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1978 LECTURE NOTES

INTRODUCTION TO RADIO TELESCOPES

J. W. Findlay

[Suggested text:* "Radiotelescopes" by W. N. Christiansen and J. A. Hogbom. 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 $\propto \dfrac{\text{Aperture area}}{\lambda^2}$

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

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.

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* A very good (but detailed) review article "High Efficiency Microwave Reflector Antennas" by Clarricoats & Poulton has appeared in Proc. IEEE, 65, 1470 - 1504, 1977.

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. Advantages of two-reflector systems. Use of shaped-reflector systems.

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 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 $\lambda/16$,

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

Note that the above is only true for random irregularities. When the irregularties themselves have a pattern, no simple theory discribes the effect.

Thus RMS surface accuracy should be better than $\lambda/16$.

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 σ = 0.26 cm and η_{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 λ_{min} > 21 cm.

Now has f/D = 0.4 and λ_{min} ~ 10 cm.

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

Alt-Az mounting--tower--limited elevation coverage. f/D = 0.41
Mesh surface--λ_{min} ~ 6 cm.

Now has inner 16.7 m diameter surfaced and good, (η_{eff} = 40%) at 7 mm.

Pointing precision by a "master equatorial" telescope.

(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 and new surface installed, (1970).

Original λ_{min} = 21 cm

New λ_{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

Now having deformable subreflector tested

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

Alt-Az in a space-fram radome.

Discuss briefly the pros and cons of use of radome:

For	Against
Telescope lighter	Absorption - leads to a shortwave limit.
Drive and control easier	
Thermal effects more predictable but not eliminated	Scattering
	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 resurfacing.

(h) The MPIfRA 100-meter Telescope

First homologous telescope.

Inner 85-meters works well at 2.8 cm and has been used at 9 mm.

4. The VLA Antennas

Twenty-eight antennas--one spare--to work in bands:

$$\left.\begin{array}{c} 1.3 - 1.73 \text{ GHz} \\ 4.5 - 5.0 \text{ GHz} \\ 14.4 - 15.4 \text{ GHz} \\ 22.0 - 24.0 \text{ GHz} \end{array}\right\} \eta_{eff} \text{ of } 40\% \text{ has been achieved.}$$

Cassegrain, using shaped reflector system and asymmetric subreflector.

5. The 25-meter Telescope

Comments on the design.

(a) To work at $\lambda = 1.2$ mm; we intend to get a surface accuracy of 70-80 microns and a pointing accuracy of 1 arc second.

(b) S. von Hoerner's homologous design.

(c) 3 main questions to answer:

(i) Should it go in the open or in a radome, or in an astrodome?

(ii) Where should it be built?

(iii) How should the surface be measured and set?

6. Recent results of measuring surfaces

We now believe there are at least four ways (two invented at NRAO) which can measure the surface to about 40 microns.

Briefly describe the stepping method as one example.