Design and Analysis of Low Frequency Strut Straddling Feed Arrays for EVLA Reflector Antennas

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URSI NRSM – Jan 7, 2011

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Expanded Very Large Array (EVLA)

EVLA consists of 27 25-meter (82 ft) diameter Cassegrain reflector antennas

- Frequency bands in the original design (1981):
  - 21 cm (1.5 GHz)
  - 6 cm (5 GHz)
  - 2 cm (15 GHz)
  - 1.3 cm (23 GHz)

- Additional low frequency capabilities implemented:
  - 90 cm (327 MHz): completed by 1989
  - 4 m (74 MHz): completed by 1997
New Low Frequency System (LFS) Proposed for the EVLA*

- Contiguous coverage to frequencies as low as 50 MHz
- Additional feeds required
- Additional feeds should not increase blockage and effect high frequency observation
- Focus of this presentation is to design low frequency feed for covering frequencies < 100 MHz

What is special at low frequencies?

At low frequencies....

- Galactic noise can dominate internal noise of the system.
- Improving impedance mismatch efficiency (IME), i.e., the matching between the antenna and the connected electronics does not necessarily improve sensitivity.
- Simple dipole-like antennas can offer large usable bandwidth from a sensitivity perspective.

For example: Eight-meter-wavelength Transient Array (ETA), Long Wavelength Array (LWA), Low Frequency Array for Radio Astronomy (LOFAR). All of these telescopes use dipole like antennas based on this principle.
What is special at low frequencies?

Distribution of power density (dB) in the focal plane of a reflector antenna (comparable in size to an EVLA reflector) wrt power density at the focus

In a reflector antenna available power spreads away from the focal region as frequency is decreased.
New Feed Design: Strut Straddling Feed Array

2 key factors at low frequencies:
- Usable sensitivity over a large bandwidth with dipole antennas.
- Spreading of the available power away from the focal region.

New design:
Dipole Feeds mounted between adjacent struts.

Advantage:
Presumably reduced blockage

Signals from the dipoles are multiplied by combining coefficients, $b_n$, and then combined.
Background: An Electromagnetic Model of an EVLA Antenna

- Origin at focus
- Axis along $-z$-axis
- $z=0$ is the focal plane

Required for Evaluation of Performance

Wire Grid Model for MoM Analysis
Baseline of performance:
Existing 4-m System on the EVLA

• Crossed dipoles (3/16 in.) in front of subreflector

• Aperture efficiency has been estimated to be 15-25%

• Sensitivity reduced by 6% at 1.5 GHz

• As a result dipoles are intermittently mounted
Aperture Efficiency Estimation using MoM

Support wire co-polarized

Support wires

Support wire cross-polarized

Support wires

Dipole

Asymmetric pattern due to tilted subreflector

$A_e = \frac{29\%}{\%}$

$A_e = \frac{11\%}{\%}$
Analysis of Sensitivity of Existing EVLA 4-m System

- Our model of the existing EVLA 4-m system

- Sensitivity analysis in terms of system equivalent flux density (SEFD)
  - Source power flux spectral density (W m\(^2\) Hz\(^{-1}\)) which yields signal-to-noise ratio (SNR) of unity at the output of the system.

\[
\begin{align*}
Z_L &= 100 \, \Omega \\
T_{\text{internal}} &= 250 \, \text{K}
\end{align*}
\]

\[Z_L\] and \[T_{\text{internal}}\] are selected to be comparable to other low frequency systems that employ dipole like antennas, e.g., LWA.
Performance Baseline: System Equivalent Flux Density (SEFD) Estimation of the Existing EVLA 4-m System

Performance of new design will be compared with these results.

Subreflector in full retracted position

Uniform $T_{\text{sky}}$ assumed
Proposed New Low Frequency (< 100 MHz) Feed for the EVLA:
Strut Straddling Feed Array

Signals from the dipoles are multiplied by combining coefficients, $b_n$ and then combined.

74 MHz resonant dipoles (3/8 in.) are located between adjacent struts.
Strut Straddling Feed Array Design: Location of Dipoles

Dipoles positioned between adjacent struts.

Which plane?

4 dipoles combined

$b_n$ selected to maximize SNR

Lowest SEFD at $z=-1.0$ m
Strut Straddling Feed Array at z=-1.0 m

SEFD (log_{10} Jy) vs. Freq (MHz)

- **Existing EVLA 4-m System Model**
- **Single Ring @ z=-1.0 m with Optimized Beamforming Coeffs.**

<table>
<thead>
<tr>
<th>Freq</th>
<th>Mag $b_n$</th>
<th>Phase $b_n$ (rad)</th>
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<td>50</td>
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</table>
Strut Straddling Feed Array at $z=-1.0$ m

![Graph showing SEFD (log_{10} Jy) vs. Frequency (MHz). The graph includes lines indicating the Existing EVLA 4-m System Model, Single Ring @ $z=-1.0$ m with Optimized Beamforming Coeffs, and Single Ring @ $z=-1.0$ m, Combined with Fixed Length (Equal) Cables.](image)
Double Ring of Strut Straddling Feed Array

Possible improvement to single ring: Double ring of dipoles

Location of the dipole rings: 
z = -1.0 m and z = -2.25 m
Double Ring at z=-1.0 m and z=-2.25 m

![Graph showing SEFD (log_{10} Jy) vs. Freq (MHz) for different models.](graph.png)

- **Existing EVLA 4-m System Model**
- **Double Ring at z=-1.0 m & z=-2.25 m with Optimized Beamforming Coeffs.**
Double Ring at \( z = -1.0 \) m and \( z = -2.25 \) m

![Graph showing SEFD vs. Freq (MHz) for different configurations of Double Rings. The configurations include:
- Existing EVLA 4-m System Model
- Double Ring at \( z = -1.0 \) m & \( z = -2.25 \) m with Optimized Beamforming Coeffs
- Double Ring at \( z = -1.0 \) m & \( z = -2.25 \) m, Combined with Fixed Length (Non-Equal) Cables]
Summary

• Strut Straddling Feed Array
  – Single Ring
  – Double Ring
• Comparable performance to the existing EVLA 4-m system
• Advantage: Presumably reduced blockage

Future Work:
• Implementation
• Obtain 2 orthogonal polarizations

Acknowledgements:
Jim Ruff (NRAO)
Frazer Owen (NRAO)
Rick Perley (NRAO)