Brief Introduction to Radio Telescopes

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GREEN BANK OBSERVATORY

GBO/Arecibo Single Dish Workshop August 19 2019

Terms and Concepts

Parabolic reflector
Blocked/unblocked
Subreflector
Frontend/backend
Feed horn
Local oscillator
Mixer
Noise Cal
Flux density

Jansky
Bandwidth
Resolution
Antenna power pattern
Half-power beamwidth
Side lobes
Beam solid angle
dB (deciBels)
Main beam efficiency
Effective aperture

Aperture efficiency
Antenna Temperature
Aperture illumination function
Spillover
Gain
System temperature
Receiver temperature
convolution

Text books on Radio Astronomy

- Essential Radio Astronomy
- https://science.nrao.edu/opportunities/courses/era

Essential Radio Astronomy

James J. Condon, Scott M. Ransom

Princeton University Press, Apr 5, 2016 - Science - 376 pages

Essential Radio Astronomy is the only textbook on the subject specifically designed for a one-semester introductory course for advanced undergraduates or graduate students in

More »

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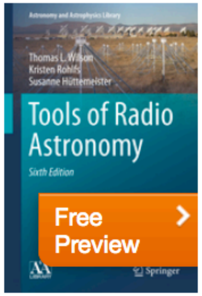

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Tools of Radio Astronomy

Authors: **Wilson**, Thomas, **Rohlfs**, Kristen, **Huettemeister**, Susanne

Presents the 6th edition of a leading textbook on radio astronomy to include state-of-the-art descriptions of instrumentation and new observations

Pioneers of Radio Astronomy

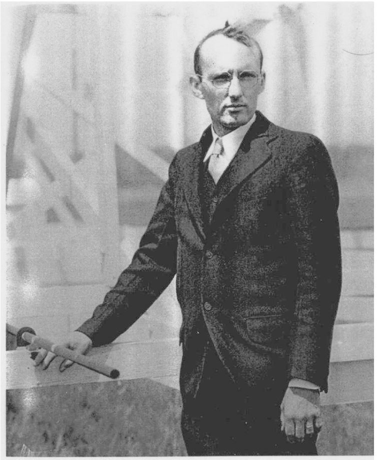
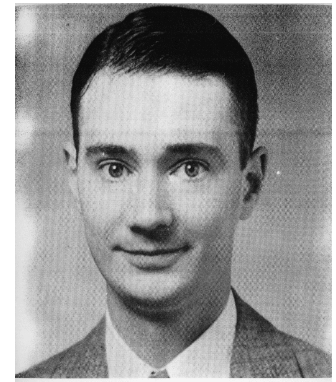


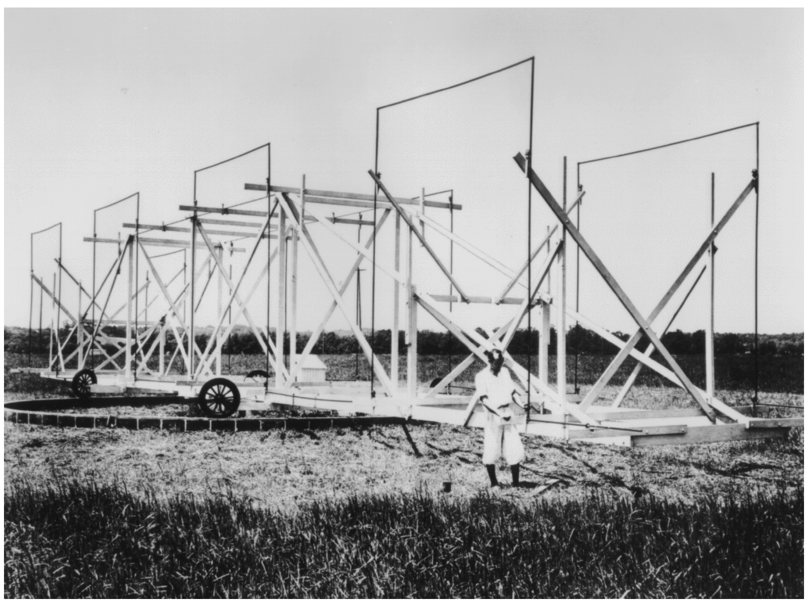
FIG. 1—Karl Guthe Jansky, about 1933.

Karl Jansky
1932

Grote Reber
1938

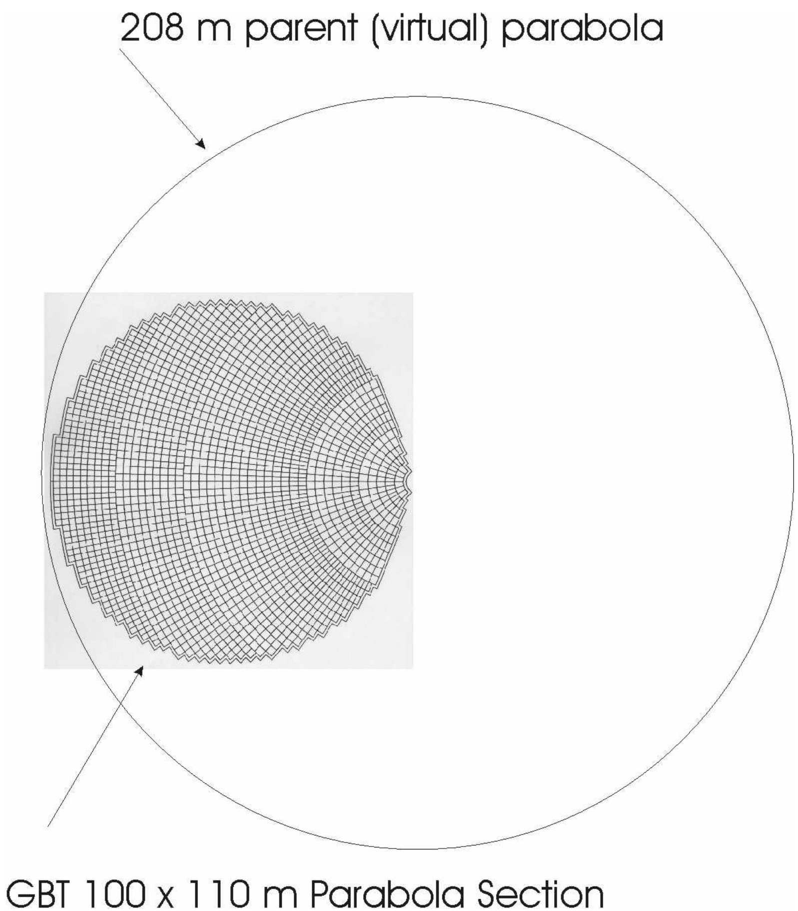


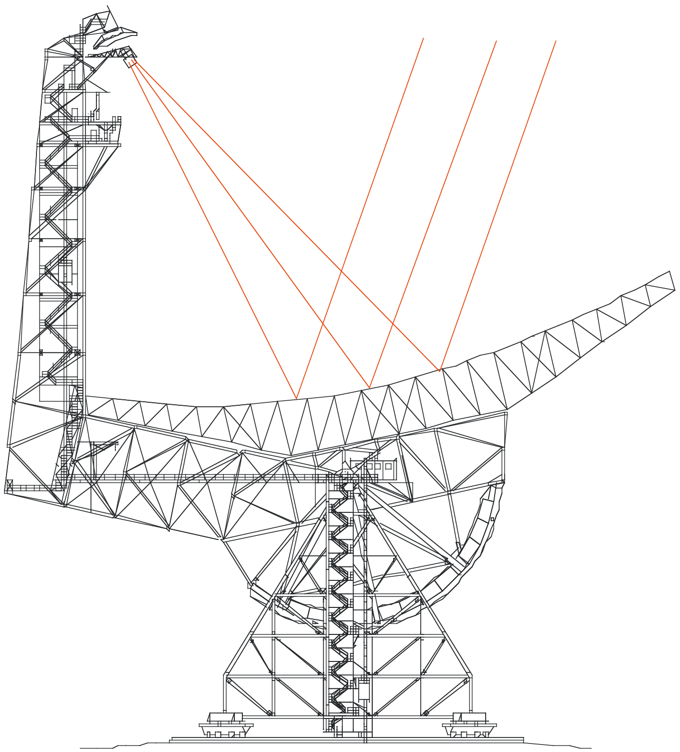
—Grote Reber, about 1937.

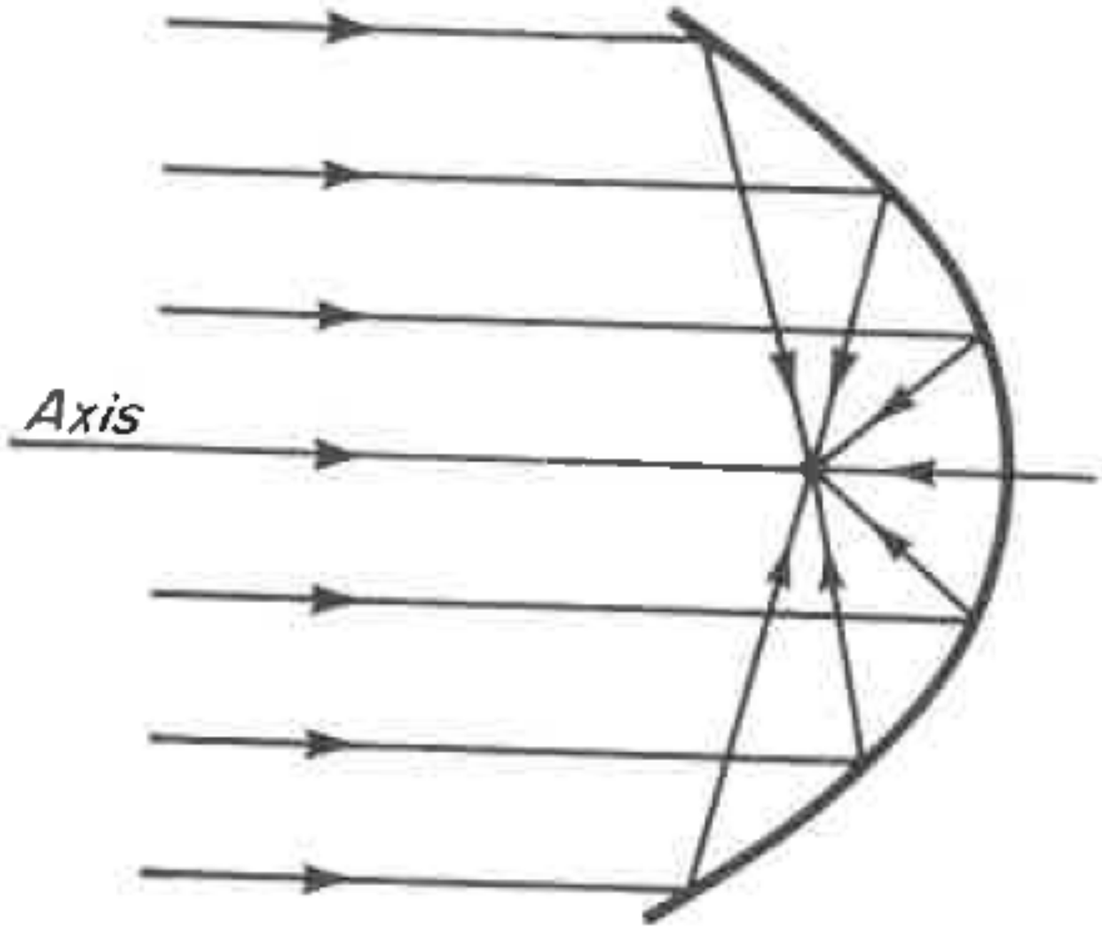


Unblocked Aperture

- 100 x 110 m section of a parent parabola 208 m in diameter
- Cantilevered feed arm is at focus of the parent parabola







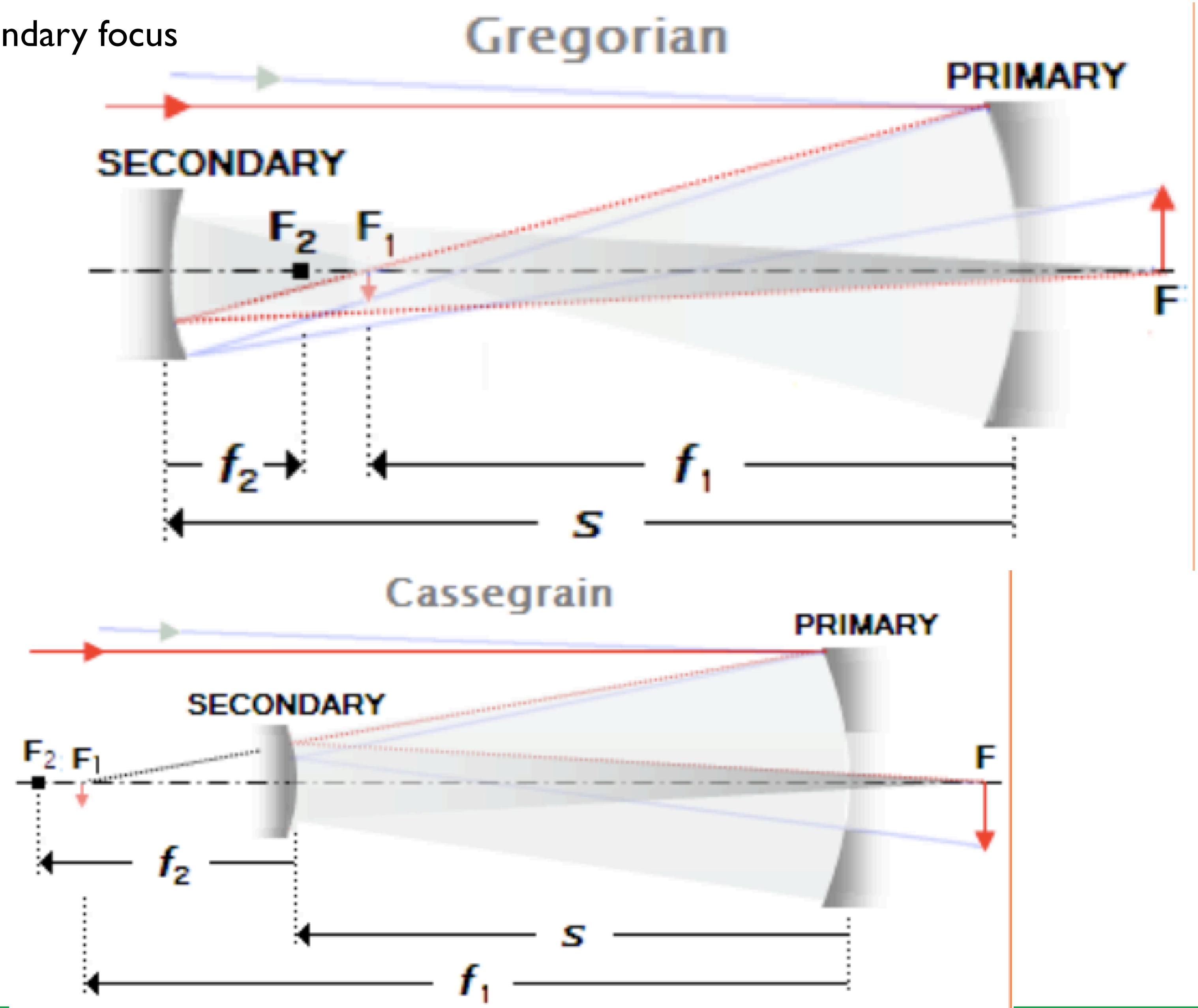
Paraboloidal mirror

Spherical reflector : Arecibo telescope

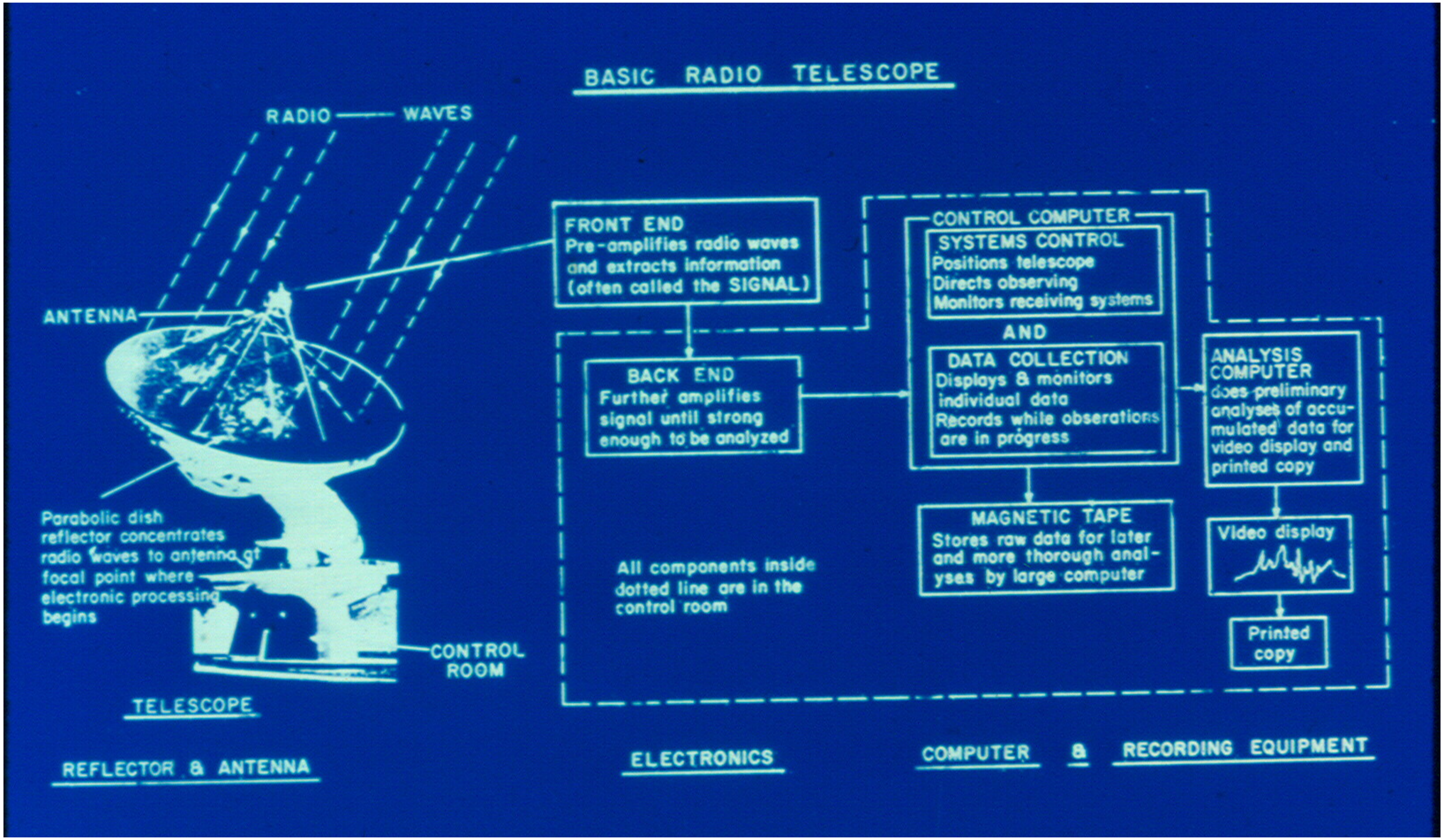
Subreflector and receiver room

On the receiver turret

Secondary focus

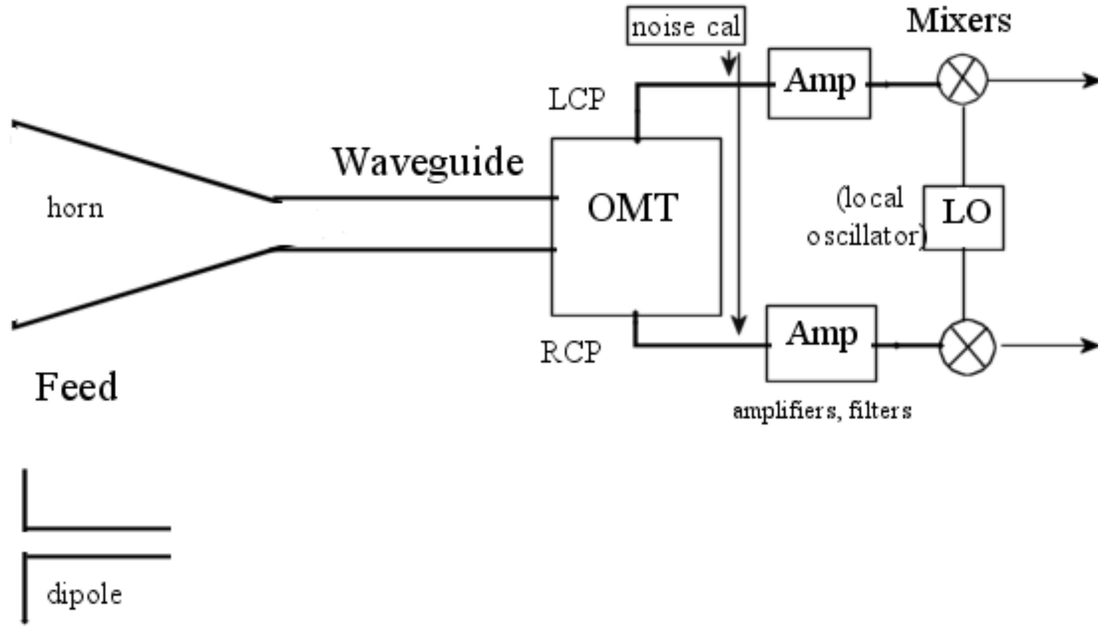


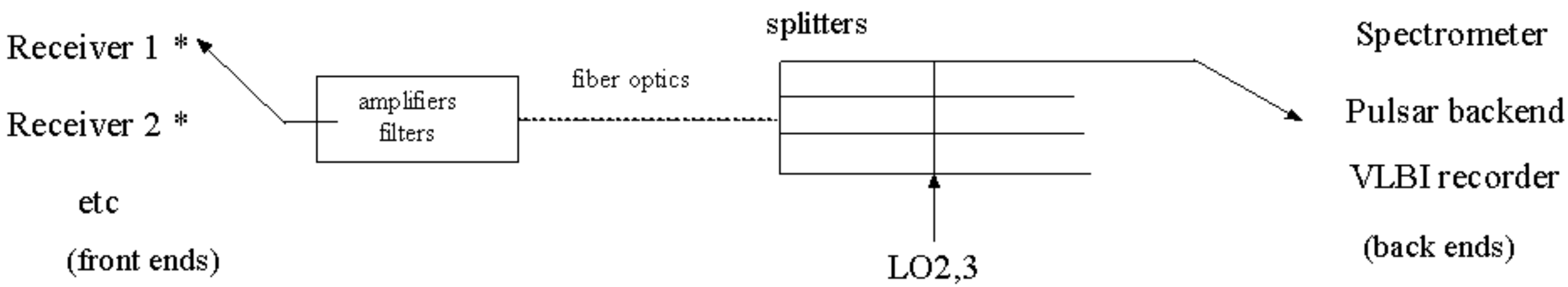
Basic Radio Telescopes



Verschuur, 1985. Slide set produced by the Astronomical Society of the Pacific, slide #1.

Signal paths





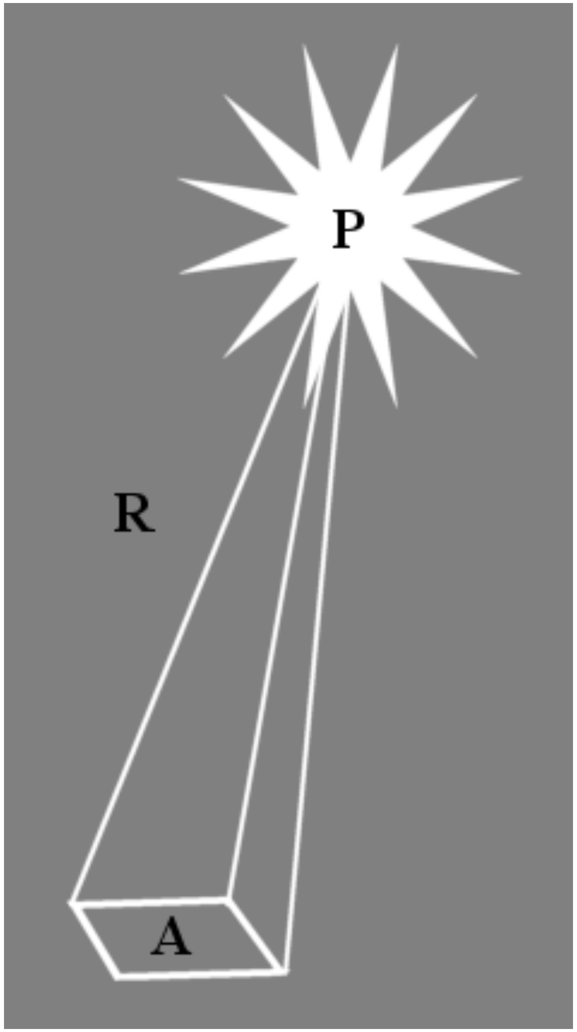
Intrinsic Power P (Watts)
Distance R (meters)
Aperture A (sq.m.)

Flux = Power/Area
Flux Density (S) =
Power/Area/bandwidth
Bandwidth (β)

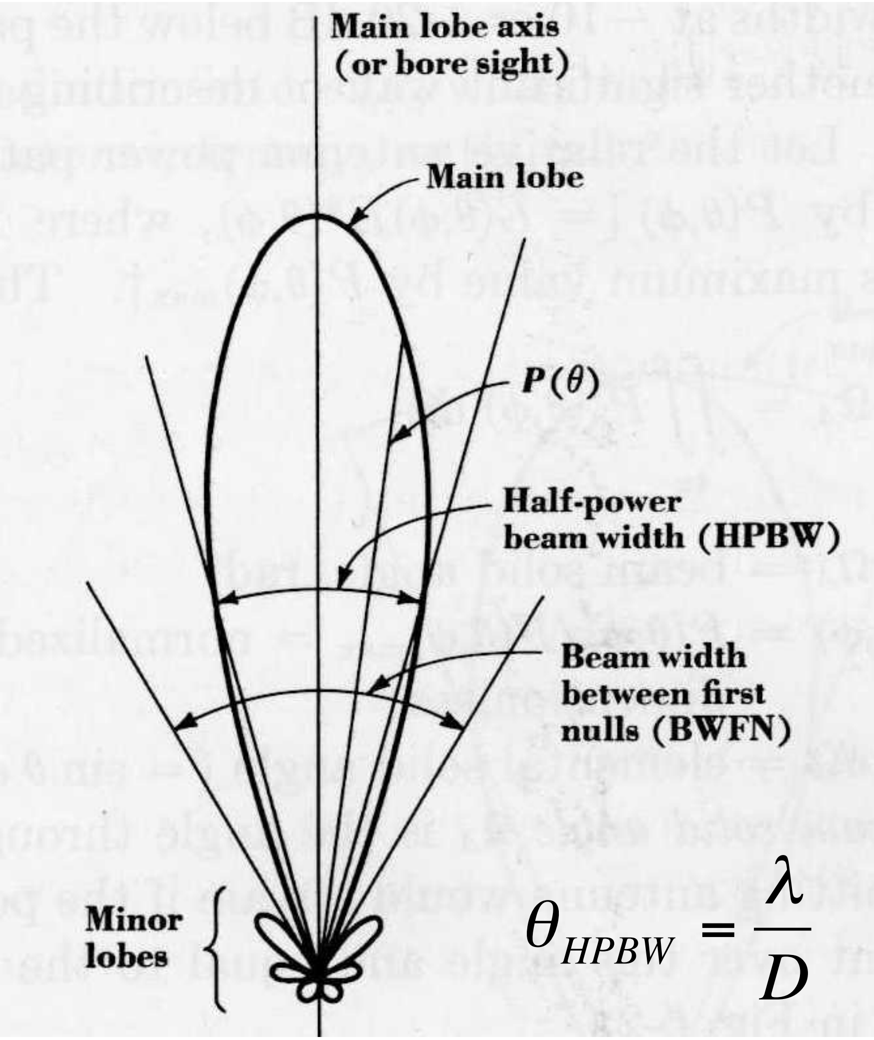
A "Jansky" is a unit of flux density

$$10^{-26} Watts / m^2 / Hz$$

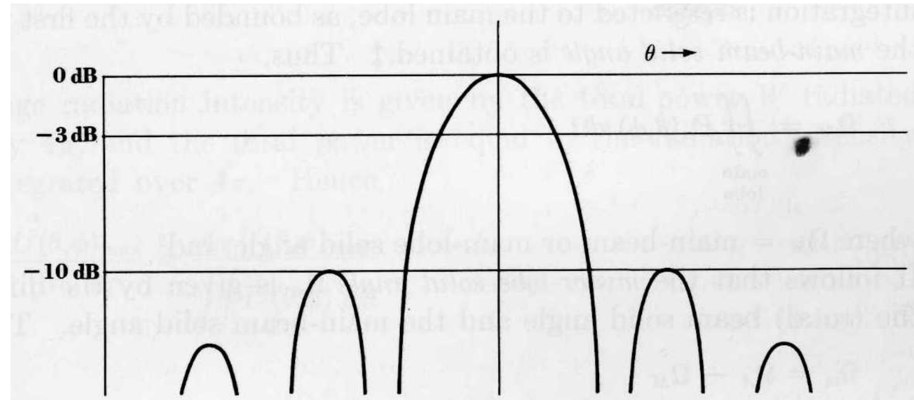
$$P = 10^{-26} 4\pi R^2 S\beta$$



Antenna Beam Pattern (power pattern)



$$\theta_{HPBW} = \frac{\lambda}{D}$$



Beam Solid Angle (steradians)

$$\Omega_A = \iint_{4\pi} P_n(\theta,\phi)\, d\Omega$$

Main Beam Solid Angle

$$\Omega_M = \iint_{\substack{main \\ lobe}} P_n(\theta,\phi)\, d\Omega$$

P_n = normalized power pattern

Kraus, 1966. Fig.6-1, p. 153.

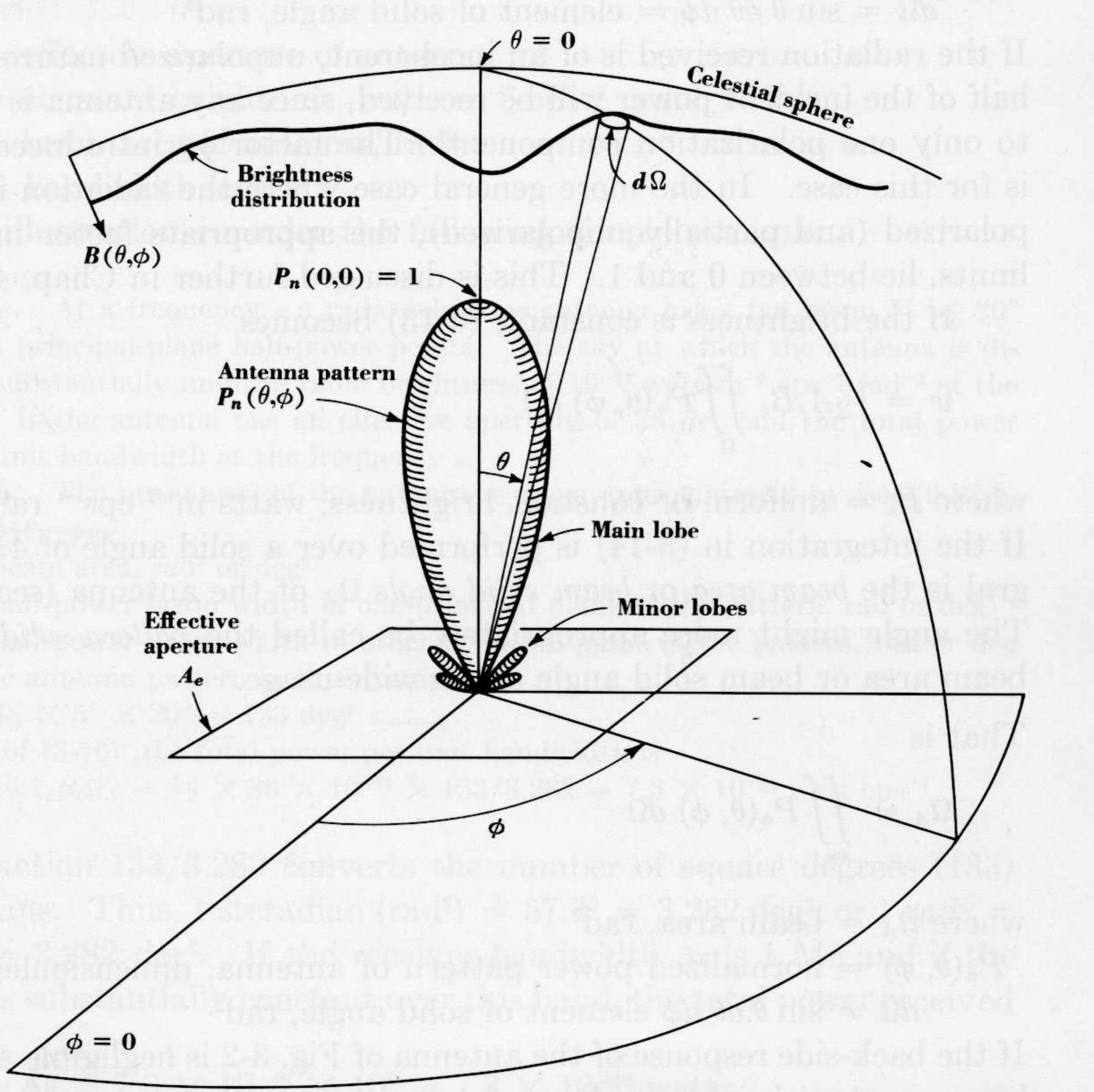


Fig. 3-2. Relation of antenna pattern to celestial sphere with associated coordinates.

dB ??

$$\Delta p(dB) = 10\log_{10}(\frac{P_1}{P_2})$$

P1/P2	Δp(dB)
1	0
2	3
10	10
100	20
1000	30

Convolution relation for observed brightness distribution

$$S(\theta) \propto \int_{source} A(\theta' - \theta) I(\theta') d\theta'$$

(Note: A is antenna pattern,
Means the same as P in
Previous slides.)

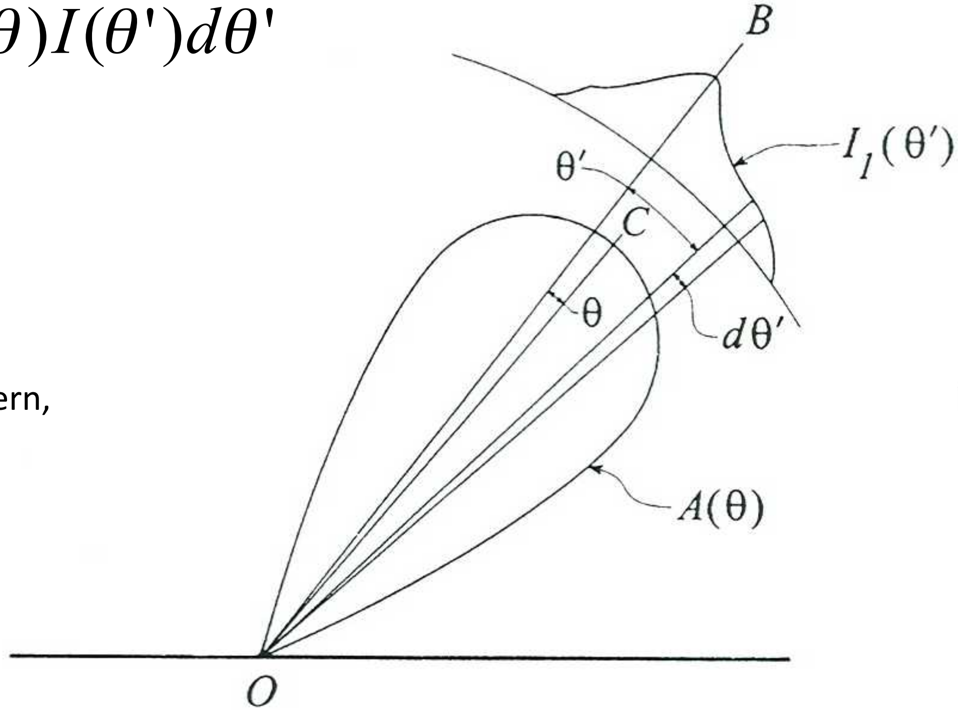


Figure 2.5 The power pattern of an antenna $A(\theta)$ and the intensity profile of a source $I_1(\theta')$ used to illustrate the convolution relationship. The angle θ is measured with respect to the beam center OC and θ' is measured with respect to the direction of the nominal position of the source OB.

Smoothing by the beam

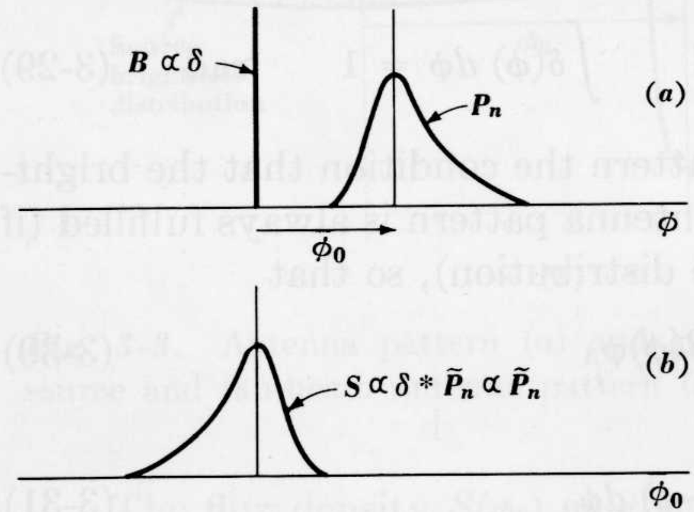


Fig. 3-6. For a point source the observed distribution is the same as the mirror image of the antenna pattern.

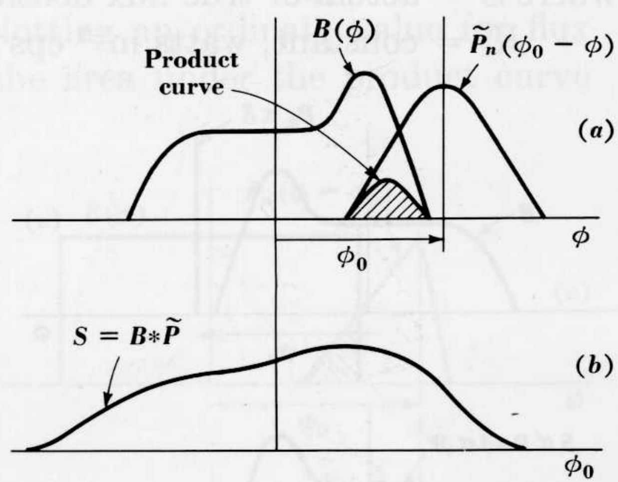


Fig. 3-4. The true brightness distribution B scanned by, or convolved with, the antenna pattern $\tilde{P}$, as in (a) yields the observed flux-density distribution S, as in (b).

Kraus, 1966. Fig. 3-6. p. 70; Fig. 3-5, p. 69.

Some definitions and relations

Main beam efficiency, ε_M

$$\boxed{\varepsilon_M = \frac{\Omega_M}{\Omega_A}}$$

Antenna theorem

$$\boxed{\Omega_A = \frac{\lambda^2}{A_e}}$$

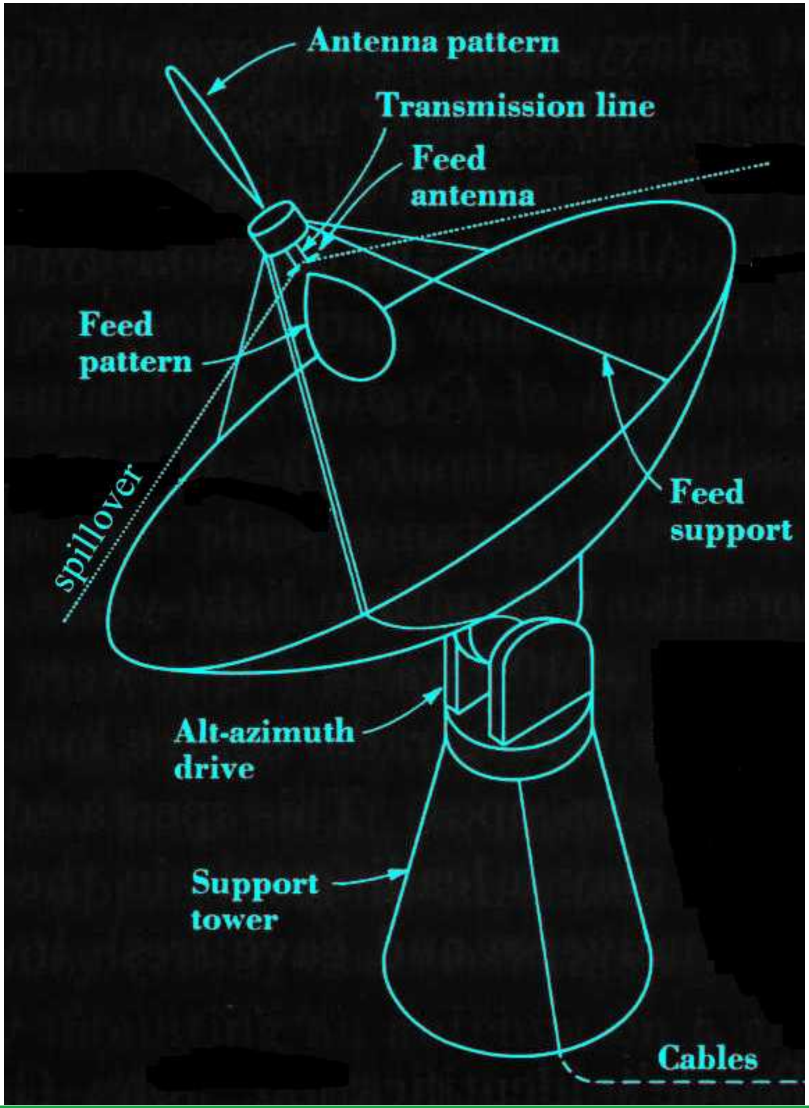
Aperture efficiency, ε_{ap}
Effective aperture, A_e
Geometric aperture, A_g

$$\boxed{\varepsilon_{ap} = \frac{A_e}{A_g}}$$

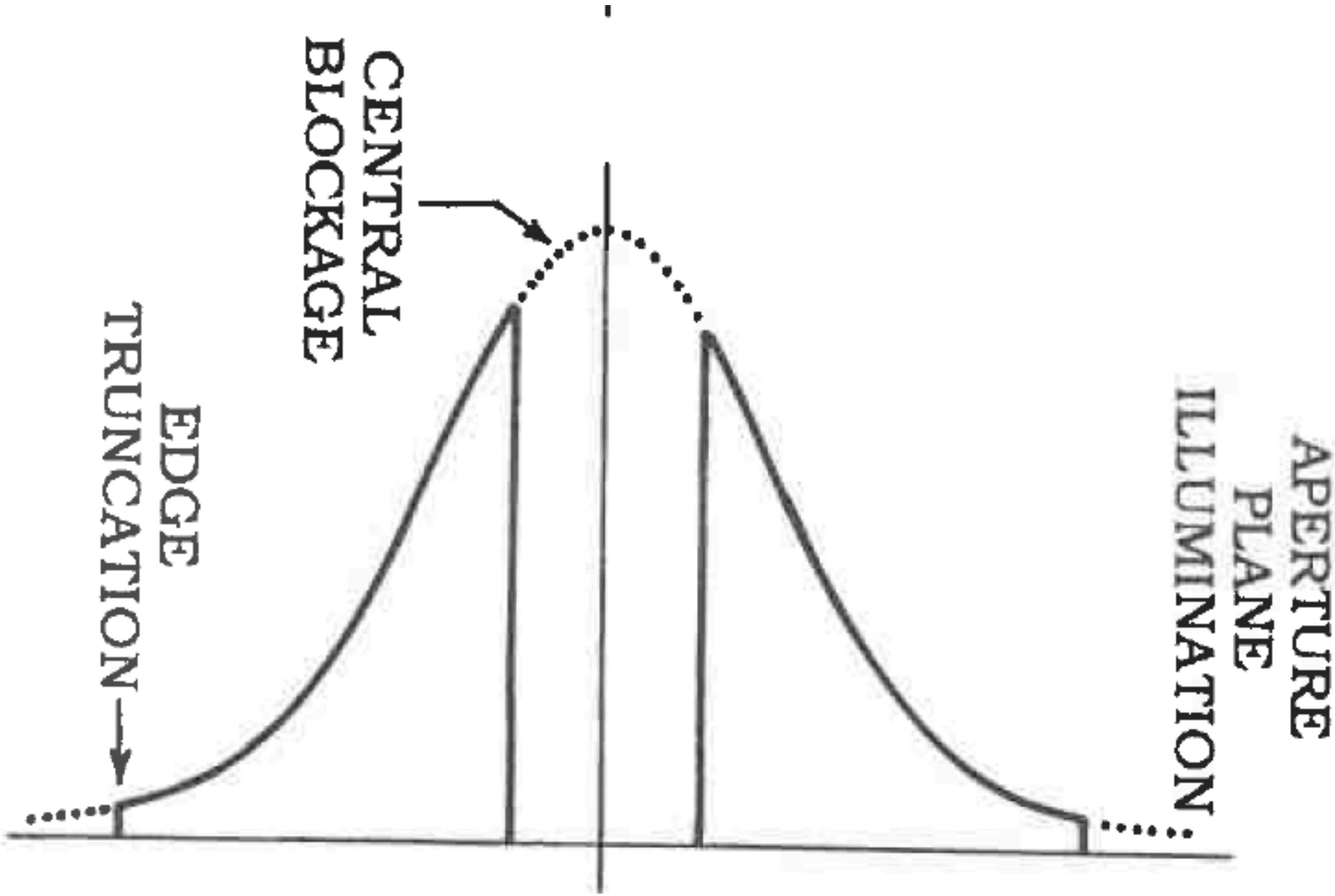
$$A_g(GBT) = \pi\left\{\frac{1}{2}(100m)\right\}^2 = 7854m^2$$

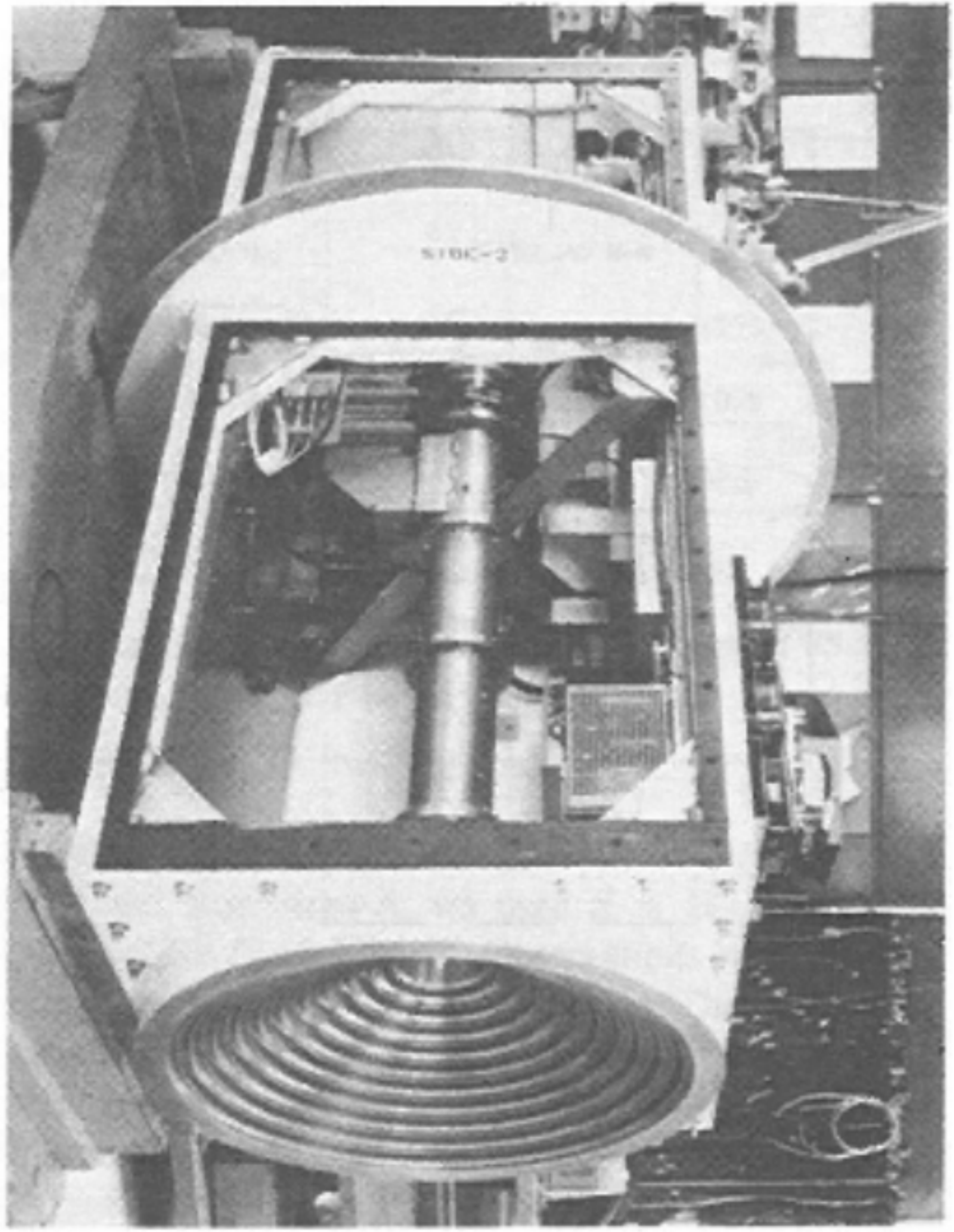
$$\boxed{\varepsilon_{ap} = \varepsilon_{pat}\varepsilon_{surf}\varepsilon_{block}\varepsilon_{ohmic}\cdots}$$

another Basic Radio Telescope

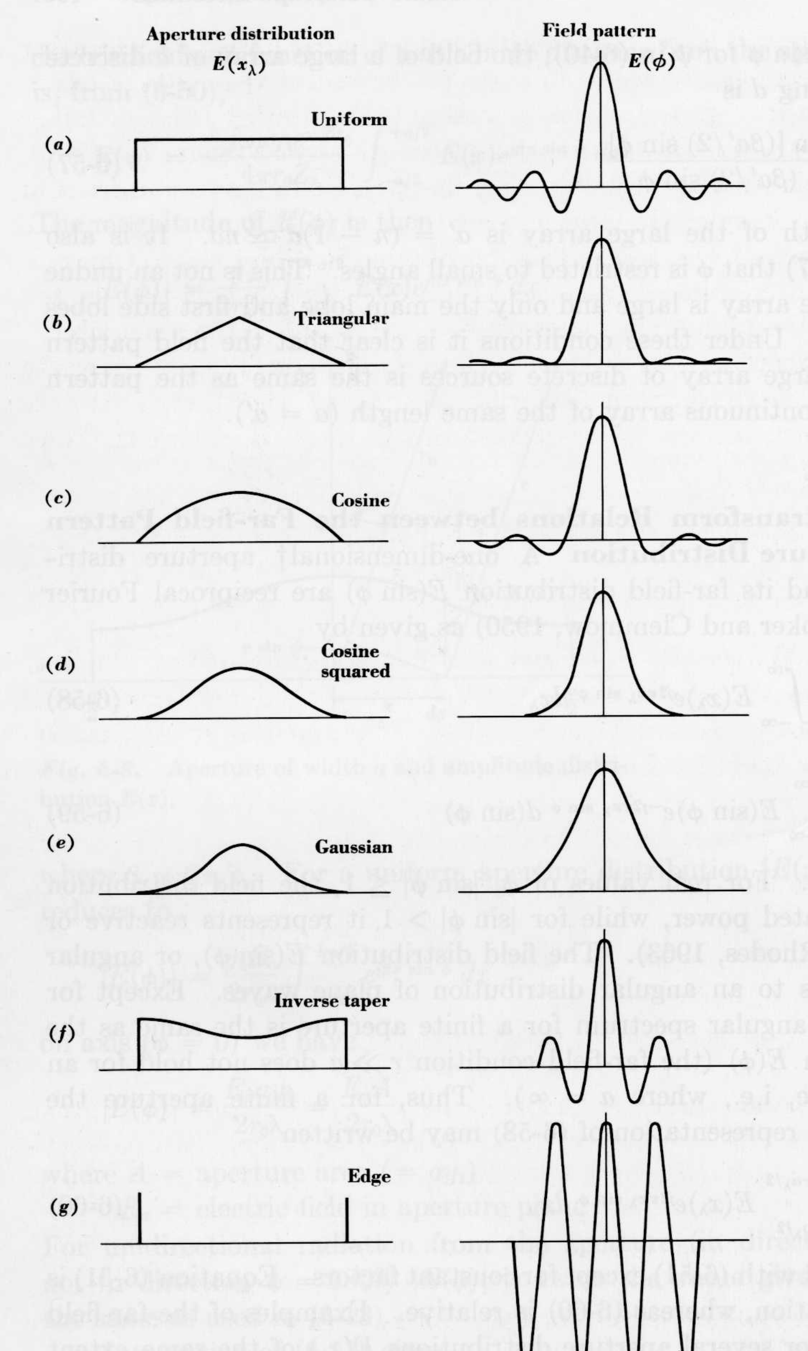


Kraus, 1966. Fig.1-6, p. 14.


CENTRAL BLOCKAGE
EDGE TRUNCATION
APERTURE PLANE ILLUMINATION



Aperture Illumination Function
←→
Beam Pattern



Kraus, 1966. Fig.6-9, p. 168.

A gaussian aperture illumination gives a gaussian beam:

$$\varepsilon_{pat} \approx 0.7$$

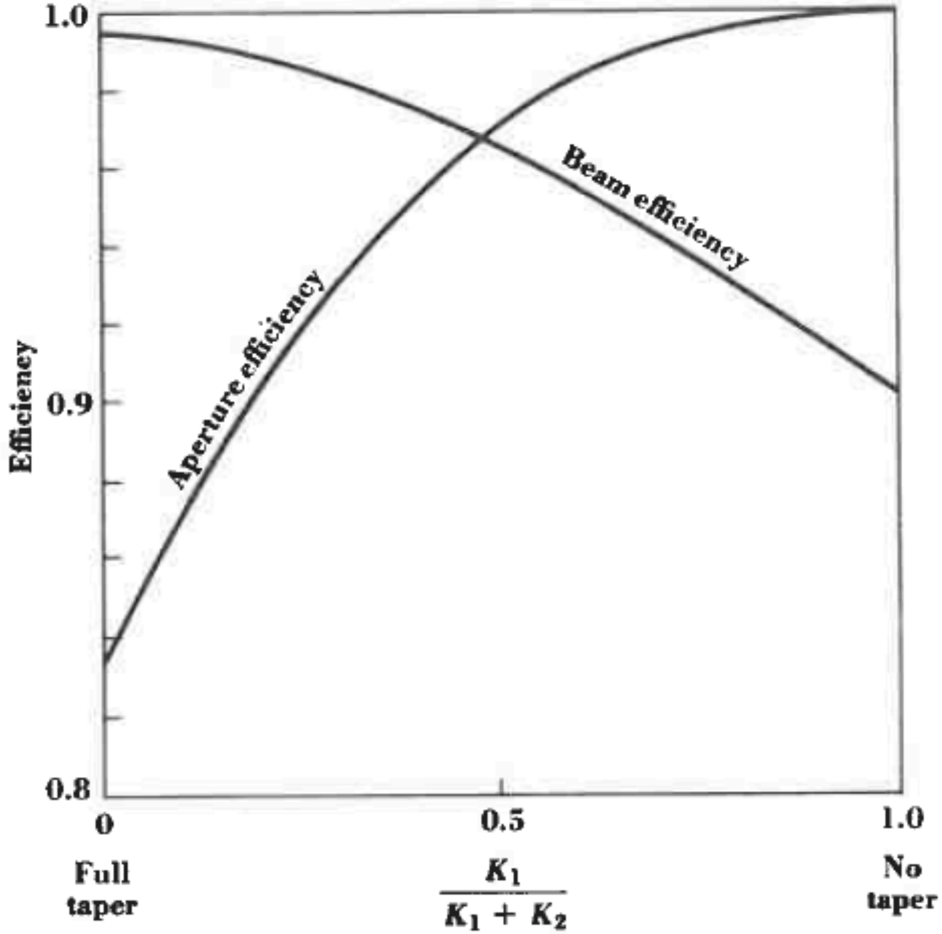
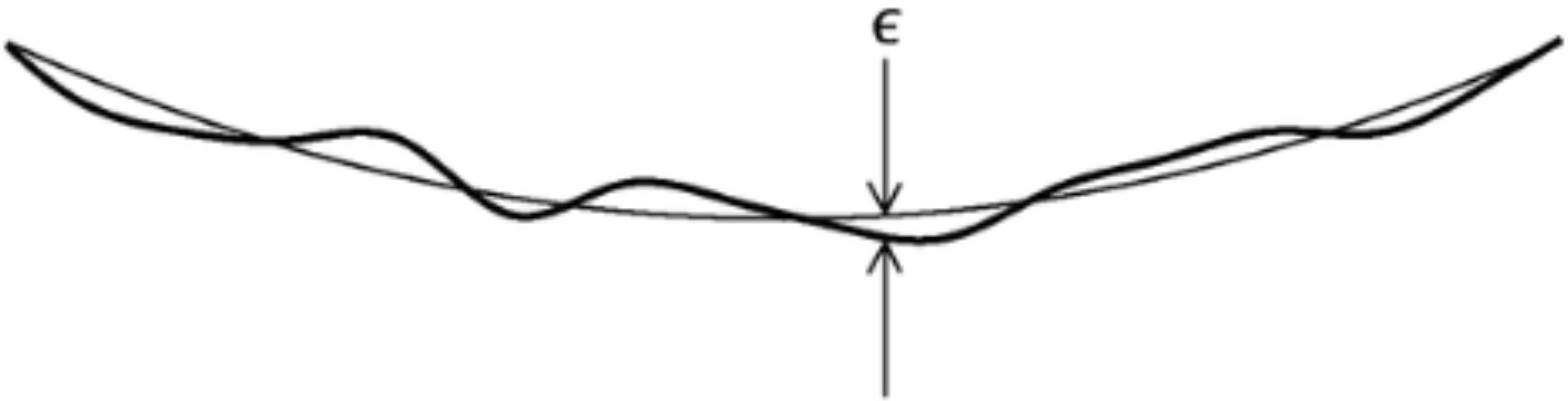


Fig. 6–104 Beam and aperture efficiencies for a one-dimensional aperture as a function of taper. (*After Nash*, 1964.) The aperture efficiency is a maximum with no taper, while the beam efficiency is a maximum with full taper.



Not-quite-perfect parabola

σ = rms surface error

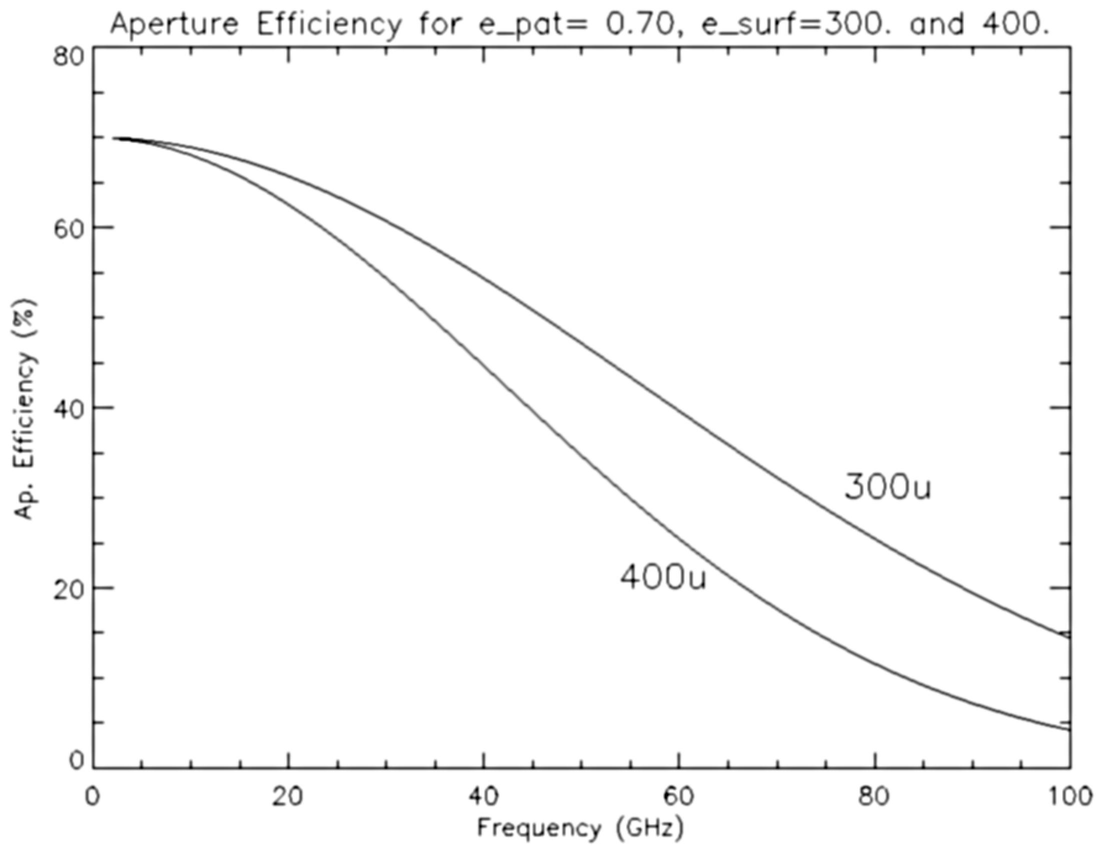
Surface efficiency -- Ruze formula

$$\varepsilon_{surf} = e^{-(4\pi\sigma/\lambda)^2}$$

σ = rms surface error

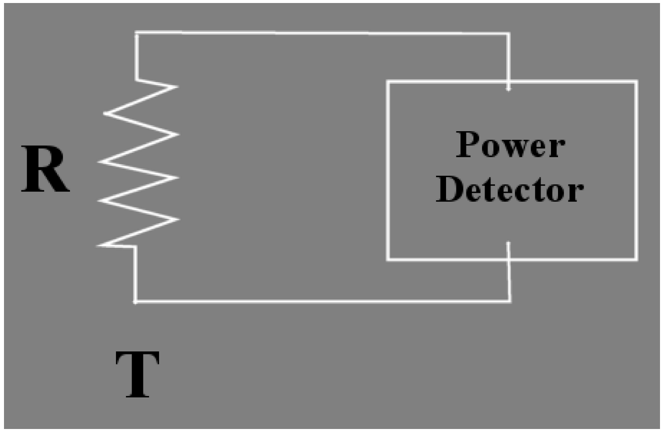
Effect of surface efficiency

$$\varepsilon_{ap} = \varepsilon_{pat}\varepsilon_{surf}\cdots$$



John Ruze of MIT -- Proc. IEEE vol 54, no. 4, p.633, April 1966.

Detected power (P, watts) from a resistor R at temperature T (kelvin) over bandwidth β(Hz)



$$P = kT\beta$$

Power P_A detected in a radio telescope Due to a source of flux density S

$$P_A = \tfrac{1}{2} A S \beta$$

power as equivalent temperature.
Antenna Temperature T_A
Effective Aperture A_e

$$S = \frac{2kT_A}{A_e}$$

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