

October 22nd, 2024

Maxwell's Wave Equation

Assumptions: $\rho = 0$, $\sigma = 0$, $\vec{J} = 0$, i.e. region is a source-free perfect dielectric.

Wave equation: $\nabla^2 \vec{E} = \mu \epsilon \frac{\partial^2 \vec{E}}{\partial t^2}$. Solutions are 'TEM wa ∂t^2 . Columns are referred . Solutions are 'TEM waves.' TEM = Transverse ElectroMagnetic. TEM = Transverse ElectroMagnetic.
 \vec{E} and \vec{H} point **perpendicular** to the direction c

• Why can't they point in the direction of trave
General form of cosinusoidal solution:

and H point $\boldsymbol{\mathsf{perpendicular}}$ to the direction of travel.

Why can't they point in the direction of travel?

Wave Formulae

$$
v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}
$$

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

$$
\omega = 2\pi f = \frac{2\pi}{T}
$$

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

Getting E from H and vice versa

Poynting Vector & Theorem

. Units: W/m2 . "Instantaneous" power per unit area passing through surface in direction of \vec{S}

Energy unit volume balance equation:

$$
\frac{\partial}{\partial t} \left(\frac{1}{2} \epsilon \vec{E} \cdot \vec{E} + \frac{1}{2} \mu \vec{H} \cdot \vec{H} \right) + \nabla \cdot \vec{S} + \vec{J} \cdot \vec{E} = 0
$$

Phasor Notation

Phasor Notation
\n
$$
\vec{E}(x,t) = A\cos(\omega t - \beta x)\hat{z} = \text{Re}\{Ae^{j\omega t}e^{-j\beta x}\} \leftrightarrow Ae^{-j\beta x} = \tilde{E}(x)
$$
\n^{Time domain} Phase

$$
\sin(x) = \cos\left(x - \frac{\pi}{2}\right)
$$

Time-Averaging

If TEM wave \vec{E} is cosinusoidal,

- Then corresponding \vec{H} is cosinusoidal
- Then phasors \tilde{E} and \tilde{H} exist
- Also, $\dot{S} = \dot{E} \times \dot{H}$ (instantaneous power per unit area) is cosinusoidal squared • Then phasors \tilde{E} and \tilde{H} exist

• Also, $\vec{S} = \vec{E} \times \vec{H}$ (instantaneous power per unit area) is cosinusoidal

squared

• We can write \vec{S} in phasor form too: $\tilde{S} = \tilde{E} \times \tilde{H}^*$

• Time-average o
- We can write \vec{S} in phasor form too: $\tilde{S} = \tilde{E} \times \tilde{H}^*$
- cosinusoidal:

$$
\langle \vec{S} \rangle = \frac{1}{2} \text{Re}\{\tilde{E} \times \tilde{H}^*\}
$$

Problem 1

What is the time derivative of a phasor? What are Maxwell's Equations in phasor form?

Problem 2

Given a uniform TEM wave with $\vec{E}(x,t) = -3\cos(\omega t + \beta x)\hat{z}$ V/m with $f = 100$ MHz and $v = \frac{2}{3}c$ propagating through a homogenous medium with $\epsilon = 1.5\epsilon_0$, find $_r$, λ , β , $H(x,t)$, $\bar{H}(x)$, instantaneous power per unit area crossing $x=1$ in + \hat{x} direction, and time-averaged power per unit area crossing $x = 1$ in + \hat{x} direction.

Radiation from Current Sheets

Static $\bar{J}_\mathcal{S}$ on a current sheet produces static H and no \bar{E} , as seen before.

Time-varying f_s produces time-varying H , with changes in $\overline{f_s}$ causing changes in \vec{H} propagating out of the current sheet. To satisfy Faraday's Law, time-varying \vec{H} must produce accompanying timevarying \vec{E} .

Time-varying current sheets produce TEM waves propagating outward!

Problem 3

On the $x=0$ plane a current sheet exists carrying $\displaystyle{J_{\scriptscriptstyle S}=2t(u(t)-u(t-2))\hat{z}}$ A/m. Regions adjacent to the sheet are vacuum. **Problem 3**
On the $x = 0$ plane a current
Regions adjacent to the shee
1. Plot $\vec{J}_s(t)$.
2. Determine and plot nonz **Problem 3**

On the $x = 0$ plane a current sheet exists carrying $\vec{J}_s = 2t(u(t) - u(t - 2))\hat{z}$ A/m.

Regions adjacent to the sheet are vacuum.

1. Plot $\vec{J}_s(t)$.

2. Determine and plot nonzero components of \vec{E} and $\$ 3. Determine and plot nonzero components of \vec{E} and \vec{H} against t at $z = 9 * 10^8$ m.

3. Determine and plot nonzero components of \vec{E} and \vec{H} against t at $z = 9 * 10^8$ m.

4. Determine and plot nonzero But the $x = 0$ plane a current sheet exists carrying $f_s = 2t(u(t) - u(t - 2))Z$ A/H
Regions adjacent to the sheet are vacuum.
1. Plot $\vec{f}_s(t)$.
2. Determine and plot nonzero components of \vec{E} and \vec{H} against t at $z = 9$

-
- 2. Determine and plot nonzero components of \vec{E} and \vec{H} against t at $z = 9 * 10^8$ m. 1. Plot $\vec{J}_s(t)$.

2. Determine and plot nonzero components of \vec{E} and \vec{H} against t at $z = 9 *$

3. Determine and plot nonzero components of \vec{E} and \vec{H} against t at $z = -9$

4. Determine and plot non
- m.
-
-

Midterm 1 equations, in one place

 1^{42} $\hat{ }$ $\epsilon \Phi$ 0^{T} 99 2' as $\mathcal{A} \cap \overrightarrow{D}$ $2 \quad \alpha \quad \text{d}b \, F$ 0^{r} $I 2¹$ and $\frac{1}{2}$ $\vec{F} = q_1 \vec{E} + q_1 (\vec{v}_1 \times \vec{B})$

$$
\hat{n} \cdot (\vec{D}_1 - \vec{D}_2) = \rho_s
$$

$$
\hat{n} \times (\vec{E}_1 - \vec{E}_2) = 0
$$

$$
\hat{n} \cdot (\vec{P}_1 - \vec{P}_2) = -\rho_{b,s}
$$

$$
\vec{P} = \epsilon_0 \chi_e \vec{E}
$$

$$
\vec{D} = \epsilon_0 \vec{E} + \vec{P}
$$

$$
\epsilon \oint \vec{E} \cdot d\vec{S} = Q_{\text{enclosed}}
$$

\n
$$
\oint \vec{D} \cdot d\vec{S} = Q_{\text{enclosed}}
$$

\n
$$
\iiint \rho dV = Q_{\text{enclosed}}
$$

\n
$$
\oint \vec{B} \cdot d\vec{S} = 0
$$

\n
$$
I = \oint \vec{J} \cdot d\vec{S} = -\frac{\partial Q_{\text{enclosed}}}{\partial t}
$$

2C
\n
$$
\nabla \times \vec{E} = 0
$$
\n
$$
\vec{E} = -\nabla V
$$
\n
$$
\oint \vec{E} \cdot d\vec{l} = 0
$$
\n
$$
V_{ab} = V(b) - V(a) = -\int_{a}^{b} \vec{E} \cdot d\vec{l}
$$
\n
$$
d\vec{E} = -\int_{a}^{b} d\vec{l} \cdot d\vec{l}
$$

$$
\epsilon = \epsilon_0 (1 + \chi_e)
$$

\n
$$
\vec{P} = \epsilon_0 \chi_e \vec{E}
$$

\n
$$
\vec{D} = \epsilon_0 \vec{E} + \vec{P} = \epsilon \vec{E}
$$

\n
$$
\vec{J} = \sigma \vec{E}
$$

\n
$$
\rho_b = -\nabla \cdot \vec{P}
$$

\n
$$
\nabla \cdot \epsilon_0 \vec{E} = \rho_f + \rho_b
$$

\n
$$
\vec{E} = \rho_f + \rho_b
$$

$$
\oint \vec{D} \cdot d\vec{S} = \iiint \nabla \cdot \vec{D} dV
$$

$$
\oint \vec{E} \cdot d\vec{l} = \iint (\nabla \times \vec{E}) \cdot d\vec{S}
$$

$$
\int_{a}^{b} \nabla V \cdot d\vec{l} = V(b) - V(a)
$$

Midterm 2 equations, in one place

 $Q = CV$
 $R = \frac{1}{G}$ $Q = CV$
 $G = \frac{\sigma}{\epsilon}C$ $R = \frac{1}{G}$
 $\vec{J}_b = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$ σ $p = \frac{1}{\sigma}$ 2π ϵ G $Q = CV$
 C $R = \frac{1}{G}$
 $\frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$ 1 $\sqrt{ }$ G and G a = 2 1 $\vec{B} = \frac{\mu I}{2\pi r} \hat{\phi}$ $d\vec{B} = \frac{\mu Id\vec{\ell} \times \hat{r}}{4\pi r^2}$ **Midterm 2 equations, in**
 $\frac{d}{dr}\hat{\phi}$ $\Psi = \iint_S \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda f =$
 $\frac{\mu I d\vec{\ell} \times \hat{r}}{4\pi r^2}$ $-\frac{d}{dt} \iint_S \vec{B} \cdot d\vec{S} = \oint_c \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f =$
 $\vec{l} = \iint_S \vec{f} \cdot d\vec{S}$ $\nabla \times \vec{E} = -\frac{\partial \vec{B}}$ $4\pi r^2$ $-\frac{1}{dt} \iint_{S} B \cdot dS =$ **Midterm 2 equation:**
 $\vec{B} = \frac{\mu I}{2\pi r} \hat{\phi}$ $\psi = \iint_{S} \vec{B} \cdot d\vec{S}$ $v = d\vec{B} = \frac{\mu I d\vec{l} \times \hat{r}}{4\pi r^2}$ $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ α
 $\oint_{C} \vec{H} \cdot d\vec{l} = \iint_{S} \vec{J} \cdot d\vec{S}$ $\nabla \times \vec{E} = -\frac{\partial \$ $\oint_C \vec{B} \cdot d\vec{\ell} = \mu I_{\text{encl}} \qquad \oint \vec{E} \cdot d\vec{l} = \varepsilon$ **Vidterm 2 equations, i**
 $\psi = \iint_{S} \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda$
 $\frac{d\vec{d} \times \hat{r}}{4\pi r^2}$ $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = 2\pi$
 $= \iint_{S} \vec{j} \cdot d\vec{S}$ $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\eta = \mu I_{\text{encl}}$ $\$ **PURICUMPLE PRIME CONSECTIVE**
 $\vec{B} = \frac{\mu l}{2\pi r} \hat{\phi}$ $\psi = \iint_{S} \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \frac{\mu l d \vec{\ell} \times \hat{r}}{4\pi r^2}$ $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{C} \vec{E} \cdot d\vec{l}$ $\omega = \oint_{C} \vec{H} \cdot d\vec{\ell} = \iint_{S} \vec{J} \cdot d\vec{S}$ $\nabla \times \vec{$ ∂D $W = \oint F d\vec{r}$ ∂t q $B = \frac{\mu}{2\pi r} \varphi$ $\Psi = \iint_{S} B \cdot dS$ $v = \frac{\pi}{\beta}$
 $d\vec{B} = \frac{\mu}{4\pi r^2}$ $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = \oint_{c} \vec{H} \cdot d\vec{\ell} = \iint_{S} \vec{J} \cdot d\vec{S}$ $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ η
 $\oint_{C} \vec{B} \cdot d\vec{\ell} = \mu I_{en$ **Midterm 2 equations, in c**
 $\vec{B} = \frac{\mu I}{2\pi r} \hat{\phi}$ $\psi = \iint_{S} \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda f = \frac{\omega}{\sqrt{\beta}}$
 $d\vec{B} = \frac{\mu I d\vec{\ell} \times \hat{r}}{4\pi r^2}$ $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2}{\gamma}$
 $\oint_{C} \vec{$ **n 2 equations, in one place**
 $\Psi = \iint_S \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $-\frac{d}{dt} \iint_S \vec{B} \cdot d\vec{S} = \oint_c \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$ $d \int \vec{r}$ **2 equations, in one place**
 $=\iint_{s} \vec{B} \cdot d\vec{S}$
 $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\frac{d}{dt} \iint_{s} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$
 $\omega = 2\pi f = \frac{2\pi}{T}$
 $\omega = 2\pi f = \frac{2\pi}{T}$
 $\vec{B} = \frac{\sigma}{\epsilon}$
 $\vec{C} = -\frac{\partial \vec{B}}{\partial t}$
 $\vec{$ **n 2 equations, in one pl**
 $\Psi = \iint_{S} \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$
 $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\oint_{c} \vec{E} \cdot d\vec{l} = \v$ **equations, in one plac**
 $\vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\vec{B} \cdot d\vec{S} = \oint_c \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$
 $-\frac{\partial \vec{B}}{\partial t}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\beta = \omega \sqrt{\mu \epsilon}$
 $= \epsilon$
 $\nabla^2 \vec{E} = \mu \epsilon \frac{\partial^2 \vec{E}}{\partial t^2}$
 The Actions, In One p
 $\Psi = \iint_{S} \vec{B} \cdot d\vec{S}$ $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$
 $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\oint_{c} \vec{E} \cdot d\vec{l} = \varepsilon$ $W \qquad \int \vec{F} \qquad \vec{r}$ $\frac{dV}{q} = \oint_C \frac{\vec{F}}{q} \cdot d\vec{l}$ **CONS, IN ONE PIACE**
 $d\vec{s}$ $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $d\vec{s} = \oint_c \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$
 $\frac{\partial \vec{B}}{\partial t}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\beta = \omega \sqrt{\mu \epsilon}$
 ϵ
 $\nabla^2 \vec{E} = \mu \epsilon \frac{\partial^2 \vec{E}}{\partial t^2}$ \vec{B}
 $\frac{\vec{F}}{c \vec{$ $-\frac{d}{dt}\iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$
 $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\oint_{c} \vec{E} \cdot d\vec{l} = \varepsilon$
 $\varepsilon = \frac{W}{q} = \oint_{C} \frac{\vec{F}}{q} \cdot d\vec{l}$
 $\Psi = LI$ $\vec{S} = \vec{E} \times \vec{H}$
 $\overline{\psi} = IR$ $\$ **n 2 equations, in one plat**
 $\Psi = \iint_{S} \vec{B} \cdot d\vec{S}$
 $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$
 $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
 $\oint_{c} \vec{E} \cdot d\vec{l} = \varepsilon$
 $\nabla^{2} \vec{E} = \mu \varepsilon \frac{\partial^{2} \vec{E}}{\partial t^{2}}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$ $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
 $\eta = \frac{\nabla F}{\sqrt{\epsilon}}$
 $\beta = \omega \sqrt{\mu \epsilon}$ $v = \frac{d}{\beta} = \lambda f = \frac{\lambda}{\sqrt{\mu \epsilon}}$
 $-\frac{d}{dt} \iint_{S} \vec{B} \cdot d\vec{S} = \oint_{c} \vec{E} \cdot d\vec{l}$ $\omega = 2\pi f = \frac{2\pi}{T}$
 $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\oint_{c} \vec{E} \cdot d\vec{l} = \varepsilon$
 $\varepsilon = \frac{W}{q} = \oint_{c} \frac{\vec{F}}{q} \cdot d\vec{l}$
 $\Psi = LI$ \vec $\vec{J}_b = \frac{\partial T}{\partial t} + \nabla \times \vec{M}$ T and $\partial \vec{P}$ and \vec{P} $Q = CV$
 C $R = \frac{1}{G}$
 $\frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$
 $\vec{P} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{l} = \gamma_m \vec{H}$ $H=-M$ \overrightarrow{B} \rightarrow μ_0 \vec{r}
 \vec{r} $Q = CV$
 $\frac{d\vec{P}}{dt} = C$ $R = \frac{1}{G}$
 $\frac{d\vec{P}}{dt} + \nabla \times \vec{M}$
 $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{M} = \chi_m \vec{H}$
 $\vec{H} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $\frac{d\vec{H}}{dt} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$ $Q = CV$
 $= \frac{\sigma}{\epsilon} C$ $R = \frac{1}{G}$
 $\vec{r}_b = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$
 $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{M} = \chi_m \vec{H}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $-\beta x \hat{z} \leftrightarrow A e^{-j\beta x}$ $\vec{J}_b = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$
 $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{M} = \chi_m \vec{H}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $(\omega t - \beta x) \hat{z} \leftrightarrow A e^{-j\beta x}$
 $\hat{n} \cdot (\vec{B}_1 - \vec{B}_2) = 0$
 $\hat{n} \times (\vec{H}_1 - \vec{H}_2) = \vec{J}_s$
 $\hat{n} \times (\vec{M}_1 - \vec{M}_2) = \vec$ $\hat{n} \times (\vec{M}_1 - \vec{M}_2) = \vec{J}_{b.s}$ **S, in one place**
 $=\frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\omega = 2\pi f = \frac{2\pi}{T}$
 $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\vec{r} = \frac{\vec{\theta} \cdot \vec{B}}{\vec{a} \cdot \vec{b}} + \nabla \times \vec{M}$
 $\vec{r} = \frac{\vec{B}}{\mu} - \vec{M}$ **ns, in one place**
 $v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\omega = 2\pi f = \frac{2\pi}{T}$
 $\vec{r} = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{r}$ **s, in one place**
 $\frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $= 2\pi f = \frac{2\pi}{T}$
 $\frac{\omega}{\alpha} = \frac{\sigma}{\epsilon}c$
 $\frac{\sigma}{\alpha} = \frac{\sigma}{\epsilon}c$
 $\frac{\sigma}{\alpha} = \frac{\partial \vec{P}}{\alpha} + \nabla \times \vec{M}$ $\overline{\mu \epsilon}$ 0 **i, in one place**
 $\frac{1}{\sqrt{3}} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $= 2\pi f = \frac{2\pi}{T}$
 $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $= \omega \sqrt{\mu \epsilon}$
 $\vec{a} = \frac{\partial^2 \vec{B}}{\partial t^2} + \vec{v} \times \vec{M}$
 $\vec{B} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{B} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{B} = \frac{\vec{B}}{\mu_0} - \vec$ $\overline{\mu}$ J_b $\overline{\epsilon}$ **S, in one place**
 $\frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\omega = 2\pi f = \frac{2\pi}{T}$
 $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\beta = \omega \sqrt{\mu \epsilon}$
 $\frac{\partial^2 \vec{E}}{\partial t^2}$
 $\vec{E} = \mu \epsilon \frac{\partial^2 \vec{E}}{\partial t^2}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$ $\nabla^2 E = \mu \epsilon \frac{E}{\gamma + 2}$ **s, in one place**
 $\frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\omega = 2\pi f = \frac{2\pi}{T}$
 $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\beta = \omega \sqrt{\mu \epsilon}$
 $\frac{\partial^2 \vec{E}}{\partial t^2}$
 $\vec{E} = \mu \epsilon \frac{\partial^2 \vec{E}}{\partial t^2}$
 $\vec{E} = \vec{E} \times \vec{H}$
 $\vec{E} = \vec{E} \times \vec{H}$
 $\vec{E} = \vec{E} \times \vec{H}$ $\partial^2 \vec{E}$ ∂t^2 $D - \mu_0$ $G = \frac{\sigma}{\epsilon} C$ $R = \frac{1}{G}$
 $\vec{J}_b = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$
 $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $\vec{M} = \chi_m \vec{H}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $\omega t - \beta x \hat{i} \leftrightarrow A e^{-j\beta x}$
 $\hat{n} \cdot (\vec{B}_1 - \vec{B}_2) = 0$
 $\times (\vec{H}_1 - \vec{H}_2) = \vec{J}_s$
 \times ∂ $\left(1 \right)$ \Rightarrow $\left(1 \right)$ \Rightarrow $\left(1 \right)$ \Rightarrow $\left(1 \right)$ $\partial t \left(2 \right)$ 2μ $1 \Rightarrow 1 \Rightarrow \overrightarrow{z}$ 2^{c} 2^{p} 1^{p} $\epsilon \vec{E} \cdot \vec{E} + \frac{1}{2} \mu \vec{H} \cdot \vec{H}$ + $\nabla \cdot \vec{S} + \vec{J} \cdot \vec{E} = 0$ $1 \frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $\frac{1}{\sqrt{2}}$ $2^{1/2}$ (1) (0) (1) (2) $\mu \vec{H} \cdot \vec{H}$ + $\nabla \cdot \vec{S} + \vec{j} \cdot \vec{E} = 0$ $\Delta \mu (\vec{M} \cdot \vec{M})$ $Q = CV$
 $\frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu \epsilon}}$
 $\rho = 2\pi f = \frac{2\pi}{T}$
 $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\vec{\delta} = \vec{E} \times \vec{H}$
 $\vec{S} = \vec{E}$ $\begin{aligned}\n\vec{a} \times \vec{b} &= 2\pi f = \frac{2\pi}{T} \\
\vec{b} \times \vec{c} &= \frac{2\pi}{T} \\
\vec{c} \times \vec{d} &= \frac{2\pi}{T} \\
\vec{c} \times \vec{d} &= \frac{2\pi}{T} \\
\vec{c} \times \vec{e} &= \frac{\partial^2 \vec{E}}{\partial t^2} \\
\vec{d} \times \vec{e} &= \frac{\partial^2 \vec{E}}{\partial t^2} \\
\vec{e} \times \vec{e} &= \frac{\partial^2 \vec{E}}{\partial t^2} \\
\vec$ $\tilde{S} = \tilde{E} \times \tilde{H}^*$
 $<\vec{S} > \frac{1}{2} \text{Re}\{\tilde{E} \times \tilde{H}^*\}$ $\hat{n} \cdot (\vec{B}_1 - \vec{B}_2) = 0$ $2\pi f = \frac{2\pi}{T}$
 $= \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\vec{B} = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$
 $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$
 $= \mu \epsilon \frac{\partial^2 \vec{E}}{\partial t^2}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$
 $\vec{B} =$ } $\overline{\beta} = Af = \frac{2\pi}{\sqrt{\mu \epsilon}}$
 $\gamma = 2\pi f = \frac{2\pi}{T}$
 $\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$
 $\beta = \omega \sqrt{\mu \epsilon}$
 $\overrightarrow{B} = \frac{\partial}{\partial t} + \nabla \times \overrightarrow{M}$
 $\overrightarrow{H} = \frac{\overrightarrow{B}}{\mu_0} - \overrightarrow{M}$
 $\overrightarrow{B} = \mu_0 \mu_r \overrightarrow{H} = \mu \overrightarrow{H}$
 $\overrightarrow{S} = \overrightarrow{E} \times \overrightarrow{H}$
 $\overrightarrow{S} = \overrightarrow{E} \$

Units

Charge $Q: C$ Current *I*: A Electric field strength \vec{E} : N/C or V/m Electric flux density \vec{D} : C/m² Polarization field \vec{P} : C/m² Electric potential $V: V$ Capacitance $C: F$ Magnetic flux density \vec{B} : T or Wb/m² Magnetic field strength \vec{H} : A/m Magnetic flux Ψ : Wb Electromotive force ε : V Inductance $L: H$

Electric permittivity ϵ : F/m Magnetic permeability μ : H/m Conductivity σ : Si/m

Charge density ρ : C/m³ Surface charge density $\rho_{\rm s}$: C/m 2 $\qquad\qquad\leftarrow$ Current density \vec{f} : A/m²

Intrinsic impedance η : Ohm Wave number β : rad/m

Office Hours

Any questions?

