① 2020

UPW → Ex// 5G - IEEE links
- IT'18

↳ $f = 2.45\,GHz$

$\epsilon_R = 48.1$

$\sigma = 1.81\ S/m$

$\mu_R = 1$

↳ $f = 28\ GHz$

$\epsilon_R = 21$

$\sigma = 30\ S/m$

$\mu_R = 1$

$\alpha = 48.7\ Np/m$

$\beta = 3.59 \times 10^{12}$

$\eta = 53.3 \angle 0.135\ rad$

$\delta \approx 2cm$

↳ 33% of original value

$\alpha = 1.14 \times 10^3\ Np/m$

$\beta = 2.92 \times 10^3$

$\eta = 70.57 \angle 0.37\ rad$

$\delta \sim 0.88mm$

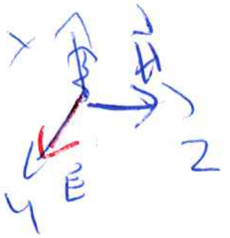
⇓

$$\vec{E}(x,t) = 10e^{-\alpha x} \cos(\omega t - \beta x)\vec{a}_y$$

$$\vec{H}(y,t)$$

$$\vec{E}(x,t) = 10e^{-48.7x} \cos(2\pi \times 2.45 \times 10^9 t - 3.59 \times 10^{12} x)\vec{a}_y$$

$$\vec{H}(x,t) = \frac{10}{53.3} e^{-48.7x} \cos(2\pi \times 2.45 \times 10^9 t - 3.59 \times 10^{12} x - 0.135)\vec{a}_z$$



UPW - Special cases

(1) perfect dielectric $\rightarrow \sigma = 0$

$$\alpha = \omega \sqrt{\frac{\mu\epsilon}{2}\left[\sqrt{1+(\cancel{\sigma/\omega\epsilon})^2} - 1\right]}$$

$\cancel{\sigma/\omega\epsilon} \rightarrow 0$, $-1 \rightarrow 0$

$$= 0$$

$$\beta = \omega \sqrt{\frac{\mu\epsilon}{2}\left[\sqrt{1+(\cancel{\sigma/\omega\epsilon})^2} + 1\right]}$$

$\cancel{\sigma/\omega\epsilon} \rightarrow 0$

$$= \omega \sqrt{\frac{\mu\epsilon}{2}(2)}$$

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

$$= \omega\sqrt{\mu_r\mu_0\epsilon_R\epsilon_0}$$

$$\eta = \sqrt{\mu/\epsilon}$$

$$= \sqrt{\frac{\mu_r\mu_0}{\epsilon_R\epsilon_0}}$$

$\Rightarrow \lambda = \frac{2\pi}{\beta}$ and $v_p = \omega/\beta$

Ex) $\vec{E}(x,t) = 50\cos(10^8 t + \beta x)\vec{a}_y$

$\epsilon_R = 9$

$\mu_R = 1$

$\sigma = 0$

- Calculate β + time to travel $\lambda/2$
- Find $\vec{H}(x,t)$.
- Find v_p + compare to free space.

Ex// $\vec{E}(x,t) = 50\cos(10^8 t + \beta x)a_y$

$\epsilon_r = 9$

$\mu_r = 1$

$\sigma = 0$

- Calculate β and time to travel $\lambda/2$
- Find $\vec{H}(x,t)$
- Find v_p + compare to free space ($v_p = 3\times10^8$ m/s)

$$\beta = \omega\sqrt{9\epsilon_0\mu_0} = \frac{10^8\sqrt{9}}{3\times10^8} = 1 \text{ rad/m}$$

free space: $\frac{1}{\sqrt{\mu_0\epsilon_0}} = 3\times10^8$

$\beta_0 = 0.333$ rad/m

$$\lambda = \frac{2\pi}{\beta} = 2\pi \text{ m}$$

$\lambda_0 = 6\pi$ m

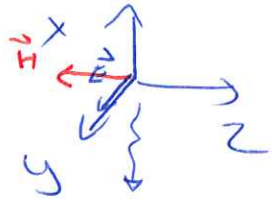
$$v_p = \omega/\beta = 10^8 \text{ m/s}$$

$$t = \frac{\pi}{10^8} = 31.4 \text{ ns}$$

$t = 31.4$ ns

$\eta_0 = 120\pi\ \Omega$

$$\vec{H}(x,t) = -\frac{50}{40\pi}\cos(10^8 t + x)\vec{a}_z$$



$$\eta = \sqrt{\frac{\mu_0}{9\epsilon_0}} = 40\pi$$

$\epsilon_r = 9$

$$\beta = 10^8 \sqrt{\mu_0 9 \epsilon_0}$$

$$= \left(\frac{10^8}{3\times10^8}\right)\left(\sqrt{9}\right)$$

$$= 1 \text{ rad/m}$$

$$\lambda = \frac{2\pi}{\beta}$$

$$\doteq 2\pi \text{ m}$$

$$v_p = \omega/\beta$$

$$= 10^8/1$$

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

$$t = \pi/10^8$$

$$= 31.4 \text{ ns}$$

$$\eta = \sqrt{\frac{\mu_0}{9\epsilon_0}}$$

$$= 40\pi \ \Omega$$

$$\vec{H}(x,t) = \frac{-50}{40\pi} \cos(10^8 t + x)\, \vec{a}_z$$

free space

$$\beta_0 = 0.33 \text{ rad/m}$$

$$\lambda_0 = 6\pi \text{ m}$$

$$v_p = 3\times10^8 \text{ m/s}$$

$$t = 31.4 \text{ ns}$$

$$\eta_0 = 120\pi \ \Omega$$

② special case: good conductor

$$\frac{\sigma}{\omega\epsilon} >> 1$$

$$\alpha = \omega\sqrt{\frac{\mu\epsilon}{2}\left[\sqrt{\cancel{1}+(\sigma/\omega\epsilon)^2} \cancel{-1}\right]}$$

$$= \omega\sqrt{\frac{\mu\cancel{\epsilon}}{2}\left(\frac{\sigma}{\omega\cancel{\epsilon}}\right)}$$

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

$$\beta = \sqrt{\frac{\omega\mu\sigma}{2}}$$

$$|\eta| = \frac{\sqrt{\mu/\epsilon}}{\left[\cancel{1} + (\sigma/\omega\epsilon)^2\right]^{1/4}}$$

$$= \frac{\sqrt{\mu/\epsilon}}{\sqrt{\sigma/\omega\epsilon}}$$

$$= \sqrt{\frac{\omega\mu}{\sigma}}$$

$$\tan(2\theta_\eta) = \frac{\sigma}{\omega\epsilon}$$

$$\theta_\eta = 45^\circ$$

$$= \pi/4$$

Ex// A 1MHz UPW propagates in medium

$\epsilon_r = 8$

$\sigma = 4.8 \times 10^{-2}$ S/m

$\mu_r = 1$

The wave propagates in +z. At $z=0$, $|\vec{E}| = 150$ V/m & is oriented in $-y$.

Find expressions for $\vec{E}$ & $\vec{H}$

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$$\frac{\sigma}{\omega\epsilon} = ? \quad \Rightarrow \quad \frac{\sigma}{\omega\epsilon} = \frac{4.8 \times 10^{-2}}{(2\pi \times 10^{6})(8)(8.85 \times 10^{-12})}$$

$$= 107.9 \gg 1 \Rightarrow \text{good conduction approximation}$$