FLAG: Focal L-band Array for the GBT

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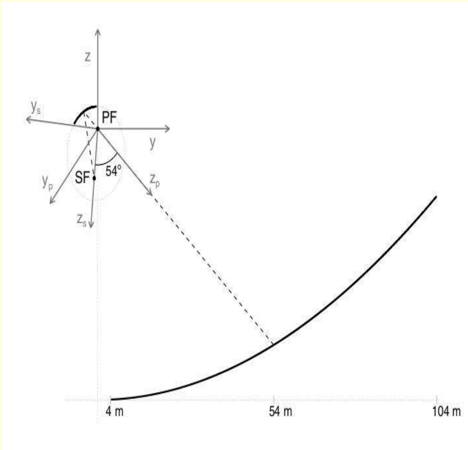
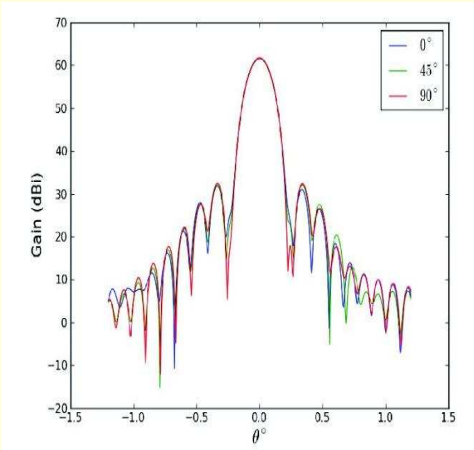
- Angular resolution and Field of View
- FPA and PAF
- FLAG and some test results with its prototypes.

1. Angular resolution and Field of View

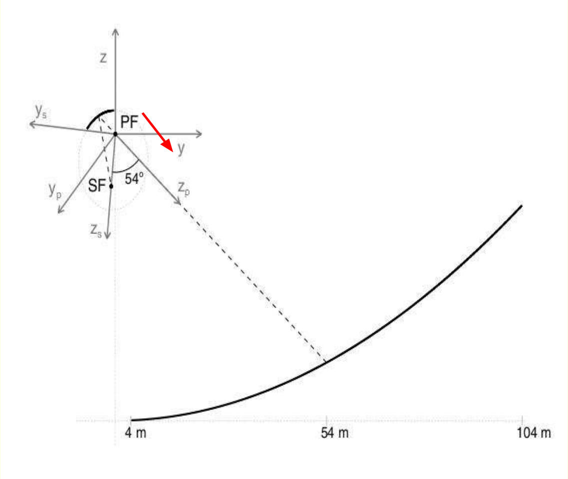




(Boothroyd et al 2011)

- Radio Astronomy needs large telescopes for higher sensitivity
- Large telescope $\Rightarrow$ higher angular resolution (FWHM $\sim \frac{\lambda}{D}$)
- Higher angular resolution $\Rightarrow$ smaller instantaneous viewing angle.

2. Angular resolution and Field of View



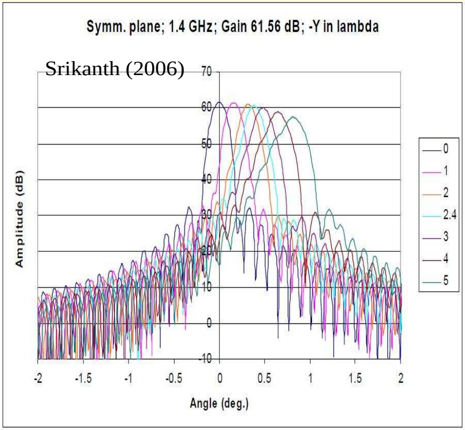
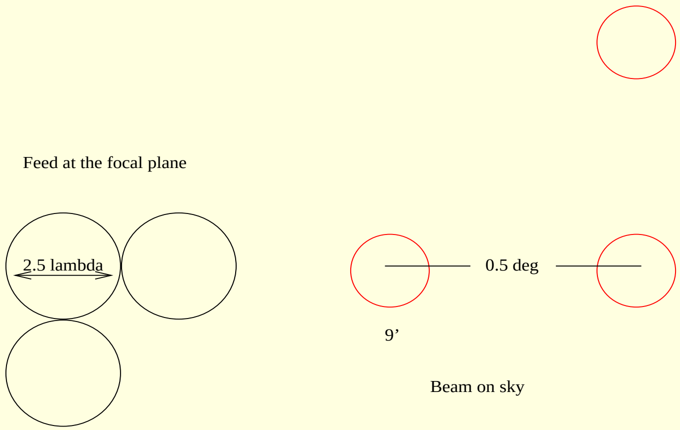


Figure 2. GBT beams at 1.4 GHz for offsets (λ) in symmetric plane towards the feed arm

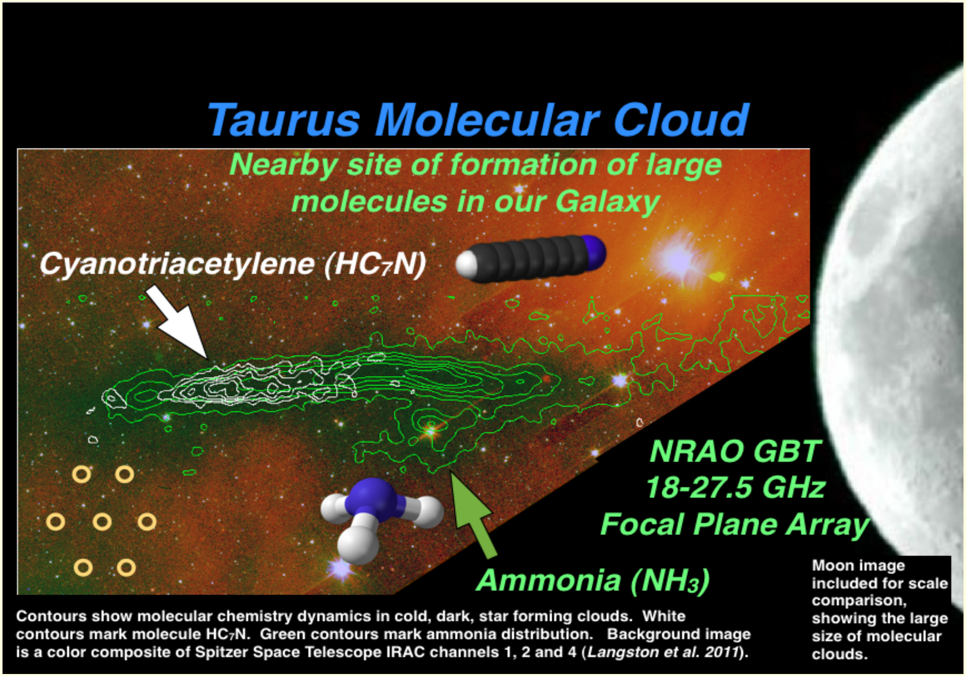
- Field of View (FOV) – angular regions where the beam errors ('aberration') are within a specified tolerance.
- For GBT at L-band – FOV is about $\sim 1^o \times 1^o$ for a 1 dB loss in gain.
- $\Rightarrow$ for GBT the observing efficiency for an 'extended' source ~ 2 %

3. Focal Plane Arrays vs Phased Array Feeds



- Feed design requirement – maximize gain ('conjugate matching'), minimize spillover
- For GBT L-band: feed aperture size 2.5 λ (illumination taper of -12 dB).
- $\Rightarrow$ beam separation $\sim 0.5^o$.
- Sky sampling is not good for imaging.

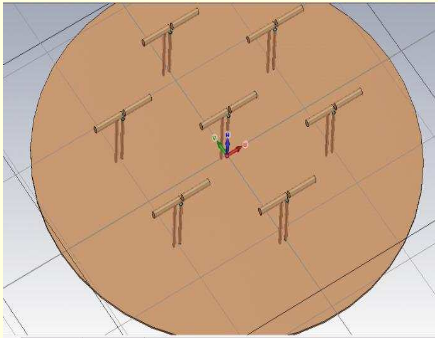
4. An example: K-band (18 – 27.5 GHz) Focal Plane Arrays

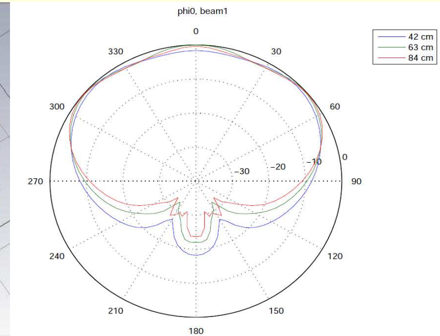


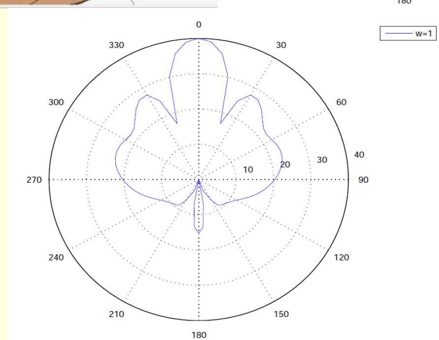
(courtesy Glen Langston)

- KFPA – FWHM 30"; separation 93"

5. Phased Array Feeds

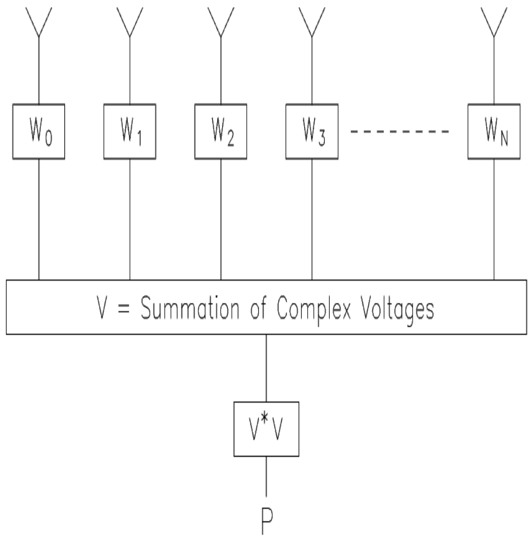


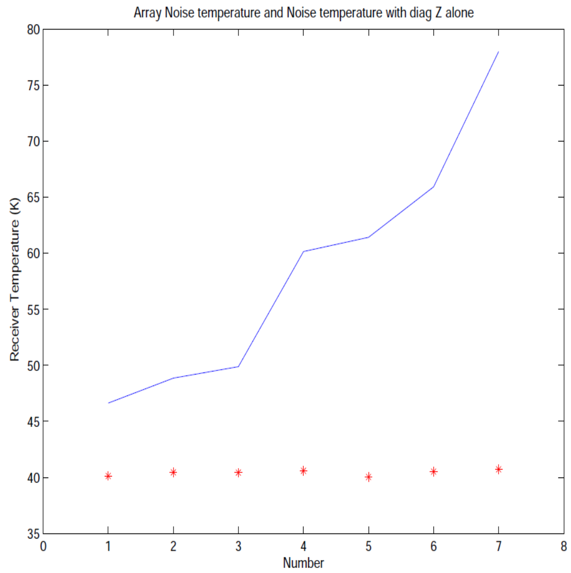




- CST simulation study of an array

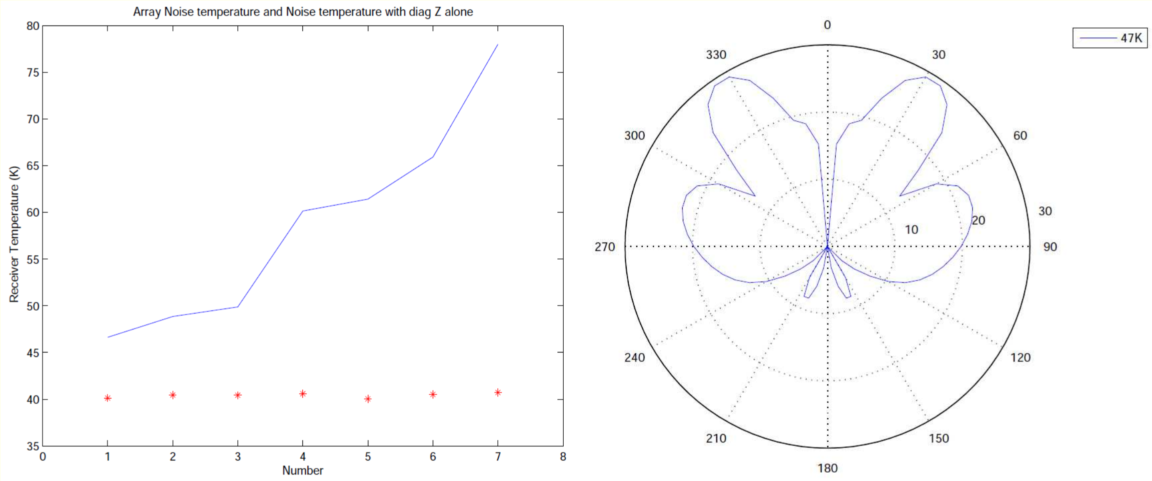
6. Phased Array Feeds





- Array phasing – weighted sum
- Receiver temperature depends on weight due to mutual coupling

7. Phased Array Feeds

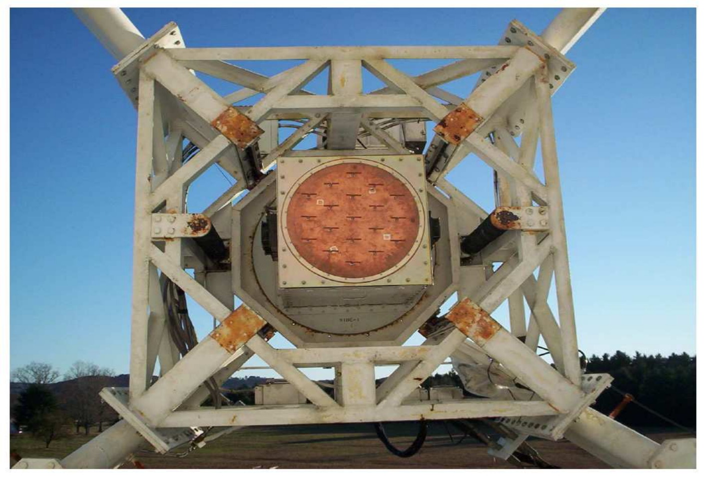


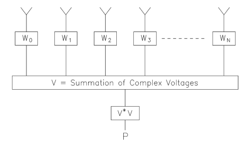
- Phase beam is also a function of weights
- Design challenge: to get a 'good' phased beam with 'minimum' receiver temp (+ spillover temp)
- Figure of Merit : $\frac{Tsys}{\eta}$

8. Focal L-band Array for the GBT (FLAG)

- 19 dual polarized elements. Cryogenic PAF system
- Tsys $\sim$ 20 K; Aperture efficiency $\sim$ 75 to 80 % ; $\frac{Tsys}{\eta} \sim 25$ K
- 7 beams; spacing 0.5 FWHM to 1 FWHM
- Frequency coverage – 1300 to 1800 MHz
- Backend for processing signals (beamforming, calibration etc)

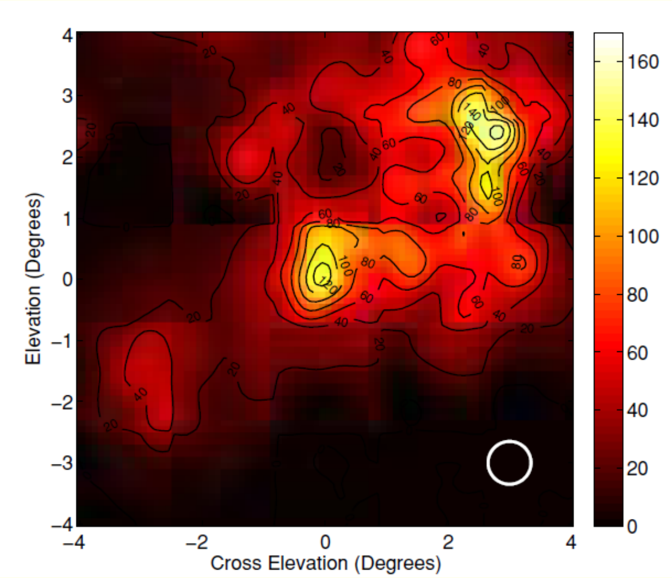
9. FLAG: first prototype (BYU)





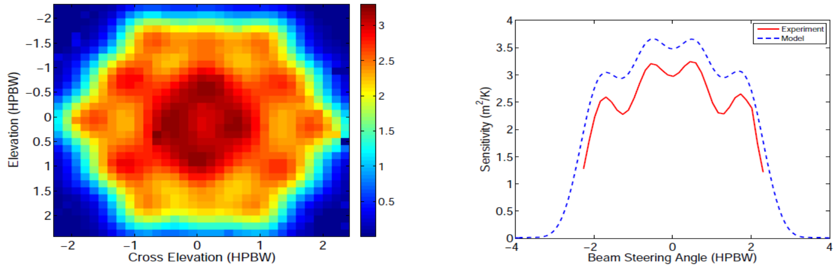
- Prototype is a 19 element single polarized array. Freq $\sim$ 1600 MHz.

10. FLAG: mapping made with the first prototype (BYU)



- Image of Cygnus-X made with PAF on the 20 m telescope; 1600 MHz

11. FLAG: System performance of the first prototype



(a) (b)

Figure 4: (a) Measured beam sensitivity map (m^2/K) for the 19 element prototype dipole array on the 20-Meter Telescope ($f/D = 0.43$). Each pixel in the image corresponds to the measured sensitivity of one formed beam. The half-power beamwidth (HPBW) is 0.7 degrees. (b) Measured and modeled beam sensitivity for an elevation cut through the PAF field of view.

Table 1: Measured and modeled peak beam sensitivity, system temperature, and aperture efficiency for a 19 element prototype dipole array.

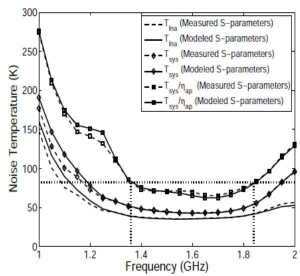
	Center Element	Formed Beam	Model
Sensitivity	2 m^2/K	3.3 m^2/K	3.7 m^2/K
$T_{\rm sys}$	101 K	66 K	69 K
$\eta_{\rm ap}$	64%	69%	81%

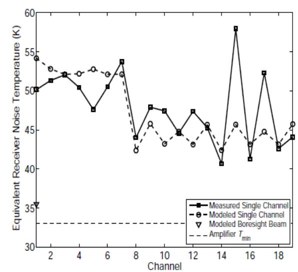
- Measured $\frac{Tsys}{\eta} \sim 95$ K

12. Next generation prototype: system noise budget

Table 2: System noise budgets.

	19 Element Array July 2008	Active Impedance Matched Array Nov. 2009	19 × 2 Cryogenic Array Design Target
LNA T_{min}	33 K	33 K	4 K
Mutual coupling	16 K	2 K	1 K
Spillover	7 K	5 K	5 K
Sky	5 K	5 K	5 K
Loss	5 K	5 K	5 K
T_{sys}	66 K	50 K	20 K





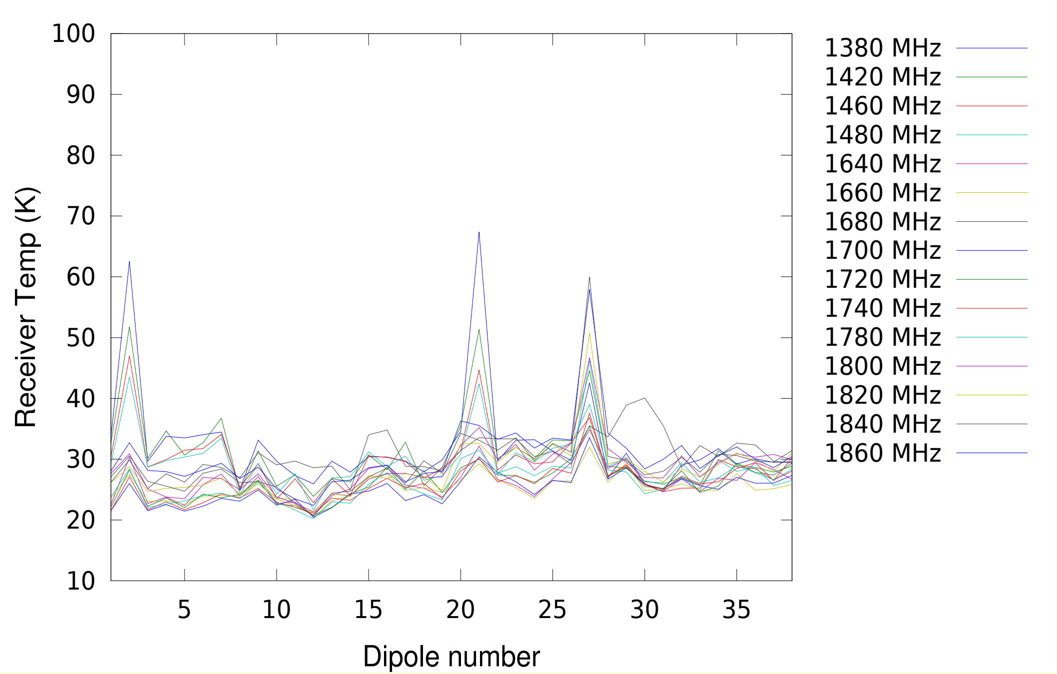
- Measured $\frac{Tsys}{\eta}$ for 'active impedance' matched array ∼ 90 K

13. Cryogenic Phase Array Feed prototype

Figure 2: Left: Dual-pol phased array element "kite" design matched to cryogenic low noise amplifiers. Right: L-band phased array feed cryostat (R. Norrod, NRAO).

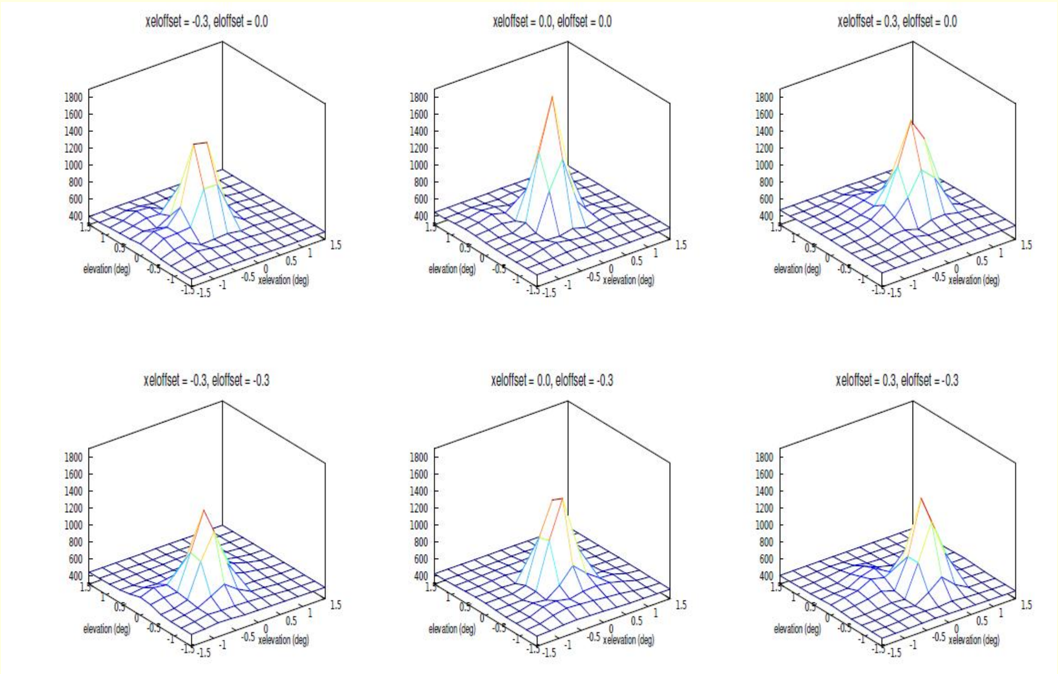
(BYU designed and built the array elements)

14. Cryogenic PAF : Receiver Temperature



Element receiver temperature $\sim$ 28 K

15. Cryogenic PAF : Beam shape measured on 20m Telescope



$$\frac{Tsys}{\eta} \sim 50 \text{ K (bore-side beam)}$$

16. Cryogenic PAF : Current status and future work

- Measured $\frac{Tsys}{\eta} \sim 50$ K
- For $\eta \sim 70\%$ gives $Tsys \sim 35K$

- Work in progress to make element beam shape measurement to compare with estimated η from model.
- Work in progress to make an uncooled array with the ‘right’ element spacing for the GBT