Antennas in Radio Astronomy
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Outline

• Interferometer block diagram
• Antenna fundamentals
• Types of antennas
• Antenna performance parameters
• Receivers

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Importance of the Antenna Elements

• Antenna amplitude pattern causes amplitude to vary across the source.
• Antenna phase pattern causes phase to vary across the source.
• Polarization properties of the antenna modify the apparent polarization of the source.
• Antenna pointing errors can cause time varying amplitude and phase errors.
• Variation in noise pickup from the ground can cause time variable amplitude errors.
• Deformations of the antenna surface can cause amplitude and phase errors, especially at short wavelengths.

General Antenna Types

Wavelength > 1 m (approx)
Wire Antennas
- Dipole
- Yagi
- Helix
- or arrays of these

Wavelength < 1 m (approx)
Reflector antennas

Wavelength ~ 1 m (approx)
Hybrid antennas (wire reflectors or feeds)
Basic Antenna Formulas

Effective collecting area \( A(v, \theta, \phi) \) m²

On-axis response \( A_0 = \eta A \)

\( \eta = \) aperture efficiency

Normalized pattern (primary beam)

\( A(v, \theta, \phi) = A(v, \theta, \phi)/A_0 \)

Beam solid angle \( \Omega = \int A(v, \theta, \phi) \, d\Omega \)

\( A_0 \, \Omega_0 = \lambda^2 \)

Aperture-Beam Fourier Transform Relationship

\( f(u, v) = \text{complex aperture field distribution} \)

\( u, v = \text{aperture coordinates (wavelengths)} \)

\( F(l, m) = \text{complex far-field voltage pattern} \)

\( l = \sin \theta \cos \phi, \quad m = \sin \theta \sin \phi \)

\( F(l, m) = \int f(u, v) \, \exp (2\pi i (u l + v m)) \, du \, dv \)

\( f(u, v) = \int \frac{F(l, m)}{A_0} \, \exp (-2\pi i (u l + v m)) \, dl \, dm \)

For VLA: \( \theta_{3\text{dB}} = 1.02/D \), First null = 1.22/D.

\( D = \text{reflector diameter in wavelengths} \)

Primary Antenna Key Features

+ Beam does not rotate
+ Better tracking accuracy
- Higher cost
- Poorer gravity performance
- Non-intersecting axis

Types of Antenna Mount

+ Lower cost
+ Better gravity performance
- Beam rotates on the sky

Beam Rotation on the Sky

Parallactic angle

Reflector Types

- Prime focus (GMRT)
- Cassegrain focus (AT)
- Offset Cassegrain (VLA)
- Narymsh (DyRO)
- Beam Waveguide (NRO)
- Dual Offset (ATA)
**Reflector Types**

- Prime focus (GMRT)
- Cassagrain focus (AT)
- Offset Cassagrain (VLA)
- Naysmith (OVRD)
- Beam Waveguide (NRO)
- Dual Offset (ATA)

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**Antenna Performance Parameters**

Aperture Efficiency

\[ A_0 = \eta_A \eta_t \eta_r \eta_n \eta_b \eta_s \eta_t \eta_m \]

- \( \eta_A \) = reflector surface efficiency
- \( \eta_b \) = blockage efficiency
- \( \eta_s \) = feed spillover efficiency
- \( \eta_t \) = feed illumination efficiency
- \( \eta_m \) = diffraction, phase, match, loss

\[ \eta_s = \exp(-4\pi\sigma/\lambda)^2 \]

e.g., \( \sigma = \lambda/16 \), \( \eta_s = 0.5 \)

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**Antenna Pointing Design**

- Reflector structure
- Subreflector mount
- Quadrupod
- El encoder
- Az encoder
- Rail flatness
- Foundation

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**Antenna Performance Parameters**

- VLA and EVLA Feed System Design

- Primary Beam

- Error Scatter Pattern

- dB = 10log(power ratio) = 20log(voltage ratio)

- For VLA, \( \eta_s = 1.02/D \), First null = 1.22/D

- Contours: -3, -6, -10, -15, -20, -25, -30, -35, -40 dB

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**Antenna Performance Parameters**

- Pointing Accuracy

\[ \sigma_\theta = \text{rms pointing error} \]

Often \( \sigma_\theta < \theta_{3dB}/10 \) acceptable

Because \( A(\theta_{3dB}/10) \approx 0.97 \)

BUT, at half power point in beam

\[ A(\theta_{3dB}/2) \approx 0.63 \]

For best VLA pointing use Reference Pointing.

\[ \sigma_\theta = 3\text{ arcsec} = \theta_{3dB}/17 \text{ @ 50 GHz} \]
**ALMA 12m Antenna Design**

Surface: $\sigma = 25 \mu$m  
Pointing: $\Delta \theta = 0.6$ arcsec  
Carbon fiber and invar reflector structure  
Pointing metrology structure inside alidade

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**Antenna Performance Parameters**

Polarization

Antenna can modify the apparent polarization properties of the source:  
- Symmetry of the optics  
- Quality of feed polarization splitter  
- Circularity of feed radiation patterns  
- Reflections in the optics  
- Curvature of the reflectors

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**Off-Axis Cross Polarization**

Cross polarized aperture distribution  
Cross polarized primary beam

VLA 4.8 GHz  
cross polarized primary beam

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**Antenna Holography**

VLA 4.8 GHz  
Far field pattern amplitude  
Phase not shown

Aperture field distribution amplitude  
Phase not shown

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**Receivers**

<table>
<thead>
<tr>
<th>Noise Temperature</th>
<th>Matched load</th>
<th>Temp $T$ (°K)</th>
<th>Gain $G$</th>
<th>B/W (GHz)</th>
<th>$P_{\text{out}}$</th>
<th>$P_{\text{in}}$</th>
<th>$P_{\text{in}} = G \times P_{\text{in}}$</th>
</tr>
</thead>
</table>
| Rayleigh-Jeans approximation  
$P_{\text{in}} = n T_{\text{RJ}}$ (W),  
$n = $ Boltzman's constant (1.38*10^{-23} J/°K)  
When observing a radio source  
$T_{\text{rad}} = T_{\text{s}} + T_{\text{th}}$  
Toys = system noise when not looking  
at a discrete radio source  
$T_{\text{rad}} = $ source antenna temperature  
$T_{\text{s}} = n AS(2k\lambda) = KS$  
$S = $ source flux (Jy)  
SEFD = system equivalent flux density  
SEFD = $T_{\text{s}}K_{\text{SEFD}}$ (Jy)  
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** Corrections to Chapter 3 of Synthesis Imaging in Radio Astronomy II**

Equation 3-8: replace $u,v$ with $l,m$  
Figure 3-7: abscissa title should be $\Delta DI$