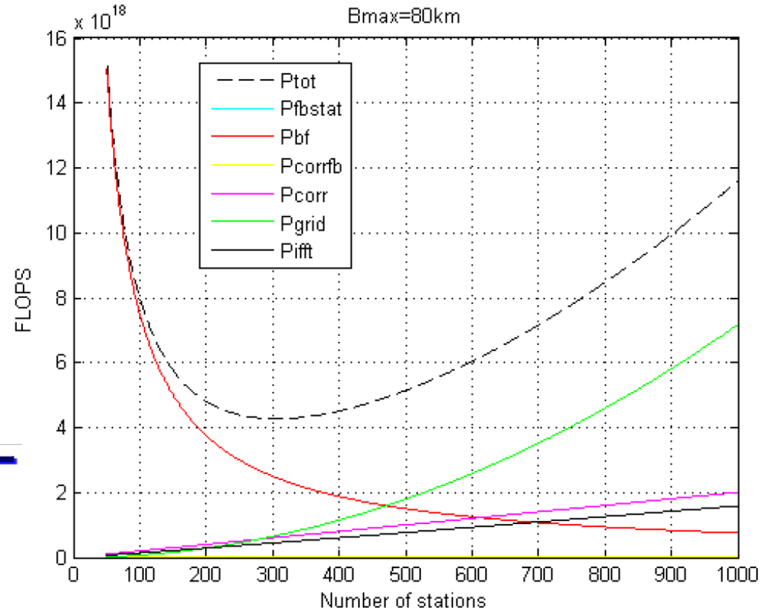
- Large stations
  - small station beams
  - more digital beams required to synthesize the FoV
  - smaller amount of stations to correlate



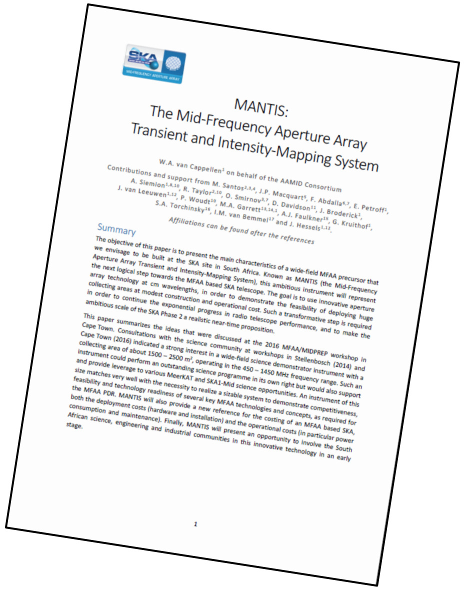
- Small stations
  - large station beams
  - less digital beams required to synthesize the FoV
  - more stations to correlate



- Interesting fact
  - total data rate from MFAA to correlator is constant



MFAA Status


MANTIS:
The Mid-Frequency Aperture Array
Transient and Intensity-Mapping System

W.A. van Cappellen on behalf of the AAMID Consortium

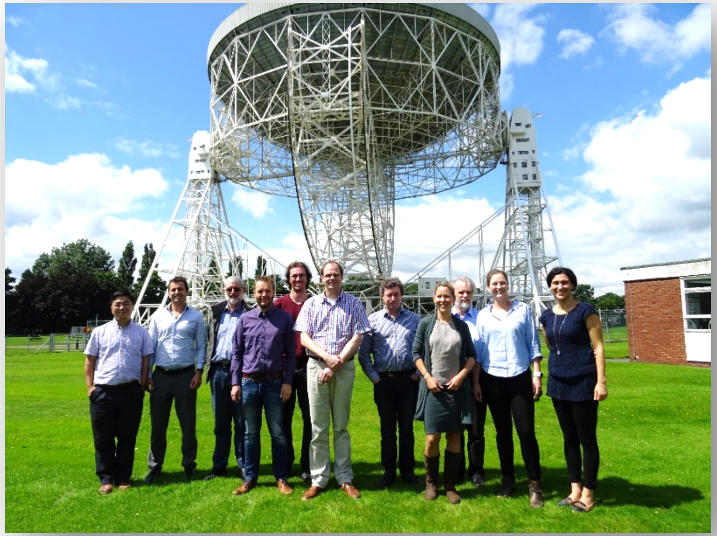
Affiliations can be found after the references

Summary

- ✓ Passed the System Requirements Review
  https://arxiv.org/abs/1610.00683
- ✓ Whitepaper on an MFAA demonstrator
  https://arxiv.org/abs/1612.07917
- ✓ Continued technology R&D and prototyping

+

- Science requirements
- System requirements
- Architectural Design
- Technology
- Risks
- Costs
- …



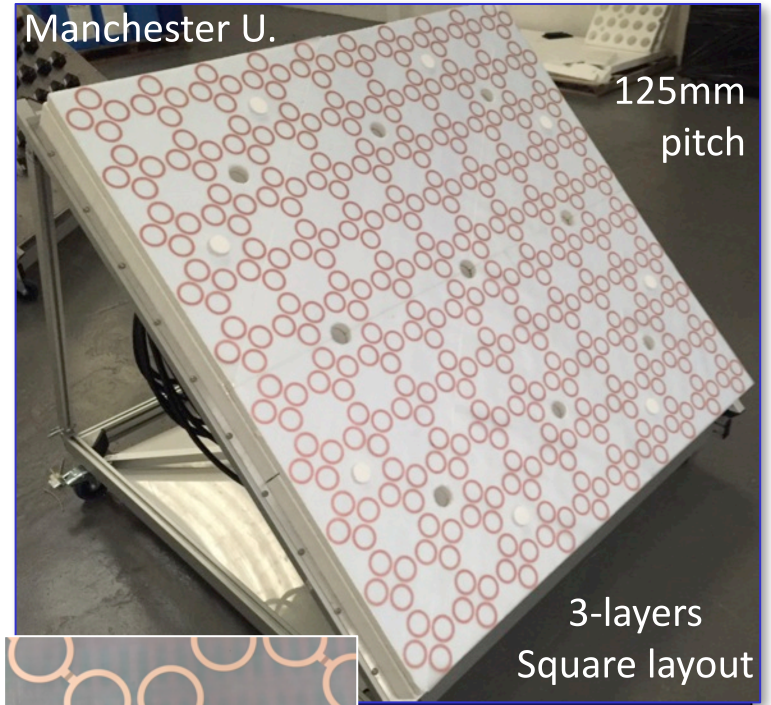
MFAA Key challenges

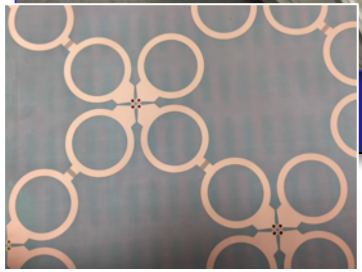
- Reducing power consumption
  - Integration
  - System optimization

- 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)

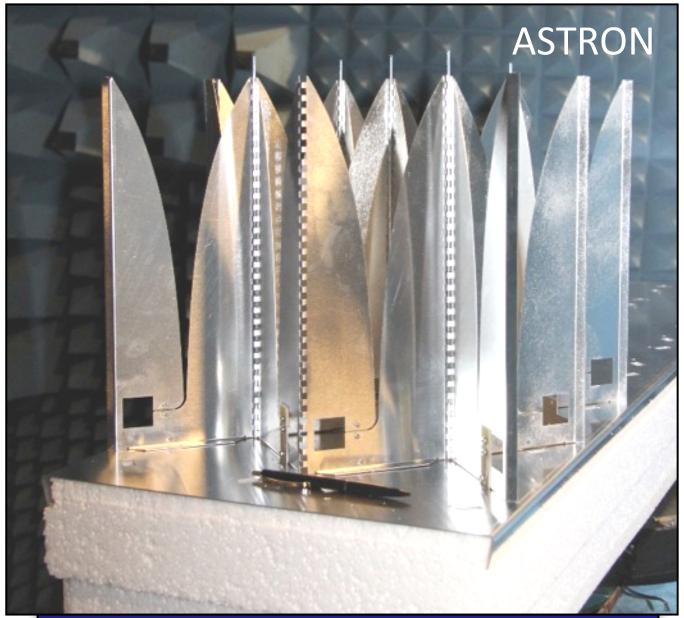
Antennas - Dense



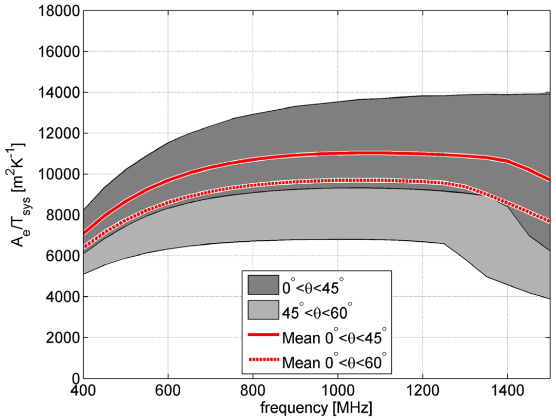


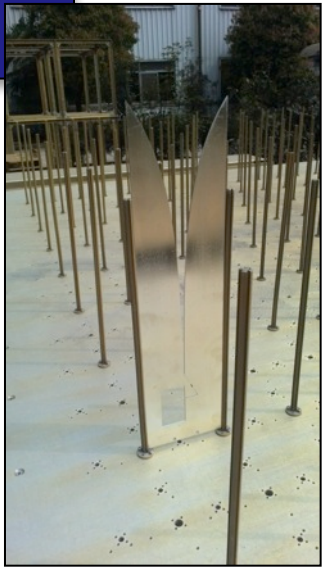
Planar - ORA

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

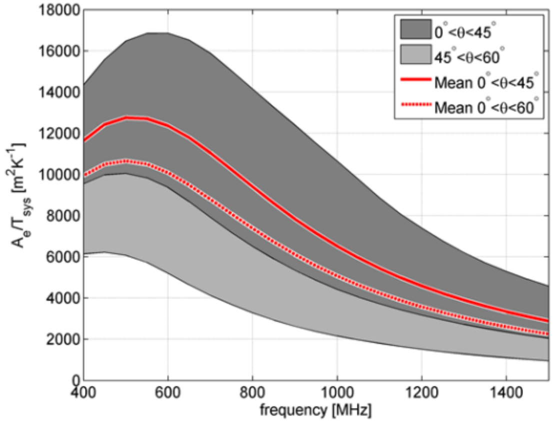


Vivaldi elements





Antennas - Sparse

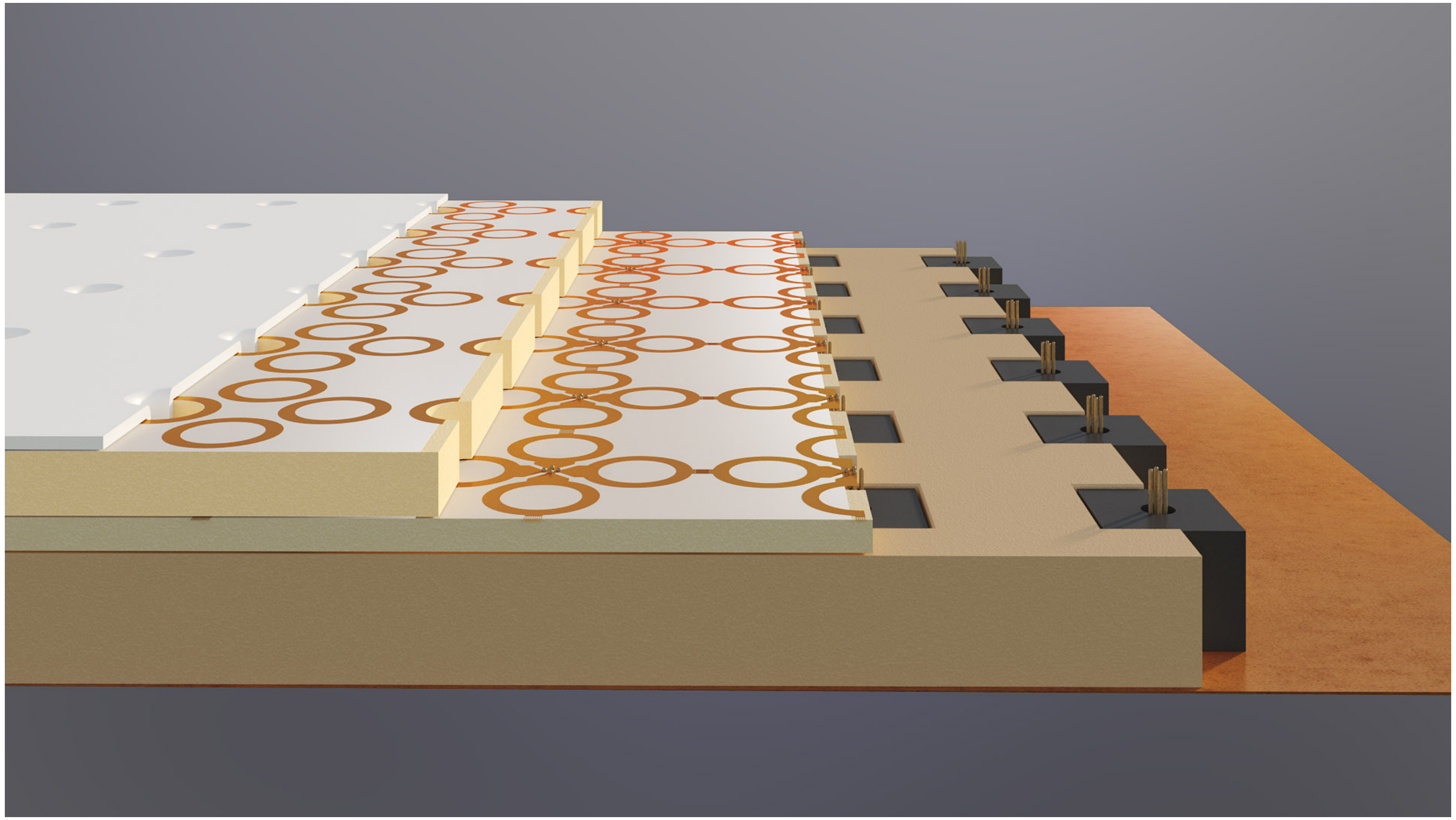


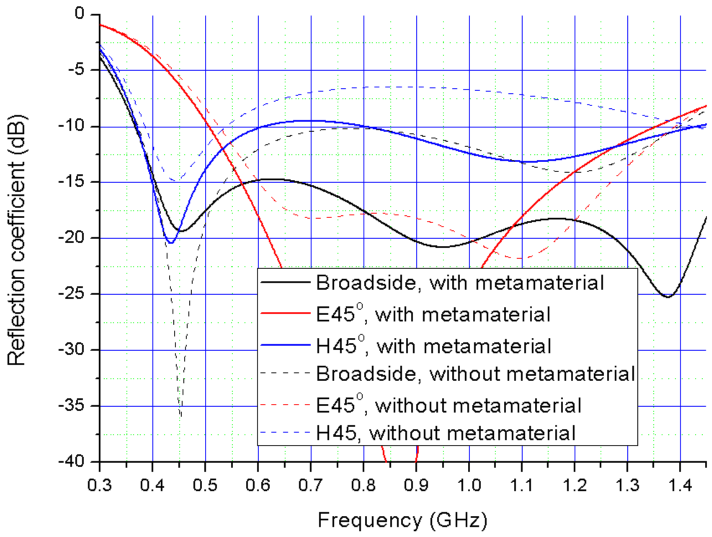
- Log-periodic antenna
- Random layout
- Spacing λ/2 @ **low** frequency

Same concept as LFAA!

Crossed Octagonal Ring Antenna (C-ORA) Design

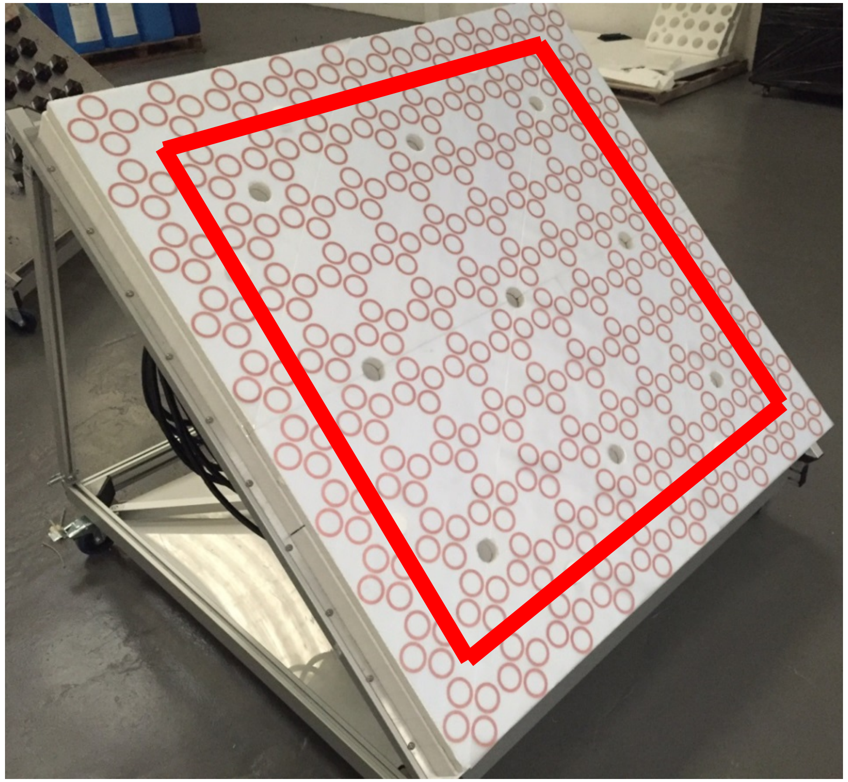
The ORA Layered Structure

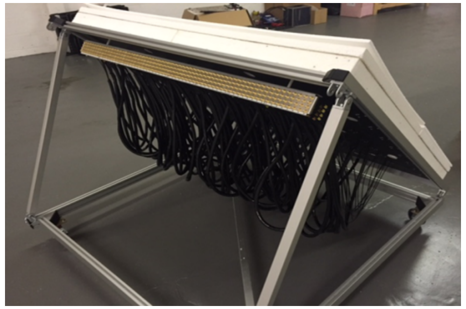




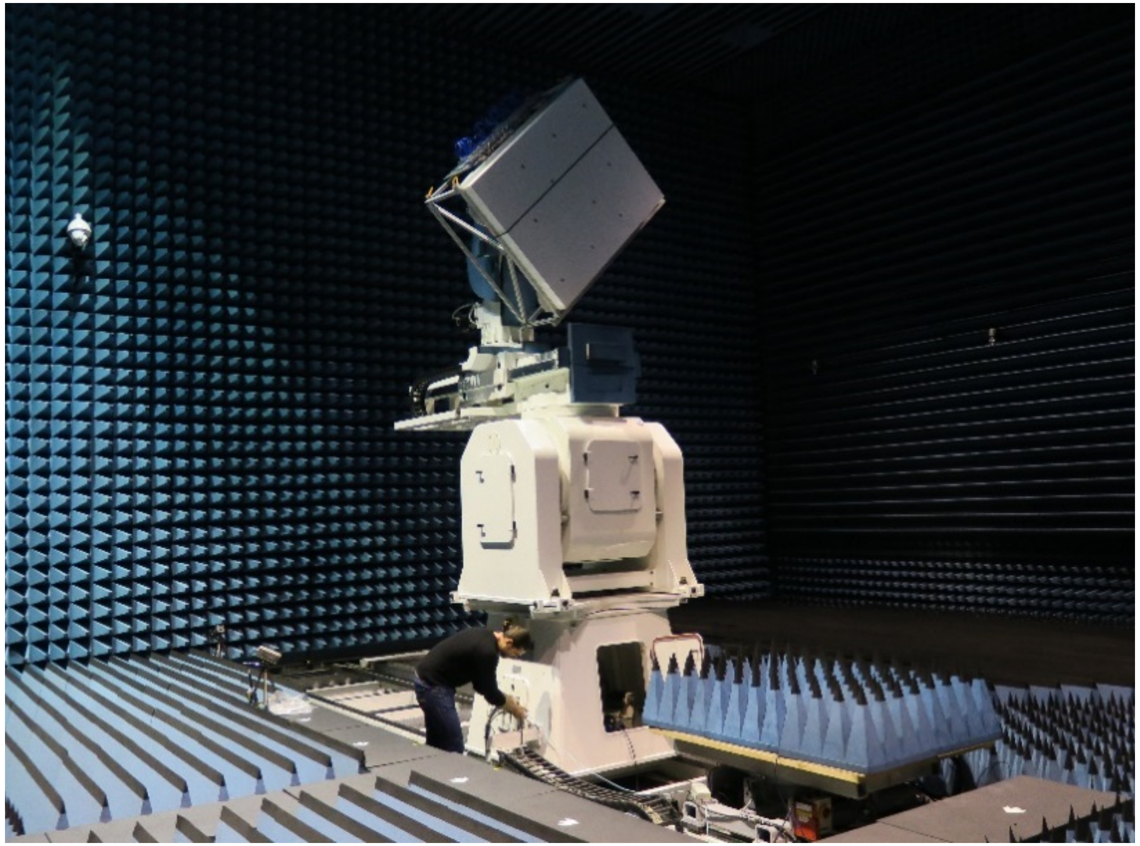
The 1 m² ORA prototype facts

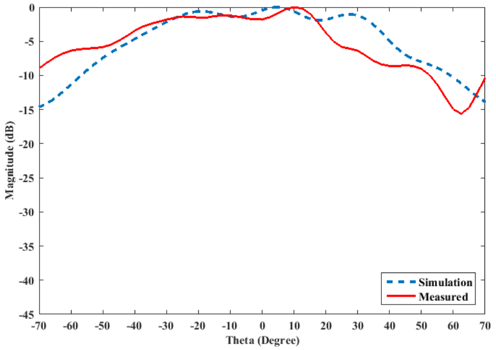
- 10x10 elements(1.25m x 1.25m)
- Dual-polarised for each element
- Frequency 400MHz to 1450MHz
- Element separation: 125mm
- Low profile (array thickness <10cm)
- 64 (8x8) central elements excited (within the red box)
- 36 edge elements terminated with the matched load
- 128 LNAs integrated (64 for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



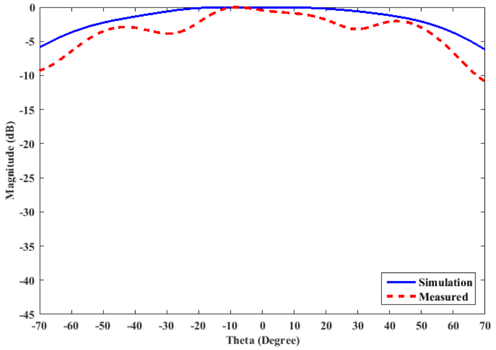


Radiation pattern measurement

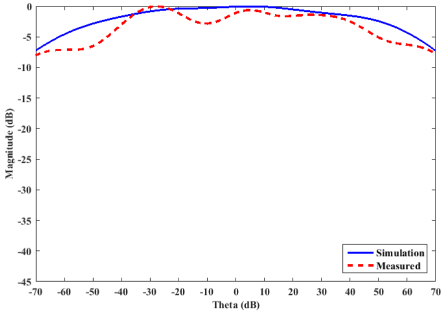




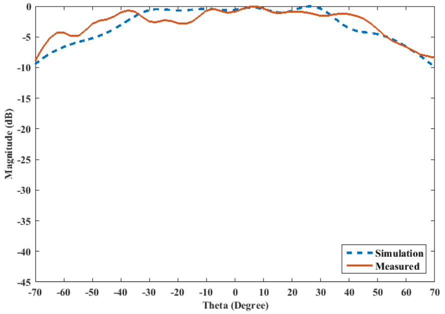
900MHz, E-plane



1400MHz, E-plane

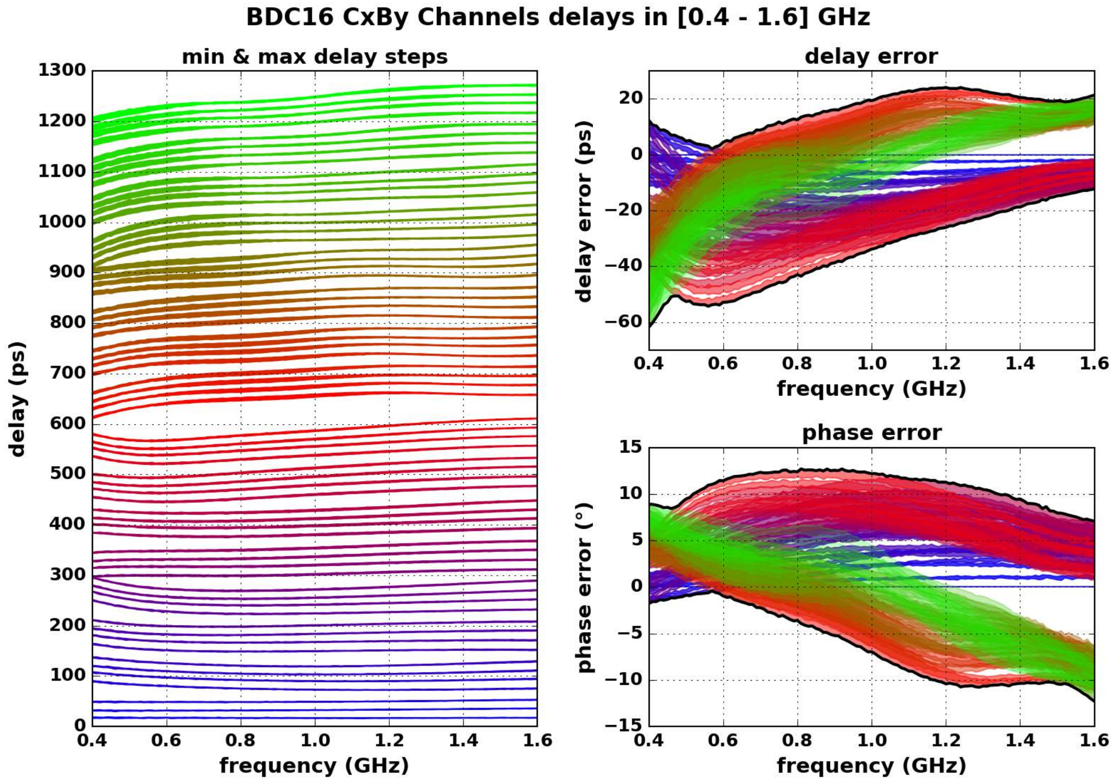


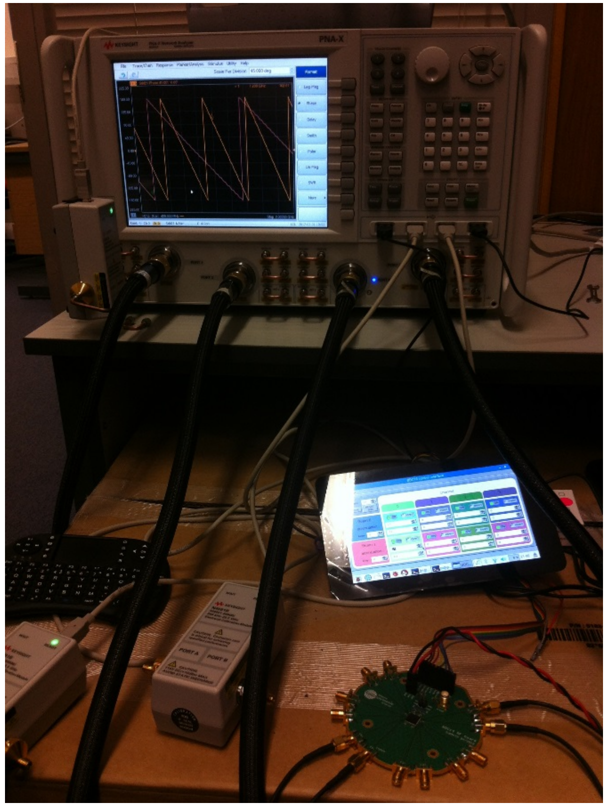
900MHz, H-plane



1400MHz, H-plane

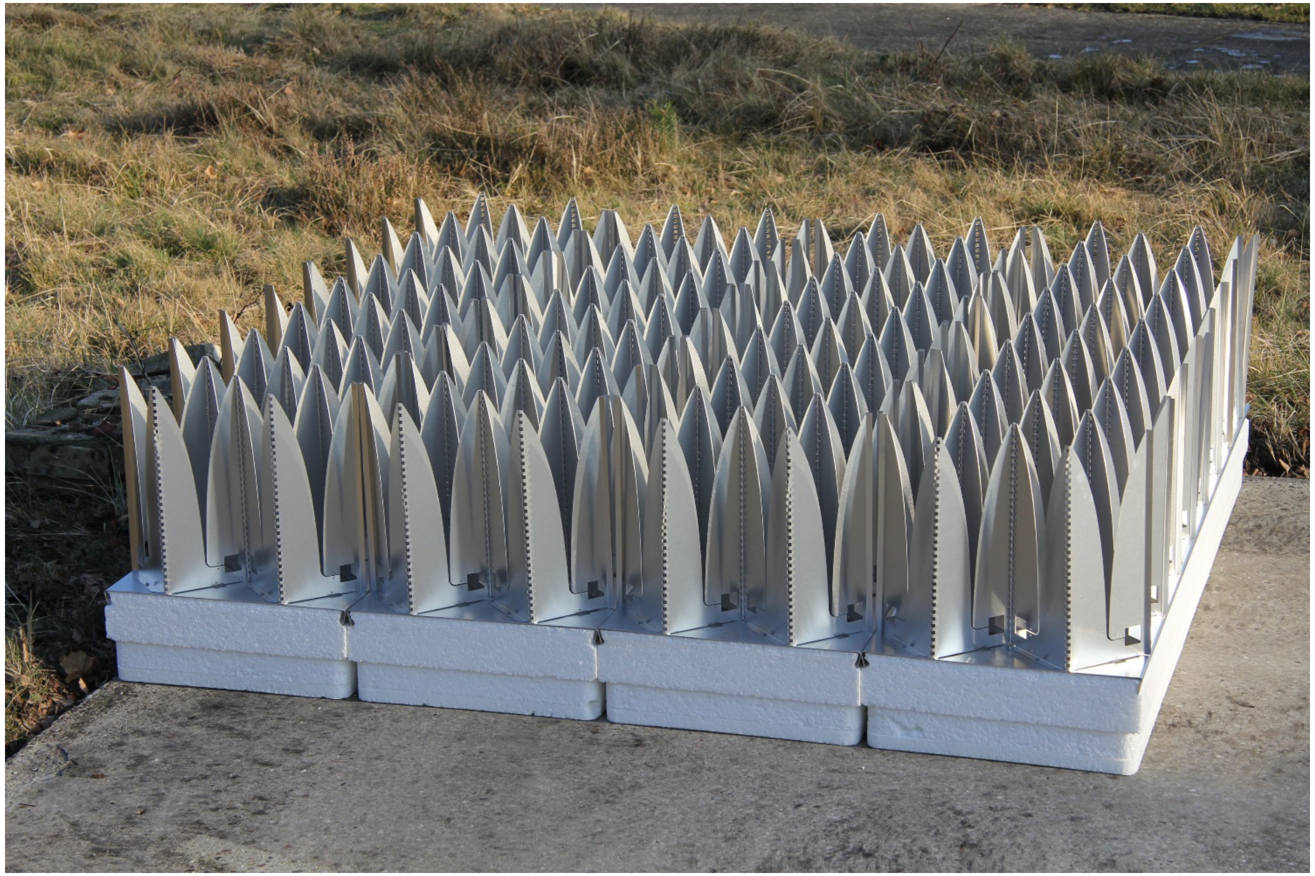
Beamformer board performance

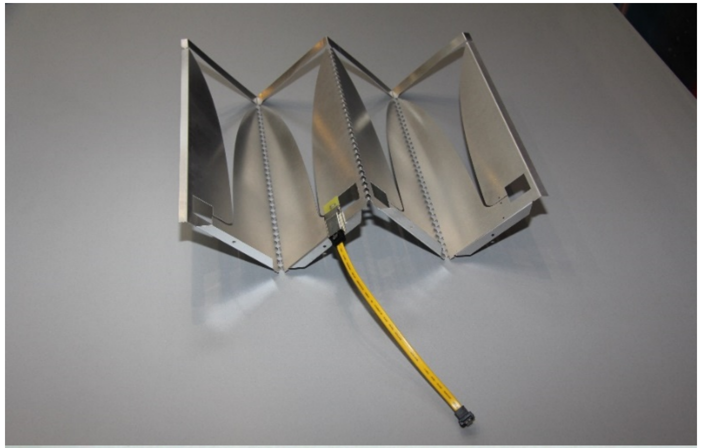


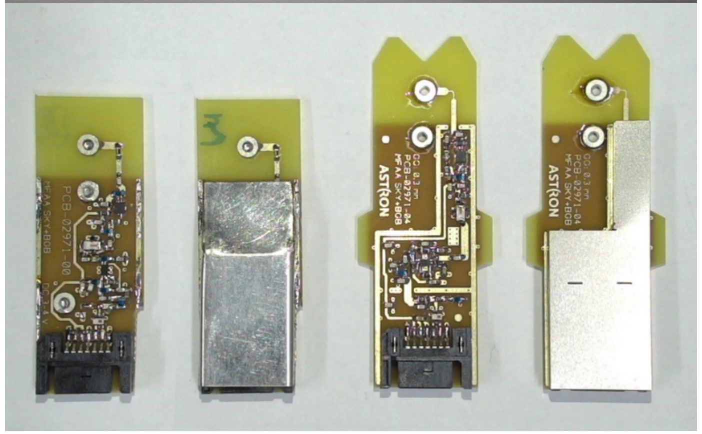


Single-Ended Front-End Development
ASTRON

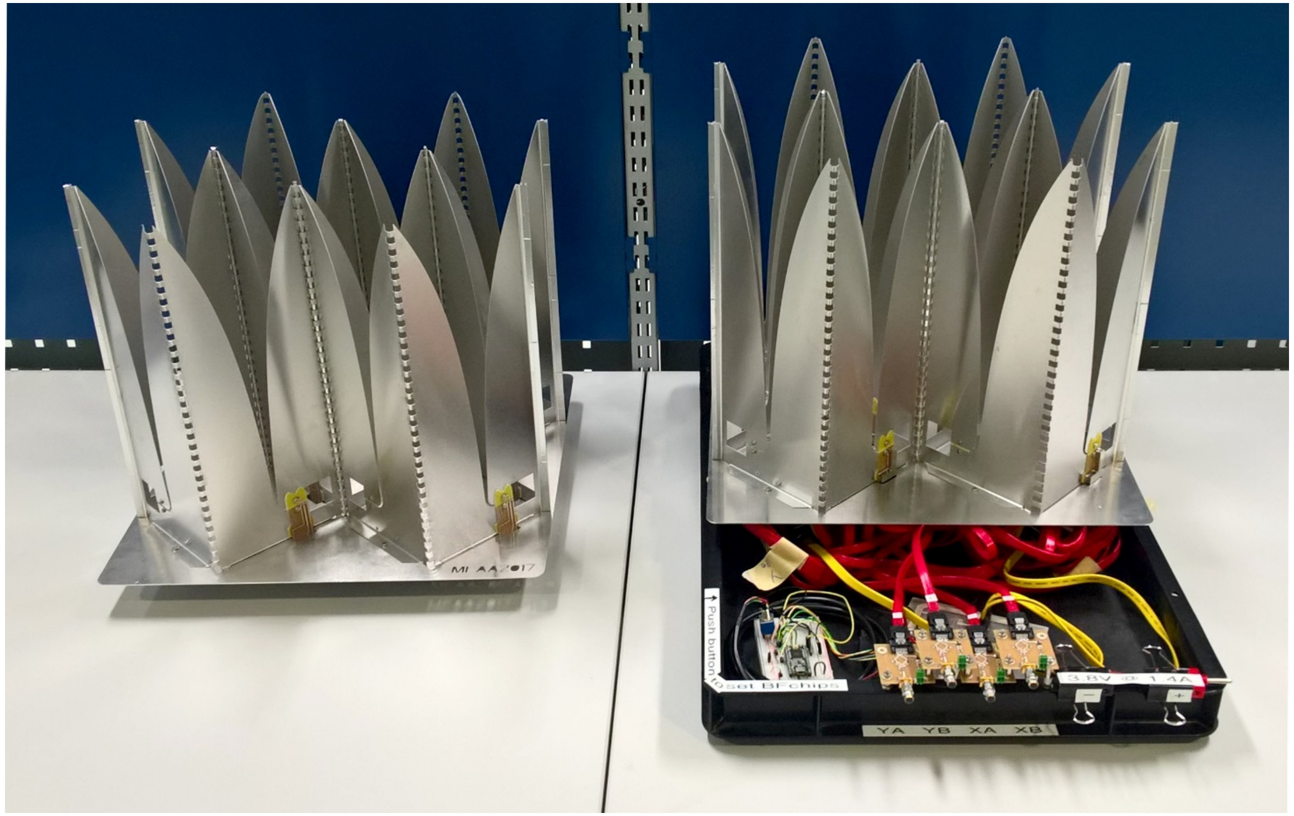
Vivaldi Tile for MFAA







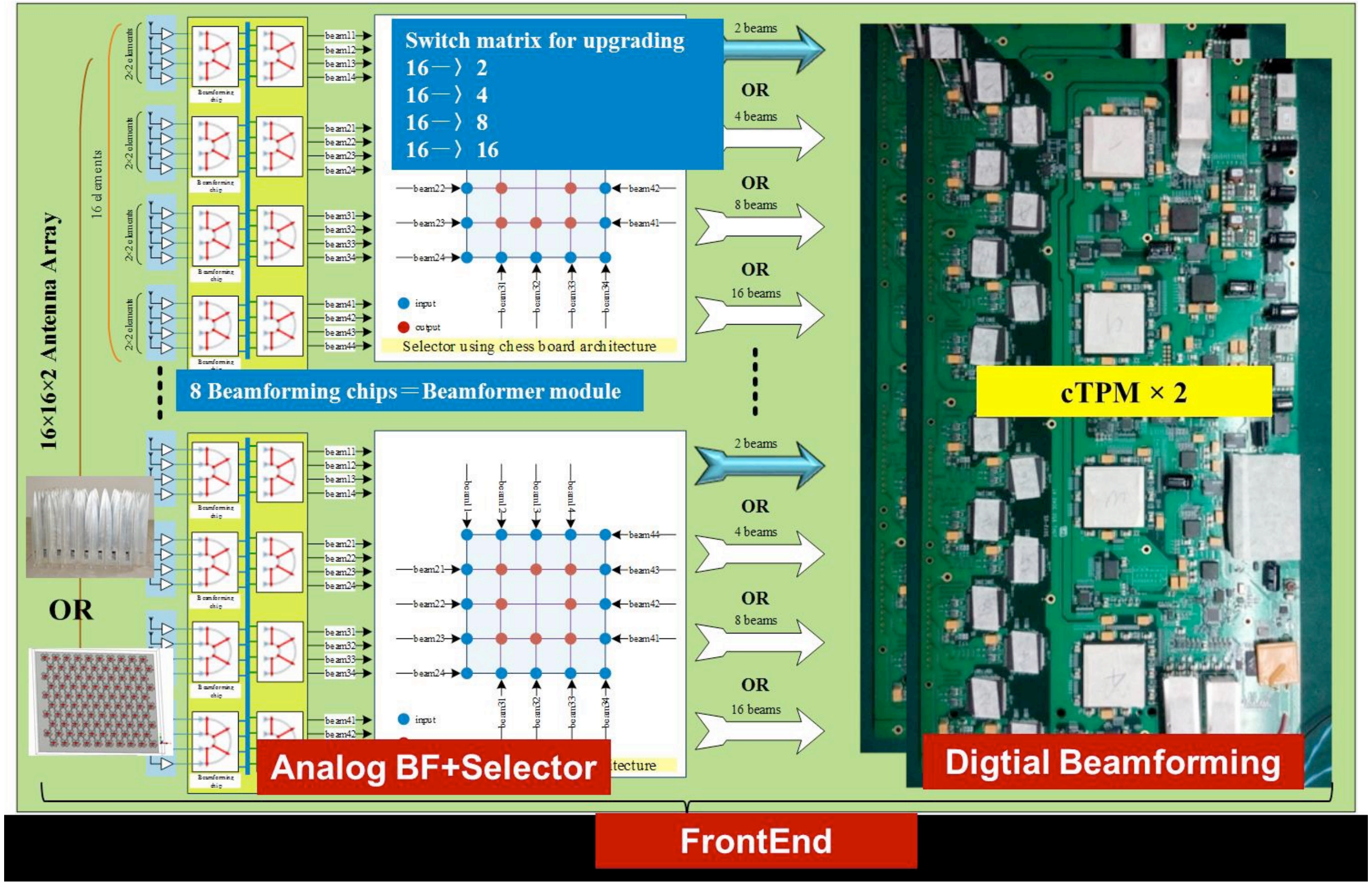
Dual polarisation two beams beamformer



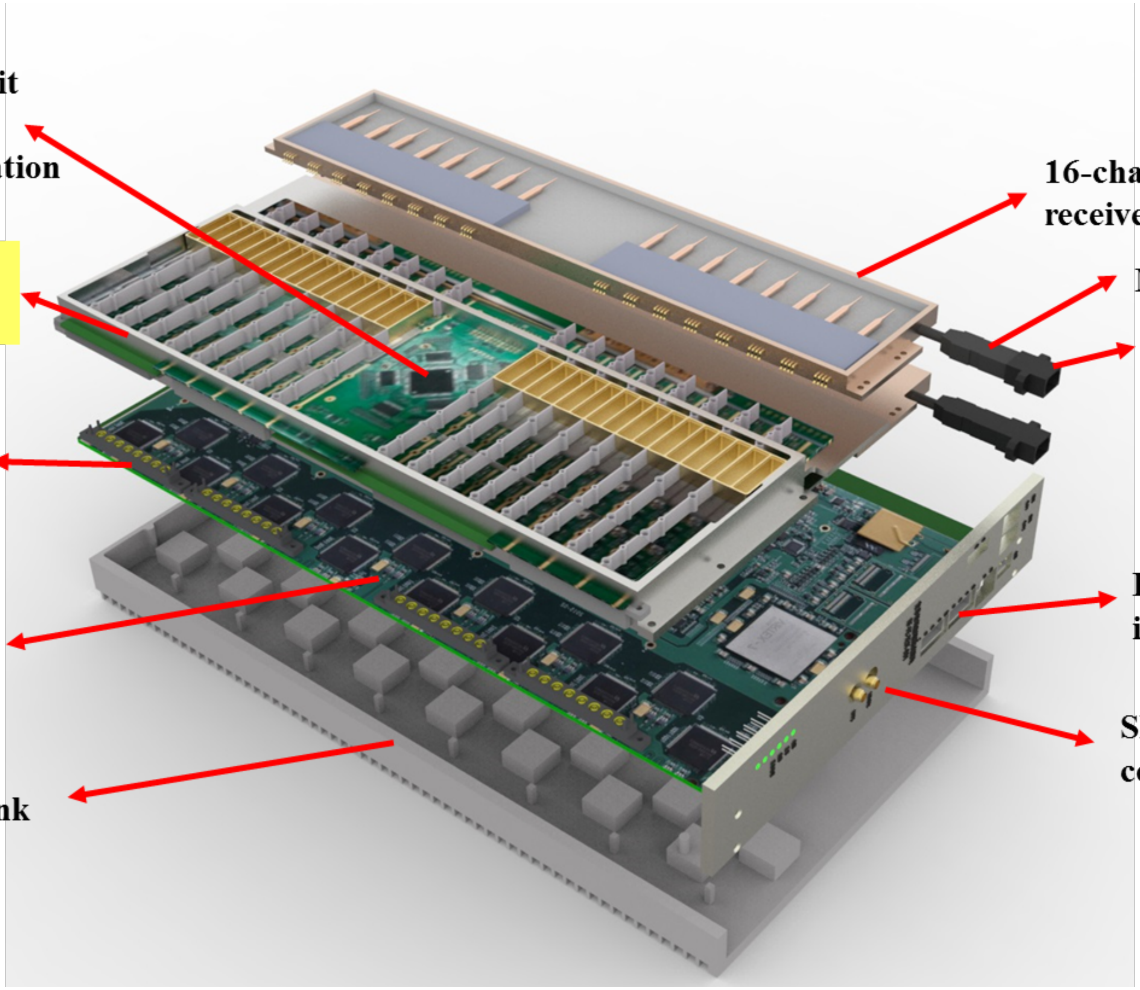
8 elements beamformer PCB for dual polarisations
2 beams for X polarisations
2 beams for Y polarisations

Single-Ended Front-End Development
KLAASA

Architecture

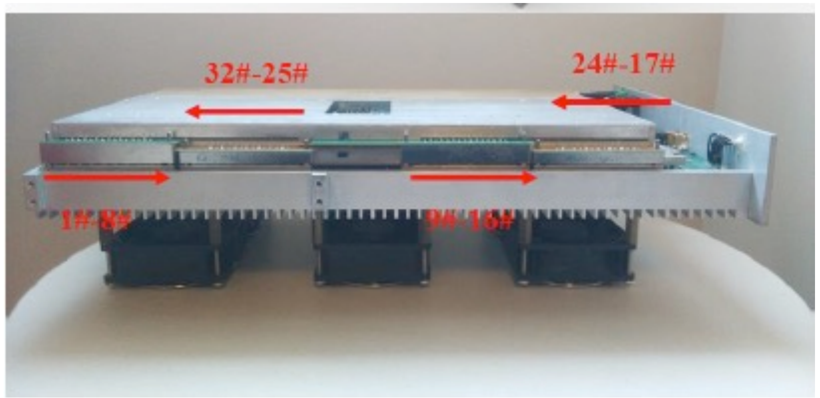


CTPM with three layered structure



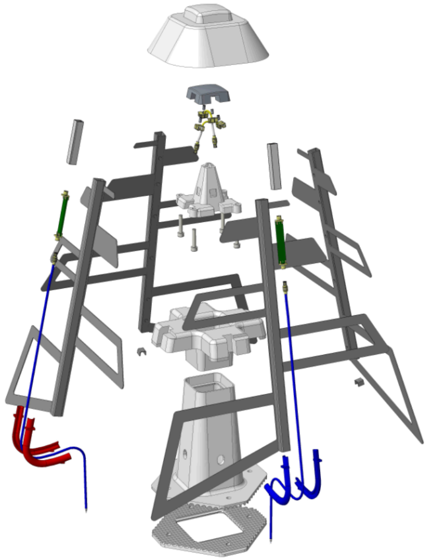
CTPM for MFAA

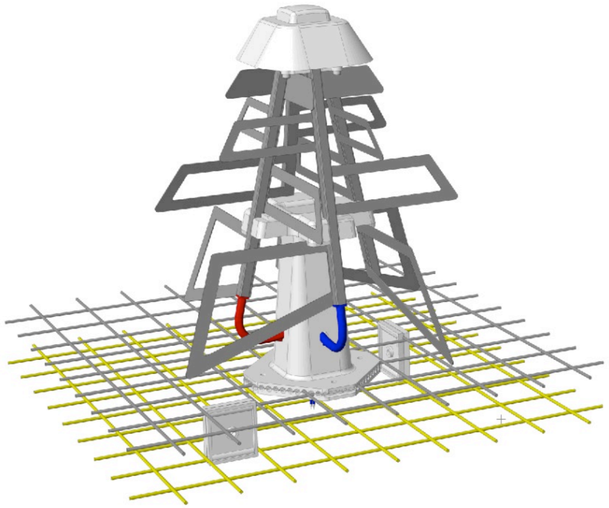
Frequency	500MHz-1500MHz
Rx Channels	32
Band width	400MHz(700MHz-1100MHz)
Amplitude Flatness	≤±1.5dB (Rx)
Band Suppression	≥40dB (Rx)
Attenuator	4bit, 1dB step
Power supply	DC -48V
Digital Output	40Gb/s
Adjacent frequency channel suppression	60dB
Power consumption	≤120W
Size	≤233.35mm×430mm×50mm

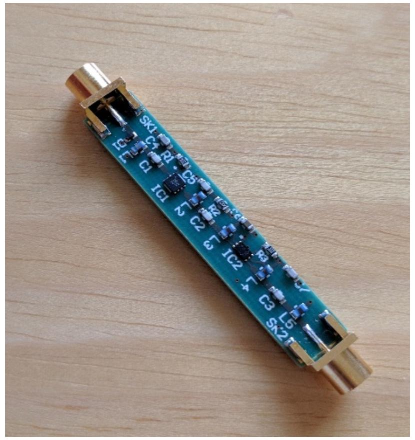


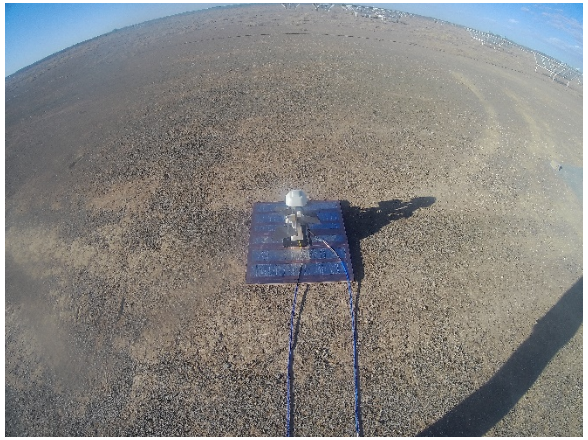
University of Cambridge

- 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









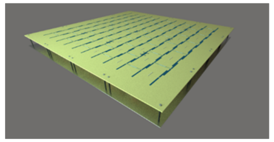
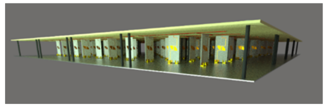
University of Stellenbosch

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

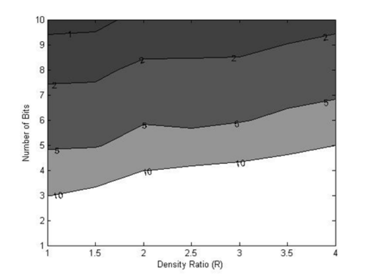


Figure 1: Pointing error with a very basic beamforming algorithm

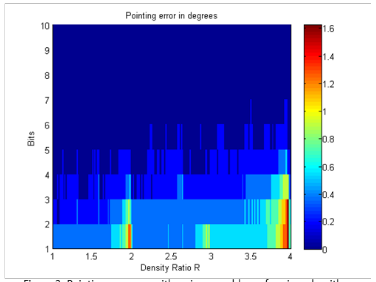
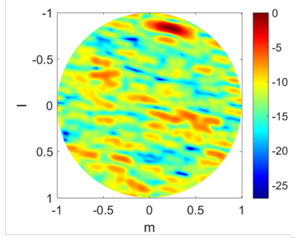


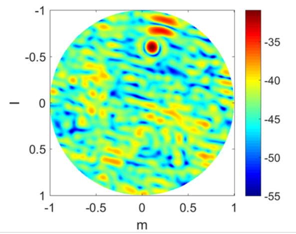
Figure 2: Pointing accuracy with an improved beamforming algorithm

RFI mitigation using spatial filtering

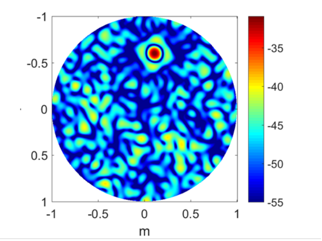
- PhD student: Jan-Willem W. Steeb. Supervisors: Prof Davidson and Wijnholds
- Results below for a LOFAR station with a UAV source.



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.

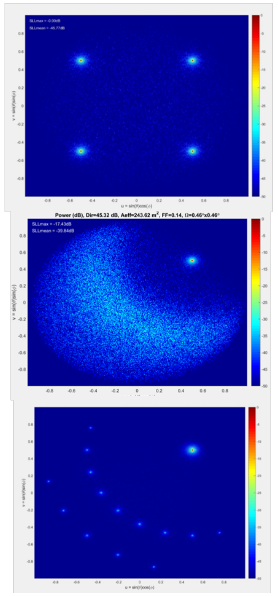


(c) Full skymap with RFI source removed using the adapted orthogonal projection with bias correction in dB. The secondary RFI sources are removed and only the cosmic source is present.

Array Design for a Sparse-Regular FFT SKA Radio Telescope

- 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

- **SKA Phase 1 is only the very first goal of the SKA!**
- 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!