

Strokovno izobraževanje

ELEKTROMAGNETNO SEVANJE

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Seznam prosojnic predavanja: ELEKTROMAGNETNO SEVANJE

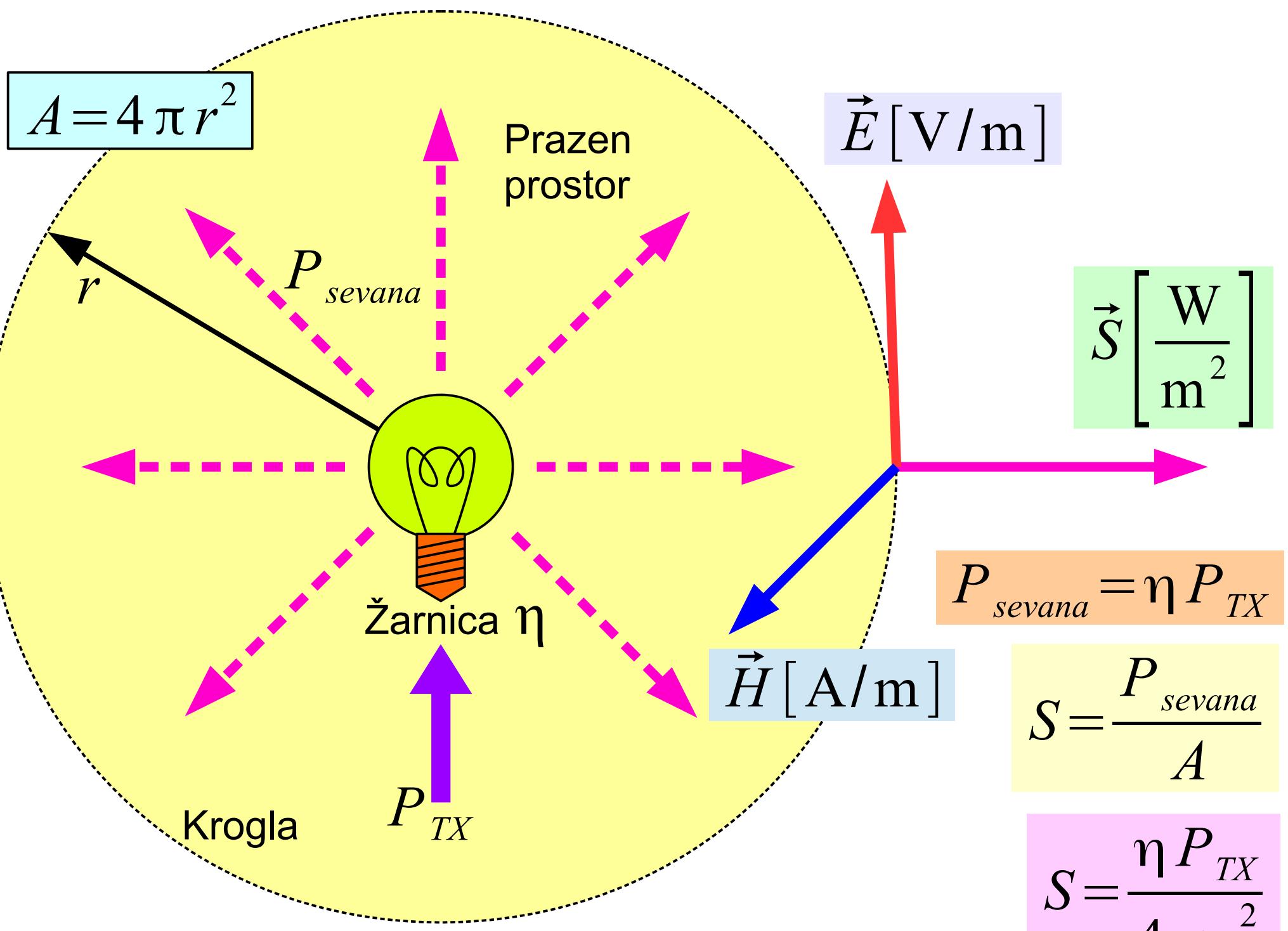
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- 4 - Toplotni učinki sevanja
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$$A = 4 \pi r^2$$

Prazen prostor

$$\vec{E} [\text{V/m}]$$

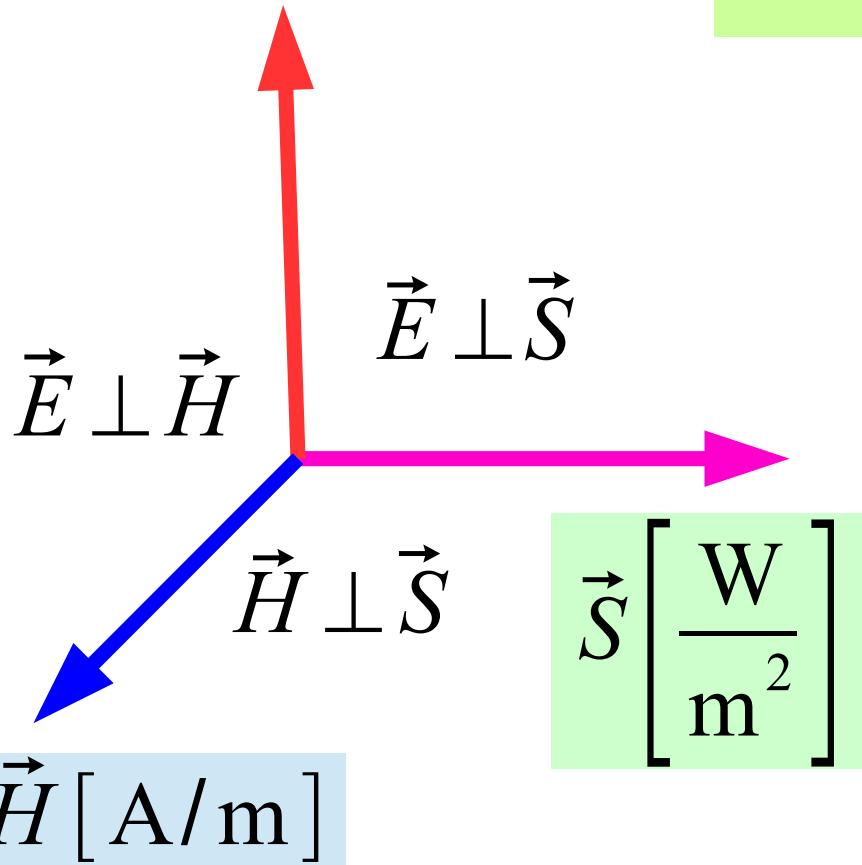
$$\vec{S} \left[\frac{\text{W}}{\text{m}^2} \right]$$



1 - Sevanje neusmerjenega vira

$$S = \frac{\eta P_{TX}}{4 \pi r^2}$$

\vec{E} [V/m]



Prazen prostor μ_0, ϵ_0
brez izgub!

2 - Sevana polja in moči

Sevanje:

$$\frac{E}{H} = Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \approx 377 \Omega$$

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

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

$$E = \sqrt{2 Z_0 S}$$

Vršne
vrednosti
polja

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

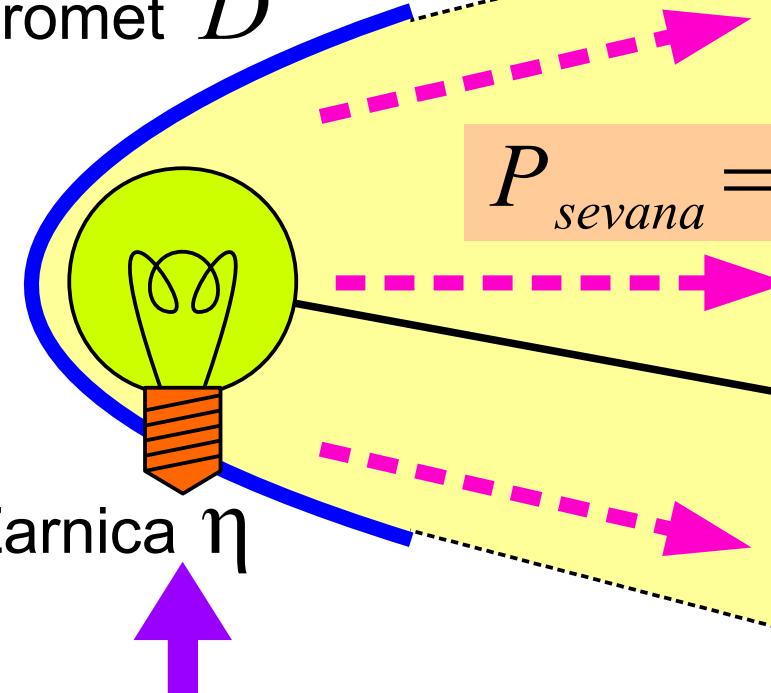
$$S = \frac{|\vec{E}_{eff}|^2}{Z_0}$$

$$E_{eff} = \sqrt{Z_0 S}$$

Efektivne
vrednosti
polja

Smernost $D = \frac{4\pi}{\Omega}$

Žaromet D



Žarnica η

$$P_{TX}$$

$$EIRP = D P_{sevana} = G P_{TX}$$

Prostorski
kot
 Ω [srđ]

$$S = \frac{P_{sevana}}{A}$$

$$A = \Omega r^2$$

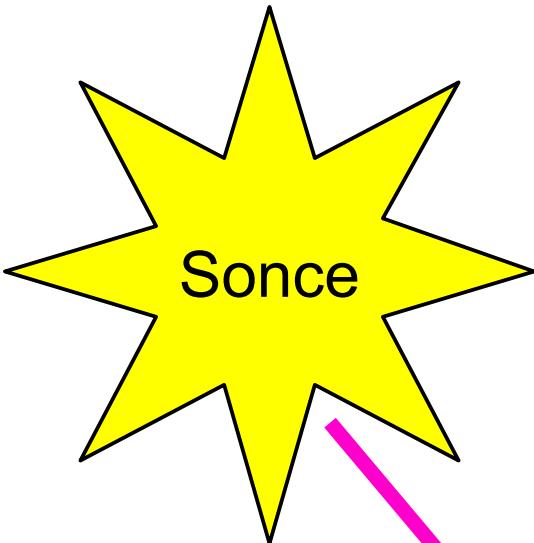
$$r$$

$$\vec{S}$$

Dobitek $G = \eta D$

3 - Sevanje usmerjenega izvora

$$S = \frac{\eta P_{TX}}{\Omega r^2} = \frac{\eta D P_{TX}}{4\pi r^2} = \frac{G P_{TX}}{4\pi r^2}$$



Učinek sevanja	Gostota pretoka moči S		Poljska jakost E_{eff}
Sončna svetloba	1kW/m ²	100mW/cm ²	614V _{eff} /m
Zaznaven učinek	100W/m ²	10mW/cm ²	194V _{eff} /m
Varna meja	10W/m ²	1mW/cm ²	61V _{eff} /m
Zakonska omejitev	0.1W/m ²	10μW/cm ²	6V _{eff} /m

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

(na površini Zemlje)

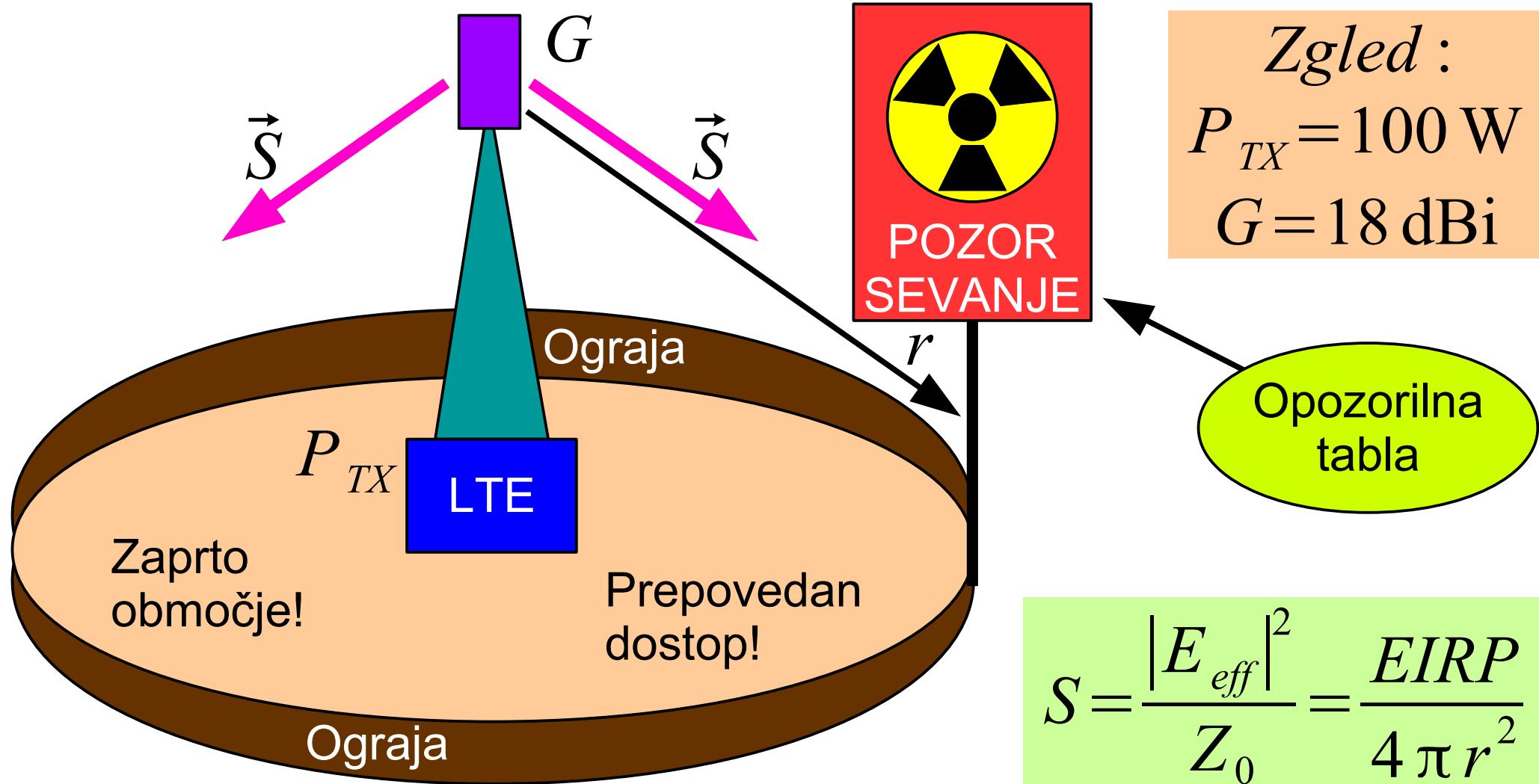
$$P_{RX} = S \cdot A_{maček}$$



$$A_{maček} = 0.05 \text{ m}^2$$

$$P_{RX} = 50 \text{ W}$$

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



EU zakonodaja

$$E_{eff} \leq 6 \text{ V}_{eff}/\text{m}$$

5 - Ograja okoli vira sevanja



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

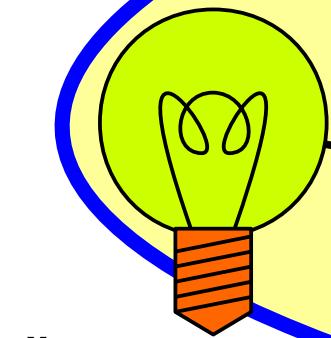
Smernost $D = \frac{4\pi}{\Omega}$

Žaromet D

Prostorski
kot
 Ω

$$A > A_{RX}$$

$$P_{sevana} = \eta_{TX} P_{TX}$$



Žarnica η_{TX}



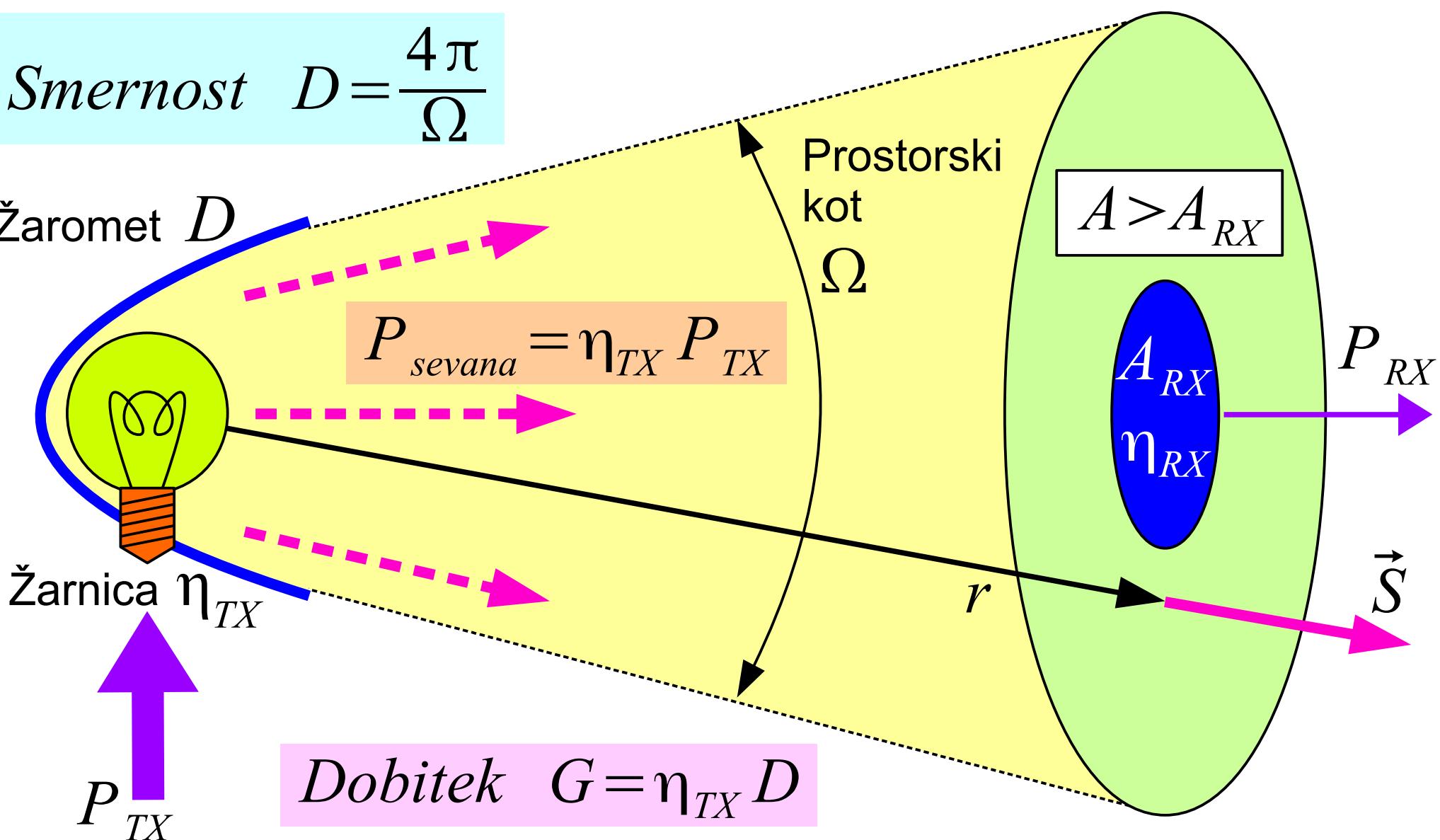
$$Dobitek \quad G = \eta_{TX} D$$

r

$$P_{RX}$$



$$A_{RX} \quad \eta_{RX}$$

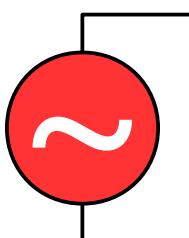


$$P_{RX} = A_{RX} \eta_{RX} S = \frac{A_{RX} \eta_{RX} \eta_{TX} D P_{TX}}{4\pi r^2} = P_{TX} \cdot \frac{A_{RX} \eta_{RX} G}{4\pi r^2}$$

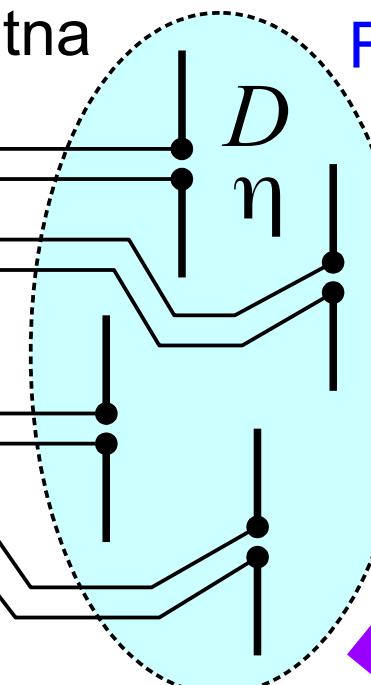
Koherentna oddaja

Fazna skupina
LASER

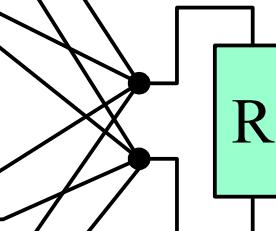
Nekoherentni sprejem



Faza določena!



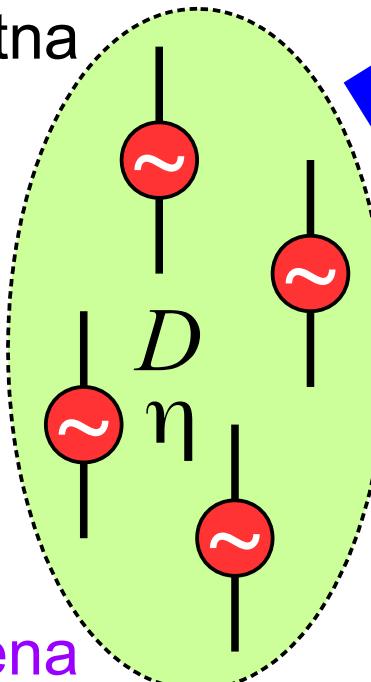
Prenos energije



Elektrarna
Fotodioda
nepomembna

Nekoherentna oddaja

Toplotni vir
LED

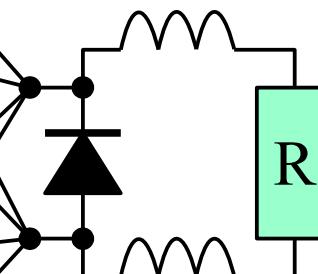
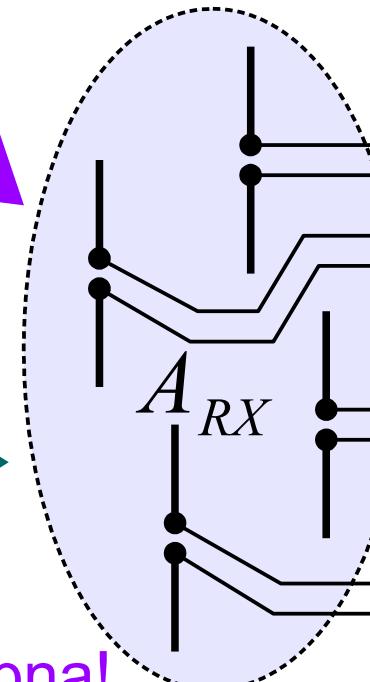


Faza nedoločena

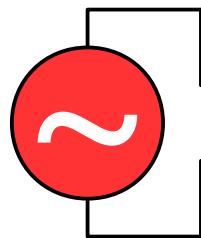
IR
Radijska zveza

Toplotni šum

Faza pomembna!



Koherentna
oddaja



Faza
določena!

$$D_{TX}, \eta_{TX}, G_{TX}, A_{effTX}$$

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

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

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

Radajska zveza

$\eta_O \equiv$ izkoristek osvetlitve

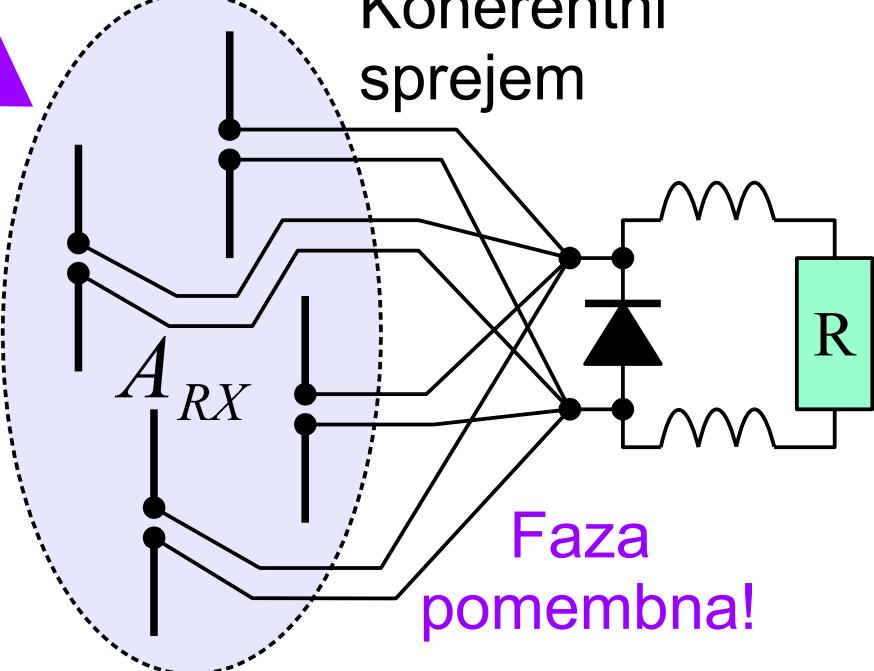
$$\eta_O \approx 50\% \dots 80\%$$

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

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

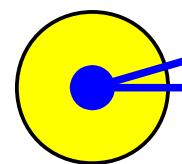
$$A_{effRX}, \eta_{RX}, D_{RX}, G_{RX}$$

Koherentni
sprejem



$$\Delta l \approx d^2/8r$$

Točkasti
vir sevanja

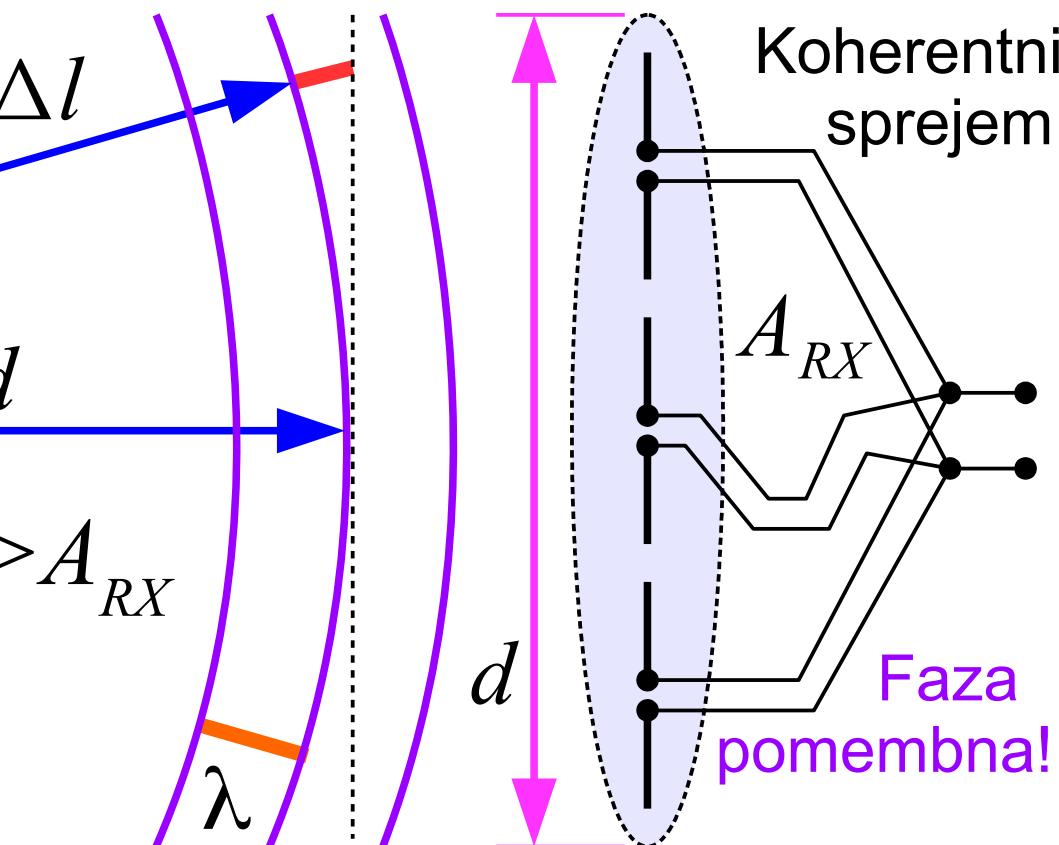


$$r + \Delta l$$

$$r \gg d$$

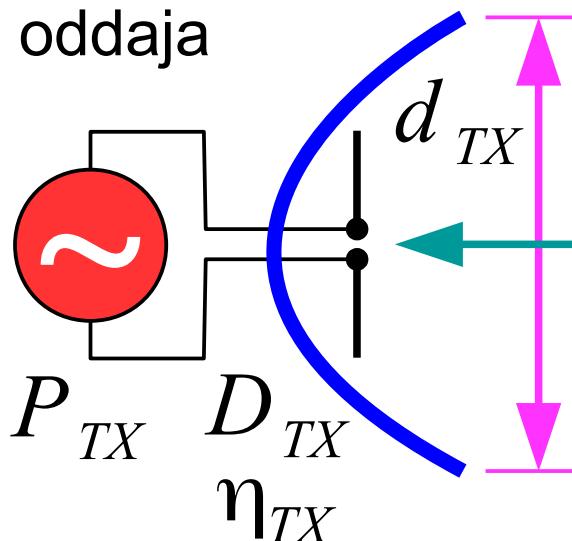
Pogoj faze strožji od amplitudo $A > A_{RX}$

$$\Delta P_{dB} \approx 20 \log_{10} \frac{\sin \Delta\phi/2}{\Delta\phi/2}$$



Δl	$\Delta\phi[\text{rd}]$	$\Delta P[\text{dB}]$	$r \geq$	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

Koherentna
oddaja



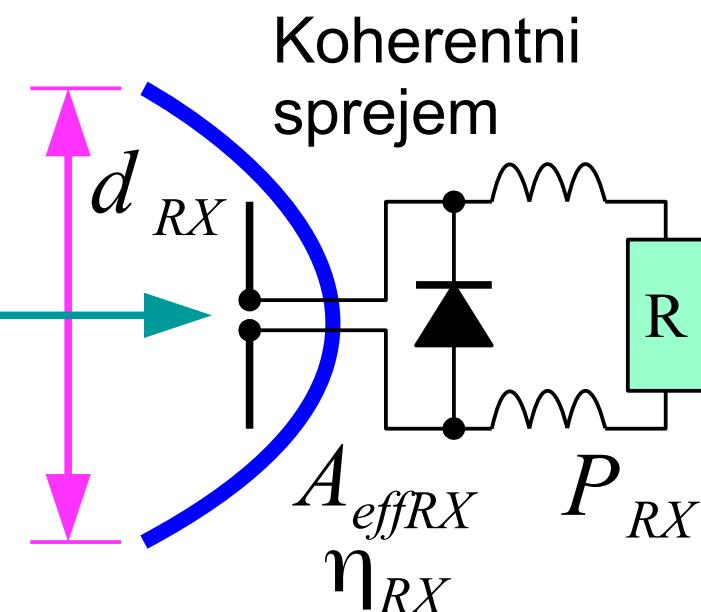
P_{TX} D_{TX}
 η_{TX}

G_{TX}
 A_{effTX}

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

Prazen prostor

Harald Friis 1945



A_{effRX} η_{RX}
 P_{RX}

D_{RX}
 G_{RX}

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

Zapis z dobitki anten:

Recipročnost!

Zapis s površinami anten:

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

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

10 - Friisova enačba za domet koherentne zveze

$$D[\text{dBi}] = 10 \log_{10} D$$

$$G[\text{dBi}] = 10 \log_{10} G$$

$\text{dBi} \equiv \text{dB glede na neusmerjen (izotropni) vir}$

$$D[\text{dBd}] = D[\text{dBi}] - 2.15 \text{ dB}$$

$$G[\text{dBd}] = G[\text{dBi}] - 2.15 \text{ dB}$$

$\text{dBd} \equiv \text{dB glede na polvalni dipol}$

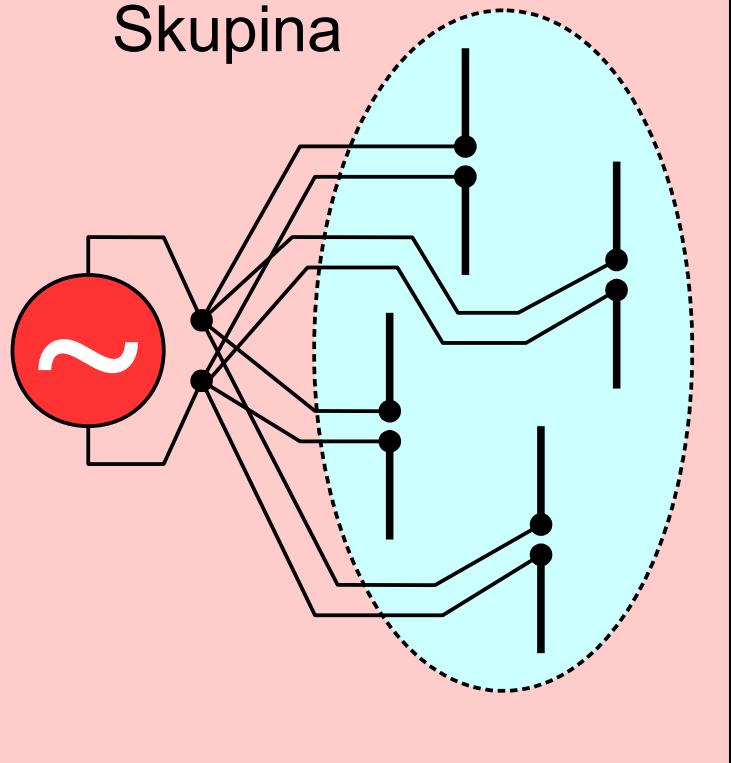
Iskanje nesreče s Friisovo enačbo na tisoč in en način:

$$\begin{aligned} P_{RX}[\text{dBm}] &= P_{TX}[\text{dBm}] + G_{TX}[\text{dBi}] + G_{RX}[\text{dBi}] + \\ &+ 20 \log_{10} \lambda [\text{m}] - 20 \log_{10} r [\text{m}] - 21.98 \text{ dB} \end{aligned}$$

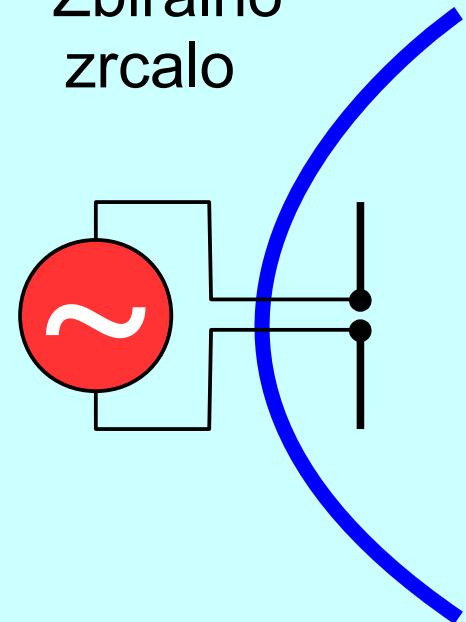
$$\lambda [\text{m}] \approx 299.7 / f [\text{MHz}] \quad zrak: \quad n = 1.0003$$

$$\begin{aligned} P_{RX}[\text{dBm}] &= P_{TX}[\text{dBm}] + G_{TX}[\text{dBi}] + G_{RX}[\text{dBi}] - \\ &- 20 \log_{10} f [\text{MHz}] - 20 \log_{10} r [\text{m}] + 27.55 \text{ dB} \end{aligned}$$

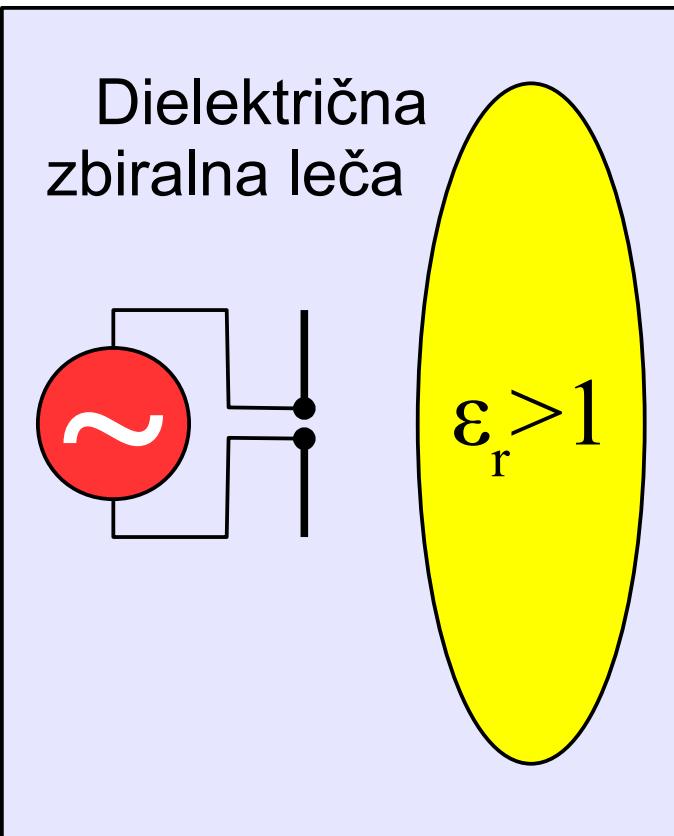
Skupina



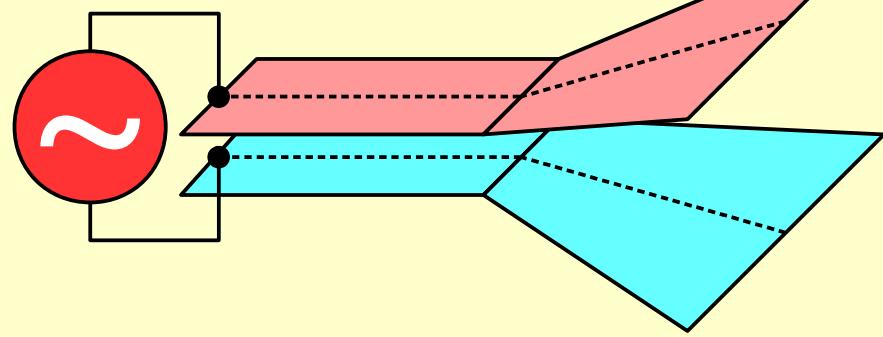
Zbiralno zrcalo



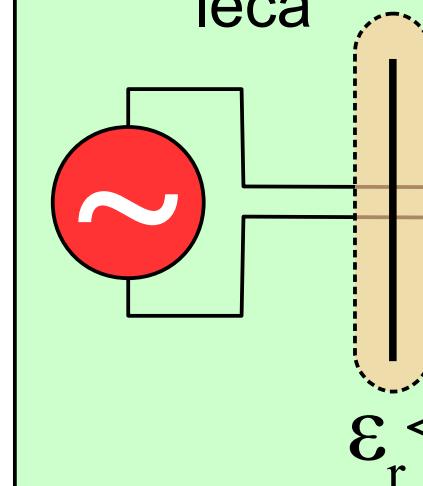
Dielektrična zbiralna leča



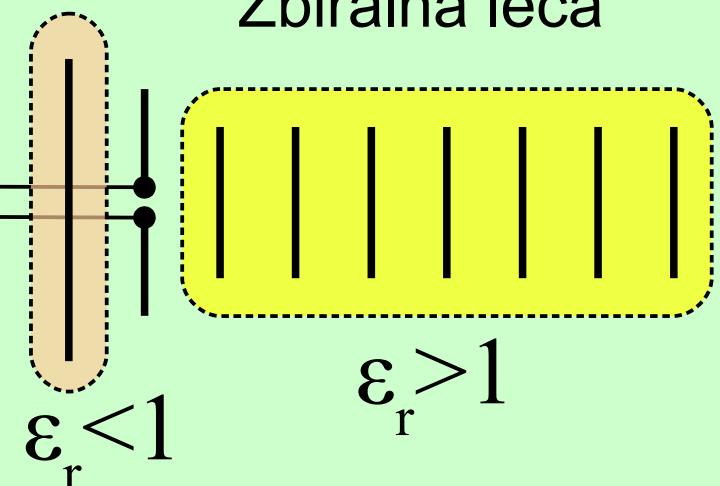
TEM lijak



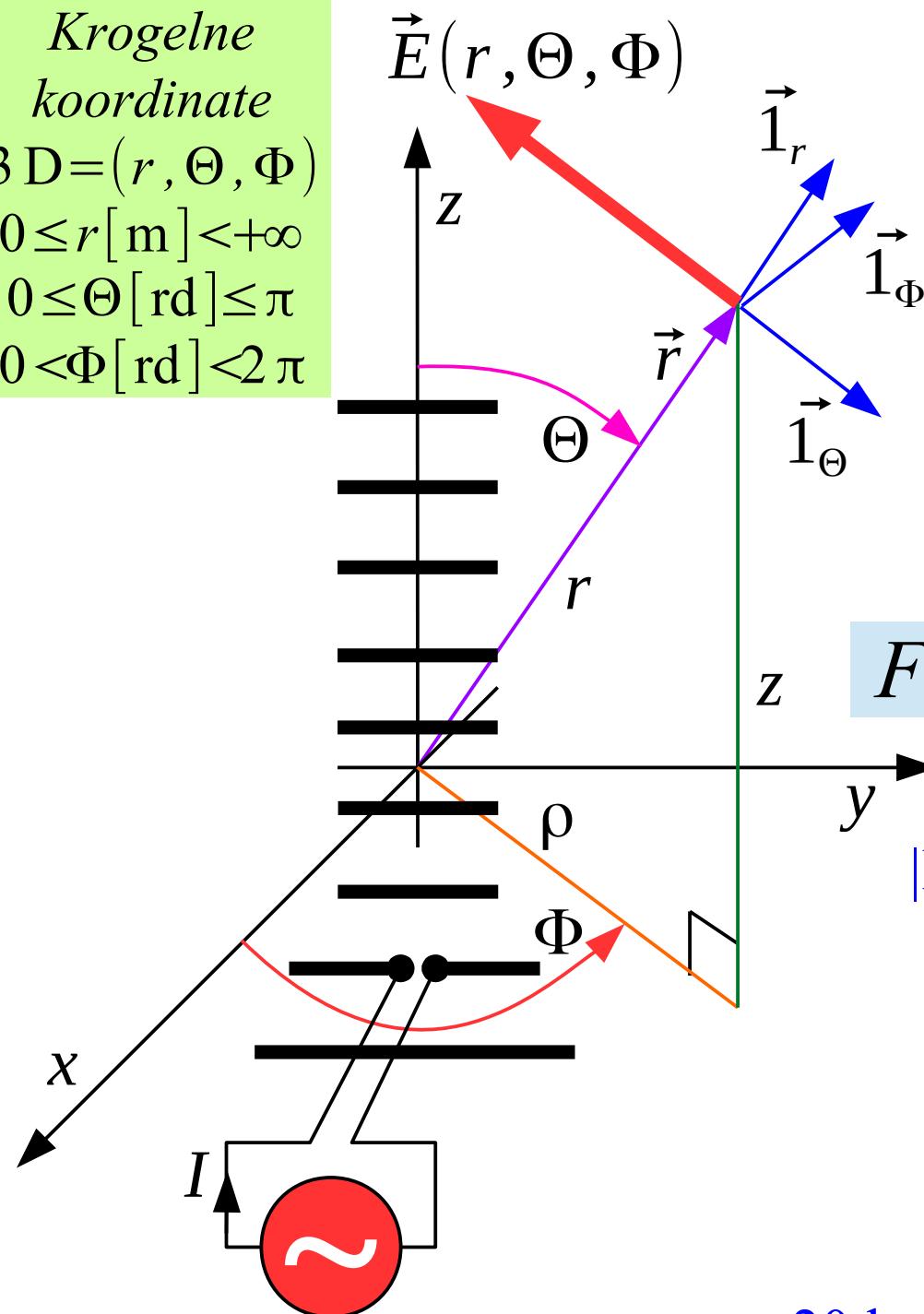
Razpršilna leča



Umetni dielektriki
Zbiralna leča



Krogelne
koordinate
 $3D = (r, \Theta, \Phi)$
 $0 \leq r [m] < +\infty$
 $0 \leq \Theta [rd] \leq \pi$
 $0 < \Phi [rd] < 2\pi$



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

$\vec{1}_P \equiv$ polarizacija

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

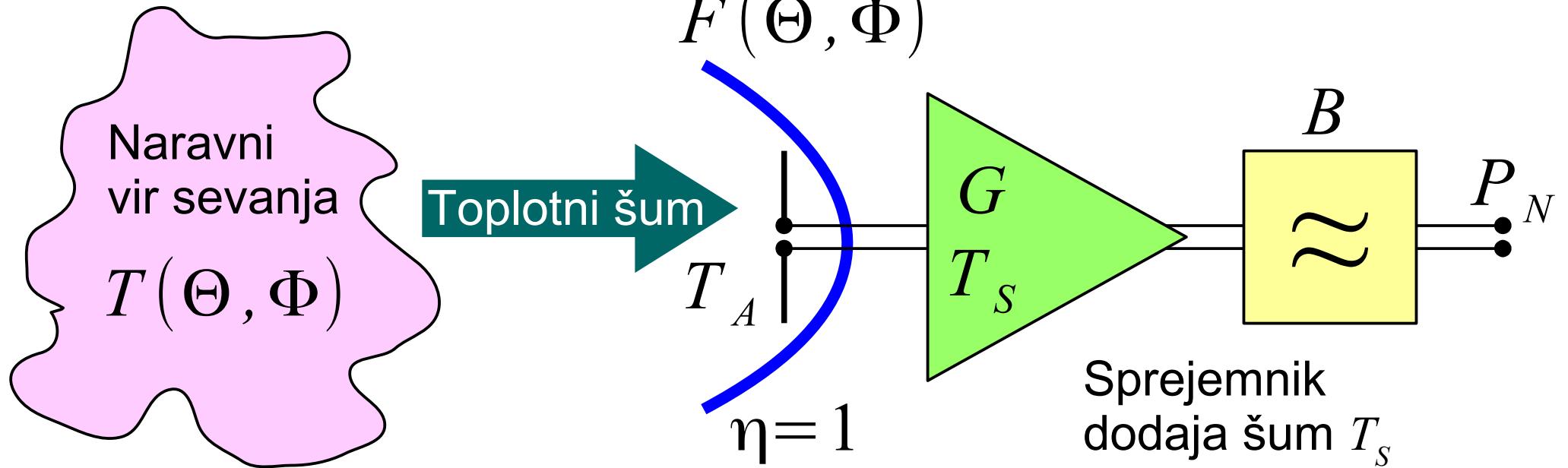
$F(\Theta, \Phi=0) \equiv$ Ravnina H

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

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

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

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



Vir dodaja šum T_A

Brezizgubna antena
ne dodaja šuma!

Sprejemnik
dodaja šum T_S

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

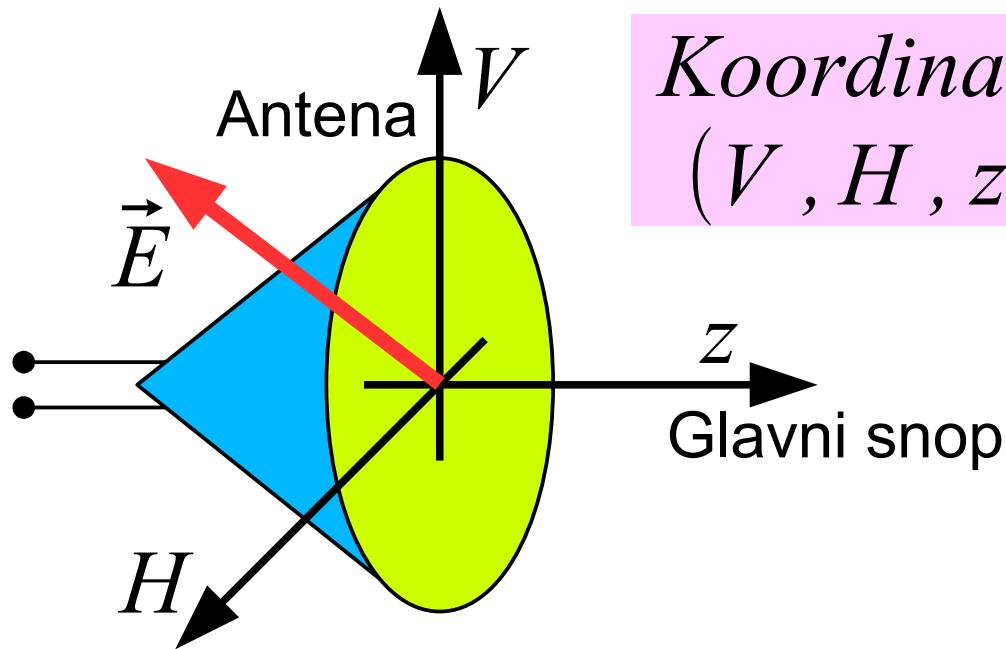
$T_A \equiv$ utežena vsota šuma $T(\Theta, \Phi)$

Boltzmannova konstanta za toplotni šum:

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

Moč šuma na izhodu sprejemnika:

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



Prečno valovanje: dve neodvisni polarizaciji!

Linearne komponente:

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

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

Krožne komponente:

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

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

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

Krožni smerniki:

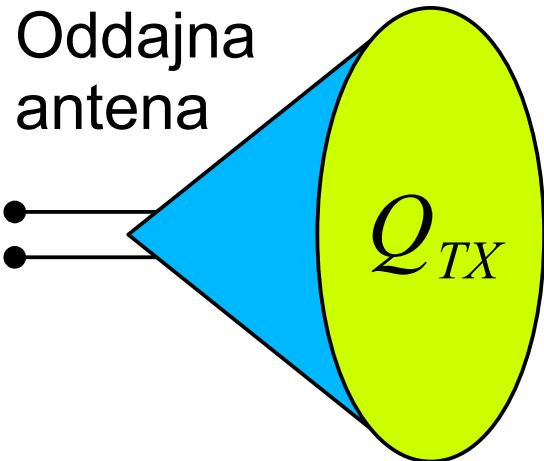
$$\vec{1}_L = \frac{\vec{1}_V + j \vec{1}_H}{\sqrt{2}}$$

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

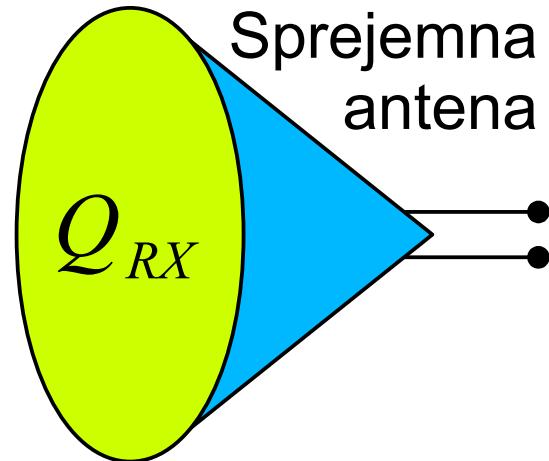
Osnovno razmerje:

$$R = \left| \frac{1 + |Q|}{1 - |Q|} \right|$$

$$R_{dB} = 20 \log_{10} R$$



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



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

Fraunhofer:
daljne polje

$$\frac{E}{H} = Z_0$$

Dve polarizaciji
 $C/B \leq 10$ bit

MIMO:
 $C/B \approx 20$ bit

$$r = \frac{2d^2}{\lambda}$$

Samo tu obstajajo:

$$D, G,$$

 $F(\Theta, \Phi),$

Friisova enačba

Gulielmo
Marconi

$$\frac{E}{H} \approx Z_0$$

$$r = \frac{\lambda}{2\pi}$$

Fresnel:
sevano polje

Večrodoni prenos
 $C/B \geq 50$ bit

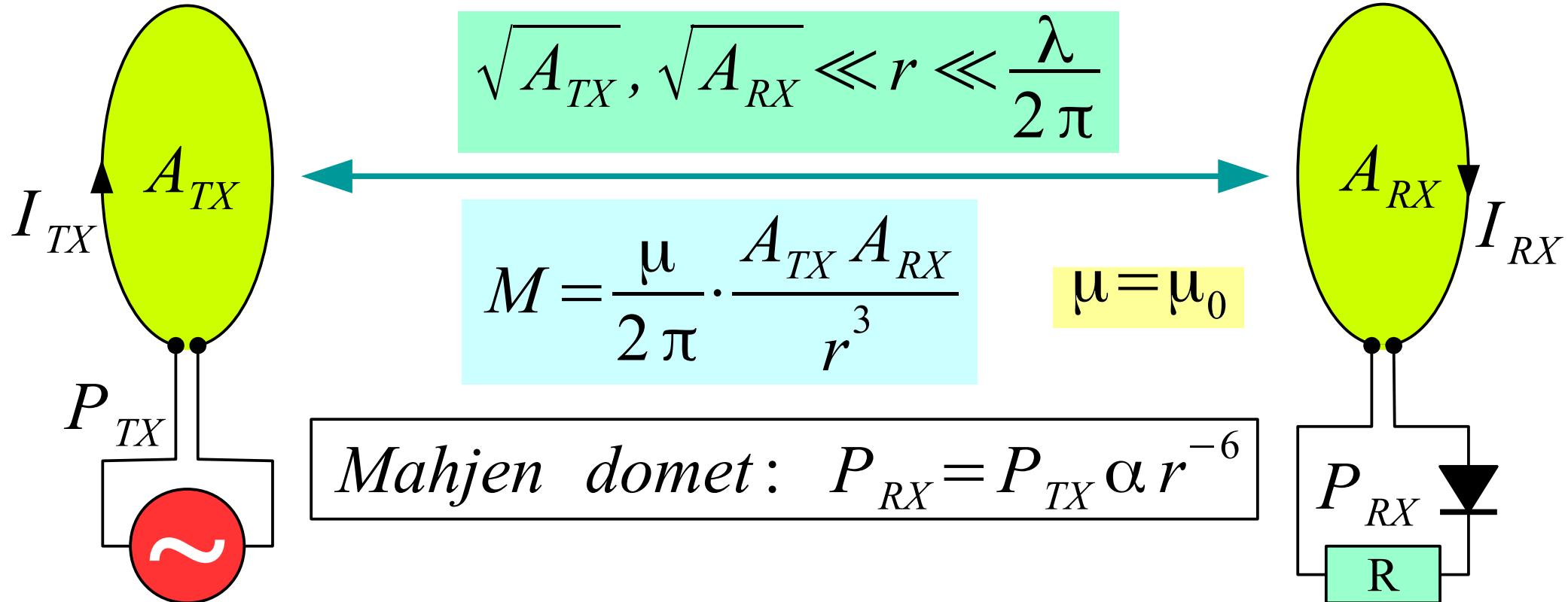
$$\frac{E}{H} \neq Z_0$$

Statika:
bližnje polje

Nikola
Tesla

Točkasti
vir sevanja

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



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

Brez sevanja!

Uporaba:

RFID in druge zveze kratkega doseg
Prenos energije (brezžično polnjenje)