$$\nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}$$

$$\nabla \times \vec{H} = \varepsilon \frac{\partial \vec{E}}{\partial t} + \vec{J}_{ext}$$

$$\nabla \cdot \vec{D} = \rho_{ext} \qquad (\vec{D} = \varepsilon \vec{E})$$

$$\nabla \cdot \vec{B} = 0 \qquad (\vec{B} = \mu \vec{H})$$

—— // ——

$$\nabla = \frac{\partial}{\partial x}\hat{x} + \frac{\partial}{\partial y}\hat{y} + \frac{\partial}{\partial z}\hat{z}$$

$$\nabla^2 = \nabla \cdot \nabla = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

$$\nabla \times \nabla \times \vec{A} = \nabla(\nabla \cdot \vec{A}) - \nabla^2 \vec{A}$$

$$\nabla \cdot (\vec{A} \times \vec{B}) = -\vec{A} \cdot \nabla \times \vec{B} + \vec{B} \cdot \nabla \times \vec{A}$$

$$\nabla f = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial f}{\partial z}\right)$$

$$\nabla \cdot \vec{A} = \frac{\partial}{\partial x}A_x + \frac{\partial}{\partial y}A_y + \frac{\partial}{\partial z}A_z$$

$$\nabla \times \vec{A} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix} = \hat{x}\left(\frac{\partial}{\partial y}A_z - \frac{\partial}{\partial z}A_y\right) + \hat{y}\left(\frac{\partial}{\partial z}A_x - \frac{\partial}{\partial x}A_z\right) + \hat{z}\left(\frac{\partial}{\partial x}A_y - \frac{\partial}{\partial y}A_x\right)$$

—— // ——

$$\vec{E} = \vec{E}_0 \cos(\omega t - \vec{k} \cdot \vec{r} + \theta)$$

$$\underline{\vec{E}} = \vec{E}_0 e^{j(\omega t - \vec{k} \cdot \vec{r} + \theta)} = \vec{E}_0 e^{-j(\vec{k} \cdot \vec{r} - \theta)}$$

$$\vec{k} = \|\vec{k}\| \cdot \hat{n} = k \cdot \hat{n}$$

$$\lambda = \frac{2\pi}{k} \qquad f = \frac{\omega}{2\pi} \qquad T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$\sigma = 0$
$\downarrow$

$$c = \lambda f = \frac{1}{\sqrt{\mu \varepsilon}} \qquad v_f = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f \qquad v_g = \frac{d\omega}{dk}$$

$$k = \omega \sqrt{\mu \varepsilon} = \frac{\omega}{c} \qquad Z = \sqrt{\frac{\mu}{\varepsilon}}$$

$$\underline{\vec{H}} = \hat{n} \times \frac{\underline{\vec{E}}}{Z} \qquad \underline{\vec{E}} = Z\,\underline{\vec{H}} \times \hat{n}$$

—— // ——

$$\varepsilon = \varepsilon_0 \varepsilon_r \qquad \mu = \mu_0 \mu_r$$

$$v_f = c = \frac{1}{\sqrt{\mu \varepsilon}} = \frac{1}{\sqrt{\mu_0 \varepsilon_0} \cdot \sqrt{\mu_r \varepsilon_r}} = \frac{c_0}{\sqrt{\mu_r \varepsilon_r}} = \frac{c_0}{n}$$

$$n = \sqrt{\mu_r \varepsilon_r}$$

$$k = \omega \sqrt{\mu \varepsilon} = \frac{\omega}{c_0} \cdot n$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \cdot \sqrt{\frac{\mu_r}{\varepsilon_r}} = Z_0 \sqrt{\frac{\mu_r}{\varepsilon_r}} \approx 120\pi \sqrt{\frac{\mu_r}{\varepsilon_r}}$$

$$\mu_0 = 4\pi \times 10^{-7}$$

$$\varepsilon_0 = \frac{10^{-9}}{36\pi}$$

$$c_0 = 3 \times 10^{8}$$

m - 10^{-3}
μ - 10^{-6}
n - 10^{-9}
p - 10^{-12}
f - 10^{-16}

k - 10^{3}
M - 10^{6}
G - 10^{9}
T - 10^{12}
P - 10^{16}

$$jk = \gamma = \alpha + j\beta = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} = j\omega\sqrt{\mu\varepsilon}\sqrt{1 - j\frac{\sigma}{\omega\varepsilon}} = j\omega\sqrt{\varepsilon^c \mu}$$

$$Z = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} = \sqrt{\frac{\mu}{\varepsilon^c}} \qquad \beta = \frac{2\pi}{\lambda}$$

$$\varepsilon^c = \varepsilon + \frac{\sigma}{j\omega} = \varepsilon\left(1 + \frac{\sigma}{j\omega\varepsilon}\right) = \varepsilon_r \varepsilon_0 \left(1 + \frac{\sigma}{j\omega\varepsilon_r\varepsilon_0}\right)$$

—— // ——

$$\rightarrow \sigma = 0$$

$$\alpha = 0 \qquad \beta = \frac{2\pi}{\lambda} = \omega\sqrt{\mu\varepsilon} = \frac{\omega}{c}$$

$$c = \frac{c_0}{\sqrt{\varepsilon_r \mu_r}} \qquad \lambda = \frac{\lambda_0}{\sqrt{\varepsilon_r \mu_r}} \qquad Z = \sqrt{\frac{\mu}{\varepsilon}} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}$$

—— // ——

$$\rightarrow \sigma \ll \omega\varepsilon \Rightarrow \tan(\theta_p) = \frac{\sigma}{\omega\varepsilon} \ll 1$$

$$\sqrt{1 - x} \approx 1 - \frac{x}{2} \quad (x \ll)$$

$$\beta \cong \frac{2\pi}{\lambda} = \omega\sqrt{\mu\varepsilon} = \frac{\omega}{c} \qquad \alpha \cong \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}} = \beta\,\frac{\tan(\theta_p)}{2}$$

$$c = \frac{c_0}{\sqrt{\varepsilon_r \mu_r}} \qquad \lambda = \frac{\lambda_0}{\sqrt{\varepsilon_r \mu_r}} \qquad Z \cong \sqrt{\frac{\mu}{\varepsilon}}\left(1 + j\frac{\sigma}{2\omega\varepsilon}\right)$$

—— // ——

$$\rightarrow \sigma \gg \omega\varepsilon \Rightarrow \tan(\theta_p) = \frac{\sigma}{\omega\varepsilon} \gg 1$$

$$\alpha = \beta = \frac{1}{\delta} \cong \sqrt{\frac{\omega\mu\sigma}{2}} \qquad Z \cong \sqrt{\frac{\omega\mu}{2\sigma}}(1 + j)$$

—— // ——

$$\theta_E - \theta_H = \measuredangle\{Z\} \qquad \delta = \frac{1}{\alpha}$$

—— // ——

$$\underline{\vec{E}} = \underline{\vec{E}_0}\, e^{-jk\vec{r}\cdot\hat{n}} = E_1\hat{e}_1 + E_2\hat{e}_2 \qquad \hat{e}_1 \times \hat{e}_2 = \hat{n}$$

$$P = \frac{E_2}{E_1} = |P|\,e^{j\phi}$$

i) $|P| = 1 \wedge \phi = \pm\frac{\pi}{2} \Rightarrow \begin{cases} + \rightarrow \text{PCL} \\ - \rightarrow \text{PCR} \end{cases}$

ii) $p = 0 \vee p = \infty \vee \phi = 0 \vee \phi = \pi \Rightarrow$ PL

iii) PE $\begin{cases} 0 < \phi < \pi \rightarrow \text{PEL} \\ -\pi < \phi < 0 \rightarrow \text{PED} \end{cases}$

$$\hat{x} \times \hat{x} = 0 \qquad \hat{y} \times \hat{x} = -\hat{z} \qquad \hat{z} \times \hat{x} = \hat{y}$$

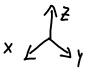
$$\hat{x} \times \hat{y} = \hat{z} \qquad \hat{y} \times \hat{y} = 0 \qquad \hat{z} \times \hat{y} = -\hat{x}$$

$$\hat{x} \times \hat{z} = -\hat{y} \qquad \hat{y} \times \hat{z} = \hat{x} \qquad \hat{z} \times \hat{z} = 0$$

$$\hat{e}^{i}_{\parallel} \times \hat{e}_{\perp} = \hat{n}^{i} \qquad 1 + R_\perp = T_\perp$$

$$\hat{e}^{r}_{\parallel} \times \hat{e}_{\perp} = \hat{n}^{r} \qquad 1 + R_\parallel = T_\parallel \frac{\cos(\theta_t)}{\cos(\theta_i)}$$

$$\hat{e}^{t}_{\parallel} \times \hat{e}_{\perp} = \hat{n}^{t}$$



$$\sigma = 0: \quad \frac{d\mathcal{E}_{EM}}{dt} = -P_\Sigma(t) + P_{in}(t)$$

$$\nabla \cdot (\vec{E} \times \vec{H}) = -\vec{E} \cdot \vec{J}_{ext} - \frac{\partial}{\partial t} w_{EM}$$

$$w_{EM} = \frac{1}{2}\left[\varepsilon \vec{E}^2 + \mu \vec{H}^2\right]$$

$$\int_V \nabla \cdot (\vec{E} \times \vec{H})\,dv = -\int_V \vec{E} \cdot \vec{J}_{ext} - \frac{d}{dt}\int_V w_{EM}$$

$$\mathcal{E}_{EM} = \int_V w_{EM}\,dv$$

$$P_{in}(t) = -\int_V \vec{E} \cdot \vec{J}_{ext}\,dV$$

$$P_\Sigma(t) = \int_V \nabla \cdot (\vec{E} \times \vec{H})\,dv = \int_\Sigma \vec{S} \cdot \hat{r}\,ds$$

$$\vec{S} = \vec{E} \times \vec{H} \qquad S(t) = E(t) \times H(t)$$

$$\vec{S}_{av} = \frac{1}{2}\mathrm{Re}\{\underline{\vec{E}} \times \underline{\vec{H}}^*\}$$

$$\vec{S}_{av} = \frac{1}{2}\mathrm{Re}\left\{\frac{1}{Z}\right\}|\vec{E}|^2 \cdot \hat{n}$$

—— // ——

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad T = 1 + R = \frac{2Z_2}{Z_1 + Z_2}$$

$$E_0^{ref} = R\,E_0^{inc} \qquad E_0^{tx} = T\,E_0^{inc}$$

$$\frac{S^{ref}}{S^{inc}} = R^2 \qquad \frac{S^{tx}}{S^{inc}} = 1 - R^2$$

—— // ——

$$\begin{cases} \theta_i = \theta_r \\ \mathrm{sen}(\theta_t)\,n_2 = \mathrm{sen}(\theta_i)\,n_1 \end{cases} \qquad |R_T| = 1 \rightarrow \mathrm{sen}(\theta_{lim}) = n_{21}$$

$$\theta_t = 90^\circ \Rightarrow \theta_{lim} = \theta_{crit} = \mathrm{arcsen}\left(\frac{n_2}{n_1}\right)$$

$$\cos(\theta_B) = \frac{1}{\sqrt{\left(\frac{n_2}{n_1}\right)^2 + 1}} = \frac{1}{\sqrt{1 + \frac{\varepsilon_2}{\varepsilon_1}}}$$

$$tg(\theta_B) = \sqrt{\frac{\varepsilon_2}{\varepsilon_1}}$$

$$R_\perp = \frac{Z_2\cos(\theta_i) - Z_1\cos(\theta_t)}{Z_2\cos(\theta_i) + Z_1\cos(\theta_t)} \qquad \sigma = 0$$

$$R_\parallel = \frac{Z_1\cos(\theta_i) - Z_2\cos(\theta_t)}{Z_1\cos(\theta_i) + Z_2\cos(\theta_t)} \qquad \sigma = 0$$

$$\underline{\vec{E}}^{inc} = (E^i_{\parallel 0}\hat{e}^i_\parallel + E^i_{\perp 0}\hat{e}_\perp)\,e^{-jk_1\vec{r}\cdot\hat{n}^i}$$

$$\underline{\vec{E}}^{ref} = (R_\parallel E^i_{\parallel 0}\hat{e}^r_\parallel + R_\perp E^i_{\perp 0}\hat{e}_\perp)\,e^{-jk_1\vec{r}\cdot\hat{n}^r}$$

$$\underline{\vec{E}}^{tx} = \left(\frac{Z_2}{Z_1}(1 + R_\parallel)E^i_{\parallel 0}\hat{e}^t_\parallel + (1 + R_\perp)E^i_{\perp 0}\hat{e}_\perp\right)e^{-jk_2\vec{r}\cdot\hat{n}^t}$$

$$p_i = \frac{E^i_{\perp 0}}{E^i_{\parallel 0}} \qquad p_r = \frac{E^r_{\perp 0}}{E^r_{\parallel 0}} = \frac{R_\perp}{R_\parallel}\,p_i$$

$$p_t = \frac{1 + R_\perp}{\frac{Z_2}{Z_1}(1 + R_\parallel)}\,p_i \qquad SWR = \frac{1 + |R|}{1 - |R|} = \frac{|E|_{max}}{|E|_{min}}$$