
SKA AA Implementation
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Deployment

- Systems *must* be designed ready for deployment
- Major cost and timescale issue
- Specific AA station considerations discussed
  - Manufacture and Transport
  - Maintenance
  - Cost
  - Power
- Not considered here:
  - Accommodation for site workers
  - Heat disposal systems
  - Wide area Power distribution and communications

Some deployment considerations:

Environmental

- Temp, water, wind, etc

Minimise work on site

- Build in factories where possible

Minimise site preparation reqts.

- Easy foundations
- Reduce need to level ground – just smooth it
- Use surface cabling if possible

Minimise transport reqts.

- Reduce material used
- Tight packing with easy

Local control

- Test and maintenance need to take over control locally

Cooling in a desert

- Transport of heat away from processing heat sources
- Disposing of heat – particularly in the core

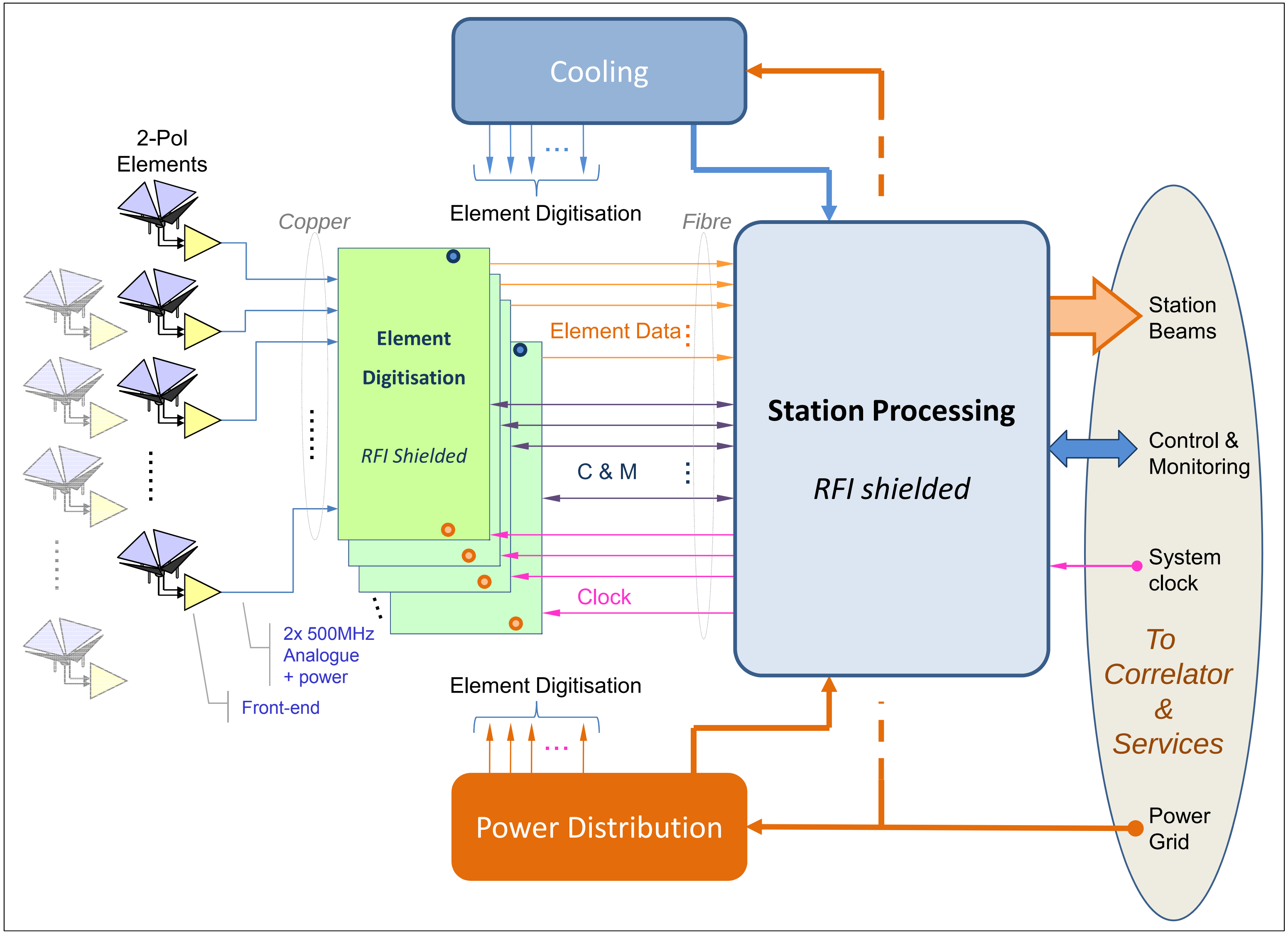
Site substrate.

- Could be a major impact: how hard? What support? Conductivity?
- Not a choice really!

AA-low Core issues

- The core needs to be virtually fully filled – particularly SKA_2
- AA-low in Phase 2 is ~4 km^2
- Sea of elements with processing bunkers
- Station processor bunkers are an issue:
  - 2-3m high metal box close to elements will cause reflections etc
  - Need to part bury to lower the height to give max few degrees to element
- Interconnect between processing bunkers needs some consideration

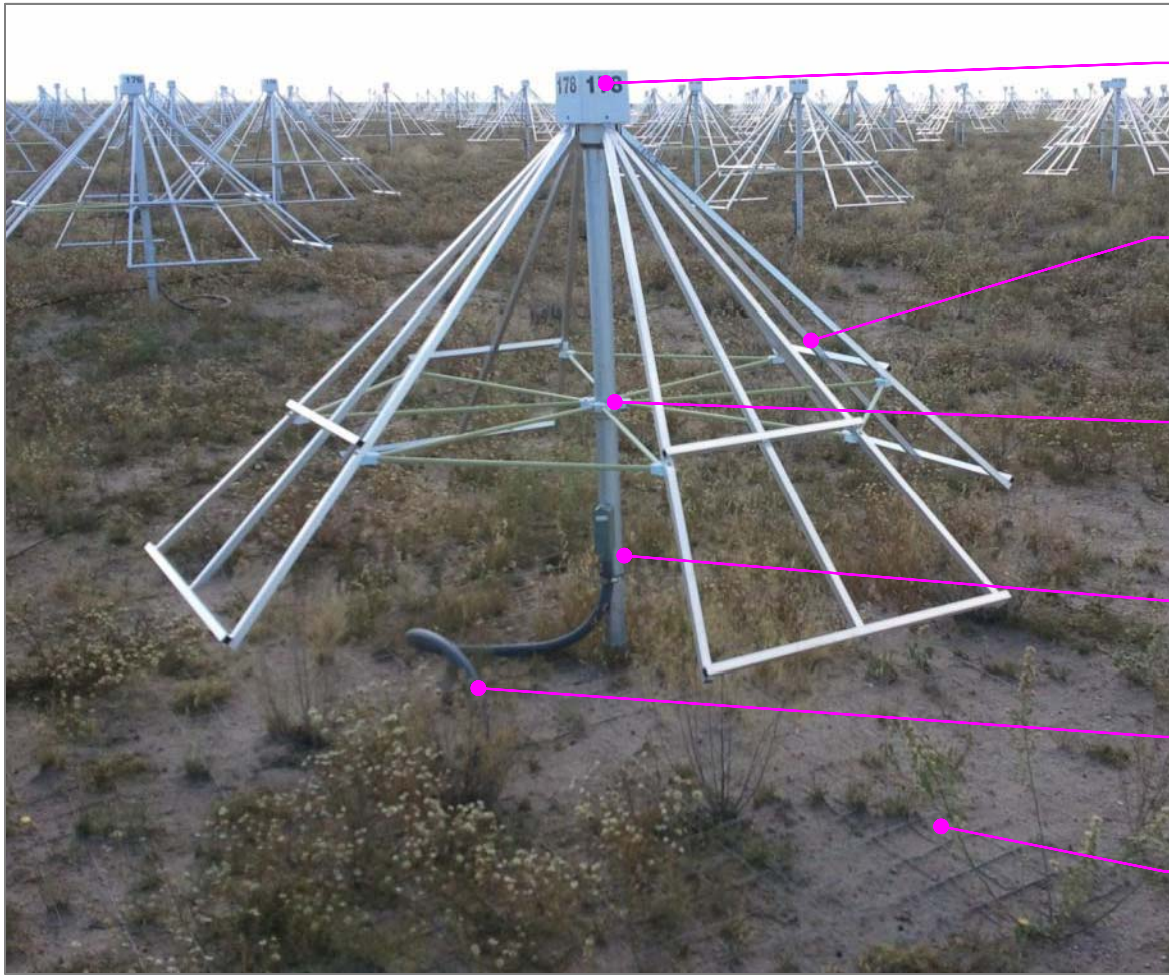
AA-low station layout



AA-low element deployment....

- Manufacture the electronics in a factory and have it fully sealed for integration at the site;
- The elements are large and cannot be shipped opened out, so they must be packed as flat as possible;
- Simple, effective position fixing e.g. the LWA and LOFAR low band elements;
- Orientation should be simple. Rotating the element to align polarisations should be quick and simple;
- It should be robust in the face of environmental issues: temperature range, humidity, possibility of flooding, dust ingress etc.;
- It must be low cost and reliable.

LWA element: mechanical example



- Electronics at top – well away from floods etc.
- Simple “skeleton” elements (delivered flat)
- Clamp type rotational adjustment
- Single pole fixing – just sunk into ground
- Buried cables
- Cheap mesh groundplane

Easy and quick deployment

AA-low design for costing

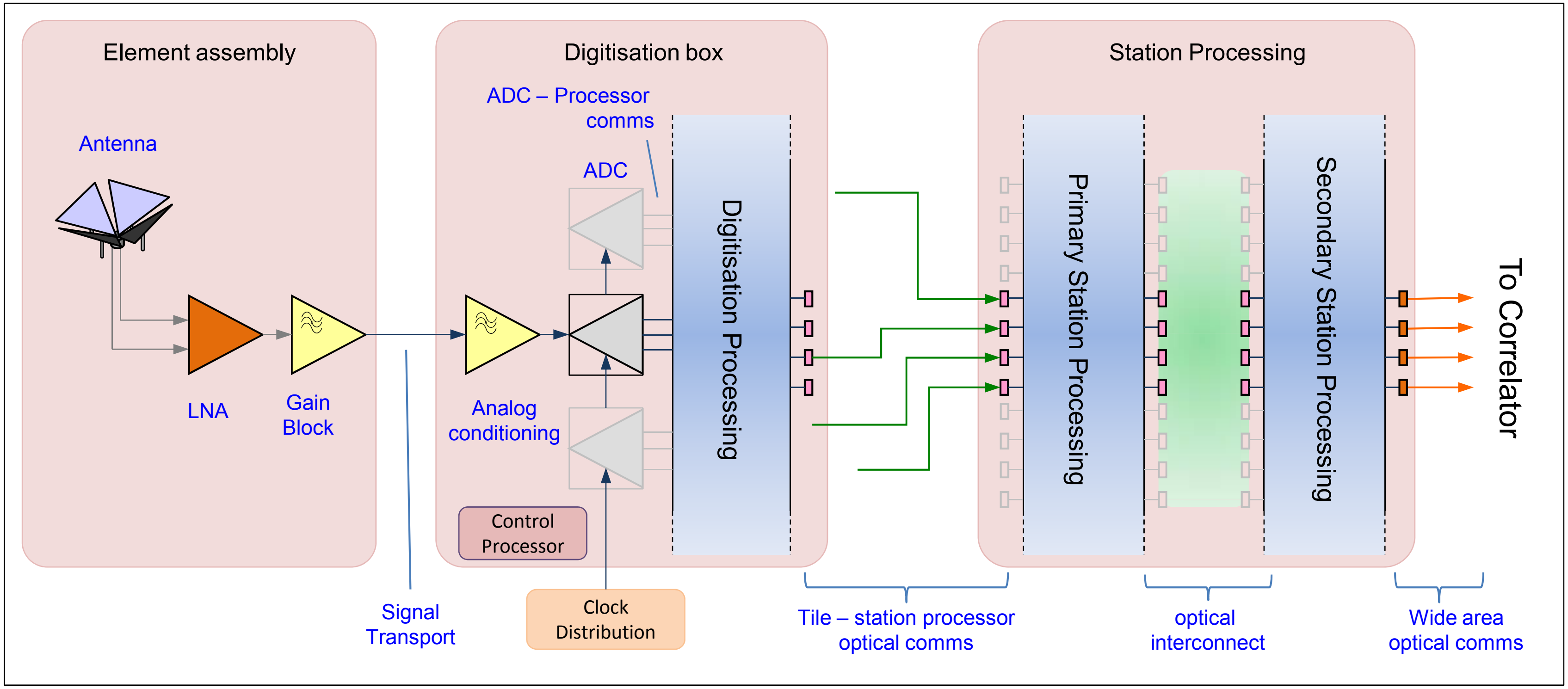
Parameter	Value	Comments
Type of array	Single element	Sparse array using a single wide-band element
Number of elements	11,264	
Approx. Size of elements	1m cube	
No. of polarisations	2	Each element has two receiver chains
Diameter of station	180m	
Number of stations SKA_1	50	Anticipated number of Phase 1 SKA Stations
Number of stations SKA_2	250	Anticipated number of Phase 2 SKA Stations
Element communication	Copper	Includes Phantom power
Layout	Random/ semi- random	The elements may be in clusters, the most flexible for array design is as individual elements.
Frequency range	70-450 MHz	Single element covering the full AA-low frequency
Digitisation rate	1GSamples/s	There is no frequency conversion, covers full frequency range with guard bands
Digitisation depth	6 or 8-bit	Required for RFI environment at these frequencies
Max instantaneous bandwidth	380 MHz	Covers operating band of array
Output data rate SKA_1	1Tb/s	Organised as 4+4bit complex data
Output data rate SKA_2	16Tb/s	Organised as 4+4bit complex data

AA-low station design

1. There are 11,300 dual polarisation elements in a station;
2. Station diameter is 180m;
3. There is no analogue beamforming*, every element is digitised;
4. The digitisation is in 44 Tiles of 256 elements each;
5. Data rate off each digitisation box set at 240Gb/s, after some beamforming;
6. The full active bandwidth from the digitisers is returned to the central processor;
7. A station has 22,400 digital receiver channels.

** There may be a need to use analogue beamforming if costs/power are too high*

AA-low signal path



AA-low Costing:

Realistic development

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**	

AA-low Costing:

System extrapolated from LOFAR

Output bandwidth ~50MHz

RF beamforming

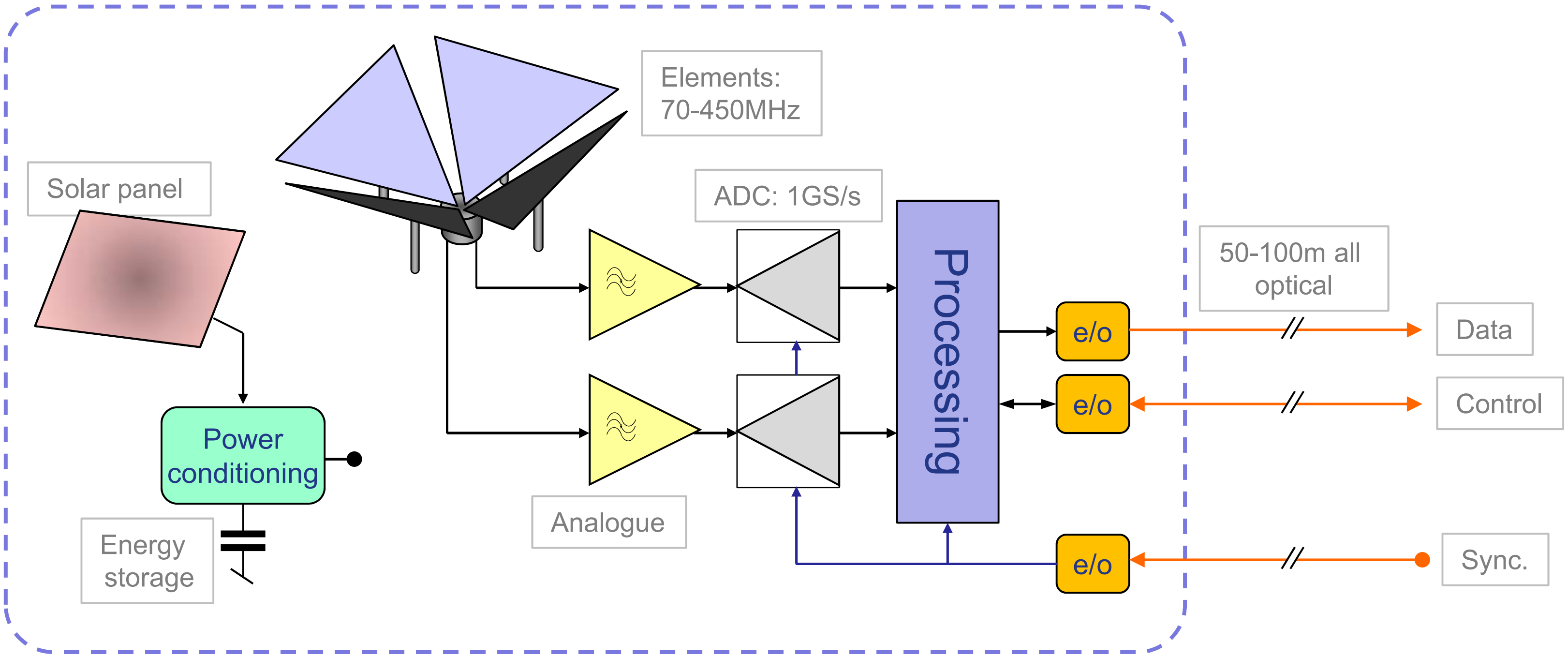
Item	Number	Cost/unit	Cost/Station	Comment
Antenna elements:				
Elements LNAs Gain and filter Housing Analog beamforming	11,264	€179	€2,011,328	Dual polarisation antennas. The cost is derived from LOFAR experience and the size of elements
Cabling, coax:				Element to digitisation
Cable Connectors	704	€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**	

AA-low Power:

Realistic development

	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**

Standalone SKA-low element (option)



Benefits:

Integrated single unit
No copper connection
Easy to deploy
Minimum RFI
Lightning “immunity”

Challenges:

Low total power
Integration
Manufacturability
Packaging

No need for digitisation boxes

AA-low: SKA$_1$ to SKA$_2$

Fixed Aspects

- Frequency range
  - Intrinsic to the design
- Element & array electromagnetic design
- Front end functionality
- Analogue implementation
  - Unlikely to change
- Interfaces
  - Could bypass the digitisation boxes

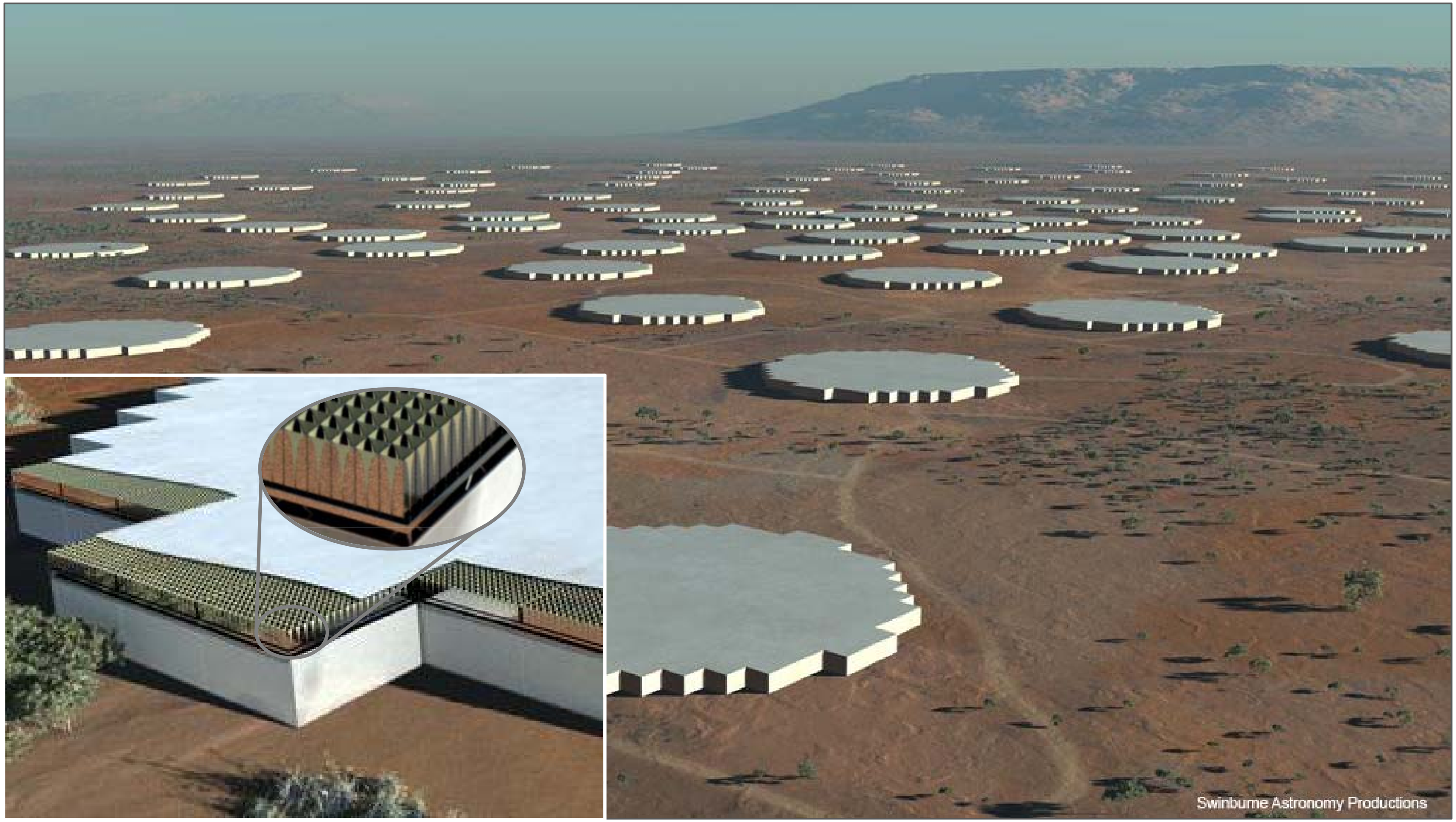
Possible Variables

- Station size & configuration
- Core layout (getting bigger)
  - Move element positions.....?
  - Trenching etc. (if required)
- Processing technology level
  - **Essential** for economical deployment
- Upgraded calibration methods
  - Needs flexible processing system

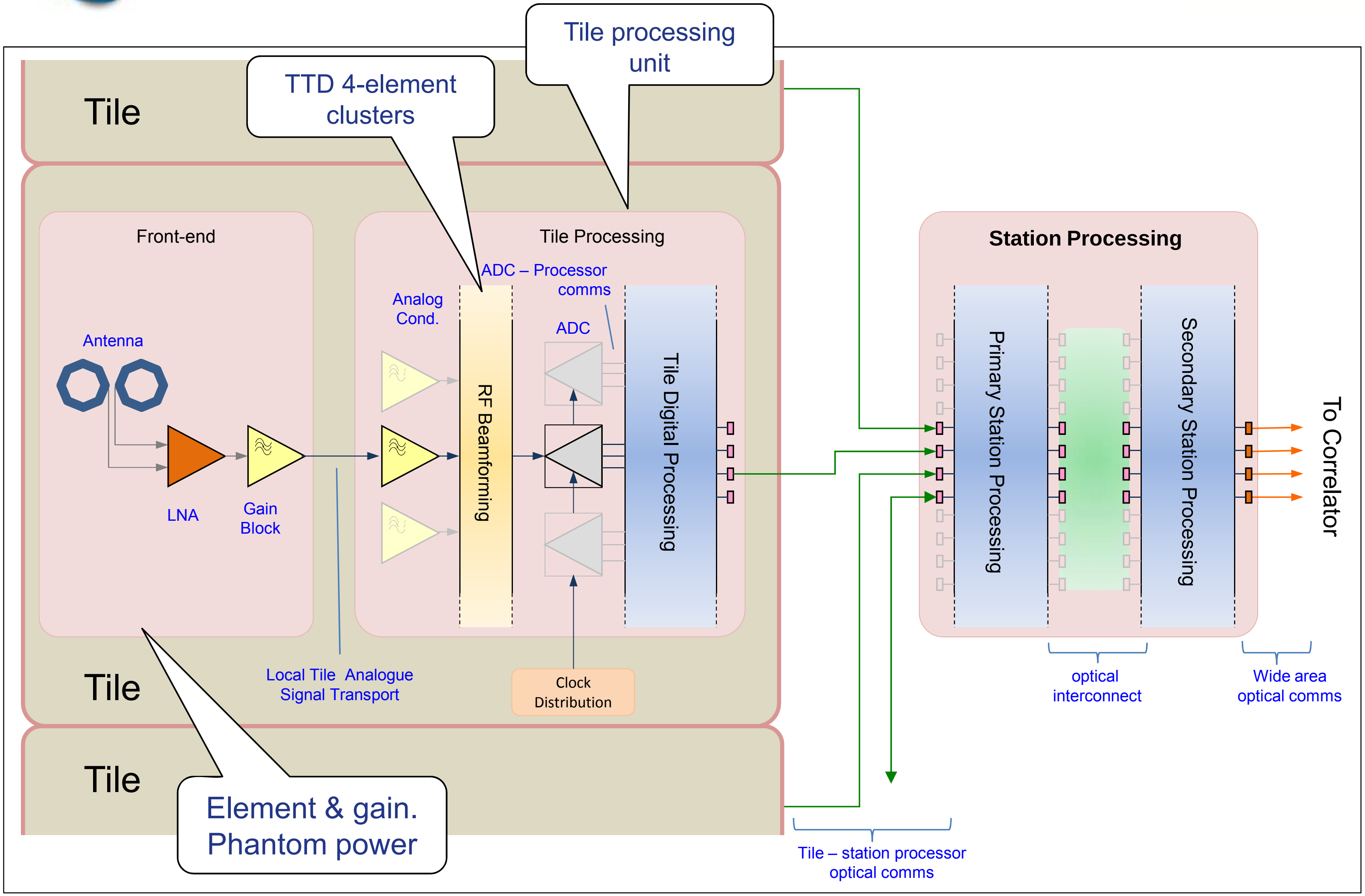
Processing Bunker considerations

- Shipping and deployment
  - Use Standard shipping container dimensions
  - Ship pre-loaded with electronics and tested – needs to be designed for this.
- Keeping it RFI sealed
  - All interfaces via fibre only power via copper
  - Use liquid cooling via metal pipes
- Impact on elements electromagnetics
  - Locate at a distance to give <TBD degrees angle at top
  - Possibly part bury the bunker
- Upgradeability
  - Use standard racks etc.

AA-mid Array



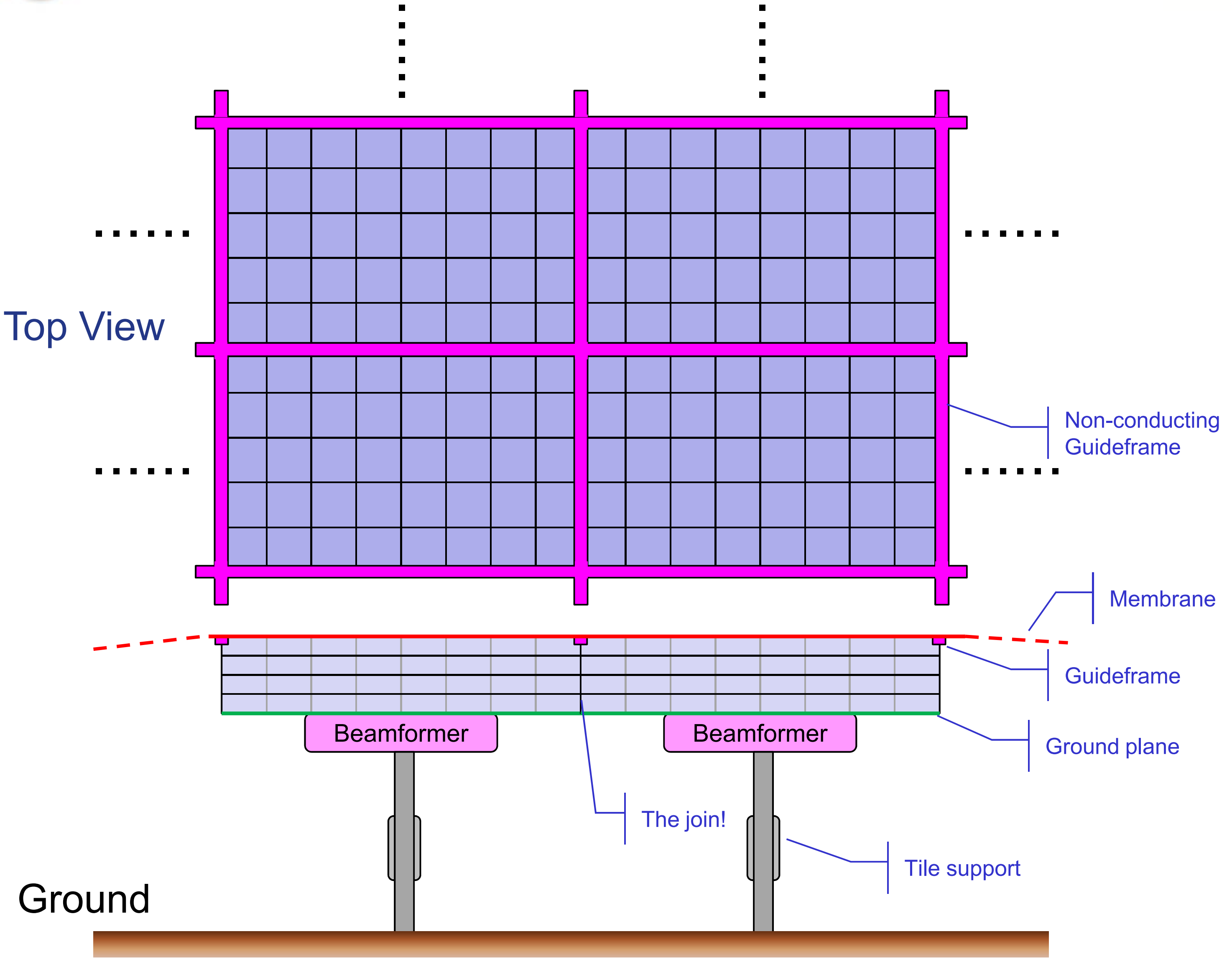
AA-mid proposed signal path



AA-mid construction considerations

- High dynamic range system, so needs to be ‘perfect’
- Elements need to be kept at a constant pitch
- Build as pre-tested Tiles for simple deployment
- Elements need electrical links between Tiles
- Fibre links to station processor
- Need to be able to remove a Tile from the array as a maintenance item
- The Tile beamformers will create heat that needs to be removed
- Protect from environment and wildlife

Possible AA-mid construction



AA-mid station design

1. The element pitch is 15 cm (λ/2 at 1GHz);
2. Station diameter is 56m, or ~2500m^2;
3. Analogue beamform 4 elements;
4. Tiles are 16x16 dual polarisation elements (2.4m square);
5. Tiles have 128 digitisation channels (256*2/4);
6. Data rate off each Tile set at 120Gb/s
7. A Station has 430 Tiles or 110,000 elements or 220,000 receiver chains.
8. A station has 55,000 digital receiver channels.

AA-mid design for costing

Parameter	Value	Comments
Type of array	Single element	Dense array using Vivaldi or ORA.
Number of elements	110,000	
Pitch of elements	15 cm	λ/2 at 1000MHz
No. of polarisations	2	Each element has two receiver chains
Diameter of station	56m	
Cluster size	4 elements	Uses true time delay beamforming*
Tile size	16 x 16 elements	Built out of 4 x 4 clusters
No. of Tiles	430	Each tile is ~2.4m square
Number of stations SKA_2	250	Anticipated number of Phase 2 SKA Stations
Element communication	Copper	Includes Phantom power
Layout	Dense rectangular	Regularly spaced
Frequency range	400-1450 MHz	
Digitisation rate	3GSamples/s	There is no frequency conversion,
Digitisation depth	6-bit	Required for RFI environment at these frequencies
Beamforming technology	Digital	Using cluster outputs
Max inst. bandwidth	1000 MHz	Covers operating band of array
Max output data rate	16Tb/s	Organised as 4+4bit complex data

*may need to be greater amount of analogue b/f, depends on implementation date

AA-mid Costing

		Quantity	€ each	€ system	Comments
Tile					Dual polarisation
	Elements assembly	256	11.21	2,870	
	LNA				
	Gain + filter				
	Interconnect	128	5.00	640	
	Processing	1	1,000	1,000	Processing on the Tile
	TTD beamform				
	Gain + filter				
	ADC				
	Mechanics	1	200	200	
	Communications links	1	117	117	120 Gb/s per Tile
	Tile each			4,827	
	Tile Total	430	4,827	**2,075,507**	
Station processor					
	Processor boards	48	2,731	131,065	
	internal comm.	864	117	101,088	
	Fibre driver boards	25	746	18,650	
Infrastructure					
	Support structure			250,000	
	Bunker				
	Racks				
	Cooling				
	Total			**€2.58M**	AA-mid station SKA_2

AA-mid Power

	Subsystem	SKA_2	Remarks
	Front-end (Quads of 4 elements):	mW	
1	LNA total	120	4xLNAs at 30mW each
2	Antenna gain block	120	4 units at 30mW each
	Tile beamformer:		
3	Analogue sig conditioning	160	4 channels at 40mW each
4	Analogue beamforming	100	Combiner for 4 elements for digitisation
5	ADC	50	2.5 GS/s, 10Gb/s each channel
6	Clock distribution	10	estimate (less with more ADC per chip)
7	*Coms:* ADC to processor		Integrated ADC and processor
8	Tile Processor	200	25 W for 128 digital channels
9	Tile Control ccts etc.	100	13 W for 128 digital channels
10	*Copper comms:* Processor to optical driver	10	1.2 W for 128 digital channels
11	*Optical Coms:* Tile to Station proc.	20	2.5 W for 128 digital channels
	Station Processor:		
12	Primary Station processor	130	600 W for 4608 digital channels
13	*Copper comms:* Processor to optical driver	10	1.2 W for 128 digital channels
14	*Optical Coms:* Primary to Secondary Station proc.	20	2.5 W for 128 digital channels
15	Secondary Station processor	130	600 W for 4608 digital channels
16	*Copper comms:* Processor to optical driver	10	16 Tb/s station output with 153,000 receivers @ 10mW/Gb/s
	Long Distance comms:		
17	Wide area comms		Accounted for separately
	Electrical power used	**1,190**	Per digital channel
	Electrical power supplied @ 85% efficiency	1,400	
	Power incl cooling at 25% cooling power	1,750	
	Total station power	**96**	**kW**

Upgradeability

With a 30+ year life the SKA is bound to be upgraded....

Front end: antennas, LNAs, & analogue — Unlikely

- Difficult and dispersed

Tile beamformers and digitisers — Maybe

- Inconvenient
- Baseband digitisation
- Should be full bandwidth, but could save power

Intra station communications — Unlikely

- Difficult and should carry large bandwidth

Station processors — Likely

- These are in standard racks and accessible
- Major performance and power benefits

Reliability and redundancy

Reliability

- Large number of components
- Stable operating temperature
- Connectors need to be left alone and protected
- Low semiconductor junction temperature
- Minimise component count: high integration
- Physical stability: no vibration or other movement

Redundancy

- Not got many explicitly redundant systems e.g. Power supplies, clock generator, cooling pumps
- However, degrade gracefully as elements/tiles are lost

Considerations for availability

- Individual elements plus receiver chains to be monitored for correct operation
- Recalibrate if elements are lost
- Failed Tiles or groups of antennas e.g. Faulty processing board etc. Needs study to find if the array can be recalibrated accurately
- Station processing. Endeavour to make it dispersed across systems. Potential for re-routing.
- Wide area comms links inherently dispersed.

Summary

- Work so far show that AAs can be deployed successfully
- Power and cost should be within SKA budgets
- Need to concentrate on design for deployment
  - Factory manufacture
  - Minimise transport
  - Minimise site preparation
- AAs are inherently redundant giving potentially good availability
- Capable of ongoing upgradeability