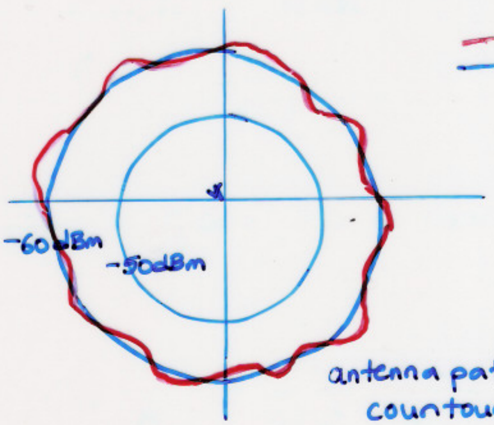
SYSC 5608 Wireless Communications Systems Engineering

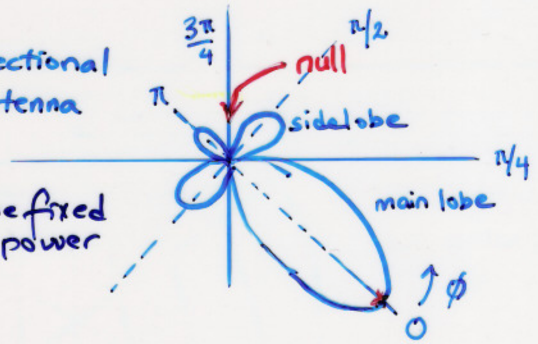
ANTENNAS

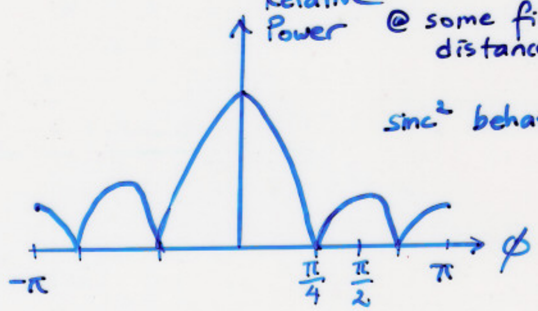
Antenna: the coupler between the transmitter and air.



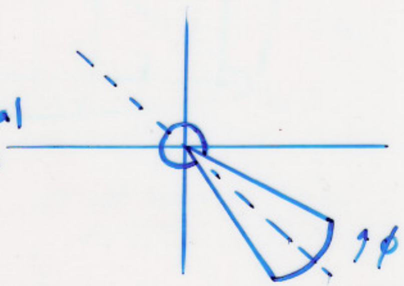
— practical omnidirectional antenna
— ideal omnidirectional antenna (isotropic)

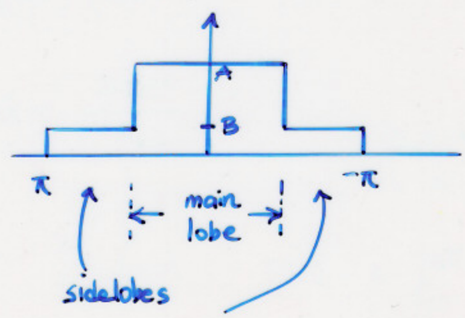
Antenna pattern: the surface at which the received power is constant.





created by antenna arrays



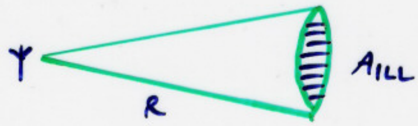


$\frac{A}{B}$: front-to-back ratio

Power Density: $\bar{S} \triangleq \bar{E} \times \bar{H}$ (watts/m²)

↳ Poynting vector

$$S \triangleq \frac{P_t \text{ (transmit power)}}{A_{ILL} \text{ (area illuminated)}}$$



* ideal isotropic antenna :

$$A_{ILL} = 4\pi R^2$$

$$S_{iso} = \frac{P_t}{4\pi R^2} \text{ watts/m}^2$$

Gain of an antenna:

$$G \triangleq \frac{S}{S_{iso}} = \frac{4\pi R^2}{A_{ILL}}$$

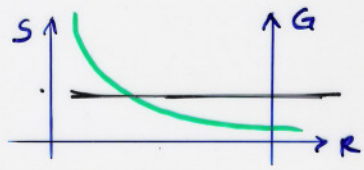
$$\left(G = \frac{P_t}{A_{ILL}} \cdot \frac{4\pi R^2}{P_t} \right)$$

$$S = \frac{P_t}{A_{ILL}} \times \frac{4\pi R^2}{4\pi R^2} = \frac{P_t G}{4\pi R^2}$$

dependence on distance (R) from the transmitter

G: ✗

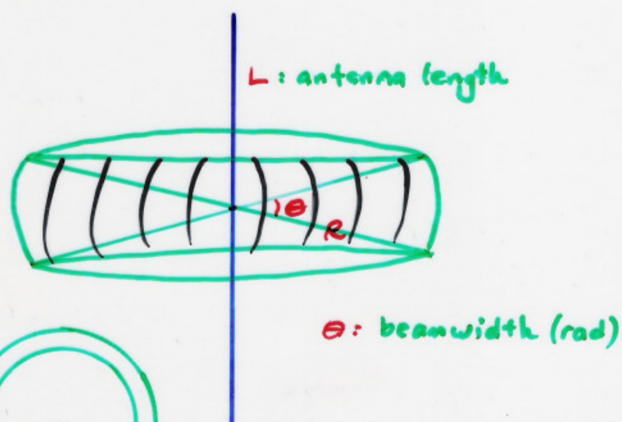
S: ✓



Effect of Antenna Size

(1) Linear Antenna

$\lambda = \frac{c}{f}$ — λ: wavelength; c: speed of light; f: frequency



$$A_{ILL} \simeq (\theta R) \times (2\pi R) = 2\pi R^2 \theta$$

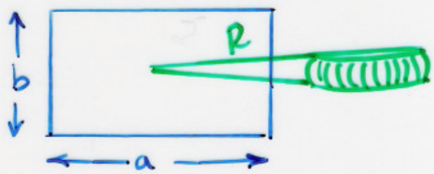
$$G = \frac{4\pi R^2}{A_{ILL}} \simeq \frac{2}{\theta}$$

$$\theta = \frac{\lambda}{L}$$ (without proof), valid for $\theta \ll 1$ rad.

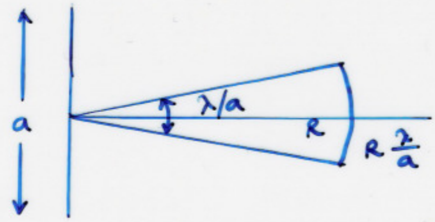
$$G \simeq \frac{2}{\theta} = \frac{2 L_{eff}}{\lambda}$$ ... linear antenna gain

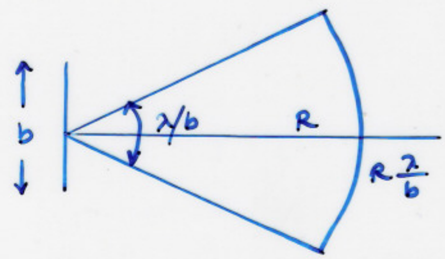
$L_{eff} = \mu L$ — μ: efficiency

(2) Area Antenna



Area = A = ab





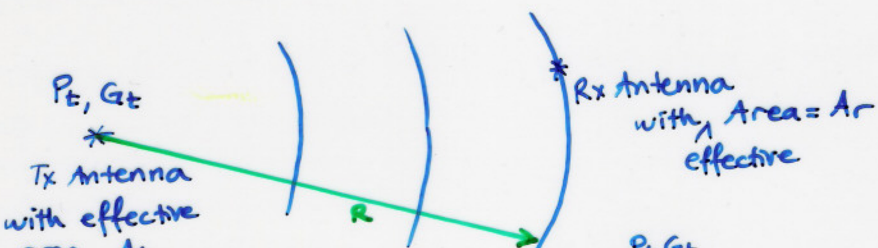
$$A_{ILL} \cong \left(\frac{\lambda}{a}R\right) \times \left(\frac{\lambda}{b}R\right)$$

$$= \frac{\lambda^2}{A_{ant}} R^2$$

$$\text{Gain} = G = \frac{4\pi R^2}{A_{ILL}} \cong 4\pi \frac{A_{eff}}{\lambda^2}$$

$A_{eff} = \mu A_{ant}$, $\mu < 1$

Received Power



$$S = \frac{P_t G_t}{4\pi R^2}$$

$$\boxed{P_r = S A_r}$$

$$G_t = \frac{4\pi A_t}{\lambda^2}, \quad G_r = \frac{4\pi A_r}{\lambda^2}$$

→ effective receiving area can be calculated for any type of antenna

$$P_r = \underbrace{\frac{P_t G_t}{4\pi R^2}}_{S} \cdot A_r = \boxed{\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 R^2}}$$

← free space

$$\left[P_r \simeq P_t G_t G_r \left(\frac{\lambda}{4\pi d_o}\right)^2 \left(\frac{d_o}{R}\right)^n \right]$$

← terrestrial (free space propagation upto d_o)

d_o → reference distance

EIRP: equivalent isotropic radiated power

$= P_t G_t$ (transmitter dependent)

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi)^2 R^2} = P_t \frac{A_r A_t}{R^2 \lambda^2}$$

$$P_r = EIRP \times G_r \times \frac{\lambda^2}{(4\pi R)^2}$$

$$L_p = \text{free-space path loss} = \left(\frac{4\pi R}{\lambda}\right)^2$$

$$\rightarrow P_r = \frac{EIRP \times G_r}{L_p}$$

remark: directional antenna → 2D
2D can be realized through antenna arrays

Example: (Prof. Yen, UofT)

Q: A terrestrial microwave radio link operating at 4 GHz uses antennas of gain 35 dB for both transmit and receive. The transmitter power is 10W and the average distance between repeaters is 40 km.

1) Find the power density S at a receiving antenna.
2) The antennas are circular aperture and are illuminated uniformly. What is the approximate diameter of the antennas?
3) What is the approximate beamwidth of the antennas?

A: $f = 4\text{ GHz} \rightarrow \lambda = \frac{c}{f} = \frac{3\times10^8 \text{ m/s}}{4\times10^9 \text{ 1/s}} = 7.5\times10^{-2}\text{ m}$

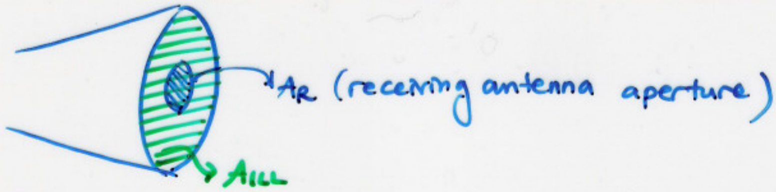
$G = 35\text{dB} = 3162$

$P_t = 10\text{W}$ $\quad R = 4\times10^4\text{ m}$

1) $$S = \frac{P_t}{A_{ILL}} = \frac{P_t}{A_{ILL}} \times \frac{4\pi R^2}{4\pi R^2} = \frac{P_t G}{4\pi R^2} = 1.57\times10^{-6} \text{ watts/m}^2$$

$$\left(A_{ILL} = \frac{P_t}{S} = 6.36\text{ km}^2\right)$$

2)

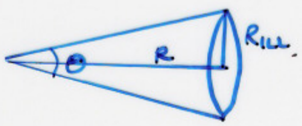


$$G = \frac{4\pi A}{\lambda^2} \rightarrow \frac{G\lambda^2}{4\pi^2} = r^2 \Rightarrow r = 0.671\,m$$

(r → antenna radius)

$$P_R = A_R S = 2.226 \times 10^{-6} \text{ watts}$$

3)



$$A_{ILL} = \frac{P_t}{S} = \pi R_{ILL}^2 \rightarrow R_{ILL} = 1422.6\,m$$

$$\frac{1}{2}\tan\Theta = \frac{R_{ILL}}{R} = \frac{1422.6}{40000}$$

$$\rightarrow \Theta = 0.0711 \text{ radians} = 4^\circ$$

Example 2 (Yen)

A Base station in a 900 MHz cellular mobile radio system has an antenna of 10 dB gain. An incoming signal from a mobile set as seen at the base station receiver input is 20μV. The transmission line between the antenna and the receiver has a characteristic impedance $Z_0 = 75\Omega$.

1) Find the power received at the base station.

2) Find the power density (S) of the incident (incoming) wave.

3) The base station antenna is linear and has an "efficiency" of 50%. What is its length?