Interference Mitigation Using a Multiple Feed Array for Radio Astronomy

Chad Hansen, Karl F. Warnick, and Brian D. Jeffs
Department of Electrical and Computer Engineering
Brigham Young University
Provo, UT

J. Richard Fisher and Richard Bradley
National Radio Astronomy Observatory
Green Bank, West Virginia

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RFI Mitigation

Techniques:

- Spatial filtering
  - Requires multiple spatially separated looks at interferer
- Adaptive cancellation
- Time blanking
Array Feed - Design Goals

- **High Sensitivity**
  
  Sensitivity = \( \frac{\text{Gain}}{\text{System Temperature}} \) \( \sim \) SNR

- **Beam steering**
  - Beam shape control
  - Gain stability

- **RFI Mitigation**
Previous Work: Array Feeds

- Most implementations: 1 feed = 1 beam

  e.g: Parkes HIPASS Array – Multibeam feed.
19-element Array at NRAO

- Electrically small elements
- Hexagonal array
- Beamforming
Approach

- 25 meter paraboloid

- GRASP8 (TICRA) PTD reflector analysis software

- Array weights – three methods:
  - Conjugate field match (CFM)
  - Brute force sensitivity optimization
  - Max SNR/LCMV (beamforming + RFI nulling)

- Compare to single waveguide feed
Assumptions

Array:
- Operating frequency: 1612 MHz
- 7 and 19-element hexagonal arrays with 0.6λ spacing
- Hertzian dipoles
- No mutual coupling between array elements
- Hemispherical element patterns

Noise model:
- Individual LNA noise temperature: 15 K
- Spillover noise: 300K warm ground below reflector
- Atmospheric and cosmic background noise is neglected
Interference Mitigation

max-SNR/LCMV

\[ x_1[n] \]

\[ x_2[n] \]

\[ x_N[n] \]

\[ y[n] \]

Spillover noise

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Sensitivity

- 25 meter reflector
- Boresight beam
Gain and Spillover Efficiency
Reflector Illumination Pattern

![Graph showing gain (dB) vs. degrees from boresight for array feed (optimum) and waveguide feed.]
Steered Beams/Offset Feed

![Graph showing sensitivity versus degrees from boresight for different feed types.](image)

- **Array feed, focal plane**
- **Array feed, 0.25 wavelengths**
- **Array feed, 0.15 wavelengths**
- **Array feed, 0.25 wavelengths**
- **Array feed, CFM**
- **Waveguide feed**

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Focal Field Distribution

Boresight

Beam steered to 0.3°
Results (7 Element Array)

Interferer at 30 degrees, INR=0 dB
Main Beam Distortion

![Graph showing gain vs degrees from boresight]
Interferer at 30 deg, $\text{INR}_{\text{In}}$ changing
Moving Interferer

![Graph showing effective sensitivity vs degrees from boresight]
Interference Rejection

- Low sensitivity corresponds to poor spillover efficiency and gain loss
Signal/Interferer Array Responses

- Angle cosine between interferer and signal response vectors
- Sensitivity decreases when responses are similar
- Sensitivity loss is a grating lobe-like effect
19-element array, moving interferer
Conclusions

• Good sensitivity can be achieved using an array feed

• In the presence of an interferer
  • Interference at all INR levels and all angles was effectively rejected.
  • Main beam distortion occurs due to beam steering/RFI mitigation
  • Sensitivity fluctuates by a few dB with moving angle of arrival

• Future work:
  • Algorithms: beam shape control, defocusing (larger arrays)?
  • Broadband elements
  • Mutual coupling
  • Prototype…
Gain and Spillover Efficiency

![Graph showing Gain and Spillover Efficiency vs. Degrees from Boresight]

- **Gain**
  - Blue line: Array feed, focal plane
  - Dashed line: Array feed, −.25 wavelengths
  - Orange line: Array feed, +.15 wavelengths
  - Green line: Array feed, −.25 wavelengths
  - Pink line: Array feed, +.25 wavelengths
  - Black dashed line: Array feed, CFM
  - Black dashed line: Waveguide feed

- **Spillover Efficiency (%)**
  - Green line: Array feed, focal plane
  - Orange line: Array feed, −.25 wavelengths
  - Blue line: Array feed, +.15 wavelengths
  - Black dashed line: Array feed, −.25 wavelengths
  - Black dashed line: Array feed, +.25 wavelengths
  - Black dashed line: Array feed, CFM
  - Black dashed line: Waveguide feed

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Multiple Beams

$\theta = 0.3^\circ$

$\theta$-cut

Degrees from Boresight

Gain (dBi)

Degrees from Boresight

Gain (dBi)
Sum of outer weights
Center element, $\text{INR}_{\text{IN}}$
Assumptions

\[ S = \frac{G}{T_{\text{rec}} + T_{\text{spill}}} \]

\[ T_{\text{rec}} = \sum_{i=1}^{N} (W_i)^2 T_i \]