

# 16. Elektromagnetická vlna ve vodiči, skin efekt

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Maxwellky:

$$\textcircled{1} \operatorname{div} \vec{B} = 0 \quad \textcircled{2} \operatorname{div} \vec{D} = \rho_a \quad \textcircled{3} \operatorname{rot} \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad \textcircled{4} \operatorname{rot} \vec{H} = \vec{j}_a + \frac{\partial \vec{D}}{\partial t}$$

• Ve vodivém prostředí platí:  $\vec{D} = \epsilon \vec{E}$ ,  $\vec{B} = \mu \vec{H}$ ,  $\vec{j}_a = \sigma \vec{E}$

• Zrotujeme  $\textcircled{3}$ :  $\operatorname{rot} \operatorname{rot} \vec{E} = -\frac{\partial}{\partial t} \operatorname{rot}(\mu \vec{H})$  /  $\operatorname{rot} \vec{H} = \sigma \vec{E} + \epsilon \frac{\partial \vec{E}}{\partial t}$

$$\bullet \operatorname{grad} \operatorname{div} \vec{E} - \Delta \vec{E} = -\sigma \mu \frac{\partial \vec{E}}{\partial t} - \epsilon \mu \frac{\partial^2 \vec{E}}{\partial t^2}$$

$$\bullet \underbrace{\Delta \vec{E} - \epsilon \mu \frac{\partial^2 \vec{E}}{\partial t^2}}_{\text{vlnová rovnice}} - \underbrace{\sigma \mu \frac{\partial \vec{E}}{\partial t}}_{\text{útlum vlny}} = 0$$

• Zfurijeme:  $(-k^2 + \epsilon \mu \omega^2 + i \omega \sigma \mu) \vec{E} = 0$

• Disperzní rel.:  $-k^2 + \epsilon \mu \omega^2 + i \omega \sigma \mu = 0$

$$k = \sqrt{\epsilon \mu \omega^2 + i \omega \sigma \mu}$$

vysoká vodivost  
tento člen vyhraje

$$k \hat{=} \sqrt{i \omega \sigma \mu} = \sqrt{\frac{\omega \sigma \mu}{2}} + i \sqrt{\frac{\omega \sigma \mu}{2}}$$

• Zkoumáme  $\left. \begin{array}{l} \text{prostorové} \\ \text{chování} \\ \text{vlny} \end{array} \right\} \psi(x) = A e^{i(kx)} = A \exp(i(\sqrt{\frac{\omega \sigma \mu}{2}} + i \sqrt{\frac{\omega \sigma \mu}{2}})x)$

$$= A \underbrace{e^{-\sqrt{\frac{\omega \sigma \mu}{2}} x}}_{\text{útlum}} \underbrace{e^{i \sqrt{\frac{\omega \sigma \mu}{2}} x}}_{\text{sin a cos}}$$

• Charakteristická hloubka  $\delta \dots A = \frac{A_0}{e}$

$$\sqrt{\frac{\omega \sigma \mu}{2}} x = 1$$

$$\delta = \sqrt{\frac{2}{\omega \sigma \mu}} \quad ; \text{skinová hloubka} \rightarrow \text{útlum amplitudy e-krát (skin efekt)}$$