# 16. Zemeljsko ozračje

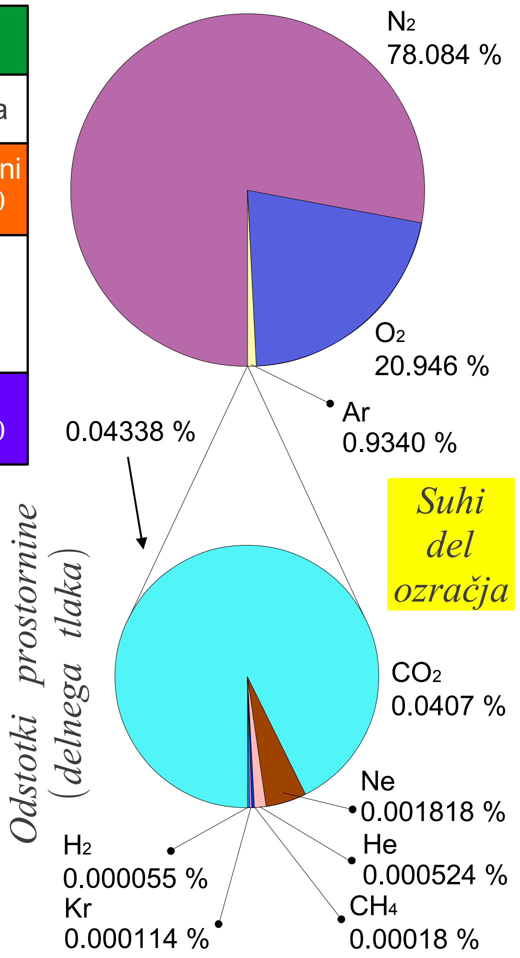
Zrak pogosto obravnavamo povsem enako kot prazen prostor (vakuum), ki za radijsko valovanje nima dielektričnih $\epsilon \approx \epsilon_0$ lastnosti niti feromagnetnih $\mu \approx \mu_0$ lastnosti niti izgub $\gamma \approx 0$ .

| Plast ozračja | Višina $h$ | Temperatura | EM učinek |
|---|---|---|---|
| Eksosfera | >700km | dT/dh≈0 | Praznina vesolja |
| Termosfera | 80km−700km | dT/dh>0 | Ionosfera elektroni $\varepsilon_r(\omega)<1$ $\gamma(\omega)>0$ |
| Mezosfera | 50km−80km | dT/dh<0 | Brez večjega učinka ($O_3$) |
| Stratosfera | 12km−50km | dT/dh>0 | |
| Troposfera | 0−12km | dT/dh<0 | Nevtralni plini $\varepsilon_r(\omega)>1$ $\gamma(\omega)>0$ |

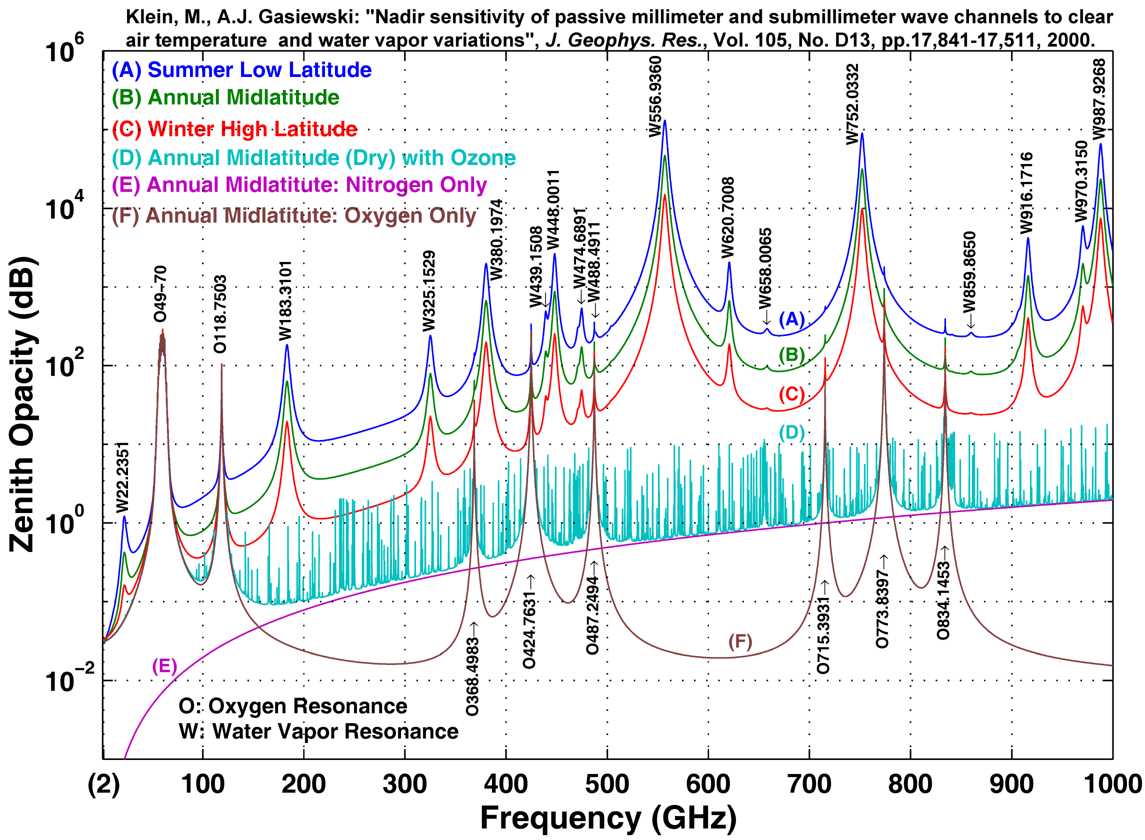
*Mokri del ozračja*

*0.4% vodne pare v povprečju*
*1% vodne pare ob gladini morja*
*5% vodne pare v vročih tropskih krajih*

*vsebnost vodne pare hitro upada s temperaturo/višino*

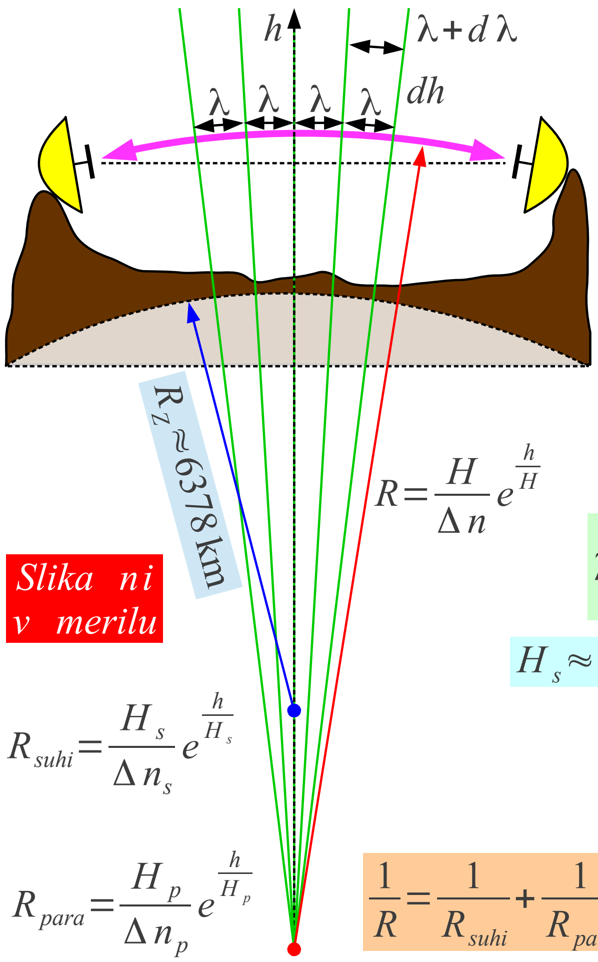



Sestava zemeljskega ozračja




Zenitno slabljenje zemeljskega ozračja

## Lom radijskih valov v troposferi




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

$$R_{suhi}=\frac{H_s}{\Delta n_s}e^{\frac{h}{H_s}}$$

$$R_{para}=\frac{H_p}{\Delta n_p}e^{\frac{h}{H_p}}$$

Dobro premešano ozračje

$$n(h)=\sqrt{\epsilon_r(h)}\approx 1+\Delta n\, e^{-\frac{h}{H}}$$

Suhi del

$$H_s\approx\begin{bmatrix}9\text{km} & \textit{poleti}\\ 8\text{km} & \textit{pozimi}\end{bmatrix}$$

$$\Delta n_s\approx\begin{bmatrix}0.0003 & \textit{radio}\\ 0.00015 & \textit{vidna svetloba}\end{bmatrix}$$

*Podobni trikotniki* $\frac{\lambda}{R}=\frac{\lambda+d\lambda}{R+dh}=\frac{d\lambda}{dh}$

$$\lambda(h)=\frac{\lambda_0}{n(h)}\rightarrow\frac{d\lambda}{dh}=-\frac{\lambda_0}{n^2}\frac{dn}{dh}\approx\lambda\frac{\Delta n}{H}e^{-\frac{h}{H}}$$

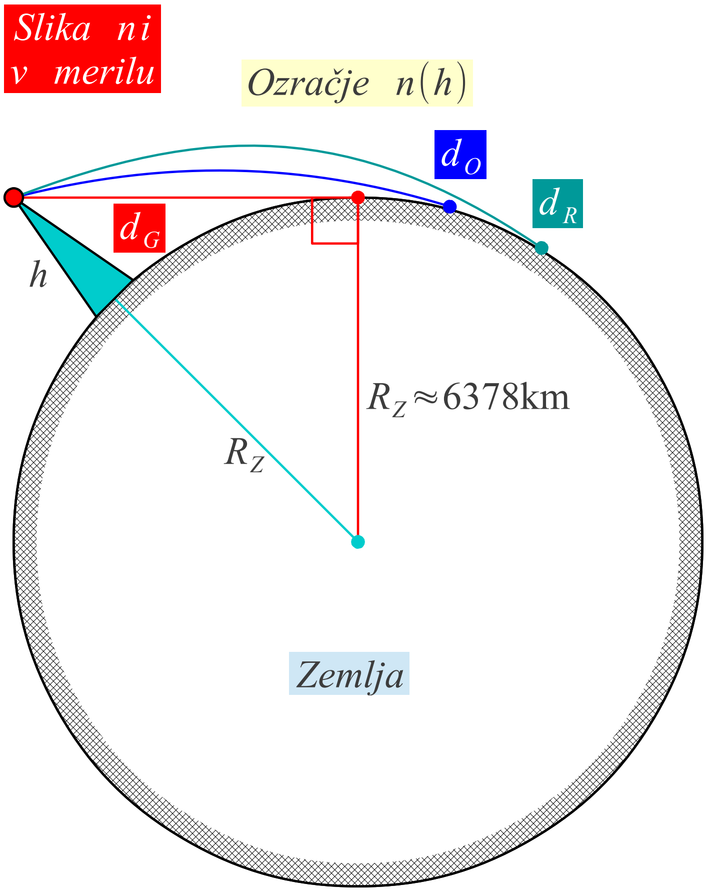
$$H_s\approx 8.5\text{km}\rightarrow R_{suhi}(h=0)\approx 28333\text{km}\ (\textit{radio})$$

*Upoštevanje vodne pare* $H_p\approx 1.5$km

$$n(h)\approx 1+\Delta n_s e^{-\frac{h}{H_s}}+\Delta n_p e^{-\frac{h}{H_p}}$$

$$\frac{1}{R}=\frac{1}{R_{suhi}}+\frac{1}{R_{para}}$$

$$R(h=0)\approx\begin{bmatrix}25000\text{km} & \textit{radio}\\ 50000\text{km} & \textit{vidna svetloba}\end{bmatrix}$$




Geometrijska, optična in radijska vidljivost

$$R \approx \begin{bmatrix} 25000\text{km} & \textit{radio} \\ 50000\text{km} & \textit{vidna svetloba} \end{bmatrix}$$

*Odštevanje ukrivljenosti*

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

$$R_{eff} \approx \begin{bmatrix} 8562\text{km} & \textit{radio} \\ 7310\text{km} & \textit{vidna svetloba} \end{bmatrix}$$

$$K = \frac{R_{eff}}{R_Z} \approx \frac{4}{3} \quad (\textit{radio})$$

*Geometrijska vidljivost*

$$d_G = \sqrt{(R_Z + h)^2 - R_Z^2} \approx \sqrt{2 R_Z h}$$

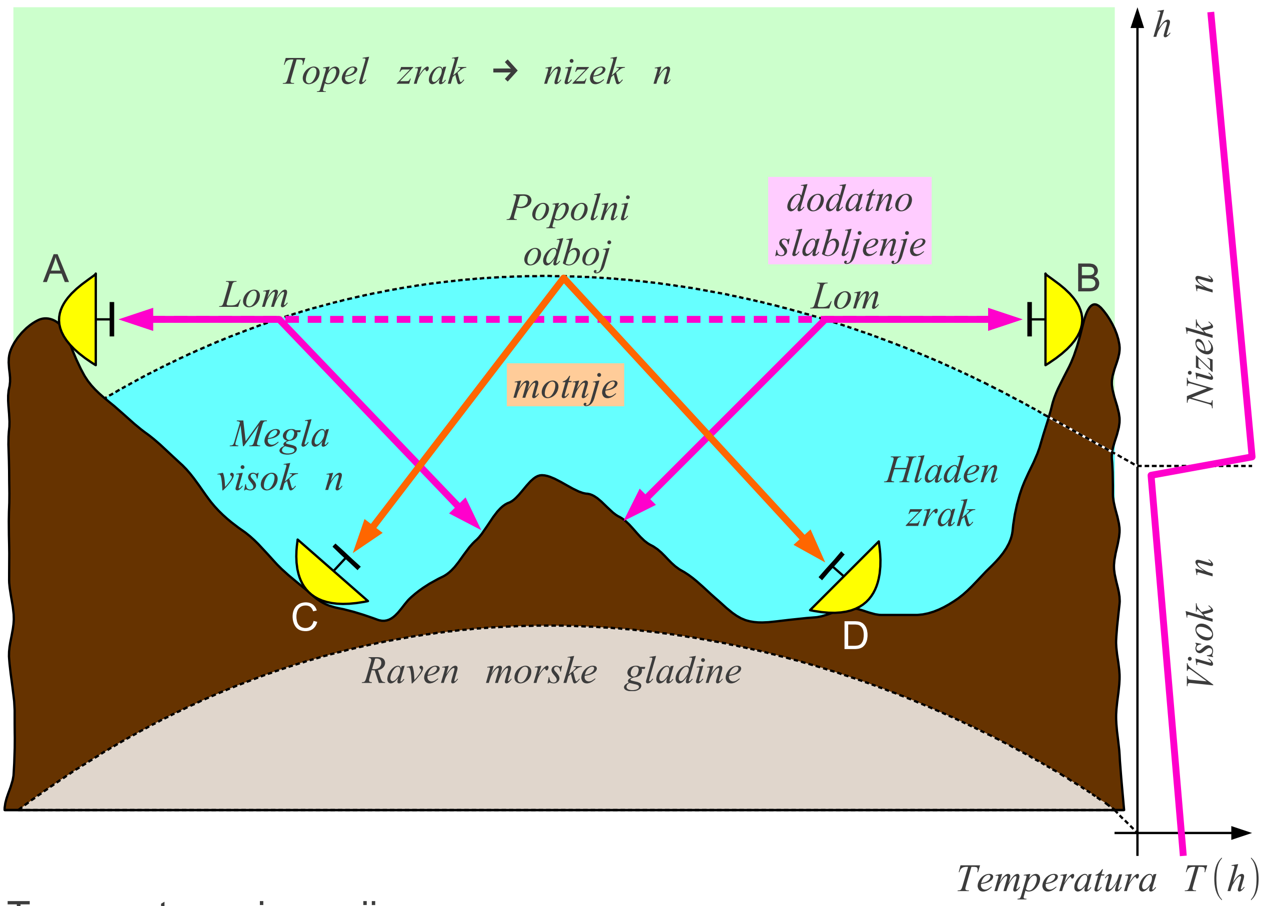
*Zgled* $h = 100\text{m} \rightarrow d_G \approx 35.7\text{km}$

*Optična/radijska vidljivost*

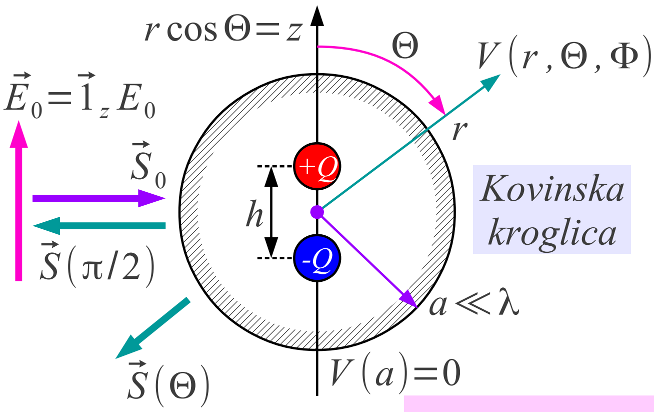
$$d = \sqrt{(R_{eff} + h)^2 - R_{eff}^2} \approx \sqrt{2 R_{eff} h}$$

*Zgled* $h = 100\text{m} \rightarrow$

$$d \approx \begin{bmatrix} 41.4\text{km} & \textit{radio} \\ 38.2\text{km} & \textit{vidna svetloba} \end{bmatrix}$$




Temperaturna inverzija




*Prazen prostor* $\Delta V + k^2 V = 0$

$a \ll \lambda \rightarrow$ *Statika* $\Delta V \approx 0$

*Pogoja* $V(a)=0$ *in* $V(\infty) = -E_0 z$

$$V(r,\Theta,\Phi) = E_0\left(-r + \frac{a^3}{r^2}\right)\cos\Theta$$

*Statika* $V(r,\Theta,\Phi) = \dfrac{Qh}{4\pi\epsilon_0}\dfrac{\cos\Theta}{r^2}$

*Zveznost* $I = j\omega Q$

*Sevanje točkastega dipola* $\vec{E} \approx \vec{1}_\Theta \dfrac{jkZ_0}{4\pi} Ih \dfrac{e^{-jkr}}{r}\sin\Theta$

$$Qh = 4\pi\epsilon_0 a^3 E_0 \rightarrow Ih = 4\pi\epsilon_0 j\omega a^3 E_0 \rightarrow \vec{E} \approx -\vec{1}_\Theta k^2 a^3 E_0 \frac{e^{-jkr}}{r}\sin\Theta$$

*Gostota sevane moči* $\vec{S}(\Theta) = \vec{1}_r \dfrac{|\vec{E}|^2}{2Z_0} = \vec{1}_r k^4 a^6 \dfrac{|E_0|^2}{2Z_0}\dfrac{\sin^2\Theta}{r^2} = \vec{1}_r k^4 a^6 |\vec{S}_0| \dfrac{\sin^2\Theta}{r^2}$

$$\vec{S}(\Theta) = \vec{1}_r \frac{|\vec{S}_0|\sigma}{4\pi r^2} \ \&\ \sin\Theta = 1 \rightarrow \sigma = 4\pi r^2 \frac{|\vec{S}(\pi/2)|}{|\vec{S}_0|} = 4\pi k^4 a^6 = 64\pi^5 \frac{a^6}{\lambda^4}$$

*Dielektrik* $\sigma = 64\pi^5 \dfrac{a^6}{\lambda^4}\left|\dfrac{\epsilon_r - 1}{\epsilon_r + 2}\right|^2$

Odmevna površina majhne krogle

$$\textit{Dežna kapljica}\quad \sigma=\frac{\pi^5}{\lambda^4}\left|\frac{\epsilon_r-1}{\epsilon_r+2}\right|^2(2a)^6$$

$$\left|\frac{\epsilon_r-1}{\epsilon_r+2}\right|^2=|K|^2\equiv \textit{delektrični faktor}$$

$$\left|\frac{\epsilon_r-1}{\epsilon_r+2}\right|^2\approx\begin{bmatrix}0.93 & (\textit{voda}\ \ \epsilon_r\approx 80)\\ 0.207 & (\textit{led}\ \ \epsilon_r\approx 3.5)\\ 1 & (\textit{kovina}\ \ \epsilon_r\rightarrow\infty)\end{bmatrix}$$

$$\textit{Naključna faza}\ \rightarrow\ \sigma=\sum_i\sigma_i$$

$$Z=\frac{1}{\Delta V}\sum_i(2a_i)^6\equiv \textit{faktor odboja}$$

$$\eta=\frac{d\sigma}{dV}=\frac{\pi^5}{\lambda^4}\left|\frac{\epsilon_r-1}{\epsilon_r+2}\right|^2 Z$$

$$\textit{Dež}\quad \sigma=V\eta=V\frac{\pi^5}{\lambda^4}\left|\frac{\epsilon_r-1}{\epsilon_r+2}\right|^2 Z$$

Odmevna površina padavin

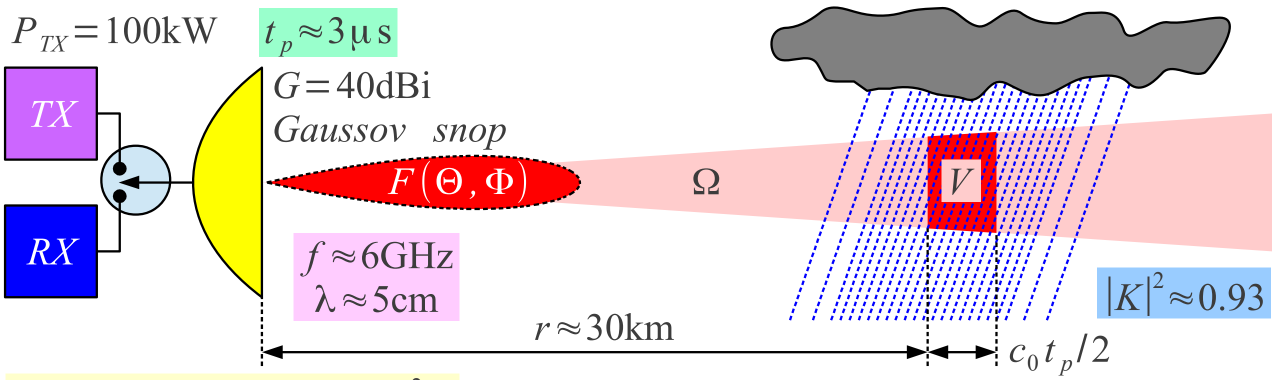
*J. S. Marshall & W. M. Palmer* 1948

$$R\left[\frac{mm}{h}\right]\equiv \textit{jakost padavin}$$

$$Z\left[\frac{mm^6}{m^3}\right]=200\,R^{1.6}\qquad R=\left(\frac{Z}{200}\right)^{0.625}$$

$$Z_{\mathrm{dBZ}}=10\log_{10}\frac{Z}{Z_0}\qquad Z_0=\frac{1\mathrm{mm}^6}{1\mathrm{m}^3}$$

| *R*[mm/h] | *Padavine* | *Z*[dBZ] | *Barva* |
|---|---|---|---|
| 205mm/h | *Toča* | 60dBZ | |
| 100mm/h | | 55dBZ | |
| 49mm/h | *Naliv* | 50dBZ | |
| 24mm/h | | 45dBZ | |
| 12mm/h | *Dež* | 40dBZ | |
| 5.6mm/h | | 35dBZ | |
| 2.7mm/h | | 30dBZ | |
| 1.3mm/h | *Rosenje* | 25dBZ | |
| 0.6mm/h | | 20dBZ | |




$$\vec{S}_0=\vec{1}_r \frac{P_{TX} G}{4\pi r^2}\frac{|F(\Theta,\Phi)|^2}{|F(\Theta_{MAX}=0)|^2}$$

$$dV=\frac{c_0 t_p}{2} r^2 \, d\Omega$$

$$\eta=\frac{d\sigma}{dV}=\frac{\pi^5}{\lambda^4}|K|^2 Z$$

$R\approx 12\text{mm}/h$

$Z\approx 40\text{dBZ}$

$$dP_{RX}=\frac{G\lambda^2}{4\pi}\frac{|F(\Theta,\Phi)|^2}{|F(\Theta_{MAX}=0)|^2}|d\vec{S}|$$

$$d\vec{S}=\frac{-\vec{S}_0}{4\pi r^2}\eta \, dV$$

Stožčast snop

$$F(\Theta)=\begin{bmatrix} 1 & (\Theta<\alpha/2) \\ 0 & (\Theta>\alpha/2) \end{bmatrix}$$

$$I=\Omega\approx\frac{4\pi}{G}$$

$$P_{RX}=\frac{P_{TX} G^2 \lambda^2}{(4\pi)^3 r^2}\eta \frac{c_0 t_p}{2} I \qquad I=\iint_{4\pi}\left(\frac{|F(\Theta,\Phi)|^2}{|F(\Theta_{MAX}=0)|^2}\right)^2 d\Omega$$

$$P_{RX}\approx\frac{P_{TX} G \lambda^2}{64\pi^2 r^2}\eta c_0 t_p=\frac{P_{TX} G \pi^3 c_0 t_p |K|^2}{64 r^2 \lambda^2} Z \approx 5.8\cdot 10^{-11}\,\text{W}$$

Gaussov snop

$$|F(\Theta)|^2=e^{-(\Theta/\Theta_{-3\text{dB}})^2 \ln 2}$$

$$I\approx\frac{\pi \Theta^2_{-3\text{dB}}}{2\ln 2}\approx\frac{2\pi}{G}$$

Vremenski radar

$$P_{RX}\approx 58\text{pW}\approx -72.4\text{dBm}$$

$$I=\iint_{4\pi}\left(\frac{|F(\Theta,\Phi)|^2}{|F(\Theta_{MAX}=0)|^2}\right)^2 d\Omega$$

$$Gaussov\quad snop\quad |F(\Theta)|^2=e^{-(\Theta/\Theta_{-3dB})^2\ln 2}$$

$$Rotacijsko-simetričen\quad snop\quad \alpha_E=\alpha_H=2\Theta_{-3dB}$$

$$I=\int_0^{\pi}\int_0^{2\pi}\left(e^{-(\Theta/\Theta_{-3dB})^2\ln 2}\right)^2\sin\Theta\, d\Theta\, d\Phi$$

$$D=\frac{4\pi|F(\Theta_{MAX}=0)|^2}{\iint_{4\pi}|F(\Theta,\Phi)|^2 d\Omega}$$

$$Kraussov\ približek\quad D\approx\frac{\pi}{\Theta_{-3dB}^2}$$

$$I=2\pi\int_0^{\pi}e^{-2(\Theta/\Theta_{-3dB})^2\ln 2}\sin\Theta\, d\Theta$$

$$D=\frac{4\pi}{\int_0^{\pi}\int_0^{2\pi}e^{-(\Theta/\Theta_{-3dB})^2\ln 2}\sin\Theta\, d\Theta\, d\Phi}$$

$$\Theta_{-3dB}\ll 1\qquad \sin\Theta\approx\Theta$$

$$I\approx 2\pi\int_0^{\infty}e^{-2(\Theta/\Theta_{-3dB})^2\ln 2}\,\Theta\, d\Theta$$

$$D\approx\frac{2}{\int_0^{\infty}e^{-(\Theta/\Theta_{-3dB})^2\ln 2}\,\Theta\, d\Theta}$$

$$u=(\Theta/\Theta_{-3dB})^2$$

$$I\approx\pi\Theta_{-3dB}^2\int_0^{\infty}e^{-2u\ln 2}du=\frac{\pi\Theta_{-3dB}^2}{2\ln 2}$$

$$G\approx D\approx\frac{4}{\Theta_{-3dB}^2\int_0^{\infty}e^{-u\ln 2}du}=\frac{4\ln 2}{\Theta_{-3dB}^2}\approx\frac{2.77}{\Theta_{-3dB}^2}$$

Gaussov snop

$$I\approx\frac{\pi\Theta_{-3dB}^2}{2\ln 2}\approx\frac{2\pi}{G}$$

$$\Theta_{-3dB}^2\approx\frac{4\ln 2}{G}\approx\frac{2.77}{G}$$

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