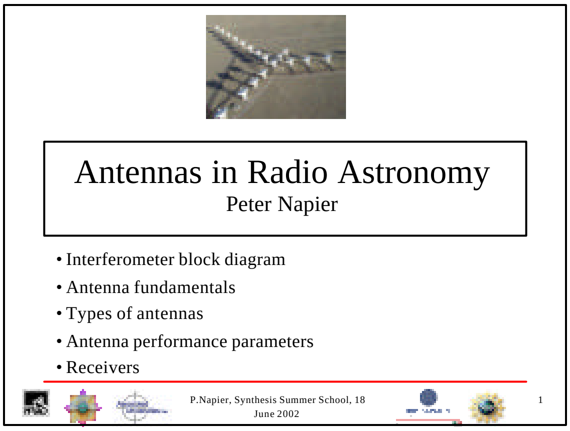
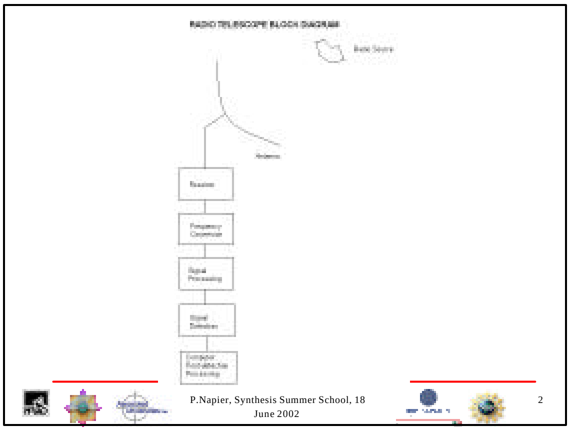
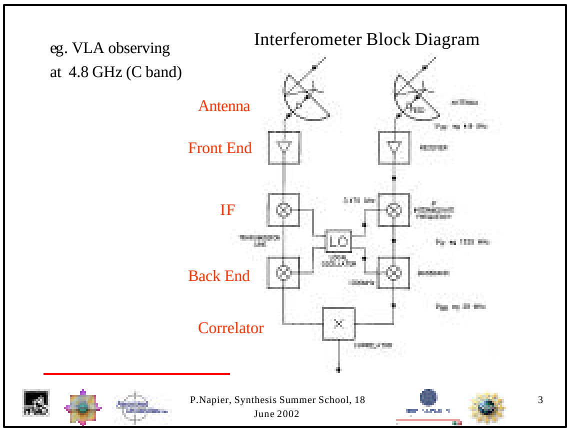


Antennas in Radio Astronomy

Peter Napier

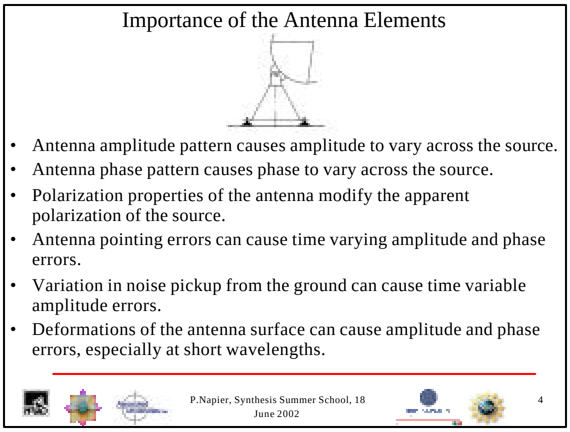
- Interferometer block diagram
- Antenna fundamentals
- Types of antennas
- Antenna performance parameters
- Receivers





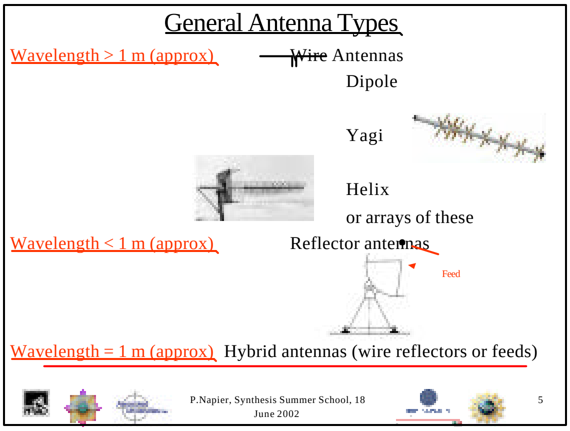
eg. VLA observing
at 4.8 GHz (C band)

Interferometer Block Diagram



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

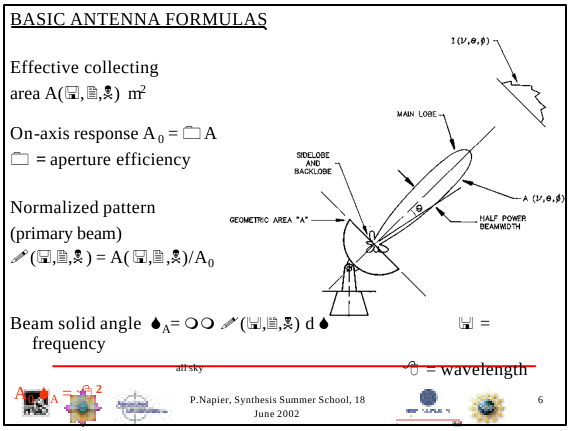
Yagi

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(🖫,🗎,☠) m²

On-axis response A₀ = 🗀 A

🗀 = aperture efficiency

Normalized pattern (primary beam)

✎(🖫,🗎,☠) = A(🖫,🗎,☠)/A₀

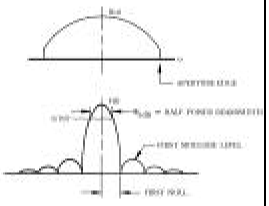
Beam solid angle 🌢ₐ = ❍❍ ✎(🖫,🗎,☠) d 🌢 (all sky)

🖫 = frequency

🖰 = wavelength

A₀ 🌢ₐ = 🖰²

Aperture-Beam Fourier Transform Relationship



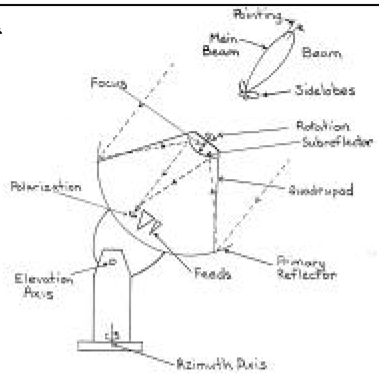
f(u,v) = complex aperture field distribution
u,v = aperture coordinates (wavelengths)

F(l,m) = complex far-field voltage pattern
l = sin📄cos☠ , m = sin📄sin☠

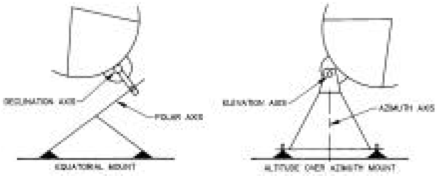
F(l,m) = 🖐🖐$_{aperture}$f(u,v)exp(2👌i(ul+vm)dudv
f(u,v) = 🖐🖐$_{aperture}$F(l,m)exp(-2👌i(ul+vm)dldm

For VLA: 📄$_{3dB}$ = 1.02/D, First null = 1.22/D ,
D = reflector diameter in wavelengths

Primary Antenna Key Features



Types of Antenna Mount



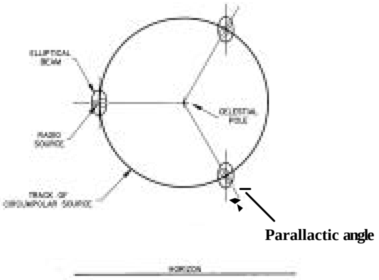
+ Beam does not rotate
+ Better tracking accuracy

- Higher cost
- Poorer gravity performance
- Non-intersecting axis

+ Lower cost
+ Better gravity performance

- Beam rotates on the sky

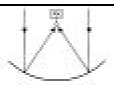
Beam Rotation on the Sky

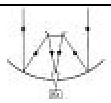


Parallactic angle

REFLECTOR TYPES

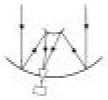
Prime focus
(GMRT)

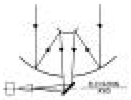




Cassegrain focus
(AT)

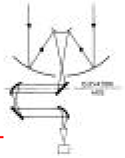
Offset Cassegrain
(VLA)

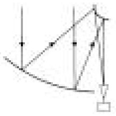




Naysmith
(OVRO)

Beam Waveguide
(NRO)





Dual Offset
(ATA)

REFLECTOR TYPES

Prime focus
(GMRT)

Cassegrain focus
(AT)

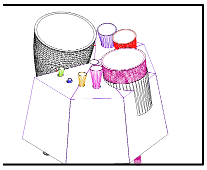
Offset Cassegrain
(VLA)

Naysmith
(OVRO)

Beam Waveguide
(NRO)

Dual Offset
(ATA)

VLA and EVLA Feed System Design



Antenna Performance Parameters

Aperture Efficiency

A$_0$ = 🗀A 🗀 = 🗀$_{sf}$ x 🗀$_{bl}$ x 🗀$_s$ x 🗀$_t$ x 🗀$_{misc}$

🗀$_{sf}$ = reflector surface efficiency

🗀$_{bl}$= blockage efficiency

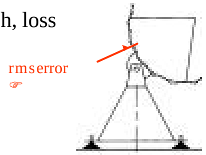
🗀$_s$ = feed spillover efficiency

🗀$_t$ = feed illumination efficiency

🗀$_{misc}$= diffraction, phase, match, loss

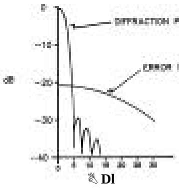
🗀$_{sf}$ = exp(-(4👌☞/🖰)^2)

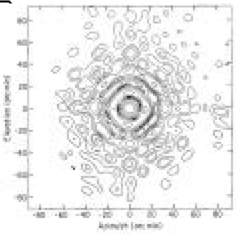
eg ☞ = 🖰/16 , 🗀$_{sf}$ = 0.5



Antenna Performance Parameters

Primary Beam





l=sin(🖹), D = antenna diameter in wavelengths

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

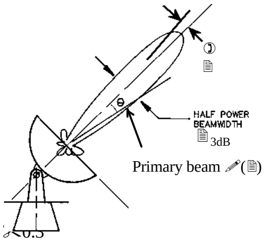
dB = 10log(power ratio) = 20log(voltage ratio)

For VLA: 🖹$_{3dB}$ = 1.02/D, First null = 1.22/D

Antenna Performance Parameters

Pointing Accuracy

✆🖹 = rms pointing error



Primary beam 🖉(🖹)

Often ✆🖹 < 🖹$_{3dB}$ /10 acceptable

Because 🖉(🖹$_{3dB}$ /10) ~ 0.97

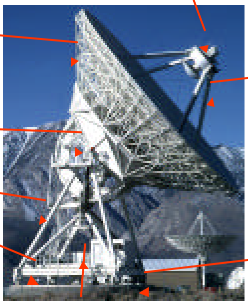
BUT, at half power point in beam

🖉(🖹$_{3dB}$ /2✂ 🖹$_{3dB}$ /10)/ 🖉(🖹$_{3dB}$ /2) = ✂0.5

For best VLA pointing use Reference Pointing.

✆🖹 = 3 arcsec = 🖹$_{3dB}$ /17 @ 50 GHz

Antenna pointing design



Subreflector mount

Reflector structure

Quadrupod

El encoder

Alidade structure

Rail flatness

Foundation

Az encoder

ALMA 12 m Antenna Design

Surface: ☞ = 25 💻m

Pointing: ✆🖹 = 0.6 arcsec

Carbon fiber and invar reflector structure

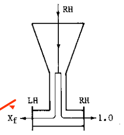
Pointing metrology structure inside alidade

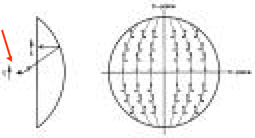
Antenna Performance Parameters

Polarization

Antenna can modify the apparent polarization properties of the source:

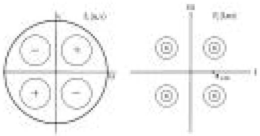
- Symmetry of the optics
- Quality of feed polarization splitter
- Circularity of feed radiation patterns
- Reflections in the optics
- Curvature of the reflectors





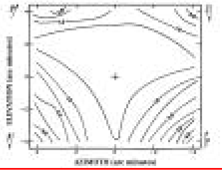
Off-axis Cross Polarization

Cross polarized aperture disribution



Cross polarized primary beam

VLA 4.8 GHz cross polarized primary beam

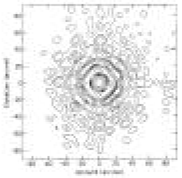


Antenna Holography

VLA 4.8 GHz

Far field pattern amplitude

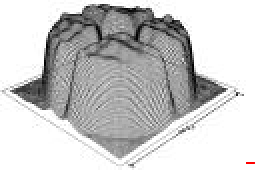
Phase not shown



Aperture field distribution

Amplitude.

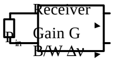
Phase not shown



Receivers

Noise Temperature

Matched load Temp T (°K)



$P_{out} = G*P_{in}$

Rayleigh-Jeans approximation

$P_{in} = k_B T \Delta\nu$ (w) k_B = Boltzman's constant ($1.38*10^{-23}$ J/°K)

When observing a radio source $T_{total} = T_A + T_{sys}$

Tsys = system noise when not looking at a discrete radio source

T_A = source antenna temperature

$T_A = \eta AS/(2k_B) = KS$ S = source flux (Jy)

SEFD = system equivalent flux density

SEFD = Tsys/K (Jy)

EVLA Sensitivities

Band (GHz)	h	T_{sys}	SEFD
1-2	.50	21	236
2-4	.62	27	245
4-8	.60	28	262
8-12	.56	31	311
12-18	.54	37	385
18-26	.51	55	606
26-40	.39	58	836
40-50	.34	78	1290

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 ✍Dl