1972 Lecture Notes

FILLED APERTURE RADIO TELESCOPES

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[Suggested text: "Radiotelescopes" by W. N. Christiansen and J. A. Högbom, C.U.P. 1969.]

1. Deal only with filled-aperture instruments, i.e., those where the gain and beamwidth are both directly determined by the size of the illuminated aperture. Best example: the parabolic reflector antenna.

2. Main Characteristics

(a) Gain $\propto \frac{\text{Aperture area}}{\lambda^2}$

(b) HPBW $\propto \frac{\lambda}{\text{Aperture size}}$

Describe the need for high gain and small beamwidth.

Note that these factors are directly connected for filled aperture antennas and their disconnection in aperture synthesis, for example, is an important advantage.

High gain → high collecting area → larger signals from small diameter sources.

Define A_{eff} = effective collecting area = area of uniformly illuminated aperture which collects the same energy. $\eta = A_{eff}/A \simeq 60\%$ in practice.

What determines gain and A_{eff}? Size and illumination or, for short wavelengths, the surface accuracy. Minor factors such as aperture blocking.

Size

A_{eff} for NRAO dishes:

	A	A_{eff}
140-foot	1430 sq. m.	787 sq. m.
300-foot	6550 sq. m.	3600 sq. m.

Illumination

Describe typical primary feed patterns--show edge taper--refer to spill-over and unwanted radiation. Brief comments on the attempts to increase η and the side effects on beam shape and spill-over.

The Antenna Pattern

Describe what it is and how it may be measured.

Main beam shape--described by HPBW--for a practical dish:

$$\text{HPBW} = 1.4\ \lambda/D\ \text{(radians)}$$

For a uniformly illuminated dish:

$$\text{HPBW} = 1.02\ \lambda/D$$

For 140-foot telescope using HPBW = 1.4 λ/D,

λ	21 cm	10 cm	3 cm
HPBW	23.7'	11.3'	3.4'

Actual main beam shape is closely Gaussian

Sidelobes

Near-in sidelobes are similar to aperture diffraction pattern. Far-out sidelobes are confused--describe effects. Mention difficulties which result from the more distant sidelobes--interference, T_A rises due to ground--errors in maps--H, for example.

Effects of Surface Irregularities

$$G/G_o = \exp - \left(\frac{4\pi\sigma}{\lambda}\right)^2$$

where σ is the RMS surface accuracy and λ the wavelength. For a dish with an RMS surface accuracy of λ/16,

$$G/G_o = \exp - \left(\frac{4\pi}{16}\right)^2 = 0.540.$$

Thus RMS surface accuracy should be better than λ/16.

Effects also on sidelobes can be important.

Example

300-foot telescope (with its new surface--at the zenith)

λ	Measured η_{eff}	η_{eff} calculated for $\sigma = 0.26$ cm and $\eta_{max} = 54\%$
21 cm	52%	53%
11 cm	50%	49%
6.0 cm	40%	40%

3. Illustrate some of the further points in radio telescopes by describing examples.

(a) Jodrell Bank 250-foot (~1954-59)

Alt-az mounting. Wheel and track.

Focal plane -- f/D = 0.25.

Solid surface -- but $\lambda_{min} > 21$ cm.

(b) CSIRO 210-foot. (~1956-61)

Alt-az mounting--tower--limited elevation coverage. f/D = 0.41

Mesh surface--$\lambda_{min} \sim 6$ cm

Pointing precision by a "master equatorial" telescope.

Briefly discuss coordinate conversion systems.

(c) NRAO 300-foot (1961-62)

Transit telescope--limited elevation coverage.

f/D = 0.427 (true for all Green Bank telescopes)

Limitations due to transit system--weighed against low telescope cost.

Partially offset by use of traveling feed.

Feed support and cabin replaced--new surface now installed.

Original $\lambda_{min} = 21$ cm
New $\lambda_{min} = 6$ cm

(d) NRAO 140-foot (1957-63)

Largest ever equatorially mounted telescope.

Solid surface. λ_{min} (design) 3 cm

λ_{min} (used) to 1.9 cm

(e) Haystack, MIT Lincoln Lab (1958-62)

Alt-Az in a space-frame radome.

Discuss briefly the pros and cons of use of radome:

For	Against
Telescope lighter	Absorption
Drive and control easier	Scattering
Thermal effects more predictable but not eliminated	Long wave limit

One of the first examples of computer-controlled telescope.

(f) NRAO 36-foot on Kitt Peak (1965-67)

Alt-Az in an astrodome.

λ_{min} certainly 3.5 mm, has been used at 1 mm.

Computer control.

(g) Arecibo-Cornell University

First large spherical reflector.

Brief description of the feed difficulties and advantages.

Results of recent 300 MHz feed.

Plans for resurfacing.

(h) The MPIfRA 100-meter Telescope

4. The Design of a 65-meter Millimeter Wave Antenna

(a) The performance specification

Dish diameter	:	65 meters (213 feet)
Mounting	:	Altitude-Azimuth
Sky cover	:	Complete--but no tracking inside a small zone near zenith
*RMS surface accuracy	:	0.22 mm (0.009 inches)
*Short wavelength limit	:	3.5 mm (86 GHz)
*Tracking accuracy	:	3 arc seconds RMS

Slew rates (both axes)	:	20° per minute
Optics	:	Prime focus f/D = 0.42 Cassegrain--subreflector diameter 3.7 m (12 feet)
Instrument cabins	:	Behind prime focus; behind Cassegrain focus
Equipment room	:	Rotates in azimuth

* The highest precision performance is only possible when the wind velocity is below 17 miles per hour and when no temperature differences greater than 2° F exist across parts of the structure.

(b) <u>The main problems</u>

(i) Gravity deflexions--explain homology briefly.

(ii) The surface plates, making and setting them to 0.22 mm.

(iii) Pointing precision--15 arc second beamwidth--should be ∿ 3 arc seconds.

(iv) Effects of wind, temperature and atmospheric effects.