- $k_c = \sqrt{k^2-\beta^2} = \sqrt{\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2} \Rightarrow k > k_c$
- $f_c = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2} \Rightarrow f > f_c$
- $\lambda_c = 2\pi/k_c \Rightarrow \lambda < \lambda_c$

	TM_{mn}	TE_{mn}
E_z	$E_0 \sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}e^{-\gamma z}$	0
H_z	0	$H_0\cos\frac{m\pi x}{a}\cos\frac{n\pi y}{b}e^{-\gamma z}$
E_x (y)	$\frac{\mp\gamma \overset{n}{m}\pi}{k_c^2 \underset{b}{a}} E_0 \underset{\sin}{\cos}\frac{m\pi}{a}x\cdot \underset{\cos}{\sin}\frac{n\pi}{b}y\cdot e^{\mp\gamma z}$	$\frac{\mp j\omega\mu \overset{m}{n}\pi}{k_c^2 \underset{-a}{b}} H_0 \underset{\sin}{\cos}\frac{m\pi}{a}x\cdot \underset{\cos}{\sin}\frac{n\pi}{b}y\cdot e^{\mp\gamma z}$
H_x (y)	$\frac{\mp j\omega\varepsilon \overset{m}{n}\pi}{k_c^2 \underset{-a}{b}} E_0 \underset{\cos}{\sin}\frac{m\pi}{a}x\cdot \underset{\sin}{\cos}\frac{n\pi}{b}y\cdot e^{\mp\gamma z}$	$\frac{\pm\gamma \overset{n}{m}\pi}{k_c^2 \underset{b}{a}} H_0 \underset{\cos}{\sin}\frac{m\pi}{a}x\cdot \underset{\sin}{\cos}\frac{n\pi}{b}y\cdot e^{\mp\gamma z}$
主模	TM_{11}	$\begin{cases} a>b & TE_{10} \\ a<b & TE_{01}\end{cases}$

- $\mathcal{P}_{avg} = \frac{1}{2}\mathrm{Re}\{\vec{E}\times\vec{H}^*\}$
$$= \frac{|E_x|^2+|E_y|^2}{2\eta}\vec{a}_z$$
- $P_{avg} = \int_0^a\int_0^b \mathcal{P}_{avg}\,dy\,dx$
- $\alpha_c = \frac{P_L}{2P_{avg}}$
- $\alpha_d = \frac{\sigma_d\sqrt{\mu/\varepsilon}}{2\sqrt{1-(f_c/f)^2}}$

σ_c $(\varepsilon,\mu,\sigma_d)$

$$\alpha_c = \frac{P_L}{2P_{ave}} \quad n\neq 0$$

$$\alpha_c\big|_{TE_{mn}} = \frac{2R_s}{b\eta'\sqrt{1-\left(\frac{f_c}{f}\right)^2}}\left[\left(1+\frac{b}{a}\right)\left(\frac{f_c}{f}\right)^2+\frac{\frac{b}{a}\left(\frac{b}{a}m^2+n^2\right)}{\frac{b^2}{a^2}m^2+n^2}\left(1-\left(\frac{f_c}{f}\right)^2\right)\right]$$

$$\alpha_c\big|_{TM_{mn}} = \frac{2R_s}{b\eta'\sqrt{1-\left(\frac{f_c}{f}\right)^2}}\frac{\left(\frac{b}{a}\right)^3m^2+n^2}{\left(\frac{b}{a}\right)^2m^2+n^2}$$

$$R_s = \frac{1}{\sigma_c\delta} = \sqrt{\frac{\pi f\mu}{\sigma_c}}$$

$$\eta' = \sqrt{\frac{\mu}{\varepsilon}}$$

- $k_{mnp} = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$

  $f_{mnp} = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2}$

  $\lambda_{mnp} = 2\pi / k_{mnp}$

	TM_{mnp}	TE_{mnp}
E_z	$E_0 \sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)\cos\left(\frac{p\pi z}{d}\right)$	0
H_z	0	$H_0 \cos\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)\sin\left(\frac{p\pi z}{d}\right)$
E_x (y)	$-\frac{1}{k_c^2}\frac{\overset{n}{m}\pi}{\underset{b}{a}}\frac{p\pi}{d}E_0 \underset{\sin}{\cos}\left(\frac{m\pi x}{a}\right)\underset{\cos}{\sin}\left(\frac{n\pi y}{b}\right)\sin\left(\frac{p\pi z}{d}\right)$	$\frac{j\omega\mu}{k_c^2}\frac{\overset{m}{n}\pi}{\underset{a}{b}}H_0 \underset{\sin}{\cos}\left(\frac{m\pi x}{a}\right)\underset{\cos}{\sin}\left(\frac{n\pi y}{b}\right)\sin\left(\frac{p\pi z}{d}\right)$
H_x (y)	$\frac{j\omega\varepsilon}{k_c^2}\frac{\overset{m}{n}\pi}{\underset{a}{b}}E_0 \underset{\cos}{\sin}\left(\frac{m\pi x}{a}\right)\underset{\sin}{\cos}\left(\frac{n\pi y}{b}\right)\cos\left(\frac{p\pi z}{d}\right)$	$-\frac{1}{k_c^2}\frac{\overset{n}{m}\pi}{\underset{b}{a}}\frac{p\pi}{d}H_0 \underset{\cos}{\sin}\left(\frac{m\pi x}{a}\right)\underset{\sin}{\cos}\left(\frac{n\pi y}{b}\right)\cos\left(\frac{p\pi z}{d}\right)$
主模	TM_{110}	$\begin{cases} a>b: TE_{101} \\ a<b: TE_{011} \end{cases}$

- Quality factor: $Q = \omega \frac{W_{stored}}{P_{Loss}}$

Hertzian Dipole

- $\vec{A} = \underline{\vec{a}_z} \dfrac{\mu_0 I d\ell}{4\pi r} e^{-j\beta r}$

  $\hookrightarrow \vec{a}_r \cos\theta - \vec{a}_\theta \sin\theta$

- $\vec{H} = \vec{a}_\phi \dfrac{I d\ell}{4\pi} \sin\theta \left[\dfrac{j\beta}{r} + \dfrac{1}{r^2}\right] e^{-j\beta r}$

- $\vec{E} = \begin{cases} \vec{E}_r = \dfrac{\eta I d\ell}{2\pi} \cos\theta \left[\dfrac{1}{r^2} - \dfrac{j}{\beta r^3}\right] e^{-j\beta r} \\ \vec{E}_\theta = \dfrac{\eta I d\ell}{4\pi} \sin\theta \left[\dfrac{j\beta}{r} + \dfrac{1}{r^2} - \dfrac{j}{\beta r^3}\right] e^{-j\beta r} \end{cases}$

Far field : $(\nabla \times \approx -jk\vec{a}_r \times)$

- $\vec{H} = \vec{a}_\phi \dfrac{I d\ell}{4\pi} \sin\theta \dfrac{j\beta}{r} e^{-j\beta r}$

- $\vec{E} = \vec{a}_\theta \eta H_\phi$

- $\vec{P}_{avg} = \frac{1}{2}\eta H_\phi^2 \vec{a}_r = \dfrac{\eta \beta^2 I^2 d\ell^2}{32\pi^2 r^2} \sin^2\theta$

- $P_{rad} = \int_0^{2\pi}\int_0^{\pi} \underbrace{\vec{P}_{avg} r^2}_{=U(\theta,\phi)} \sin\theta \, d\theta \, d\phi$

  $= \dfrac{\eta \beta^2 I^2 d\ell^2}{16\pi} \dfrac{4}{3} = \dfrac{\eta \pi I^2}{3} \left[\dfrac{d\ell}{\lambda}\right]^2$

- $R_{rad} = \dfrac{2 P_{rad}}{I^2}$

- $U(\theta,\phi) = \vec{P}_{avg} r^2$

- $U_{avg} = P_{rad}/4\pi$

- $G_D(\theta,\phi) = \dfrac{U(\theta,\phi)}{U_{avg}} = \frac{3}{2}\sin^2\theta$ $\hookrightarrow$ for HD

- $D = G_D|_{max} = 1.5$ $\Rightarrow$ for HD

  $= \dfrac{F(\theta,\phi)_{max}}{F(\theta,\phi)_{avg}}$

- $G_P = D \times \eta_r$

  $\hookrightarrow P_{rad}/P_{in} = G_P/G_d$

- $A_e = \underbrace{\boxed{\dfrac{\lambda^2}{4\pi}}}_{A_{iso}} D$ $\quad \begin{cases} D_r = \dfrac{4\pi A_{er}}{\lambda^2} \\ D_t = \dfrac{4\pi A_{et}}{\lambda^2} \end{cases} \Rightarrow \dfrac{P_r}{P_t} = \dfrac{A_{et} A_{er}}{\lambda^2 r^2}$

- $\Omega_A = \dfrac{4\pi}{D}$

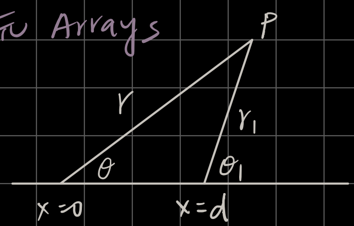
- $\dfrac{P_r}{P_t} = G_t G_r \left[\dfrac{\lambda}{4\pi r}\right]^2 \cdot \dfrac{\sigma}{4\pi r^2}$

Half-wave

- $A_z = \frac{\mu I}{2\pi r} \frac{e^{-j\beta r}}{\sin^2\theta} \cos\left(\frac{\pi}{2}\cos\theta\right)$
- $\vec{H} = \frac{1}{\mu} \nabla \times \vec{A} = \frac{jIe^{-j\beta r}}{2\pi r\sin\theta} \cos\left(\frac{\pi}{2}\cos\theta\right) \vec{a_\phi}$

  $\vec{E} = \eta H_\phi \vec{a_\theta}$
- $f(\theta) = \cos\left(\frac{\pi}{2}\cos\theta\right) / \sin\theta$

二元 Arrays



- $E_1 = E_0 e^{j\varphi}$

  $\varphi = \alpha + \beta d\cos\theta$ $(\varphi = \alpha + \beta d\sin\theta\cos\phi)$
- $AF = e^{j\frac{\varphi}{2}} \cdot 2\cos\frac{\varphi}{2}$
- $NAF = \frac{|AF|}{2} = \left|\cos\frac{\varphi}{2}\right|$

N 元 Arrays

- $AF = e^{j\frac{(N-1)\varphi}{2}} \cdot \frac{\sin\frac{N\varphi}{2}}{\sin\frac{\varphi}{2}}$
- $NAF = \frac{1}{N} \left|\frac{\sin\frac{N\varphi}{2}}{\sin\frac{\varphi}{2}}\right|$
- Normalized power pattern $= \frac{|AF|^2}{N^2}$

Radar transmission eq.

$$P_r = \frac{(\lambda G_0)^2 \sigma}{(4\pi)^3 r^4} P_{rad}$$

- $HPBW = 70\lambda/d$

  $FNBW \Rightarrow |AF| = 0$