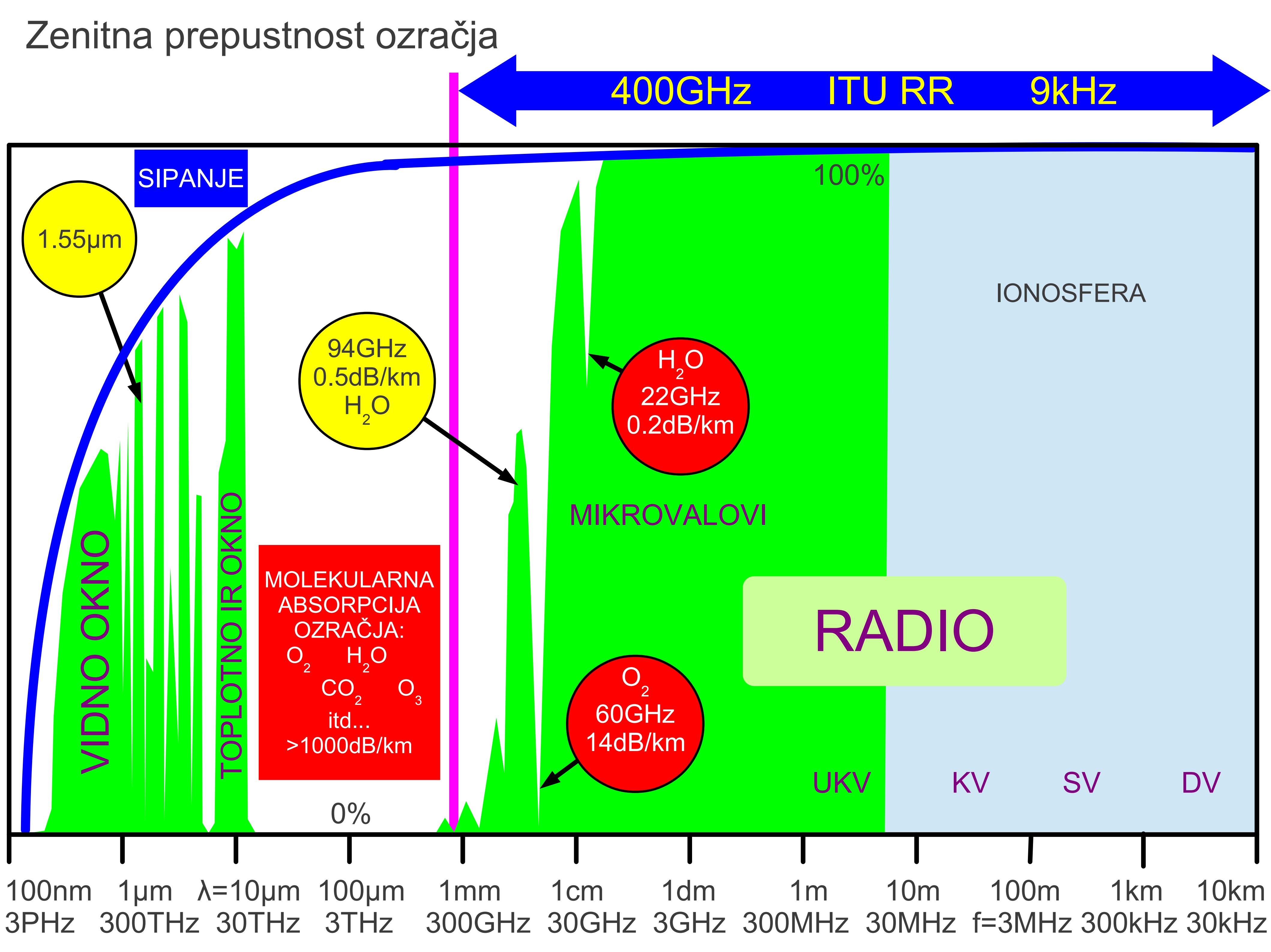


Zenitna prepustnost ozračja
400GHz
ITU RR
9kHz
SIPANJE
100%
1.55µm
IONOSFERA
94GHz
0.5dB/km
H_2O
H_2O
22GHz
0.2dB/km
MIKROVALOVI
VIDNO OKNO
TOPLOTNO IR OKNO
MOLEKULARNA ABSORPCIJA OZRAČJA:
O_2 H_2O
CO_2 O_3
itd...
>1000dB/km
RADIO
O_2
60GHz
14dB/km
UKV
KV
SV
DV
0%
100nm 3PHz
1µm 300THz
λ=10µm 30THz
100µm 3THz
1mm 300GHz
1cm 30GHz
1dm 3GHz
1m 300MHz
10m 30MHz
100m f=3MHz
1km 300kHz
10km 30kHz

Elektromagnetika

$$\text{Harmonske veličine:}\quad \partial/\partial t = j\omega \quad \omega \equiv \text{krožna frekvenca}\ [\mathrm{rd/s}]$$

$$\vec{H} \equiv \text{magnetna poljska jakost}\ \left[\frac{\mathrm{A}}{\mathrm{m}}\right]$$

$$\vec{J} \equiv \text{gostota toka}\ \left[\frac{\mathrm{A}}{\mathrm{m}^2}\right]$$

$$\text{Ampère:}\quad \mathrm{rot}\,\vec{H} = \vec{J} + j\omega\epsilon\vec{E}$$

$$\vec{E} \equiv \text{električna poljska jakost}\ \left[\frac{\mathrm{V}}{\mathrm{m}}\right]$$

$$\text{Faraday:}\quad \mathrm{rot}\,\vec{E} = -j\omega\mu\vec{H}$$

$$\rho \equiv \text{gostota elektrine}\ \left[\frac{\mathrm{As}}{\mathrm{m}^3}\right]$$

$$\text{Gauss:}\quad \mathrm{div}\,\epsilon\vec{E} = \rho$$

$$\epsilon \equiv \text{dielektričnost}\ \left[\frac{\mathrm{As}}{\mathrm{Vm}}\right] \rightarrow \vec{D} = \epsilon\vec{E}$$

$$\mu \equiv \text{permeabilnost}\ \left[\frac{\mathrm{Vs}}{\mathrm{Am}}\right] \rightarrow \vec{B} = \mu\vec{H}$$

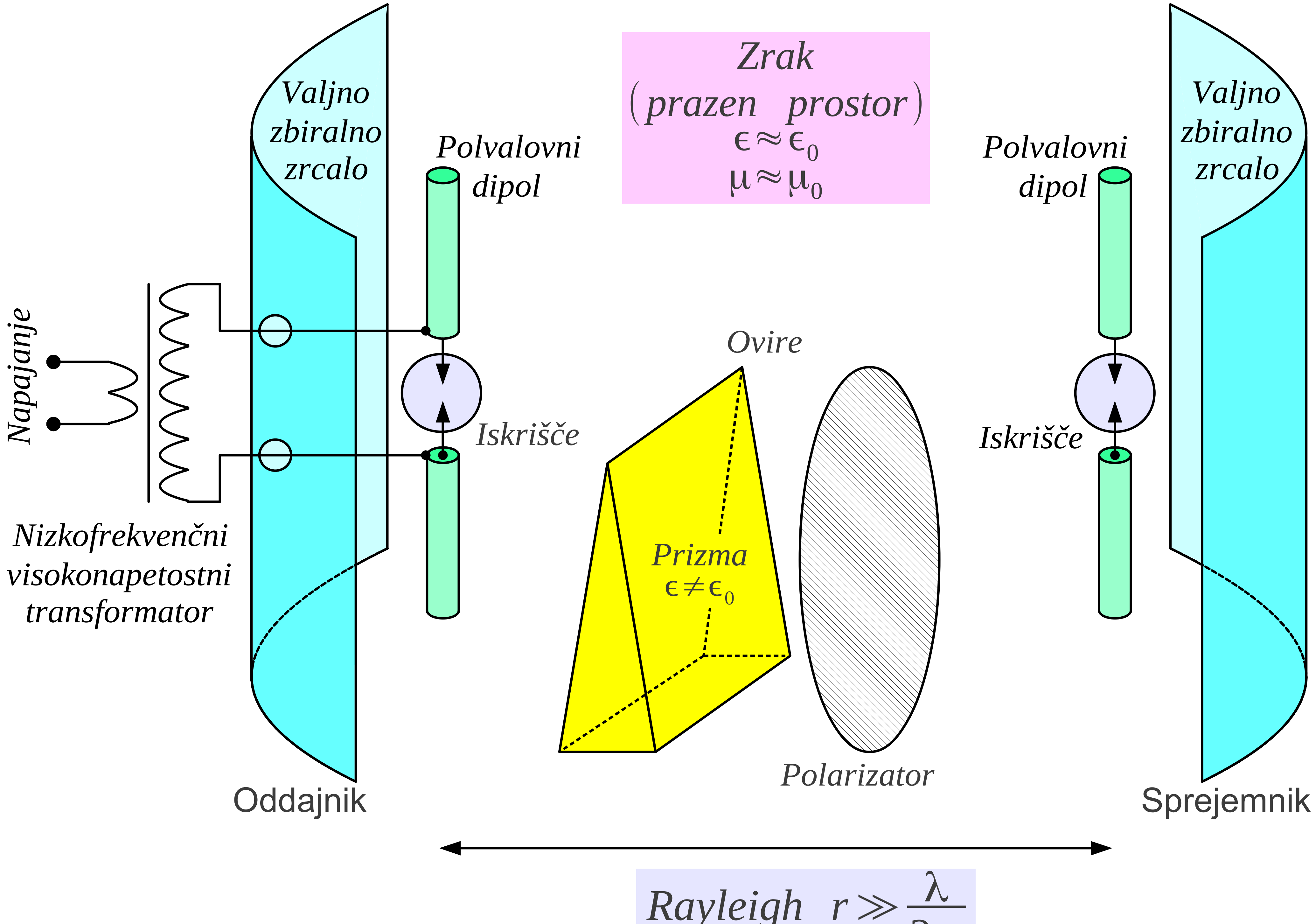
$$\text{Poynting:}\quad \vec{S} = \frac{1}{2}\vec{E}\times\vec{H}^* \equiv \text{gostota pretoka moči}\ \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right]$$

$$\vec{A}(\vec{r}) = \frac{\mu}{4\pi}\int_{V'} \vec{J}(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV' \equiv \text{vektorski potencial}\ \left[\frac{\mathrm{Vs}}{\mathrm{m}}\right]$$

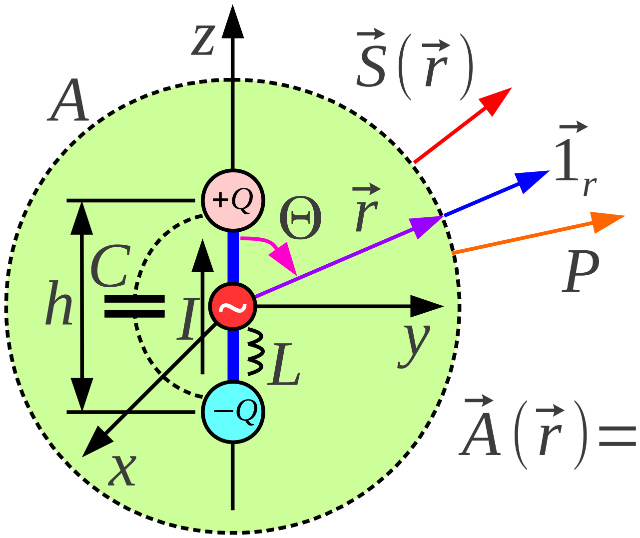
$$\vec{H} = \frac{1}{\mu}\mathrm{rot}\,\vec{A}$$

$$V(\vec{r}) = \frac{1}{4\pi\epsilon}\int_{V'} \rho(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV' \equiv \text{skalarni potencial}\ [\mathrm{V}]$$

$$\vec{E} = -j\omega\vec{A} - \mathrm{grad}\,V$$



Hertzov poskus



Sevanje kratkega dipola

$\omega \neq 0$

$$k = \omega\sqrt{\mu\epsilon} = \frac{2\pi}{\lambda}$$

Poenostavitve:

(1) $h \ll r$

(2) $h \ll \lambda$

$$\vec{A}(\vec{r}) = \frac{\mu}{4\pi}\int_{V'}\vec{J}(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV' \approx \left(\vec{1}_r\cos\Theta - \vec{1}_\Theta\sin\Theta\right)\frac{\mu I h}{4\pi}\frac{e^{-jkr}}{r}$$

$$\vec{H}(\vec{r}) = \frac{1}{\mu}\,\mathrm{rot}\,\vec{A} = \vec{1}_\Phi\frac{I h}{4\pi}e^{-jkr}\left(\frac{jk}{r}+\frac{1}{r^2}\right)\sin\Theta$$

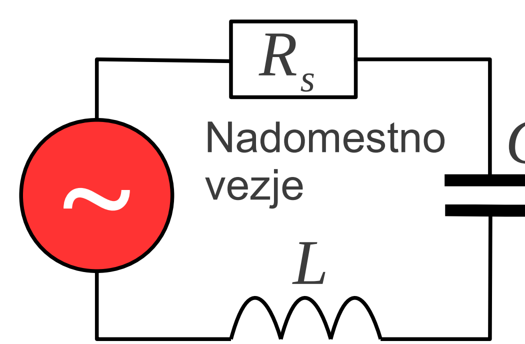
$$\frac{1}{\omega\epsilon} = \frac{1}{\omega\sqrt{\mu\epsilon}}\sqrt{\frac{\mu}{\epsilon}} = \frac{Z}{k}$$

$$\vec{E}(\vec{r}) = \frac{1}{j\omega\epsilon}\,\mathrm{rot}\,\vec{H} = \frac{I h}{4\pi j\omega\epsilon}e^{-jkr}\left[\vec{1}_r\left(\frac{jk}{r^2}+\frac{1}{r^3}\right)2\cos\Theta + \vec{1}_\Theta\left(-\frac{k^2}{r}+\frac{jk}{r^2}+\frac{1}{r^3}\right)\sin\Theta\right]$$

$$\vec{S}(\vec{r}) = \frac{1}{2}\vec{E}(\vec{r})\times\vec{H}(\vec{r})^* = \frac{|I|^2h^2}{32\pi^2\omega\epsilon}\left[\vec{1}_r\left(\frac{k^3}{r^2}-\frac{j}{r^5}\right)\sin^2\Theta + \vec{1}_\Theta\left(\frac{jk^2}{r^3}+\frac{j}{r^5}\right)2\cos\Theta\sin\Theta\right]$$

$$P = \oiint_{r\to\infty}\vec{S}(\vec{r})\cdot\vec{1}_r r^2\sin\Theta\,d\Theta\,d\Phi \approx \frac{|I|^2h^2Zk^2}{12\pi}$$

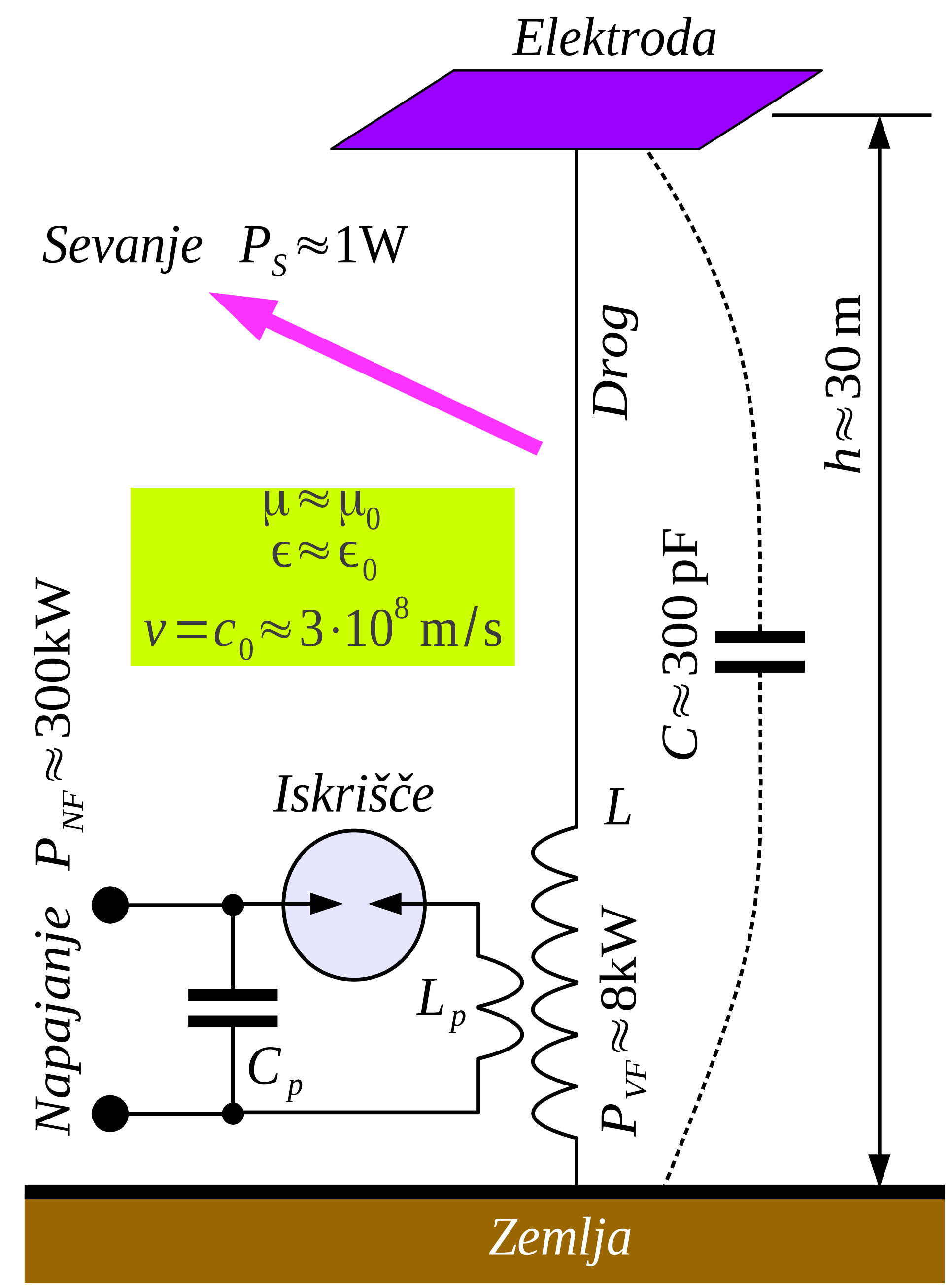
$$R_s = \frac{2P}{|I|^2} = \frac{h^2Zk^2}{6\pi} = \frac{2\pi Z}{3}\left(\frac{h}{\lambda}\right)^2$$



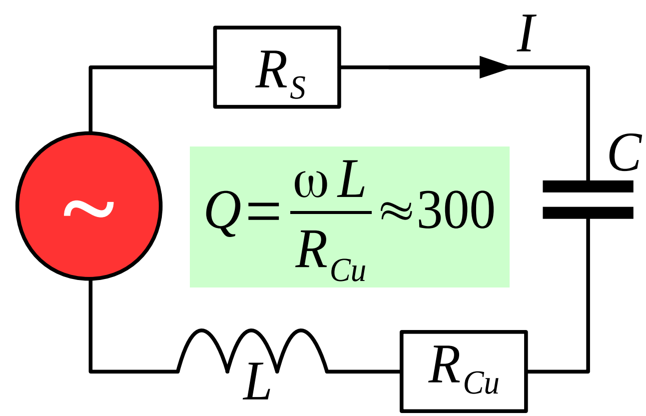
Teslov transformator

$$f \approx 30\,\mathrm{kHz}$$
$$\omega = 2\pi f \approx 1.885 \cdot 10^5\,\mathrm{rd/s}$$
$$\lambda = \frac{c_0}{f} \approx 10\,\mathrm{km}$$

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \approx 120\pi\,\Omega$$



$$R_S = \frac{2\pi Z_0}{3}\left(\frac{h}{\lambda}\right)^2 \approx 80\pi^2\Omega\left(\frac{h}{\lambda}\right)^2 \approx 7.1\,\mathrm{m}\Omega$$

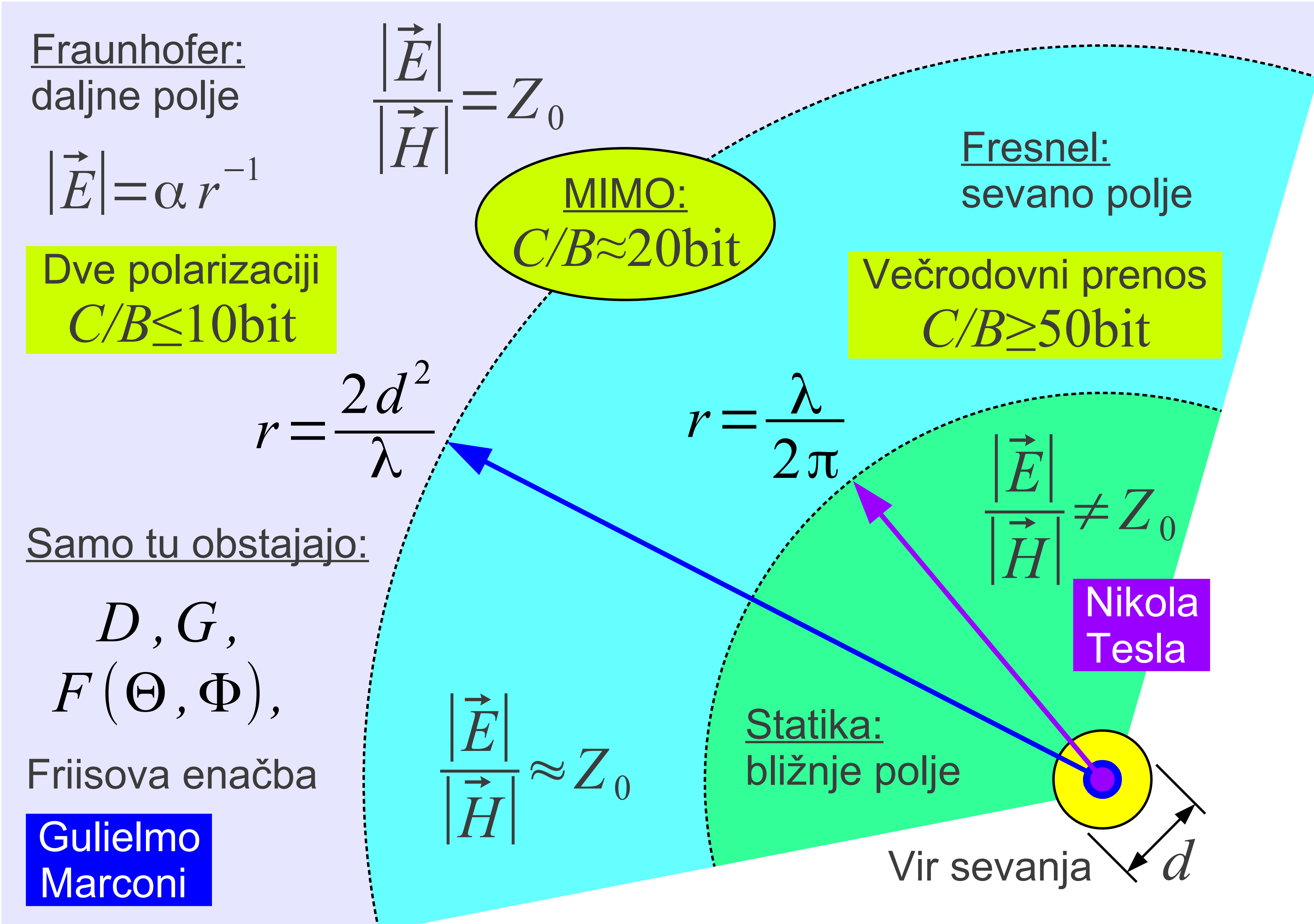


$$\omega L = \frac{1}{\omega C} \approx 17.68\,\mathrm{k}\Omega$$

$$R_{Cu} = \frac{\omega L}{Q} \approx 58.9\,\Omega$$

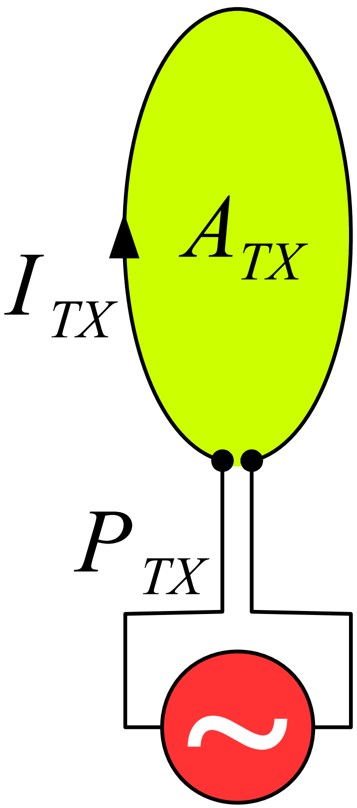
$$\eta = \frac{P_S}{P_{VF}} = \frac{P_S}{P_S + P_{Cu}} = \frac{R_S}{R_S + R_{Cu}} \equiv \textit{sevalni izkoristek}$$

$$\eta \approx \frac{0.0071\,\Omega}{0.0071\,\Omega + 58.9\,\Omega} \approx 1.2 \cdot 10^{-4}$$



Statika, Fresnel in Fraunhofer

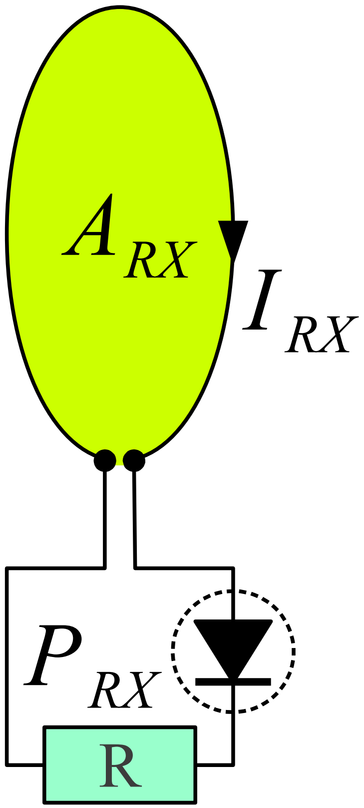
$$\frac{E}{H} \neq Z_0 \rightarrow \text{Potrebna ločena meritev } \vec{E} \text{ ter } \vec{H}$$



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

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

$$\mu = \mu_0$$



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

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

Brez sevanja!

Uporaba:

RFID in druge zveze kratkega dosega

Prenos energije (brezžično polnjenje)

Induktivni sklop v bližnjem polju

Zmogljivost radijske zveze

$$Informacija \quad I=\frac{1}{2}\cdot\log_2\left(1+\frac{W_S}{W_N}\right) \quad [\mathrm{bit}] \quad (Claude \ Shannon \ 1948)$$

$W_S \equiv energija \ signala$ $\quad W_N \equiv energija \ šuma$ $\quad T \equiv perioda \ signala$

$$Pasovna \ širina \quad B=\frac{1}{2T} \quad [\mathrm{Hz}] \quad (Harry \ Nyquist \ 1924)$$

$P_S \equiv moč \ signala$ $\quad P_N \equiv moč \ šuma$ $\quad N_0 \equiv spektralna \ gostota \ šuma$

$$Zmogljivost \quad C=m\cdot B\cdot\log_2\left(1+\frac{P_S}{P_N}\right)=m\cdot B\cdot\log_2\left(1+\frac{P_S}{B\cdot N_0}\right) \quad [\mathrm{bit/s=bps}]$$

$m \equiv število \ rodov$

$$Spektralna \ učinkovitost \quad C/B=m\cdot\log_2\left(1+\frac{P_S}{B\cdot N_0}\right) \quad [\mathrm{bit}/s/\mathrm{Hz=bit}]$$

Leto	Vrsta radijske zveze	Pasovna širina B	Zmogljivost C	Spektralna učinkovitost C/B
~1910	Telegrafija s sprejemom na sluh	500Hz	10bit/s	0.02bit/s/Hz
~1950	Radioteleprinter	250Hz	50bit/s	0.2bit/s/Hz
~1990	GSM telefon	200kHz	271kbit/s	1.355bit/s/Hz
~2010	WiFi 802.11n (m=2)	40MHz	300Mbit/s	7.5bit/s/Hz