In the name of Allah, Most Gracious, Most Merciful.

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

Electrical Engineering Department

Electromagnetics Theory

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Summary of Electromagnetic Wave Propagation (Plane waves),

Assuming $e^{j\omega t}$; $\boldsymbol{E}_s = E_{xs}(z)\boldsymbol{a}_x$; $\dfrac{\partial^2 E_{xs}(z)}{\partial x^2} = \dfrac{\partial^2 E_{xs}(z)}{\partial y^2} = 0$; $\rho_v = 0$

$\boldsymbol{E}_s = E_o e^{-\underline{\gamma} z}\boldsymbol{a}_x$; $\boldsymbol{H}_s = H_o e^{-\underline{\gamma} z}\boldsymbol{a}_y$, with propagation in the positive z-direction

Propagation constant $\underline{\gamma} = \alpha + j\beta$; Attenuation constant α; Phase constant β; Intrinsic impedance $\underline{\eta}$;

Loss tangent $\tan\theta = \dfrac{\sigma}{\omega\varepsilon}$; Skin depth $\delta = \dfrac{1}{\alpha} = \dfrac{1}{\sqrt{\pi f\mu\sigma}}$; For TEM $\boldsymbol{a}_E \times \boldsymbol{a}_H = \boldsymbol{a}_k$;

Speed of light in free space $C = 3\times10^8$ m/s; Wave velocity $u = \omega/\beta$

Lossy Dielectric	**Lossless Dielectric**	**Free Space**	**Good Conductor**
$\sigma\neq 0,\ \varepsilon=\varepsilon_r\varepsilon_o,\ \mu=\mu_r\mu_o$	$\sigma<<\omega\varepsilon,\ \sigma=0,\ \varepsilon=\varepsilon_r\varepsilon_o,\ \mu=\mu_r\mu_o$	$\sigma=0,\ \varepsilon=\varepsilon_o,\ \mu=\mu_o$	$\sigma>>\omega\varepsilon,\ \sigma\approx\infty,\ \varepsilon=\varepsilon_o,\ \mu=\mu_r\mu_o$
$\alpha = \omega\sqrt{\dfrac{\mu\varepsilon}{2}\left[\sqrt{1+\left(\dfrac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}$	$\alpha = 0$	$\alpha = 0$	$\alpha = \sqrt{\dfrac{\omega\mu\sigma}{2}} = \sqrt{\pi f\mu\sigma}$
$\beta = \omega\sqrt{\dfrac{\mu\varepsilon}{2}\left[\sqrt{1+\left(\dfrac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}$	$\beta = \omega\sqrt{\mu\varepsilon}$	$\beta = \omega\sqrt{\mu_o\varepsilon_o} = \dfrac{\omega}{C}$	$\beta = \sqrt{\dfrac{\omega\mu\sigma}{2}} = \sqrt{\pi f\mu\sigma}$
$u = \dfrac{\omega}{\beta}$	$u = \dfrac{\omega}{\beta} = \dfrac{1}{\sqrt{\mu\varepsilon}}$	$u = \dfrac{\omega}{\beta} = \dfrac{1}{\sqrt{\mu_o\varepsilon_o}} = C$	$u = \dfrac{\omega}{\beta} = \sqrt{\dfrac{2\omega}{\mu\sigma}}$
$\underline{\eta} = \sqrt{\dfrac{j\omega\mu}{\sigma + j\omega\varepsilon}}$ $\lvert\underline{\eta}\rvert = \dfrac{\sqrt{\mu/\varepsilon}}{\left[1+\left(\dfrac{\sigma}{\omega\varepsilon}\right)^2\right]^{1/4}}$; $\tan 2\theta_\eta = \dfrac{\sigma}{\omega\varepsilon}$	$\underline{\eta} = \sqrt{\dfrac{\mu}{\varepsilon}}\angle 0^o$	$\eta = \sqrt{\dfrac{\mu_o}{\varepsilon_o}} = 377$	$\underline{\eta} = \sqrt{\dfrac{\omega\mu}{\sigma}}\angle 45^o$
$\boldsymbol{E}(z,t) = E_o e^{-\alpha z}\cos(\omega t - \beta z)\boldsymbol{a}_x$	$\boldsymbol{E}(z,t) = E_o\cos(\omega t - \beta z)\boldsymbol{a}_x$	$\boldsymbol{E}(z,t) = E_o\cos(\omega t - \beta z)\boldsymbol{a}_x$	$\boldsymbol{E}(z,t) = E_o e^{-\alpha z}\cos(\omega t - \beta z)\boldsymbol{a}_x$
$\boldsymbol{H}(z,t) = \dfrac{E_o}{\lvert\underline{\eta}\rvert} e^{-\alpha z}\cos(\omega t - \beta z - \theta_\eta)\boldsymbol{a}_y$	$\boldsymbol{H}(z,t) = \dfrac{E_o}{\eta}\cos(\omega t - \beta z)\boldsymbol{a}_y$	$\boldsymbol{H}(z,t) = \dfrac{E_o}{\eta_o}\cos(\omega t - \beta z)\boldsymbol{a}_y$	$\boldsymbol{H}(z,t) = \dfrac{E_o}{\lvert\underline{\eta}\rvert} e^{-\alpha z}\cos(\omega t - \beta z - 45^o)\boldsymbol{a}_y$