

Antennas

The primary elements of a synthesis array

M. Kesteven
ATNF
25/September/2001



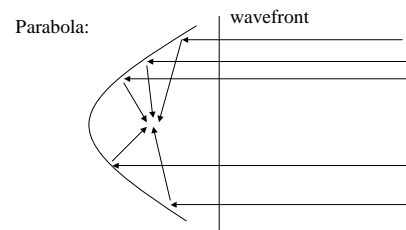
The Antenna Structure

- * Backup structure
- * Reflector surface(s)
 - shape
 - accuracy
 - construction
- * Two axis Mount

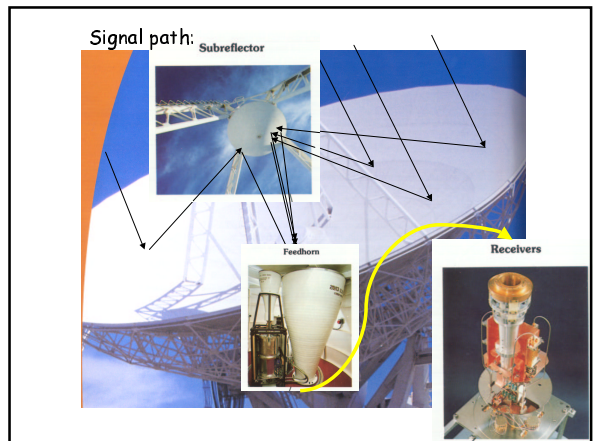
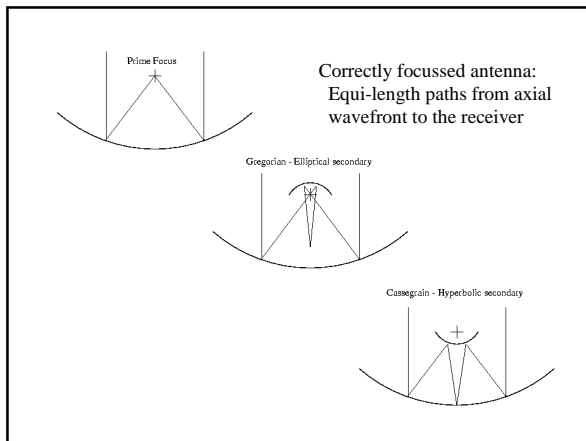
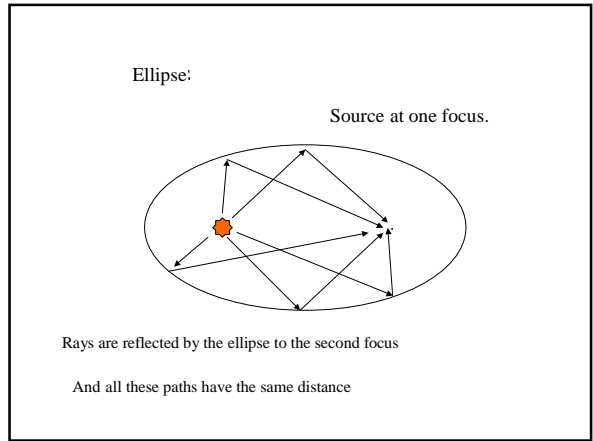
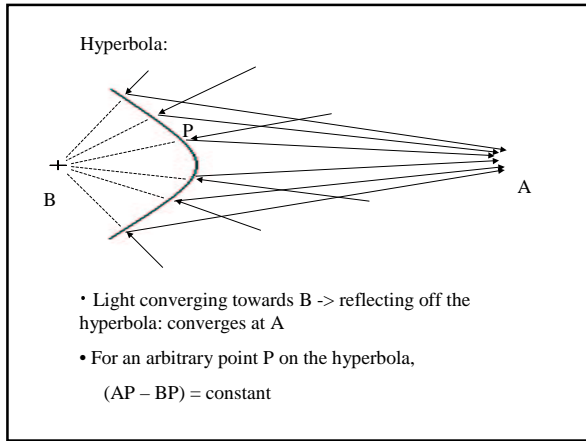
Antenna Design Kit

Basic shapes : conic sections

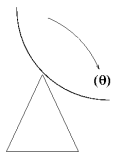
Parabola
Hyperbola
Ellipse



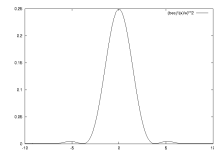
All rays parallel to the axis are concentrated to a point (the focus).
All paths from a wavefront to the focus are of equal length.



Operational Characteristics (I)

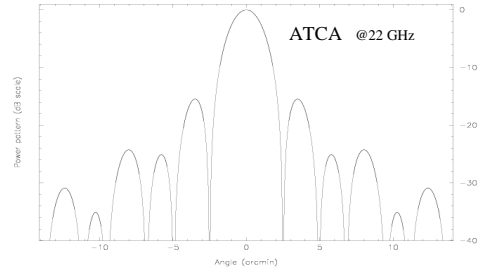


* Scan telescope over distant radio source



Beam width = Full Width at Half Power

Main Beam – the central lobe
Sidelobes – the secondary responses
Note: logarithmic scale (dB)



Operational Characteristics (II)

GAIN:

How much energy can the antenna extract from a wavefront?

Depends on:

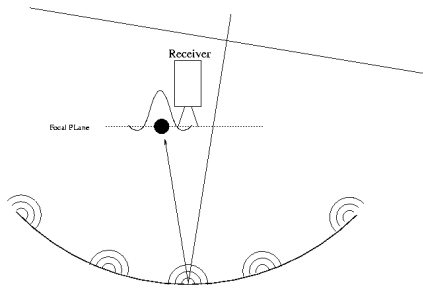
- antenna size
- efficiency
- wavefront orientation relative to boresight (beam pattern)

Antennas as primary elements in an aperture synthesis array

1. Beamwidth defines the field of view
2. Collecting Area defines Gain which defines sensitivity
3. Large diameter = high sensitivity = small beamwidth

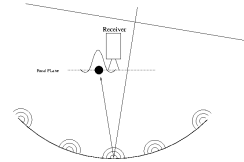
To calculate the radiation pattern :

Compute field in focal plane from surface currents excited by the incoming wavefront.

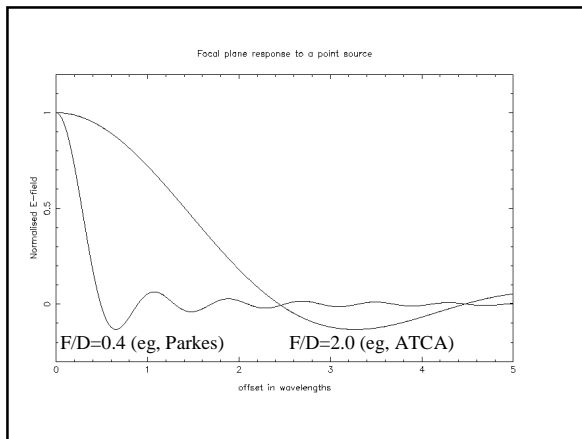


In detail:

1. Compute the phase of the currents on the surface –
 $= 2 \pi (\text{path from wavefront}) / \lambda$



2. For each point in the focal plane, sum the contribution from each surface current. Need path from surface to focal plane for phase and $(1/R)$ field reduction.
3. Compute the coupling of the electric field distribution to the feedhorn.



Notes.

1. These curves are generic as to (Focal Length/Diameter)
2. The plate scale (=displacement in focal plane for a given angle offset from boresight) is proportional to Focal Length
 Antennas with same (F/D) have same focal plane function;
 BUT the larger the antenna, the smaller the beamwidth.
3. The axis is expressed in wavelengths
4. The higher the frequency, the smaller the beamwidth

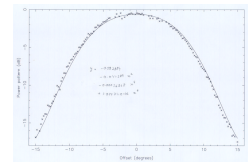
GAIN : The Problem.

The coupling of the feed horn to the focal plane field is critical.

It sets the efficiency of the antenna – typically 60%.

The feed horn expects a particular field distribution (phase and amplitude) which a conic section reflector cannot deliver.

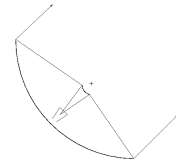
Alternative view : the feed horn as a transmitter



This is the AT feed pattern, designed for a subreflector which subtends 28 deg. at the feed.
– it is down 50% at 7 degrees from boresight

It is difficult to reconcile the goals:

1. Uniform illumination on reflector (broad beam)
2. Not wasting energy, with some radiation missing the subreflector (narrow beam).



Remedies:

1. Shaped reflectors to modify the focal plane distribution - equivalent to the Schmidt Corrector plate.
2. Focal plane array to construct a “super-feed”

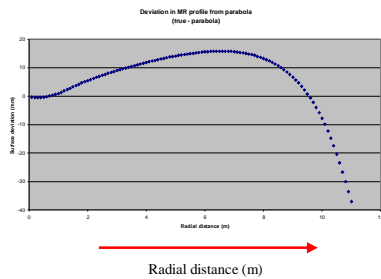
Shaped Reflectors

The secondary is slightly conical in the central region to redistribute the energy flow from main reflector to the feed.

- Uniform plane wave at the main reflector
- Converging gaussian at the feed.

The main reflector has to be tweaked to retain the constant path length criterion.

The main reflector deviates from a parabola by about 30 mm



Sensitivity to subreflector mis-positioning

- Lateral (in focal plane)
 - null for $\sim 0.5\lambda$ displacement.
 - largely recovered with a pointing correction
- Axial
 - null for $\sim 1\lambda$ displacement
 - no operational fix.

Additional losses : Blockage

1. Subreflector
 - plane wave shadows (radiation which does not reach the main reflector)
2. Feed Legs (quadrupod on the AT antennas)
 - spherical wave shadows (radiation blocked between the main and the sub-reflector)

The blockage paradox :

The loss can scale as TWICE the area.

A thought experiment: remove the outer ring of panels.

- you lose first of all because the collecting area is reduced.
- you lose a second time because the feed is designed for the original F/D. You could recover this second component with a new feed.

The AT shaping performs a similar trick on the sub-reflector blockage.

Surface Errors – Ruze formula

Let σ be the rms surface error. This translates to an rms phase error of $(4\pi\sigma/\lambda)$.

In computing the focal plane field, the sum will be reduced by the phase error – by $\sim \cos(4\pi\sigma/\lambda)$, and the power, by the square of this.

More correctly : $G = G_0 e^{-4\pi\sigma^2/\lambda^2}$

Unwanted Stray Radiation

The receiver signal = astronomical signal
+ 3 K background
+ atmosphere
+ scattered, stray radiation

Alternative approach – assess antenna as a transmitter.

Reciprocity Theorem : transmit pattern = receive pattern

Algorithm:

1. Launch wave from the feed (= expanding spherical wave)
2. Compute the phase and amplitude of the surface currents
3. Transform to the Aperture Plane
4. Compute the far-field wave due to the aperture plane fields

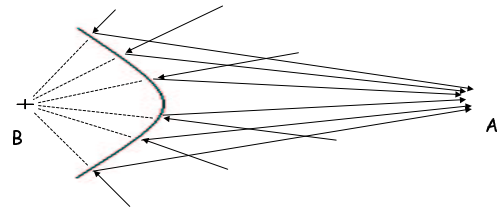
Shaped Reflector

- Subreflector is slightly conical in the central region to redistribute the feed's radiation.
- More uniform illumination.
- Reduce impact of central blockage
- Improve efficiency

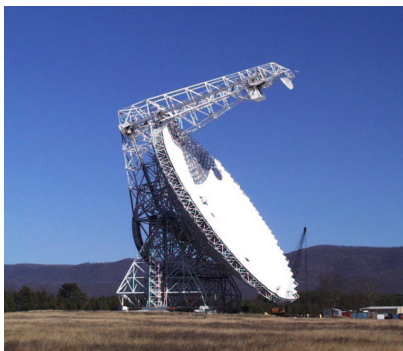
- Sidelobes
 - $J_1(x)/x$ --- 2% sidelobe
 - Aggravation due to blockage
- Surface Errors
- Spillover

$$\frac{G}{G_0} = e^{-(4\pi\sigma/\lambda)^2} \quad (\text{Ruze})$$

Hyperbola:



• Light converging towards B -> reflecting off the hyperbola: converges at A



The Antenna Structural Characteristics

- Backup structure
- Reflector surface(s)
 - Shape
 - Accuracy
 - Construction
- Two-axis mount

Antenna Design

- Focussing
 - Ray tracing
 - Equi-phase paths
- Single Reflector (“Prime Focus”)
 - parabola
- Dual-Reflectors
 - Cassegrain (parabola+hyperbola)
 - Gregorian (parabola+ellipse)

Electromagnetic Characteristics

- Gain
 - Collecting Area : antenna aperture that intercepts an incoming wavefront.
 - Efficiency : the useful fraction of the aperture
- Radiation Pattern
 - Beamwidth
 - sidelobes

Focal Plane Considerations

- Energy distribution in the focal plane
- Feed Antenna + Receiver
- Focal Plane Arrays
 - = radio photographic plate

Antenna - Design

- Reciprocity
 - Transmit pattern = Receive pattern
- Procedure
 - Feed pattern > (ray tracing) : field distribution in aperture plane > far field pattern
- Aperture Plane as intermediate step