Strokovno izobraževanje

ELEKTROMAGNETNO SEVANJE

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Seznam prosojnic predavanja: ELEKTROMAGNETNO SEVANJE

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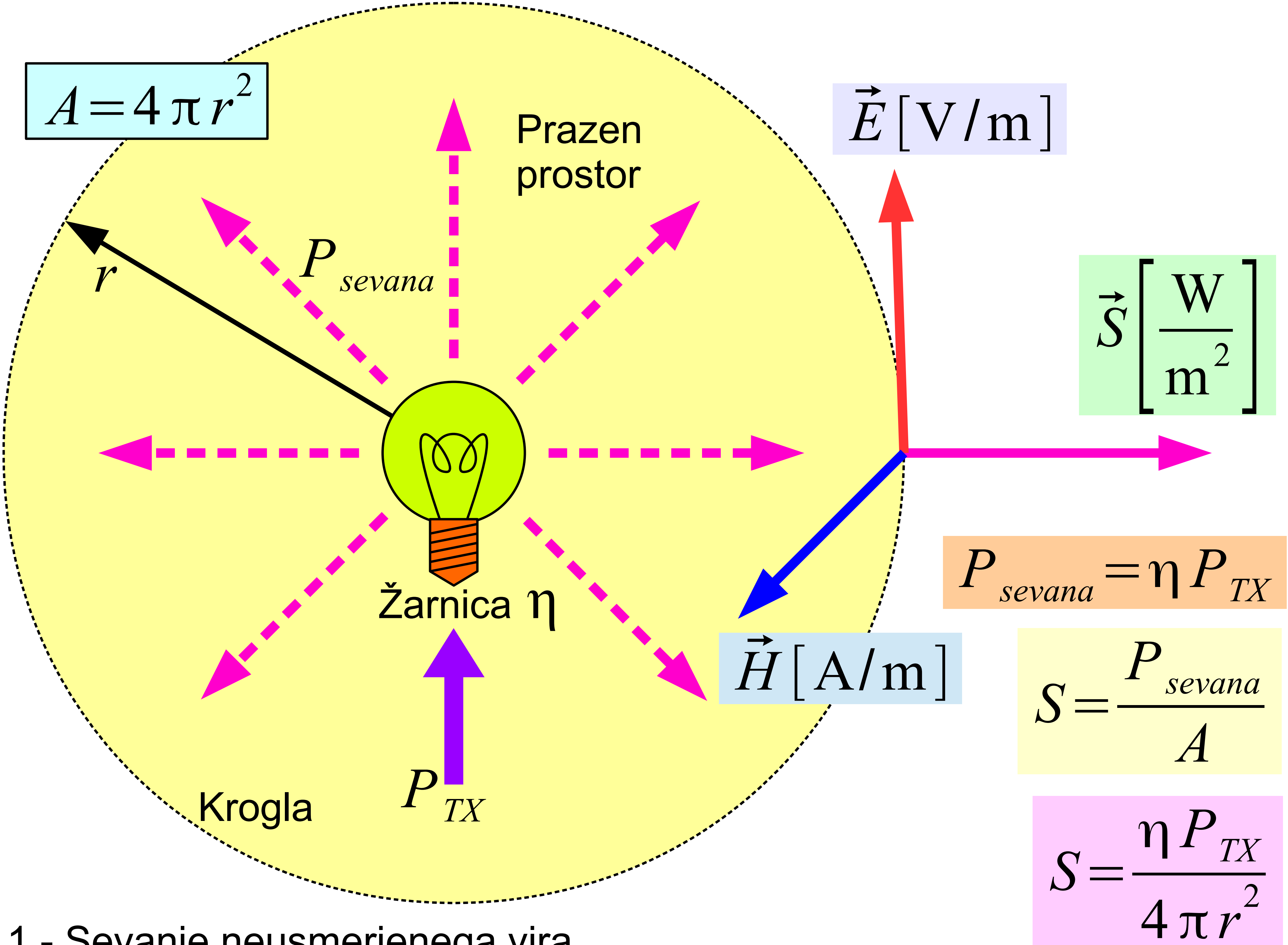
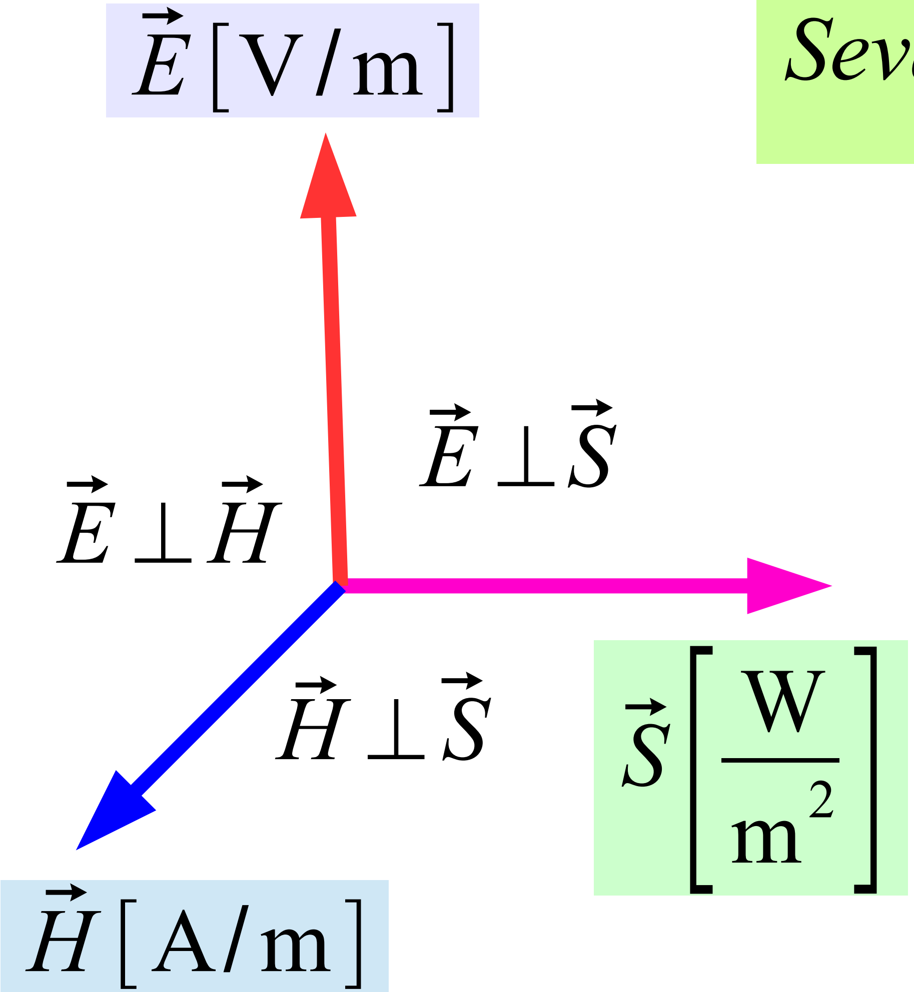


1 - Sevanje neusmerjenega vira



Sevanje: $\dfrac{E}{H} = Z_0 = \sqrt{\dfrac{\mu_0}{\epsilon_0}} \approx 377\,\Omega$

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

Vršne vrednosti polja

$$S = \frac{|\vec{E}|^2}{2Z_0} \qquad E = \sqrt{2 Z_0 S}$$

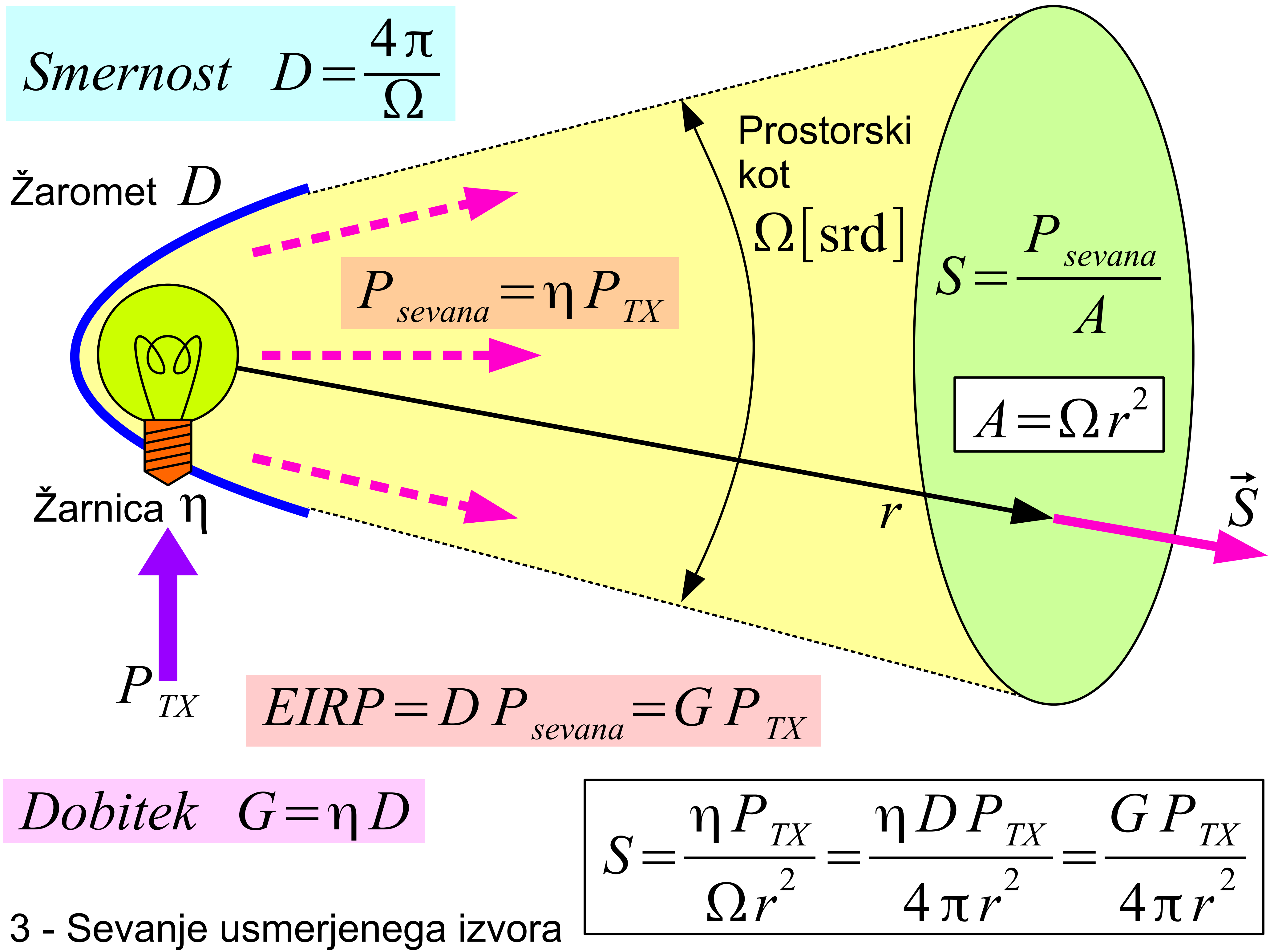
$$\vec{S} = \vec{E}_{eff} \times \vec{H}_{eff}^*$$

Efektivne vrednosti polja

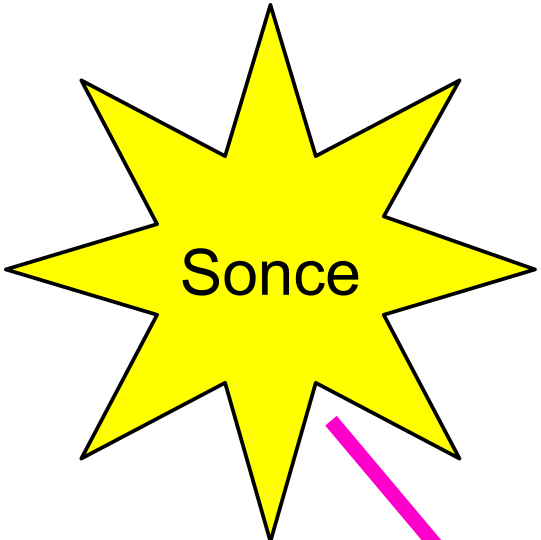
$$S = \frac{|\vec{E}_{eff}|^2}{Z_0} \qquad E_{eff} = \sqrt{Z_0 S}$$

Prazen prostor μ_0, ϵ_0

brez izgub!



3 - Sevanje usmerjenega izvora



Učinek sevanja	Gostota pretoka moči S		Poljska jakost E_{eff}
Sončna svetloba	$1\,\mathrm{kW/m^2}$	$100\,\mathrm{mW/cm^2}$	$614\,\mathrm{V_{eff}/m}$
Zaznaven učinek	$100\,\mathrm{W/m^2}$	$10\,\mathrm{mW/cm^2}$	$194\,\mathrm{V_{eff}/m}$
Varna meja	$10\,\mathrm{W/m^2}$	$1\,\mathrm{mW/cm^2}$	$61\,\mathrm{V_{eff}/m}$
Zakonska omejitev	$0.1\,\mathrm{W/m^2}$	$10\,\mu\mathrm{W/cm^2}$	$6\,\mathrm{V_{eff}/m}$

$$S = 1\,\mathrm{kW/m^2}$$

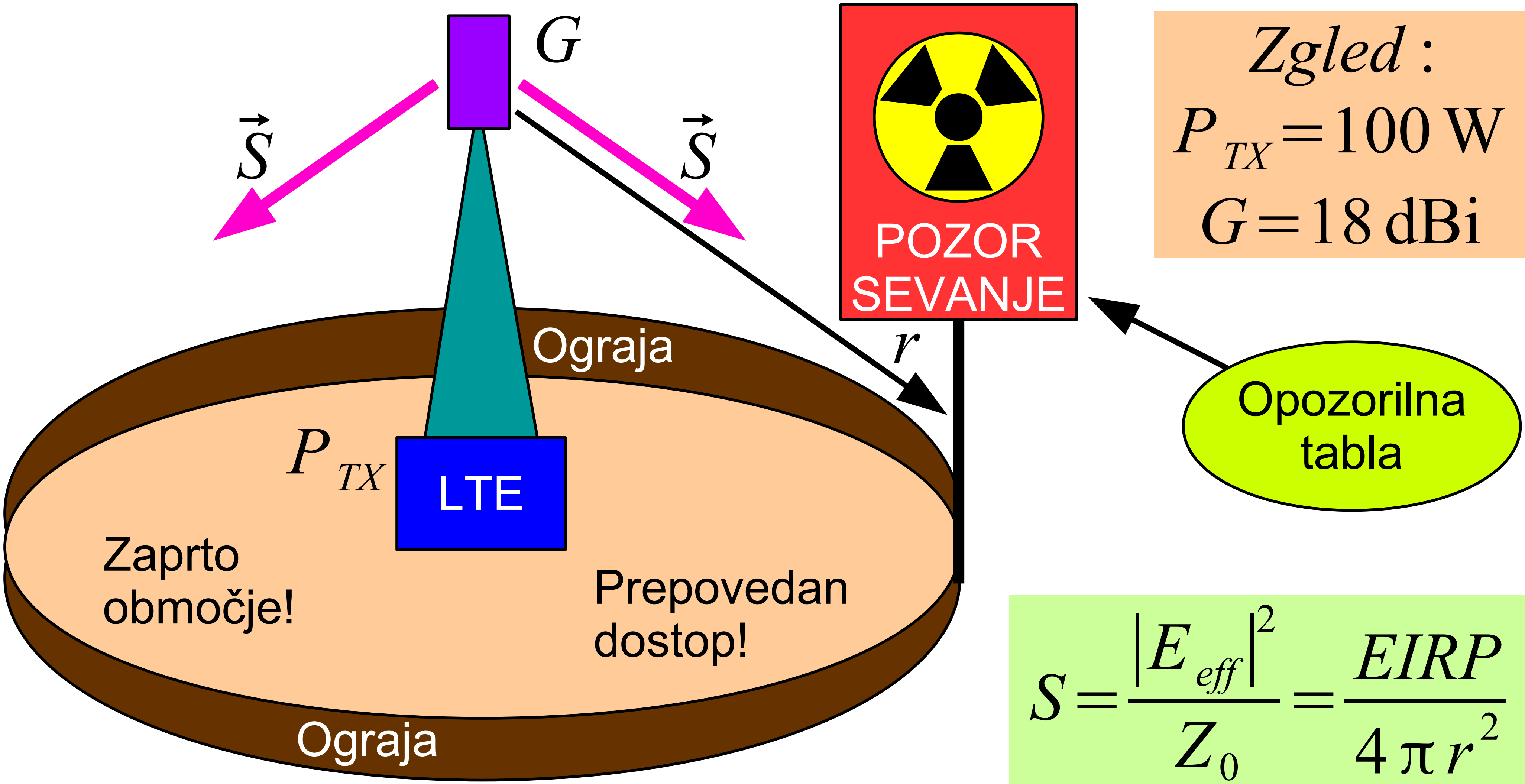
(na površini Zemlje)

$$A_{maček} = 0.05\,\mathrm{m^2}$$

$$P_{RX} = S \cdot A_{maček}$$

$$P_{RX} = 50\,\mathrm{W}$$

$$EIRP = +68\,\mathrm{dBm} = 10^{(68/10)} \cdot 1\,\mathrm{mW} = 6.3\,\mathrm{kW}$$



Zgled:

$$P_{TX} = 100\,\mathrm{W}$$

$$G = 18\,\mathrm{dBi}$$

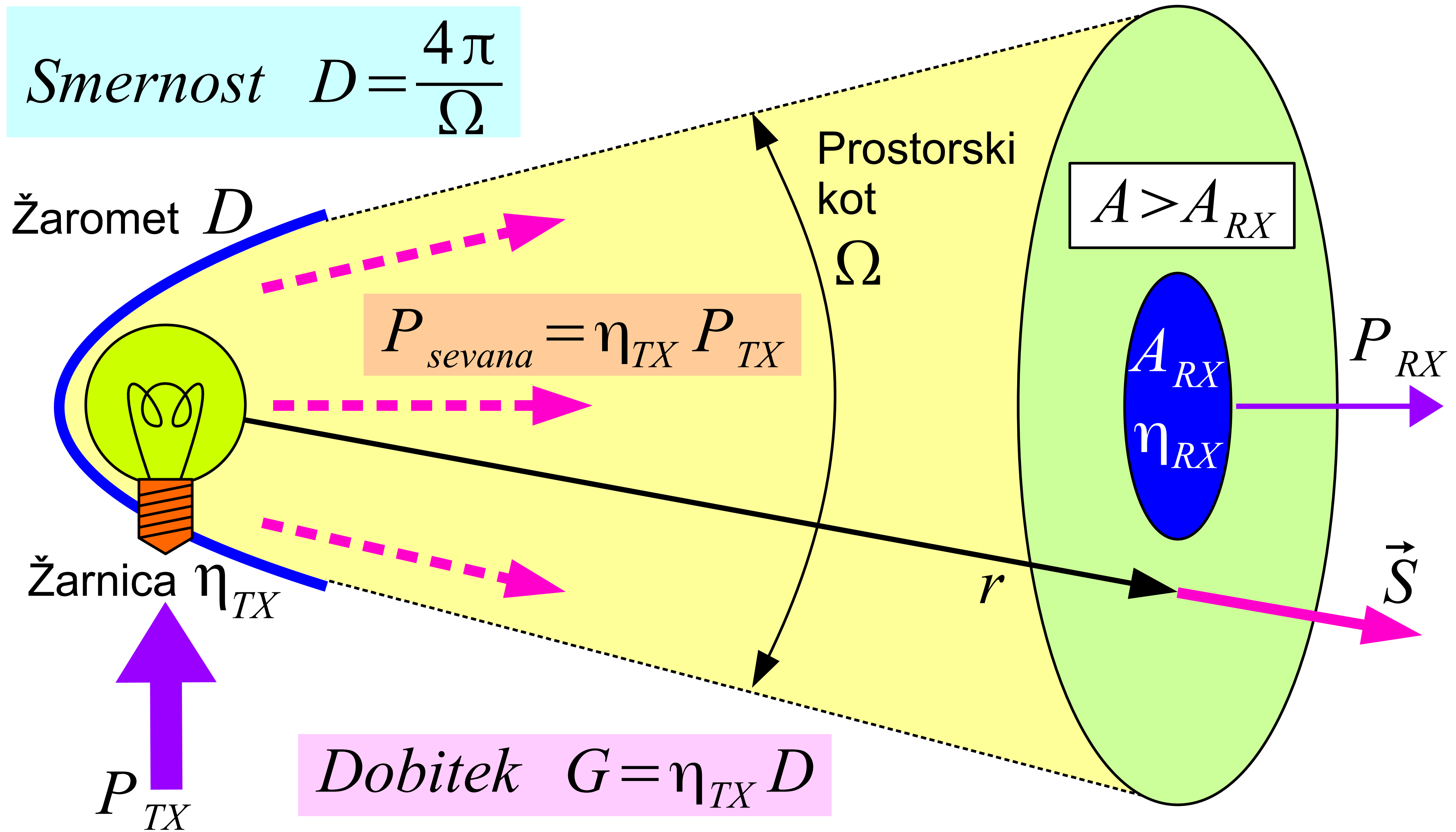
$$S = \frac{|E_{eff}|^2}{Z_0} = \frac{EIRP}{4\pi r^2}$$

EU zakonodaja

$$E_{eff} \leq 6\,\mathrm{V_{eff}}/\mathrm{m}$$

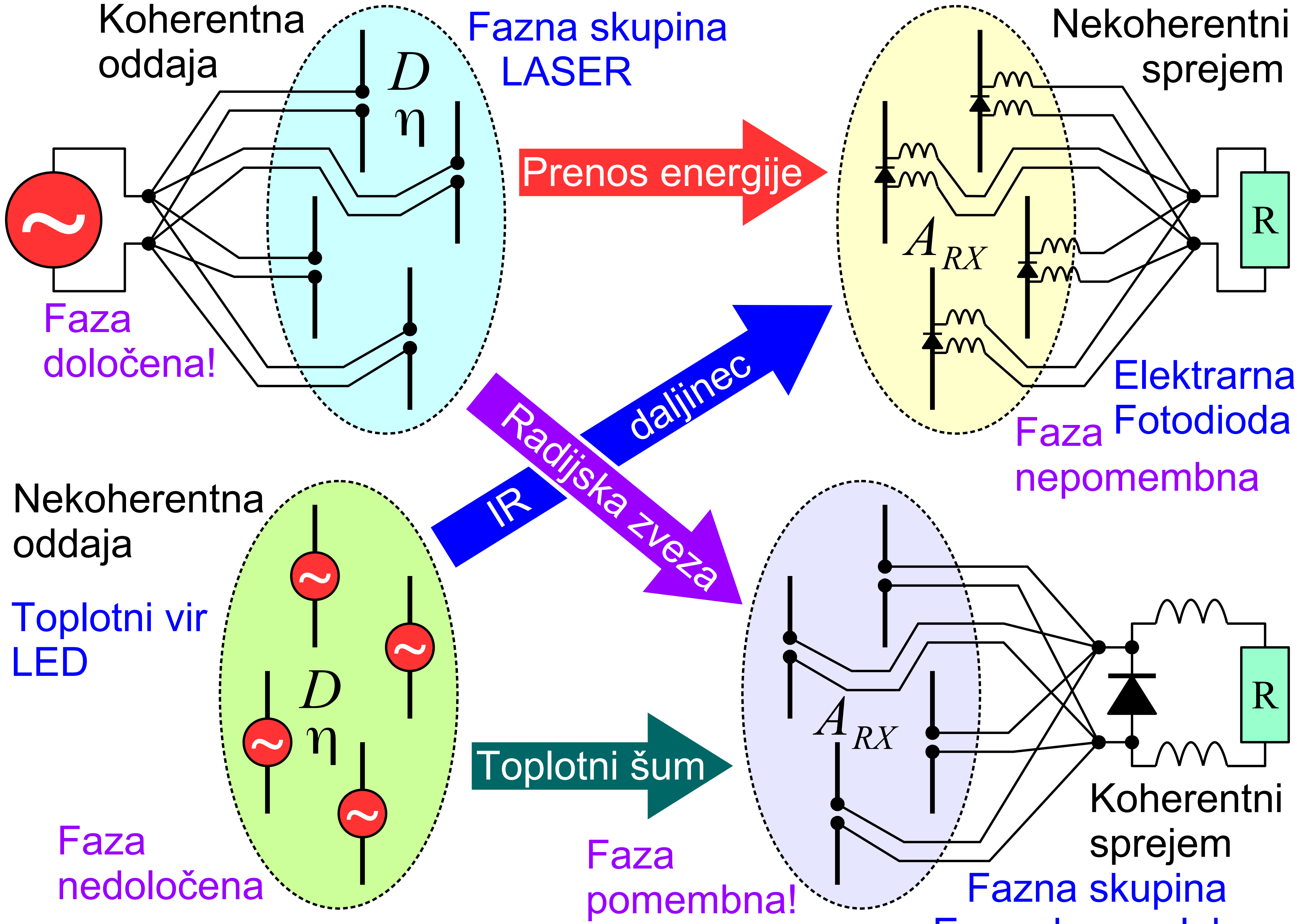
$$r \geq \sqrt{\frac{Z_0 EIRP}{4\pi |E_{eff}|^2}} = 72.5\,\mathrm{m}$$

5 - Ograja okoli vira sevanja

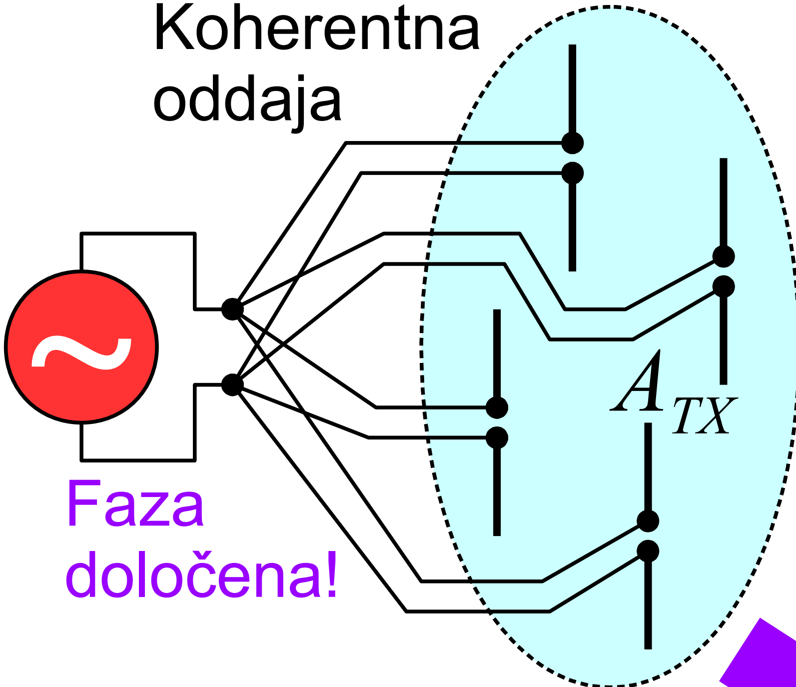


$$P_{RX}=A_{RX}\eta_{RX}S=\frac{A_{RX}\eta_{RX}\eta_{TX}DP_{TX}}{4\pi r^2}=P_{TX}\cdot\frac{A_{RX}\eta_{RX}G}{4\pi r^2}$$

6 - Domet brezvrvične zveze v praznem prostoru



7 - Nekoherentna in koherentna oddaja in sprejem



D_{TX}
η_{TX}
G_{TX}
A_{effTX}

$$A_{effTX} = \frac{\lambda^2}{4\pi} \cdot D_{TX}$$

$$A_{effTX} = \frac{\lambda^2}{4\pi} \cdot \frac{G_{TX}}{\eta_{TX}}$$

$$A_{eff} = A \cdot \eta_O \equiv efektivna \quad površina$$

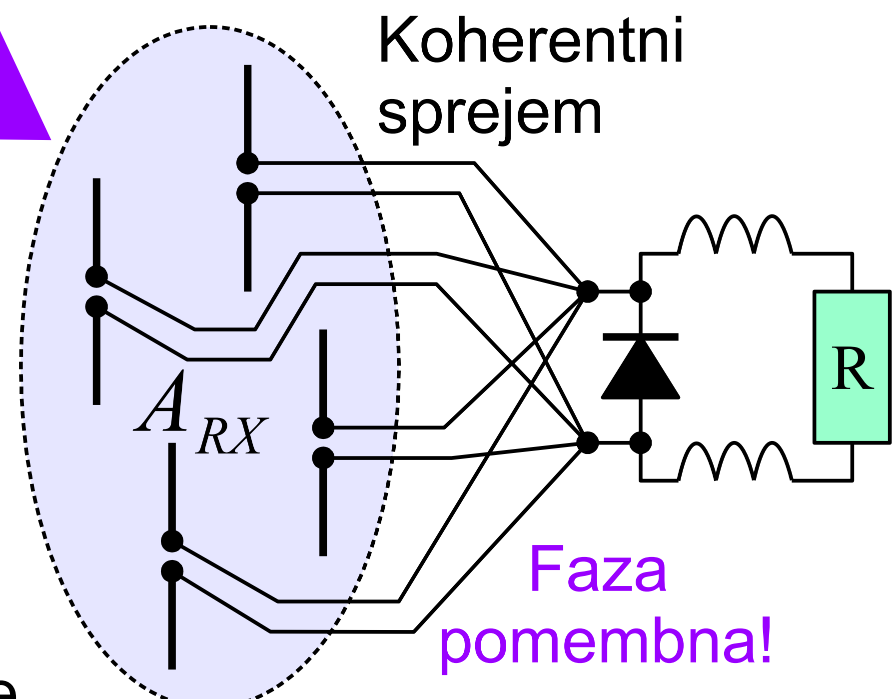
$$\eta_O \equiv izkoristek \quad osvetlitve$$

$$\eta_O \approx 50\% ... 80\%$$

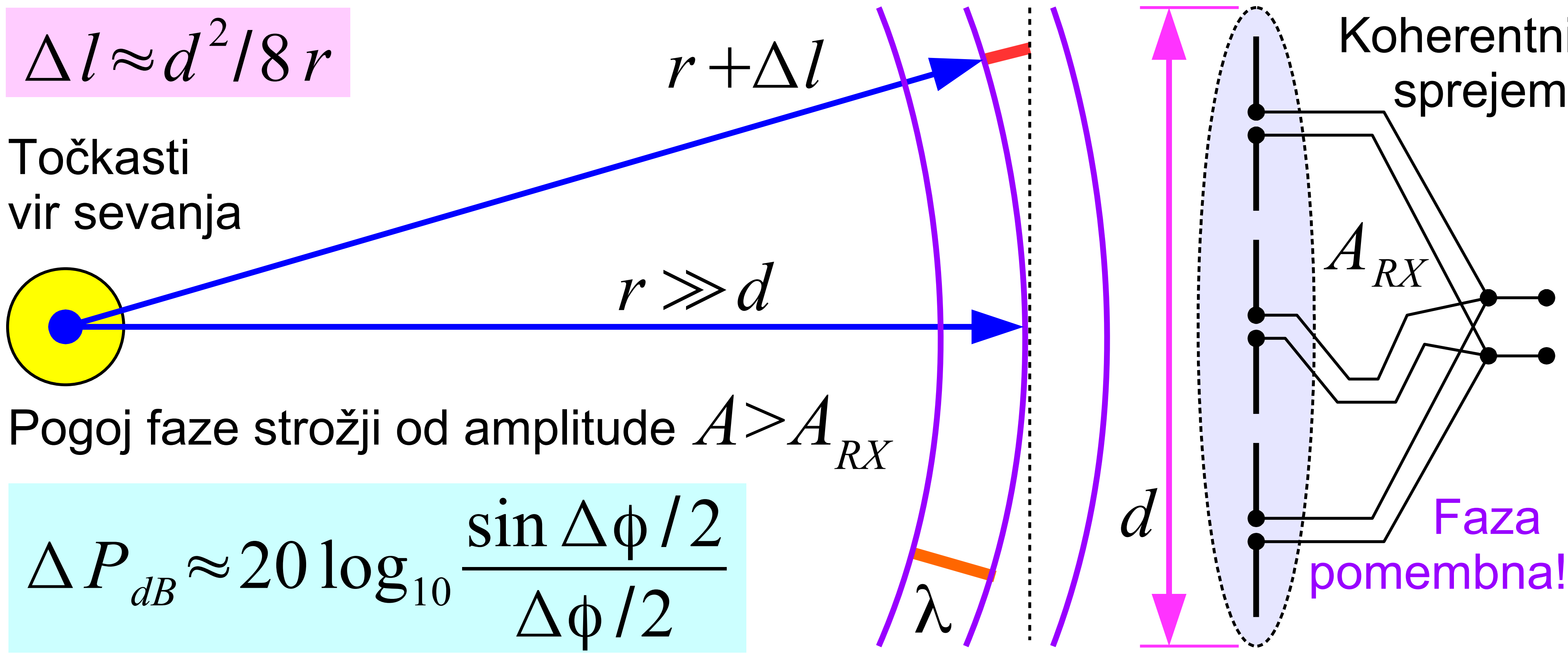
$$D_{RX} = \frac{4\pi}{\lambda^2} \cdot A_{effRX}$$

$$G_{RX} = \frac{4\pi}{\lambda^2} \cdot A_{effRX} \cdot \eta_{RX}$$

A_{effRX}
η_{RX}
D_{RX}
G_{RX}

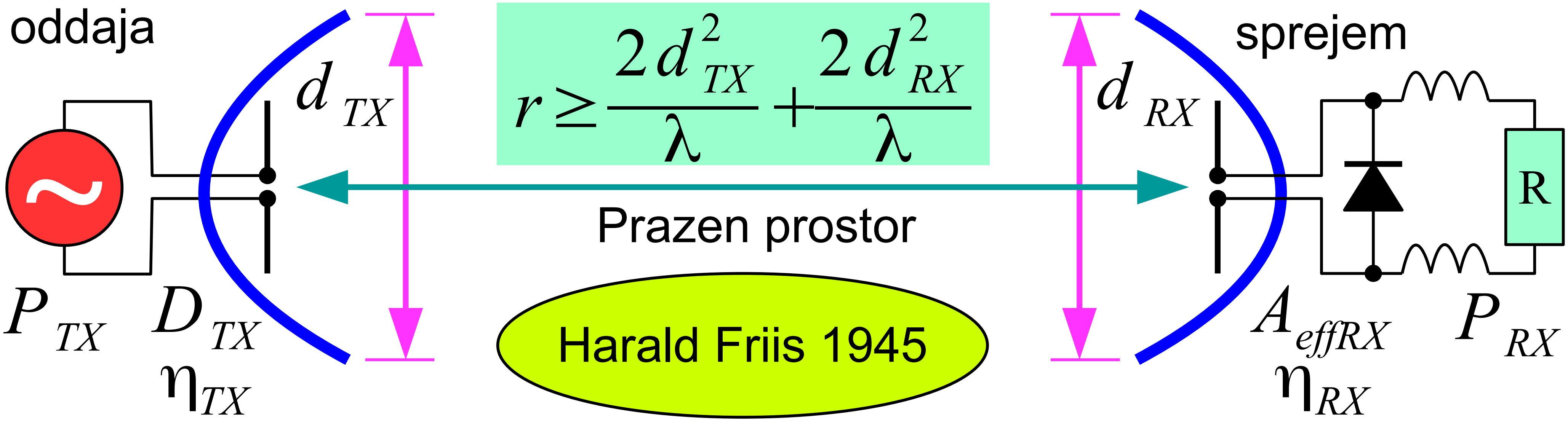


8 - Efektivna površina koherentne antene



Δl	$\Delta\varphi$[rd]	ΔP[dB]	r≥	Uporaba
$\lambda/2$	π	-3.922	$d^2/4\lambda$	Globinska ostrina fotoaparata
$\lambda/4$	$\pi/2$	-0.912	$d^2/2\lambda$	Lord Rayleigh 1891
$\lambda/8$	$\pi/4$	-0.224	d^2/λ	
$\lambda/16$	$\pi/8$	-0.056	$2d^2/\lambda$	Meritev radijskih signalov

9 - Fraunhoferjev pogoj (Rayleighjeva razdalja)



$$r \geq \frac{2d_{TX}^2}{\lambda} + \frac{2d_{RX}^2}{\lambda}$$

$$P_{RX} = P_{TX} \frac{\eta_{TX} D_{TX} A_{effRX} \eta_{RX}}{4\pi r^2}$$

Zapis z dobitki anten:

$$P_{RX} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi r} \right)^2$$

Recipročnost !

Zapis s površinami anten:

$$P_{RX} = P_{TX} \frac{\eta_{TX} A_{effTX} A_{effRX} \eta_{RX}}{\lambda^2 r^2}$$

10 - Friisova enačba za domet koherentne zveze

$$D[\mathrm{dBi}] = 10\log_{10} D$$
$$G[\mathrm{dBi}] = 10\log_{10} G$$

dBi ≡ dB glede na neusmerjen (izotropni) vir

$$D[\mathrm{dBd}] = D[\mathrm{dBi}] - 2.15\,\mathrm{dB}$$
$$G[\mathrm{dBd}] = G[\mathrm{dBi}] - 2.15\,\mathrm{dB}$$

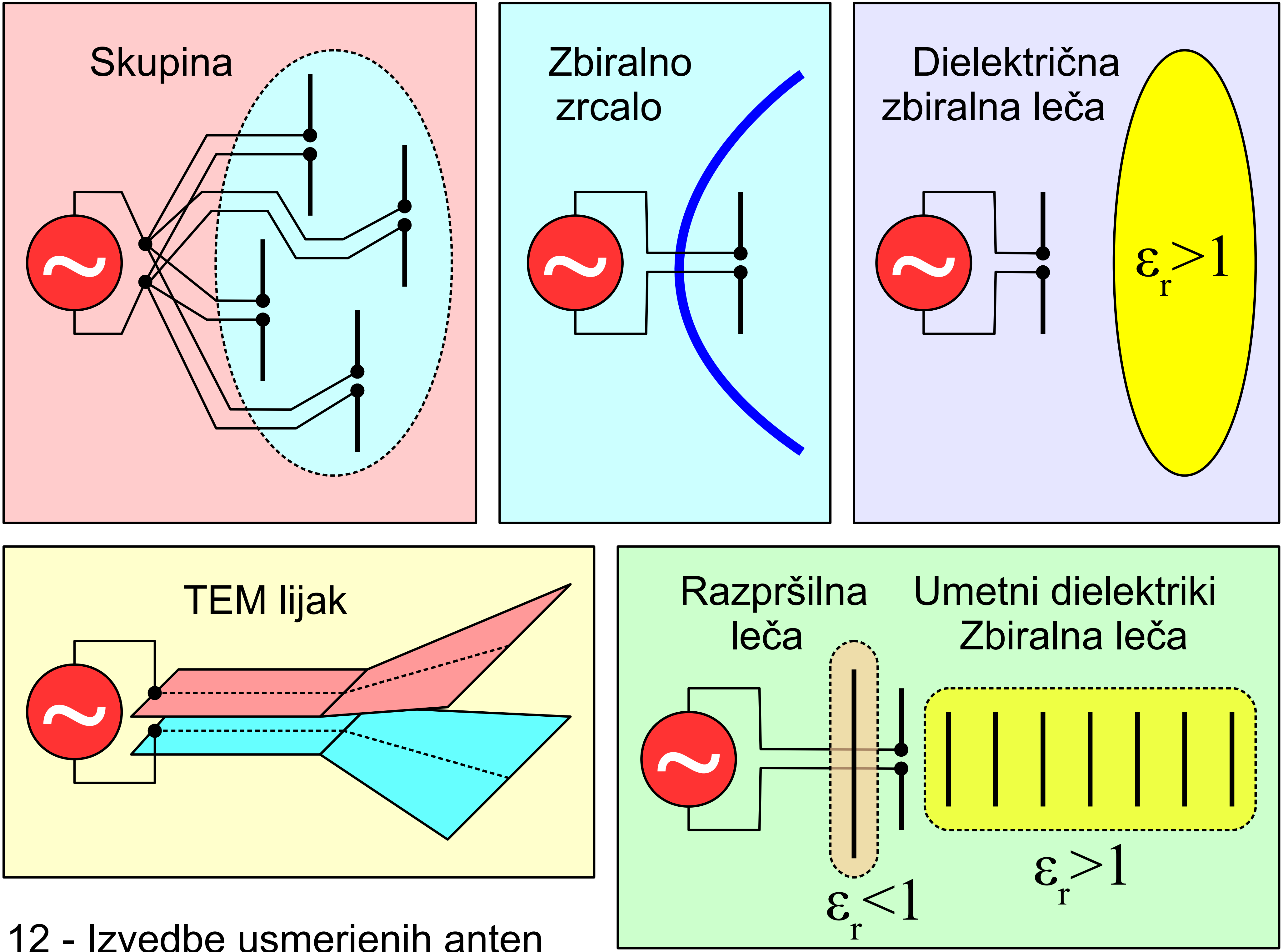
dBd ≡ dB glede na polvalni dipol

Iskanje nesreče s Friisovo enačbo na tisoč in en način:

$$P_{RX}[\mathrm{dBm}] = P_{TX}[\mathrm{dBm}] + G_{TX}[\mathrm{dBi}] + G_{RX}[\mathrm{dBi}] + \\ + 20\log_{10}\lambda[\mathrm{m}] - 20\log_{10} r[\mathrm{m}] - 21.98\,\mathrm{dB}$$

$$\lambda[\mathrm{m}] \approx 299.7/f[\mathrm{MHz}] \qquad zrak: \; n = 1.0003$$

$$P_{RX}[\mathrm{dBm}] = P_{TX}[\mathrm{dBm}] + G_{TX}[\mathrm{dBi}] + G_{RX}[\mathrm{dBi}] - \\ - 20\log_{10} f[\mathrm{MHz}] - 20\log_{10} r[\mathrm{m}] + 27.55\,\mathrm{dB}$$



12 - Izvedbe usmerjenih anten

13 - Smerni diagram antene

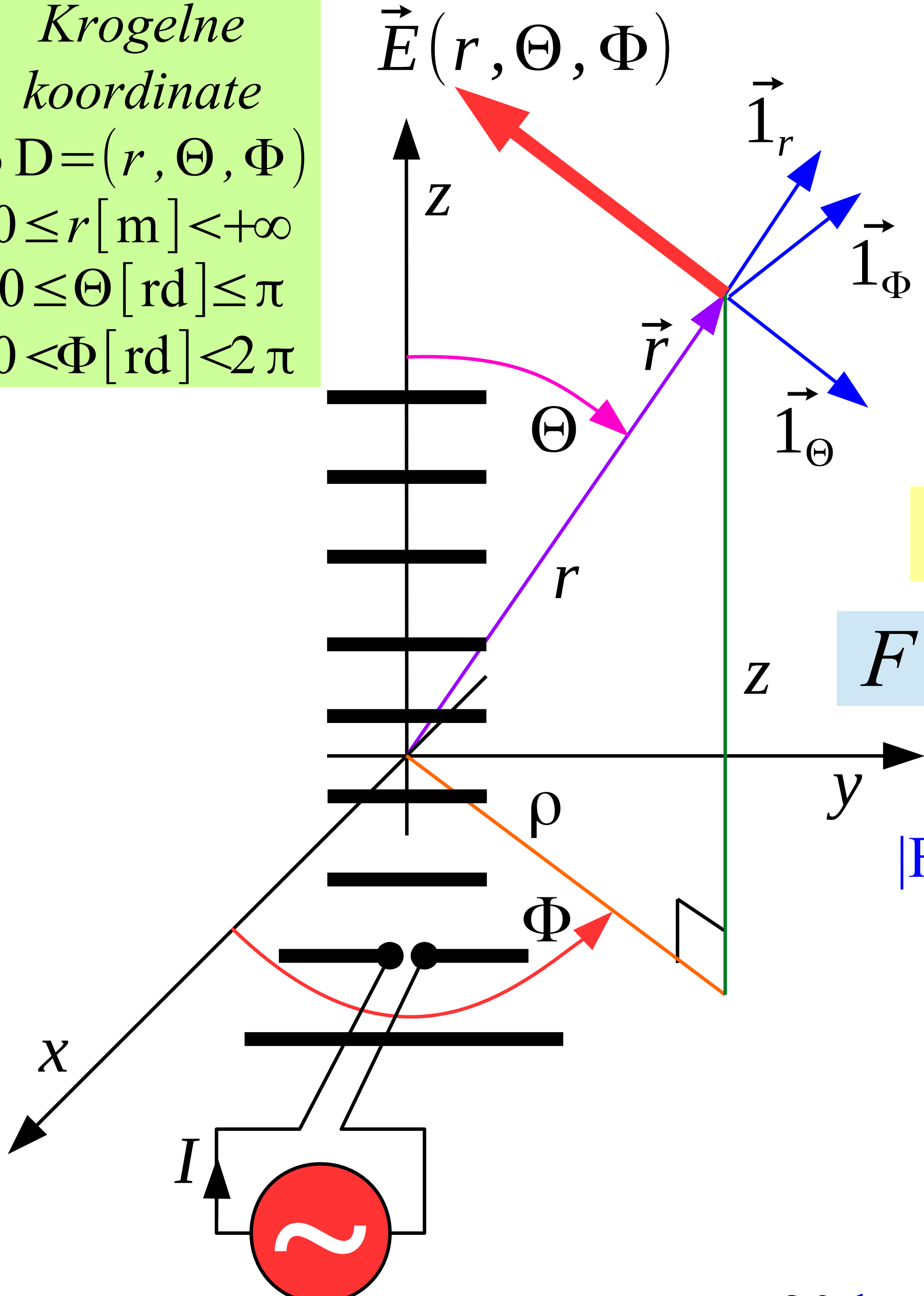
Krogelne koordinate

$3\,\mathrm{D} = (r, \Theta, \Phi)$

$0 \le r[\mathrm{m}] < +\infty$

$0 \le \Theta[\mathrm{rd}] \le \pi$

$0 < \Phi[\mathrm{rd}] < 2\pi$



$$\vec{E} = \vec{1}_P\, \alpha\, I \frac{e^{-j 2\pi \frac{r}{\lambda}}}{r} F(\Theta, \Phi)$$

$\vec{1}_P \equiv$ polarizacija

$F(\theta,\Phi) \equiv$ amplitudni smerni diagram

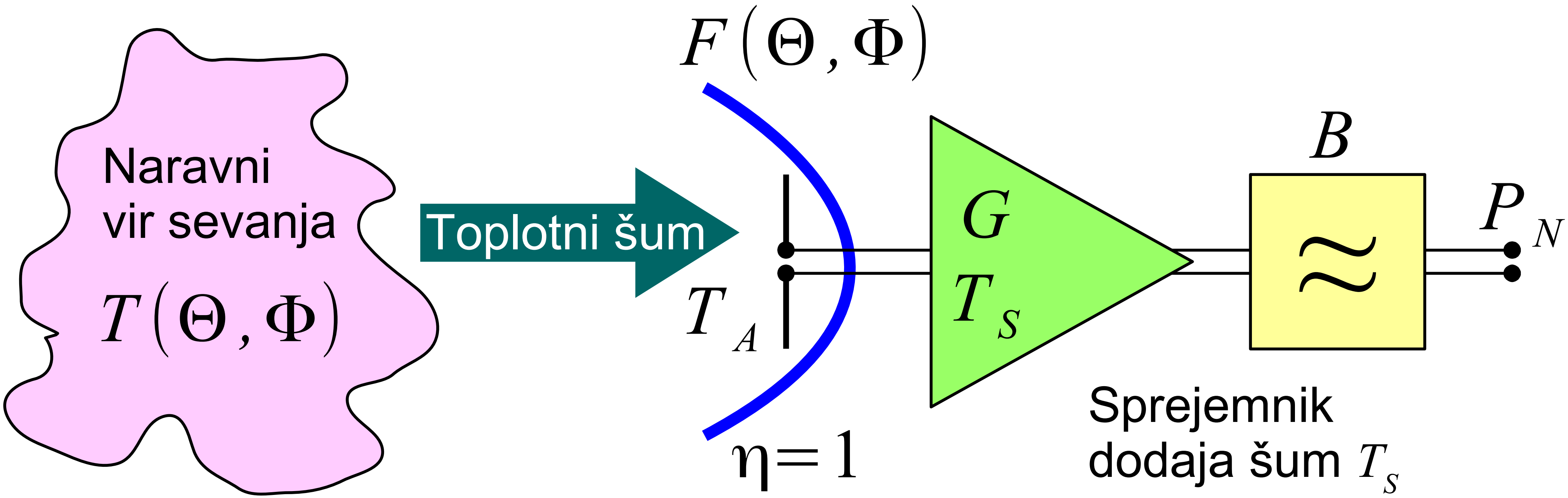
$F(\Theta, \Phi = 0) \equiv Ravnina \quad H$

$F(\Theta, \Phi = \pi/2) \equiv Ravnina \quad E$

$|F(\theta,\Phi)|^2 \equiv$ močnostni smerni diagram

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

$20 \log|F(\theta,\Phi)| \equiv$ decibelski smerni diagram



Vir dodaja šum T_A

Brezizgubna antena ne dodaja šuma!

$$T_A = \frac{\iint\limits_{4\pi} T(\Theta,\Phi)\left|F(\Theta,\Phi)\right|^2 d\Omega}{\iint\limits_{4\pi} \left|F(\Theta,\Phi)\right|^2 d\Omega}$$

$T_A \equiv$ utežena vsota šuma $T(\Theta,\Phi)$

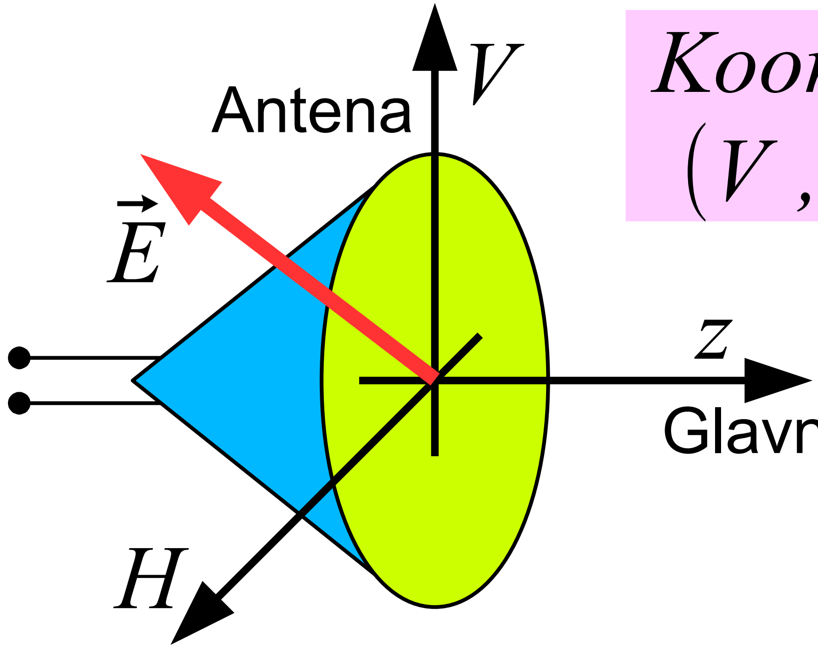
Boltzmannova konstanta za toplotni šum:

$$k_B \approx 1.38 \cdot 10^{-23}\ \mathrm{J/K}$$

Moč šuma na izhodu sprejemnika:

$$P_N = G \cdot B \cdot k_B \cdot (T_A + T_S)$$

14 - Šumna temperatura antene



Koordinate
(V, H, z)

Linearne komponente:

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

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

Krožne komponente:

$$E_L = \vec{E} \cdot \vec{1}_L^{\,*}$$

$$E_D = \vec{E} \cdot \vec{1}_D^{\,*}$$

$$Q = \frac{E_L}{E_D}$$

Prečno valovanje: dve neodvisni polarizaciji!

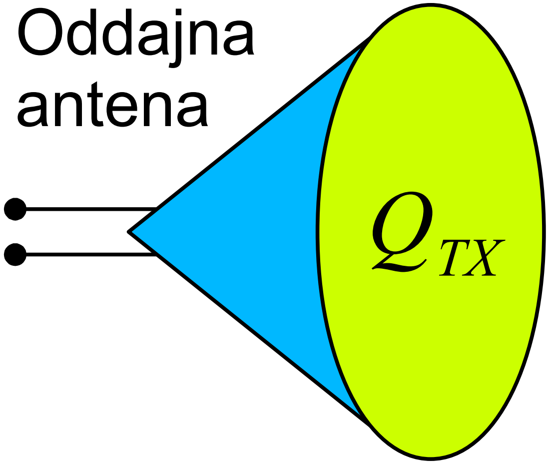
Krožni smerniki:

$$\vec{1}_L = \frac{\vec{1}_V + j\,\vec{1}_H}{\sqrt{2}}$$

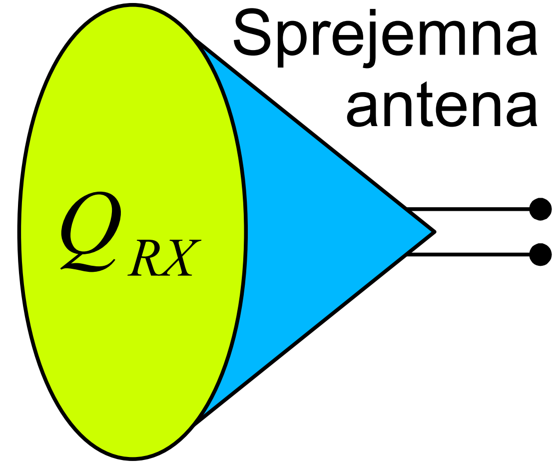
$$\vec{1}_D = \frac{\vec{1}_V - j\,\vec{1}_H}{\sqrt{2}}$$

Osno razmerje:

$$R = \left| \frac{1 + |Q|}{1 - |Q|} \right| \qquad R_{dB} = 20 \log_{10} R$$

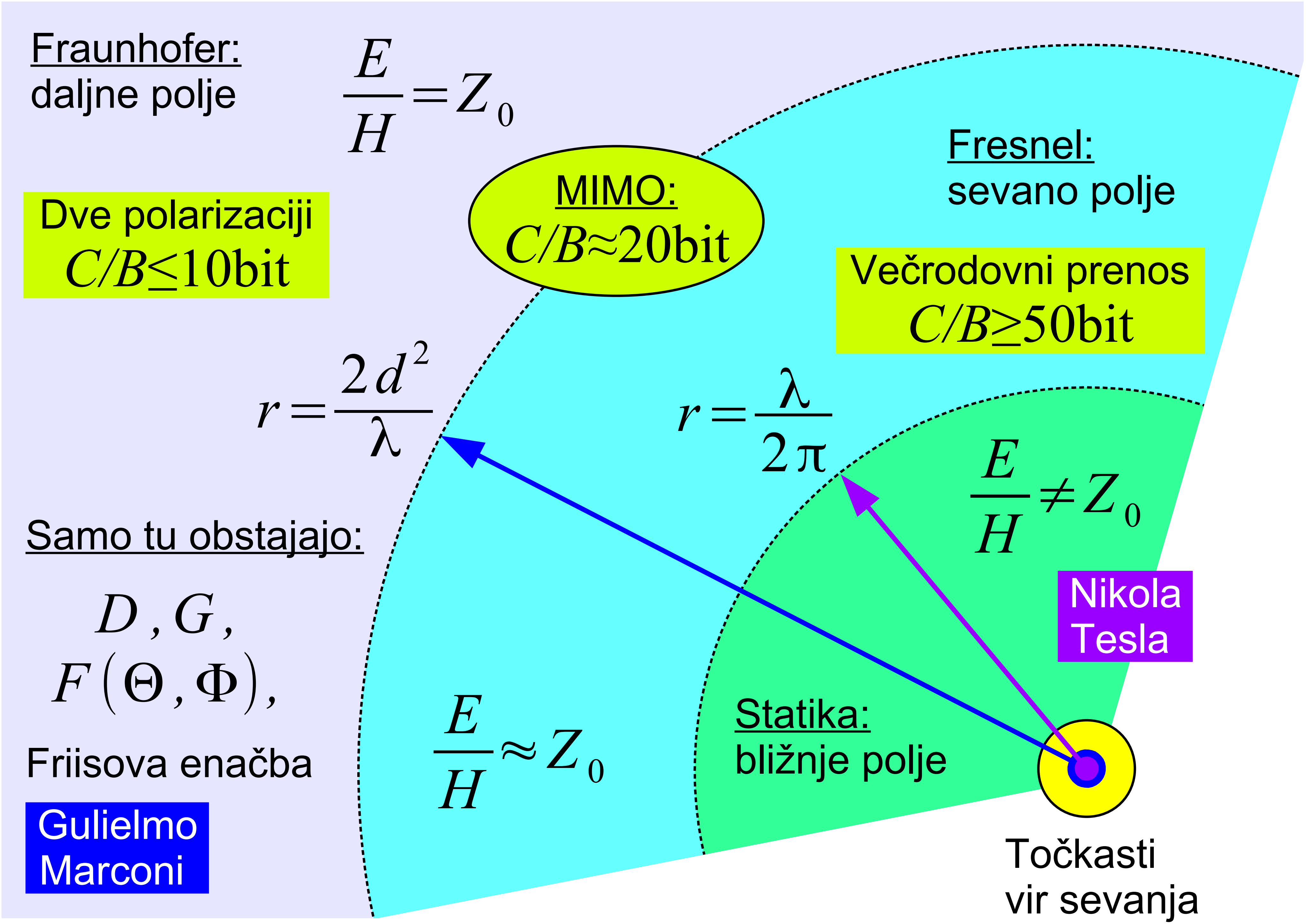


$$\eta = \frac{\left|1 + Q_{TX} Q_{RX}\right|^2}{\left(1 + \left|Q_{TX}\right|^2\right)\left(1 + \left|Q_{RX}\right|^2\right)}$$



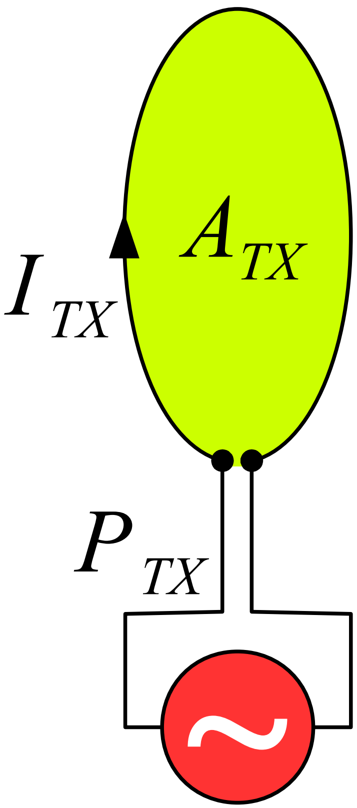
Polarizacija TX		Q_{TX}	R_{TX}	Faktor skladnosti η / polarizacija RX					
				VP	HP	RHCP	LHCP	PP_{45}	PP_{135}
VP	$\vec{1}_V$	1	∞	1	0	1/2	1/2	1/2	1/2
HP	$\vec{1}_H$	-1	∞	0	1	1/2	1/2	1/2	1/2
RHCP	$\vec{1}_D$	0	1	1/2	1/2	1	0	1/2	1/2
LHCP	$\vec{1}_L$	∞	1	1/2	1/2	0	1	1/2	1/2
PP_{45}	$(\vec{1}_V + \vec{1}_H)/\sqrt{2}$	-j	∞	1/2	1/2	1/2	1/2	0	1
PP_{135}	$(\vec{1}_V - \vec{1}_H)/\sqrt{2}$	j	∞	1/2	1/2	1/2	1/2	1	0

16 - Faktor skladnosti polarizacije



17 - Statika, Fresnel in Fraunhofer

$$\frac{E}{H} \neq Z_0 \rightarrow \text{ Potrebna ločena meritev } \vec{E} \text{ ter } \vec{H}$$

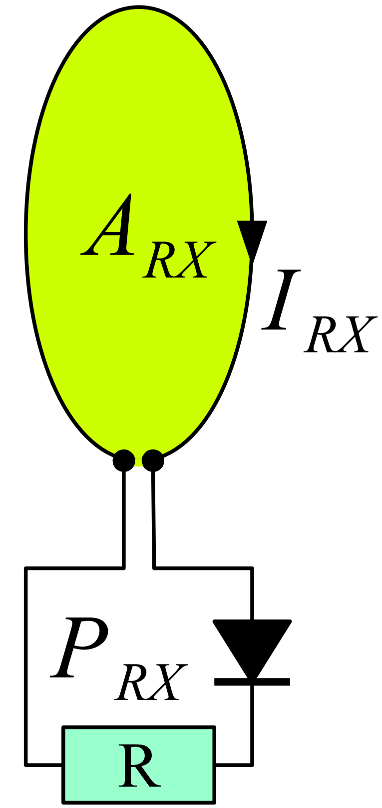


$$\sqrt{A_{TX}}, \sqrt{A_{RX}} \ll r \ll \frac{\lambda}{2\pi}$$

$$M = \frac{\mu}{2\pi} \cdot \frac{A_{TX} A_{RX}}{r^3}$$

$$\mu = \mu_0$$

$$\text{Mahjen domet: } P_{RX} = P_{TX} \, \alpha \, r^{-6}$$



$$\mathrm{Re}\left[\vec{S}\right] = f\left(I_{TX}, I_{RX}\right)$$

Brez sevanja!

Uporaba:

RFID in druge zveze kratkega dosega

Prenos energije (brezžično polnjenje)

18 - Induktivni sklop v bližnjem polju