3. CIKLUS

ELEKTRODINAMIKA

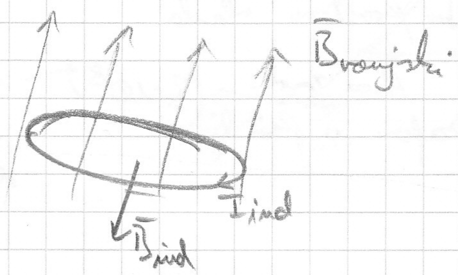
naboji u nejednolikom gibanju

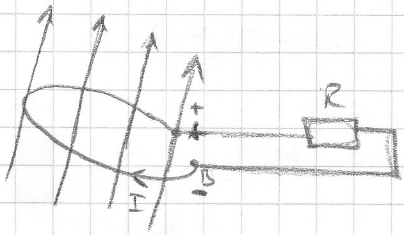
$$e = \oint_c \bar{E}_{ind} \cdot d\bar{l} = -\frac{d\Phi}{dt} = -\frac{d}{dt}\iint_S \bar{B} \cdot \bar{n}\, dS$$

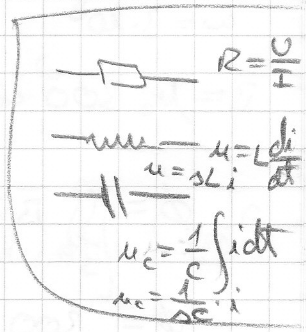
u vremenski promjenjivim mag. poljima se inducira elektromotorna sila

- Inducirana struja protivi se promjeni magnetskog toka

$$e = -\frac{d\Phi}{dt}$$







$$\oint_c \bar{E}_{ind}\, d\bar{l} = -\iint_S \frac{\partial \bar{B}}{\partial t}\bar{n}\, dS + \oint_c (\bar{v} \times \bar{B})\, d\bar{l}$$

promjena toka u vremenu

gibanje petlje

$$\nabla \times \bar{E}_{ind} = -\frac{\partial \bar{B}}{\partial t} + \nabla \times (\bar{v} \times \bar{B})$$

ako petlja miruje

$$\nabla \times \bar{E}_{ind} = -\frac{\partial \bar{B}}{\partial t}$$

$$e = BS\omega \sin(\omega t)$$

za N namota

$$e = NBS\omega \sin(\omega t)$$

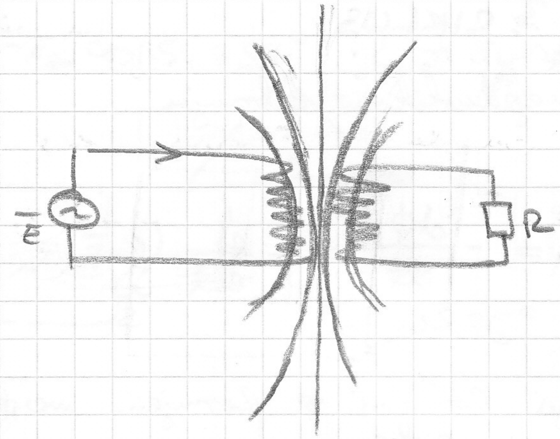
trafo

$$\frac{U_1}{U_2} = \frac{N_1}{N_2}$$

$$N_1 i_1 = N_2 i_2$$

$$p_1 = u_1 i_1$$

$$p_1 = p_2 = u_2 i_2 = u_1 i_1$$

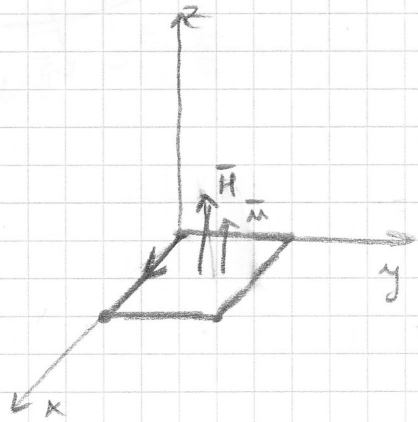


Zad. U slobodnom prostoru vlada

$$\bar{H} = 300\cos(3\cdot 10^8 t - y)\,\bar{a}_z$$

Inducirani napon u petlji

(000)
(100)
(110)
(010)



$$\bar{n} = \bar{a}_z$$

$$\omega = 3\cdot 10^8$$

$$B = \mu_0\, 300\cos(\omega t - y)\,\bar{a}_z$$

$$\phi = \iint_S \bar{B}\,\bar{n}\, dS$$

$$\phi = 300\mu_0 \int_{x=0}^{1}\int_{y=0}^{1} \cos(\omega t - y)\, dx\, dy$$

$$\phi = 300\mu_0 \cdot x\Big|_0^1 \left(-\sin(\omega t - y)\right)\Big|_0^1$$

$$\phi = \overset{(-1)}{300}\mu_0 \left(\sin(\omega t - 1) - \sin \omega t\right)$$

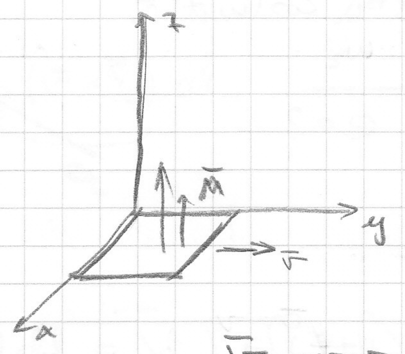
$$e = -\frac{d\phi}{dt} = 300\mu_0\omega\left(\cos(\omega t - 1) - \cos\omega t\right)$$

$$= 113.1\cdot 10^3 \left(\cos(3\cdot 10^8 t - 1) - \cos(3\cdot 10^8 t)\right)$$

Zad. Kvadratna petlja stranice 25 cm je u trenutku $t=0$ u ravni $z=0$ sa vrhovima $(0\ 0\ 0)$, $(0.25\ 0\ 0)$, $(0.25\ 0.25\ 0)$, $(0\ 0.25\ 0)$

Petlja se kreće sa $v = 50\,\bar{a}_y$ m/s u polju $\bar{B} = 8\cos(1.5\cdot10^8 t - 0.5x)\,\bar{a}_z\ \mu T$

Odredi napon indukovan u petlji



$$e = \underbrace{-\iint_S \frac{\partial B}{\partial t}\,\bar{n}\,dS}_{e_1} + \underbrace{\oint_c (\bar{v}\times\bar{B})\,d\bar{l}}_{e_2}$$

$\bar{v} = v\,\bar{a}_y$

$$\bar{B} = 8\cos(\omega t - 0.5x)\,\bar{a}_z \quad [\mu T]$$

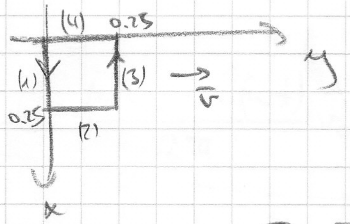
$$\omega = 1.5\cdot10^8$$

$$-\frac{\partial B}{\partial t} = 8\omega\sin(\omega t - 0.5x)\,\bar{a}_z$$

$$e_1 = -\iint \frac{\partial B}{\partial t}\,\bar{n}\,dS = \int_{x=0}^{0.25}\int_{y=0} 8\omega\sin(\omega t - 0.5x)\,dx\,dy \cdot 10^{-6}$$

$$= 8\cdot0.25\cdot\frac{-\omega}{-0.5}\left[\cos(\omega t - 0.125) - \cos(\omega t)\right]\cdot10^{-6}$$

$$= 600\left[\cos(\omega t - 0.125) - \cos(\omega t)\right]$$



$$\bar{v}\times\bar{B} = \bar{a}_x\,v\cdot8\cos(\omega t - 0.5x)$$

$$e_2 = \int_{(1)} \bar{v}\times\bar{B}\,dl + \cancel{\int_{(2)}()}^{\,0} + \int_{(3)}() + \cancel{\int_{(4)}()}^{\,0}$$

$$e_2 = \int_{(1)} + \int_{(2)} = 0$$

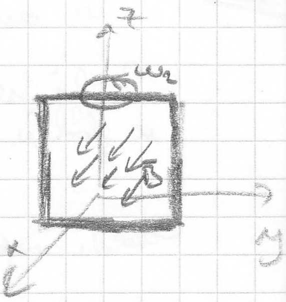
$$e = e_1 + e_2 = 600\left[\cos(\omega t - 0.125) - \cos\omega t\right]$$

Zad

Gustoća mag. toka je $\bar{B} = B_0 \cos(\omega_1 t)\,\bar{a}_x$

Pravokutna žičana petlja površine S je smještena simetrično obzirom na os z i rotira oko nje konstantnom kutnom brzinom ω_2

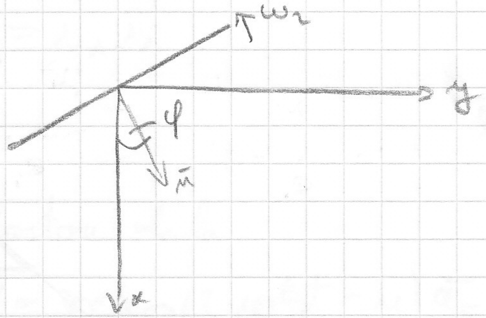
Odredi napon induciran u petlji



$\bar{B} = B_0 \cos(\omega_1 t)\,\bar{a}_x$

ω_2

$e = ?$



$\varphi = \omega_2 t + \varphi_0$

$\bar{n} = \cos\varphi\,\bar{a}_x + \sin\varphi\,\bar{a}_y$

$$\phi = \iint_S \bar{B}\bar{n}\,dS = \bar{B}\bar{n}\iint dS$$

$$= B_0 \cos(\omega_1 t)\,\bar{a}_x \left[\cos\varphi\,\bar{a}_x + \sin\varphi\,\bar{a}_y\right] \cdot S$$

$$= B_0 S \cos(\omega_1 t)\cos(\omega_2 t + \varphi_0)$$

$$e = -\frac{d\phi}{dt} = -B_0 S \left\{ -\omega_1 \sin(\omega_1 t)\cos(\omega_2 t + \varphi_1) - \omega_2 \cos(\omega_1 t)\sin(\omega_2 t + \varphi_0) \right.$$

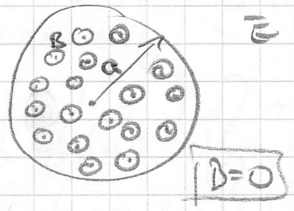
Zad

Gustoća mag. toka je u cilindričnom koord. sustavu

$$\bar{B} = \begin{cases} B_0 \sin\omega t\,\bar{a}_z & r < a \\ 0 & r > a \end{cases}$$

Odredi inducirano el. polje u prostoru

$$e = -\frac{d\phi}{dt}$$



$\bar{E} = E_\alpha\,\bar{a}_\alpha$

$$\oint \bar{E}\,dl = -\frac{d\phi}{dt}$$

$$\phi = \begin{cases} B_0 r^2\pi \sin\omega t, & r < a \\ B_0 a^2\pi \sin\omega t, & r > a \end{cases}$$

$r < a$

$$E_\alpha 2\pi r = -B_0 r^2\pi\,\omega\cos(\omega t)$$

$$E_\alpha = -\frac{B_0 r\omega}{2}\cos(\omega t)$$

$r > a$

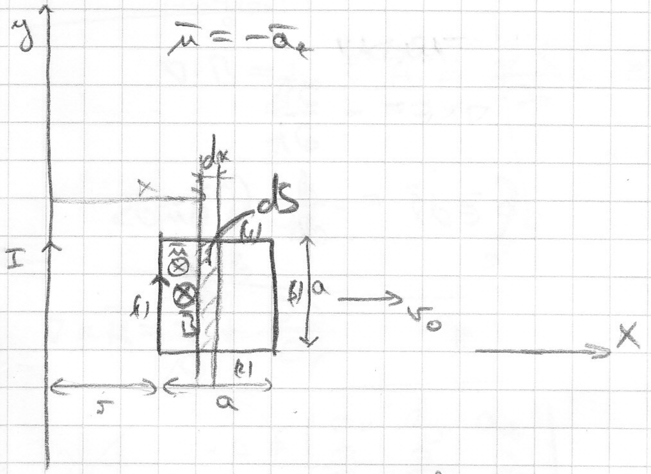
$$E_\alpha 2\pi r = -B_0 a^2\pi\,\omega\cos(\omega t)$$

$$E_\alpha = -\frac{B_0 a^2\omega}{2r}\cos(\omega t)$$

Beskonačno duga ravna strujnica polijegana je izmjeničnom strujom
$i(t) = I_m \sin(\omega t)$

U ravnini strujnice giba se kvadratna vodljiva petlja stranice a konst. brzinom v_0 okomito na strujnicu

Odredi amplitudu induciranog napona kad je petlja u položaju $r = a$



$$\bar{n} = -\bar{a}_z$$

$$e = \underbrace{-\iint_S \frac{d\bar{B}}{dt}\,\bar{n}\,dS}_{e_1} + \underbrace{\oint (\bar{v}\times\bar{B})\,d\bar{l}}_{e_2}$$

$$e_2 = \oint (\bar{v}\times\bar{B})\,dl = \int_{(1)}(\,) + \int_{(2)}(\,) + \int_{(3)}(\,) + \int_{(4)}(\,)$$

$$B(x) = \frac{\mu_0\, i(t)}{2\pi x}(-\bar{a}_z)$$

$$v\times B = v_0 \frac{\mu_0\, i(t)}{2\pi x}\bar{a}_y$$

$$v = v_0\,\bar{a}_x$$

$$\frac{\partial B}{\partial t}(x) = \frac{\mu_0 I_m \omega \cos(\omega t)}{2\pi x}(-a_z)$$

(1) $d\bar{l} = dy\,\bar{a}_y$

(2) $d\bar{l} = -dx\,\bar{a}_x \rightarrow (v\times B)\,dl = 0$

(3) $d\bar{l} = -dy\,\bar{a}_y$

(4) $dl = dx\,\bar{a}_x \rightarrow (v\times B)\,dl = 0$

$$e_1 = -\frac{\mu_0 I_m \omega \cos(\omega t)}{2\pi}\int_r^{r+a}\frac{1}{x}\,dx$$

$$e_1 = \frac{-\mu_0 I_m \omega \cos(\omega t)}{2\pi}\ln\frac{r+a}{r}$$

(1) $$e_2 = \oint (v\times B)\,dl = \int_{y=0}^{a}\frac{\mu_0 I_m \sin(\omega t)}{2\pi r}v_0\,dy$$

$$= \frac{\mu_0 I_m \sin(\omega t)\cdot v_0\cdot a}{2\pi r}$$

(3) $$e_2 = -\int_{y=0}^{a}\frac{\mu_0 I_m \sin(\omega t)}{2\pi(r+a)}v_0\,dy$$

$$= -\frac{\mu_0 I_m \sin(\omega t)}{2\pi(r+a)}v_0\cdot a$$

$$e_2 = \frac{\mu_0 I_m \sin(\omega t)}{2\pi}v_0 a\left[\frac{1}{r} - \frac{1}{r+a}\right]$$

$$e = e_1 + e_2$$

za $r = a$

$$e = +\frac{\mu_0 I_m\cdot a}{2\pi}\left[-\omega\cos(\omega t)\ln\left(\frac{r+a}{r}\right) + v_0\sin(\omega t)\left(\frac{1}{r} - \frac{1}{r+a}\right)\right]$$

$$e = \frac{\mu_0 I_m a}{2\pi}\left[-\omega\ln(2)\cos(\omega t) + \frac{v_0}{2a}\sin(\omega t)\right]$$

$$|e(r)| = \frac{\mu_0 I a}{2\pi}\sqrt{\frac{v_0^2}{4a^2} + \omega^2\ln^2(2)}$$

MAXWELLOVE JEDNADŽBE

Proširenje Ampereovog zakona

$$\nabla \times \bar{H} = \bar{J} \Rightarrow \oint_c \bar{H} d\bar{l} = \iint_S \bar{J} \bar{n} dS$$

Maxwellovo proširenje zakona

$$\nabla \cdot (\nabla \times A) = 0$$

$$\nabla \cdot (\nabla \times \bar{H}) = 0 = \nabla \cdot \bar{J}$$

Korekcija

$$\nabla \left(\bar{J} + \frac{\partial \bar{D}}{\partial t} \right) = 0 \Rightarrow \nabla \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$$

FARADAY

$$\nabla \times E = -\frac{\partial \bar{B}}{\partial t}$$

$$\oint_c \bar{E} d\bar{l} = -\frac{d}{dt} \iint_S \bar{B} \bar{n} dS$$

Zad. Ako u vakuumu (zraku) vlada el. polje

$$\bar{E} = E_m \sin(\alpha x) \cos(\omega t - \beta z)\, \bar{a}_y$$

Odredi jakost mag. polja.

$\bar{H} = ?$

$$\nabla \times \bar{E} = -\frac{\partial B}{dt}$$

$$\nabla \times \bar{E} = \begin{vmatrix} \bar{a}_x & \bar{a}_y & \bar{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & E_y & 0 \end{vmatrix} = \bar{a}_z \frac{\partial E_y}{\partial x} - \bar{a}_x \frac{\partial E_y}{\partial z}$$

$$\nabla \times \bar{E} = \bar{a}_z E_m \alpha \cos(\alpha x) \cos(\omega t - \beta z) - \bar{a}_x E_m \sin(\alpha x)(-1)(-\beta)\sin(\omega$$

$$= \mu_0 \frac{\partial \bar{H}}{\partial t} \quad / \int$$

$$\bar{H} = -\frac{1}{\mu_0} \Big[\bar{a}_z E_m \alpha \cos(\alpha x) \int \cos(\omega t - \beta z)\, dt$$
$$+ \bar{a}_x \beta E_m \sin(\alpha x) \int \sin(\omega t - \beta z)\, dt \Big]$$

$$\bar{H} = -\bar{a}_x E_m \frac{\beta}{\omega \mu_0} \sin(\alpha x) \cos(\omega t - \beta t)$$
$$- \bar{a}_z E_m \frac{\alpha}{\omega \mu_0} \cdot \cos(\alpha x) \sin(\omega t - \beta z)$$

+ ISTOSMJERNA KOMPONENTA ← C - konst

$$\nabla\cdot\bar{D} = \varepsilon_0 \nabla\cdot\bar{E} = \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = 0$$

NEMA SLOBODNOG NABOJA

PROVJERA ZADATKA

$$\boxed{\nabla\cdot\bar{B} = 0} \leftarrow \text{mora biti}$$

provjera:

$$\nabla\cdot\bar{B} = \mu_0 \nabla\cdot\bar{H} = \frac{\partial H_x}{\partial x} + \frac{\partial H_z}{\partial z} = -\frac{E_m \beta}{\omega\mu_0}\cdot\alpha\cdot\cos(\alpha x)\cdot\cos(\omega t - \beta z)$$

$$- \frac{E_m \alpha}{\omega\mu_0}(-\beta)\cos(\alpha x)\cos(\omega t - \beta z) = 0$$

$$\nabla\times\bar{H} = \cancelto{0}{\bar{J}} + \frac{\partial\bar{D}}{\partial t}$$

$$\nabla\times\bar{H} = \begin{vmatrix} a_x & a_y & a_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ H_x & 0 & H_z \end{vmatrix} = \bar{a}_x \cancelto{0}{\frac{\partial H_z}{\partial y}} + \bar{a}_y\left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x}\right) - a_z \cancelto{0}{\frac{\partial H_x}{\partial y}}$$

$$= a_y\left[-E_m \frac{\beta}{\omega\mu_0}\sin(\alpha x)\left[-\sin(\omega t - \beta z)\right](-\beta) + E_m \frac{\alpha}{\omega\mu_0}(-\sin\alpha x)\cdot\alpha\cdot\sin(\omega t - \beta z)\right]$$

$$= \left[-\frac{E_m}{\omega\mu_0}\sin(\alpha x)\sin(\omega t - \beta z)(\beta^2 + \alpha^2)\right]\bar{a}_y$$

$$\frac{\partial\bar{D}}{\partial t} = \varepsilon_0 \frac{\partial\bar{E}}{\partial t} = \varepsilon_0 E_m(-\omega)\sin(\alpha x)\sin(\omega t - \beta z)\,\bar{a}_y$$

$-\beta z)$

→ IZJEDNAČAVANJE

$$-\frac{E_m}{\omega\mu_0}(\alpha^2 + \beta^2) = -\varepsilon_0 \omega E_m$$

$$\boxed{\alpha^2 + \beta^2 = \varepsilon_0 \mu_0 \omega^2}$$

brzina prostiranja po z osi
modulacija amplitude
$(\alpha\ i\ \beta)$

$$\boxed{\alpha^2 + \beta^2 = \varepsilon\mu\omega^2}$$

U materijalu sa gubicima

Zad

$\mu = 3 \cdot 10^{-5}\ H/m$

$\varepsilon = 1.2 \cdot 10^{-10}\ F/m$

$\kappa = 0$

$\bar{J} = \kappa \bar{E} = 0$

vlada $H = 2\cos(10^{10}t - \beta x)\,\bar{a}_z$

Odredi β.

$\omega = 10^{10}$

$$\nabla \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$$

$$\boxed{\bar{J} = \kappa \bar{E}}$$

$$\nabla \times \bar{H} = \begin{vmatrix} a_x & a_y & a_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \cancel{H_x} & \cancel{H_y} & H_z \end{vmatrix} = -\bar{a}_y \frac{\partial H_z}{\partial x} = -\bar{a}_y \cdot 2 \cdot \beta \sin(\omega t - \beta x) = \frac{\partial \bar{D}}{\partial t} \Big/ \int$$

$$\bar{D} = -\bar{a}_y \cdot 2 \cdot \beta \int_t \sin(\omega t - \beta x)\, dt$$

$$= \bar{a}_y \frac{2\beta}{\omega} \cos(\omega t - \beta x) + C$$

ISTOSMJERNA KOMPONENTA

$$\bar{E} = \frac{\bar{D}}{\varepsilon} = \bar{a}_y \frac{2\beta}{\omega\varepsilon} \cos(\omega t - \beta x)$$

$$\boxed{\bar{E} = \frac{\bar{D}}{\varepsilon}}$$

$$\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t}$$

$$\nabla \times \bar{E} = \begin{vmatrix} a_x & a_y & a_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & E_y & 0 \end{vmatrix} = \bar{a}_z \frac{\partial E_y}{\partial x} = \bar{a}_z \frac{2\beta^2}{\omega\varepsilon} \sin(\omega t - \beta x)$$

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

$$-\frac{\partial B}{\partial t} = +\mu \cdot 2 \cdot \omega \cdot \sin(\omega t - \beta x)\,\bar{a}_z$$

$$2\omega\mu = \frac{2\beta^2}{\omega\varepsilon}$$

$$\boxed{\beta^2 = \omega^2 \mu \varepsilon}$$

$$\beta = \pm 600\ rad/m$$

Tijek snage

$$\boxed{F = q(\bar{E} + \bar{v} \times \bar{B})}$$ - sila na naboj u polju koji se giba brzinom v

$dW = q\bar{E} \cdot d\bar{l}$ - na putu dl obavi se rad dW

$\frac{dW}{dt} = q\bar{E} \cdot \bar{v}$ - polje je naboju predalo snagu

$\frac{dW}{dt} = \rho \cdot \bar{v} \bar{E} dV = \bar{J} \bar{E} dV$ - za volumnu raspodjelu naboja

$$\boxed{P = \iiint_V \bar{J} \cdot \bar{E} \, dV}$$ - ukupna utrošena snaga

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

$w = \frac{\bar{B} \bar{H}}{2}$

$w = \frac{\bar{D} \cdot \bar{E}}{2}$

Poyntingov vektor $\longrightarrow$ $\bar{N} = \bar{E} \times \bar{H}$

gustoća snage pridružena elemag. polju u točki

$P = -\oiint (\bar{E} \times \bar{H}) \bar{n} \, dS \longrightarrow$ integral Poyntingovog vektora odgovara snazi

$\bar{E} = \bar{E}_r + \bar{E}_\vartheta + \bar{E}_\alpha$

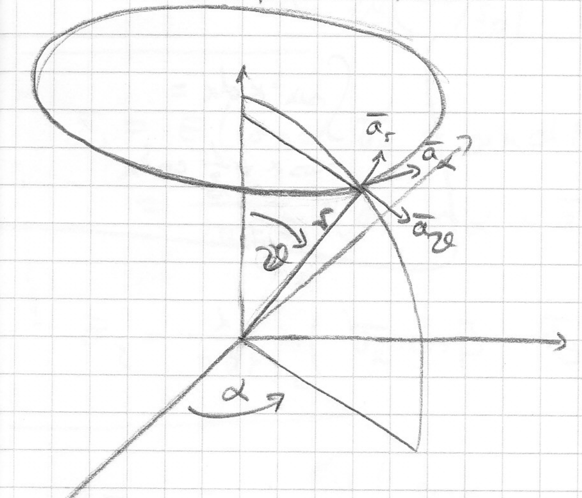
<u>Zad</u> Jakost el. polja antene koja se nalazi u ishodištu sfernog sustava je

$$\bar{E} = E_0 \frac{\sin\Theta}{r} \cos(\omega t - \beta r) \bar{a}_\vartheta = E_\vartheta \bar{a}_\vartheta$$

E_0, ω i β su konstante

$\beta = \omega\sqrt{\mu_0 \varepsilon_0}$

Odredi snagu koju emitira antena



$$\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t} = -\mu_0 \frac{\partial \bar{H}}{\partial t}$$

$$\nabla \times \bar{E} = \bar{a}_r \frac{1}{r \sin\Theta} \left\{ \cancel{\frac{\partial}{\partial \vartheta}(\sin\vartheta \, E_\alpha)} - \cancel{\frac{\partial E_\vartheta}{\partial \alpha}} \right\}$$
$$+ a_\vartheta \frac{1}{r} \left[\cancel{\frac{1}{\sin\vartheta} \frac{\partial E_r}{\partial \alpha}} - \cancel{\frac{\partial}{\partial r}(r E_\alpha)} \right]$$
$$+ a_\alpha \frac{1}{r} \left[\frac{\partial}{\partial r}[r E_\vartheta] - \cancel{\frac{\partial E_r}{\partial \vartheta}} \right]$$

$$\nabla \times \bar{E} = \bar{a}_\alpha \frac{1}{r} \left[\frac{\partial}{\partial r}(r E_\vartheta) \right] = -\mu_0 \frac{\partial \bar{H}}{\partial t}$$

$$\nabla \times \bar{E} = a_\alpha \frac{1}{r}\left[\frac{\partial}{\partial r}\left(E_0 \sin\vartheta \cos(\omega t - \beta r)\right)\right]$$

$$= a_\alpha \frac{1}{r}\left[-E_0 \sin(\vartheta)(-\beta)\sin(\omega t - \beta r)\right]$$

$$= -\mu_0 \frac{\partial H}{dt} \longrightarrow \text{in formule} \longrightarrow$$

$$\boxed{\nabla \times E = -\frac{\partial B}{\partial t} = -\mu_0 \frac{\partial H}{dt}}$$

$$\bar{H} = -\frac{\bar{a}_\alpha E_0 \beta}{\mu_0 r} \sin\vartheta \int_* \sin(\omega t - \beta r)\, dt$$

$$\bar{H} = \frac{\bar{a}_\alpha E_0 \beta}{\mu_0 \omega r} \sin\vartheta \cos(\omega t - \beta r)$$

$$\bar{N} = \bar{E} \times \bar{H} = (\bar{a}_\vartheta \times \bar{a}_\alpha)\frac{E_0^2 \cdot \beta}{\mu_0 \omega r^2} \sin^2\vartheta \cos^2(\omega t - \beta r)$$

$$= \bar{a}_r \frac{E_0^2 \beta}{\mu_0 \omega r^2} \sin^2\vartheta \cos^2(\omega t - \beta r)$$

$$P = \oint\!\!\oint_S \bar{N} \cdot \bar{n}\, dS \qquad \bar{n} = \bar{a}_r$$

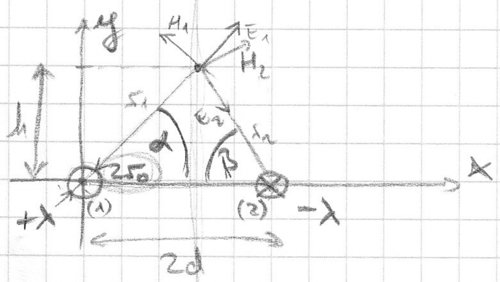
$$dS = r^2 \sin\vartheta\, d\vartheta\, d\alpha$$

$$P = \frac{\beta E_0^2}{\mu_0 \omega} \int_{\alpha=0}^{2\pi} \cdot \int_{\vartheta=0}^{\pi} \frac{\sin^2\vartheta}{r^2} \cos^2(\omega t - \beta r) \cdot r^2 \sin\vartheta\, d\vartheta\, d\alpha$$

$$\boxed{P = \frac{8\pi \beta E_0^2}{3\mu_0 \omega} \cos^2(\omega t - \beta r)}$$

$$\boxed{\int \sin^3 x\, dx = -\cos x + \frac{1}{3}\cos^3 x}$$

Zad Analiziraj prijenos snage dvožičnim vodom prema slici



$$E(r) = \frac{\lambda}{2\pi\varepsilon r}$$

$$\varphi(r) = -\int_{r_{ref}}^{r} \overline{E}\, dl$$

$$\varphi(r) = \frac{\lambda}{2\pi\varepsilon} \ln \frac{r_{ref}}{r}$$

UKUPNI φ
$(+\lambda \text{ i } -\lambda)$

$$\varphi = \frac{\lambda}{2\pi\varepsilon} \ln \frac{r_{ref}}{r_1} - \frac{\lambda}{2\pi\varepsilon} \ln \frac{r_{ref}}{r_2}$$

$$= \frac{\lambda}{2\pi\varepsilon} \left(\ln \frac{r_2}{r_1} \right)$$

$$\left.\begin{aligned} \varphi_{+\lambda} &= \frac{\lambda}{2\pi\varepsilon} \ln\left(\frac{2d}{r_0}\right) \\ \varphi_{-\lambda} &= \frac{\lambda}{2\pi\varepsilon} \ln\left(\frac{r_0}{2d}\right) \end{aligned}\right\} \quad U = \varphi_{+\lambda} - \varphi_{-\lambda} = \frac{\lambda}{\pi\varepsilon} \ln \frac{2d}{r_0}$$

$$= \frac{\lambda}{2\pi\varepsilon} \ln\left(\frac{2d}{r_0}\right) + \frac{\lambda}{2\pi\varepsilon} \ln\left(\frac{2d}{r_0}\right)$$

$$= \frac{\cancel{2}\lambda}{\cancel{2}\pi\varepsilon} \ln\left(\frac{2d}{r_0}\right)$$

???

$$\lambda = \frac{U \cdot \pi\varepsilon}{\ln(2d/r_0)}$$

$$E_1 = \frac{U}{2 r_1 \ln(2d/r_0)}$$

$$E_2 = \frac{U}{2 r_2 \ln(2d/r_0)}$$

$$\overline{E}_1 = E(\cos\alpha\, \overline{a}_x + \sin\alpha\, \overline{a}_y)$$

$$= \frac{\lambda}{2\pi\varepsilon r_1} (\overline{a}_x \cos\alpha + \overline{a}_y \sin\alpha)$$

$$\overline{E}_2 = \frac{\lambda}{2\pi\varepsilon r_2} (\overline{a}_x \cos\beta - \overline{a}_y \sin\beta)$$

$$\overline{E}_x = \overline{a}_x \frac{\lambda}{2\pi\varepsilon} \left(\frac{\cos\alpha}{r_1} + \frac{\cos\beta}{r_2} \right)$$

$$\overline{E}_y = \overline{a}_y \frac{\lambda}{2\pi\varepsilon} \left(\frac{\sin\alpha}{r_1} - \frac{\sin\beta}{r_2} \right)$$

$$\overline{E} = E_x \overline{a}_x + E_y \overline{a}_y$$

$$H_1 = \frac{I}{2\pi r_1} \qquad H_2 = \frac{I}{2\pi r_2}$$

$$\bar{H}_1 = \frac{I}{2\pi r_1}\left[+\cos\alpha\,\bar{a}_y - \sin\alpha\,\bar{a}_x\right]$$

$$\bar{H}_2 = \frac{I}{2\pi r_2}\left[\cos\beta\,\bar{a}_y + \sin\beta\,\bar{a}_x\right]$$

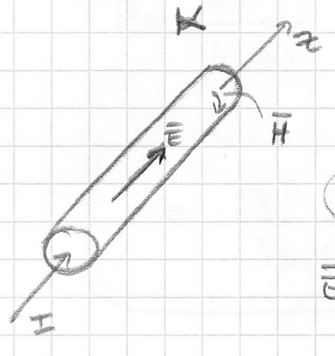
$$H_x = \frac{I}{2\pi}\left[-\frac{\sin\alpha}{r_1} + \frac{\sin\beta}{r_2}\right]\bar{a}_x$$

$$H_y = \frac{I}{2\pi}\left[\frac{\cos\alpha}{r_1} + \frac{\cos\beta}{r_2}\right]\bar{a}_y$$

$$\bar{N} = \bar{E}\times\bar{H} = \bar{a}_z\left(\bar{E}_x H_y - \bar{E}_y H_x\right)$$

$$\bar{N} = \bar{a}_z \frac{U\cdot I}{4\pi \ln(2d/r_0)}\left[\left(\frac{\cos\alpha}{r_1} + \frac{\cos\beta}{r_2}\right)^2 + \left(\frac{\sin\alpha}{r_1} - \frac{\sin\beta}{r_2}\right)^2\right]$$

Primjer REALNI VODIČ

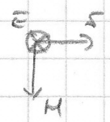


$$\bar{J} = K\bar{E}_0$$

CILINDRIČNI SUSTAV

$$\bar{E}_0 = \frac{\bar{J}}{K}\bar{a}_z = \frac{I}{K r^2\pi}\bar{a}_z$$

$$H = \frac{I}{2\pi r_0}\bar{a}_\alpha$$



$$N = \bar{E}_0\times\bar{H} = -\bar{a}_r \frac{I^2}{K r_0^2\pi\, 2\pi r_0}$$

$$\oiint_S \bar{N}\bar{n}\,dS$$ SAMO PO OPLOŠJU

$$\bar{n} = \bar{a}_r$$

$$P = \frac{I^2}{K r_0^2\pi\, 2\pi r_0}\iint_S dS = \frac{I^2}{K r_0^2\pi\, \cancel{2\pi r_0}}\cdot \cancel{2\pi r_0}\cdot l = I^2\left[\frac{1}{K}\cdot\frac{l}{r_0^2\pi}\right]$$

SKENIRANO DOVDE
V1

Sinusno promjenjiva polja

sve veličine su sinusno promjenjiva polja

$$\bar{E}(\bar{r},t) = E_x(\bar{r})\cos[\omega_0 t + \varphi_x(\bar{r})]\bar{a}_x + E_y(\bar{r})\cos[\omega_0 t + \varphi_y(\bar{r})]\bar{a}_y + E_z(\bar{r})\cos[\omega_0 t + \varphi_z(\bar{r})]\bar{a}_z$$

$$A\cos(\omega t + \varphi) = Re\{A e^{j\varphi} e^{j\omega t}\} = Re\{\underline{A} e^{j\omega t}\}$$

KOMPL. BROJ
FAZOR

$$\nabla \times \underline{E} = -j\omega\underline{B} \qquad \nabla \times \underline{H} = \underline{J} + j\omega\underline{D}$$

$$\nabla \times \underline{D} = \underline{\rho} \qquad \nabla \cdot \underline{B} = 0$$

$\underline{X}$ označava da je ovo komp. broj

EM potencijal u fazorskoj domeni: $\underline{B} = \nabla \times \underline{A}$

$$\underline{E} = -\nabla\underline{\varphi} - j\omega\underline{A}$$

$$\bar{E} = E_x\cos(\omega_0 t + \varphi_{E_x})\bar{a}_x + E_y\cos(\omega_0 t + \varphi_{E_y})\bar{a}_y + E_z\cos(\omega_0 t + \varphi_{E_z})\bar{a}_z$$

$$\bar{H} = H_x\cos(\omega_0 + \varphi_{H_x})\bar{a}_x \ldots$$

H_x – max vrijednost

$$N_{sr} = \frac{1}{T}\int_0^T (\bar{E} \times \bar{H})\, dH$$

srednja vrijednost Poyntingovog vektora

$$N_{sr} = \frac{1}{2}\left[E_y H_z \cos(\varphi_{E_y} - \varphi_{H_z}) - E_z H_y \cos(\varphi_{E_z} - \varphi_{H_y})\right]\bar{a}_x + \frac{1}{2}\left[E_z H_x \cos(\varphi_{E_z} - \varphi_{H_x}) - E_x H_z \cos(\varphi_{E_x} - \varphi_{H_z})\right]\bar{a}_y + \frac{1}{2}\left[E_x H_y \cos(\varphi_{E_x} - \varphi_{H_y}) - E_y H_x \cos(\varphi_{E_y} - \varphi_{H_x})\right]\bar{a}_z$$

$$\text{GUBITCI} = \frac{1}{2}\iiint \bar{E}\cdot\bar{J}\, dV$$

Srednja energija pohranjena u mag polju

$$W_{m,sr} = \frac{\mu}{4} \iiint_V |\bar{H}|^2 dV = \frac{\mu}{4} \iiint_V \underline{\bar{H}} \cdot \underline{\bar{H}}\, dV$$

Srednja en. pohranjena u el. polju

$$W_{e,sr} = \frac{\varepsilon}{4} \iiint_V |\underline{E}|^2 dV = \frac{\varepsilon}{4} \iiint_V \underline{E} \cdot \underline{\bar{E}}\, dV$$

Poopćeni Amperov kružni zakon za konjugirano kompleksne fazore

$$\nabla \times \underline{H} = \underline{\bar{J}} - j\omega\varepsilon \underline{\bar{E}}$$

$$\nabla \times \underline{E} = -j\omega\mu \underline{\bar{H}}$$

$$-\nabla(\underline{E} \times \underline{\bar{H}}) = \underline{E}(\nabla \times \underline{\bar{H}}) - \underline{\bar{H}}(\nabla \cdot \underline{E})$$

Kompleksna relacija za Poyntingov teorem

$$P_N = \frac{1}{2} \oiint_S \underline{N} \cdot \bar{n}\, dS = -P_{g,sr} + j2\omega(W_{e,sr} - W_{m,sr})$$

PRIVIDNA SREDNJA SNAGA

$$P_{g,sr} = \mathrm{Re}\left\{ -\frac{1}{2} \oiint_S (\underline{E} \times \underline{\bar{H}})\, n\, dS \right\}$$

$$W_{m,sr} - W_{e,sr} = \mathrm{Im}\left\{ -\frac{1}{4\omega} \oiint_S (\underline{E} \times \underline{\bar{H}})\, \bar{n}\, dS \right\}$$

ELEMAGNETSKI VALOVI U SREDSTVIMA
BEZ GUBITAKA

$\rho_s = J_s = \kappa = 0$

Rješenja ovise o vremenu i o samo jednoj prostornoj varijabli → RAVNI VALOVI

$$\Delta E_i - \mu\varepsilon \frac{\partial^2 E_i}{\partial t^2} = 0$$ → Po svim dimenzijama $i = (x, y, z)$

$$\frac{\partial E_x}{\partial z^2} - \mu\varepsilon \frac{\partial^2 E_x}{\partial t^2} = 0$$ → 1D skalarna valna jednadžba

---

brzina širenja

$$c = \frac{z_2 - z_1}{t_2 - t_1} = \frac{1}{\sqrt{\mu\varepsilon}}$$

$$H = H_y(z,t)\bar{a}_y = A\sqrt{\frac{\varepsilon}{\mu}}\, f(t - z\sqrt{\mu\varepsilon}) - B\sqrt{\frac{\varepsilon}{\mu}}\, g(t + z\sqrt{\mu\varepsilon})$$

valna impedancija sredstva

$$Z = \sqrt{\frac{\mu}{\varepsilon}} \quad [\Omega]$$

ako $E_x = E_x^+ + E_x^-$
$H_y = H_y^+ + H_y^-$
onda

$$H_y^+ = \frac{E_x^+}{Z}, \quad H_y^- = -\frac{E_x^-}{Z}$$

Poyntingov vektor

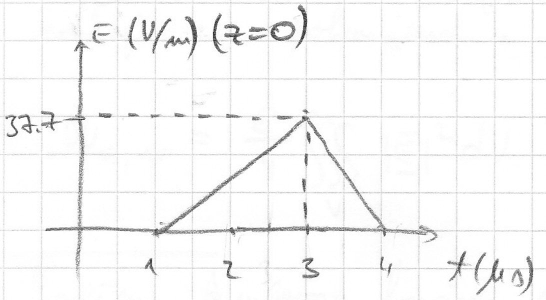
$$\bar{P}^+ = E_x^+ \bar{a}_x \times H_y^+ \bar{a}_y = \frac{(E_x^+)^2}{Z}\bar{a}_z$$

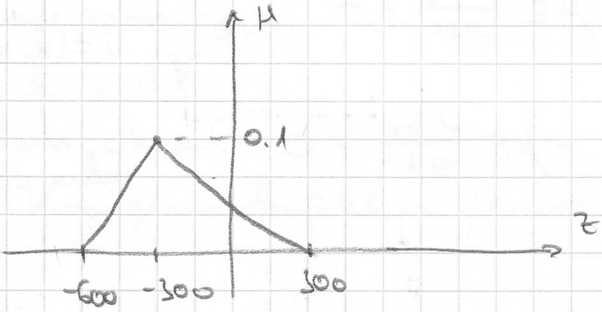
$$\bar{P}^- = E_x^- \bar{a}_x \times H_y^- \bar{a}_y = -\frac{(E_x^-)^2}{Z}\bar{a}_z$$

Ravni val širi se u $+z$ smjeru u prostoru

Jakost el. polja ima samo x komponentu a vremenska promjena jakosti el. polja u ravnini $z=0$ dana je slikom

Skiciraj prostornu promjenu jakosti mag. polja u trenutku $t = 2\,\mu s$





E_x

$$A \cdot f\left(t - \frac{z}{c}\right) \qquad A f(u)$$

$$Z = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\,\Omega$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \cdot 10^8 \frac{m}{s}$$

$$H_y = \frac{E}{Z} = \frac{37.7}{377} = 0.1\ A/m$$

H_1:

$$10^{-6} = 2 \cdot 10^{-6} - \frac{z_1}{3 \cdot 10^8}$$

$$z_1 = 300\,m$$

H_3:

$$3 \cdot 10^{-6} = 2 \cdot 10^{-6} - \frac{z_3}{3 \cdot 10^8}$$

$$z_3 = -300\,m$$

H_4:

$$4 \cdot 10^{-6} = 2 \cdot 10^{-6} - \frac{z_4}{3 \cdot 10^8}$$

$$z_4 = -600\,m$$

$$\frac{E_0}{H_0} = Z = \sqrt{\frac{\mu}{\varepsilon}} = \frac{\omega\mu}{\omega\sqrt{\mu\varepsilon}} = \frac{\omega\mu}{\beta}$$

$$\boxed{\bar{H}_0 = \frac{1}{\omega\mu}\bar{\beta}\times\bar{E}_0}$$

$$\boxed{\bar{H} = \frac{1}{\omega\mu}\bar{\beta}\times\bar{E}}$$

$\mu_0 = 4\cdot\pi\cdot10^{-7}$

$\varepsilon_0 =$

Jakost el. polja ravnog vala koji se širi diel. prostorom ($\mu_r = 1$) jest

$$\bar{E} = 2\cos(10^8 t - x)\bar{a}_y + 4\cos(10^8 t - x)\bar{a}_z$$

$\lambda, \varepsilon_r, H = ?$

$\beta = 1\cdot\bar{a}_x$

$\omega = 10^8$ rad/s

$$\beta = \frac{\omega}{v_f}$$

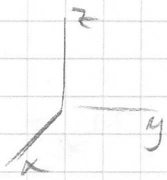
$$v_f = 10^8 \text{ m/s}$$

$$v_f = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_0\varepsilon_0}\sqrt{\mu_r\varepsilon_r}} = \frac{c}{\sqrt{\varepsilon_r}} = \frac{3\cdot10^8}{\sqrt{\varepsilon_r}} = 10^8$$

$$\lambda = \frac{2\pi}{\beta} = 2\pi\ [m]$$

$$\varepsilon_r = 9$$

$$\bar{H} = \frac{1}{\omega\mu}\bar{\beta}\times\bar{E}$$



$$\bar{H} = \frac{1}{10\cdot10^8\cdot4\cdot\pi\cdot10^{-7}}\left[\bar{a}_x \times \left(2\cos(10^8 t - x)\bar{a}_y + 4\cos(10^8 t - x)\bar{a}_z\right)\right]$$

$$\bar{H} = \frac{1}{40\pi}\left[-4\cos(10^8 t - x)\bar{a}_y + 2\cos(10^8 t - x)\bar{a}_z\right]$$

$$H = \frac{E}{Z} \qquad Z = 40\pi$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}}$$

$$40\pi = \sqrt{\frac{1\cdot4\pi\cdot10^{-7}}{9\cdot8{,}854\cdot10^{-12}}}$$

Zad. Ravni val amplitude 100 V/m i frekvencije 300MHz putuje u smjeru +z osi u prostoru sa $\varepsilon_r = 9$ i $\mu_r = 1$

Napiši izraze za $\bar{E}$ i H ako $\bar{E}$ ima samo x komponentu te odredite srednju gustoću snage.

$$v_f = \frac{c}{\sqrt{\varepsilon_r}} = \frac{3\cdot 10^8}{3} = 10^8 \text{ m/s}$$

$$\boxed{\beta = \frac{\omega}{v_f} = \frac{2\pi f}{10^8} = \frac{\pi\cdot 6\cdot 10^8}{10^8} = 6\pi \; \boxed{\text{rad/m}}} \quad !!!$$

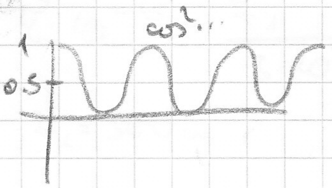
$$\bar{E} = 100\cos(6\pi\cdot 10^8 t - 6\pi z)\,\bar{a}_x$$

$$H = \frac{1}{\omega\mu}\bar{\beta}\times\bar{E} = \frac{\cancel{6\pi}}{\cancel{6\pi}\cdot 10^8\cdot 4\pi\cdot 10^{-7}}\left[\bar{a}_z \times \bar{a}_x\, 100\cos(6\pi\, 10^8 t - 6\pi z)\right]$$

$$= \frac{1}{40\pi}\cdot 100\cdot\cos(6\pi\cdot 10^8 t - 6\pi z)\,\bar{a}_y$$

$$\bar{N} = \bar{E}\times\bar{H}$$

$$= \frac{100^2}{40\pi}\cos^2(6\pi\cdot 10^8 t - 6\pi z)\,\bar{a}_z$$



$$N_{sr} = \frac{N_{max}}{2} = \frac{100^2}{2\cdot 40\pi} = \frac{125}{\pi}\left[\frac{W}{m^2}\right]$$

$$N_{sr} = \frac{125}{\pi}\bar{a}_z$$

el. polja od 100 V/m u smjeru osi z.

Ako je $\lambda = 25$ cm i brzina prostiranja $2\cdot10^8$ m/s odredi f, ε_r, $\bar{E}$ i $\bar{H}$.

$E_0 = 100$ V/m
$\lambda = 25$ cm
$v_f = 2\cdot10^8$ m/s

$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi}{0.25} = 8\pi \text{ rad/m}$$

$$\bar{\beta} = 8\pi\,\bar{a}_x$$

$$\lambda = \frac{v_f}{f}$$

$$f = \frac{v_f}{\lambda} = \frac{2\cdot10^8}{0.25} = 800\text{ MHz}$$

$$v_f = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\varepsilon_0\mu_0}\sqrt{\mu_r\varepsilon_r}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$$

$$\sqrt{\varepsilon_r} = \frac{c}{v_f} = \frac{3\cdot10^8}{2\cdot10^8} =$$

$$\varepsilon_r = \frac{9}{4}$$

$$\bar{E} = 100\cos(2\pi\cdot800\cdot10^6 t - 8\pi x)\cdot\bar{a}_z$$

$$\boxed{\bar{H} = \frac{1}{\omega\mu}\bar{\beta}\times\bar{E}}$$

$$\bar{H} = \frac{1\cdot8\pi\cdot100}{2\pi\,800\cdot10^6\,4\pi\cdot10^{-7}}\cos(2\pi\,800\cdot10^6 t - 8\pi x)(-\bar{a}_y)$$

$$\bar{H} = \frac{-10}{8\pi}\cos(16\pi\cdot10^8 t - 8\pi x)\,\bar{a}_y$$

$$\bar{H} = \frac{1}{\omega\mu}\bar{\beta}\times\bar{E} \quad \text{- vektori}$$

$$H = \frac{1}{\omega\mu}\beta\cdot E$$

$$E = \frac{\omega\mu}{\beta}H \quad \text{moduli}$$

$$E = \frac{\omega\mu}{\beta^2}\cdot H\cdot\beta$$

$$\bar{E} = \frac{\omega\mu}{\beta^2}\bar{H}\times\bar{\beta} \quad \text{- vektori}$$

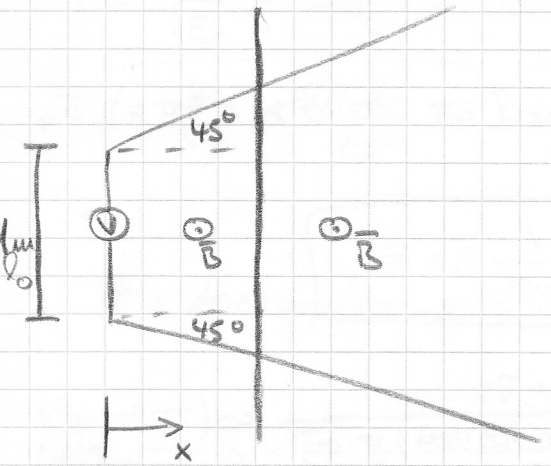
$$\bar{E} = \frac{2\pi\,800\cdot10^6\cdot4\pi\cdot10^{-7}}{8\pi}\left(\frac{-10}{8\pi}\right)\cos(\;)\,(\bar{a}_y\times\bar{a}_x)$$

$$\bar{E} = 100\cos(\;)\,\bar{a}_z$$

ZAVRŠNI

Zad. Vodljivi štap giba se po vodljivim tračnicama jednolikom v u homogenom mag. polju ind. $B = 1\,T$ prema slici.
U $t=0 \rightarrow x=0$

Odredi brzinu kojom se štap treba gibati da bi nakon 1 sekunde napon koji mjeri voltmetar bio 10V.



$U_V(t = 1s) = ?$

$$e = -\frac{\partial\phi}{\partial t} = \int \frac{\partial B}{\partial t}\bar{n}\,dS - \oint (\bar{v}\times\bar{B})\,d\bar{l}$$

$$U_V = B\cdot l\cdot v$$

$$l = l_0 + 2\Delta l = l_0 + 2x = l_0 + 2vt$$ → samo dio petlje koja se giba doprinosi promjeni toka

$$U_V = (l_0 + 2vt)\cdot B\cdot v = 2Bv^2t + Bvl_0 = 10V$$

$$v^2\cdot 2Bt + Bl_0 v - 10 = 0$$

$$v_1 = 2\ m/s$$

$$\cancel{v_2 = -\frac{5}{2}}$$

$$\phi = B\cdot S$$

$$S = l_0 x + 2\frac{x^2}{2} = l_0 x + x^2 = l_0 vt + v^2t^2$$

Zad. U slobodnom prostoru sa značajkama $\kappa = 0$, $\varepsilon_r = 1$, $\mu_r = 1$

vlada el. polje jakosti:

$$\bar{E} = E_{0x} \exp(\alpha y - bt)\, \bar{a}_x + E_{0y} \exp(\beta x - bt)\, \bar{a}_y$$

b, E_{0x}, E_{0y} - zadano

$\alpha, \beta, \rho_s, \bar{H} = ?$

$$\boxed{\begin{aligned} \nabla \times \bar{E} &= -\frac{\partial \bar{B}}{\partial t} \\ \nabla \times \bar{H} &= \bar{J} + \frac{\partial \bar{D}}{\partial t} \\ \bar{J} &= \kappa \bar{E} \end{aligned}}$$

$$\nabla \times E = -\mu_0 \frac{\partial \bar{H}}{\partial t}$$

$\kappa = 0$

$\bar{J} = \kappa \bar{E} = 0$

$$\bar{E} = E_x \bar{a}_x + E_y \bar{a}_y$$

$$\nabla \times \bar{E} = \bar{a}_x \left(\cancel{\frac{\partial E_z}{\partial y}} - \cancel{\frac{\partial E_y}{\partial z}} \right) + \bar{a}_y \left(\cancel{\frac{\partial E_x}{\partial z}} - \cancel{\frac{\partial E_z}{\partial x}} \right) + \bar{a}_z \left(\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} \right)$$

$$\nabla \times E = \bar{a}_z \left[E_{0y} \beta \exp(\beta x - bt) - E_{0x} \alpha \exp(\alpha y - bt) \right] = -\mu_0 \frac{\partial \bar{H}}{\partial t}$$

$$\bar{H} = -\frac{\bar{a}_z}{\mu_0} \left[-\frac{E_{0y}\beta}{b} \exp(\beta x - bt) + \frac{E_{0x}\alpha}{b} \exp(\alpha y - bt) \right]$$

$$\nabla \times \bar{H} = \bar{a}_x \frac{\partial H_z}{\partial y} - \bar{a}_y \frac{\partial H_z}{\partial x}$$

$$\nabla \times H = \frac{1}{\mu_0} \bar{a}_x \left[-\frac{E_{0x}\alpha^2}{b} \exp(\alpha y - bt) \right] - \frac{1}{\mu_0} \bar{a}_y \left[\frac{E_{0y}\beta^2}{b} \exp(\beta x - bt) \right]$$

$$= \varepsilon_0 \varepsilon_r \frac{\partial \bar{E}}{\partial t}$$

$$E = \frac{1}{\mu_0 \varepsilon_0} \bar{a}_x \left[\frac{E_{0x}\alpha^2}{b^2} \exp(\alpha y - bt) \right] - \frac{1}{\mu_0 \varepsilon_0} \bar{a}_y \left[\frac{-E_{0y}\beta^2}{b^2} \exp(\beta x - bt) \right]$$

$$\cancel{E_{0x}} = \frac{E_{0x}\,\alpha^2}{\mu_0 \varepsilon_0 b^2}$$

$$\cancel{E_{0y}} = \frac{E_{0y}\,\beta^2}{\mu_0 \varepsilon_0 b^2}$$

$$\alpha = \sqrt{\mu_0 \varepsilon_0} \cdot b$$

$$\beta = \sqrt{\mu_0 \varepsilon_0} \cdot b$$

$$\overline{H} = \frac{-\overline{a}_z}{\mu_0}\left[\frac{-E_{0y}\sqrt{\mu_0 \varepsilon_0}\cdot b}{b} e^{(\,)} + \frac{E_{0x}\sqrt{\mu_0 \varepsilon_0}\, b}{b} e^{(\,)}\right]$$

$$\overline{H} = \left[E_{0y}\sqrt{\frac{\varepsilon_0}{\mu_0}}\, e^{\beta x - bt} - E_{0x}\sqrt{\frac{\varepsilon_0}{\mu_0}}\, e^{\alpha y - bt}\right]\overline{a}_z$$

$\rho_S = ?$

$$\nabla \cdot \overline{D} = \rho_S \qquad \frac{\partial E_x}{\partial x} = 0 \quad \frac{\partial E_y}{\partial y} = 0 \quad \frac{\partial E_z}{\partial z} = 0$$

$$\nabla \cdot \overline{D} = 0$$

$$\rho_S = 0$$

Zad Vektor jakosti mag. polja antene u ishodištu sfernog sustava je

$$\overline{H} = \frac{\sin^2 \vartheta}{r}\cos(\omega t - \beta r)\,\overline{a}_\varphi \qquad \vartheta = \frac{\pi}{4}\,r$$

$r = 100\,m$

$\varepsilon = \varepsilon_0$

$\mu = \mu_0$

$f = 100\,MHz$

$$\beta = \frac{\omega}{v_f} = \frac{2}{3}\pi$$

$v_f = c = 3\cdot 10^8$

$$\overline{E} = \frac{\omega\mu}{\beta^2}\left(\overline{H}\times\overline{\beta}\right)$$

$$\overline{\beta} = \beta\cdot\overline{a}_r$$

$$\overline{E} = \frac{\omega\mu}{\beta}\frac{\sin^2\vartheta}{r}\cos(\omega t - \beta r)\,\overline{a}_\vartheta = 1.88\cos(\omega t - \beta r)\,\overline{a}_\vartheta$$

$$\boxed{1.88\ V}$$

$N = \bar{E} \times \bar{H}$ - Poyntingov vektor

$P_{SR} = \oint\!\!\oint_S \bar{N}\,\bar{n}\,dS$ - Srednja snaga

MATERIJALI SA QUBICITA → nema u ispitu

- faraday - step...
- raštimavanje sustava - koord.
- ravni val - $\bar{E}, \bar{H}$ u nekom trenutku točki

Snaga

- antena - Snaga

petlja - smjerovi indukcije
gaussov zakon za mag. polje
centripetalna i centrifugalna sila

završni