
Engineering the AA Concepts
Jan Geralt Bij de Vaate

# Engineering the AA Concepts

- AA-low
  - Pathfinders
  - Engineering issues
  - Summary
- AA-mid
  - Pathfinders
  - Engineering issues
  - Summary

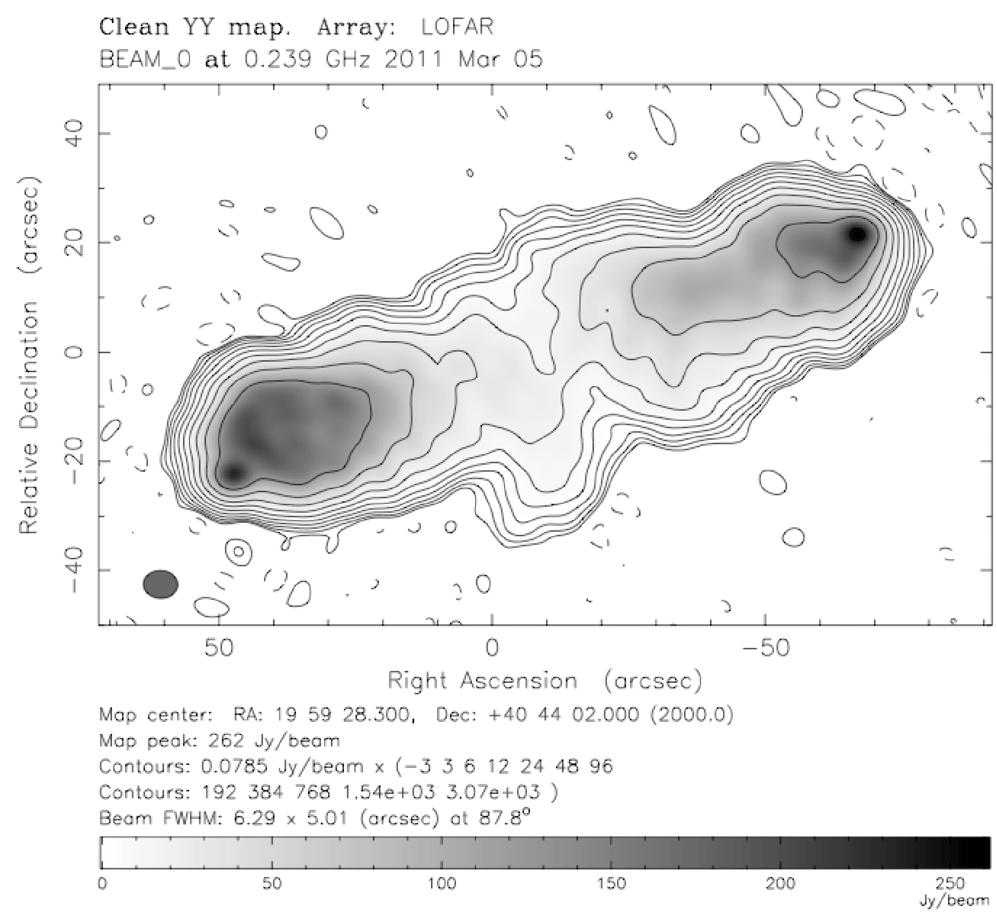
# AA-low Pathfinders

- LOFAR
- Murchison Widefield Array (MWA)
- (Long Wavelength Array (LWA), Paper)

# Pathfinder: LOFAR

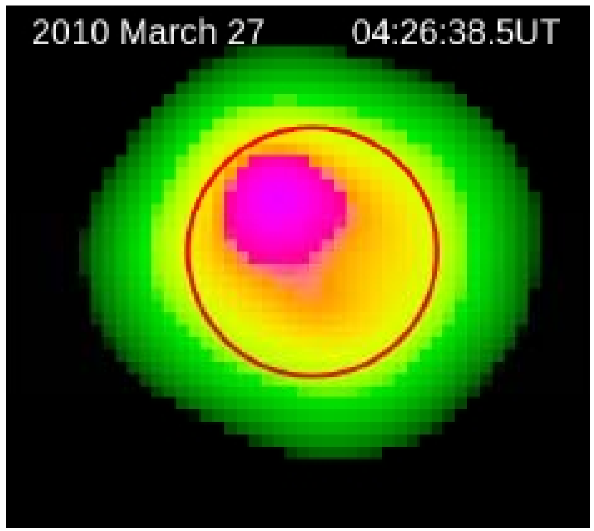
- 33 Dutch stations ready
- 7 International stations ready
- First science results

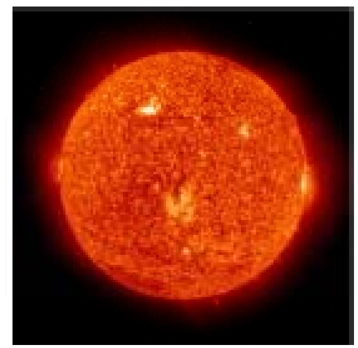
Cygnus A
15 hour observation
with 26 stations



# Pathfinder: MWA

- Low Frequency spectroscopic Imaging of the Sun
- 32 Tiles

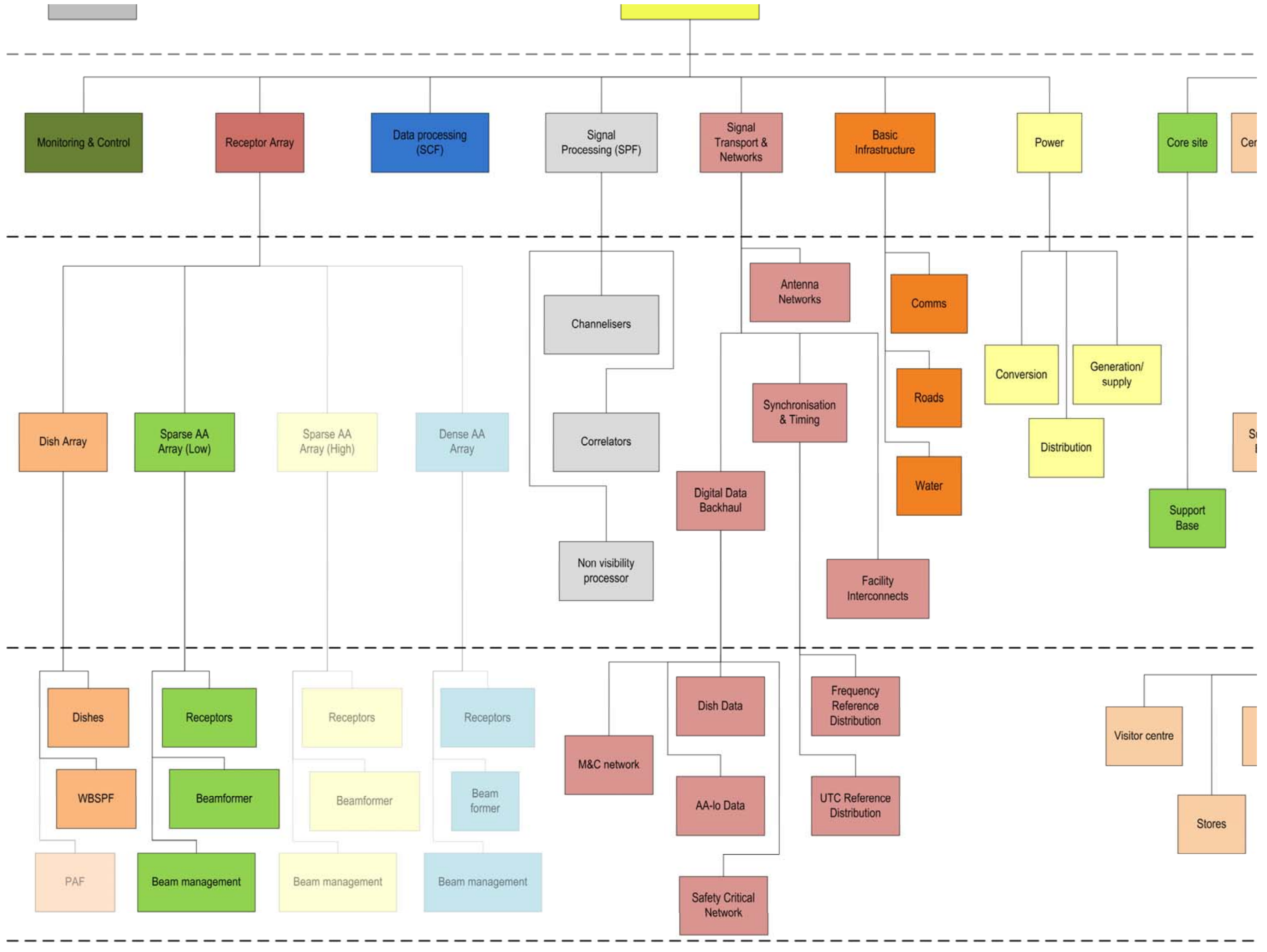


Oberoi ApJ Letters 2011
MWA left SOHO right

# From AA-low Pathfinders to $SKA_1$

- Extended (instantaneous) Frequency range
- Improved $T_{sys}$
- Improved dynamic range
- Improved Field of View
- Cost reduction



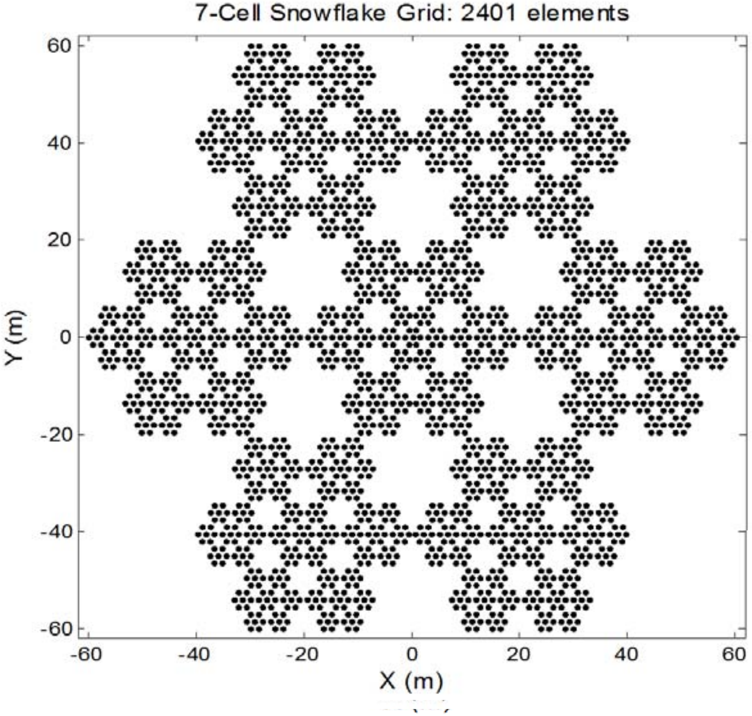
Monitoring & Control
Receptor Array
Data processing (SCF)
Signal Processing (SPF)
Signal Transport & Networks
Basic Infrastructure
Power
Core site
Dish Array
Sparse AA Array (Low)
Sparse AA Array (High)
Dense AA Array
Channelisers
Correlators
Non visibility processor
Antenna Networks
Synchronisation & Timing
Digital Data Backhaul
Facility Interconnects
Comms
Roads
Water
Conversion
Generation/ supply
Distribution
Support Base
Dishes
WBSPF
PAF
Receptors
Beamformer
Beam management
Receptors
Beamformer
Beam management
Receptors
Beam former
Beam management
M&C network
Dish Data
AA-lo Data
Safety Critical Network
Frequency Reference Distribution
UTC Reference Distribution
Visitor centre
Stores

# Issues

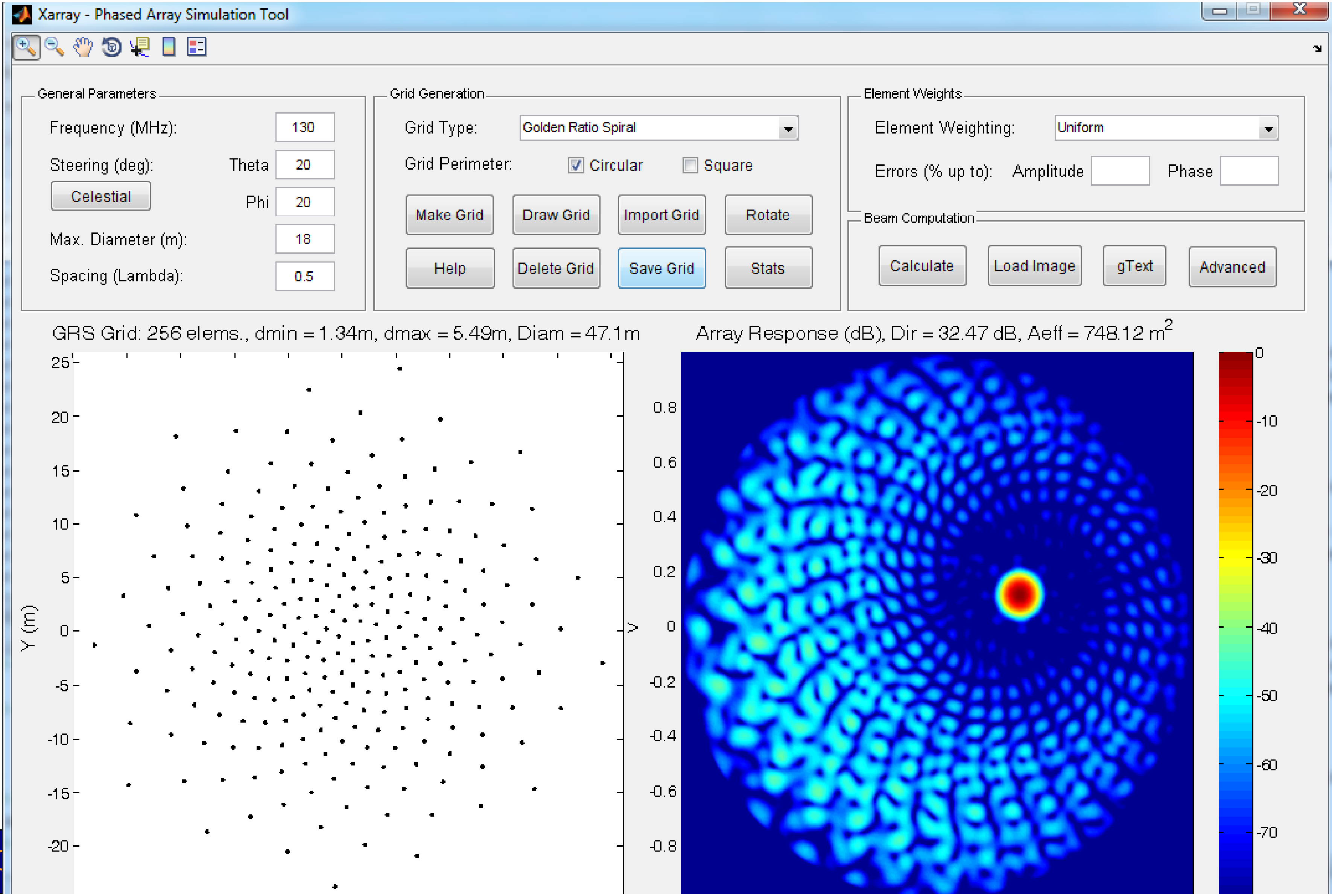
- Tier 3: Array Concepts
- Tier 4:
  - Antenna
  - Low Noise Amplifier
  - Receiver + ADC
  - Tile Signal Processing
  - Station Processing

# Antenna Array Concepts

- Regular Lattice grid
- Random Sparse
- Golden Ratio Spiral
- Snow flake



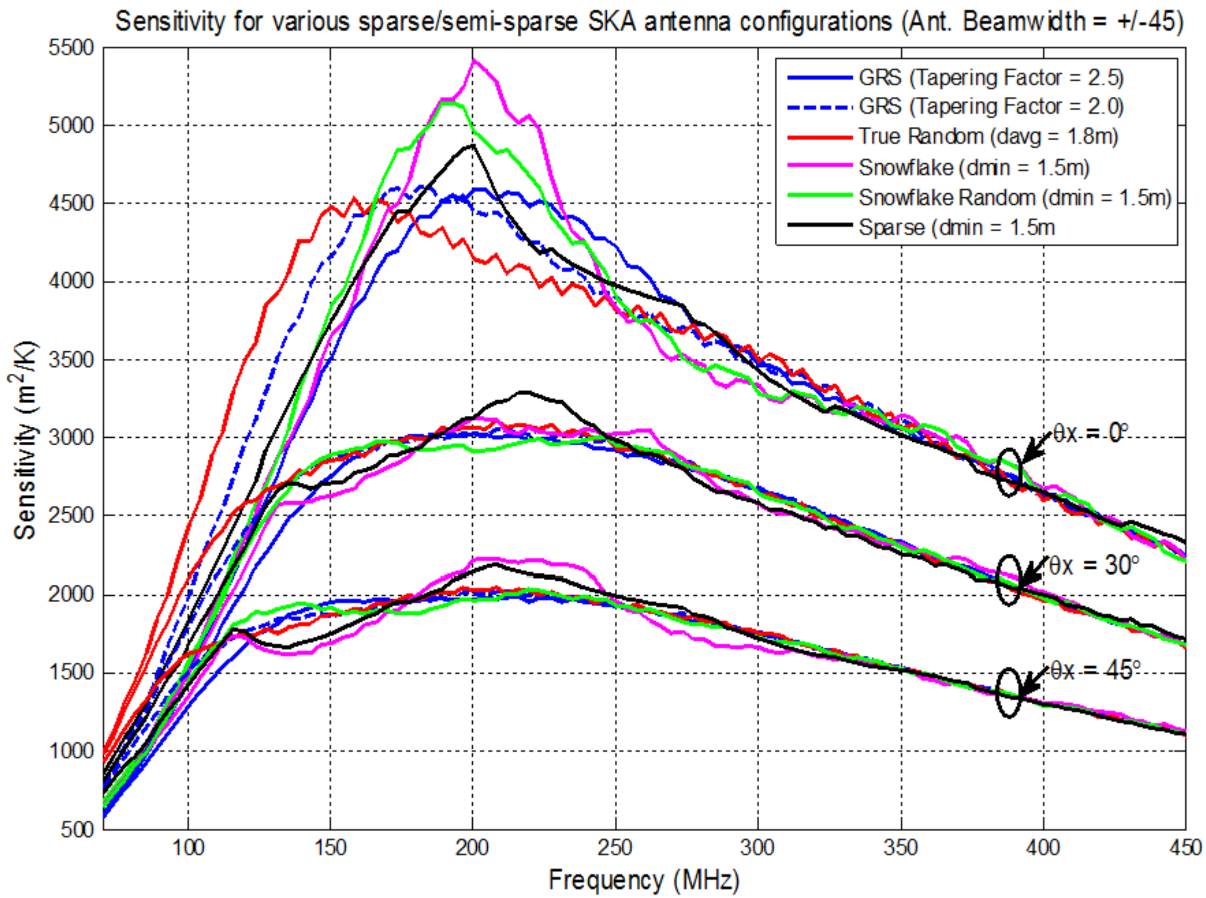
# Antenna Array Concepts: xarray



# Antenna Array Concepts: xarray

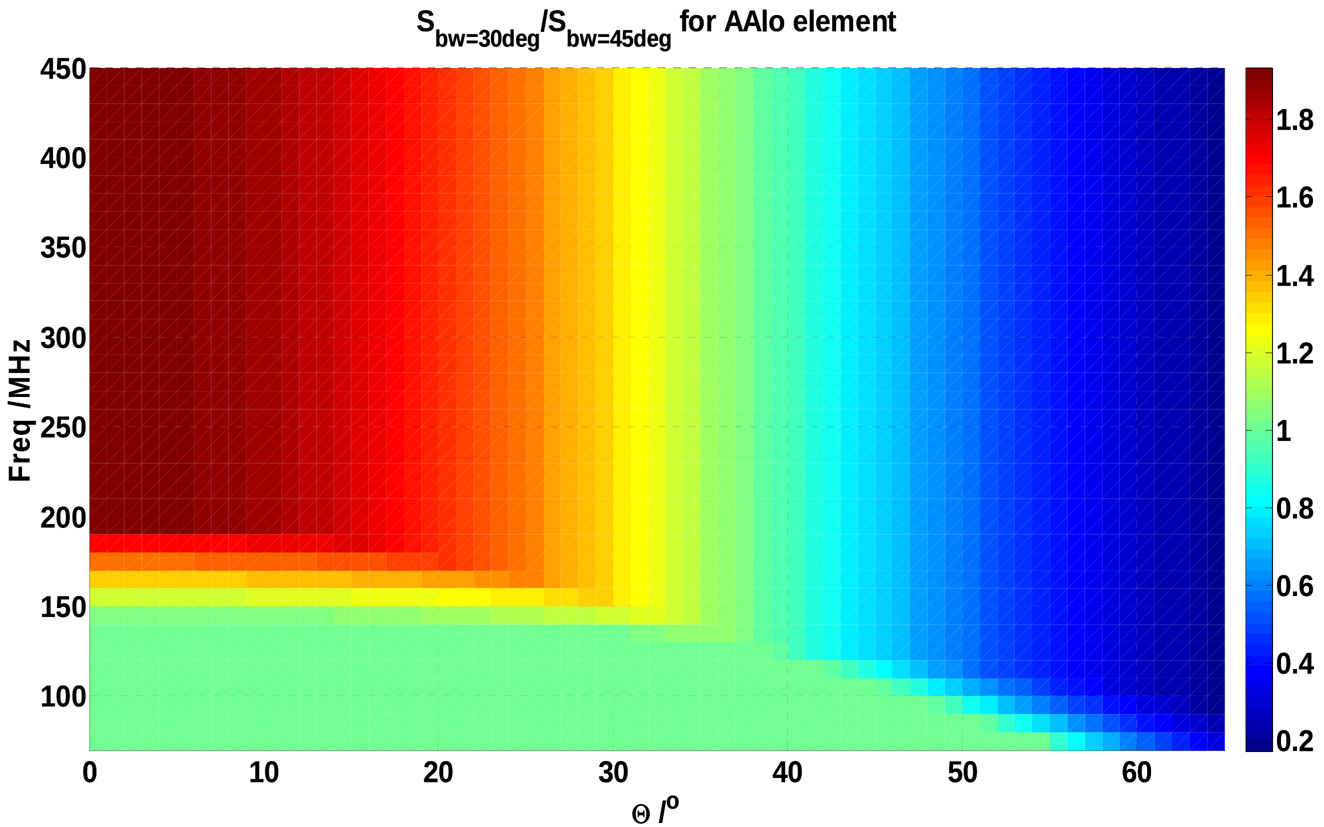
SKA-AAVP

- This example:
  - Medium gain antenna (+/-45 degree Beam width)



# Antenna Array Concepts: xarray

- Ratio between Low gain (45 degree) and High gain (30 degree) Antenna



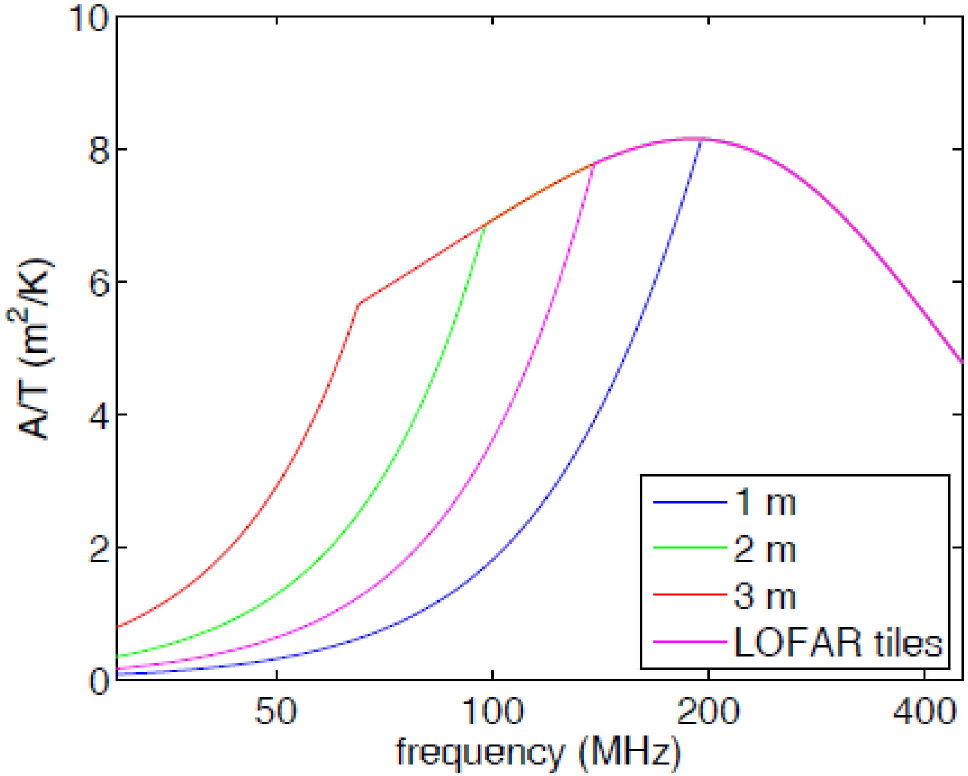
# Antenna Array Concepts

| | Deployment cost | Freq bandwidth | $A_{eff}/T_{sys}$ | Dynamic range |
|---|---|---|---|---|
| Random elements | High | Good | Optimal | Optimal |
| Random tiles | Moderate | Good | Good | Good |
| Regular grid tiles | Low | Optimal | Good | (strong gratings) |

-LOFAR, MWA, AAVP will need to confirm/complete the trade-offs and array simulations

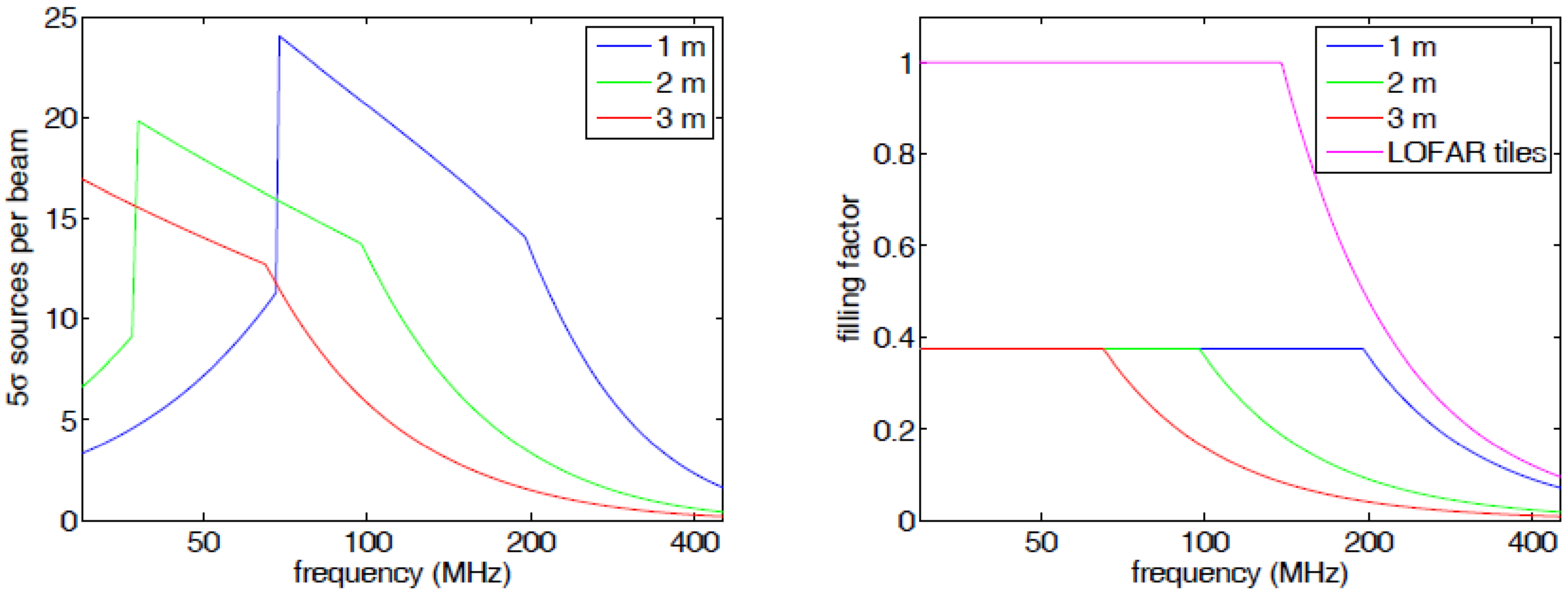
-***More:*** Filling factor, uv coverage, calibration, FoV, redudant baselines

# Array Concepts: $A_{eff}$



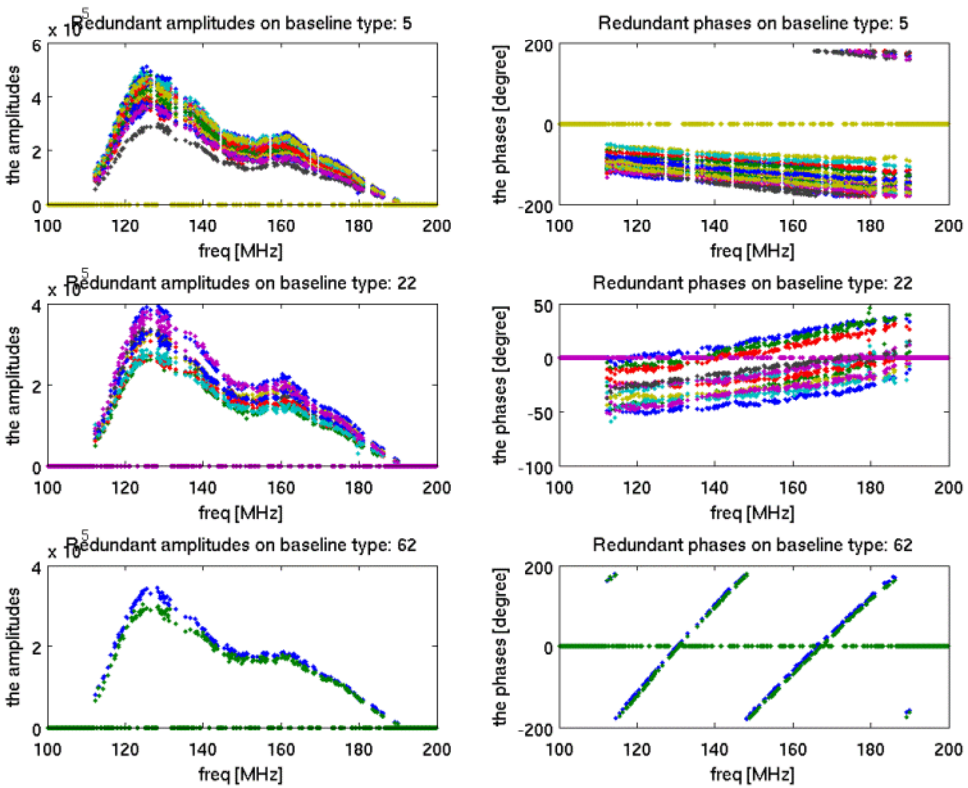

- Sensitivity as function of unit spacing

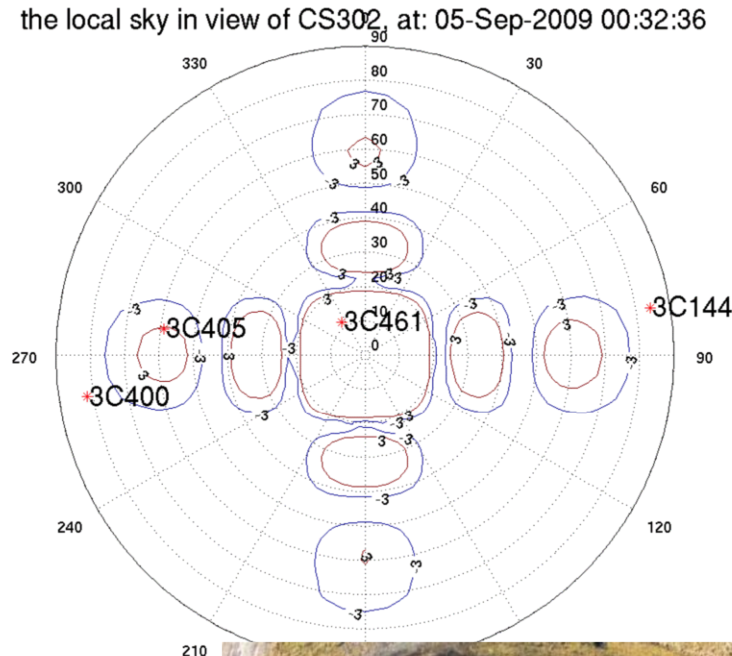
# Array Concepts: filling factor

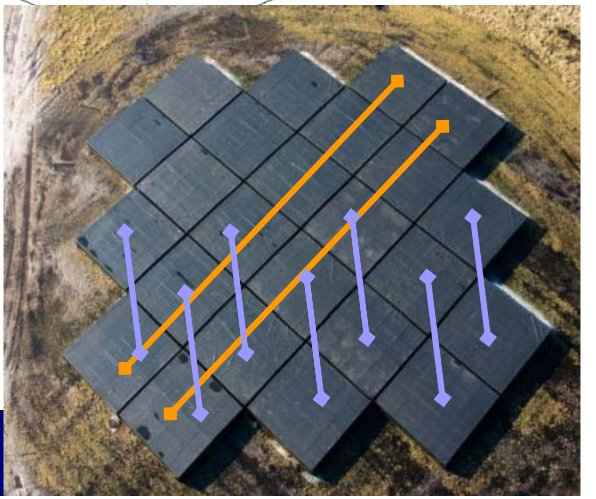



- The number of 5sigma sources in a 10 sec snapshot observation

# Demo redundancy monitoring: 24h obs at CS302, LOFAR HBA zenith tile beam is formed



*When redundancy assumption holds for HBAs, its calibration algorithm works well*

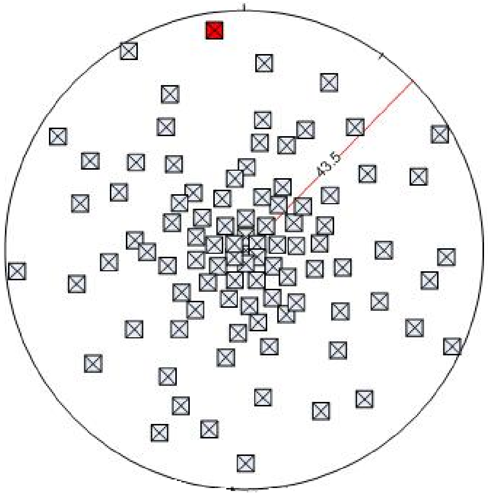
Courtesy: Parisa Noorishad, Stefan Wijnholts

# LOFAR Low Band Antenna

96 Low Band Antennas per station

Station diameter: 45 – 85 m (LBA)

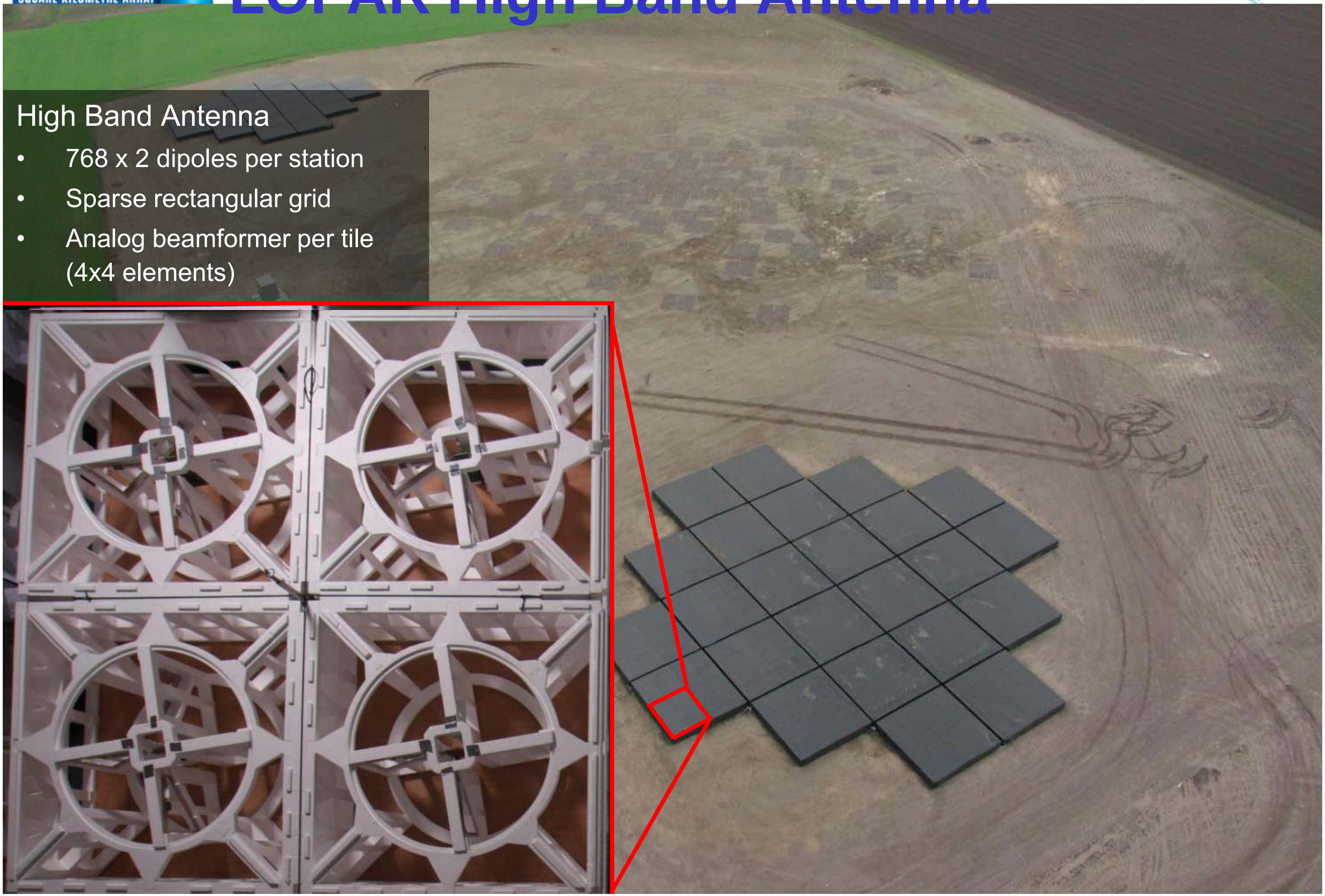
Sparse pseudo-random configuration



# LOFAR High Band Antenna

High Band Antenna

- 768 x 2 dipoles per station
- Sparse rectangular grid
- Analog beamformer per tile (4x4 elements)



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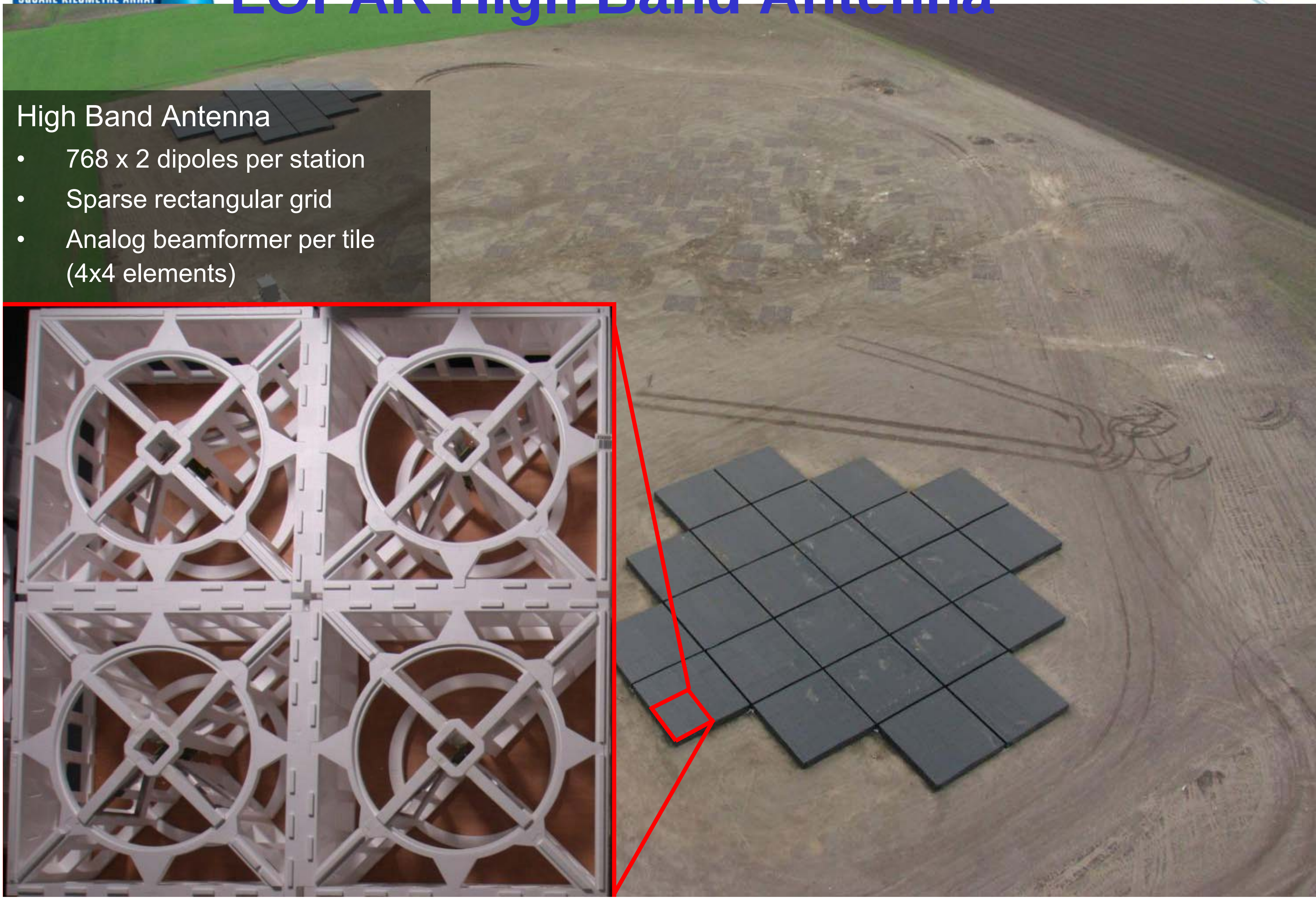
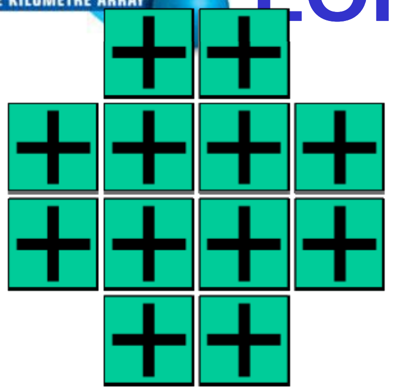
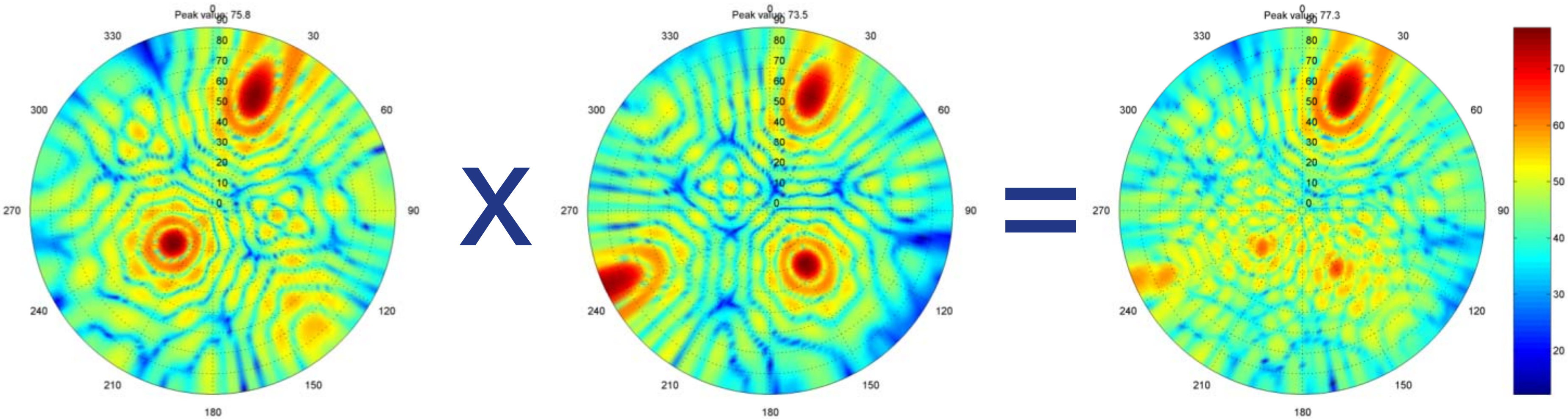


# LOFAR HBA Station rotation






- HBA tiles have a different orientation in every station
- The product beam suppresses grating lobes
- Individual dipoles are rotated back for calibration purpose

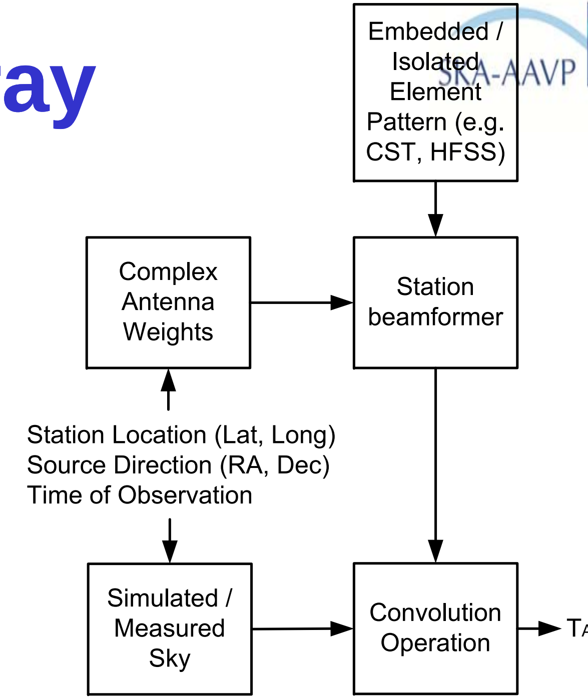
# Array Concepts: MWA

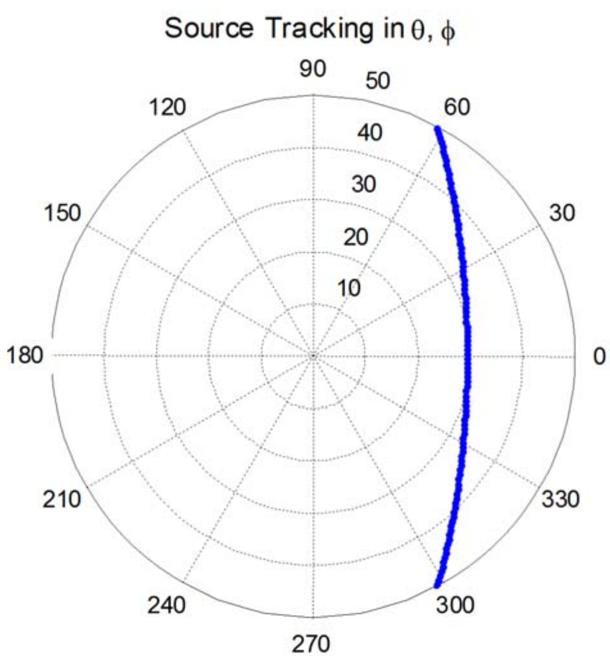
# Array Concepts: MWA

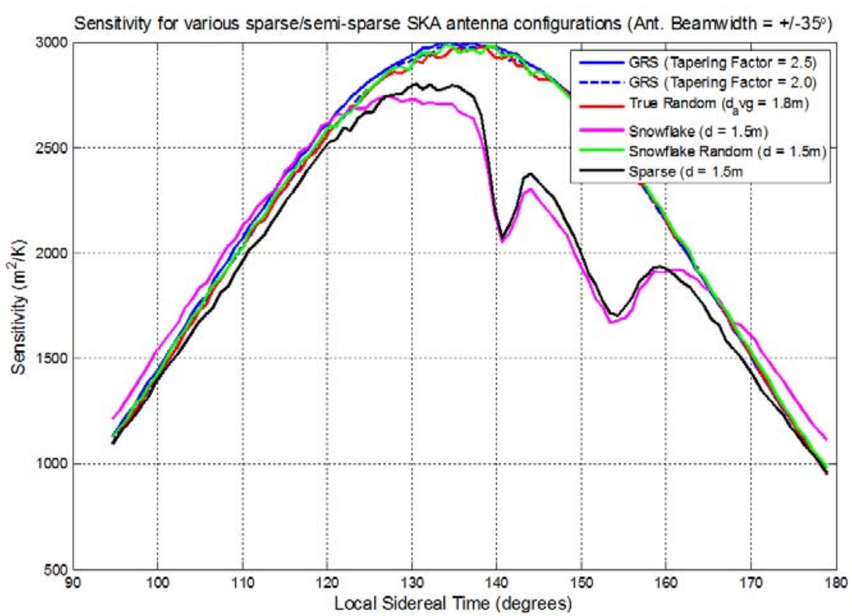
- MWA 512 tile configuration
- Active Tile placement (controlled random)
  - uv Coverage
  - Beampattern
  - Landscape
  - Cabling

# Array Concepts: xarray

- Extend the simulations with:
  - Sky model
  - Antenna pattern



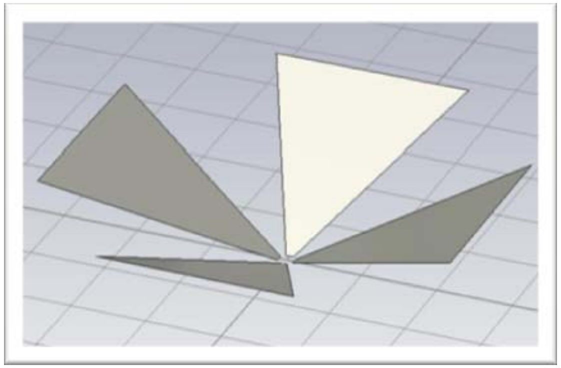
# Antenna Concepts

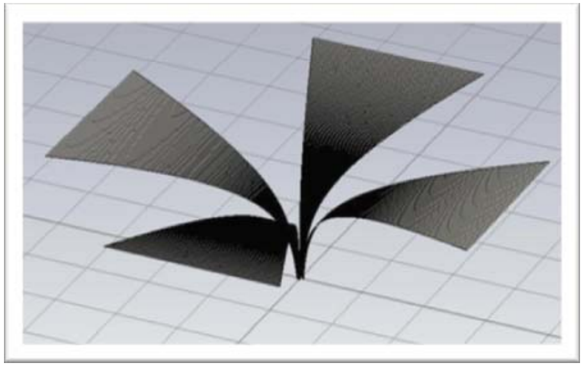
- MWA / LOFAR antenna concepts are not sufficient for the large bandwidth requirement

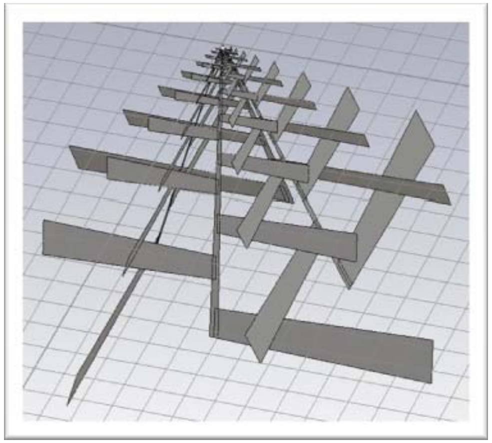
- ‘Enhanced’ Dipole
- Conical Spiral
- Vivaldi

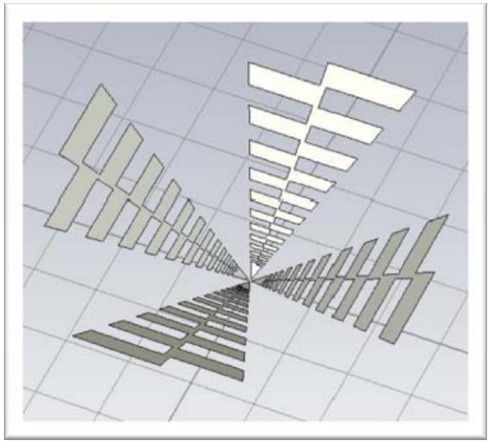
# Antenna Concepts

- Bow Tie, Log Periodic, Toothed log periodic



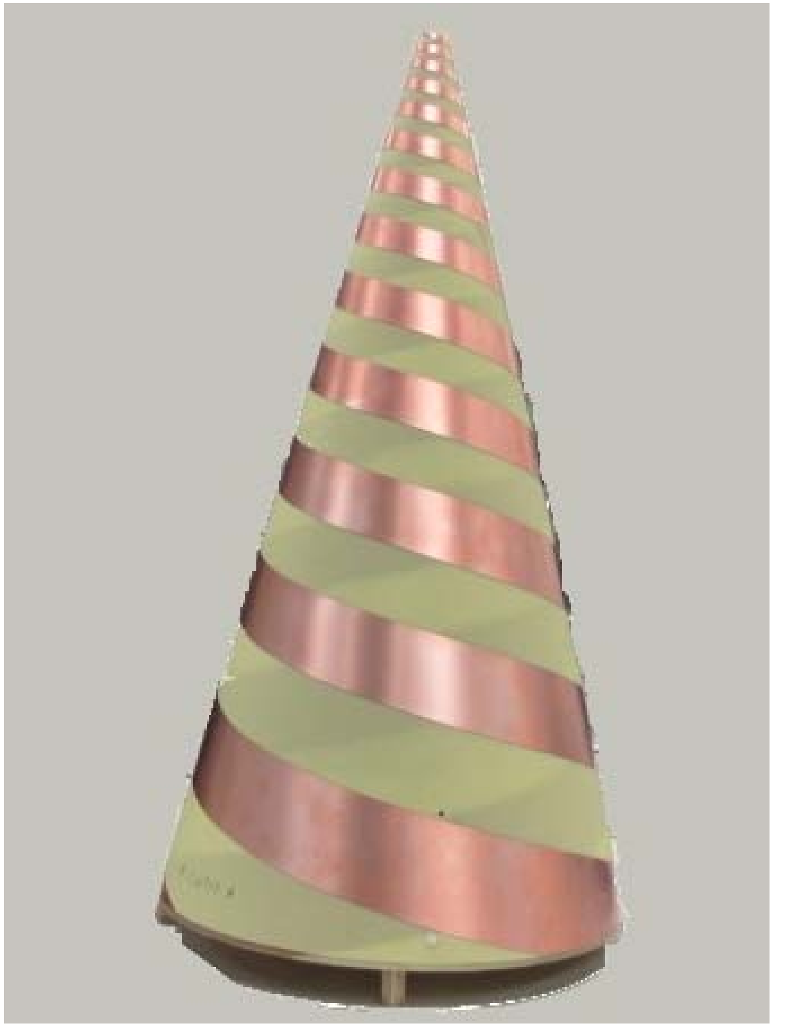






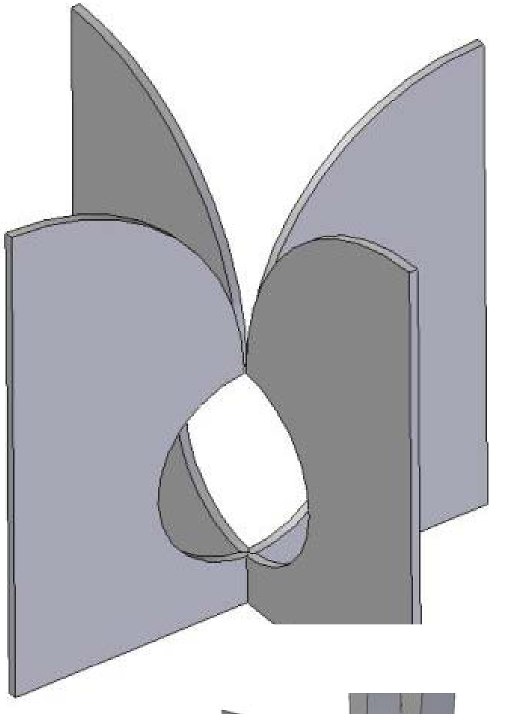
# Conical Spiral

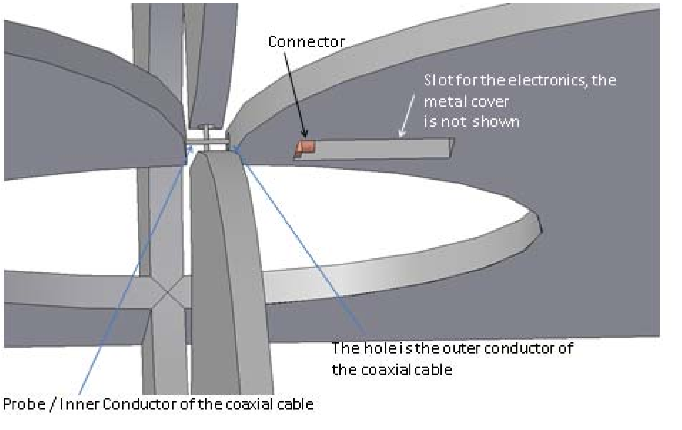
- Single polarization  well known
- Very Benign impedance
- Limited dual polarization results
- Equal E and H plane



# Vivaldi

- Large bandwidth
- Well known concept
- Good polarization behavior





# Antenna Concepts

- Antenna Gain, Directivity -- $A_{eff}$
- Antenna gain -- Sky Coverage

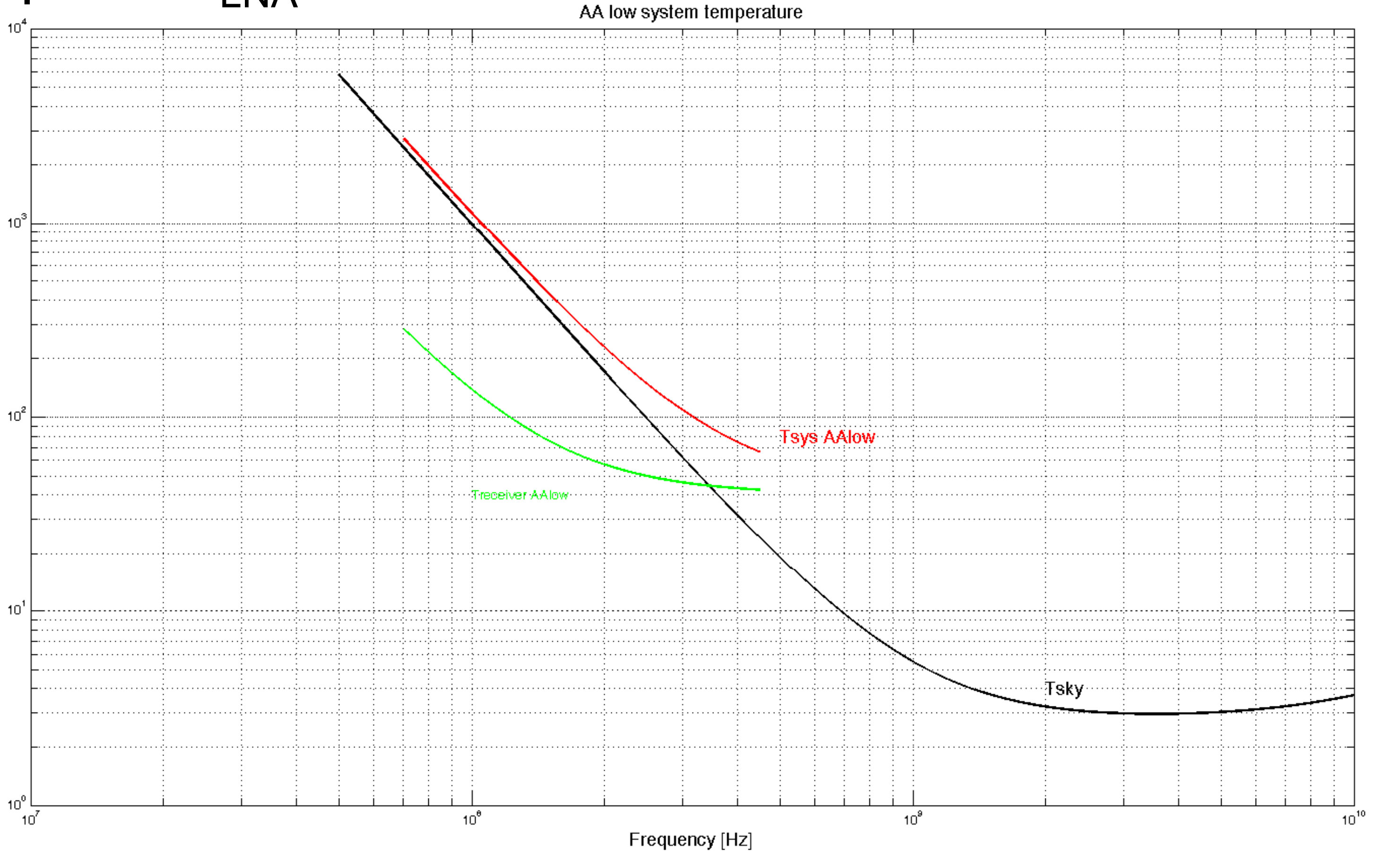
| | Enhanced Dipole | Log Periodic | Spiral | Vivaldi |
|---|---|---|---|---|
| Gain / sky coverage | Low / Good | High / Low | Medium | Medium |
| Impedance | Medium | Good | Good | Good |
| Cost | Low | High? | Medium | High? |

# AA-low Dual band Concept

- Receiving the AA-low 70-450MHz band with two receptors
  - AA-low$_1$: 70 – 200 MHz
  - AA-low$_2$: 200 - 450MHz
- AA-low$_1$ doable with LOFAR / MWA stile antenna
- AA-low$_2$ requires better (impedance) antenna
- Station processing could be shared
- More antennas, LNAs, infrastructure etc.

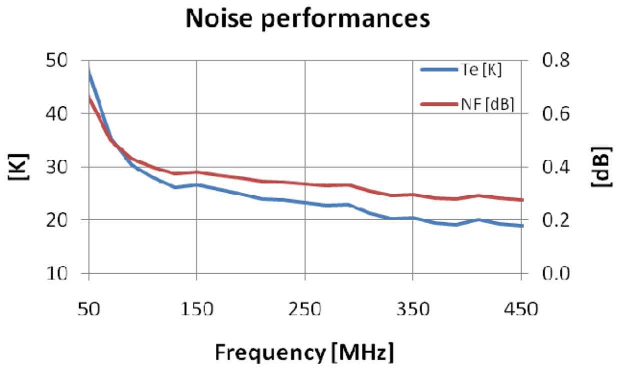
# Receiver AA-low

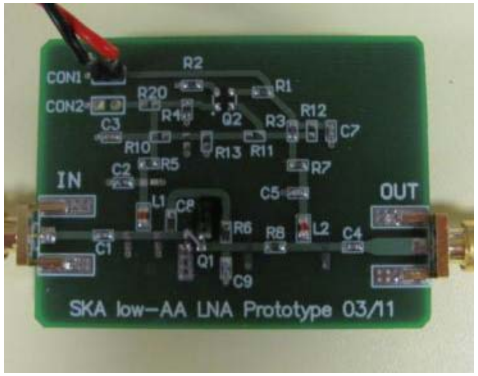
- $T_{system}$ requirement: $T_{rec} = 10\%T_{sky} + 40K$
- Requires $T_{LNA} \sim 20K$

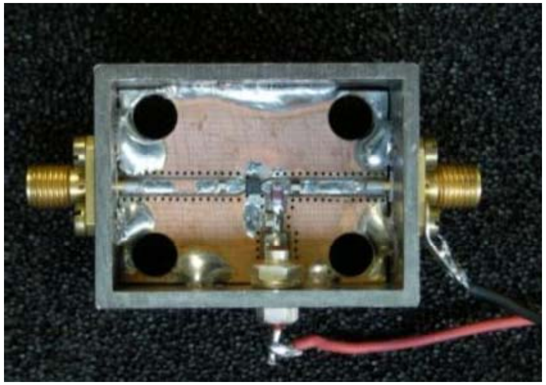


# Receiver AA-low

- 7:1 band width
  - GaAs PsHEMT
  - SiGe BJT
  - Should not be a problem with stable antenna impedance

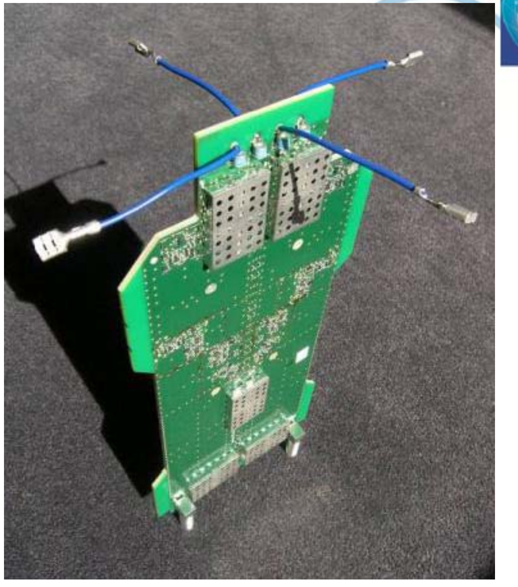


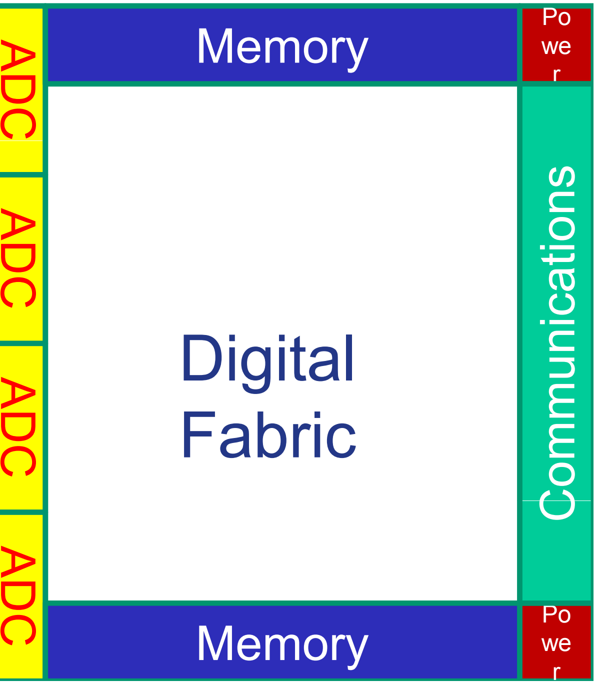



# Receiver AA-low

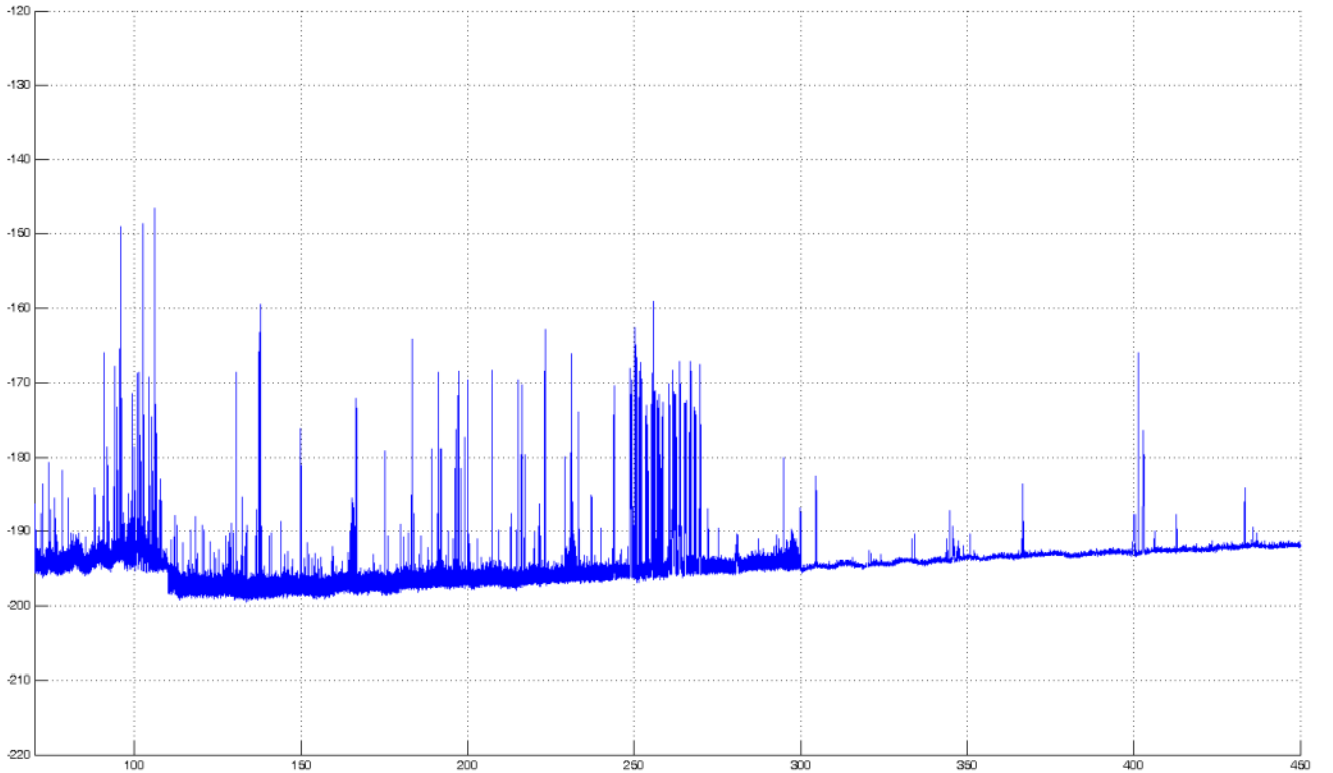
- First stage beamforming
  - Analogue beamforming: Time delay
    - Reduces signal processing load
    - Reduces power consumption
    - ‘Quantization’ side lobes
  - Digital beamforming
    - High level of integration
    - ‘full’ control, high accuracy
    - High NRE





# Receiver AA-low ADC

- RFI: 2005 data
  - Max hold combined South-Africa and Australia

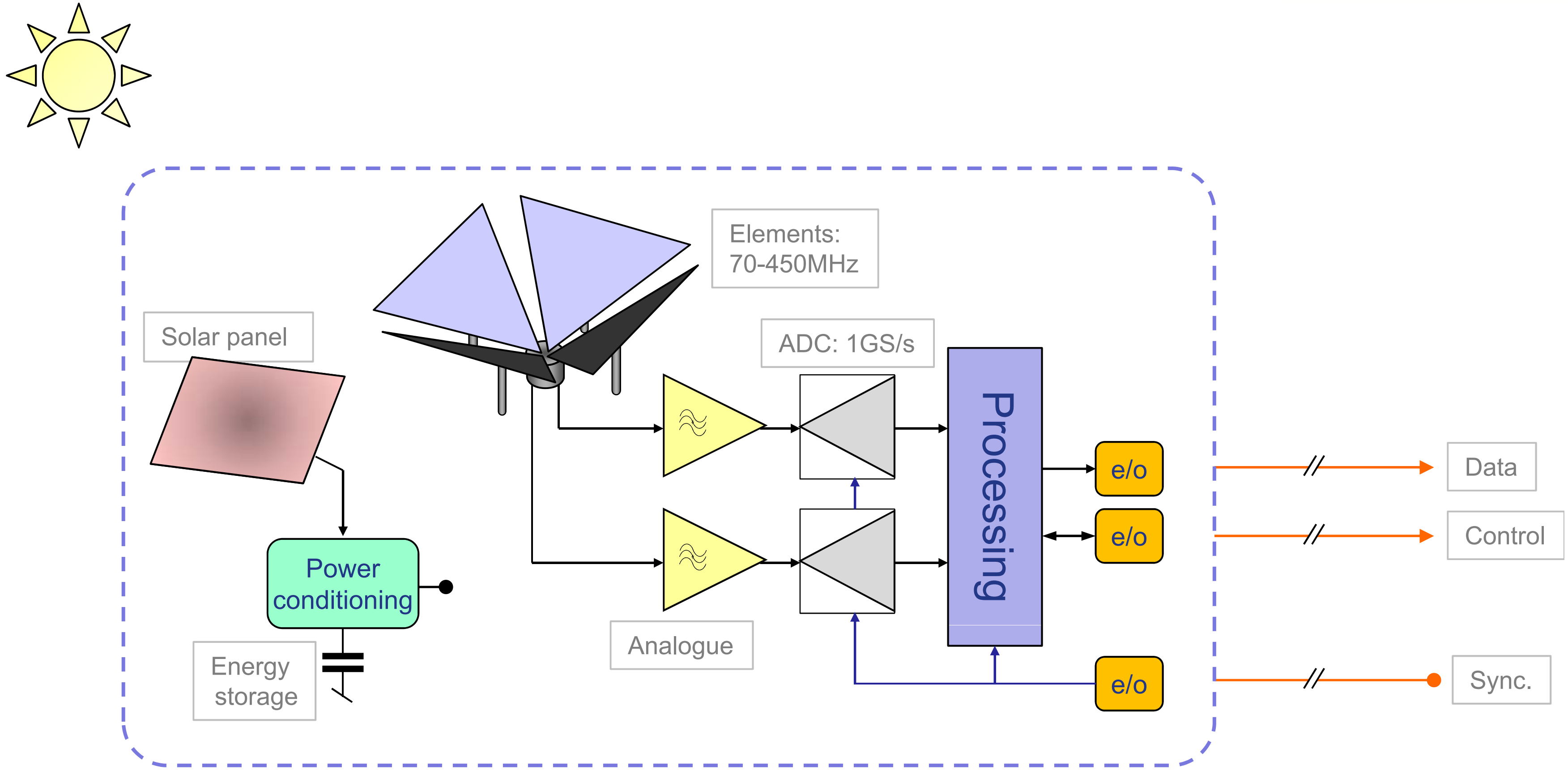


# Receiver AA-low ADC

- After pre-whitening and linear addition of RFI powers (assuming 3dB antenna gain):
- 22dB dB ratio between RFI and noise power
  - 4 bit for RFI headroom
  - 2 bit for gain variations/setting
  - 2.2 bit for noise sampling (quantization)
  - 0.5 Noise floor ADC

- 8 bit should be fine
- 6 bit only if SKA site is much better

# Receiver AA-low

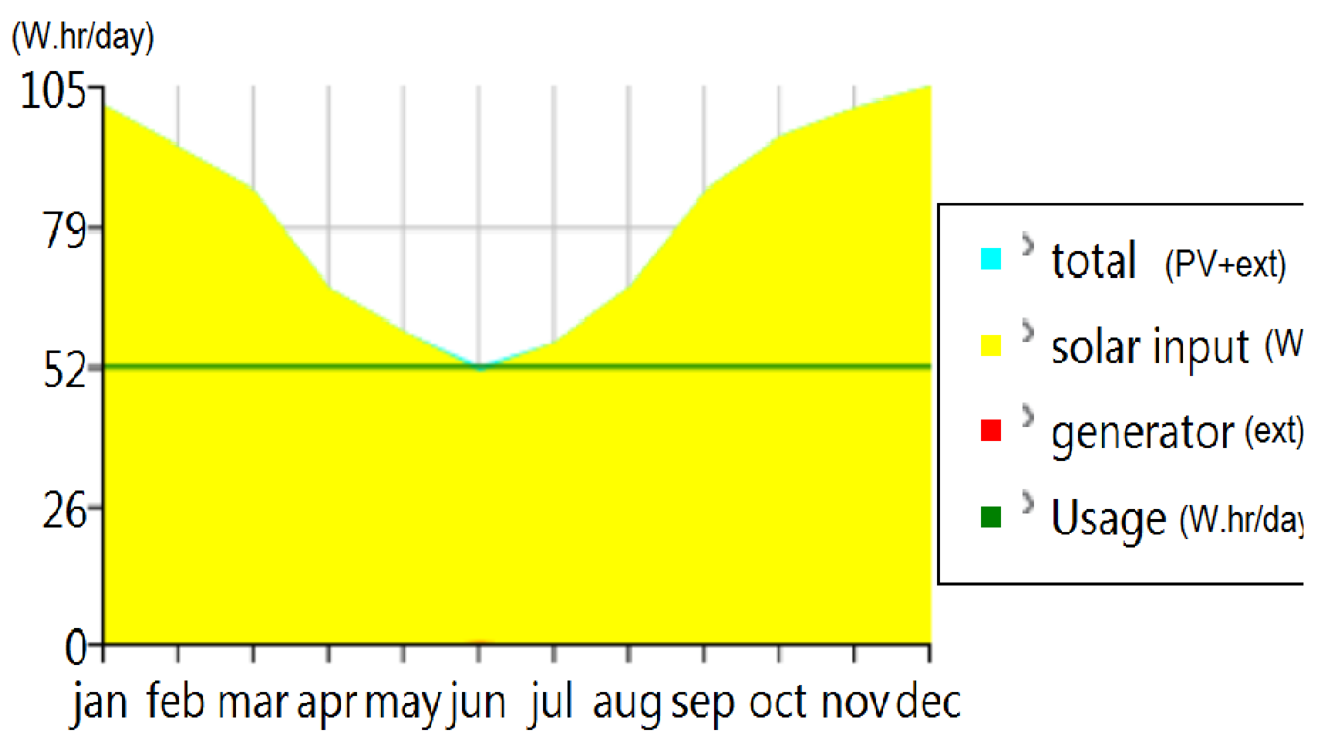



- Can be expended to tile level

# Receiver Power

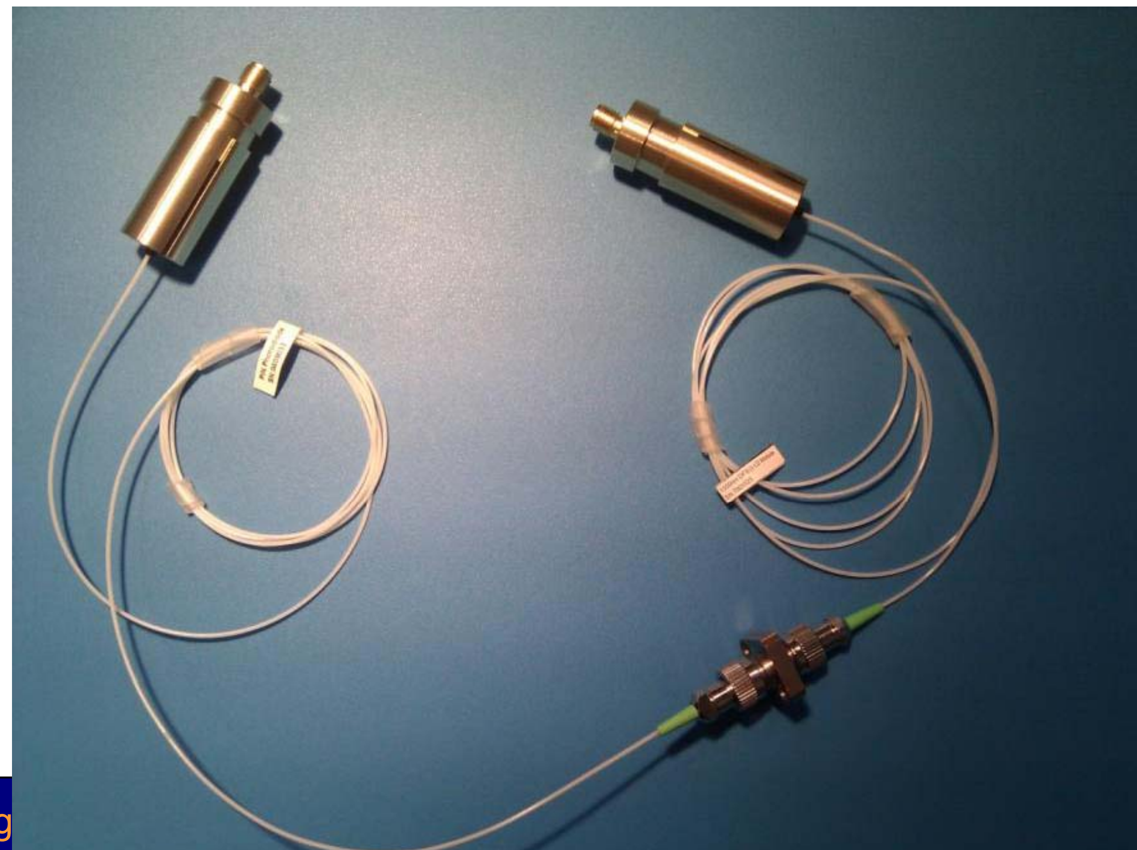
- For 24 hour operation 2 Watt receivers need a 10-15 W Photo Voltanic panel: 40x30cm and battery
  - 100mW LNA
  - 1400mW RF fibre link

Graph of annual system performance*



# Receiver AA-low

- Photonic RF transmission
  - Current cost ~100 euros
  - 60mW power each side
  - 0dB gain
  - Kilometers range
  - (20x15cm panel?)



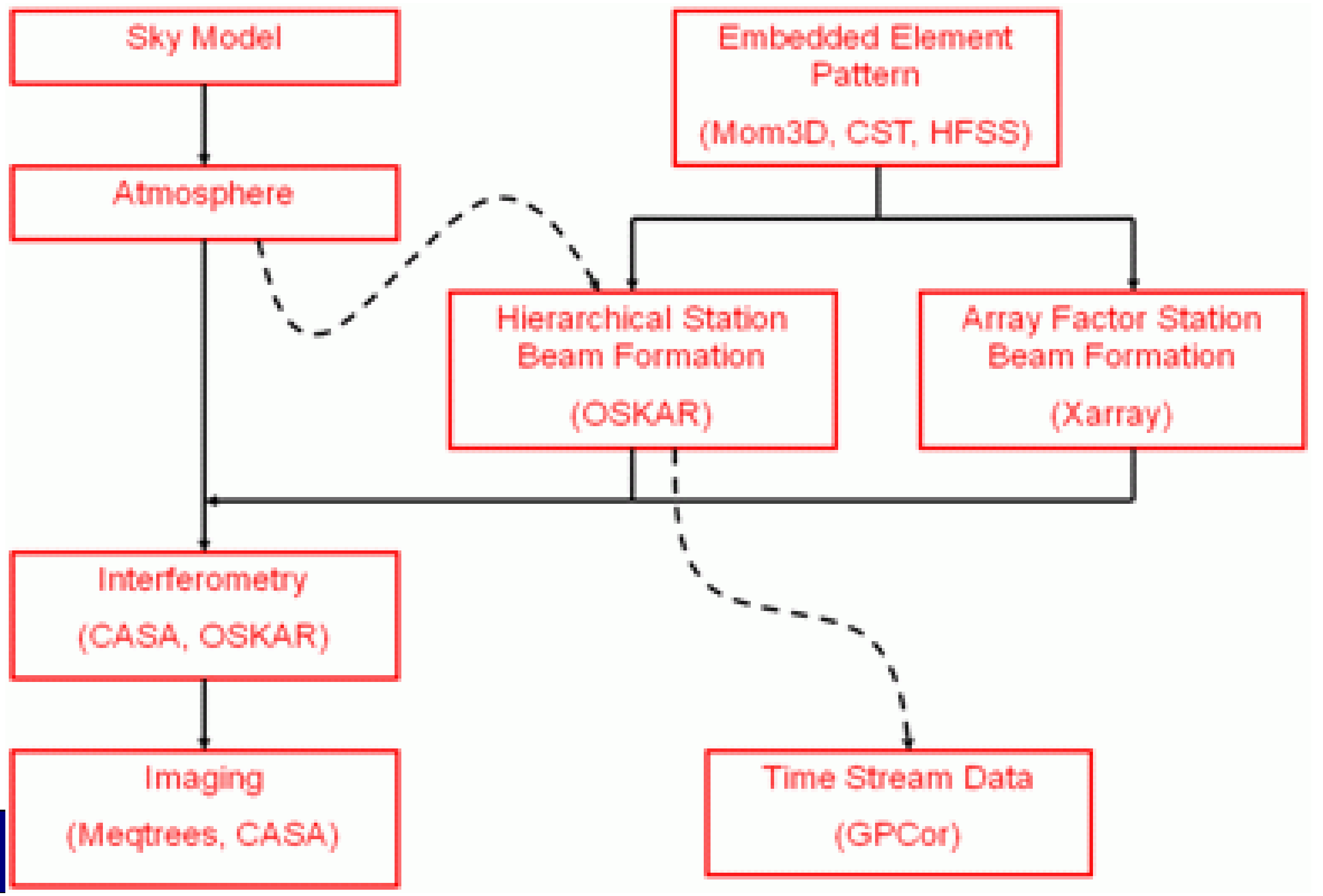
# AA-low Station processing

- To generate 160 beams out of the 700 inputs
  - Requires 170 TMAC/sec
- 1st generation Uniboard requires 84 boards
- Or much less when e.g. PChip technology can be used

Uniboard

# Calibration

- Combination of modeling, selfcall, measurement equation..LOFAR / MWA



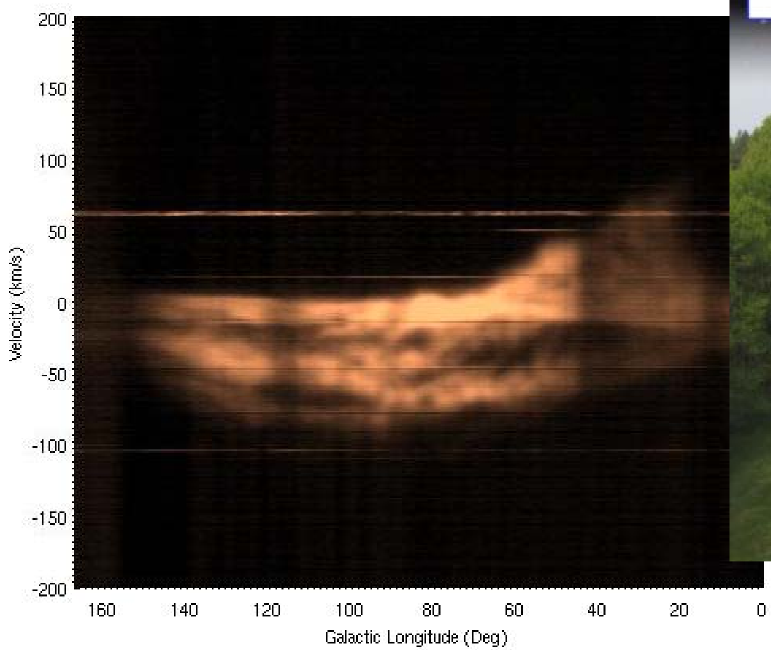
# AA-low summary

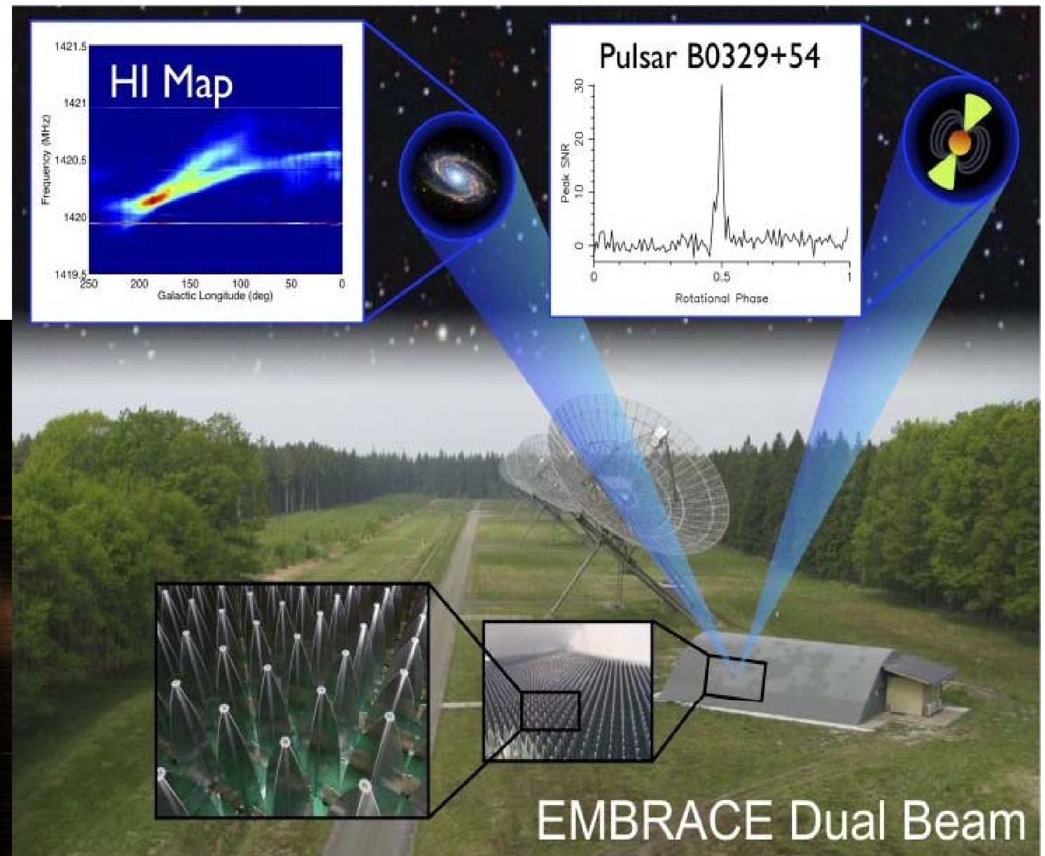
- Array configuration
  - Tiled Golden Ratio Spiral?
  - Optimization Criteria to be determined
- Antenna element choice
  - No favorite yet
- Single band / dual band
  - Design effort focuses on single
- Analogue beamforming / Digital tile beamforming

# AA-mid

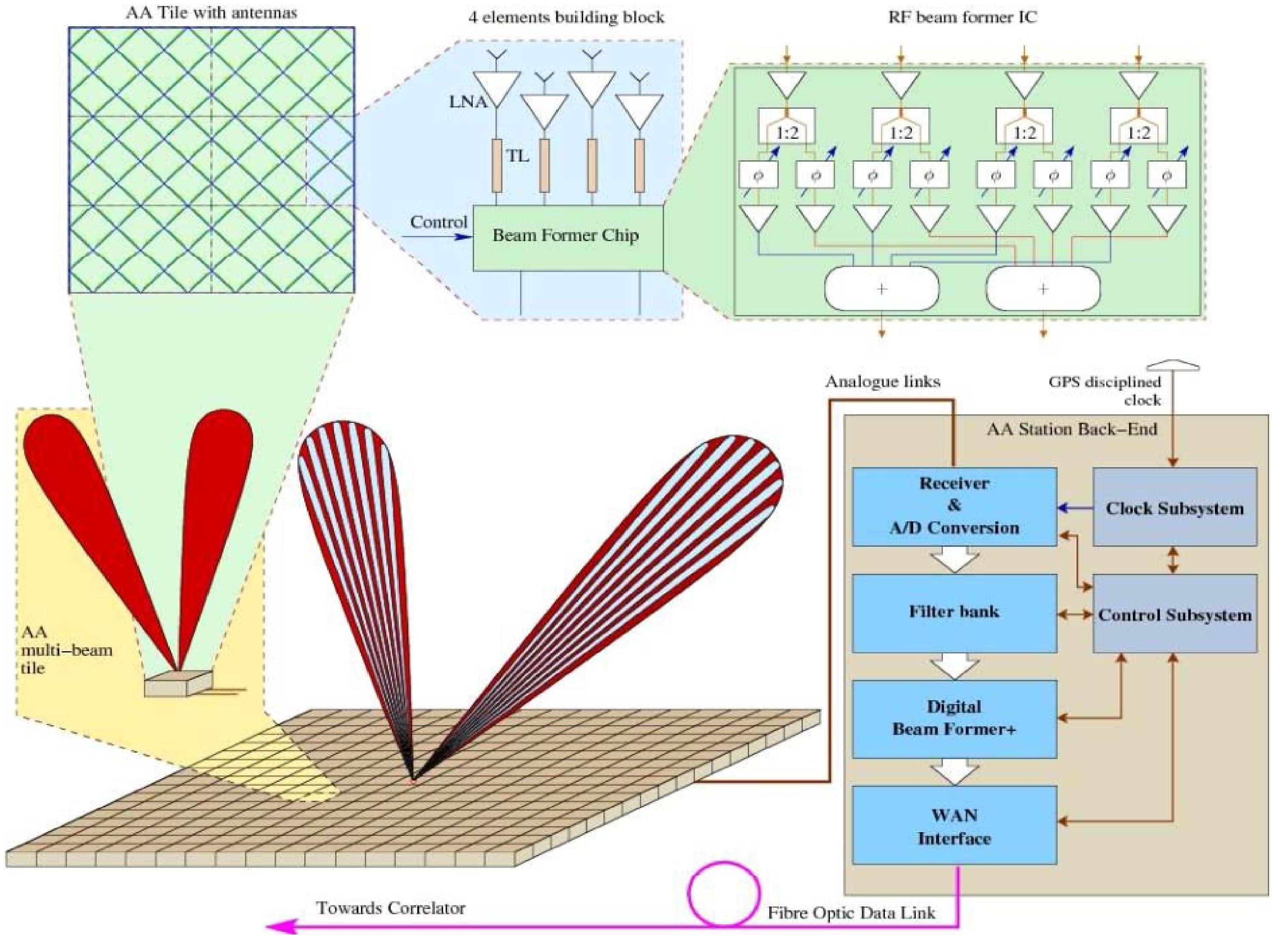
- Electronic Multi-Beam Radio Astronomy Concept: *EMBRACE*

# EMBRACE

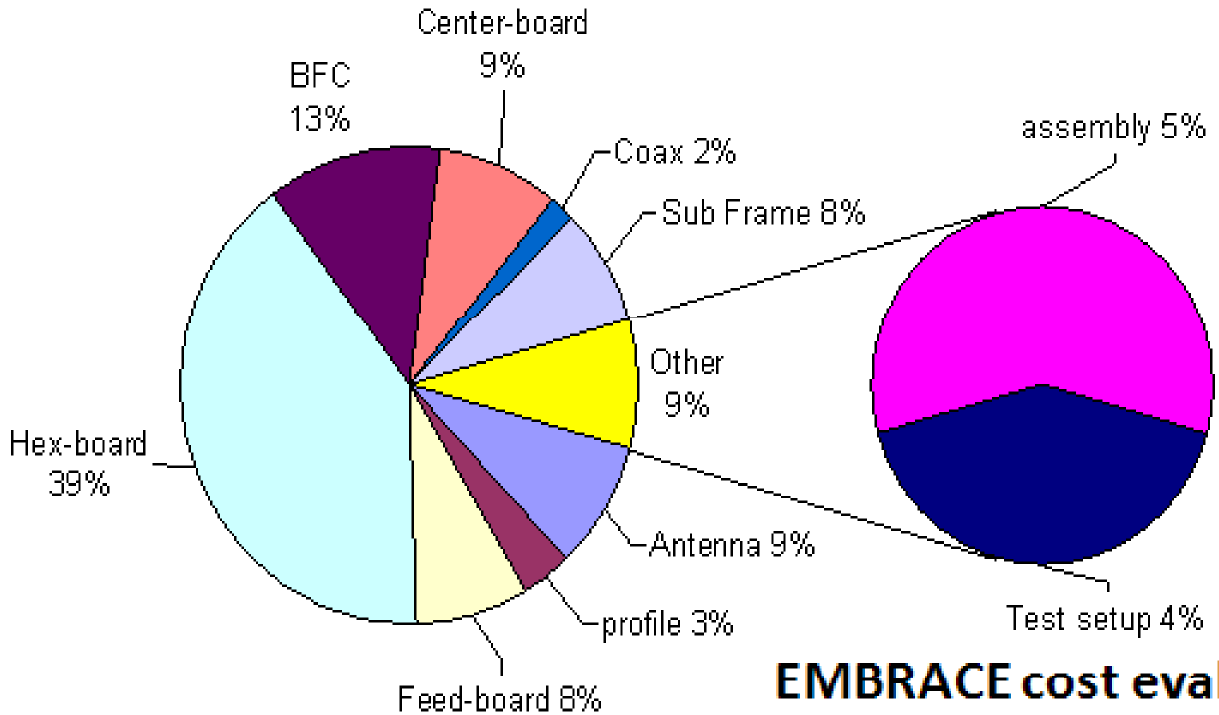

Velocity (km/s)
200
150
100
50
0
-50
-100
-150
-200
160
140
120
100
80
60
40
20
0
Galactic Longitude (Deg)


HI Map
Frequency (MHz)
1421.5
1421
1420.5
1420
1419.5
250
200
150
100
50
0
Galactic Longitude (deg)
Pulsar B0329+54
Peak SNR
0
10
20
30
0
0.5
1
Rotational Phase
EMBRACE Dual Beam

# EMBRACE—AA-mid



# EMBRACE Costs




EMBRACE cost evaluation

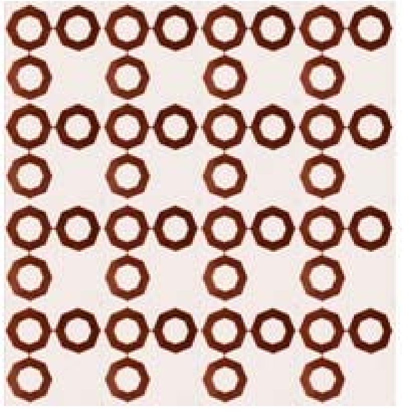
- Material bill only!

# AA-mid: from EMBRACE to SKA

- $T_{sys}$
- Receiver bandwidth (eq. to AA-low)
- FoV processing (eq. to AA-low)
- Cost!

# AA-mid Antenna Array

- Dense
- λ/2 frequency
  - 1000MHz: reduced performance at 1450MHz
  - 1200MHz: EMBRACE, nearly full performance at 1450MHz
  - 800MHz not considered
- Antenna element
  - Besides Vivaldi ORA element considered
    - Better polarization characteristics?
    - Lower costs?



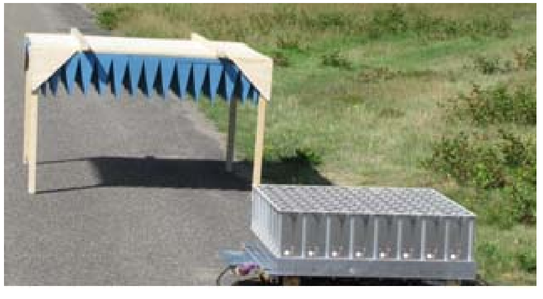
# AA-mid Receiver

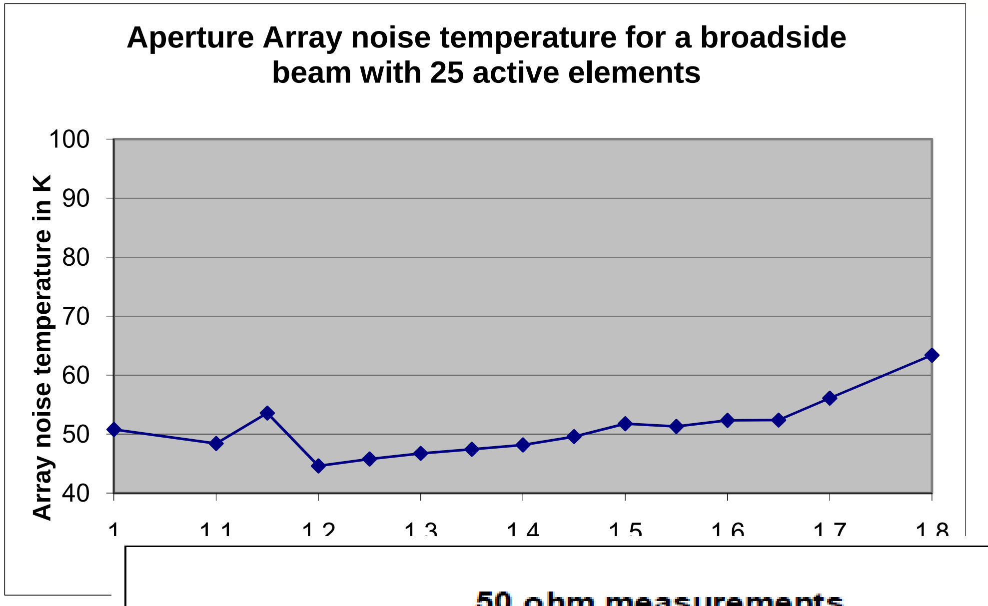
- $T_{sys}$ budget

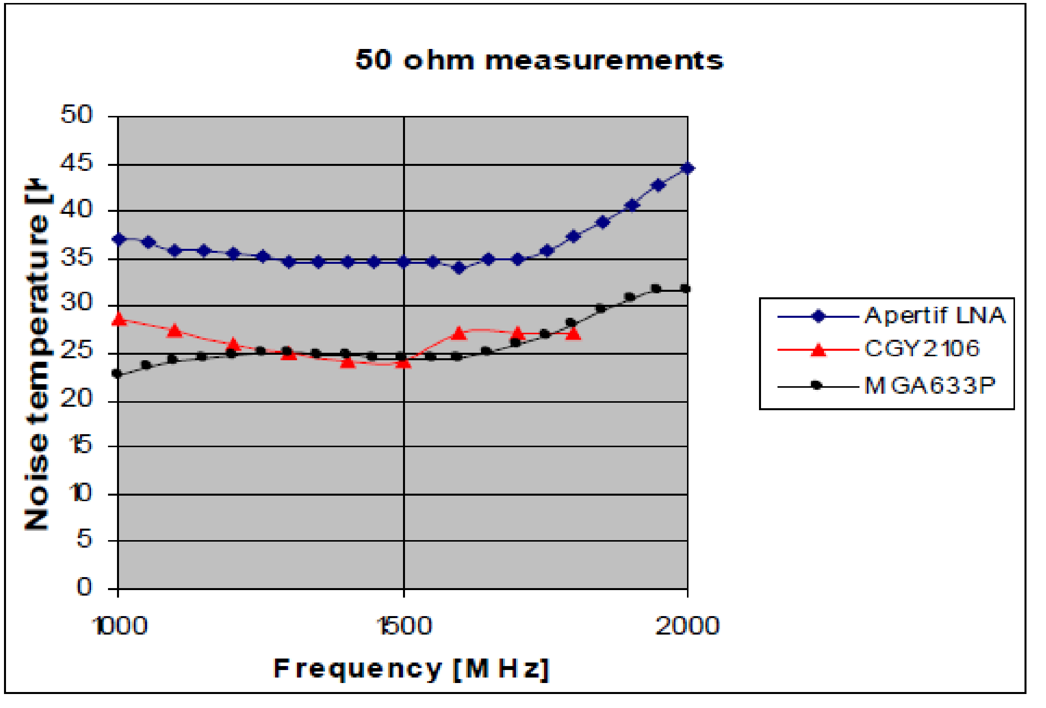
| Aperture Array | |
|---|---|
| Spill-over | 0 K |
| Antenna feed loss | 4 K |
| Low Noise Amplifier | 25 K |
| Noise mismatch / coupling /2nd stage | 7 K |
| Sky | 3 K |
| Total | 39 K |

# AA-mid Receiver

- Small array tests

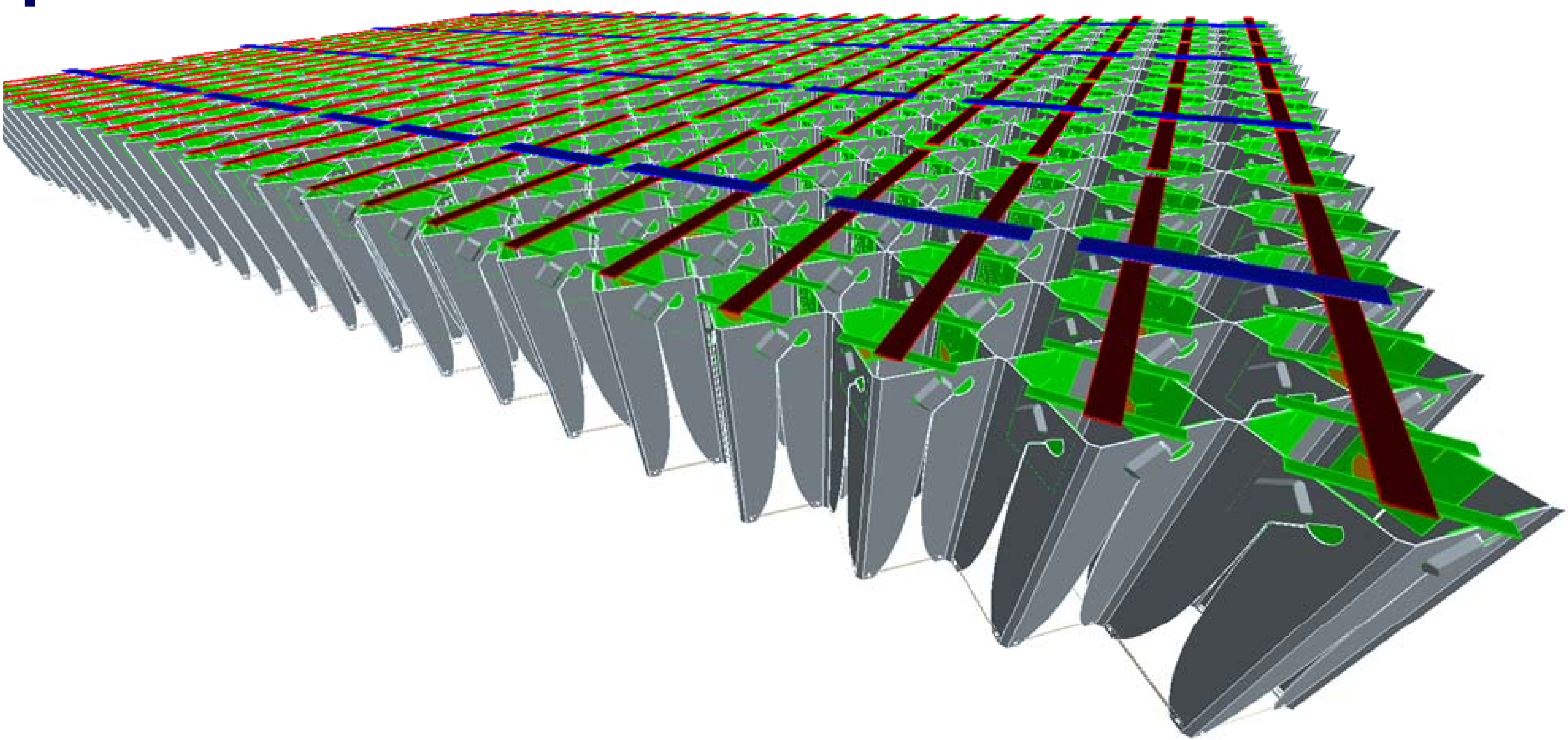




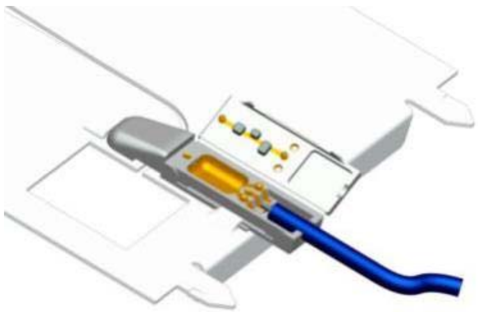
# AA-mid Array Concept

- Improved manufacturability with high level of integration

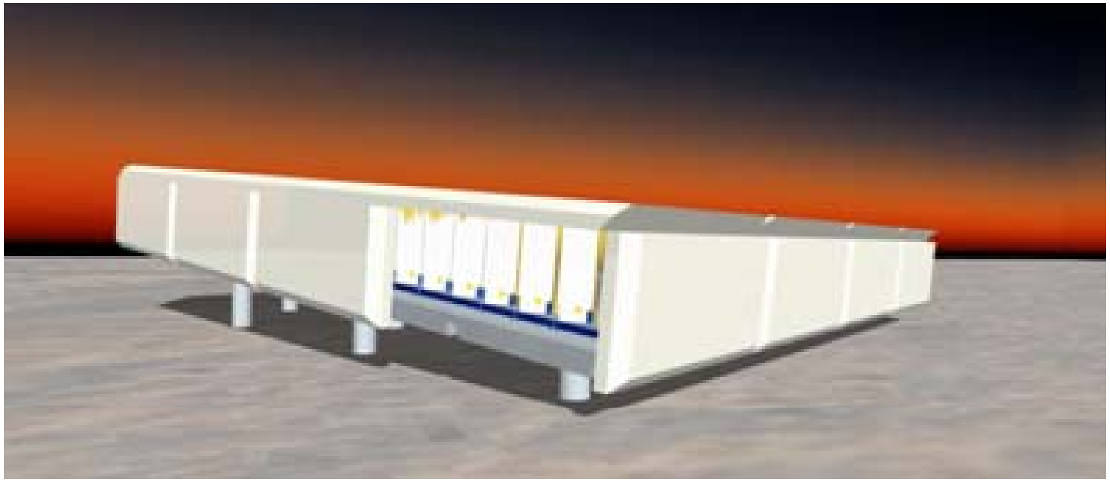


# AA-mid

- Improved manufacturability

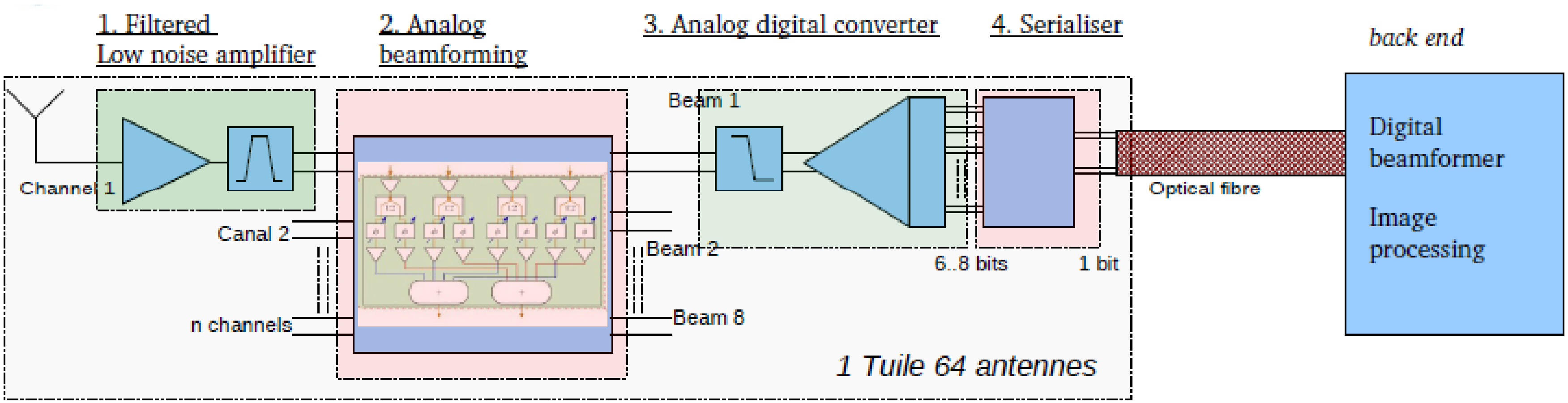


MID connector replacement



EPS tile concept

# AA-mid Receiver Integration




- Time delay analogue beamforming
- >3Gs/s ADC

# AA-mid summary

- $T_{sys}$ to be demonstrated for full AA-mid bandwidth
  - Requires low RFI environment
- Dual polarization
- Receiver bandwidth increased
- Dynamic range
- Integration / industrialization

- As in AA-low signal processing back-end to be scaled up