1975 Lecture Notes

INTRODUCTION TO RADIO TELESCOPES

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

A. Filled-Aperture Telescopes

1. Deal first 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

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

$$\text{HPBW} \propto \frac{\lambda}{\text{Aperture size}}$$

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-ft	1430 sq. m.	787 sq. m.
300-ft	6550 sq. m.	3600 sq. m.

Illumination

Describe typical primary feed patterns—how 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.

Antenna Pattern

Describe what it is and how it may be measured.

Main beam shape—describe 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 λ 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.

Prime Focus and Cassegrain Optics

Compare the relative values of the two systems.

Prime Focus - Simple to install but more difficult if heavy front-ends needed.
Spill-over from feed horn sees the ground--thus increasing antenna temperature.
Some limitations to the use of off-axis feeds.

Cassegrain - Gives effectively a much longer focal length.
Vertex cabin can hold many receivers.
Multiple beams and beam-switching are easier.
Spill-over from feeds sees the cold sky, giving lower antenna temperatures.
Secondary reflector and larger feeds can increase cost.
Secondary may be shaped to switch frequencies and also, with shaped primary, A_{eff} can be improved.
Can lead to baseline problems in line work.

Gregorian - Essentially the same as Cassegrain--only (to my knowledge) used at Bonn.

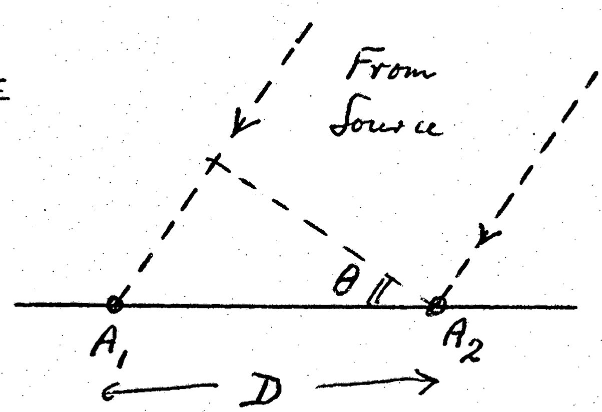
B. Interferometers

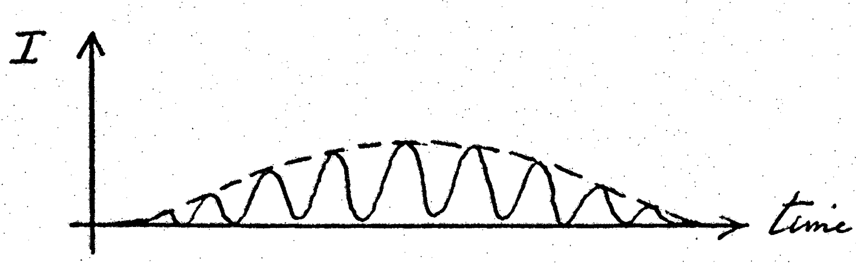
(a) Two-element adding interferometer

Signals in A_1 A_2 are equal with phase difference

$$\phi = \frac{2\pi}{\lambda} D \sin \theta$$

Hence fringes if signals from a point source are added.

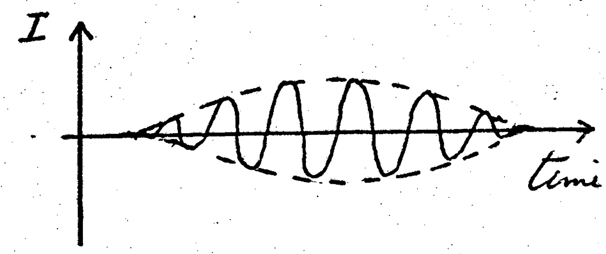




(b) Two-element phase-switched interferometer

Can be achieved:

- by switching 180° in phase to one element
- by correlating outputs from the two antennas.

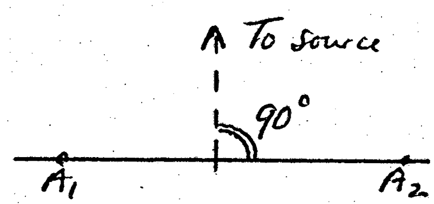


(c) An interferometer observes:

The fringe amplitude - which can be related by suitable calibration to the correlated power received from the source and

The fringe phase - which needs to be described and defined.

If we observe a point source which lies at exactly $\theta = 90°$ at $t = 0$, we see a fringe maximum at $t = 0$ (obvious).

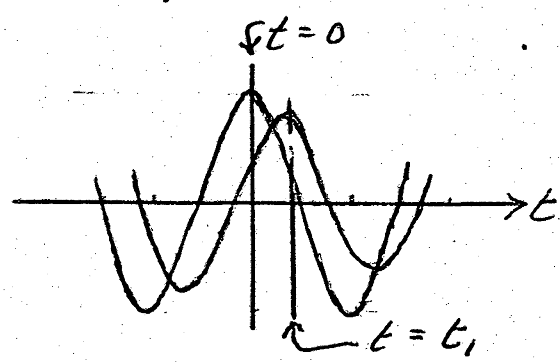


Now extend our point source somewhat (around $\theta = 90°$). We still see fringes (of a different amplitude) but the fringe maximum may not now occur at $t = 0$, but at $t = t_1$.

We say the fringe phase is

$$2\pi \times \frac{t_1}{\tau}$$

where τ is the period of one fringe.



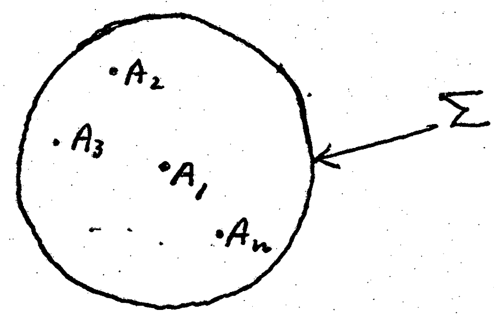
Why is t_1 not zero for an extended source? It is if the source has symmetry about $t = 0$. A little thought shows that it is the asymmetry of the source about $t = 0$ which introduces a phase $\neq 0$. Similarly it is the angular extent of the source which mainly changes the fringe amplitude.

(d) The interferometer as one element in a synthetic antenna

What we have shown qualitatively is that the fringe amplitude and phase depend on the angular extent and position in the sky of the source intensity. It can be shown quantitatively that one such measurement by an interferometer with angular fringe separation = α gives the amplitude and phase of one Fourier component (of angular frequency α) of the source brightness distribution.

C. Aperture Synthesis

Above statement is the basis for A.S. Can be seen qualitatively as follows: Σ is an area on the ground onto which wavefronts from the sky fall (from a variety of unvarying radio sources). If we knew the amplitude and phase at every point on this wavefront we could map the sources in the sky which produce it.



We could find this by putting one antenna A_1 (to be used as a phase reference) at the center and A_2 ... A_n at points within Σ and observing fringes. Or without loss, if everything is unchanging with time, we could move a single antenna to many different points in Σ and observe fringes. From these observations we could reconstruct the wave amplitude and phase, and thus the sources in the sky.