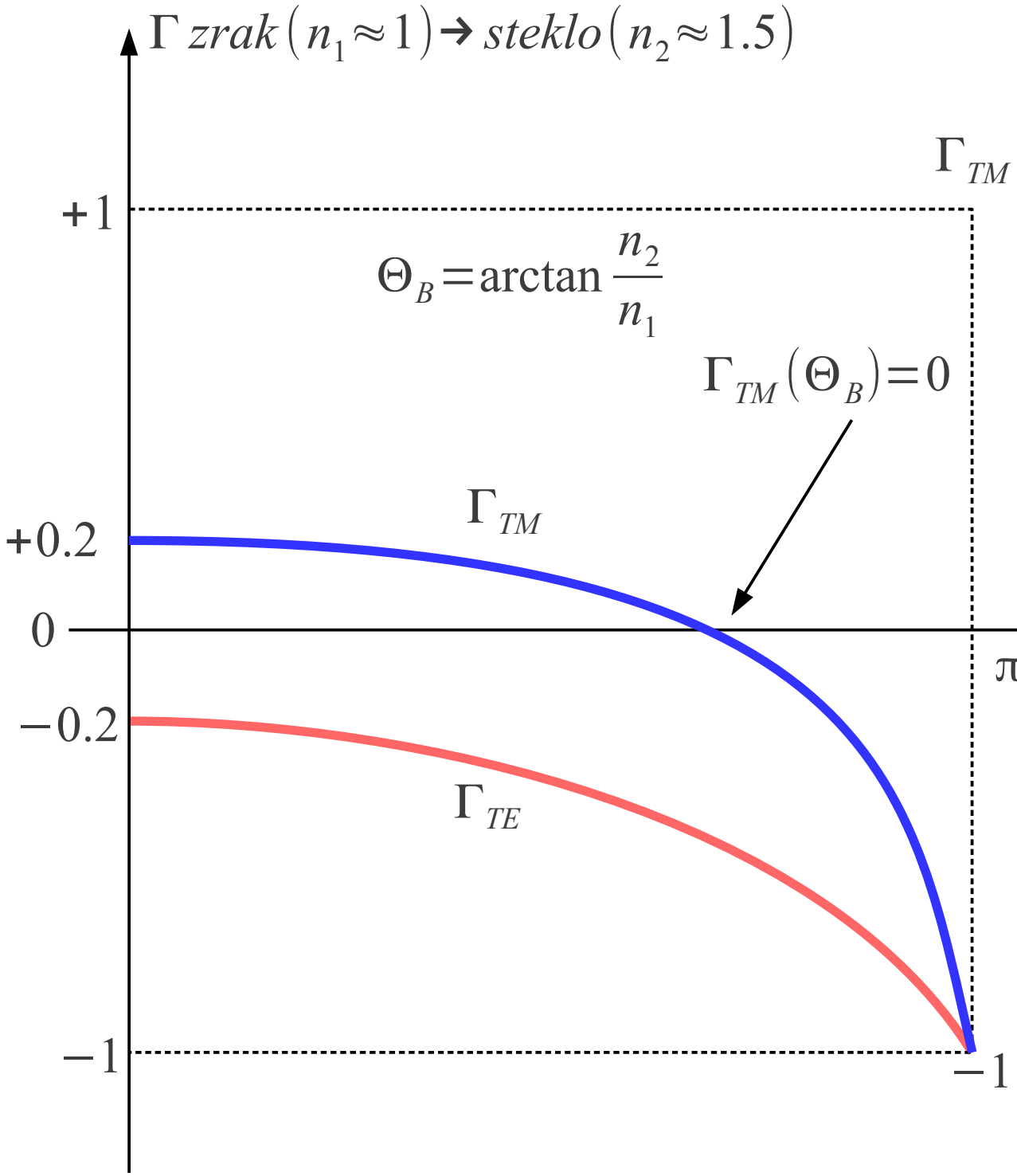
Optične komunikacije

Predavanje 3:

Popolni odboj v dielektričnem valovodu



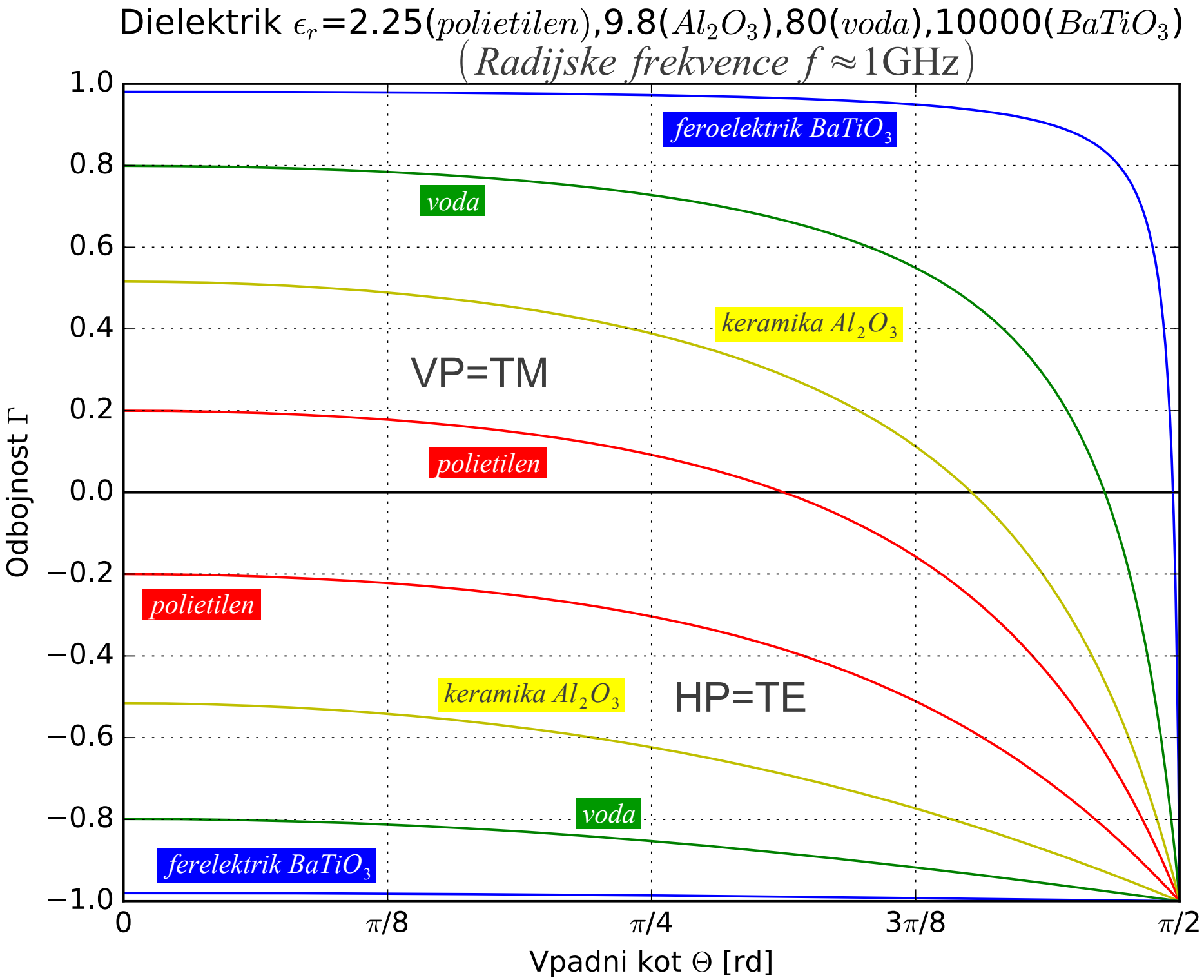
$$\Gamma_{TM}=\frac{\left(\frac{n_2}{n_1}\right)^2\cos\Theta-\sqrt{\left(\frac{n_2}{n_1}\right)^2-\sin^2\Theta}}{\left(\frac{n_2}{n_1}\right)^2\cos\Theta+\sqrt{\left(\frac{n_2}{n_1}\right)^2-\sin^2\Theta}}$$

Neferomagnetiki $\mu_{r1}=\mu_{r2}=1$

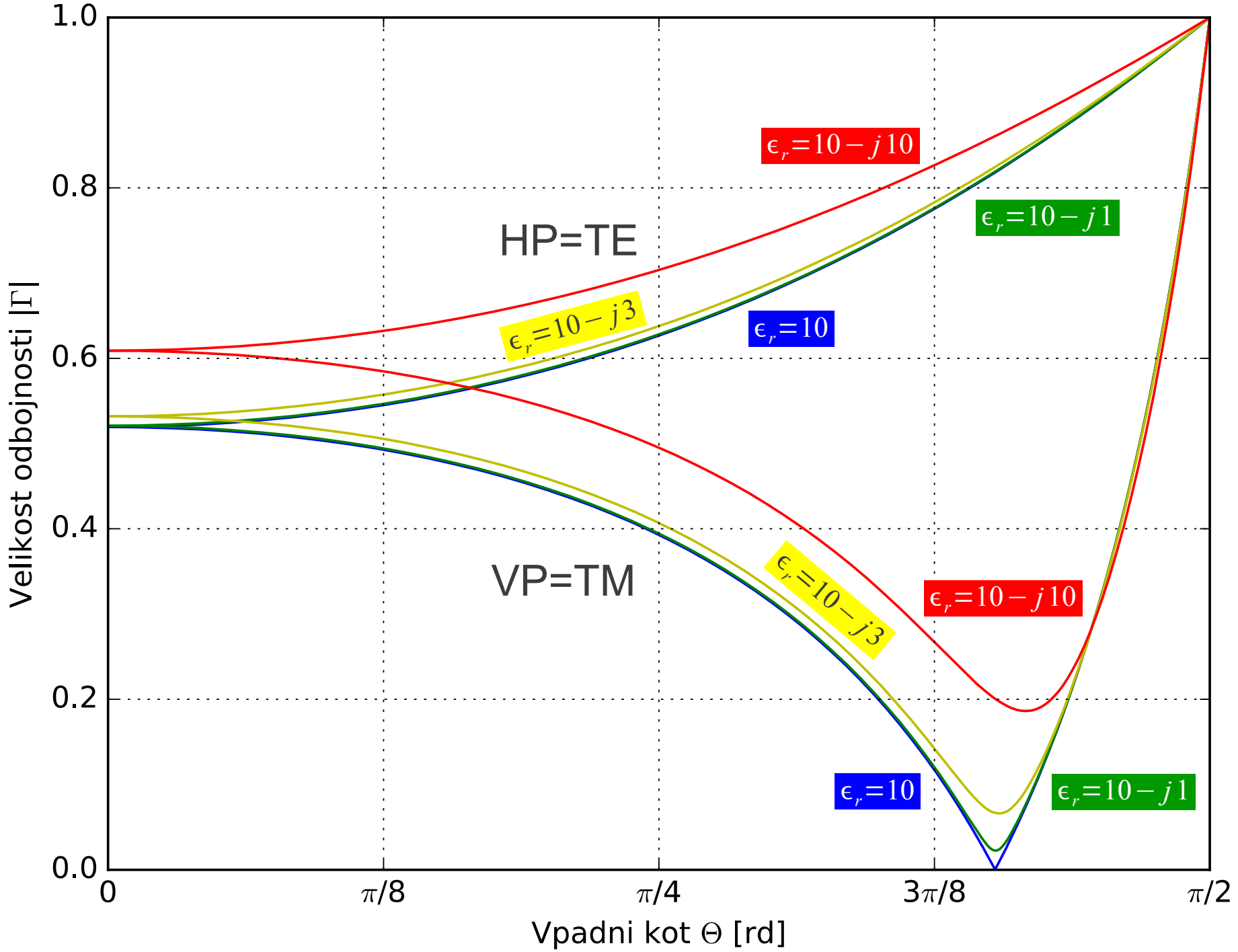
$$n_1=\sqrt{\epsilon_{r1}}\approx\sqrt{1}=1$$

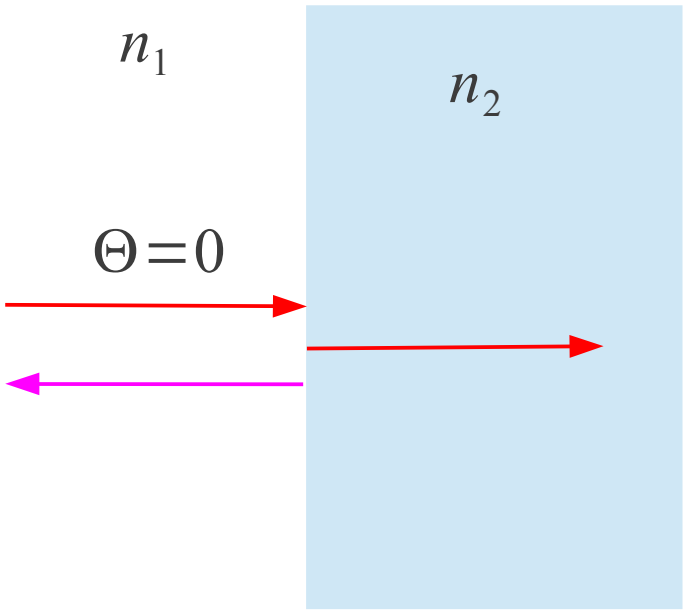
$$n_2=\sqrt{\epsilon_{r2}}\approx\sqrt{2.25}=1.5$$

$$\Gamma_{TE}=\frac{\cos\Theta-\sqrt{\left(\frac{n_2}{n_1}\right)^2-\sin^2\Theta}}{\cos\Theta+\sqrt{\left(\frac{n_2}{n_1}\right)^2-\sin^2\Theta}}$$


Dielektrik ϵ_r=2.25($polietilen$),9.8(Al_2O_3),80($voda$),10000($BaTiO_3$)
$(Radijske\ frekvence\ f \approx 1\mathrm{GHz})$
feroelektrik $BaTiO_3$
voda
keramika Al_2O_3
VP=TM
polietilen
polietilen
keramika Al_2O_3
HP=TE
voda
ferelektrik $BaTiO_3$
Odbojnost Γ
Vpadni kot Θ [rd]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
π/8
π/4
3π/8
π/2

$Zrak\left(\epsilon_r \approx 1\right)$ → Dielektrik z izgubami ϵ_r=10,10-j1,10-j3,10-j10



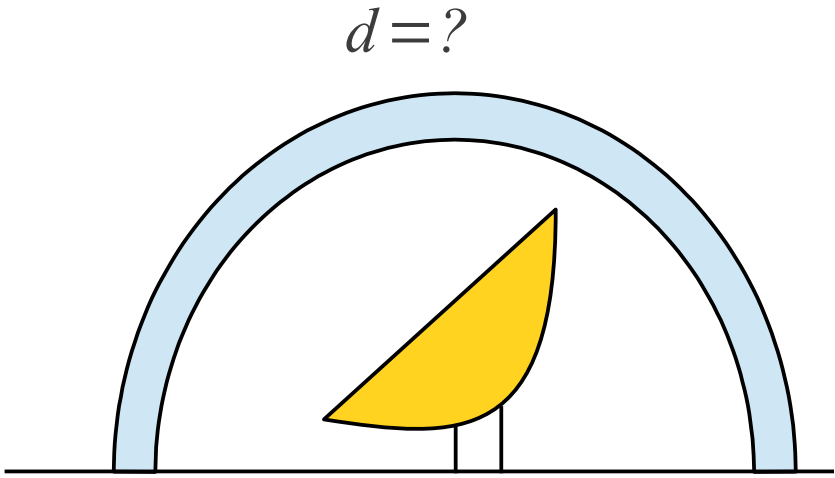


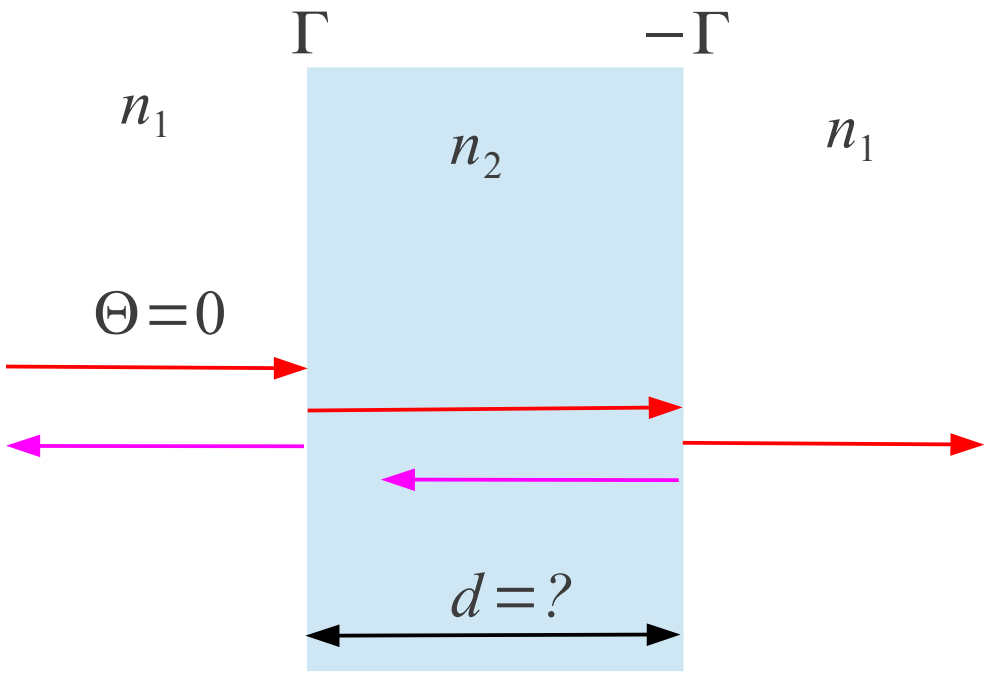
$$\Gamma_{TE} = \frac{n_1 - n_2}{n_1 + n_2} = -\Gamma_{TM}$$

$$\Gamma = \left| \frac{n_1 - n_2}{n_1 + n_2} \right|$$

$$P_O = P_V |\Gamma^2|$$

Prozoren pokrov za anteno





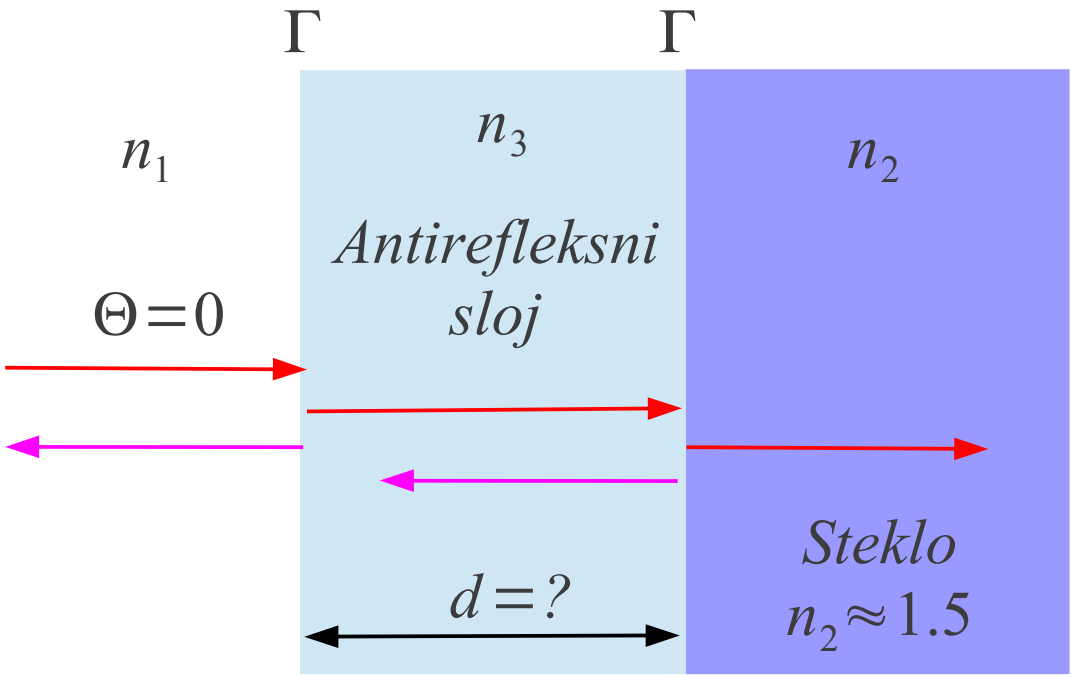
n_1

$$\phi = 2\,d\,k_2 = m\,2\pi$$

$$2\,d = m\,\lambda_2$$

$$k_2 = \frac{2\pi}{\lambda_2}$$

$$\lambda_2 = \frac{\lambda_0}{n_2} = \frac{\lambda_0}{\sqrt{\epsilon_r}}$$



$Zrak\ n_1 \approx 1$

$Steklo\ n_2 \approx 1.5$

$n_3 = \sqrt{n_1 n_2}$

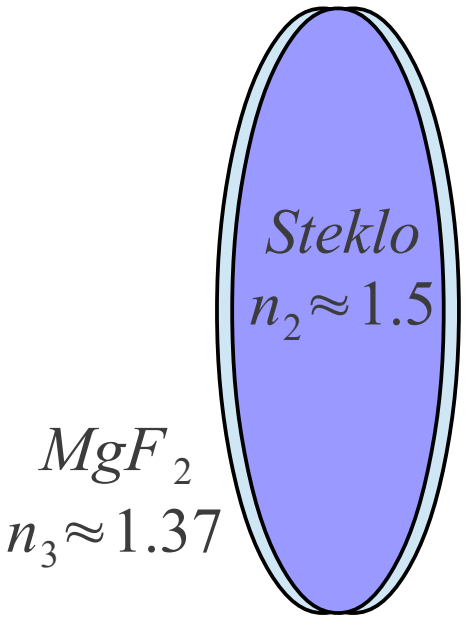
$\sqrt{1.5} \approx 1.23$

$\phi = 2 d k_2 = \pi + m 2\pi$

$2 d = \lambda_3/2 + m \lambda_3$

$d = \lambda_3/4 + m \lambda_3/2$

$d = \lambda_3/4$



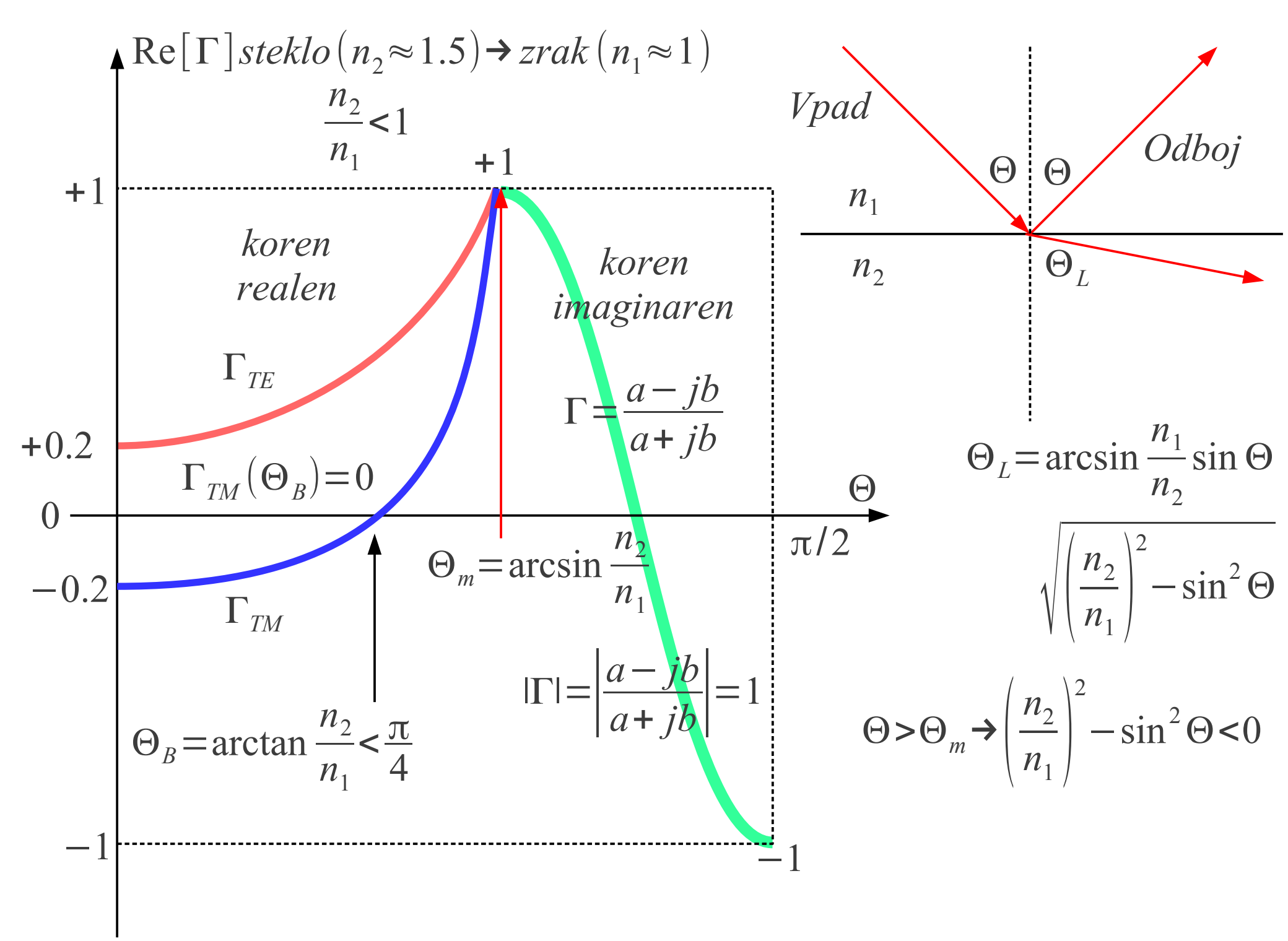
Antirefleksni sloj

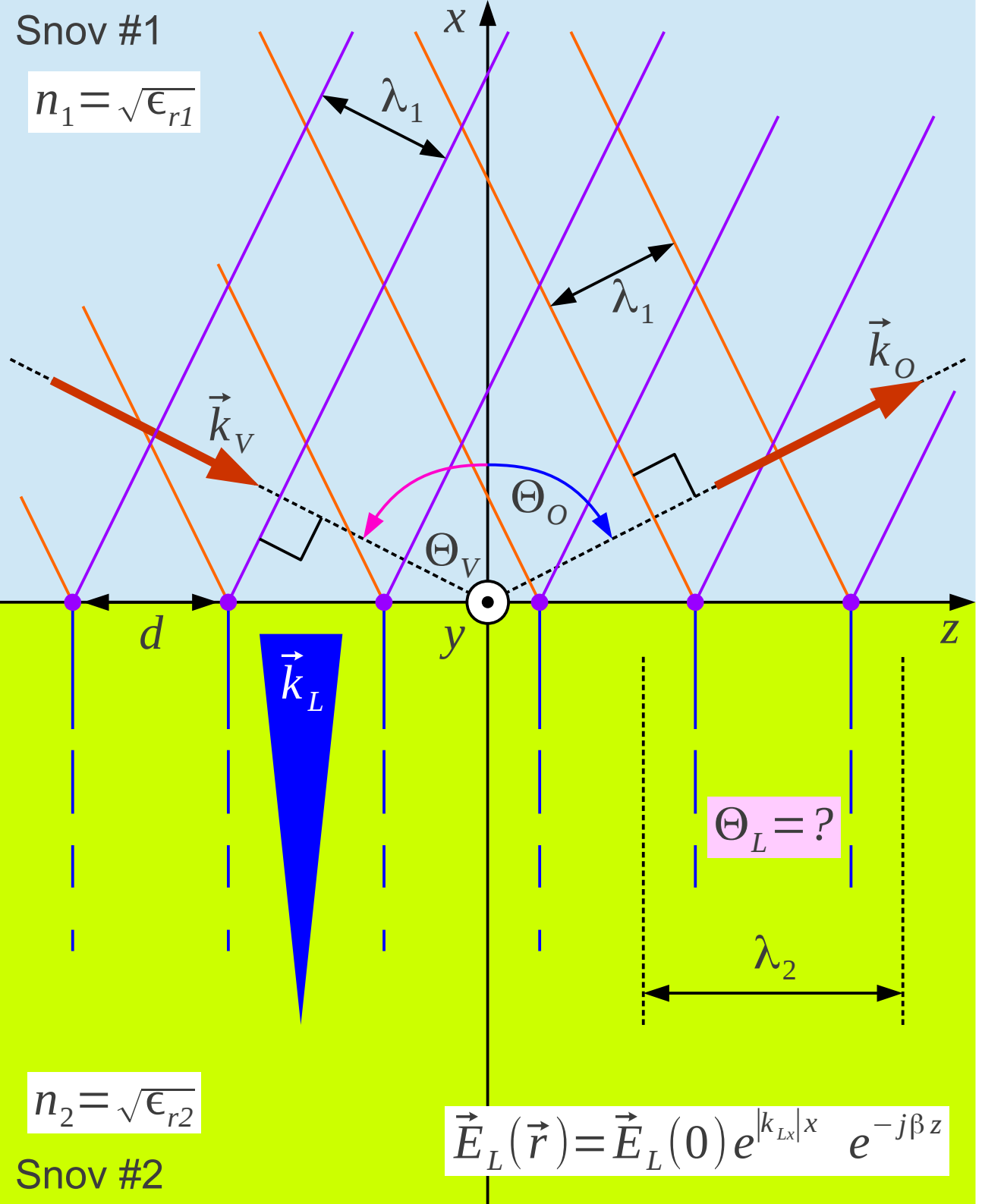
$MgF_2 \quad n_3 \approx 1.37$

$\lambda_0 \approx 0.5\,\mu m \equiv vidna\ svetloba$

$\lambda_3 \approx 0.4\,\mu m$

$d = \lambda_3/4 \approx 0.1\,\mu m$


$\mathrm{Re}[\Gamma]\ steklo\,(n_2 \approx 1.5) \rightarrow zrak\,(n_1 \approx 1)$
$\frac{n_2}{n_1} < 1$
+1
+0.2
0
−0.2
−1
koren realen
koren imaginaren
Γ_{TE}
Γ_{TM}
$\Gamma_{TM}(\Theta_B) = 0$
$\Gamma = \frac{a - jb}{a + jb}$
Θ
$\pi/2$
$\Theta_m = \arcsin \frac{n_2}{n_1}$
$|\Gamma| = \left|\frac{a - jb}{a + jb}\right| = 1$
$\Theta_B = \arctan \frac{n_2}{n_1} < \frac{\pi}{4}$
−1
Vpad
Odboj
Θ
Θ
n_1
n_2
Θ_L
$\Theta_L = \arcsin \frac{n_1}{n_2} \sin\Theta$
$\sqrt{\left(\frac{n_2}{n_1}\right)^2 - \sin^2\Theta}$
$\Theta > \Theta_m \rightarrow \left(\frac{n_2}{n_1}\right)^2 - \sin^2\Theta < 0$



Primer $n_2<n_1$ *velik* $\sin\Theta_V$

$\lambda_2>d>\lambda_1$

$$\sin\Theta_L=\frac{n_1}{n_2}\sin\Theta_V>1$$

Lomljeni žarek ne obstaja ?

$$\vec{S}=\frac{1}{2}\vec{E}\times\vec{H}^*\equiv Poynting\left[\frac{W}{m^2}\right]$$

$$k_{Vx}^2+\beta^2=k_{Ox}^2+\beta^2=k_1^2=n_1^2k_0^2$$

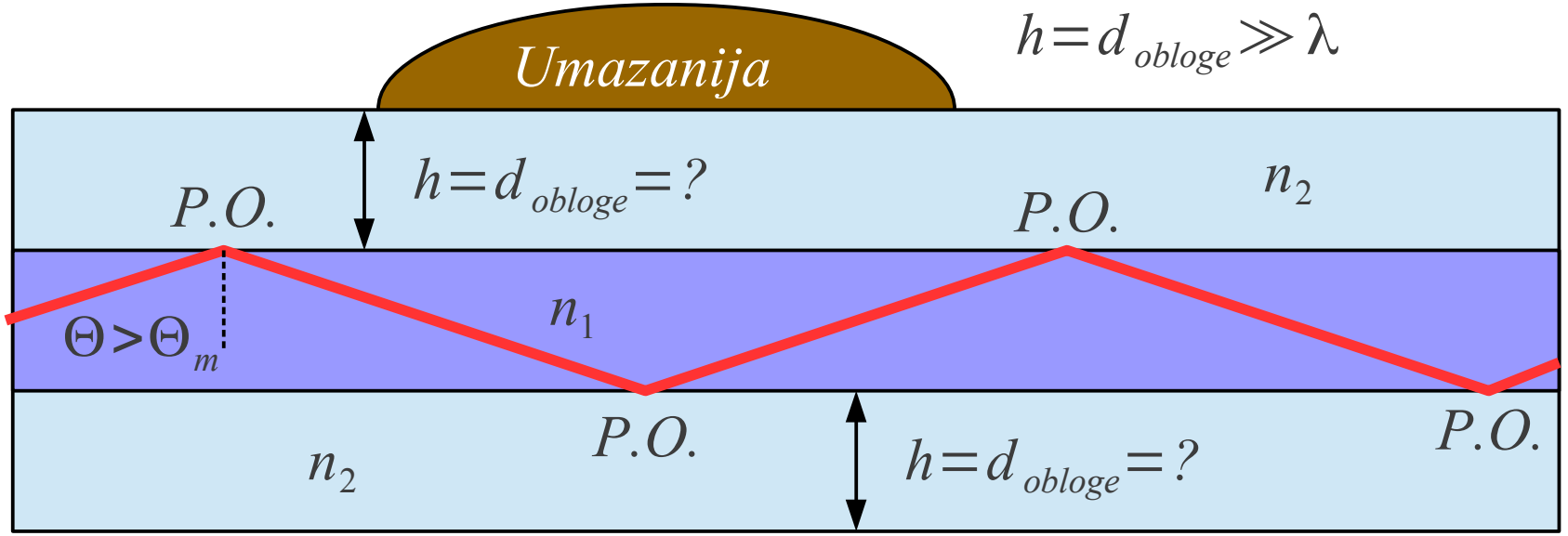
$$k_{Lx}^2+\beta^2=k_2^2=n_2^2k_0^2$$

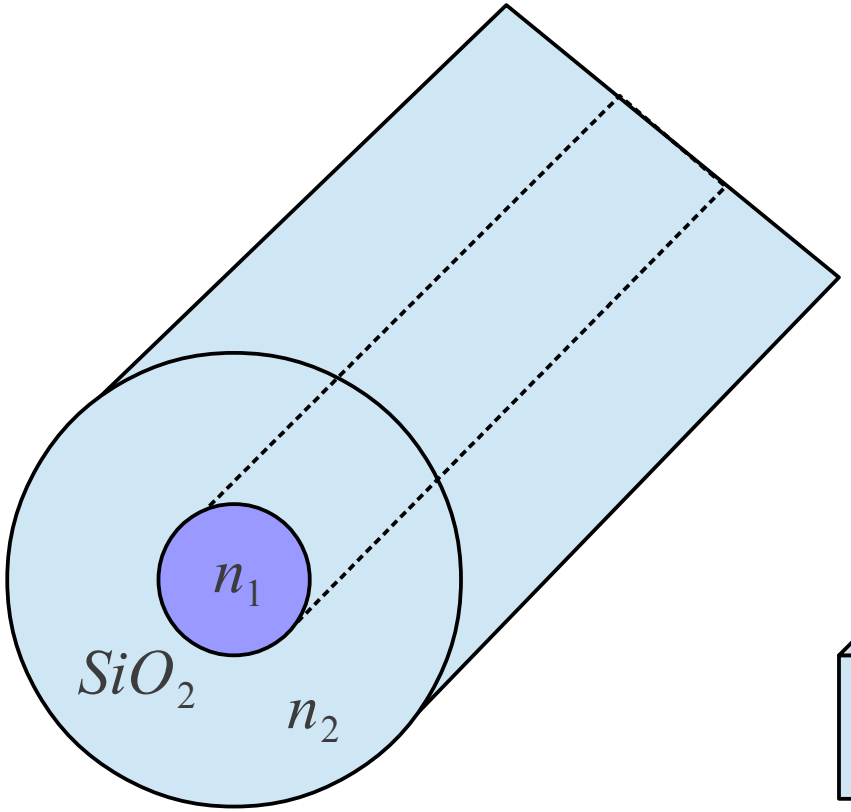
$$k_{Lx}^2=n_2^2k_0^2-\beta^2=$$
$$=\left(n_2^2-n_1^2\sin^2\Theta_V\right)k_0^2<0$$

$$k_{Lx}=j\sqrt{\beta^2-k_2^2}=j\left|k_{Lx}\right|$$

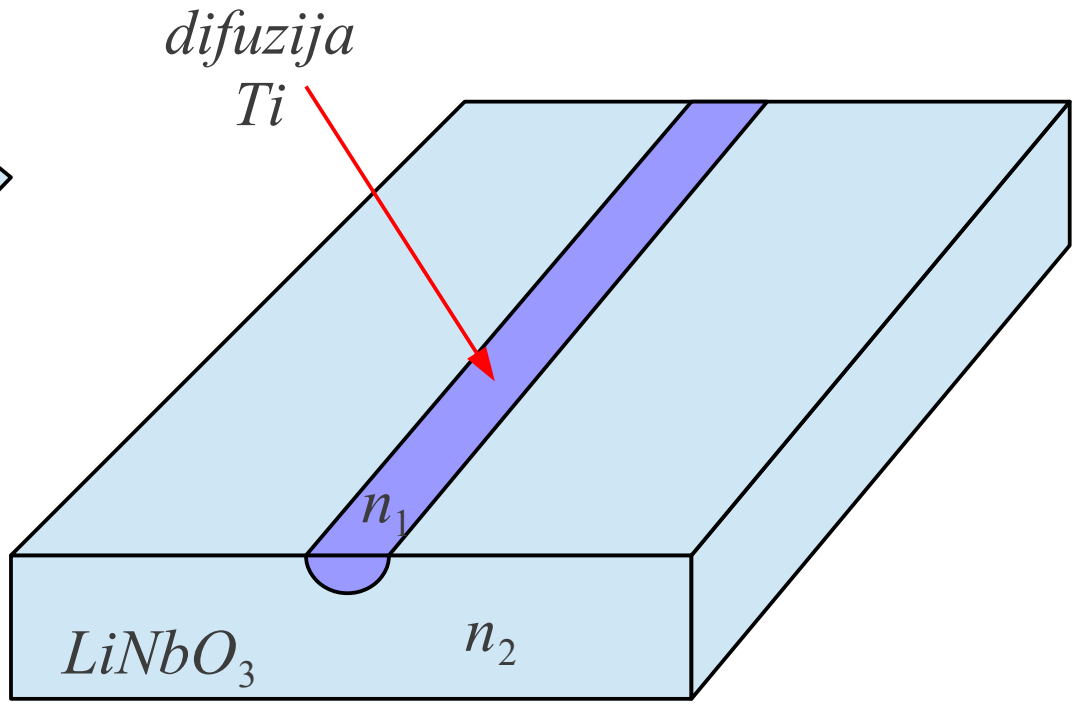
$$\vec{k}_L=\vec{1}_x\left(j\left|k_{Lx}\right|\right)+\vec{1}_z\beta$$

$$\mathrm{Re}\left[-\vec{1}_x\cdot\vec{S}_2\right]=0$$





Vlakno krožnega prereza



Planarni dielektrični valovod

Vpad + odboj

$$-k_{Vx} = k_{Ox} = \sqrt{n_1^2 k_0^2 - \beta^2}$$

$$\vec{E}_1(\vec{r}) = \vec{E}_V(0) e^{+jk_{1x}x} e^{-j\beta z} + \vec{E}_O(0) e^{-jk_{1x}x} e^{-j\beta z}$$

$$n_2 < n_1 < n_3$$

$$\lambda_2 > d > \lambda_1 > \lambda_3$$

$$\sin\Theta_T > 1$$

Tuneliranje

$$\pm|k_{Tx}| = \pm\sqrt{\beta^2 - n_2^2 k_0^2}$$

$$\vec{E}_2(\vec{r}) = \vec{E}_{T+}(0) e^{+|k_{Tx}|x} e^{-j\beta z} + \vec{E}_{T-}(0) e^{-|k_{Tx}|x} e^{-j\beta z}$$

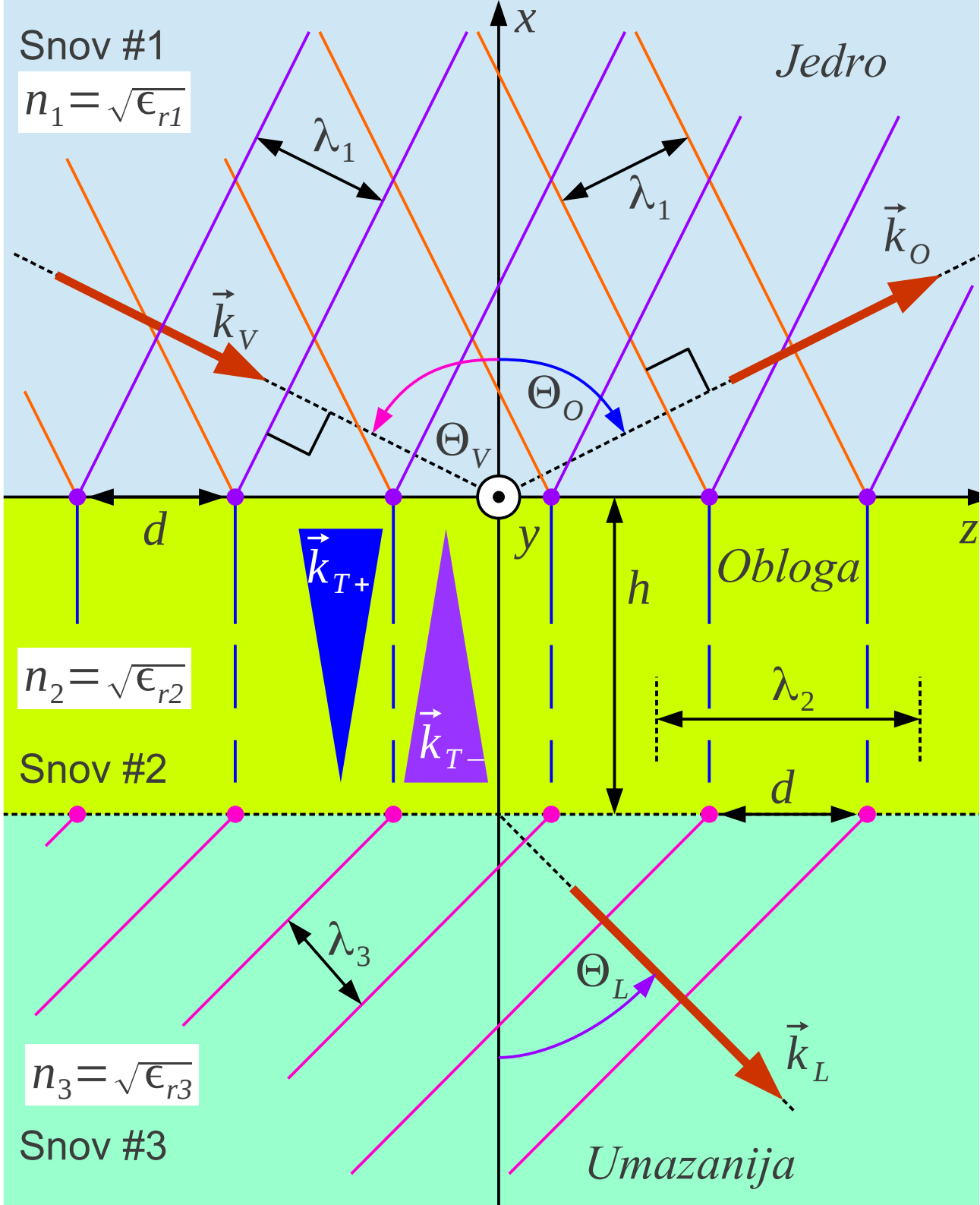
$$\mathrm{Re}[\vec{E}_{T+} \cdot \vec{E}_{T-}{}^*] = 0$$

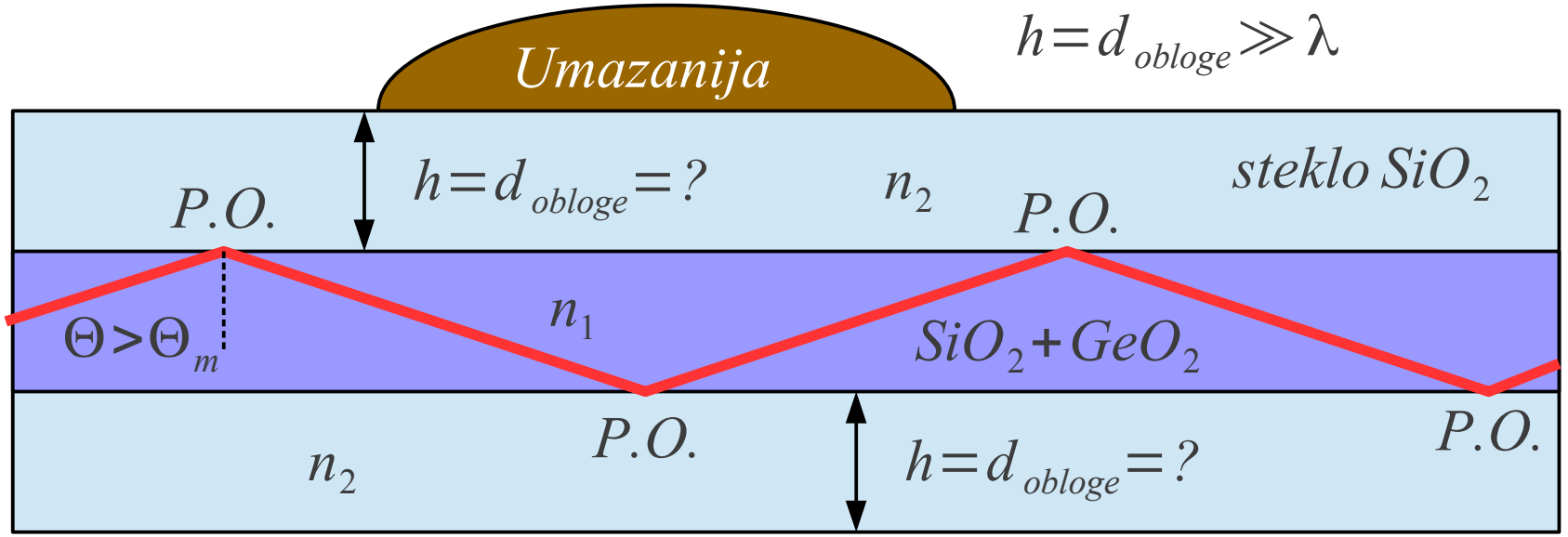
$$\mathrm{Re}[-\vec{1}_x \cdot \vec{S}_2] \neq 0$$

Lom

$$k_{Lx} = -k_{3x} = -\sqrt{n_3^2 k_0^2 - \beta^2}$$

$$\vec{E}_3(\vec{r}) = \vec{E}_L(0) e^{+jk_{3x}x} e^{-j\beta z}$$



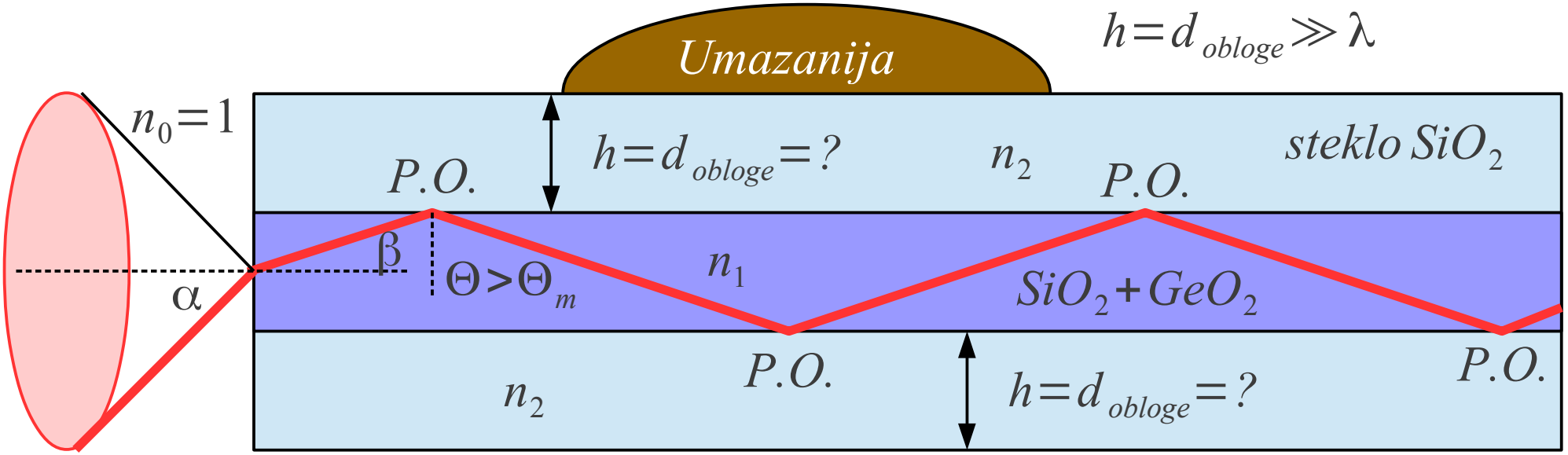


$n_2 \approx 1.463$ $n_1 \approx 1.473$

$\Delta \approx 0.007 \rightarrow tehnologija = ?$

Majhna razlika n → *šibkolomno vlakno* (*valovod*)

$$\Delta = \frac{n_1 - n_2}{n_1} \approx \frac{n_1 - n_2}{n} \equiv relativna\ razlika\ lomnih\ količnikov$$



$n_2 \approx 1.463$ $\quad n_1 \approx 1.473$ $\quad \Delta \approx 0.007$

$$\beta + \Theta = \pi/2$$

$$\sin\alpha = \frac{n_1}{n_0}\sin\beta = n_1\cos\Theta$$

$$\cos\Theta_m = \sqrt{1-\sin^2\Theta_m} = \sqrt{1-\left(\frac{n_2}{n_1}\right)^2}$$

Numerična apertura $\equiv NA = \sin\alpha_m = n_1\cos\Theta_m$

Šibkolomni valovod

Numerična apertura $\equiv NA = \sqrt{n_1^2 - n_2^2}$

$1 \gg NA = \sin\alpha \approx \alpha$

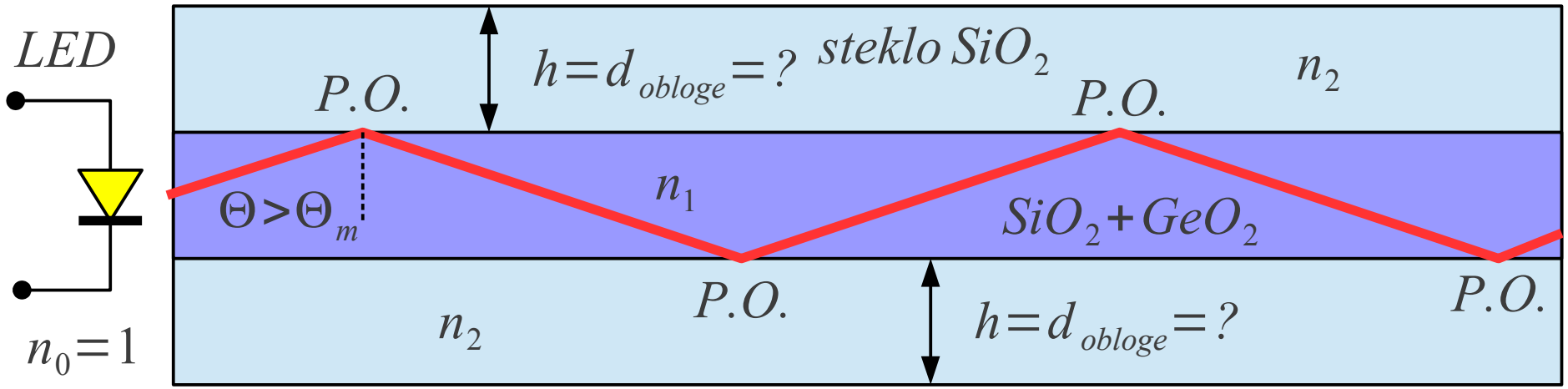
$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(n_1 + n_2)(n_1 - n_2)}$$

$$n_1 + n_2 \approx 2\, n_1$$

$$n_1 - n_2 = \Delta\, n_1$$

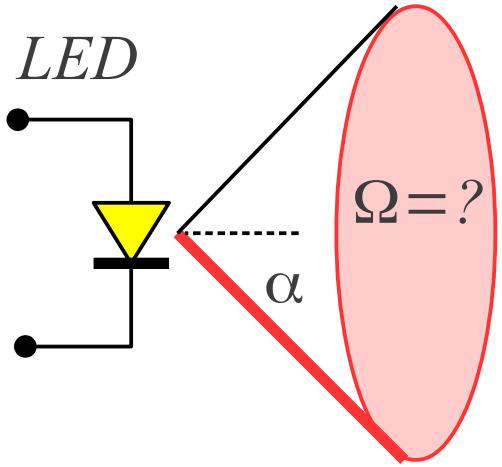
$$NA \approx \sqrt{2\, n_1\, \Delta\, n_1} = n_1 \sqrt{2\, \Delta}$$

$$\Delta \approx \frac{1}{2}\left(\frac{NA}{n_1}\right)^2$$



$$\textit{Sklopni izkoristek} \equiv \eta = \frac{\Omega}{4\pi} = \frac{1-\cos\alpha}{2} = \frac{1-\sqrt{1-NA^2}}{2} \approx \frac{NA^2}{4}$$

$$\cos\alpha = \sqrt{1-NA^2} \approx 1 - \frac{NA^2}{2}$$

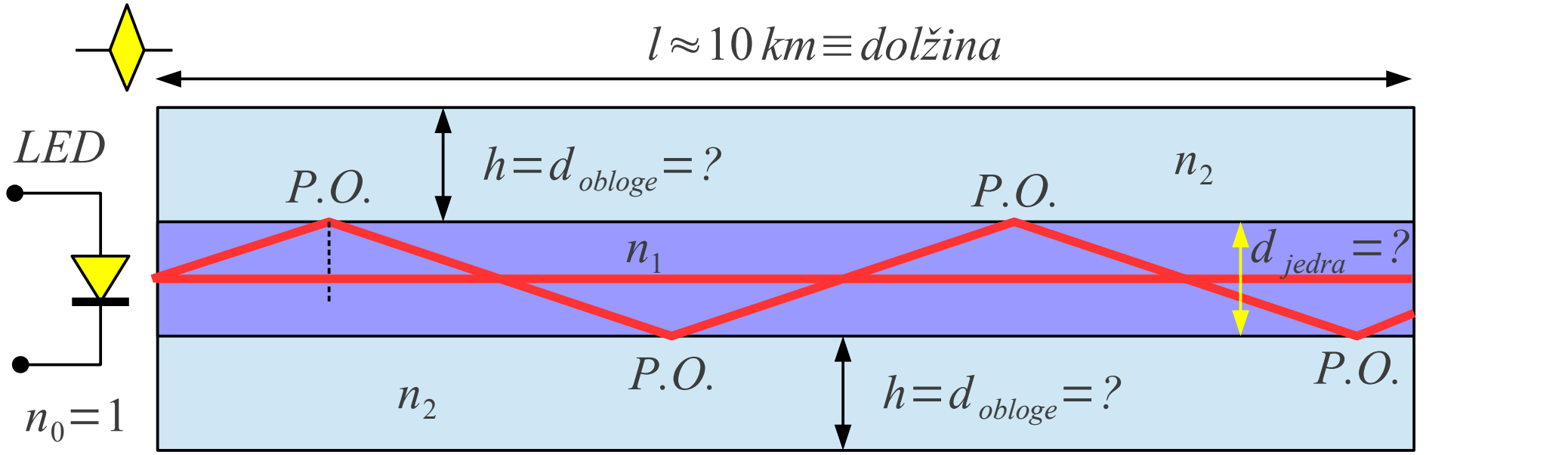


$$h = r(1-\cos\alpha)$$

$$\Omega = \frac{A}{r^2} = \frac{2\pi r h}{r^2} = 2\pi(1-\cos\alpha)$$

Zgled $NA \approx 0.2$

$$\eta \approx \frac{0.2^2}{4} = 0.01$$



Večpotje

Raven žarek $t_1 = \frac{l\, n_1}{c_0}$

$l' = \frac{l}{\sin \Theta_m} = l \frac{n_1}{n_2}$

$\Delta t = t_2 - t_1$

Cikcak $t_2 = \frac{l'\, n_1}{c_0} = t_1 \frac{n_1}{n_2}$

$n_1 \approx 1.5$

$\Delta \approx 0.009$

$\Delta t \approx 0.45\,\mu s$

$\Delta t < \frac{T_{bit}}{3}$

$\Delta t = \frac{l\, n_1}{c_0}\left(\frac{n_1}{n_2} - 1\right) = \frac{l\, n_1^2}{c_0 n_2}\Delta \approx \frac{l\, n_1}{c_0}\Delta$

$C[bit/s] \approx \frac{1}{3\,\Delta t} \approx 740\,kbit/s$