Beating down standing waves with

APERTIF phased array feeds in the WSRT

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SKA 2010

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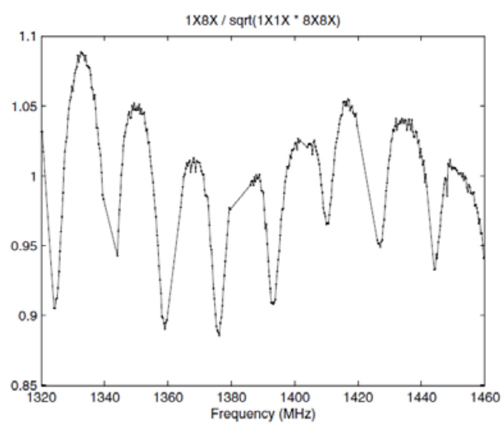
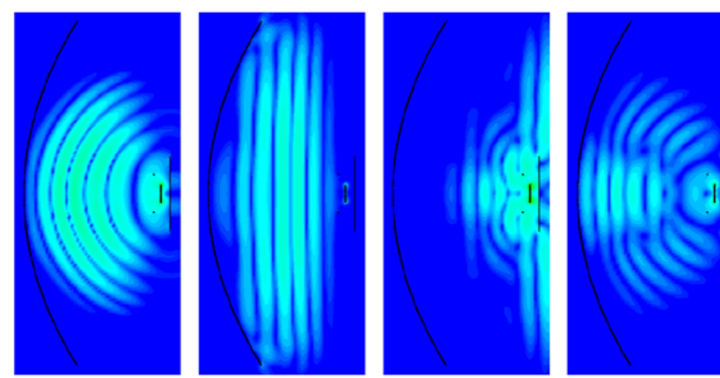
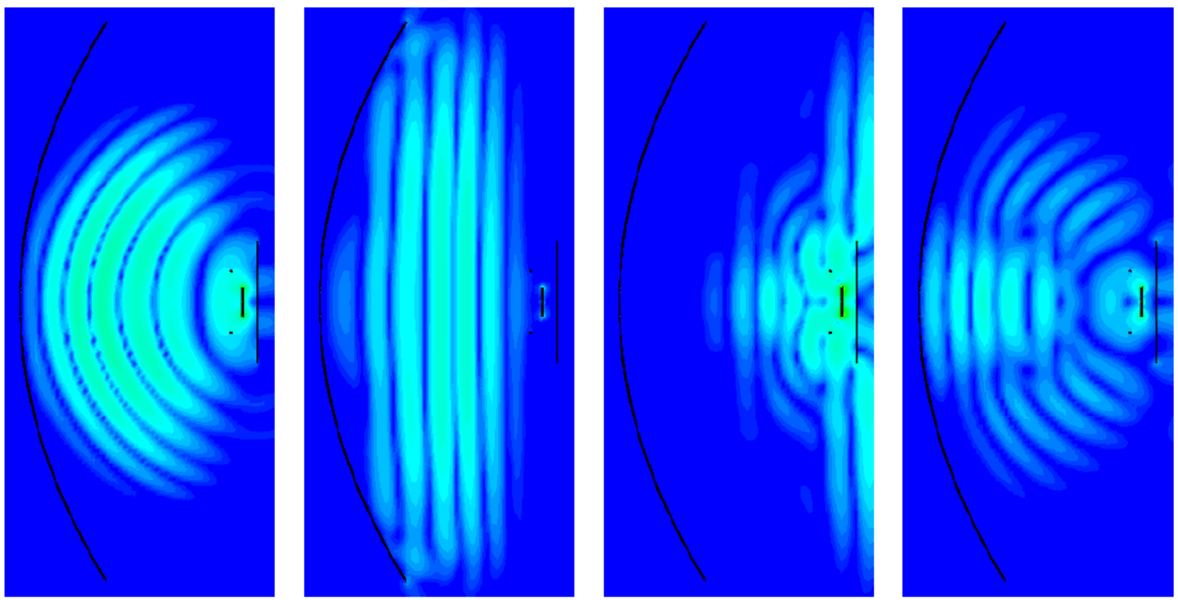




(a) t=3.5ns (b) t=5.7ns (c) t=7.4ns (d) t=8.8ns

Standing wave effect

- Wave ‘bouncing’ between reflector and feed (or sub-reflector)
- Time domain simulation of prime-focus system
- Main contributors:
  - Reflector
  - Scattering behavior of the feed (Radar Cross Section)

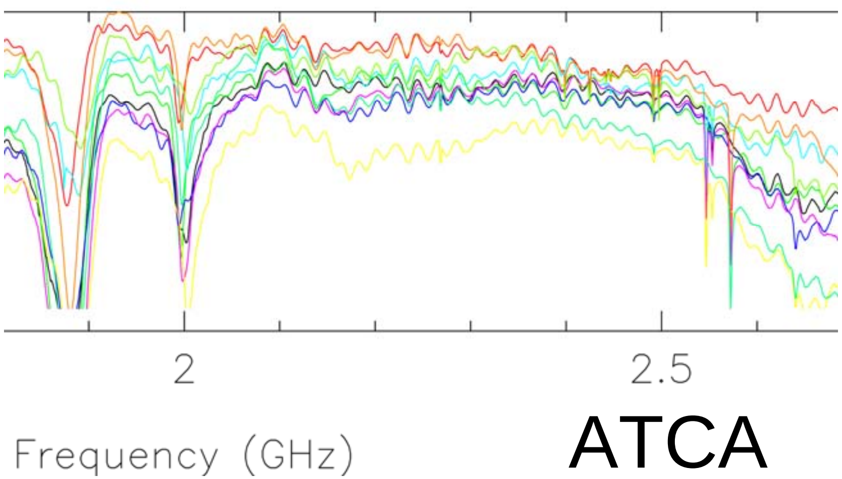


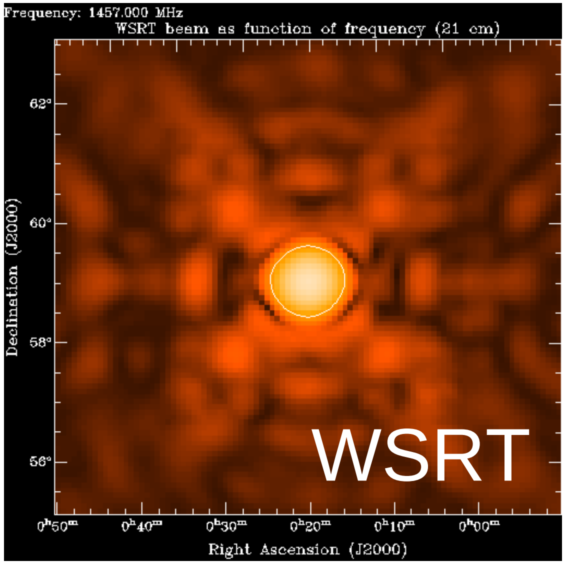
(a) t=3.5ns (b) t=5.7ns (c) t=7.4ns (d) t=8.8ns

Credits: M. Apeldoorn, TU Delft

Impact

- The effect occurs in many reflector systems
- Standing waves cause a varying beam pattern over frequency
  - Off-axis response is position and frequency dependent
  - Different for both polarizations
- Calibration of off-axis sources should take this into account
  - Either calibrate in many narrow bands using simple beam model
  - Or wideband calibration with a complicated beam model





Horn feed

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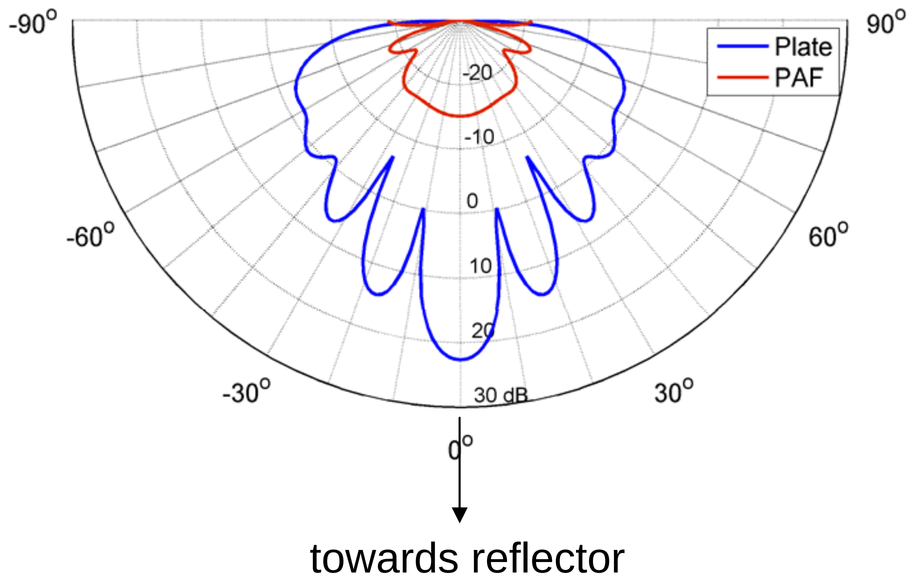
- WSRT Feed cabin, as seen from reflector
- Simulated radar cross section (scattered field) when plane wave incident from reflector

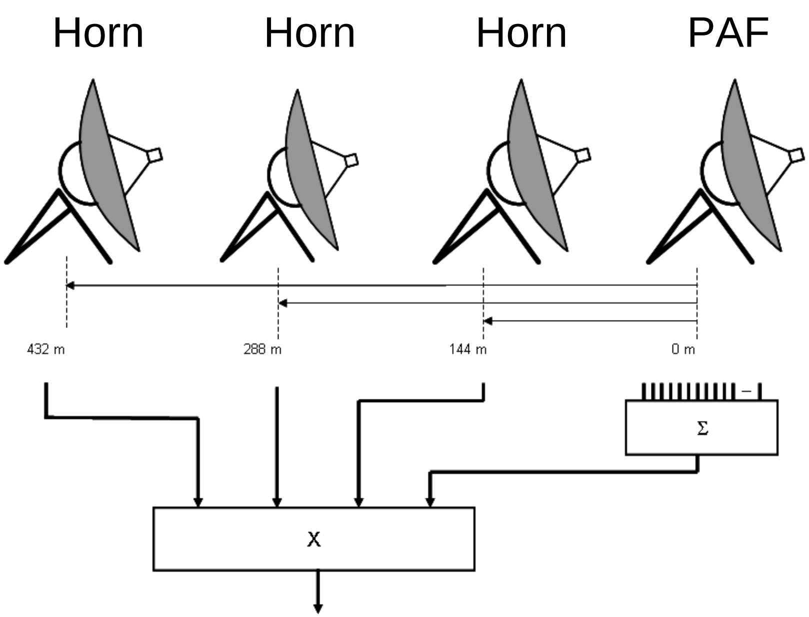


- Phased Array Feed (PAF)
  - Expected to absorb more energy and scatter energy more uniformly

37 dB less energy scattered in forward direction!

Sensitivity measurement

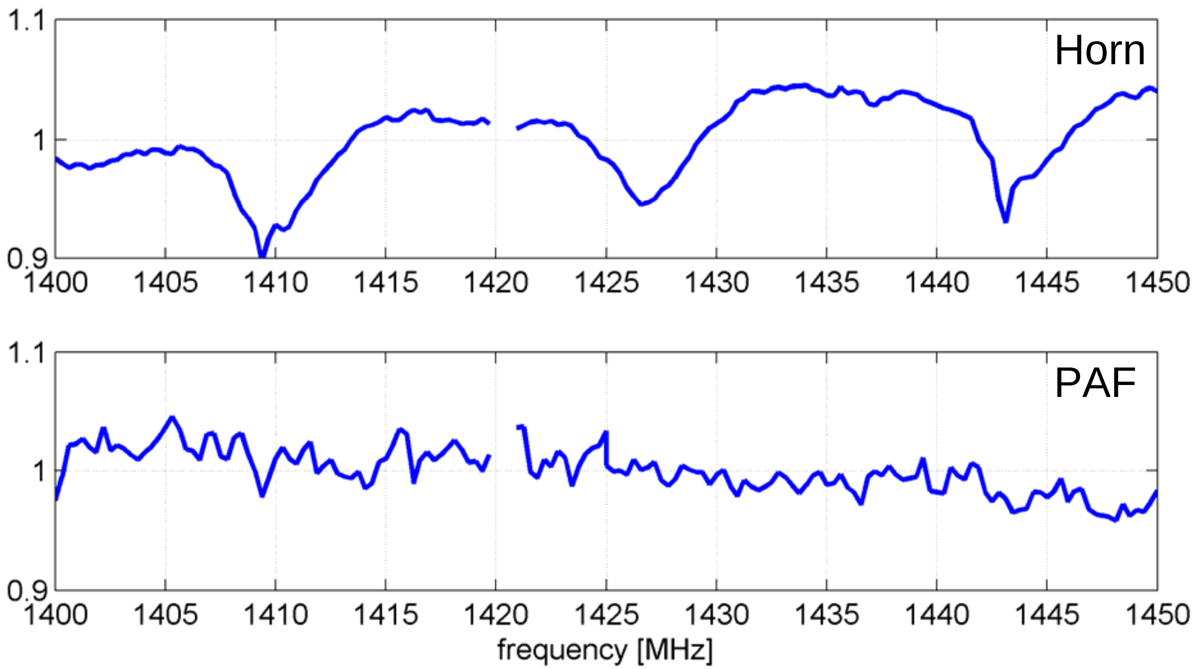
- 4-Dish interferometer: 3 x horn feed, 1 x PAF
- Point dishes to strong point source (3C48)
- Using EVLA Memo 127 (Perley):
  - Solve $(A_e/T_{sys})_{Horn}$ from Horn – Horn cross-correlation
  - Solve $(A_e/T_{sys})_{PAF}$ from Horn – PAF cross-correlation and $(A_e/T_{sys})_{Horn}$

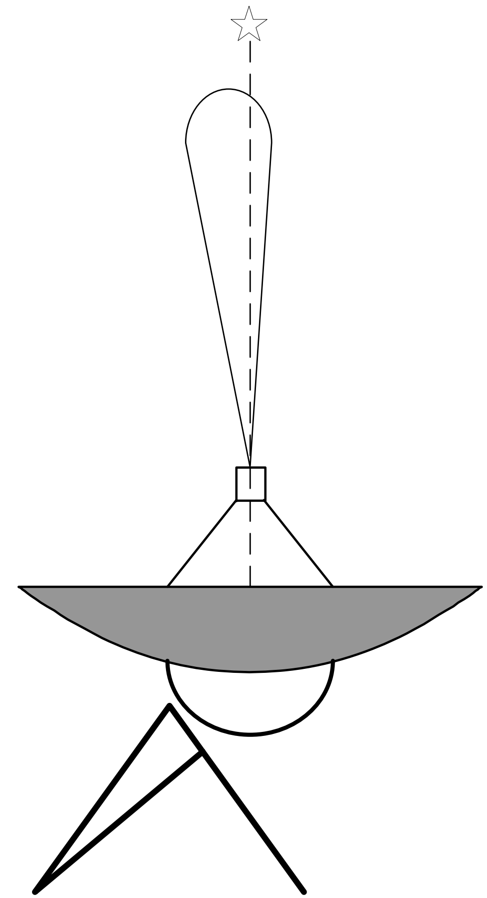


$$\frac{\rho_{i,j}}{\sqrt{\rho_{i,i}\cdot\rho_{j,j}}} = \frac{S}{\sqrt{\left(S+\frac{2k}{\left(A_e/T_{sys}\right)_i}\right)\left(S+\frac{2k}{\left(A_e/T_{sys}\right)_j}\right)}}$$

Single PAF element

- On-axis horn sensitivity (top)
- Single PAF element on-axis sensitivity (bottom)
- Element is slightly off-axis → scanned beam
- All lines scaled to unity mean

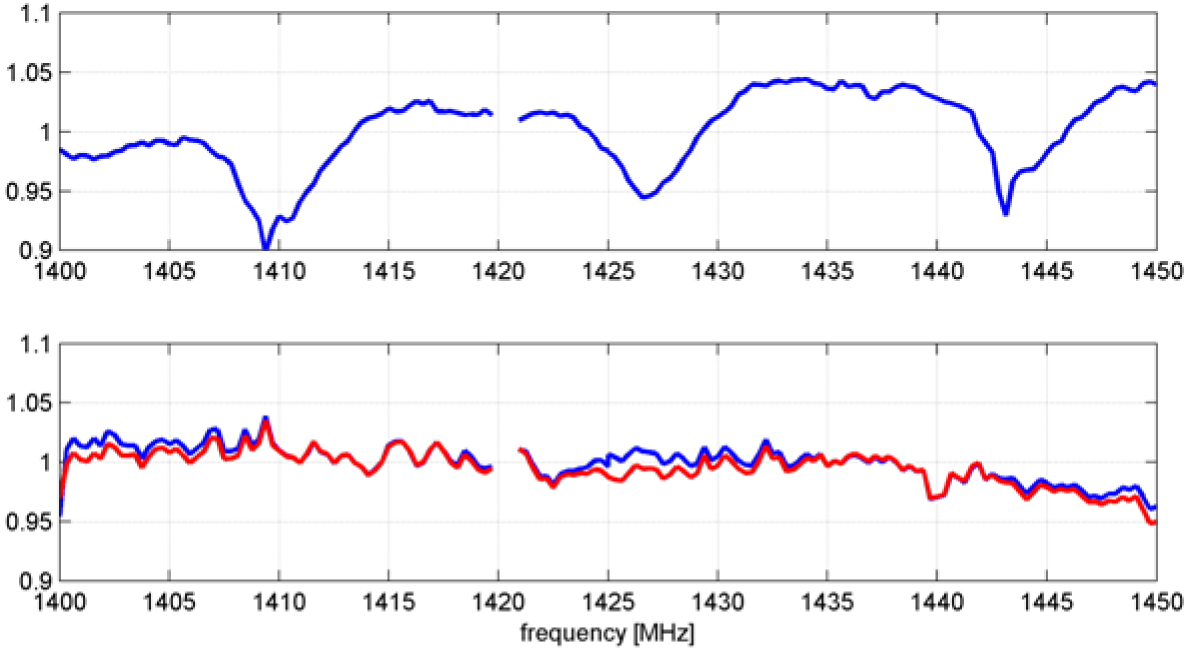


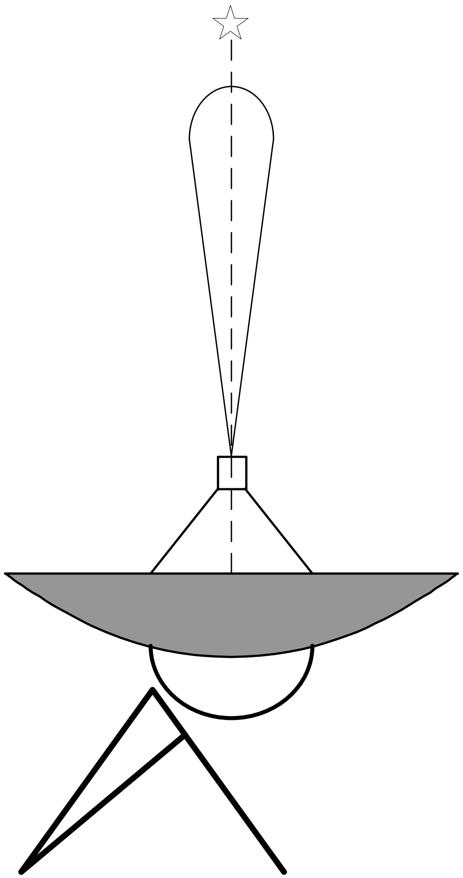


- Slight slope in PAF sensitivity due to narrowing beam

Compound PAF beam

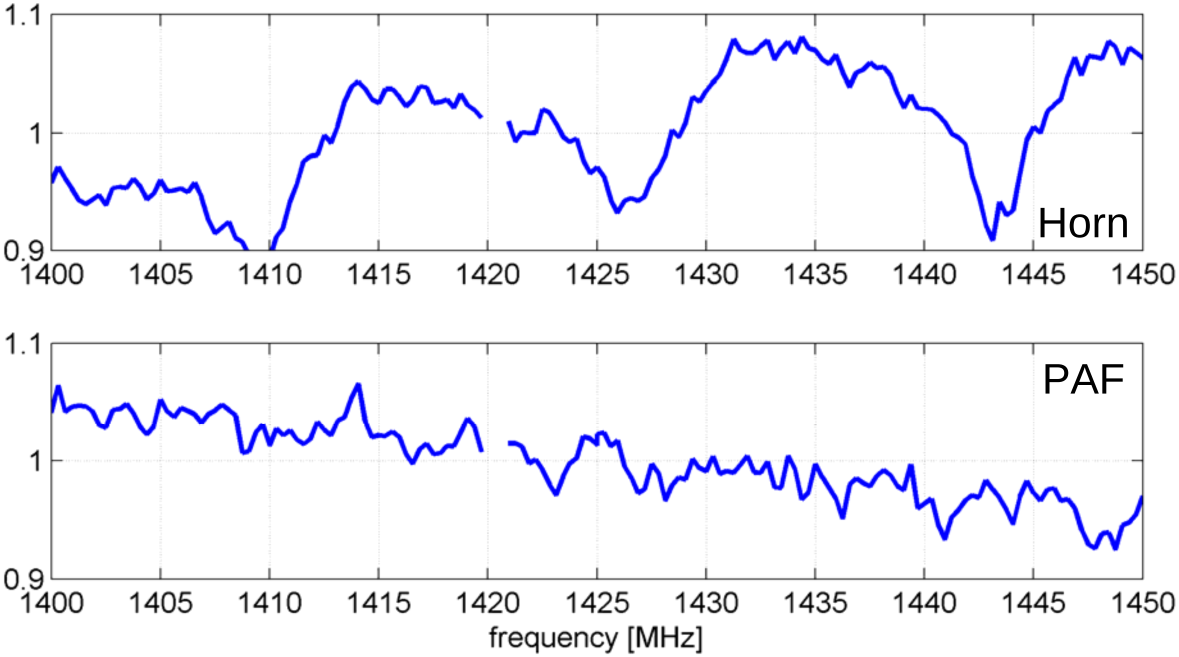
- On-axis horn sensitivity (top)
- On-axis compound PAF beam sensitivity (bottom)
- Weights maximizing sensitivity at every freq point (blue)
- Weights fixed over frequency (red)

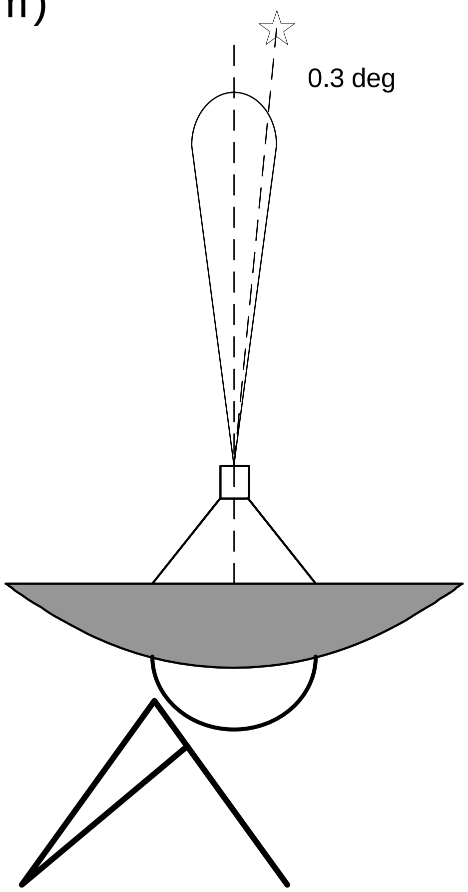




Compound PAF beam @ offset

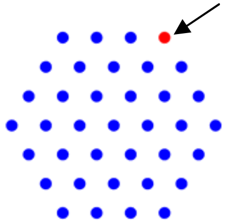
- Horn sensitivity at 0.3 deg offset (top)
- Compound PAF beam sensitivity at 0.3 deg offset (bottom)
- Weights maximizing sensitivity (on-axis)



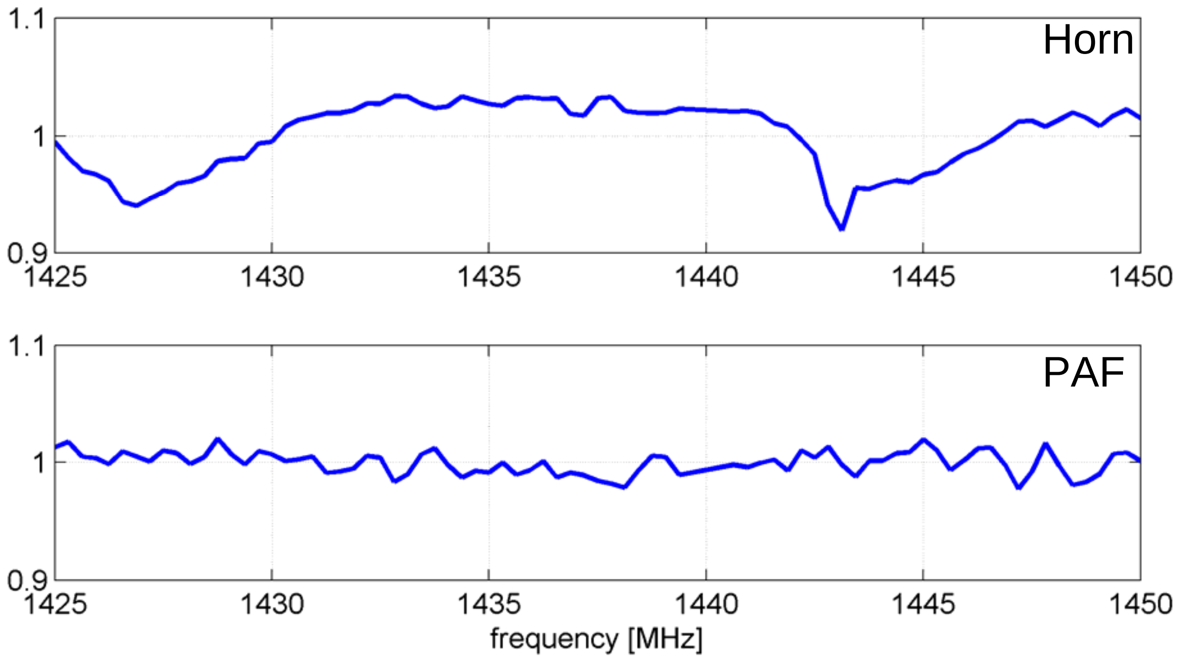


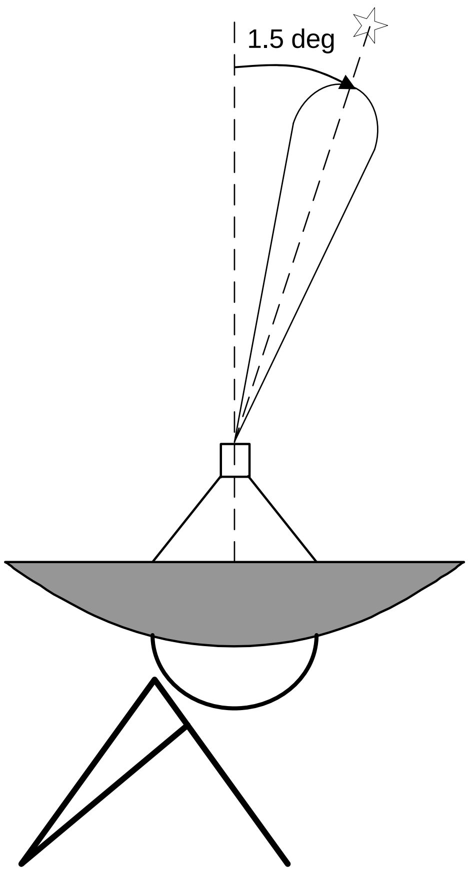
- Noisier due to reduced sensitivity (~ half-power)
- Slope in PAF sensitivity due to narrowing beam

Scanned compound beam



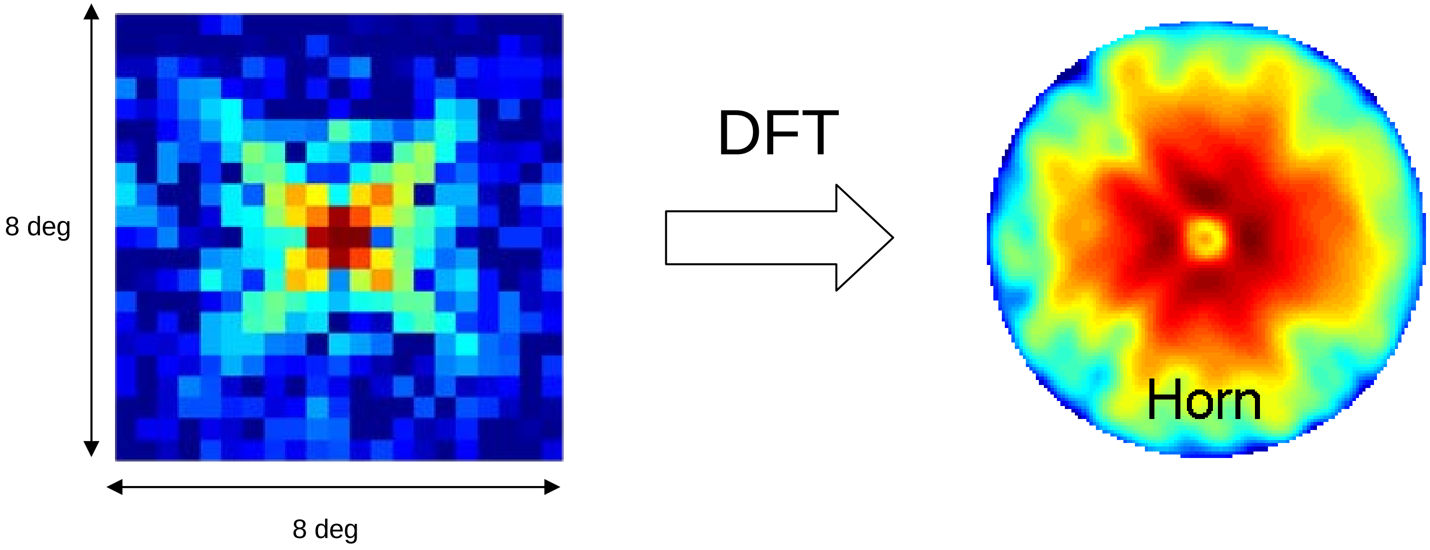
- On-axis horn sensitivity (top)
- 1.5° Scanned compound PAF beam sensitivity (bottom)





Holography

- Reference telescope tracking source (Cygnus A)
- Horn and PAF telescope scanned 21 x 21 grid (8 x 8 deg)
- Cross-correlation $\propto$ voltage pattern
- Integration time per point: 0.4 s
- DFT to transform from voltage pattern to aperture field



A four-leaf clover!

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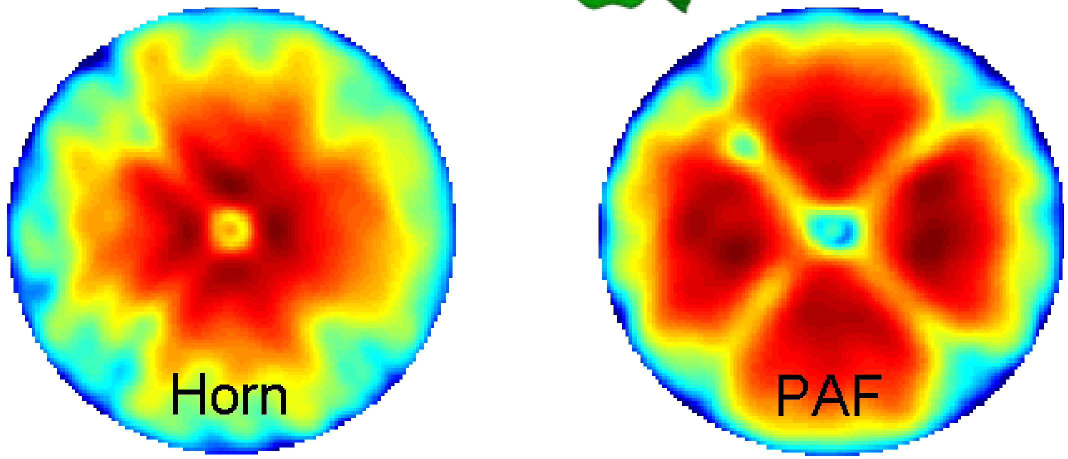
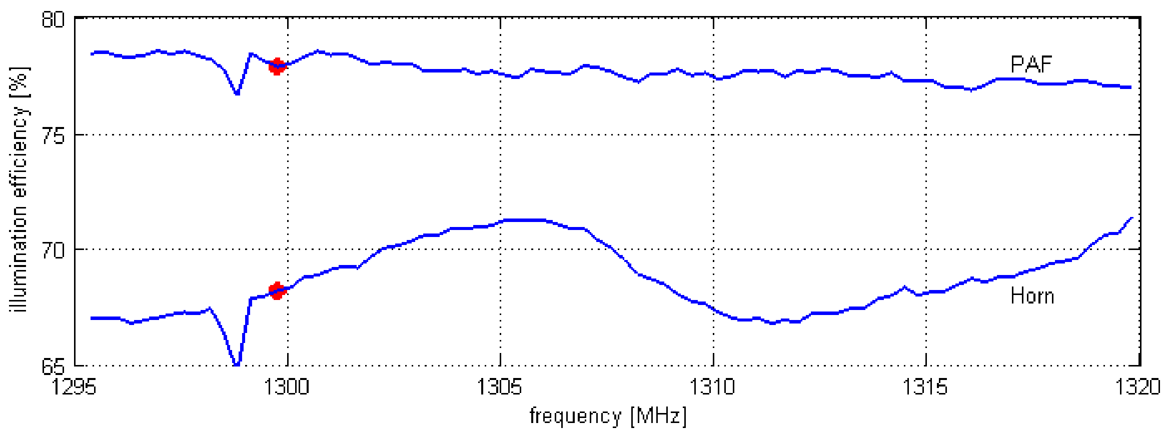


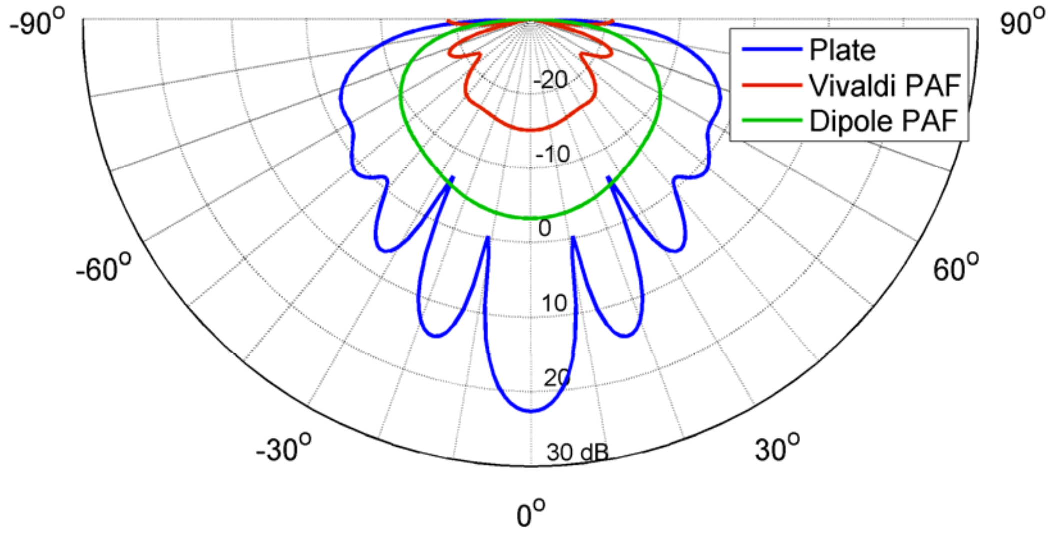
Illumination efficiency [%]



- See the animation at: http://www.astron.nl/dailyimage/main.php?date=20100322

RCS of a dipole array

- Several other PAF groups use dipole-like PAFs (NRAO/BYU, ASKAP)
- Simulated radar cross section of dipole array
  - 0.6λ element spacing



Conclusions

- The radar cross section of the feed (+cabin) is an important factor in the standing wave effect
- The 17 MHz ripple in the WSRT is significantly reduced by replacing the MFFE with a PAF
- The PAF beamformer weights do not contribute to reduction. The ripple is absent in the sensitivity of a single element and the sensitivity with fixed weights over frequency.
- These results have major impact on the APERTIF calibration approach and processing power.