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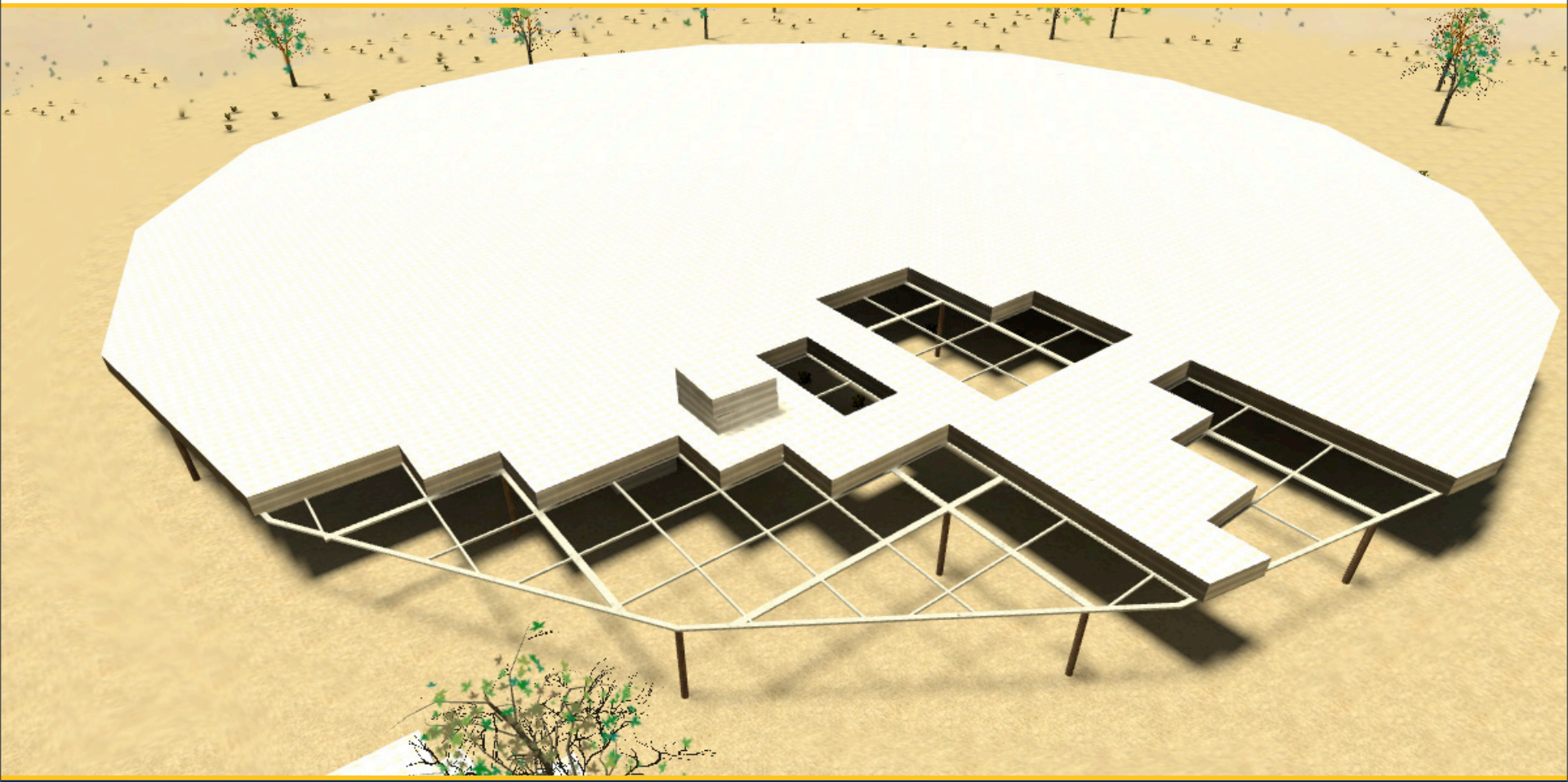
PAD

Advantages and Disadvantages of Sparse Aperture Arrays



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Fermilab: October 2009

http://2-

Motivation and Contents

- Introduce some of the concepts of mid-frequency, sparse aperture arrays
- Show that 2-PAD is the perfect test-bed for experimentally investigating these concepts
- Aperture Array Review
- Sparse Aperture Array Concepts
  - Effective Area
  - High-Gain Antenna Strategy
  - Instantaneous Field of View
  - Sky Coverage
  - Dynamic Range
  - Computational Complexity
- 2-PAD Sparse Configuration

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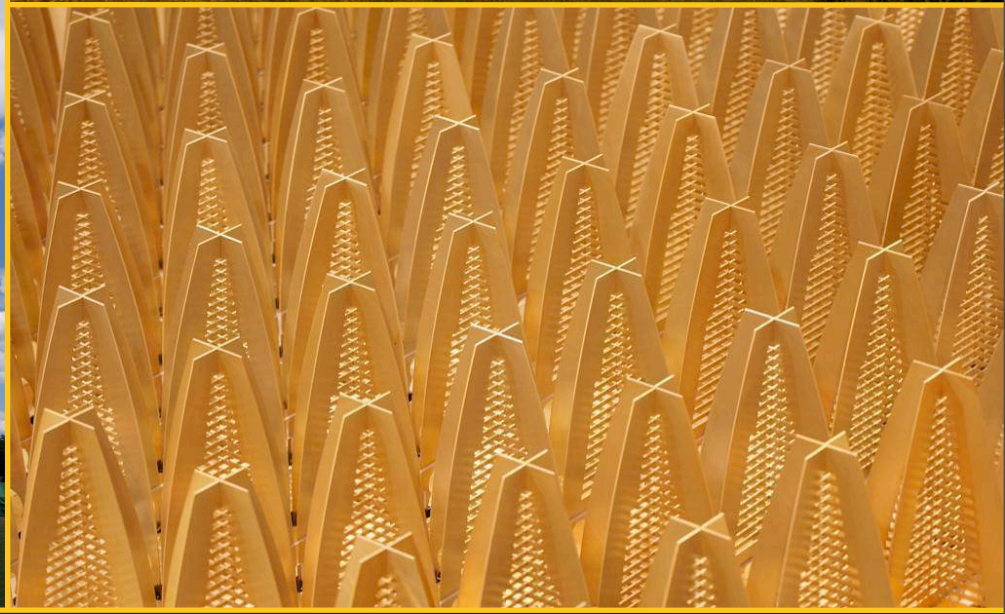
Aperture Arrays

PAD



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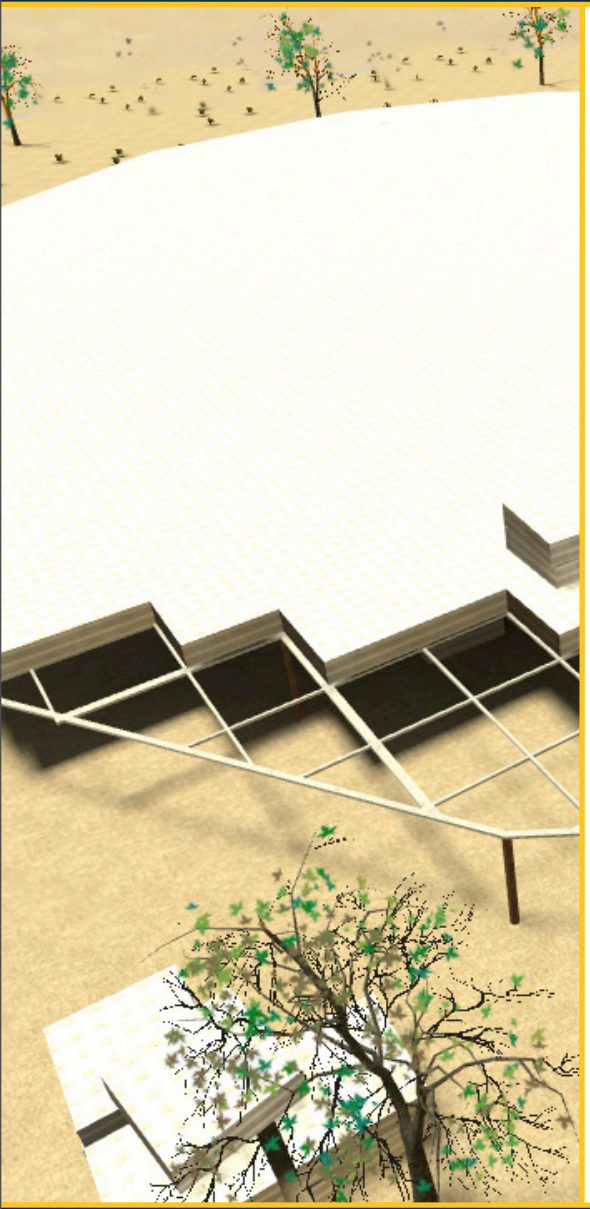

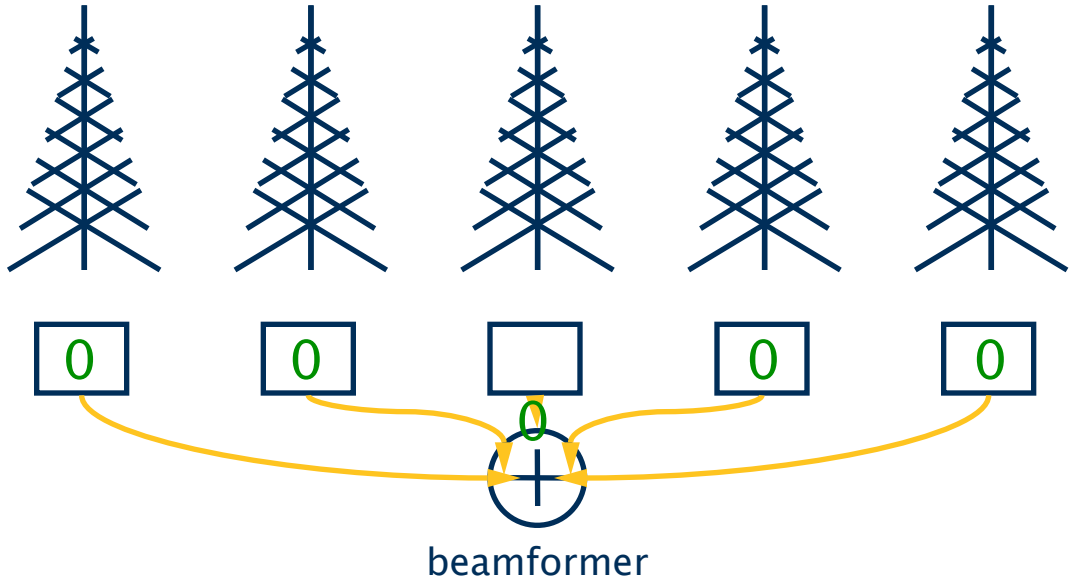

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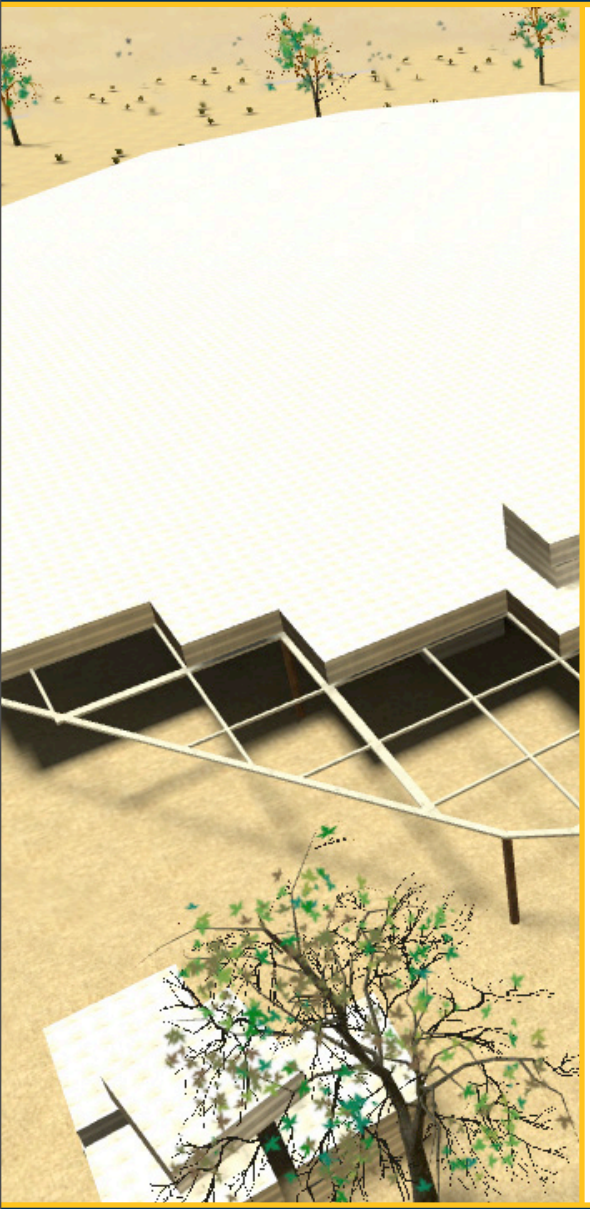

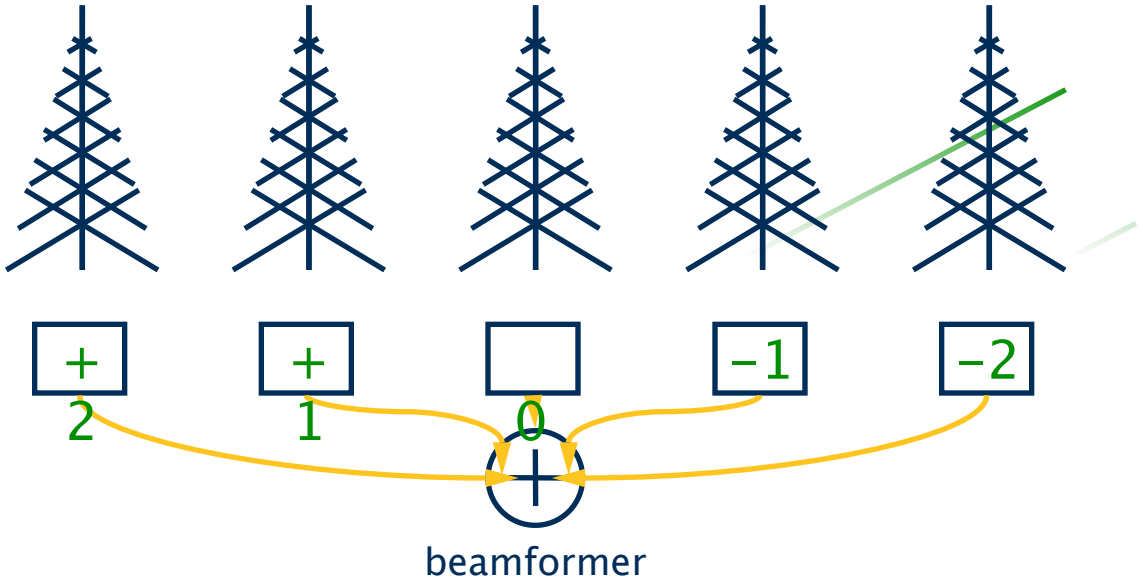

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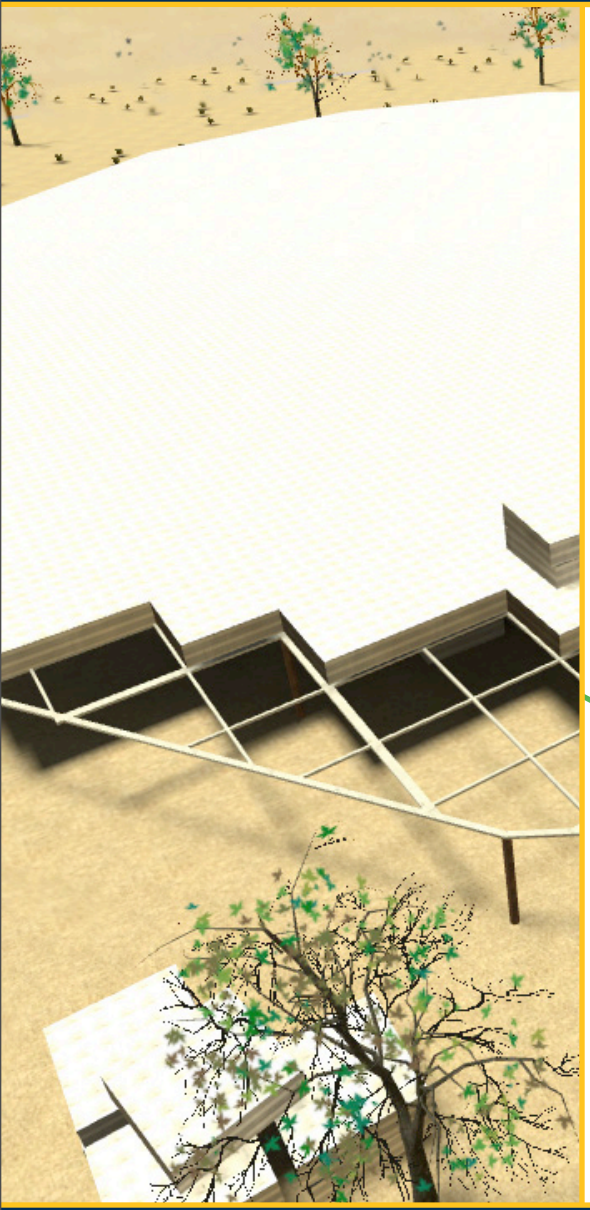
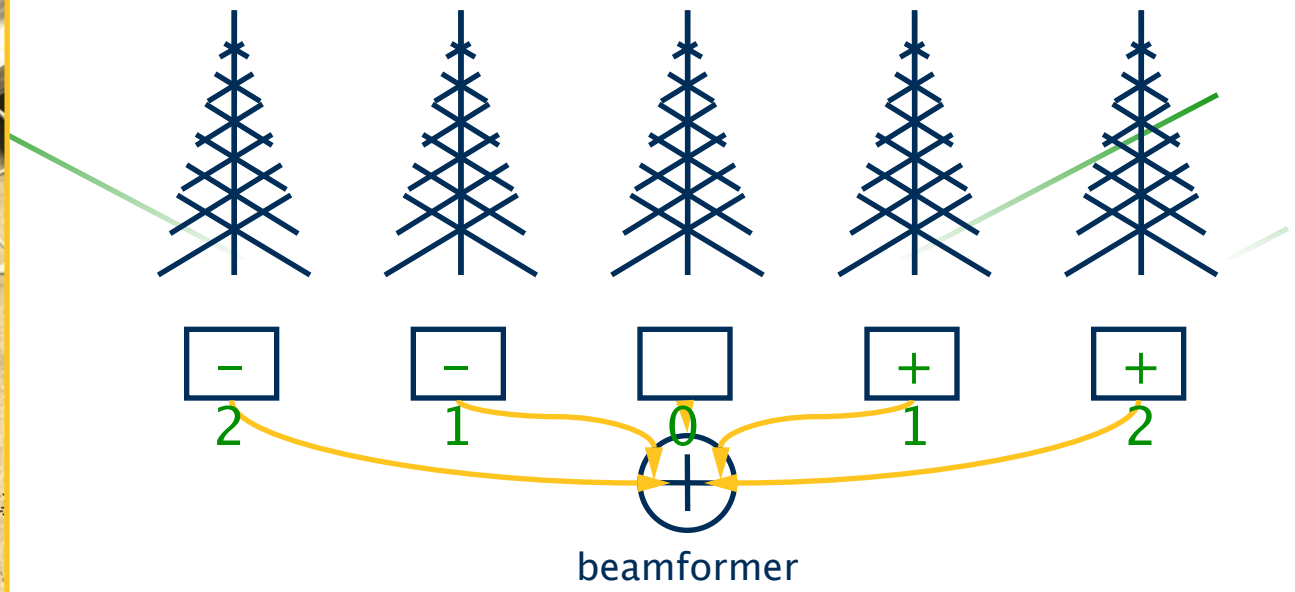
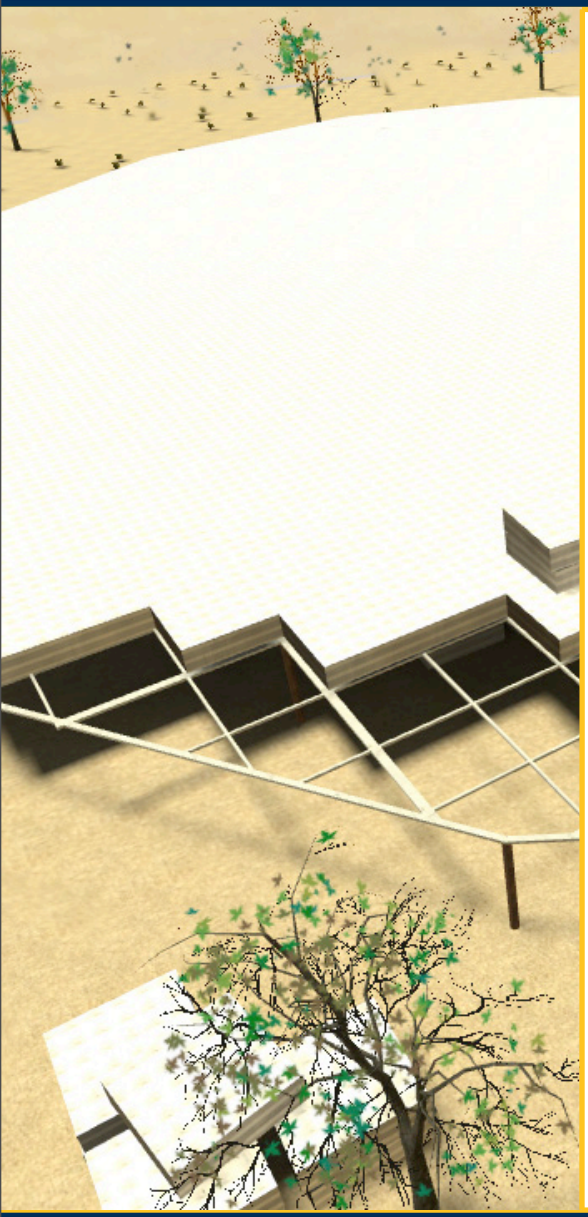
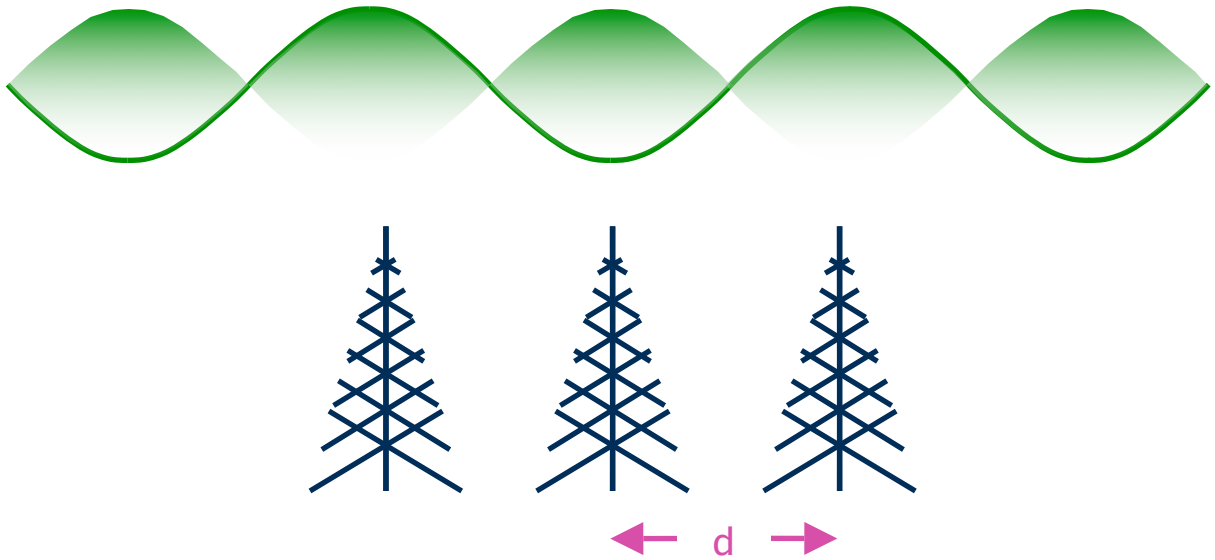




Sparse Aperture Arrays



- Dense: $d \leq \lambda/\sqrt{2}$, Sparse: $d > \lambda/\sqrt{2}$



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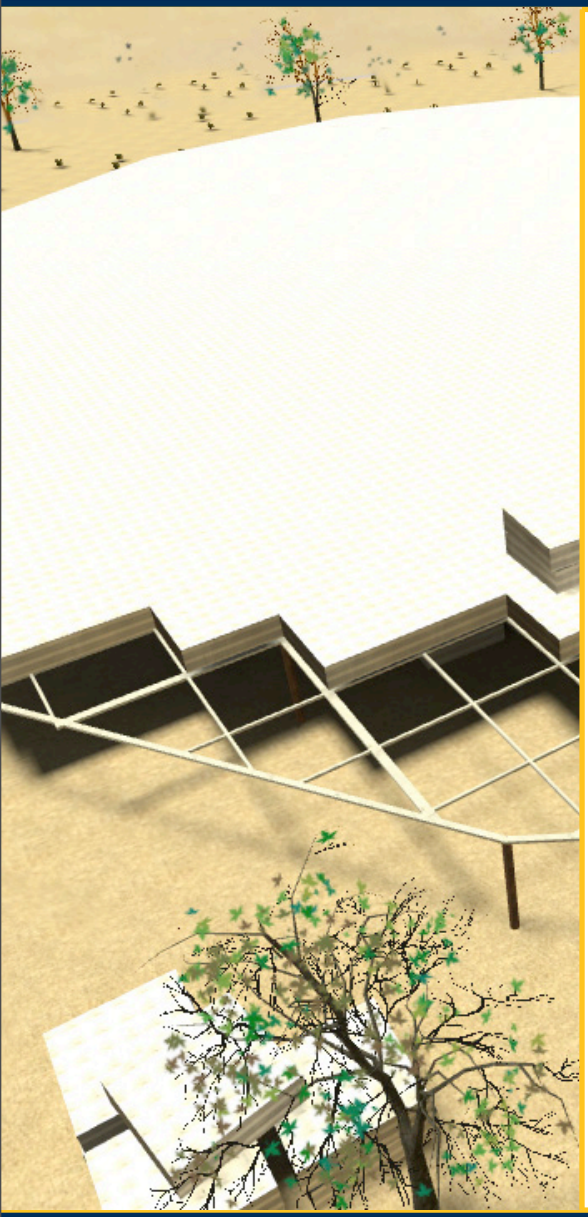

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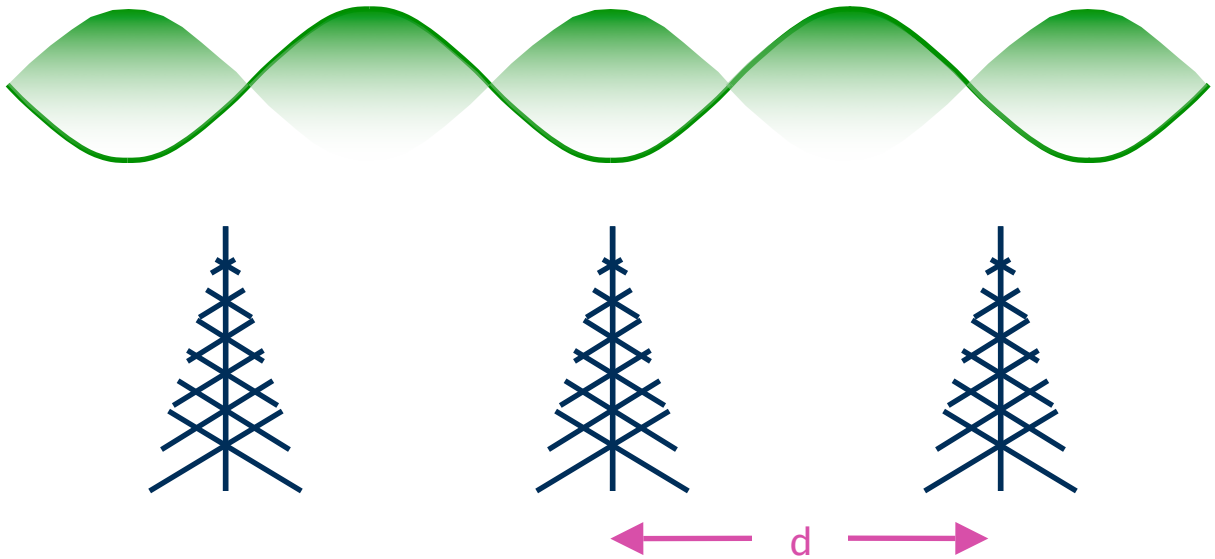
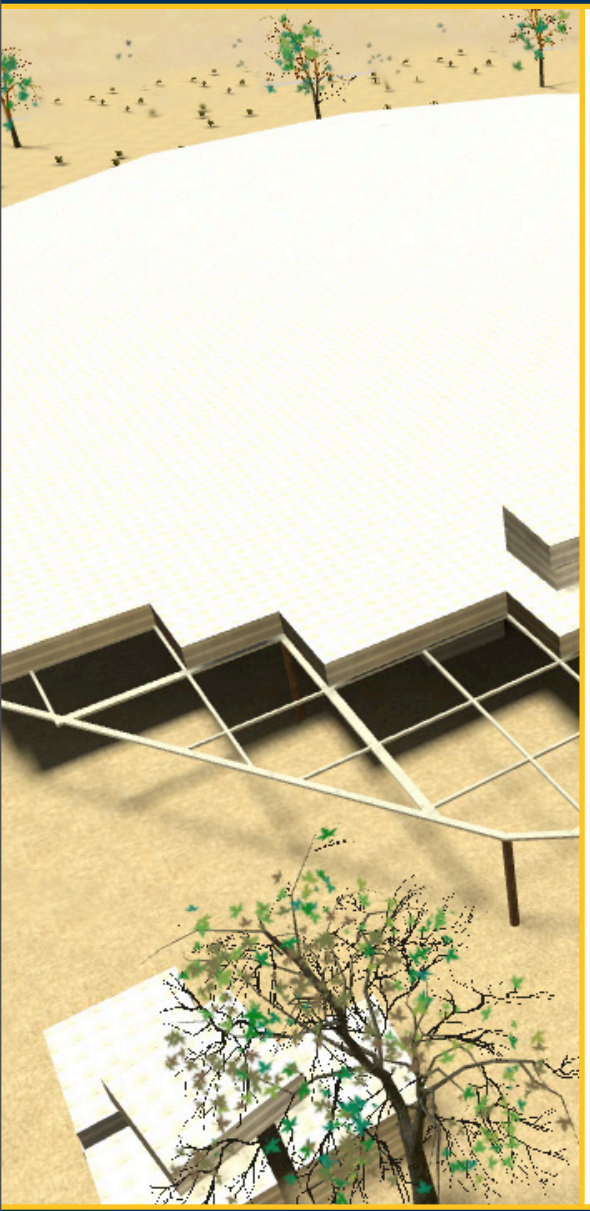
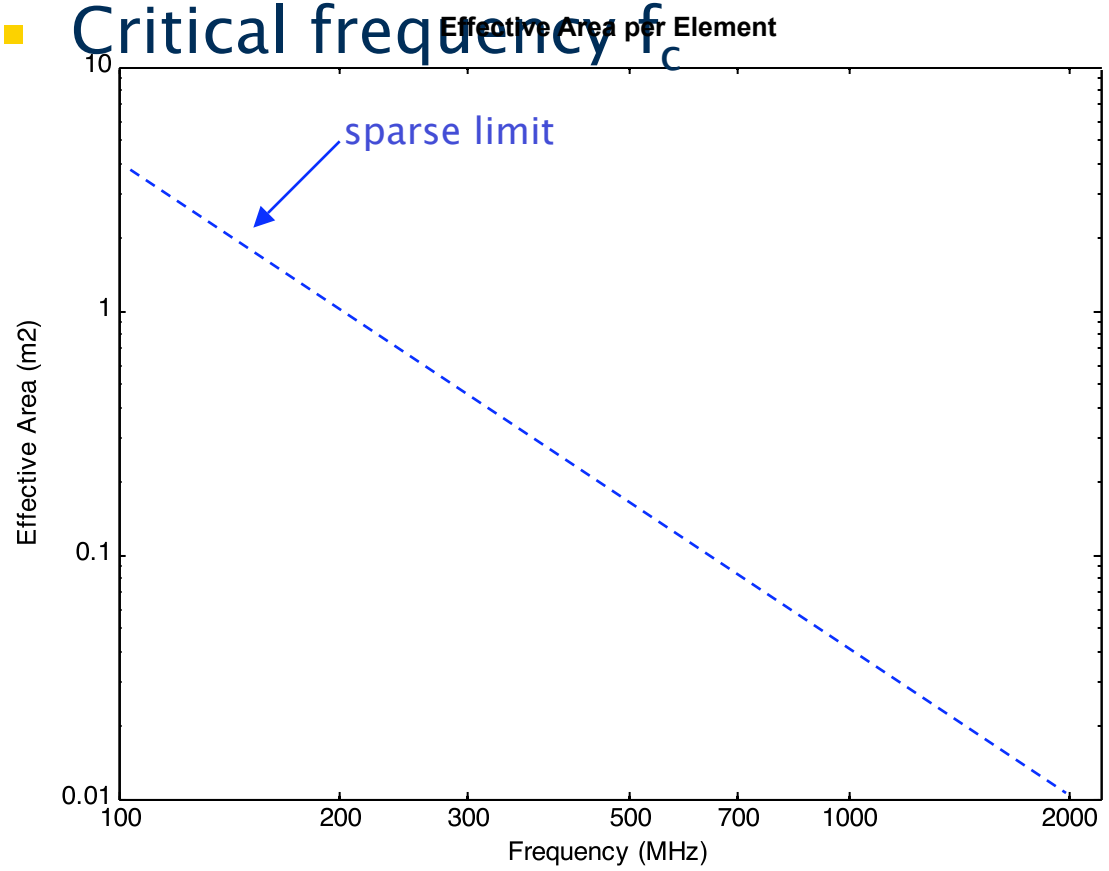


Effective Area



- Dense: $A_{eff} = \lambda_c^2/2$, Sparse: $A_{eff} = \lambda^2/2$
- Critical frequency f_c



[SKA Memo 100]

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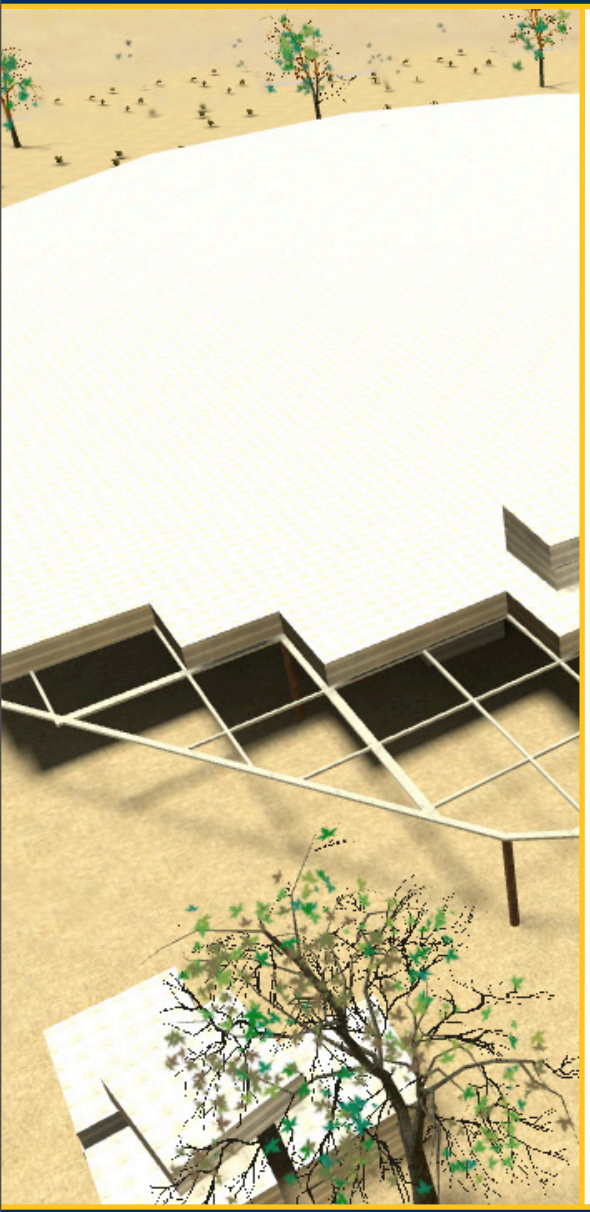

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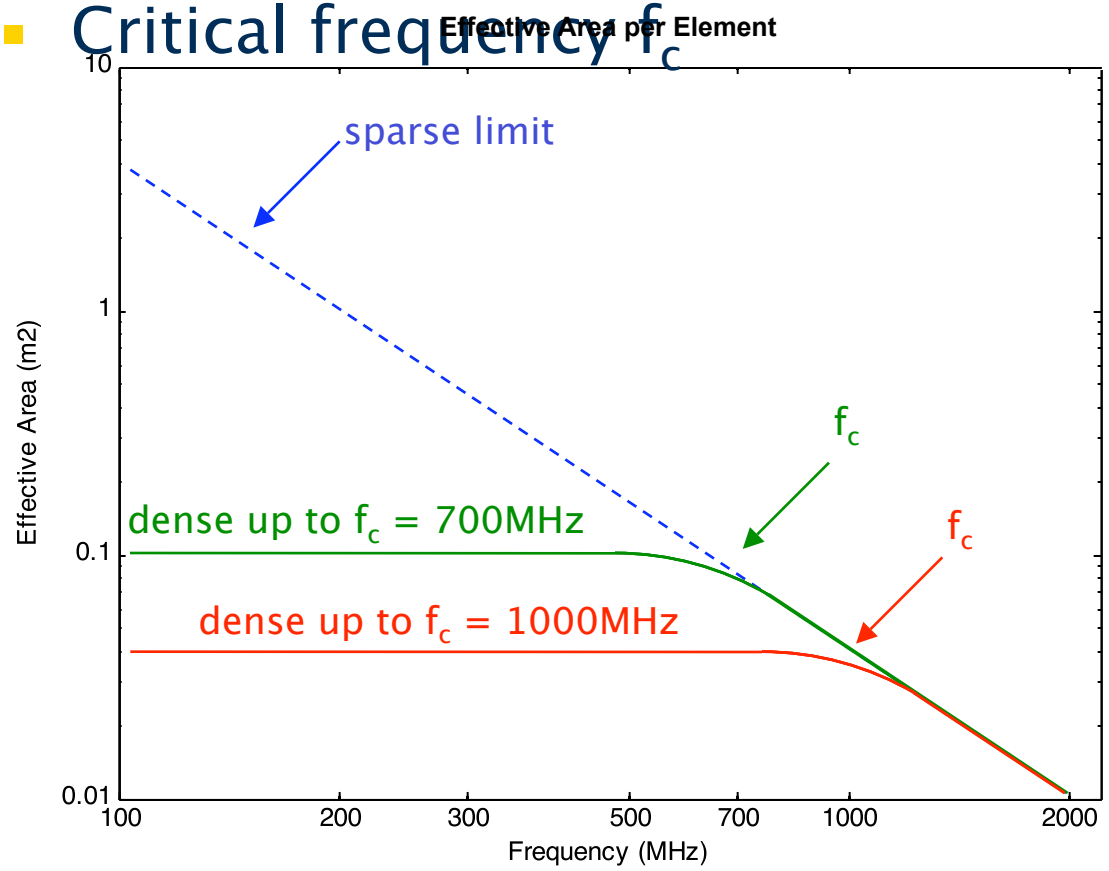

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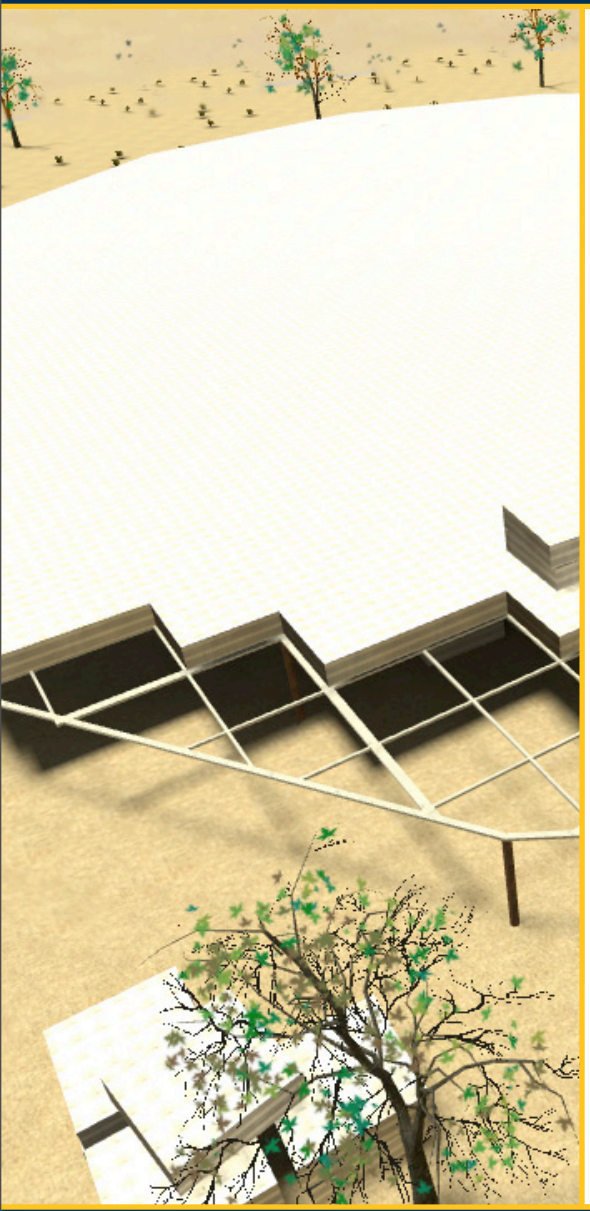

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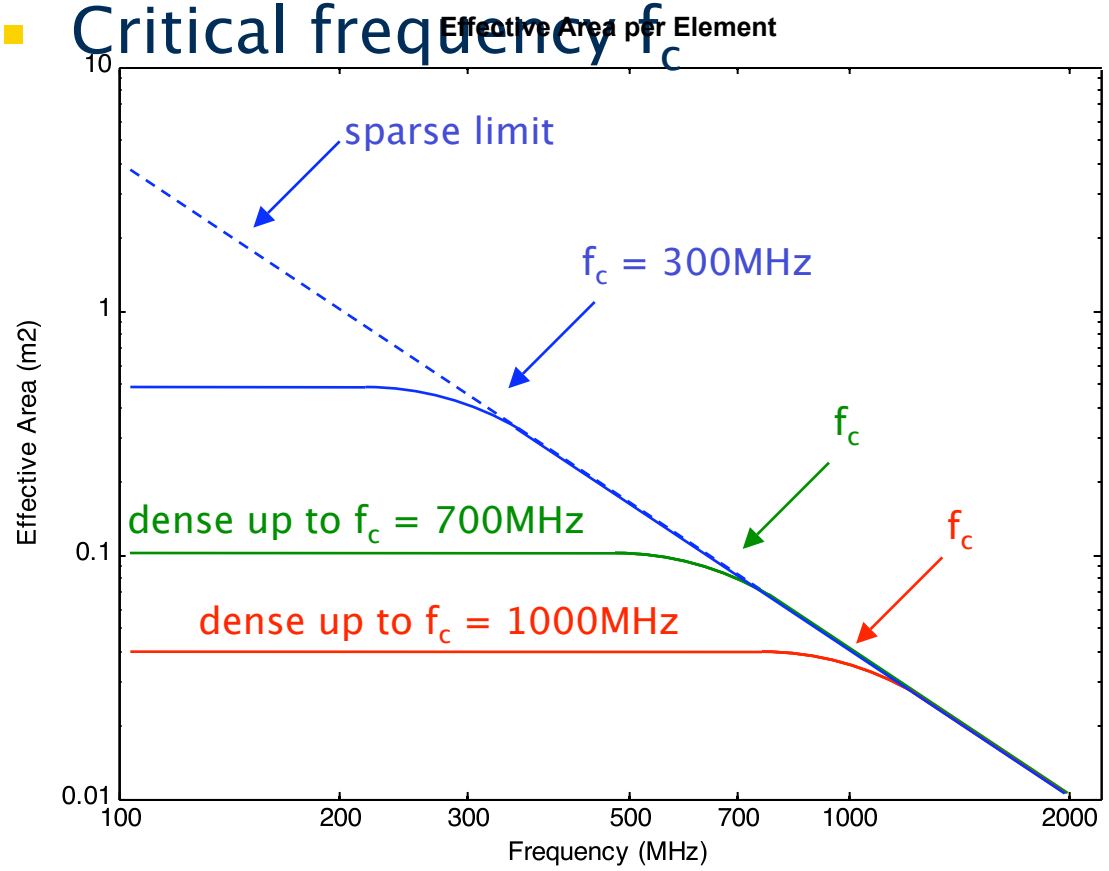
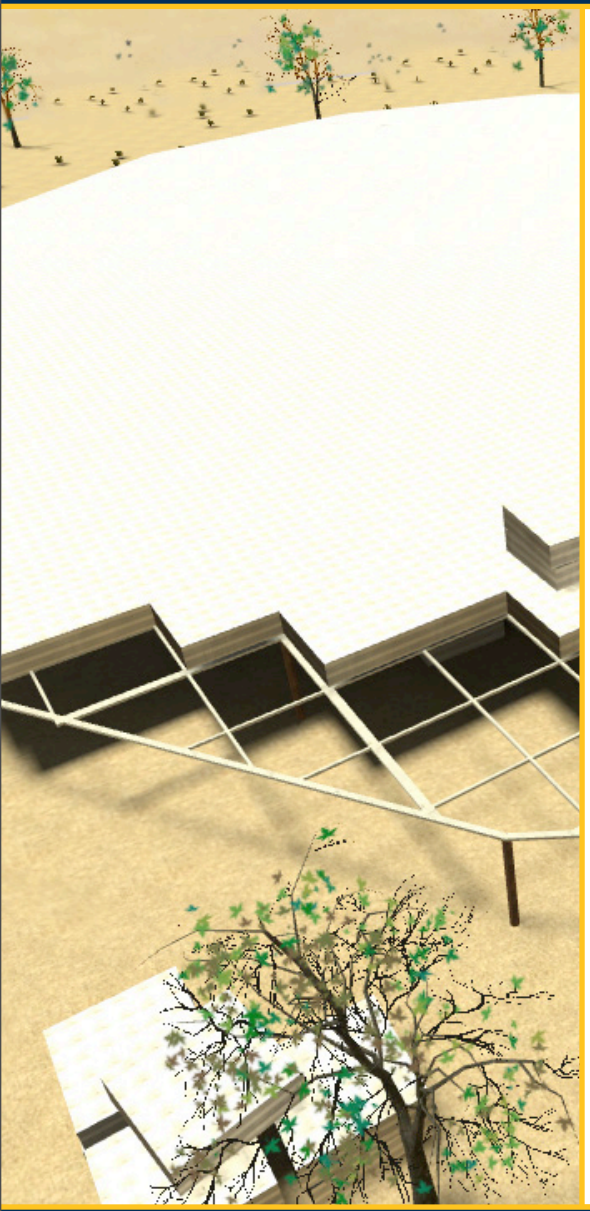


[SKA Memo 100]

High-Gain Antenna



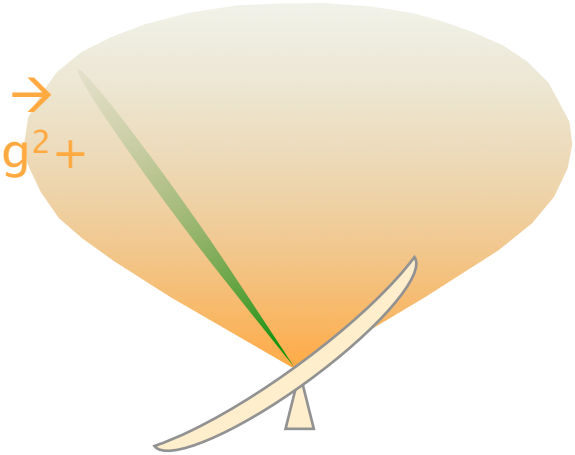
- "The total cost of aperture array is strongly correlated with number of receiver chains" [SKA Memo 100]
- If each antenna element has more forward gain, you can use less antennas while still maintaining comparable effective area, but make drastic cost savings due to the reduction in receiver chains

$$S = A_{eff} / T_{sys}$$

$$SS_{FoM} = (A_{eff} / T_{sys})^2 \cdot FoV$$

Instantaneous Field of

- 60m Dish + Phased Array Feed
  - 120deg+ → 10,000deg^2+
  - 18deg → 250deg^2



- Fully Digital Dense A. Array
  - 120deg → 10,000deg^2
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- Hybrid Dense A. Array
  - 120deg → 10,000deg^2
  - 28deg → 625deg^2
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- Sparse High Gain A. Array
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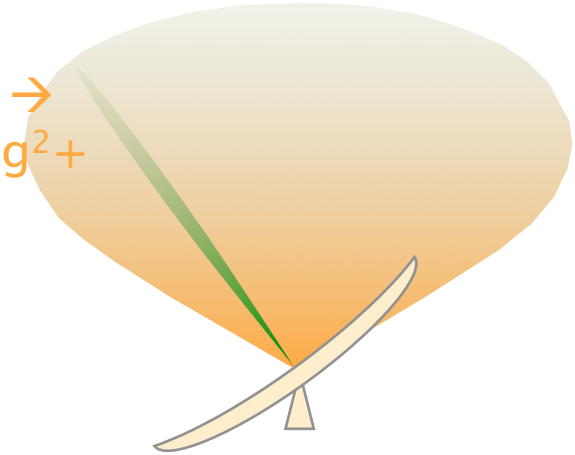

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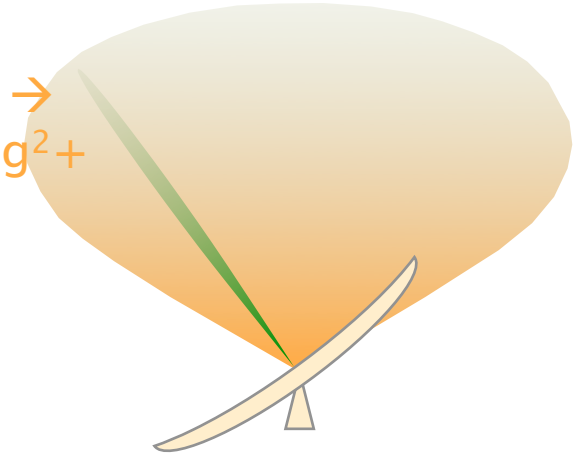

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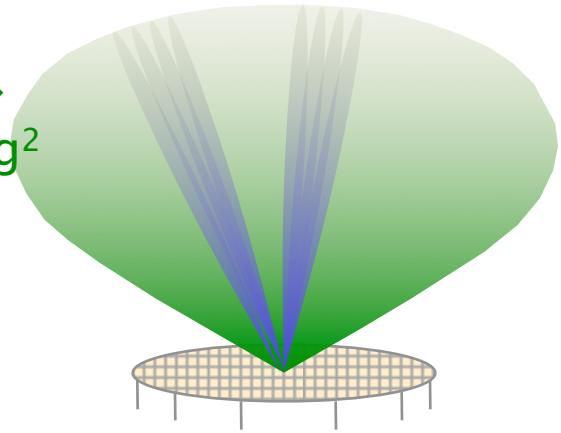

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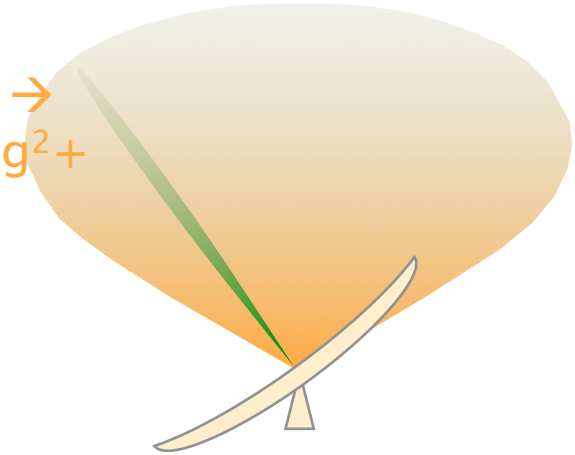

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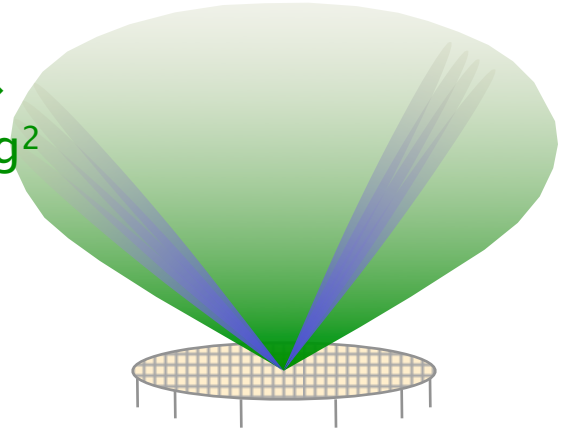

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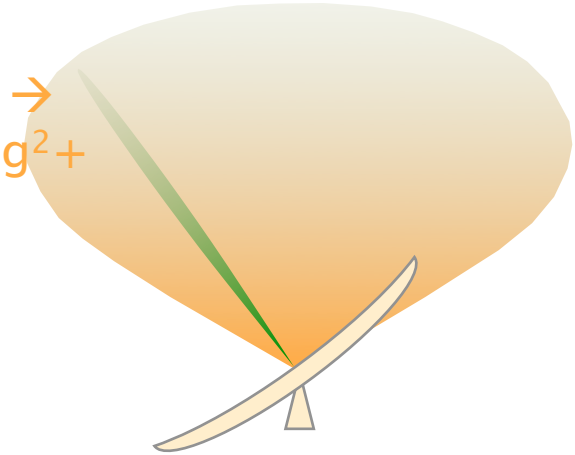

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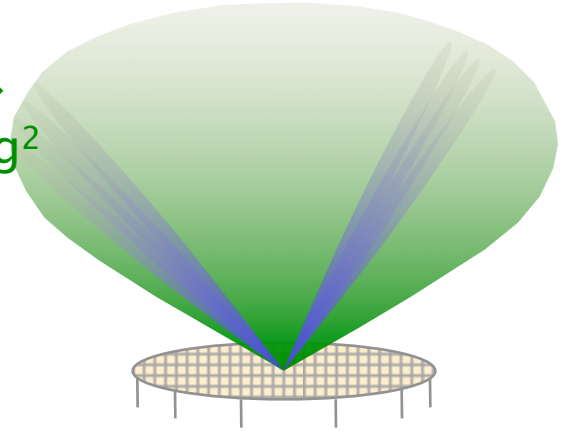

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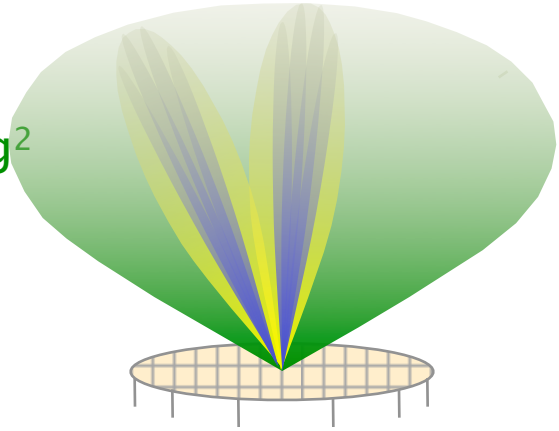

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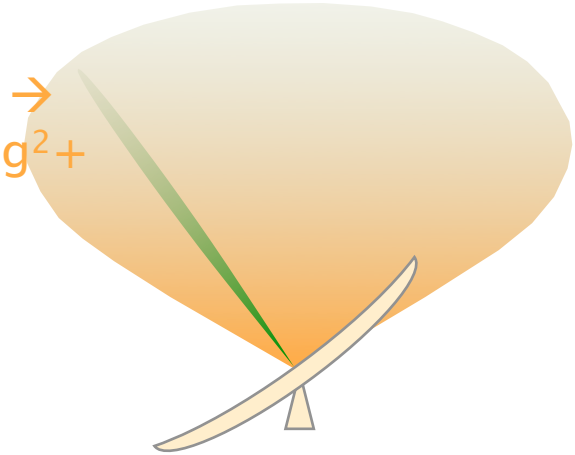

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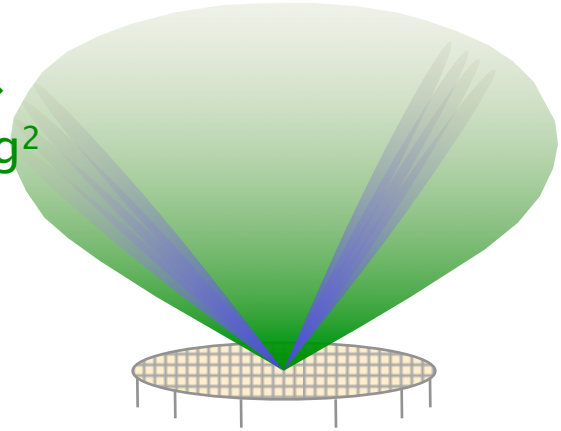

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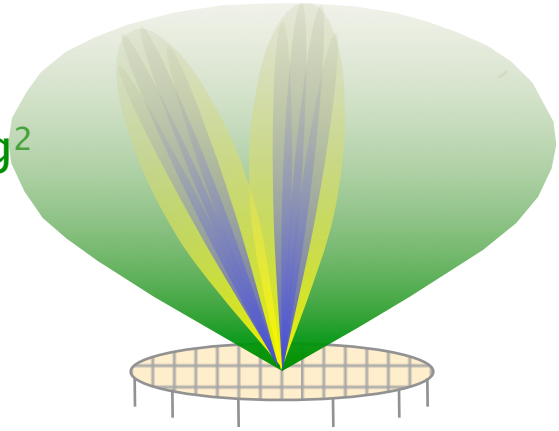

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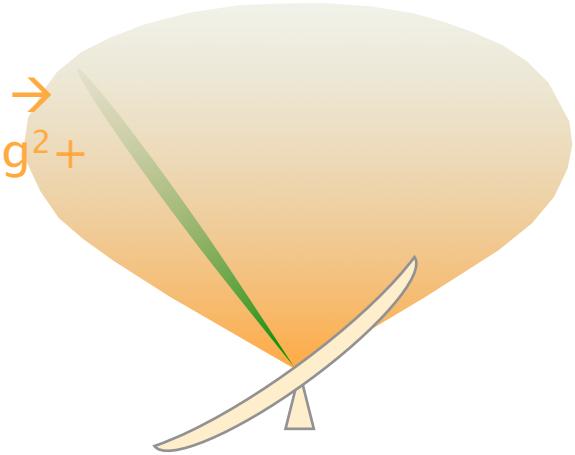

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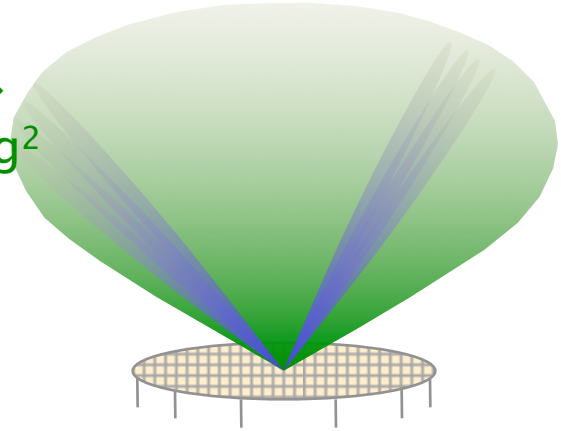

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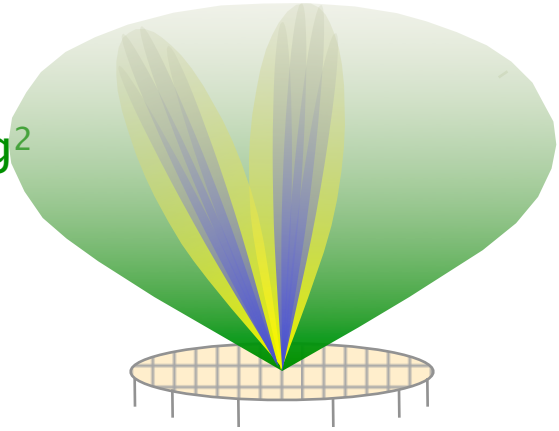

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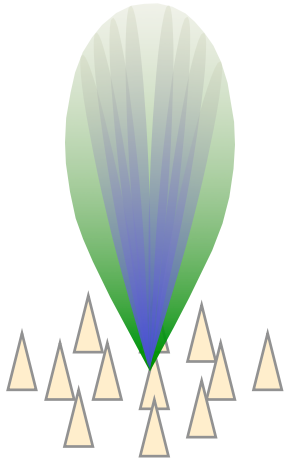
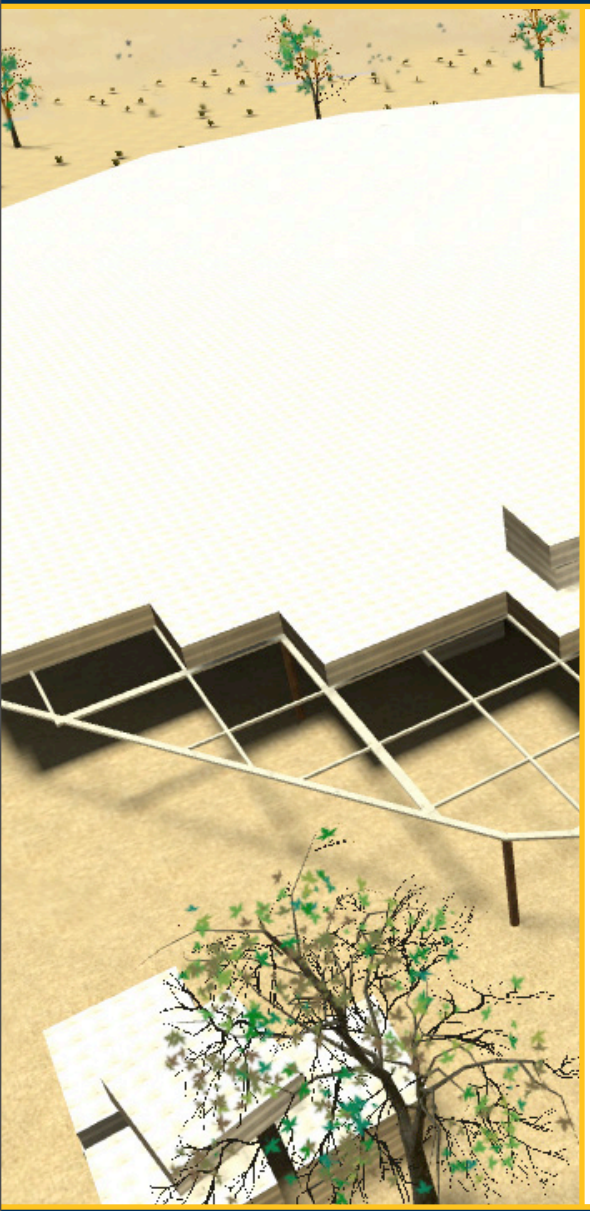
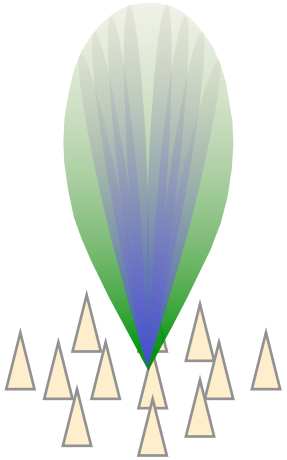


Overall Sky Coverage



- Earth rotation gives full coverage in RA
- Trick: 3-way 36° switching mechanism to get a 108° of declination
  - Karoo SKA site (SA) 30.5°S
  - Murchison SKA site (WA) 26.5°S



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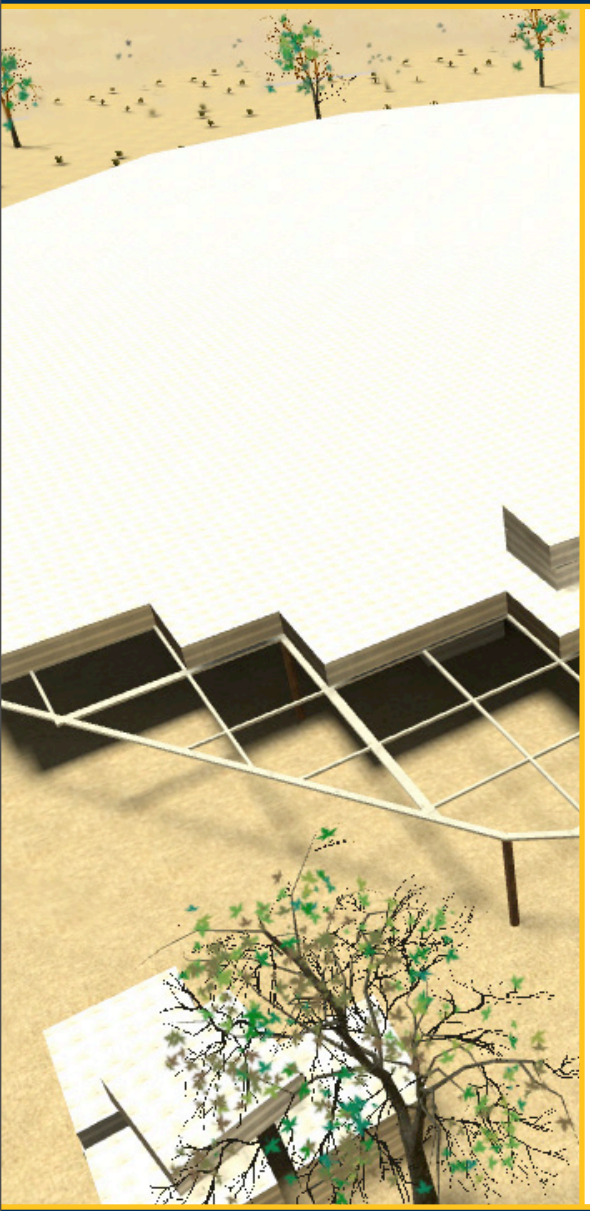

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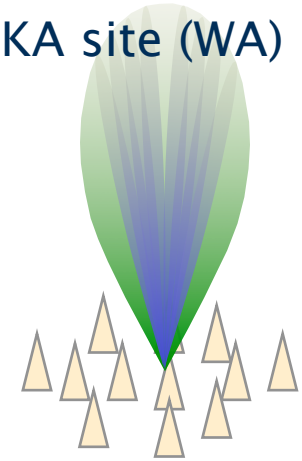

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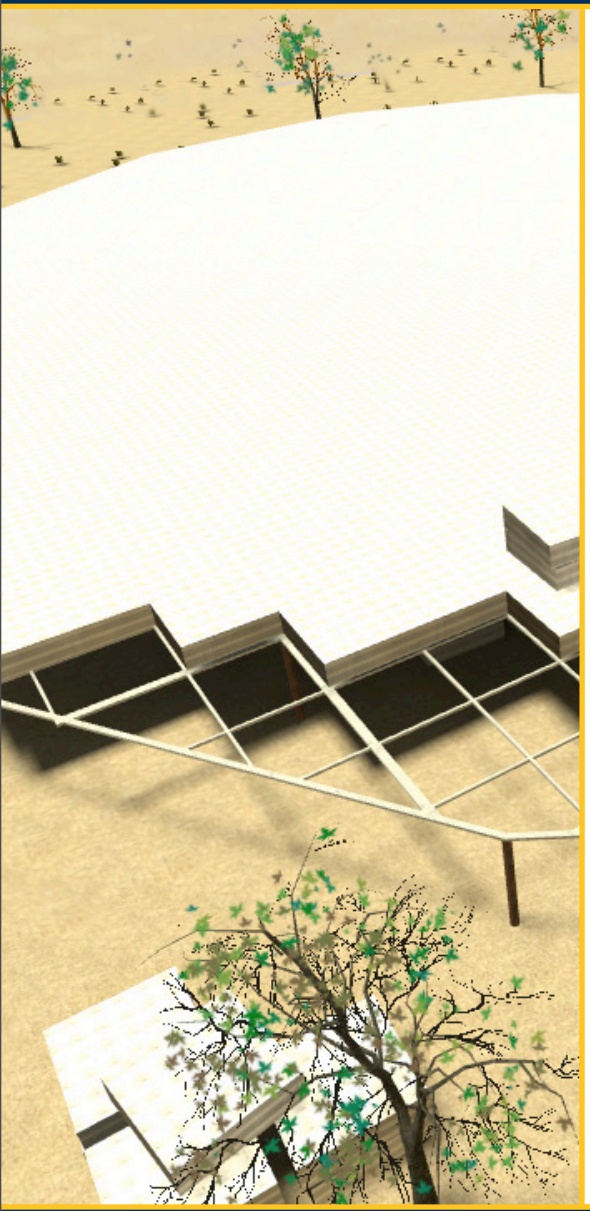

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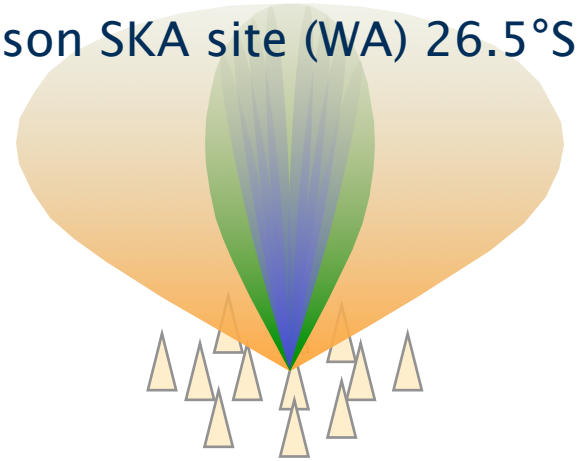
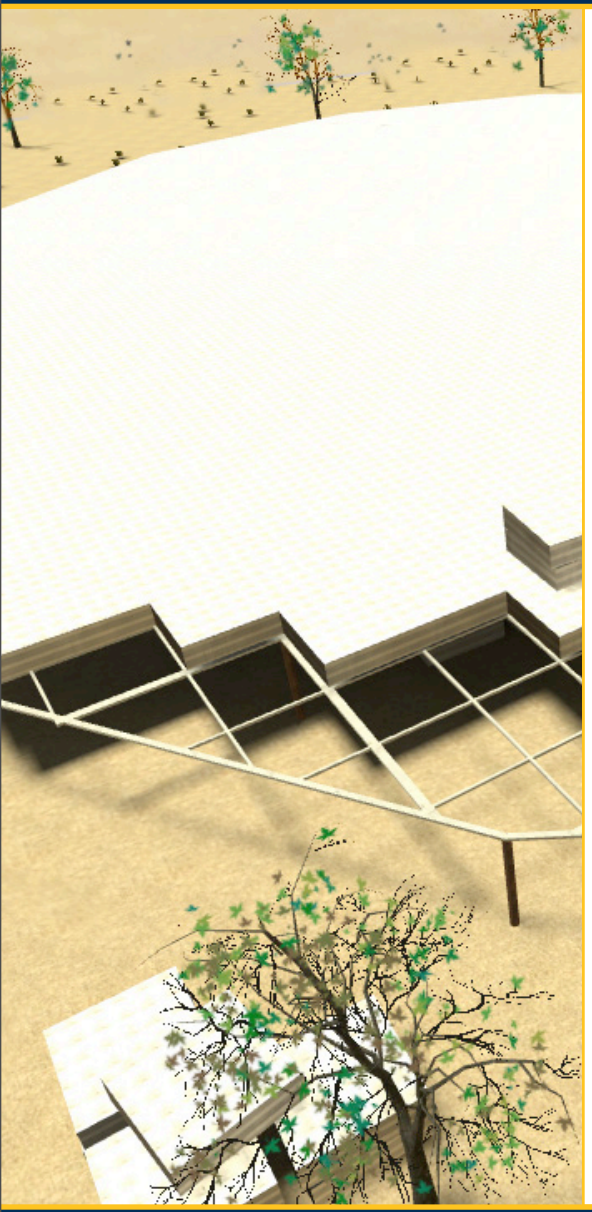


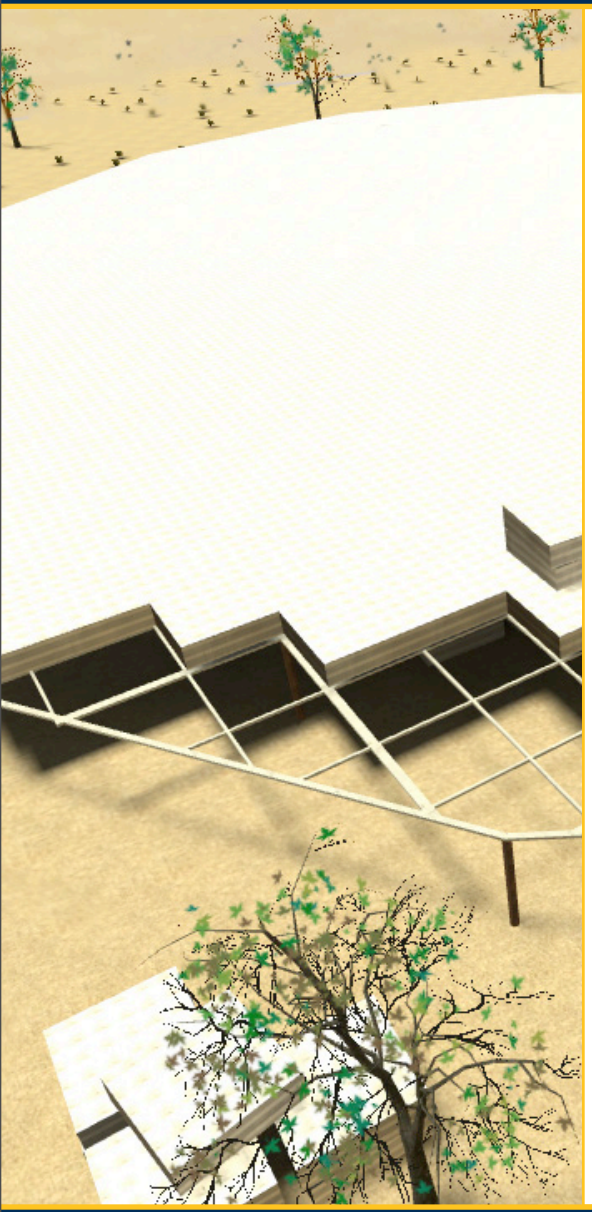
Instantaneous Sky



- Which key science projects require pointing in opposite parts of the sky?

- 1 – The Dark Ages
- 2 – G. Evolution, Cosmology & Dark Energy
- 3 – Cosmic Magnetism
- 5 – Cradle of Life
- 6 – Exploration of the Unknown

Instantaneous Sky



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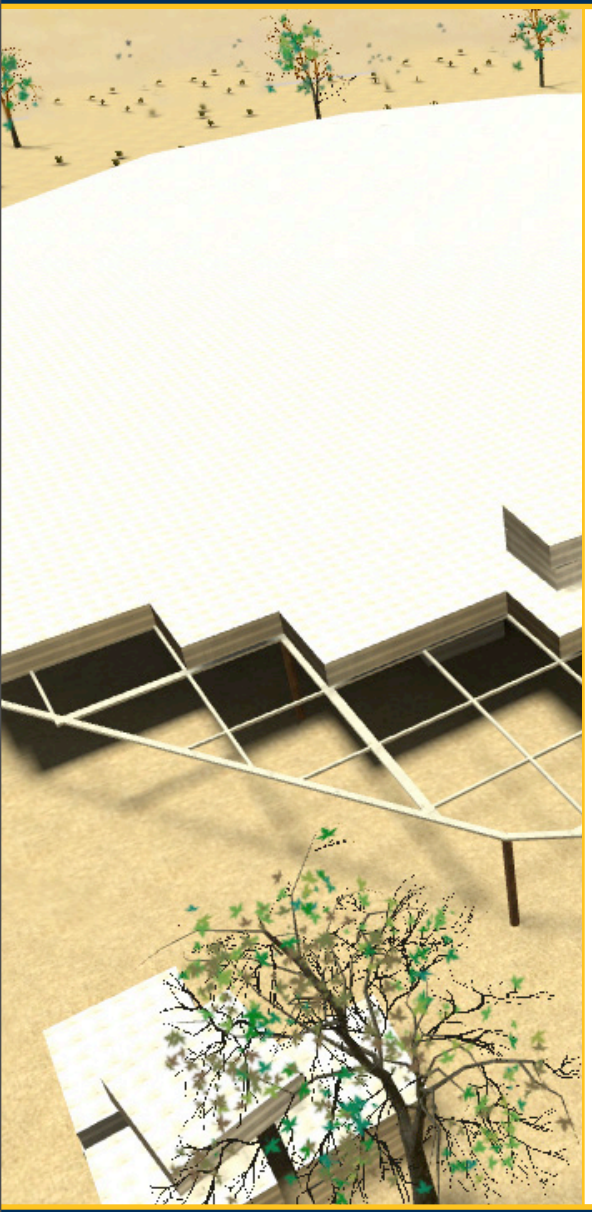

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- 1 – The Dark Ages ✗
- 2 – G. Evolution, Cosmology & Dark Energy ✗
- 3 – Cosmic Magnetism ✗
- 4 – GR using Pulsars & Black Holes
  - Search
  - 4a – Gravitational Waves
  - 4b – BH Spin
- 5 – Cradle of Life
- 6 – Exploration of the Unknown

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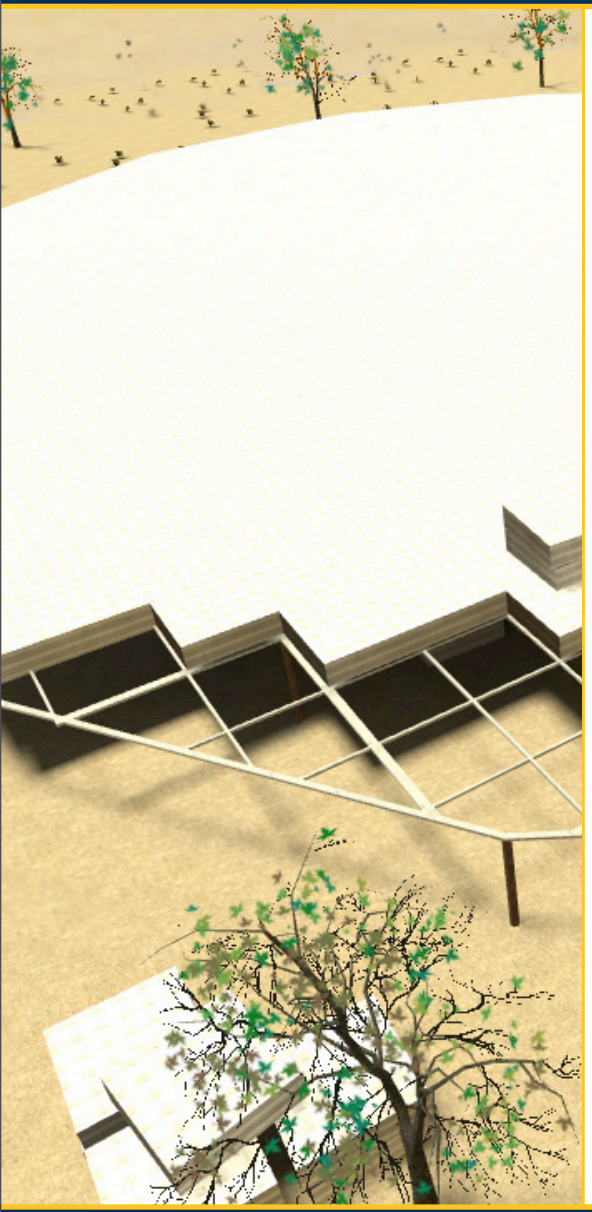

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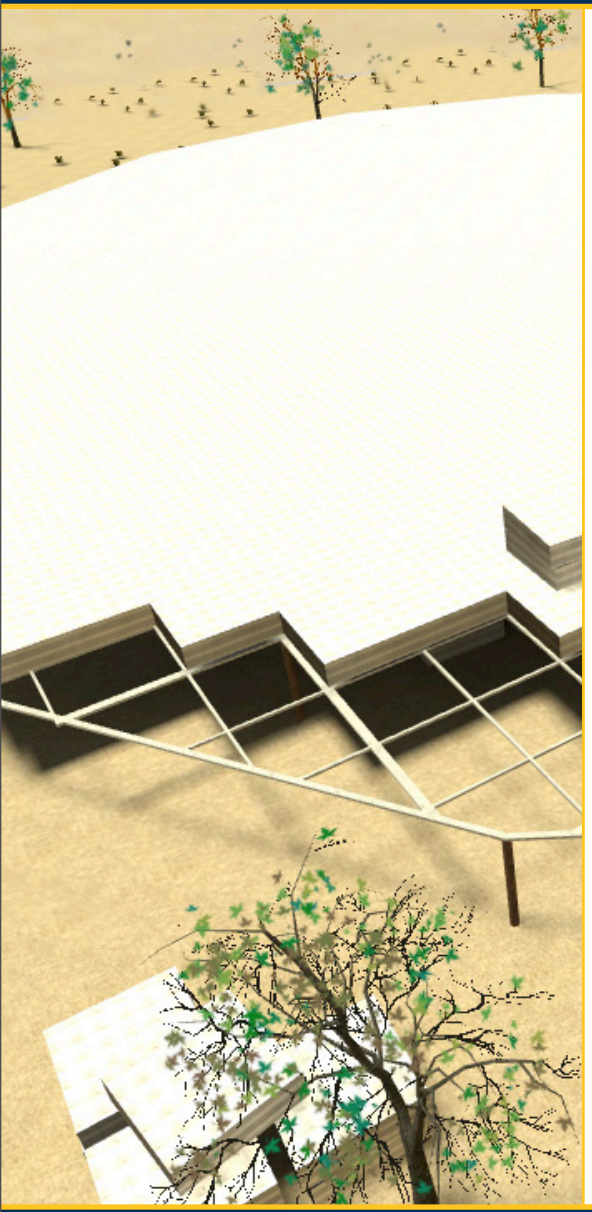
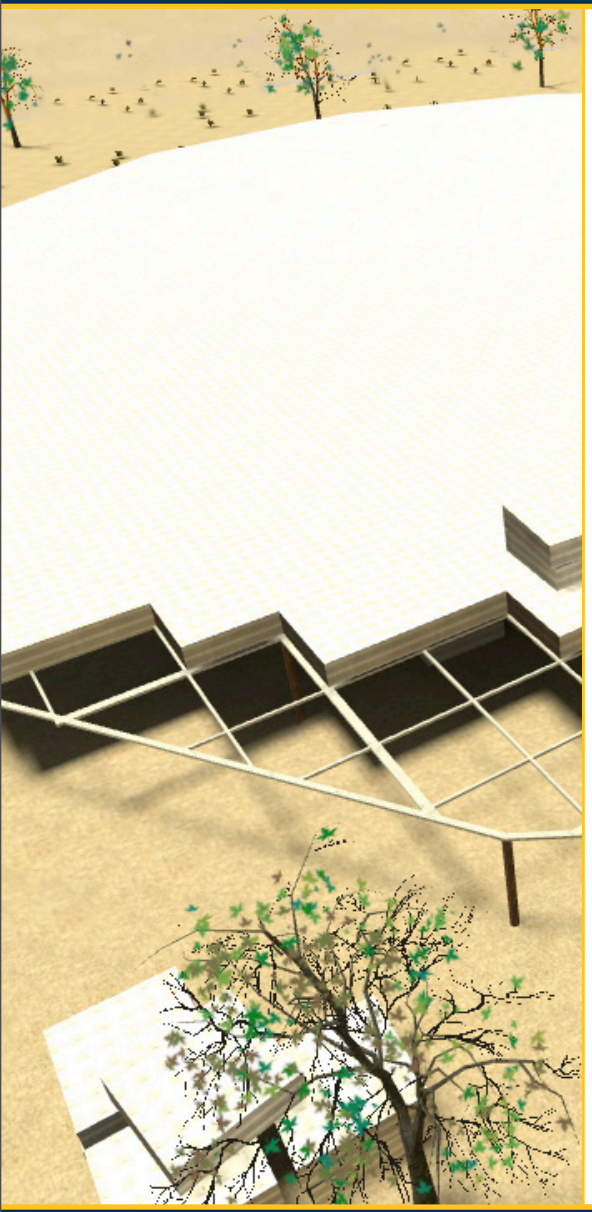


- Which key science projects require pointing in opposite parts of the sky?

- 1 – The Dark Ages ✗
- 2 – G. Evolution, Cosmology & Dark Energy ✗
- 3 – Cosmic Magnetism ✗ ✓
- 5 – Cradle of Life
  - 5a – Proto-planetary Disks
  - 5b – Prebiotic Molecules
  - 5c – SETI
- 6 – Exploration of the Unknown

Instantaneous Sky



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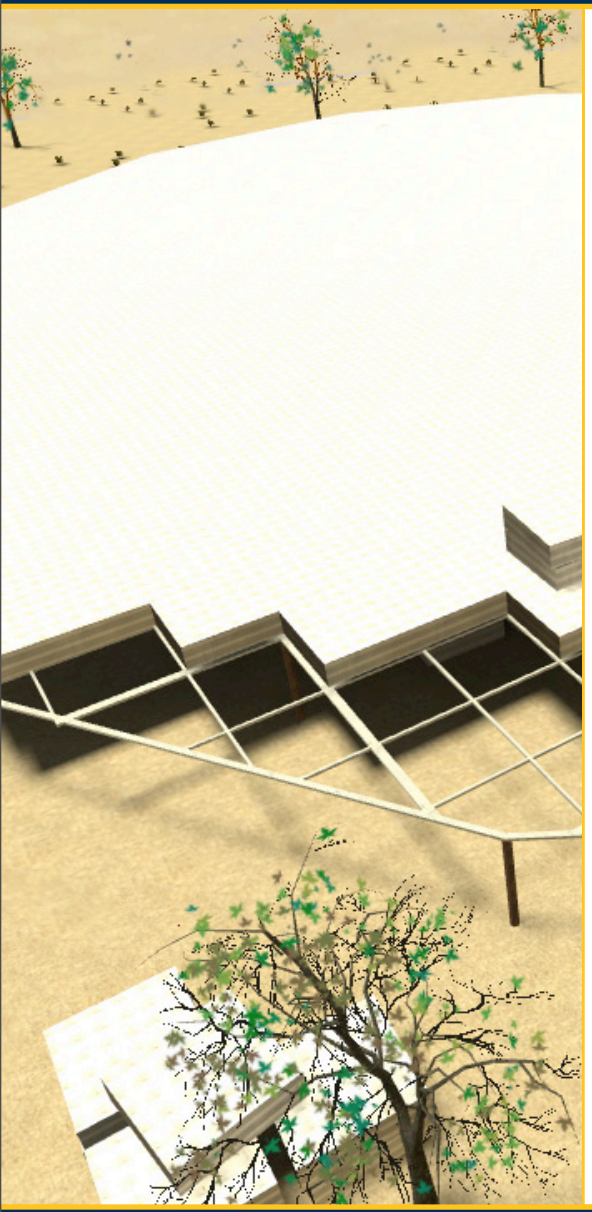
Instantaneous Sky



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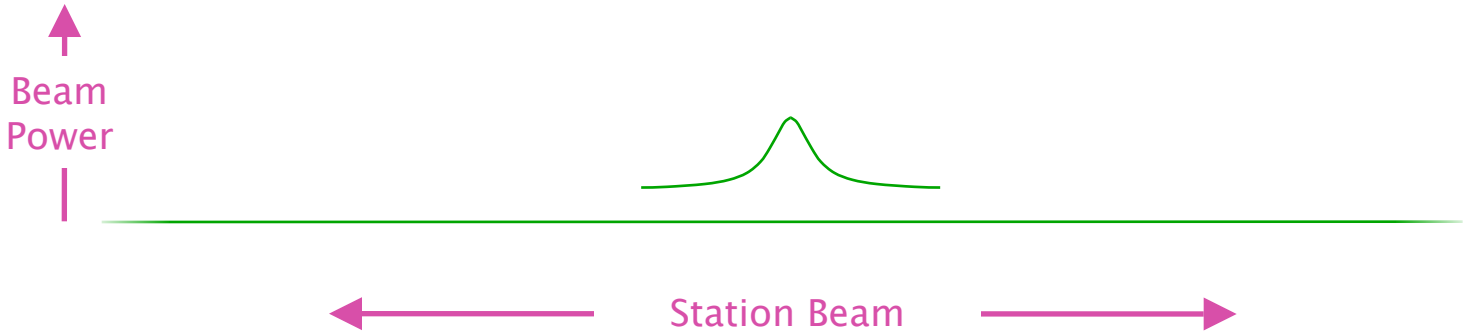
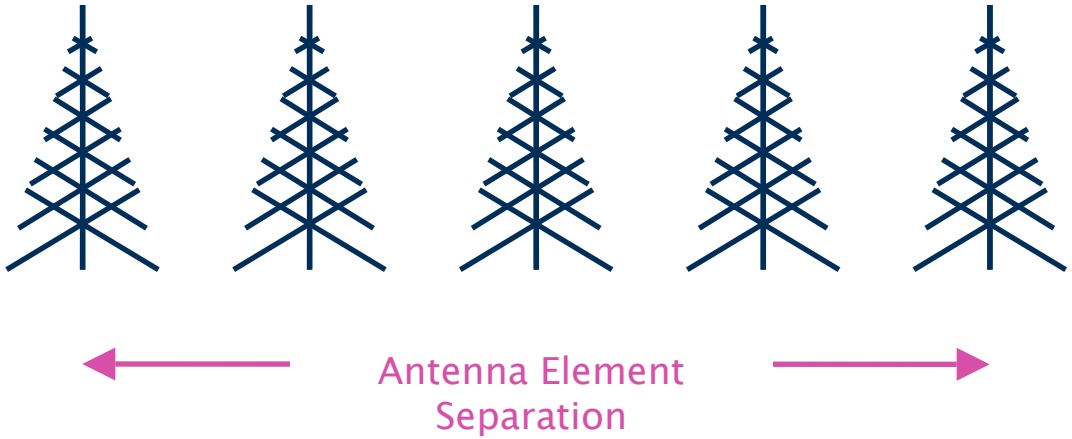
Dynamic Range

- Station beam pattern



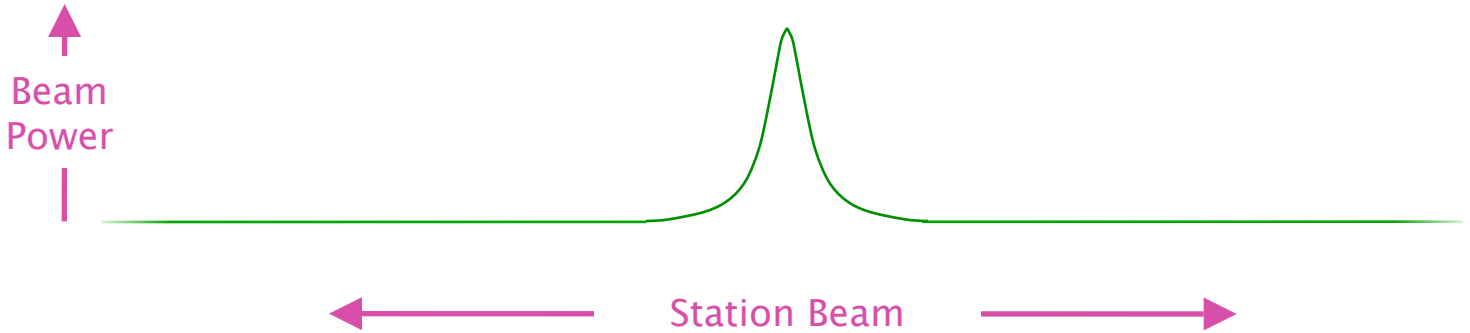
- Antenna separation: dense (f < 1)



[SKA Memo 87]

Dynamic Range

- Station beam pattern

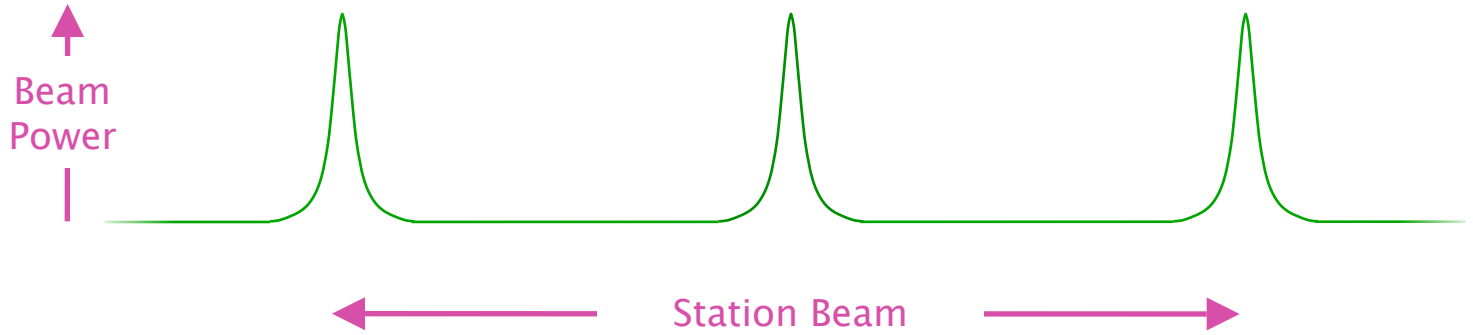


- Antenna separation: nominal (f = 1)

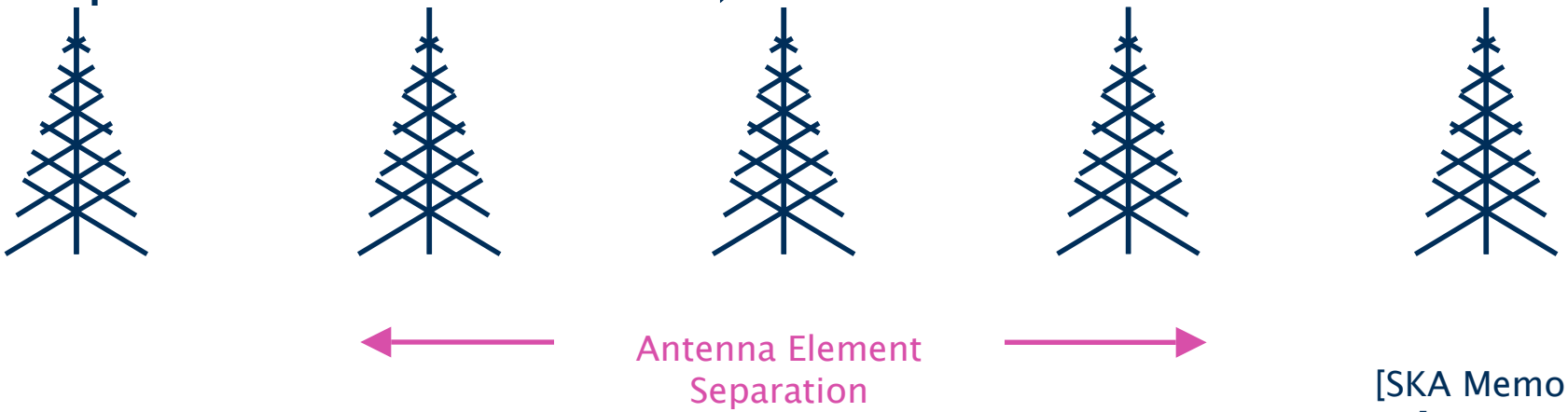
[SKA Memo 87]

Dynamic Range

- Station beam pattern



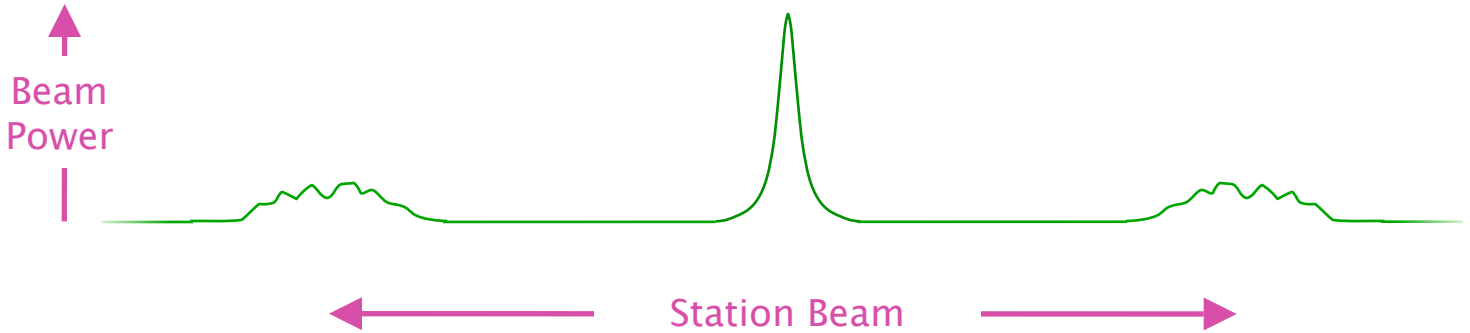
- Antenna separation: sparse (f > 1)



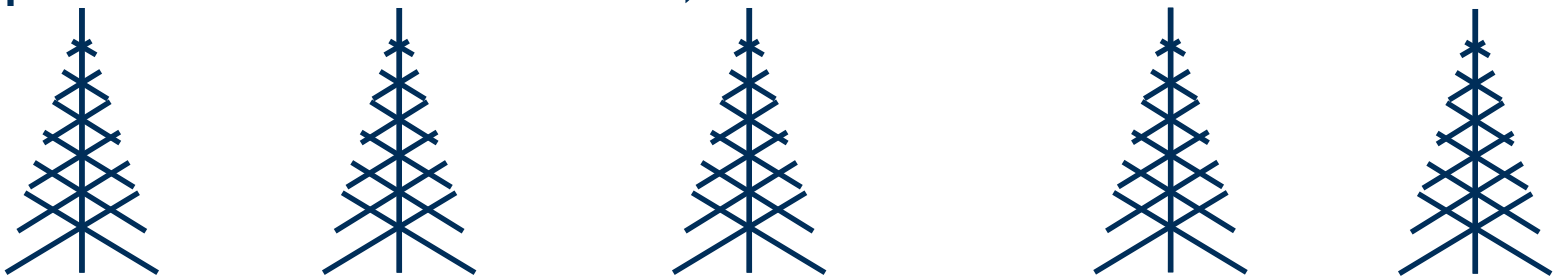
[SKA Memo 87]

Dynamic Range

- Station beam pattern



- Antenna separation: random (f > 1)



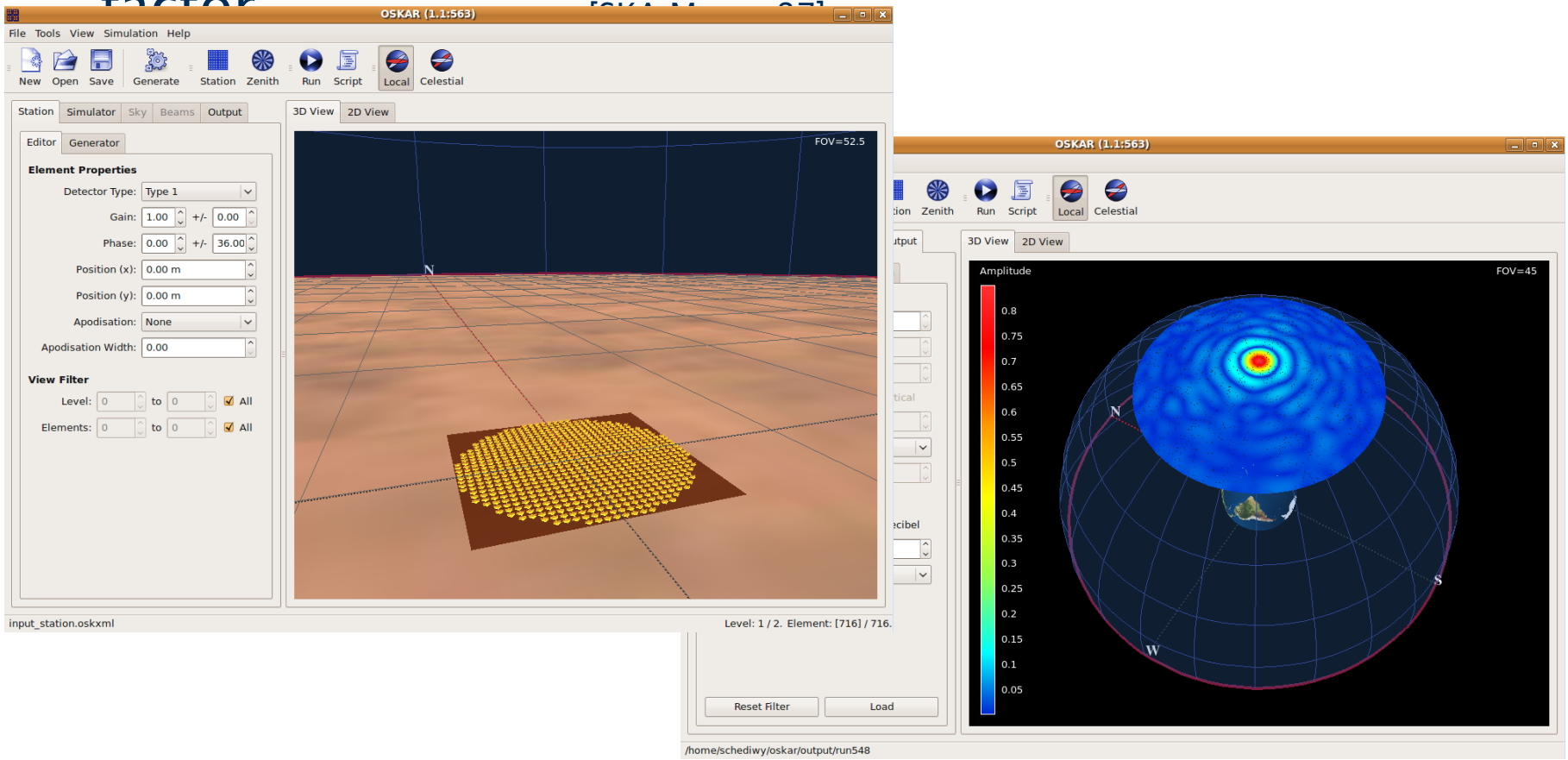
[SKA Memo 87]

Computational

- For a constant processed FoV, the digital processing complexity increases as the square of the sparseness factor [SKA Memo 87]

Computational

- For a constant processed FoV, the digital processing complexity increases as the square of the sparseness factor [SKA Memo 97]



- www.oerc.ox.ac.uk/research/

OSKAR Simulator

OSKAR Simulator

2-PAD Aperture Array

- Dual-Polarisation All Digital Aperture Array
  - Dual Polarisation plug and play antennas
  - 4x4 antenna array
  - Various interchangeable antennas
  - 300-1000MHz RF range
  - Digital backend processing
  - Multi-FPGA boards, Multi-ASIC boards
  - 200MHz processed bandwidth
  - Multiple independent beams
  - No. of Beam vs. Bandwidth trade-off

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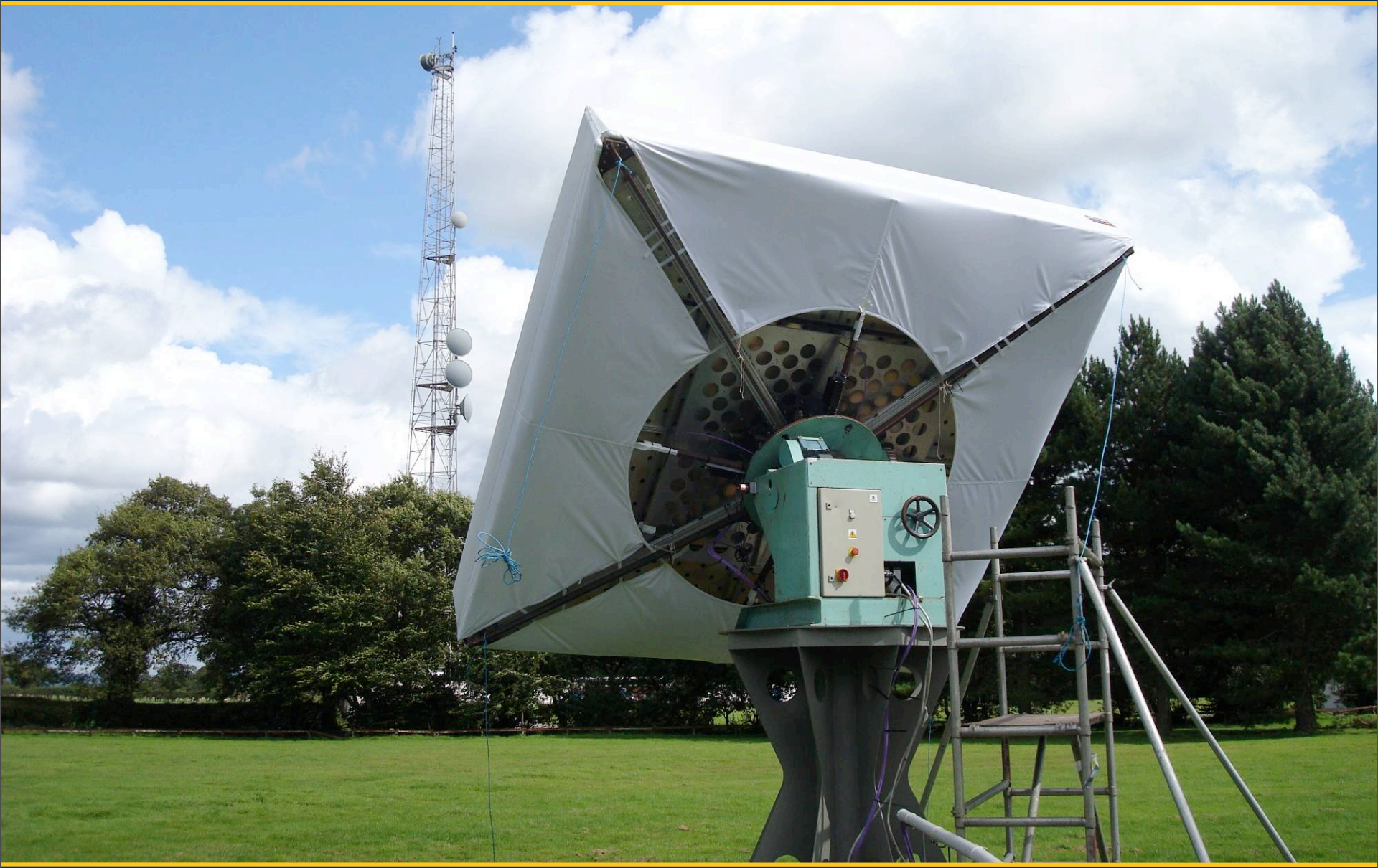
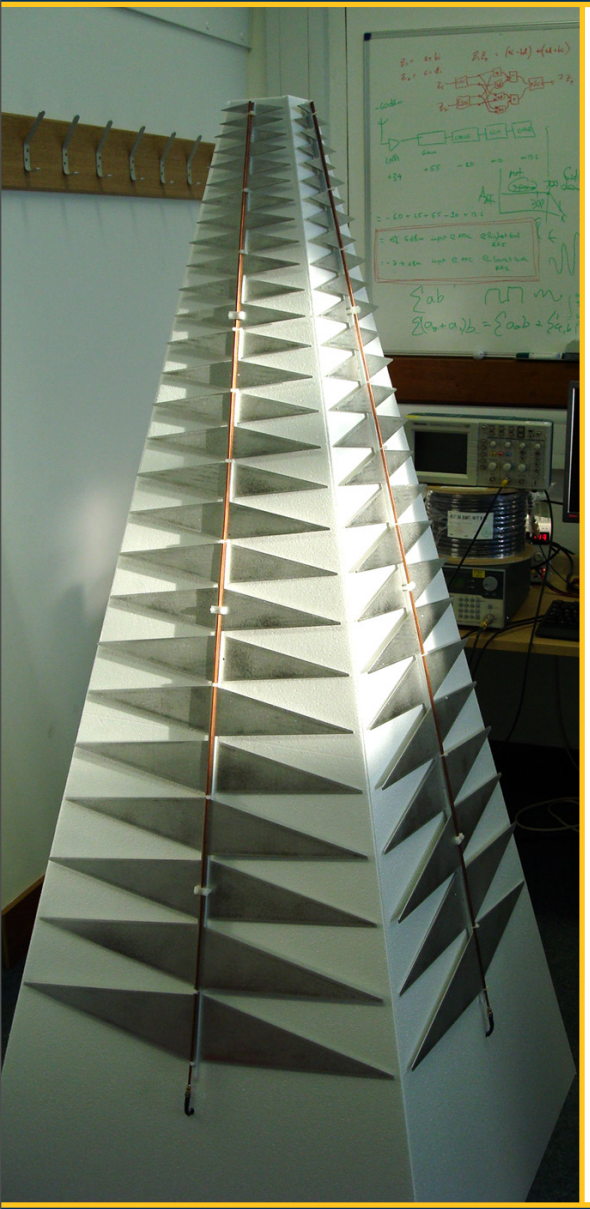
2-PAD Aperture Array

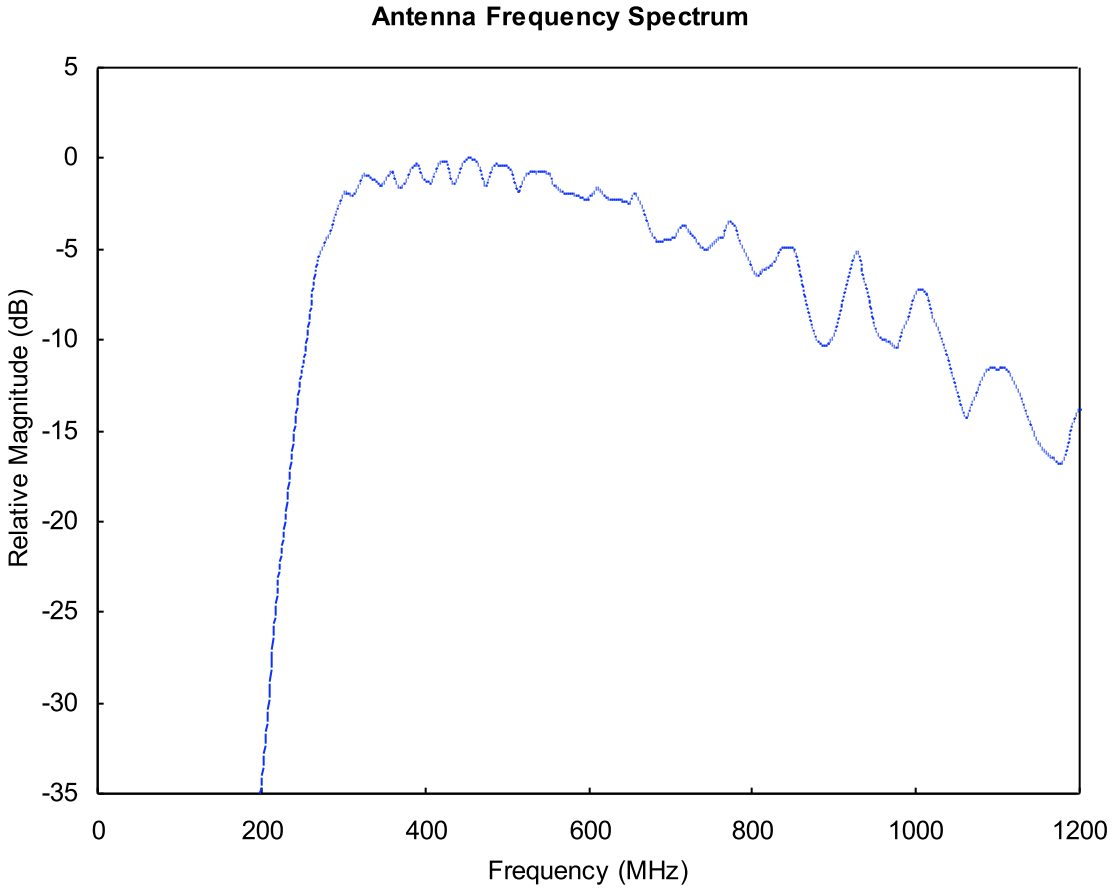
PAD



2-PAD High Gain Antenna



- Log-periodic dipole array (LPDA) antenna
- Frequency range = 300-1000+ MHz



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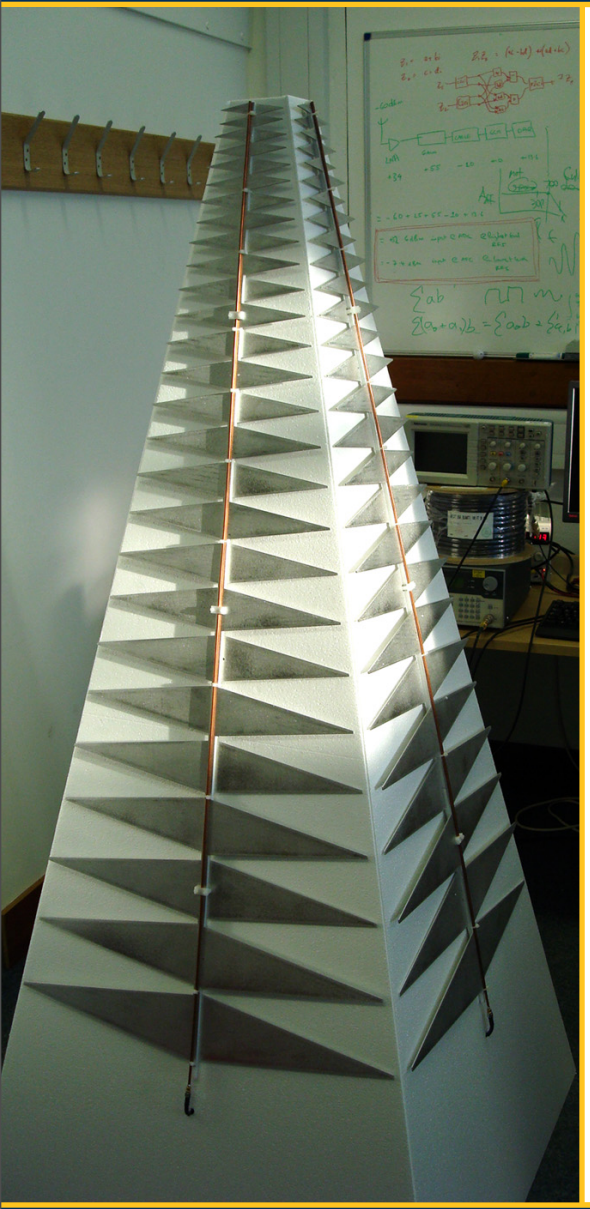
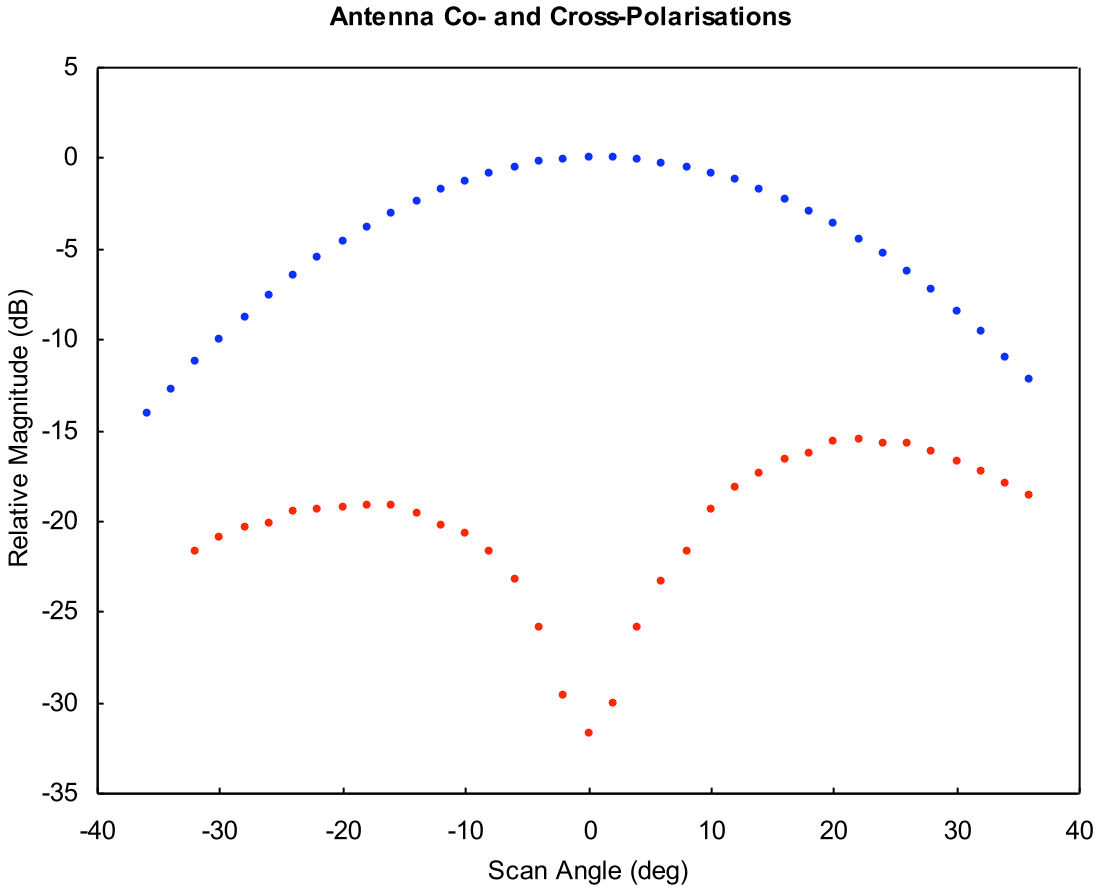


- Beam-width = 34.5° (Field of View = 928deg^2)
- Gain = 13.2dBi (20.9x isotropic)



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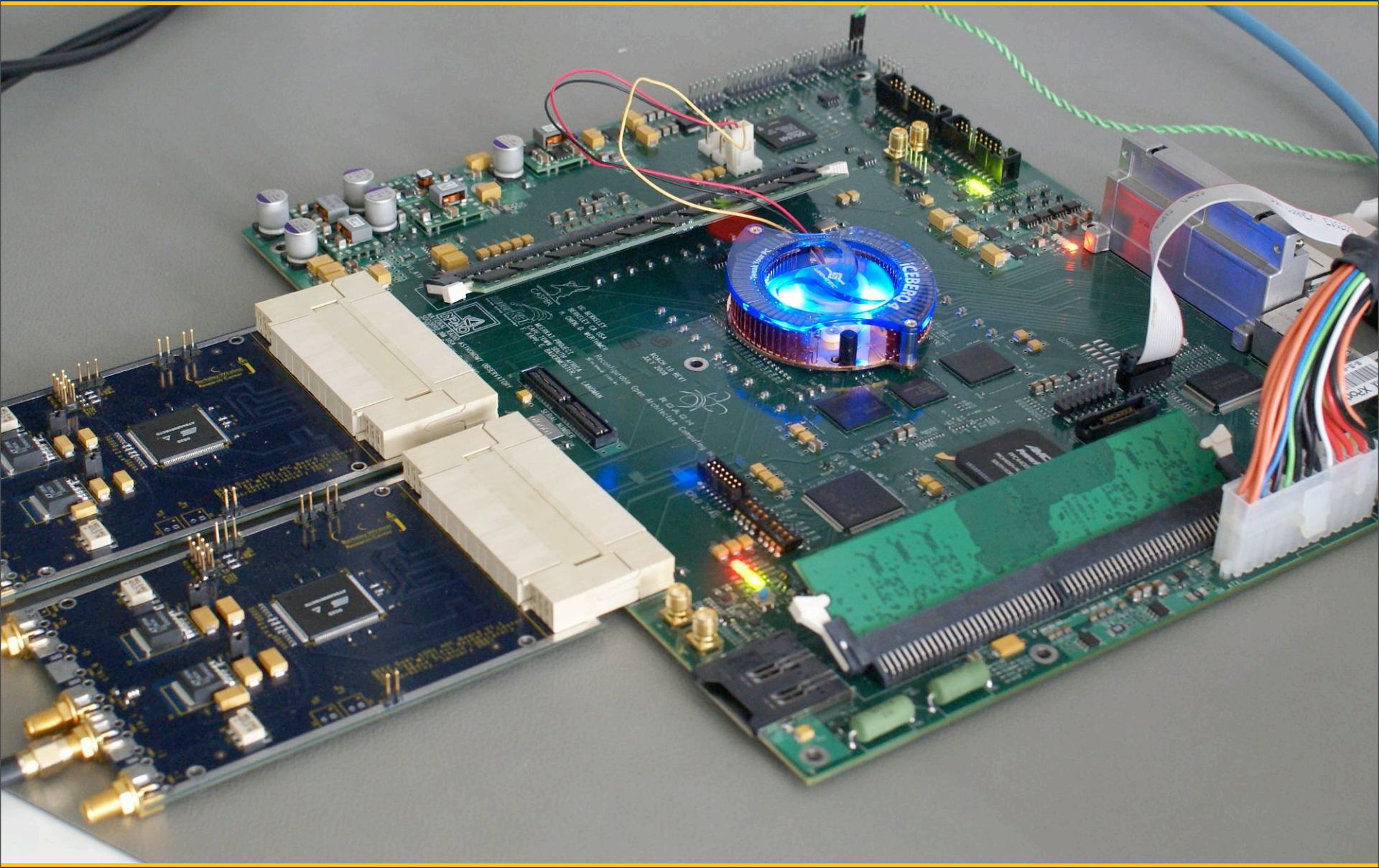
ROACH Correlator

PAD



Jodrell Bank RFI

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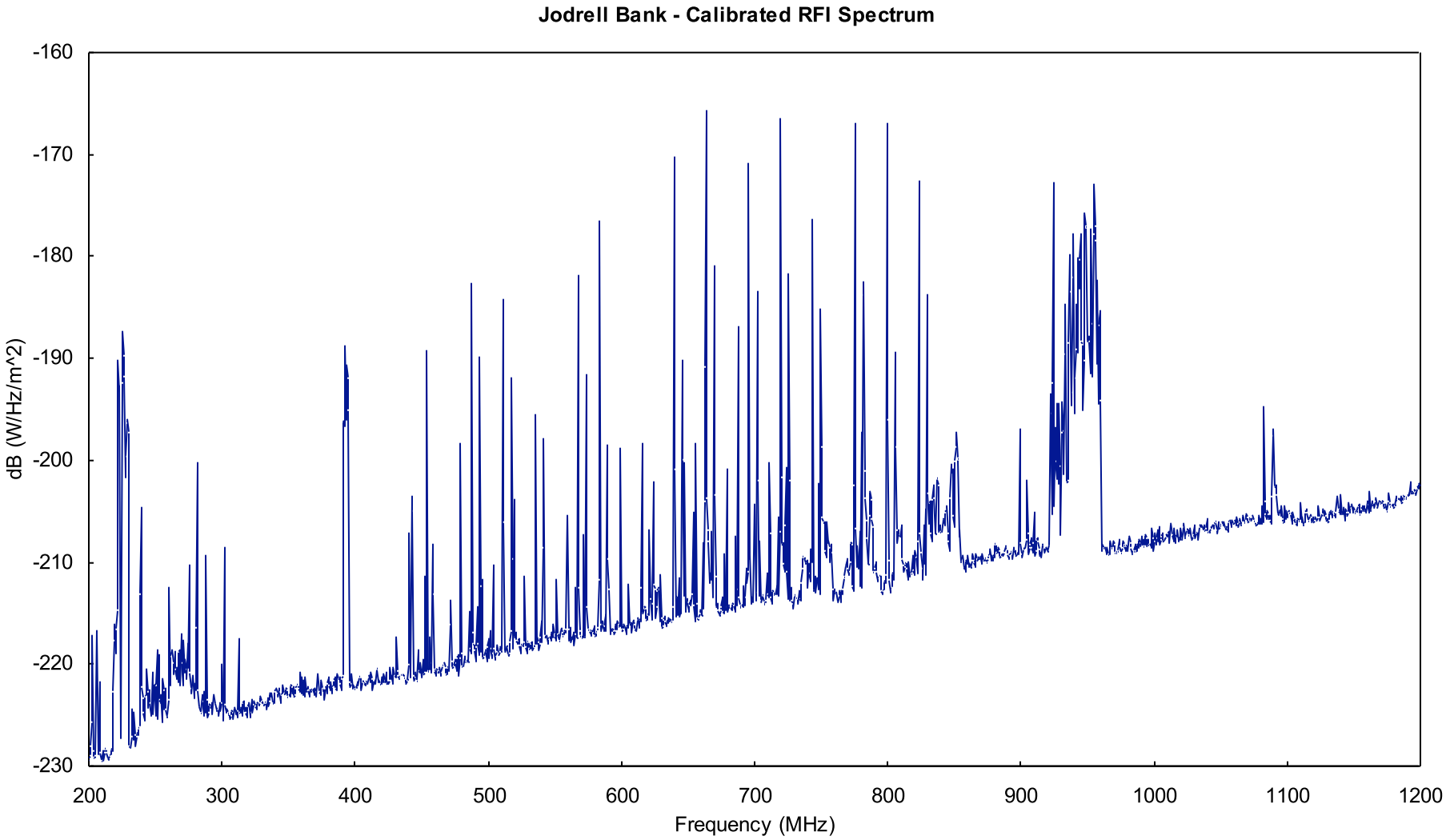
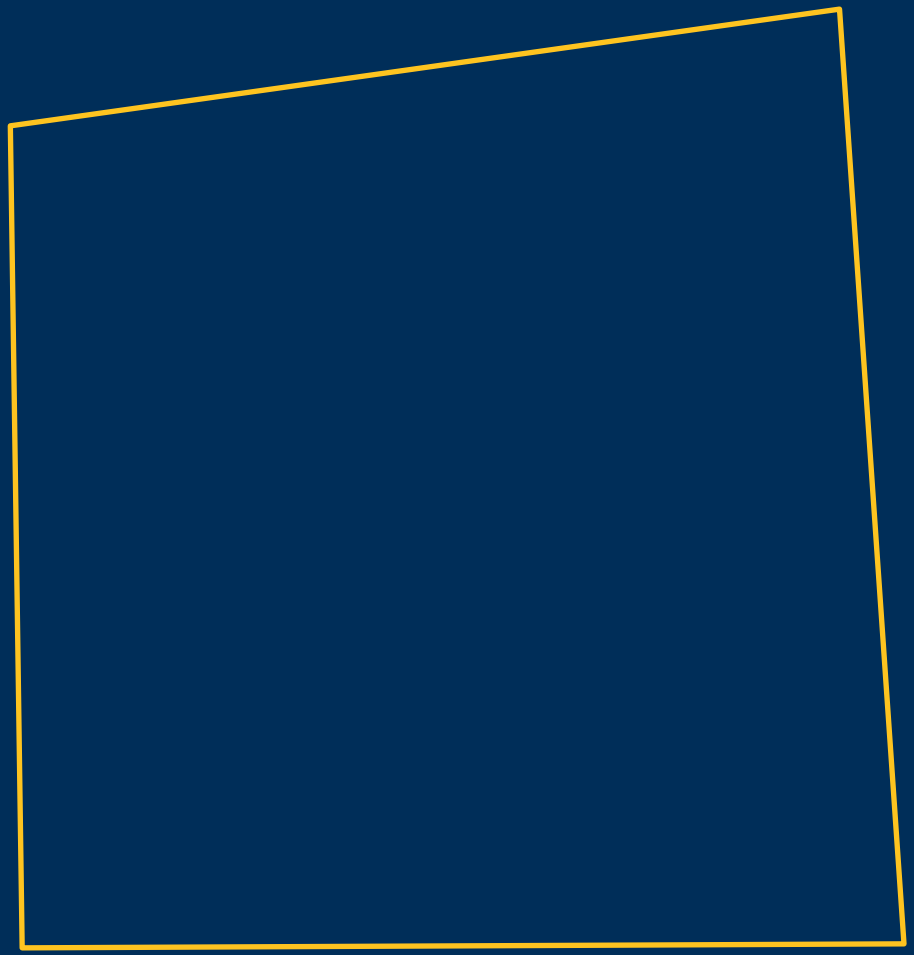
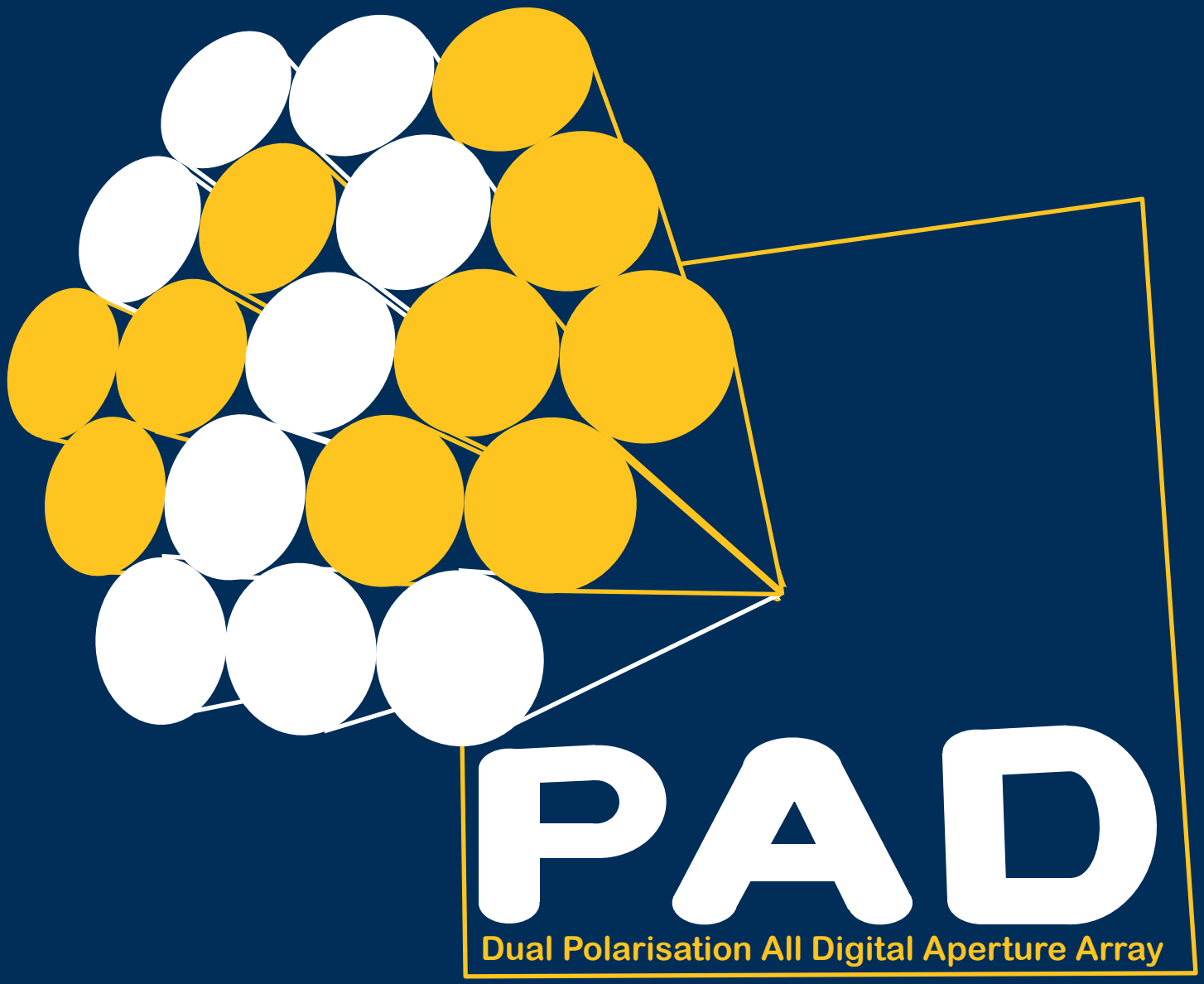


Future Deployment

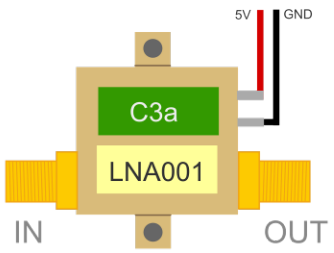



PAD
Dual Polarisation All Digital Aperture Array

Antenna (ANT) & Balun

ANT | BAL | LNA | SRC | FIL | CXA | GC M | CAT | SPL | CXB | SCM | MID | TLB | CXC

Low Noise Amplifiers



Component: Mini-Circuits ZX60-33LN-S+ Low Noise Amplifier

Quantity: 32

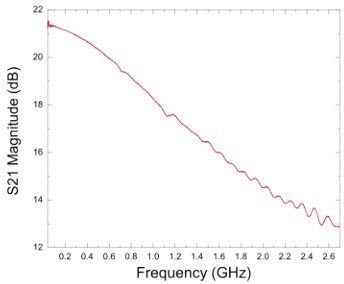
Voltage: 3-5.5V DC @ 70mA

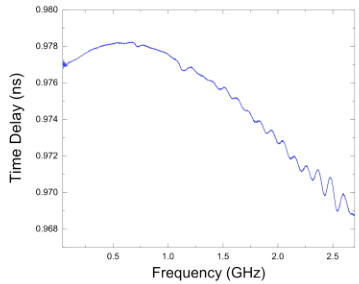
Input: SMA (male)

Output: SMA (male)

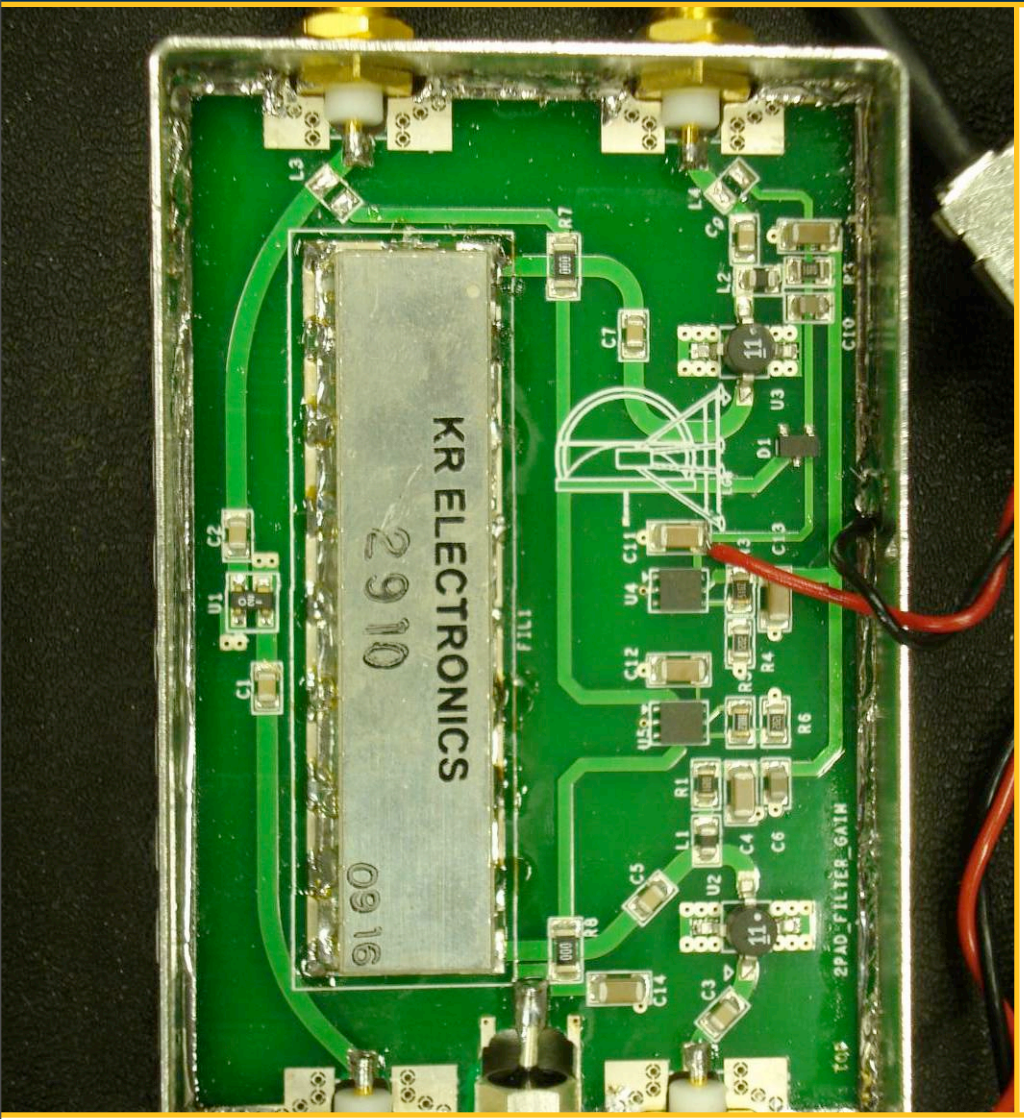
Schematic: Front and Back

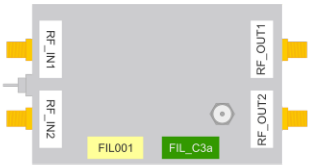
S21 Transmission and Time Delay





Filter Module (FIL)





Component: Filter Module

Quantity: 32

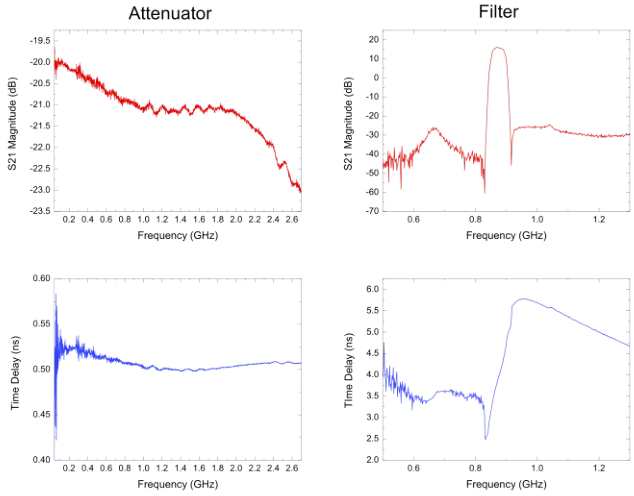
Voltage: 3-7.5V DC @ 100mA

Input: SMA (male)

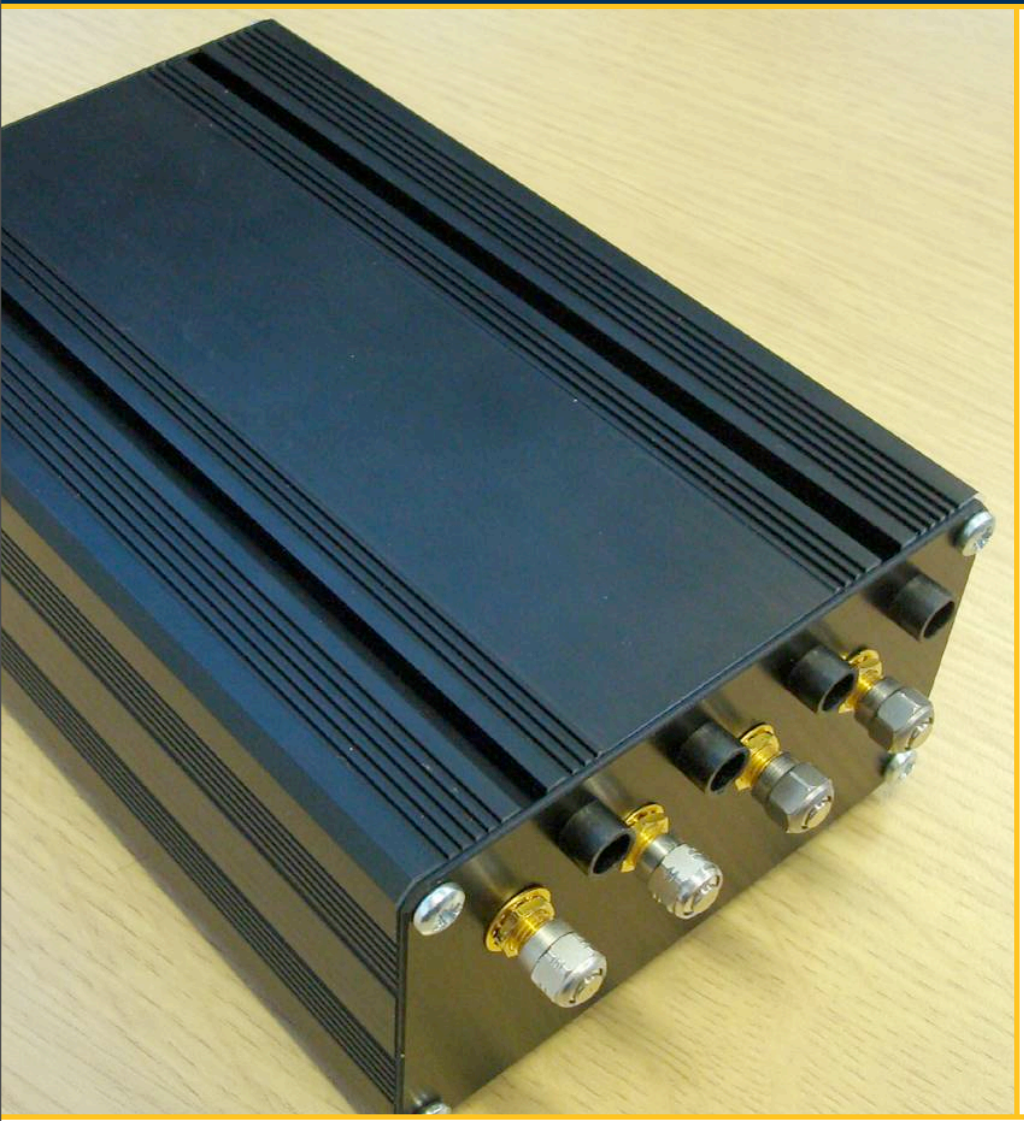
Output: SMA (male)

Schematic: Front and Back

S21 Transmission and Time Delay



Gain Chain Module (GCM)



Component: Gain Chain Module

Quantity: 8

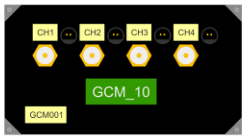
Voltage: 7.5-15V DC @ 183mA

Input: 4x SMA (male)

Output: 1x Cat-7 TERA

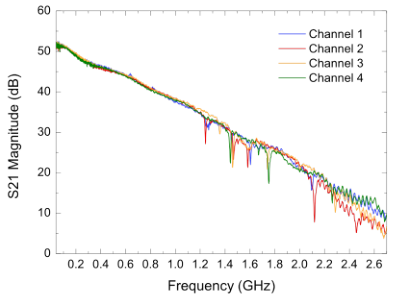
Schematic: Front and Back

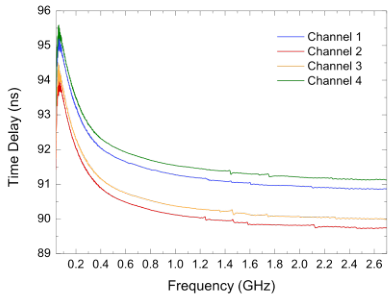
FRONT



BACK

S21 Transmission and Time Delay





Nb: Graph data are GCM, CAT and SPL as combined measurements

Category-7 Cable (CAT)

Component: Gain Chain Module

Quantity: 8

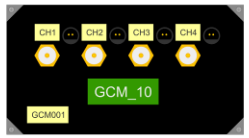
Voltage: 7.5-15V DC @ 183mA

Input: 4x SMA (male)

Output: 1x Cat-7 TERA

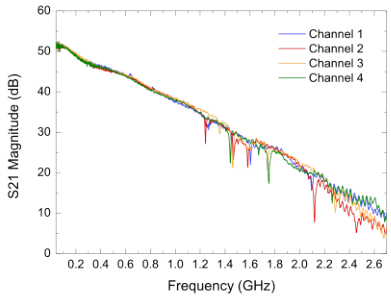
Schematic: Front and Back

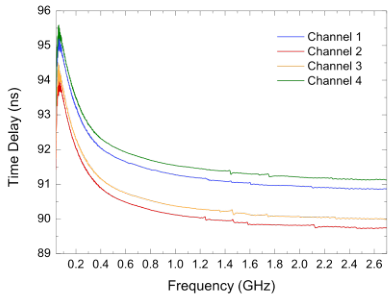
FRONT



BACK

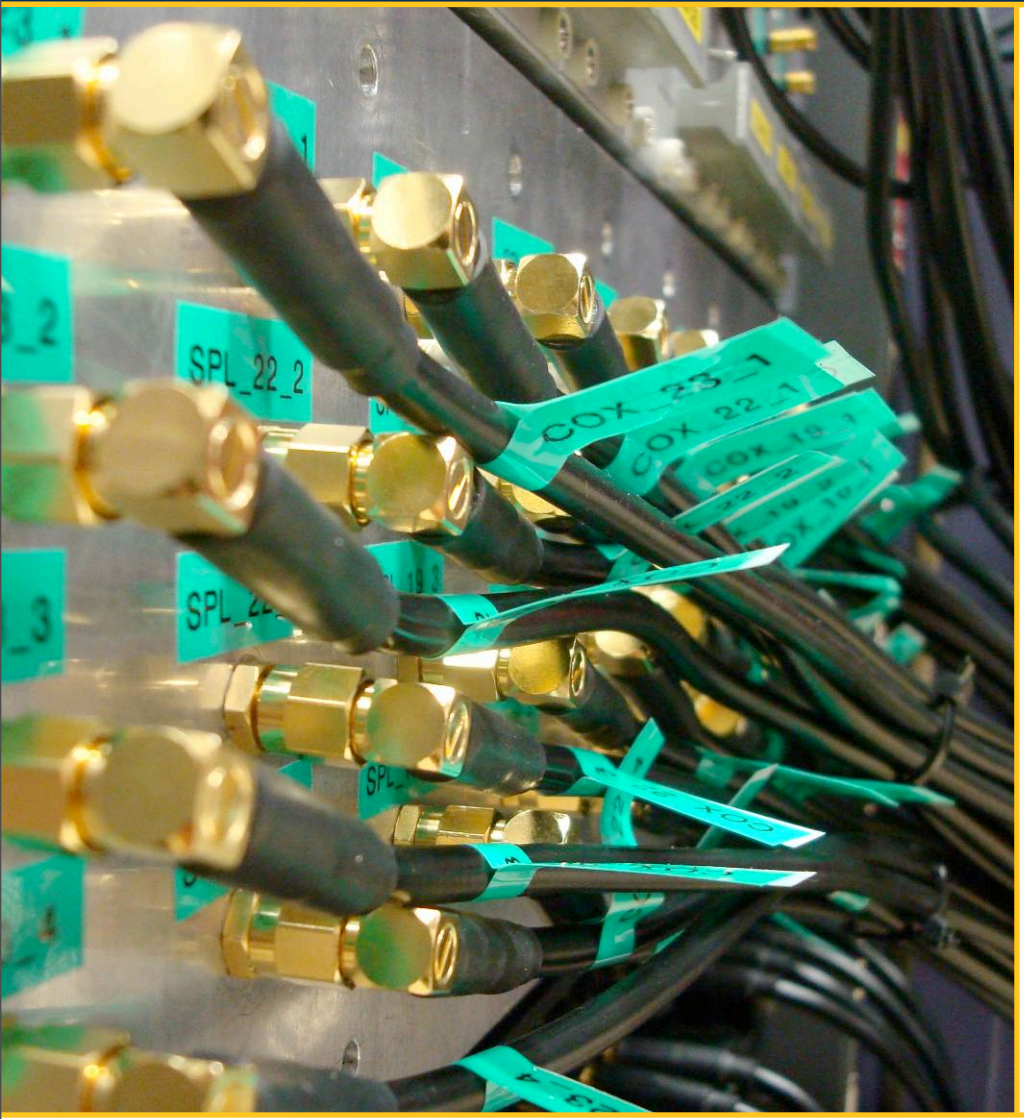
S21 Transmission and Time Delay





Nb: Graph data are GCM, CAT and SPL as combined measurements

Splitter Balun (SPL)



Component: Gain Chain Module

Quantity: 8

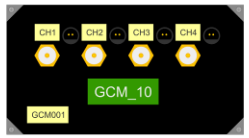
Voltage: 7.5-15V DC @ 183mA

Input: 4x SMA (male)

Output: 1x Cat-7 TERA

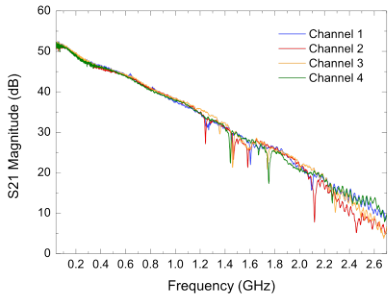
Schematic: Front and Back

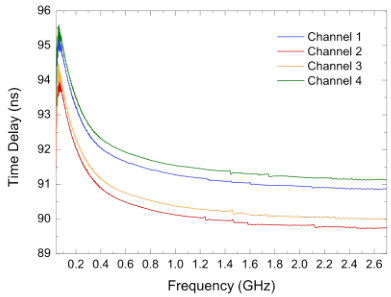
FRONT



BACK

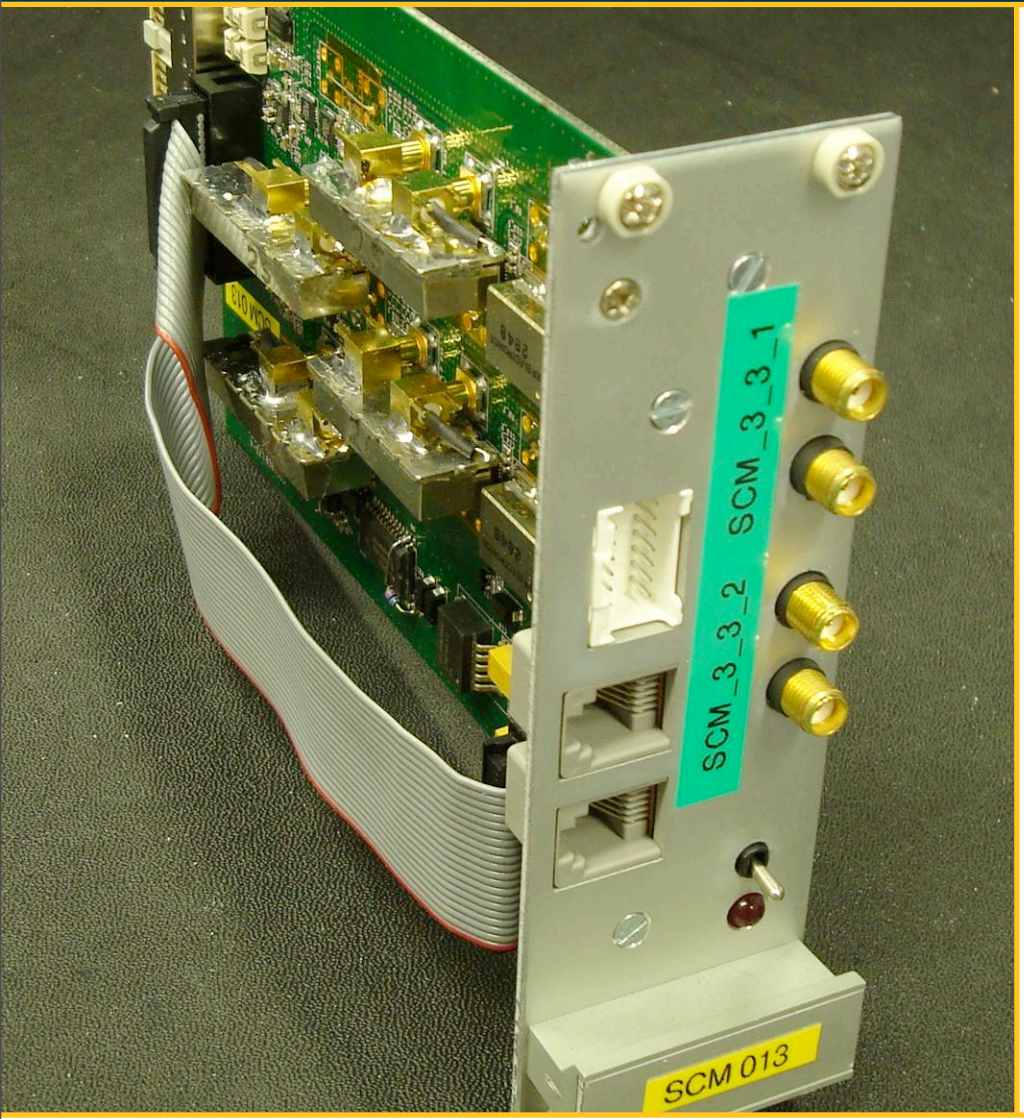
S21 Transmission and Time Delay

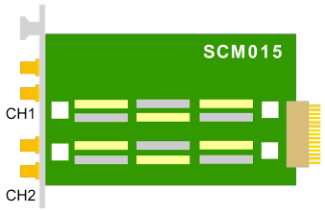




Nb: Graph data are GCM, CAT and SPL as combined measurements

Signal Conditioning





Component: Signal Conditioning Module

Quantity: 16

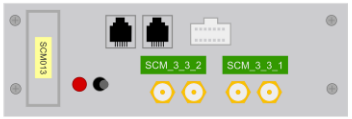
Voltage: +8V DC in series with -8V DC; 8-15V DC

Input: SMA (male) x2 channels

Output: SMA (male) x2 channels

Schematic: Front and Back

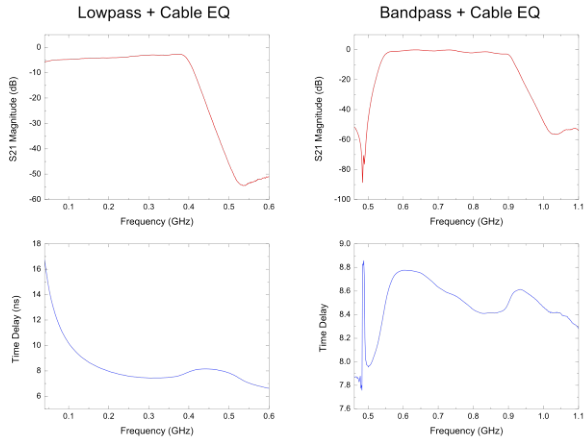
FRONT



BACK

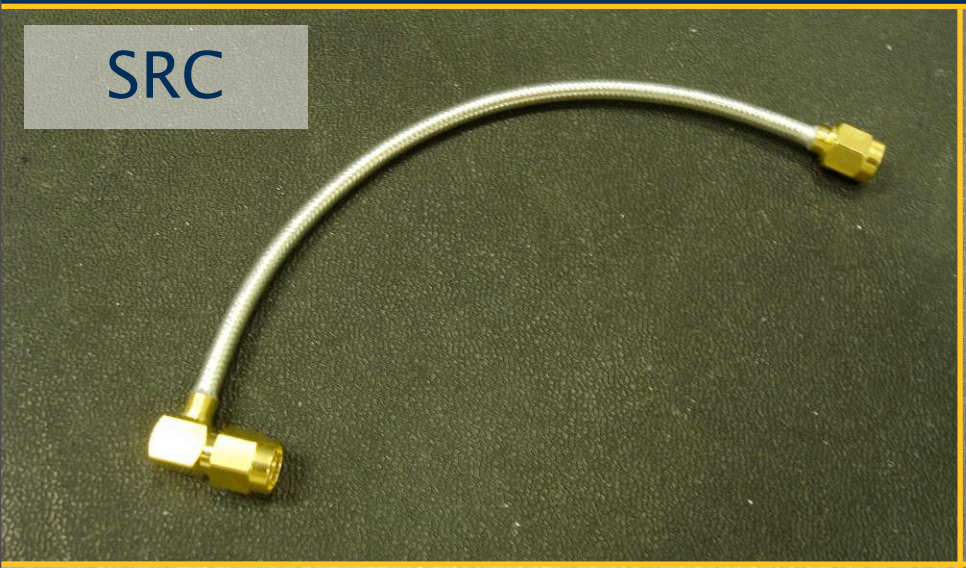
Adaptor connection

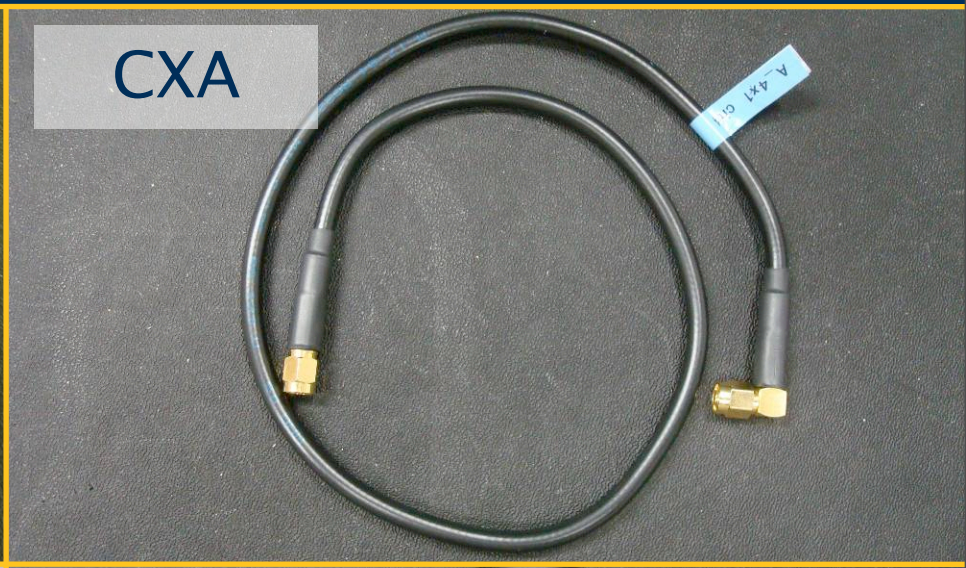
S21 Transmission and Time Delay



Translator Board (TLB)

Coaxial Cables





ANT | BAL | LNA | **SRC** | FIL | **CXA** | GC M | CAT | SPL | **CXB** | SCM | MID | TLB | **CXC**