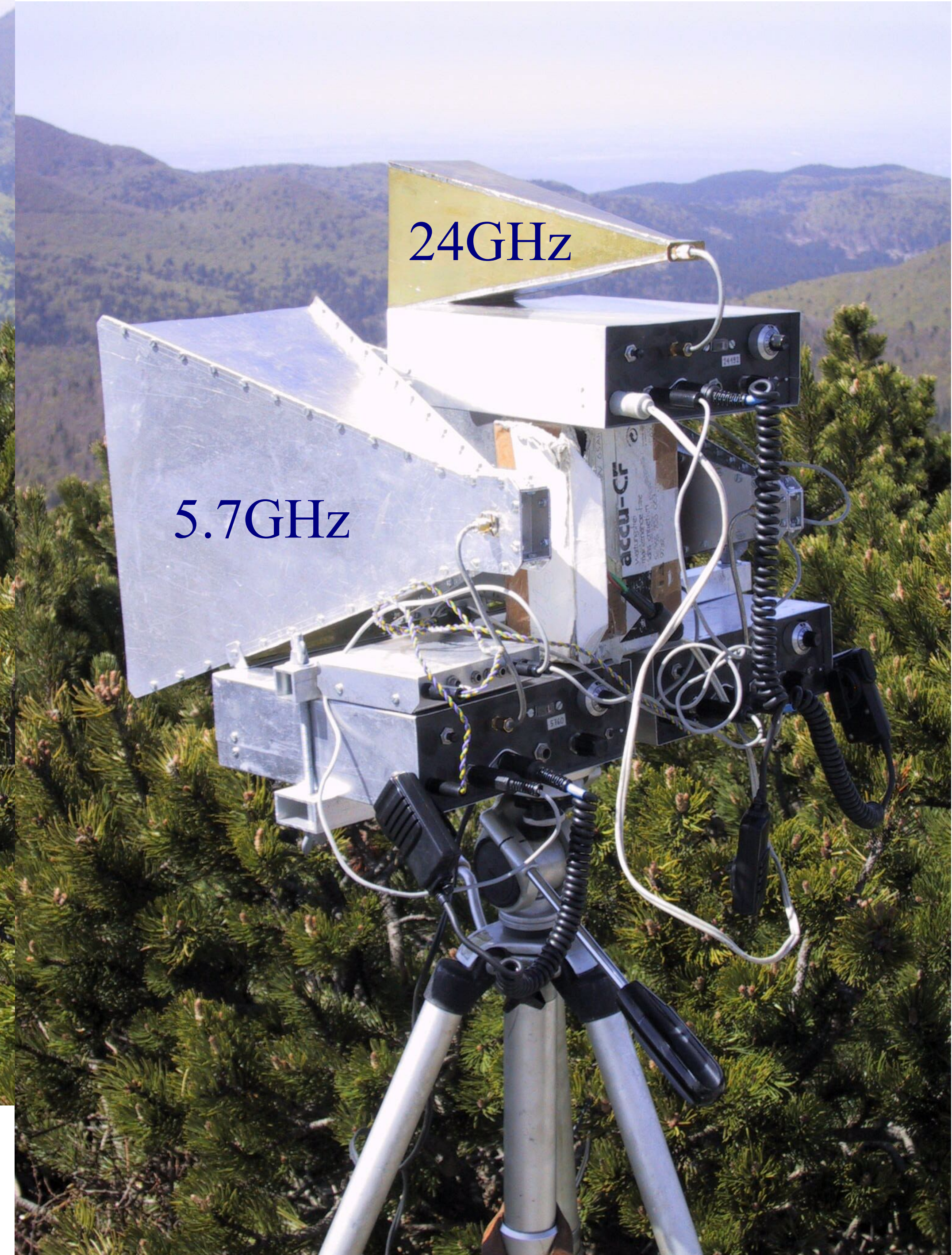
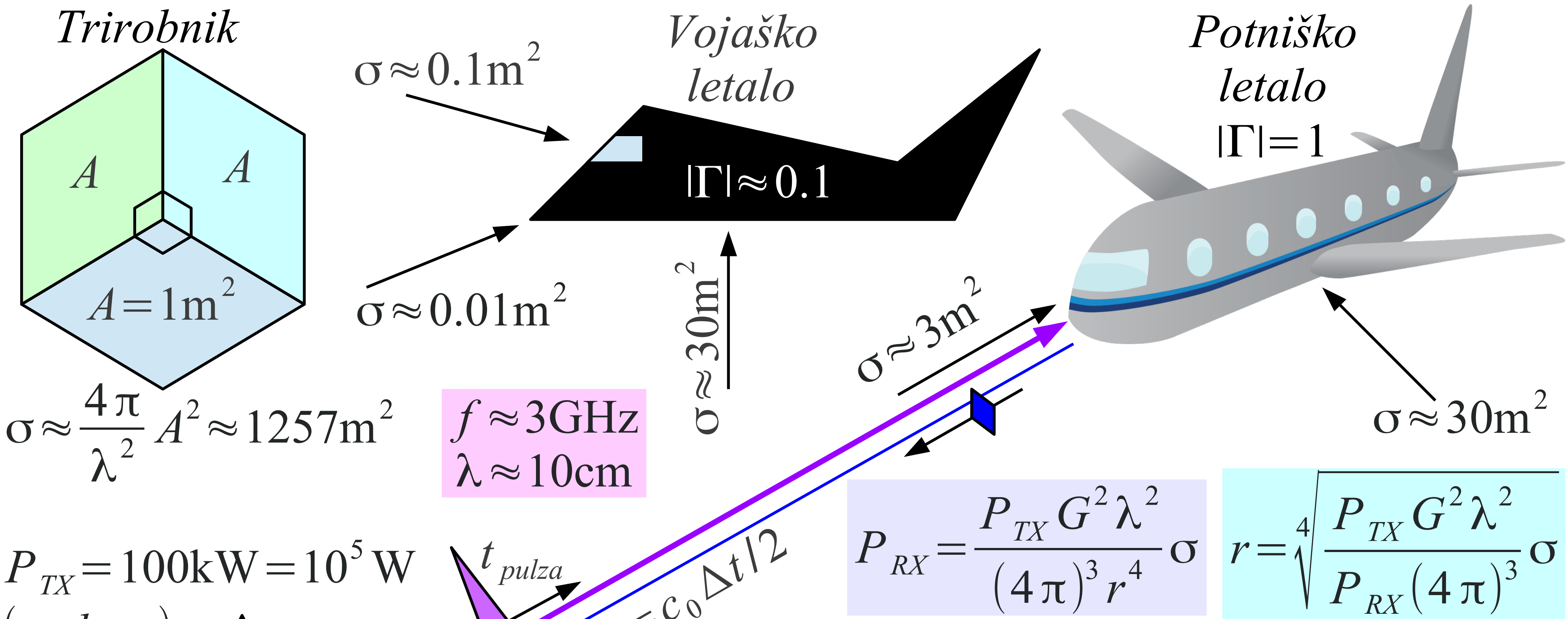
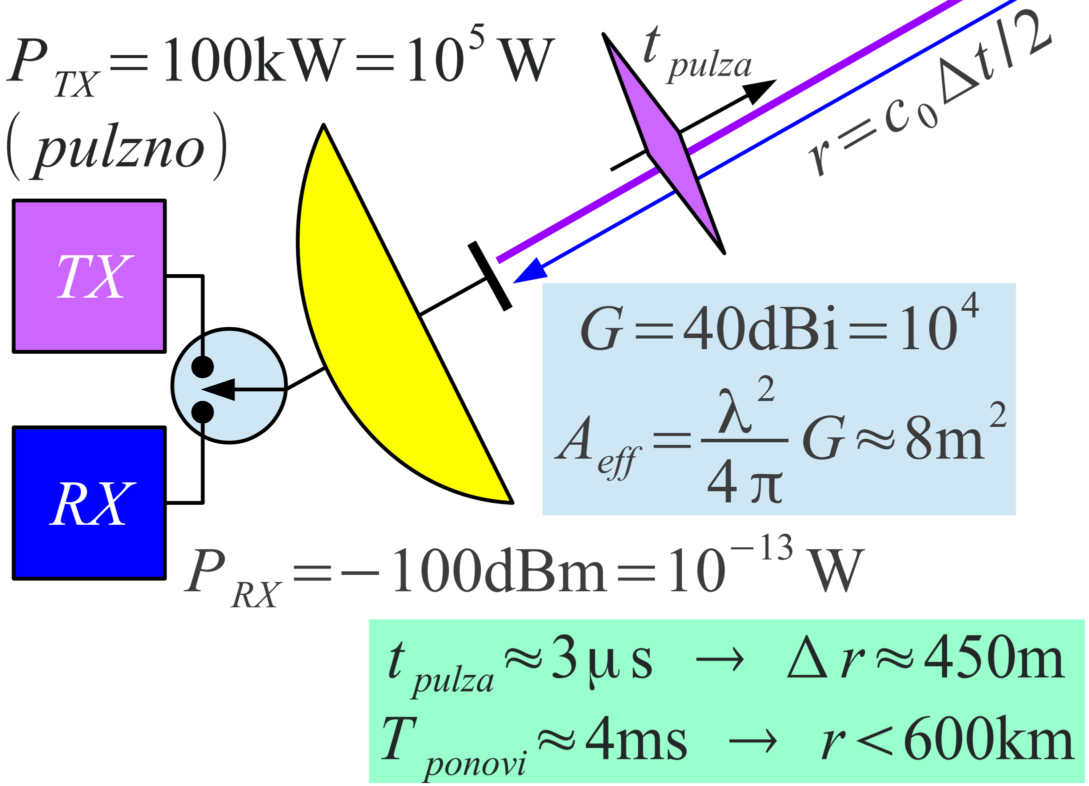
Vremenski radar

Mali Golak maj 2003



Mali Golak maj 2003

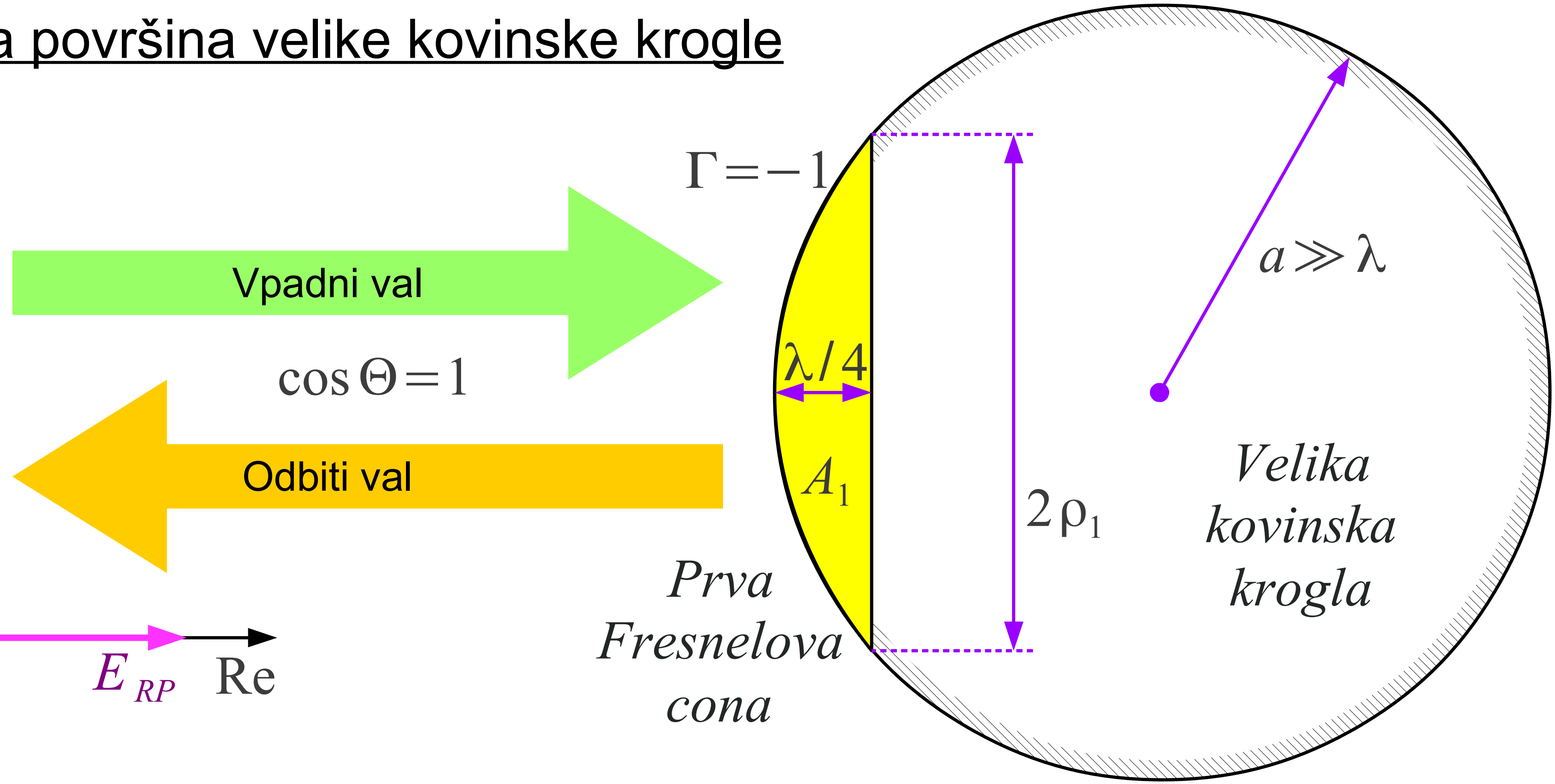


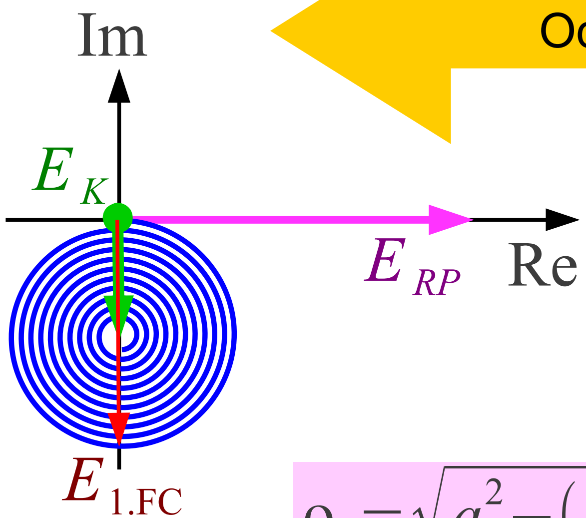


Cilj	*Odmevna površina* σ	*Domet* r
Trirobnik	$1257\,\mathrm{m}^2$	892km
Potniško letalo	$30\,\mathrm{m}^2$	351km
	$3\,\mathrm{m}^2$	197km
Vojaško letalo	$0.1\,\mathrm{m}^2$	84km
	$0.01\,\mathrm{m}^2$	47km

Domet letalskega radarja

Odmevna površina velike kovinske krogle





$$\rho_1=\sqrt{a^2-(a-\lambda/4)^2}=\sqrt{2a\lambda/4-(\lambda/4)^2}\approx\sqrt{a\lambda/2}$$

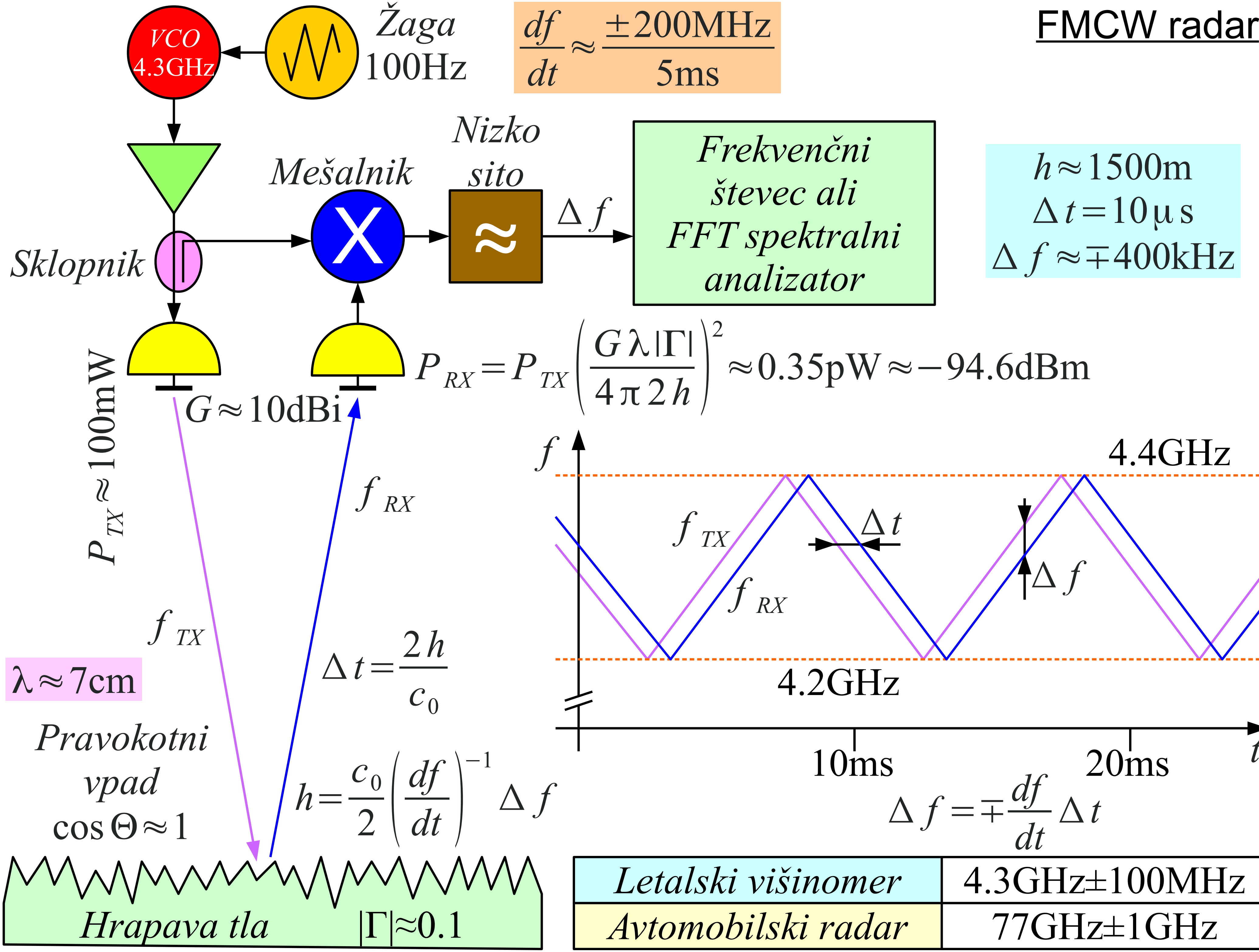
$$A_1=\pi\rho_1^2\approx\pi a\lambda/2$$

$$\textit{Ravna plošča } A_1 \rightarrow \sigma_{RP}=\frac{4\pi}{\lambda^2}A_1^2\approx\frac{4\pi}{\lambda^2}(\pi a\lambda/2)^2=\pi^3a^2$$

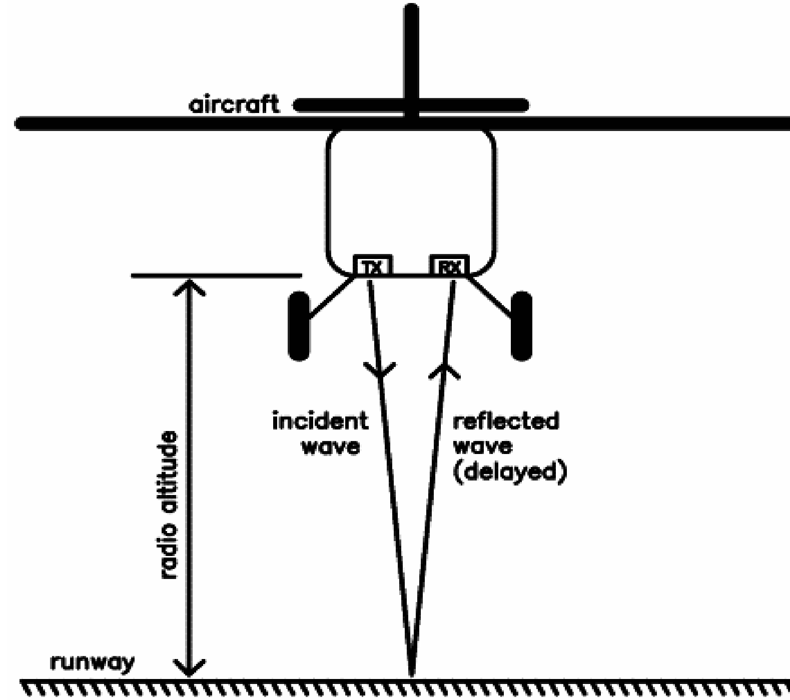
$$\textit{Prva Fresnelova cona } A_1 \rightarrow E_{1.FC}=-j\left(\frac{2}{\pi}\right)E_{RP} \rightarrow \sigma_{1.FC}=\left(\frac{2}{\pi}\right)^2\sigma_{RP}\approx4\pi a^2$$

$$\textit{Velika kovinska krogla} \rightarrow E_K=\frac{1}{2}E_{1.FC} \rightarrow \sigma_K=\frac{1}{4}\sigma_{1.FC}\approx\pi a^2$$

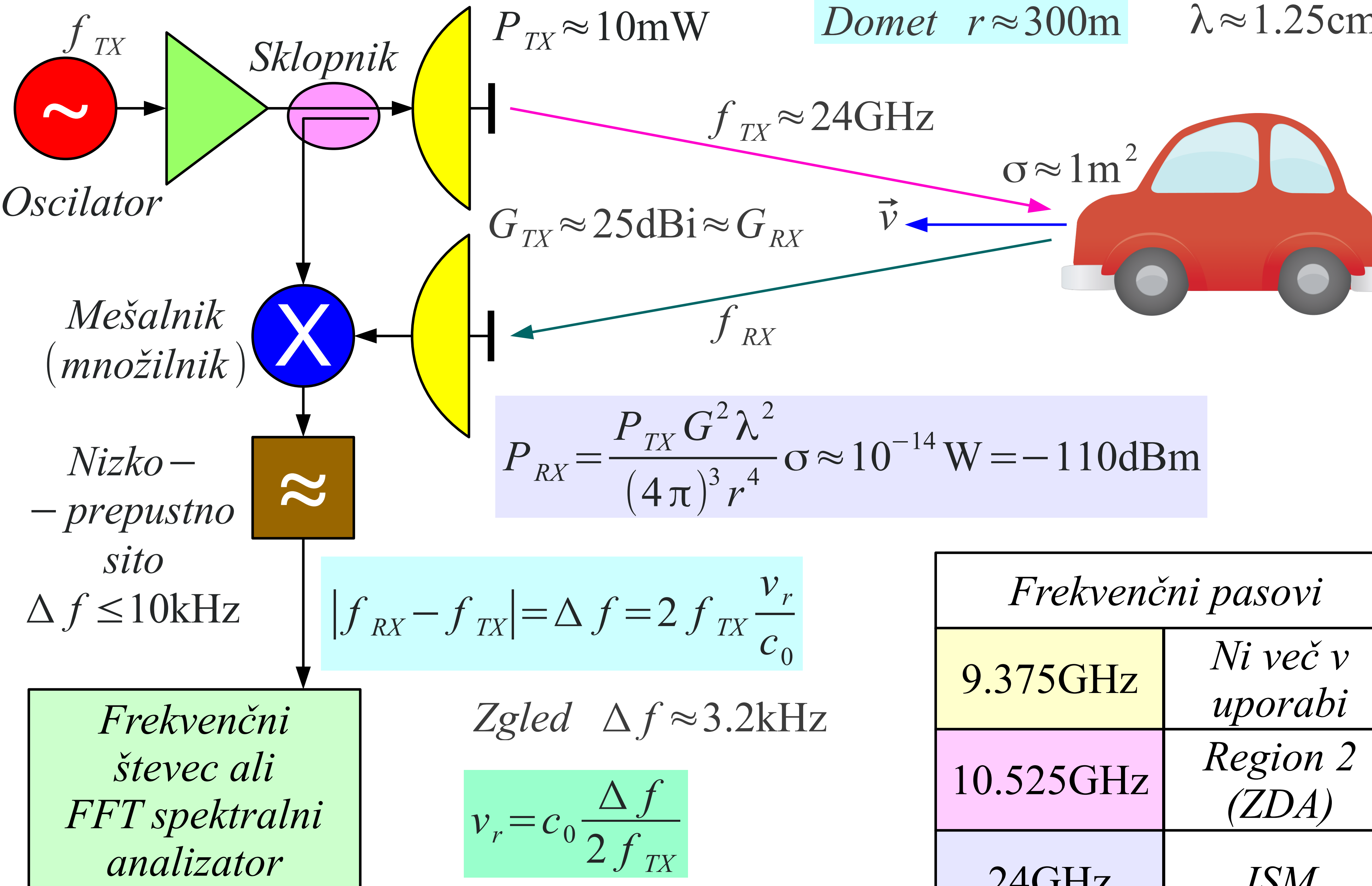
FMCW radar



Letalski višinomer	4.3GHz±100MHz
Avtomobilski radar	77GHz±1GHz



Višinomer in daljnovod



Domet $r \approx 300\mathrm{m}$

$\lambda \approx 1.25\mathrm{cm}$

$$P_{RX} = \frac{P_{TX} G^2 \lambda^2}{(4\pi)^3 r^4} \sigma \approx 10^{-14}\mathrm{W} = -110\mathrm{dBm}$$

$$|f_{RX} - f_{TX}| = \Delta f = 2 f_{TX} \frac{v_r}{c_0}$$

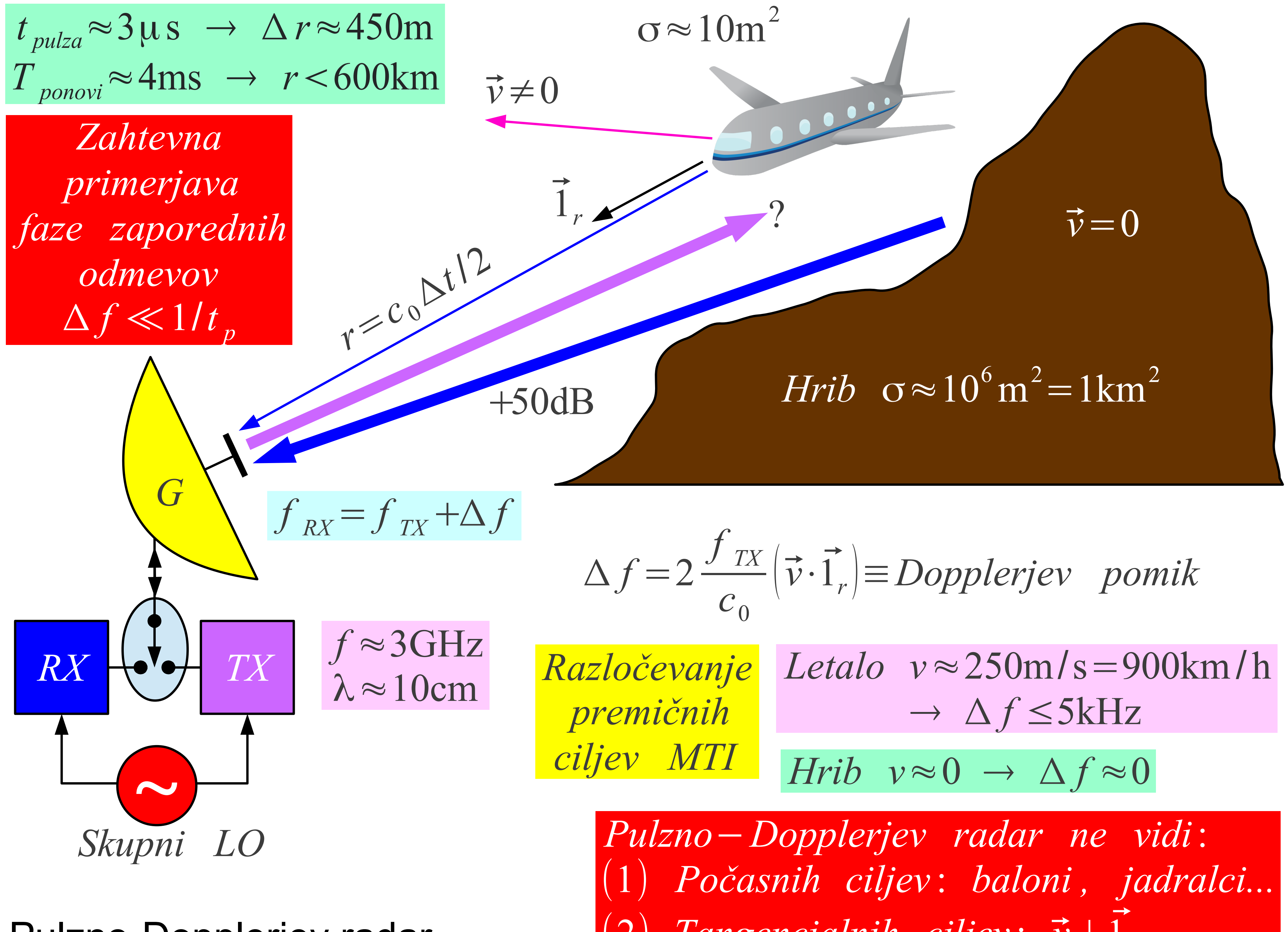
Zgled $\Delta f \approx 3.2\mathrm{kHz}$

$$v_r = c_0 \frac{\Delta f}{2 f_{TX}}$$

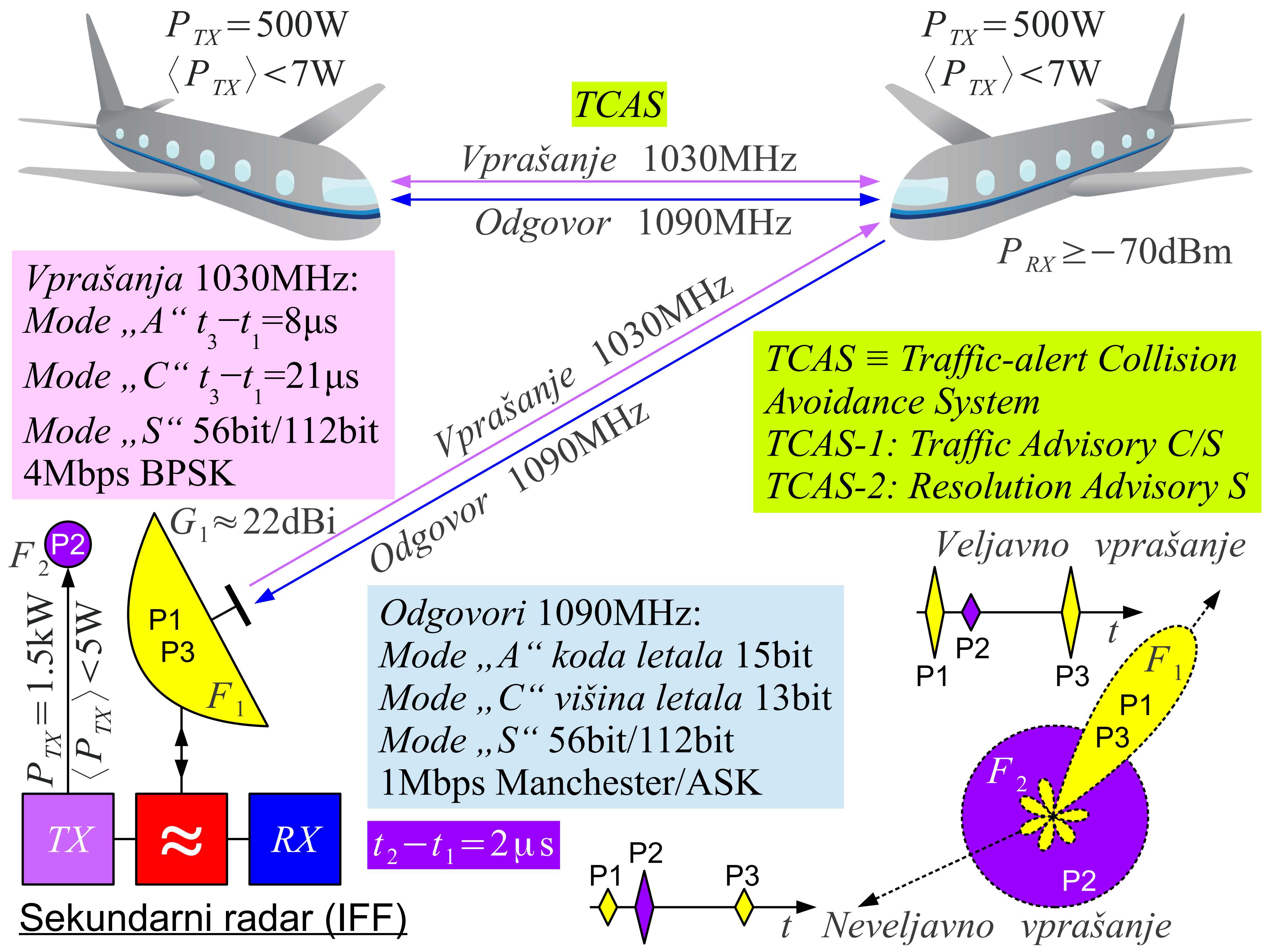
$v_r \approx 20\mathrm{m/s} = 72\mathrm{km/h}$

Frekvenčni pasovi	
9.375GHz	*Ni več v uporabi*
10.525GHz	*Region 2 (ZDA)*
24GHz	*ISM*
34GHz	*Licenciran*

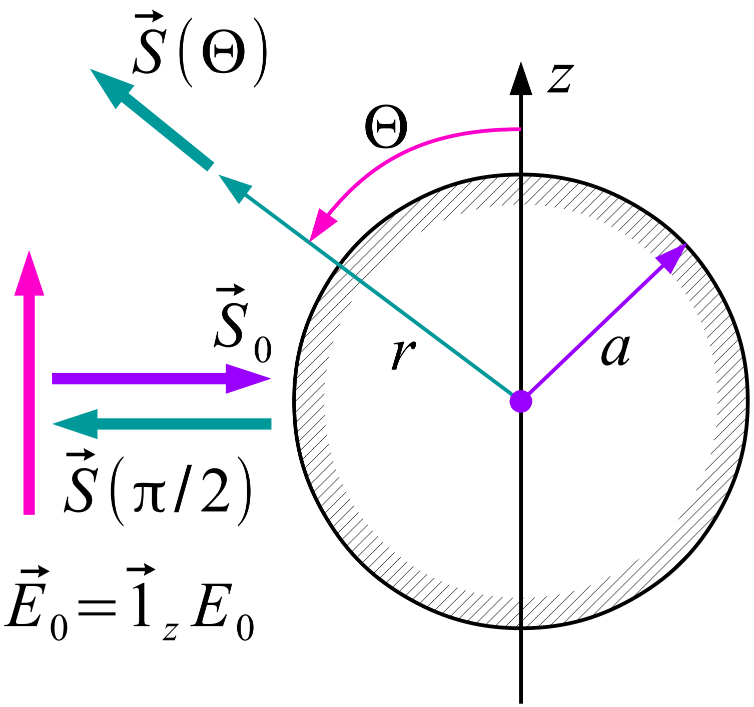
CW Dopplerjev radar



Pulzno-Dopplerjev radar

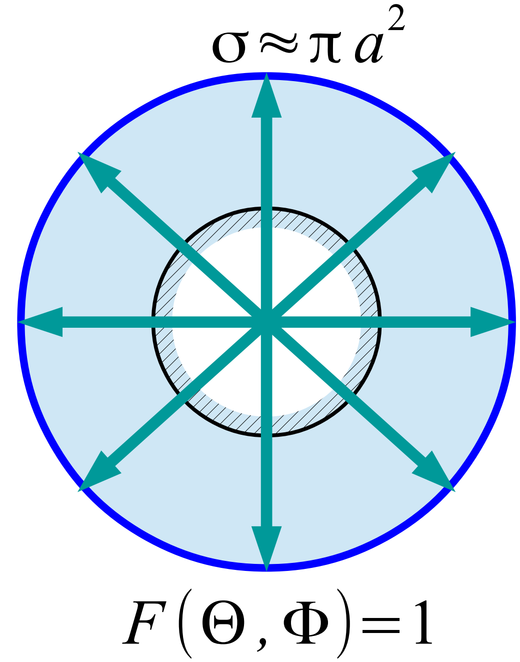


$P_{TX} = 500W$
$\langle P_{TX} \rangle < 7W$
$P_{TX} = 500W$
$\langle P_{TX} \rangle < 7W$
TCAS
Vprašanje 1030MHz
Odgovor 1090MHz
$P_{RX} \geq -70dBm$
Vprašanja 1030MHz:
Mode „A“ $t_3 - t_1 = 8\mu s$
Mode „C“ $t_3 - t_1 = 21\mu s$
Mode „S“ 56bit/112bit
4Mbps BPSK
Vprašanje 1030MHz
Odgovor 1090MHz
TCAS ≡ Traffic-alert Collision Avoidance System
TCAS-1: Traffic Advisory C/S
TCAS-2: Resolution Advisory S
$G_1 \approx 22dBi$
F_2
P2
P1
P3
F_1
$P_{TX} = 1.5kW$
$\langle P_{TX} \rangle < 5W$
TX
≈
RX
Odgovori 1090MHz:
Mode „A“ koda letala 15bit
Mode „C“ višina letala 13bit
Mode „S“ 56bit/112bit
1Mbps Manchester/ASK
$t_2 - t_1 = 2\mu s$
Veljavno vprašanje
P1
P2
P3
t
F_1
P1
P3
F_2
P2
P1
P2
P3
t
Neveljavno vprašanje
Sekundarni radar (IFF)



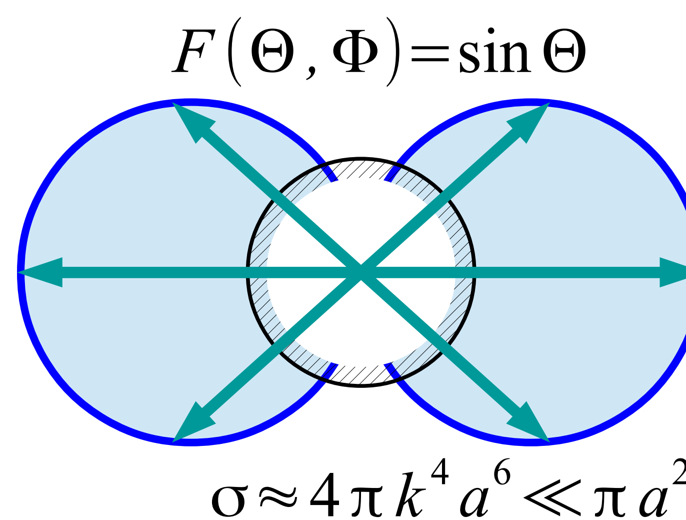
Kovinska kroglica

$a \gg \lambda$ neodvisno od frekvence ter polarizacije (bel oblak)

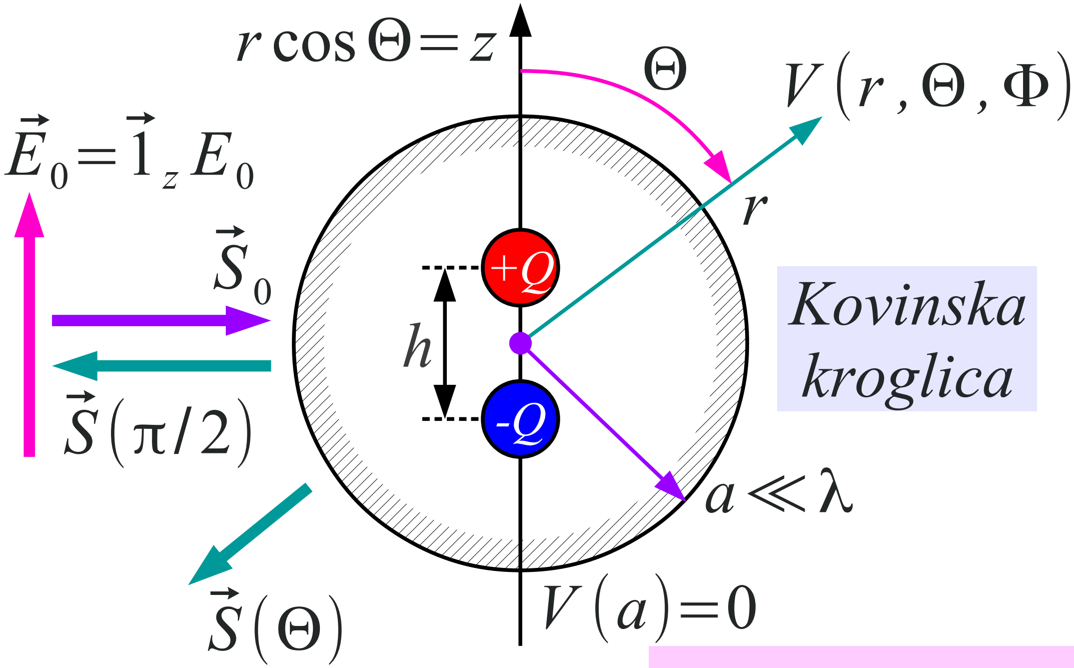


Rezonance (Mie) $a \approx \lambda$

Rayleigh $a \ll \lambda$ polarizacijsko ter frekvenčno odvisno (modro nebo)



Odboj od prevodne krogle



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 $V_{dipol}(r,\Theta,\Phi) = \dfrac{Qh}{4\pi\epsilon_0}\dfrac{\cos\Theta}{r^2}$

Zveznost $I = j\omega Q$

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

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

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

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

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

Odmevna površina majhne krogle

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

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

$$\left|\frac{\epsilon_r - 1}{\epsilon_r + 2}\right|^2 \approx \begin{cases} 0.93 & (voda \quad \epsilon_r \approx 80) \\ 0.21 & (led \quad \epsilon_r \approx 3.5) \\ 1 & (kovina \quad \epsilon_r \to \infty) \end{cases}$$

$$Naključna \quad faza \quad \to \quad \sigma = \sum_i \sigma_i$$

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

$$\eta = \frac{d\sigma}{dV} = \frac{\pi^5}{\lambda^4}\left|\frac{\epsilon_r - 1}{\epsilon_r + 2}\right|^2 Z \quad \leftarrow \quad Z[\mathrm{m}^3]$$

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

Odmevna površina padavin

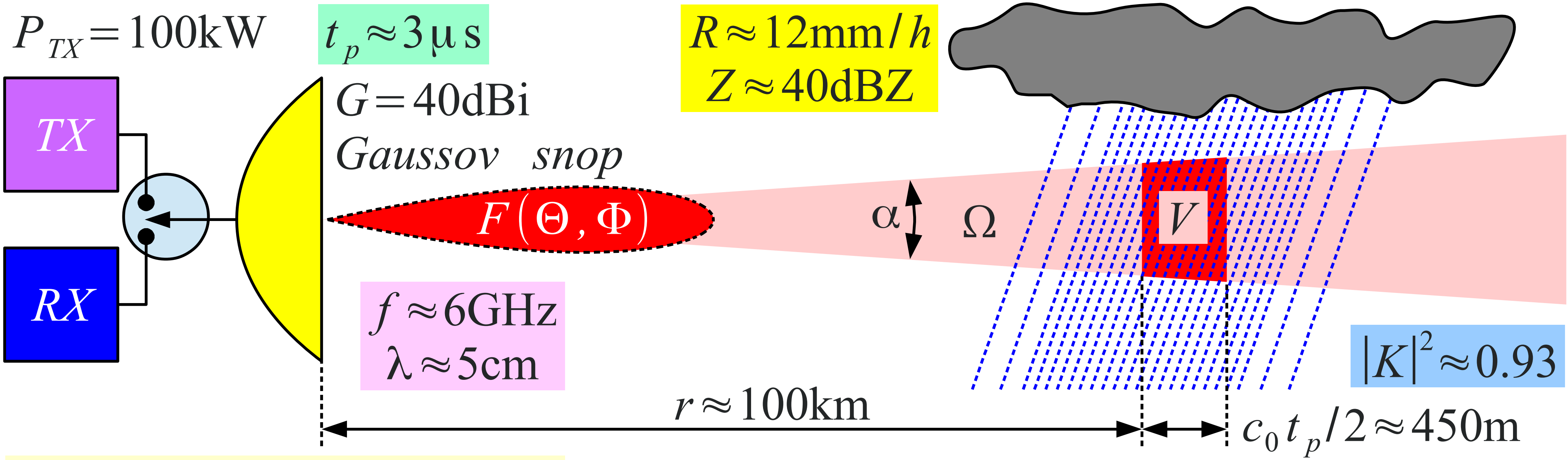
J. S. Marshall & W. M. Palmer 1948

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

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

$$Z_{\mathrm{dBZ}} = 10\log_{10}\frac{Z}{Z_0} \qquad Z_0 = \frac{1\mathrm{mm}^6}{1\mathrm{m}^3} = 10^{-18}\,\mathrm{m}^3$$

Padavine	*R*[mm/h]	*Z*[dBZ]	*Z*[m^3]	*Barva*
Toča	205mm/h	60dBZ	10^{-12}m^3	
	100mm/h	55dBZ	$3\cdot10^{-13}$m^3	
Naliv	49mm/h	50dBZ	10^{-13}m^3	
	24mm/h	45dBZ	$3\cdot10^{-14}$m^3	
Dež	12mm/h	40dBZ	10^{-14}m^3	
	5.6mm/h	35dBZ	$3\cdot10^{-15}$m^3	
	2.7mm/h	30dBZ	10^{-15}m^3	
Rosenje	1.3mm/h	25dBZ	$3\cdot10^{-16}$m^3	
	0.6mm/h	20dBZ	10^{-16}m^3	



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

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

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

$$40\text{dBZ}==10^{-14}\text{m}^3$$

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

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

Stožčast snop

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

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

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

$$P_{RX}\approx\frac{P_{TX}G\lambda^2}{64\pi^2 r^2}\eta c_0 t_p=\frac{P_{TX}G\pi^3 c_0 t_p|K|^2}{64 r^2\lambda^2}Z\approx 1.62\cdot 10^{-10}\,\text{W}$$

Gaussov snop

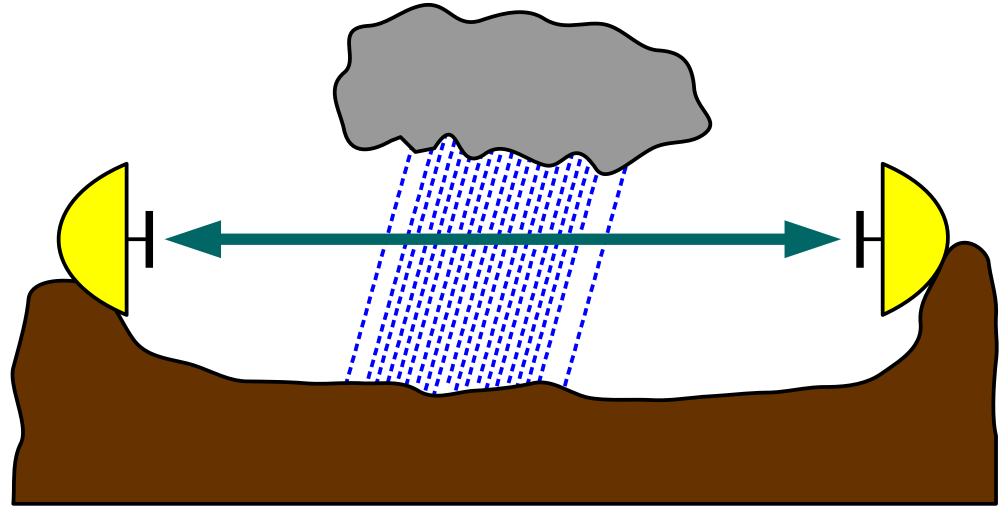
$$|F(\Theta)|^2=e^{-(\Theta/\Theta_{-3\text{dB}})^2\ln 2}$$

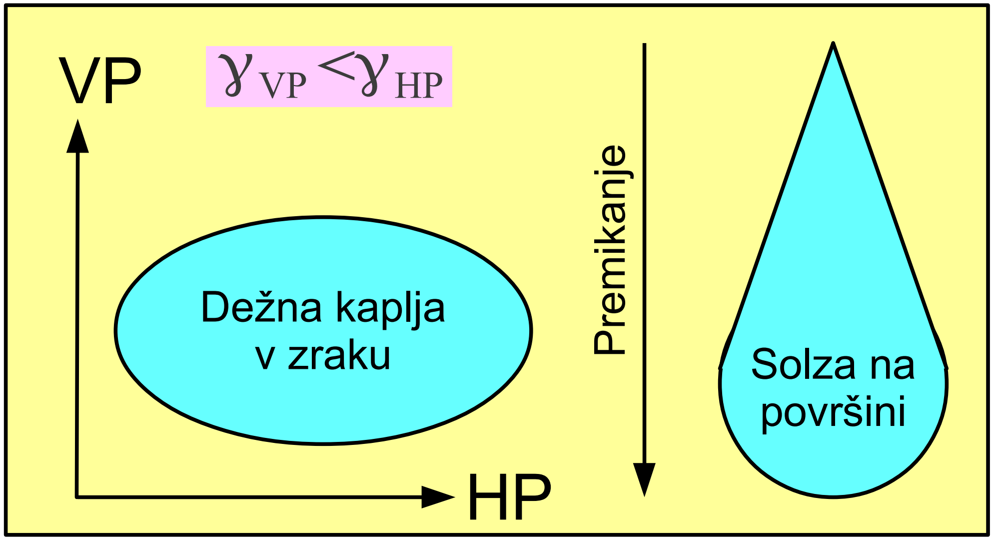
$$I\approx\frac{\pi\Theta^2_{-3\text{dB}}}{2\ln 2}\approx\frac{2\pi}{G}$$

$$P_{RX}\approx 162\text{pW}\approx -67.9\text{dBm}$$

<u>Vremenski radar</u>

Dielektrične lastnosti vode		
f	$\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$	$n = \sqrt{\varepsilon_r}$
300GHz	5.81−*j*4.85	2.59−*j*0.94
150GHz	6.75−*j*9.57	3.04−*j*1.57
100GHz	8.26−*j*14.07	3.50−*j*2.01
60GHz	12.69−*j*22.00	4.36−*j*2.52
30GHz	26.40−*j*34.22	5.90−*j*2.90
18.5GHz	42.54−*j*35.62	7.00−*j*2.54
16GHz	50.00−*j*37.50	7.50−*j*2.50
11GHz	61.16−*j*32.12	8.07−*j*1.99
6GHz	73.72−*j*20.84	8.67−*j*1.20
4GHz	76.08−*j*16.05	8.77−*j*0.92
3GHz	78.30−*j*11.14	8.87−*j*0.63
2GHz	79.32−*j*7.53	8.92−*j*0.42
1.43GHz	80.92−*j*4.95	9.00−*j*0.28





Priporočilo ITU-R P.838-3

$$\gamma[\mathrm{dB/km}] \approx k(f)\left(R[\mathrm{mm/h}]\right)^{\alpha(f)}$$

Enačbe/tabele za $k(f)$ & $\alpha(f)$ posebej za HP oziroma za VP

<u>Slabljenje padavin</u>

$$\gamma = -a_{\mathrm{dB}}/l$$

Koeficienti priporočila ITU-R P.838-3

FIGURE 1

k coefficient for horizontal polarization

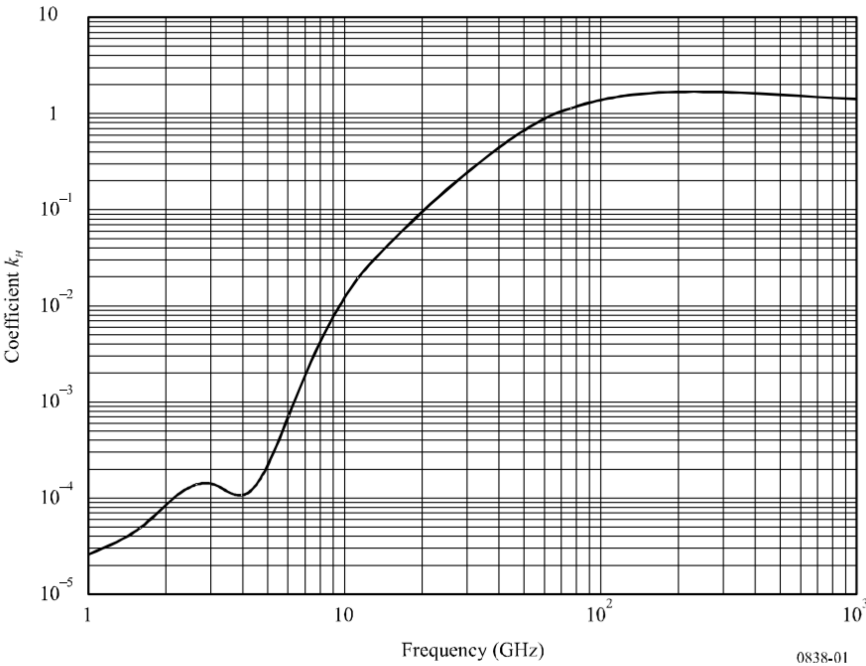


FIGURE 2

α coefficient for horizontal polarization

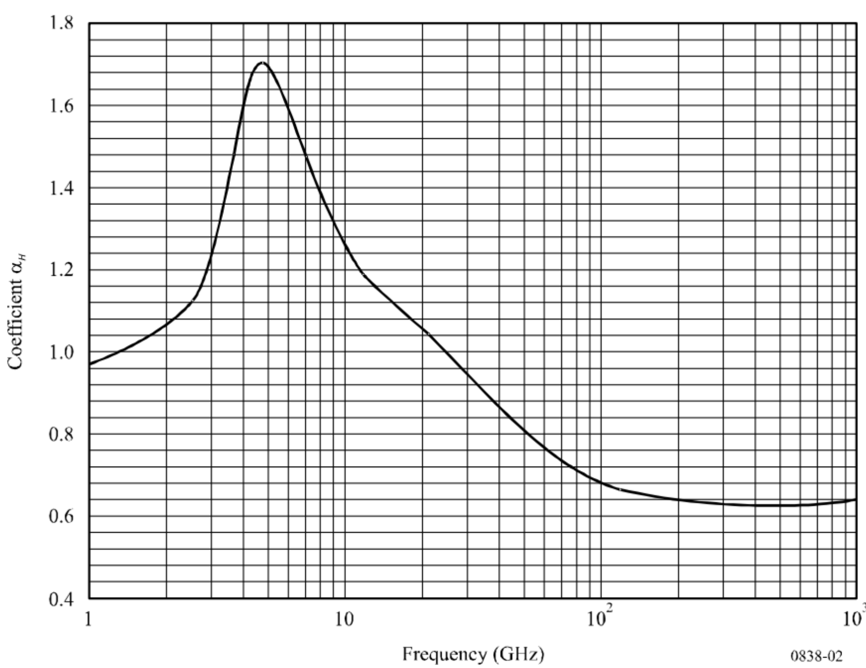


FIGURE 3

k coefficient for vertical polarization

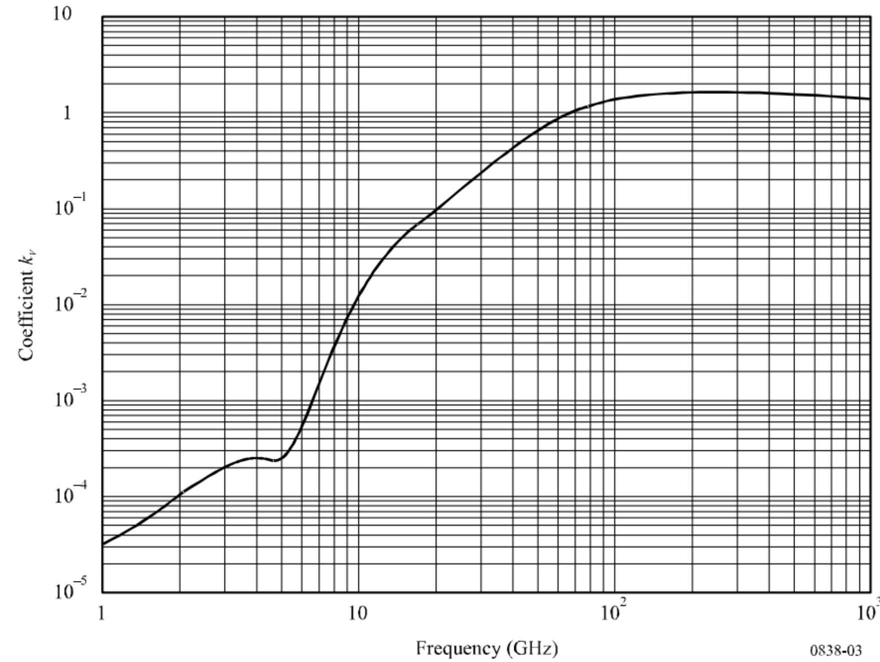
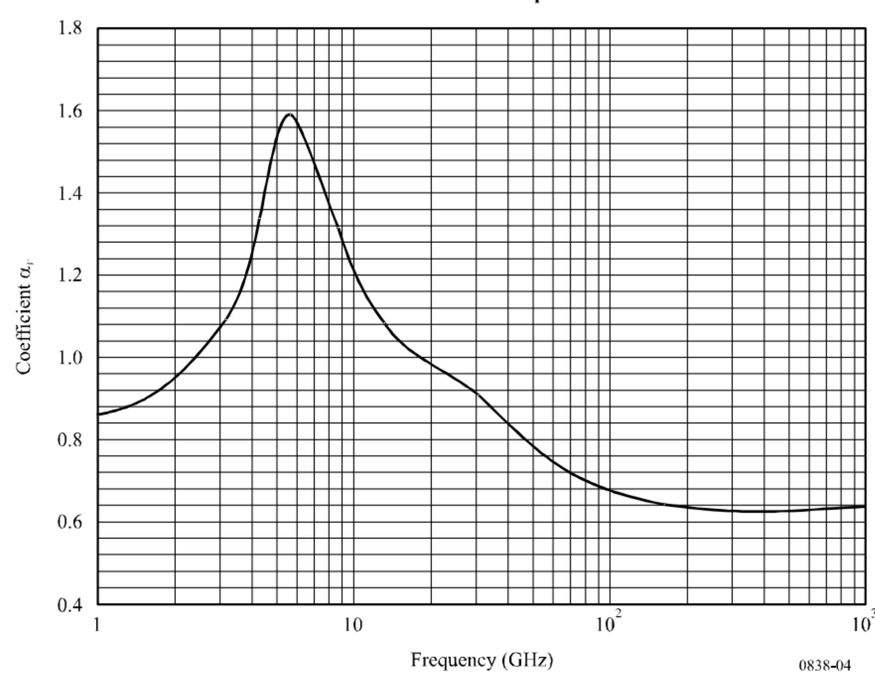
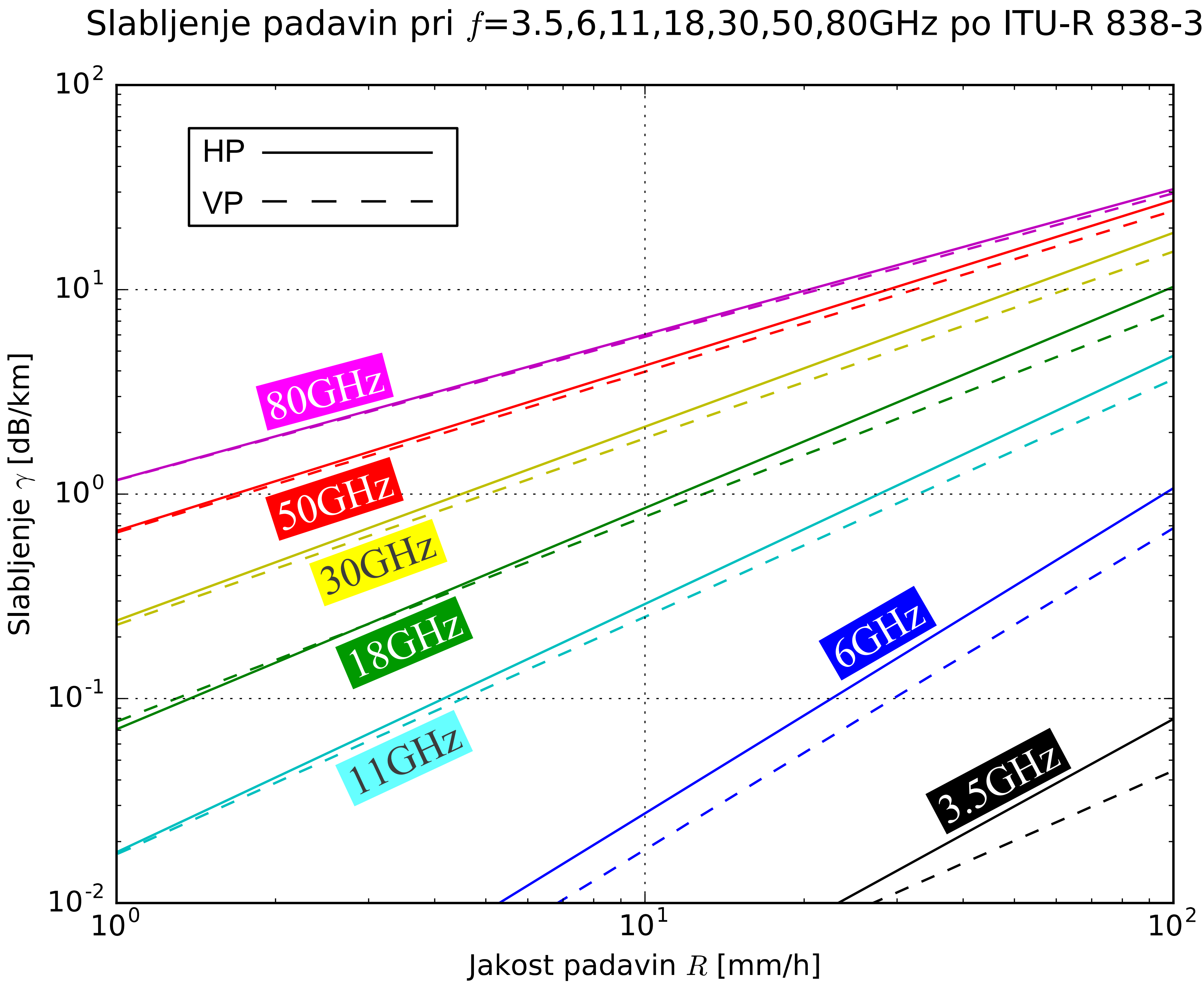


FIGURE 4

α coefficient for vertical polarization





Slabljenje padavin pri f=3.5,6,11,18,30,50,80GHz po ITU-R 838-3
HP
VP
80GHz
50GHz
30GHz
18GHz
11GHz
6GHz
3.5GHz
Slabljenje γ [dB/km]
Jakost padavin R [mm/h]