1. **Equações de Maxwell no domínio do tempo**

$$\oint_c \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\int_s \vec{B}\cdot d\vec{s} \qquad \nabla\times\vec{E} = -\frac{\partial\vec{B}}{\partial t}$$
$$\oint_c \vec{H}\cdot d\vec{l} = \frac{d}{dt}\int_s \vec{D}\cdot d\vec{s} + \int_s \vec{J}\cdot d\vec{s} \qquad \nabla\times\vec{H} = \frac{\partial\vec{D}}{\partial t} + \vec{J}$$
$$\oint_s \vec{D}\cdot d\vec{s} = \int_v \rho_v\, dv \qquad \nabla\cdot\vec{D} = \rho_v$$
$$\oint_s \vec{B}\cdot d\vec{s} = 0 \qquad \nabla\cdot\vec{B} = 0$$

2. **Vetor de Poynting**

$$\oint_S (\vec{E}\times\vec{H})\cdot d\vec{s} = -\int_V \left[\vec{E}\cdot\vec{J}\right] dv - \frac{\partial}{\partial t}\int_V \left[\frac{\mu}{2}|\vec{H}|^2 + \frac{\epsilon}{2}|\vec{E}|^2\right] dv$$
$$P_e = \oint_S (\vec{E}\times\vec{H})\cdot d\vec{s} = \oint_S \vec{P}\cdot d\vec{s} \quad \vec{P} = \vec{E}\times\vec{H}$$
$$P_f = -\int_V \left[\vec{E}\cdot\vec{J}_i\right] dv \qquad P_d = -\int_V \left[\vec{E}\cdot\vec{J}_c\right] dv$$
$$W_e = \int_V \frac{\epsilon}{2}|\vec{E}|^2 dv \qquad W_m = \int_V \frac{\mu}{2}|\vec{H}|^2 dv$$
$$P_f = P_e + P_d + \frac{\partial(W_e + W_m)}{\partial t}$$

3. **Campos Harmônicos**

$$\mathbf{E}(\vec{r},\omega) = \int_{-\infty}^{\infty}\vec{E}(\vec{r},t)\, e^{-j\omega t}dt \quad \mathbf{H}(\vec{r},\omega) = \int_{-\infty}^{\infty}\vec{H}(\vec{r},t)\, e^{-j\omega t}dt$$
$$\vec{E}(\vec{r},t) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\mathbf{E}(\vec{r},\omega)\, e^{j\omega t}d\omega \quad \vec{H}(\vec{r},t) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\mathbf{H}(\vec{r},\omega)\, e^{j\omega t}d\omega$$
$$\vec{E}(\vec{r},t) = \Re e\left\{\mathbf{E}(\vec{r})\, e^{j\omega t}\right\} \quad \vec{H}(\vec{r},t) = \Re e\left\{\mathbf{H}(\vec{r})\, e^{j\omega t}\right\}$$
$$\vec{D}(\vec{r},t) = \Re e\left\{\mathbf{D}(\vec{r})\, e^{j\omega t}\right\} \quad \vec{B}(\vec{r},t) = \Re e\left\{\mathbf{B}(\vec{r})\, e^{j\omega t}\right\}$$
$$\vec{J}(\vec{r},t) = \Re e\left\{\mathbf{J}(\vec{r})\, e^{j\omega t}\right\} \quad \rho(\vec{r},t) = \Re e\left\{q_e(\vec{r})\, e^{j\omega t}\right\}$$

4. **Equações de Maxwell no domínio da frequência**

$$\oint_c \mathbf{E}\cdot d\vec{l} = -j\omega\int_s \mathbf{B}\cdot d\vec{s} \qquad \nabla\times\mathbf{E} = -j\omega\mathbf{B}$$
$$\oint_c \mathbf{H}\cdot d\vec{l} = j\omega\int_s \mathbf{D}\cdot d\vec{s} + \int_s \mathbf{J}\cdot d\vec{s} \qquad \nabla\times\mathbf{H} = j\omega\mathbf{D} + \mathbf{J}$$
$$\oint_s \mathbf{D}\cdot d\vec{s} = \int_v q_e\, dv \qquad \nabla\cdot\mathbf{D} = q_e$$
$$\oint_s \mathbf{B}\cdot d\vec{s} = 0 \qquad \nabla\cdot\mathbf{B} = 0$$

5. **Condições de Fronteira**

$$\vec{n}\times(\vec{E}_2 - \vec{E}_1) = 0 \qquad \vec{n}\times(\mathbf{E}_2 - \mathbf{E}_1) = 0$$
$$\vec{n}\times(\vec{H}_2 - \vec{H}_1) = \vec{J}_s \qquad \vec{n}\times(\mathbf{H}_2 - \mathbf{H}_1) = \mathbf{J}_s$$
$$\vec{n}\cdot(\vec{D}_2 - \vec{D}_1) = \rho_s \qquad \vec{n}\cdot(\mathbf{D}_2 - \mathbf{D}_1) = q_e$$
$$\vec{n}\cdot(\vec{B}_2 - \vec{B}_1) = 0 \qquad \vec{n}\cdot(\mathbf{B}_2 - \mathbf{B}_1) = 0$$

6. **Vetor de Poynting Complexo**

$$\vec{P} = \frac{1}{2}\left[\Re e(\mathbf{E}\times\overline{\mathbf{H}}) + \Re e(\mathbf{E}\times\mathbf{H}\, e^{j\,2\,\omega\,t})\right]$$
$$\vec{P}_m = \frac{1}{2}\Re e(\mathbf{E}\times\overline{\mathbf{H}}) \qquad \vec{P}_{rea} = \frac{1}{2}\left[\Re e(\mathbf{E}\times\mathbf{H}\, e^{j\,2\,\omega\,t})\right]$$

7. **Equação de Onda no domínio do tempo**

$$\nabla^2\vec{E} = \frac{\nabla\rho}{\epsilon} + \mu\frac{\partial\vec{J}_i}{\partial t} + \mu\sigma\frac{\partial\vec{E}}{\partial t} + \mu\epsilon\frac{\partial^2\vec{E}}{\partial t^2}$$
$$\nabla^2\vec{H} = -\nabla\times\vec{J}_i + \mu\sigma\frac{\partial\vec{H}}{\partial t} + \mu\epsilon\frac{\partial^2\vec{H}}{\partial t^2}$$
$$\nabla^2\vec{E} = \mu\sigma\frac{\partial\vec{E}}{\partial t} + \mu\epsilon\frac{\partial^2\vec{E}}{\partial t^2}$$
$$\nabla^2\vec{H} = \mu\sigma\frac{\partial\vec{H}}{\partial t} + \mu\epsilon\frac{\partial^2\vec{H}}{\partial t^2}$$

8. **Equação de Onda no domínio da frequência**

$$\nabla^2\mathbf{E} = \frac{\nabla q_e}{\epsilon} + j\,\omega\mu\,\mathbf{J}_i + j\,\omega\,\mu\,\sigma\,\mathbf{E} - \omega^2\,\mu\,\epsilon\,\mathbf{E}$$
$$\nabla^2\mathbf{H} = -\nabla\times\mathbf{J}_i + j\,\omega\,\mu\,\sigma\,\mathbf{H} - \omega^2\,\mu\,\epsilon\,\mathbf{H}$$
$$\nabla^2\mathbf{E} = \gamma^2\,\mathbf{E} \quad \nabla^2\mathbf{H} = \gamma^2\,\mathbf{H}$$
$$\nabla^2\mathbf{E} = -k^2\,\mathbf{E} \quad \nabla^2\mathbf{H} = -k^2\,\mathbf{H}$$
$$\gamma^2 = j\,\omega\,\mu\,\sigma - \omega^2\,\mu\,\epsilon \quad k^2 = \omega^2\,\mu\,\epsilon$$

9. **Equações de Maxwell para Ondas Planas**

$$\mathbf{E}(\vec{r}) = \mathbf{E}\; e^{\pm j\,\vec{k}\cdot\vec{r}} \quad \mathbf{H}(\vec{r}) = \mathbf{H}\; e^{\pm j\,\vec{k}\cdot\vec{r}}$$
$$\vec{k}\times\mathbf{E} = \omega\,\mu\,\mathbf{H} \quad \vec{k}\times\mathbf{H} = -\omega\,\varepsilon\,\mathbf{E}$$
$$\vec{k}\cdot\mathbf{D} = 0 \quad \vec{k}\cdot\mathbf{B} = 0$$

10. **Parâmetros de Ondas Eletromagnéticas**

$$Z = \frac{E}{H} \quad v_f = \frac{\omega}{k} \quad v_g = v_f + k\,\frac{dv_f}{dk} \quad v_g = v_f - \lambda\,\frac{dv_f}{d\lambda}$$
$$\mathbf{E} = \left(\vec{a}_x + \vec{a}_y\,A\,e^{j\phi}\right)\,e^{-jk_z z} \quad A = \frac{E_{y0}}{E_{x0}} \quad \phi = \phi_y - \phi_x$$

polarização linear - $A = 0$ ou $A = \infty$; $\phi = n\,\pi$

polarização circular - $A = 1$ e $\phi = \pm(2n+1)\,\pi/2$

polarização elíptica - $\begin{cases} A \neq \ \text{ e } \phi = \pm(2n+1)\,\pi/2 \\ \phi \neq \pm\dfrac{n}{2}\pi \end{cases}$

11. **Ondas Estacionárias**

$$\mathbf{E} = \left[E_0^+\,e^{-jkz} + E_0^-\,e^{+jkz}\right]\,\vec{a}_x$$
$$E_x(z,t) = \sqrt{(E_0^+)^2 + (E_0^-)^2 + 2\,E_0^+\,E_0^-\,cos2kz}$$
$$\times\ cos\left[\omega t - tan^{-1}\left\{\frac{E_0^+ - E_0^-}{E_0^+ + E_0^-}\ tankz\right\}\right]$$
$$TOE = \frac{|E|_{max}}{|E|_{min}} = \frac{|E_0^+| + |E_0^-|}{|E_0^+| - |E_0^-|} \quad \Gamma = \frac{E_0^-}{E_0^+}$$
$$TOE = \frac{1+|\Gamma|}{1-|\Gamma|}$$

12. **Meio com perdas**

$$\nabla^2\mathbf{E} - \gamma^2\,\mathbf{E} = 0 \quad \mathbf{E} = \mathbf{E}_0\,e^{\pm\vec{\gamma}\cdot\vec{r}} \quad \gamma = \alpha + j\beta$$
$$\alpha = \omega\sqrt{\frac{\mu\,\varepsilon}{2}\left(\sqrt{1 + \left(\frac{\sigma}{\omega\,\varepsilon}\right)^2} - 1\right)},\ (Np/m)$$
$$\beta = \omega\sqrt{\frac{\mu\,\varepsilon}{2}\left(\sqrt{1 + \left(\frac{\sigma}{\omega\,\varepsilon}\right)^2} + 1\right)},\ (rad/m)$$
$$\mathbf{E} = \mathbf{E}_0\,e^{\pm\,\alpha\,\vec{a}_\gamma\cdot\vec{r}}\,e^{\pm j\,\beta\,\vec{a}_\gamma\cdot\vec{r}}$$

13. **Classificação dos Meios**

1. Dielétricos: $\frac{\sigma}{\omega\,\varepsilon} < \frac{1}{100}$
2. Quase condutores: $\frac{1}{100} < \frac{\sigma}{\omega\,\varepsilon} < 100$
3. Condutores: $\frac{\sigma}{\omega\,\varepsilon} > 100$

tangente de perdas - $tan\theta = \dfrac{\sigma}{\omega\varepsilon}$

profundidade de penetração - $\delta = \frac{1}{\alpha}$

impedância dos meios condutores - $Z_c = \dfrac{E}{H} = \dfrac{j\,\omega\,\mu}{\gamma}\ \Omega.$

$$Z_c = \sqrt{\frac{j\,\omega\mu}{\sigma + j\,\omega\,\varepsilon}} \quad Z_c = \frac{\sqrt{\dfrac{\mu}{\varepsilon}}}{\left[1 + \left(\dfrac{\sigma}{\omega\varepsilon}\right)^2\right]^{1/4}}\, e^{j\,(1/2)\,tan^{-1}(\sigma/\omega\varepsilon)}$$

14. **Onda Plana - Incidência normal**

coeficiente de transmissão - $T = \dfrac{\mathbf{E}_t}{\mathbf{E}_i} = \dfrac{2\,Z_2}{Z_2 + Z_1}$

coeficiente de reflexão - $\Gamma = \dfrac{\mathbf{E}_r}{\mathbf{E}_i} = \dfrac{Z_2 - Z_1}{Z_2 + Z_1}$

$$\vec{P}^i_m = \Re e\left[\frac{1}{Z_1}\right]\frac{|\mathbf{E}_0|^2}{2}\,\vec{a}_z\,e^{-2\,\alpha_1\,z}$$

$$\begin{aligned}\vec{P}^r_m &= \Re e\left[\frac{1}{Z_1}\right]\frac{-|\Gamma|^2\,|\mathbf{E}_0|^2}{2}\,\vec{a}_z\,e^{+2\,\alpha_1\,z}\\ &= -|\Gamma|^2\,P^i_m\,\vec{a}_z\,e^{+2\,\alpha_1\,z}\end{aligned}$$

$$\begin{aligned}\vec{P}^t_m &= \Re e\left[\frac{1}{Z_2}\right]\frac{|T|^2\,|\mathbf{E}_0|^2}{2}\,\vec{a}_z\,e^{-2\,\alpha_2\,z}\\ &= \frac{\Re e\left[\frac{1}{Z_2}\right]}{\Re e\left[\frac{1}{Z_1}\right]}|T|^2\,P^i_m\,\vec{a}_z\,e^{-2\,\alpha_2\,z}\end{aligned}$$

15. **Onda Plana - Incidência Oblíqua**

$$\mathbf{E} = \mathbf{E}_\perp + \mathbf{E}_{||} \quad \mathbf{H} = \mathbf{H}_\perp + \mathbf{H}_{||}$$

lei de Snell da reflexão - $\theta_i = \theta_r$

lei de Snell da refração - $\dfrac{sen\theta_i}{sen\theta_t} = \dfrac{\gamma_2}{\gamma_1}$

lei de Snell da refração - $\dfrac{sen\theta_i}{sen\theta_t} = \dfrac{k_2}{k_1} = \sqrt{\dfrac{\mu_2\,\varepsilon_2}{\mu_1\,\varepsilon_1}}$

$$\begin{aligned}\Gamma_\perp &= \frac{\mathbf{E}^r_\perp}{\mathbf{E}^i_\perp} = \frac{Z_2\,cos\theta_i - Z_1\,cos\theta_t}{Z_2\,cos\theta_i + Z_1\,cos\theta_t}\\ T_\perp &= \frac{\mathbf{E}^t_\perp}{\mathbf{E}^i_\perp} = \frac{2\,Z_2\,cos\theta_i}{Z_2\,cos\theta_i + Z_1\,cos\theta_t}\end{aligned}$$

$$\begin{aligned}\Gamma_\perp &= \frac{\sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_i - \sqrt{\frac{\mu_1}{\varepsilon_1}}\,cos\theta_t}{\sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_i + \sqrt{\frac{\mu_1}{\varepsilon_1}}\,cos\theta_t}\\ T_\perp &= \frac{2\sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_i}{\sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_i + \sqrt{\frac{\mu_1}{\varepsilon_1}}\,cos\theta_t}\end{aligned}$$

$$\begin{aligned}\Gamma_\perp &= \frac{cos\theta_i - \sqrt{\frac{\varepsilon_2}{\varepsilon_1}}\sqrt{1-\left(\frac{\varepsilon_1}{\varepsilon_2}\right)sen^2\theta_i}}{cos\theta_i + \sqrt{\frac{\varepsilon_2}{\varepsilon_1}}\sqrt{1-\left(\frac{\varepsilon_1}{\varepsilon_2}\right)sen^2\theta_i}}\\ T_\perp &= \frac{2\,cos\theta_i}{cos\theta_i + \sqrt{\frac{\varepsilon_2}{\varepsilon_1}}\sqrt{1-\left(\frac{\varepsilon_1}{\varepsilon_2}\right)sen^2\theta_i}}\end{aligned}$$

$$\begin{aligned}\Gamma_{||} &= \frac{\mathbf{E}^r_{||}}{\mathbf{E}^i_{||}} = \frac{-Z_1\,cos\theta_i + Z_2\,cos\theta_t}{Z_1\,cos\theta_i + Z_2\,cos\theta_t}\\ T_{||} &= \frac{\mathbf{E}^t_{||}}{\mathbf{E}^i_{||}} = \frac{2\,Z_2\,cos\theta_i}{Z_1\,cos\theta_i + Z_2\,cos\theta_t}\end{aligned}$$

$$\begin{aligned}\Gamma_{||} &= \frac{-\sqrt{\frac{\mu_1}{\varepsilon_1}}\,cos\theta_i + \sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_t}{\sqrt{\frac{\mu_1}{\varepsilon_1}}\,cos\theta_i + \sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_t}\\ T_{||} &= \frac{2\sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_i}{\sqrt{\frac{\mu_1}{\varepsilon_1}}\,cos\theta_i + \sqrt{\frac{\mu_2}{\varepsilon_2}}\,cos\theta_t}\end{aligned}$$

$$\begin{aligned}\Gamma_{||} &= \frac{-cos\theta_i + \sqrt{\frac{\varepsilon_1}{\varepsilon_2}}\sqrt{1-\left(\frac{\varepsilon_1}{\varepsilon_2}\right)sen^2\theta_i}}{cos\theta_i + \sqrt{\frac{\varepsilon_1}{\varepsilon_2}}\sqrt{1-\left(\frac{\varepsilon_1}{\varepsilon_2}\right)sen^2\theta_i}}\\ T_{||} &= \frac{2\sqrt{\frac{\varepsilon_1}{\varepsilon_2}}\,cos\theta_i}{cos\theta_i + \sqrt{\frac{\varepsilon_1}{\varepsilon_2}}\sqrt{1-\left(\frac{\varepsilon_1}{\varepsilon_2}\right)sen^2\theta_i}}\end{aligned}$$

ângulo de Brewster - $\theta_\beta = \tan^{-1}\left(\sqrt{\dfrac{\varepsilon_2}{\varepsilon_1}}\right)$

reflexão total - $\theta_c = \mathrm{sen}^{-1}\left(\sqrt{\dfrac{\varepsilon_2}{\varepsilon_1}}\right)$