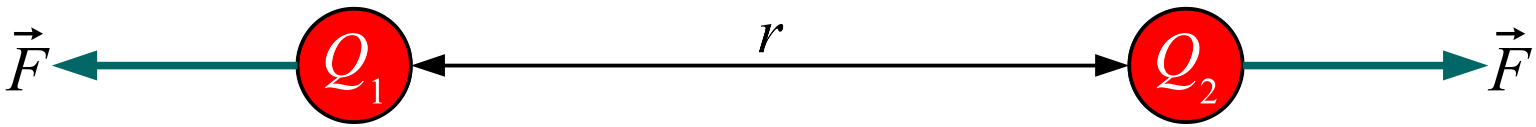
Radio

Električna sila med nabojema

Definicija [A] 2019
Električni naboj elektrona
$Q_e = -1.602176634 \cdot 10^{-19}\ \mathrm{As}$

$Q_1, Q_2 \equiv elektrini\,(električna\ naboja)$

$\epsilon_0 \equiv prazen\ prostor$



$$|\vec{F}| = F_{odbojna} = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q_1 Q_2}{r^2}$$

$$\frac{1}{4\pi\epsilon_0} \equiv konstanta\ za\ merske\ enote\,!$$

Ena od osnovnih štirih naravnih sil:

(1) *močna jedrska*, (2) *šibka jedrska*, (3) *težnost in* (4) *električna*

Albert Einstein: Posebna teorija relativnosti 1905

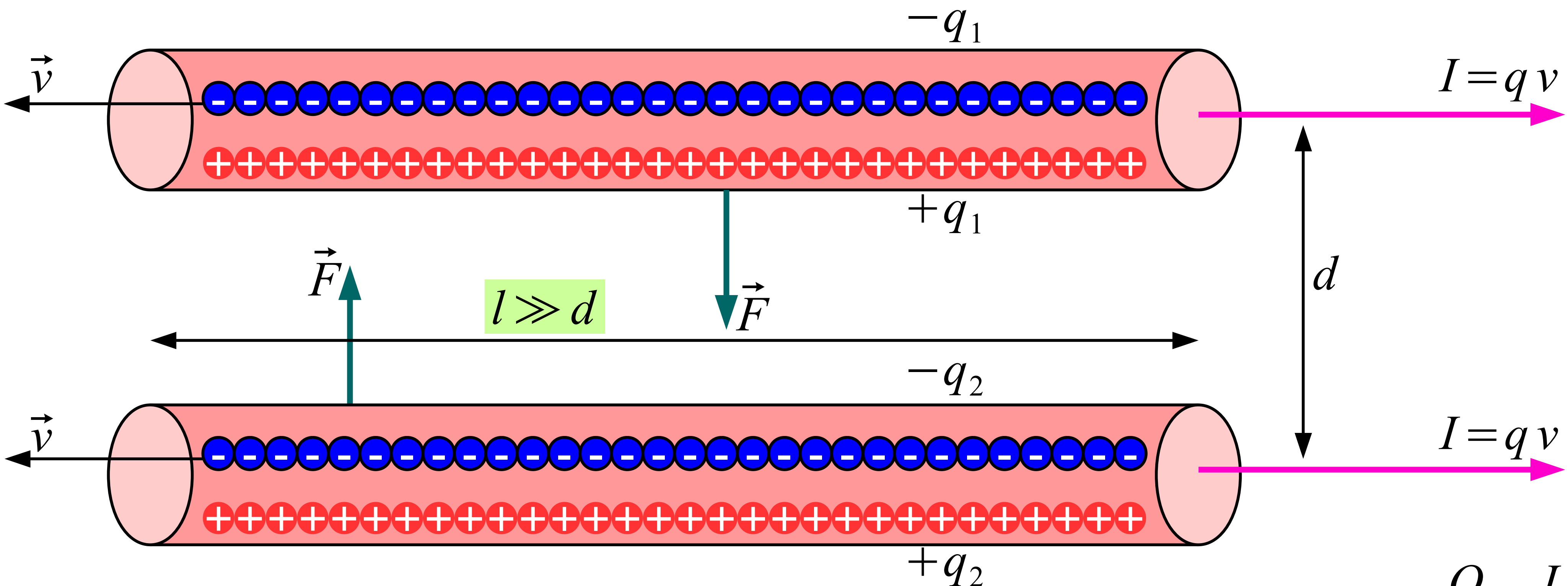
$\vec{v} \neq 0 \equiv$ *Enakomerno gibanje* $Q \rightarrow$ *Statično magnetno polje*

$\vec{a} \neq 0 \equiv$ *Pospešeno gibanje* $Q \rightarrow$ *Elektromagnetno sevanje*

Magnetni naboji NE obstajajo $\rightarrow$ *predznak magnetnih veličin stvar dogovora!*

Magnetna sila med vodnikoma

Miljutin Željeznov : Elektromagnetika 1974



$$q = \frac{Q}{l} = \frac{I}{v}$$

$$|\vec{F}| = F_{privlačna} = \frac{-l}{2\pi\epsilon_0 d}\left[(-q)(-q)+(-q')(+q)+(+q)(-q')+(+q)(+q)\right]$$

Lorentzov skrček
Hendrik Lorentz 1892

$$l' = l\sqrt{1-v^2/c_0^2}$$

$$q' = \frac{Q}{l'} = \frac{Q}{l\sqrt{1-v^2/c_0^2}} = \frac{q}{\sqrt{1-v^2/c_0^2}} \approx \frac{I}{v}\left(1+\frac{v^2}{2c_0^2}\right)$$

$$|\vec{F}| = F_{privlačna} = \frac{l}{2\pi\epsilon_0}\left[\frac{I^2}{c_0^2}\right]$$

$$\mu_0 = \frac{1}{\epsilon_0 c_0^2} = 4\pi 10^{-7}\,\frac{\mathrm{Vs}}{\mathrm{Am}} \equiv \textit{definicija}\,[\mathrm{A}]\ \textit{pred}\ 2019$$

$$F_{privlačna} = \frac{\mu_0 I^2 l}{2\pi d}$$

Elektromagnetika

Harmonske veličine: $\frac{\partial}{\partial t} = j\omega$

$\omega \equiv$ *krožna frekvenca* $[\mathrm{rd/s}]$

Maxwell → Heaviside

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

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

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

Predznak $\vec{H} = ?$

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

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

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

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

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

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

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

$k = \omega\sqrt{\mu\epsilon} \equiv$ *valovno število*

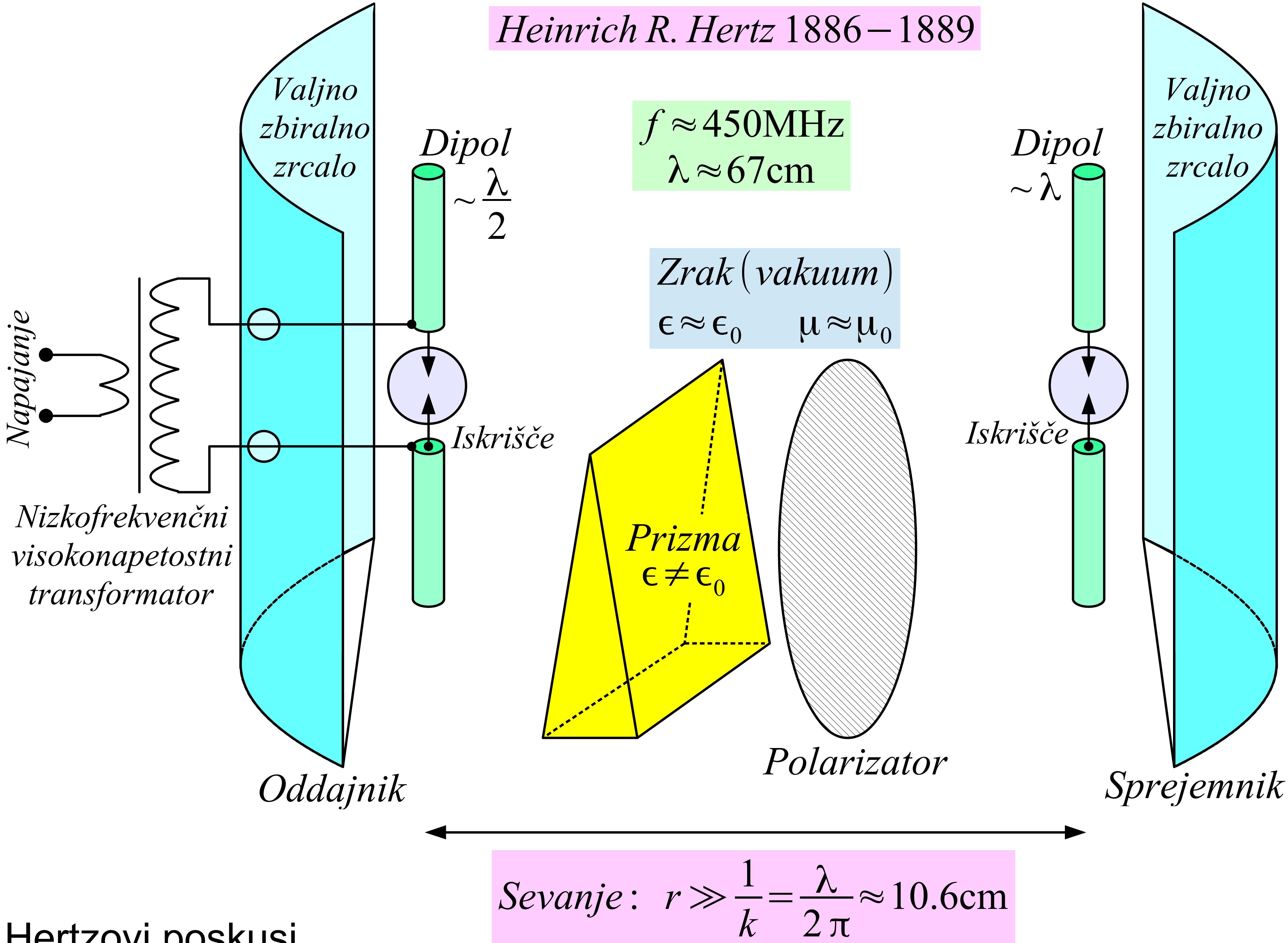
$$\vec{A}(\vec{r}) = \frac{\mu}{4\pi}\int_{V'} \vec{J}(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV' \equiv \textit{vektorski potencial} \left[\frac{\mathrm{Vs}}{\mathrm{m}}\right]$$

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

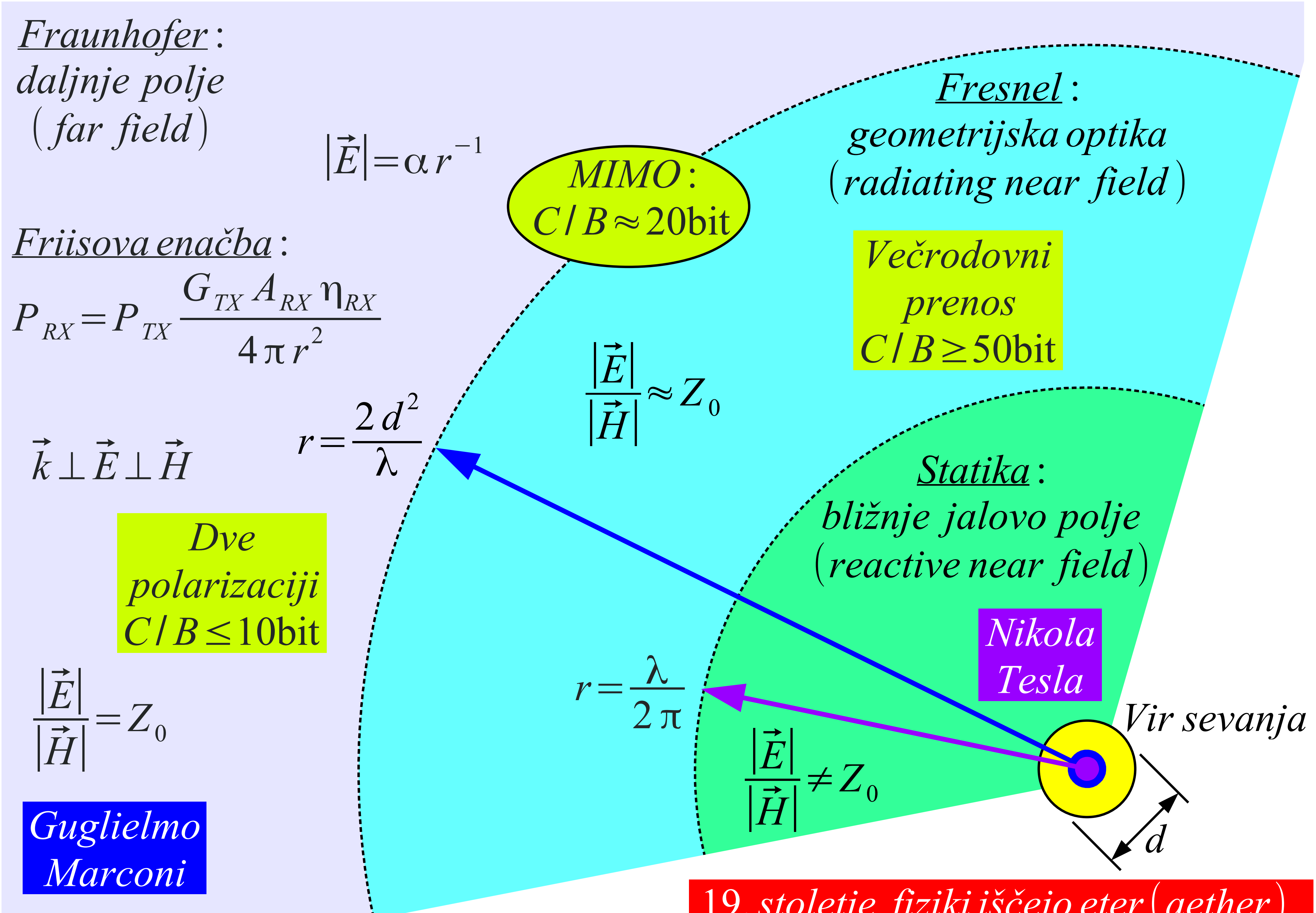
$$V(\vec{r}) = \frac{1}{4\pi\epsilon}\int_{V'} \rho(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV' \equiv \textit{skalarni potencial} \; [\mathrm{V}]$$

Lorenzova izbira:

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



Hertzovi poskusi



19. stoletje fiziki iščejo eter (aether).
Najbolj znan neuspel poskus v fiziki?

Statika, Fresnel in Fraunhofer

IEEE STANDARDS ASSOCIATION

IEEE Standard for Definitions of Terms for Antennas

IEEE Antennas and Propagation Society

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Slovar angleških izrazov

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 145™-2013
(Revision of
IEEE Std 145-1993)

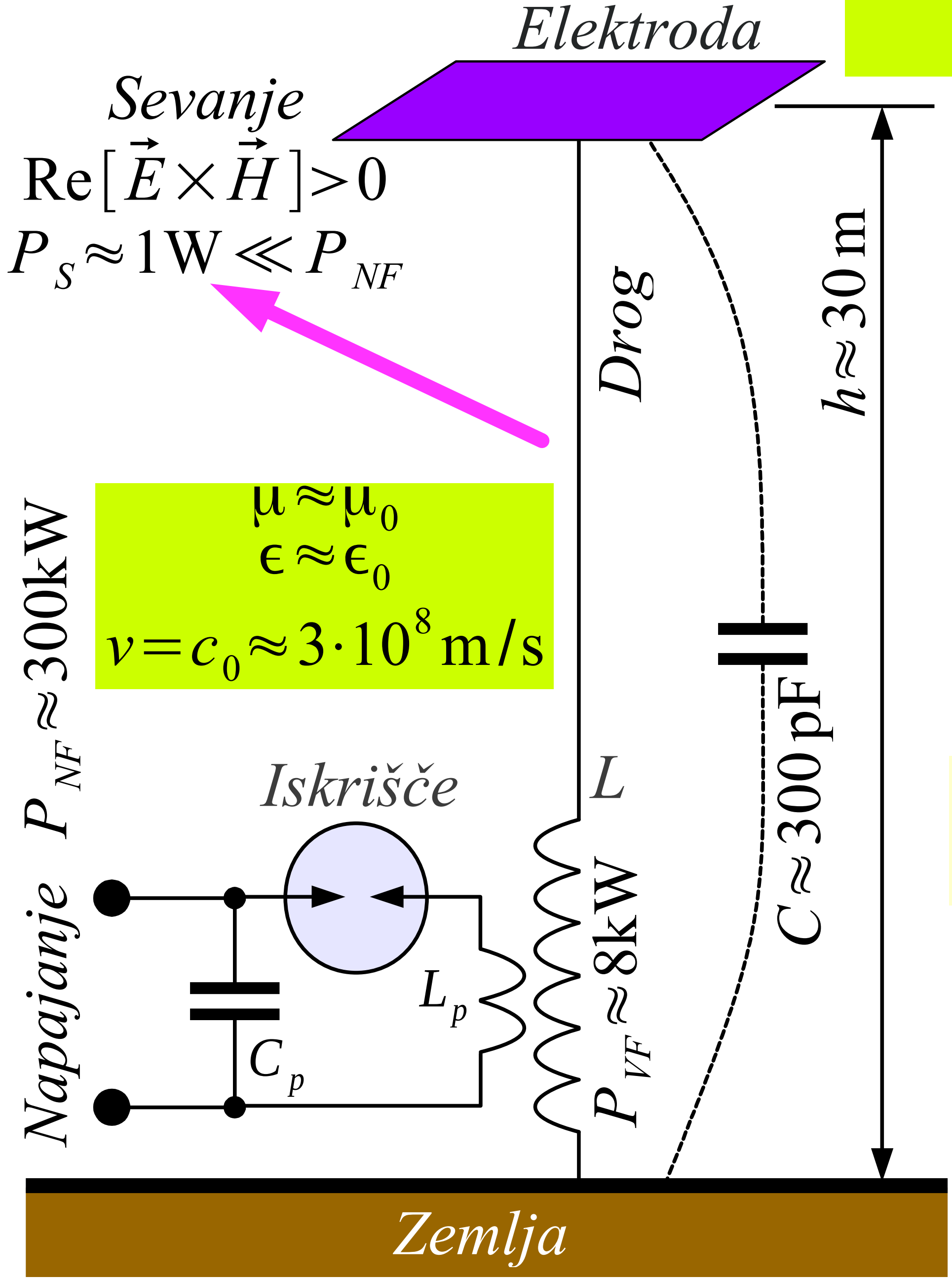
Teslov transformator

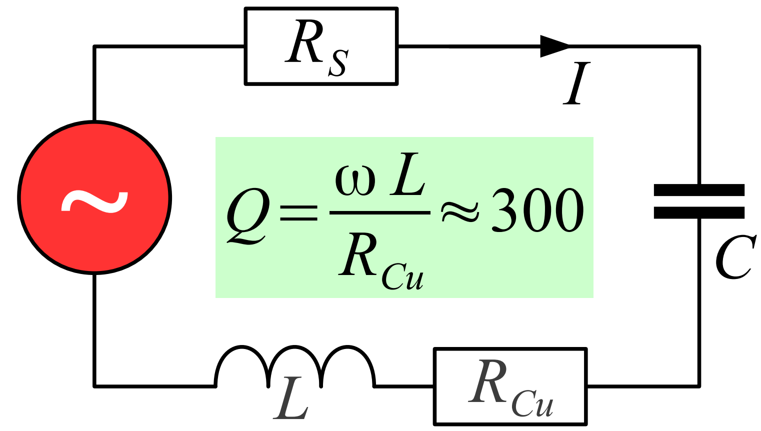
$R_S \equiv$ *sevalna upornost*

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

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

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





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

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

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

$$\eta \approx \frac{0.0071\,\Omega}{0.0071\,\Omega + 58.9\,\Omega} \approx 1.2 \cdot 10^{-4} = 0.012\,\%$$

Brez sevanja

$$\mathrm{Re}[\vec{E}_1 \times \vec{H}_1] \rightarrow 0$$

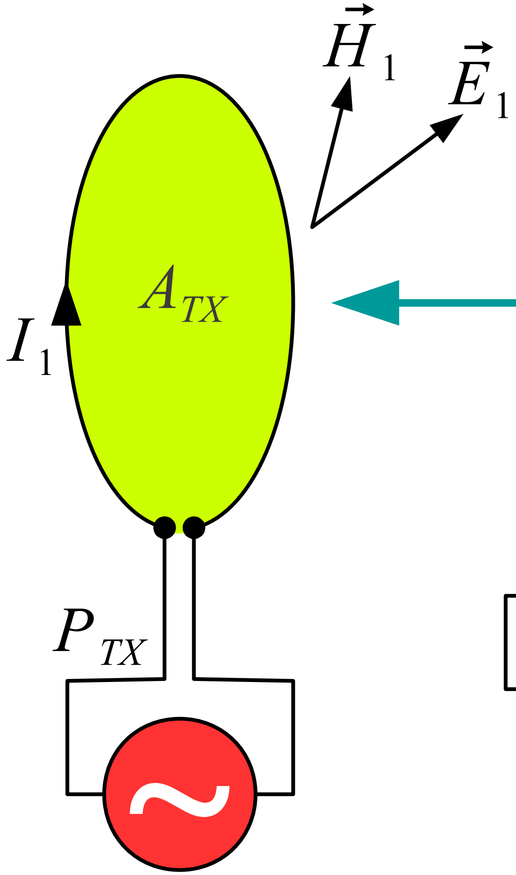
$$\textit{Kvadratura}\ \mathrm{Re}\left[\frac{I_1}{I_2}\right] = 0$$

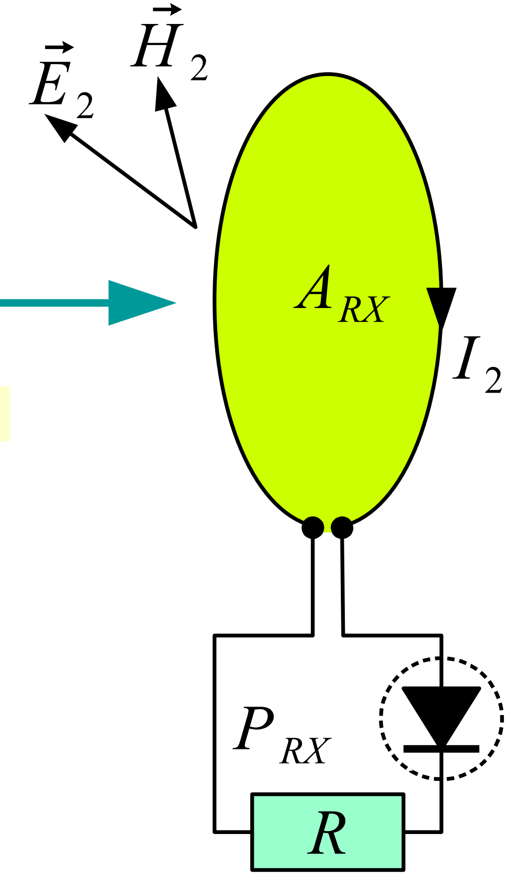
$$\downarrow$$

$$\left.\begin{array}{l}\mathrm{Re}[\vec{E}_1 \times \vec{H}_2] \neq 0 \\ \mathrm{Re}[\vec{E}_2 \times \vec{H}_1] \neq 0\end{array}\right\} \equiv \textit{prenos moči}$$

Brez sevanja

$$\mathrm{Re}[\vec{E}_2 \times \vec{H}_2] \rightarrow 0$$





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

$$\mu = \mu_0$$

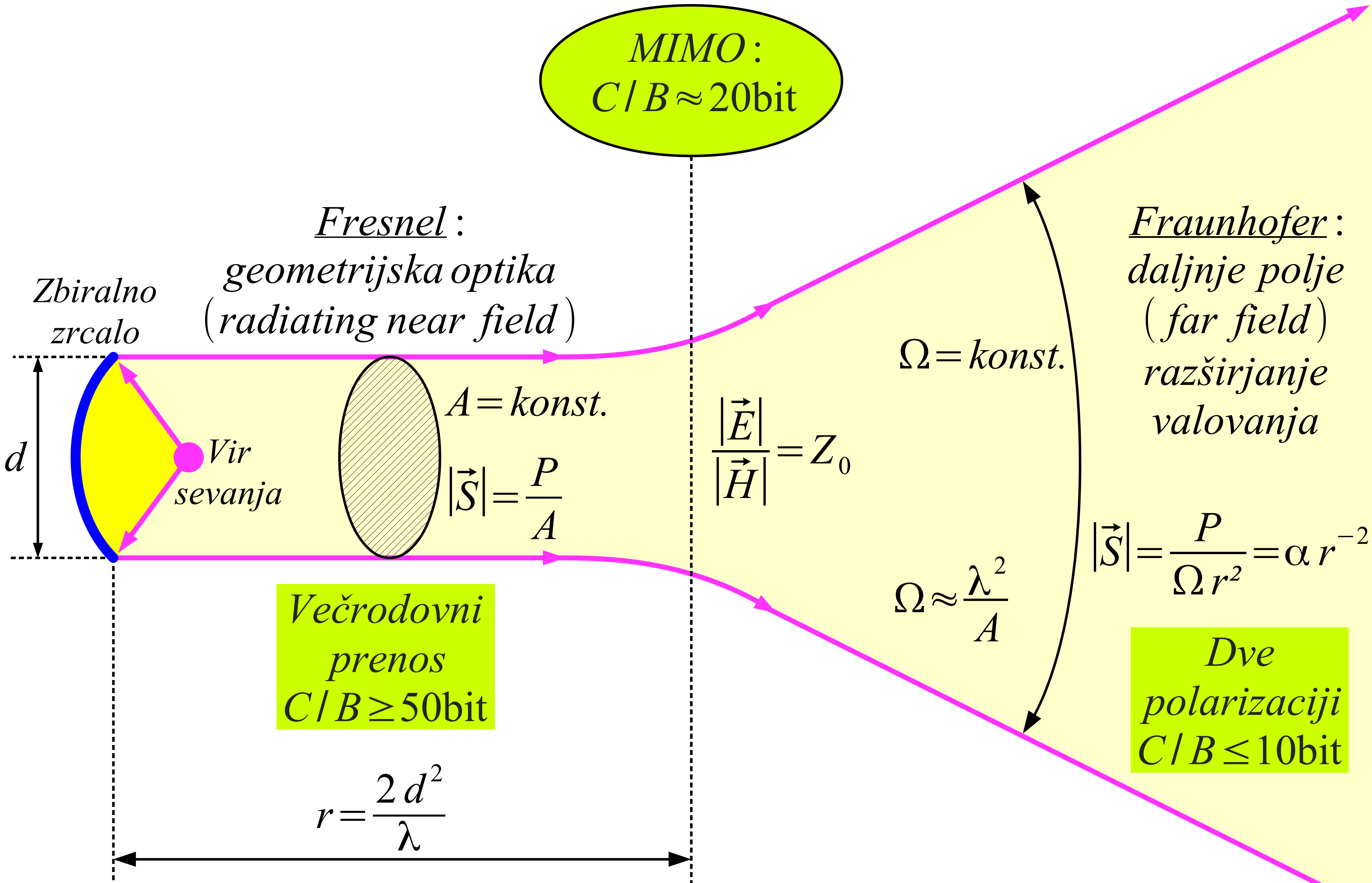
$$\textit{Majhen domet}: \quad P_{RX} = P_{TX}\, \alpha\, r^{-6}$$

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

RFID in druge zveze kratkega dosega
prenos energije (indukcijski kuhalnik, brezžično polnjenje)

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

Induktivni sklop v bližnjem polju



Rayleighjeva razdalja

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

$W_S \equiv \textit{energija signala}$ $\quad W_N \equiv \textit{energija šuma}$ $\quad T \equiv \textit{perioda signala}$

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

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

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

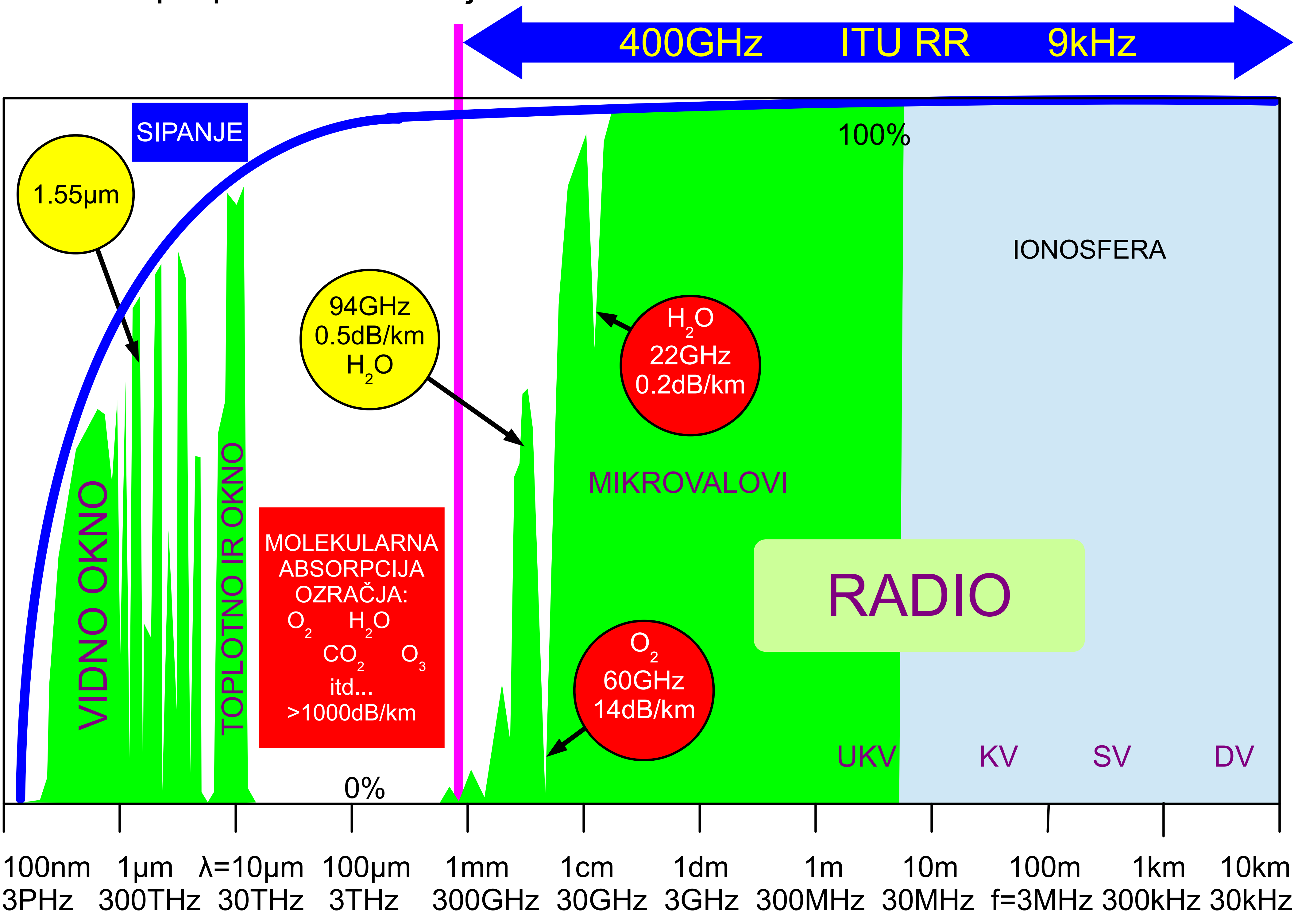
$m \equiv \textit{število rodov}$

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

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

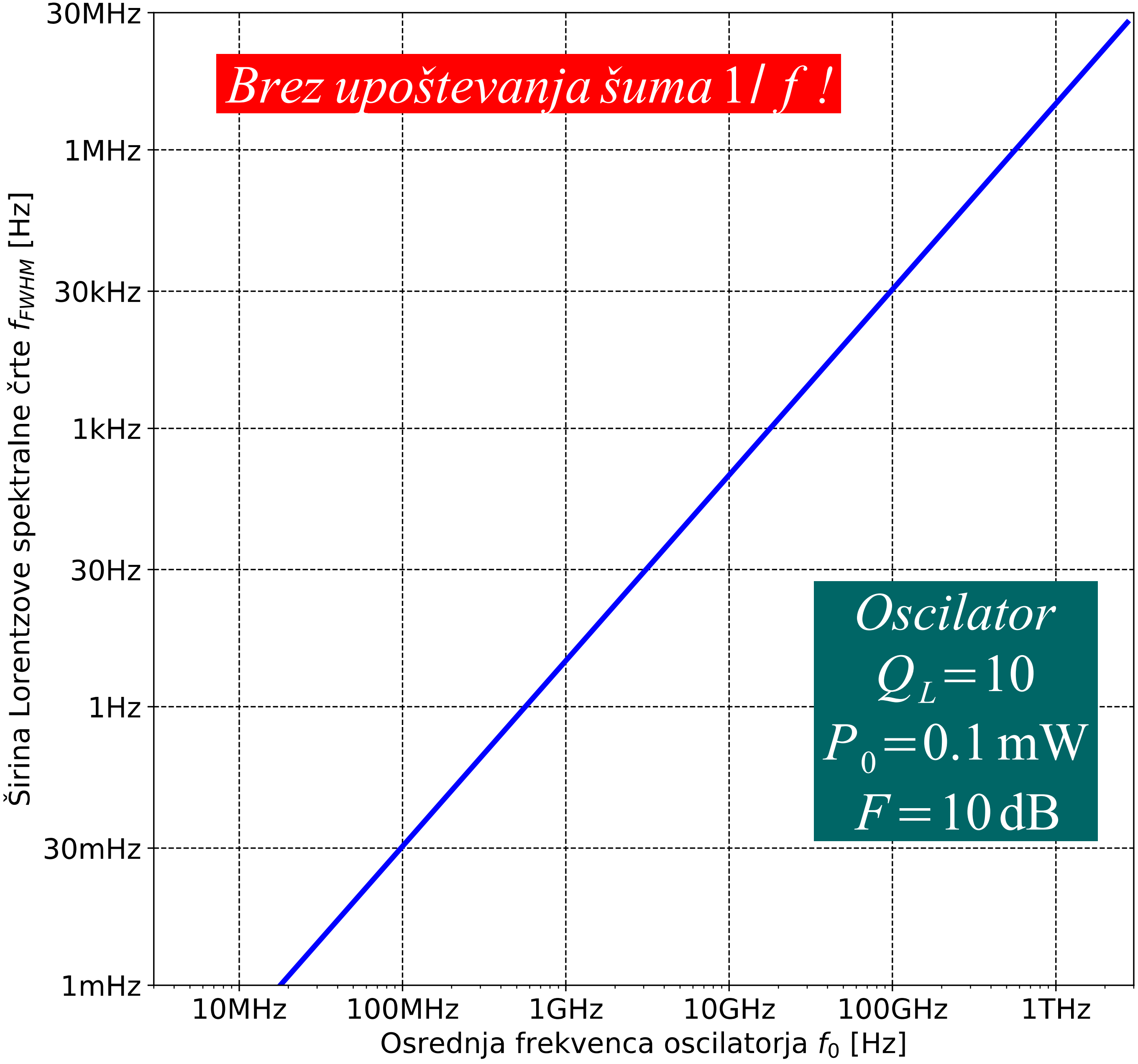
Zmogljivost radijske zveze

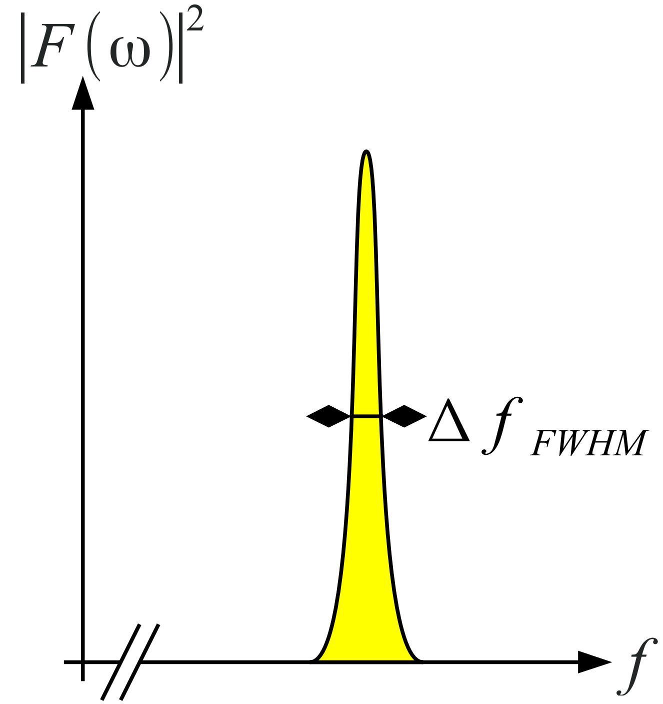
Zenitna prepustnost ozračja



Širina črte oscilatorja

$$\Delta f_{FWHM} \approx \frac{\pi k_B T_0 F}{4 P_0} \cdot \left(\frac{f_0}{Q_L} \right)^2$$





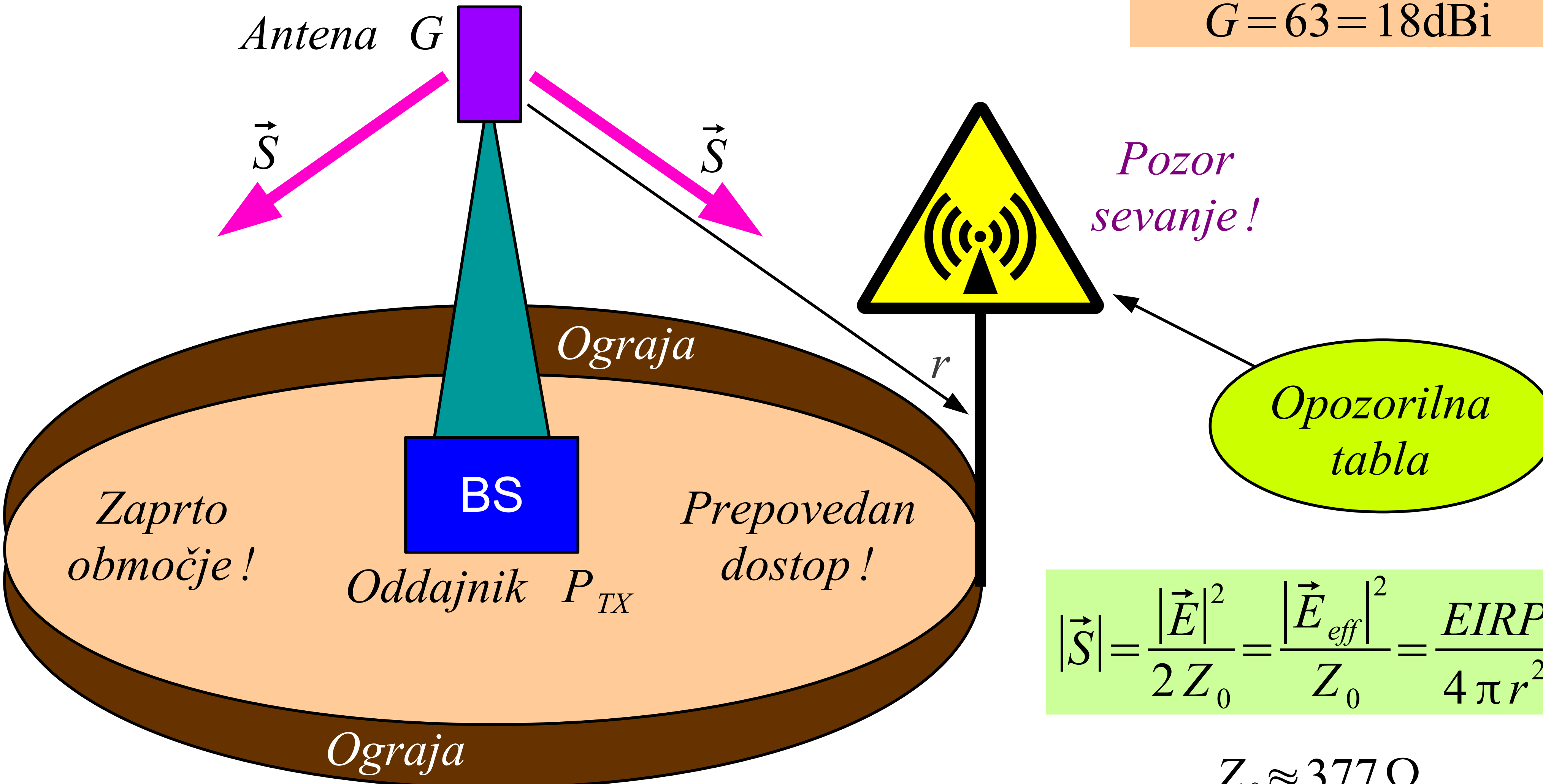
Osrednja frekvenca oscilatorja	Širina spektralne črte
3MHz	28μHz
30MHz	2.8mHz
300MHz	0.28Hz
3GHz	28Hz
30GHz	2.8kHz
300GHz	280kHz
3THz	28MHz

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

Zgled

$$P_{TX} = 100\text{W} = 50\text{dBm}$$

$$G = 63 = 18\text{dBi}$$



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

$$Z_0 \approx 377\,\Omega$$

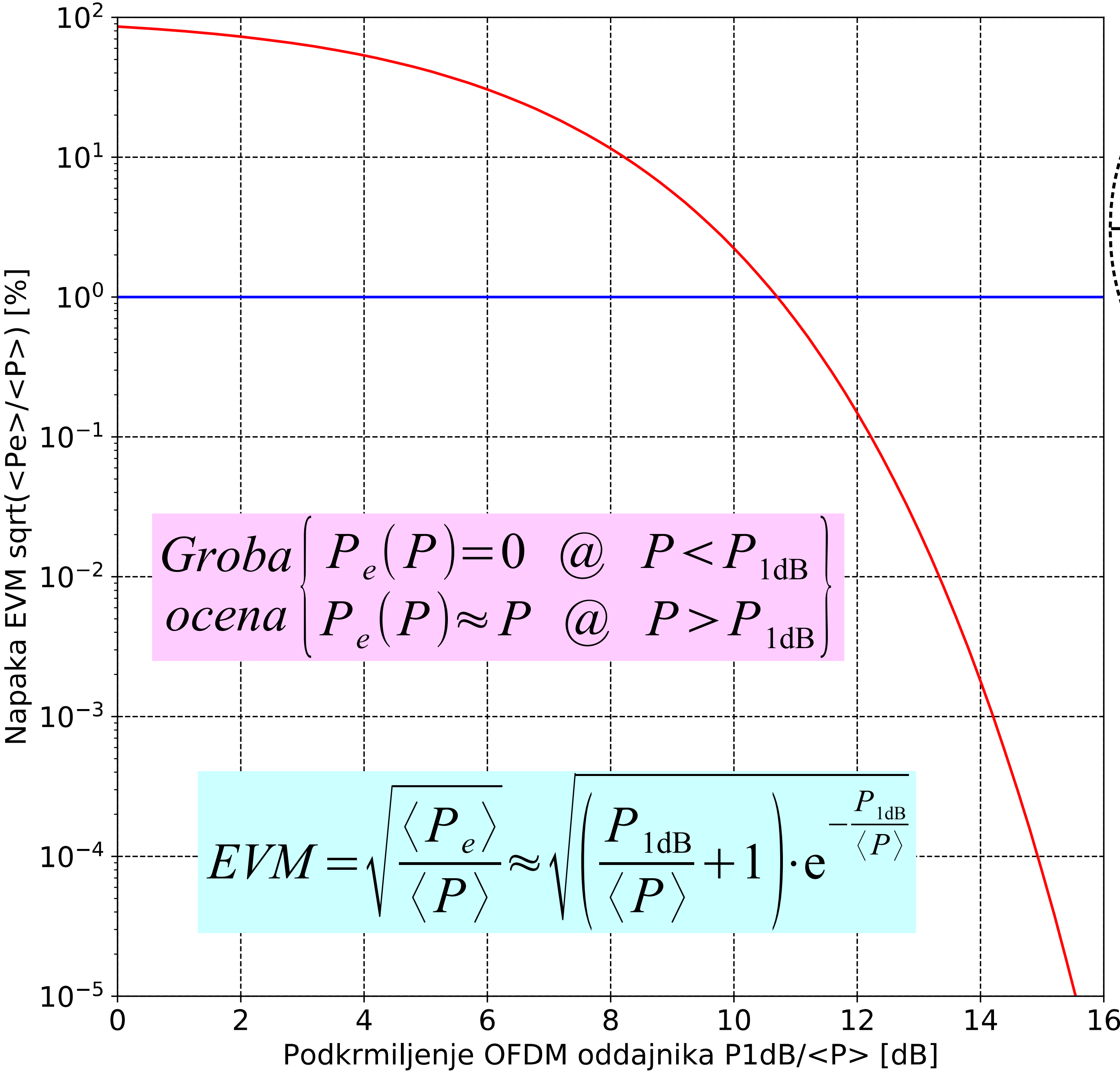
EU zakonodaja

$$|\vec{E}_{eff}| \leq 6\,\text{V}_{\text{eff}}/\text{m}$$

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

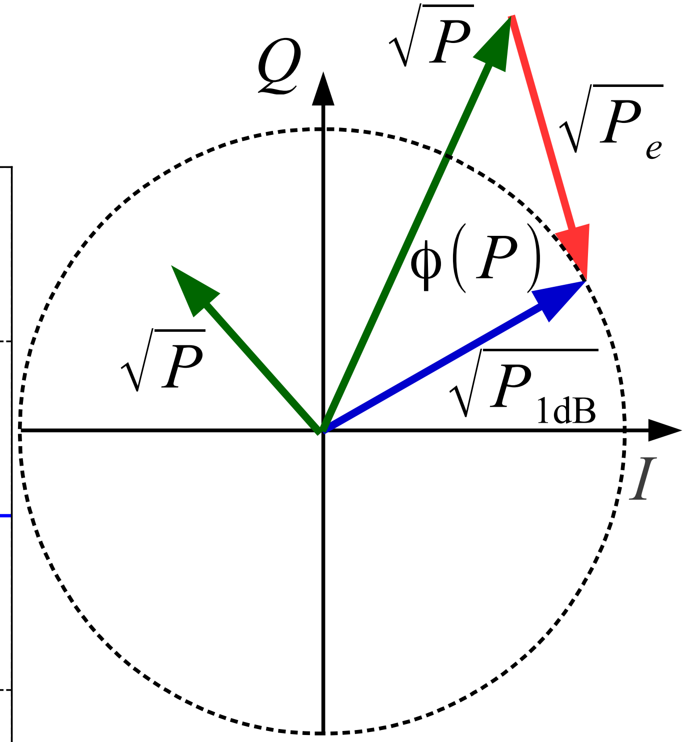
Ograja okoli vira sevanja

Error Vector Magnitude



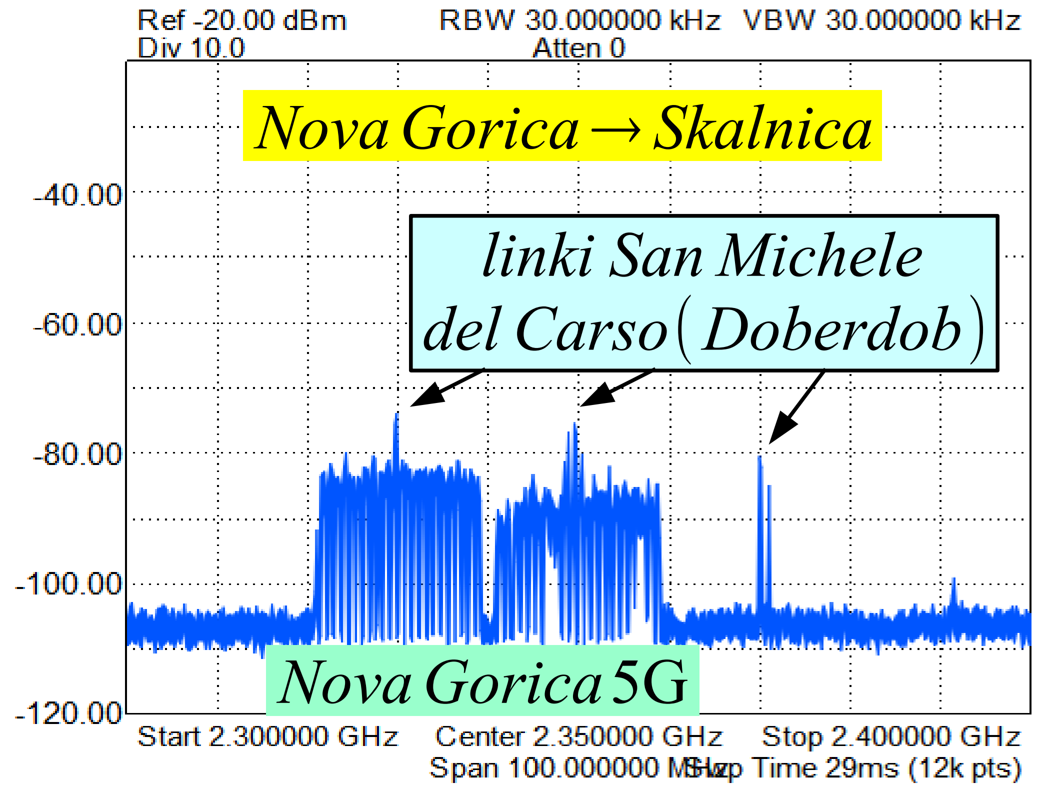
$$\text{Groba ocena}\begin{cases} P_e(P)=0 & @\quad P<P_{1\mathrm{dB}} \\ P_e(P)\approx P & @\quad P>P_{1\mathrm{dB}} \end{cases}$$

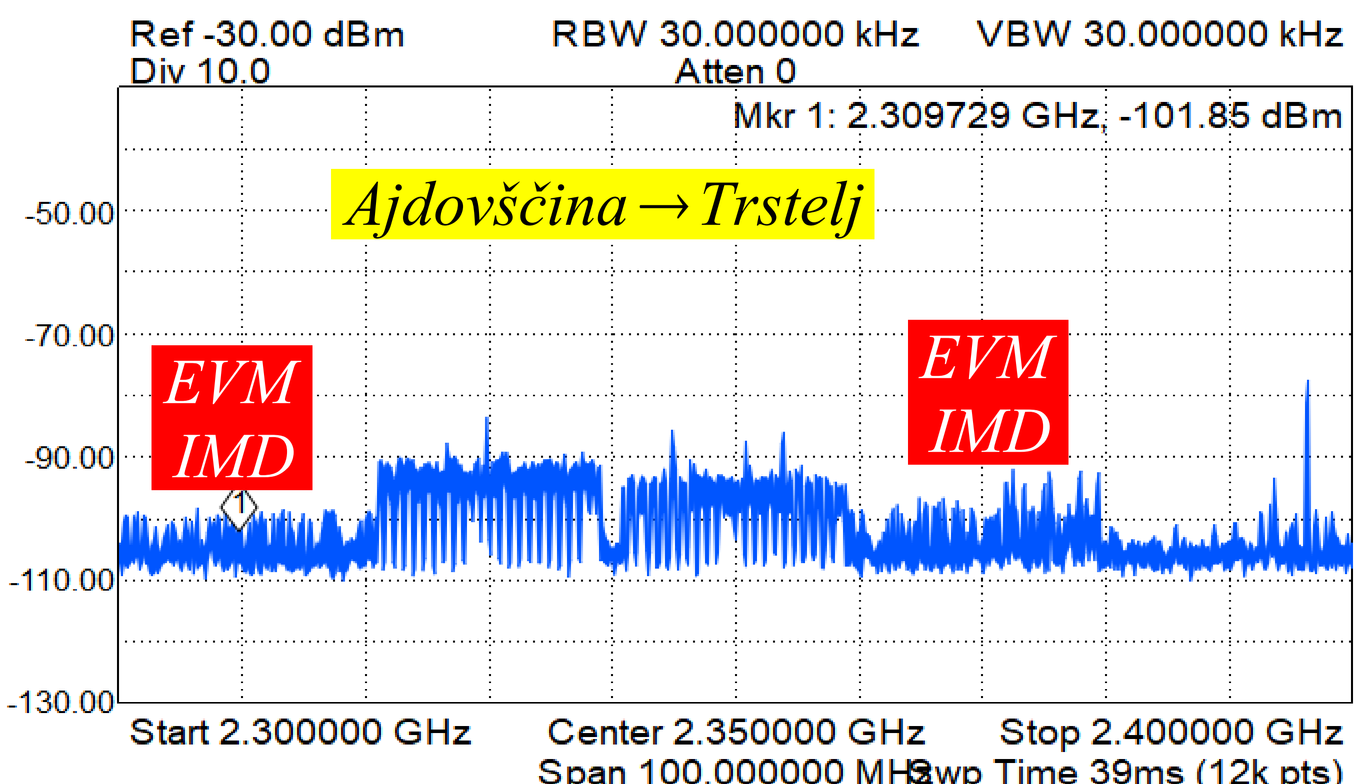
$$EVM=\sqrt{\frac{\langle P_e\rangle}{\langle P\rangle}}\approx\sqrt{\left(\frac{P_{1\mathrm{dB}}}{\langle P\rangle}+1\right)\cdot e^{-\frac{P_{1\mathrm{dB}}}{\langle P\rangle}}}$$



Motnje

Brez dogovora s sosedi...





Pri EVM > 10 % je OFDM neuporaben...