Brief Introduction to Radio Telescopes

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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

Pioneers of radio astronomy

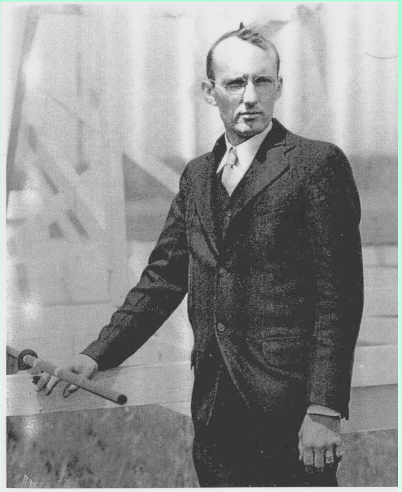
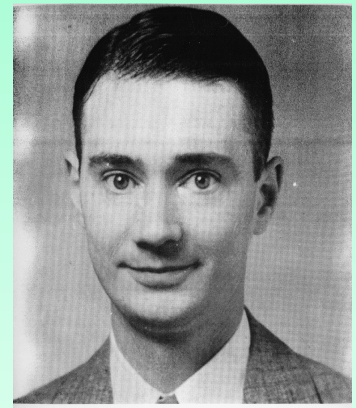


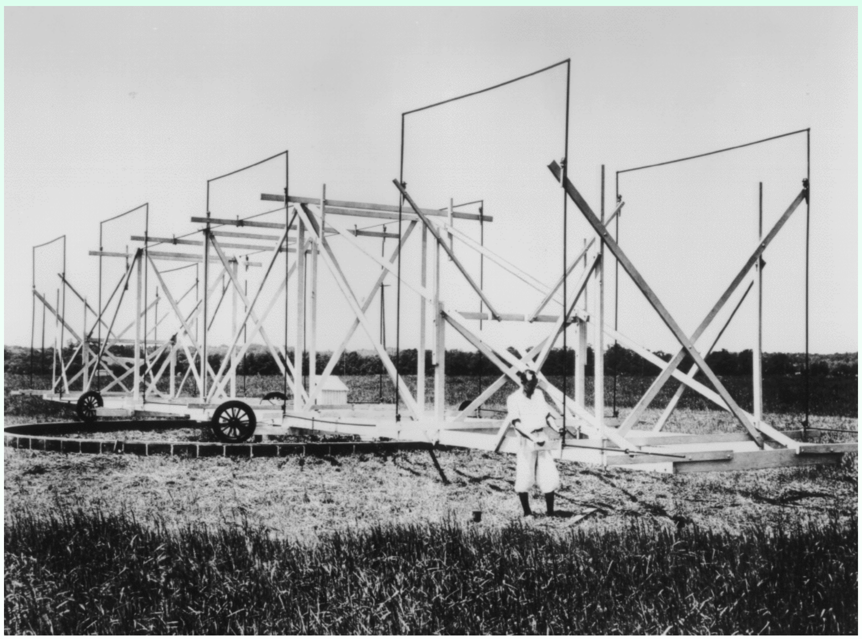
FIG. 1—Karl Guthe Jansky, about 1933.

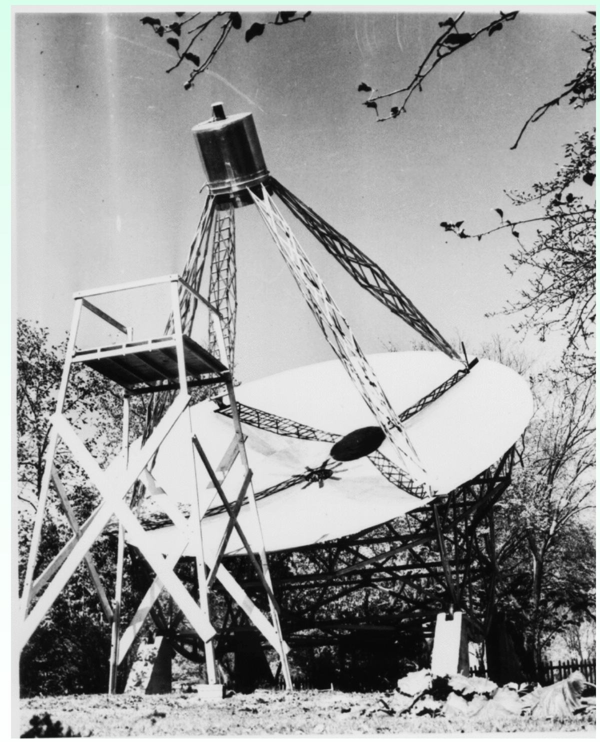
Karl Jansky
1932

Grote Reber
1938



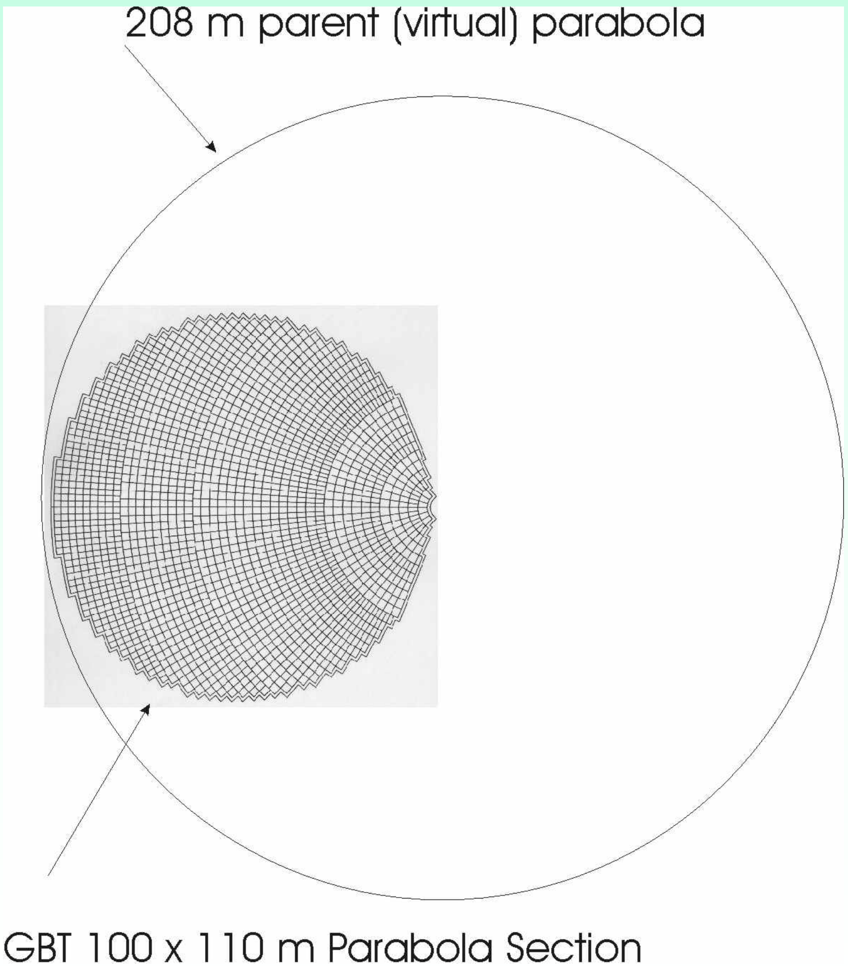
--Grote Reber, about 1937.

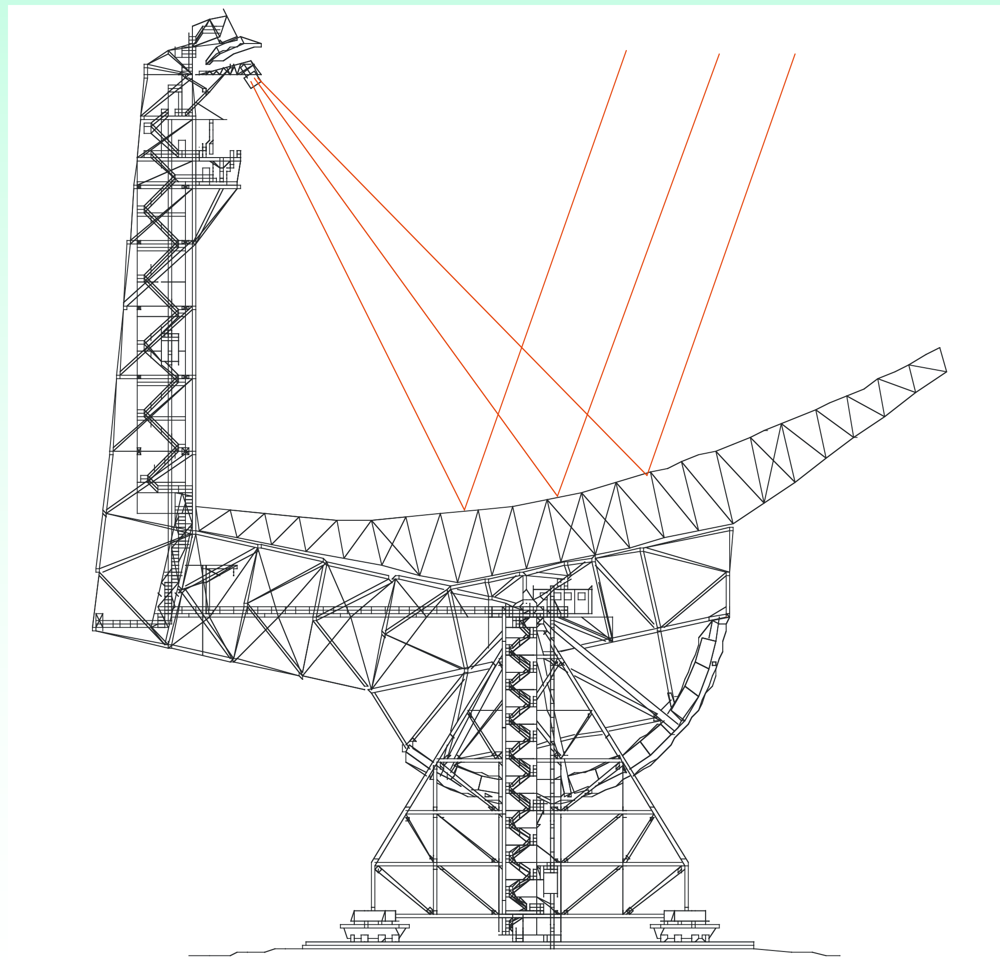




Unblocked Aperture

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

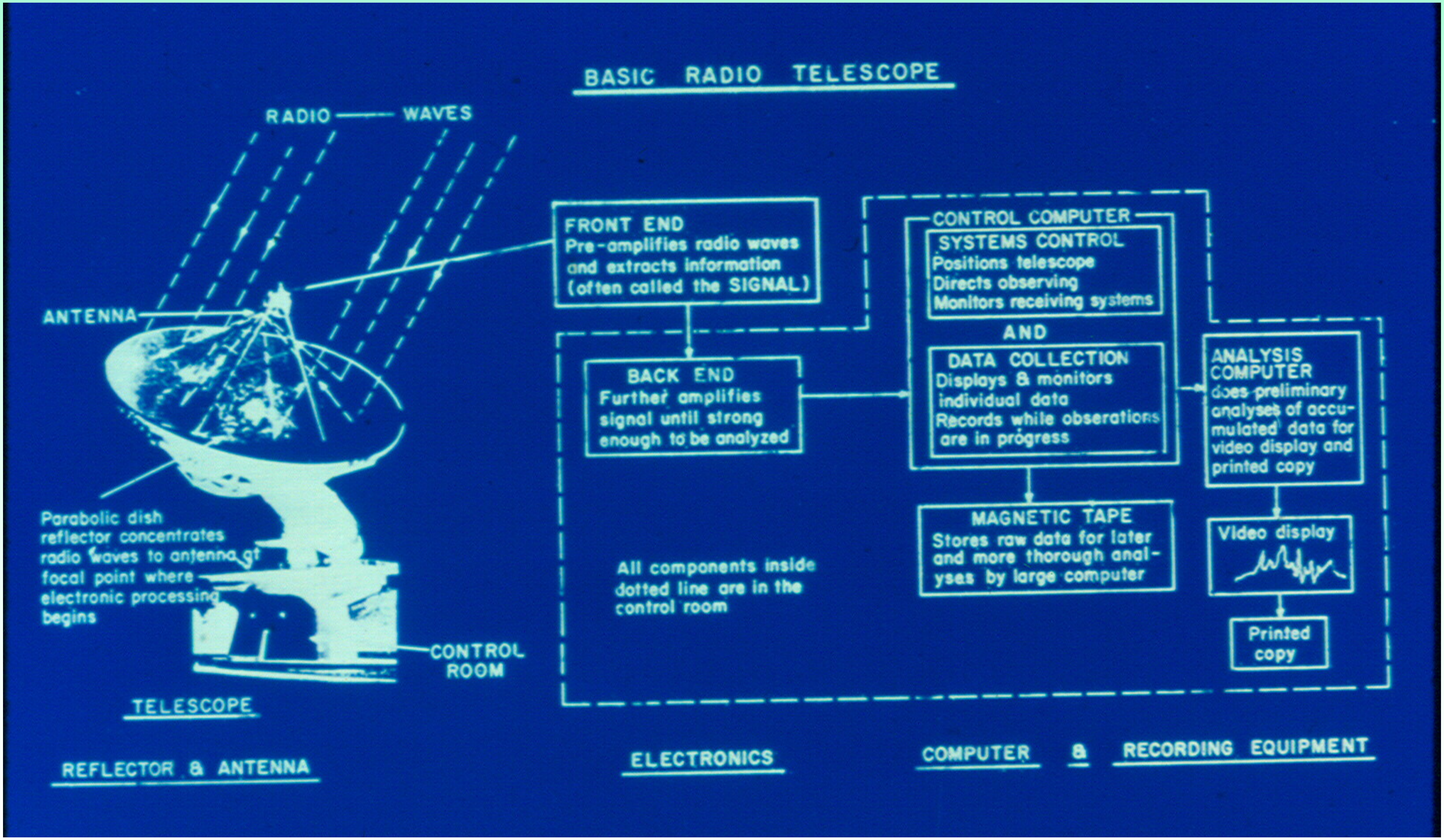




Subreflector and receiver room

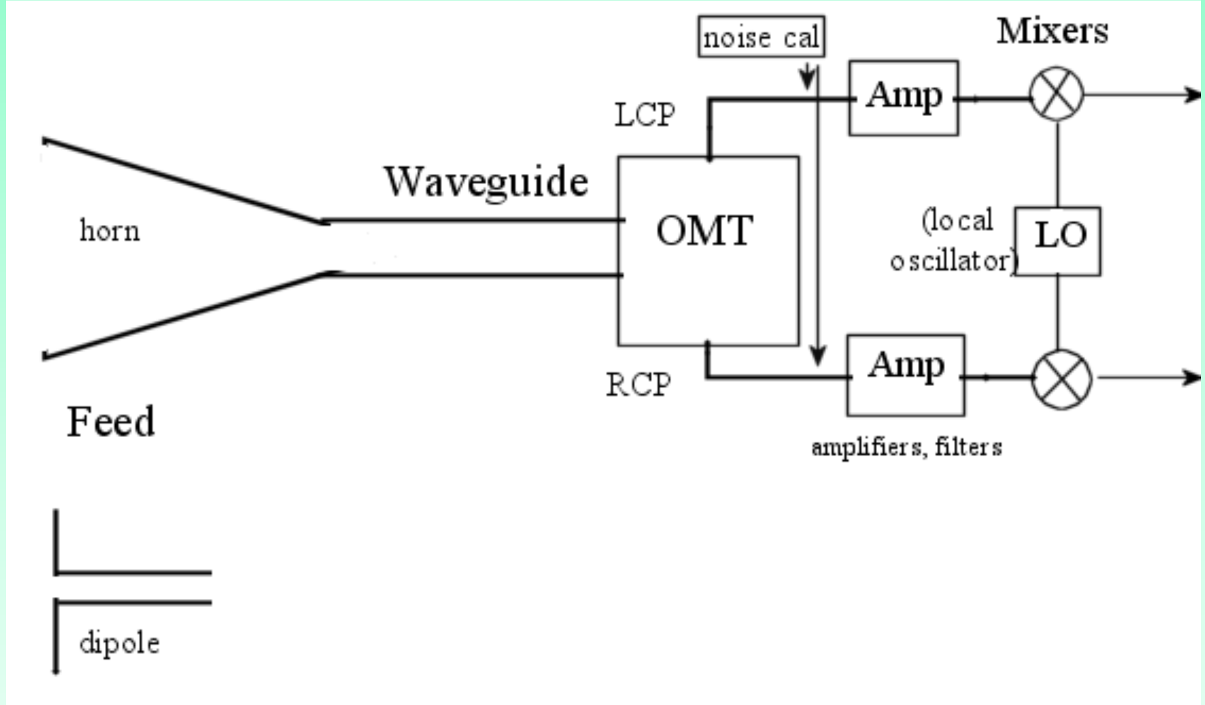
On the receiver turret

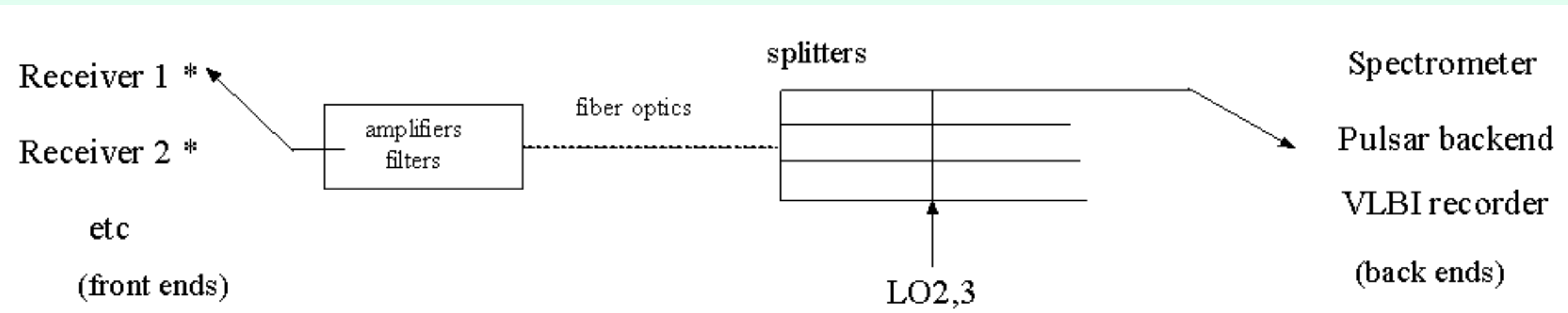
Basic Radio Telescope



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

Signal paths





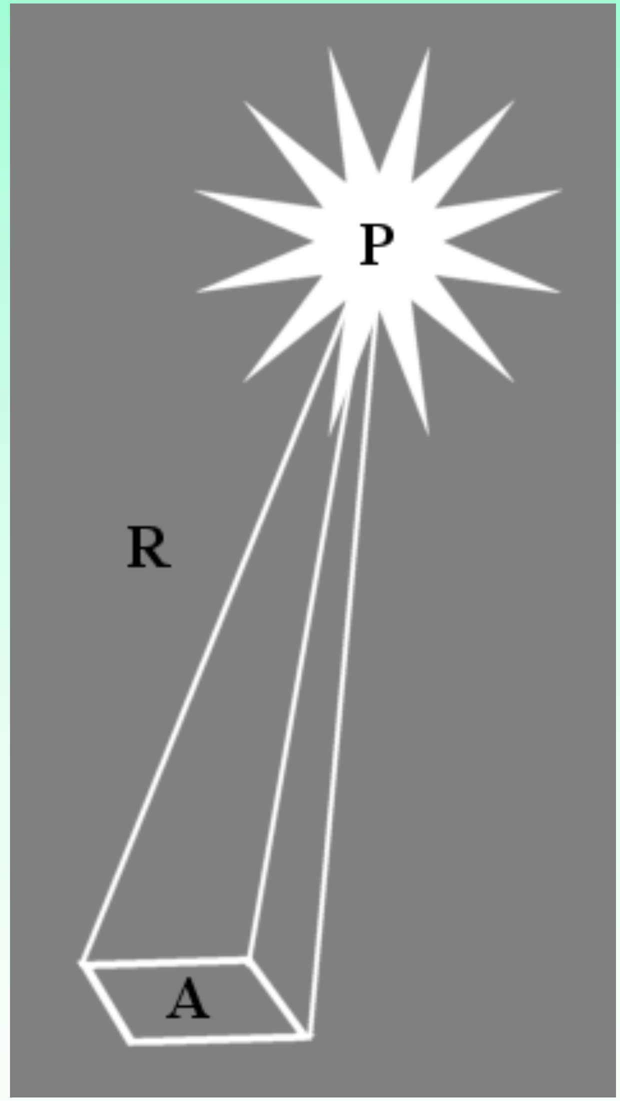
Intrinsic Power P (Watts)
Distance R (meters)
Aperture A (sq.m.)

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

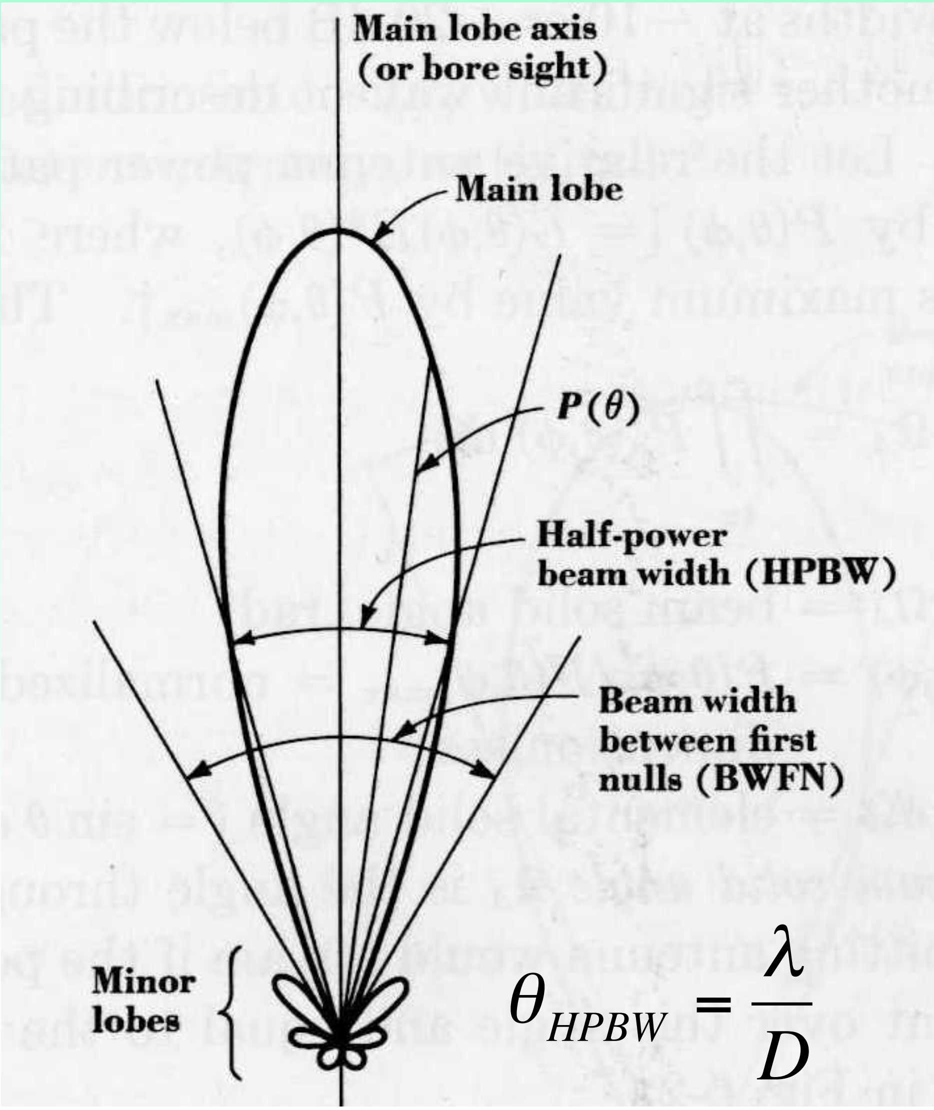
A "Jansky" is a unit of flux density

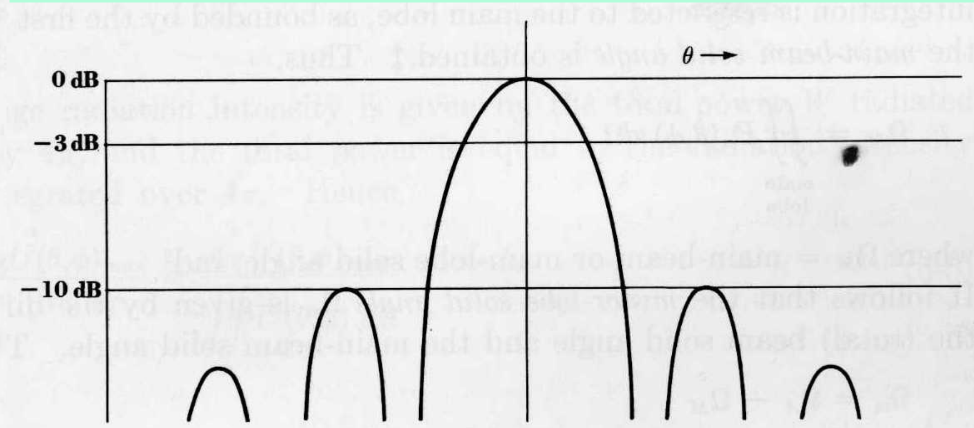
$$10^{-26} Watts / m^2 / Hz$$

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



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.

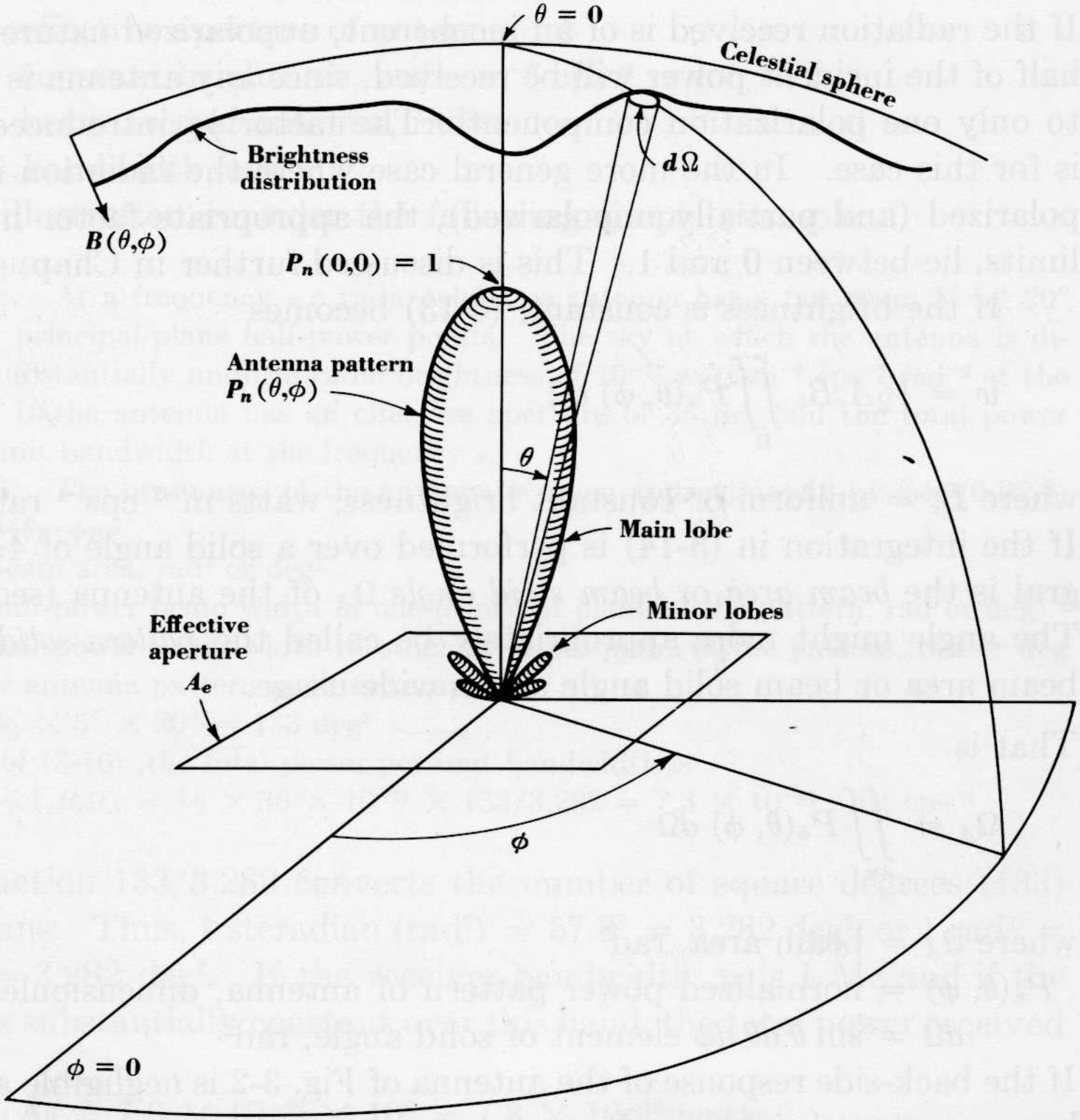


Fig. 3-2. Relation of antenna pattern to celestial sphere with associated coordinates.

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

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

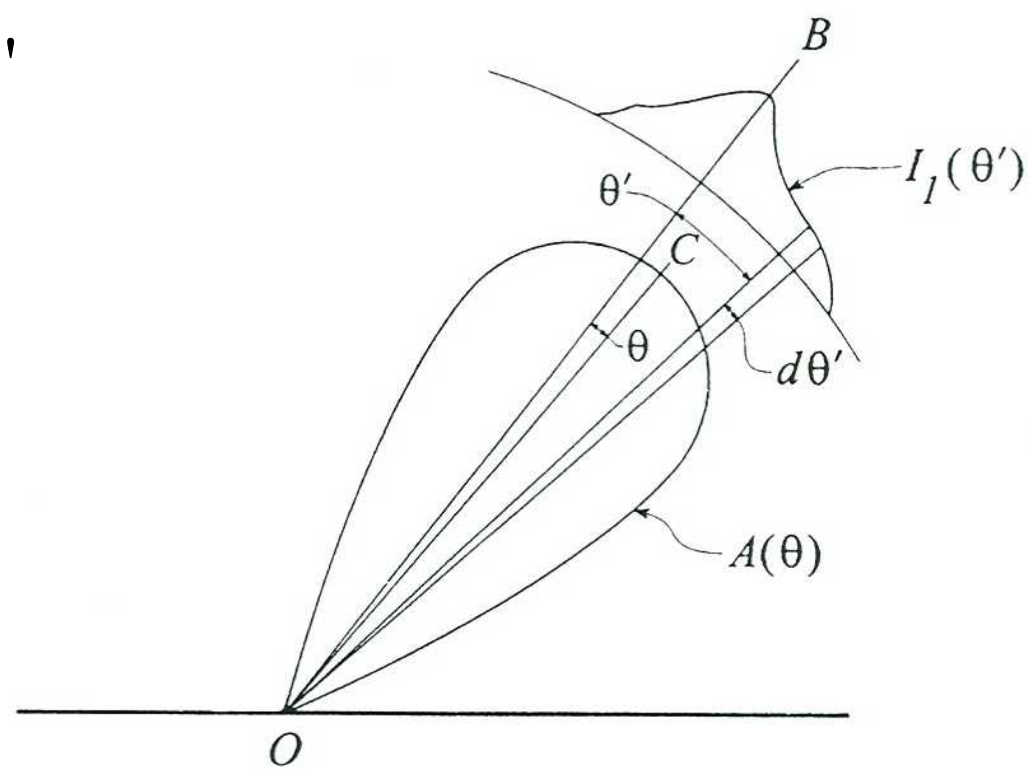


Figure 2.5 The power pattern of an antenna $A(\theta)$ and the intensity profile of a source $I_1(\theta')$ used to illustrate the convolution relationship. The angle θ is measured with respect to the beam center *OC* and θ' is measured with respect to the direction of the nominal position of the source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

Thompson, Moran, Swenson, 2001. Fig 2.5, p. 58.

Smoothing by the beam

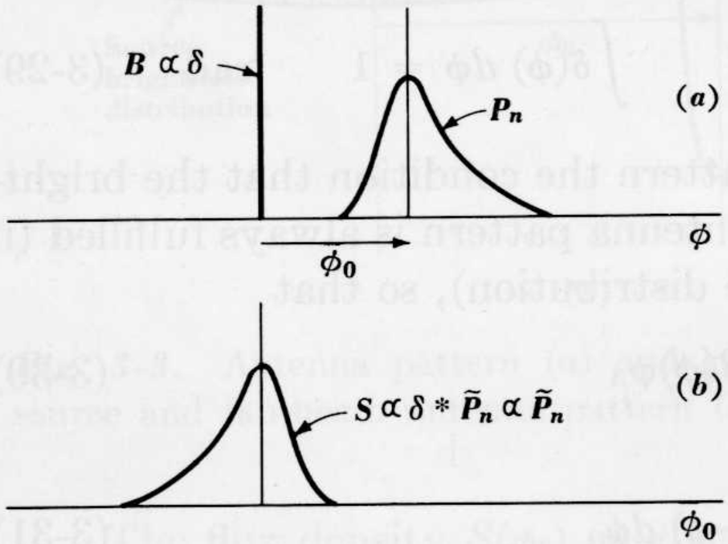


Fig. 3-6. For a point source the observed distribution is the same as the mirror image of the antenna pattern.

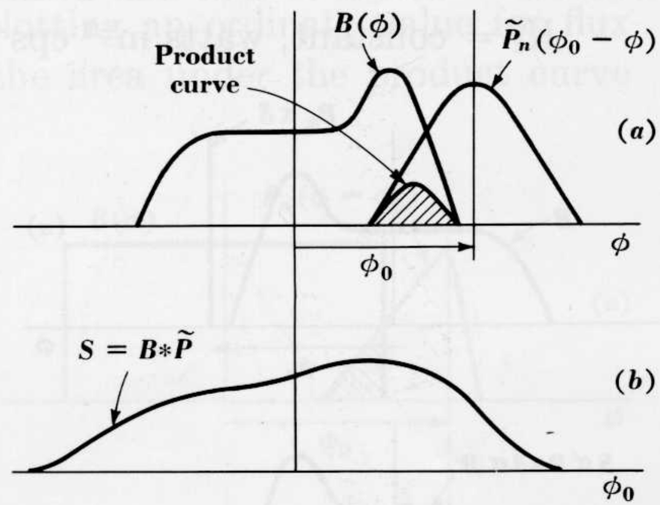


Fig. 3-4. The true brightness distribution B scanned by, or convolved with, the antenna pattern $\tilde{P}$, as in (a) yields the observed flux-density distribution S, as in (b).

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

Some definitions and relations

Main beam efficiency, ε_M

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

Antenna theorem

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

Aperture efficiency, ϵ_{ap}

Effective aperture, A_e

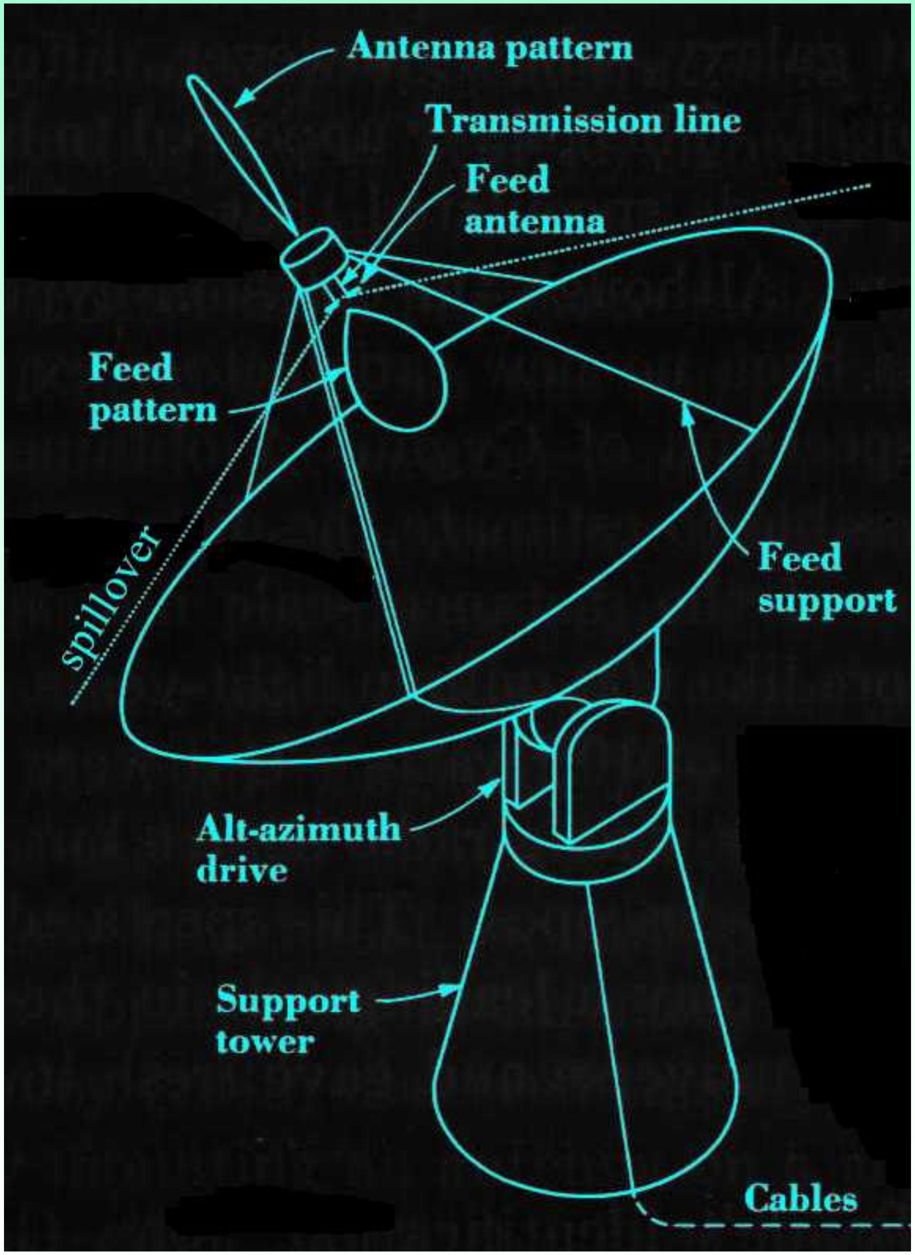
Geometric aperture, A_g

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

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

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

another Basic Radio Telescope

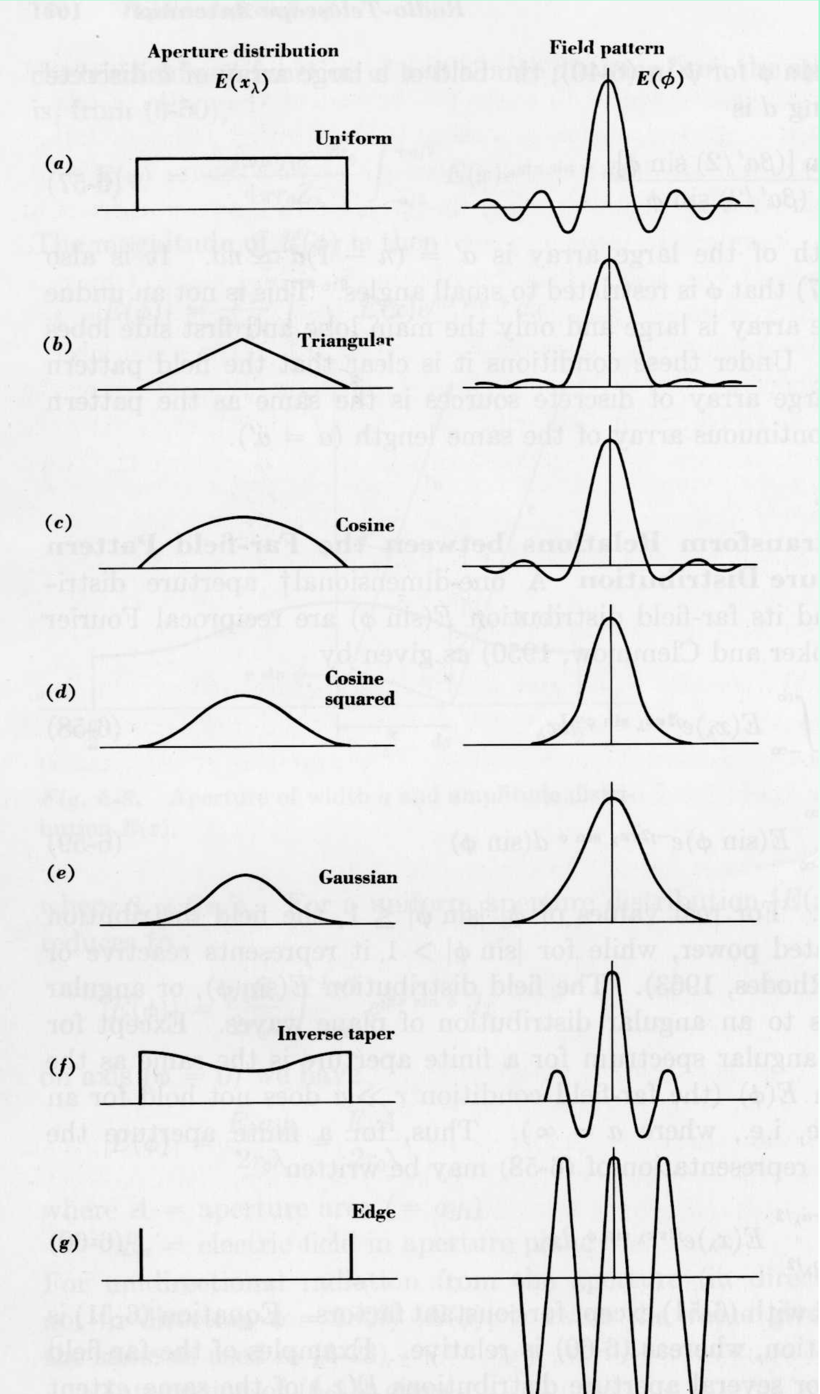


Kraus, 1966. Fig.1-6, p. 14.

Aperture Illumination Function

←→

Beam Pattern



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

A gaussian aperture illumination gives a gaussian beam:

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

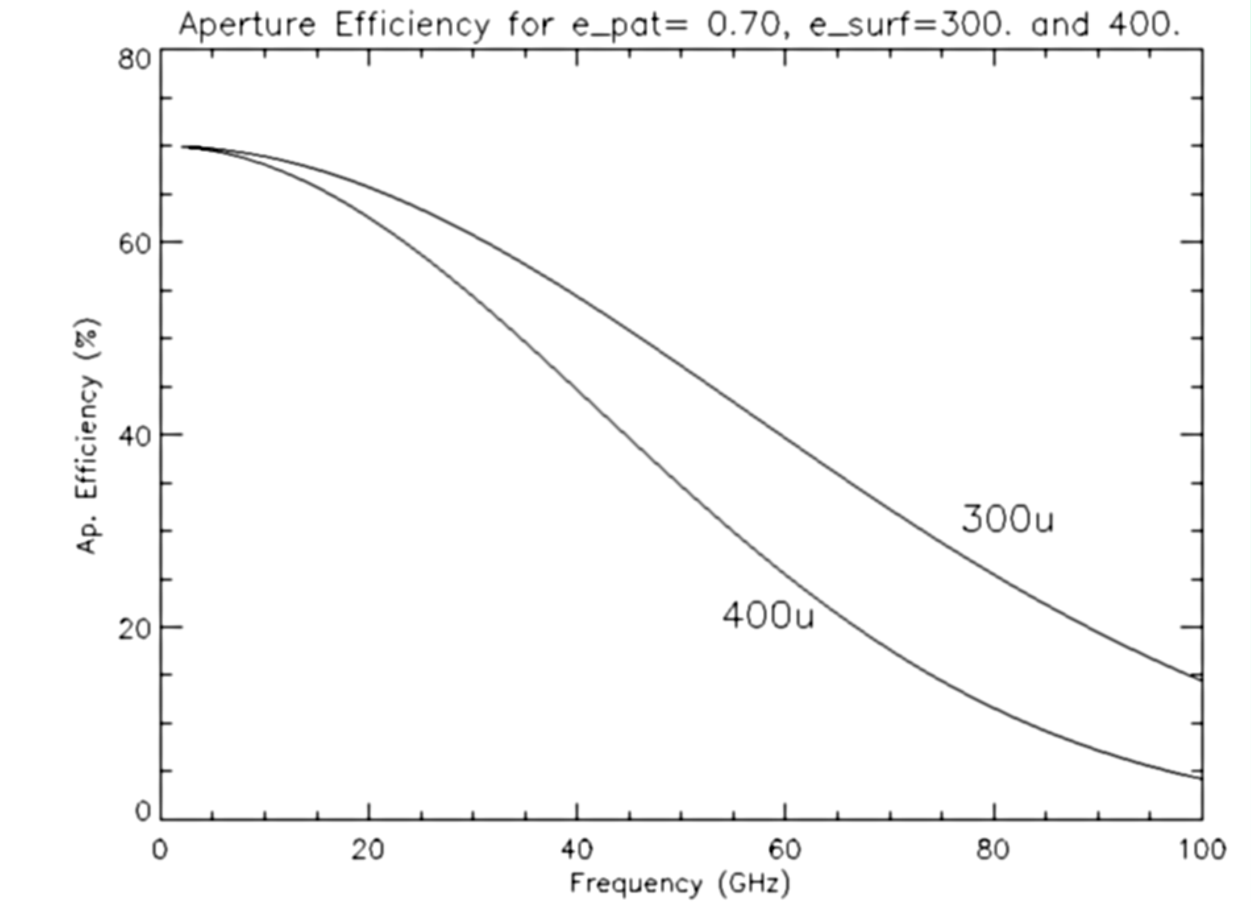
Surface efficiency -- Ruze formula

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

?= rms surface error

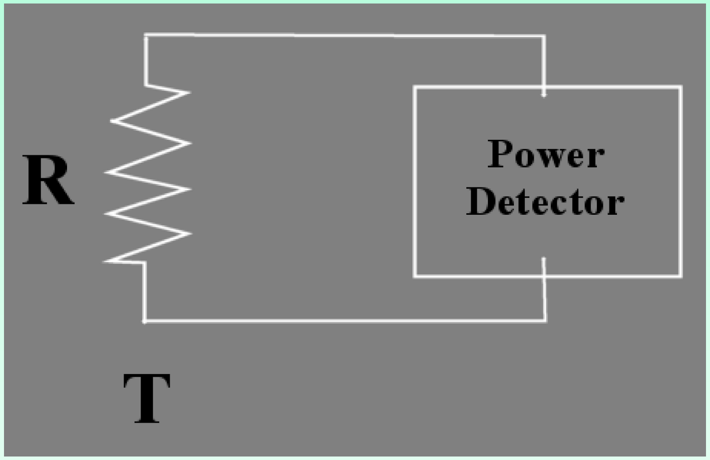
Effect of surface efficiency

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



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

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

System Temperature

= total noise power detected, a result of many contributions

$$T_{sys} = T_{ant} + T_{rcvr} + T_{atm}(1 - e^{-\tau a}) + T_{spill} + T_{CMB} + \cdots$$

Thermal noise ΔT

= minimum detectable signal

$$\Delta T = k_1 \frac{T_{sys}}{\sqrt{\Delta\nu \cdot t_{\mathrm{int}}}}$$

Gain(K/Jy) for the GBT

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

Including atmospheric absorption:

$$S = \frac{2kT_A}{A_e} e^{\tau a}$$

$$G = \frac{T_A}{S} = \frac{\varepsilon_{ap} A_g}{2k}$$

$$G(K / Jy) = 2.84 \cdot \varepsilon_{ap}$$

Physical temperature vs antenna temperature

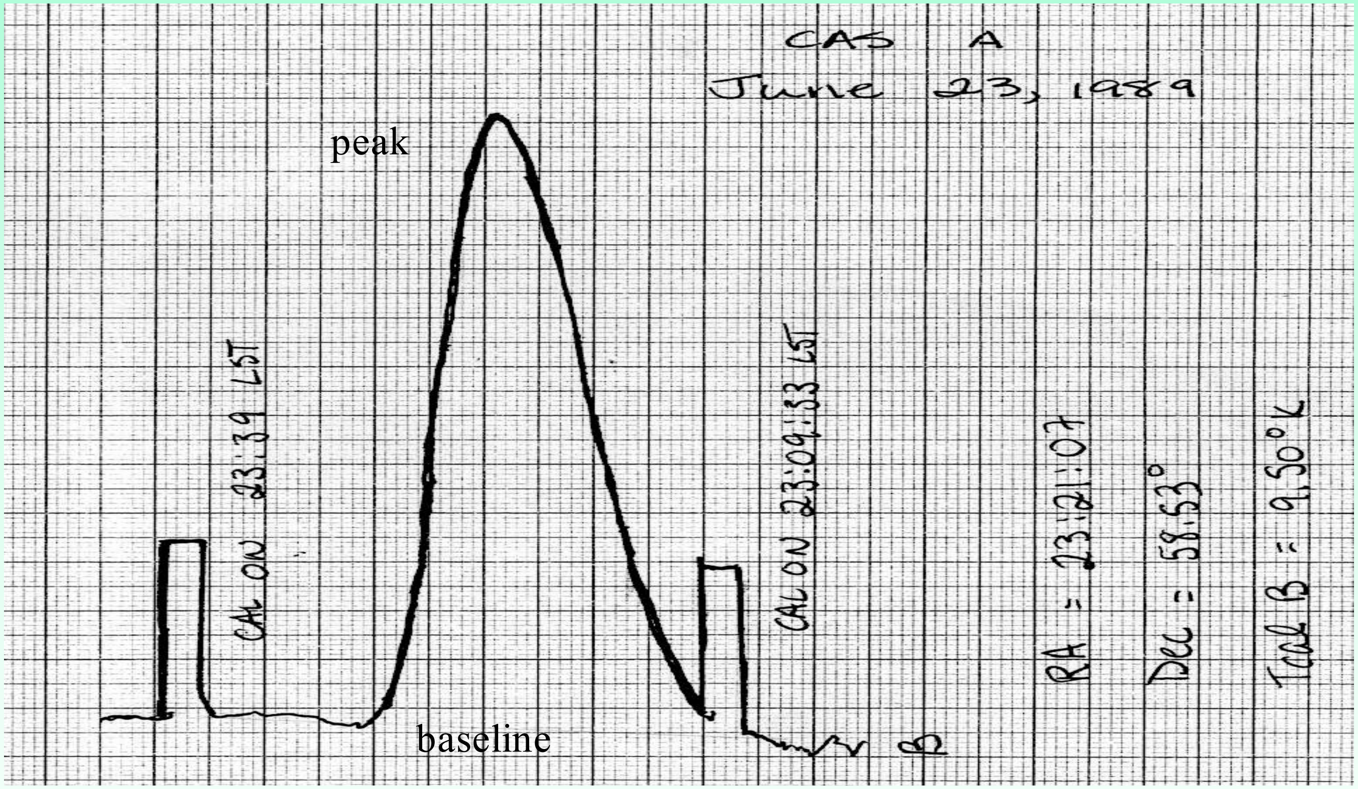
For an extended object with source solid angle Ω_s,
And physical temperature T_s, then

for $\Omega_s < \Omega_A$ $$T_A = \frac{\Omega_s}{\Omega_A} T_s$$

for $\Omega_s > \Omega_A$ $$T_A = T_s$$

In general : $$T_A = \frac{1}{\Omega_A} \iint_{source} P_n(\theta,\phi) T_s(\theta,\phi)\, d\Omega$$

Calibration: Scan of Cass A with the 40-Foot.



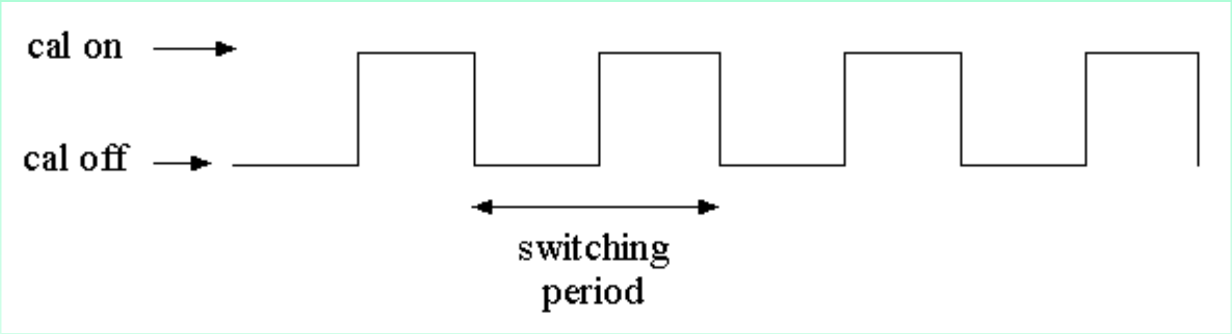
Tant = Tcal * (peak-baseline)/(cal – baseline)

(Tcal is known)

More Calibration : GBT

Convert counts to T

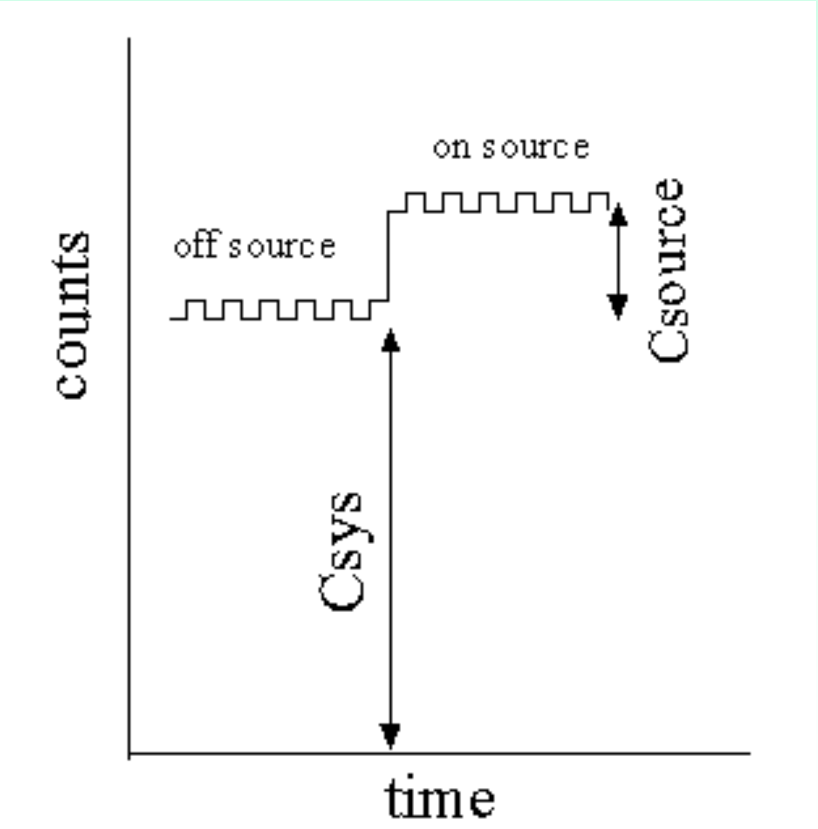
$$K = \frac{T_{cal}}{\left\langle C_{cal-on} - C_{cal-off} \right\rangle}$$



$$T_{sys} = K \cdot C_{sys}$$

$$= \frac{1}{2} K \cdot (C_{offsource,calon} + C_{offsource,caloff}) - \frac{1}{2} T_{cal}$$

$$T_{ant} = K \cdot C_{source}$$



Position switching