$$\frac{e^{-jkR}}{R}$$

$$\bar{E}(\bar{R}) = j\omega\mu IL \frac{e^{-jkR}}{4\pi R}\left[\bar{a}_R\left(\frac{1}{jkR}+\frac{1}{(jkR)^2}\right)2\cos\theta + \bar{a}_\theta \sin\theta\left(1+\frac{1}{jkR}+\frac{1}{(jkR)^2}\right)\right]$$

$$\bar{H}(\bar{R}) = jk IL \frac{e^{-jkR}}{4\pi R}\sin\theta \ \bar{a}_\phi \left(1+\frac{1}{jkR}\right)$$

$$kR = \omega\sqrt{\mu\varepsilon}\,R = \frac{\omega R}{c} \ll 1$$

$\omega \to 0$ STATICS

$R \to 0$ NEAR FIELD

$c \to \infty$ INSTANTANEOUS RESPONSE

FAR-FIELD

$$\bar{E}(\bar{R}) = j\omega\mu\, IL\, \frac{e^{-jkR}}{4\pi R} \sin\theta \;\bar{a}_\theta$$

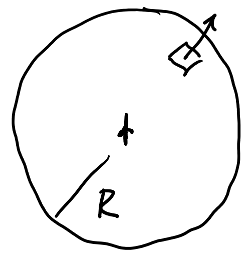
$$\bar{H}(\bar{R}) = jk\, IL\, \frac{e^{-jkR}}{4\pi R} \sin\theta \;\bar{a}_\phi$$

$$\bar{S} = \frac{1}{2}\bar{E}\times\bar{H}^* = \frac{1}{2} j\omega\mu\, IL\, \frac{\cancel{e^{-jkR}}}{4\pi R}\sin\theta\;\bar{a}_\theta \times \left(-jkIL\,\frac{\cancel{e^{+jkR}}}{4\pi R}\sin\theta\;\bar{a}_\phi\right)$$

$$= \frac{1}{2}\,\omega\mu k\,(IL)^2\,\frac{\sin^2\theta}{(4\pi R)^2}\;\bar{a}_R$$

$$= \frac{\eta}{2}(kIL)^2\,\frac{\sin^2\theta}{(4\pi R)^2}\;\bar{a}_R$$

$$\omega\mu = \eta k = \sqrt{\frac{\mu}{\epsilon}}\;\omega\sqrt{\mu\epsilon}$$



$R^2 \sin\theta\, d\theta\, d\phi\;\bar{a}_R$

$$P_{rad} = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} \frac{\eta}{2}(kIL)^2\,\frac{\sin^2\theta}{(4\pi \cancel{R})^2}\;\bar{a}_R\cdot \cancel{R^2}\sin\theta\, d\theta\, d\phi\;\bar{a}_R$$

$$= \frac{\eta\,(kIL)^2}{2\cdot 16\pi^2}\;\underbrace{\underbrace{\int_0^{2\pi} d\phi}_{2\pi}\int_0^{\pi}\sin^3\theta\, d\theta}_{8\pi/3}$$

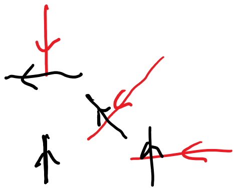
$$\int_0^{\pi}\sin\theta\,(1-\cos^2\theta)\,d\theta$$

$$= \int_0^{\pi}\sin\theta\, d\theta - \int_0^{\pi}\sin\theta\cos^2\theta\, d\theta$$

$$= \Big[-\cos\theta\Big]_0^{\pi} + \Big[\frac{1}{3}\cos^3\theta\Big]_0^{\pi}$$

$$= 2 - \frac{1}{3} - \frac{1}{3} = 4/3$$

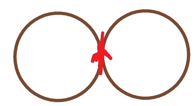
$$P_{rad} = \frac{\eta}{12\pi}(kIL)^2$$



RECEPTION $\sin\theta$

$$\frac{|\bar{E}(\theta,\phi)|}{|\bar{E}_{max}|} = F(\theta)$$

$F(\theta)$



RADIATION PATTERN

Hertz: $F(\theta) = \sin\theta$

DIRECTIVITY

$$\int F^2(\theta,\phi)\, d\Omega$$

$\sin\theta\, d\theta\, d\phi$

$$\int d\Omega = 4\pi$$

$$F(\theta,\phi) = 1$$

$$D = \frac{1}{\frac{1}{4\pi}\int F^2 d\Omega} = \frac{4\pi}{\int F^2 d\Omega}$$

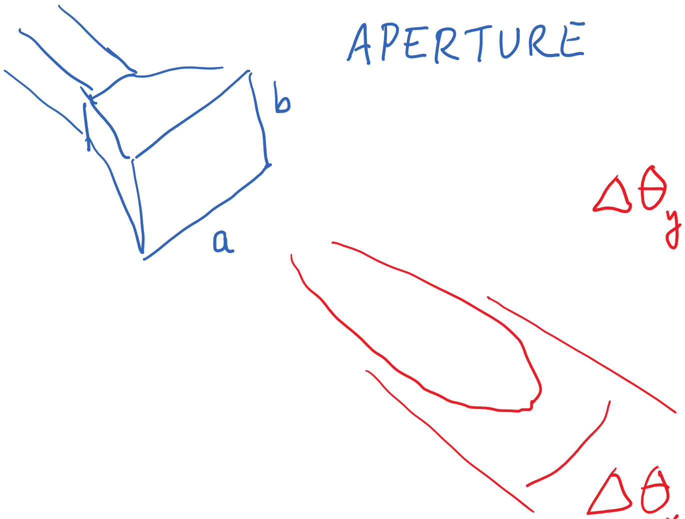
Hertz $F(\theta) = \sin\theta$

$$\int_0^{2\pi}\int_0^{\pi} \sin^2\theta \cdot \sin\theta\, d\theta\, d\phi = 2\pi \underbrace{\int_0^{\pi} \sin^3\theta\, d\theta}_{4/3}$$

$$D = \frac{4\pi}{2\pi\, 4/3} = \frac{3}{2} = 1.5$$

$$10\lg(1.5) = 1.76\text{ dB}$$

APERTURE



$$\Delta\theta_y = \frac{\lambda}{b}$$

$$\Delta\theta_x = \frac{\lambda}{a}$$

$$\Omega_p = \frac{\lambda^2}{ab} = \frac{\lambda^2}{A}$$

$$D = \frac{4\pi}{\Omega_p} = \frac{4\pi}{\lambda^2} A$$

RECEIVING ANTENNA:

EFFECTIVE AREA

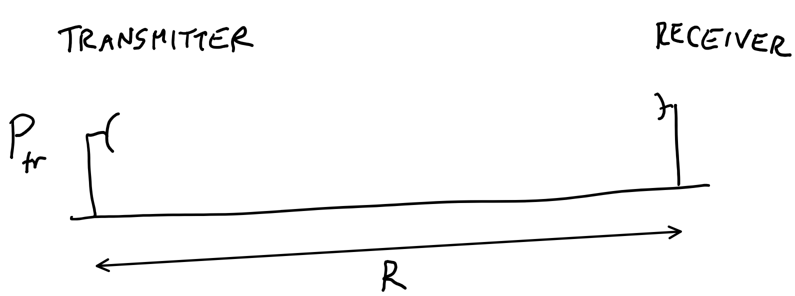
GAIN

$$A_e = \frac{\lambda^2}{4\pi} G$$

βD

EFFICIENCY
< 100%

FRIIS TRANSMISSION FORMULA



$$S \simeq \frac{G_{tr} P_{tr}}{}$$

$$P_{rec} = A_e S = \frac{\lambda^2}{4\pi} G_{rec} S$$

$$S \simeq \frac{G_{tr} P_{tr}}{4\pi R^2}$$

$$P_{rec} = A_e S = \frac{\text{[illegible]}}{4\pi} G_{rec} S$$

$$P_{rec} = G_{tr} G_{rec} \left(\frac{\lambda}{4\pi R} \right)^2 P_{tr}$$