Eliminating sensitivity ripples in prime focus reflectors
with low-scattering Phased Array Feeds

Wim van Cappellen

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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)

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

- 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 \( \frac{A_e}{T_{sys}} \)\(_{Horn} \) from Horn – Horn cross-correlation
  - Solve \( \frac{A_e}{T_{sys}} \)\(_{PAF} \) from Horn – PAF cross-correlation and \( \frac{A_e}{T_{sys}} \)\(_{Horn} \)

\[
\rho_{i,j} \sqrt{\rho_{i,i} \rho_{j,j}} = \frac{S}{\sqrt{(S + \frac{2kT_{sys,i}}{A_{e,i}})(S + \frac{2kT_{sys,j}}{A_{e,j}})}}
\]
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!
Weighting schemes

Max SNR

$\eta_{\text{ill}} \sim 76\%$

CFM (Max Ae)

$\eta_{\text{ill}} \sim 79\%$

Single Element
Holog phase

Max SNR

CFM (Max Ae)

Single Element
RCS of a dipole array

- Several other PAF groups use dipole-like PAFs (NRAO/BYU, ASKAP)

- Simulated radar cross section of dipole array
  - $0.6\lambda$ 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.