24. Seminar Radijske Komunikacije

Postopki računalniške simulacije anten s praktičnimi zgledi

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Seznam prosojnic: Postopki računalniške simulacije anten s praktičnimi zgledi

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Časovni prostor

Ampère $\mathrm{rot}\,\vec{H}=\vec{J}+\frac{\partial\vec{D}}{\partial t}$

Faraday $\mathrm{rot}\,\vec{E}=-\frac{\partial\vec{B}}{\partial t}$

Gauss $\mathrm{div}\,\vec{D}=\rho$

Preprosta snov

$\vec{D}=\epsilon\vec{E}$

$\vec{B}=\mu\vec{H}$

$\mathrm{rot}\,\vec{H}=\vec{J}+\epsilon\frac{\partial\vec{E}}{\partial t}$

$\mathrm{rot}\,\vec{E}=-\mu\frac{\partial\vec{H}}{\partial t}$

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

Frekvenčni prostor $\frac{\partial}{\partial t}\rightarrow j\omega$

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

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

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

Diferencialna oblika v elektrodinamiki!

1 − Maxwellove enačbe v časovnem in frekvenčnem prostoru

Smerni odvod

$$\operatorname{grad} T = \nabla T = \vec{1}_{q1}\frac{1}{h_1}\frac{\partial T}{\partial q_1} + \vec{1}_{q2}\frac{1}{h_2}\frac{\partial T}{\partial q_2} + \vec{1}_{q3}\frac{1}{h_3}\frac{\partial T}{\partial q_3}$$

Izvornost

$$\operatorname{div} \vec{F} = \frac{1}{h_1 h_2 h_3}\left[\frac{\partial\left(h_2 h_3 F_1\right)}{\partial q_1} + \frac{\partial\left(h_1 h_3 F_2\right)}{\partial q_2} + \frac{\partial\left(h_1 h_2 F_3\right)}{\partial q_3}\right]$$

Vrtinčenje

$$\operatorname{rot} \vec{F} = \frac{1}{h_1 h_2 h_3}\begin{vmatrix} h_1 \vec{1}_{q1} & h_2 \vec{1}_{q2} & h_3 \vec{1}_{q3} \\ \dfrac{\partial}{\partial q_1} & \dfrac{\partial}{\partial q_2} & \dfrac{\partial}{\partial q_3} \\ h_1 F_1 & h_2 F_2 & h_3 F_3 \end{vmatrix}$$

Koordinate

$$q_1, q_2, q_3$$

Faktorji skale

$(\textit{Lamé})$

$$h_1, h_2, h_3$$

$$\text{Antenska naloga: izvori } \vec{J}, \rho \rightarrow \text{ polja } \vec{E}, \vec{H}$$

$$\text{Gostota prevodniškega toka } \vec{J}\,[\mathrm{A/m^2}]$$

$$\text{Gostota elektrine } \rho\,[\mathrm{As/m^3}]$$

$$\text{Laplace } \Delta\vec{F} = \mathrm{grad}(\mathrm{div}\,\vec{F}) - \mathrm{rot}(\mathrm{rot}\,\vec{F})$$

$$\text{Valovna enačba za } \vec{E}\,[\mathrm{V/m}]$$

$$\Delta\vec{E} + \omega^2\mu\epsilon\vec{E} = j\omega\mu\vec{J} + \frac{1}{\epsilon}\mathrm{grad}\,\rho$$

$$\text{Valovna enačba za } \vec{H}\,[\mathrm{A/m}]$$

$$\Delta\vec{H} + \omega^2\mu\epsilon\vec{H} = -\mathrm{rot}\,\vec{J}$$

Uporabno v prostoru brez izvorov

$\vec{J}=0 \quad \rho=0$

oziroma v izgubni snovi

$\vec{J}=\gamma\vec{E}$

Skalarni potencial $V[\mathrm{V}]$

Vektorski potencial $\vec{A}[\mathrm{Vs/m}]$

Izračun polja:

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

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

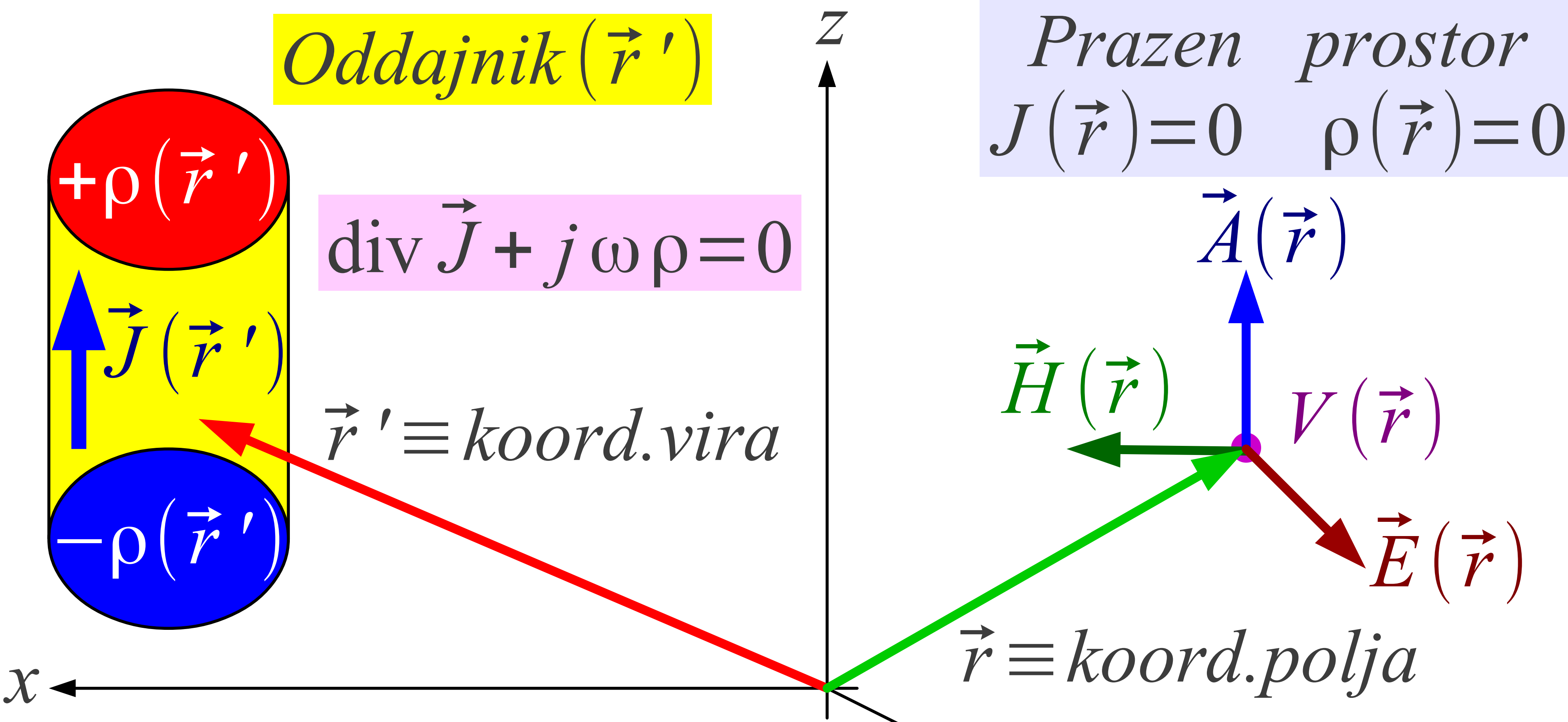
Valovno število $k^2 = \omega^2\mu\epsilon$

Lorenzova izbira: $\mathrm{div}\,\vec{A} = -j\omega\mu\epsilon V$

$$\Delta\vec{A} + \omega^2\mu\epsilon\vec{A} = -\mu\vec{J}$$

$$\Delta V + \omega^2\mu\epsilon V = -\frac{\rho}{\epsilon}$$

Valovni enačbi za potenciala imata analitsko rešitev!



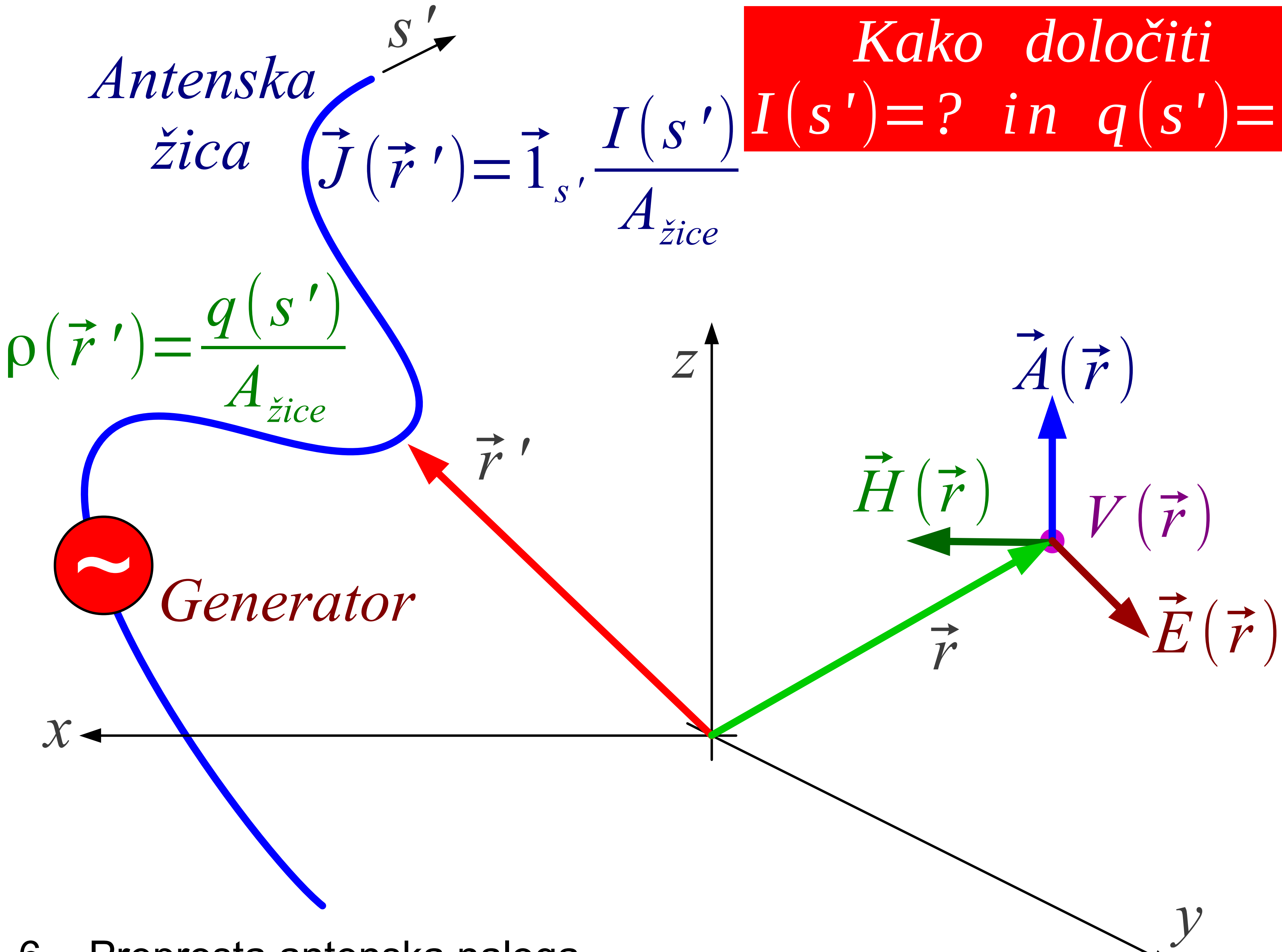
$$V(\vec{r})=\frac{1}{4\pi\epsilon}\iiint_{V'}\rho(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV'$$

$$k=\omega\sqrt{\mu\epsilon}$$

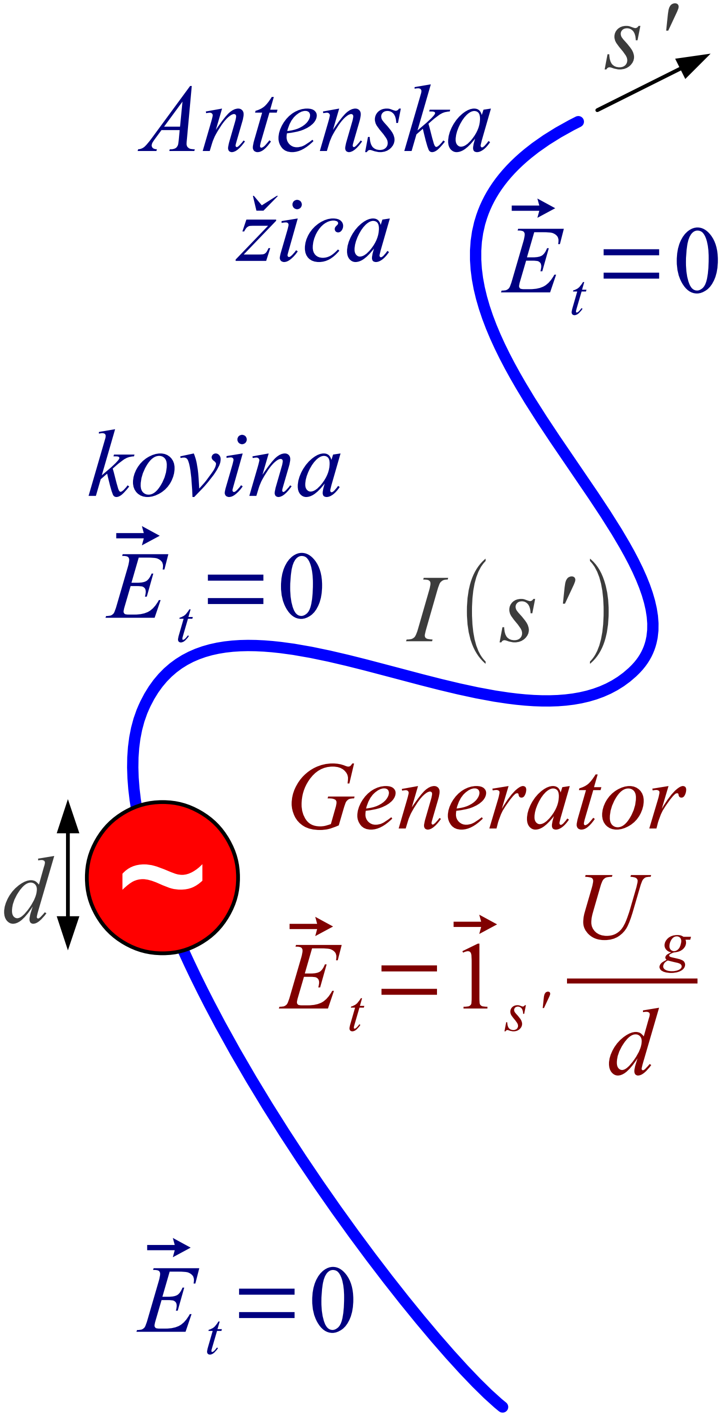
$$\vec{A}(\vec{r})=\frac{\mu}{4\pi}\iiint_{V'}\vec{J}(\vec{r}\,')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}dV'$$

5 − Zakasnjeni potenciali

Kako določiti
$I(s')=?$ in $q(s')=?$



6 − Preprosta antenska naloga



7 − Integralska enačba

$$\mathit{Lorenz}: \quad V=\frac{j}{\omega\mu\epsilon}\,\mathrm{div}\,\vec{A}$$

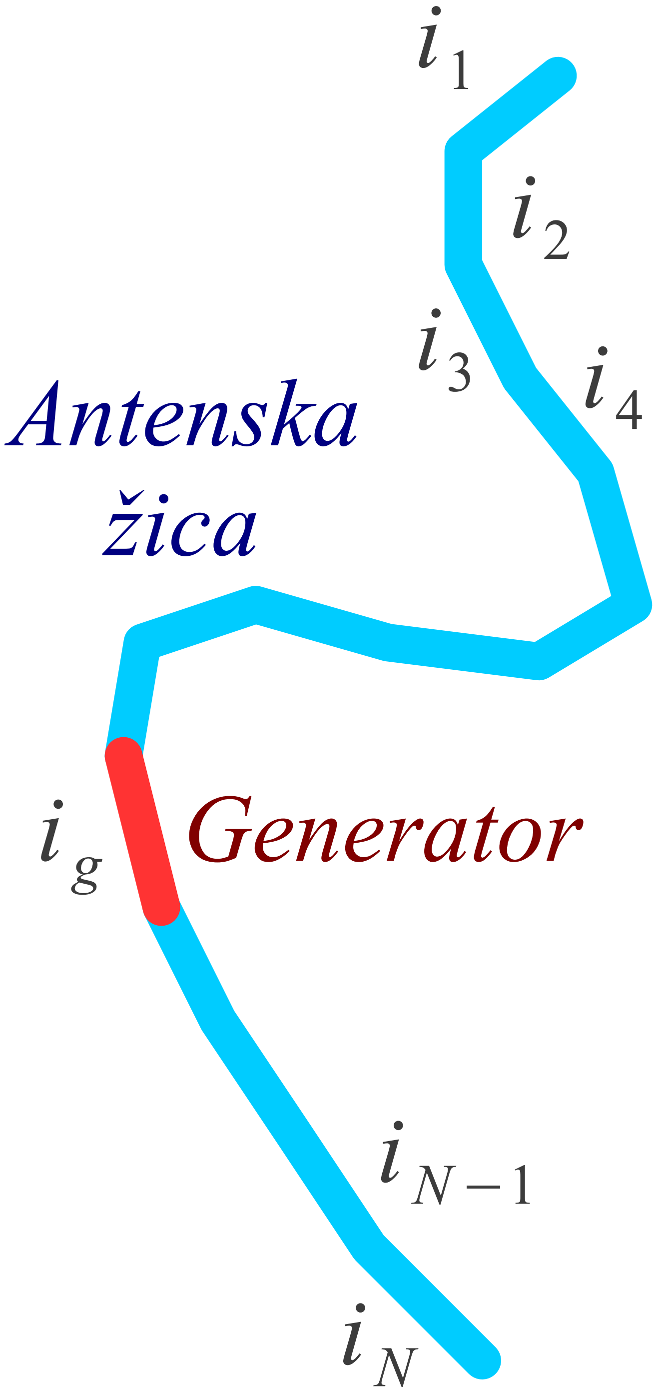
$$\vec{E}=-j\omega\vec{A}-\mathrm{grad}\left[\frac{j}{\omega\mu\epsilon}\,\mathrm{div}\,\vec{A}\right]$$

$$\vec{A}(\vec{r})=\frac{\mu}{4\pi}\int_{s'}\vec{1}_{s'}I(s')\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}ds'$$

$$\vec{E}_t(\vec{r}) \quad \mathit{na} \quad \check{z}\mathit{ici} \;\rightarrow\; I(s')=?$$

$$\vec{E}(\vec{r})=\frac{-j\omega\mu}{4\pi}\int_{s'}\vec{1}_{s'}I(s')\cdot$$

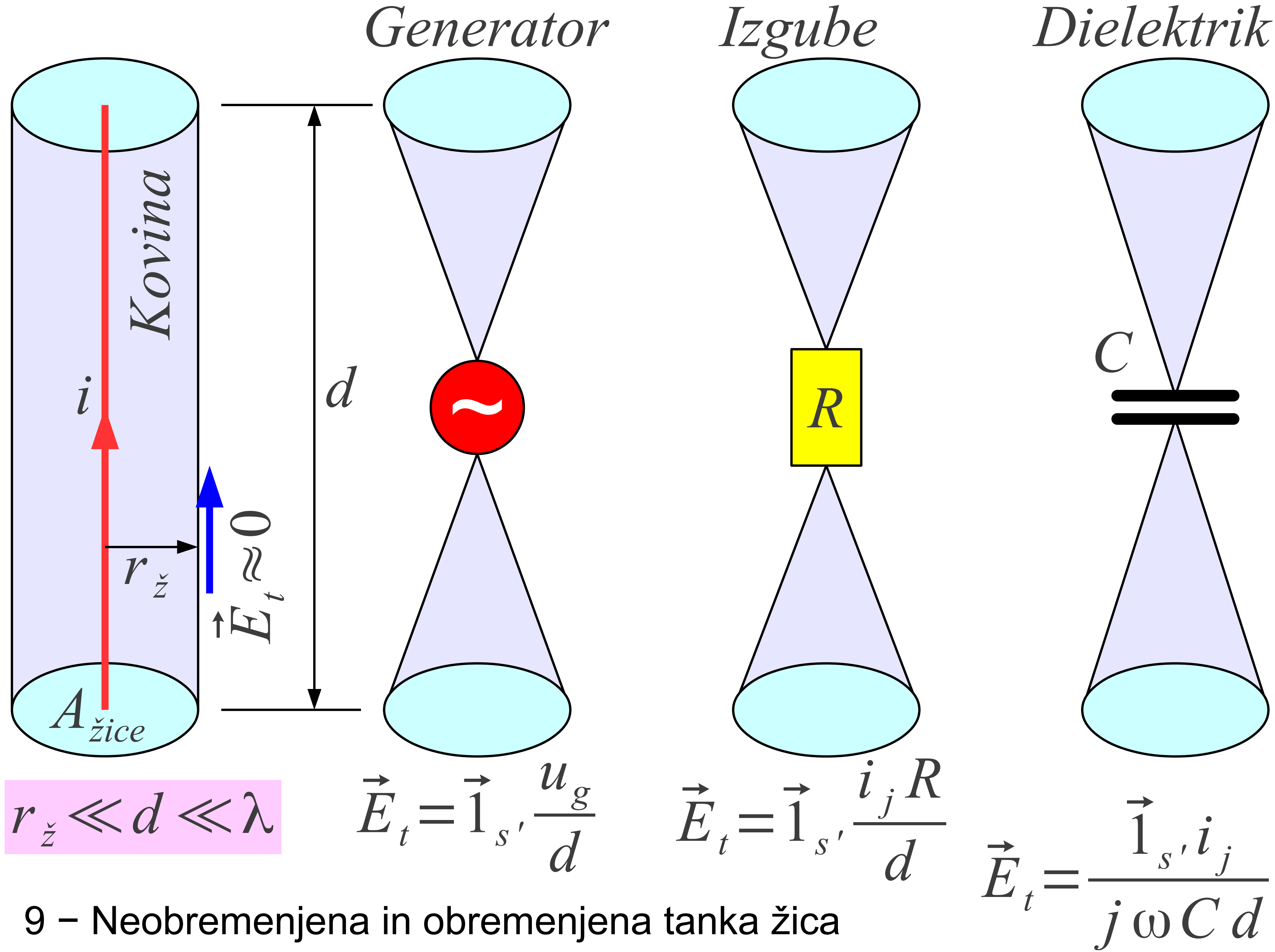
$$\cdot\left[1+\frac{1}{k^2}\mathrm{grad}_r(\mathrm{div}_r)\right]\frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}ds'$$



$$\text{Številski približek} \quad I(s') \approx \begin{bmatrix} i_1 \\ i_2 \\ \cdot \\ i_N \end{bmatrix}$$

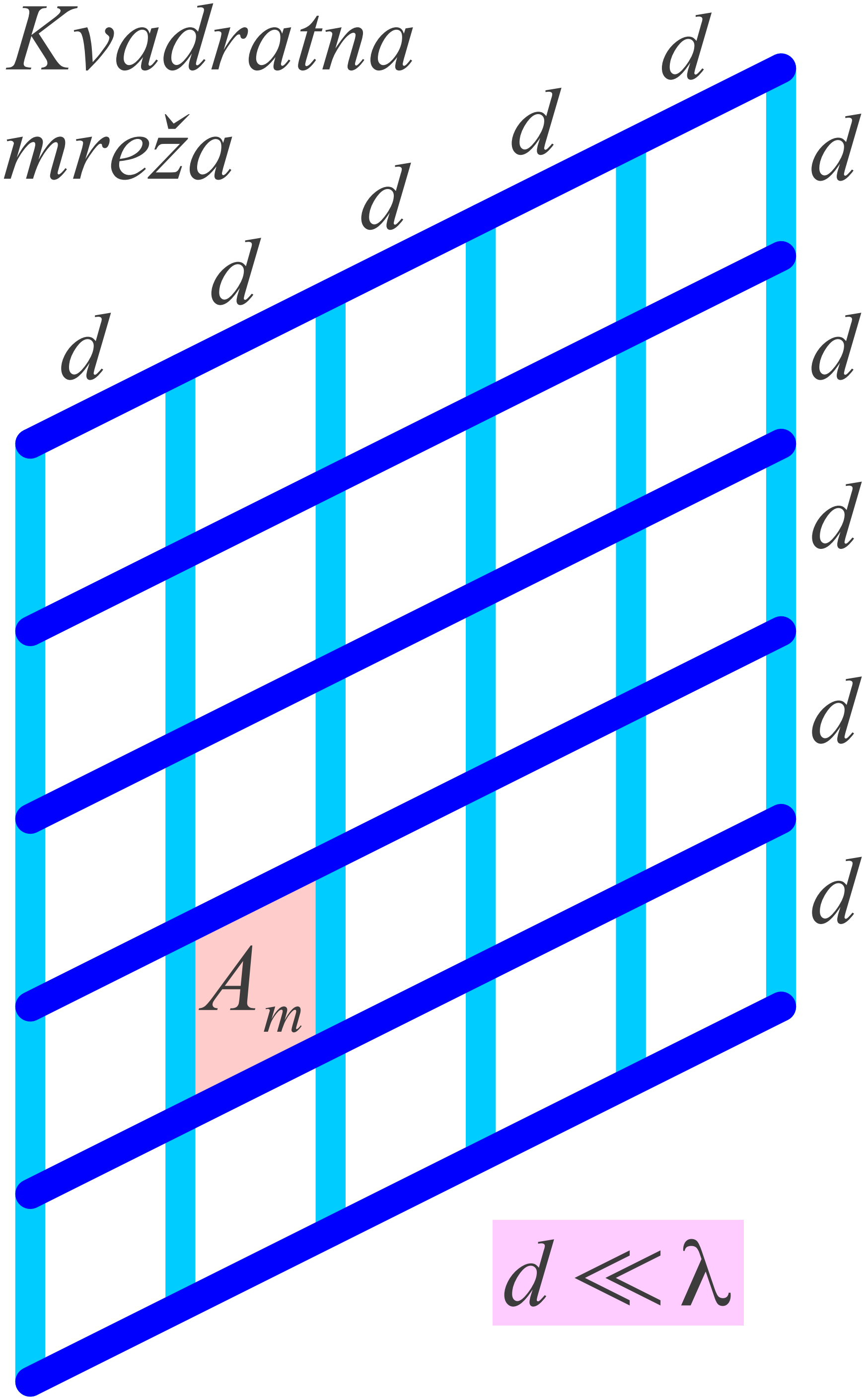
Sistem linearnih enačb

$$\begin{bmatrix} z_{11} & z_{12} & \cdot & z_{1N} \\ z_{21} & z_{22} & \cdot & z_{2N} \\ \cdot & \cdot & \cdot & \cdot \\ z_{N1} & z_{N2} & \cdot & z_{NN} \end{bmatrix} \cdot \begin{bmatrix} i_1 \\ i_2 \\ \cdot \\ i_N \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \cdot \\ u_g/d \\ \cdot \\ 0 \end{bmatrix}$$



9 − Neobremenjena in obremenjena tanka žica

Kvadratna mreža



$$A_m = d^2$$

$$d \ll \lambda$$

$$A_p = 2\pi r_ž d$$

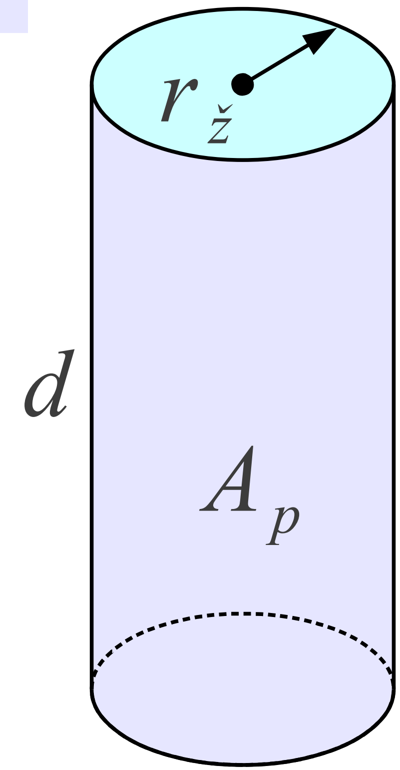
Pravilo enakih površin

$$A_m \approx A_p$$

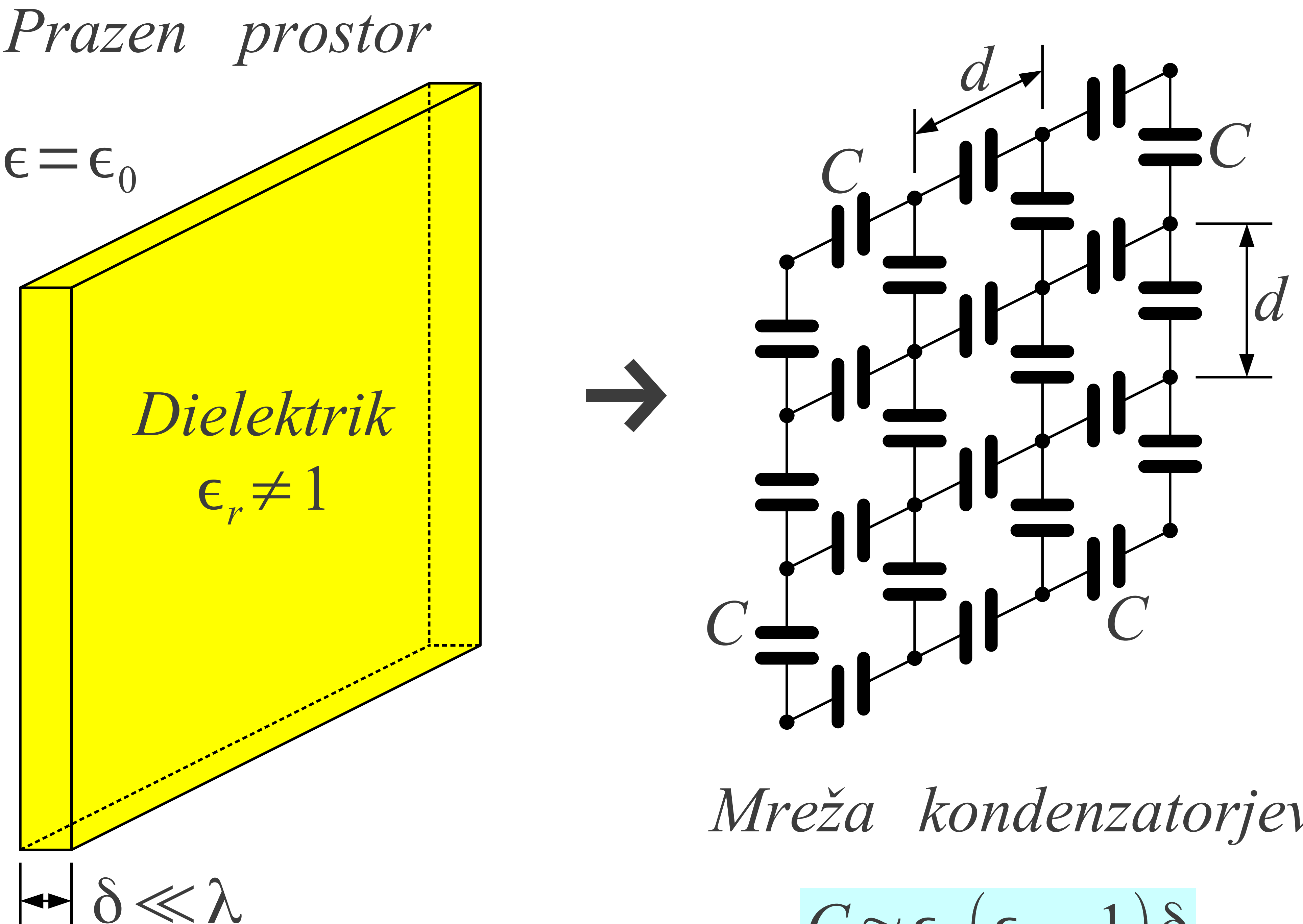
$$d^2 \approx 2\pi r_ž d$$

$$d \approx 2\pi r_ž$$

Odsek žične mreže

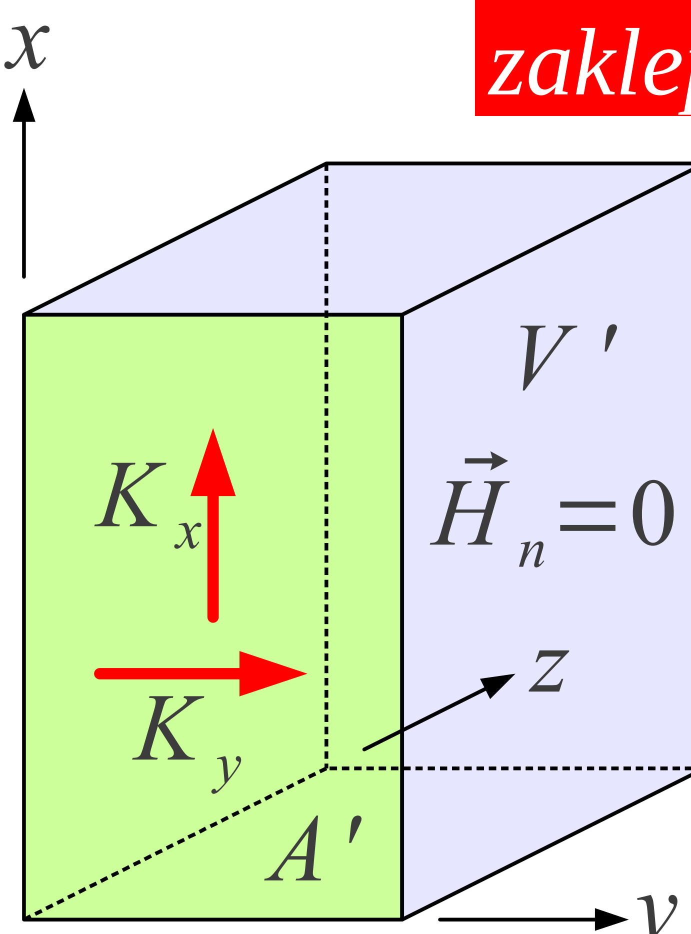


10 − Tanka kovinska ploskev



$$C \approx \epsilon_0 (\epsilon_r - 1) \delta$$

11 − Tanka dielektrična plošča



Pogoj: sklenjena ploskev A' zaklepa neničelno prostornino $V' \neq 0$

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

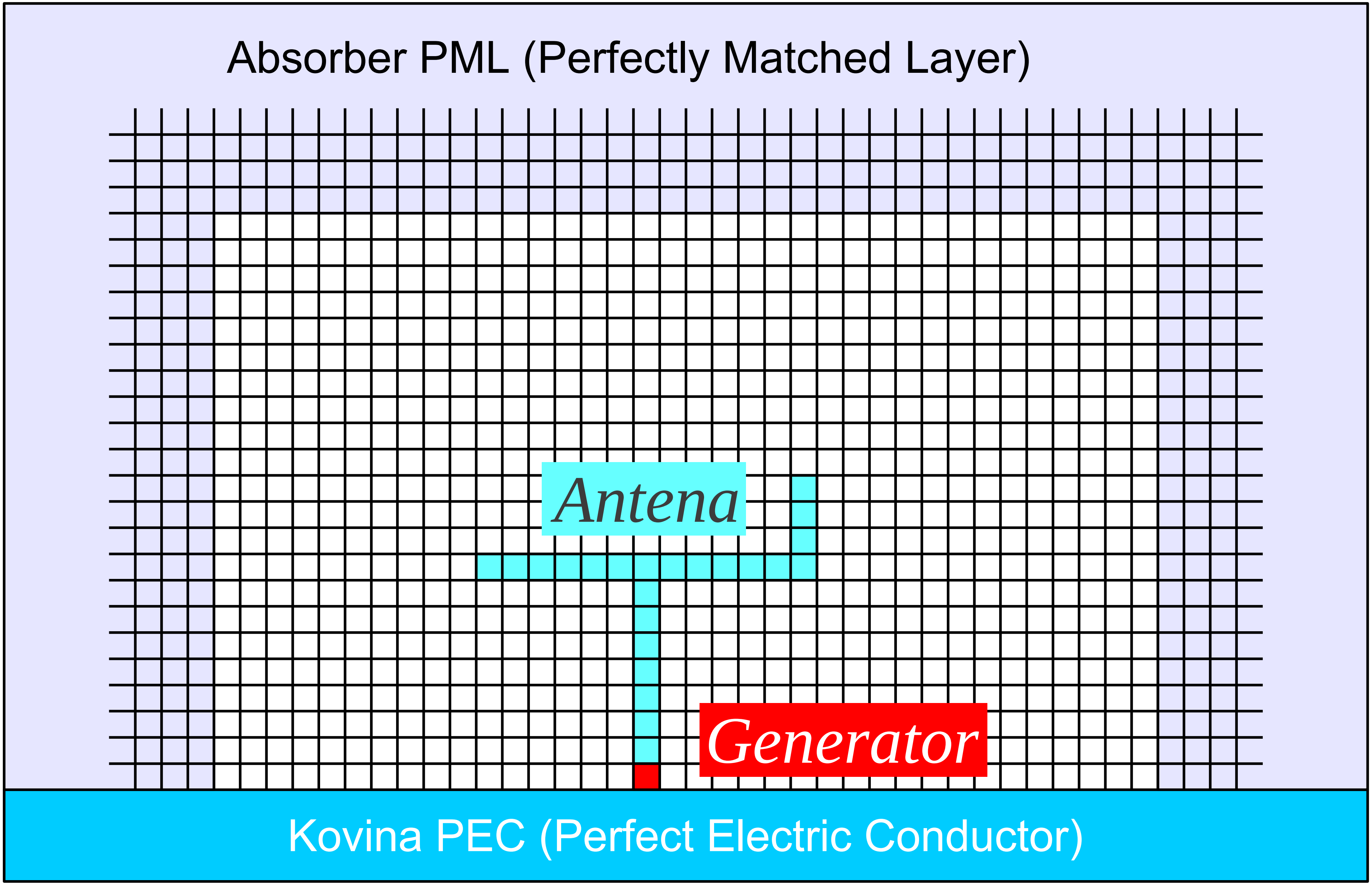
$$\vec{A}(\vec{r}) = \frac{\mu}{4\pi} \int_{A'} \vec{K}(\vec{r}\,') \frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|} dA'$$

Integralska enačba za $\vec{H}_{nt}$

$H_{nx} = 0, H_{ny} = 0 \;\rightarrow\; K_x = ?, K_y = ?$

$$\vec{H}(\vec{r}) = \frac{1}{4\pi} \int_{A'} \vec{K}(\vec{r}\,') \operatorname{rot}_r \frac{e^{-jk|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|} dA'$$

12 − Kovinsko telo neničelne prostornine


Absorber PML (Perfectly Matched Layer)
Antena
Generator
Kovina PEC (Perfect Electric Conductor)