Antene in razširjanje valov #1 1/10/2013

Fizikalne veličine:

- merske enote
- skalarji in vektorji

Skalarni produkt:

$W[J] = \vec{F}[N] \cdot \vec{s}[m]$

$W = |\vec{F}||\vec{s}|\cos\alpha$

Vektorski produkt:

$\vec{v}[m/s] = \vec{\omega}[rd/s] \times \vec{r}[m]$

$|\vec{v}| = |\vec{\omega}||\vec{r}|\sin\alpha$

smer $\vec{v}$ = ?

Koordinatni sistem:

1) 3D
2) PRAVOKOTNI $\vec{1}_x \cdot \vec{1}_y = 0$
3) DESNOROČNI $\vec{1}_x \times \vec{1}_y = \vec{1}_z$

Kartezični KS (x, y, z):

$-\infty < x[m] < +\infty$
$-\infty < y[m] < +\infty$
$-\infty < z[m] < +\infty$

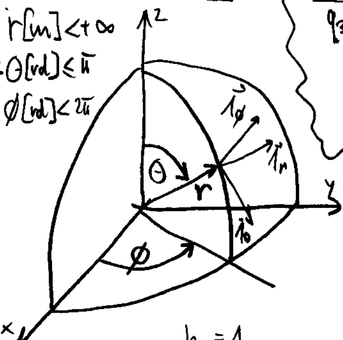
$|\vec{r}_1 - \vec{r}_2| = \sqrt{(x_1-x_2)^2 + (y_1-y_2)^2 + (z_1-z_2)^2}$

$\vec{F} \cdot \vec{s} = F_x s_x + F_y s_y + F_z s_z$

$\vec{\omega} \times \vec{r} = \begin{vmatrix} \vec{1}_x & \vec{1}_y & \vec{1}_z \\ \omega_x & \omega_y & \omega_z \\ r_x & r_y & r_z \end{vmatrix}$

Krogelni KS (r, θ, ϕ):

$0 \le r[m] < +\infty$
$0 \le \theta[rd] \le \pi$
$0 \le \phi[rd] < 2\pi$



$$\left.\begin{aligned} x &= r\sin\theta\cos\phi \\ y &= r\sin\theta\sin\phi \\ z &= r\cos\theta \end{aligned}\right\} \quad \begin{aligned} h_r &= 1 \\ h_\theta &= r \\ h_\phi &= r\sin\theta \end{aligned}$$

① $l_1 = h_\theta \Delta\theta$; $h_\theta = r = 111\,km/°$

② $l_2 = h_\phi \Delta\phi$; $h_\phi = r\sin\theta = 111\,km/° \cdot \sin\theta$

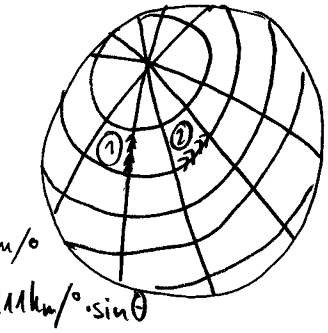
Krivočrtni KS (q_1, q_2, q_3):

$dl_i = h_i\, dq_i$

$h_i = \sqrt{\left(\frac{\partial x}{\partial q_i}\right)^2 + \left(\frac{\partial y}{\partial q_i}\right)^2 + \left(\frac{\partial z}{\partial q_i}\right)^2}$

Zemljepis:

$\lambda = \phi$, $\varphi = \pi/2 - \theta$



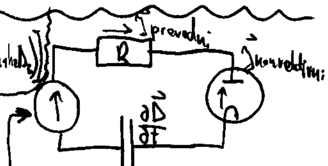
Gauss:

$\oint_A \vec{D} \cdot \vec{1}_n dA = Q = \int_V \rho\, dv$

Izvornost

$\operatorname{div}\vec{D} = \frac{1}{h_1h_2h_3}\left[\frac{\partial}{\partial q_1}(h_2h_3D_1) + \frac{\partial}{\partial q_2}(h_1h_3D_2) + \frac{\partial}{\partial q_3}(h_1h_2D_3)\right]$

$\operatorname{div}\vec{D} = \lim_{v\to 0} \frac{\oint_A \vec{D}\cdot\vec{1}_n dA}{v} \Longrightarrow \operatorname{div}\vec{D} = \rho$



$J_{prevodni}$, $J_{konvekcijski}$, $\frac{\partial \vec{D}}{\partial t}$

Ampere:

$\oint_s \vec{H}\cdot\vec{1}_s ds = I = \int_A \vec{J}\cdot\vec{1}_n dA$

Vrtinčenje

$\vec{1}_n \cdot \operatorname{rot}\vec{J} = \lim_{A\to 0} \frac{\oint_s \vec{H}\cdot\vec{1}_s ds}{A}$

$\operatorname{rot}\vec{H} = \vec{J} = \vec{J}_{prevodni} + \vec{J}_{konvekcijski} + \frac{\partial \vec{D}}{\partial t}$

$\operatorname{rot}\vec{E} = -\frac{\partial \vec{B}}{\partial t}$

$\operatorname{rot}\vec{E} = \frac{1}{h_1h_2h_3}\begin{vmatrix} h_1\vec{1}_1 & h_2\vec{1}_2 & h_3\vec{1}_3 \\ \frac{\partial}{\partial q_1} & \frac{\partial}{\partial q_2} & \frac{\partial}{\partial q_3} \\ h_1E_1 & h_2E_2 & h_3E_3 \end{vmatrix}$

Faraday:

$u_i = \oint_s \vec{E}\cdot\vec{1}_s ds = -\frac{d\phi}{dt} = -\frac{\partial}{\partial t}\int_A \vec{B}\cdot\vec{1}_n d\vec{A}$

ME:

① $\operatorname{rot}\vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} = \vec{J} + j\omega\vec{D}$

② $\operatorname{rot}\vec{E} = -\frac{\partial \vec{B}}{\partial t} = -j\omega\vec{B}$

③ $\operatorname{div}\vec{D} = \rho$

$\frac{\partial}{\partial t} = j\omega$

SNOV/VAKUUM $(\mu_0, \varepsilon_0, \gamma = 0)$

$\vec{D} = \varepsilon\vec{E} = \varepsilon_r\varepsilon_0\vec{E}$

$\vec{B} = \mu\vec{H} = \mu_r\mu_0\vec{H}$

$\vec{J} = \gamma\vec{E}$

ME:
① $\operatorname{rot}\vec{H} = \vec{J} + j\omega\varepsilon\vec{E}$
② $\operatorname{rot}\vec{E} = -j\omega\mu\vec{H}$
③ $\operatorname{div}(\varepsilon\vec{E}) = \rho$

Antenska naloga

znani $\vec{J}(\vec{r})$, $\rho(\vec{r})$

$\vec{E}(\vec{r}) = ?$ $\vec{H}(\vec{r}) = ?$

Potenciali:

$\vec{B} = \operatorname{rot}\vec{A}$

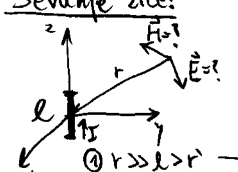
$\vec{E} = -j\omega\vec{A} - \operatorname{grad}V$

$\xrightarrow{\text{ME + Lorentz}}$

$\Delta V + \omega^2\mu\varepsilon V = -\frac{\rho}{\varepsilon} \longrightarrow V(\vec{r}) = \frac{1}{4\pi\varepsilon}\int_{v'} \rho(\vec{r}')\frac{e^{-jk|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|}dv'$

$\Delta\vec{A} + \omega^2\mu\varepsilon\vec{A} = -\mu\vec{J} \longrightarrow \vec{A}(\vec{r}) = \frac{\mu}{4\pi}\int_{v'}\vec{J}(\vec{r}')\frac{e^{-jk|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|}dv'$

Sevanje žice:



$\vec{A} = \frac{\mu}{4\pi}\int_{v'}\vec{1}_z\frac{I}{A'}\frac{e^{-jk|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|}A'dz' = \vec{1}_z\frac{\mu I l}{4\pi}\frac{e^{-jkr}}{r} = \left(\vec{1}_r\cos\theta - \vec{1}_\theta\sin\theta\right)\frac{\mu I l}{4\pi}\frac{e^{-jkr}}{r}$

$\vec{J} = \vec{1}_z\frac{I}{A'}$

$\vec{1}_z = \vec{1}_r\cos\theta - \vec{1}_\theta\sin\theta$

① $r \gg l > r'$ $\longrightarrow \frac{1}{|\vec{r}-\vec{r}'|} \approx \frac{1}{r}$

② $\frac{1}{k} \gg l > r'$ $\longrightarrow e^{-jk|\vec{r}-\vec{r}'|} \approx e^{-jkr}$

$\vec{H} = \frac{1}{\mu}\operatorname{rot}\vec{A} = \frac{1}{\mu r^2\sin\theta}\begin{vmatrix} \vec{1}_r & r\vec{1}_\theta & r\sin\theta\vec{1}_\phi \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial\theta} & \frac{\partial}{\partial\phi} \\ \frac{\mu I l}{4\pi}\frac{e^{-jkr}}{r}\cos\theta & -\frac{\mu I l}{4\pi}e^{-jkr}\sin\theta & 0 \end{vmatrix} = \vec{1}_\phi\frac{Il}{4\pi}e^{-jkr}\left(\frac{jk}{r} + \frac{1}{r^2}\right)\sin\theta$

SEVANJE, BIOT SAVART

f	k	r
50Hz	10^{-6} rd/m	1000km
900MHz	20 rd/m	5cm
600THz	~10^{7} rd/m	~0,1µm

$+Q$: $\frac{dQ}{dt} = I$; $I = j\omega Q$; $-Q$: $-\frac{d(-Q)}{dt} = I$

Zveznost toka

$Q \neq 0 \Rightarrow \vec{E} \neq 0$

① ME, $\vec{J} = 0$ $\quad Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$

$\vec{E} = \frac{1}{j\omega\varepsilon}\operatorname{rot}\vec{H} \approx \vec{1}_\theta\, jkZ_0\frac{Il}{4\pi}\frac{e^{-jkr}}{r}\sin\theta$

$r \gg \frac{1}{k}$

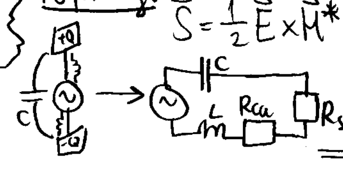
SAMO SEVANJE:

$\frac{\partial}{\partial r} \approx -jk$, $\frac{\partial}{\partial\theta} \approx \frac{\partial}{\partial\phi} \approx 0$

Poynting:

$\vec{S} = \frac{1}{2}\vec{E}\times\vec{H}^* = \vec{1}_r k^2 Z_0\frac{|I|^2 l^2}{2(4\pi)^2}\frac{\sin^2\theta}{r^2}$

$P_s = \int_0^{2\pi}\int_0^{\pi}\oint \vec{S}\cdot\vec{1}_r r^2\sin\theta\, d\theta\, d\phi = \frac{|I|^2 l^2 k^2 Z_0}{12\pi}$



$R_s = \frac{l^2k^2Z_0}{6\pi}$

Teslov transformator

$R_{cu} \approx 60\,\Omega$, $R_s = 6\,m\Omega$

$f = 30\,kHz$, $l = 30\,m$

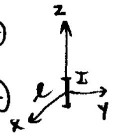
$P_s = 1\,W$, $P_{cu} = 10\,kW$

Antene in razširjanje valov #2 8/10/2013

Ponovitev: sevanje malega el. dipola $l \ll \lambda$

$\vec{E} = \vec{1}_\Theta \frac{jkZ_0}{4\pi} I l \frac{e^{-jkr}}{r} \sin\Theta$

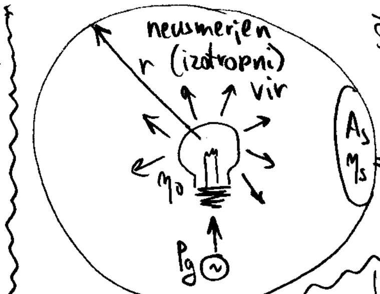
$\vec{H} = \vec{1}_\phi \frac{jk}{4\pi} I l \frac{e^{-jkr}}{r} \sin\Theta$



$\vec{S} = \frac{1}{2}\vec{E}\times\vec{H}^* = \vec{1}_r \frac{k^2 Z_0 |I|^2 l^2}{32\pi^2} \frac{\sin^2\Theta}{r^2}$

$P_s = \oint_A \vec{S}\cdot\vec{1}_n dA = \frac{k^2 Z_0 |I|^2 l^2}{12\pi} = \frac{1}{2}|I|^2 R_s$

$R_s = \frac{k^2 Z_0 l^2}{6\pi} = \frac{2\pi Z_0}{3}\left(\frac{l}{\lambda}\right)^2$

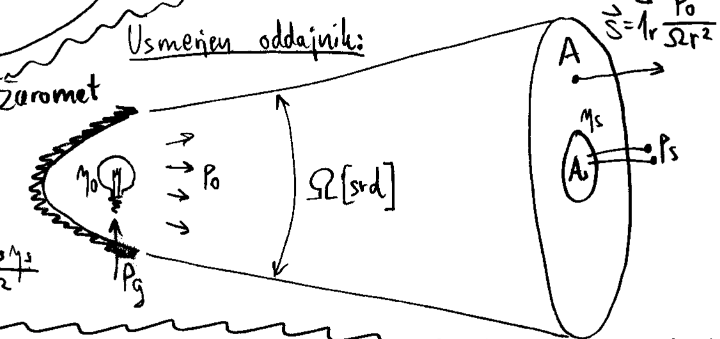


$\vec{S} = \vec{1}_r \frac{P_0}{4\pi r^2} = \frac{P_g \eta_0}{4\pi r^2}$ $\quad \Omega = 4\pi$ $\quad A = 4\pi r^2$

$P_s = \eta_s \int_{A_s} \vec{S}\cdot\vec{1}_n dA = |\vec{S}| A_s \eta_s = \frac{P_g \eta_0 A_s \eta_s}{4\pi r^2}$

Usmerjen oddajnik:

$\vec{S} = \vec{1}_r \frac{P_0}{\Omega r^2}$



$P_s = \frac{P_g \eta_0 A_s \eta_s}{\Omega r^2}$

Smernost (Directivity)

$D = \frac{|\vec{S}|}{|\vec{S}_i|} = \frac{4\pi}{\Omega} \geq 1 \quad P_s = \frac{P_g D \eta_0 A_s \eta_s}{4\pi r^2}$

Poljuben oddajnik:

$\vec{E} = \vec{1}_p \propto I \underbrace{\frac{e^{-jkr}}{r}}_{\text{SEVANJE}} F(\Theta,\phi)$

POLARIZACIJA, VIR, AMPLITUDNI SMERNI DIAGRAM

$\vec{S} = \frac{1}{2}\vec{E}\times\vec{H}^* = \vec{1}_r \frac{|\vec{E}|^2}{2Z_0}$

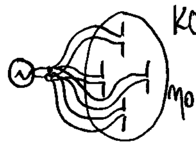
$\vec{S}_i = \vec{1}_r \frac{P_0}{4\pi r^2} \quad P_0 = \oint \vec{S}\cdot\vec{1}_n dA$

$D = \frac{|\vec{S}|}{|\vec{S}_i|} = \frac{4\pi r^2 \frac{|\vec{E}|^2}{2Z_0}}{\int_{4\pi} \frac{|\vec{E}|^2}{2Z_0} r^2 d\Omega} = \frac{4\pi |F(\Theta_{max},\phi_{max})|^2}{\int_0^{2\pi}\int_0^{\pi} |F(\Theta,\phi)|^2 \sin\Theta d\Theta d\phi}$

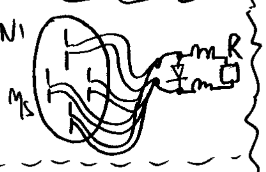
Zgled: $F(\Theta,\phi) = \sin\Theta$, $D = 1.5$

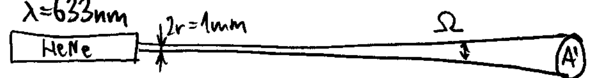
Dobitek (Gain): $G = \eta D$

Log. enote: $G[dBi] = 10\log_{10} G[lin]$, $D[dBi] = 10\log_{10} D[lin]$



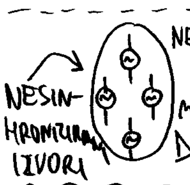
$D = \frac{4\pi}{\lambda^2} A$

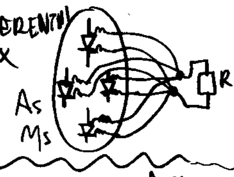




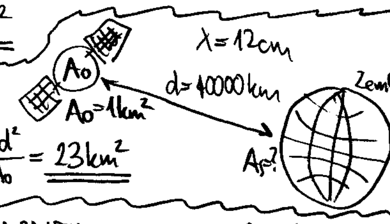
$D = \frac{4\pi}{\lambda^2} A = 2.5\cdot10^7 = 74\,dBi \quad \Omega = \frac{4\pi}{D} = 5\cdot10^{-7}\,srd$

$A'(1km) = 0.5\,m^2$



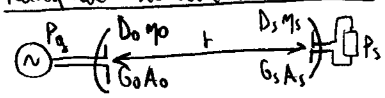


Vesoljska elektrarna:



$A_s = \Omega d^2 = \frac{4\pi}{D} d^2 = \frac{\lambda^2 d^2}{A_0} = 23\,km^2$

Radijska koherentna zveza:

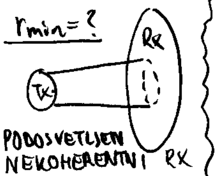


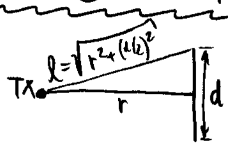
① $P_s = P_g D_0 \eta_0 \frac{A_s \eta_s}{4\pi r^2} = P_g G_0 \frac{A_s \eta_s}{4\pi r^2}$ ⟶ RADIODIFUZIJA ~ NEODVISNO OD λ

② $P_s = P_g D_0 \eta_0 D_s \eta_s \left(\frac{\lambda}{4\pi r}\right)^2 = P_g G_0 G_s \left(\frac{\lambda}{4\pi r}\right)^2$ ⟶ ZGODOVINA, TELEFON ~ λ^2

③ $P_s = P_g \frac{A_0 \eta_0 A_s \eta_s}{r^2 \lambda^2}$ ⟶ CILJANJE ? ⟶ TOČKA–TOČKA ~ λ^{-2} $\quad \boxed{r > r_{min}}$

$r_{min} = ?$





$(r \gg d)$

$\Delta\varphi = k\Delta l = k\left(\sqrt{r^2 + (d/2)^2} - r\right) \approx k\frac{d^2}{8r}$

$r_{min} = \frac{kd^2}{8\Delta\varphi} \quad r_{min} = \frac{\pi d^2}{4\lambda\Delta\varphi}$

$\Delta\varphi$	ΔG	r_{min}
π	−4dB	$d^2/4\lambda$
$\pi/2$	−1dB	$d^2/2\lambda$
$\pi/4$	−0.25dB	d^2/λ
$\pi/8$	−0.06dB	$2d^2/\lambda$

CCD $\quad d^2 \quad r_{min} \quad \infty$

⟶ globinska ostrina

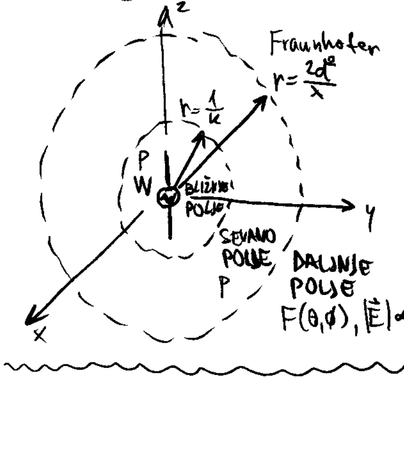
$\lambda = 0.5\mu m$, $d = 1mm \to r_{min} = 0.5m$

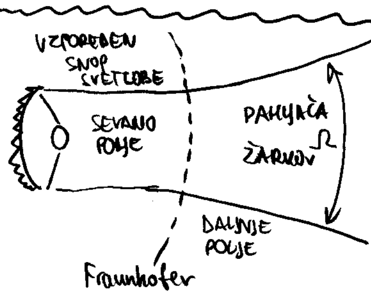
točne! Fraunhofer

⟶ meritve anten

$\lambda = 3cm$, $d = 11cm \to r_{min} = 0.8m$

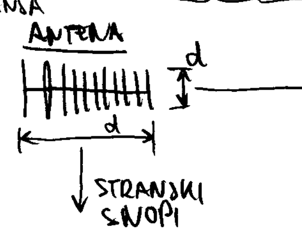
$f = 12GHz$, $d = 1m \to r_{min} = 80m$





Definicija d:

PREČNO NA SMER SEVANJA



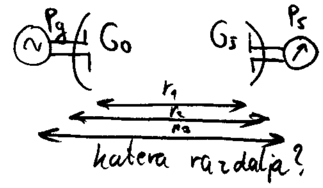
Antene in razširjanje valov #3 15/10/2013

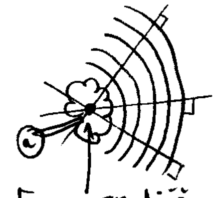
Ponovitev

KOM. ZVEZA: $P_s = P_g G_o G_s \left(\frac{\lambda}{4\pi r}\right)^2$

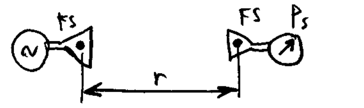
Fraunhofer: $r > r_{min} = \frac{2d^2}{\lambda}$

(antene fokusirane v ∞)





Fazno središče antene



Pravilna razdalja med FS!

Vrtenje okoli FS!

$F(\theta,\phi) = \underbrace{A(\theta,\phi)}_{Re} e^{j\underbrace{\varphi(\theta,\phi)}_{konst!}}$

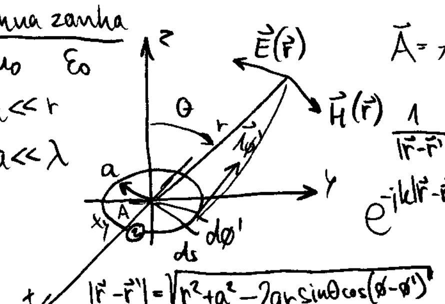
Nekatere antene nimajo FS?

Majhna zanka

$\mu_0 \quad \varepsilon_0$

① $a \ll r$

② $a \ll \lambda$



$\vec{A} = \frac{\mu_0}{4\pi}\int_0^{2\pi} \vec{1}_{\phi'} I \frac{e^{-jk|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|} a\,d\phi'$

$\frac{1}{|\vec{r}-\vec{r}'|} \approx \frac{1}{r}\left(1+\frac{a}{r}\sin\theta\cos(\phi-\phi')\right)$

$e^{-jk|\vec{r}-\vec{r}'|} \approx e^{-jkr}\left(1+jka\sin\theta\cos(\phi-\phi')\right)$

$\vec{1}_{\phi'} = -\vec{1}_x \sin\phi' + \vec{1}_y\cos\phi'$

$|\vec{r}-\vec{r}'| = \sqrt{r^2+a^2-2ar\sin\theta\cos(\phi-\phi')}$

$\vec{A} \approx \vec{1}_\phi \frac{\mu_0}{4\pi} I\pi a^2 \frac{e^{-jkr}}{r}\left(jk+\frac{1}{r}\right)\sin\theta$ $\qquad A = \pi a^2$

$\vec{E} = -j\omega\vec{A} - \underbrace{\mathrm{grad}\,V}_{=0} \approx \vec{1}_\phi \frac{k^2 Z_0}{4\pi} I A \frac{e^{-jkr}}{r}\sin\theta$

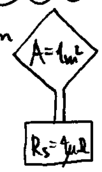
SAMO SEVANJE

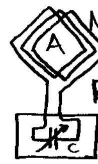
$\vec{H} = \frac{1}{\mu_0}\mathrm{rot}\vec{A} = \left(\text{Sčlenov } \frac{1}{r}, \frac{1}{r^2}, \frac{1}{r^3}\right)$

$\vec{S} = \vec{1}_r \frac{|\vec{E}|^2}{2Z_0} = \vec{1}_r \frac{k^4 Z_0}{32\pi^2}|I|^2 A^2 \frac{\sin^2\theta}{r^2}$

$R_s = \frac{P}{\frac{1}{2}|I|^2} = \frac{k^4 Z_0}{6\pi}A^2 = \frac{8\pi^3 Z_0}{3}\frac{A^2}{\lambda^4} = \frac{8\pi^5 Z_0}{3}\left(\frac{a}{\lambda}\right)^4$

$\lambda = 300\,m$

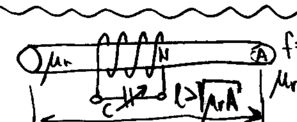




$N = 10$ ov.

$R_s = \frac{8\pi^3 Z_0}{3}\frac{N^2 A^2}{\lambda^4}$

$R_s = 0{,}4\,m\Omega$

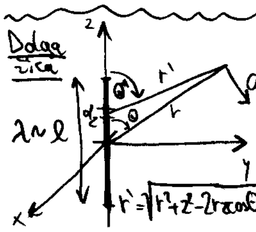


$f = 1\,MHz$

$\mu_r \approx 100$

$R_s \approx \frac{8\pi^3 Z_0}{3}\frac{\mu_r^2 N^2 A^2}{\lambda^4}$

Dolga žica

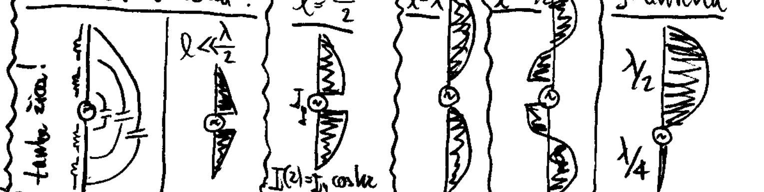


$d\vec{E} = \vec{1}_{\theta'} \frac{jkZ_0}{4\pi} I\,dz \frac{e^{-jkr'}}{r'}\sin\theta'$

Fraunhofer: $\vec{1}_{\theta} \approx \vec{1}_{\theta'}, \frac{1}{r'} \approx \frac{1}{r}, \sin\theta' \approx \sin\theta$

$r' = \sqrt{r^2+z^2-2rz\cos\theta} \approx r - z\cos\theta$; $e^{-jkr'} \approx e^{-jkr}e^{jkz\cos\theta}$

Porazdelitev toka?



Polvalovni dipol:

$\boxed{I(z) = I_g \cos kz}$

$\vec{E} = \int_{-\frac{\lambda}{4}}^{+\frac{\lambda}{4}} d\vec{E} = \vec{1}_\theta \frac{jkZ_0}{4\pi} I_g \frac{e^{-jkr}}{r}\sin\theta \int_{-\frac{\lambda}{4}}^{+\frac{\lambda}{4}} \cos kz\, e^{jkz\cos\theta} dz = \vec{1}_\theta \frac{jZ_0}{2\pi} I_g \frac{e^{-jkr}}{r}\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$

$F(\theta,\phi) = \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$

$\vec{S} = \vec{1}_r \frac{Z_0}{8\pi^2}|I_g|^2 \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{r^2\sin^2\theta}$

$R_s = \frac{1}{\frac{1}{2}|I_g|^2}\oint_{4\pi} \vec{S}\cdot\vec{1}_r r^2\sin\theta\,d\theta\,d\phi = \frac{Z_0}{2\pi} I = 60\,\Omega\, I = \underline{73\,\Omega}$

$I = \int_{-1}^{+1} \frac{\cos^2\left(\frac{\pi}{2}u\right)}{1-u^2}du = \mathbf{1{,}22}$

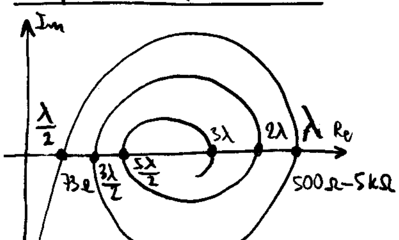
Smernost:

$D = \frac{4\pi|F(\theta_m,\phi_m)|^2}{\oint_{4\pi}|F(\theta,\phi)|^2 d\Omega} = \frac{4\pi}{2\pi\int_0^{\pi}\frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin^2\theta}\sin\theta\,d\theta} = \frac{2}{I} = \underline{\underline{1{,}64 = 2{,}15\,dBi}}$

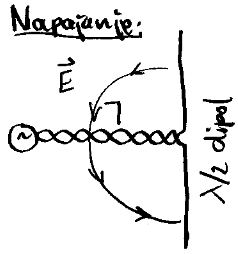
Primerjava s polvalovnim dipolom

$D[dBi] = 10\log_{10} D = D[dBd] + 2{,}15\,dB$

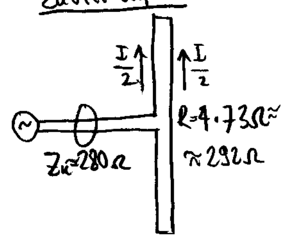
Impedanca dipola $Z(l)$:



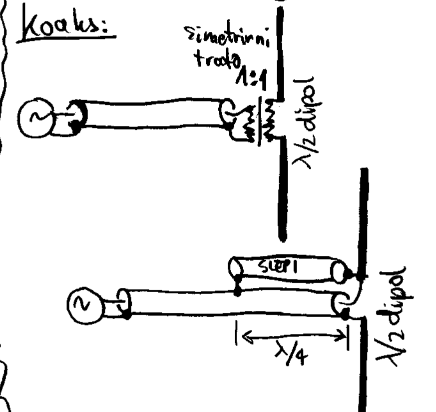
Napajanje:

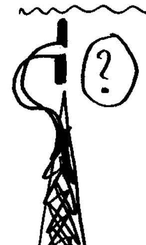


Zaviti dipol:

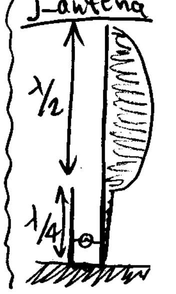


Koaks:

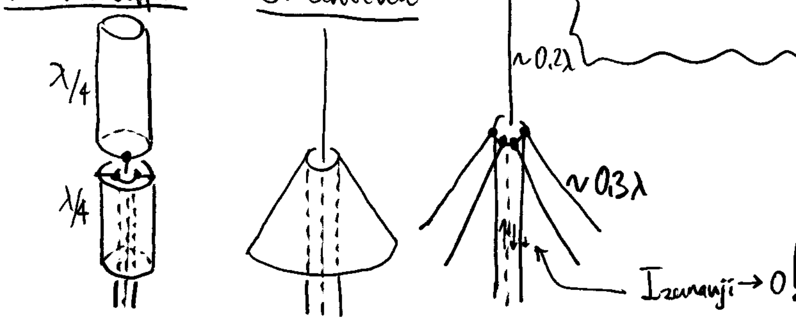




J-antena

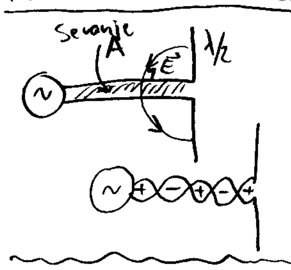


Rokavni dipol → GP antena

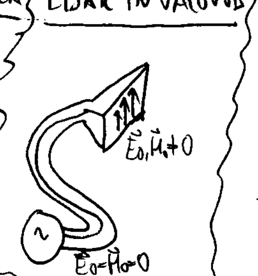


Antene in razširjanje valov #4 22/10/2013

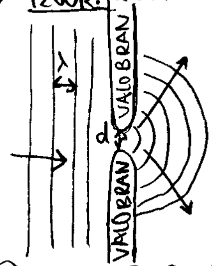
PONOVITEV: NAPAJANJE DIPOLA



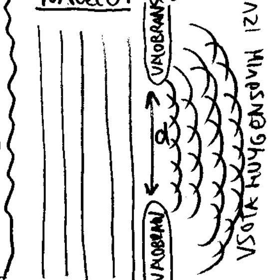
LIJAK IN VALOVOD



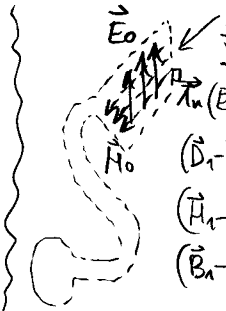
HUYGENSOV IZVOR: $d \ll \lambda$



HUYGENS-OVO NAČELO: $d \gg \lambda$



NADOMESTNI VIRI?



$\vec{1}_n \times (\vec{E}_1 - \vec{E}_2) \times \vec{1}_n = 0$?

$(\vec{D}_1 - \vec{D}_2) \cdot \vec{1}_n = \sigma$ ✓

$(\vec{H}_1 - \vec{H}_2) \times \vec{1}_n = \vec{K}$ ✓

$(\vec{B}_1 - \vec{B}_2) \cdot \vec{1}_n = 0$?

Razširjene ME:

1. $\text{rot}\,\vec{H} = \vec{J} + j\omega\varepsilon\vec{E}$
2. $\text{rot}\,\vec{E} = -\vec{J}_m - j\omega\mu\vec{H}$
3. $\text{div}\,(\varepsilon\vec{E}) = \rho$
4. $\text{div}\,(\mu\vec{H}) = \rho_m$

Razširjeni prestopni pogoji:

$$(\vec{E}_1 - \vec{E}_2) \times \vec{1}_n = -\vec{K}_m$$
$$(\vec{D}_1 - \vec{D}_2) \cdot \vec{1}_n = \sigma$$
$$(\vec{H}_1 - \vec{H}_2) \times \vec{1}_n = \vec{K}$$
$$(\vec{B}_1 - \vec{B}_2) \cdot \vec{1}_n = \sigma_m$$

Recipročnost Lorentz:

$\text{rot}\,\vec{H}_1 = \vec{J}_1 + j\omega\varepsilon\vec{E}_1 \;/\vec{E}_2\cdot$ $\qquad$ $\text{rot}\,\vec{H}_2 = \vec{J}_2 + j\omega\varepsilon\vec{E}_2 \;/\vec{E}_1\cdot$

$\text{rot}\,\vec{E}_1 = -\vec{J}_{m1} - j\omega\mu\vec{H}_1 \;/\vec{H}_2\cdot$ $\qquad$ $\text{rot}\,\vec{E}_2 = -\vec{J}_{m2} - j\omega\mu\vec{H}_2 \;/\vec{H}_1\cdot$

$\varepsilon \equiv$ skalar $\longrightarrow \vec{E}_2\cdot\text{rot}\,\vec{H}_1 - \vec{E}_1\cdot\text{rot}\,\vec{H}_2 = \vec{E}_2\cdot\vec{J}_1 - \vec{E}_1\cdot\vec{J}_2$

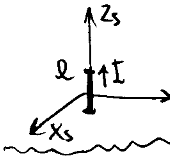
$\mu \equiv$ skalar $\longrightarrow \vec{H}_2\cdot\text{rot}\,\vec{E}_1 - \vec{H}_1\cdot\text{rot}\,\vec{E}_2 = -\vec{H}_2\cdot\vec{J}_{m1} + \vec{H}_1\cdot\vec{J}_{m2}$

člena v ∞ enako!

$$\int_{V\to\infty}\left(\vec{E}_2\cdot\text{rot}\,\vec{H}_1 - \vec{H}_1\cdot\text{rot}\,\vec{E}_2 + \vec{H}_2\cdot\text{rot}\,\vec{E}_1 - \vec{E}_1\cdot\text{rot}\,\vec{H}_2\right)dv = \int_{V\to\infty}\text{div}\left(\vec{H}_1\times\vec{E}_2 + \vec{E}_1\times\vec{H}_2\right)dv = \oint_{A\to\infty}\left(\vec{E}_1\times\vec{H}_2 - \vec{E}_2\times\vec{H}_1\right)\cdot\vec{1}_n\,dA = 0$$

$$0 = \int_{V\to\infty}\left(\vec{E}_2\cdot\vec{J}_1 - \vec{E}_1\cdot\vec{J}_2 - \vec{H}_2\cdot\vec{J}_{m1} + \vec{H}_1\cdot\vec{J}_{m2}\right)dv \longrightarrow \int_{V_1}\left(\vec{E}_2\cdot\vec{J}_1 - \vec{H}_2\cdot\vec{J}_{m1}\right)dv_1 = \int_{V_2}\left(\vec{E}_1\cdot\vec{J}_2 - \vec{H}_1\cdot\vec{J}_{m2}\right)dv_2$$

Sonda = tokovni element:



Samo sevanje

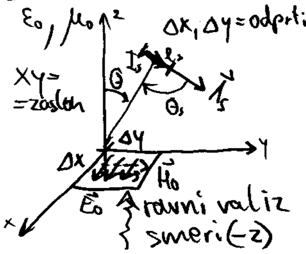
$$\begin{cases}\vec{E}_s = \vec{1}_{\theta_s}\,\dfrac{jkZ_0}{4\pi}\,I_s l_s\,\dfrac{e^{-jkr}}{r}\sin\theta_s \\[2mm] \vec{H}_s = \vec{1}_{\phi_s}\,\dfrac{jk}{4\pi}\,I_s l_s\,\dfrac{e^{-jkr}}{r}\sin\theta_s\end{cases}$$

$\vec{J}_2 = \vec{1}_s\dfrac{I_s}{A_s}$ $\qquad$ $\vec{J}_{m2} = 0$

$$\int_{V_s}\left(\vec{E}\cdot\vec{J}_s - \vec{H}\cdot\vec{J}_{ms}\right)dv_s = \vec{E}\cdot\vec{1}_s I_s l_s$$

$$\boxed{\vec{E}\cdot\vec{1}_s = \frac{1}{I_s l_s}\int_V\left(\vec{E}_s\cdot\vec{J} - \vec{H}_s\cdot\vec{J}_m\right)dv}$$

EM Huygensov izvor:



$\vec{E}_0 = \vec{1}_x E_0$

$\vec{H}_0 = \vec{1}_y \dfrac{E_0}{Z_0}$

$\vec{K} = \vec{1}_n \times \vec{H}_0 = -\vec{1}_x \dfrac{E_0}{Z_0}$

$\vec{K}_m = \vec{E}_0 \times \vec{1}_n = -\vec{1}_y E_0$

$$\vec{E}\cdot\vec{1}_s = \frac{1}{I_s l_s}\int_A\left(\vec{E}_s\cdot\vec{K} - \vec{H}_s\cdot\vec{K}_m\right)dA = \frac{jk}{4\pi}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}\left[\vec{1}_{\theta_s}\cdot(-\vec{1}_x) - \vec{1}_{\phi_s}\cdot(-\vec{1}_y)\right]$$

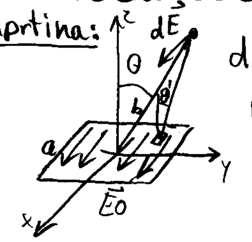
$$\vec{1}_s = \vec{1}_\theta \begin{cases}\vec{1}_{\theta_s}\cdot\vec{1}_x = -\cos\theta\cos\phi \\ \vec{1}_{\phi_s}\cdot\vec{1}_y = \cos\phi\end{cases} \quad \underline{\underline{E_\theta = \frac{j}{2\lambda}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}(\cos\theta + 1)\cos\phi}}$$

$$\vec{1}_s = \vec{1}_\phi \begin{cases}\vec{1}_{\theta_s}\cdot\vec{1}_x = \sin\phi \\ \vec{1}_{\phi_s}\cdot\vec{1}_y = -\cos\theta\sin\phi\end{cases} \quad \underline{\underline{E_\phi = \frac{j}{2\lambda}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}(\cos\theta + 1)(-\sin\phi)}}$$

Polje EM Huygens:

$$\vec{E} = \underbrace{\left(\vec{1}_\theta\cos\phi - \vec{1}_\phi\sin\phi\right)}_{\text{enotin smernik} \equiv\, \text{polarizacija } \vec{1}_x}\;\underbrace{\frac{j}{2\lambda}E_0\Delta x\Delta y}_{\text{jakost izvora}}\;\frac{e^{-jkr}}{r}\;\underbrace{(\cos\theta + 1)}_{F(\theta,\phi)}$$

Odprtina:

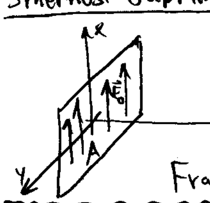


$$d\vec{E} = \left(\vec{1}_{\theta'}\cos\phi' - \vec{1}_{\phi'}\sin\phi'\right)\frac{j}{2\lambda}E_0(x,y)\,dx\,dy\,\frac{e^{-jkr'}}{r'}(\cos\theta' + 1)$$

Fraunhofer: $\vec{1}_{\theta'} \approx \vec{1}_\theta,\ \vec{1}_{\phi'} \approx \vec{1}_\phi,\ \theta' \approx \theta,\ \phi' \approx \phi,\ \frac{1}{r'} \approx \frac{1}{r}$

$$\vec{E} = \int_{-\frac{a}{2}}^{+\frac{a}{2}}\int_{-\frac{b}{2}}^{+\frac{b}{2}} d\vec{E} \qquad \boxed{e^{-jkr'} \neq e^{-jkr}}$$

Smernost odprtine na osi z ($\theta = 0$):



$$D_{max}(\theta=0,\phi) = \frac{|\vec{S}_{max}|}{|\vec{S}_i|} = \frac{\dfrac{|\vec{E}(\theta=0)|^2}{2Z_0}}{\dfrac{P_0}{4\pi r^2}} = \frac{4\pi r^2\left|\int_A \frac{j}{2\lambda}E_0(x,y)\frac{1}{r}\,2\,dx\,dy\right|^2}{2Z_0\int_A\frac{|E_0(x,y)|^2}{2Z_0}dx\,dy} = \underline{\underline{\frac{4\pi\left|\int_A E_0(x,y)\,dx\,dy\right|^2}{\lambda^2\int_A|E_0(x,y)|^2dx\,dy}}}$$

Fraunhofer $(\theta=0) \rightarrow e^{-jkr'} \approx e^{-jkz} = $ konst.

Zgled: $E_0(x,y) = $ konst. $\rightarrow \max D$!

$$D = \frac{4\pi}{\lambda^2}\frac{|E_0|^2A^2}{|E_0|^2A} = \underline{\underline{\frac{4\pi}{\lambda^2}A}}$$

Poljuben $E_0(x,y)$:

$$D = \frac{4\pi}{\lambda^2}A_{eff} = \frac{4\pi}{\lambda^2}\eta_0 A$$

Izkoristek osvetlitve:

$$\eta_0 = \frac{\left|\int_A E_0(x,y)\,dx\,dy\right|^2}{A\int_A|E_0(x,y)|^2dx\,dy}$$

Efektivna površina:

$$A_{eff} = \frac{\left|\int_A E_0(x,y)\,dx\,dy\right|^2}{\int_A|E_0(x,y)|^2dx\,dy}$$

Antene in razširjanje valov #5 29. 10. 2013

Huygens-ov izvor: v ravnini xy, sevanje v smeri $+z$

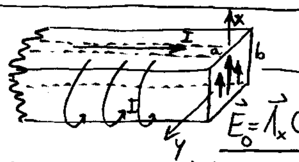
$$d\vec{E} = (\vec{1}_\Theta \cos\phi - \vec{1}_\phi \sin\phi)\frac{j}{2\lambda}E_0(x,y)\,dx\,dy\,\frac{e^{-jkr}}{r}(\cos\Theta+1) \quad @\ \vec{E}_0=\vec{1}_x E_0$$

$$d\vec{E} = (\vec{1}_\Theta \sin\phi + \vec{1}_\phi \cos\phi)\frac{j}{2\lambda}E_0(x,y)\,dx\,dy\,\frac{e^{-jkr}}{r}(\cos\Theta+1) \quad @\ \vec{E}_0=\vec{1}_y E_0$$

Max smernost, A_{eff}, η_0: $A_{eff}=A\eta_0$

$$D=\frac{4\pi}{\lambda^2}\frac{\left|\int_A E_0(x,y)\,dx\,dy\right|^2}{\int_A |E_0(x,y)|^2\,dx\,dy}=\frac{4\pi}{\lambda^2}A_{eff}$$

Pravokotni kovinski valovod:



$$\lambda_g=\frac{2\pi}{\beta} \qquad k^2=\left(\frac{\pi}{a}\right)^2+\beta_z^2$$

$$\vec{E}_0=\vec{1}_x C\cos\frac{\pi}{a}y\, e^{-j\beta z}$$

$$\vec{H}_0=\frac{j}{\omega\mu}\operatorname{rot}\vec{E}=\vec{1}_y\frac{\beta}{\omega\mu}C\cos\frac{\pi}{a}y\,e^{-j\beta z}+\vec{1}_z\frac{j\pi/a}{\omega\mu}C\sin\frac{\pi}{a}y\,e^{-j\beta z}$$

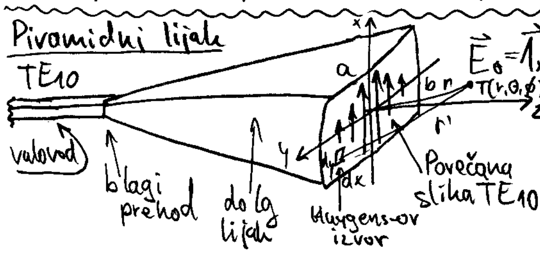
Izkoristek osvetlitve $\vec{E}=\vec{1}_x C\cos\frac{\pi}{a}y$

$$\eta_0=\frac{\left|\int_A C\cos\frac{\pi}{a}y\,dx\,dy\right|^2}{A\int_A\left|C\cos\frac{\pi}{a}y\right|^2dx\,dy}=\frac{|C|a^2b^2\frac{4}{\pi^2}}{|C|a^2b^2\frac{1}{2}}=\frac{8}{\pi^2}$$

$\eta_0 \approx 82\%$

Zgled: $a=\lambda$, $b=\frac{\lambda}{2} \rightarrow D=\frac{16}{\pi}\approx 5$

Piramidni lijak



$$\vec{E}_0=\vec{1}_x C\cos\frac{\pi}{a}y \qquad d\vec{E}=(\vec{1}_\Theta\cos\phi-\vec{1}_\phi\sin\phi)\frac{j}{2\lambda}C\cos\frac{\pi}{a}y\,dx\,dy\,\frac{e^{-jkr'}}{r'}(1+\cos\Theta)$$

Fraunhofer: $r>\frac{2d^2}{\lambda}\rightarrow$ zanemarimo amplitudo Θ', ϕ', r'

$\cos\Theta_x=\sin\Theta\cos\phi$ $\cos\Theta_y=\sin\Theta\sin\phi$ POMEMBNA FAZA $e^{-jkr'}\approx e^{-jkr}e^{jkx\cos\Theta_x}e^{jky\cos\Theta_y}$

$$r'=\sqrt{(r\sin\Theta\cos\phi-x)^2+(r\sin\Theta\sin\phi-y)^2+(r\cos\Theta)^2}\approx r-x\cos\Theta_x-y\cos\Theta_y$$

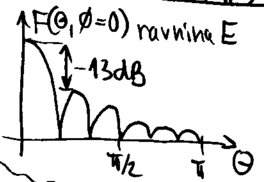
$$\vec{E}=\int_{-\frac{a}{2}}^{+\frac{a}{2}}\int_{-\frac{b}{2}}^{+\frac{b}{2}}d\vec{E}=(\vec{1}_\Theta\cos\phi-\vec{1}_\phi\sin\phi)\frac{jC}{2\lambda}\frac{e^{-jkr}}{r}\underbrace{\int_{-\frac{a}{2}}^{+\frac{a}{2}}\cos\frac{\pi}{a}y\,e^{jky\cos\Theta_y}dy}_{I_y}\ \underbrace{\int_{-\frac{b}{2}}^{+\frac{b}{2}}e^{jkx\cos\Theta_x}dx}_{I_x}\ \underbrace{(1+\cos\Theta)}_{\text{Huygens}}$$

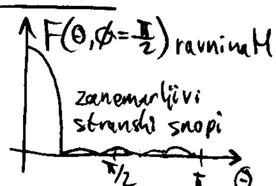
$$I_x=\int_{-\frac{b}{2}}^{+\frac{b}{2}}e^{jkx\cos\Theta}dx=\left.\frac{e^{jkx\cos\Theta_x}}{jk\cos\Theta_x}\right|_{-\frac{b}{2}}^{+\frac{b}{2}}=\frac{2j\sin\left(\frac{kb}{2}\cos\Theta_x\right)}{jk\cos\Theta_x}\cdot\frac{b/2}{b/2}=b\cdot\frac{\sin\left(\frac{kb}{2}\sin\Theta\cos\phi\right)}{\frac{kb}{2}\sin\Theta\cos\phi}$$

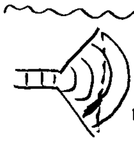
$$I_y=\int_{-\frac{a}{2}}^{+\frac{a}{2}}\cos\frac{\pi}{a}y\,e^{jky\cos\Theta_y}dy=\frac{1}{2}\int_{-\frac{a}{2}}^{+\frac{a}{2}}\left[e^{j(k\cos\Theta_y+\frac{\pi}{a})y}+e^{j(k\cos\Theta_y-\frac{\pi}{a})y}\right]dy=\frac{2j\sin\left(\frac{ka}{2}\cos\Theta_y+\frac{\pi}{2}\right)}{2j\left(k\cos\Theta_y+\frac{\pi}{a}\right)}+\frac{2j\sin\left(\frac{ka}{2}\cos\Theta_y-\frac{\pi}{2}\right)}{2j\left(k\cos\Theta_y-\frac{\pi}{a}\right)}=$$

$$=\frac{\cos\left(\frac{ka}{2}\cos\Theta_y\right)}{k\cos\Theta_y+\frac{\pi}{a}}-\frac{\cos\left(\frac{ka}{2}\cos\Theta_y\right)}{k\cos\Theta_y-\frac{\pi}{a}}=\frac{2\frac{\pi}{a}\cos\left(\frac{ka}{2}\cos\Theta_y\right)}{\left(\frac{\pi}{a}\right)^2-k^2\cos^2\Theta_y}\cdot\frac{\left(\frac{a}{\pi}\right)^2}{\left(\frac{a}{\pi}\right)^2}=a\frac{2}{\pi}\cdot\frac{\cos\left(\frac{ka}{2}\sin\Theta\sin\phi\right)}{1-\left(\frac{ka}{\pi}\right)^2\sin^2\Theta\sin^2\phi}$$

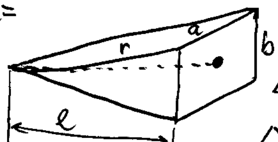
$$\boxed{F(\Theta,\phi)=(1+\cos\Theta)\frac{\sin\left(\frac{kb}{2}\sin\Theta\cos\phi\right)}{\frac{kb}{2}\sin\Theta\cos\phi}\cdot\frac{\cos\left(\frac{ka}{2}\sin\Theta\sin\phi\right)}{1-\left(\frac{ka}{\pi}\right)^2\sin^2\Theta\sin^2\phi}}$$







kroglaste fronte = = kvadratna napaka faze

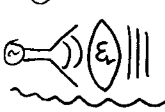


$$r=\sqrt{l^2+\left(\frac{a}{2}\right)^2+\left(\frac{b}{2}\right)^2}$$

$$\Delta\varphi=k(r-l)\approx k\frac{a^2+b^2}{8l}=\frac{\pi(a^2+b^2)}{4l\lambda}$$

Popravek faze:

① LEČA ② ZRCALO ③ SKUPINA



$\Delta\varphi$	ΔG
2π	$-\infty$ dB
π	-4 dB
$\pi/2$	-1 dB
$\pi/4$	$-0{,}25$ dB

$$\frac{\pi}{2}=\frac{\pi(a^2+b^2)}{4l\lambda}$$

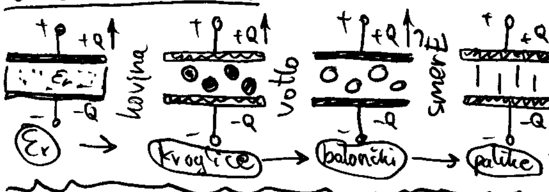
$$l=\frac{a^2+b^2}{2\lambda}$$

Zgled: $f=12\,\text{GHz}\rightarrow\lambda=2{,}5\,\text{cm}$

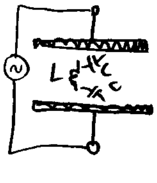
$a=b=50\,\text{cm}$

$$l=\frac{2500\,\text{cm}^2+2500\,\text{cm}^2}{2\cdot 2{,}5\,\text{cm}}=10\,\text{m}!$$

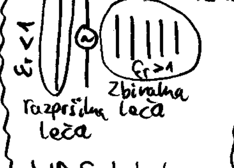
Umetni dielektrik:



→ + rezonanca



Yagi-Uda 1928



NBS tabele

SLOW-WAVE STRUCTURE

IIIIII palike

XXXXX križci 2×pol

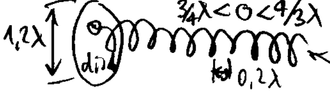
OOOOO zankice

UUUU Uji-Vji VVVV

ΛΛΛΛ ΛΛΛΛ

●●●●●● diski

Vijačna antena z osnim sevanjem



$\frac{3}{4}\lambda<O<\frac{4}{3}\lambda$

$R_s\sim 140\,\Omega$

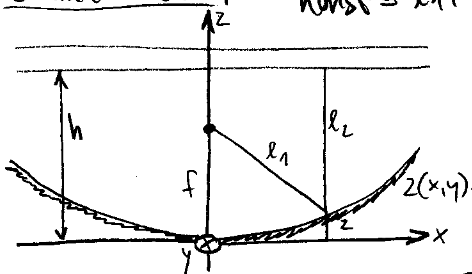
desna = RHCP

leva = LHCP

Antene in razširjanje valov #6 5/11/2013

Oblika zrcala:

$$konst = l_1 + l_2 = f + h = \sqrt{x^2+y^2+(f-z)^2} + h - z$$



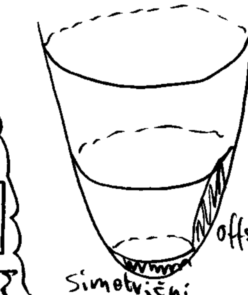
$$l_1 = \sqrt{x^2+y^2+(f-z)^2} \qquad \sqrt{x^2+y^2+(f-z)^2} = f+z$$

$$l_2 = h - z$$

$$x^2+y^2+f^2-2fz+z^2 = f^2+2fz+z^2$$

$$x^2+y^2 = 4fz \longrightarrow \boxed{z(x,y) = \frac{x^2+y^2}{4f}}$$

Izrez

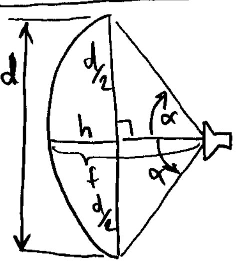


Simetrično zrcalo:

$$\boxed{f = \frac{d^2}{16h}}$$

$f/d = 0.3 \ldots 0.4$ (zaslonka fotoaparata f/d=1.8 … 22)

$$f/d = 0.4 \longrightarrow \alpha = 64^\circ;\ 2\alpha = 128^\circ$$

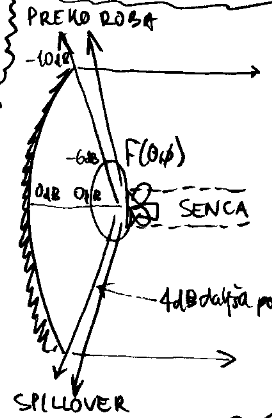


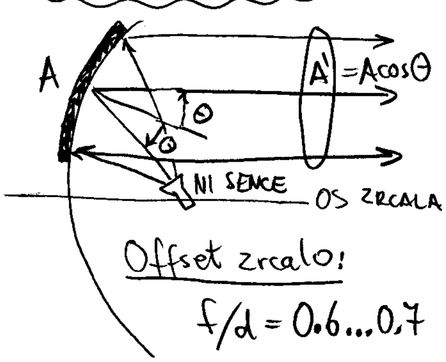
$$\alpha = \mathrm{arctg}\frac{d/2}{f-h}$$

$$\boxed{\alpha = \mathrm{arctg}\frac{1}{2f/d - \frac{1}{8f/d}}}$$

SENCA ŽARILCA → $d > 5\lambda$

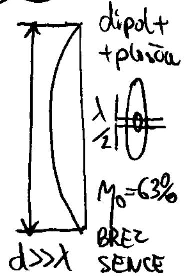
OSVETLITEV ROBA → −6dB F(θ,φ) − 4dB daljša pot



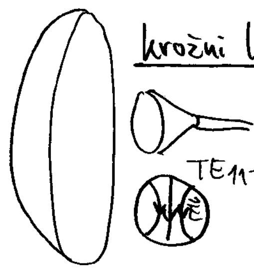


Offset zrcalo:

$$f/d = 0.6 \ldots 0.7$$



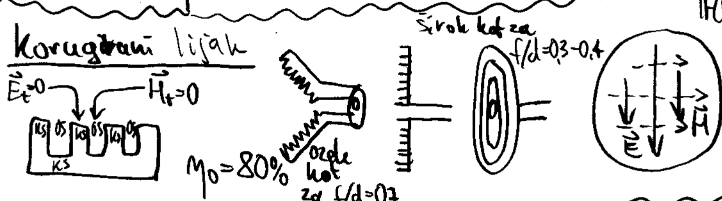
krožni lijak

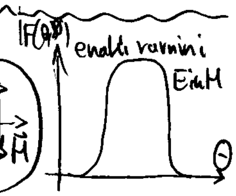


TE11 → nesimetričen

$F(\theta,\phi) \to \eta = 60\%$

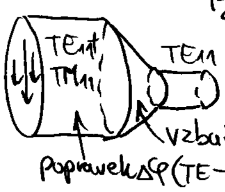
Korugirani lijak





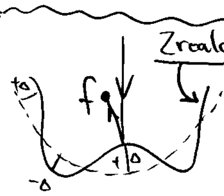
Dvorodovni lijak TE11+TM11

$$\beta_{TE11} > \beta_{TM11}$$



$$\eta_0 = 80\%$$

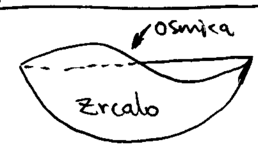
Zrcalo z napako



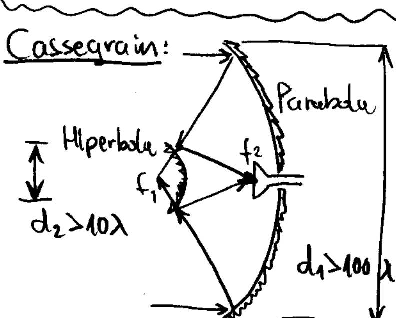
$\pm\Delta\varphi = 2k\Delta$

$\pm\Delta\varphi$	ΔG	$\pm\Delta$
$\pm\pi$	$-\infty$	$\pm\lambda/4$
$\pm\pi/2$	-4dB	$\pm\lambda/8$
$\pm\pi/4$	-1dB	$\pm\lambda/16$
$\pm\pi/8$	-0.25dB	$\pm\lambda/32$

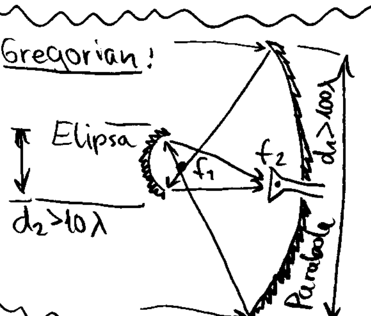
$f = 12\,GHz \to \pm\lambda/32 = \pm 0.8\,mm$



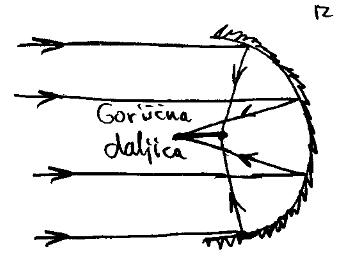
Cassegrain:



Gregorian:

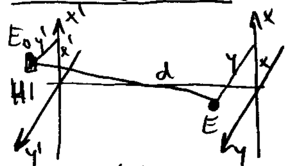


Krogelno zrcalo → istočasni sprejem iz več smeri



→ žarilec brez faznega središča

2D − Fourier:

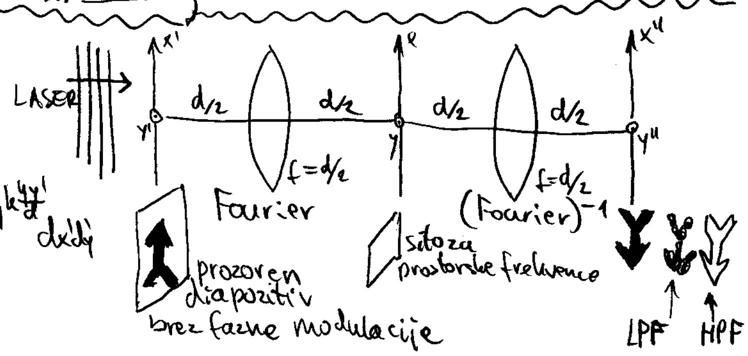


$$dE = \frac{j}{\lambda} E_0(x',y') \frac{e^{-jk|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|} dx'dy'$$

$\cos\Theta \approx 1$

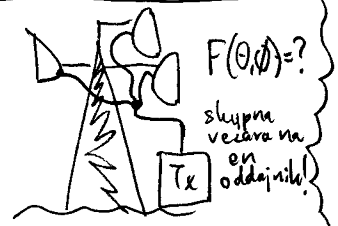
$$\frac{1}{|\vec{r}-\vec{r}'|} \approx \frac{1}{d}$$

$$E = \frac{j}{\lambda}\frac{e^{-jkd}}{d} e^{-jk\frac{x^2+y^2}{2d}} \iint_{x'y'} \underbrace{E_0(x',y') e^{-jk\frac{x'^2+y'^2}{2d}}}_{f(x',y')} e^{jk\frac{xx'}{d}} e^{jk\frac{yy'}{d}} dx'dy'$$



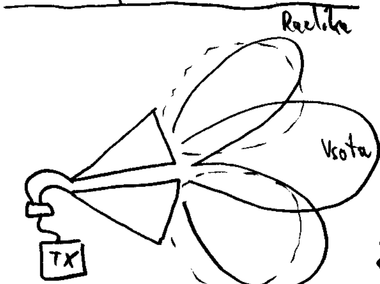
Antene in razširjanje valov # 7 12/11/2013

Koherentna skupina

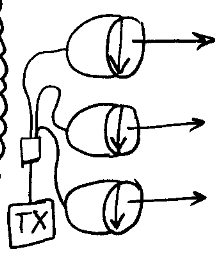


skupna vezava na en oddajnik!

Seštevanje kazalcev polja!



Pravilo o množenju $F(\theta,\phi)$

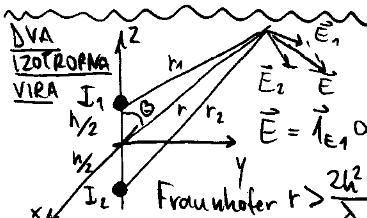


1. ENAKE ANTENE
2. ENAKO ORIENTIRANE
3. ENAKO POLARIZIRANE

$$F(\theta,\phi)=F_e(\theta,\phi)\cdot F_s(\theta,\phi)$$

$D \neq D_e \cdot D_s$ NE VELJA!

DVA IZOTROPNA VIRA



$$\vec{E}=\vec{E}_1+\vec{E}_2$$

$$\vec{E}=\vec{1}_{E_1}\alpha I_1\frac{e^{-jkr_1}}{r_1}+\vec{1}_{E_2}\alpha I_2\frac{e^{-jkr_2}}{r_2}$$

Fraunhofer $r>\frac{2h^2}{\lambda}$; $\vec{1}_{E_1}=\vec{1}_{E_2}=\vec{1}_E$, $\frac{1}{r_1}=\frac{1}{r_2}=\frac{1}{r}$

$$r_1=\sqrt{r^2+(h/2)^2-rh\cos\theta}\approx r-\frac{h}{2}\cos\theta$$

$$r_2=\sqrt{r^2+(h/2)^2+rh\cos\theta}\approx r+\frac{h}{2}\cos\theta$$

$$\vec{E}=\vec{1}_E\alpha\frac{e^{-jkr}}{r}\left(I_1e^{j\frac{kh}{2}\cos\theta}+I_2e^{-j\frac{kh}{2}\cos\theta}\right)$$

Najzanimivejši primer: $|I_1|=|I_2|\to I_1=I_0e^{j\frac{\varphi}{2}}$, $I_2=I_0e^{-j\frac{\varphi}{2}}$

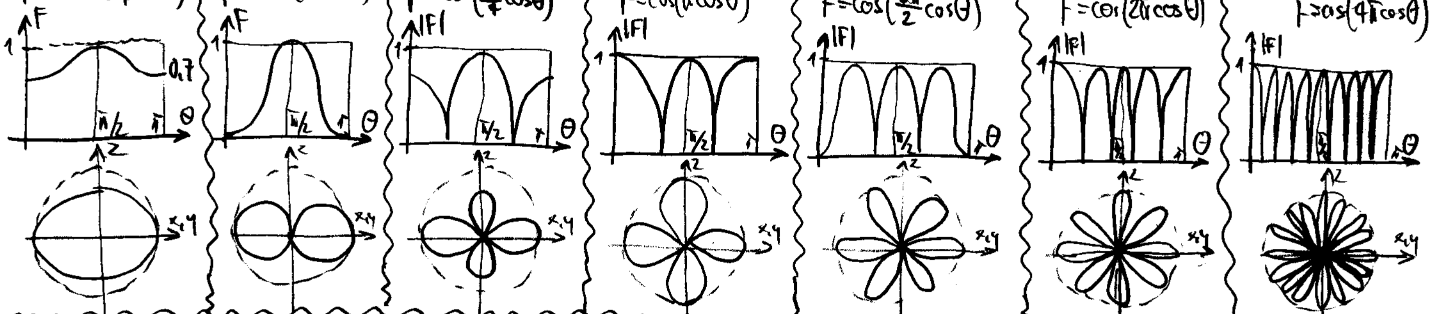
$$\vec{E}=\vec{1}_E I_0\alpha\frac{e^{-jkr}}{r}\left(e^{j\left(\frac{\varphi}{2}+\frac{kh}{2}\cos\theta\right)}+e^{-j\left(\frac{\varphi}{2}+\frac{kh}{2}\cos\theta\right)}\right)$$

$$\boxed{\vec{E}=\vec{1}_E I_0\alpha\frac{e^{-jkr}}{r}2\cos\left(\frac{\varphi}{2}+\frac{kh}{2}\cos\theta\right)}\to F(\theta,\phi)=\cos\left(\frac{\varphi}{2}+\frac{kh}{2}\cos\theta\right)$$

Bočna skupina

$\varphi=0\to F(\theta,\phi)=\cos\left(\frac{kh}{2}\cos\theta\right)$; $k=\frac{2\pi}{\lambda}\to F(\theta,\phi)=\cos(\pi h/\lambda\cos\theta)$

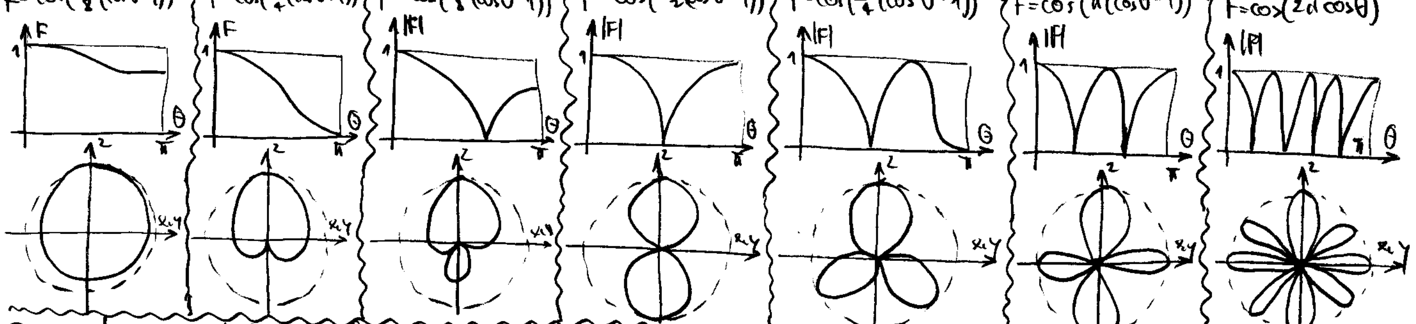
$h=\lambda/4$	$h=\lambda/2$	$h=3\lambda/4$	$h=\lambda$	$h=3\lambda/2$	$h=2\lambda$	$h=4\lambda$
$F=\cos(\frac{\pi}{4}\cos\theta)$	$F=\cos(\frac{\pi}{2}\cos\theta)$	$F=\cos(\frac{3\pi}{4}\cos\theta)$	$F=\cos(\pi\cos\theta)$	$F=\cos(\frac{3\pi}{2}\cos\theta)$	$F=\cos(2\pi\cos\theta)$	$F=\cos(4\pi\cos\theta)$



Osna skupina

$\varphi=-kh$ možna izbira $\to F(\theta,\phi)=\cos\left(\frac{kh}{2}(\cos\theta-1)\right)=\cos\left(\pi\frac{h}{\lambda}(\cos\theta-1)\right)$

$h=\lambda/8$	$h=\lambda/4$	$h=3\lambda/8$	$h=\lambda/2$	$h=3\lambda/4$	$h=\lambda$	$h=2\lambda$
$F=\cos(\frac{\pi}{8}(\cos\theta-1))$	$F=\cos(\frac{\pi}{4}(\cos\theta-1))$	$F=\cos(\frac{3\pi}{8}(\cos\theta-1))$	$F=\cos(\frac{\pi}{2}(\cos\theta-1))$	$F=\cos(\frac{3\pi}{4}(\cos\theta-1))$	$F=\cos(\pi(\cos\theta-1))$	$F=\cos(2\pi\cos\theta)$



Smernost:

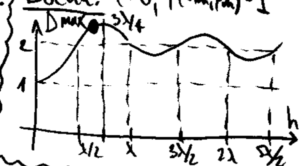
$$D=\frac{4\pi|F(\theta_m,\phi_m)|^2}{\int|F(\theta,\phi)|^2d\Omega}$$

$$D=\frac{4\pi|F(\theta_m,\phi_m)|^2}{2\pi\int_0^{\pi}\cos^2\left(\frac{\varphi}{2}+\frac{kh}{2}\cos\theta\right)\sin\theta d\theta}$$

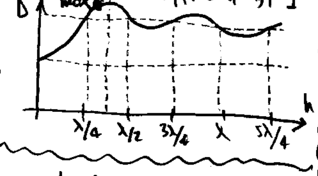
$$D=\frac{2|F(\theta_m,\phi_m)|^2}{\frac{1}{2}\int_{-1}^{+1}(1+\cos(\varphi+khu))du}$$

$$\boxed{D=\frac{2|F(\theta_m,\phi_m)|^2}{1+\frac{\sin kh}{kh}\cos\varphi}}$$

Bočna: $\varphi=0$, $F(\theta_m,\phi_m)=1$



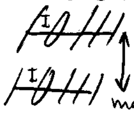
Osna: $\varphi=-kh$, $|F(\theta_m,\phi_m)|=1$



Osna max D: $\varphi\to\pi$, $h\to0$ $R_s=?$

$|F(\theta_m,\phi_m)|\ll1$

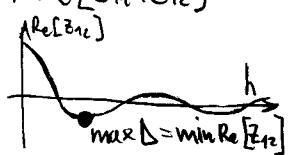
$D_{max}\to\underline{4}$



$P_s=4P_{s1}$ $\quad P_g=|I|^2\mathrm{Re}[Z_{11}+Z_{12}]$

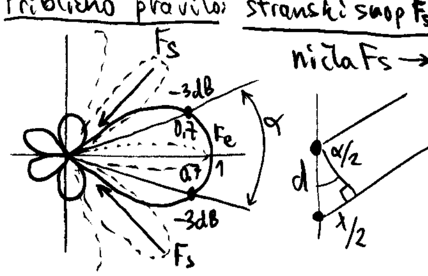
$P_{g1}=\frac{1}{2}|I|^2\mathrm{Re}[Z_{11}]$

$$D=D_e\frac{P_s}{P_{s1}}\frac{P_{g1}}{P_g}=D_e\frac{2\,\mathrm{Re}[Z_{11}]}{\mathrm{Re}[Z_{11}+Z_{12}]}$$



Približno pravilo: stranski snop $F_s\to$ ničla F_e!!!

ničla $F_s\to-3\text{dB}\,F_e$



$$\boxed{d=\frac{\lambda/2}{\sin\alpha/2}}$$

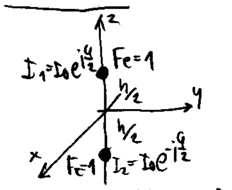
Ocena točnosti

$|Z_{12}|\ll|Z_{11}|$

$D\approx D_e\cdot D_s$

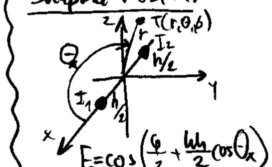
Antene in razširjanje valov #8 19/11/2013

Ponovitev:



$F_s = \cos\left(\frac{\varphi}{2} + \frac{kh}{2}\cos\theta\right)$

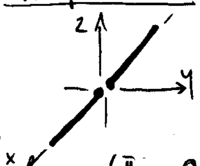
Skupina v osi X:



$F_s = \cos\left(\frac{\varphi}{2} + \frac{kh}{2}\cos\theta_x\right)$

$F_s = \cos\left(\frac{\varphi}{2} + \frac{kh}{2}\sin\theta\cos\phi\right)$

$\lambda/2$ dipol v osi X:



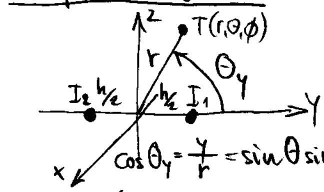
$\cos\theta_x = \sin\theta\cos\phi = \frac{x}{r}$

$\sin\theta_x = \pm\sqrt{1-\cos^2\theta_x}$

$\sin\theta_x = \pm\sqrt{1-\sin^2\theta\cos^2\phi}$

$$F = \frac{\cos\left(\frac{\pi}{2}\cos\theta_x\right)}{\sin\theta_x} = \frac{\cos\left(\frac{\pi}{2}\sin\theta\cos\phi\right)}{\sqrt{1-\sin^2\theta\cos^2\phi}}$$

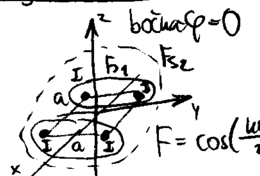
Skupina v osi Y:



$\cos\theta_y = \frac{y}{r} = \sin\theta\sin\phi$

$F_s = \cos\left(\frac{\varphi}{2} + \frac{kh}{2}\sin\theta\sin\phi\right)$

Oglišča kvadrata XY:

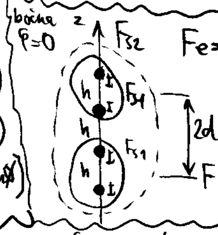


$F_e = 1$

$F_{s1} = \cos\left(\frac{ka}{2}\sin\theta\sin\phi\right)$

$F_{s2} = \cos\left(\frac{ka}{2}\sin\theta\cos\phi\right)$

$F = \cos\left(\frac{ka}{2}\sin\theta\cos\phi\right)\cos\left(\frac{ka}{2}\sin\theta\sin\phi\right)$

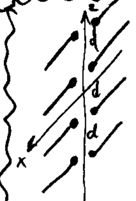


$F_e = 1$ $F_{s1} = \cos\left(\frac{kd}{2}\cos\theta\right)$

$F_{s2} = \cos\left(\frac{k2d}{2}\cos\theta\right)$

$F = \cos(kd\cos\theta)\cos\left(\frac{kd}{2}\cos\theta\right)$

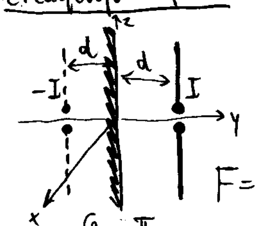
4 dipoli v X na osi Z:



$F = F_{s2}\cdot F_{s1}\cdot F_e$ $\varphi = 0$

$F = \cos(kd\cos\theta)\cos\left(\frac{kd}{2}\cos\theta\right)\cdot\frac{\cos\left(\frac{\pi}{2}\sin\theta\cos\phi\right)}{\sqrt{1-\sin^2\theta\cos^2\phi}}$

Zrcaljenje dipola



$F_s = \cos\left(\frac{\varphi}{2} + kd\cos\theta_y\right)$

$F_s = \cos\left(-\frac{\pi}{2} + kd\sin\theta\sin\phi\right)$

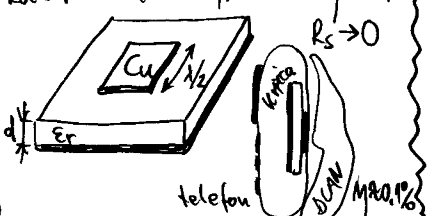
$F_s = \sin(kd\sin\theta\sin\phi)$

$F = \sin(kd\sin\theta\sin\phi)\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$

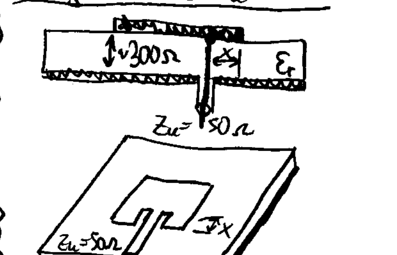
Mikrostrip krpica

$kd \ll 1 \rightarrow \sin(kd\cos\theta_y) \ll 1 \rightarrow \eta \ll 1$

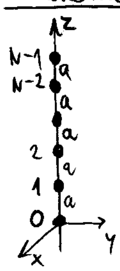
$R_s \rightarrow 0$



Prilagoditev R_s na 50Ω



Enakomerna skupina



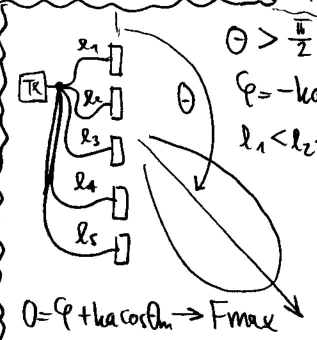
$I_m = I_0 e^{jm\varphi}$

$\vec{E}_0 = \vec{1}_E \propto I_0 \frac{e^{-jkr}}{r}$ Fraunhofer samo faza:

$\vec{E} = \vec{1}_E \propto \frac{e^{-jkr}}{r}\left[I_0 + I_1 e^{j(\varphi + ka\cos\theta)} + \ldots + I_{N-1}e^{j(N-1)(\varphi + ka\cos\theta)}\right]$

$\vec{E} = \vec{1}_E I_0 \propto \frac{e^{-jkr}}{r}\frac{1-e^{jN(\varphi+ka\cos\theta)}}{1-e^{j(\varphi+ka\cos\theta)}}$

$$\boxed{F_s(\theta,\phi) = \frac{\sin\frac{N}{2}(\varphi + ka\cos\theta)}{\sin\frac{1}{2}(\varphi + ka\cos\theta)}}$$

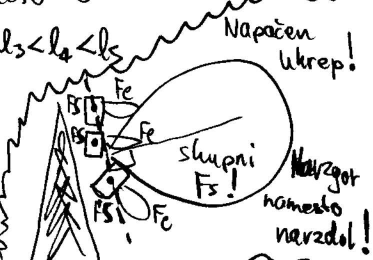


$0 = \varphi + ka\cos\theta_m \rightarrow F_{max}$

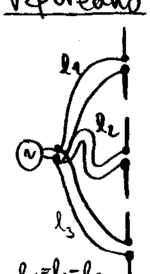
$\theta > \frac{\pi}{2}$ Električni odklon navzdol

$\varphi = -ka\cos\theta > 0$

$l_1 < l_2 < l_3 < l_4 < l_5$



Vzporedno

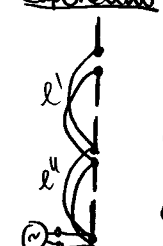


$l_1 = l_2 = l_3$

frekvenčno neodvisno

NAPAJANJE SKUPINE

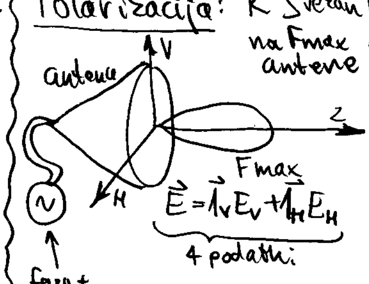
Zaporedno



frekvenčno zelo odvisno

Polarizacija:

K S vezan na Fmax antene!



$\underbrace{\vec{E} = \vec{1}_V E_V + \vec{1}_H E_H}_{\text{4 podatki}}$

faza + amplituda = 2 podatka

Razmerje linearnih komponent:

$\frac{E_V}{E_H} \equiv$ dva podatka polarizacije (odvisna od izbire $\vec{1}_V$!)

$E_V = \vec{1}_V \cdot \vec{E}$ $E_H = \vec{1}_H \cdot \vec{E}$

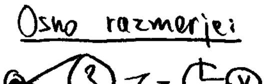
Krožna smernika (IEEE):

$\vec{1}_L \cdot \vec{1}_L^* = 1; \vec{1}_L \cdot \vec{1}_\Delta^* = 0$

$\vec{1}_L = \frac{\vec{1}_V + j\vec{1}_H}{\sqrt{2}}$ $E_L = \vec{E}\cdot\vec{1}_L^*$ $E_\Delta = \vec{E}\cdot\vec{1}_\Delta^*$

$\vec{1}_\Delta = \frac{\vec{1}_V - j\vec{1}_H}{\sqrt{2}}$ $Q = \frac{E_L}{E_\Delta} \equiv$ razmerje krožnih komponent

Osno razmerje:

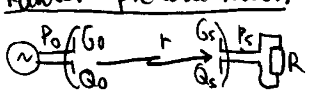


$\frac{U_{max}}{U_{min}} = R$

$1 \leq R = \left|\frac{1+|Q|}{1-|Q|}\right|$ $R_{dB} = 20\log R$

R in $|Q|$ neodvisna od $\vec{1}_V$!

Faktor prenosa moči:



$$P_s = P_0 G_0 G_s \left(\frac{\lambda}{4\pi r}\right)^2 \underbrace{\frac{|1+Q_0 Q_s|^2}{(1+|Q_0|^2)(1+|Q_s|^2)}}_{0 \leq \eta \leq 1}$$

Polarizacija	Q	R	Faktor η VP	HP	RHCP	LHCP	PP45	PP135
VP	1	∞	1	0	1/2	1/2	1/2	1/2
HP	−1	∞	0	1	1/2	1/2	1/2	1/2
RHCP	0	1	1/2	1/2	1	0	1/2	1/2
LHCP	∞	1	1/2	1/2	0	1	1/2	1/2
PP45	−j	∞	1/2	1/2	1/2	1/2	0	1
PP135	+j	∞	1/2	1/2	1/2	1/2	1	0

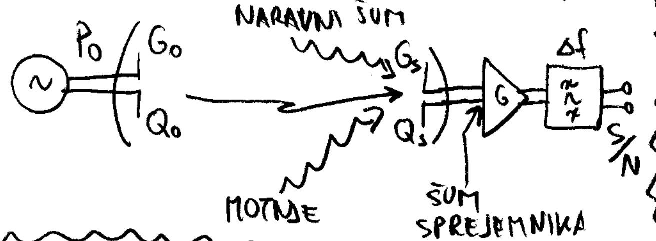
Krožno-polarizirane antene

- $90°$ fazni zamik → zamaknjeni anteni
- 2 anteni pod pravim kotom → napajanje $\Delta l = \lambda/4$
  → napajanje $R+C$, $R+L$
  → dipoli različnih dolžin

→ obrezana krpica
→ eliptični valovod $\Delta\beta$
→ vijaki pod $45°$, ploščica ε_r
→ dvoosni dielektrik
→ vijačna antena z osnim sevanjem
→ spiralna antena

Antene in razširjanje valov #9 26/11/2013

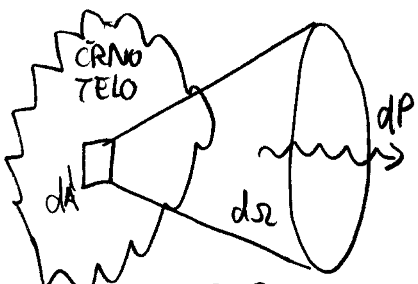
Koherentna zveza, nekoherentne motnje



Spektralna svetlost

$$B_f = \frac{dP}{df\, dA'\, d\Omega}$$

$$B_\lambda = \frac{dP}{d\lambda\, dA'\, d\Omega}$$



Planck-ov zakon

(ČRNO TELO)

$$B_f = \frac{2hf^3}{c_0^2}\frac{1}{e^{\frac{hf}{k_BT}}-1}$$

$h = 6{,}625\cdot 10^{-34}\,\mathrm{Js}$

$k_B = 1{,}38\cdot 10^{-23}\,\mathrm{J/K}$

$c_0 = 3\cdot 10^{8}\,\mathrm{m/s}$

Rayleigh-Jeans

približek $hf \ll k_BT$

$$e^{\frac{hf}{k_BT}} - 1 \approx \frac{hf}{k_BT}$$

$$B_f = \frac{2k_BTf^2}{c_0^2}$$

$$B_f = \frac{2k_BT}{\lambda^2}$$

Wien

približek $hf \gg k_BT$

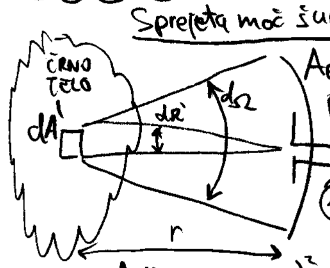
$$B_f = \frac{2hf^3}{c_0^2}e^{-\frac{hf}{k_BT}}$$

$f = 100\,\mathrm{GHz}$, $T = 300\,\mathrm{K}$

$$\frac{hf}{k_BT} = \frac{6{,}625\cdot10^{-34}\,\mathrm{Js}\cdot 10^{11}\,\mathrm{s^{-1}}}{1{,}38\cdot 10^{-23}\,\mathrm{J/K}\cdot 300\,\mathrm{K}} \approx 0{,}016$$

Sprejeta moč šuma

$\eta = 1$



$A_{eff}(\Theta,\phi)$ BREZIZGUBNA ANTENA! SAMO ① polarizacija!

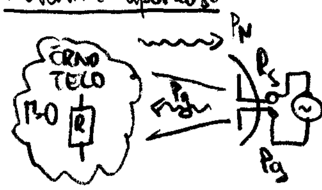
$d\Omega = \frac{A_{eff}}{r^2}$ $\quad A_{eff} = \frac{\lambda^2}{4\pi}D(\Theta,\phi)$

$dA' = r^2 d\Omega'$ $\quad A_{eff}(\Theta,\phi) = \lambda^2\frac{|F(\Theta,\phi)|^2}{\int_{4\pi}|F(\Theta',\phi')|^2 d\Omega'}$

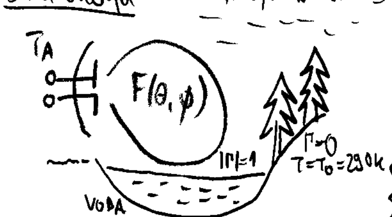
$$P_N = \underbrace{\frac{1}{2}}_{\text{ena polarizacija}}\int B_f\,\Delta f\, d\Omega\, dA' = \frac{\Delta f}{2}\int_{4\pi} B_f\frac{A_{eff}}{r^2}r^2 d\Omega' = \frac{\Delta f}{2}\int_{4\pi}B_f\lambda^2\frac{|F(\Theta',\phi')|^2 d\Omega'}{\int_{4\pi}|F(\Theta'',\phi'')|^2 d\Omega''} = \frac{\Delta f\lambda^2}{2}\frac{\int_{4\pi}B_f(\Theta,\phi)|F(\Theta,\phi)|^2 d\Omega}{\int_{4\pi}|F(\Theta,\phi)|^2 d\Omega}$$

Rayleigh-Jeans: $B_f(\Theta,\phi) = \frac{2k_B}{\lambda^2}T(\Theta,\phi) \rightarrow P_N = \Delta f k_B\frac{\int_{4\pi}T(\Theta,\phi)|F(\Theta,\phi)|^2 d\Omega}{\int_{4\pi}|F(\Theta,\phi)|^2 d\Omega}$; $T_A = \frac{\int_{4\pi}T(\Theta,\phi)|F(\Theta,\phi)|^2 d\Omega}{\int_{4\pi}|F(\Theta,\phi)|^2 d\Omega}$; $P_N = \Delta f k_B T_A$

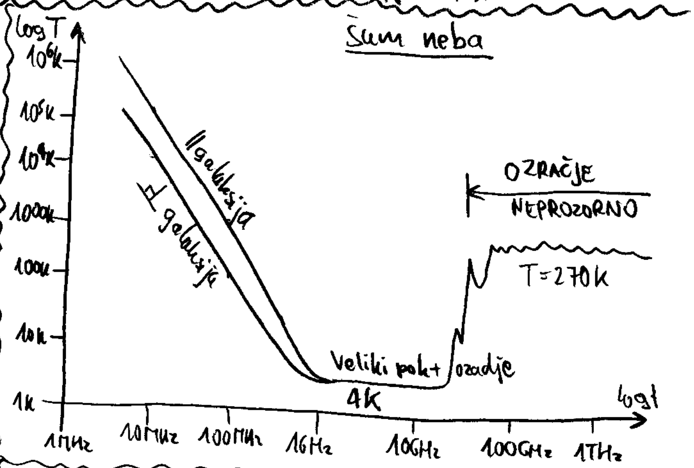
Sevalna upornost



Šum okolja

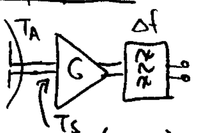


Šum neba



$k_BT_0 = 1{,}38\cdot10^{-23}\,\mathrm{J/K}\cdot 293\,\mathrm{K} = 4\cdot10^{-21}\,\mathrm{Ws} = -174\,\mathrm{dBm/Hz}$

Sprejemnik:



$P_N = \Delta f\, k_B(T_A + T_s)$

polprevodniki $T_s = 30\,\mathrm{K} - 300\,\mathrm{K}$

Cel sprejemnik $T_s = 100\,\mathrm{K} - 1000\,\mathrm{K}$

Zgled: GSM telefon $S/N = 10\,\mathrm{dB}$

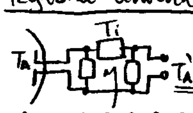
$\Delta f = 200\,\mathrm{kHz}$ $\quad T_A + T_s = 1000\,\mathrm{K}$

$P_N = \Delta f\cdot k_B(T_A+T_s) = 2\cdot10^5\,\mathrm{s^{-1}}\cdot 1{,}38\cdot10^{-23}\,\mathrm{J/K}\cdot 1000\,\mathrm{K} = \underline{2{,}76\cdot10^{-15}\,\mathrm{W}}$

$P_s = S/N\cdot P_N = \underline{2{,}76\cdot10^{-14}\,\mathrm{W}}$

$P_s[\mathrm{dBm}] = 10\log\frac{P_s}{1\,\mathrm{mW}} \approx \underline{\underline{-106\,\mathrm{dBm}}}$

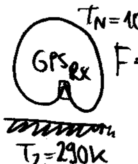
Izgubna antena $\eta < 1$



$T_A' = \eta T_A + (1-\eta)T_i$

$\int(1+u)^2du = u + u^2 + \frac{u^3}{3} + C$

Zgled GPS RX:



$T_N = 10\,\mathrm{K}$

$F = 1 + \cos\Theta$

$u = \cos\Theta$

$T_Z = 290\,\mathrm{K}$

$$T_A = \frac{\frac{7}{3}T_N + \frac{1}{3}T_Z}{\frac{8}{3}}$$

$$T_A = \frac{7\cdot10\,\mathrm{K} + 1\cdot290\,\mathrm{K}}{8}$$

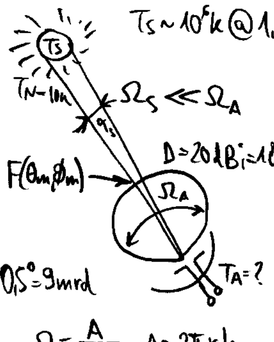
$$\underline{\underline{T_A = 45\,\mathrm{K}}}$$

$$T_A = \frac{\int_{4\pi}T(\Theta)(1+\cos\Theta)^2 d\Omega}{\int_{4\pi}(1+\cos\Theta)^2 d\Omega}$$

$$T_A = \frac{T_N\int_0^1(1+u)^2du + T_Z\int_{-1}^0(1+u)^2du}{\int_{-1}^1(1+u)^2du}$$

Antena v Sonce:

$T_S \sim 10^6\,\mathrm{K}$ @ 1,5 GHz



$\Omega_S \ll \Omega_A$

$\alpha_S = 0{,}5° = 9\,\mathrm{mrd}$

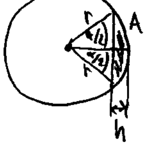
$$T_A = \frac{T_S\int_{\Omega_S}|F(\Theta,\phi)|^2 d\Omega + T_N\int_{4\pi-\Omega_S}|F(\Theta,\phi)|^2 d\Omega}{\int_{4\pi}|F(\Theta,\phi)|^2 d\Omega}$$

$$T_A \approx T_S\Omega_S\frac{|F(\Theta_m,\phi_m)|^2}{\int_{4\pi}|F(\Theta,\phi)|^2 d\Omega} + T_N$$

$$T_A \approx T_S\frac{\Omega_S}{4\pi}D + T_N$$

$$T_A = 10^6\,\mathrm{K}\frac{64\cdot10^{-6}\,\mathrm{srd}}{4\pi}\cdot100 + 10\,\mathrm{K}$$

$$T_A = 506\,\mathrm{K} + 10\,\mathrm{K} = \underline{\underline{516\,\mathrm{K}}}$$



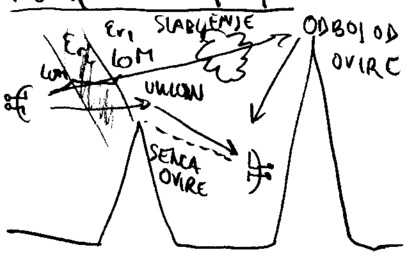
$\Omega = \frac{A}{r^2}$ $\quad A = 2\pi r h$

$\Omega = 2\pi(1-\cos(\alpha/2))$

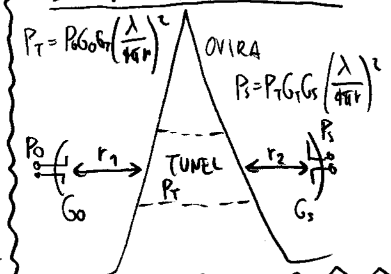
$\Omega \approx \frac{\pi}{4}\alpha^2[\mathrm{rd}] = \underline{64\cdot10^{-6}\,\mathrm{srd}}$

Antene in razširjanje valov #10 — 3/12/2013

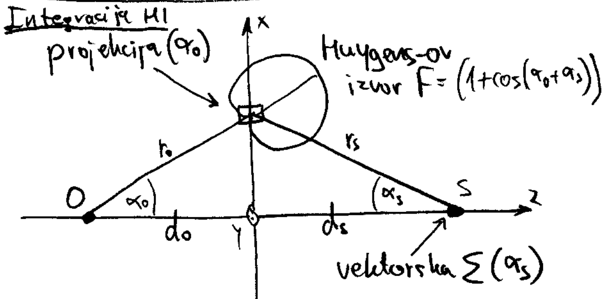
Motnje razširjanja:



2 zaporedni zvezi $\propto r^{-4}$



Integracija HI



$$r_0 = \sqrt{d_0^2+x^2+y^2} \approx d_0 + \frac{x^2+y^2}{2d_0}$$

$$r_s = \sqrt{d_s^2+x^2+y^2} \approx d_s + \frac{x^2+y^2}{2d_s}$$

$$E_0 = \alpha I \frac{e^{-jkr_0}}{r_0} \qquad dE = \frac{j}{2\lambda} E_0\, dx\, dy \frac{e^{-jkr_s}}{r_s} F(\alpha_0,\alpha_s)$$

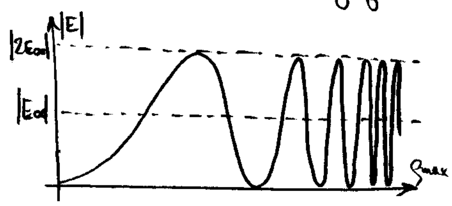
$d_0, d_s \gg x, y \rightarrow$ poenostavim amplitudo: $\frac{1}{r_s} \approx \frac{1}{d_s}, \frac{1}{r_0} \approx \frac{1}{d_0}, F(\alpha_0,\alpha_s) \approx 2$

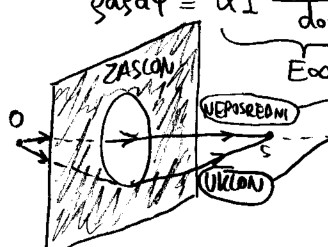
$\rightarrow$ poenostavim fazo: $e^{-jkr_0} \approx e^{-jkd_0} e^{-jk\frac{x^2+y^2}{2d_0}}$, $e^{-jkr_s} \approx e^{-jkd_s} e^{-jk\frac{x^2+y^2}{2d_s}}$

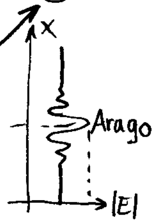
$$E = \iint_{x\,y} \frac{j}{2\lambda} \alpha I \frac{e^{-jkr_0}}{r_0} dx\,dy \frac{e^{-jkr_s}}{r_s} F(\alpha_0,\alpha_s) \approx \frac{j}{\lambda} \alpha I \frac{e^{-jk(d_0+d_s)}}{d_0 d_s} \iint_{x\,y} e^{-jk\frac{d_0+d_s}{2d_0d_s}(x^2+y^2)} dx\,dy$$

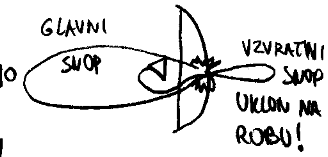
$x, y \rightarrow \rho, \varphi$

$$E = \frac{j}{\lambda} \alpha I \frac{e^{-jk(d_0+d_s)}}{d_0 d_s} \int_0^{\rho_{max}} \int_0^{2\pi} e^{-jk\frac{d_0+d_s}{2d_0d_s}\rho^2} \rho\, d\rho\, d\varphi = \underbrace{\alpha I \frac{e^{-jk(d_0+d_s)}}{d_0+d_s}}_{E_\infty} \left(1 - e^{-jk\frac{d_0+d_s}{2d_0d_s}\rho_{max}^2}\right)$$

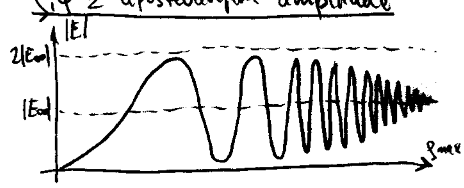




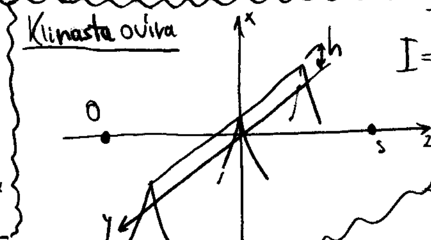




ρ, φ z upoštevanjem amplitude

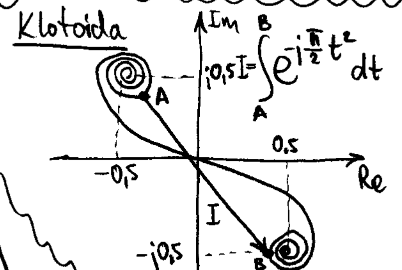


Klinasta ovira

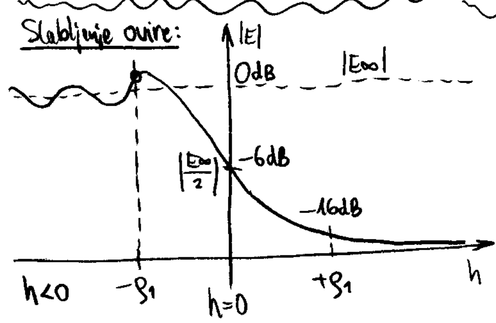


$$I = \int_h^{+\infty} e^{-jk\frac{d_0+d_s}{2d_0d_s}x^2} dx \int_{-\infty}^{+\infty} e^{-jk\frac{d_0+d_s}{2d_0d_s}y^2} dy$$

Klotoida



Slabljenje ovire:

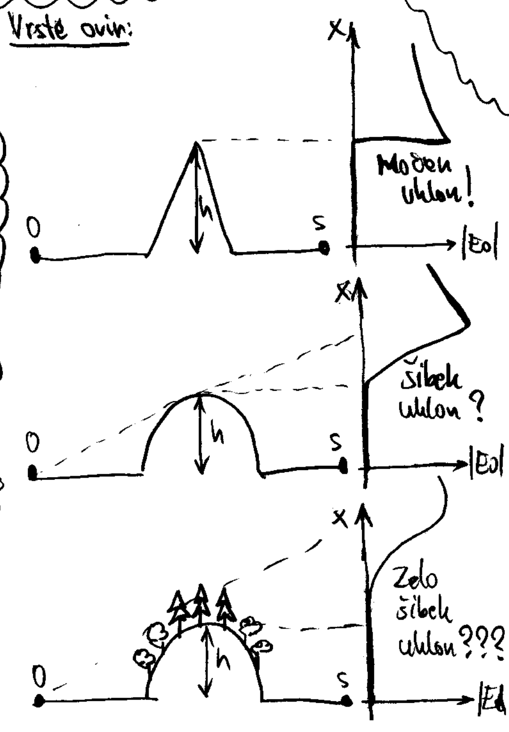


$h < -\rho_1 \longrightarrow a \approx 0\,dB$

$h = 0 \longrightarrow a = 6\,dB$

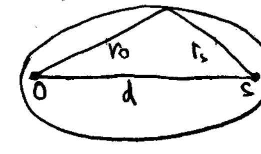
$h > \rho_1 \longrightarrow a = 16\,dB + 20 \log \frac{h}{\rho_1}$

Vrste ovir:



Fresnelovi elipsoidi:

$$r_0 + r_s = d + n\frac{\lambda}{2}$$

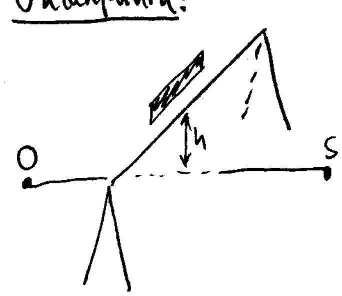


Polmeri FC:

$$r_0 + r_s = d_0 + d_s + n\frac{\lambda}{2}$$

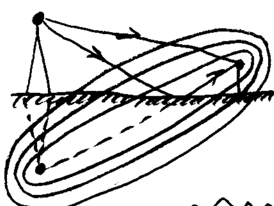
$$\rho_n = \sqrt{n\lambda \frac{d_0 d_s}{d_0+d_s}}$$

Uklanjalnik:

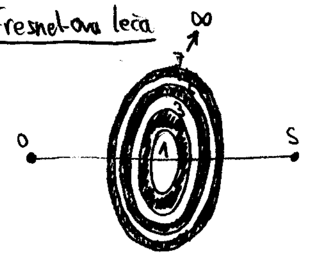


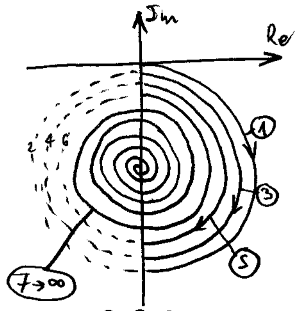
Antene in razširjanje valov #11 10/12/2013

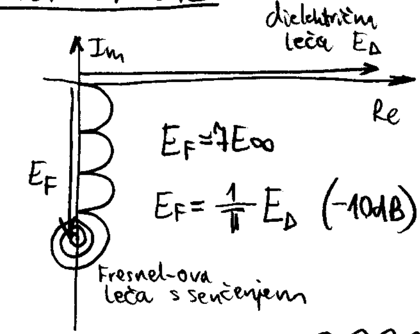
FC pri odboju:



Fresnel-ova leča



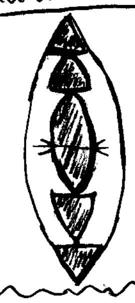




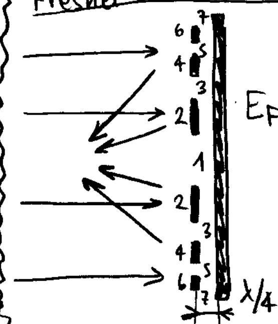
$E_F \approx 7E_\infty$

$E_F = \frac{1}{\pi} E_\Delta$ (−10dB)

Fresnel-ova dielektrična:



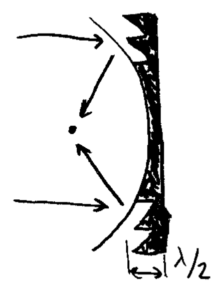
Fresnel-ovo zrcalo:



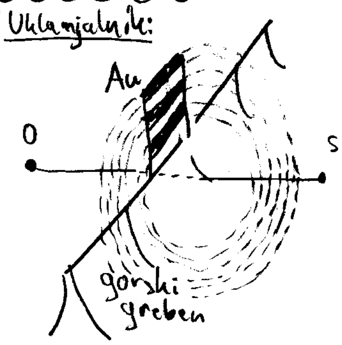
$E_{FZ} = \frac{2}{\pi} E_{PZ}$

(−4dB)

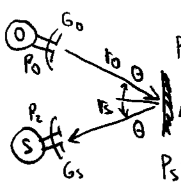
Fresnel-parabolično:



Uklanjalnik:



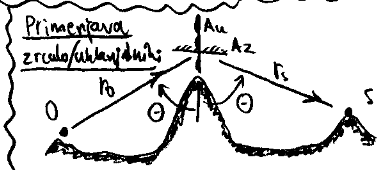
Ravno zrcalo:



$P_z = P_0 G_0 \frac{A_z \cos\theta}{4\pi r_0^2}$

$P_s = P_z G_s \frac{A_z \cos\theta}{4\pi r_s^2}$

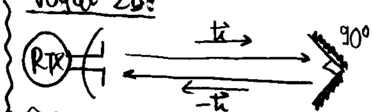
Primerjava zrcalo/uklanjalnik:



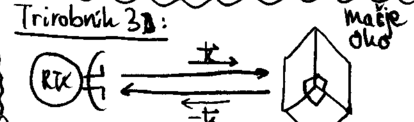
$\boxed{\frac{P_{su}}{P_{sz}} = \frac{A_u^2}{A_z^2} \frac{tg^2\theta}{\pi^2}}$

$P_{sz} = \frac{P_0 G_0 G_s}{(4\pi)^2 r_0^2 r_s^2} A_z^2 \cos^2\theta$ $\quad P_u = \frac{P_0 G_0 G_s}{(4\pi)^2 r_0^2 r_s^2} \frac{A_u^2 \sin^2\theta}{\pi^2}$

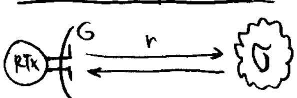
Vogal 2D:



Trirobnik 3D:



Odmevna površina σ:

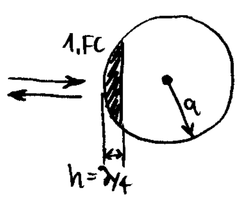


$\boxed{P_s = P_0 G^2 \frac{\lambda^2 \sigma}{(4\pi)^3 r^4}}$

Ravna plošča (trirobnik) $\boxed{\sigma_r = \frac{4\pi}{\lambda^2} A^2}$

σ velike krogle $a \gg \lambda$:

$A_1 = 2\pi a h$



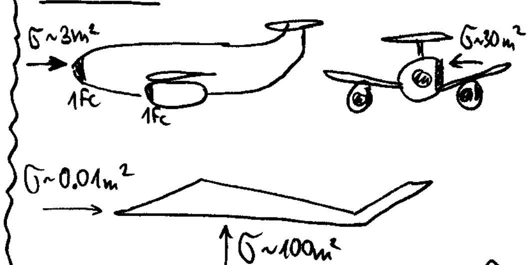
$\sigma_k = \frac{1}{4} \sigma_{1FC}$

$\sigma_k = \frac{1}{4} \frac{4\pi}{\lambda^2} (2\pi)^2 a^2 \left(\frac{\lambda}{4}\right)^2 \left(\frac{2}{\pi}\right)^2$

$\sigma_{1FC} = \frac{4\pi}{\lambda^2} A_1^2 \left(\frac{2}{\pi}\right)^2$

$\boxed{\sigma_k = \pi a^2}$

σ letala:



Domet radarja:

$P_0 = 10^6 W = 1MW$

$P_s = 10^{-12} W = 1pW$

$G = 40 dB$ ($\sim 10m^2$)

$\lambda = 0{,}1m$ (3GHz)

$r = ?$

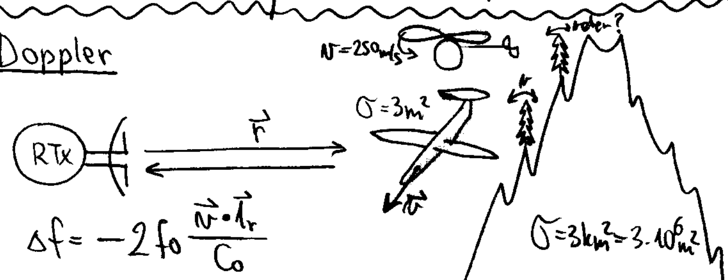
$r = \sqrt[4]{\frac{P_0}{P_s} \frac{G^2 \lambda^2}{(4\pi)^3} \sigma}$

$\sigma = 30m^2 \rightarrow r = 350km$

$\sigma = 3m^2 \rightarrow r = 197km$

$\sigma = 0{,}01m^2 \rightarrow r = 47km$

Doppler



$\Delta f = -2 f_0 \frac{\vec{v} \cdot \vec{1}_r}{c_0}$

$|\vec{v} \cdot \vec{1}_r| > 40m/s$

Meritev hitrosti

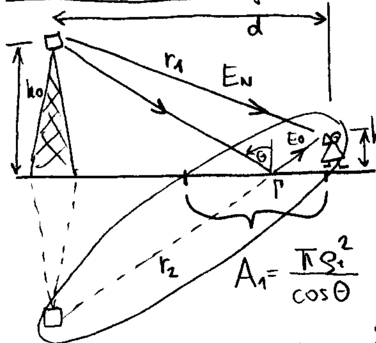
$f_0 = 24GHz \rightarrow \lambda = 1{,}2cm$

$f_0 = 34GHz \rightarrow \lambda = 0{,}9cm$

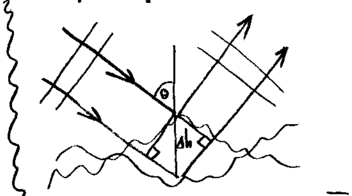
$\Delta f = 2 f_0 \frac{v}{c_0}$

Antene in razširjanje valov # 12 17/12/2013

1. FC pri odboju



$$A_1 = \frac{\pi \varsigma_1^2}{\cos\Theta}$$



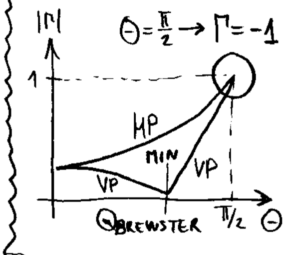
$$\Delta\varphi = 2k\,\Delta h\cos\Theta < \frac{\pi}{2}$$

za zrcalni odboj -1dB

Rayleigh-ov kriterij za hrapavost: $\Delta h < \frac{\lambda}{8\cos\Theta}$

Odbojnost slabega dielektrika

$\Theta = \frac{\pi}{2} \rightarrow \Gamma = -1$



$$E_s = E_N + E_O$$

$$E_s = \alpha I \frac{e^{-jkr_1}}{r_1} + \Gamma\alpha I \frac{e^{-jkr_2}}{r_2}$$

$$E_s \approx \frac{\alpha I}{d}\left[e^{-jkr_1} + \Gamma e^{-jkr_2}\right]$$

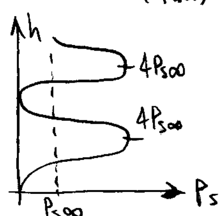
$$r_1 = \sqrt{d^2 + (h_o - h_s)^2} \approx d + \frac{(h_o - h_s)^2}{2d}$$

$$r_2 = \sqrt{d^2 + (h_o + h_s)^2} \approx d + \frac{(h_o + h_s)^2}{2d}$$

$$E_s \approx \frac{\alpha I}{d} e^{-jk\left(d + \frac{h_o^2 + h_s^2}{2d}\right)}\left[e^{jk\frac{h_o h_s}{d}} - e^{-jk\frac{h_o h_s}{d}}\right]$$

$$|E_s| \approx \frac{\alpha I}{d}\, 2\sin\left(k\frac{h_o h_s}{d}\right)$$

$$P_s = P_0 G_o G_s \left(\frac{\lambda}{4\pi d}\right)^2 4\sin^2\left(k\frac{h_o h_s}{d}\right)$$



$h_o, h_s \ll d$ VELIKE RAZDALJE

$$\sin\left(k\frac{h_o h_s}{d}\right) \approx k\frac{h_o h_s}{d} = 2\pi\frac{h_o h_s}{\lambda d}$$

$$\boxed{P_s = P_o G_o G_s \frac{h_o^2 h_s^2}{d^4}}$$

Mestno okolje z ovirami:

$$P_s = P_o G_o G_s \frac{h_o^2 h_s^2}{d^N}\alpha(\lambda)\ ;\ N = 3\ldots5$$

ZGLED: $\lambda = 33$cm

$P_o = 10W = +40$dBm

$P_s = 10^{-13}W = -100$dBm

$G_o = G_s = 1$

$h_s = 1{,}5$m

$h_o = 1{,}5$m$/30$m

$d = ?$

$$d = \sqrt[4]{\frac{P_o}{P_s}G_o G_s h_o^2 h_s^2}$$

$h_o = 1{,}5$m $\rightarrow$ $d = 4.74$km

$h_o = 30$m $\rightarrow$ $d = 21.2$km

Primerjava prazen prostor:

$$d = \sqrt[2]{\frac{P_o}{P_s}G_o G_s\left(\frac{\lambda}{4\pi}\right)^2} = 263\text{km}$$

OZRAČJE:

TROPOSFERA 0–10km

$\varepsilon = \varepsilon_o\varepsilon_r$, $\gamma \neq 0$

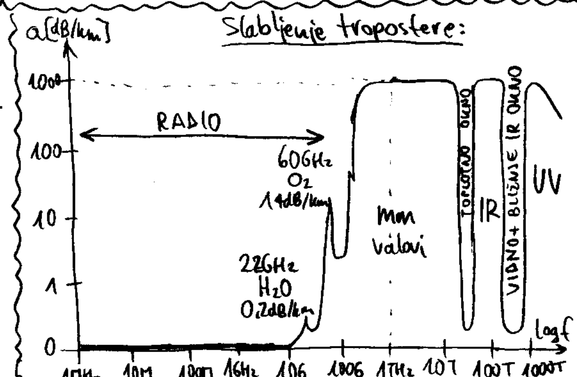
SUHI DEL ($N_2 + O_2$):

$$n = 1 + \Delta n_o e^{-\frac{h}{H}}$$

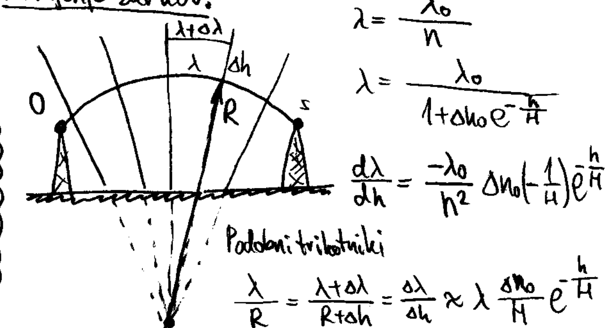
$\Delta n_o = 0{,}0003$

$H = 8500$m

Slabljenje troposfere:



Krivljenje žarkov:



$$\lambda = \frac{\lambda_o}{n}$$

$$\lambda = \frac{\lambda_o}{1 + \Delta n_o e^{-\frac{h}{H}}}$$

$$\frac{d\lambda}{dh} = \frac{-\lambda_o}{n^2}\Delta n_o\left(-\frac{1}{H}\right)e^{-\frac{h}{H}}$$

Podobni trikotniki

$$\frac{\lambda}{R} = \frac{\lambda + \Delta\lambda}{R + \Delta h} = \frac{\Delta\lambda}{\Delta h} \approx \lambda\frac{\Delta n_o}{H}e^{-\frac{h}{H}}$$

$$\boxed{R = \frac{H}{\Delta n_o}e^{\frac{h}{H}}}$$

$h = 0 \rightarrow R(0) = 28333$km

SUHI + MOKRI DEL

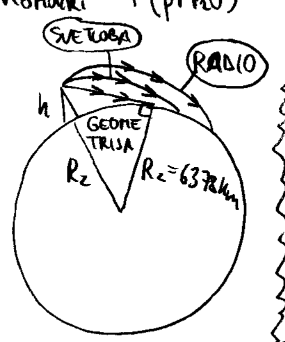
$$n = 1 + \underbrace{\Delta n_{o\,suhi}e^{-\frac{h}{H_{suhi}}}}_{(N_2 + O_2)} + \underbrace{\Delta n_{o\,mokri}e^{-\frac{h}{H_{mokri}}}}_{(H_2O)}$$

$H_{mokri} = 1{,}5$km

$\Delta n_{omokri} = f(pH_2O)$

$R(0) \approx 25000$ km (RADIO)

$R(0) \approx 50000$ km (SVETLOBA)



Efektivni polmer Zemlje:

$$\frac{1}{R_{eff}} = \frac{1}{R_z} - \frac{1}{R}$$

$R_{eff} \approx 8600$km (RADIO)

$R_{eff} \approx 7300$ km (SVETLOBA)

Zgled: Stolp

$h = 100$m

$d = ?$

$$(R_z + h)^2 = R_z^2 + d^2$$

$$R_z^2 + 2R_z h + h^2 = R_z^2 + d^2$$

$$d = \sqrt{2R_z h + h^2} \approx \sqrt{2R_z h}$$

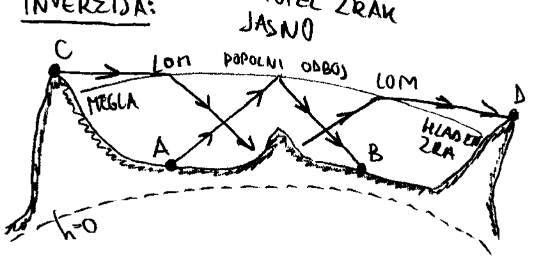
Geometrijski domet: $d = 35.7$km ($R_z = 6378$km)

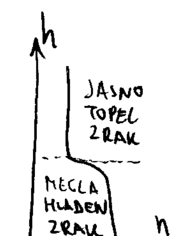
Svetlobni domet: $d = 38.2$km ($R_{eff} = 7300$km)

Radijski domet: $d = 41.5$km ($R_{eff} = 8600$km)

INVERZIJA:

TOPEL ZRAK JASNO





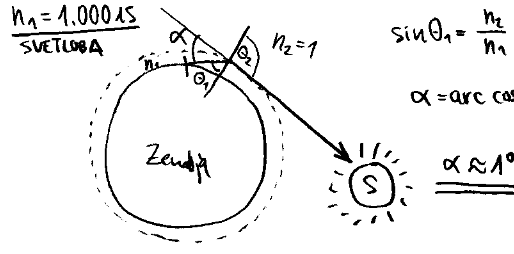
Lom ob Sončnem zahodu:

$n_1\sin\Theta_1 = n_2\sin\Theta_2$

$n_1 = 1.00015$ SVETLOBA

$$\sin\Theta_1 = \frac{n_2}{n_1} = \cos\alpha$$

$$\alpha = \arccos\frac{1}{n_1}$$



$$\underline{\underline{\alpha \approx 1°}}$$

Antene in razširjanje valov # 13 7/1/2014

Ponovitev:

TROPOSFERA < 10km

$n = 1 + \Delta n\, e^{-\frac{h}{H}}$

$\Delta n_{suhi} = 0{,}0003$

$H_{suhi} = 8{,}5km$

$H_{mokri} = 1{,}5km$

$R \sim 25000km$ @ $h=0$

$R_{eff} \approx 4/3\, R_z$

IONOSFERA:

$h > 60km$

$\vec{F} = Q\vec{E} = m\vec{a} = mj\omega\vec{v}$

$\vec{v} = \frac{Q}{j\omega m}\vec{E}$ $\quad N[m^{-3}]$

$\vec{J} = NQ\vec{v} = \frac{NQ^2}{j\omega m}\vec{E}$

KONVEKTIVNI TOK

Delci:

$m_p \approx 1800\, m_e$

$m_{iona} > m_p$

$\Rightarrow$ samo elektroni!

$m_e = 9{,}1\cdot 10^{-31}kg$

$Q_e = -1{,}6\cdot 10^{-19}As$

$\vec{J} = \frac{N_e Q_e^2}{j\omega m_e}\vec{E}$

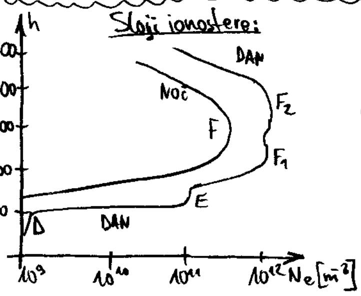
$\mathrm{rot}\vec{H} = \vec{J} + j\omega\varepsilon_0\vec{E} = \frac{N_e Q_e^2}{j\omega m_e}\vec{E} + j\omega\varepsilon_0\vec{E}$

$\mathrm{rot}\vec{H} = j\omega\varepsilon_0 \underbrace{\left(1 - \frac{N Q_e^2}{\omega^2\varepsilon_0 m_e}\right)}_{\varepsilon_r}\vec{E}$

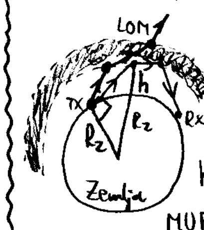
$\varepsilon_r = 1 - \frac{N_e Q_e^2}{\omega^2 \varepsilon_0 m_e} = 1 - \frac{f_p^2}{f^2}$

$f_p = \frac{1}{2\pi}\sqrt{\frac{N_e Q_e^2}{\varepsilon_0 m_e}} = \begin{cases}\sim 12MHz\ \text{DAN}\\ \sim 4MHz\ \text{NOČ}\end{cases}$

Zgled: $f_p = 12MHz \rightarrow N_e = \frac{\varepsilon_0 m_e}{Q_e^2}(2\pi f_p)^2 = \underline{1{,}8\cdot 10^{12}\ \text{elektronov}/m^3}$



Lom: $n = \sqrt{\varepsilon_r} = \sqrt{1 - (f_p/f)^2} = \sin\Theta = \frac{R_z}{h+R_z}$



$1 - \left(\frac{f_p}{MUF}\right)^2 = \left(\frac{1}{1+h/R_z}\right)^2$

$MUF \approx f_p\sqrt{\frac{R_z}{2h}}$

$h = 250km - 350km$

$MUF = 3{,}5f_p - 3f_p$

Slabljenje: trki D, E

LUF! ni točno definiran

	MUF	LUF
DAN	36MHz	5MHz
NOČ	12MHz	—

Fazna in skupinska hitrost:

$v_f = \frac{\omega}{\beta} = \frac{\omega}{n\frac{\omega}{c_0}} = \frac{c_0}{n} = \frac{c_0}{\sqrt{1-(f_p/f)^2}} > c_0$

$v_g = \frac{d\omega}{d\beta} = c_0\sqrt{1-(f_p/f)^2} < c_0$

Pogreški GPS @ 1575,42MHz >> f_p

$v_g < c_0 < v_f$ $\quad$ DAN: $|\Delta\vec{r}| \approx 30m$!

Žiromagnetna rezonanca:

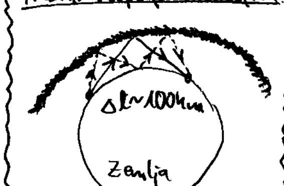
Zemeljsko magnetno polje $H_0 \approx 40A/m$

$\omega_g = \frac{Q_e\mu_0}{m_e}H_0$ $\quad$ $f_g \approx 1{,}4MHz$

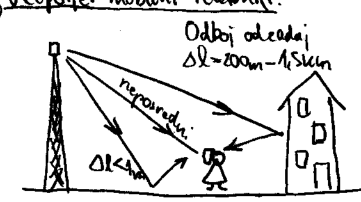
Visoko slabljenje

Faraday-evo sukanje polarizacije

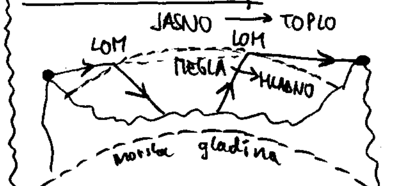
Presih: večpotje ionosferi:



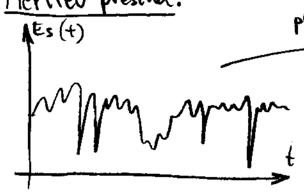
Večpotje mobilni telefoniji:

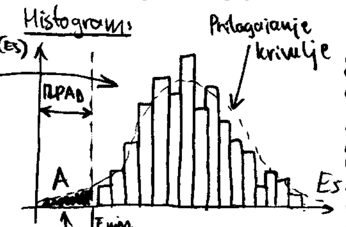


Presih zaradi inverzije



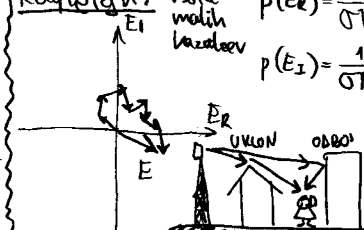
Meritev presiha:





Zelo malo meritev → verjetnost izpada

Rayleigh: vsota malih žarkov



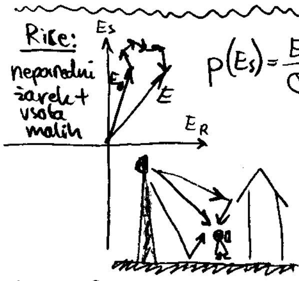
$p(E_R) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{E_R^2}{2\sigma^2}}$ $\qquad$ $E = E_R + jE_I = E_s e^{j\varphi}$

$p(E_I) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{E_I^2}{2\sigma^2}}$ $\qquad$ $p(E_s) = \int_0^{2\pi} p(E_R)p(E_I)E_s\,d\varphi$

$E_s = |E|$ $\qquad$ $p(E_s) = \frac{E_s}{\sigma^2}e^{-\frac{E_s^2}{2\sigma^2}}$

$P_{IZPADA} = \int_0^{E_{min}} p(E_s)\,dE_s$ $\qquad$ Samo en podatek σ

Rice:



$p(E_s) = \frac{E_s}{\sigma^2}e^{-\frac{E_s^2+E_0^2}{2\sigma^2}} I_0\left(\frac{E_sE_0}{\sigma^2}\right)$

Bessel-ova funkcija

dva podatka σ in E_0

Log-normalna:

$E_{dB} = 20\log|E/E_{REF}|$

$p(E_{dB}) = \frac{1}{\sigma_{dB}\sqrt{2\pi}}e^{-\frac{(E_{dB}-m_{dB})^2}{2\sigma_{dB}^2}}$

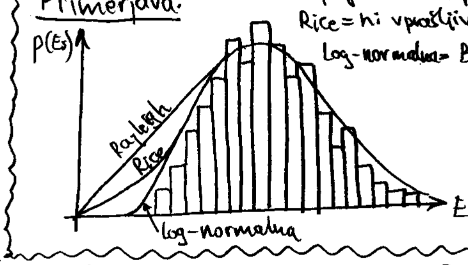
dva podatka m_{dB} in σ_{dB}

Primerjava:

Rayleigh = realni primer!

Rice = ni vprašljiv?

Log-normalna = BLEF



Rayleigh za moč:

$P_s = \alpha E_s^2 = \alpha(E_R^2 + E_I^2)$

$\langle P_s\rangle = \alpha(\langle E_R^2\rangle + \langle E_I^2\rangle) = \alpha 2\sigma^2$

$$P_{IZPADA} = \int_0^{E_{min}} \frac{E_s}{\sigma^2}e^{-\frac{E_s^2}{2\sigma^2}}dE_s = \int_0^{E_{min}^2}\frac{1}{2\sigma^2}e^{-\frac{E_s^2}{2\sigma^2}}dE_s^2 = \int_0^{P_{min}}\frac{1}{\langle P_s\rangle}e^{-\frac{P_s}{\langle P_s\rangle}}dP_s = 1 - e^{-\frac{P_{min}}{\langle P_s\rangle}}$$

Zgled: GSM telefon

$P_{min} = -105dBm = 31{,}6\cdot 10^{-15}W$

$\langle P_s\rangle = -90dBm = 10^{-12}W$

$P_{IZPADA} = ?$

$P_{IZPADA} = 1 - e^{-\frac{P_{min}}{\langle P_s\rangle}} = 1 - e^{-\frac{31{,}6}{1000}} = 0{,}0311 = 3{,}11\%$

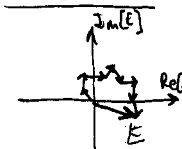
Približek: $P_{min} \ll \langle P_s\rangle$

$e^{-x} = 1 - x + \frac{x^2}{2} - \frac{x^3}{6} + \dots \approx 1 - x$

$P_{izpada} = 1 - e^{-\frac{P_{min}}{\langle P_s\rangle}} \approx \frac{P_{min}}{\langle P_s\rangle} = 3{,}16\%$

Antene in razširjanje valov #14 14/1/2014

Ponovitev: Rayleigh-ova porazdelitev



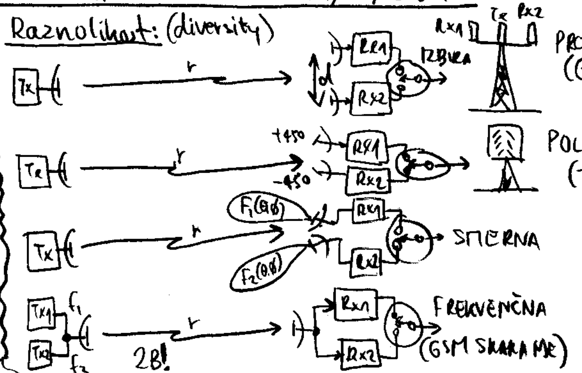
$$E_s = |E| = \alpha U_s$$

$$p(E_s) = \frac{2E_s}{\langle E_s^2\rangle} e^{-\frac{E_s^2}{\langle E_s^2\rangle}}$$

$$p(P_s) = \frac{1}{\langle P_s\rangle} e^{-\frac{P_s}{\langle P_s\rangle}}$$

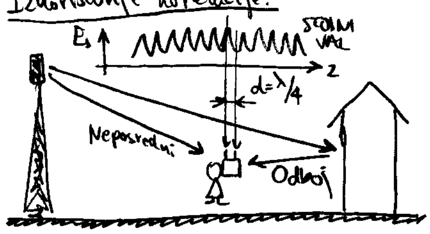
$$P_{IZPADA} = \int_0^{P_{min}} p(P_s)\,dP_s = 1 - e^{-\frac{P_{smin}}{\langle P_s\rangle}} = 1 - e^{-\frac{E_{min}^2}{\langle E_s^2\rangle}}$$

Raznolikost: (diversity)

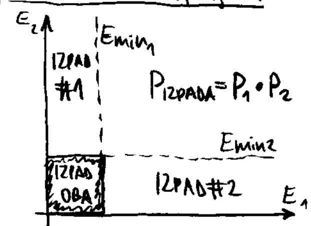


ČASOVNA (PONAVLJANJE SPOROČILA) 2B!

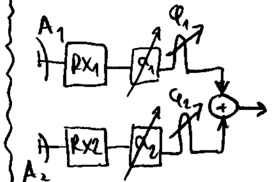
Izkoriščanje korelacije:

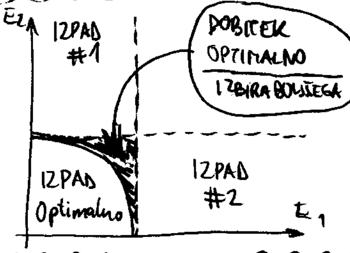


Nekoreliran sprejem:

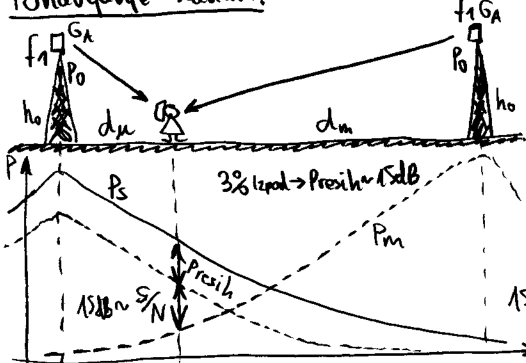


Optimalno sestavljanje:





Ponavljanje kanala:



$$P_s = P_0 G_0 G_s \frac{h_0^2 h_s^2}{d_u^4}$$

$$P_m = P_0 G_0 G_s \frac{h_0^2 h_s^2}{d_m^4}$$

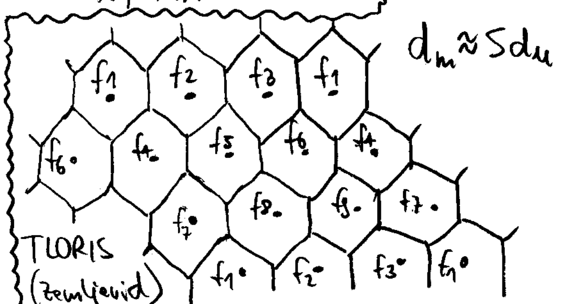
$$\frac{P_s}{P_m} = \left(\frac{d_m}{d_u}\right)^4 \approx 1000$$

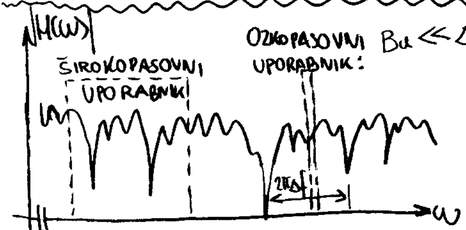
15dB(S/N) + 15dB Presih = 30dB = 1000

$$d_m = d_u \sqrt[4]{P_s/P_m} \approx 5.6 \cdot d_u$$

Celice:

$$d_m \approx 5 d_u$$





OZKOPASOVNI $B_u \ll \Delta f$ → PRESIH JAKOSTI SPREJEMA

(zgled analogni NMT telefon $B_u = 15$kHz)

Δl = 200m...1,5km @ 450MHz (mesto)

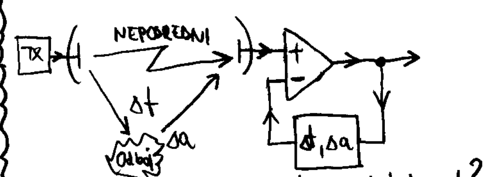
$$\Delta f = \frac{c_0}{\Delta l} = 1{,}5\text{MHz} \ldots 200\text{kHz}$$

ŠIROKOPASOVNI UPORABNIK:

$B_u \gg \Delta f$ → $\boxed{\text{POPAČENJE } H(\omega)}$

(zgled analogna TV $B_u = 6$MHz)

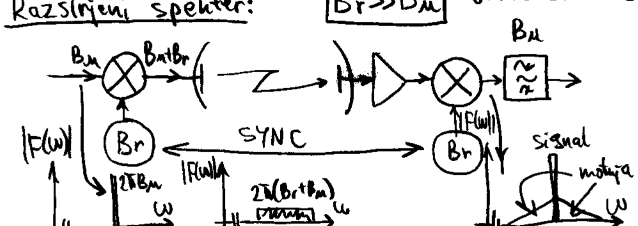
Zgled GSM: $B_u = 200$kHz → adaptivno sito



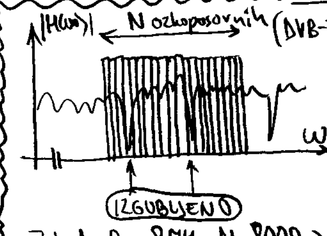
IIR sito → stabilnost?

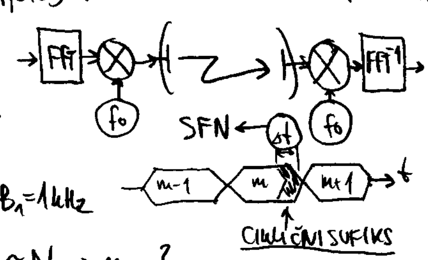
Razširjeni spekter: $\boxed{B_r \gg B_u}$

UMTS: B_r = 5MHz



OFDM: delitev širokopasovnega (DVB-T, LTE) uporabnika na N≫1 ozkopasovnih





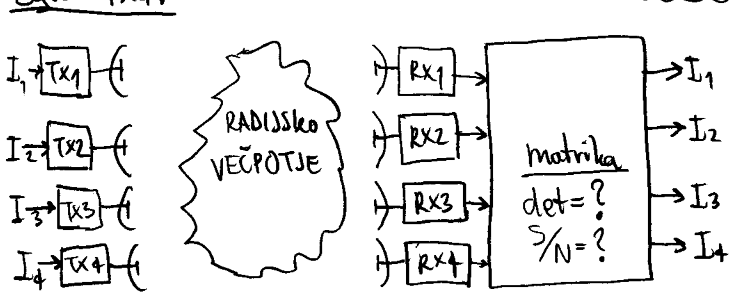
Zgled: B_u = 8MHz, N = 8000 → B_1 = 1kHz

Pomanjkljivosti: (1) $\frac{P_{max}}{\langle P\rangle} \approx N \rightarrow \eta_{TX} = ?$

(2) Odstopanje frekvence < 10% B_1 → Doppler?

MIMO: (Multiple-In-Multiple-Out)

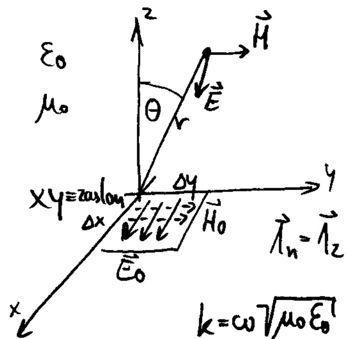
Zgled 4X4:



MIMO 2X2 = POLARIZACIJSKI MUX

(WiFi, LTE)

EM Huygens-ov izvor $\boxed{24.10.2014}$



$\vec E_0 = \vec 1_x E_0$

$\vec H_0 = \vec 1_y \frac{E_0}{Z_0}$

$\vec K = \vec 1_n \times \vec H_0 = -\vec 1_x \frac{E_0}{Z_0}$

$\vec 1_n = \vec 1_z$ $\quad$ $\vec K_m = \vec E_0 \times \vec 1_n = -\vec 1_y E_0$

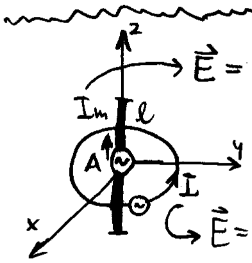
$k = \omega\sqrt{\mu_0 \varepsilon_0}$

$$\vec E_1 = \vec 1_{\Theta_x} \frac{jkZ_0}{4\pi} I\Delta x \frac{e^{-jkr}}{r}\sin\Theta_x = -\vec 1_{\Theta_x}\frac{jkZ_0}{4\pi}|\vec K|\Delta y\Delta x \frac{e^{-jkr}}{r}\sin\Theta_x$$

$$\boxed{\vec E_1 = -\vec 1_{\Theta_x}\frac{jk}{4\pi}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}\sin\Theta_x}$$

$$\vec E_2 = -\vec 1_{\phi_y}\frac{jk}{4\pi}I_m\Delta y\frac{e^{-jkr}}{r}\sin\Theta_y = \vec 1_{\phi_y}\frac{jk}{4\pi}|\vec K_m|\Delta x\Delta y\frac{e^{-jkr}}{r}\sin\Theta_y$$

$$\boxed{\vec E_2 = \vec 1_{\phi_y}\frac{jk}{4\pi}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}\sin\Theta_y}$$



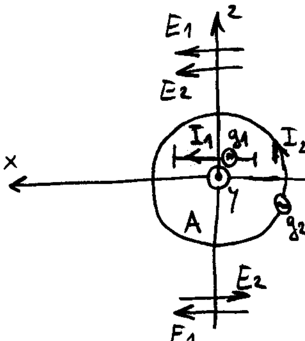
$$\vec E = -\vec 1_\phi \frac{jk}{4\pi} I_m l \frac{e^{-jkr}}{r}\sin\Theta$$

$$\boxed{-jI_m l = kZ_0 IA}$$

$$\vec E = \vec 1_\phi \frac{k^2 Z_0}{4\pi} IA \frac{e^{-jkr}}{r}\sin\Theta$$

$$\boxed{\vec E = \vec E_1 + \vec E_2 = \frac{jk}{4\pi}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}\left[-\vec 1_{\Theta_x}\sin\Theta_x + \vec 1_{\phi_y}\sin\Theta_y\right]}$$

$$-\vec 1_{\Theta_x}\sin\Theta_x + \vec 1_{\phi_y}\sin\Theta_y = (\cos\Theta+1)\left[\vec 1_\Theta\cos\phi - \vec 1_\phi\sin\phi\right]$$



$I_1 l = -\frac{E_0}{Z_0}\Delta x\Delta y$

$I_2 A = \frac{jE_0}{kZ_0}\Delta x\Delta y$

$$\vec E = (\vec 1_\Theta\cos\phi - \vec 1_\phi\sin\phi)\frac{jk}{4\pi}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}(\cos\Theta+1)$$

$$\boxed{\vec E = \underbrace{(\vec 1_\Theta\cos\phi - \vec 1_\phi\sin\phi)}_{\text{enotni vektor! POLARIZACIJA}}\frac{j}{2\lambda}E_0\Delta x\Delta y\frac{e^{-jkr}}{r}\underbrace{(\cos\Theta+1)}_{F(\Theta,\phi)}}$$

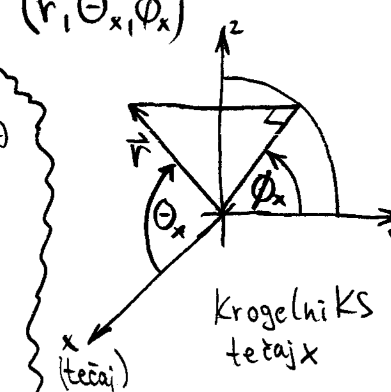
$\vec 1_\Theta = \vec 1_x\cos\Theta\cos\phi + \vec 1_y\cos\Theta\sin\phi - \vec 1_z\sin\Theta$

$\vec 1_\phi = -\vec 1_x\sin\phi + \vec 1_y\cos\phi$

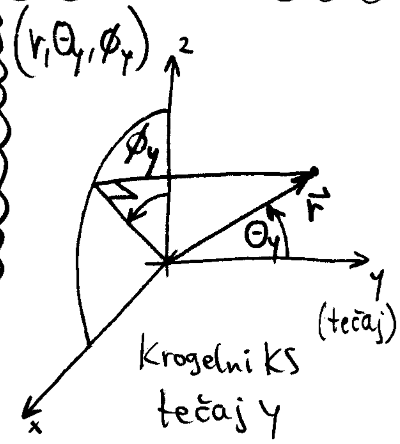
$\cos\Theta = \frac{z}{r}$ $\qquad$ $\sin\Theta = \frac{\sqrt{x^2+y^2}}{r}$

$\cos\phi = \frac{x}{\sqrt{x^2+y^2}}$ $\qquad$ $\sin\phi = \frac{y}{\sqrt{x^2+y^2}}$

(r, Θ_x, ϕ_x)



(r, Θ_y, ϕ_y)



$$\vec 1_{\Theta_x} = \vec 1_y\cos\Theta_x\cos\phi_x + \vec 1_z\cos\Theta_x\sin\phi_x - \vec 1_x\sin\Theta_x = \vec 1_y\frac{xy}{r\sqrt{y^2+z^2}} + \vec 1_z\frac{xz}{r\sqrt{y^2+z^2}} - \vec 1_x\frac{\sqrt{y^2+z^2}}{r} \qquad \sin\Theta_x = \frac{\sqrt{y^2+z^2}}{r}$$

$$-\vec 1_{\Theta_x}\sin\Theta_x = -\vec 1_y\frac{xy}{r^2} - \vec 1_z\frac{xz}{r^2} + \vec 1_x\frac{y^2+z^2}{r^2} = \vec 1_x(1-\sin^2\Theta\cos^2\phi) - \vec 1_y\sin^2\Theta\cos\phi\sin\phi - \vec 1_z\sin\Theta\cos\Theta\cos\phi$$

$$\vec 1_{\phi_y} = -\vec 1_z\sin\phi_y + \vec 1_x\cos\phi_y = -\vec 1_z\frac{x}{\sqrt{z^2+x^2}} + \vec 1_x\frac{z}{\sqrt{z^2+x^2}} \qquad \sin\Theta_y = \frac{\sqrt{z^2+x^2}}{r}$$

$$\vec 1_{\phi_y}\sin\Theta_y = -\vec 1_z\frac{x}{r} + \vec 1_x\frac{z}{r} = \vec 1_x\cos\Theta - \vec 1_z\sin\Theta\cos\phi$$

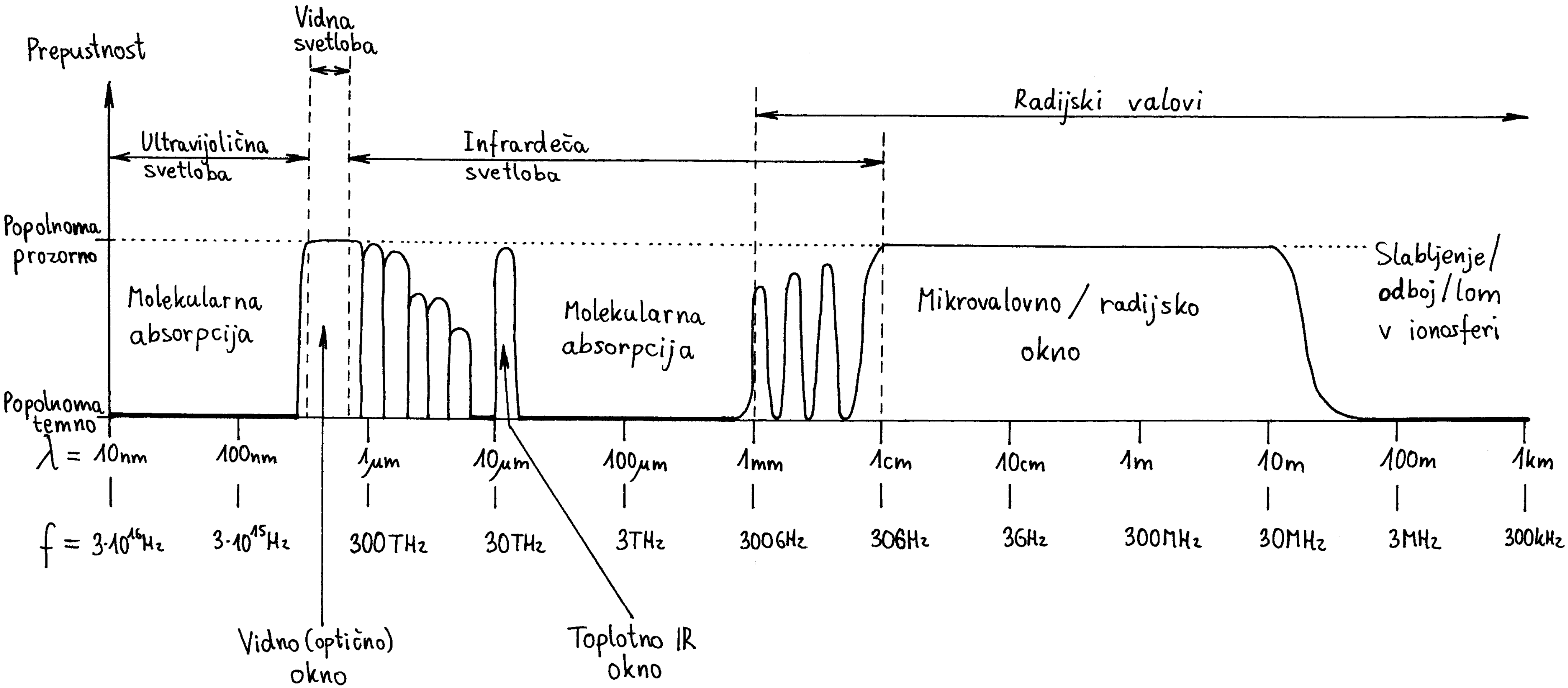
$$-\vec 1_{\Theta_x}\sin\Theta_x + \vec 1_{\phi_y}\sin\Theta_y = \vec 1_x(1+\cos\Theta-\sin^2\Theta\cos^2\phi) - \vec 1_y\sin^2\Theta\cos\phi\sin\phi - \vec 1_z(1+\cos\Theta)\sin\Theta\cos\phi =$$

$$= \vec 1_x\left(1+\cos\Theta+(\cos^2\Theta-1)\cos^2\phi\right) + \vec 1_y(\cos^2\Theta-1)\cos\phi\sin\phi - \vec 1_z(1+\cos\Theta)\sin\Theta\cos\phi =$$

$$= (\cos\Theta+1)\left[\vec 1_x(1+\cos\Theta\cos^2\phi-\cos^2\phi) + \vec 1_y(\cos\Theta\cos\phi\sin\phi - \cos\phi\sin\phi) - \vec 1_z\sin\Theta\cos\phi\right] =$$

$$= (\cos\Theta+1)\left[\vec 1_x(\cos\Theta\cos^2\phi+\sin^2\phi) + \vec 1_y(\cos\Theta\cos\phi\sin\phi - \cos\phi\sin\phi) - \vec 1_z\sin\Theta\cos\phi\right] =$$

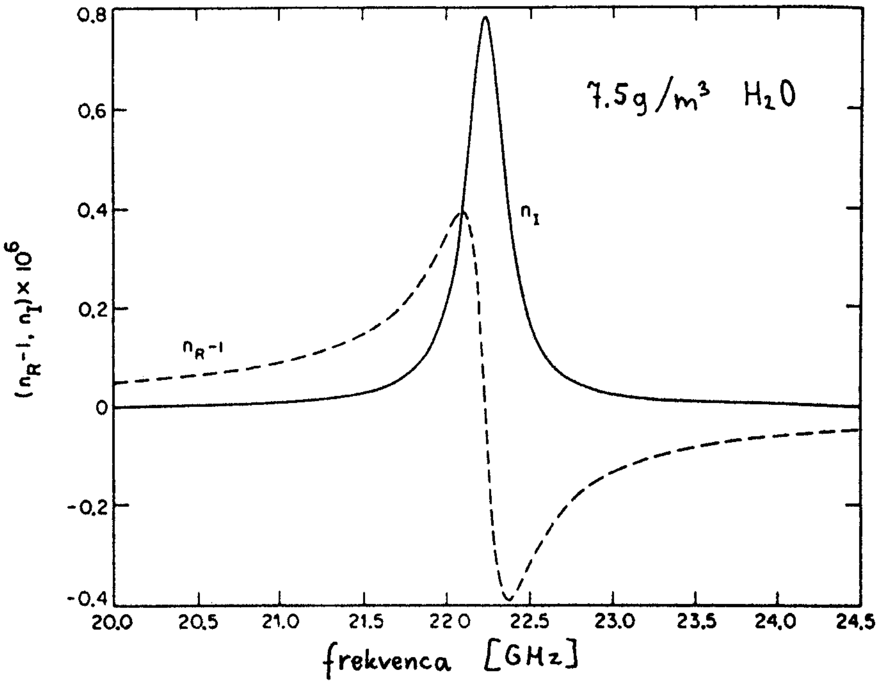
$$= (\cos\Theta+1)\left[\vec 1_\Theta\cos\phi - \vec 1_\phi\sin\phi\right]$$



Prepustnost zemeljskega ozračja za elektromagnetno valovanje

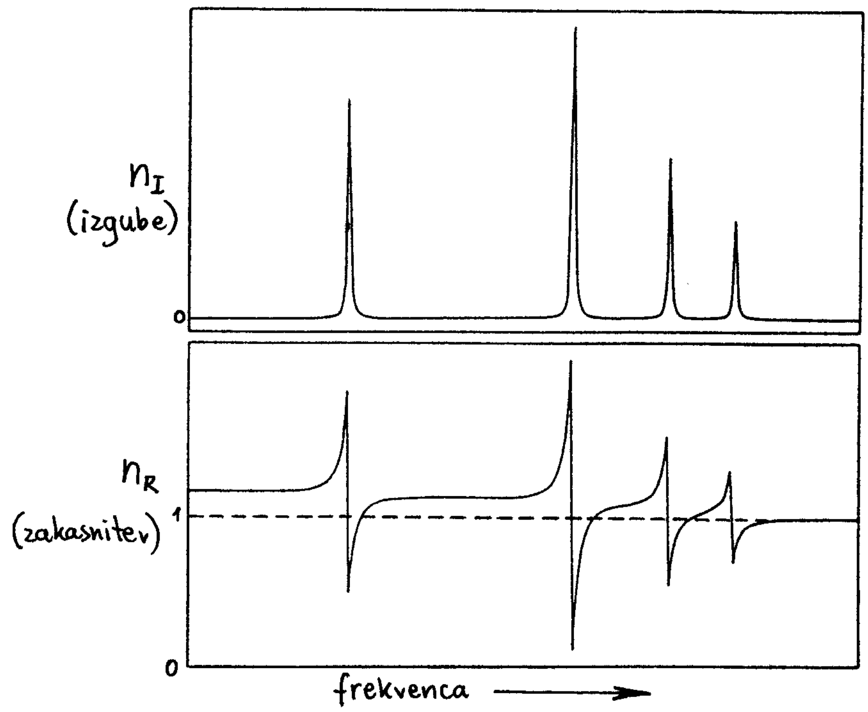
Kompleksni lomni količnik

$n = n_R + jn_I$

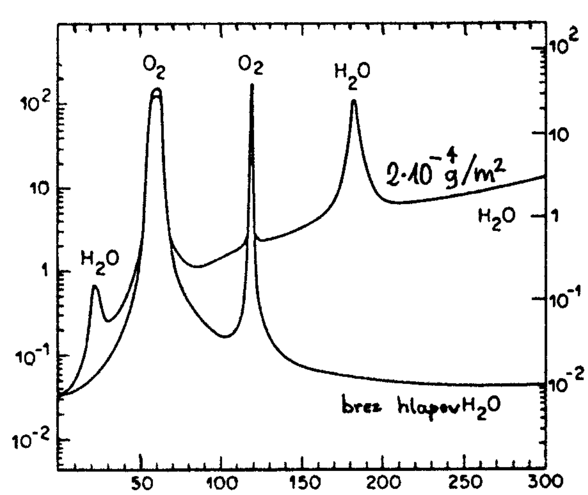


Kompleksni lomni količnik

$n = n_R + jn_I$



Zenitno slabljenje [dB]



Zenitno slabljenje [Np]

Mikrovalovna molekularna absorpcija v zemeljskem ozračju

$$\lambda = \frac{\lambda_0}{n}$$

Lomni količnik v troposferi:

$$n = 1 + \Delta n \, e^{-\frac{h}{h_0}}$$

R poiščemo iz podobnih trikotnikov:

$$\lambda = \alpha R \qquad \alpha \equiv \text{konstanta}$$

$$\frac{d\lambda}{dh} = \alpha \frac{dR}{dh} = \alpha$$

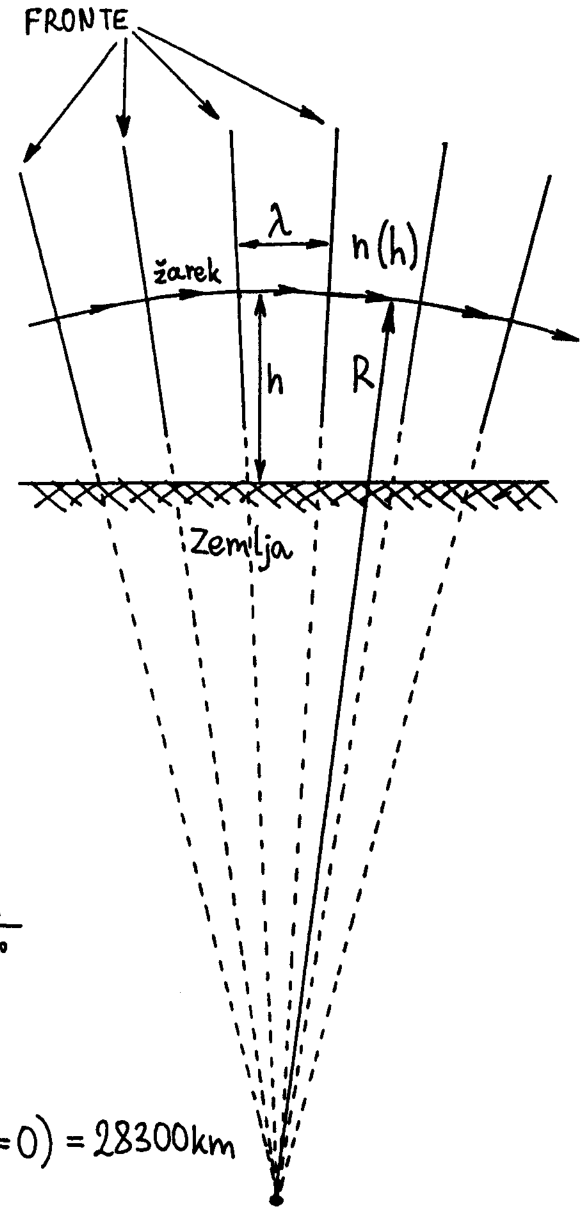
$$\frac{d\lambda}{dh} = \frac{d}{dh}\left(\frac{\lambda_0}{n}\right) = \frac{\lambda_0 \Delta n}{h_0 n^2} e^{-\frac{h}{h_0}}$$

$$R = \frac{\lambda}{\alpha} = \frac{h_0 n^2}{\Delta n} e^{\frac{h}{h_0}} \approx \frac{h_0}{\Delta n} e^{\frac{h}{h_0}}$$

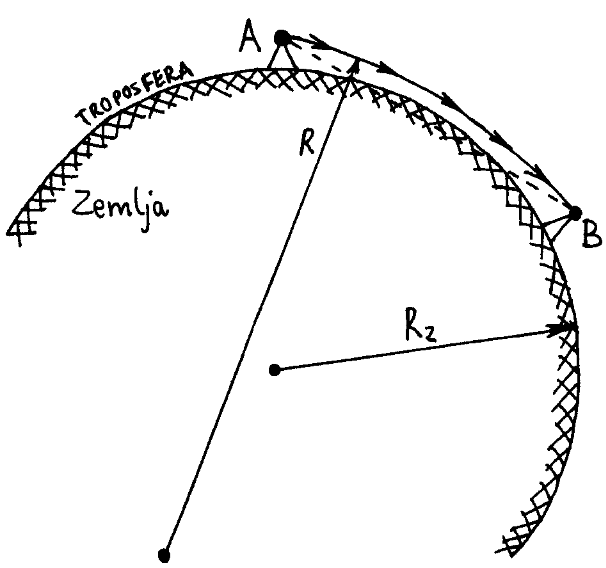
Suha troposfera:

$h_0 = 8.5\,\text{km}$; $\Delta n = 0.0003 \longrightarrow R(h=0) = 28300\,\text{km}$

Vlažna troposfera: $R(h=0) \approx 25000\,\text{km}$



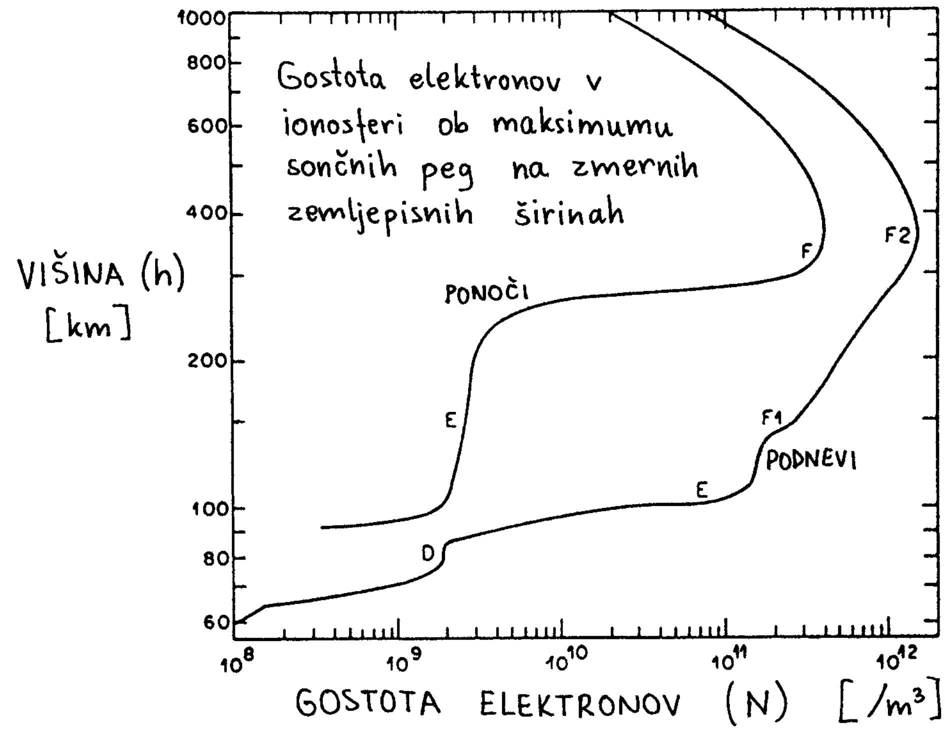
Lom radijskih valov v troposferi



$$\frac{1}{R_e} = \frac{1}{R_z} - \frac{1}{R}$$

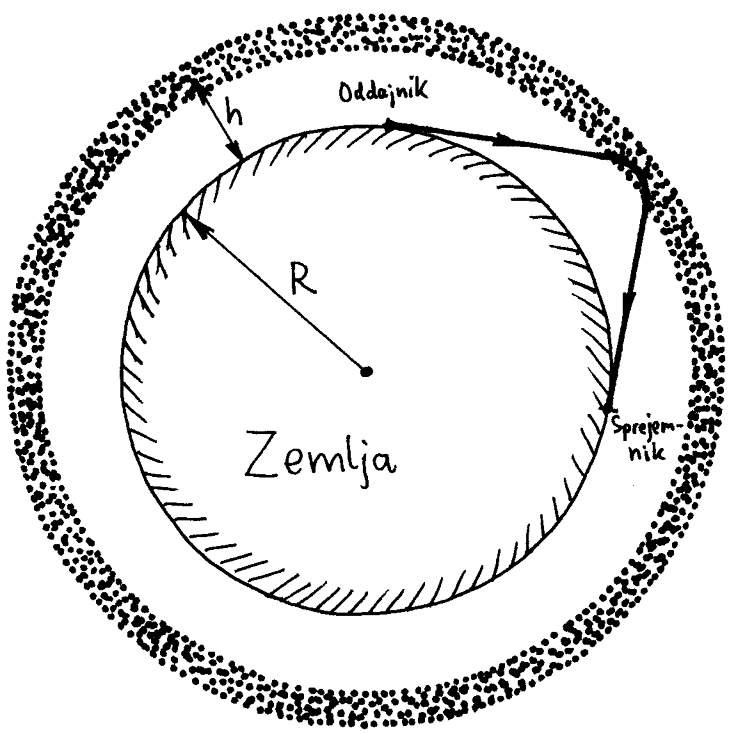
$$R_e \approx 8600\,\text{km} \approx \frac{4}{3} R_z$$

Efektivni polmer zemeljske površine



Lomni količnik: $n = \sqrt{1 - \left(\frac{f_P}{f}\right)^2}$

Frekvenca plazme: $f_P = \frac{1}{2\pi}\sqrt{\frac{N Q_e^2}{\varepsilon_0 m_e}} = \sqrt{80.8 \frac{m^3}{s^2} N} = \begin{cases} \overset{max}{\sim 12\,\mathrm{MHz}} \text{ PODNEVI} \\ \overset{max}{\sim 4\,\mathrm{MHz}} \text{ PONOČI} \end{cases}$



Zaradi loma ob poševnem vpadu valovanja:

$MUF > f_P$

$MUF \approx f_P \sqrt{\frac{R}{2h}}$

$MUF \approx 3 f_P$

$MUF \approx \begin{cases} 36\,\mathrm{MHz} \text{ PODNEVI} \\ 12\,\mathrm{MHz} \text{ PONOČI} \end{cases}$

Zelo visoka disperzija (snovna, rodovna) $\longrightarrow$ zmogljivost ~ 100 bit/s

Radijska zveza preko loma/odboja v ionosferi