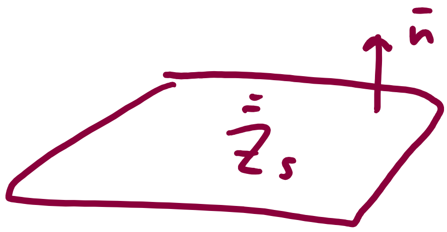
$$\bar{E}_t^r = \bar{\bar{R}}_E \cdot \bar{E}_t^i$$

$$-\bar{\bar{J}}_t \cdot \eta_0 \bar{H}_t^r \qquad \bar{\bar{J}}_t \cdot \eta_0 \bar{H}_t^i$$

$$-\bar{\bar{J}}_t \cdot \bar{H}_t^r = \bar{\bar{R}}_E \cdot \bar{\bar{J}}_t \cdot \bar{H}_t^i$$

$$\bar{H}_t^r = \underbrace{\bar{\bar{J}}_t \cdot \bar{\bar{R}}_E \cdot \bar{\bar{J}}_t}_{\bar{\bar{R}}_H} \cdot \bar{H}_t^i$$

LOSSES?



$$\bar E_t = \bar{\bar Z}_s \cdot \bar n \times \bar H_t$$

$$\bar{\bar Z}_s = Z_I \bar{\bar I}_t$$

$$\bar S = \frac{1}{2} \bar E \times \bar H^* = \frac{1}{2} Z_I (\bar n \times \bar H_t) \times \bar H_t^*$$

$$= \frac{1}{2} Z_I \, \bar H_t \underbrace{\bar n \cdot \bar H_t^*}_{0} - \frac{1}{2} Z_I \, \bar n \underbrace{\bar H_t \cdot \bar H_t^*}_{|\bar H_t|^2}$$

$$Re\{-\bar n \cdot \bar S\} = \frac{1}{2} Re\{Z_I\} |\bar H_t|^2$$

PEMC

$$\bar{\bar Z}_s = \frac{1}{M} \bar n \times \bar{\bar I}$$

$$\bar S = \frac{1}{2} \bar E_t \times \bar H_t^* = \frac{1}{2} \frac{1}{M} \left[(\bar n \times \bar{\bar I}) \times (\bar n \times \bar H_t) \right] \times \bar H_t^*$$

$$= \frac{1}{2M} \left(\bar n \, \bar n \cdot \bar H_t - \bar n \cdot \bar n \, \bar H_t \right) \times \bar H_t^*$$

$$= \frac{-1}{2M} \underbrace{\bar H_t \times \bar H_t^*}_{(\hat x H_x + \hat y H_y) \times (\quad)^*}$$

$$(\bar H_t \times \bar H_t^*)^* = \bar H_t^* \times \bar H_t = - \bar H_t \times \bar H_t^*$$

$$= \hat z (H_x H_y^* - H_y H_x^*)$$

$$= 2j \bar n \, Im\{H_x H_y^*\}$$

$$Re\{-\bar n \cdot \bar S\}$$

$$= Re\left\{ \frac{2j}{2M} Im\{H_x H_y^*\} \right\}$$

$$= \mathrm{Re}\left\{\frac{j}{M}\right\} \mathrm{Im}\left\{H_x H_y^*\right\} = -\mathrm{Im}\left\{\frac{1}{M}\right\} \mathrm{Im}\left\{H_x H_y^*\right\}$$

$$\frac{1}{M} = \frac{M^*}{|M|^2}$$

POLARITY TRANSFORMATION

$Q \to -Q \quad , \quad Q_c = -Q$

$\bar{D}_c = -\bar{D}$

$\bar{J}_c = -\bar{J}$

$\rho_c = -\rho$

$\nabla \cdot \bar{D} = \rho$

$\bar{D} = \bar{\bar{\varepsilon}} \cdot \bar{E} + \bar{\bar{\xi}} \cdot \bar{H}$

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

$\bar{E}_c \to -\bar{E}$

$\bar{\bar{\xi}}_c = \bar{\bar{\xi}}$

$\bar{H}_c \to -\bar{H}$

$\bar{B} = \bar{\bar{\zeta}} \cdot \bar{E} + \bar{\bar{\mu}} \cdot \bar{H}$

$\bar{B}_c = -\bar{B}$

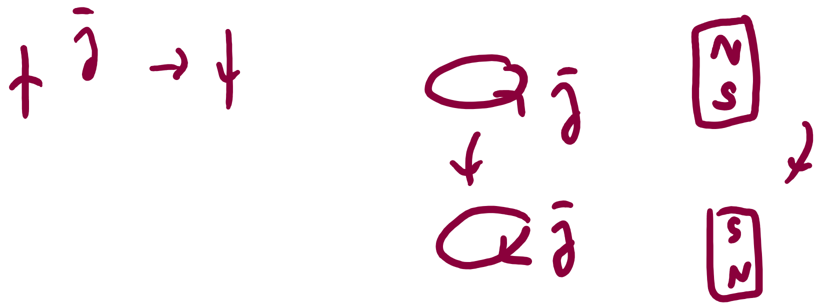
$\nabla \cdot \bar{B} = \rho_m$

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

$\rho_{m_c} = -\rho_m$

$\bar{J}_{m_c} = -\bar{J}_m$

$\bar{\bar{\zeta}}_c = \bar{\bar{\zeta}}$



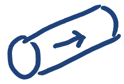
TIME REVERSAL

$t \to -t \;, \quad t_T = -t$

$\rho_T = \rho \qquad \bar{J}_T = -\bar{J}$

$\nabla_T \times \bar{H}_T = \bar{J}_T + \dfrac{\partial \bar{D}_T}{\partial t_T} \qquad \bar{D}_T = \bar{D}$

$\nabla_T = \nabla \qquad \bar{H}_T = -\bar{H}$



$\bar{J} = \rho \bar{v}$

$= \rho \dfrac{d\bar{r}}{dt}$

$\nabla \cdot \bar{D} = \rho \qquad \bar{B}_T = -\bar{B}$

$\nabla \cdot \bar{B} = \rho_m \qquad \rho_{m_T} = -\rho_m$

$E_T = \bar{E}$

$\nabla \times \bar{E} = -\dfrac{\partial \bar{B}}{\partial t} - \bar{J}_m \qquad \bar{J}_{m_T} = \bar{J}_m$

$\bar{J}_m = \rho_m \dfrac{d\bar{r}}{dt}$

$\bar{D} = \bar{\bar{\varepsilon}} \cdot \bar{E} + \bar{\bar{\xi}} \cdot \bar{H} \qquad \bar{\bar{\varepsilon}}_T = \bar{\bar{\varepsilon}} \qquad \bar{\bar{\xi}}_T = -\bar{\bar{\xi}}$

$\bar{B} = \bar{\bar{\zeta}} \cdot \bar{E} + \bar{\bar{\mu}} \cdot \bar{H} \qquad \bar{\bar{\mu}}_T = \bar{\bar{\mu}} \qquad \bar{\bar{\zeta}}_T = -\bar{\bar{\zeta}}$

(T)

INVARIANT

$\bar{E}, \bar{D}, \bar{\bar{\varepsilon}}, \bar{\bar{\mu}}, \rho, \bar{J}_m$

ANTI-INV.

$\bar{H}, \bar{B}, \bar{\bar{\xi}}, \bar{\bar{\zeta}}, \rho_m, \bar{J}$

$$F(\omega) = \int_{-\infty}^{\infty} f(t)\, e^{-j\omega t}\, dt$$

$$T \qquad \int_{-\infty}^{\infty} f(-t)\, e^{-j\omega t}\, dt$$

$$t' = -t$$

$$dt' = -dt$$

$$= -\int_{\infty}^{-\infty} f(t')\, e^{+j\omega t'}\, dt'$$

$$= \int_{-\infty}^{\infty} f(t')\, e^{-j(-\omega)t'}\, dt' \qquad = F(-\omega) = F^{*}(\omega)$$

$$\varepsilon(\omega) = \varepsilon'(\omega) - j\,\varepsilon''(\omega)$$

SPACE INVERSION

$\bar{r} \to -\bar{r}$, $\bar{r}_P = -\bar{r}$

$\rho_P = \rho$ $\quad \bar{J}_P = -\bar{J}$ $\quad \bar{J} = \rho \frac{d\bar{r}}{dt}$

$\nabla \cdot \bar{D} = \rho$ $\quad \bar{D}_P = -\bar{D}$, $\bar{E}_P = -\bar{E}$

$\nabla \times \bar{H} = \bar{J} + \frac{\partial}{\partial t}\bar{D}$ $\quad \bar{H}_P = \bar{H}$, $\bar{B}_P = \bar{B}$

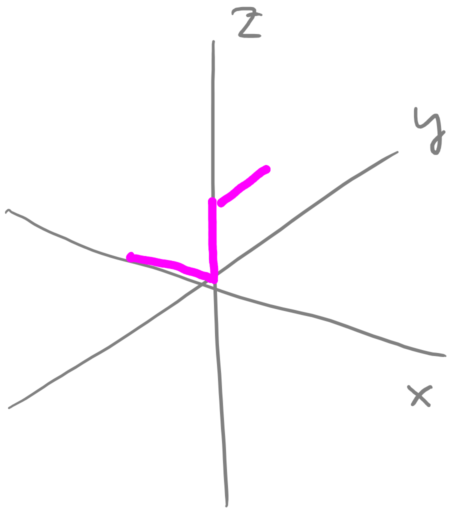
$\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t} - \bar{J}_m$ $\quad \bar{J}_{m_P} = \bar{J}_m$

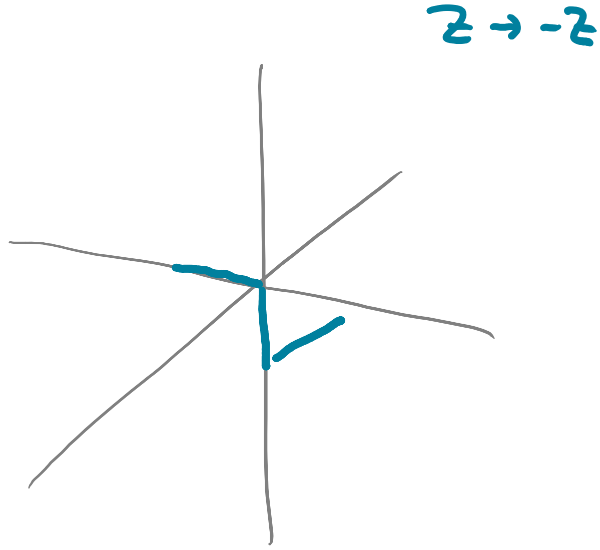
$\nabla \cdot \bar{B} = \rho_m$ $\quad \rho_{m_P} = -\rho_m$ $\quad \bar{J}_m = \rho_m \frac{d\bar{r}}{dt}$

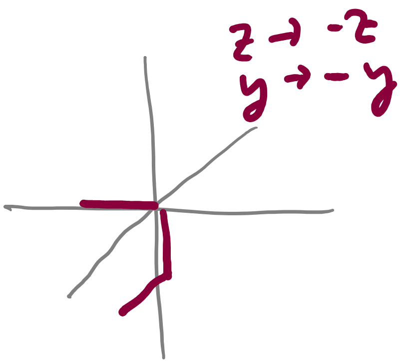
$\bar{D} = \underset{\text{INV}}{\underset{\uparrow}{\bar{\bar{\varepsilon}}}} \cdot \bar{E} + \underset{\text{A.I.}}{\underset{\uparrow}{\bar{\bar{\xi}}}} \cdot \bar{H}$ $\qquad \bar{B} = \underset{\text{A.I.}}{\bar{\bar{\zeta}}} \cdot \bar{E} + \underset{\text{INV}}{\underset{\uparrow}{\bar{\bar{\mu}}}} \cdot \bar{H}$

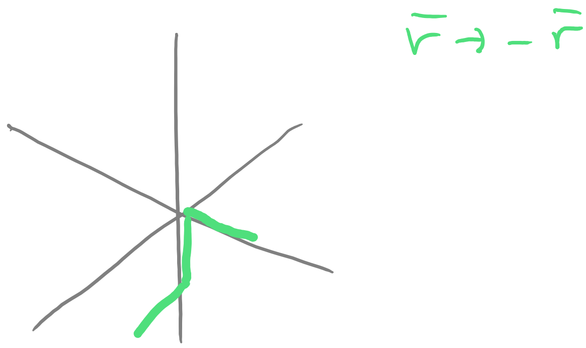
P

INVARIANT	ANTI-INVARIANT
$\bar{H}, \bar{B}, \bar{\bar{\varepsilon}}, \bar{\bar{\mu}}, \rho, \bar{J}_m$	$\bar{E}, \bar{H}, \bar{\bar{\xi}}, \bar{\bar{J}}, \rho_m, \bar{J}$


z
y
x


$z \to -z$


$z \to -z$
$y \to -y$


$\bar{r} \to -\bar{r}$