AA Performance enabled by communications

Andrew Faulkner
AAVP System Engineer

SKA Top-level description

A large radio telescope for transformational science

- Up to 1 million m^2 collecting area
- Operating from 70 MHz to 10 GHz (4m-
- Two or more detector technolo
- Connected to a signa … high performance computing sy … cal fibre network

Pro

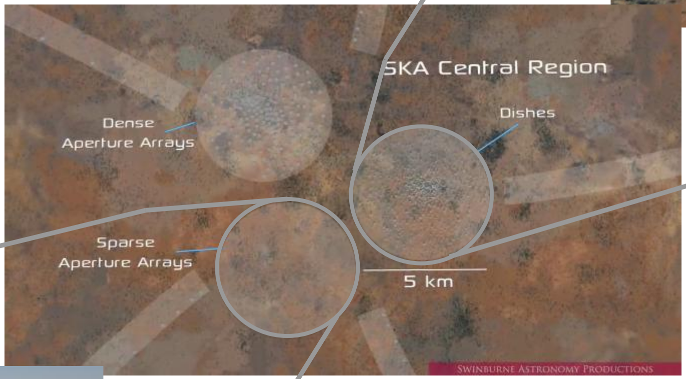
- 4 … nsitivity of the EVLA, and
- up to 100,000 x survey speed

A Discovery Telescope

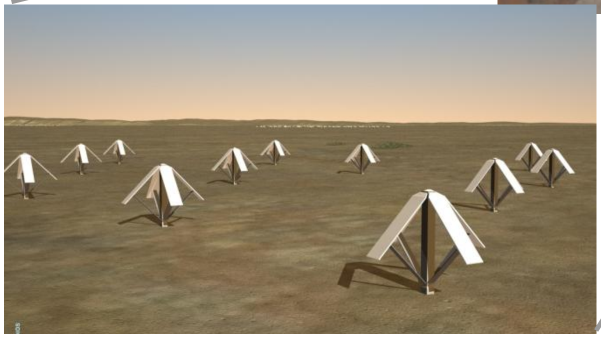
SKA$_1$ Receptor Technologies

~250 Dishes

One Core reserved for SKA$_2$ use.



2-Core Central Region



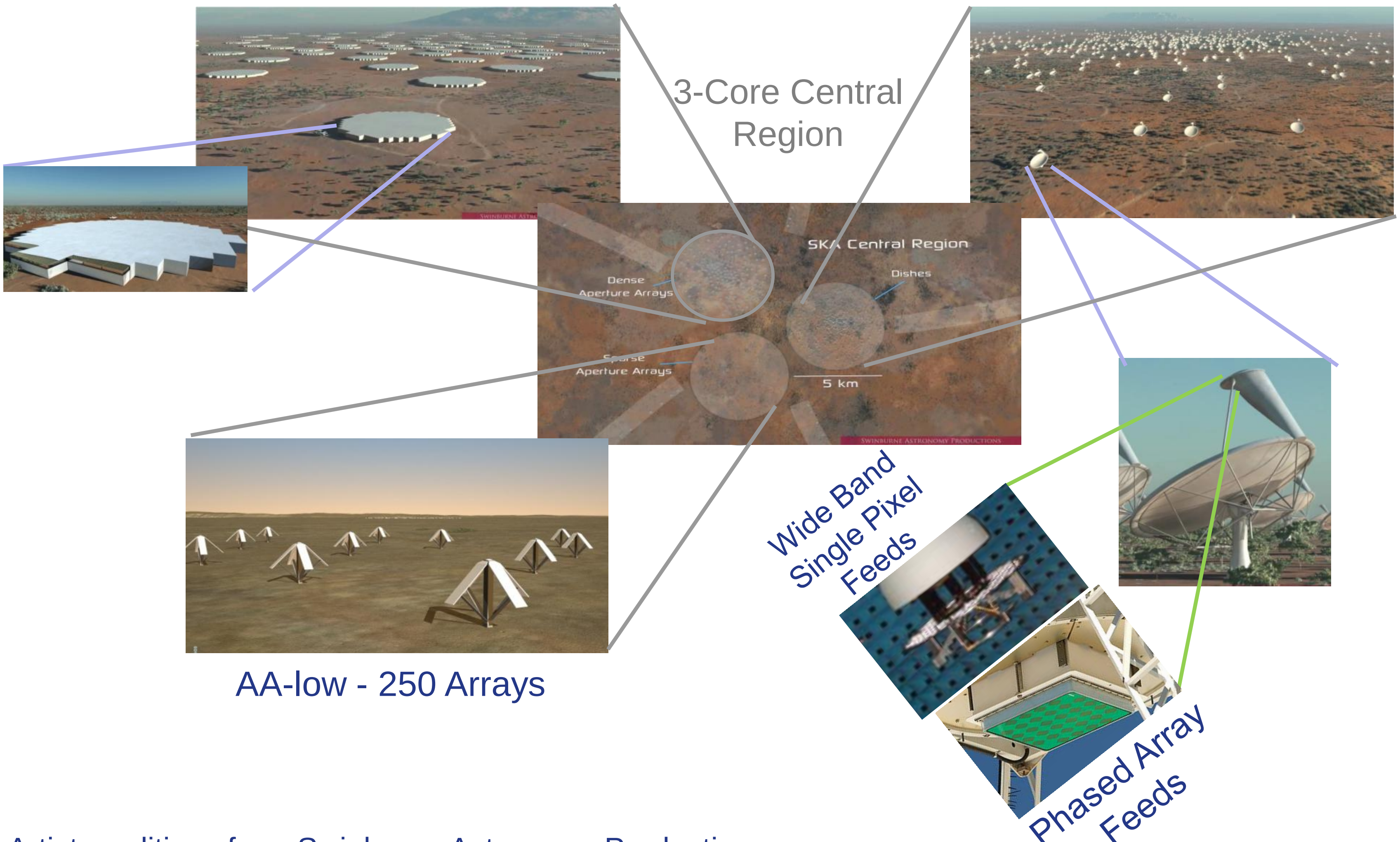
AA-low - 50 arrays

Artists' Renditions from Swinburne Astronomy Productions

SKA$_2$ Receptor Technologies

250 Dense Aperture Arrays

1-3000 Dishes

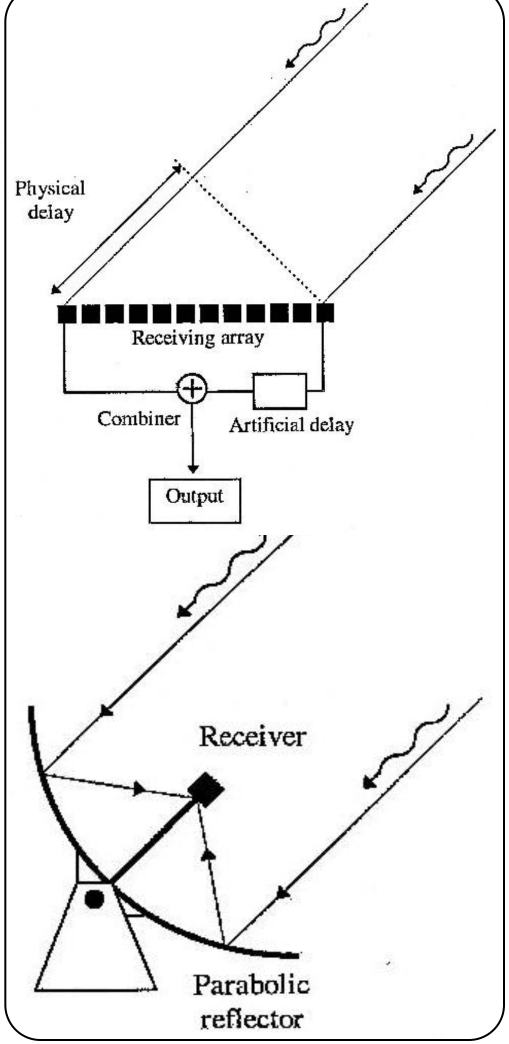


AA-low - 250 Arrays

Artist renditions from Swinburne Astronomy Productions

Aperture Arrays

Michael Kramer



Sparse or Dense….

Dense:

Element spacing ≤ λ/2 — **Constant A_{eff}**

Fully sampled wavefront — Excellent side lobe control

Regular layout pattern — Beam performance equiv to the best dish design

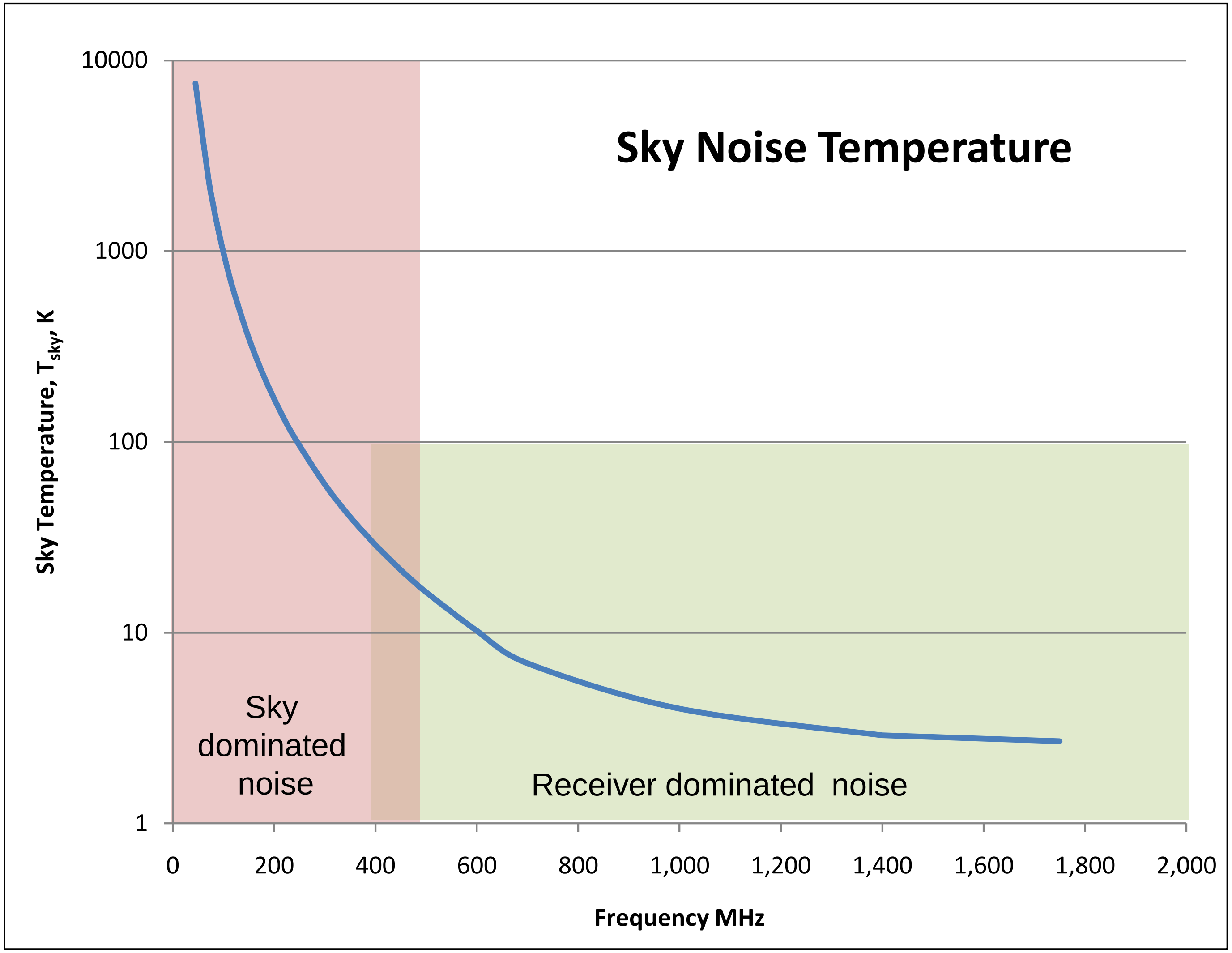
Sparse:

Element spacing >λ/2 — **A_{eff} increases as λ^2** (~ $\lambda^2/4$)

Layout irregular to control grating lobes — Increased skynoise from grating lobes

Possible dynamic range issues

Sparse and Dense regimes



Why aperture arrays?

- At **low frequencies**, <~300MHz, the only realistic way of building sufficient collecting area
- Unsurpassed ability to create **Field of View** through multiple beams
- Extremely **flexible** in observational parameters e.g. Sky area vs. bandwidth
- Can run **multiple experiments** concurrently
- Using a large amount of up front processing they reduce the back-end processing load
- Can **tune** imaging coverage, beam size, post-processing load etc.

ICT based AAs provide many new opportunities

An SKA collector summary

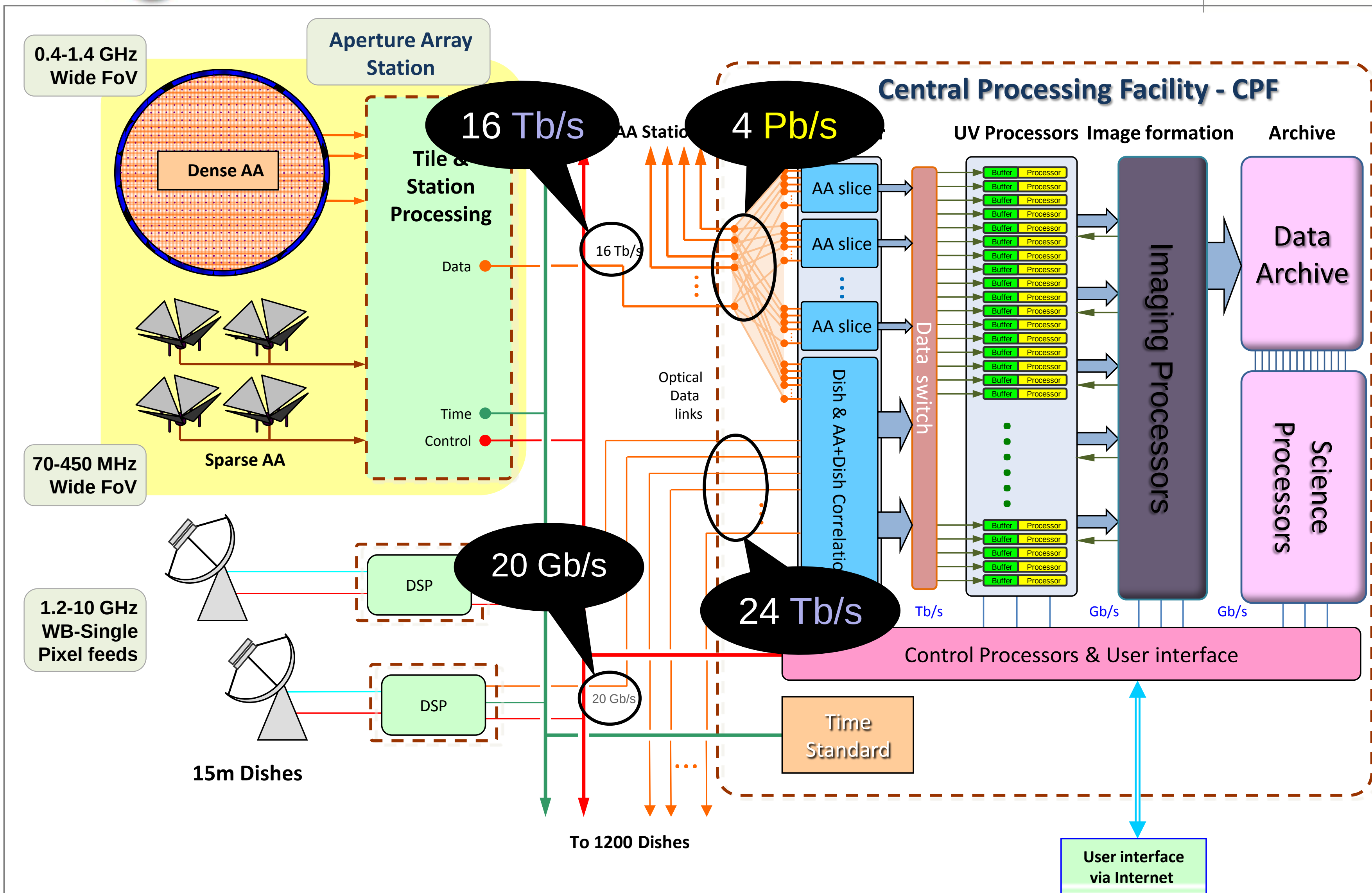
SKA_1

Freq. Range	Collector	Sensitivity	Number / size	Distribution
70 MHz to 450 MHz	**AA-low** Sparse AA	1,000 m^2/K at 100 MHz	50 arrays, Diameter 180 m	70% within 5 km dia., 30 % along 3 spiral arms out to 100 km radius
300 MHz to 3 GHz	Dishes with single pixel feed	1,000 m^2/K at 1.4 GHz	250 dishes Diameter 15 m	

SKA_2

Freq. Range	Collector	Sensitivity	Number / size	Distribution
70 MHz to 450 MHz	**AA-low** Sparse AA	4,000 m^2/K at 100 MHz	250 arrays, Diameter 180 m	66% within 5 km dia., 34% along 5 spiral arms out to 180 km radius
400 MHz to 1.45 GHz	**AA-mid** Dense AA	10,000 m^2/K at 800 MHz	250 arrays, Diameter 56 m	
300/1000 MHz to 10 GHz	Dishes with single pixel feed + PAF	10,000 m^2/K at 1.4 GHz	2000 – 3000 dishes Diameter 15 m	50% within 5 km dia, 30% 5km - 180 km 20% 180 km-3,000 km.

SKA$_2$ wide area data flow



Survey speed

Fixed

Simple survey speed: $(A_{eff}/T)^2\Omega$

Survey speed w/BW: $(A_{eff}/T)^2\Omega\Delta\nu$

Station data rate, DR_{st}: $\propto N_{beams} \propto \Omega \propto \Delta\nu$

Total data rate, Dr_{tot}: $N_{stn} * DR_{stn}$

For fixed Aeff

Station dia. $D \propto (N_{stn})^{-0.5}$ & $\Omega_{stn} \propto D^{-2}$

Critical for the SKA

a discovery instrument

A_{eff}	Effective collecting area, m^2
T	System temperature, K
Ω	Field of View. deg^2
$\Delta\nu$	Bandwidth, Hz

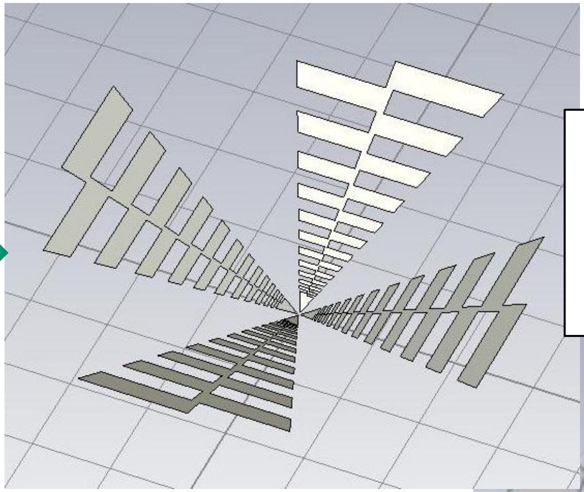
Hence

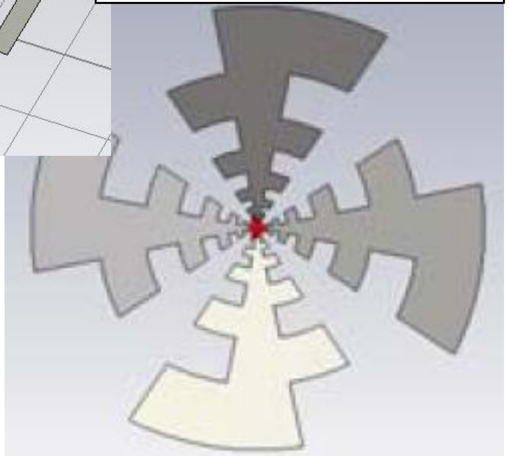
Total data rate for a fixed survey speed is ***independent*** of # of stations (fixed A_{eff} & Bandwidth)

LOFAR

AA-low element development

BLU antenna: Bow-tie Low Freq. Ultra-Wideband antenna

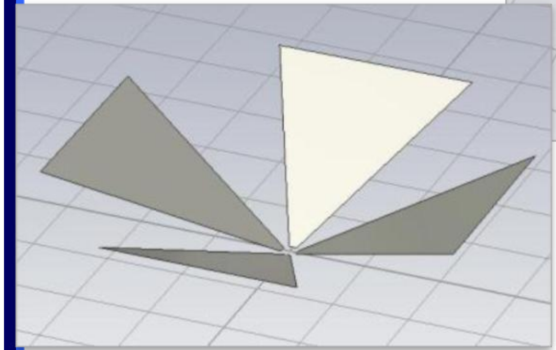


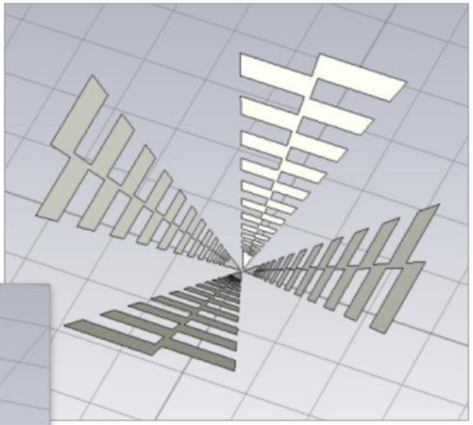


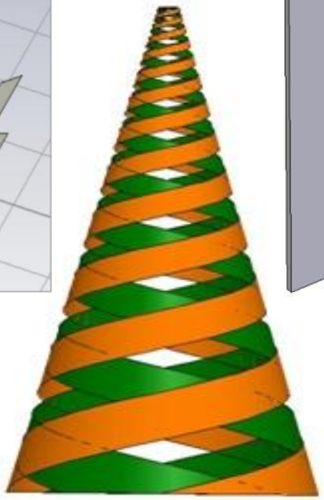
Toothed log-periodic antennas for pattern improvement

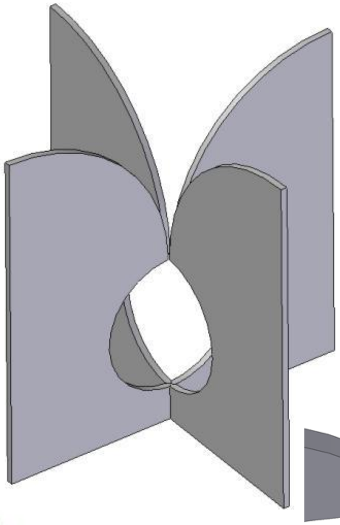
Pattern measure

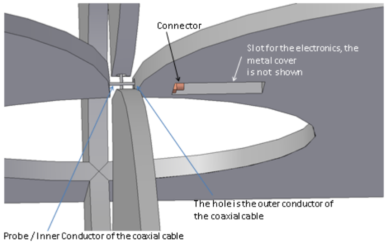
AA-low elements & array

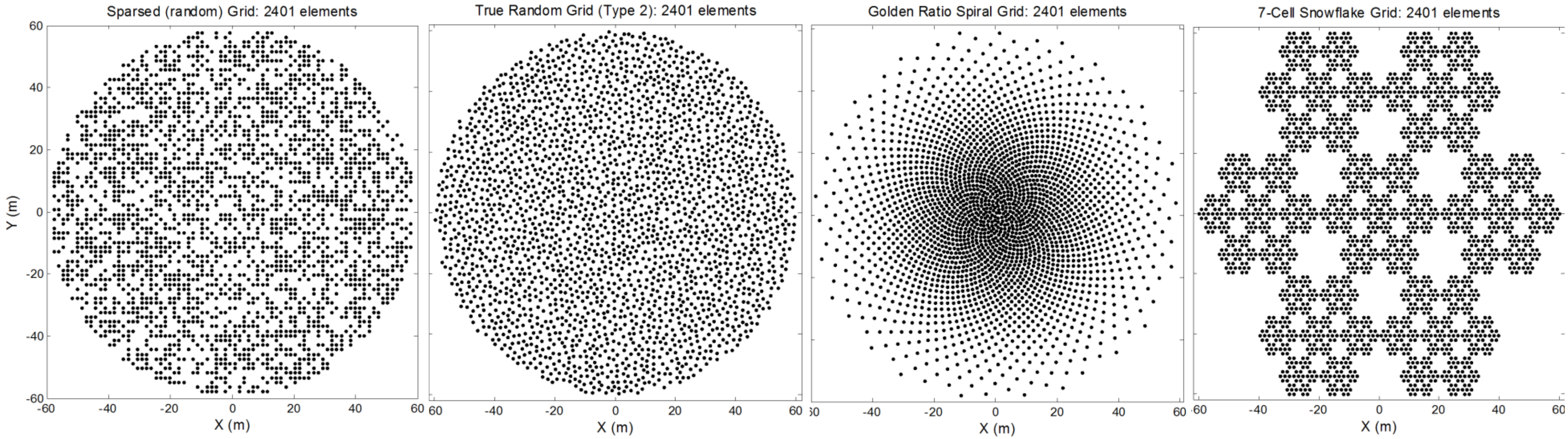




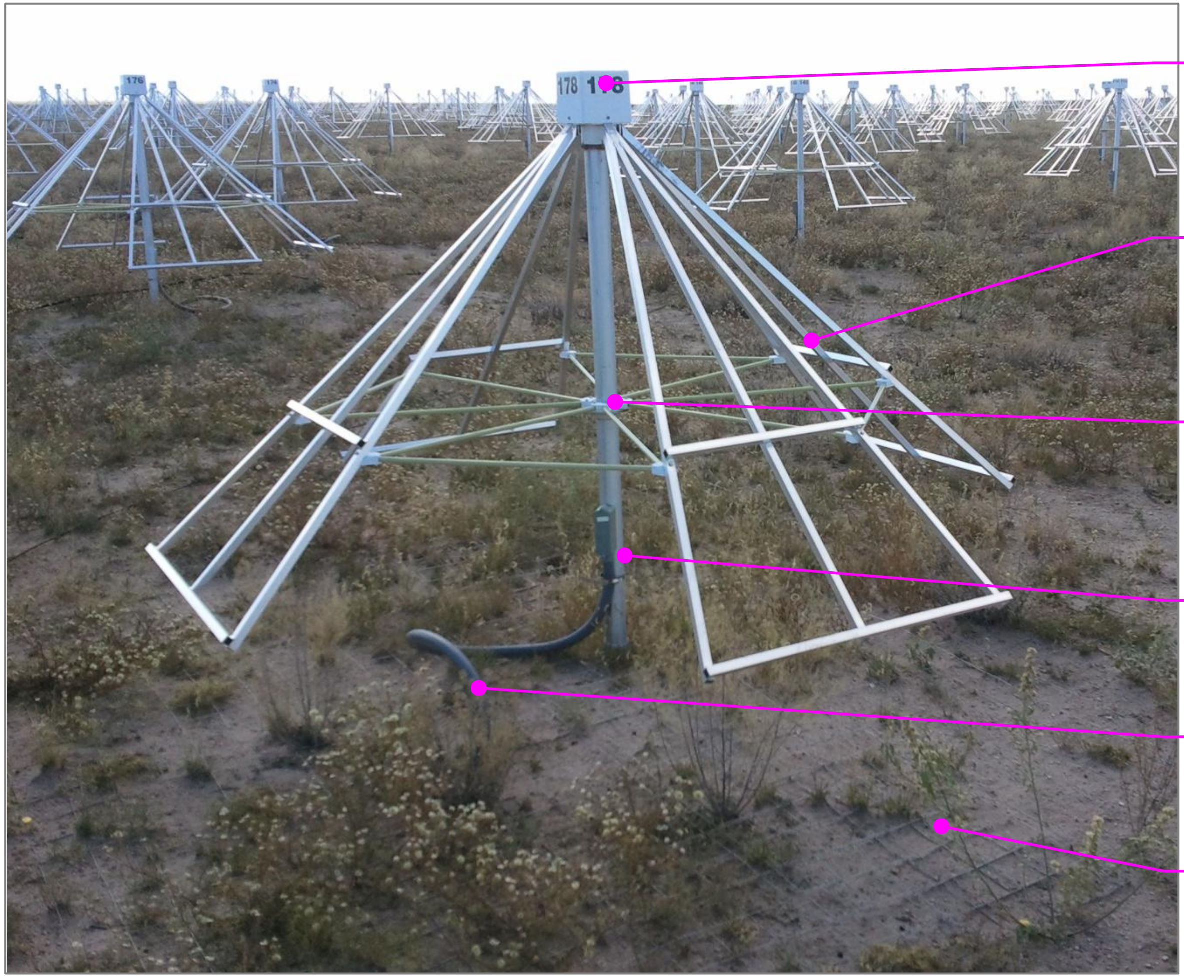








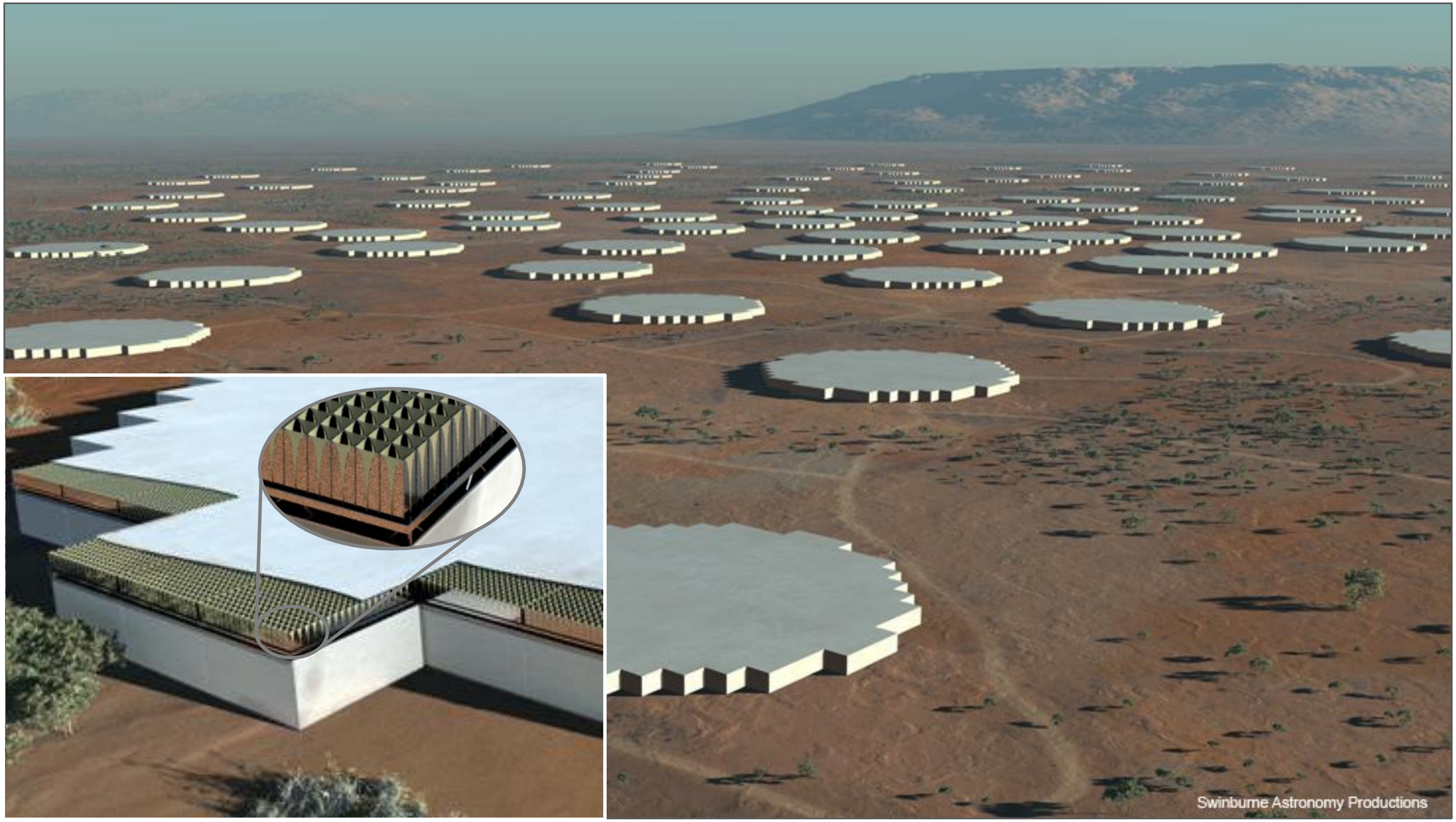
LWA element: mechanical example



- 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

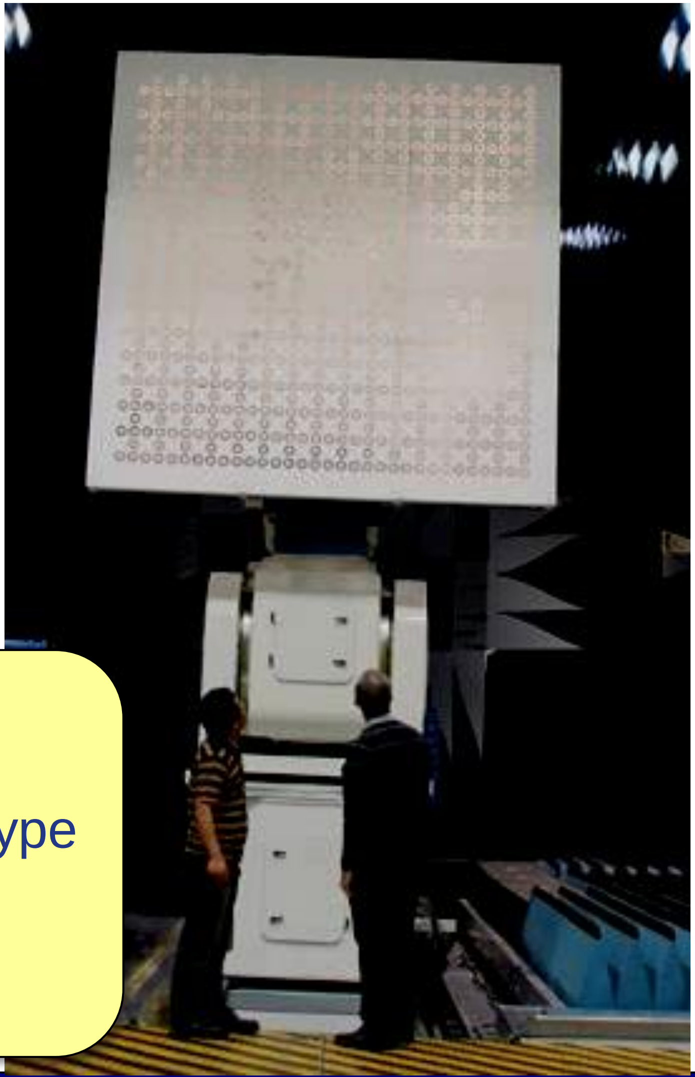
AA-mid Array



AA-mid elements and array

Vivaldi array - EMBRACE

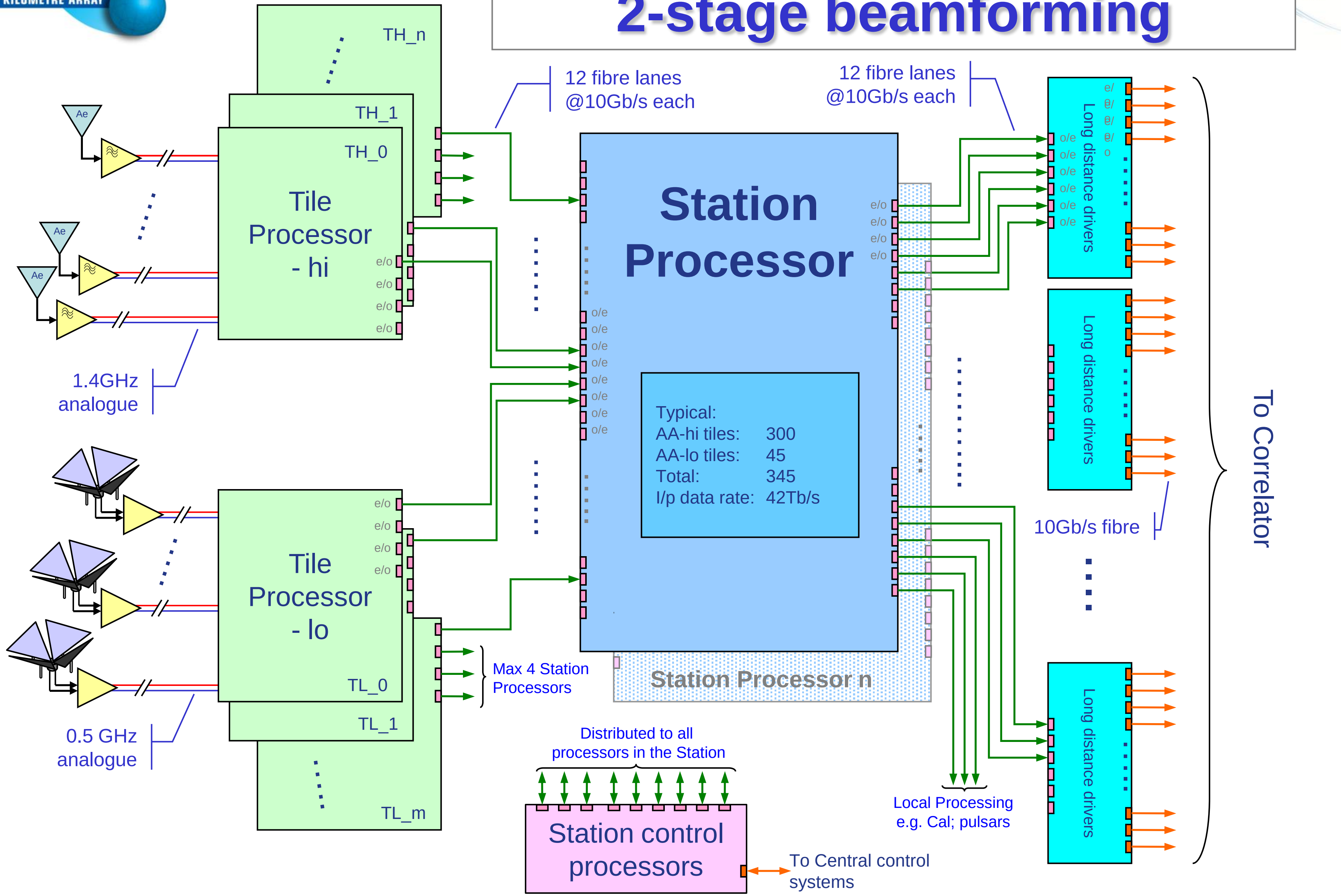
ORA array - SKADS

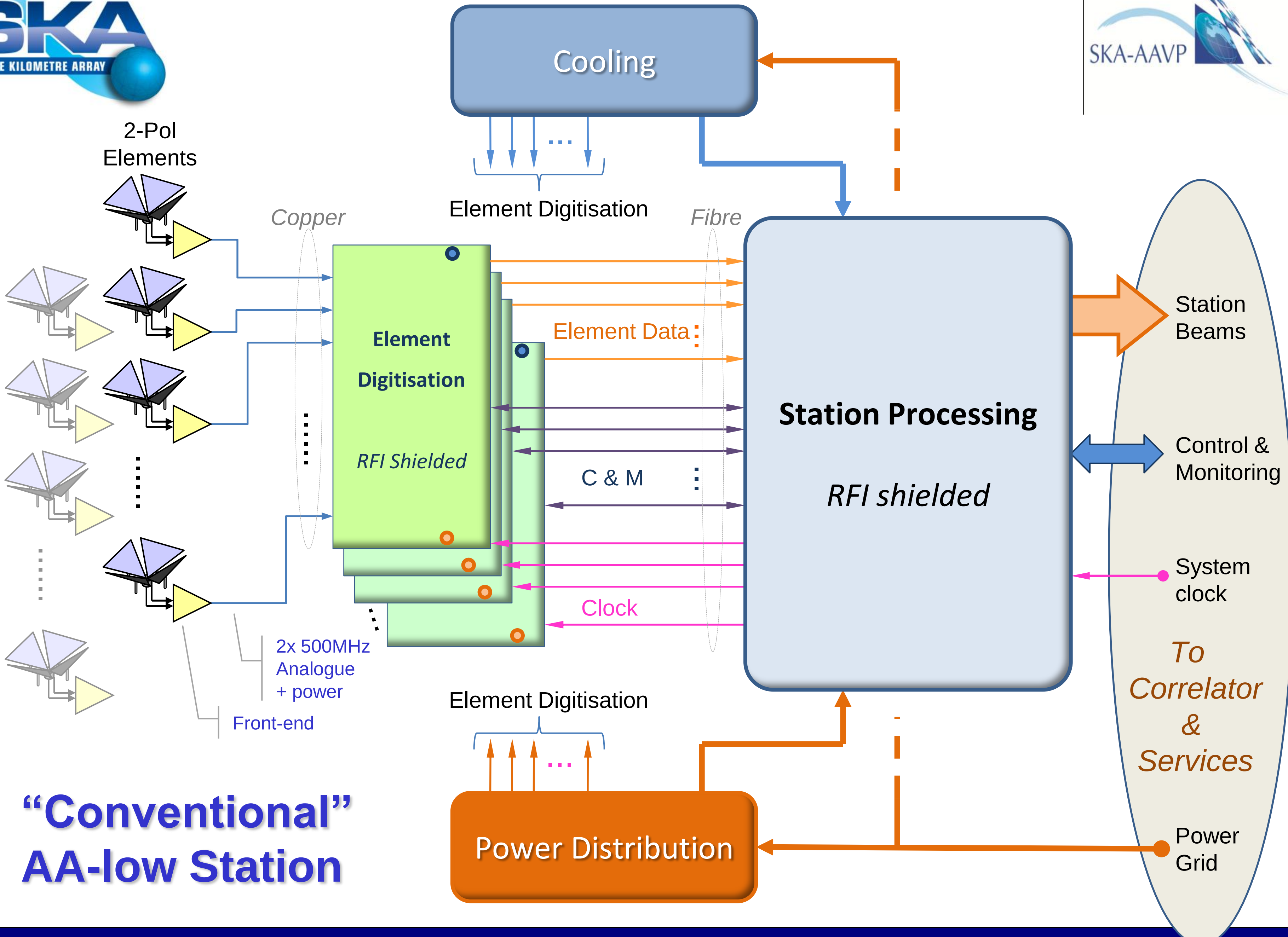


Dense array design, largely decided, select:

- Element pitch for frequency range & element type
- Element type and construction technique
- LNA: differential or single ended

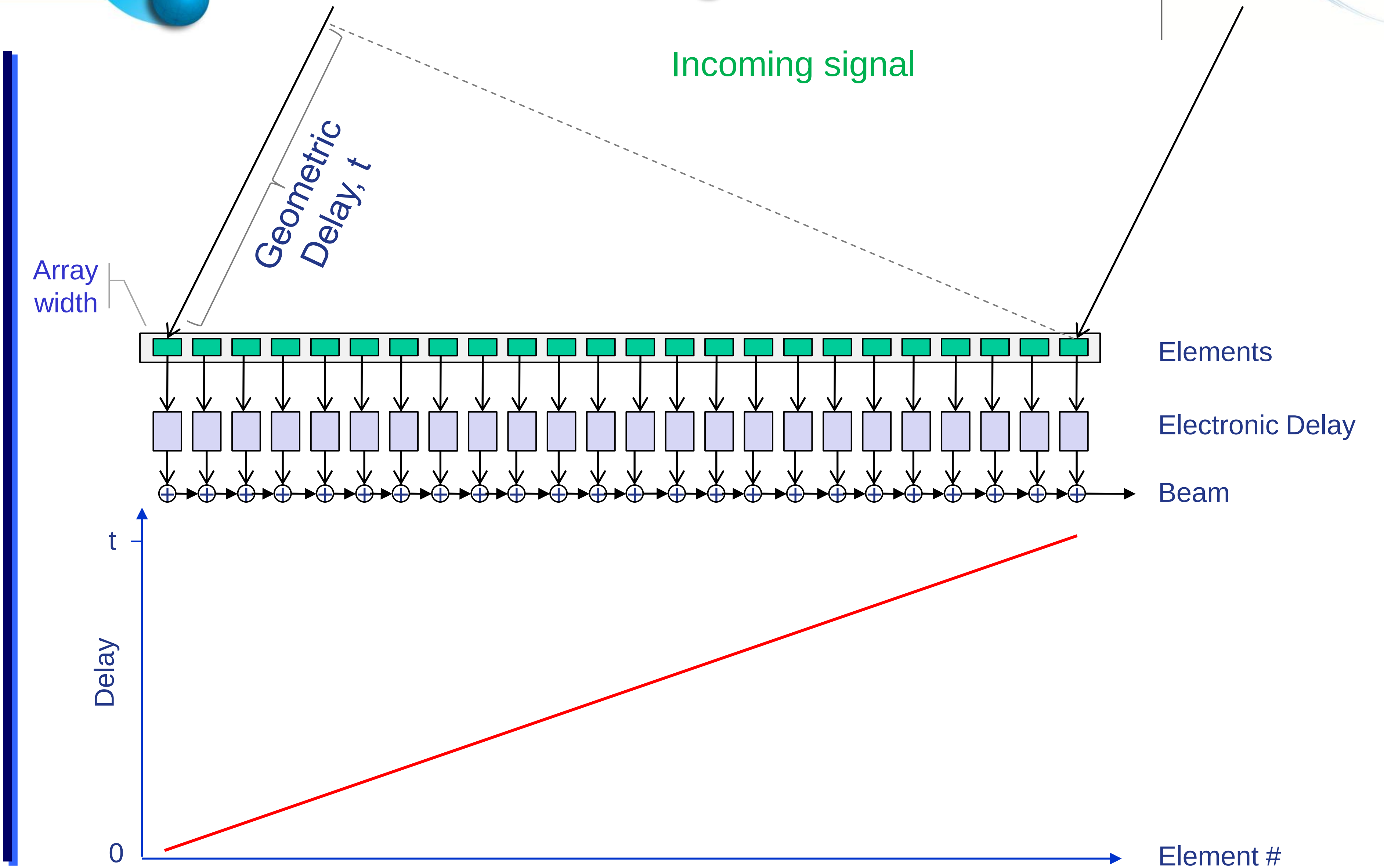
Comms in generic AA with 2-stage beamforming



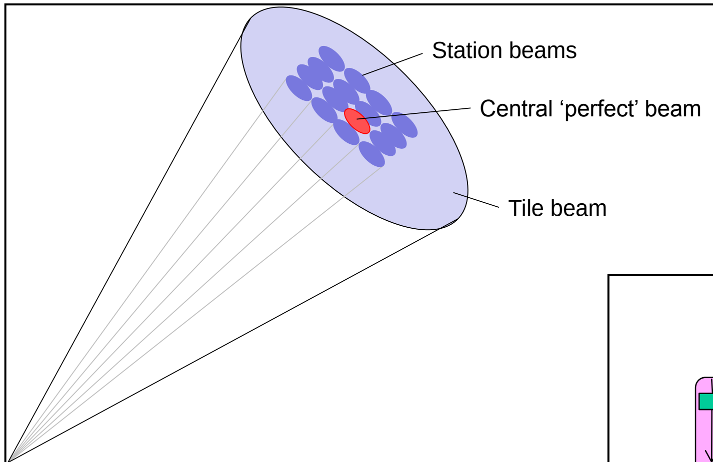


"Conventional" AA-low Station

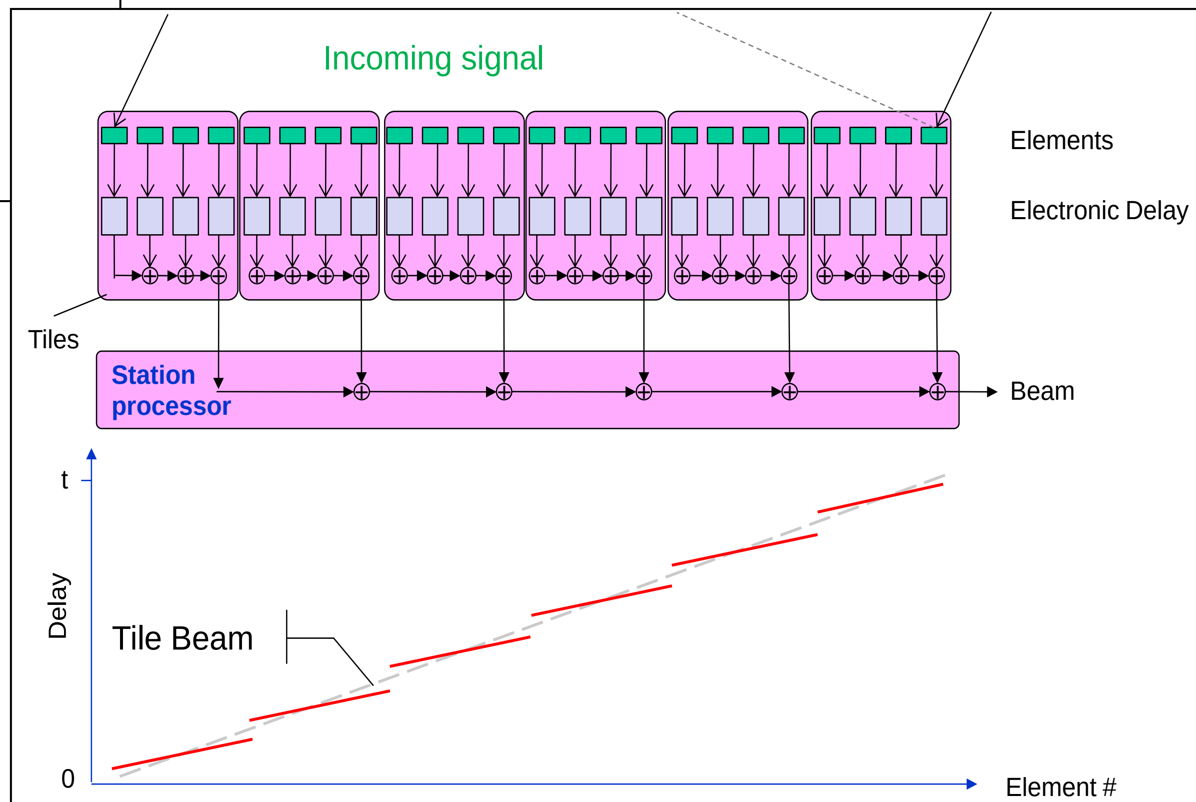
1-D Beamforming



Two stage beamforming

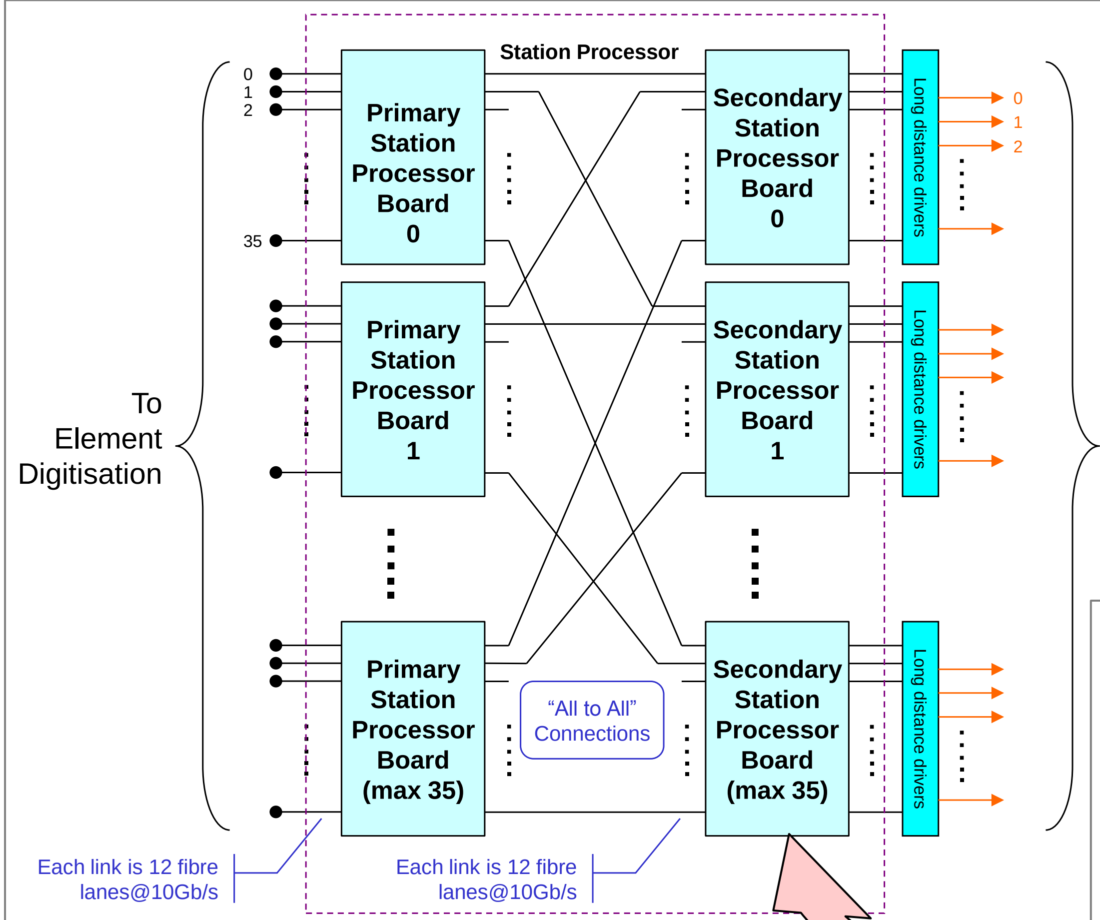


Filling “Tile beams” with station beams leads to discontinuities in the beamforming for off-centre beams

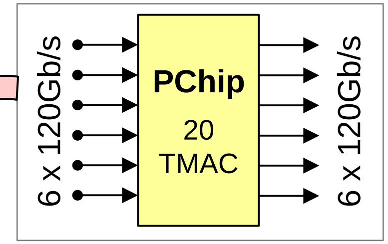


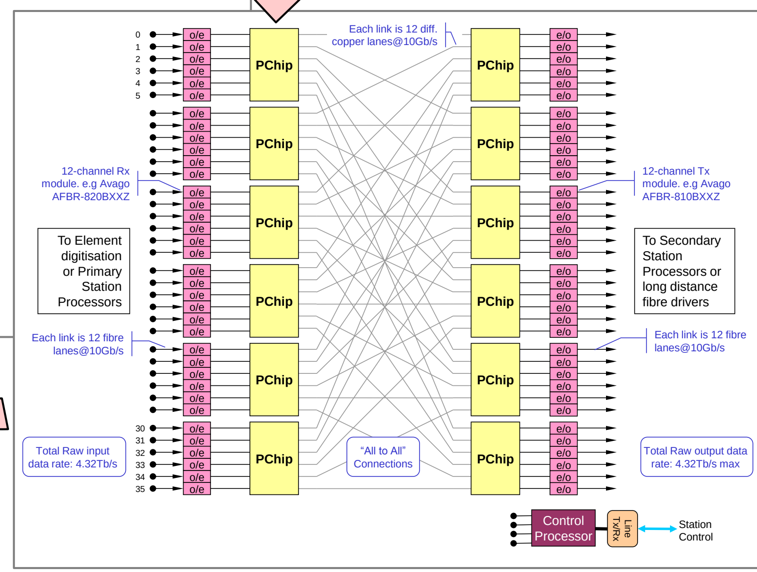
Can be resolved with **higher data rate** Tile to Station Processor

Station processor



Requirements:
- High bandwidth in
- High bandwidth out
- Largely cross connected
- Scaleable at various levels
- Programmable beamforming





Hierarchical structure:
Linked with comms

Output data rate & array performance

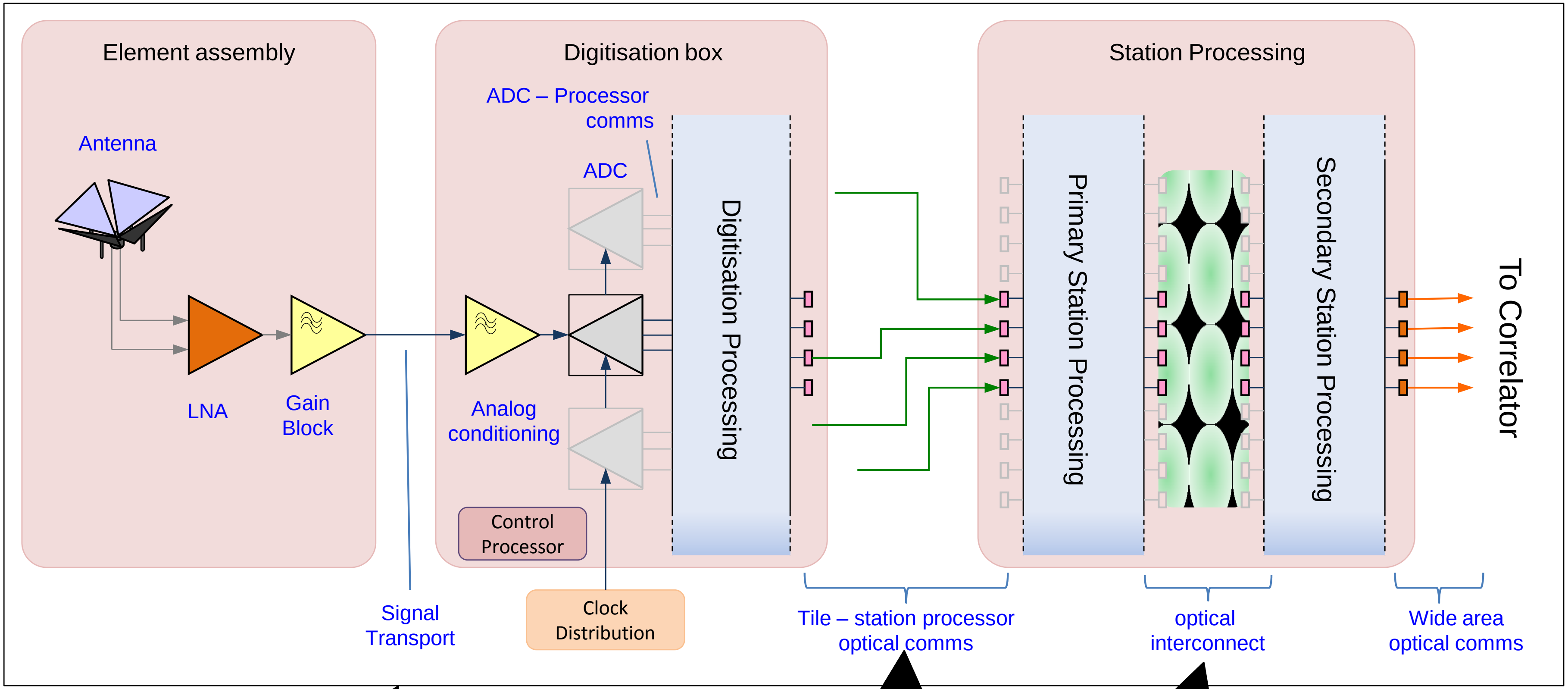
- The output data rate **defines** the performance of the array
- A better measure than “beams” since it considers flexible use of data between bandwidth and direction.
- Front end analogue beamforming restricts areas of sky that can be observed concurrently
- Changing the number of bits/sample for different observation types maximises performance
- Not a problem for the correlator which only “sees” total data rate
- Post-processor needs to interpret blocks of data

Build flexibility into the Station processor

Potential AA-low station design

1. There are 11,264 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.

AA-low station signal path



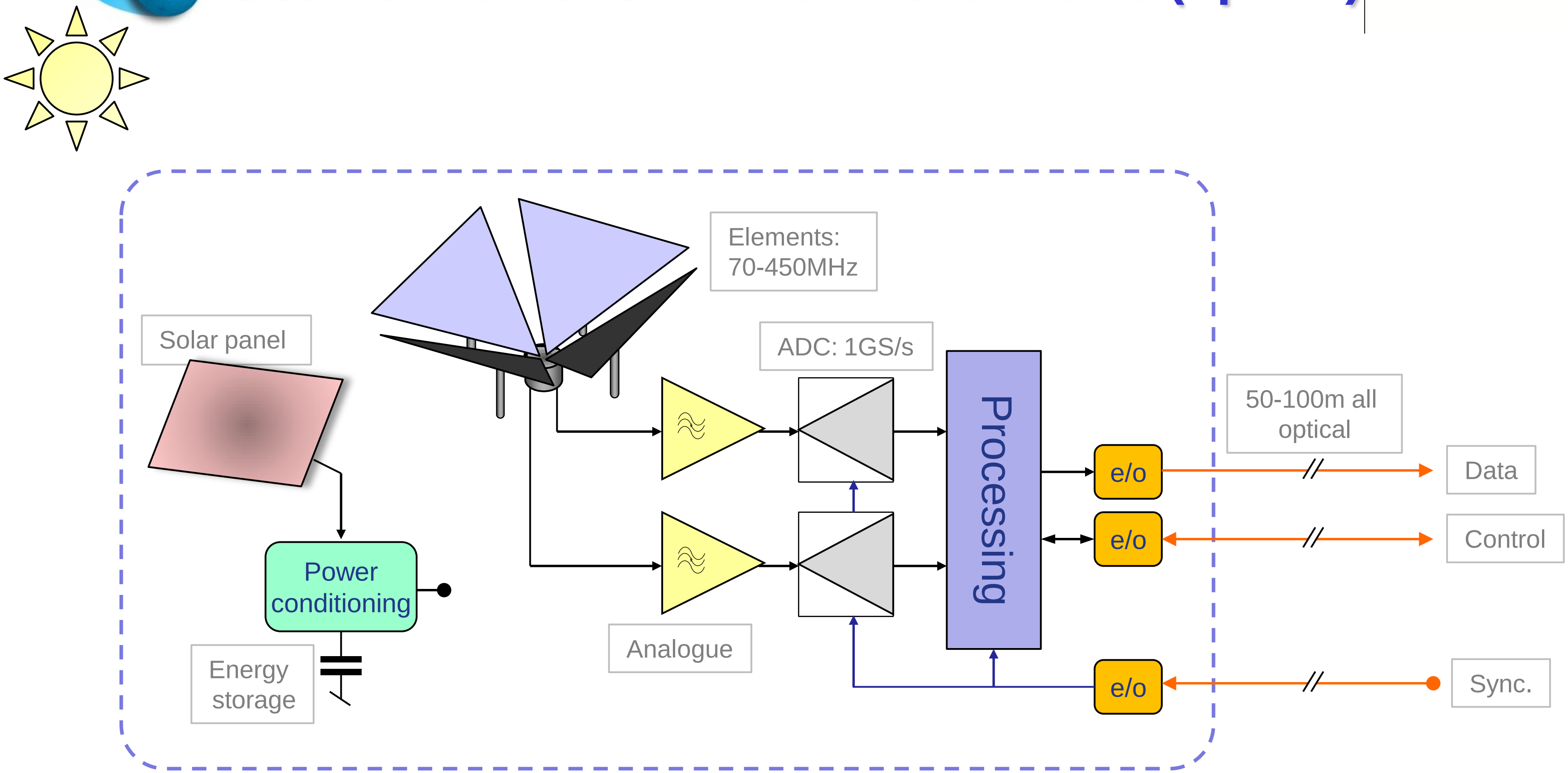
Copper:
~20m, 500MHz

Optical:
~200m, ≥10Gb/s

Optical:
<20m, ≥120Gb/s

Standalone SKA-low element (option)

SKA-AAVP



Benefits:

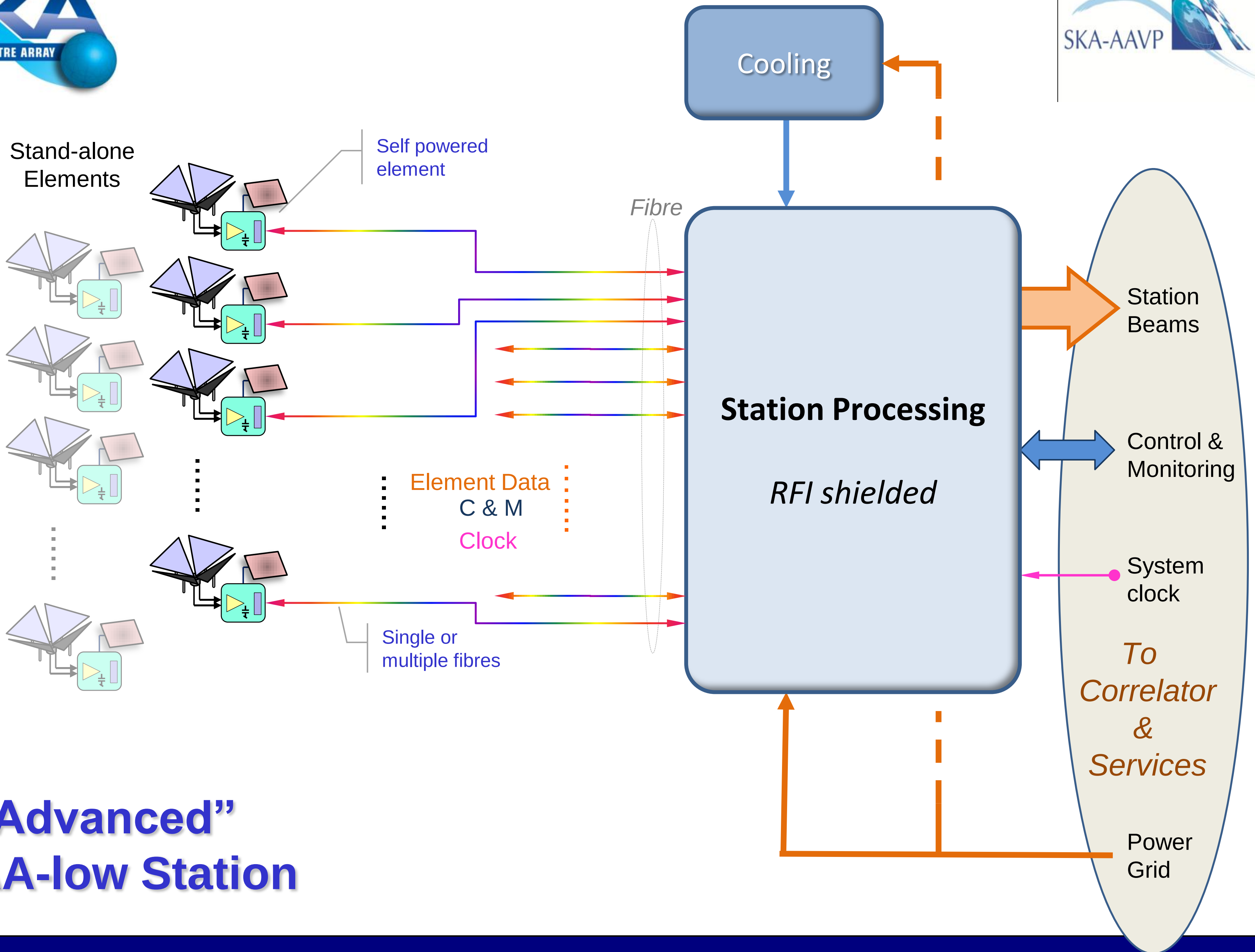
Integrated single unit
No copper connection
Easy to deploy
Minimum RFI
Lightning "immunity"

Challenges:

Low total power
Integration
Manufacturability
Packaging

No need for digitisation boxes

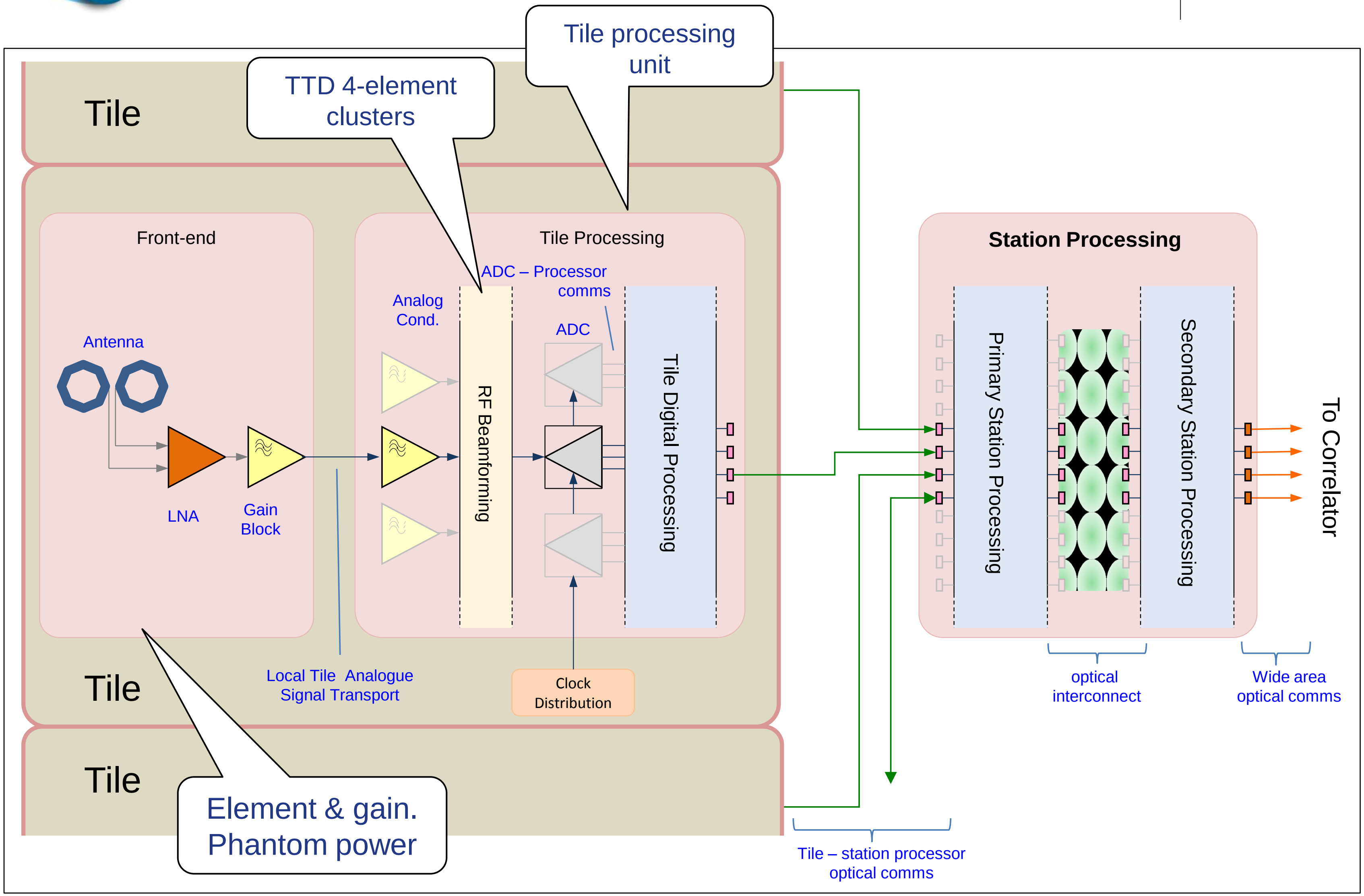
"Advanced" AA-low Station



AA-mid station design: SKA_2

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 proposed signal path



Summary

- Comms speed is critical at all levels of the AA system
- Overall requires multi-km, 100’s m, & 10’s m range comms
- AAs *depend* on high speed comms and processing
- More communications gives more performance
- Increasing comms rate and more processing is a clear upgrade path
- AA-mid is very challenging….