FPA Modelling and Concepts at CSIRO

Focal Plane Array Workshop
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Outline

- Aim
- SKA goals and antenna concept of current focus
- Antenna-related modelling requirements; NTD, xNTD and beyond
  - Some topics of interest
    - FPA design for NTD
    - FPA size vs FoV and f/D
    - FPA system modelling
    - FPA concepts for enhanced performance eg frequency range
- Summary

SKA goals

- Sensitivity
  - $A_e / T_{sys} = 20000\ m^2\ K^{-1}$
- Frequency range
  - 0.5GHz – 25GHz
- Survey speed
  - $FoV\ (A_e / T_{sys})^2\ BW = 4.6 \times 10^{15}\ m^4\ K^{-2}$ Hz at 0.7GHz

eg FoV = 100 square degrees BW = 400MHz

SKA general form with FPA antennas

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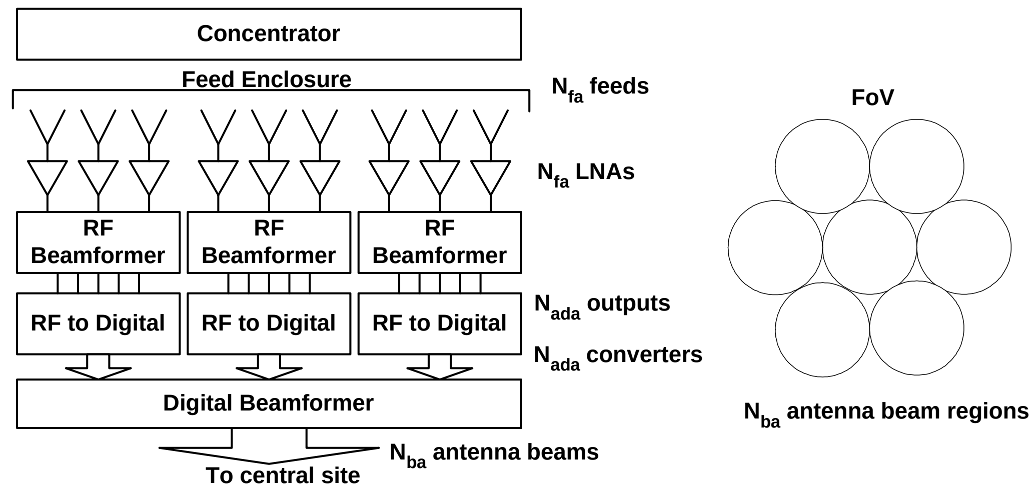

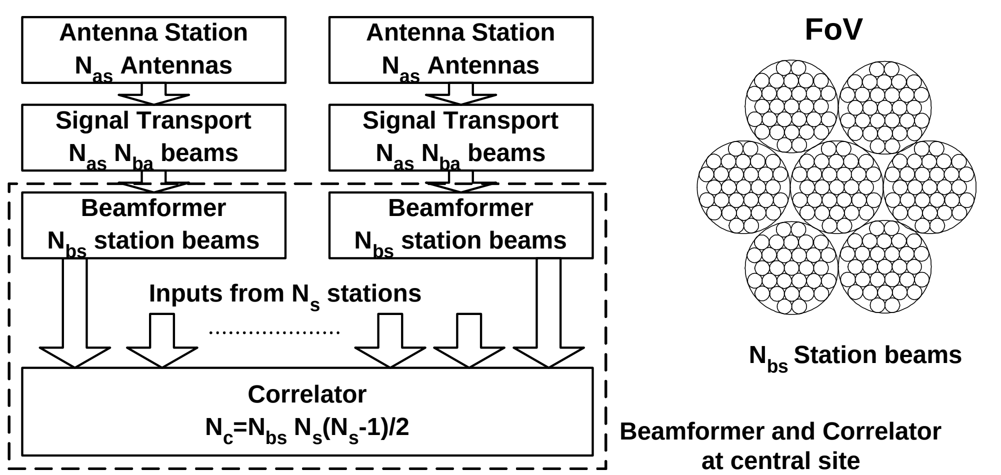

SKA antenna concept

- FPAs with all-digital beamforming in paraboloidal reflectors
  - reduce signal-transport and correlator costs
  - correct for reflector effects eg aberrations and cross polarization
  - RFI mitigation
  - contiguous FoV
  - technologies possibly with broader application

FPA antenna modelling requirements

- NTD
  - FPA design with Vivaldi or similar element, collaboration with ASTRON and U. Mass.
  - Reflector-FPA interaction
  - System model, including antenna, LNAs, digitizers and beamformer
  - Preliminary investigation of possible trades and optimum design
  - Verification
- xNTD and beyond
  - Low-cost reflector options
  - Optimum design studies; antenna/LNA/conversion/beamforming
  - Investigate other FPA elements and configurations
    - increase frequency range
    - decrease cost
    - other performance enhancements
  - Modelling capability enabling such

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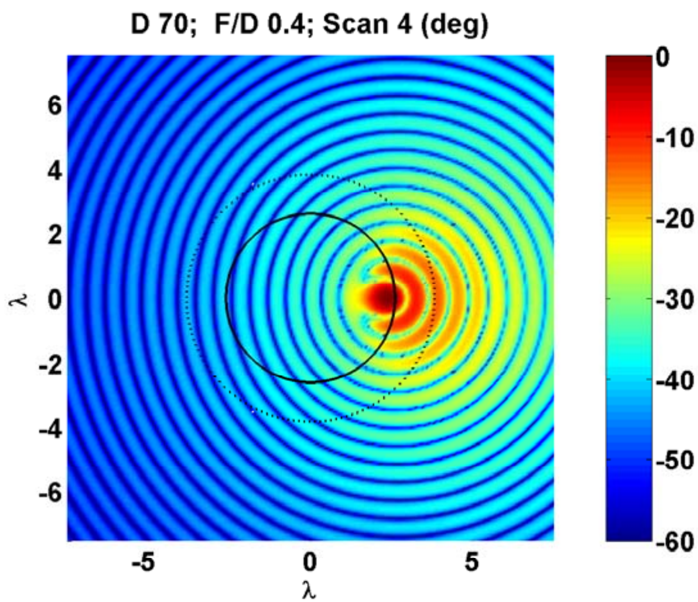
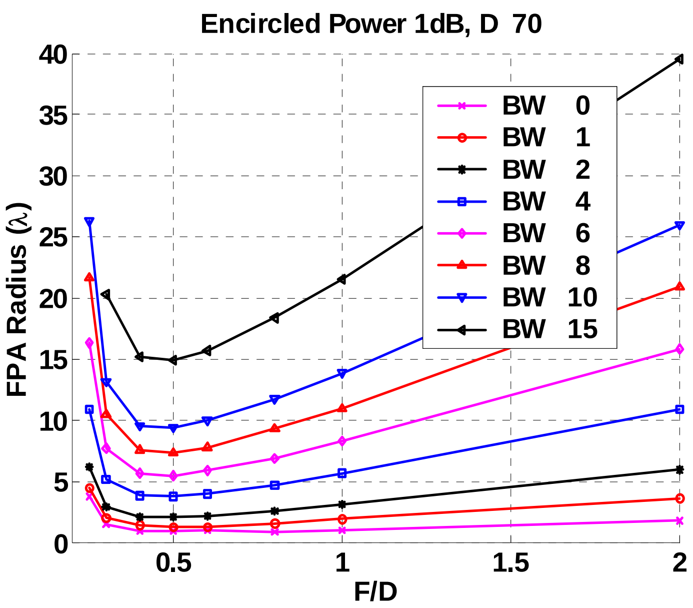
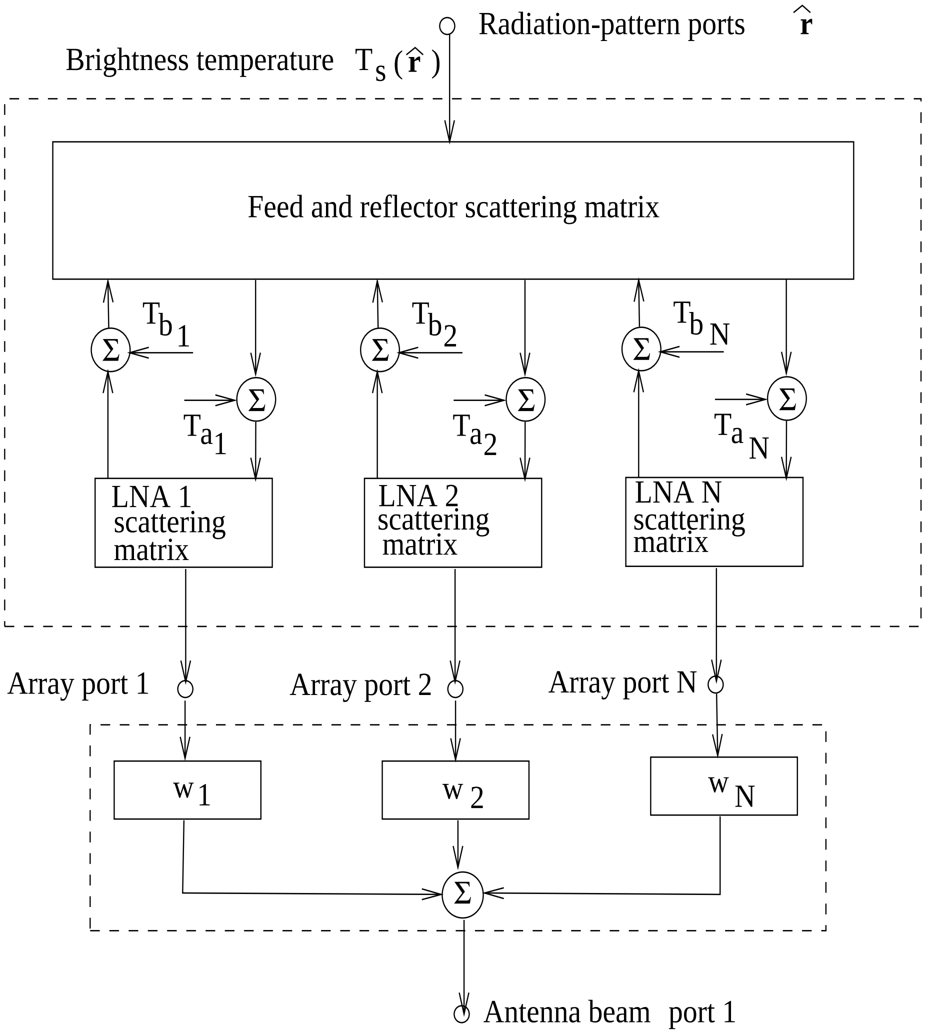
FPA size for specified Ae and f/D





- D.B. Hayman, T.S. Bird, K.P. Esselle and P. Hall, 2005 IEEE AP-S Symposium.

Sensitivity (Ae/Tsys) modelling



$$\frac{A_e(\hat{\mathbf{r}})}{T_{sys}} = \frac{|\phi^t w|^2}{\overline{w}^t M w}$$

$$\phi_i = \mathbf{S}_i(\hat{\mathbf{r}}) \cdot \hat{\mathbf{p}}$$

$$M_{i,j} = \frac{1}{\lambda^2} \iint d\Omega\, \overline{\mathbf{S}}_i(\hat{\mathbf{r}}) \cdot \mathbf{S}_j(\hat{\mathbf{r}})\, T_s(\hat{\mathbf{r}}) + \sum_p \overline{S}_{i,a_p} S_{j,a_p} T_{a_p} + \sum_p \overline{S}_{i,b_p} S_{j,b_p} T_{b_p} + 2\Re \sum_p \overline{S}_{i,a_p} S_{j,b_p} T_{a_p,b_p}$$

Previous related work on noise coupling

- Jan Peter Peeters Weem "Broad band antenna arrays and noise coupling for radioastronomy", PhD thesis, U. Colorado, 2001.
  - Directly radiating arrays
  - Role of Tx-mode reflection coefficient

Beamformer weight determination

- Maximum A_e (conjugate match)

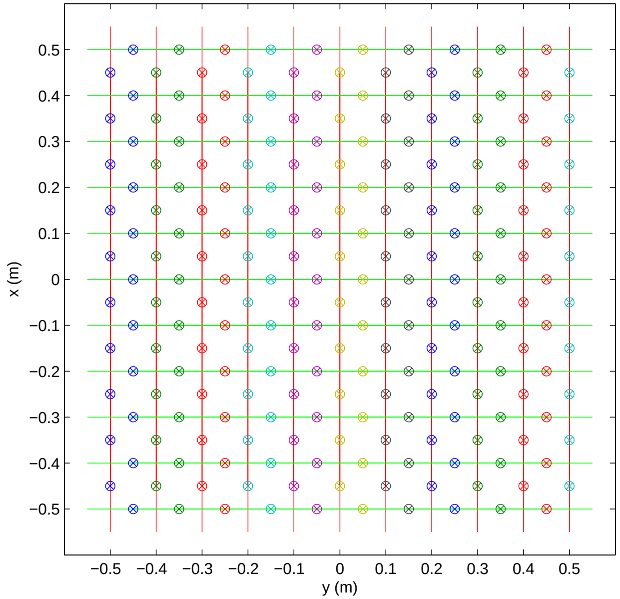
$$w = \overline{\phi}$$

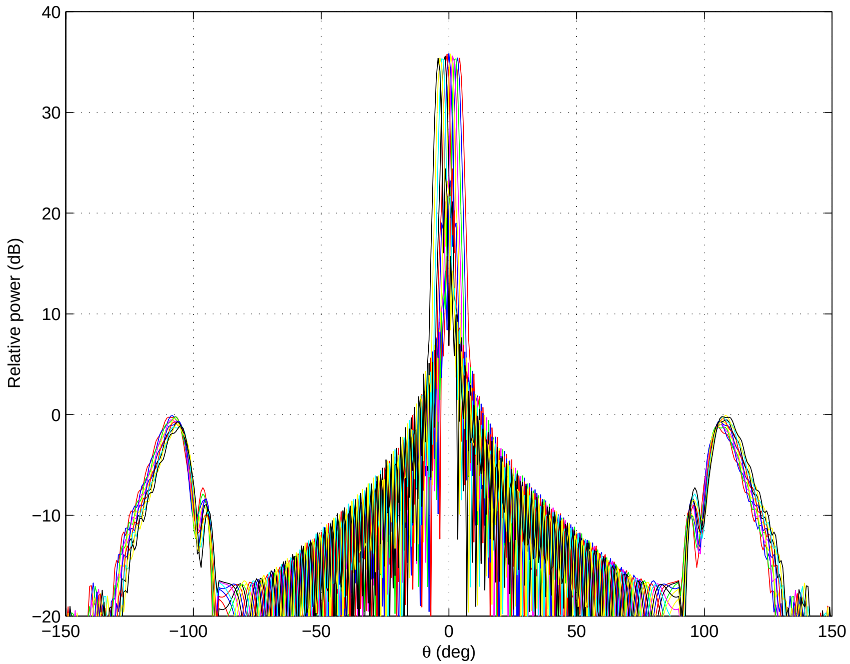
- Maximum A_e/T_{sys} (Bird and Hayman, URSI GA, 1996)

$$w = M^{-1}\overline{\phi}$$

- Maximum A_e/T_{sys} subject to upper bounds on co- and cross-polar sidelobes
  - Successive Projections (Poulton, Electron. Lett. 1986) approach is possible, perhaps including quantization or dynamic-range constraints as additional sets
- Requirements from image formation studies

Illustration - wire-grid over groundplane





- MoM solution for scattering matrix of array
- 14m-reflector f/D=0.4 at 0.7GHz and zenith
- Ground and sky noise temperature models

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Illustration – Ae/Tsys

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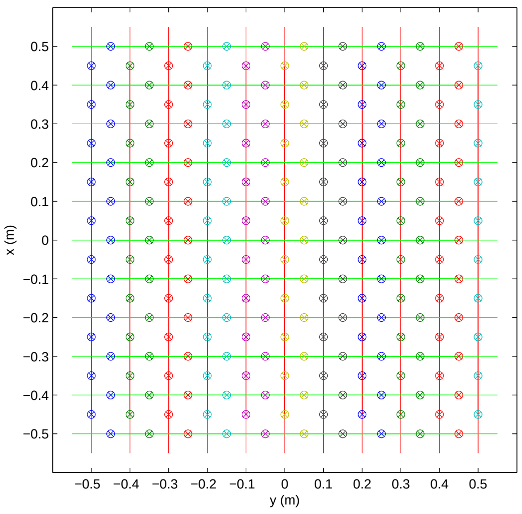


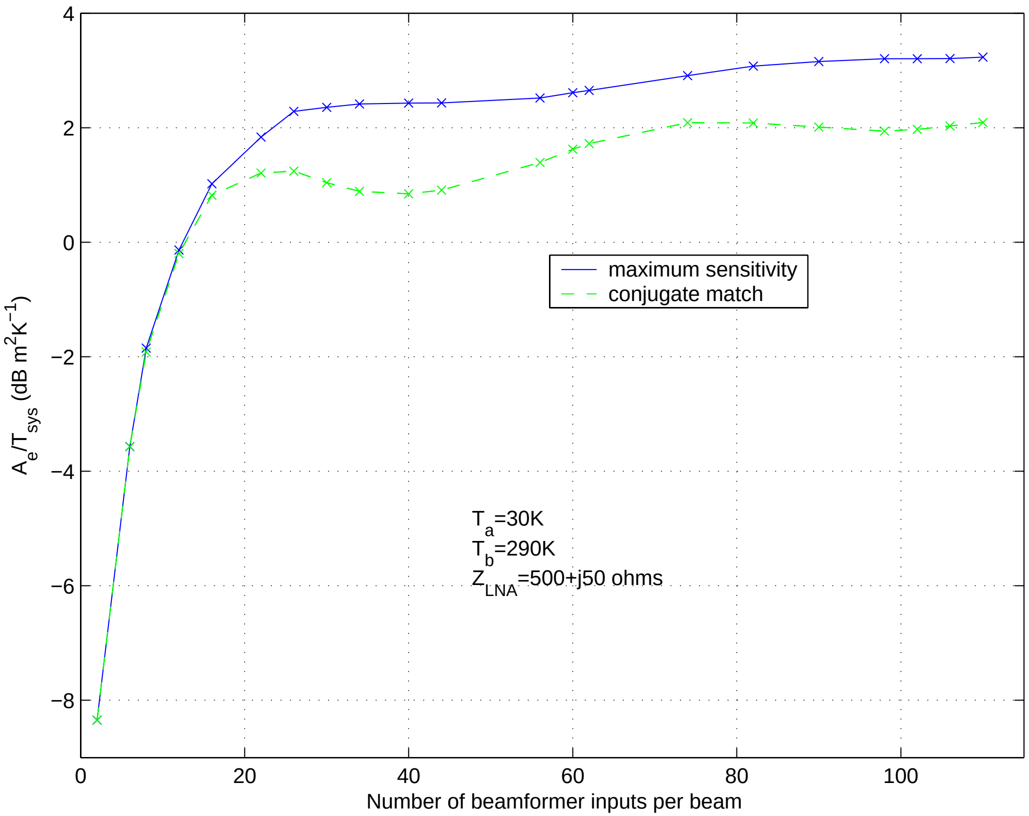
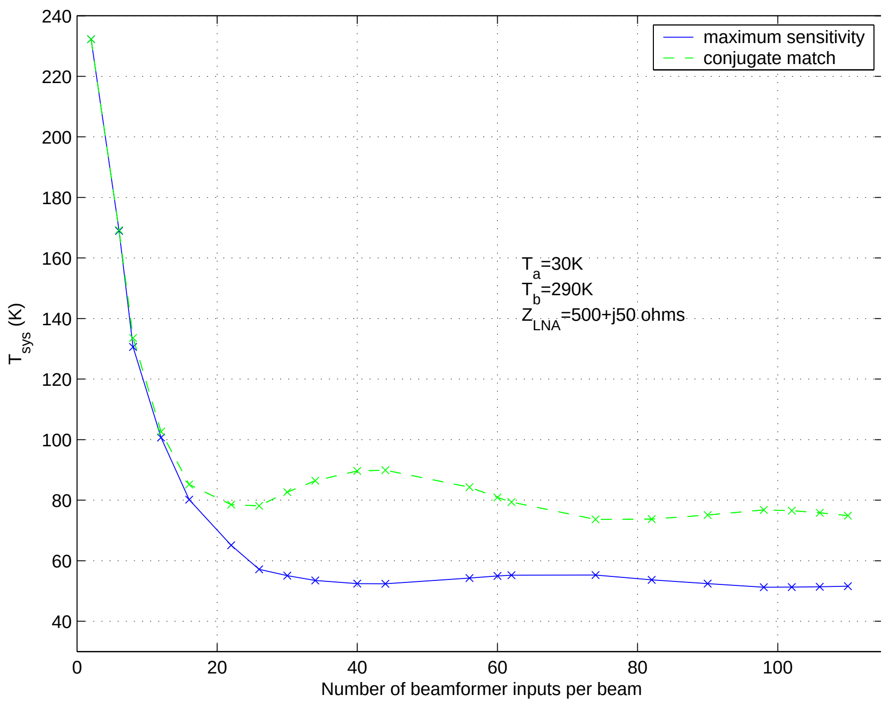


Illustration – Tsys and Ae



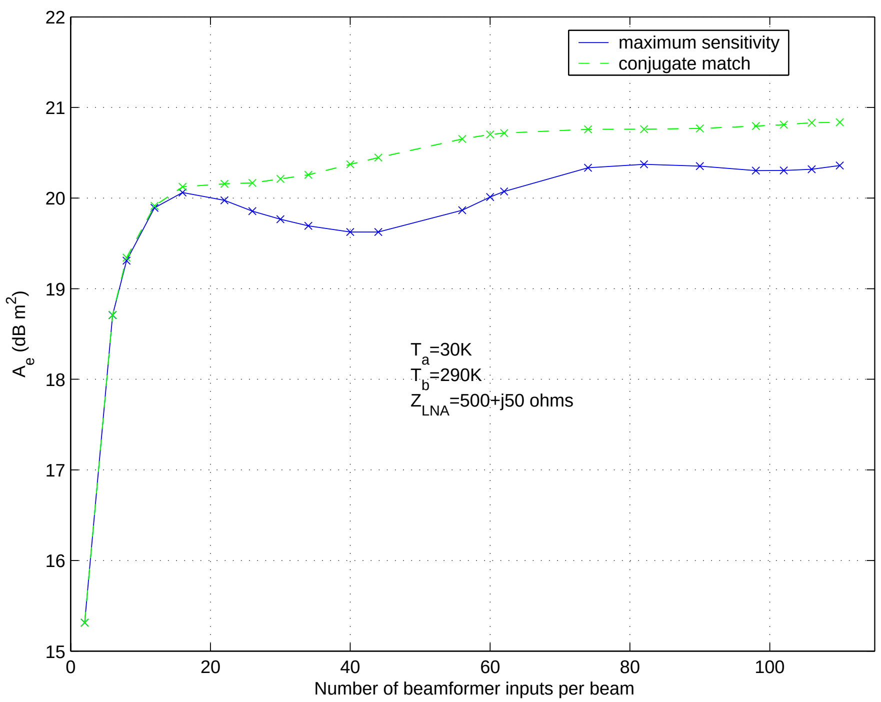


Illustration – Tb effect on Tsys

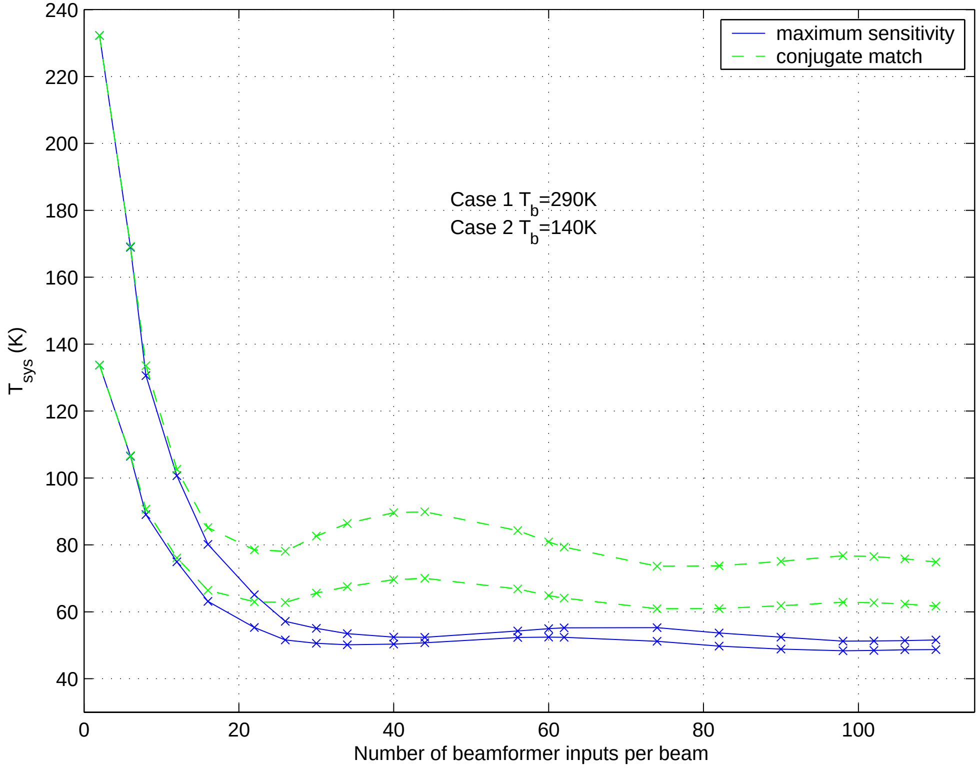


Illustration – Tx-mode reflection coefficient

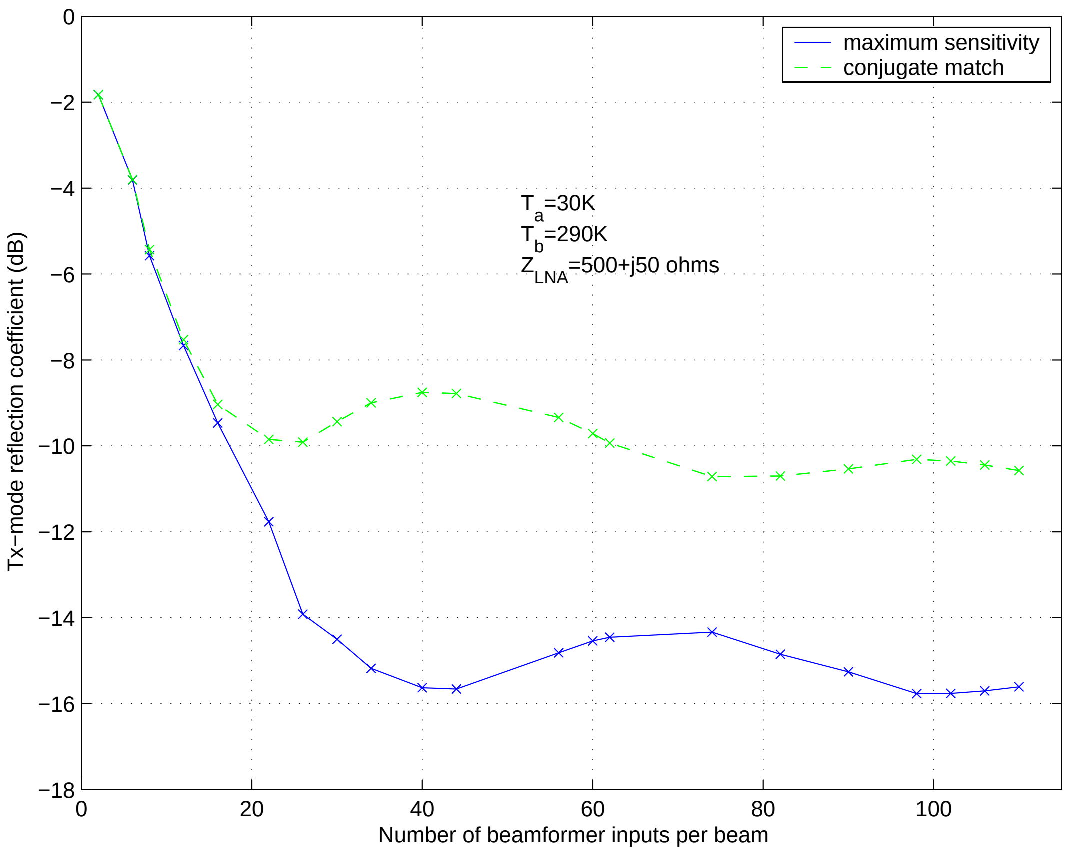


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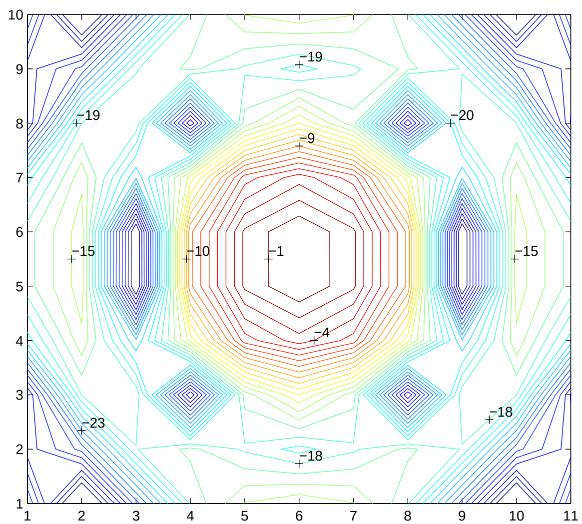
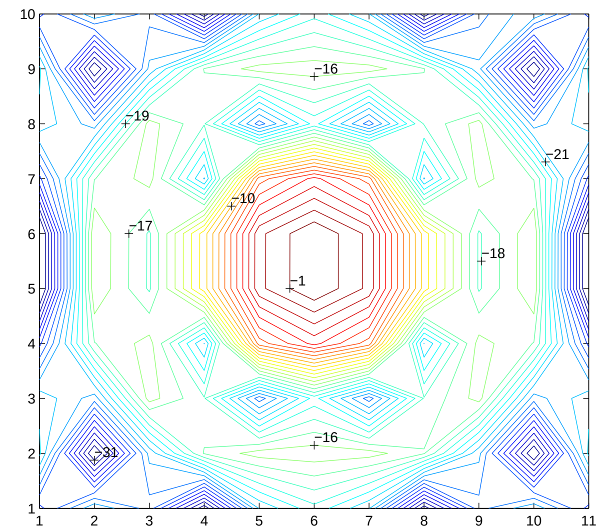
Illustration - weights





- Max Ae/Tsys (left) and conjugate match (right)

xNTD and beyond

- Other FPA configurations (increased frequency range or reduced antenna cost)
  - Other elements (eg published work on rabbit ear in radar application)
  - Fractal/nested structures
  - Conductivity switching
  - Directive self-complementary structures
  - 3-dimensional digital beamforming
  - Foveated focal-plane array
- Development of EM modelling capability
  - Flexible boundary element method
  - Interactions with other structures, eg reflector and supports, via Green's-function approach or scattering-matrix with free-space modes eg SWE
  - Implementation in grid/cluster computing

Other FPA configurations – increased frequency range

- SKA goals
  - $A_e / T_{sys} = 20000\ m^2\ K^{-1}$
  - 0.5GHz – 25GHz
  - $FoV\ (A_e / T_{sys})^2\ BW = 4.6 \times 10^{15}\ m^4\ K^{-2}$ Hz at 0.7GHz
- The data rate into the correlator is proportional to

  $(FoV/\lambda^2)BW$
- One approach: keep BW constant and let FoV vary as λ^2

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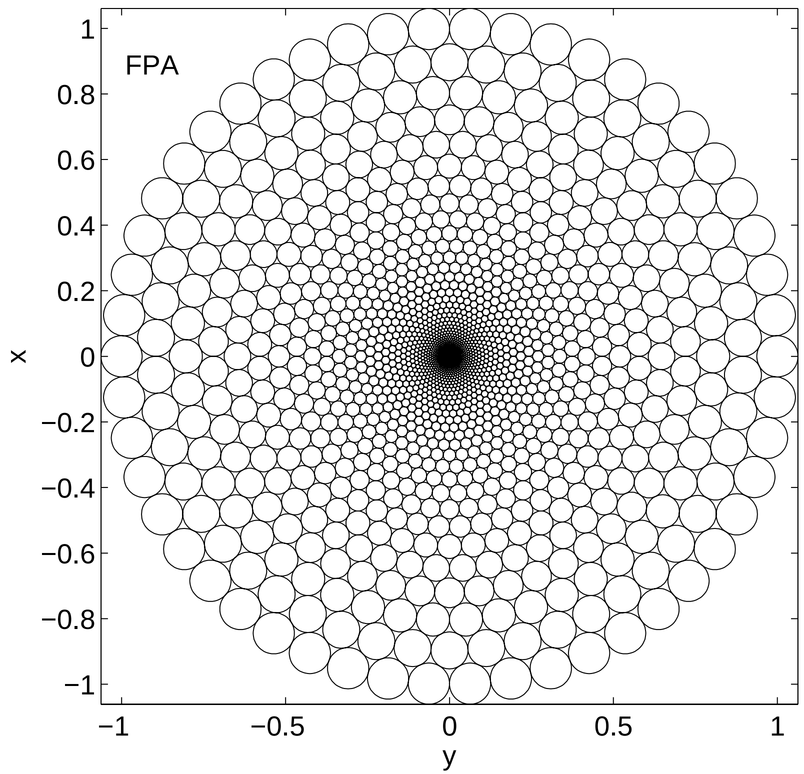
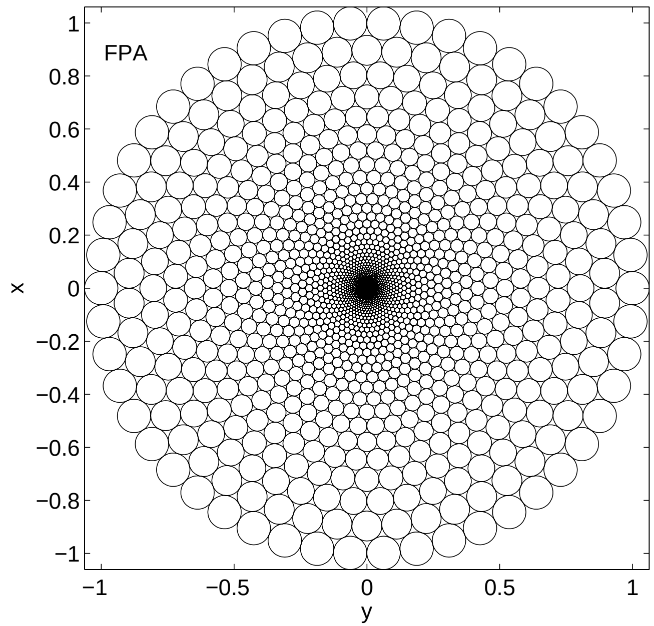
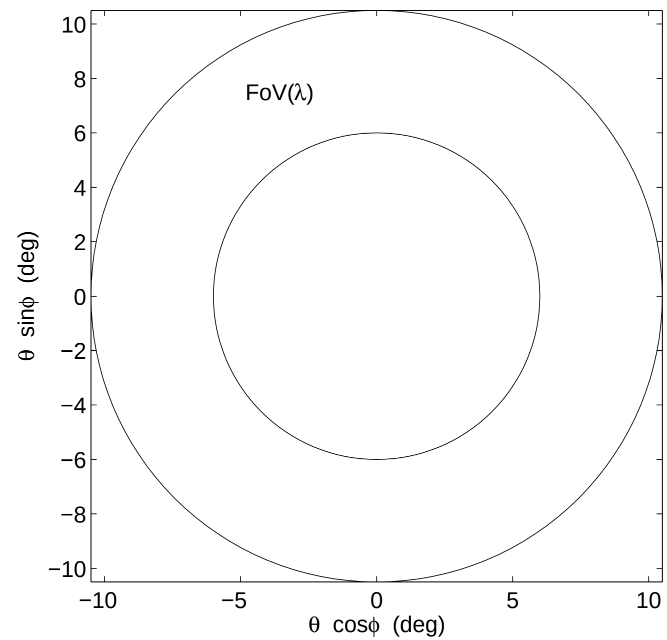
Foveated FPA



- Geometry periodic in log(x+jy)
- Suited to the aberration behaviour of focussing reflectors
- Various element types possible

Form 1 –Annular FoV





- All elements have same BW ratio, centre frequency increasing towards array centre
- Prolonged tracking still possible

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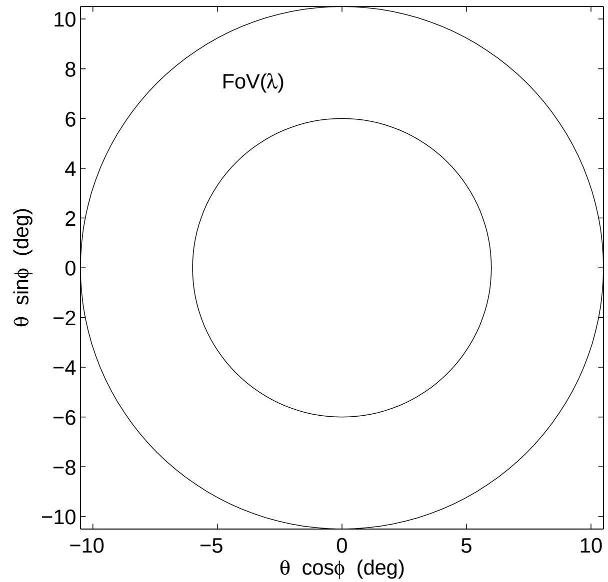
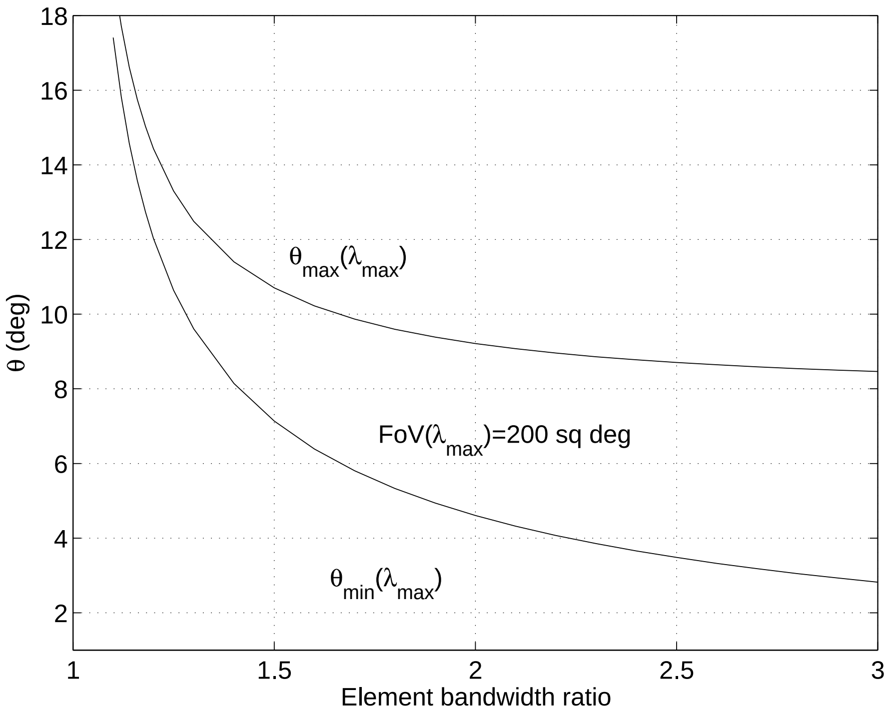
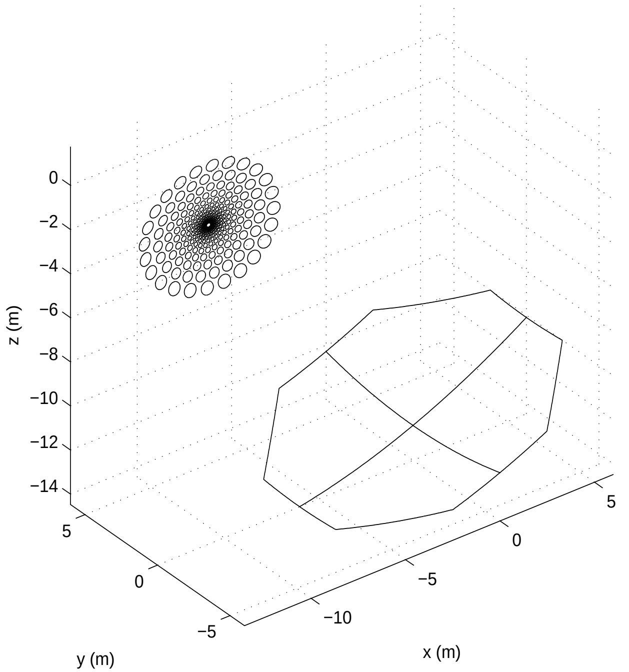
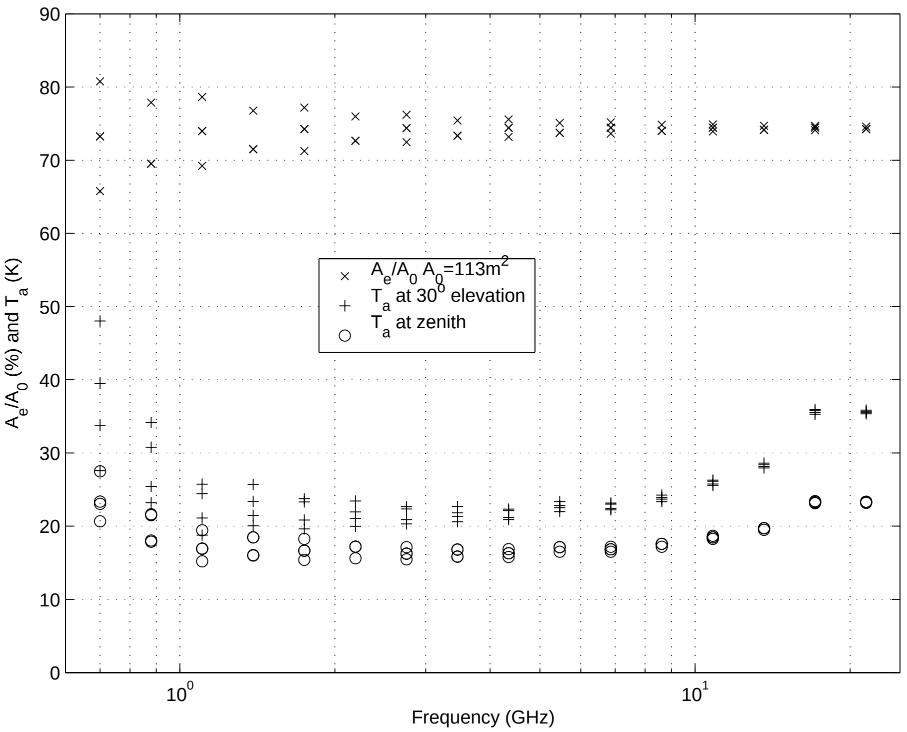
Form 1 cont


FoV(λ)
θ sinϕ (deg)
θ cosϕ (deg)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−5
0
5
10


θmax(λmax)
FoV(λmax)=200 sq deg
θmin(λmax)
θ (deg)
Element bandwidth ratio
18
16
14
12
10
8
6
4
2
1
1.5
2
2.5
3

Example with offset-fed reflector





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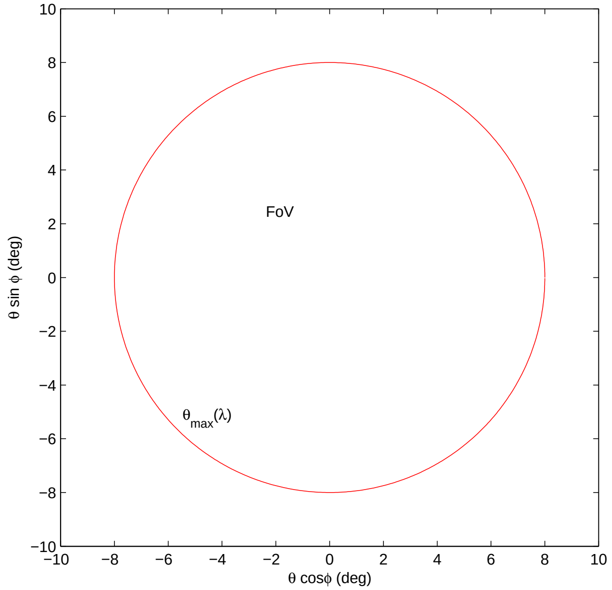
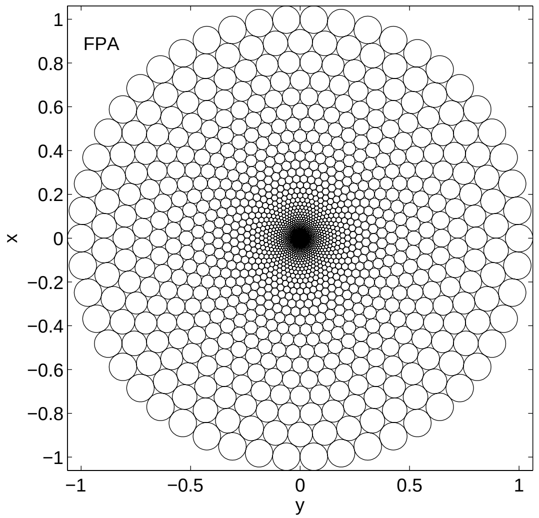
Form 2 – Circular FoV





- All elements have common lowest frequency, BW increasing towards array centre
- Still reduction in number of elements and beamformer inputs at lowest frequency, compared to non-foveated geometry

Summary

- Outline of antenna-related modelling of interest for NTD, xNTD and beyond
  - FPA antenna design for NTD and beyond
  - System modelling important for determining significance of antenna, LNA, digitizer and beamformer properties and optimum design
  - Interested in other elements and FPA configurations to get from NTD to SKA

Your Contacts

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