1.

$E = 100 \frac{I}{r}$

$P = \iint_{r=R} ds \cdot \frac{1}{2} \frac{|E|^2}{Z_0} \cdot \hat{r} = 4\pi R^2 \cdot \frac{1}{2} \frac{100^2 |I|^2}{R^2 \cdot Z_0} \cdot \hat{r} =$

$= \frac{1}{2}|I|^2 \cdot \underbrace{\frac{4\pi}{120\pi} \cdot 100^2}_{R_r} \cdot \hat{r}$

$R_r = \frac{4\pi}{120\pi} \cdot 100^2 = 333.(3)\ \Omega$

2.

$\eta = 0.9 \qquad \vec{H} = H_0(\hat{\theta} - j\hat{\varphi})\ \sin(\theta) \frac{e^{-jk_0 r}}{k_0 r}$

$H_0 = 0.01\ A/m \qquad f = 3\ GHz$

$G_p = 4\pi \frac{U_{Max}}{P_{in}} = \eta D =$

$= \eta\, 4\pi \cdot \frac{U_{Max}}{P_r}$

$U = r^2 \cdot \vec{S}_{av} =$

$= r^2 \cdot \frac{1}{2} \cdot Z_0 |\vec{H}|^2 \hat{r} =$

$= \frac{Z_0 H_0^2}{k_0^2} \cdot \sin^2(\theta) \cdot \hat{r}$

$\rightarrow U_{Max} = \frac{Z_0 H_0^2}{k_0^2}$

$\rightarrow P_r = \int_0^{2\pi}\int_0^{\pi} \frac{Z_0 H_0^2}{k_0^2} \cdot \sin^3(\theta) \cdot d\theta\, d\varphi = \frac{Z_0 H_0^2}{k_0^2} \cdot 2\pi \cdot \frac{4}{3}$

$G_p = \eta \cdot 4\pi \cdot \frac{U_{Max}}{P_r} = \eta \cdot \frac{4\pi}{\cancel{4\pi} \cdot \frac{2}{3}} = \eta \cdot \frac{3}{2} = 1.35$

3. I a)

$R_p = \frac{\lambda}{50} \cdot 5\ m\Omega/m$
$\lambda = \frac{c}{f}$
$\rightarrow R_p = 2\ \Omega$

$\eta = \frac{R_r}{R_r + R_p} = 0.136 = 13.6\%$

$R_r = 80\pi^2 \left(\frac{L}{\lambda}\right)^2 = 0.316\ \Omega$

b) $E = 1\ mV/m$

$r = 200\ Km$

$|E| = \left| j \frac{Z I_0 L}{2\lambda} \cdot \frac{e^{-jkr}}{r} \sin(\theta) \right|$

$|E| = \frac{Z_0 L}{2\lambda r} |I_0| \iff \frac{2\lambda |E|}{Z_0 L} = |I_0|$

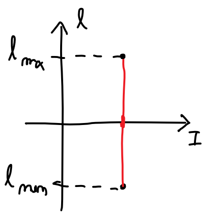
$P_{in} = \frac{1}{2} R_a \cdot |I_0|^2 = 2 R_a \cdot \frac{\lambda^2 |E|^2 r^2}{Z_0^2 L^2} = 2 R_a \left(\frac{50|E|r}{Z_0}\right)^2 = 3.26\ KW$

ou

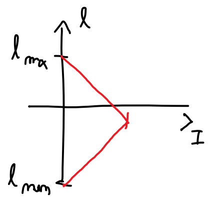
$P_r = \oint d^2 S_{av}\, d\Omega = d^2 \cdot \frac{1}{2} \cdot \frac{|E|^2}{Z_0} \int_0^{2\pi}\int_0^{\pi} \sin^3(\theta)\, d\theta\, d\varphi = d^2 \cdot \frac{4\pi}{3} \cdot \frac{|E|^2}{Z_0} = 444.(4)\ W$

$P_{in} = \frac{P_r}{\eta} = 3.26\ KW$

II c) DEH



DEC



d) Distribuição

$R_{A_H} = R_{P_H} + R_{r_H}$

$R_{A_C} = \frac{1}{3} R_{P_H} + \frac{1}{4} R_{r_H}$

$R_{r_C} = \frac{1}{4} R_{r_H} \qquad R_{P_C} = \frac{1}{3} R_{P_H}$

$\eta = 13.6\%$

$R_p = \frac{1}{3} R_{P_{DEH}}$
$R_r = \frac{1}{4} R_{r_{DEH}}$
$\rightarrow \eta = \frac{R_r}{R_r + R_p} = 10.59\%$

e) + Capacitância => - Facilidade na adaptação!

Pode ter bastantes perdas

4. $L = 3\ cm$

$f = 100\ MHz$

$I_0 = 10\ A$

a) $\theta = 45°$

$r_1 = 4\ cm$

$\frac{2\pi r_1}{\lambda} = 0.08 \ll 1$ Campo próximo

$\vec{E} = \begin{cases} \vec{E_r} = \frac{Z_0 I_0 L}{2\pi r} \cdot \left(1 + \frac{1}{jkr}\right) \cdot \frac{e^{-jkr}}{r} \cos(\theta) = 95.29\, e^{-j90.01°}\ KV/m \approx -95.29\, j\ KV/m \\ \vec{E_\theta} = j\frac{Z_0 k I_0 L}{4\pi}\left(1 + \frac{1}{jkr} + \frac{1}{(jkr)^2}\right) \cdot \frac{e^{-jkr}}{r} \sin(\theta) = 47.3\, e^{-j89.98°} \approx -47.3\, j\ KV/m \\ \vec{E_\varphi} = 0 \end{cases}$

$\vec{H} = \begin{cases} \vec{H_r} = 0 \\ \vec{H_\theta} = 0 \\ \vec{H_\varphi} = j \frac{k I_0 L}{4\pi}\left(1 + \frac{1}{jkr}\right)\frac{e^{-jkr}}{r} \sin(\theta) = 10.59\, e^{-145.169 \times 10^{-6} j} \approx 10.59\ A/m \end{cases}$

$r_2 = 20\ m$

$kr \gg 1$ Campo distante

$\vec{E} = \begin{cases} \vec{E_r} = 0 \\ \vec{E_\theta} = j\frac{Z_0 I_0 L}{2\lambda} \cdot \frac{e^{-jkr}}{r} = 0.94\, e^{-150°}\ V/m \\ \vec{E_\varphi} = 0 \end{cases}$

$\vec{H} = \begin{cases} \vec{H_r} = 0 \\ \vec{H_\theta} = 0 \\ \vec{H_\varphi} = \frac{\vec{E_\theta}}{Z_0} = 2.5\, e^{-150°}\ mA/m \end{cases}$

b) $r = r_1$: $\frac{|E_\theta|}{|E_r|} \approx \frac{1}{2} \qquad \frac{|E_\theta|}{|H_\varphi|} \approx 4468$

$r = r_2$: $\frac{|E_\theta|}{|E_r|} = \infty \qquad \frac{|E_\theta|}{|H_\varphi|} = Z_0$

c) Na zona próxima — Na zona distante

$\measuredangle = 90° \qquad \measuredangle = 0°$

H_φ e E_θ e E_r — Apenas H_φ e E_θ

d) r_1:

$\vec{S}_{av} = \frac{1}{2} Z_0 |H|^2 \hat{r} = 21.14\, \hat{r}\ kW/m^2$

r_2:

$\vec{S}_{av} = \frac{1}{2} Z_0 |H|^2 \hat{r} = 1.17\ mW/m^2$

e) $R_r = \frac{2\pi}{3} Z \left(\frac{L}{\lambda}\right)^2 = 78.96\ m\Omega$

$P_r = \frac{1}{2} R_r I_0^2 = 3.95\ W$

5. a) $f = 1\,MHz \Rightarrow \lambda = 300\,m$

$L = 50\,m$

- $r \gg \lambda \Rightarrow r > 3\,Km$!
- $r \gg L \Rightarrow r > 500\,m$
- $r > \frac{2L^2}{\lambda} \Rightarrow r > \frac{50}{3}\,m$

$\rightarrow r_{min} = 3\,Km$

b) $f = 100\,MHz \Rightarrow \lambda = 3\,m$

$L = \frac{\lambda}{2} = \frac{3}{2}$

- $r \gg \lambda \Rightarrow r > 30\,m$!
- $r \gg L \Rightarrow r > 15\,m$
- $r > \frac{2L^2}{\lambda} \Rightarrow r > 15\,m$

$\rightarrow r_{min} = 30\,m$

c) $f = 2.5\,GHz \Rightarrow \lambda = 0.12\,m$

$L = \sqrt{2} \cdot 4\,cm = 0.04 \cdot \sqrt{2}\,m$

- $r \gg \lambda \Rightarrow r > 1.2\,m$!
- $r \gg L \Rightarrow r > 0.57\,m$
- $r > \frac{2L^2}{\lambda} \Rightarrow r > 0.05\,m$

$\rightarrow r_{min} = 1.2\,m$

d) $f = 12\,GHz \Rightarrow \lambda = 0.025\,m$

$L = 0.6\,m$

- $r \gg \lambda \Rightarrow r > 0.25\,m$
- $r \gg L \Rightarrow r > 6\,m$
- $r > \frac{2L^2}{\lambda} \Rightarrow r > 28.8\,m$!

$\rightarrow r_{min} = 28.8\,m$

e) $f = 10\,GHz \Rightarrow \lambda = 0.03\,m$

$L = 305\,m$

- $r \gg \lambda \Rightarrow r > 0.3\,m$
- $r \gg L \Rightarrow r > 3.05\,Km$
- $r > \frac{2L^2}{\lambda} \Rightarrow r > 6202\,Km$!

$\rightarrow r_{min} = 6202\,Km$

f) $\bar{E}_\phi = \bar{E}_r = \bar{H}_\phi = \bar{H}_r = 0$

$\bar{E}_\theta = Z_0 \bar{H}_\phi$

6. $L = 15\,cm = 0.15\,m$

a) $f = 1\,GHz \Rightarrow \lambda = 0.3\,m$

- $r \gg \lambda \Rightarrow r > 3\,m$
- $r \gg L \Rightarrow r > 1.5\,m$
- $r > \frac{2L^2}{\lambda} \Rightarrow r > 0.15\,m$

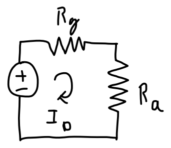
$\rightarrow r_{min} = 3\,m$

b) $R_g = 50\,\Omega$

$V_g = 10\,V$

$Z_a \approx 73.1\,\Omega$

$R_p = 0 \Rightarrow R_a = R_r$



$I_0 = \frac{V_g}{R_g + R_a}$

$P_r = \frac{1}{2} R_r |I_0|^2 = 0.2412\,W$

c) $\bar{E}_\theta = j \frac{Z_0 I_m}{2\pi} \cdot \frac{e^{-jkr}}{r} \cdot \frac{\cos\left(k\frac{L}{2}\cos(\theta)\right) - \cos\left(k\frac{L}{2}\right)}{\sin(\theta)}$

$\Downarrow L = \frac{\lambda}{2}$

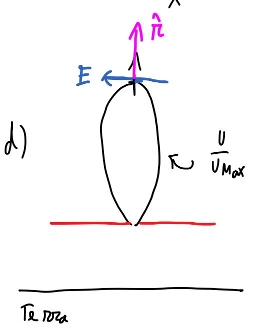
$|E| = \left| \frac{Z_0 I_m}{2\pi r} \frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)} \right|$

$L = \frac{\lambda}{2} \Rightarrow I_0 = -I_m$

$|E_{Max}| = \left| \frac{Z_0 I_0}{2\pi r} \right|$

$\vec{S}_{av} = \frac{|E_{Ma}|^2}{2 Z_0} \hat{r} \Rightarrow \vec{S}_{av_{Ma}} = \frac{Z_0 I_0^2}{8\pi^2 r^2} = 0.315\,m\,W/m^2$

d)



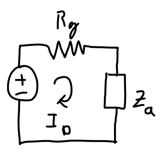
Campo vai ser horizontal !

e) $L = 1\,cm$

$R_a = \frac{R_r}{\eta} = \frac{1}{4} \cdot \frac{2\pi}{3} \cdot Z_0 \left(\frac{L}{\lambda}\right)^2 = 0.219\,\Omega$

$X_a \approx -Z_L \cot g\left(\frac{KL}{2}\right) = -3.587\,K\Omega$

$Z_a = R_a + jX_a$



$I_0 = \frac{V_g}{R_g + Z_A}$

$P_r = \frac{1}{2} R_r |I_0|^2 = 0.8522\,\mu W$

7. a)

$|\bar{E}| = \frac{Z_0 I_0}{r} \begin{cases} \cos^4(\theta), & 0 \leq \theta \leq \frac{\pi}{2} \\ 0, & \text{resto} \end{cases}$

$\vec{S}_{av} = |\vec{E}|^2 \cdot \frac{1}{2} \cdot \frac{1}{Z_0} \Rightarrow U = |\vec{E}|^2 \cdot \frac{1}{2} \cdot \frac{1}{Z_0} \cdot r^2 = \begin{cases} \frac{I_0^2}{2} \cdot Z_0 \cdot \cos^8(\theta), & 0 \leq \theta \leq \frac{\pi}{2} \\ 0, & \text{c.c} \end{cases}$

b) $P_r = \frac{1}{2} R_r \cdot I_0^2 = \int_0^{2\pi}\int_0^{\pi} U \sin(\theta)\, d\theta\, d\varphi = \frac{I_0^2}{2} \cdot 2\pi \cdot Z_0 \cdot \int_0^{\pi/2} \cos^8(\theta) \cdot \sin(\theta)\, d\theta = \frac{\pi Z_0 I_0^2}{9}$

$\frac{1}{2} R_r \cdot I_0^2 = \frac{\pi Z_0 I_0^2}{9} \Leftrightarrow R_r = \frac{2\pi}{9} Z_0 = \frac{80}{3}\pi^2\,\Omega$

c) $\alpha_{-3dB}\ XZ = \alpha_{-3dB}\ YZ$ pq. há rotação

$\frac{U}{U_{Max}} = \cos^8(\theta) = \frac{1}{2} \Leftrightarrow \cos(\theta) = \frac{1}{\sqrt[8]{2}} \Leftrightarrow \theta = \cos^{-1}\left(\frac{1}{\sqrt[8]{2}}\right) = 23.508$

$\alpha_{-3dB} = 2 \cdot \frac{U}{U_{Max}} = 47.016°$

$D \approx \frac{4\pi}{\alpha_H \alpha_V} \approx 18.66$

d)

$g(\theta,\varphi) = \frac{4\pi\, U(\theta,\varphi)}{P_r} = \begin{cases} \dfrac{\frac{I_0^2}{2} \cdot Z_0 \cdot \cos^8(\theta) \cdot 4\pi}{\frac{\pi Z_0 I_0^2}{9}}, & 0 \leq \theta \leq \frac{\pi}{2} \\ 0, & \text{cc} \end{cases} = \begin{cases} 18 \cos^8(\theta), & 0 \leq \theta \leq \frac{\pi}{2} \\ 0, & \text{cc} \end{cases}$

$g_{Max} = D = 18$

8. a) $L = 3\frac{\lambda}{2}$

$f = 300\,MHz$

$P_{in} = 2\,W$

$\eta = 0.9$

$P_r = 2 \cdot 0.9 = 1.8\,W$

b) $P_{in} = \frac{1}{2} R_a |I_0|^2 \Leftrightarrow |I_0| = \sqrt{\frac{2P_{in}}{R_a}} = 0.195\,A$

$R_a = 105\,\Omega$

$P_{in} = 2\,W$

c) $d = 100\,m$

ZD ? $\Rightarrow$ PV !

$\lambda_0 = 1\,m \Rightarrow r \gg \lambda_0$ PV

$L = \frac{3}{2}\,m \Rightarrow r \gg L$ PV

$\frac{2L^2}{\lambda} = \frac{9}{2}\,m \Rightarrow r > \frac{2L^2}{\lambda}$ PV

$\vec{H} = j \cdot \frac{I_m}{2\pi} \cdot \frac{e^{-jkd}}{d} \cdot \frac{\cos\left(k\frac{L}{2}\cos(\theta)\right) - \cos\left(k\frac{L}{2}\right)}{\sin(\theta)} \cdot \hat{\varphi}$

$I_0 = I_m \sin\left(k_0 \frac{L}{2}\right) \Rightarrow I_0 = -I_m$

$\vec{H} = j \frac{-I_0}{2\pi} \cdot \frac{e^{-jkd}}{d} \cdot (\cdots) = j\,366.64\,\mu A/m$

9.

DEH | D $\frac{\lambda}{2}$

a) $R_r = \frac{2\pi}{3} Z \left(\frac{L}{\lambda}\right)^2 = 315{,}8\ m\Omega$

$R_p = 2{,}84\ \Omega$

$R_r = 73.1\ \Omega$

$R_p = R_r\left(\frac{1}{\eta} - 1\right) = 8.12\ \Omega$

b) $r = 200\ Km \Rightarrow ZD$

$|E_0| = \left|\frac{Z I_0 L}{2\lambda r}\right| \Rightarrow |I_0| = \frac{2|E_0|\lambda r}{Z L}$

$P_{in} = \frac{1}{2} R_A |I_0|^2 = \frac{1}{2} R_A \left(\frac{2|E_0|\lambda r}{Z L}\right)^2 = 4.(4)\ KW$

$|E_0| = \left|\frac{Z I_m}{2\pi r}\right| = \left|\frac{Z I_0}{2\pi r}\right| \Rightarrow |I_0| = \frac{2\pi r |E|}{Z}$

$I_m = -I_0$

$P_{in} = \frac{1}{2} R_A |I_0|^2 = \frac{1}{2} R_A \left(\frac{2\pi r}{Z}|E|\right)^2 = 451.23\ W$

c) $\frac{U}{U_{Max}} = \frac{|E|^2}{|E_{Max}|^2} = \frac{1}{2}$

$\Downarrow$

$\sin(\theta) = \frac{1}{\sqrt{2}}$

$\alpha_{-3d} = 90^\circ$

$\frac{U}{U_{Max}} = \frac{|E|^2}{|E_{Max}|^2} = \frac{1}{2}$

$\Downarrow$

$\frac{\cos\left(k\frac{L}{2}\cos(\theta)\right) - \cos\left(k\frac{L}{2}\right)}{\sin(\theta)} = \frac{1}{\sqrt{2}}$

$\frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)} = \frac{1}{\sqrt{2}}$ $\Rightarrow$ $\theta_1 = 0.8894 \approx 50.96^\circ$, $\theta_2 = 2.2521 \approx 129.04^\circ$

$\alpha_{3dB} = \theta_2 - \theta_1 = 78.08^\circ$

e) $R_{R_{DEH}} \ll R_{R_{\frac{\lambda}{2}}}$ $\quad R_{P_{DEH}} < R_{P_{\frac{\lambda}{2}}}$

$P_{R_{DEH}} \gg P_{R_{\frac{\lambda}{2}}}$ $\Rightarrow$ DEH precisa de mais potência para o mesmo campo

$\alpha_{3dB_{DEH}} > \alpha_{3dB_{\frac{\lambda}{2}}}$ $\Rightarrow$ $\frac{\lambda}{2}$ é mais directivo o que é ótimo nas ligações ponto a ponto

$D_{DEH} < D_{\frac{\lambda}{2}}$

$G_{DEH} < G_{\frac{\lambda}{2}}$ $\Rightarrow$ DEH tem um ganho menor!

d) $D = 4\pi \frac{U_{Max}}{P_r} = 4\pi \cdot \frac{\frac{1}{8}}{\frac{\pi}{3}} = \frac{3}{2} = 1.5$

$P_r = \frac{\pi}{3} Z \left(\frac{L}{\lambda}\right)^2 |I_0|^2$

$U_{Max} = \frac{|E_M|^2 \cdot r^2}{2Z} = \frac{\left|\frac{Z I_0 L}{2\lambda r}\right|^2 \cdot r^2}{2Z} = \frac{Z}{8}\left(\frac{L}{\lambda}\right)^2 |I_0|^2$

$G = \eta D = 0.15$

$D = \frac{4\pi U_{Max}}{P_r} = 4\pi \cdot \frac{\frac{Z}{8\pi^2} I_0^2}{\frac{1}{2} R_r |I_0|^2} = \frac{Z}{\pi R_r} = 1.641$

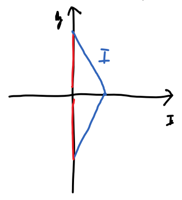
$U_{Max} = \frac{|E_M|^2 \cdot r^2}{2Z} = \frac{Z}{8\pi^2} I_0^2$

$P_r = \frac{1}{2} R_r |I_0|^2$

$G = \eta D = 1.48$

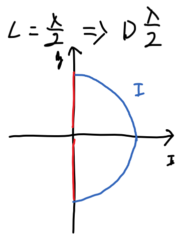
10. a) 1: $f_1 = 15\ MHz \Rightarrow \lambda = 20\ m$

$L \ll 20 \Rightarrow$ Dipolo curto



2: $f_2 = 150\ MHz \Rightarrow \lambda = 2\ m$

$L = \frac{\lambda}{2} \Rightarrow D\frac{\lambda}{2}$



b) 1: $\frac{U}{U_{Max}} = 0$

↳ Apenas interessa o fator directivo

$\left(\frac{\cos\left(k\frac{L}{2}\cos(\theta)\right) - \cos\left(k\frac{L}{2}\right)}{\sin(\theta)}\right)^2 = 0$

(*) $\Downarrow L \ll \lambda$

$\sin^2(\theta) = 0 \Leftrightarrow \sin(\theta) = 0 \Rightarrow \begin{cases}\theta' = 0 \\ \theta'' = \pi\end{cases}$

$FNBW = \theta'' - \theta' = 180^\circ$

2: $\frac{U}{U_{Max}} = 0$

$\left(\frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)}\right)^2 = 0 \Leftrightarrow \cos\left(\frac{\pi}{2}\cos(\theta)\right) = 0 \wedge \theta \neq \pi K,\ K \in \mathbb{Z} \Leftrightarrow$

$\Leftrightarrow \frac{\pi}{2}\cos(\theta) = \frac{\pi}{2} + \pi S \wedge \theta \neq \pi K\ ;\ K, S \in \mathbb{Z} \Leftrightarrow$

$\Leftrightarrow \cos(\theta) = 1 + 2S \wedge \theta \neq \pi K\ ;\ K, S \in \mathbb{Z} \Leftrightarrow$

$\Leftrightarrow \theta = \cos^{-1}(1+2S) \wedge \theta \neq \pi K\ ;\ K, S \in \mathbb{Z}$

As únicas soluções reais são π e 0!

$\lim_{\theta \to 0} \frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)} = 0$ e $\lim_{\theta \to \pi} \frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)} = 0$

Logo $FNBW = \pi - 0 = 180^\circ$!

(*) $\frac{\cos\left(k\frac{L}{2}\cos(\theta)\right) - \cos\left(k\frac{L}{2}\right)}{\sin(\theta)} = \frac{\cos\left(\pi\frac{L}{\lambda}\cos(\theta)\right) - \cos\left(\pi\frac{L}{\lambda}\right)}{\sin(\theta)} \Rightarrow$

Pela Série de Taylor e como $\frac{L}{\lambda} \ll 1$

$\Rightarrow \frac{1 - \frac{\left(\pi\frac{L}{\lambda}\cos(\theta)\right)^2}{2} - \left(1 - \frac{\left(\pi\frac{L}{\lambda}\right)^2}{2}\right)}{\sin(\theta)} = \frac{-\frac{\left(\pi\frac{L}{\lambda}\cos(\theta)\right)^2}{2} + \frac{\left(\pi\frac{L}{\lambda}\right)^2}{2}}{\sin(\theta)} =$

$= \frac{\left(\pi\frac{L}{\lambda}\right)^2}{2} \cdot \frac{\left(1 - \cos^2(\theta)\right)}{\sin(\theta)} = \frac{\left(\pi\frac{L}{\lambda}\right)^2}{2} \cdot \sin(\theta)$!

f) $dE_{DEH} = j\frac{Z K I}{4\pi}\frac{e^{-jkr'}}{r'}\sin(\theta)\,dz$

$r' = \sqrt{r^2 + z^2 - 2rz\cos(\theta)} \approx r - z\cos(\theta)$

$E_{zD} = j\frac{I_m Z K \sin(\theta)}{4\pi r} e^{-jkr} \int_{-\frac{L}{2}}^{\frac{L}{2}} \sin\left(K\left(\frac{L}{2} - |z|\right)\right) e^{jkz\cos(\theta)}\,dz =$

$= j\frac{Z I_m}{2\pi} \cdot \frac{e^{-jkr}}{r} \cdot \frac{\cos\left(k\frac{L}{2}\cos(\theta)\right) - \cos\left(k\frac{L}{2}\right)}{\sin(\theta)}$ //

c) 1: $P_r = \int_0^{2\pi}\int_0^{\pi} \frac{|E|^2}{2Z} \cdot r^2 \sin^3(\theta)\,d\theta\,d\varphi =$

$= 2\pi \cdot \frac{4}{3} \cdot \frac{|E|^2}{2Z} \cdot r^2 = \frac{4\pi|E|^2}{3Z} r^2$

$U_{Max} = r^2 \cdot \frac{|E|^2}{2Z}$

$D = \frac{4\pi \cdot r^2 \frac{|E|^2}{2Z}}{\frac{4\pi|E|^2}{3Z} r^2} = \frac{3}{2} = 1.5$

2: $P_r = \frac{1}{2} R_r \cdot I_M^2$

$U_M = \frac{I_M^2 \cdot Z}{8\pi^2}$

$D = \frac{4\pi \frac{I_M^2 \cdot Z}{8\pi^2}}{\frac{1}{2} R_r I_M^2} = \frac{Z}{\pi R_r} = 1.64$

d) $|E| = 100\ mV/m$

$r = 10\ Km$

1: $P_r = \frac{4\pi|E|^2}{3Z} \cdot r^2 = 11.(1)\ KW$

2: $|E| = \frac{Z|I_M|}{2\pi r} = \frac{Z|I_0|}{2\pi r} \Rightarrow |I_0| = \frac{|E| \cdot 2\pi \cdot r}{Z}$

$I_M = -I_0$

$P_r = \frac{1}{2} \cdot R_r \cdot \left(\frac{|E| \cdot 2\pi \cdot r}{Z}\right)^2 = 10.15\ kW$