Simulated Response of a 19 Element PAF for the Arecibo Radio Telescope PAF Feasibility Study

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Collaborators
AO PAF Feasibility Study

- Karl F. Warnick and Brian D. Jeffs (BYU)
- David Smith (MERLAB)
- Ganesh Rajagopalan, Phil Perilat, Dana Whitlow, and AO tech Staff. (AO)
Overview

- Introduction:
- Arecibo’s Shaped Optics and FOV
- Arecibo’s PAF Feasibility Study
- Simulations and Preliminary Results
- Conclusions
Introduction

• Most Sensitive Single Dish L-Band Radio telescope in the World.

• Main Spherical Reflector is 305 m in diameter
Introduction
Introduction
Introduction

• Most Sensitive Single Dish L-Band Radio Telescope in the World.

• Main Spherical Reflector is 305 m in diameter.

• Maximum scanning angle with respect to zenith: ±15°.
Arecibo Gregorian Corrector
Arecibo Gregorian Corrector
Introduction

- Main Spherical Reflector is 305 m in diameter
- Maximum scanning angle with respect to zenith: ±15°
- Arecibo Gregorian Corrector: Dual shaped Reflector System to correct for spherical aberration and produces a uniform aperture Illumination.
- Effective Elliptical Illumination of 237 x 207 m
Aperture Illumination and Radiation Pattern  L-Band @ 1.375 GHz

Aperture illumination

Far Field Radiation Pattern [dB]

HPBW=200 x 230"

30.4’ x 30.4’
ALFA

Arecibo L-Band Feed Array
ALFA

Total Incoherent Multi Beam Pattern

TE11 Mode Horn Ø25.0 cm x 26.0 cm c-c

Calculated Beam Pattern

Measured Beam Pattern

Image by Carl Heilis, Dec 2004
Beyond ALFA
Beyond ALFA

HPBW=200" x 230"

AO
Beyond ALFA

HPBW=200" x 230"

AO

ALFA

~660"

~770"

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PHASED ARRAY ANTENNA SYSTEMS FOR RADIO ASTRONOMY
Brigham Young University, Provo UT May 3-5, 2010

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Beyond ALFA

HPBW = 200" x 230"

AO

ALFA

AO PAF

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Survey Speed:

\[ SVS = N_b \Omega_b BW \left( \frac{A_{\text{eff}}}{T_{\text{sys}}} \right)^2 \]
Survey Speed:

\[ SVS = N_b \Omega_b BW \left( \frac{A_{\text{eff}}}{T_{\text{sys}}} \right)^2 \]

- \# of beams
- Bandwidth
- Beam Solid Angle
Survey Speed: Enter AO PAF

\[ SVS = N_b \Omega_b BW \left( \frac{A_{\text{eff}}}{T_{\text{sys}}} \right)^2 \]

<table>
<thead>
<tr>
<th>L-Band</th>
<th>( N_b )</th>
<th>( \Omega_b )</th>
<th>( BW )</th>
<th>( A_{\text{eff}} )</th>
<th>( T_{\text{SYS}} )</th>
<th>( \frac{A_{\text{EFF}}}{T_{\text{SYS}}} )</th>
<th>( \frac{SVS}{A_{\text{SYS}}} )</th>
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<tr>
<td>AO</td>
<td>1</td>
<td>0.0028</td>
<td>300</td>
<td>32750</td>
<td>27</td>
<td>1213</td>
<td>1</td>
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<tr>
<td>ALFA</td>
<td>7</td>
<td>0.0028</td>
<td>300</td>
<td>32750</td>
<td>27</td>
<td>1213</td>
<td>7</td>
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<td>AO FPA</td>
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<td>0.0028</td>
<td>300</td>
<td>32750</td>
<td>35</td>
<td>936</td>
<td>23.8</td>
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</table>

# of beams: \( N_b \)
Bandwidth: \( \Omega_b \)
Beam Solid Angle: \( BW \)
L-Band: \( A_{\text{eff}} \)
\( T_{\text{SYS}} \): System Temperature
\( A_{\text{EFF}}/T_{\text{SYS}} \): Effective Antenna Temperature Ratio
\( SVS/A_{\text{SYS}} \): Survey Speed Ratio
Arecibo’s AO FPA Architecture Components

1. Gregorian Optics
2. Array Elements
3. LNA’s
4. Cryogenics
5. Signal Transport
6. Beam Former
7. Spectrometer
Arecibo’s AO FPA Architecture Challenges

- FOV
- Tsys
- Bandwidth
Available Field of View
with Arecibo’s a Shaped Optics
FOV in the Gregorian Focal Plane

Gregorian Dome

Incidence 0°

Main Spherical Reflector

Ray Paths
FOV in the Gregorian Focal Plane

Incidence 0°

Main Gregorian Focus

Tertiary Mirror
FOV in the Gregorian Focal Plane

256 arcsec Right
FOV in the Gregorian Focal Plane

- Incidence 0°
- 256 arcsec Right
- 256 arcsec Left
FOV in the Gregorian Focal Plane

Incidence 0°

256 arcsec Right

256 arcsec Left

1. CAUSTICS

ØFOV
AO Gregorian FOV: Scanning Losses

Scanning Losses in Focal Plane

Relative Power [dB]

FOV radius [HPBW]
AO Gregorian FOV: Scanning Losses

Scanning Losses in Focal Plane

Relative Power [dB]

FOV radius [HPBW]

ALFA 7 Pixels
ÆFOV: 3 Beams

Xscn, 1.375 GHz
Yscn, 1.375 GHz
Xscn, 5.000 GHz
Yscn, 5.000 GHz
Xscn, 7.000 GHz
Yscn, 7.000 GHz
Xscn, 9.000 GHz
Yscn, 9.000 GHz
Xscn, 900MHz
Yscn, 900MHz
FOV in the Gregorian Focal Plane

ALFA 7 Pixels

256 arcsec Right

256 arcsec Left

ΦFOV
FOV in the Gregorian Focal Plane

ALFA 7 Pixels

256 arcsec Right

256 arcsec Left

AO FPA

Ø FOV
AO Focal Plane Field Distribution
from PO: On Axis, Wavelength: 21 cm

Co-Polar Intensity [dB]

Co-Polar Phase Distribution
AO Focal Plane Field Distribution
from PO: 430 arcsec, Wavelength: 21 cm

Co-Polar Intensity [dB]

Co-Polar Phase Distribution
Exploring the Available: FOV at AO Gregorian using PAF’s
AO PAF Feasibility Study

Exploring AO FOV with 19 BYU dipole PAF

The PAF:

Single Polarization 19 BYU Dipole PAF
AO PAF Feasibility Study
Exploring AO FOV with 19 BYU dipole PAF

How: FOV Scanning

AO Rotary Floor
AO PAF Feasibility Study
Exploring AO FOV with 19 BYU dipole PAF
AO PAF Feasibility Study
Exploring AO FOV with 19 BYU dipole PAF

The Scanning Arm: Bottom View

Cable Wraps

19 BYU PAF
AO PAF Feasibility Study

PAF Positioner/Scanning Arm

The Scanning Arm: Detail View

Cable Wraps

19 BYU PAF
AO PAF Feasibility Study

PAF Positioner Scanning Arm

The Scanning Arm: Detail View

- Cable Wraps
- Focus Stage

19 BYU PAF
AO PAF Feasibility Study

PAF Positioner/Scanning Arm

The Scanning Arm: Detail View

Focus Stage

Azimuth Stage

Radial Stage

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AO PAF Feasibility Study

PAF Positioner/Scanning Arm

- Design by Dr. David Smith
- 3 degrees of Freedom
- Radial Stage Range: 600 mm (+PAF Diam/2)
- Azimuth: +/- 180 degrees
- Focus Stage: -100 mm to +300 mm
- Weight: ~50 Kg
The Scanning Arm: Side View

- Azimuth + Focus Drive
- Electronic Cabinets
- PAF work envelope

- 8°
- 400 mm
- 1800 mm
AO PAF Feasibility Study

PAF Positioner Arm Work Envelope

The Scanning Arm: Side View

Azimuth + Focus Drive

Electronic Cabinets

PAF work envelope

400 mm

1800 mm
Exploring the Available FOV at AO using PAF’s: Simulations I
For each individual Dipole:

- Embedded Dipole Radiation Pattern
- Far Field Antenna Pattern Through AO Optics
Methodology

For each individual Dipole:
- Embedded Dipole Radiation Pattern
- Far Field Antenna Pattern Through AO Optics

PAF Beam Forming
- Mutual Coupling
- Noise model
Coordinates,
Coordinates,
Coordinates…
Arecibo Focal Phased Array Feasibility Study

Arecibo Telescope Coordinates

AO Top View (Gregorian Dome Removed)

AO Side View (Gregorian Dome Removed)

Plane of Symmetry: Z-X
Arecibo Focal Phased Array Feasibility Study

Array’s Coordinate System in Focal Plane

- Dipole Orientation
- Focal Plane X-axis
- Focal Plane Y-axis
- 644 mm
- 112.4 mm

Dipoles Out of the page
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Pointing: Case B0

Bore-sight into the page

V(X)-axis

U(Y)-axis

V(X)-axis [arcmin]

U(Y)-axis [arcmin]
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B0

Bore-sight into the page

U(Y)-axis

V(X)-axis

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Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B0

Bore-sight into the page

42.61 arcmin

U(Y)-axis

V(X)-axis

coma away from center
Exploring the Available FOV at AO using PAF’s: Simulations II
Arecibo Focal Phased Array Feasibility Study

PAF No Overlapping Positions in Focal Plane: Cases B0 to B6
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Directions: Cases B0 to B6

Bore-sight into the page
Arecibo Focal Phased Array Feasibility Study

**PAF Maps in the Sky: Cases B0 to B6**

<table>
<thead>
<tr>
<th>Case</th>
<th>Map Center $\Delta \theta_i$ [arcmin]</th>
<th>Map Center $\phi_i$ [deg]</th>
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<tbody>
<tr>
<td>B0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B1</td>
<td>14.64</td>
<td>-21.90</td>
</tr>
<tr>
<td>B2</td>
<td>13.32</td>
<td>-87.66</td>
</tr>
<tr>
<td>B3</td>
<td>16.78</td>
<td>-150.84</td>
</tr>
<tr>
<td>B4</td>
<td>17.57</td>
<td>161.83</td>
</tr>
<tr>
<td>B5</td>
<td>13.67</td>
<td>103.28</td>
</tr>
<tr>
<td>B6</td>
<td>14.22</td>
<td>34.88</td>
</tr>
</tbody>
</table>

$\Delta \theta_i = 14.64'$
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B0
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B1
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Mosaic: Case B2

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PAF Sky Beam Mosaic: Case B5
PAF Sky Beam Mosaic: Case B6
Arecibo Focal Phased Array Feasibility Study

**PAF Sky Beam Patterns:** Cases B0 to B6

Separation x3.5

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x3.5

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x2.8

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x2.5

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x2.5

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x2.0

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x1.0

Total Incoherent Beam Patterns
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x1.0
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

Separation x1.0

U(Y)-axis [arcmin]

V(X)-axis [arcmin]
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6
Arecibo Focal Phased Array Feasibility Study

PAF Sky Beam Patterns: Cases B0 to B6

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Beam Forming Simulation
Preliminary Results
PAF NO Overlapping Positions in Focal Plane: Cases B0 to B6
Arecibo Focal Phased Array Feasibility Study

PAF Overlapping Positions in Focal Plane:

Cases B0 to B6 + C1 to C6
Beam Formed PAF Pattern

- Boresight beam pattern
- HPBW is 2.8 arcmin (ideally 2.9x3.3 arcmin)
BeamFormed $\eta_A$ and $T_{sys}$ over FOV

- Aperture Efficiency
- Modeled beam equivalent $T_{sys}$ with 15 K LNA’s

$\Delta Z = 0 \text{cm}$
BeamFormed $\eta_A$ and $T_{sys}$ over FOV

- Aperture Efficiency
- Modeled beam equivalent $T_{sys}$ with 15 K LNA’s

$\Delta Z = +4 \text{cm}$
BeamFormed $A_{eff}/T_{sys}$ over FOV

- Sensitivity as a function of beam steering angle
- Maximum value for each steering direction that is achieved over the 13 array positions
BeamFormed $A_{eff}/T_{sys}$ over FOV

- Sensitivity as a function of beam steering angle
- Maximum value for each steering direction that is achieved over the 13 array positions

$\Delta Z = +4\text{cm}$
Conclusions

- We have started the PAF feasibility Study of AO Shaped Optics
- The PAF positioner is being fabricated, as well BYU’s single/dual pol PAF.
- We have made a series of simulations to calculate the expected performance of BYU’s 19 PAF at Arecibo’s Focal plane, based on the simulated pattern calculations of each of the 19 BYU dipoles.
- We obtained far field pattern data for 133 no overlapping locations of dipoles in the focal plane
- From the sensitivity plot, the 1 dB FOV (80% of peak sensitivity) is roughly 16 arcmin in diameter
- Measuring campaign of a Shaped Optics with a PAF by mid June.