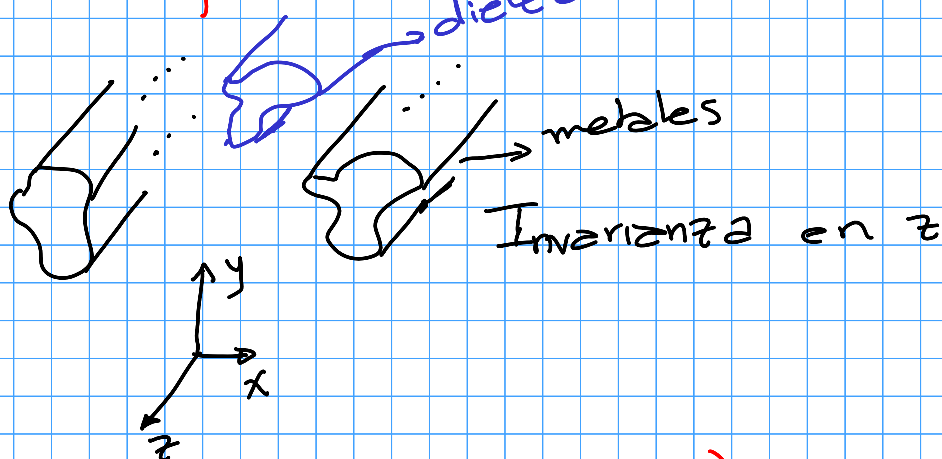
Líneas de Tx físicas.



Modo TEM: $(e_z = h_z = 0)$

(9)

① → $\underbrace{\nabla_t \times \overline{e}_t = 0}_{\rightarrow\ \overline{e}_t \text{ es conservativo}} \Rightarrow \overline{e}_t = -\nabla \underbrace{\Phi}_{\rightarrow \text{ potencial}}$

(6)

$\nabla \cdot (-\nabla \Phi) = 0$

$\nabla^2 \Phi = 0$

② : $\dfrac{\beta}{\omega\mu} \hat{z} \times \overline{e}_t = \overline{h}_t$ (7)

④ : $\hat{z} \times \left(\dfrac{-\beta}{\omega \epsilon} \hat{z} \times \overline{h}_t = \overline{e}_t \right)$

$\overline{a} \times (\overline{b} \times \overline{c}) = \overline{b}(a \cdot c) - \overline{c}(a \cdot b)$

$\hat{z} \times (\hat{z} \times \overline{h}_t)$

$= \hat{z}(\hat{z} \cdot \overline{h}_t) - \overline{h}_t(\hat{z} \cdot \hat{z})$

$= -\overline{h}_t$

$$\frac{\beta}{\omega\epsilon}\,\overline{h}_t = \hat{z}\times\overline{e}_t$$

$$\Rightarrow \frac{\beta}{\omega\mu} = \left(\frac{\beta}{\omega\epsilon}\right)^{-1} \Rightarrow \beta = \pm\omega\sqrt{\mu\epsilon} \quad (8)$$

$$\beta = \pm k$$

$$\beta \propto \omega$$

Modo TEM: no dispersivo

$(8) \rightarrow (7)$

$$\frac{\omega\sqrt{\mu\epsilon}}{\omega\mu}\,\hat{z}\times\overline{e}_t = \overline{h}_t$$

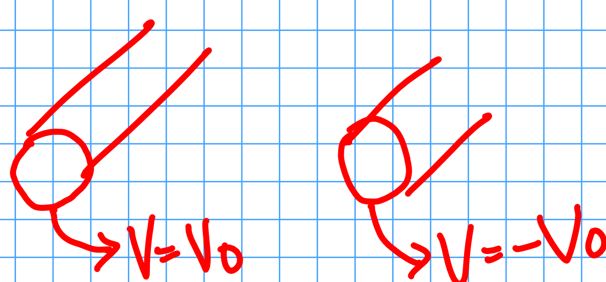
$$\hat{z}\times\overline{e}_t = \underbrace{\sqrt{\frac{\mu}{\epsilon}}}_{Z_{TEM}}\,\overline{h}_t$$

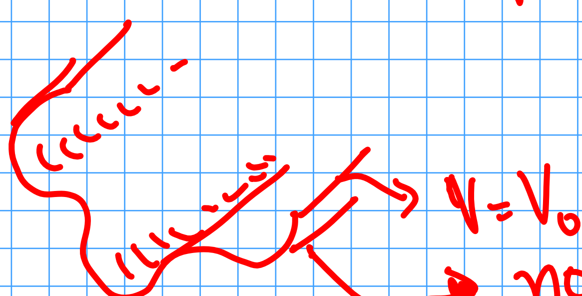
$$\beta > 0, \in \mathbb{R} \quad \forall\, \omega > 0$$

$$\overline{\Phi} \xrightarrow{(9)} \overline{e}_t \xrightarrow{(8)} \overline{h}_t$$

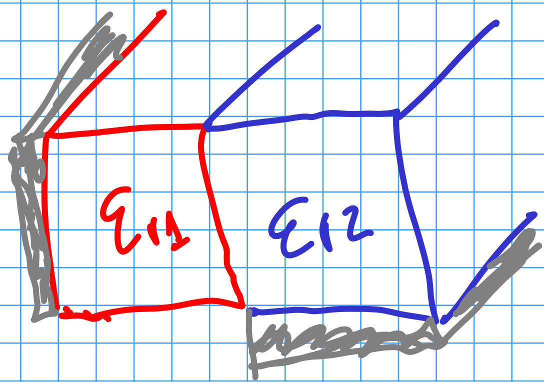
$$\underline{\underline{\beta = k}}$$

ej:





no hay modo TEM para un único conductor cerrado



$(-j)(-j) = (1)(-1) = -1$

Caso TE ($e_z = \emptyset$, $h_z \neq \emptyset$)

Ec. Helmholtz: $\nabla^2 \overline{H} + k^2 \overline{H} = \emptyset$

$(\nabla_t^2 - \beta^2)\overline{H} + k^2 \overline{H} = \emptyset \qquad \nabla_t^2 \overline{H} + k_c^2 \overline{H} = \emptyset$

$k_c \triangleq k^2 - \beta^2$

$\beta = \sqrt{k^2 - k_c^2}$

$\beta \not\propto w \rightarrow$ TE es dispersivo

$k < k_c$? $\quad \beta \in \mathbb{I} \Rightarrow$ Onda evanescente

$(e^{-j\beta z} = e^{-\alpha z})$

Existe una frec. mínima de operación

$2\pi f_c \sqrt{\mu \epsilon} = k_c$

$f_c = \dfrac{k_c}{2\pi \sqrt{\mu \epsilon}}$

$\nabla_t^2 h_z + k_c^2 h_z = \emptyset$ $\rightarrow h_z$, $\rightarrow k_c$

$\rightarrow \overline{h_t} \rightarrow \vec{e_t}$