SKA Aperture Arrays

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WP2 Meeting: 2011 October 18-20

Contents

- Overview AA CoDR
- Summary of Costs, Power, Risks
- Major Outcomes and Route Forward
- Progress since CoDR

Overview of CoDR

- Held: 19 and 20 April 2011

- Review Panel
  - Peter Dewdney (SPDO) – chair
  - Colin Lonsdale (MIT/Haystack)
  - Raf Roovers (NXP)
  - Richard Williams (Cambridge Consultants Ltd.)

Goals AA CoDR

- Evaluate
  - AA concepts (both low and mid) and their maturity
  - All AA aspects and identification of gaps
- Eight specific questions were defined

Docs Delivered

- AA Review Plan
- AA System Requirements Specification
- AA Concept Descriptions
- AA Implementation
- AA Strategy to Proceed to Next Phase
- AA Risk Register

Discussed Concepts

- AA system level
- Configuration
- Antennas
- Receiver
- Station Processing

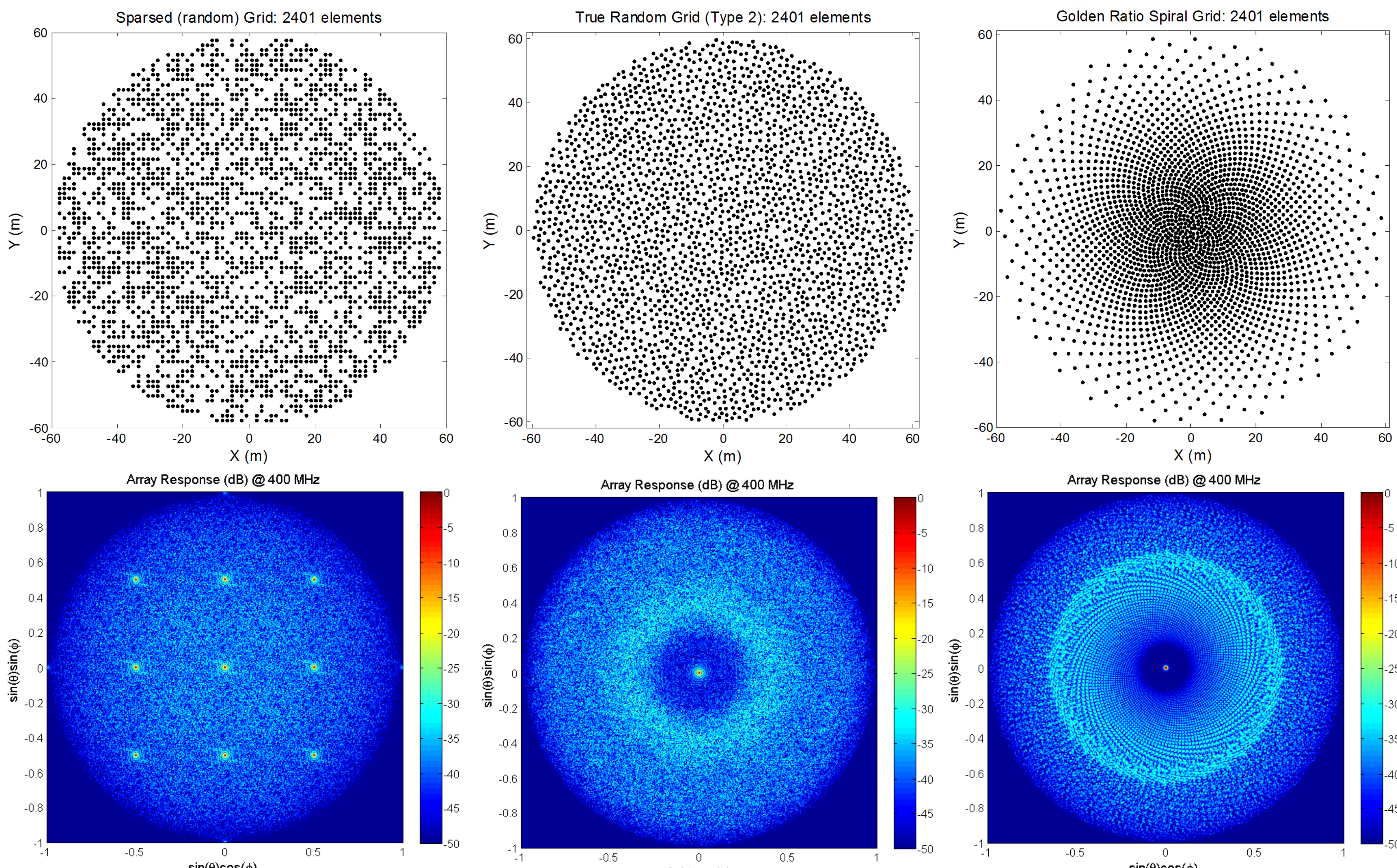
Array Concepts (1)

Characteristic	1. Single element	2. Dual: separate arrays	3. Dual: shared arrays
Element – LNA matching	Difficult due to wide frequency range	Easier due to two narrower frequency ranges	As 2.
Filling factor, station	Reducing filling factor at high frequencies.	Each array has lower frequency range, increased the FF is at high frequencies.	As 2.
Filling factor, core	The core filling factor will be the same or similar to a station. (see above)	With two AA-low cores, the FF will be the same or similar to the stations at the same frequencies.	The core filling factor is substantially reduced due to there being unused arrays present at any specific frequency.
Land area usage	Minimum. The high frequencies are completely integrated in a single array.	Higher due to there being two completely distinct arrays.	Likely to be the same or potentially higher than 2. Could be increased by use of distinct stations in the core.
Beam predictability	All elements are identical at specific frequencies leading to a well predicted beam.	Each frequency has a specific homogenous array, so well predictable beams.	As 2.
Sensitivity over frequency	Determined by the fixed element count and if the array is still in the sparse regime.	The high and low frequency sensitivity is set in two bands dependant on element count.	As 2.
Processing requirements: System	A single array with high bandwidth connections.	The core will consist of two distinct arrays, each handled in a similar way to 1.	Stations will consist of two adjacent arrays probably using one station processing system.
Processing requirements: Spectral filter.	The spectral filter will have to handle the full bandwidth of the array.	More spectral filters due to the increased no. of elements –each only handles the bandwidth of the element.	There are only as many spectral filters as elements in the biggest array. This will probably be similar to 1.
Processing requirements: Specific survey speed.	High survey speeds at high frequencies will be expensive in beamforming &data transport.	The size of the beams is kept higher due to each array minimising the under-sampling of elements.	As 2.
Cost (will need to be reviewed as a system)	Single element may be more expensive than 2 dual elements. One high performance processing system. Only one cabling network. Minimum deployment costs.	There are two network systems, two processing systems. Each may be cheaper than in 1. However, it is likely that the total will be more expensive. Each element should be low cost Deployment costs are high.	The processing system should be cheaper than 1. or 2. but less capable in terms of instantaneous bandwidth. Element costs as 2. Deployment cost is high with two arrays and interconnect.

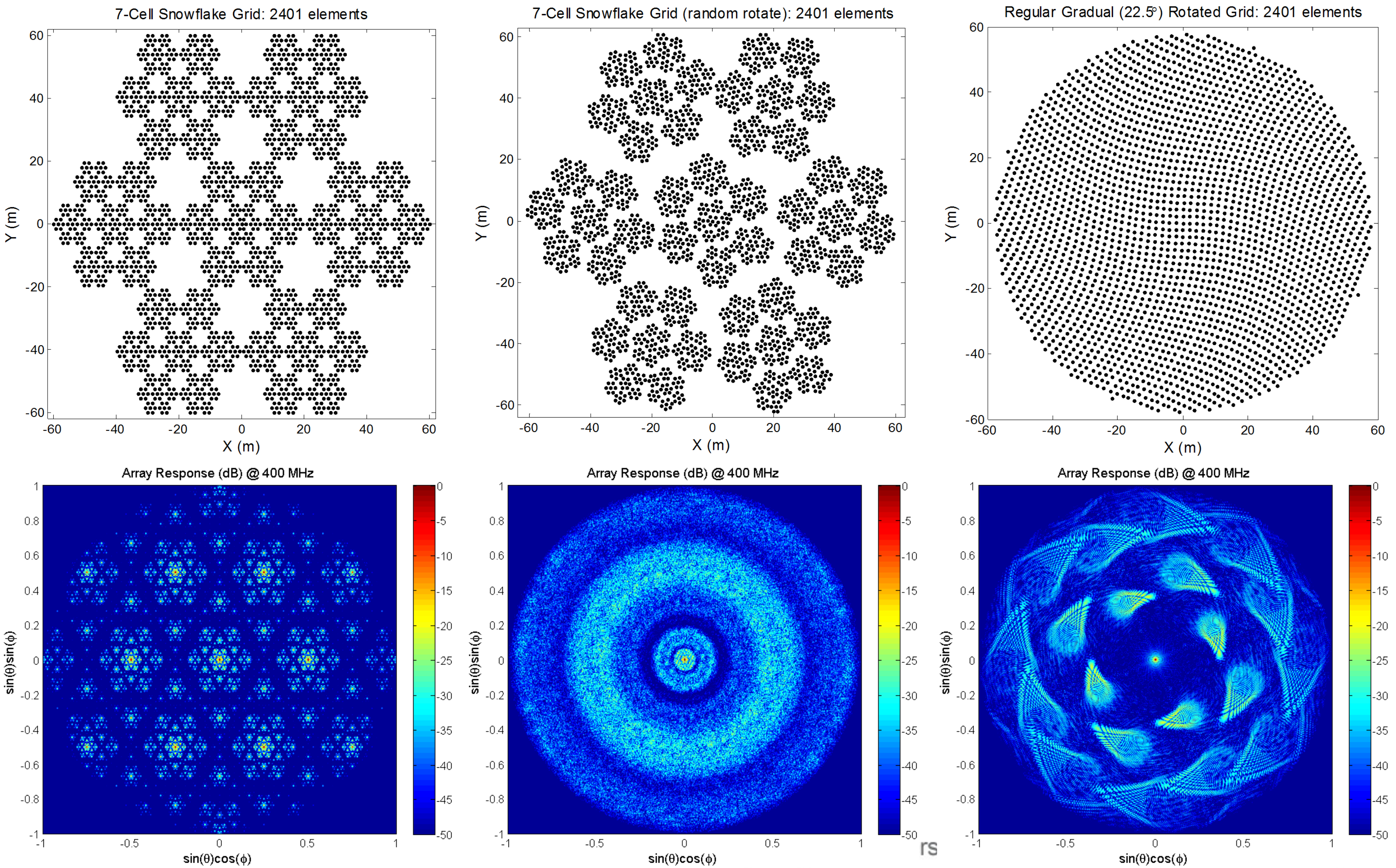
Configuration Concepts

- Studied geometries
  - Sparse random
  - True random
  - Golden Ratio Spiral (GRS)
  - Snow flake (fractal design)
  - Snow flake (incl. rotation)

Configuration Concepts (2)

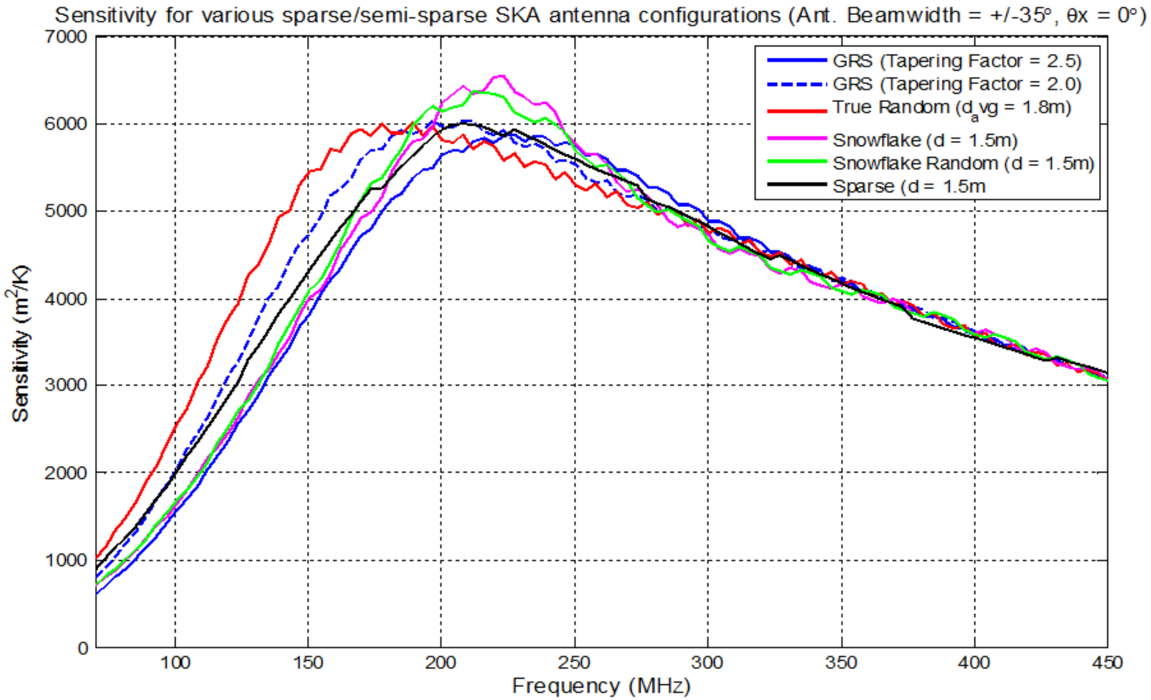


Configuration Concepts (3)



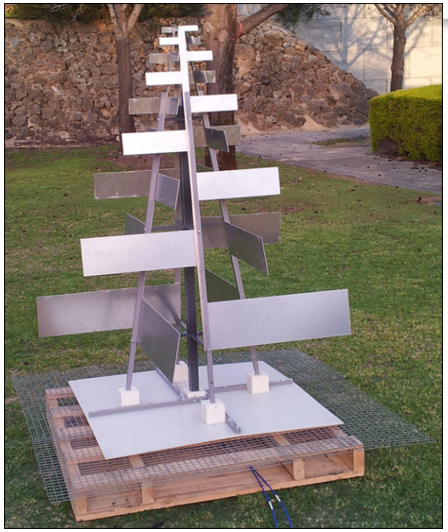
Antenna Configuration Results

- This example:
  - High gain antenna (+/-35 degree Beam width)
  - 600k elements
  - Boresight



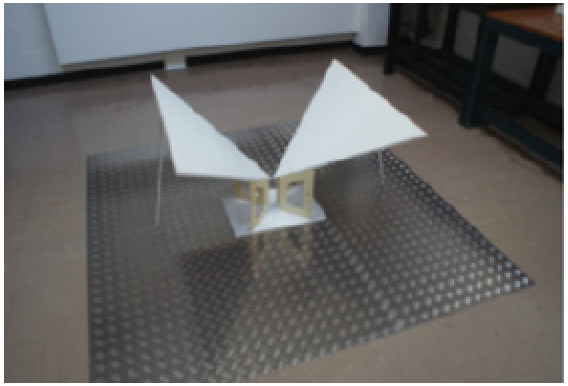
Single Element Antenna Concepts

Vivaldi



Log-periodic

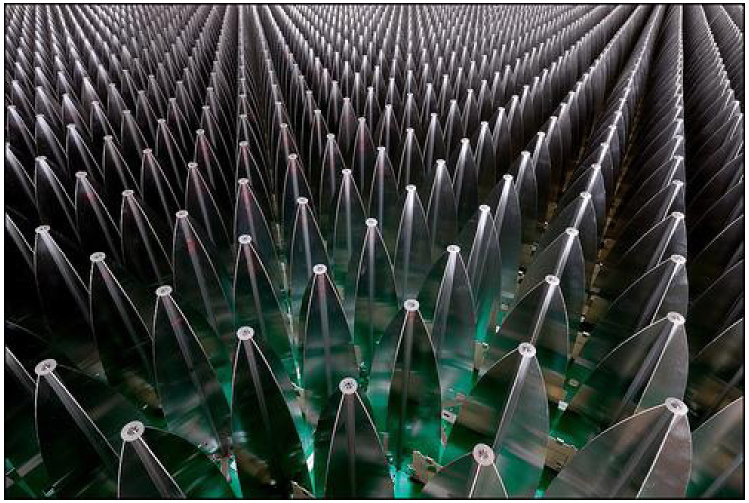
Spiral



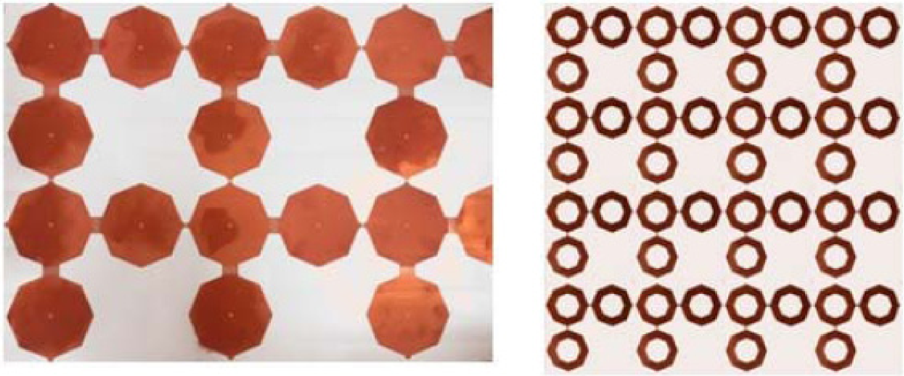
Bow-tie

AA-mid Antenna Concepts

Vivaldi



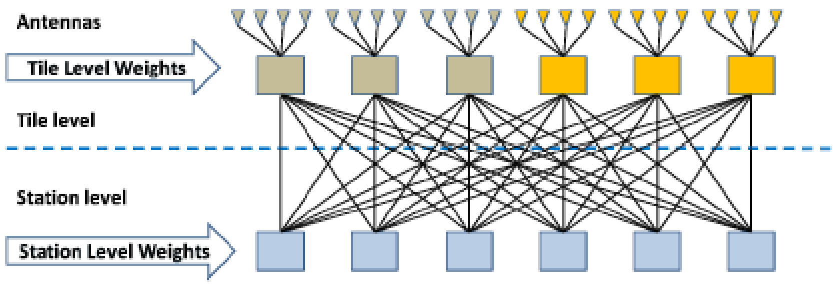
ORA

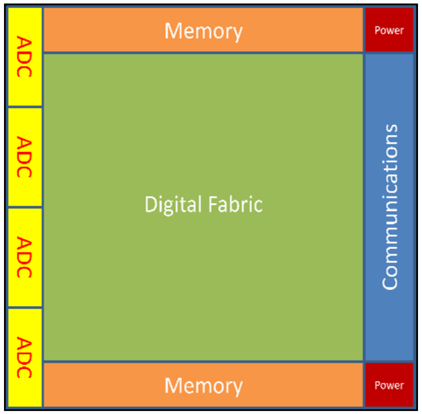


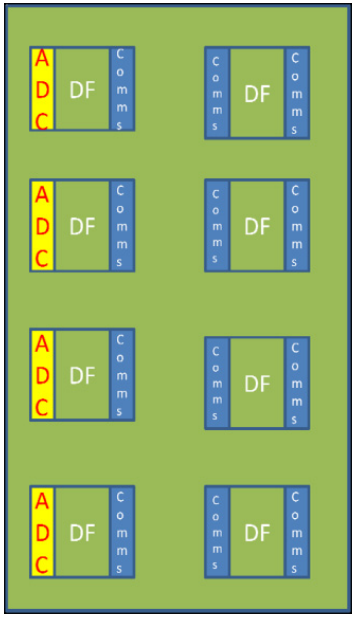
Receiver & Signal Processing

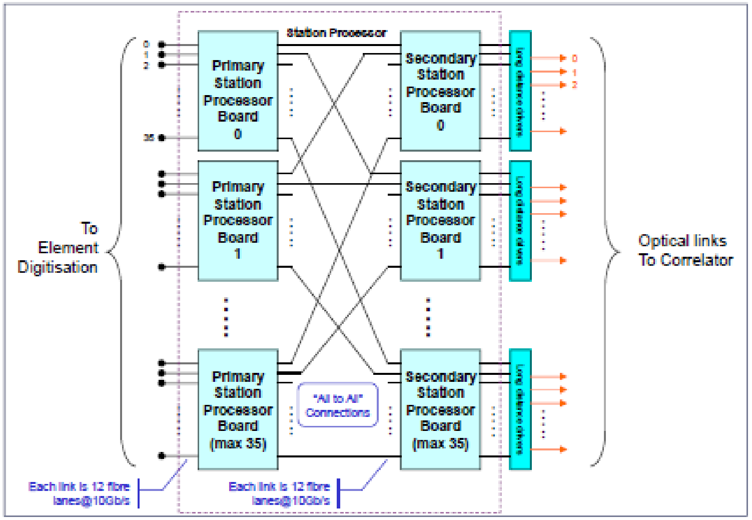
- Concepts depend on:
  - Station size
  - Station configuration
  - Technology costs

Concept 1 (digitizers in the field)

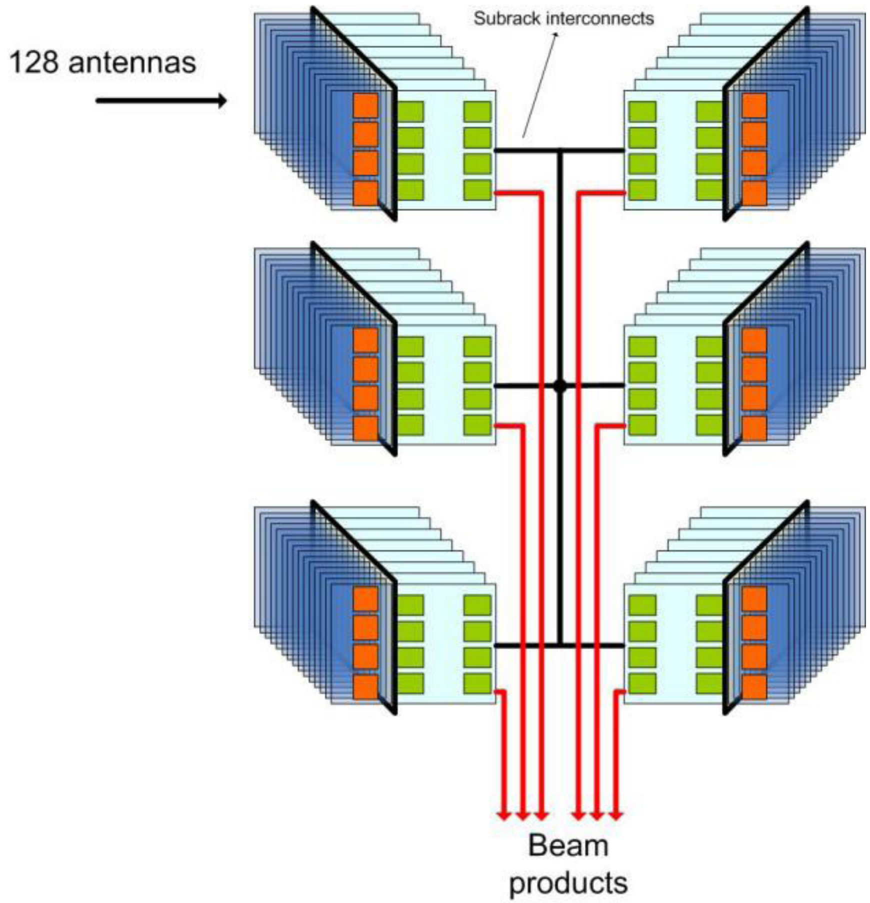








Concept 2 (digitizers central)



Concept 3

- Everything in between

Fundamental Architectural Choices

- Analog beamformer versus all digital
- ADC's near the antenna or not
- Electronics in the antenna field or not

Major Gaps

- Prime focus of AA-low currently on antennas
- Pathfinder / precursor relation not used sufficiently

Summary of AA-low Costs

Item	Number	Cost /unit	Cost /Station	Comment
Antenna elements:				
Elements LNAs Gain and filter Housing	11,264	€75	€845,000	Dual polarisation antennas. The cost is taken from existing arrays and the size of elements
Cabling, CAT7:				Element to digitisation
Cable Connectors Installation Preparation	11,264	€18	€203,000	Average cable length 10.6m CAT-7 serves both polarisations
Digitisation & 1st stage beamforming:				
Input and filters Processing devices Circuit board Case	44	€4872	€214,500	256 dual polarisation inputs
Fibre link:				Digitisation to Station processor
Short Optical Link e.g. Avago	1670	€152	€254,000	120 Gbits/s per link (12 x 10 Gbit/s fibres)
Station Processing				
Processing Boards: Processors Circuit board 'Glue'	56	€2730	€153,000	Organised as two stages as a matrix
Fibre Driver Boards	25	€746	€18,500	560 Gbits/s onto comms link per board
Infrastructure and processing bunker:				
Bunker Racks PSUs Power distribution	1		€140,500	
AA-low Station			**€1.8 M**	

Source: SKADS costing tool

All digital

11,300 antenna elements

180 m station

Summary of AA-low Costs (2)

Item	Number	Cost per unit	Cost per Station	Comment
Antenna elements:				
Elements LNAs Gain and filter Housing Analog beamforming	11,264	€179	€2,011,328	Dual polarisation antennas. The cost is derived from LOFAR experience and the size of elements
Cabling, coax:				Element to digitisation
Cable Connectors	704	€81	€57,024	11,264/16 Cable serves both polarisations
Digitisation:				
Input and filters Processing devices Circuit board Case	1408	€40	€56,320	11,264 * 2 / 16 signal paths LOFAR receiver cost of 185 Euro optimized to 40 Euro for SKA (6 bit instead of 12)
Station Processing:				
Processing Boards: Processors Circuit board 'Glue'	704	€416	€299,376	Organised as two stages as a matrix
Fibre Driver Boards	25	€746	€18,500	560 Gbits/s onto comms link per board (no LOFAR number available)
Infrastructure and processing bunker:				
Bunker Racks PSUs Power distribution	1		€367,503	
AA-low Station			**€2.8 M**	

Based on LOFAR costs
Including analog beamforming
Output bandwidth LOFAR: 48 MHz
11,300 antenna elements
180 m station

Summary of Power

	Subsystem	SKA_1	SKA_2	Remarks
	Antenna element:	mW	mW	
1	LNA	50	50	Projection from SKADS work
2	Antenna gain block	40	40	
	Digitisation and processor:			
3	Analogue sig conditioning	40	40	Estimate
4	ADC	100	75	1.0 GS/s each channel
5	Clock distribution	50	10	estimate (less with more ADC per chip)
6	*Coms:* ADC to processor	100		Phase 2: integrated ADC and processor
7	Digitiser Processor	780	300	SKA1: 100 W. SKA2: 40 W for 128 receiver inputs
8	Digitiser Control ccts etc.	390	140	SKA1: 50 W. SKA2: 20 W for 128 receiver inputs
9	*Copper comms:* Processor to optical driver	10	10	1.2 W for 128 receiver inputs
10	*Optical Coms:* Tile to Station proc.	100	60	SKA1: 4.4 W. SKA2: 2.5 W for 40 receiver inputs
	Station Processor:			
11	Primary Station processor	130	75	SKA1: 1000 W. SKA2: 600 W. for 7776 receiver inputs
12	*Copper comms:* Processor to optical driver	10	10	1.2 W for 128 receiver inputs
13	*Optical Coms:* Primary to Secondary Station proc.	35	20	SKA1: 4.4 W. SKA2: 2.5 W for 40 receiver inputs
14	Secondary Station processor	130	75	SKA1: 1000 W. SKA2: 600 W. for 7776 receiver inputs
15	*Copper comms:* Processor to optical driver	10	10	16 Tb/s station output with 153,000 receivers @ 10mW/Gb/s
	Long Distance comms:			
16	Wide area comms			Accounted for separately
	Electrical power used	**1,975**	**915**	
	Electrical power supplied @ 85% efficiency	2,323	1,076	
	Power incl cooling at 25% cooling power	2,904	1,345	
	Total station power	**65**	**31**	**kW**

Summary of Technical Risks

- AAVP team currently to research focused
- Effect of grating lobes versus side lobes
- Uncertainty of cost
- Uncertainty of power
- Manufacturability
- Deployability

Major CoDR Outcomes

- Panel impressed by:
  - Amount of work done
  - AA group adopts procedures in line with system design
- Panel unanimous recommends for AA-low:
  - Move to next phase → Syst. Req. Review

Recommendations + Route Forward

- Separate SKA_1, SKA_2 and AIP
  - AA-low and AA-mid will be separated
- Seek mutually beneficial working relationships with pathfinders
  - Formulate information expected from pathfinders/precursors
- Science should be closely linked to discussion/motivation of requirements
  - Ok
- Plans need to be more future oriented:
  - "e.g. analog beam forming will most likely limit future SKA capabilities"

Route Forward AA-low

- Accelerate agreed and reviewed requirements
  - Should be mainly done at system level
  - AA will support the iterations at system level
- Establish process to reduce number of concepts
  - Selection matrix and criteria will be formulated
  - AAVS demonstrators to measure key parameters
- Put dual-band option on equal footing as single receptor
  - Ok and agreed

Route Forward AA-mid

- Further feasibility study (incl. power & cost)
  - AA-mid Demonstrator Embrace will be used
  - + updates of it
- Draft req. necessary from SKA_2 science
  - Should be driven by system level as well
  - AA will support iterations at system level as much as possible
- Independent review process
  - Independent review process will be planned

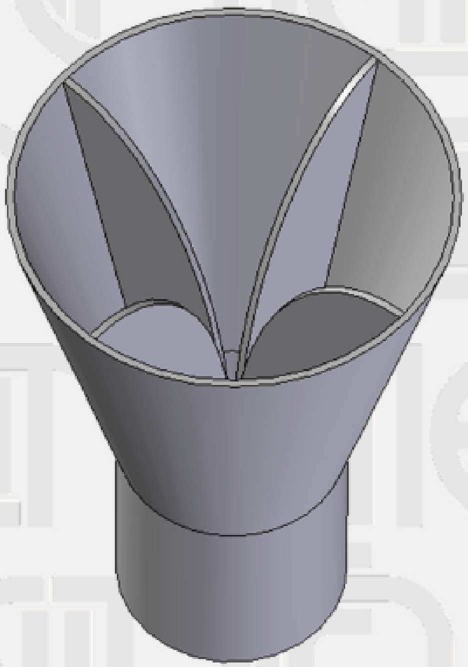
Progress Since CoDR (AA-low)

- Dual element simulations are done[1)]
- Effect grating/side lobes studied more [1)]
- Standardization of simulations & meas. [2)]
- Calibration requirements clarified (filling factor [3)], acceptable side lobe levels)
- Antenna element characterisation ongoing
  - two strong contenders (Vivaldi, log-per) and limited development on spiral (parked)

1) Talk of Nima Razavi-Ghods in "The Path to SKA-Low Workshop" 2011, Perth
2) Antenna standardization format, Shantanu Padhi
3) Paper of Stefan Wijnholds, et. al. submitted to Radio Science

Possible dual element

Quad-ridge horn concept

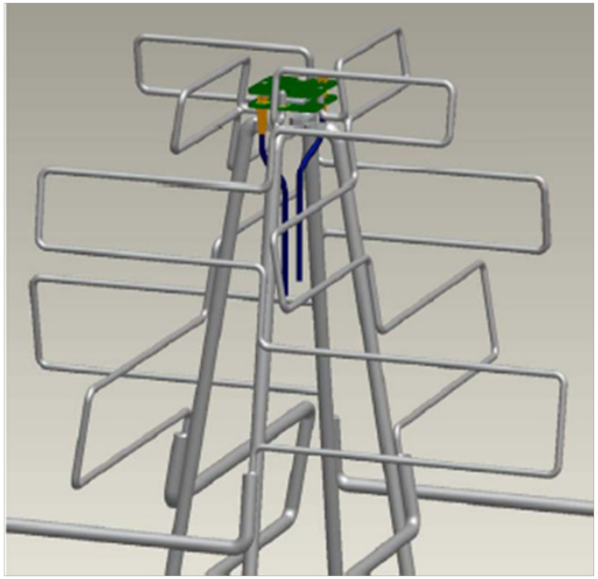


- Diameter 1m, Height 1.6 m
- Good matching in 180-450 MHz range
- Higher Directivity
- Very Low back lobe
- Possible Gridded version

Talk of Giuseppe Virone in “The Path to SKA-Low Workshop” 2011, Perth

More Progress

- Optimizing for mass production [4)]
- Selection criteria defined [5)]
- AA-low SRS written [6)]

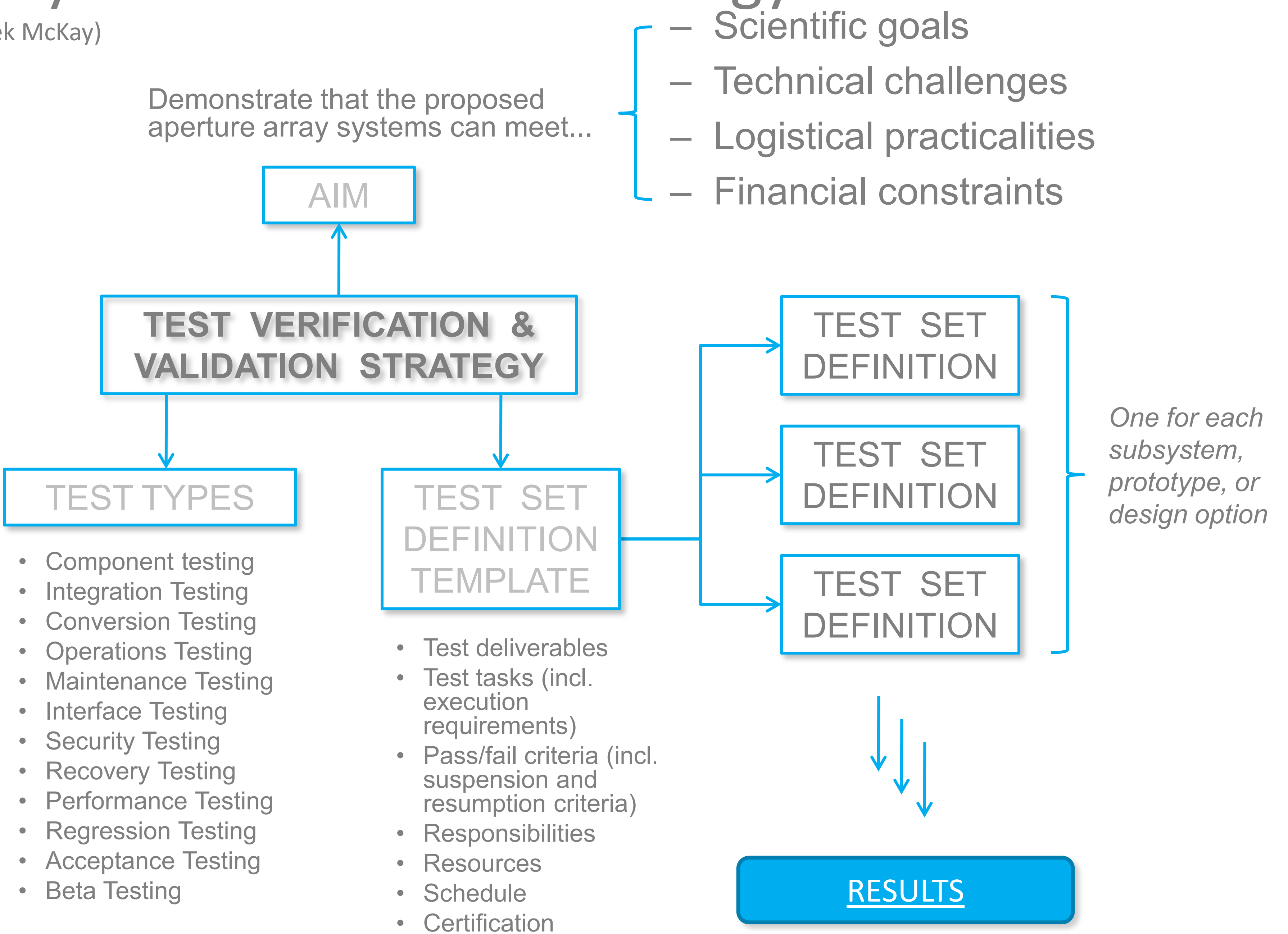


	Enhanced Dipole	Log Periodic	Spiral	Vivaldi
Gain / skycoverage	Low	High	High/Medium	Medium
Sky coverage (degrees)	+/- 45	+/-35	+/-35	+/-45
Dual pol design	Yes	Yes (feeding details!)	Difficult	Yes
Impedance	Poor/Me dium	Good	Very good (for single pol)	Good
Ground plane	Yes	No?	No?	No
E and H symmetry	-	-	Yes (also rotation sym.)	-
Maturity	Medium	High	High / Low (single / dual)	High
Coupling	Medium	Medium	Low	Medium
Cost	Low	High?	Medium	High?

5) Talk of Eloy de Lera Acedo in “The Path to SKA-Low Workshop” 2011, Perth
5) AA Sub-system Selection by Andy Faulkner
6) SKA AA-LOW SRS by Andre Gunst & Andy Faulkner

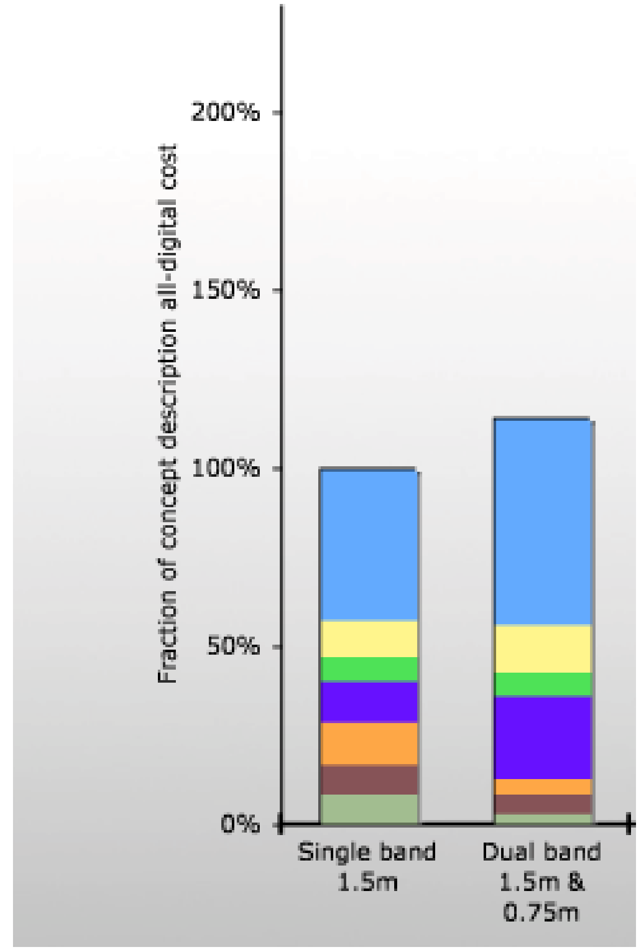
Busy with Verification Strategy

(Derek McKay)



Cost Analysis Ongoing

- Single or dual band cost difference [7)]



7) Talk of Tim Colegate in "The Path to SKA-Low Workshop" 2011, Perth

AA-mid

- Towards dCoDR
- Document package defined
- Planned at the end of November
- More information in talk of
  - Jan-Geralt bij de Vaate (14:00 today)
  - Andy Faulkner (11:15 tomorrow)

The End