Antennas & Receivers in Radio Astronomy

Mark McKinnon

Twelfth Synthesis Imaging Workshop
2010 June 8-15

Outline

Context

Types of antennas

Antenna fundamentals

Reflector antennas

Mounts

Optics

Antenna performance

Aperture efficiency

Pointing

Polarization

Receivers

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.

VLA @ 4.8 GHz (C-band)

Interferometer Block Diagram

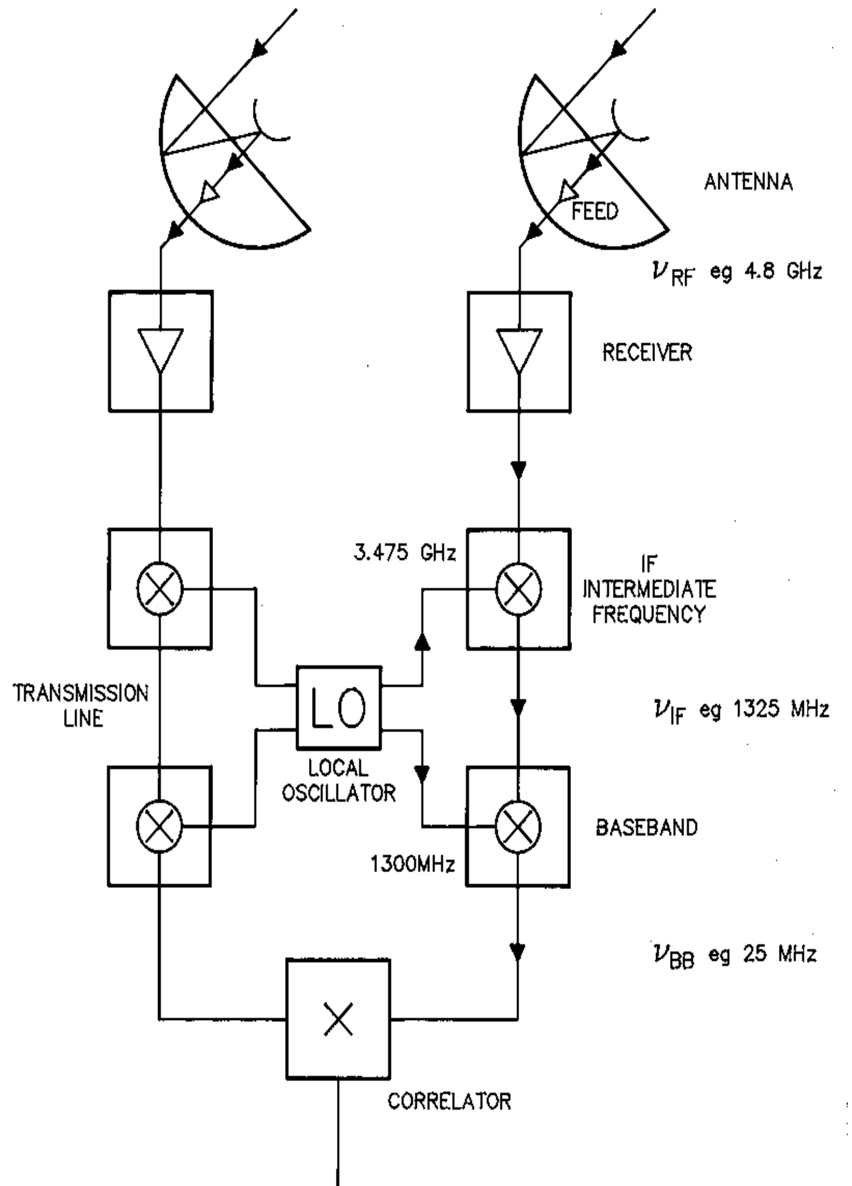
Antenna

Front End

IF

Back End

Correlator



Amplifier

Mixer

X **Correlator**

Types of Antennas

Wire antennas $(\lambda > 1\text{m})$

Dipole

Yagi

Helix

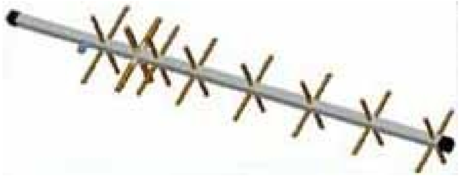
Small arrays of the above

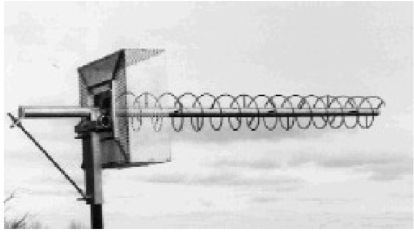
Reflector antennas $(\lambda < 1\text{m})$

Hybrid antennas $(\lambda \approx 1\text{m})$

Wire reflectors

Reflectors with dipole feeds





Basic Antenna Formulas

Effective collecting

area A(n,q,f) m2

On-axis response A0 = **h**A

h = aperture efficiency

Normalized pattern

(primary beam)

A(n,q,f) = A(n,q,f)/A0

Beam solid angle

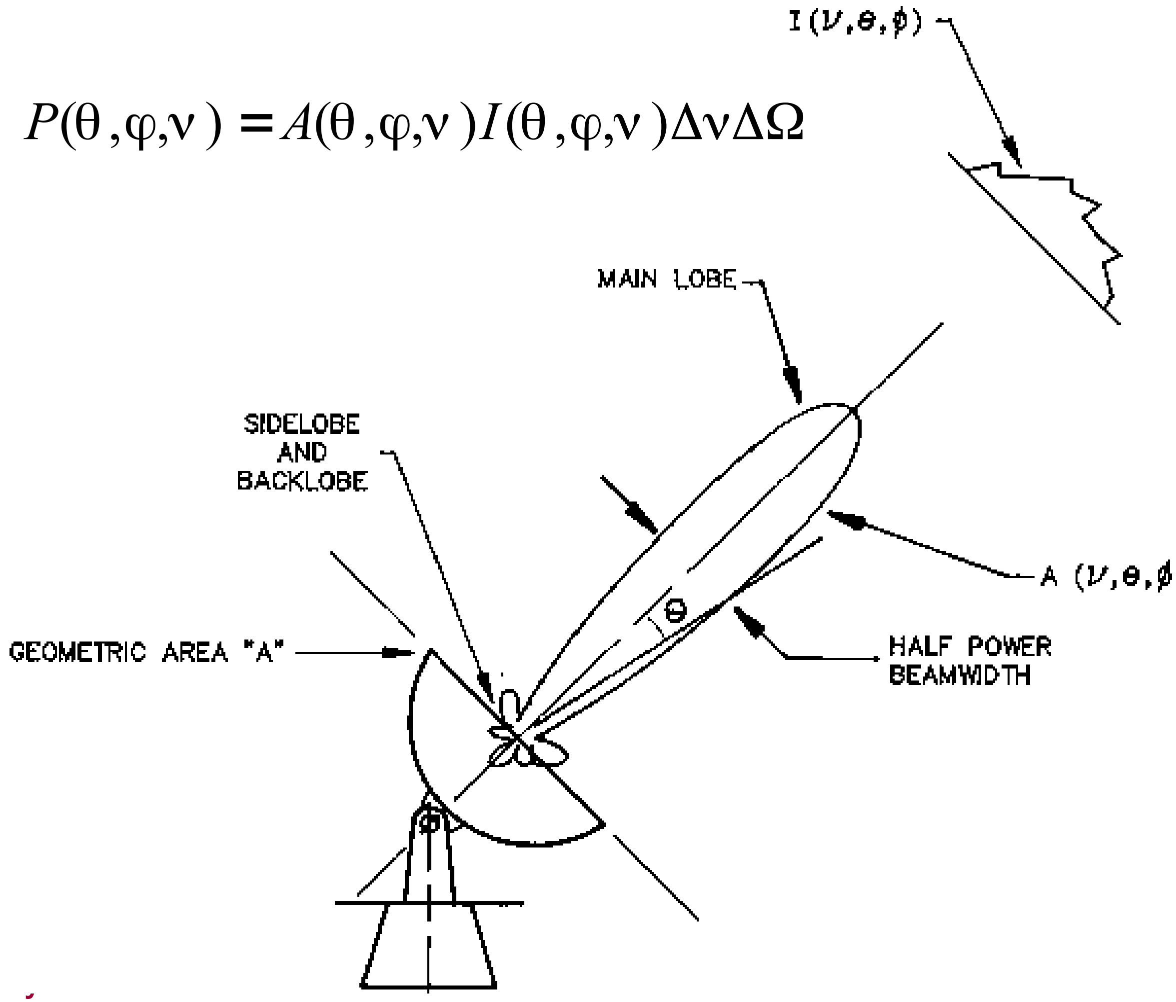
WA= ∫∫ ***A***(n,q,f) dW

all sky

A0 WA = **l**2

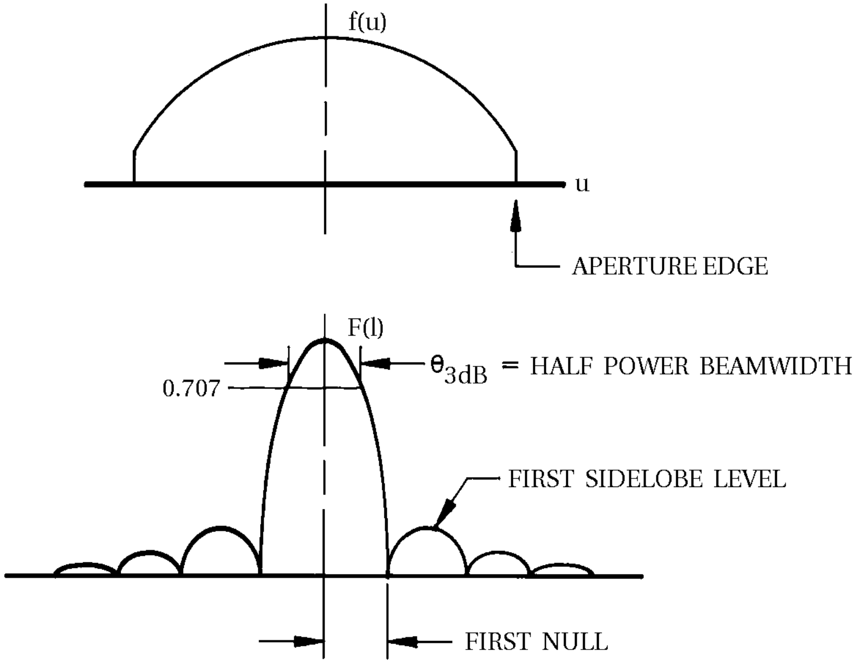
l = wavelength, **n** = freque

$$P(\theta,\varphi,\nu) = A(\theta,\varphi,\nu) I(\theta,\varphi,\nu) \Delta\nu \Delta\Omega$$



Aperture-Beam Fourier Transform Relationship

What determines the beam shape?



f(u,v) = complex aperture field distribution

u,v = aperture coordinates (wavelengths)

F(l,m) = complex far-field voltage pattern

l = sinqcosf , m = sinqsinf

F(l,m) = ∫∫aperturef(u,v)exp(2pi(ul+vm))dudv

f(u,v) = ∫∫hemisphereF(l,m)exp(-2pi(ul+vm))dldm

For VLA: q3dB = 1.02/D, First null = 1.22/D,

D = reflector diameter in wavelengths

Antenna Mounts: Altitude over Azimuth

Advantages

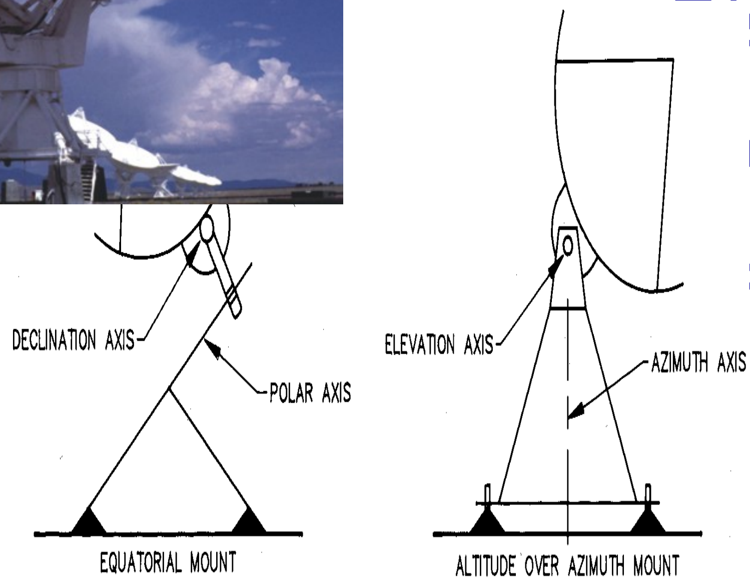
Cost

Gravity performance

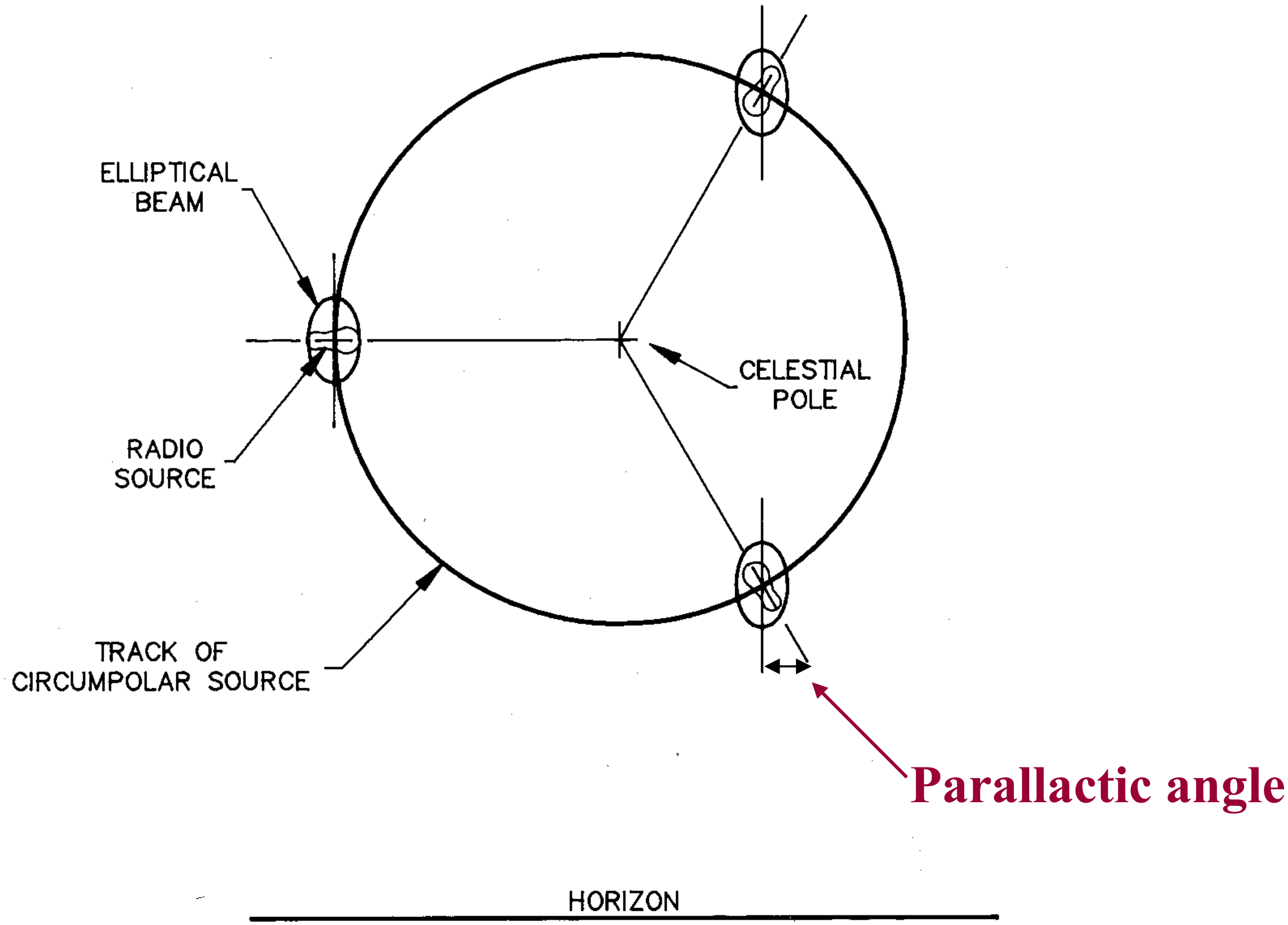
sadvantages

ne of avoidance

am rotates on sky



Beam Rotation on the Sky



Antenna Mounts: Equatorial

Advantages

Tracking accuracy

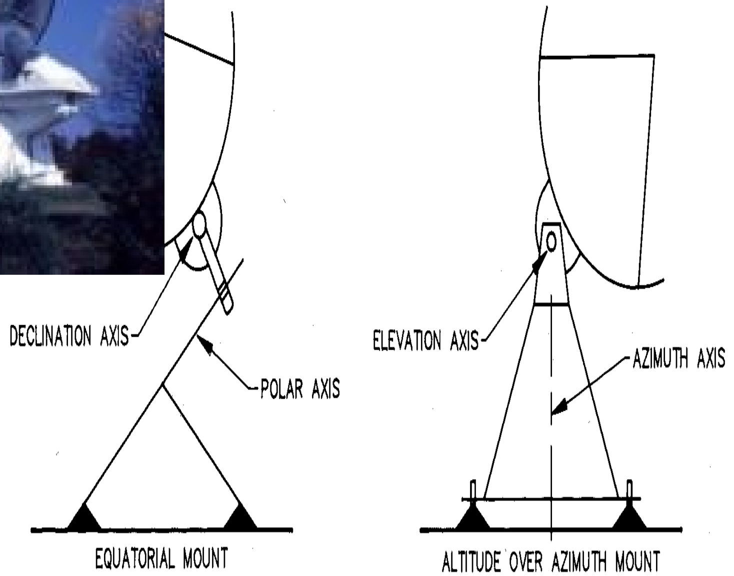
Beam doesn't rotate

Disadvantages

Cost

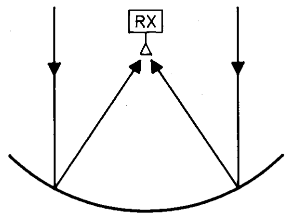
Gravity performance

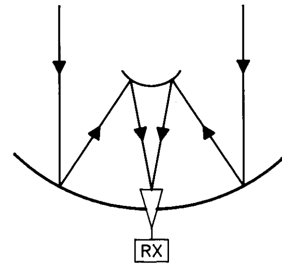
Sources on horizon at pole



Reflector Optics

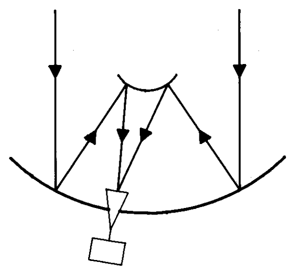
Prime focus



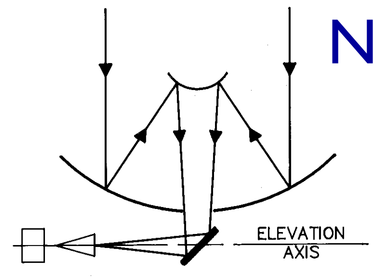


Cassegrain focus

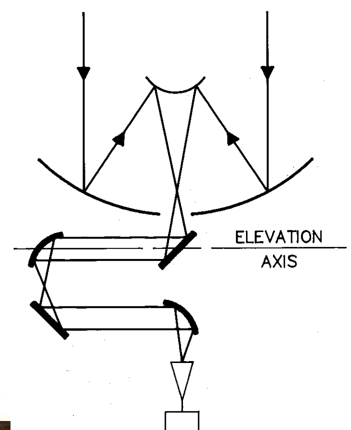
Offset Cassegrain



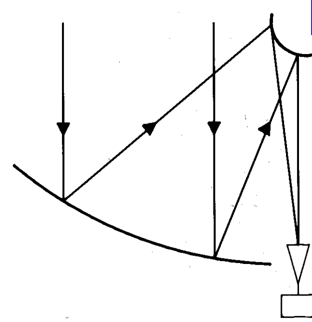
Naysmith



Beam Waveguide



Dual Offset



Reflector Optics: Limitations

Prime focus

Over-illumination (spillover) can increase system temperature due to ground pick-up

Number of receivers, and access to them, is limited

Subreflector systems

Can limit low frequency capability. Feed horn too large.

Over-illumination by feed horn can exceed gain of reflector's diffraction limited sidelobes

- Strong sources a few degrees away may limit image dynamic range

Offset optics

Support structure of offset feed is complex and expensive

Reflector Optics: Examples

Prime focus

(GMRT)

ocus

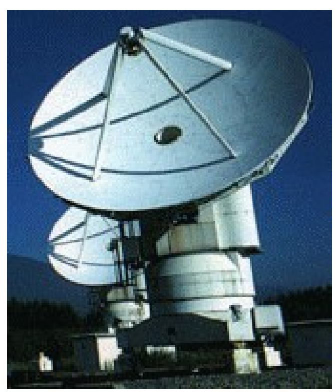
Offset Cassegrain

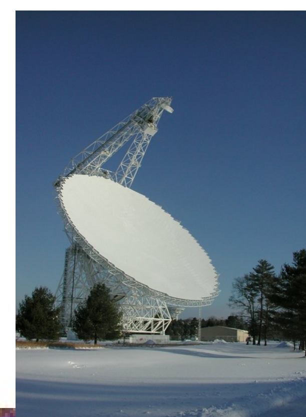
(VLA)

mith

Beam Waveguide

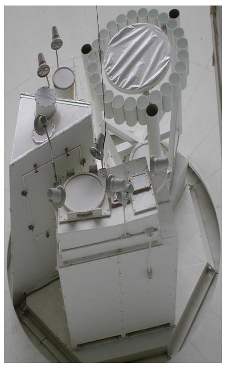
(NRO)





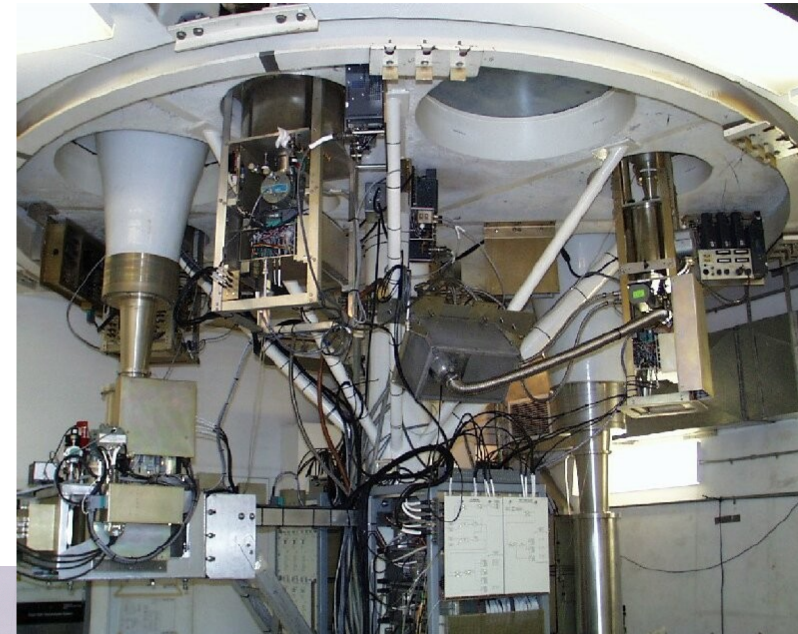
et

Feed Systems



VLA

EVLA



GBT

Antenna Performance: Aperture Efficiency

On axis response: A0 = hA

Efficiency: h = hsf . hbl . hs . ht . hmisc

hsf = Reflector surface efficiency

Due to imperfections in reflector surface

hsf = exp(-(4ps/l)2) e.g., s = l/16 , hsf = 0.5

hbl = Blockage efficiency

Caused by subreflector and its support structure

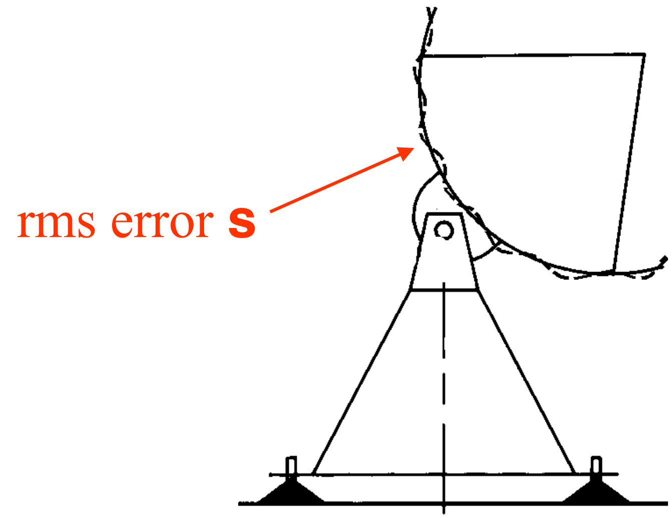
hs = Feed spillover efficiency

Fraction of power radiated by feed intercepted by subreflector

ht = Feed illumination efficiency

Outer parts of reflector illuminated at lower level than inner part

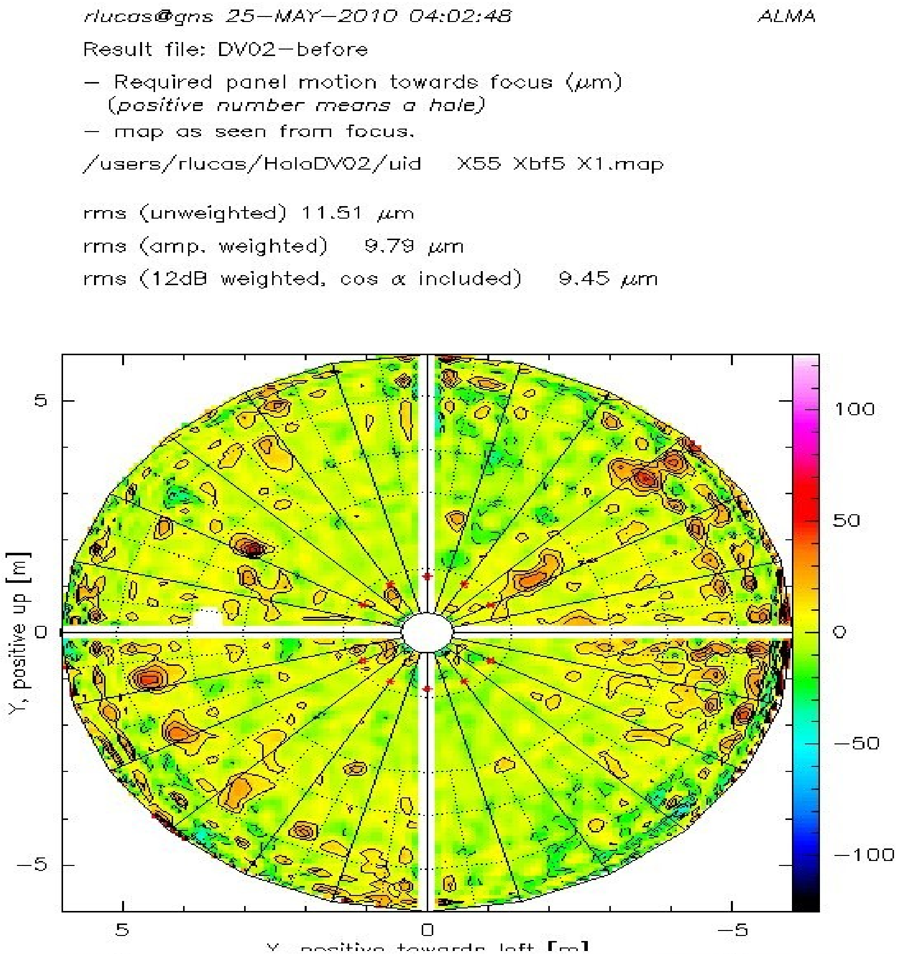
hmisc= Reflector diffraction, feed position phase errors, feed match and loss



Surface of ALMA Vertex Antenna

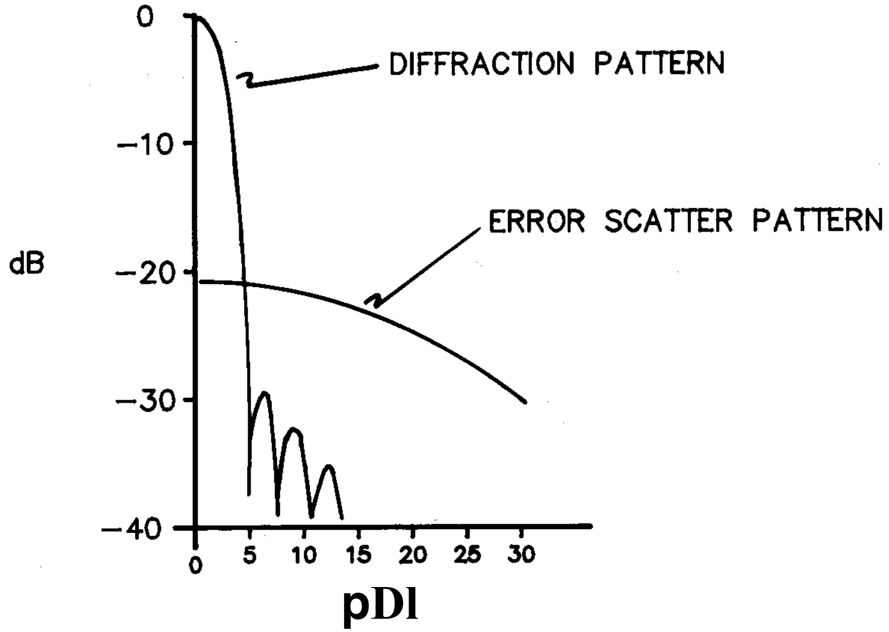
Surface measurements of DV02 made with holography

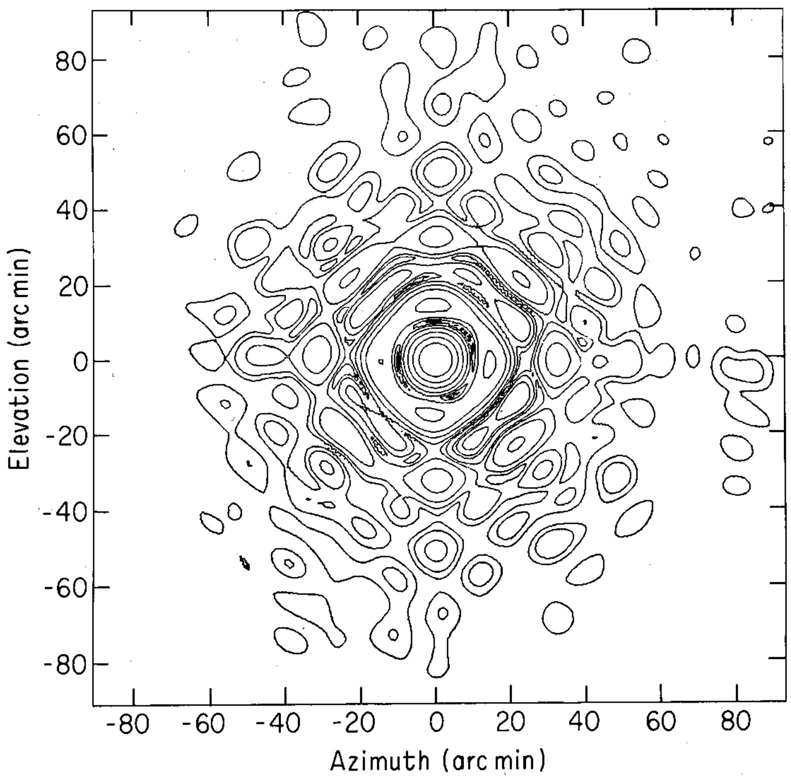
Measured surface rms =10um



Antenna Performance: Aperture Efficiency

Primary Beam





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

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

VLA: q3dB = 1.02/D, First null = 1.22/D

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

Voltage radiation pattern, |F(l,m)|

Antenna Pointing: Practical Considerations

Pointing: ALMA Vertex Antennas

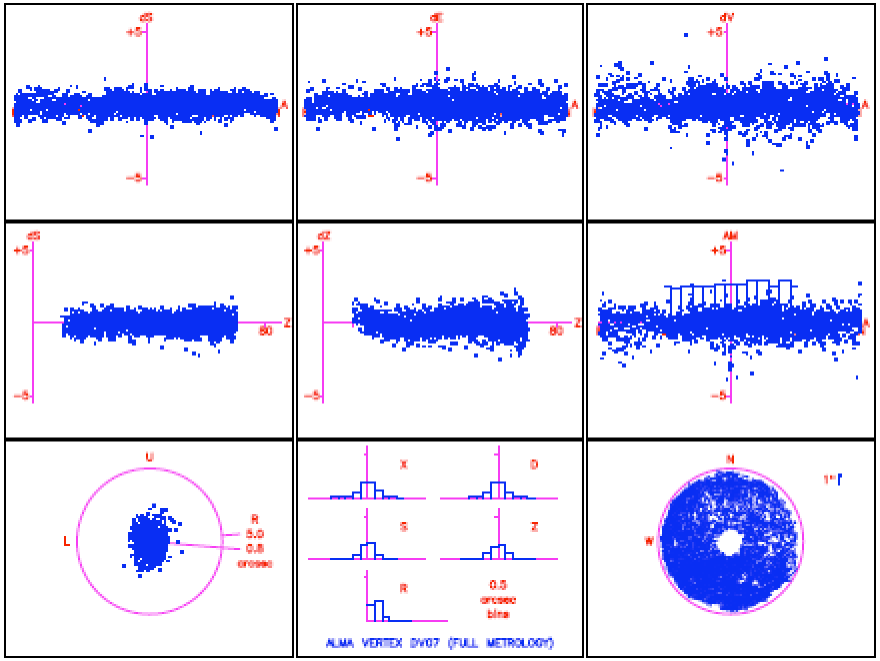
All-sky optical pointing on DV07 completed April 1-14

All-sky results (spec = 2” RMS)

0.77 ± 0.12” RMS at OSF

0.84 ± 0.13” RMS scaled to AOS

All-sky and offset pointing within specifications!



DV07 pointing residuals: Mangum, N. Emerson, Mundnich & Stenvers

Antenna Performance: Pointing

Pointing Accuracy

Dq = rms pointing error

Often Dq < q3dB /10 acceptable,

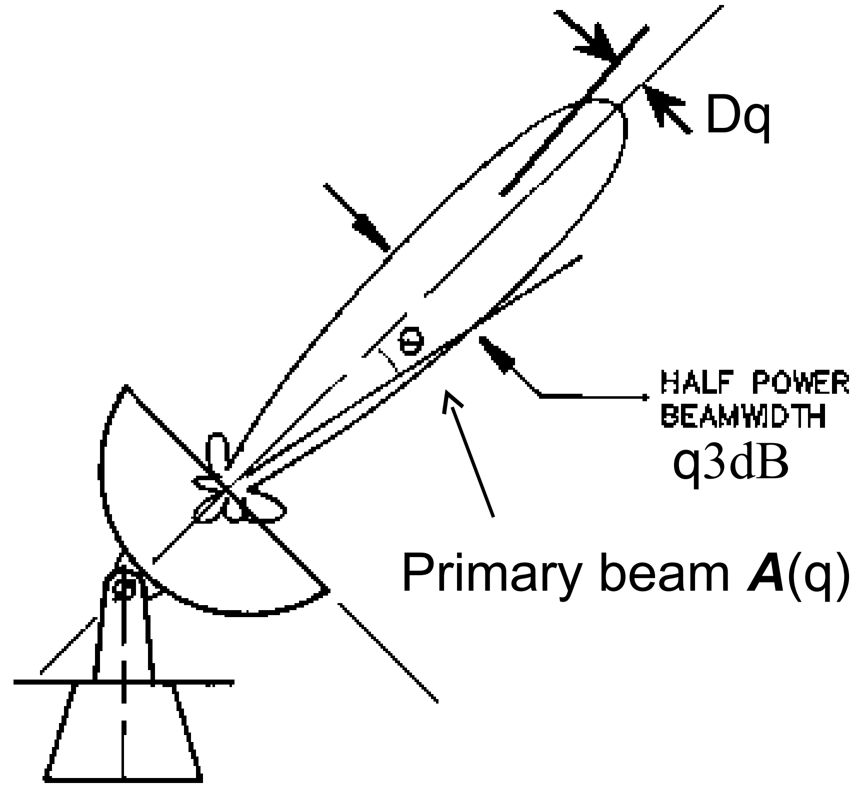
because ***A***(q3dB /10) ~ 0.97

BUT, at half power point in beam

A(q3dB /2 ± q3dB /10)/***A***(q3dB /2) = ±0.3

For best VLA pointing use Reference Pointing.

Dq = 3 arcsec = q3dB /17 @ 50 GHz



Antenna Performance: Polarization

Antenna can modify apparent polarization properties of the source:

Antenna structure

Symmetry of the optics

Reflections in the optics

Curvature of the reflectors

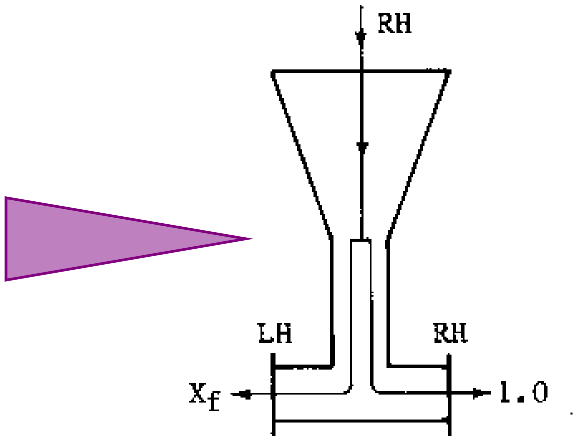
Quality of feed polarization splitter

Constant across the beam

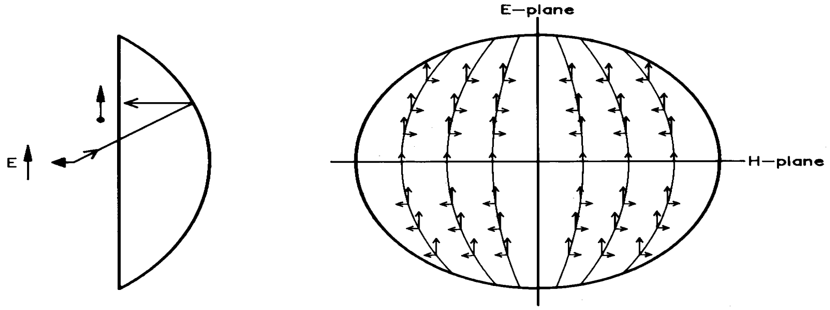
Circularity of feed radiation patterns

No instrumental polarization on-axis,

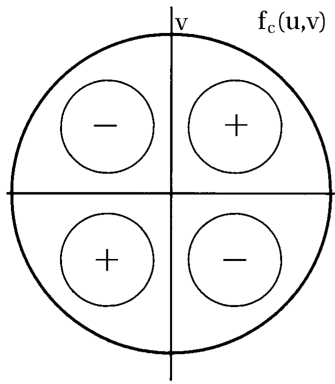
But cross-polarization varies across the beam …



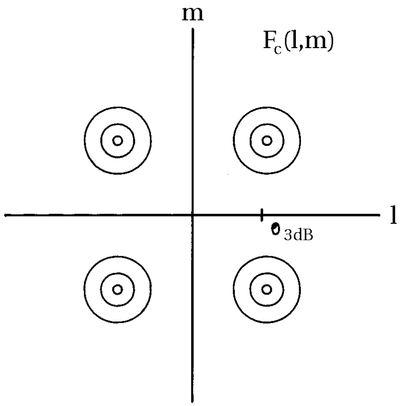
Off-Axis Cross Polarization



Field distribution in aperture of paraboloid fed by electric dipole



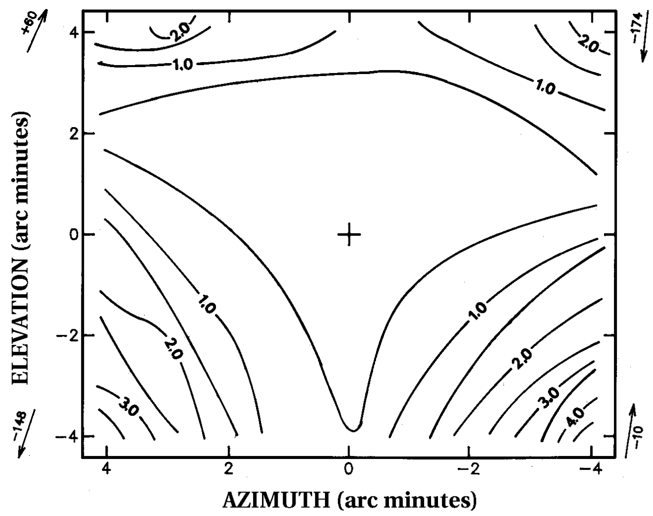
Cross-polarized aperture distribution



Cross-polarized primary beam

VLA 4.8 GHz cross-polarized

primary beam



Receivers: Noise Temperature

Reference received power to the equivalent temperature of a matched load at the input to the receiver

Rayleigh-Jeans approximation to Planck radiation law for a blackbody

Pin = kBT [illegible] (W)

kB = Boltzman's constant (1.38*10-23 J/oK)

When observing a radio source, Ttotal = TA + Tsys

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

TA = source antenna temperature

Receivers: SEFD

TA = ηAS/(2kB) = KS

S = source flux (Jy)

SEFD = system equivalent flux density

SEFD = Tsys/K (Jy)

EVLA Sensitivities

Band (GHz)	η	Tsys	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

EVLA Q-Band (40-50 GHz) Receiver