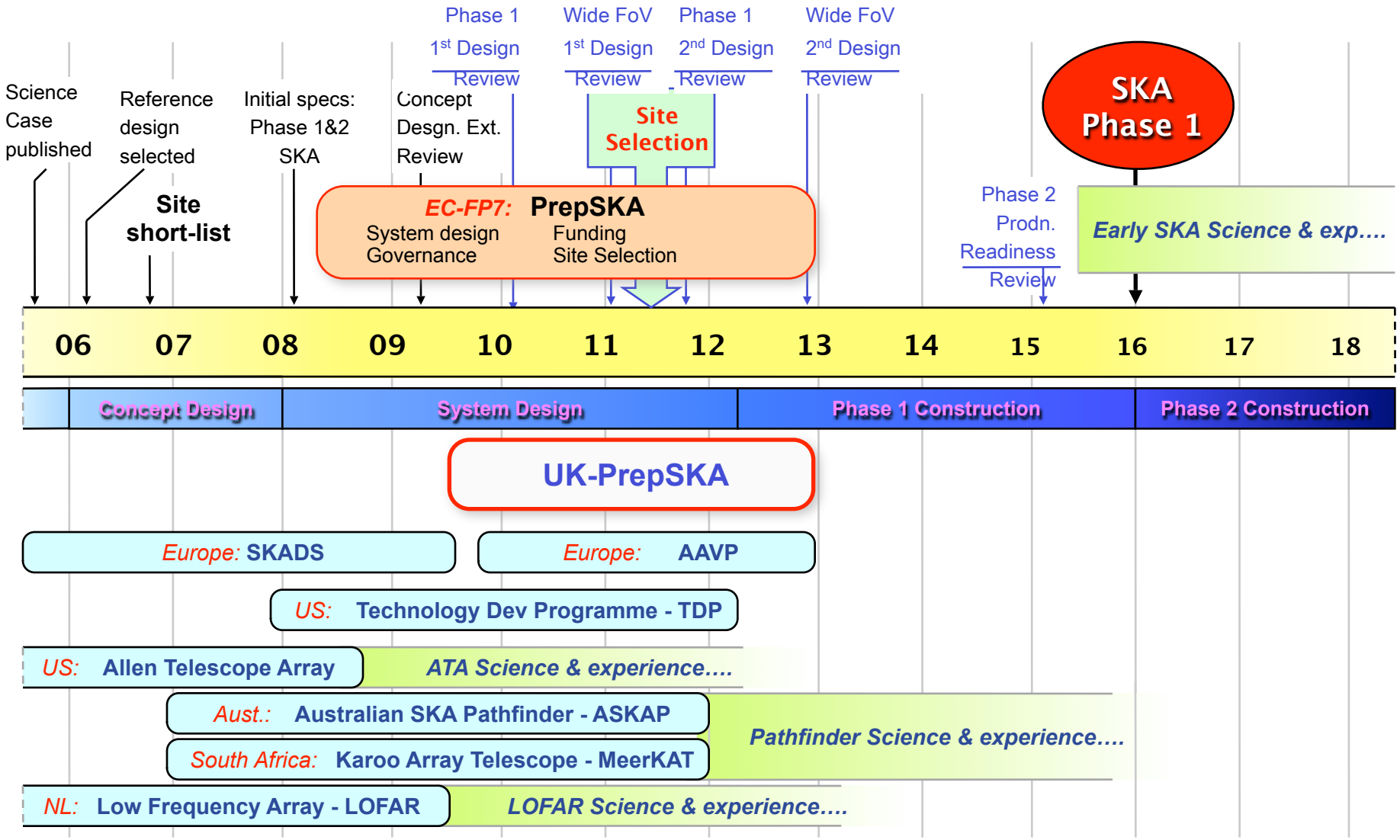
UNIVERSITY OF OXFORD

HI Science with Aperture

Obreschkow et al., 2009

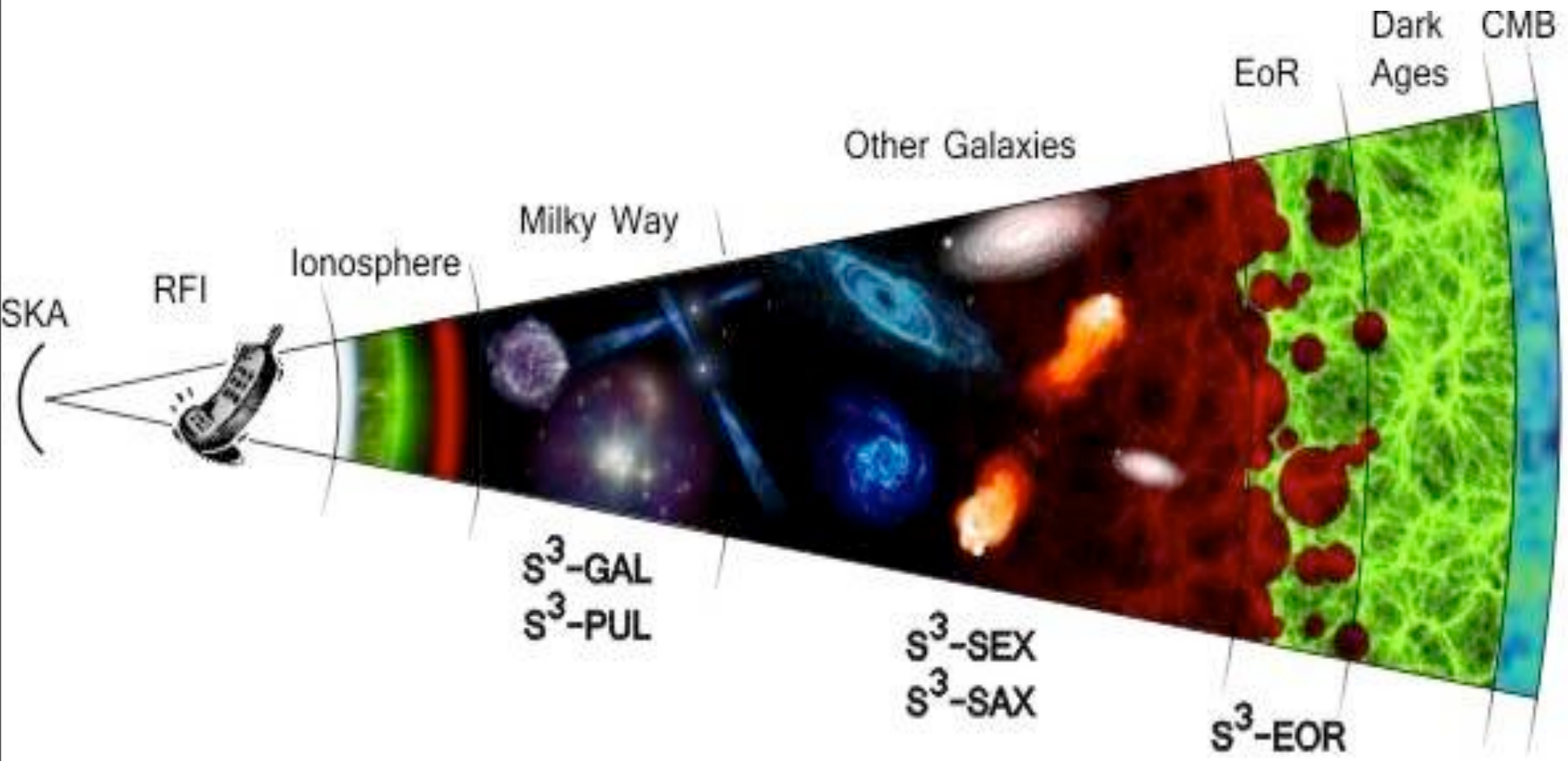
UNIVERSITY OF OXFORD

Setting the Picture



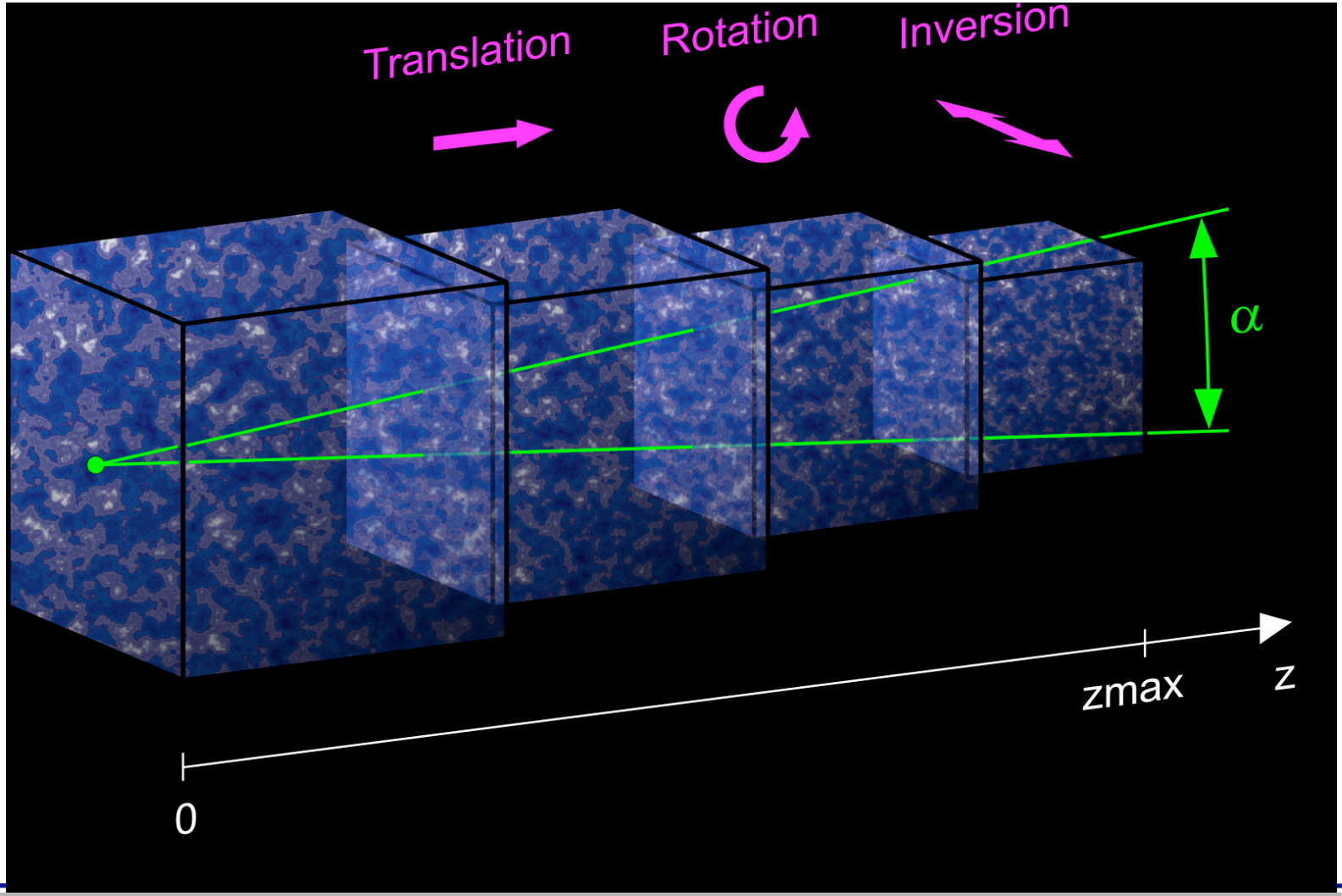
UNIVERSITY OF OXFORD

HI Science with Aperture



www.s-cubed.physics.ox.ac.uk

Mock observing cone

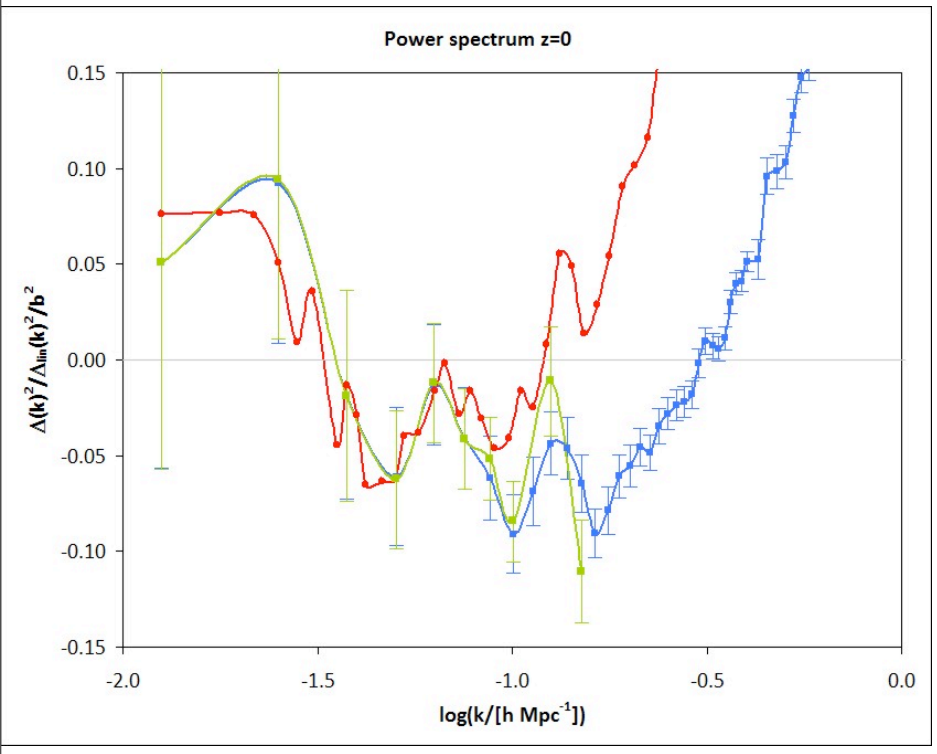


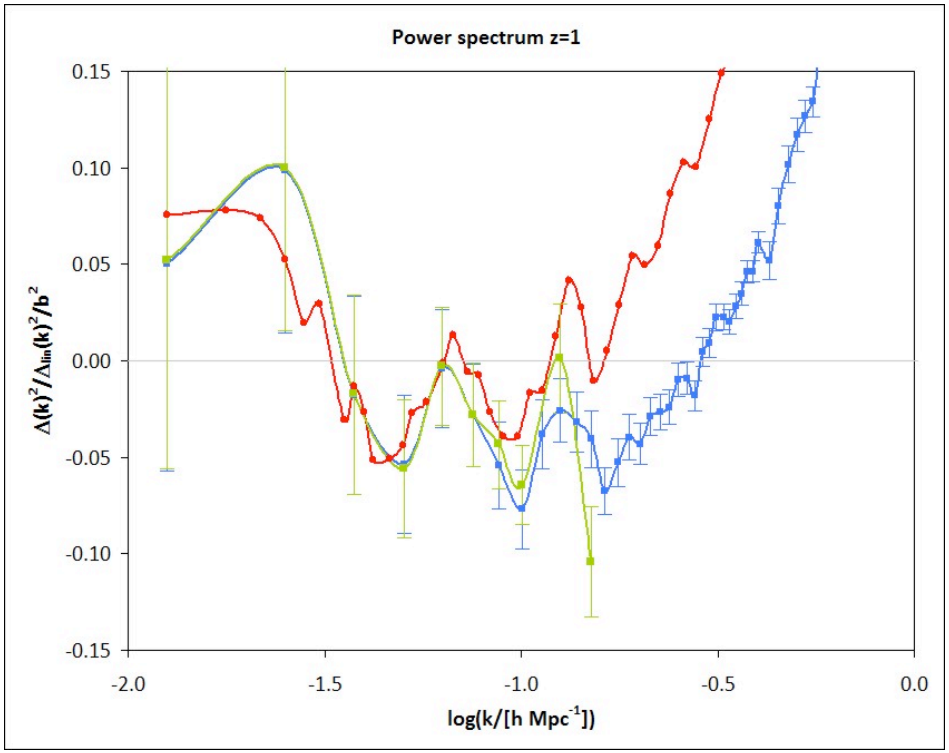
Obreshkow et al. 2009b

HI Power Spectra

Blue: HI > 10^8
Green: HI > 20'

Co-moving Volume = $(500 MPc/h)^3$





Linear bias = 0.8

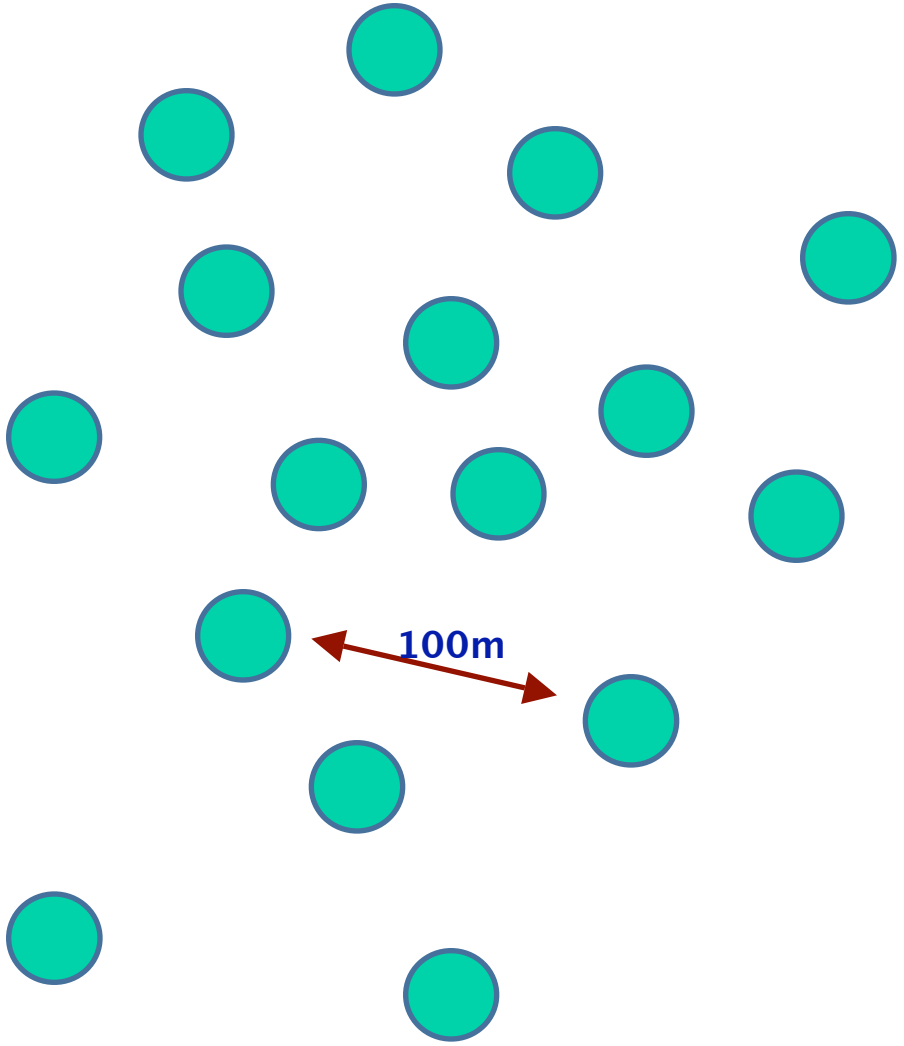
Linear Bias = 1.0

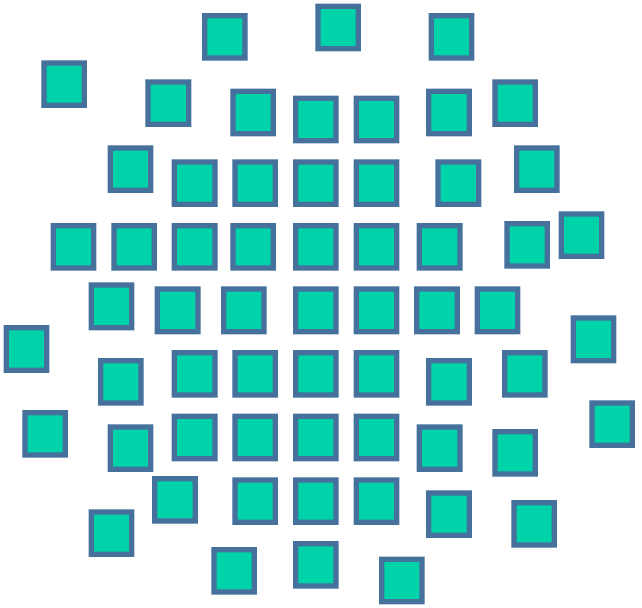
An HI Power Spectrum

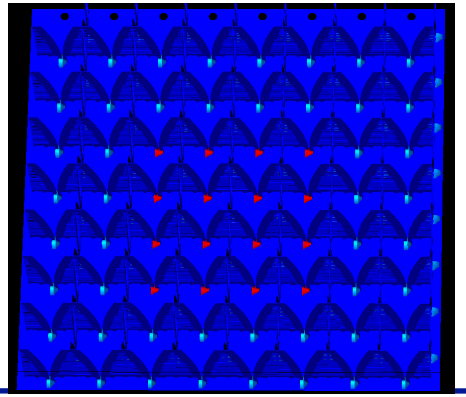
- 10,000 m^2 Collecting area
- Tunable Narrowband system between 700MHz and 1.4GHz (≈100MHz)
- 16 stations (sparsed for uv-coverage) (≈625m^2)
- Each station has 256 tiles (sparsed for A_{eff} or regular/dense for FFT)
- Each tile has 16 antennas (regular for FFT or Analogue Beamforming) (≈1m^2)
- T_{sys} ≈ 50K

AAVP Hierarchy

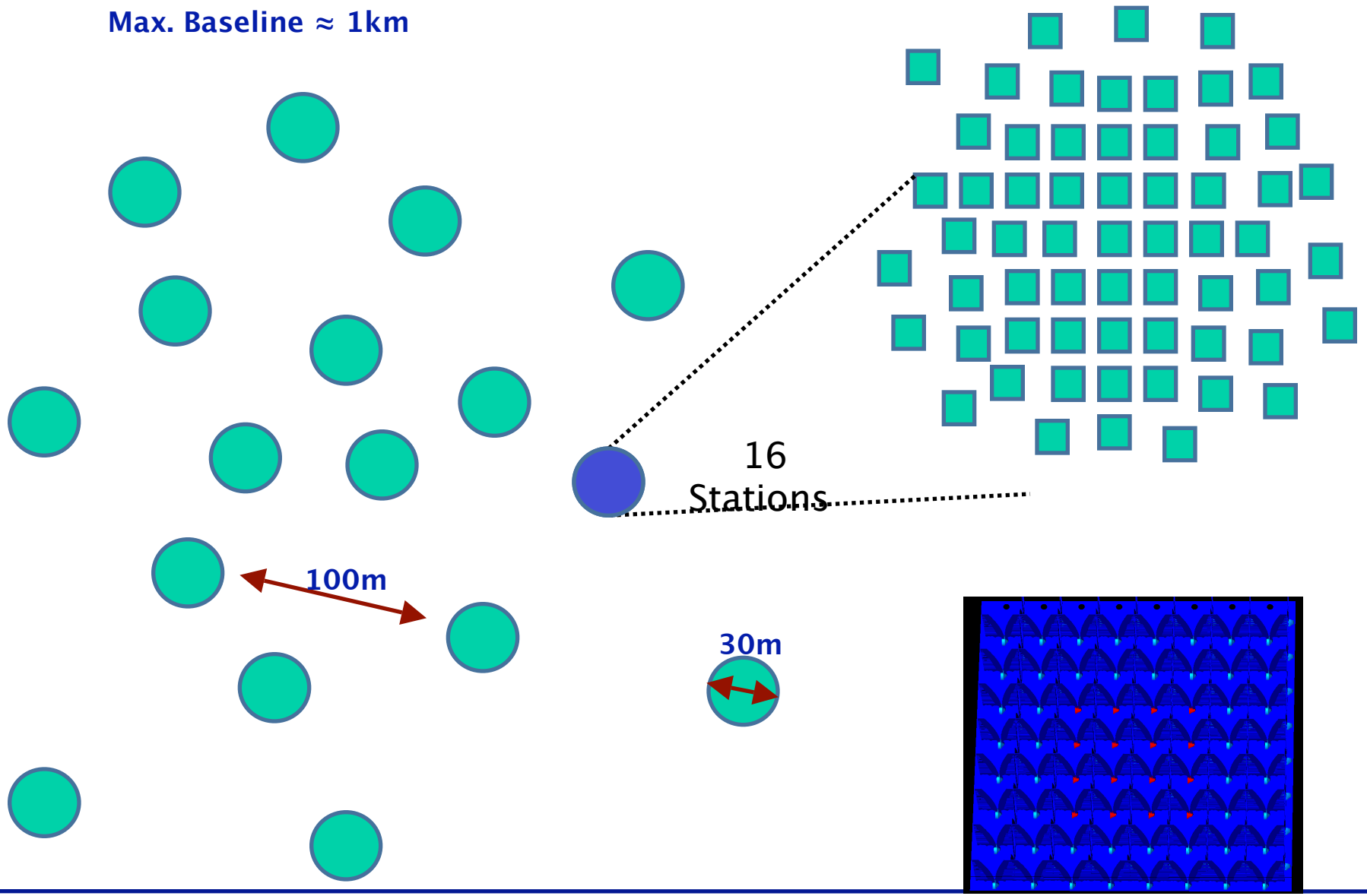
Max. Baseline ≈ 1km



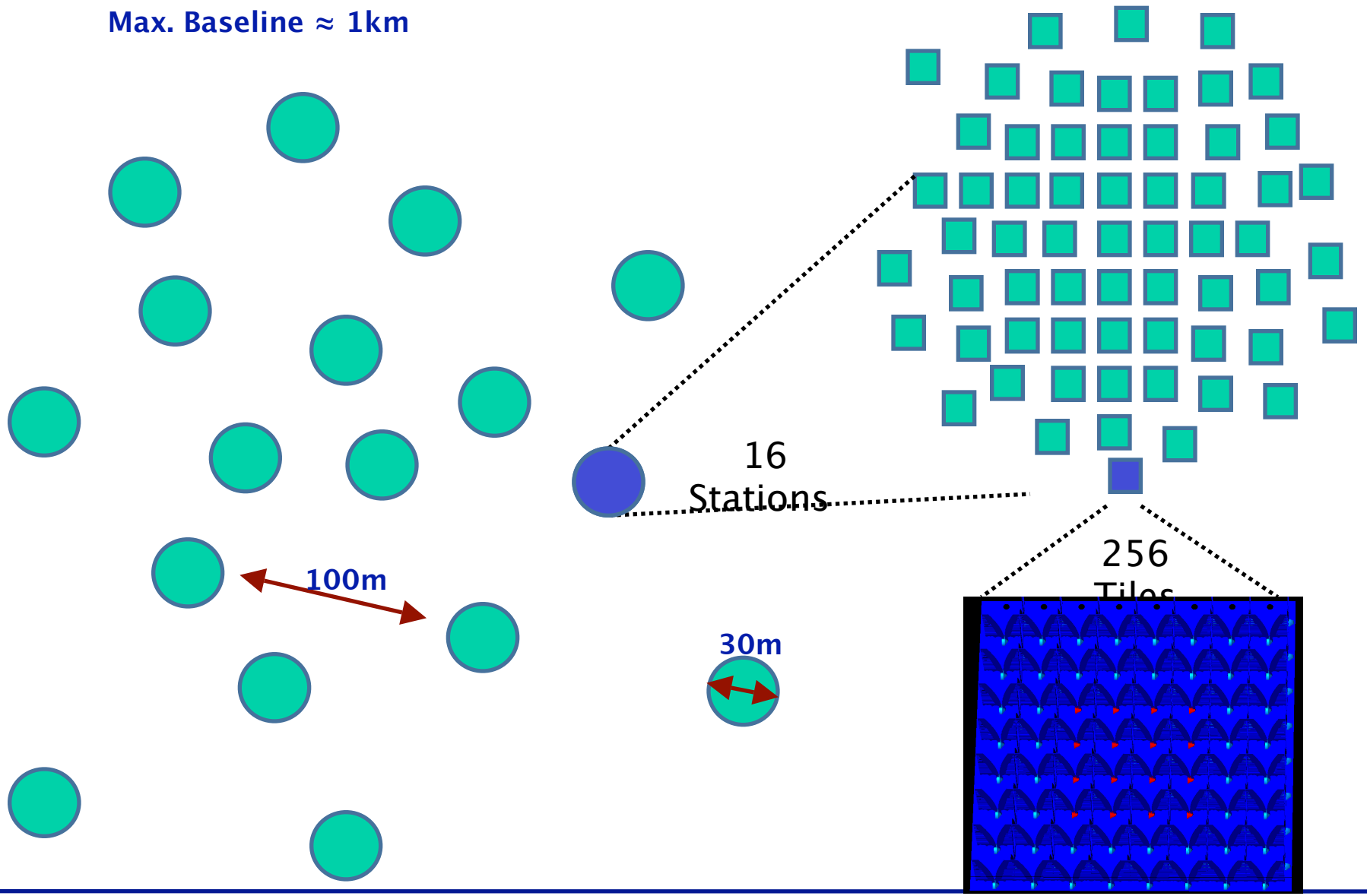




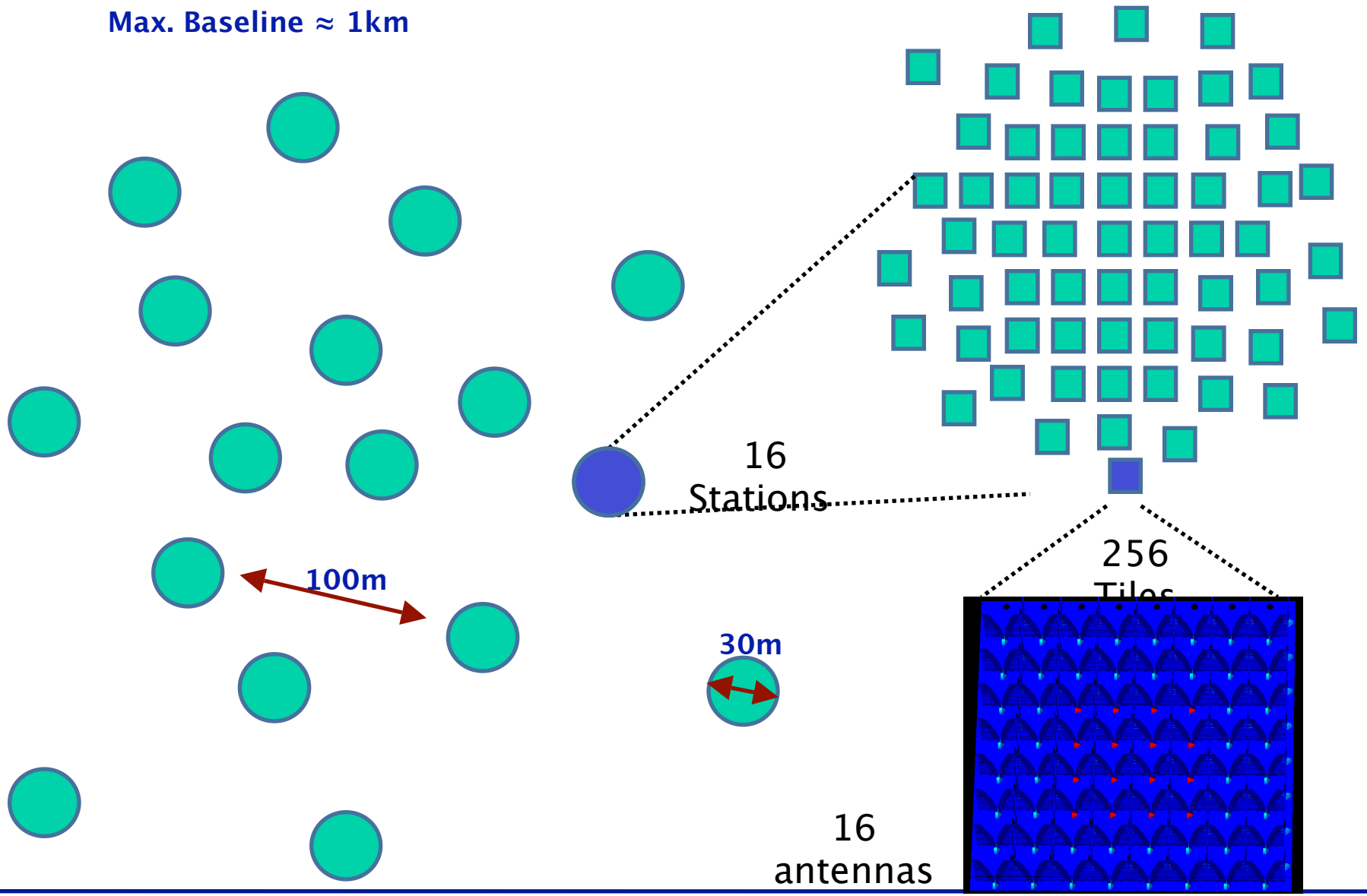
AAVP Hierarchy



AAVP Hierarchy



AAVP Hierarchy

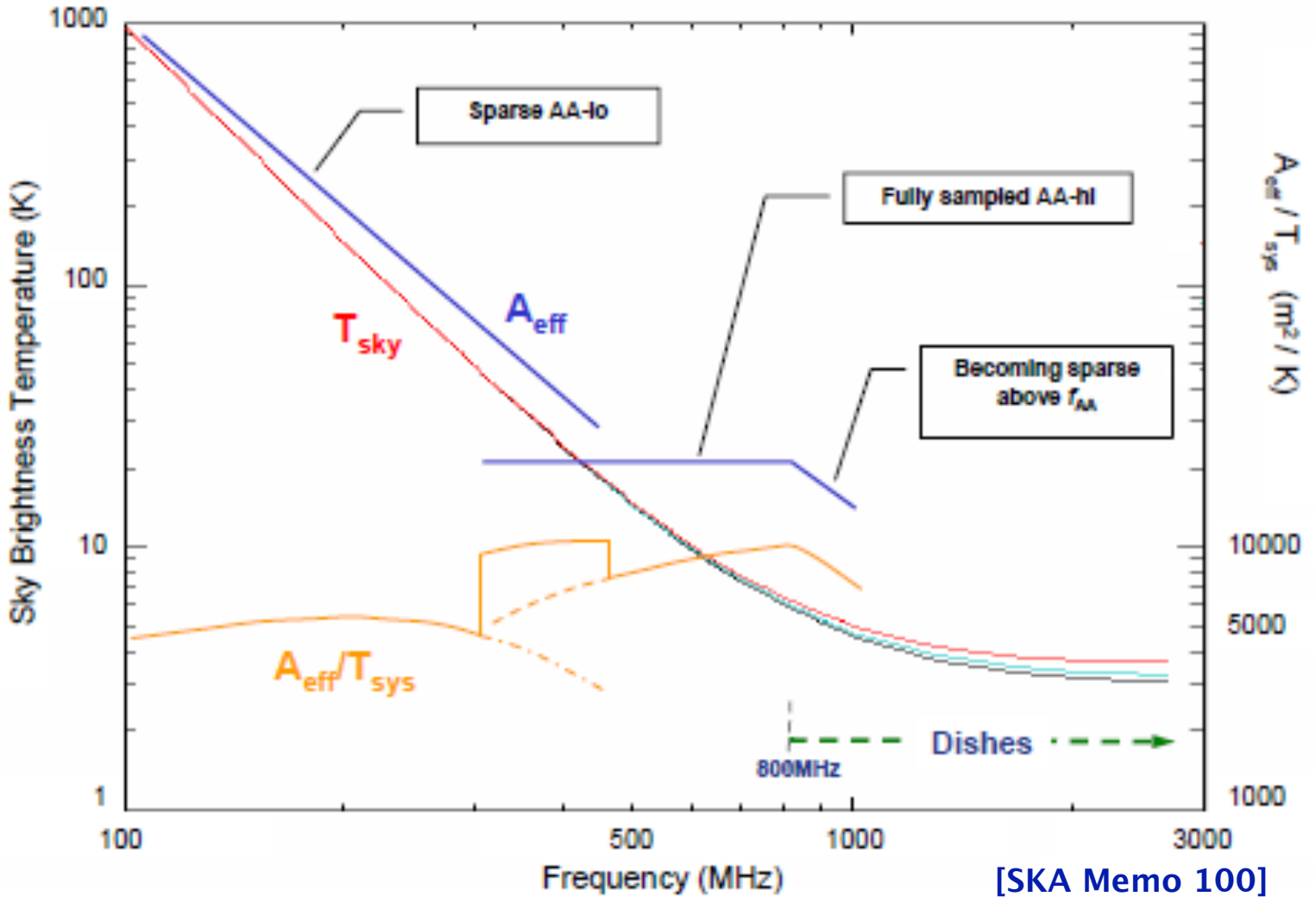


An HI instrument

- Significant Sky Simulations performed
- Results can be queried through SQL on the s-cubed website: s-cubed.physics.ox.ac.uk
- Low frequencies or high-z are limited by sky noise, which scales as: $T_{sky} = T_{s0}\lambda^{2.55}$
- In order to maintain a constant sensitivity sparse arrays where A_{eff} scales as: $A_{eff,dipole} = min\{\frac{\lambda^2}{3}, \frac{\pi d^2}{4}\}$
- such that A_{eff}/T_{sys} scales as: $\lambda^{-0.3}$

Sensitive (-ity) Issues..

See S. Schediwy's talk for a more in depth analysis

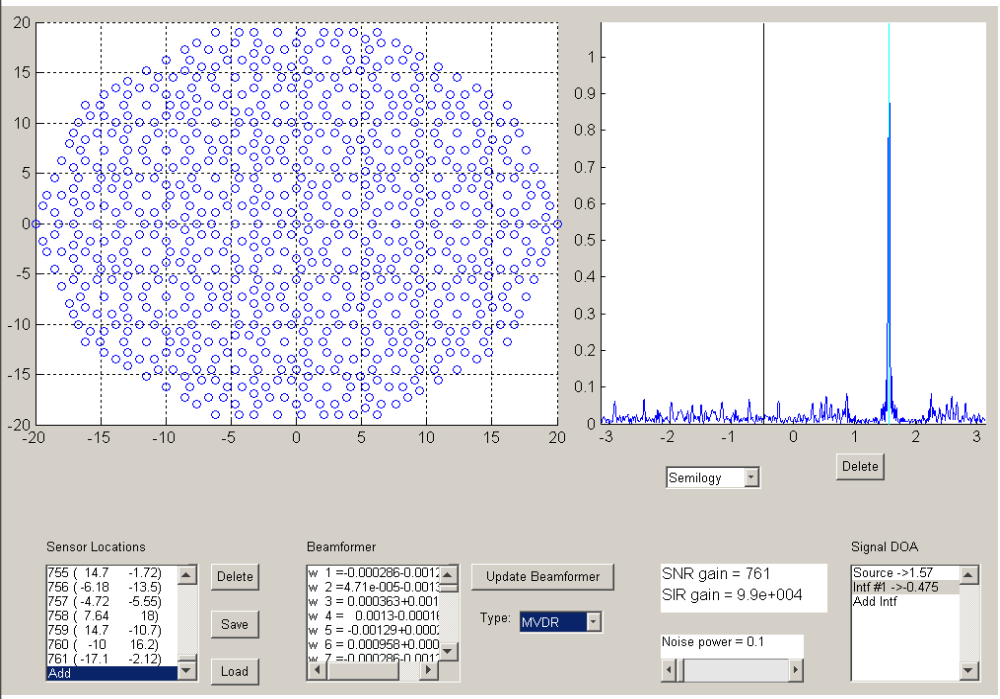


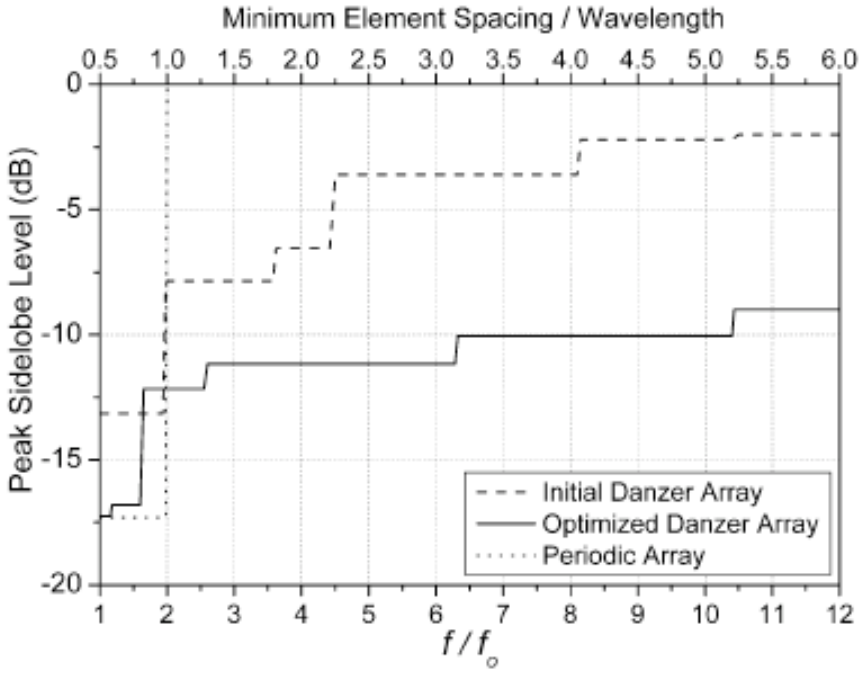
[SKA Memo 100]

Penrose tiling for the AAVP

See S. Schediwy's talk for large N Beamforming Simulator

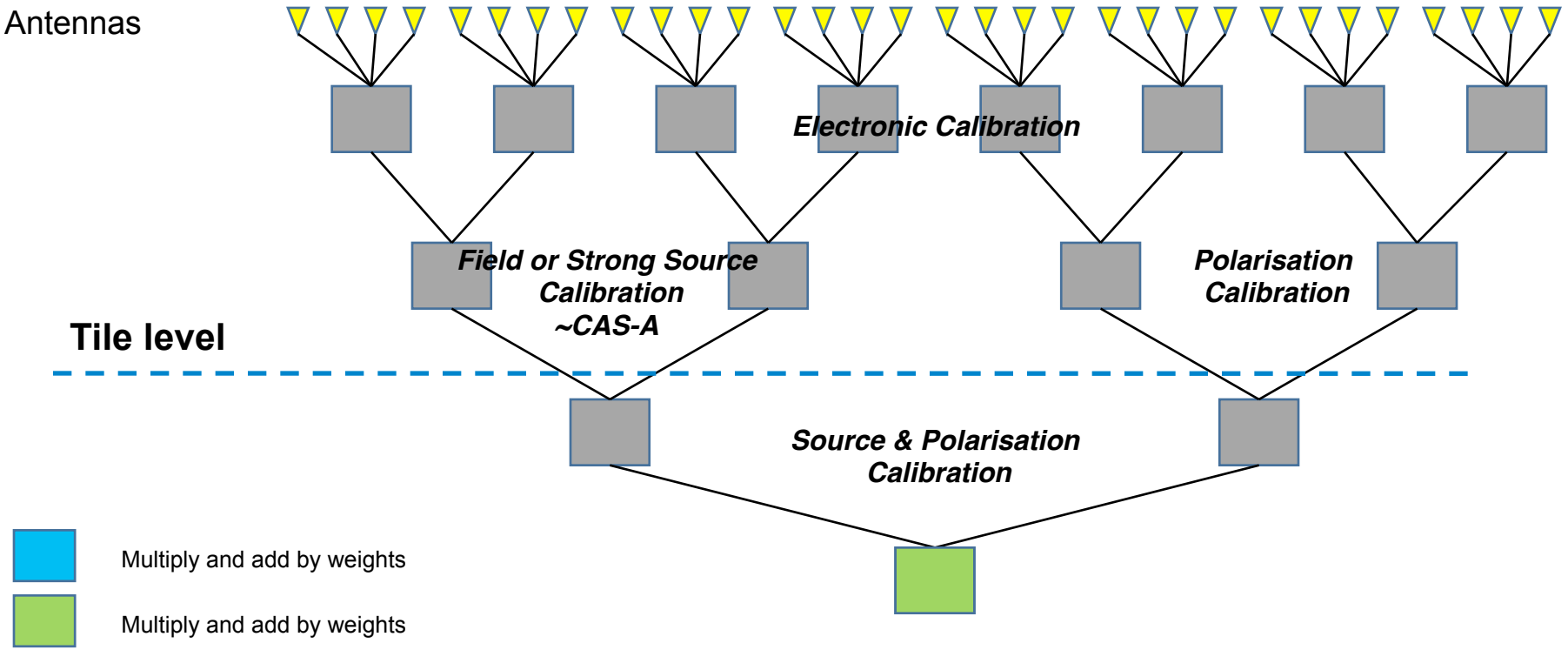
Reference: Spence et al., 2009



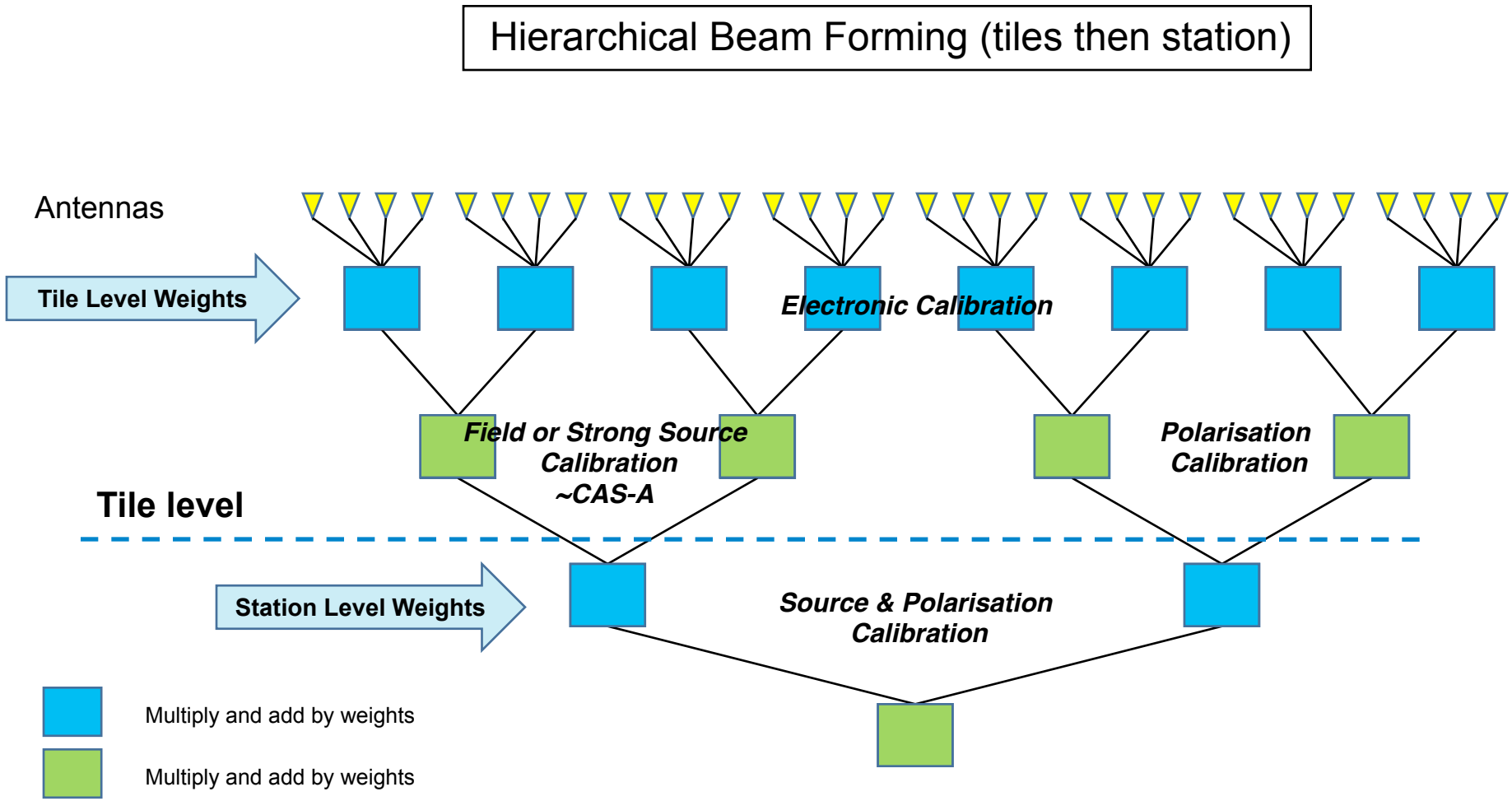


- Investigating Broadband tiling techniques for grating lobe minimisation

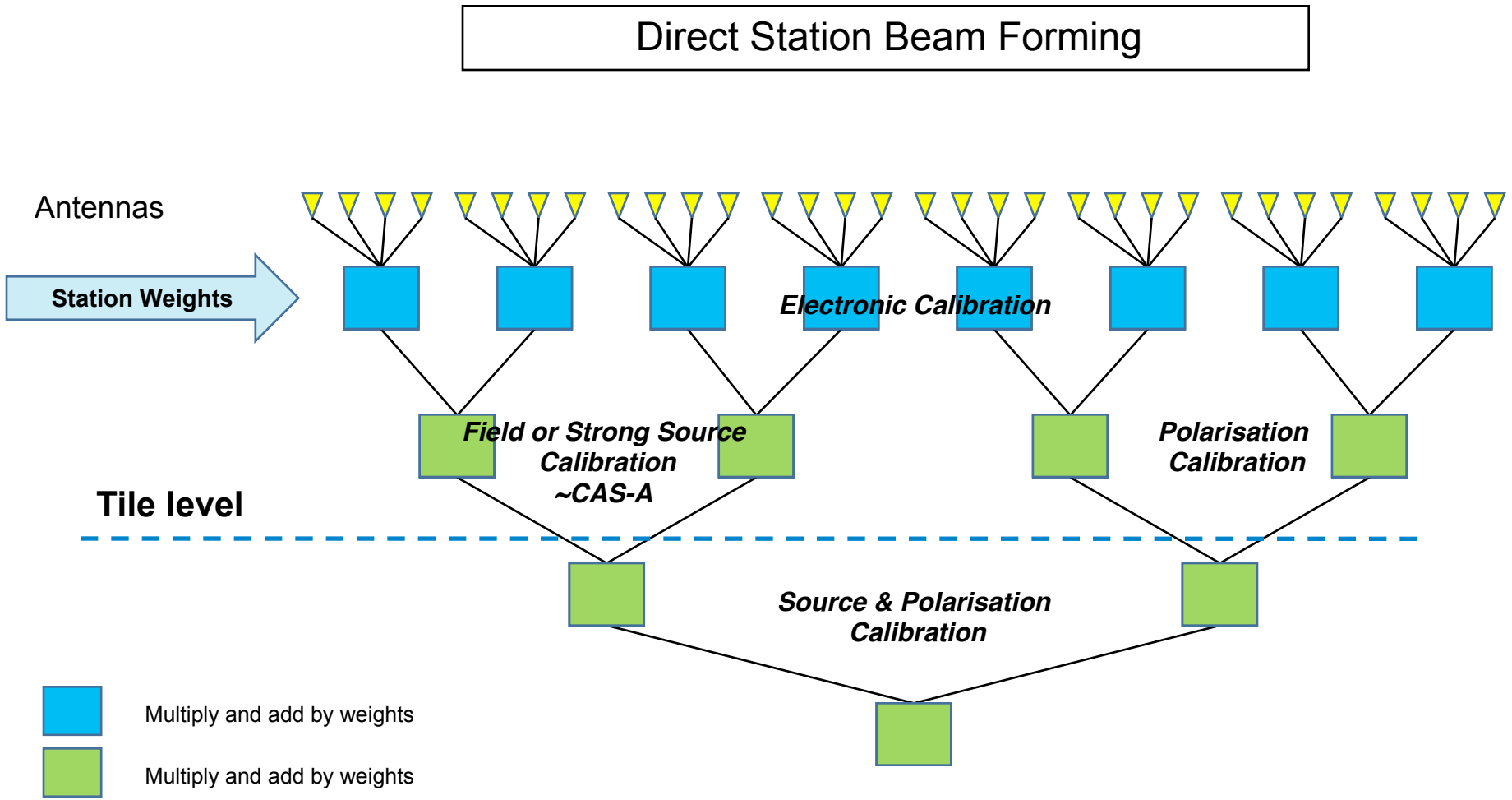
Hierarchical Architecture



Hierarchical Architecture

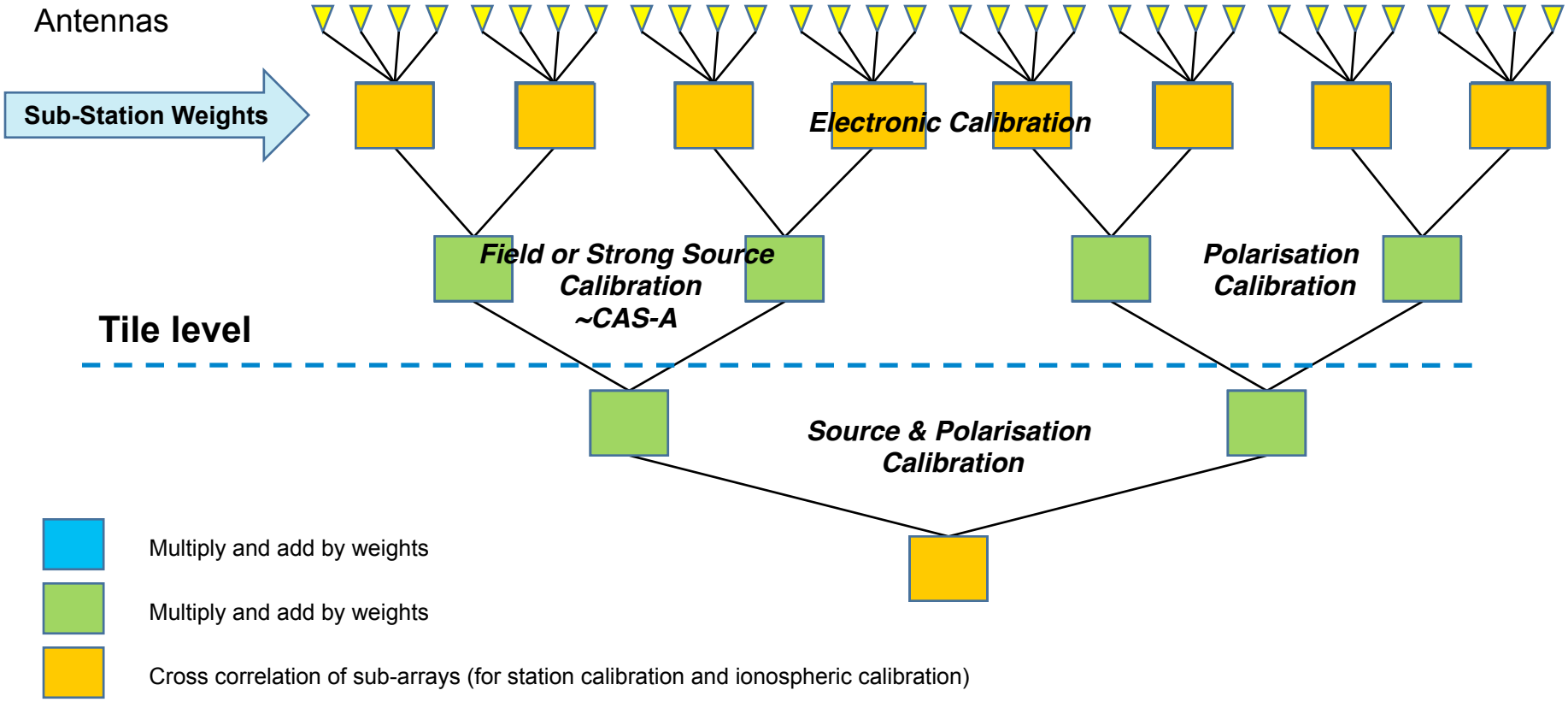


Hierarchical Architecture



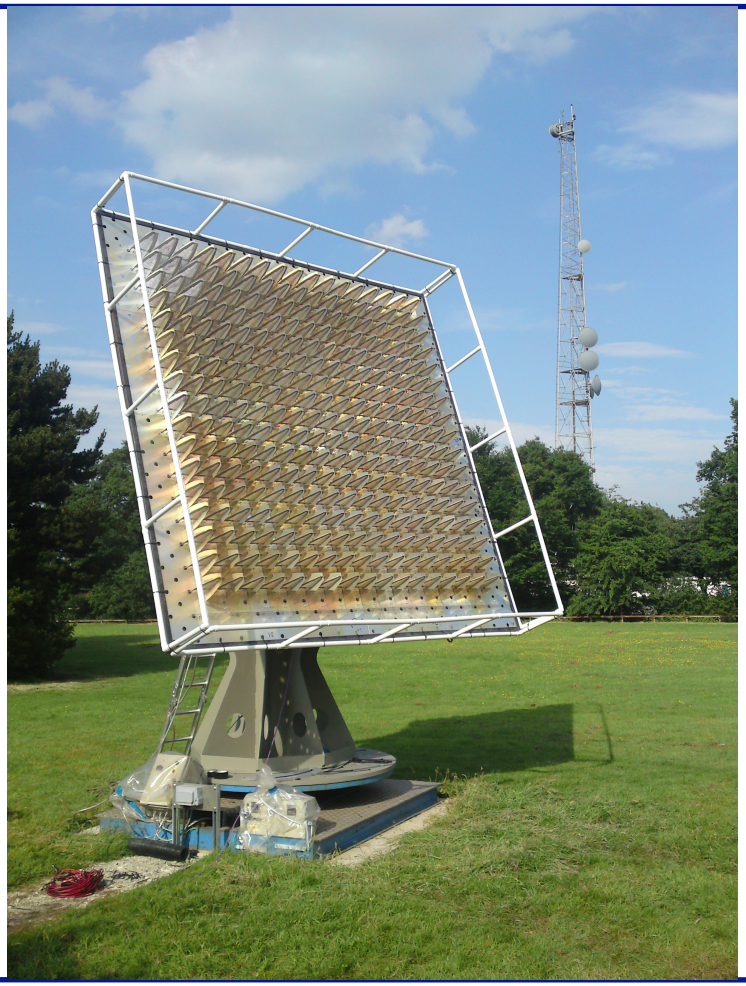
Hierarchical Architecture

Sub-Station Cross-correlation (calibration)?

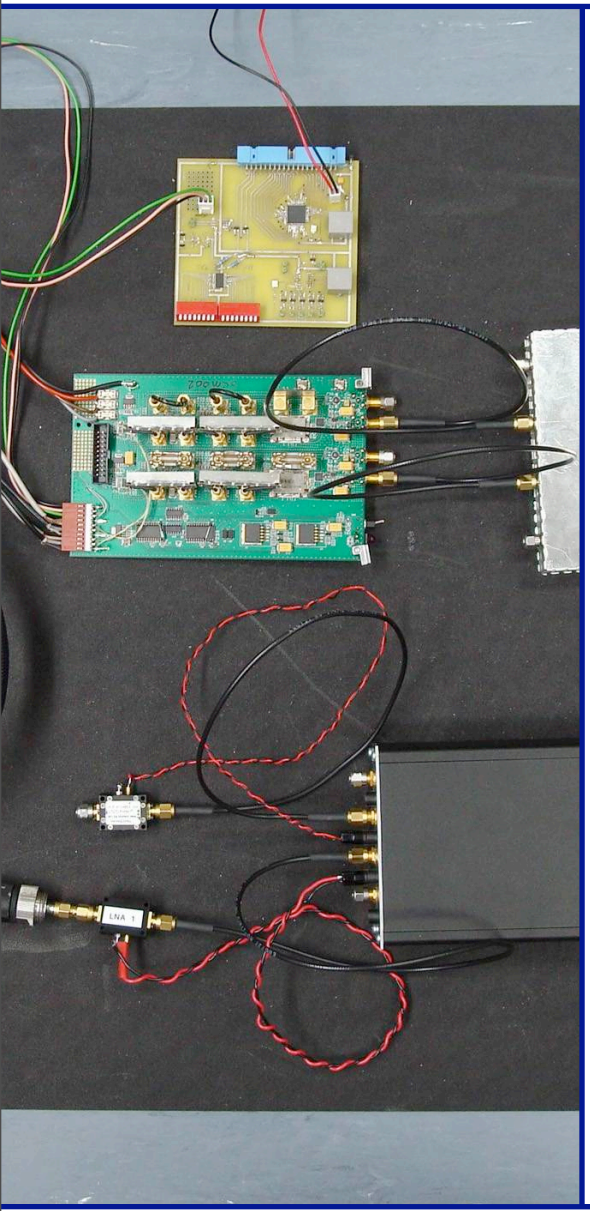


UNIVERSITY OF OXFORD

An all-digital Tile Demonstrator



2-PAD Aperture Array



- 2-PAD = "Dual-Polarisation All Digital"
  - Dual Polarisation plug&play antennas
  - RF range: 300-1000MHz
  - SKADS: 4×4 array
  - **Investigate various digital back-end processing architectures**
  - Multi-FPGA boards, Multi-ASIC boards
  - 200MHz processed bandwidth
  - Multiple independent beams
  - No. of Beam vs. Bandwidth trade-off
  - **Demonstrate upgrade path to**

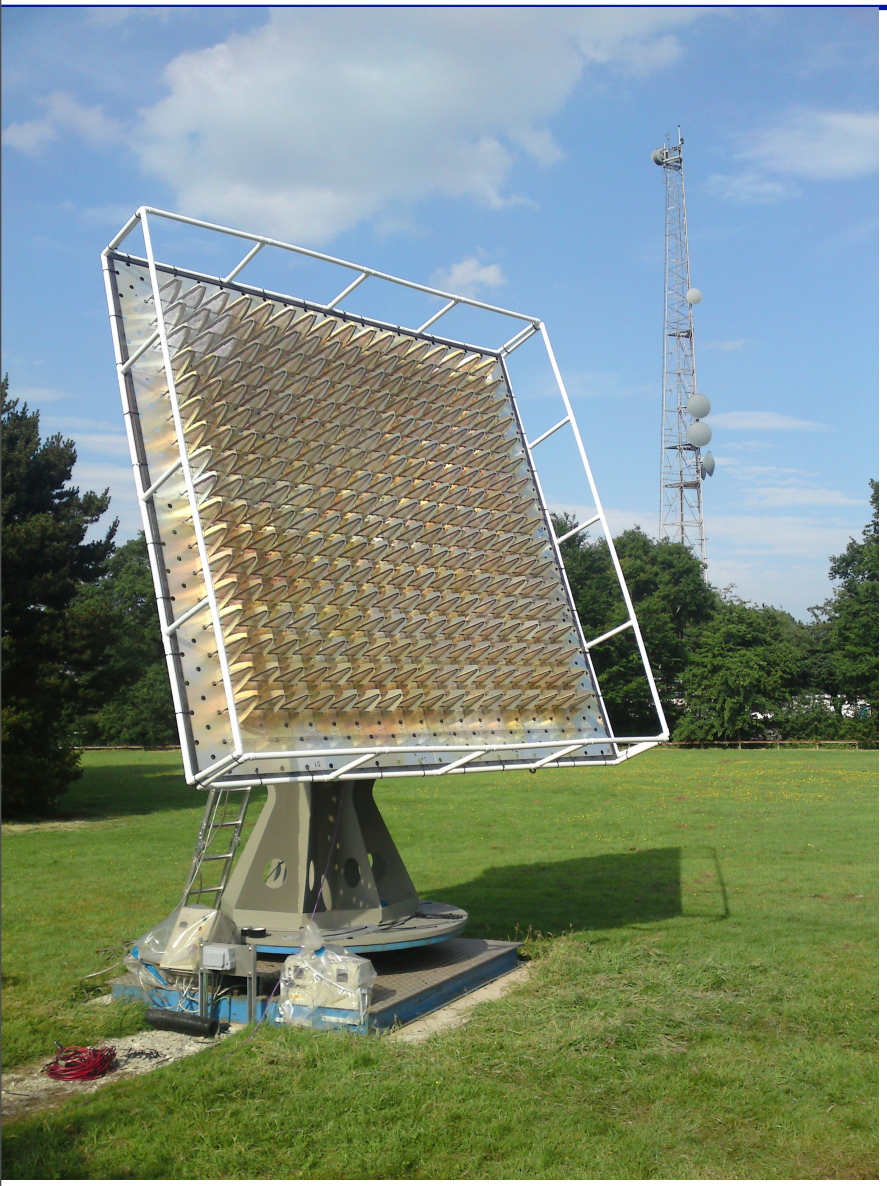
UNIVERSITY OF OXFORD

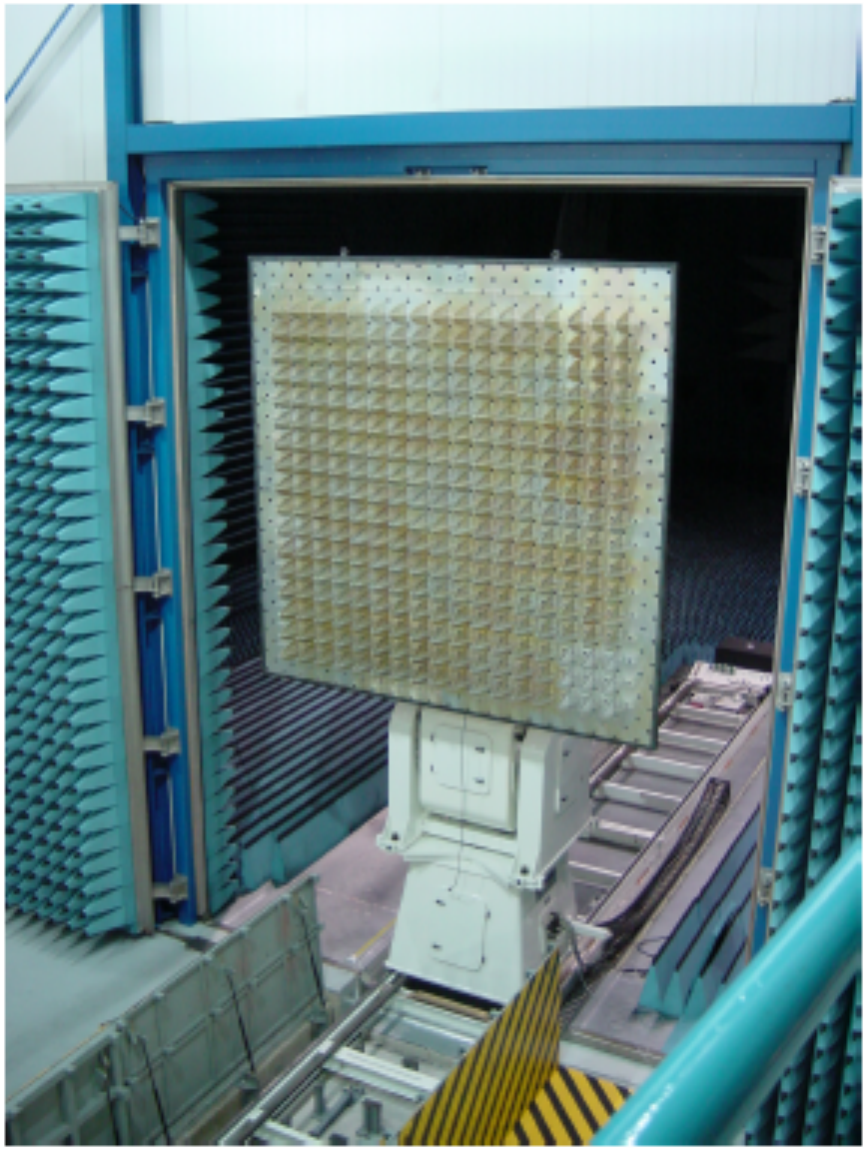
Aperture Array Research in

UNIVERSITY OF OXFORD

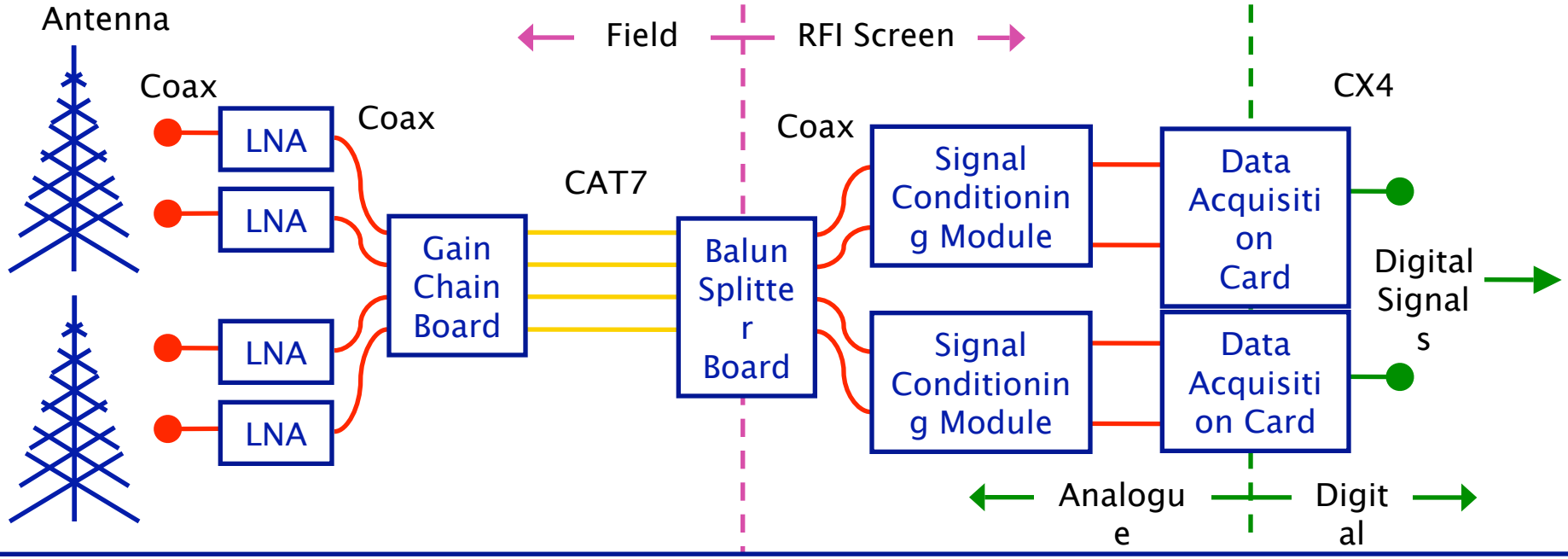
The Bunker at Jodrell Bank

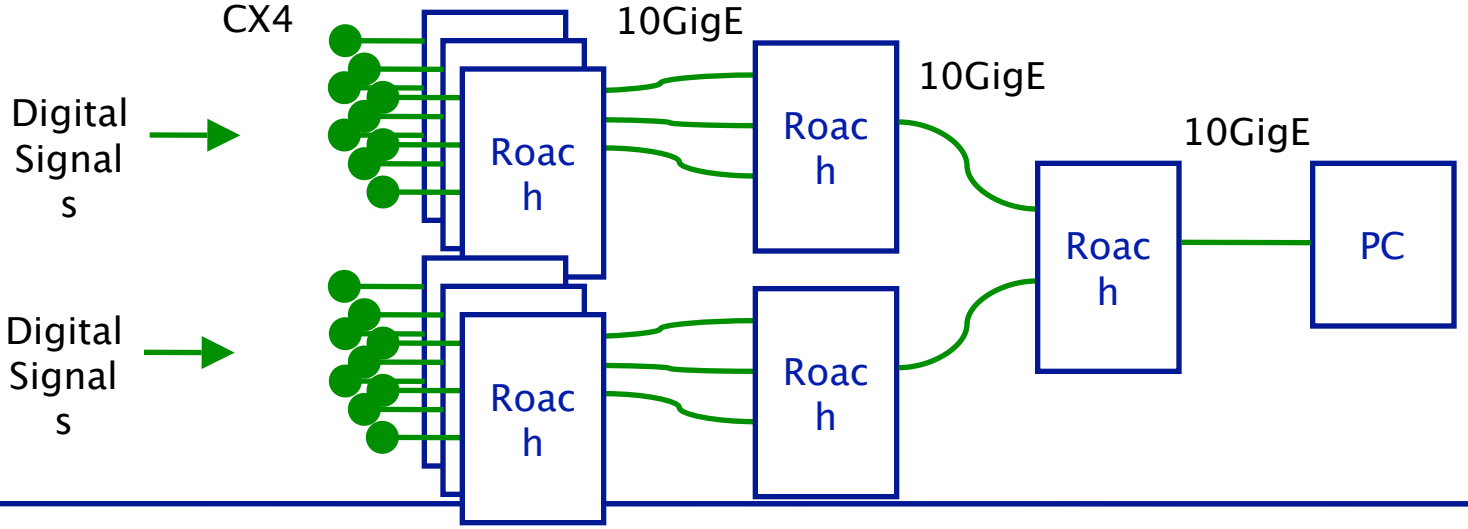
Antenna Positioner for Calibration and Testing





2-PAD System Overview

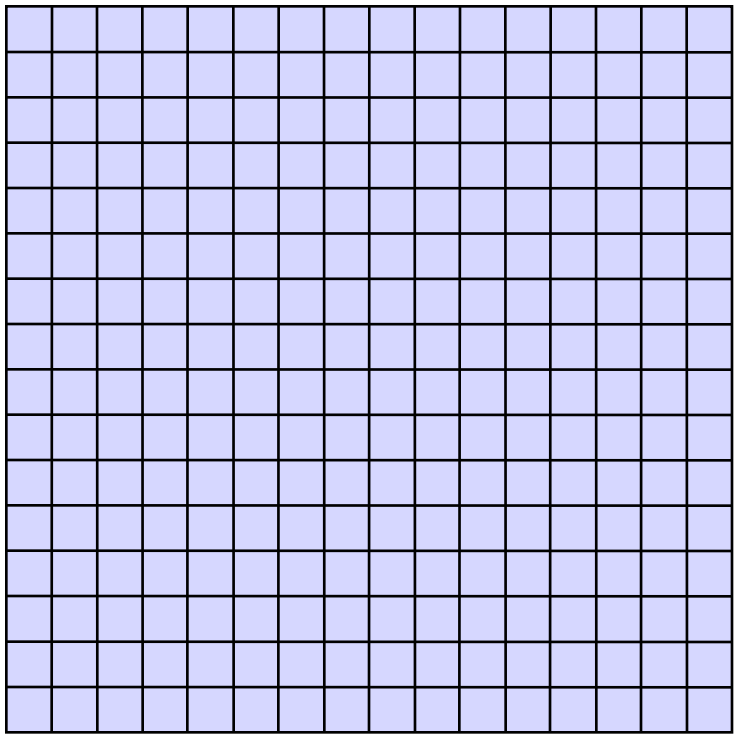




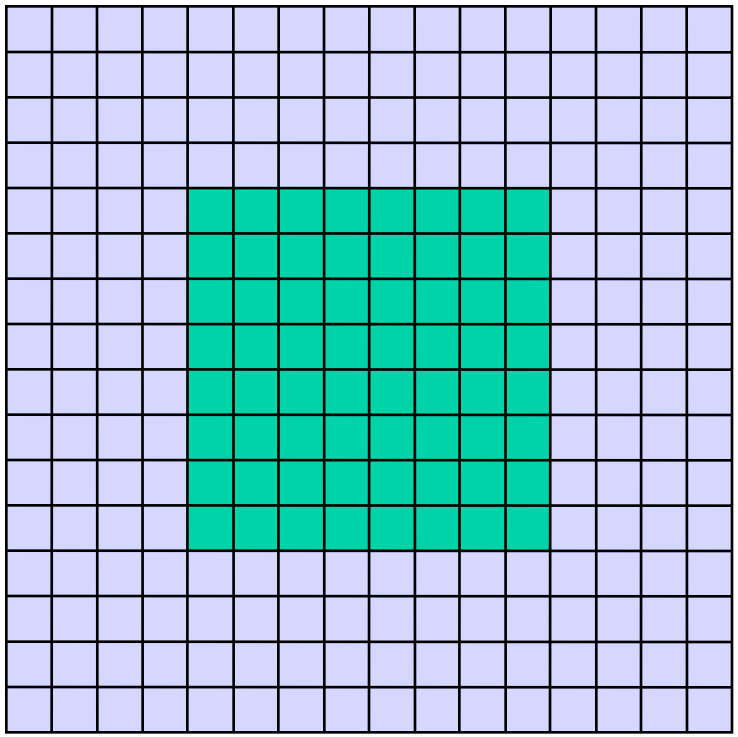
2-PAD: The Antennae

2-PAD: The Antennae

- 16 x 16 dual polarisation elements

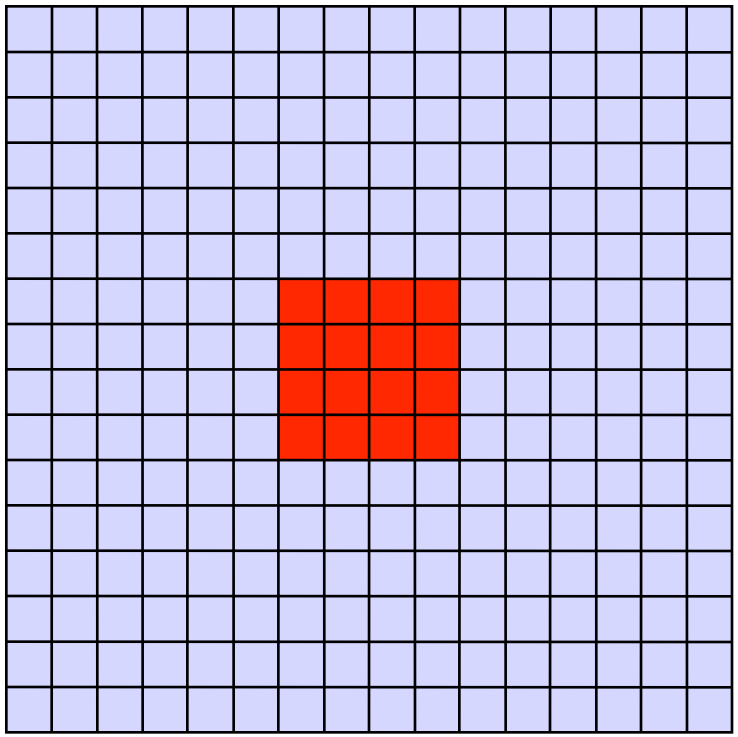


2-PAD: The Antennae



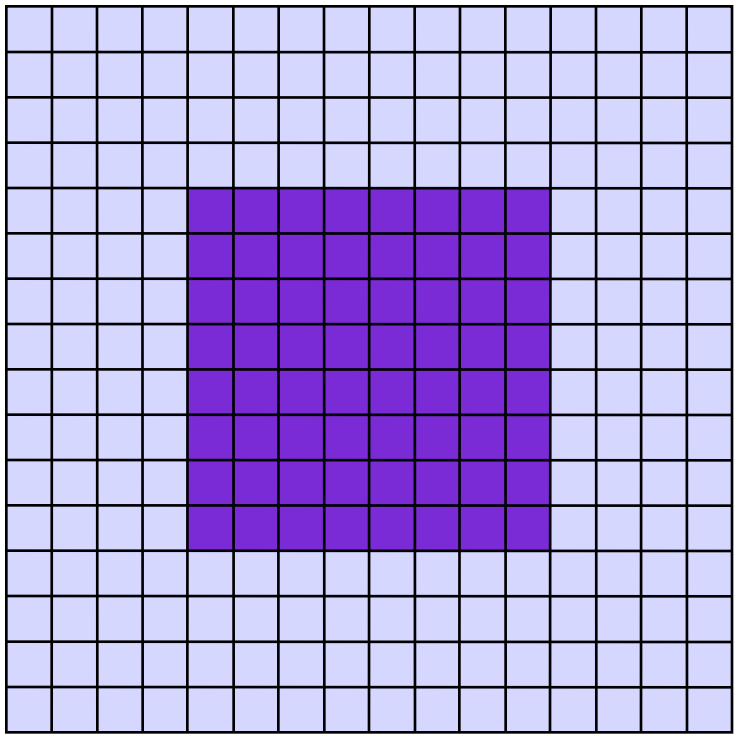
- 16 x 16 dual polarisation elements
- **RF Testing – 8 x 8 dual pole**

2-PAD: The Antennae



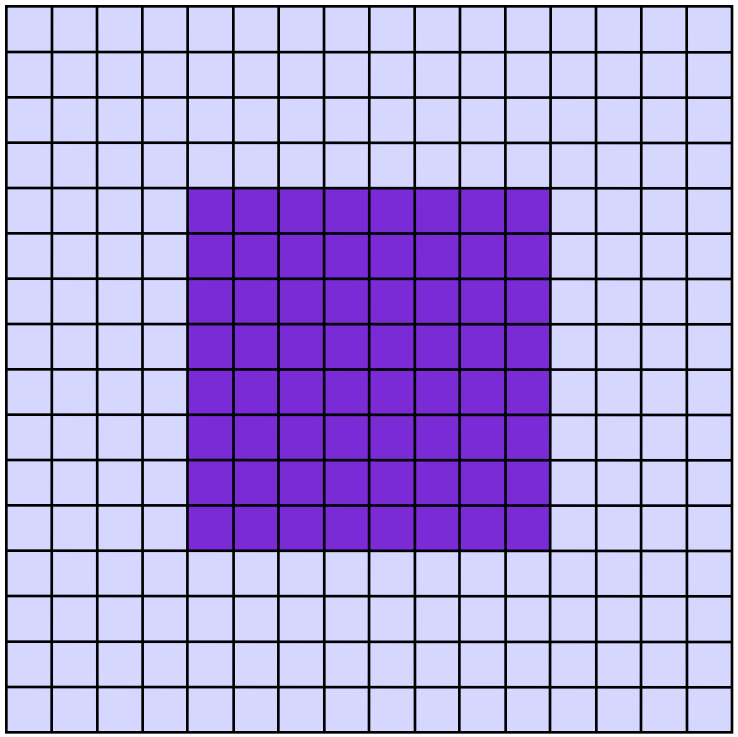
- 16 x 16 dual polarisation elements
- **RF Testing – 8 x 8 dual pole**
- **2-PAD V1 – 4 x 4 dual pole**

2-PAD: The Antennae



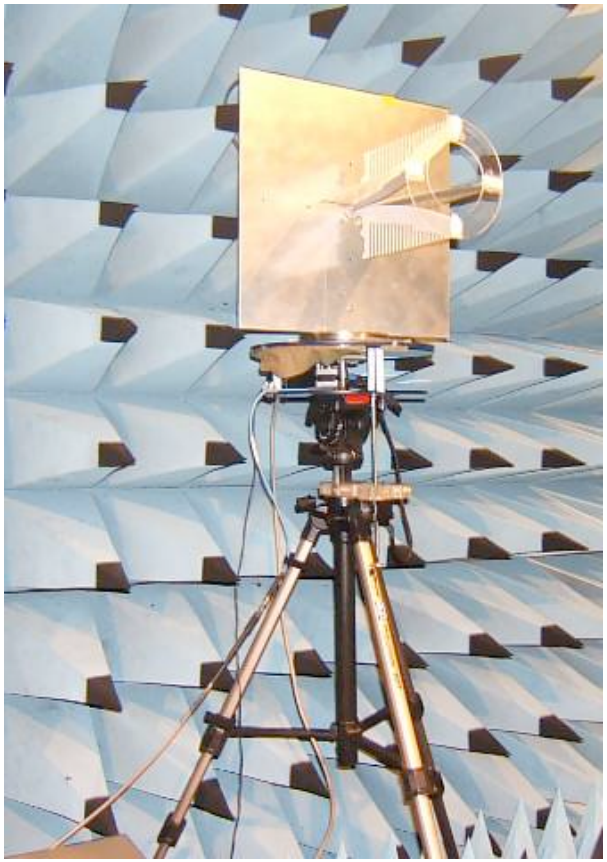
- 16 x 16 dual polarisation elements
- **RF Testing – 8 x 8 dual pole**
- **2-PAD V1 – 4 x 4 dual pole**
- **2-PAD V2 – 8 x 8 dual pole**

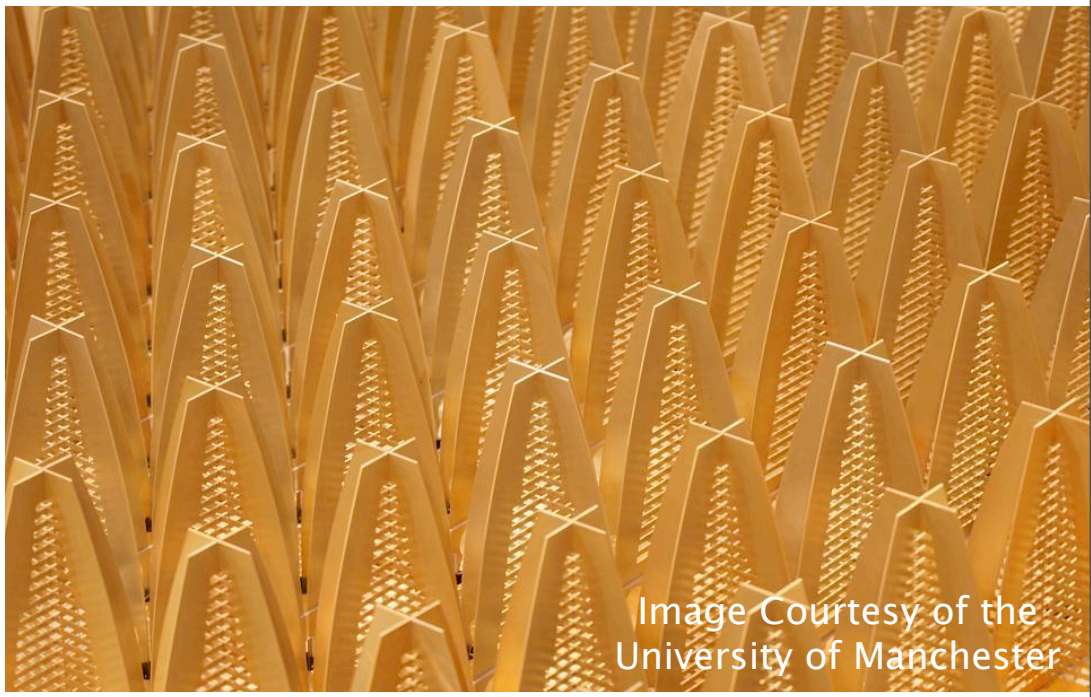
2-PAD: The Antennae



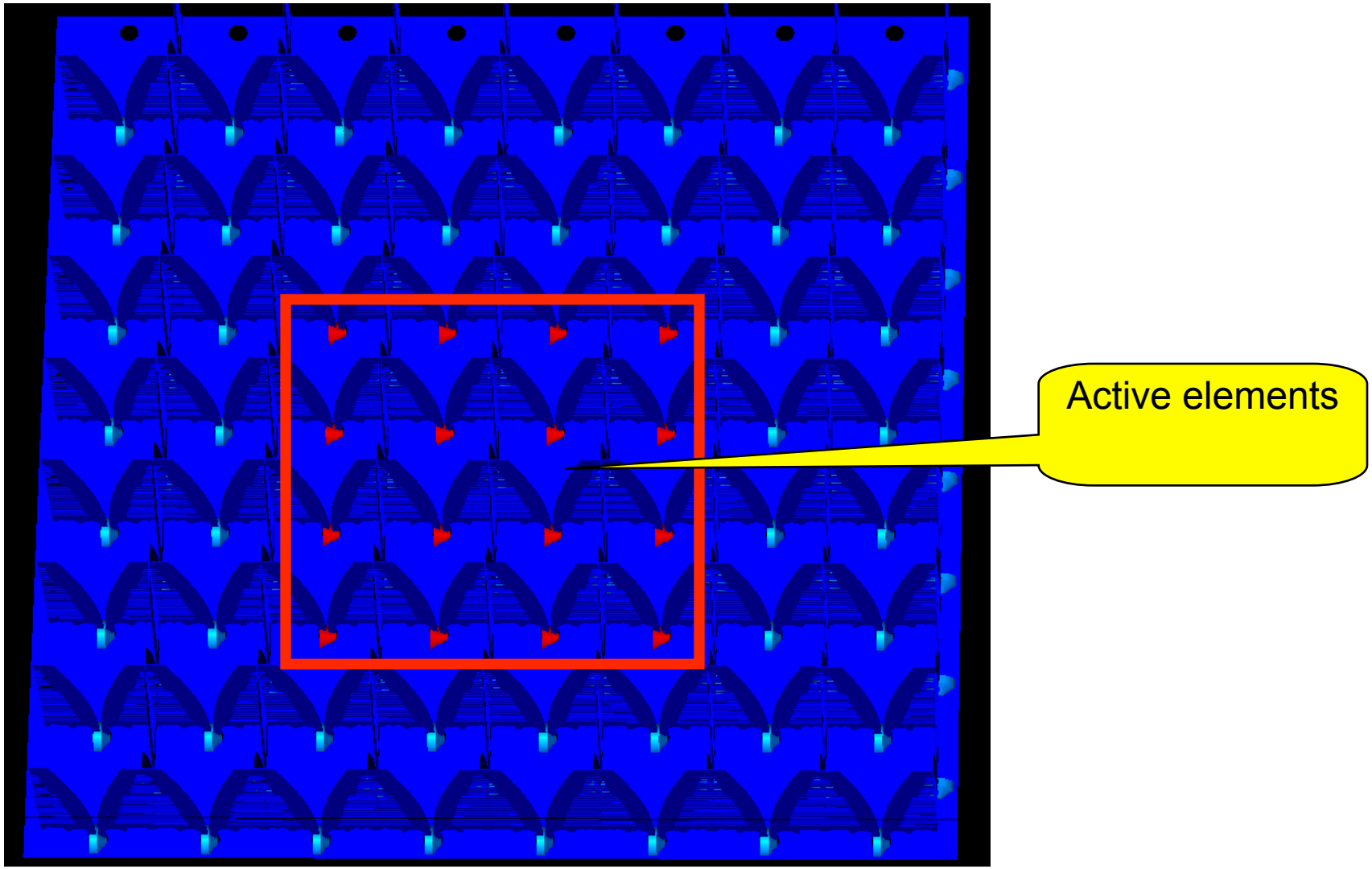
- 16 x 16 dual polarisation elements
- **RF Testing – 8 x 8 dual pole**
- **2-PAD V1 – 4 x 4 dual pole**
- **2-PAD V2 – 8 x 8 dual pole**
- Antennae at the edges are dummy loaded

Bunny Ear Comb Antenna

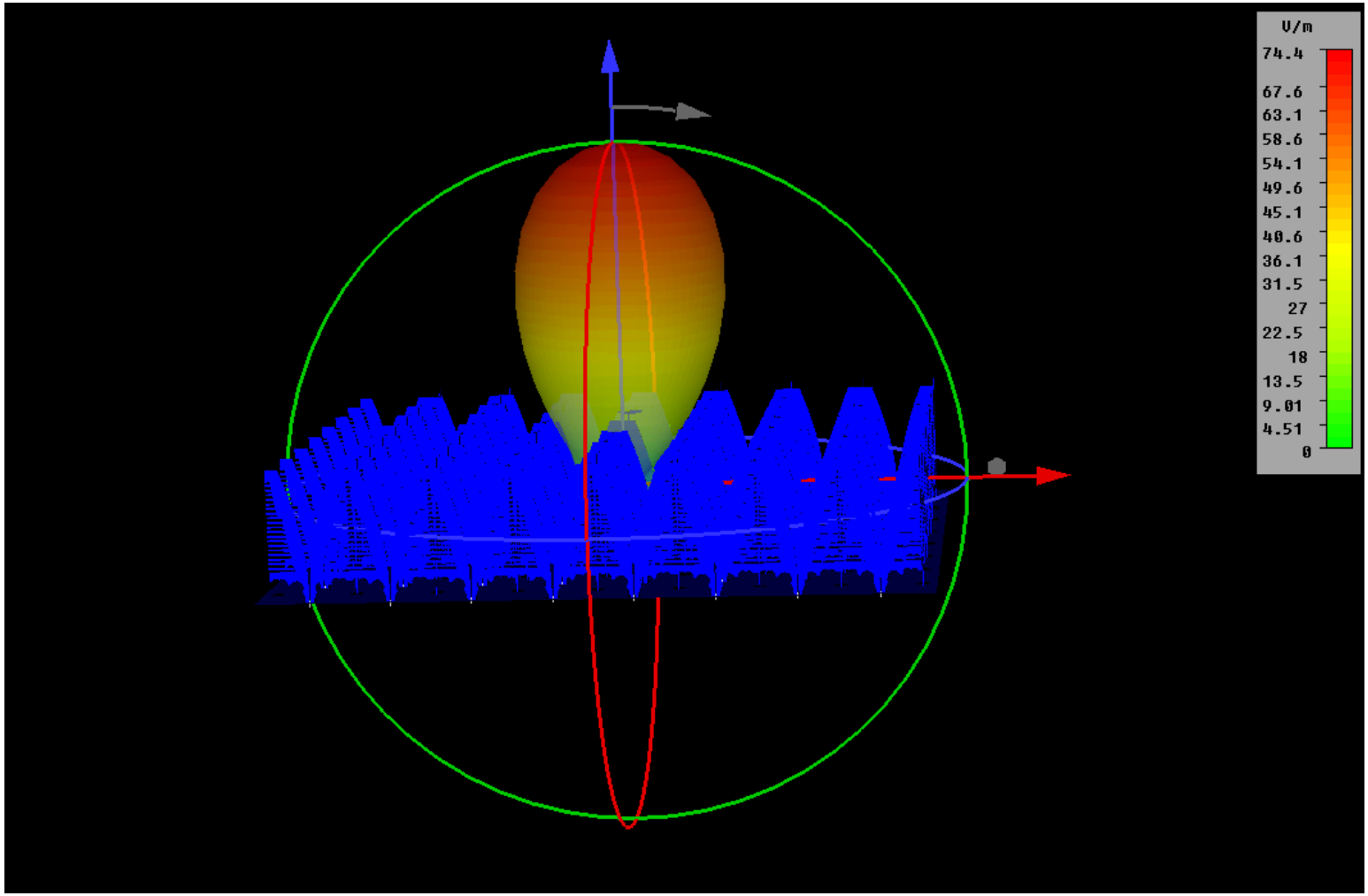




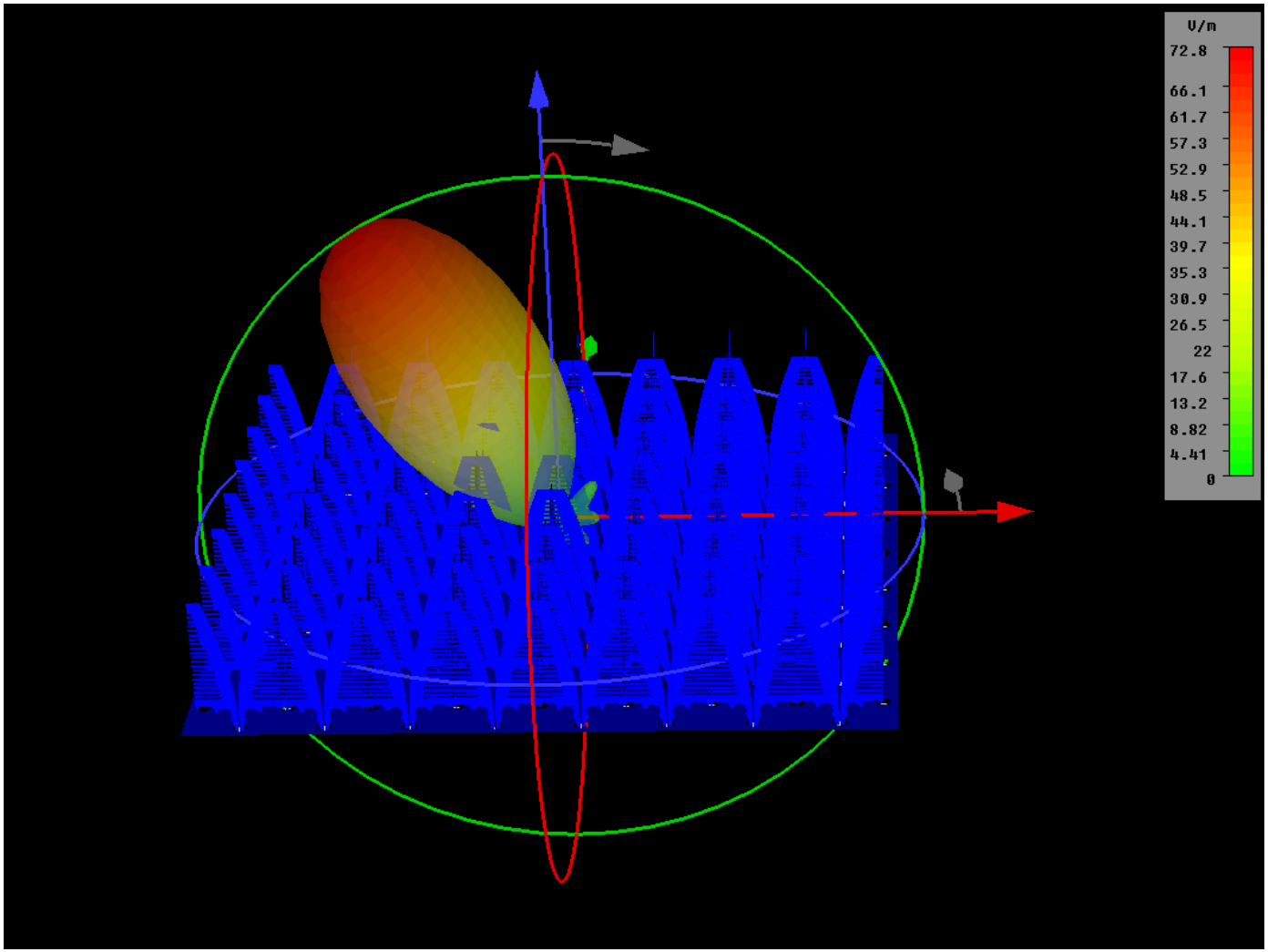
4 x 4 Elements Scan



Broad side, E-field pattern

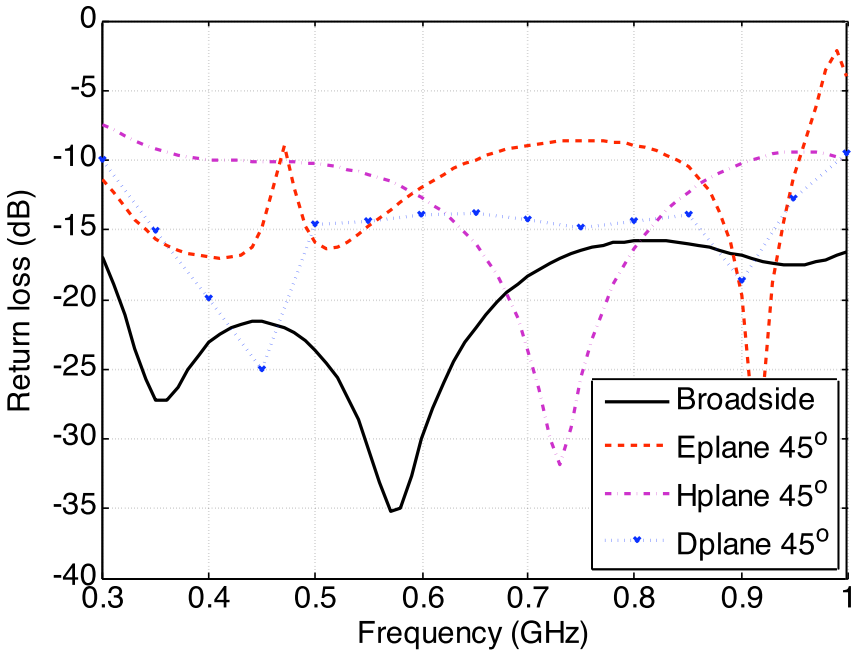


40º scan , E fields pattern

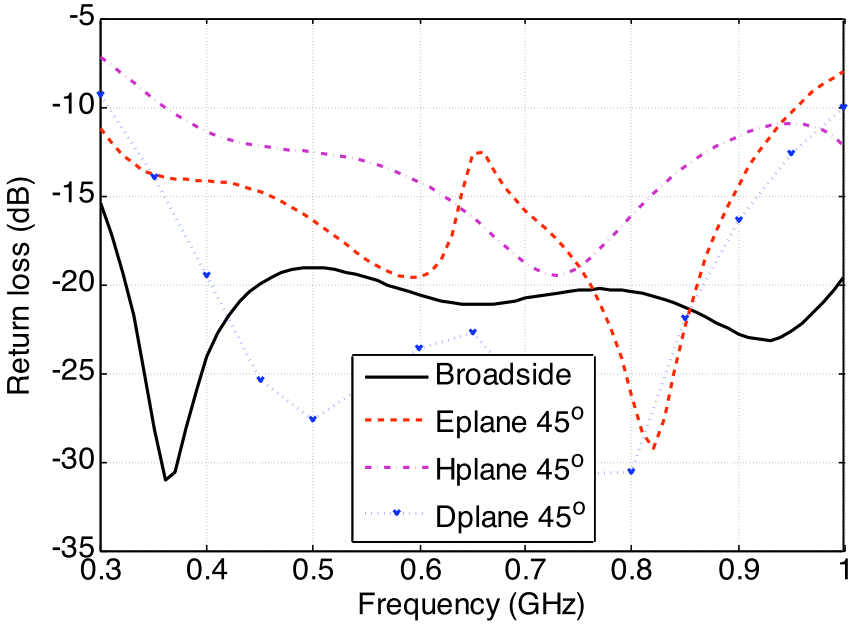


X-cfg over L-cfg for BECA

X-cfg



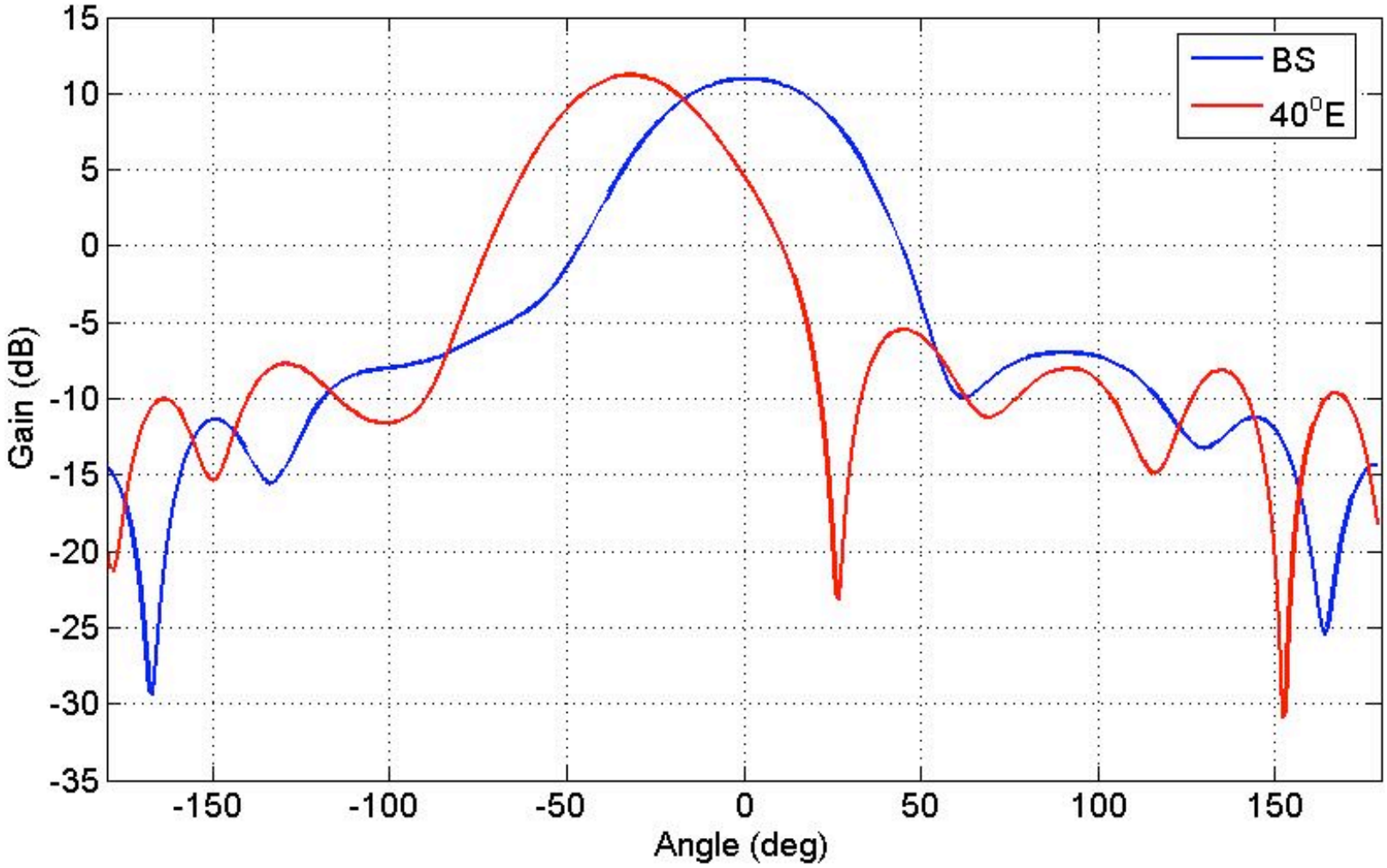
L-cfg



X-cfg has a common phase centre for both polarisation components; L-cfg shows an overall scan performance in the entire frequency band.

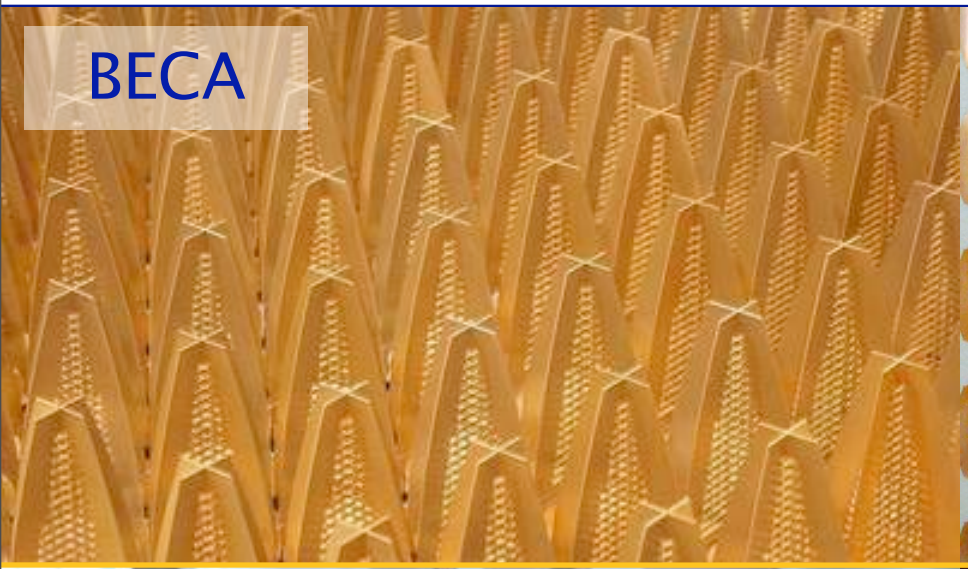
UNIVERSITY OF OXFORD

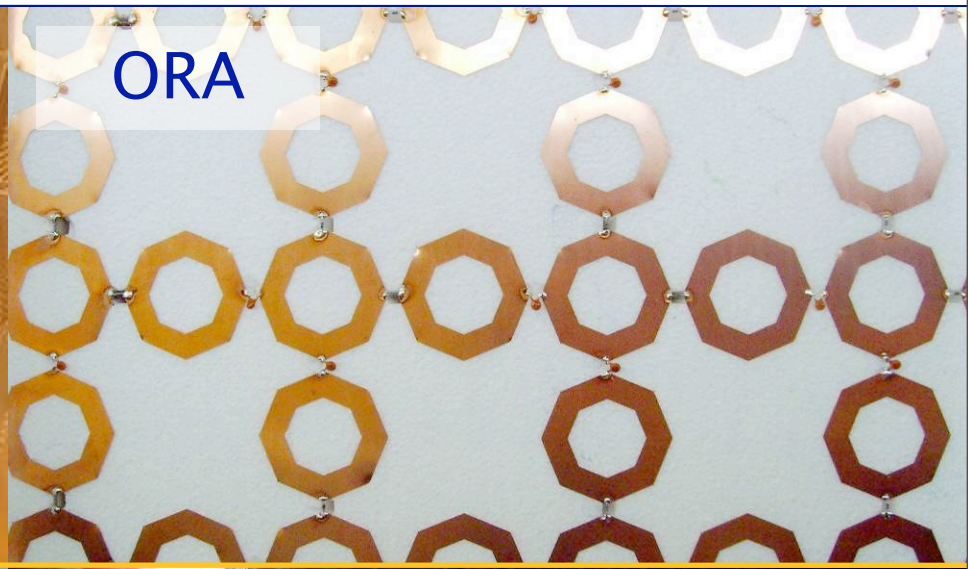
Gain in dB



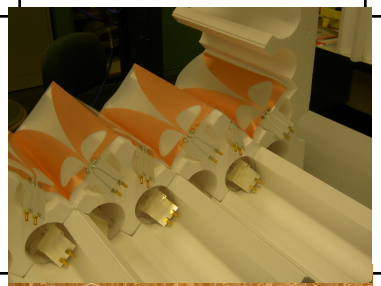
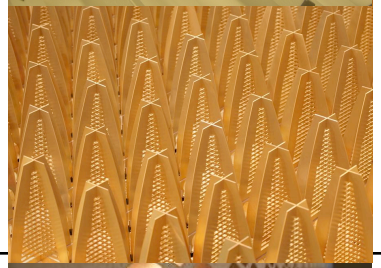
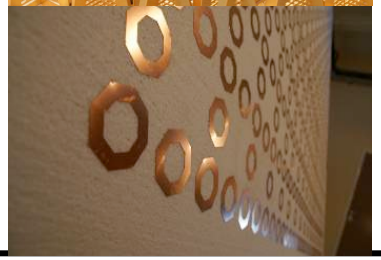
UNIVERSITY OF OXFORD

Antenna Technology





Antenna Cost Comparison

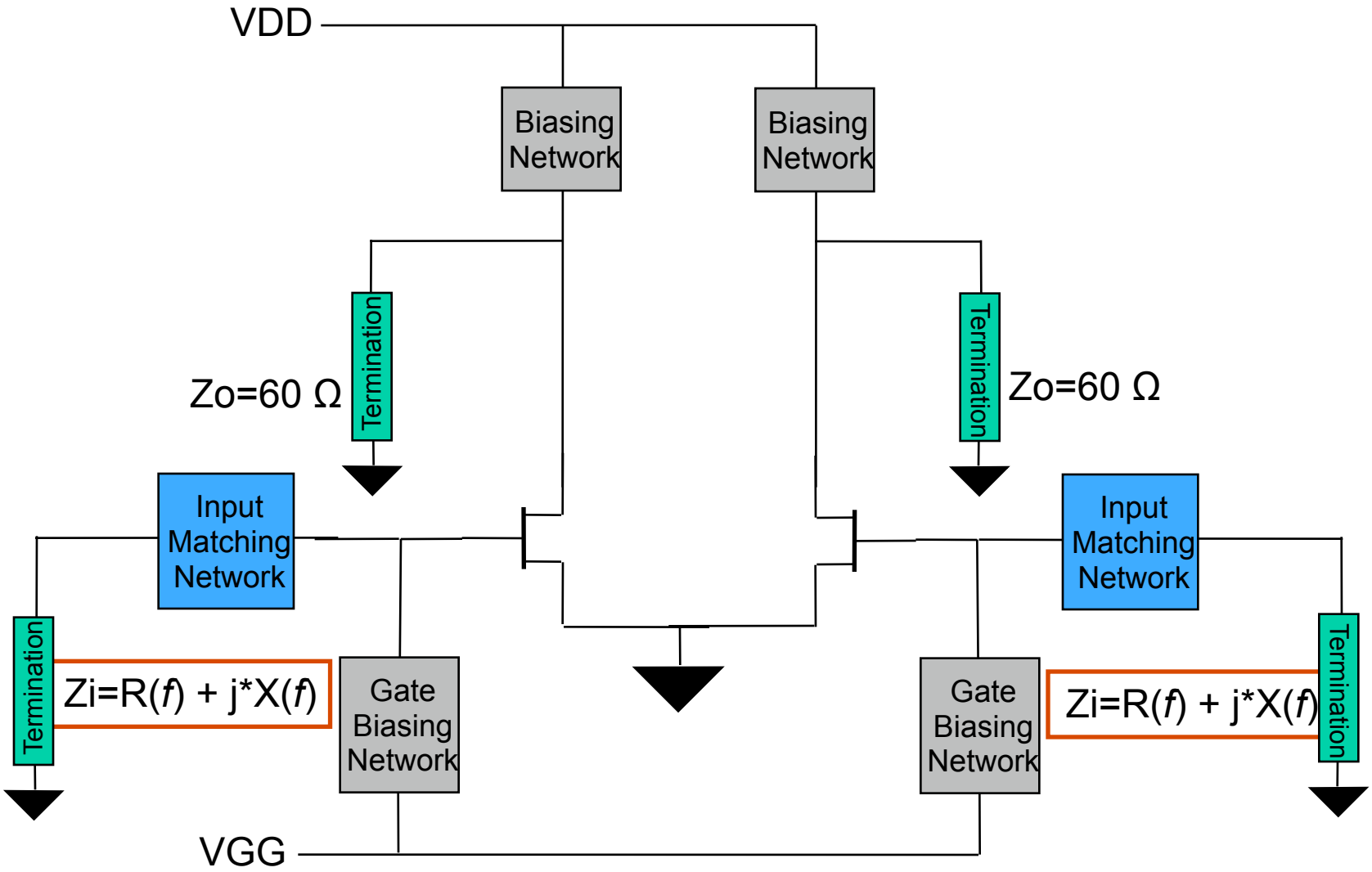
		Total cost of parts	Assembly effort	Scope for large scale manufacture
FLOTT		£14,600	150 man hours	MEDIUM – HIGH
BECA		£8.5k	**450 man hours**	LOW
ORA		£4k	100 man hours	HIGH

Low-Gain Antenna Summary

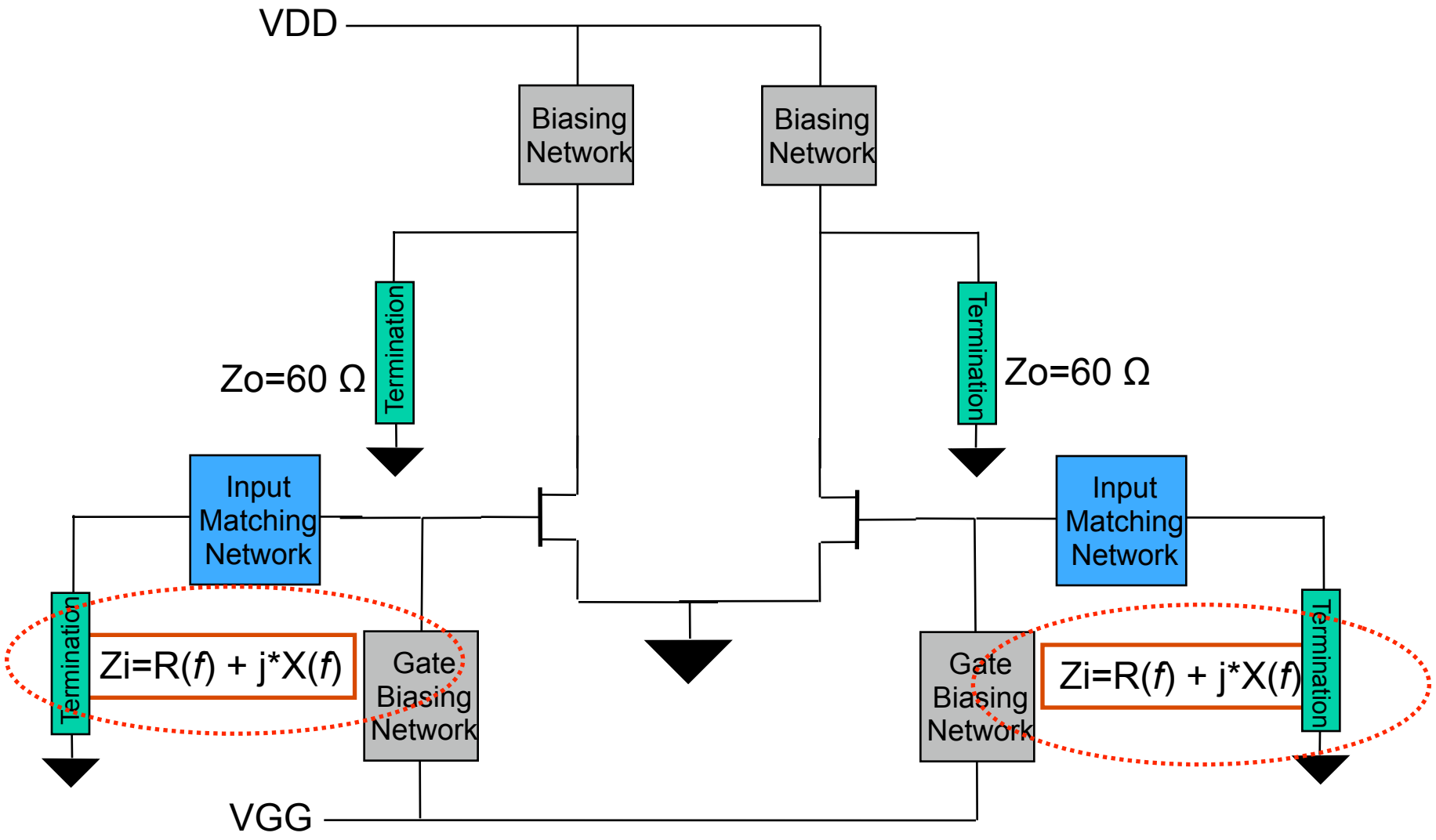
Parameters	Vivaldi	BECA	ORA
Bandwidth(45º scan, VSWR<2)	0.3-0.97GHz	0.3-0.98GHz	0.3-1 GHz
Cross polarization (0º to 45º scan)	≤ 0 dB	≤ -10dB	≤ -15dB
Immersed element pattern (Power)	Worse than a cosine function	Slightly worse than a cosine function	Close to a cosine function
Element separation to meet bandwidth	170mm	170mm	165mm

For SKADS mid frequency band between 300MHz and 1 GHz with 45º scan volume. The maximum element spacing for Vivaldi antennas showing tapered slot structure is 160mm, 168mm for BECA, and 165mm for ORA.

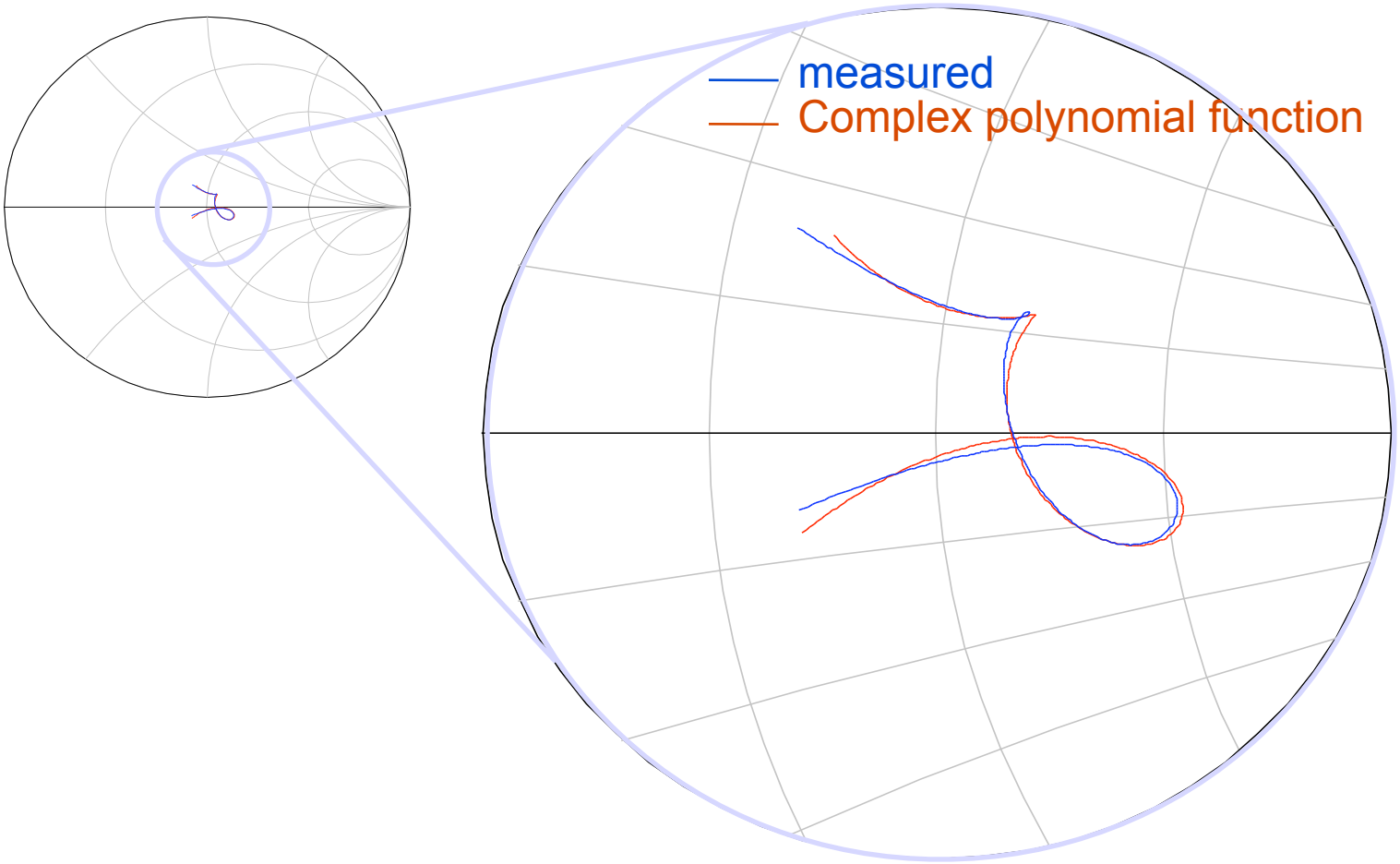
Broadband LNA design



Broadband LNA design



Complex Input Impedance



Simulated Results

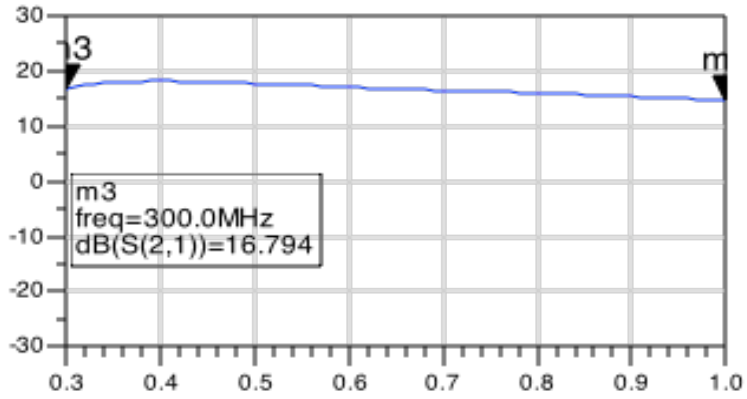
Design 1

- Bandwidth 300 –1000 MHz
- Gain ~ 20 dB
- Input match > 10 dB (above 700 MHz)
- Output match ~ 7 dB
- Noise temperature ~ 30 K

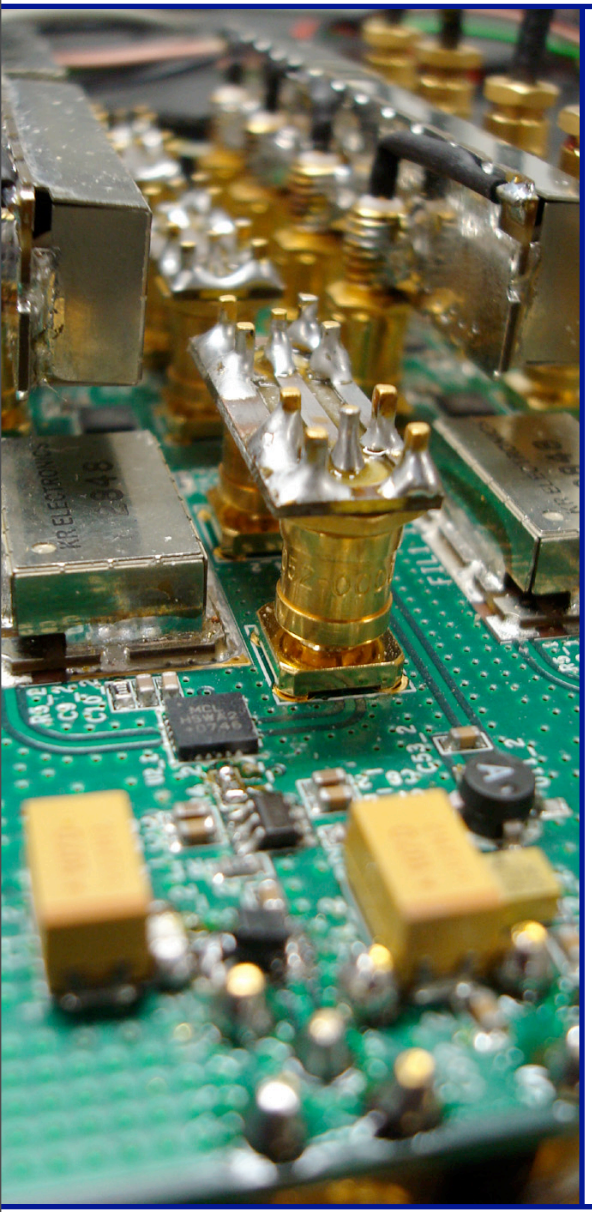
Design 2

- Bandwidth 300 –1000 MHz
- Gain ~ 20 dB
- Input match > 10 dB (above 700 MHz)
- Output match ~ 10 dB
- Noise temperature ~ 40 K

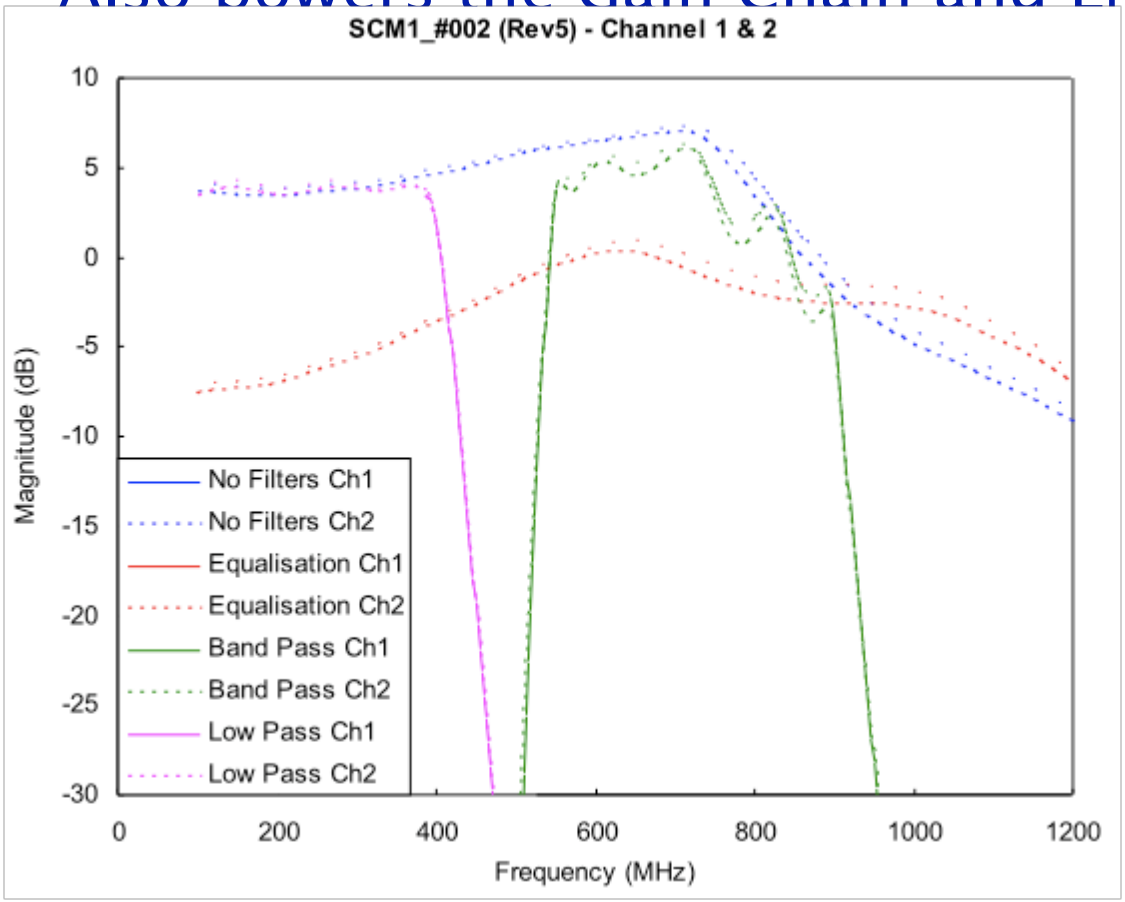
Optimised Design for Complex



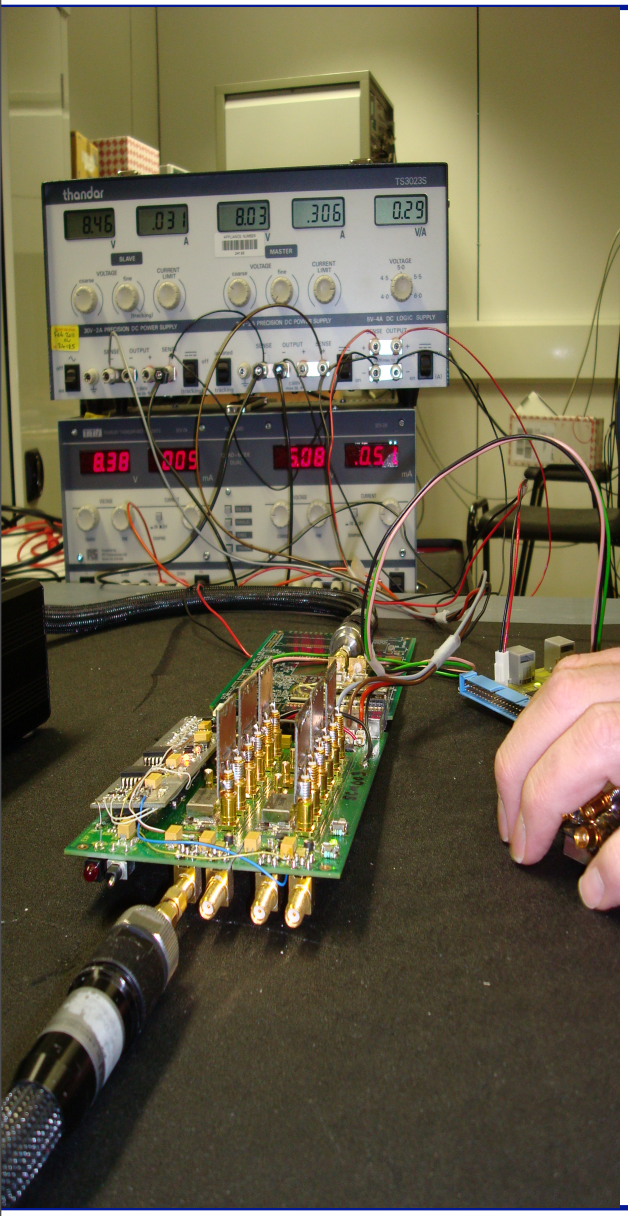
Analogue Filter Module

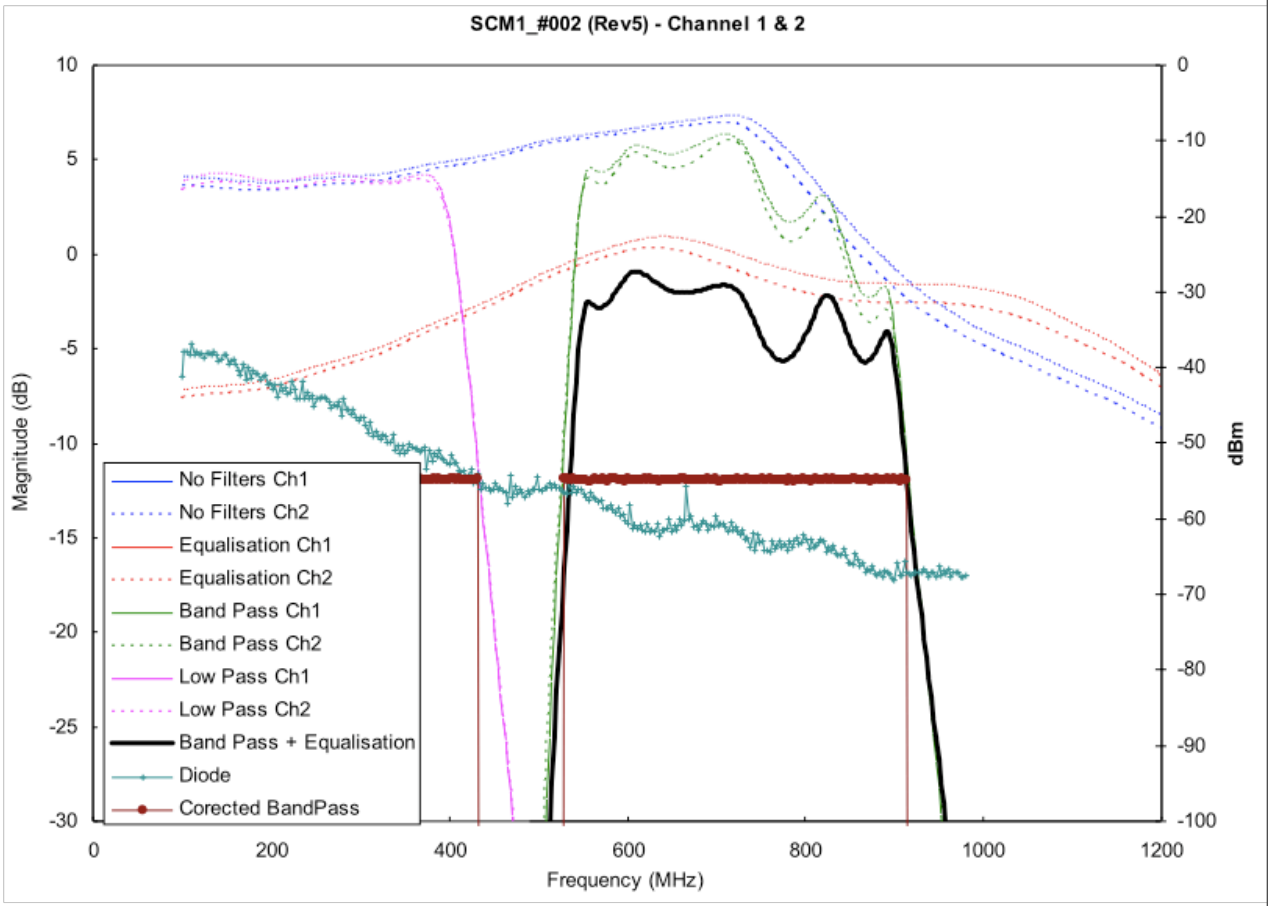


- Filters: low-/band-pass, cable equalisation
- Also powers the Gain Chain and LNA

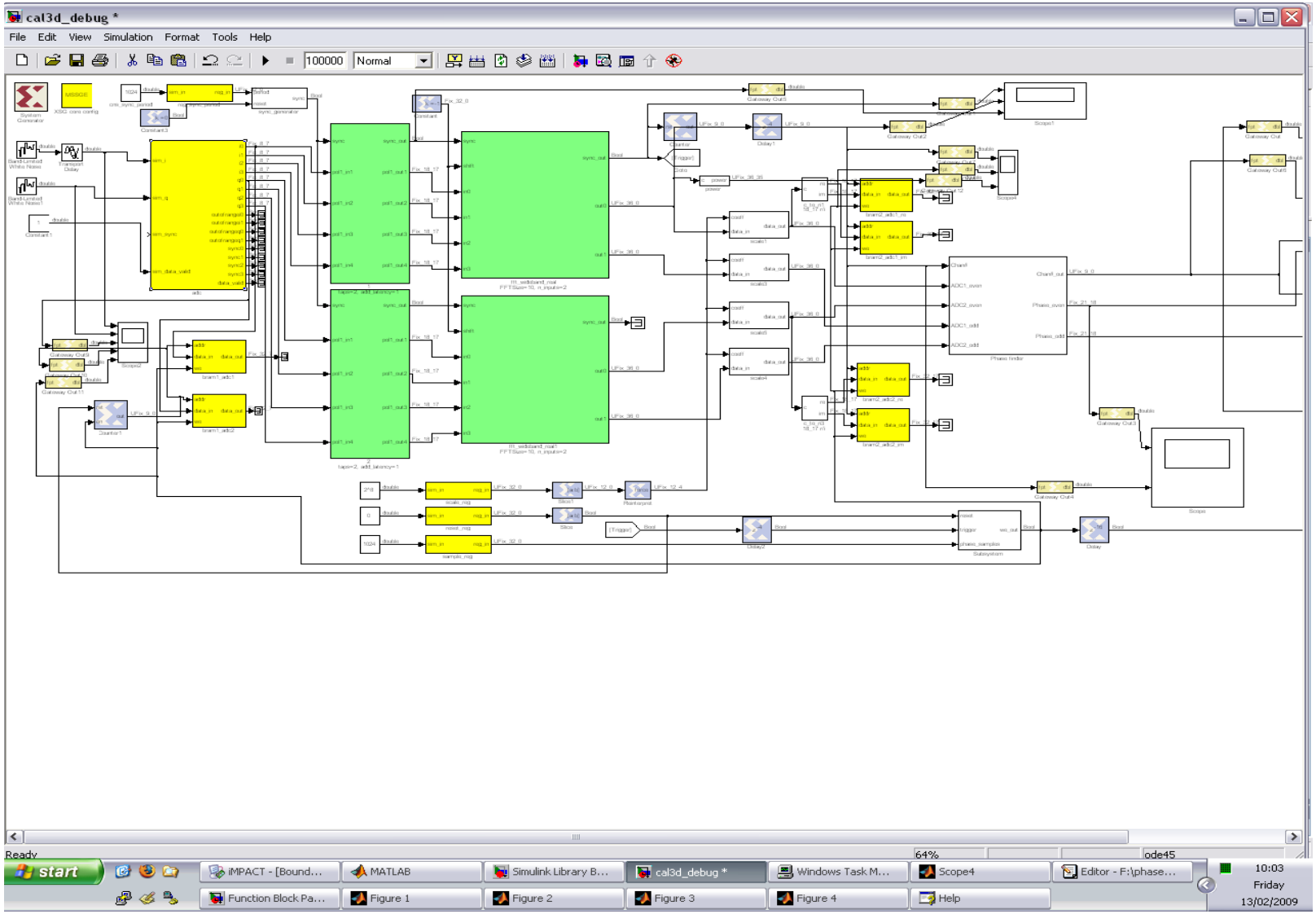


BandPass Calibration

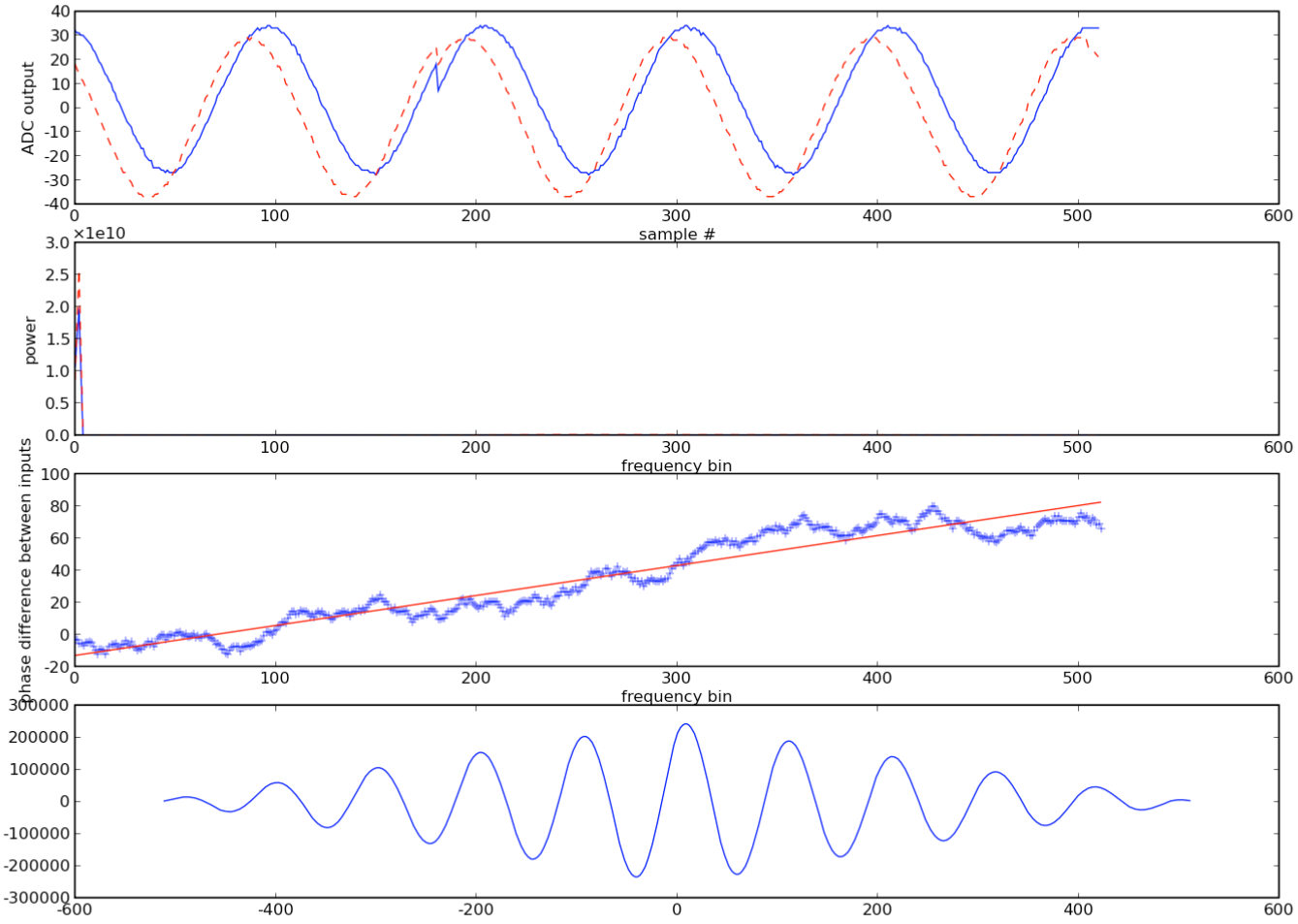




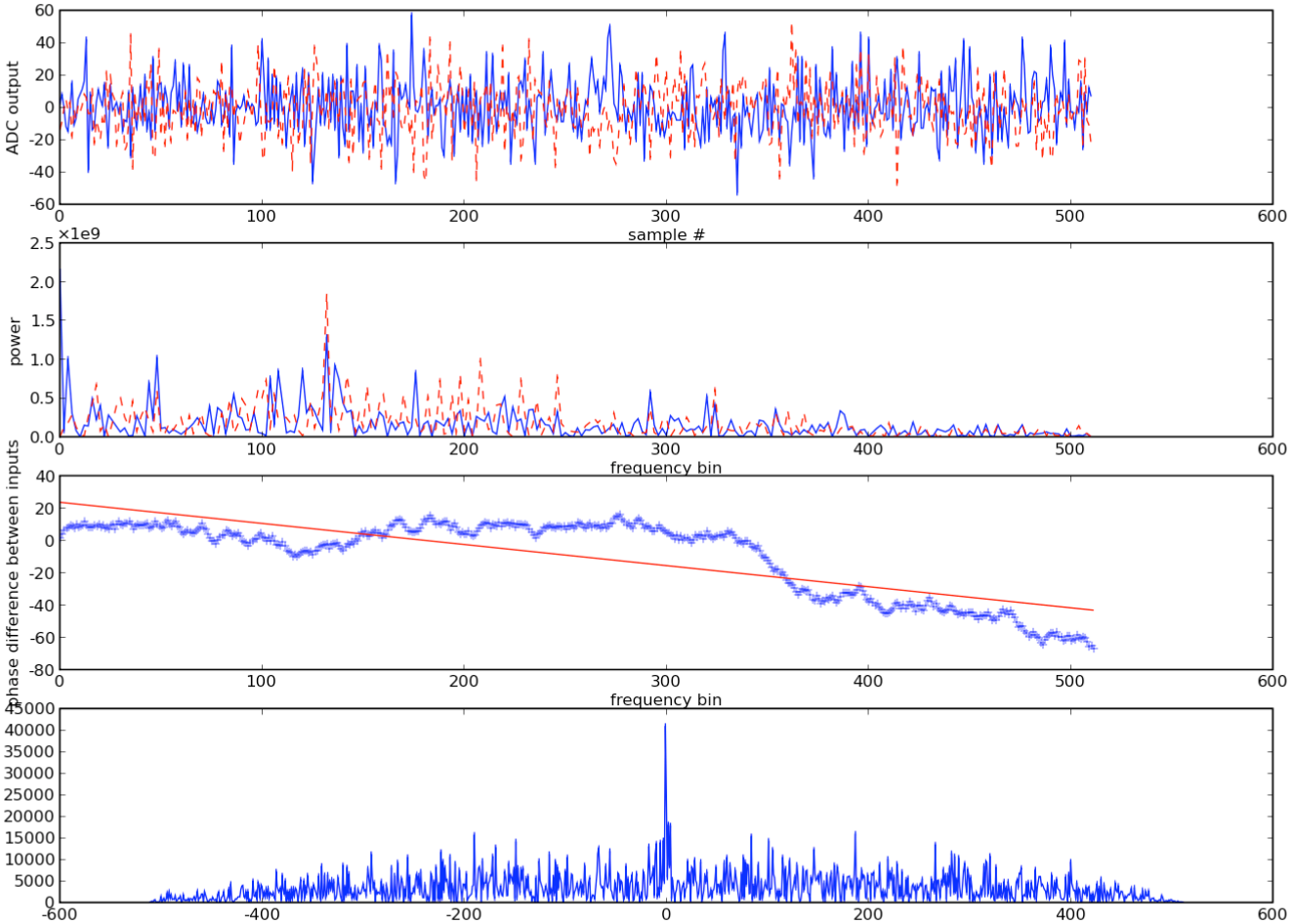
Home-Baked Correlator



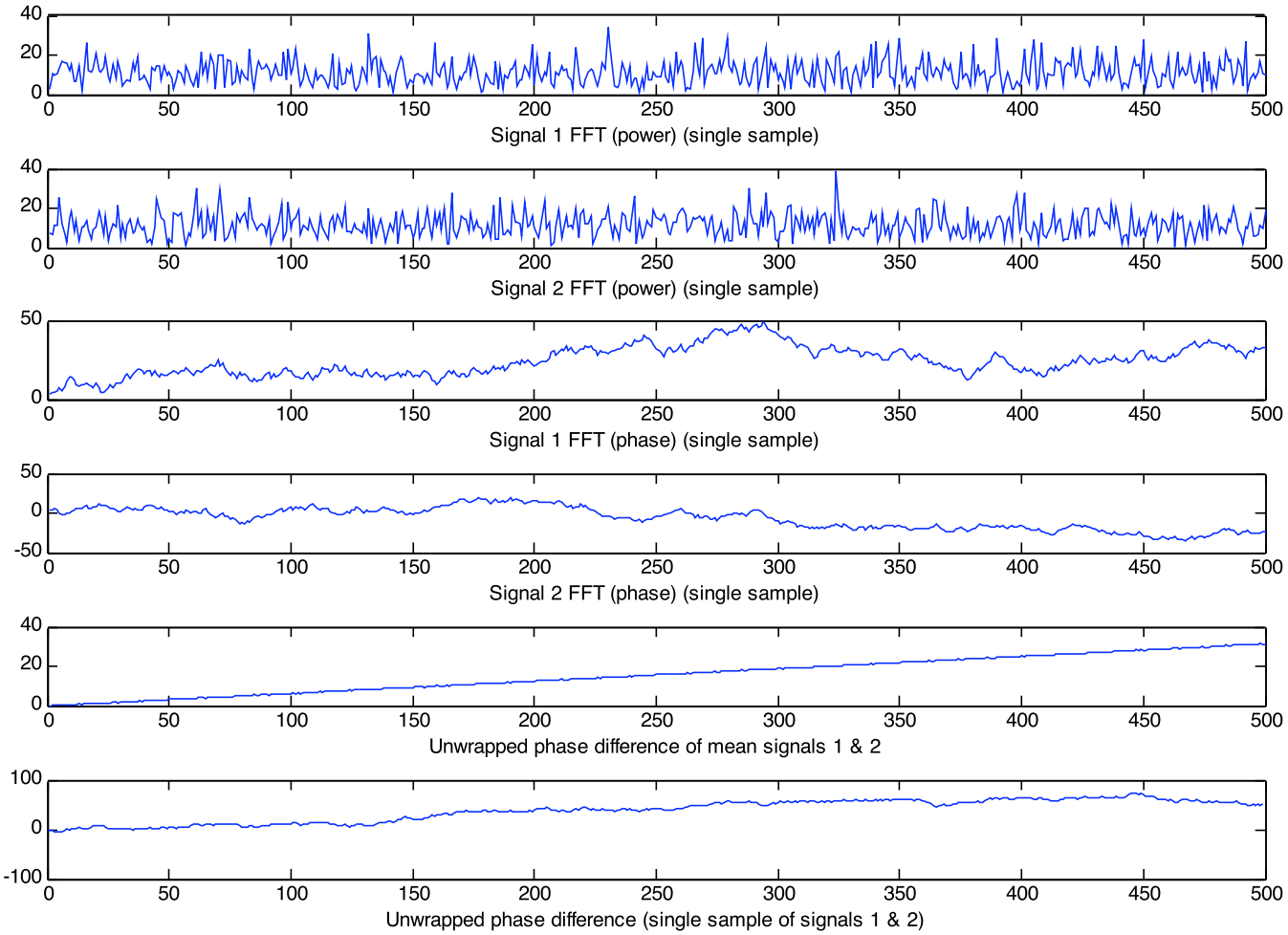
Home-Baked Correlator



Home-Baked Correlator



Home-Baked Correlator



Calibration Results

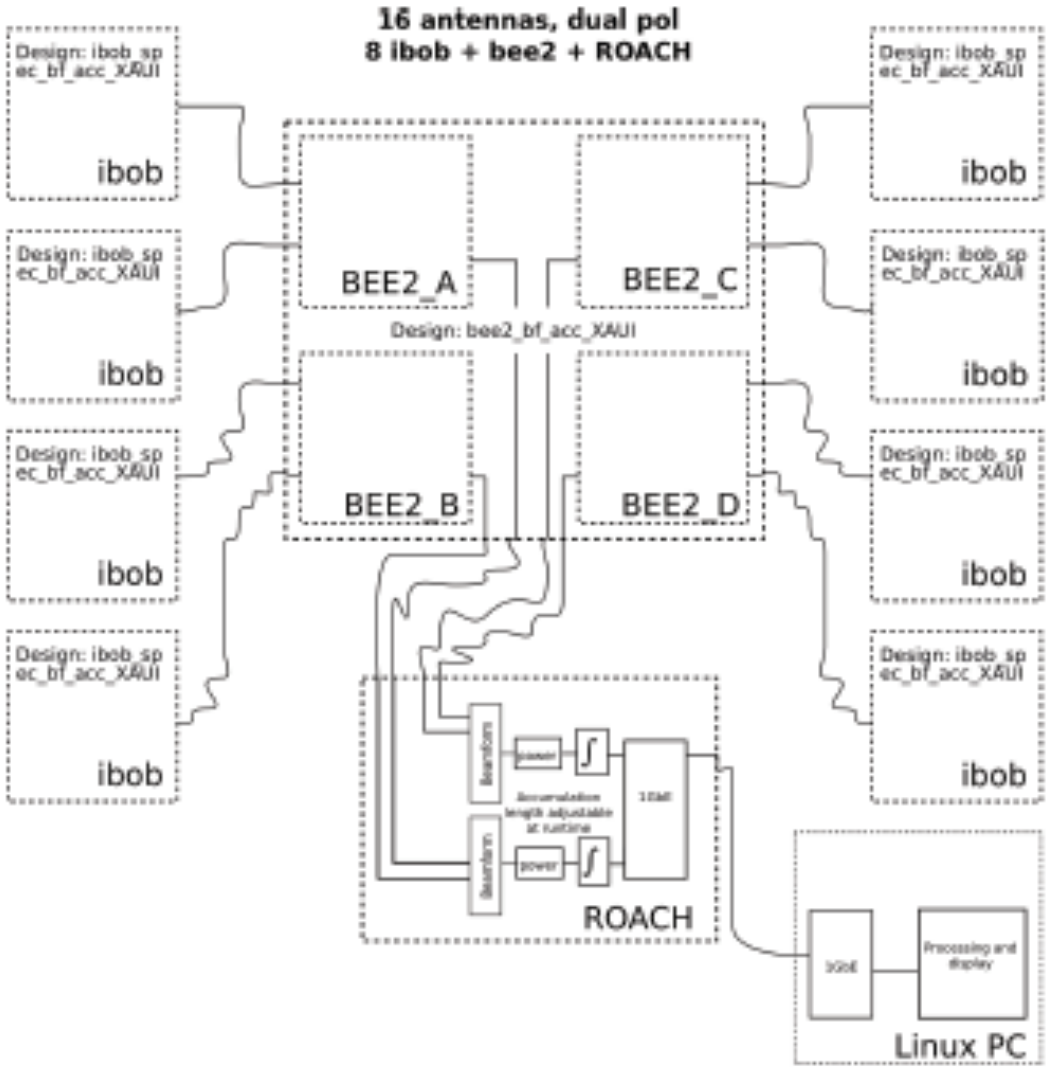
- Flatten Band-Pass to 0.3dB
- Cable lengths calibrated to 0.1ns or 1/10th of Sample Clock (can be extended with longer interpolation filter)
- Cable Corrections uploaded into Software Simulator for correction factors
- **1 Major Drawback: Efficient broadband coupling into front-end is expensive and difficult**

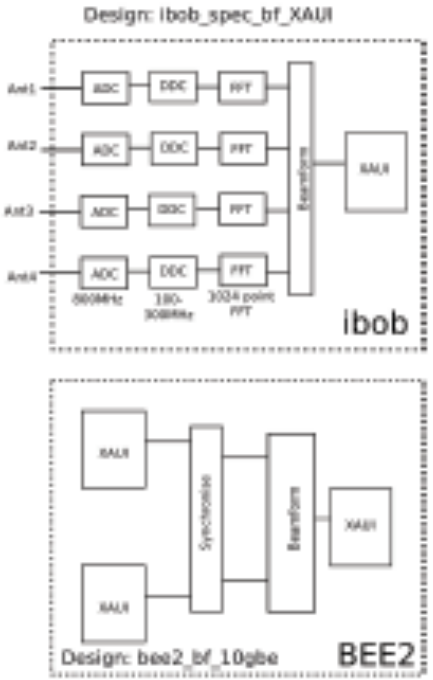
UNIVERSITY OF OXFORD

Processing Container / RFI

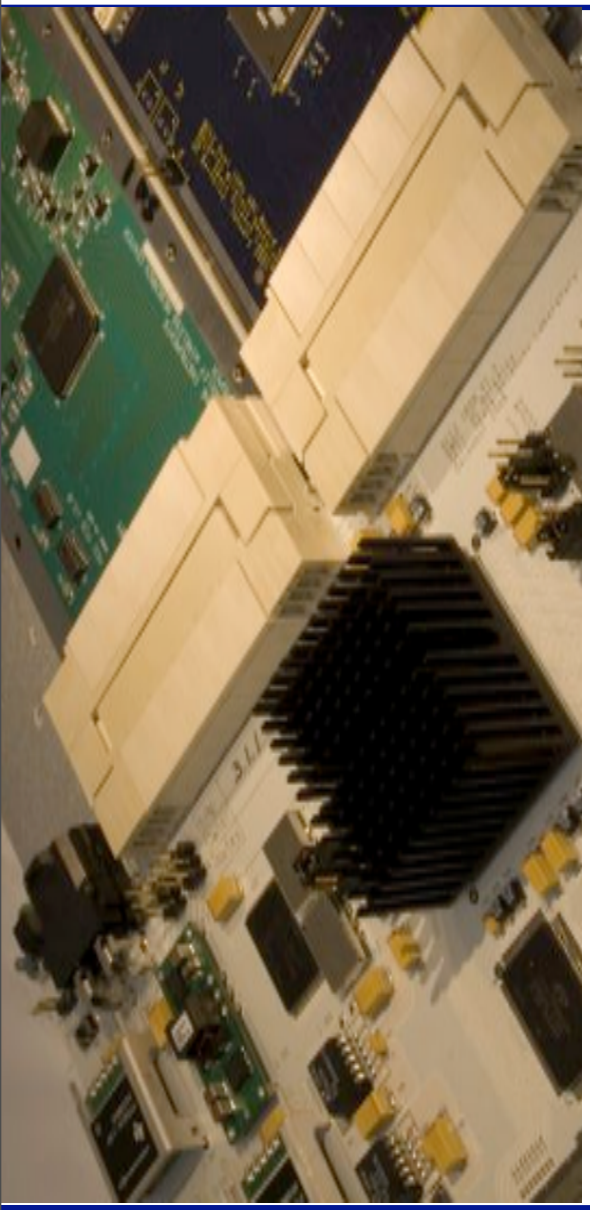
UNIVERSITY OF OXFORD

Digital Beamforming



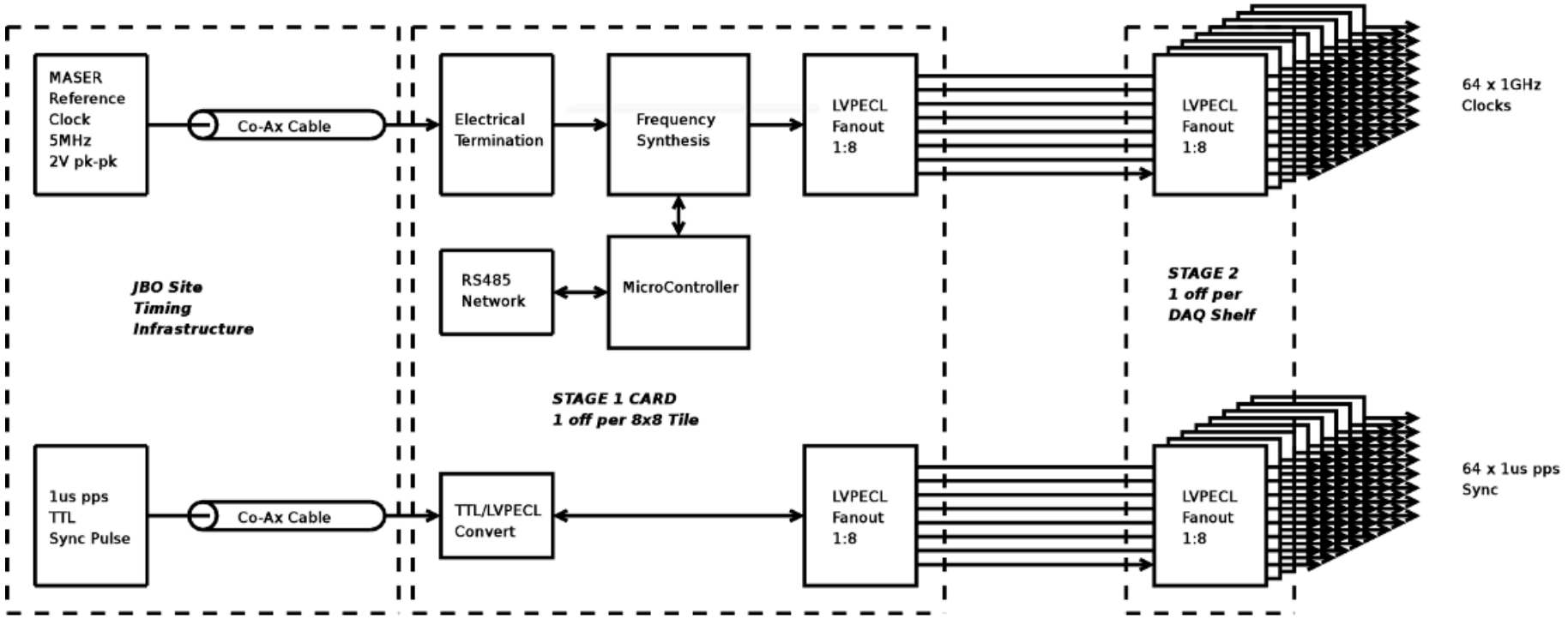


CASPER Hardware

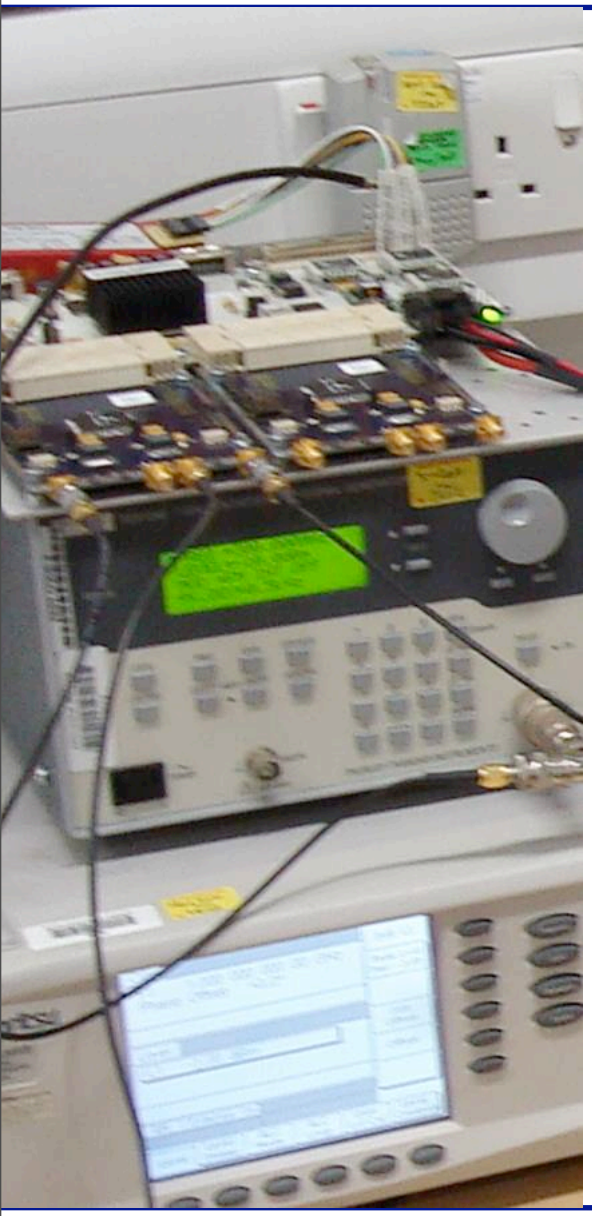


- ADC boards, FPGA boards and Ethernet Switches
- ADCs: Digitise up to 500MHz bandwidth (0-0.5 GHz or 0.5-1GHz)
- FPGAs perform 'engine' processing (F-engine, X-engine and B-engine) and interfacing to switches and ADCs
- Ethernet Switches: distribute data to the correct engines
- BEE2 forms the beams from different quadrants
- ROACH integrates

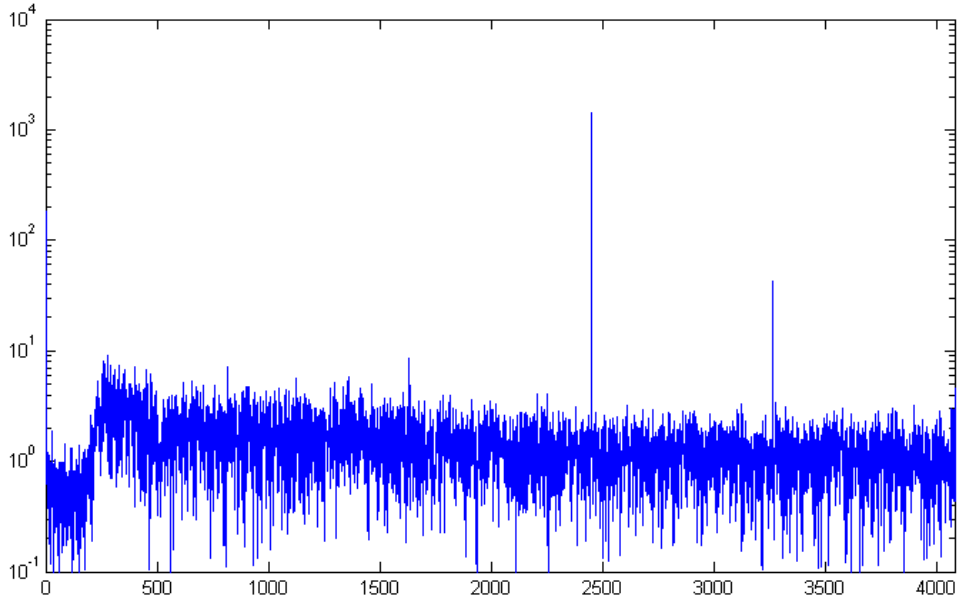
Clock Distribution



From analogue to digital

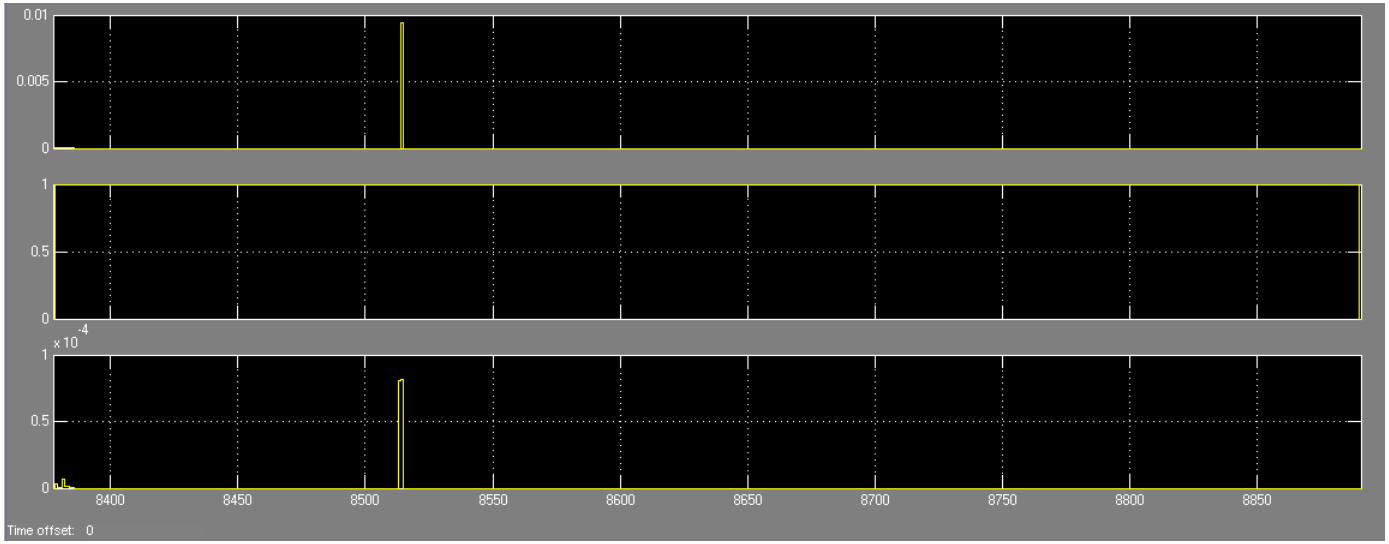


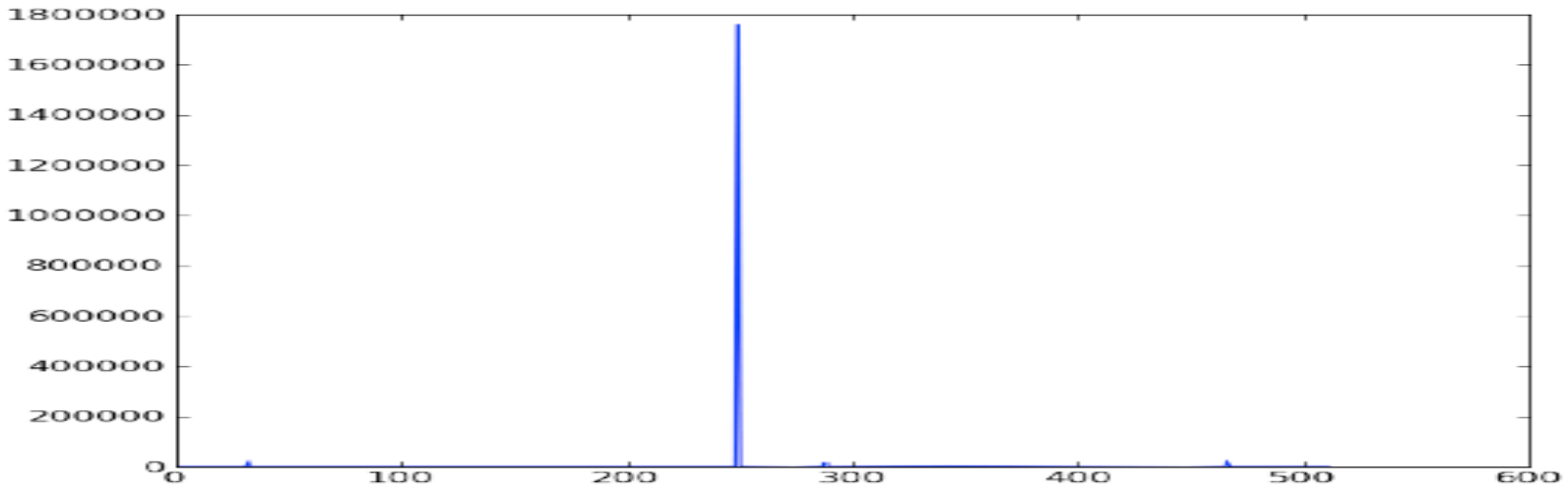
- First analogue to digital signal path
- Test Signal @ 300MHz -15dBm (ADC p_p 500



Spectrum of 300MHz test signal split into 2 channels, digitised with iADC board, dumped off iBOB FPGA (8192 bins on abcissa, ordinate in log scale, (10^6)W/Hz

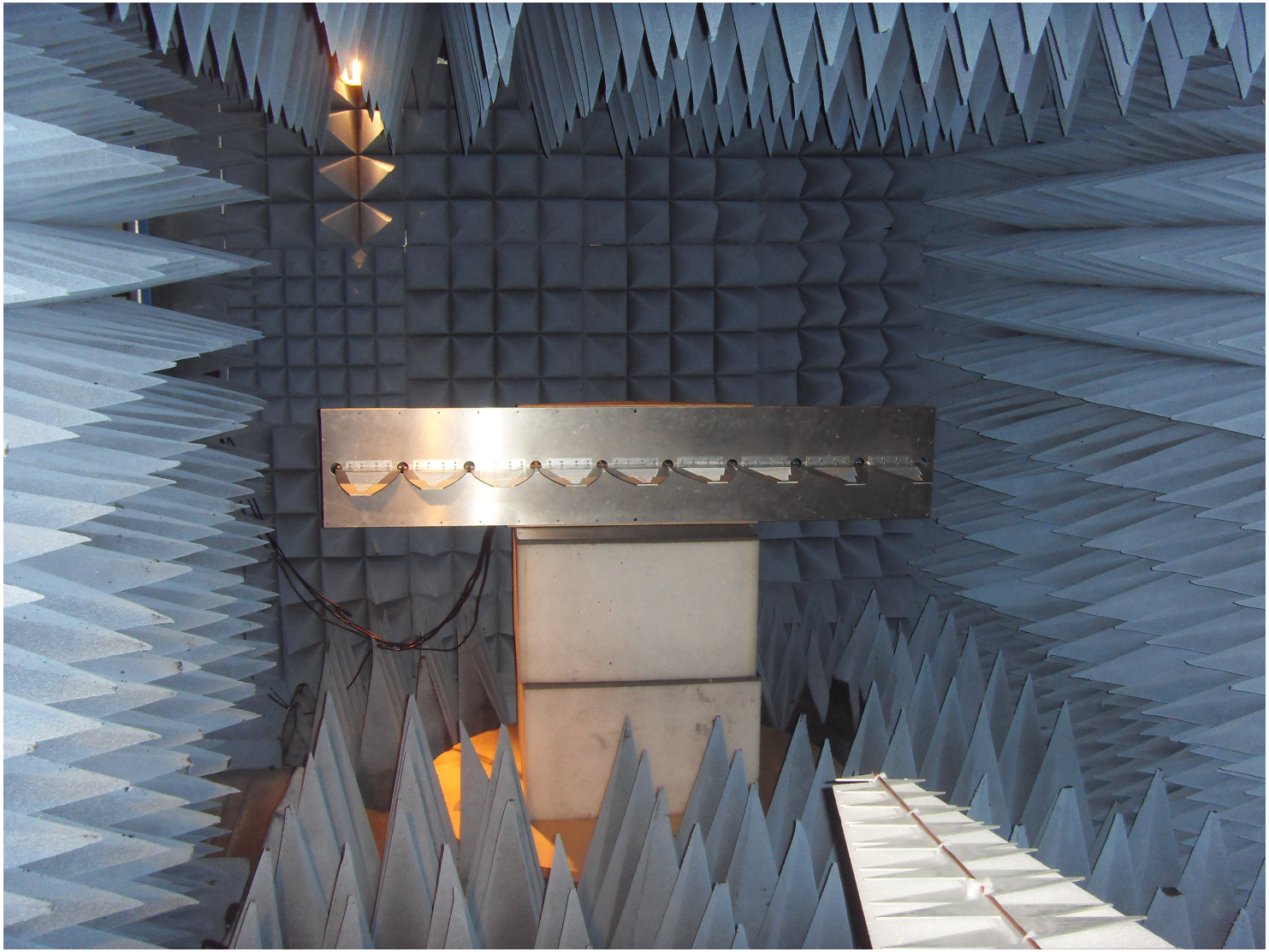
Integrated Beams



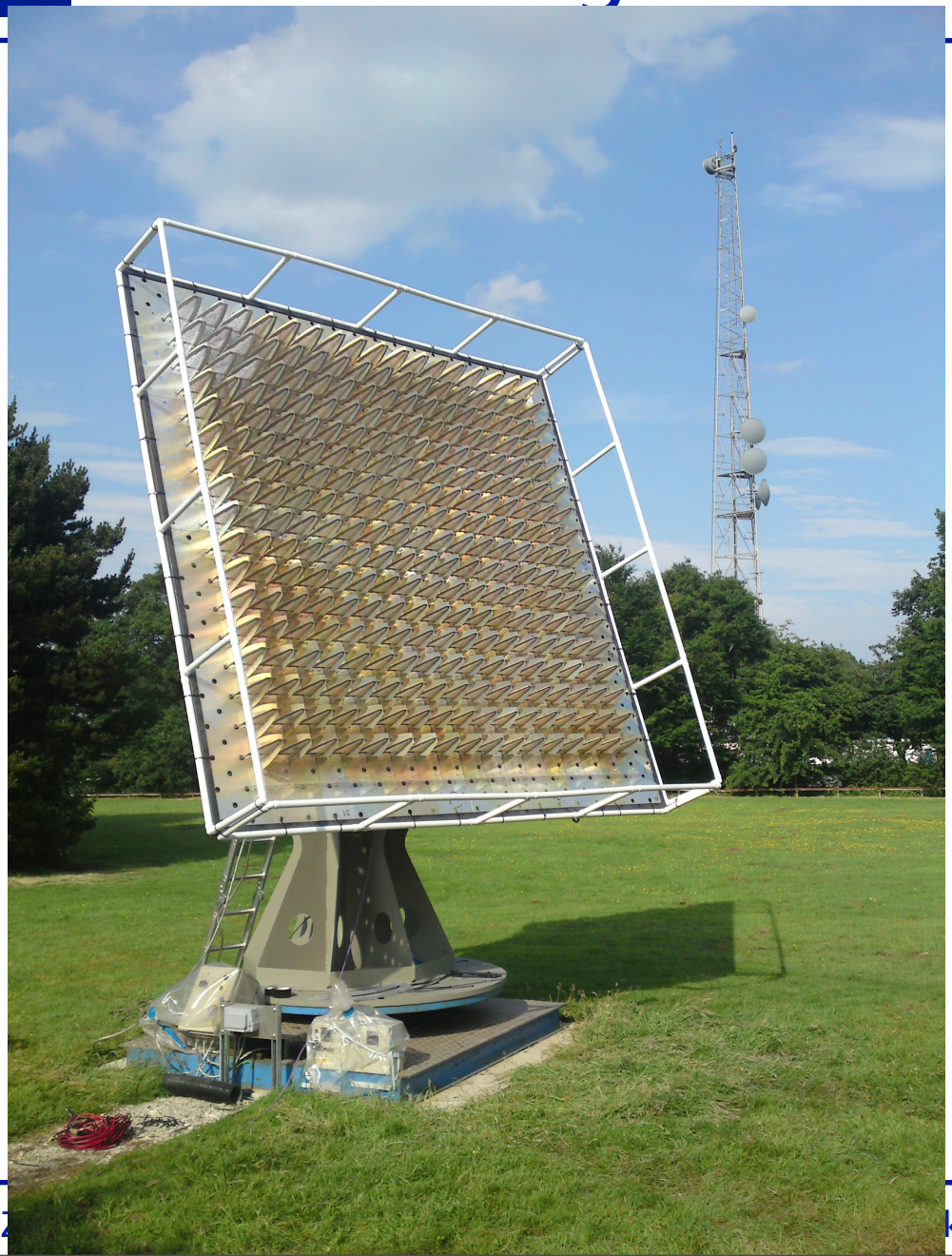


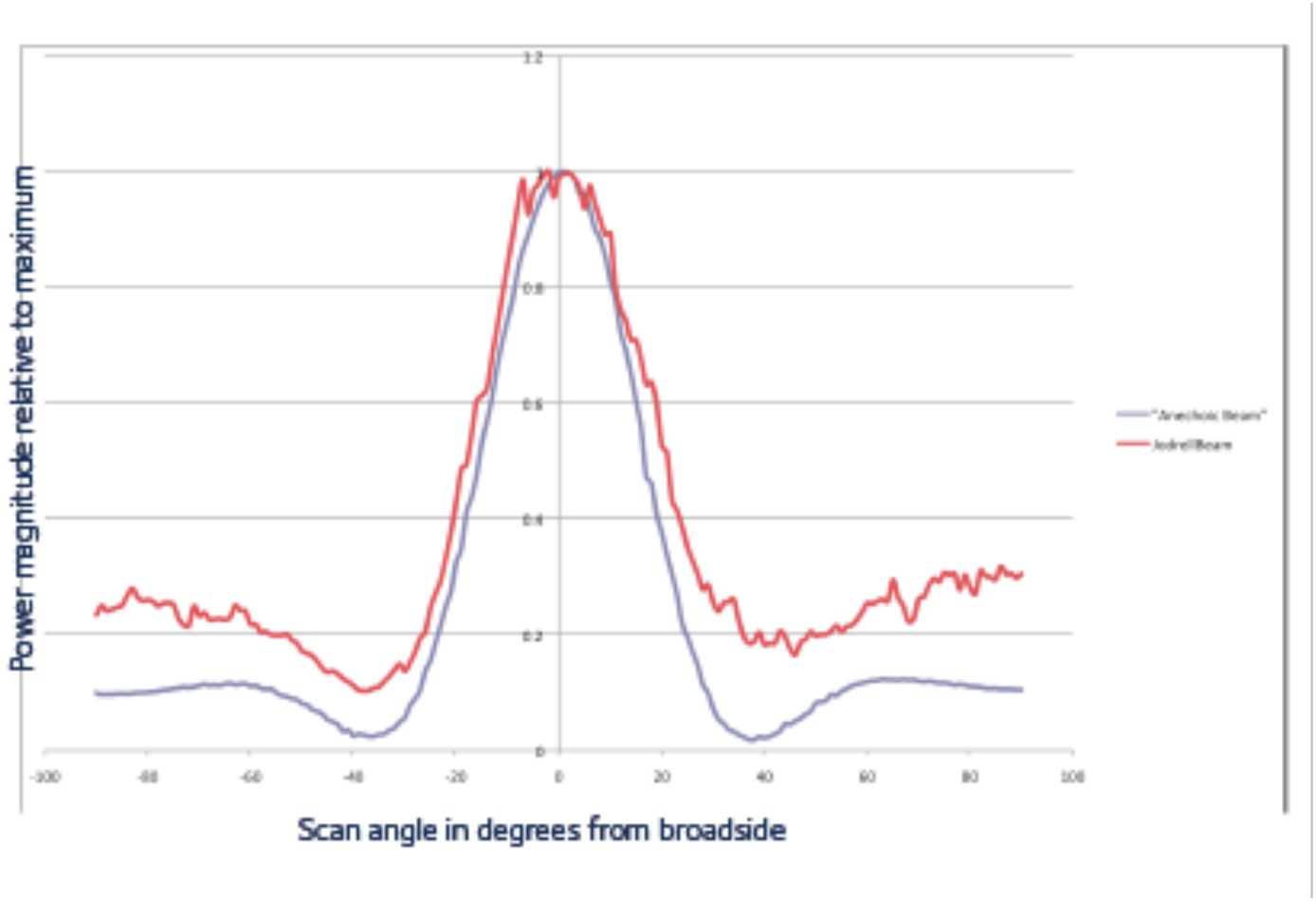
UNIVERSITY OF OXFORD

Beamforming Results

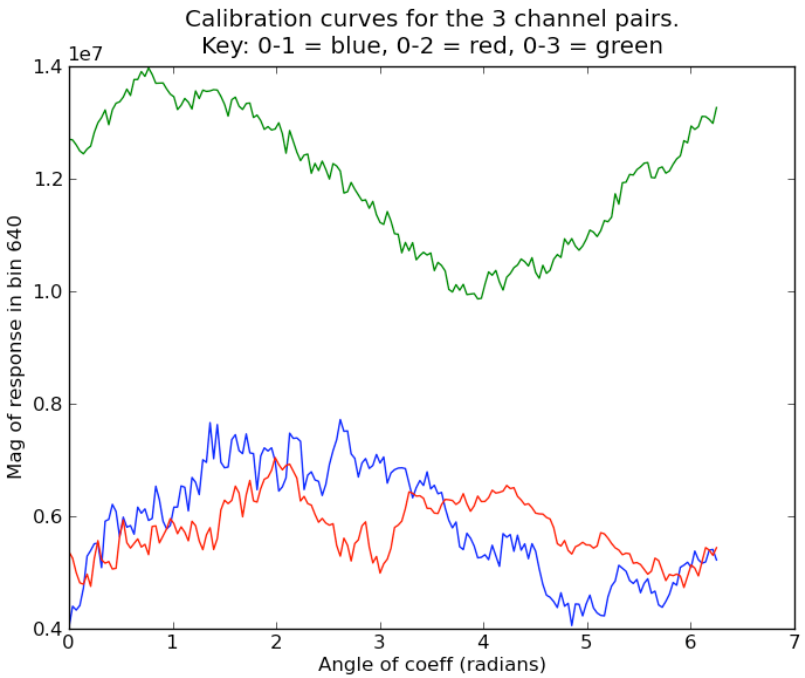


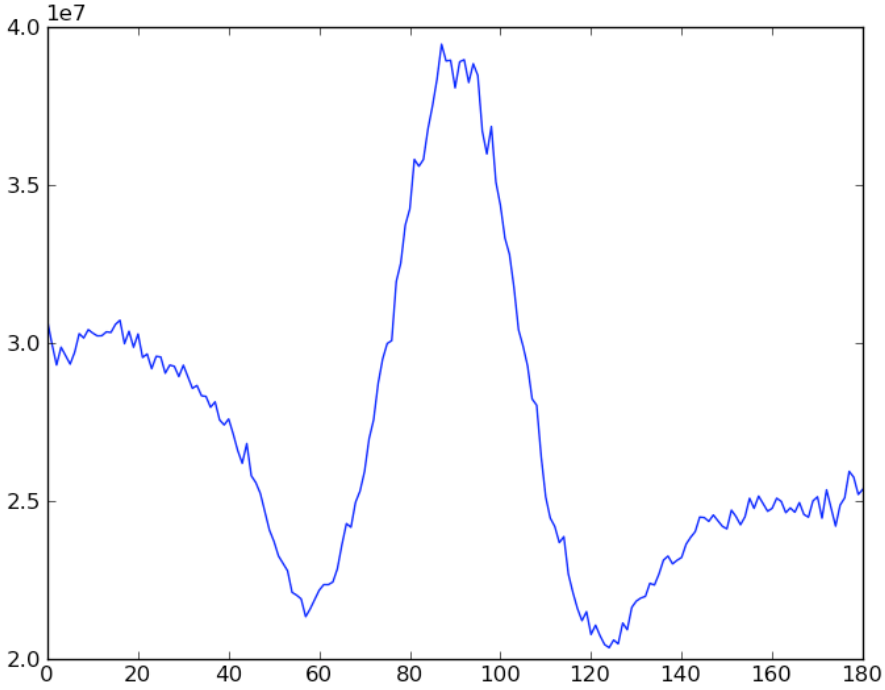
CASPER Digital Processing




Power magnitude relative to maximum
1.2
1
0.8
0.6
0.4
0.2
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
Scan angle in degrees from broadside
"Anechoic Beam"
JodrellBeam

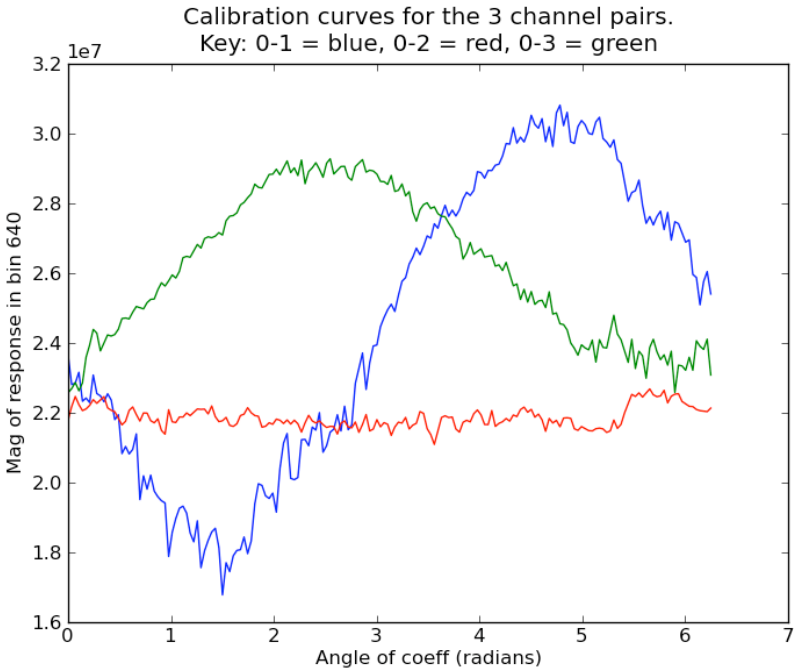
Calibrated Beam at 675 MHz

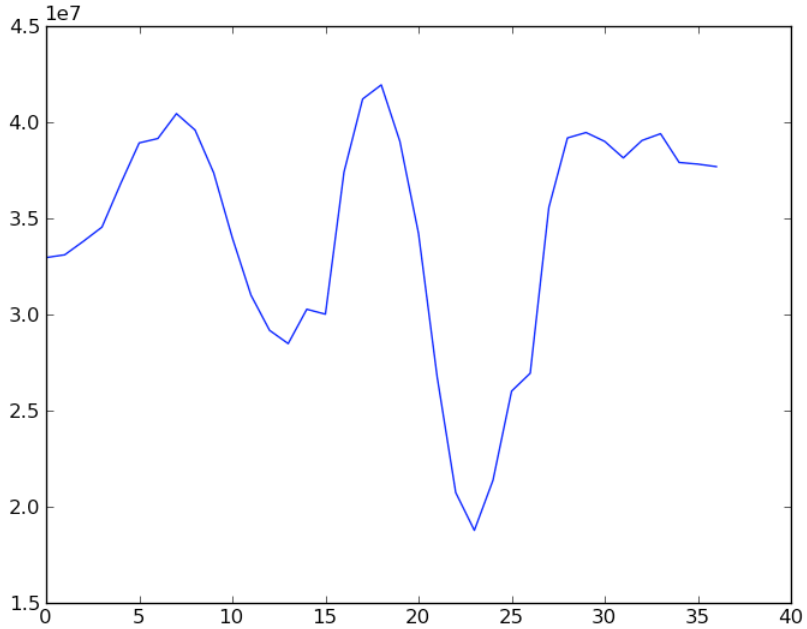




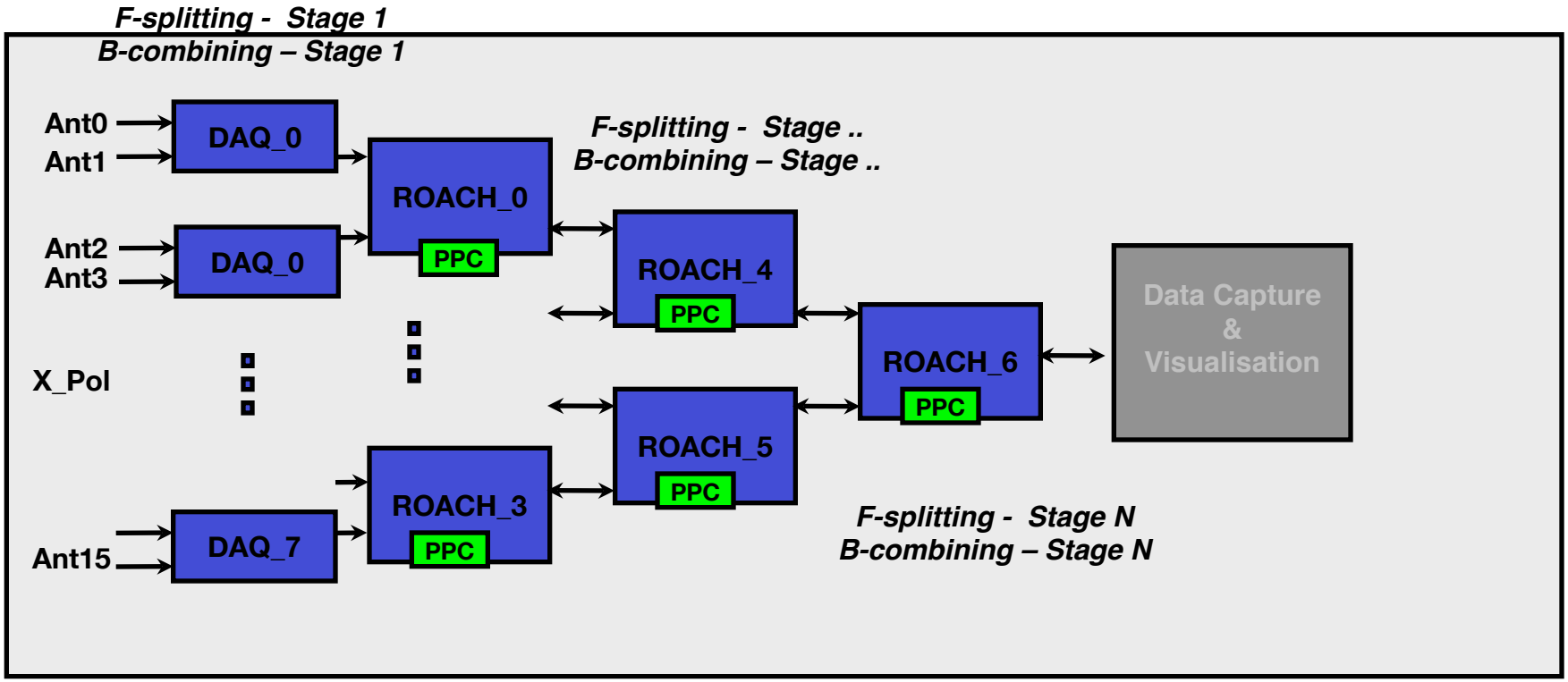
UNIVERSITY OF OXFORD

When Calibration goes





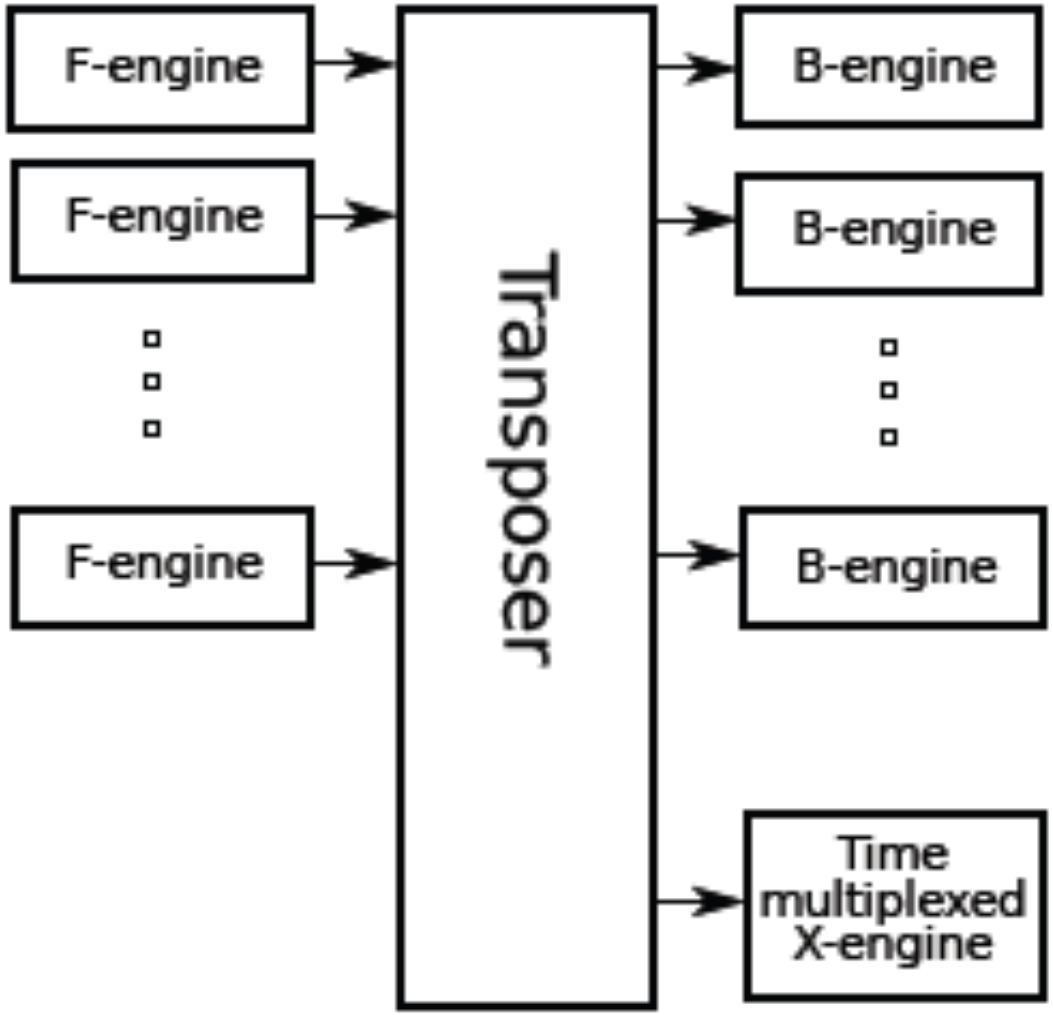
Hierarchical Architecture



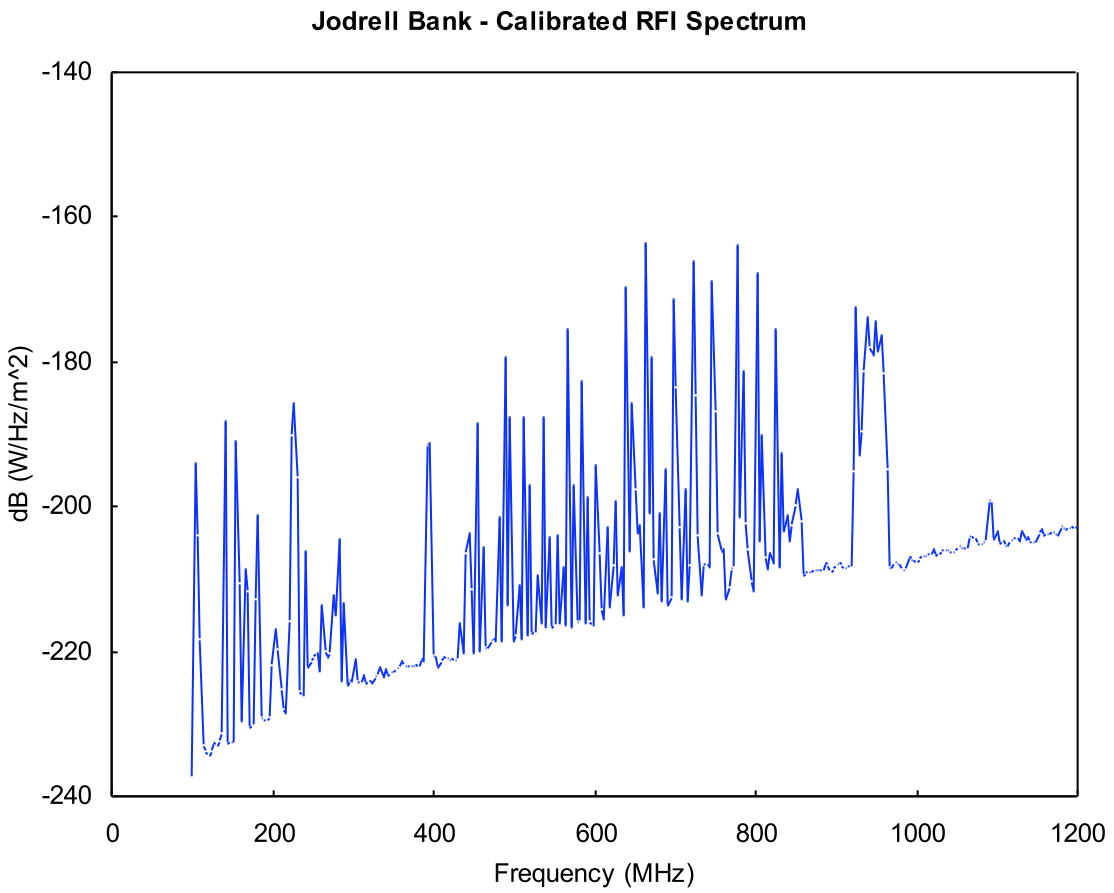
- 500MHz input BW @ 8-bit sampling. 2-el beamforming in all boards. Intermediate data cut down to (4-bit re, 4-bit im).

UNIVERSITY OF OXFORD

Future System Diagram . . .



Jodrell Bank RFI



The lessons we learnt….

- T_{sys} is hard to control over a broadband system
- S_{11} is hard to maintain over a broadband system
- Dynamic Range is **imperative** (Sparse vs. Dense (Sascha's talk))
- Digital Systems are B/W limited rather than Operation Count limited
- You cannot build a beamformer without a correlator
- Calibration difficulties with large Field(s) of View
- Telescope Site is CRUCIAL

Oxford SKA Group

Science

- Steve Rawlings (PI)
- Aris Karastergiou
- Danail Obreschkow
- Hans-Rainer Klöckner
- Ian Heywood
- Roger Deane
- Tom Mauch

Simulation

- Stef Salvini (PI)
- Ben Mort
- Chris Williams
- Fred Dulwich
- Vassily Khlebnikov

Hardware

- Mike Jones (PI)
- Adam Baird
- Danny Price
- Jack Hickish
- Kris Zarb-Adami
- Richard Armstrong
- Sascha Schediwy

Collaborators

- Uni. of Manchester
  - Dept. of Engineering
  - Chris Shenton
  - Georgina Harris
  - Aziz Ahmedsaid

Oxford SKA Group

Science

- Steve Rawlings (PI)
- Aris Karastergiou
- Danail Obreschkow
- Hans-Rainer Klöckner
- Ian Heywood
- Roger Dean
- Tom Mauch

Simulation

- Stef Salvini (PI)
- Ben Mort
- Chris Williams
- Fred Dulwich
- Vassily Khlebnikov

Hardware

- Mike Jones (PI)
- Adam Baird
- Danny Price
- Jack Hickish
- Kris Zarb-Adami
- Richard Armstrong
- Sascha Schediwy

Collaborators

- Uni. of Manchester
  - Dept. of Engineering
  - Chris Shenton
  - Georgina Harris
  - Aziz Ahmedsaid

UNIVERSITY OF OXFORD

No. of galaxies per redshift