Coulomb's Law: $\mathbf{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\mathbf{r}|^2}\hat{\mathbf{r}}$
Electric Field: $\mathbf{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{|\mathbf{r}|^2}\hat{\mathbf{r}}$
Gauss's Law: $\oint \mathbf{E}\cdot d\mathbf{A} = \frac{Q_{\text{enc}}}{\epsilon_0}$
Electric Potential: $V = -\int \mathbf{E}\cdot d\mathbf{l}$
E and V: $\mathbf{E} = -\nabla V$
Laplace's Equation: $\nabla^2 V = 0$
Poisson's Equation: $\nabla^2 V = -\frac{\rho_v}{\epsilon}$
Work Done: $W = -Q\int_a^b \mathbf{E}\cdot d\mathbf{l}$
V and W: $V_{ba} = \frac{W_{ba}}{Q}$
Electric Displacement: $\mathbf{D} = \epsilon\mathbf{E}$
Current Density: $\mathbf{J} = \sigma\mathbf{E}$
Continuity Eq: $\nabla\cdot\mathbf{J} = -\partial_t\rho_v$

Current: $I = \frac{dQ}{dt}$
Total Current: $I = \iint_S \mathbf{J}\cdot d\mathbf{A}$
Ohm's Law: $V = IR$
Capacitance: $C = \frac{Q}{V} = \iint_S \frac{1}{\int_L \frac{dL_\parallel}{\epsilon dS_\perp}}$
Parallel Plate Capacitor: $C = \frac{\epsilon A}{d}$
Current in Capacitor: $I = C\frac{dV}{dt}$
Capacitor Energy: $U = \frac{1}{2}CV^2$
Capacitor Electric Field: $E = \frac{V}{d}$
Work: $W = QV = \frac{CV^2}{2} = \frac{QV}{2} = \frac{Q^2}{2C}$
Work Density: $W_E = \frac{P_v V}{2} = \frac{D^2}{2\epsilon}$
Biot-Savart Law: $\mathbf{B} = \frac{\mu_0}{4\pi}\int\frac{I d\mathbf{l}\times\hat{\mathbf{r}}}{|\mathbf{r}|^2}$

Ampere's Law: $\oint \mathbf{H}\cdot d\mathbf{l} = I_{\text{enc}}$
Magnetic Flux Density: $\mathbf{B} = \mu\mathbf{H}$
Magnetic Flux: $\mathbf{\Phi_B} = \iint_S \mathbf{B}\cdot d\mathbf{S}$
Faraday's Law: $\mathcal{E} = -N\partial_t\Phi_B$
Lorentz force: $\mathbf{F} = q(\mathbf{E}+\mathbf{v}\times\mathbf{B})$
Wave Equation: $\nabla^2\mathbf{E} - \mu\epsilon\partial_t^2\mathbf{E} = 0$
Wave Speed: $v = \frac{1}{\sqrt{\mu\epsilon}}$
Normal Reflection: $\Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1}$
Transmission Coeff: $T = 1 + \Gamma$
Impedance: $Z = \sqrt{\frac{\mu}{\epsilon}}$
Snell's Law: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$
Poynting Vector: $\mathbf{S} = \mathbf{E}\times\mathbf{H}$

Displacement Current Density: $\mathbf{J}_d = \partial_t\mathbf{D}$
Time-Harmonic Wave: $\mathbf{E}(z,t) = \text{Re}\{\mathbf{E_0}e^{j(\omega t - \beta z)}\}$
Exponentials Form: $\mathbf{E}(z) = E_0^+ e^{-jkz} + E_0^- e^{jkz}$
For H: $\mathbf{H}(z) = \frac{k}{\omega\mu}E^+(z)$
Wavenumber: $k = \omega\sqrt{\mu\epsilon} = \frac{\omega}{v}$
Intrinsic Impedance: $\eta = \frac{|E|}{|H|} = \sqrt{\frac{\mu}{\epsilon}}$

Time Derivative–Complex Domain: $\partial_t \equiv j\omega$
Wave Equation: $\nabla^2\mathbf{E} = \boldsymbol{\nabla}(\frac{\rho_V}{\epsilon}) + \partial_t\mu(\mathbf{J}_s + \sigma\mathbf{E} + \partial_t\epsilon\mathbf{E})$
Linear Polarization: $E(z,t) = E_y e^{-\alpha t}\cos(\omega t + \beta z + \phi)$
Elliptical Polarization: $E(z,t) = \hat{\mathbf{x}}E_1\cos(\omega t - \beta z) + \hat{\mathbf{y}}E_2\cos(\omega t - \beta z + \phi)$
Wave Power: $P = \oint_A \mathbf{S}\cdot d\mathbf{A} = -\partial_t\int_V \frac{\mu H^2}{2} + \frac{\epsilon E^2}{2}dV - \int_V \mathbf{E}\cdot\mathbf{J}dV$

MEs Differential Form: $\nabla\cdot\mathbf{D} = \rho_v$, $\nabla\cdot\mathbf{B} = 0$, $\nabla\times\mathbf{E} = -\partial_t\mathbf{B}$, $\nabla\times\mathbf{H} = \mathbf{J} + \partial_t\mathbf{D}$
MEs Integral Form: $\oiint_S \mathbf{D}\cdot d\mathbf{S} = Q_{enc}$, $\oiint_S \mathbf{B}\cdot d\mathbf{S} = 0$, $\oint_C \mathbf{E}\cdot d\mathbf{l} = -\partial_t\iint_S \mathbf{B}\cdot d\mathbf{S}$, $\oint_C \mathbf{H}\cdot d\mathbf{l} = \iint_S \mathbf{J}\cdot d\mathbf{S} + \partial_t\iint_S \mathbf{D}\cdot d\mathbf{S}$
General Interface Conditions: $E_{1t} = E_{2t}, D_{1n} - D_{2n} = \rho_s; H_{1t} - H_{2t} = J_s^*, B_{1n} = B_{2n}$
* Dielectric–Dielectric $\implies \rho_s = J_s = 0$. Dielectric–Conductor $\implies E_t = B_n = 0, D_{1n} = \rho_s, H_{1t} = J_s^*$.

$\int\frac{1}{(a^2\pm x^2)^{3/2}}dx = \frac{x}{a^2\sqrt{a^2\pm x^2}}$, $\int\frac{xdx}{(a^2+x^2)^{3/2}} = \frac{-1}{\sqrt{a^2+x^2}}$, $\int\frac{1}{x^2+a^2} = \frac{1}{a}\tan^{-1}\left(\frac{x}{a}\right)$, $\int\frac{x^2dx}{(a^2+x^2)^{3/2}} = \frac{-x}{\sqrt{a^2+x^2}} + \ln(x+\sqrt{a^2+x^2})$

Cylindrical Coordinates:

$\nabla f = \partial_r f\hat{\mathbf{r}} + \frac{1}{r}\partial_\theta f\hat{\boldsymbol{\theta}} + \partial_z f\hat{\mathbf{k}}$

$\nabla\cdot\mathbf{F} = \frac{1}{r}\partial_r(rF_r) + \frac{1}{r}\partial_\theta F_\theta + \partial_z F_z$

$\nabla\times\mathbf{F} = \frac{1}{r}\begin{vmatrix}\hat{\mathbf{r}} & r\hat{\boldsymbol{\theta}} & \hat{\mathbf{z}}\\ \partial_r & \partial_\theta & \partial_z\\ F_r & rF_\theta & F_z\end{vmatrix}$

$\nabla^2 f = \frac{1}{r}\partial_r(r\partial_r f) + \frac{1}{r^2}\partial_\theta^2 f + \partial_z^2 f$

$dV = rdrd\phi dz$

$d\mathbf{l} = dr\hat{\mathbf{r}} + rd\phi\hat{\boldsymbol{\phi}} + dz\hat{\mathbf{z}}$

$d\mathbf{S}_r = rd\phi dz\hat{\mathbf{r}}$, $d\mathbf{S}_\phi = drdz\hat{\boldsymbol{\phi}}$

$d\mathbf{S}_z = rd\phi dr\hat{\mathbf{z}}$

Spherical Coordinates:

$\nabla f = \partial_r f\hat{\mathbf{r}} + \frac{1}{r}\partial_\theta f\hat{\boldsymbol{\theta}} + \frac{1}{r\sin\theta}\partial_\phi f\hat{\boldsymbol{\phi}}$

$\nabla\cdot\mathbf{F} = \frac{1}{r^2}\partial_r(r^2F_r) + \frac{1}{r\sin\theta}\partial_\theta(\sin\theta F_\theta) + \frac{1}{r\sin\theta}\partial_\phi F_\phi$

$\nabla\times\mathbf{F} = \frac{1}{r^2\sin\theta}\begin{vmatrix}\hat{\mathbf{r}} & r\hat{\boldsymbol{\theta}} & r\sin\theta\hat{\boldsymbol{\phi}}\\ \partial_r & \partial_\theta & \partial_\phi\\ F_r & rF_\theta & r\sin\theta F_\phi\end{vmatrix}$

$\nabla^2 f = \frac{1}{r^2}\partial_r(r^2\partial_r f) + \frac{1}{r^2\sin\theta}\partial_\theta(\sin\theta\partial_\theta f) + \frac{1}{r^2\sin^2\theta}\partial_\phi^2 f$

$dV = r^2\sin\theta d\theta d\phi dz$

$d\mathbf{l} = dr\hat{\mathbf{r}} + rd\theta\hat{\boldsymbol{\theta}} + r\sin\theta d\phi\hat{\boldsymbol{\phi}}$

$d\mathbf{S}_r = r^2\sin\theta d\phi d\theta\hat{\mathbf{r}}$, $d\mathbf{S}_\phi = rd\theta dr\hat{\boldsymbol{\phi}}$

$d\mathbf{S}_\theta = r\sin\theta d\phi dr\hat{\boldsymbol{\theta}}$

Vector Theorems:

$\iiint_V(\nabla\cdot\mathbf{F})\,dV = \oiint_S \mathbf{F}\cdot\hat{\mathbf{n}}\,dA$

$\iint_S(\nabla\times\mathbf{F})\cdot\hat{\mathbf{n}}\,dA = \oint_C \mathbf{F}\cdot d\mathbf{r}$

$\oint_C Pdx + Qdy = \iint_S \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y}dxdy$

Vector Identities:

$\nabla\cdot(\nabla\times\mathbf{F}) = 0$, $\nabla\times(\nabla f) = 0$

$\nabla\cdot(\nabla f) = \nabla^2 f$

$\nabla\times(\nabla\times\mathbf{F}) = \nabla(\nabla\cdot\mathbf{F}) - \nabla^2\mathbf{F}$

$\nabla(UQ) = U(\nabla Q) + Q(\nabla U)$

$\nabla\cdot(\mathbf{A}\times\mathbf{B}) = -\mathbf{A}\cdot(\nabla\times\mathbf{B}) + (\nabla\times\mathbf{A})\cdot\mathbf{B}$

$\nabla\times(U\mathbf{A}) = U(\nabla\times\mathbf{A}) + (\nabla U)\times\mathbf{A}$

$\frac{\partial^2 A}{\partial z^2} = \frac{1}{v^2}\frac{\partial^2 A}{\partial t^2}$

$\boxed{\text{Chapter 12} \quad \text{Waves}}$

$\nabla^2 A - \mu\varepsilon\frac{\partial^2 A}{\partial t^2} = -\mu J$
$\nabla^2 H - \mu\varepsilon\frac{\partial^2 H}{\partial t^2} = -\nabla\times J$
$\nabla^2 V - \mu\varepsilon\frac{\partial^2 V}{\partial t^2} = \frac{-\rho_v}{\varepsilon}$

time-harmonic
$\mu\varepsilon(j\omega)^2\vec{A} = -\omega^2\mu\varepsilon A$

$\nabla^2\vec{E} = \vec{\nabla}(\rho_v/\varepsilon) + j\omega\mu\vec{J}_s + j\omega\mu(\sigma\vec{E} + j\omega\varepsilon\vec{E}) \rightarrow \sigma$ = conductivity, 0 if lossless & source free
↳ if source free : $\nabla^2\vec{E} = j\omega\mu(\sigma\vec{E} + j\omega\varepsilon\vec{E})$ ↳ $\nabla^2\vec{E} = \omega^2\mu\varepsilon\vec{E} = 0$

GREEK LETTERS

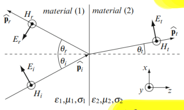
wave eq sol. 1D : $E_x(z) = E_0^+ e^{-jkz} + E_0^- e^{jkz} \rightarrow$ E_0 from boundry. z = prop. direction, $k = \omega\sqrt{\mu\varepsilon} \Rightarrow E_x^+(z,t) = E_0^+\cos(\omega t - kz + \phi)$
↳ for H : $H_y^+(z) = \frac{j}{\omega\mu}\frac{\partial E_x}{\partial z} = \frac{k}{\omega\mu}E_x^+(z)$; $\eta = \frac{E_x(z)}{H_x(y)} = \sqrt{\frac{\mu}{\varepsilon}}$ = wave/intrinsic impedance
Poynting vector EM Pwr : $\oint_s(\vec{E}\times\vec{H})\cdot d\vec{s} = \frac{-\partial}{\partial t}\int_v\left(\frac{\mu H^2}{2} + \frac{\varepsilon E^2}{2}\right)dv - \int_v E\cdot J\,dv$ — $\vec{P}(t) = (\vec{E}\times\vec{H})$ → power density {instantanous} — $P_{av} = \frac{1}{T}\int_0^T P(t)\,dt$
↳ $\frac{E_0^2}{\eta} = \eta H_0^2$ in free space tot = ∞ ← $P_{tot.inst}(t) = \oint_s\vec{P}(t)\cdot d\vec{s}$ $P_{av.surface} = \oint_s\vec{P}_{av}\cdot d\vec{s}$
↳ in complex domain → $P_{av} = \frac{1}{2}Re\{E\times H^*\}$
Lossy materials : $\nabla^2\vec{E} = j\omega\mu(\sigma + j\omega\varepsilon)\vec{E}$ ~ $\nabla^2\vec{E} = \gamma^2\vec{E} \Rightarrow$ sol = $E_x(z) = E_0^+ e^{-az}e^{-jBz} + E_0^- e^{az}e^{jBz}$
↳ time domain & +z = $E_x(z,t) = E_0^+ e^{-az}\cos(\omega t - Bz)$ ~ $H = \frac{1}{\eta}E_0^+ e^{-az}\cos(\omega t - Bz)$ → prop in +ve z.
low loss approx: $\alpha \approx \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}} = \frac{\sigma}{2}\eta$; $B \approx \omega\sqrt{\mu\varepsilon}\left(1 + \frac{1}{8}\left(\frac{\sigma}{\omega\varepsilon}\right)^2\right) \Rightarrow$ if very-low loss → $B \simeq \omega\sqrt{\mu\varepsilon}$
$\eta = \sqrt{\frac{\mu}{\varepsilon}}\left(1 + \frac{j\sigma}{2\omega\varepsilon}\right) = \sqrt{\frac{\mu}{\varepsilon}}\left(\left(1 - \frac{j\sigma}{\omega\varepsilon}\right)^{-1/2}\right)$
high-loss approx: → conductor
$\gamma = j\omega\sqrt{\mu\varepsilon}\sqrt{-\frac{j\sigma}{\omega\varepsilon}} = (1+j)\sqrt{\frac{\omega\mu\sigma}{2}} \rightarrow \alpha = B = \sqrt{\frac{\omega\mu\sigma}{2}} = \sqrt{\pi f\mu\sigma}$
$E_x(z) = E_0^+ e^{-z/\delta}e^{-jz/\delta}$ ↳ $V = \omega/B = \omega\delta = \sqrt{\frac{2\omega}{\mu\sigma}}$; $\lambda = 2\pi/B = 2\pi\delta$
$\eta = \frac{j\omega\mu}{\gamma} = (1+j)\sqrt{\frac{\omega\mu}{2\sigma}} = (1+j)\left(\frac{1}{\sigma\delta}\right) = (1+j)\left(\frac{\omega\mu\delta}{2}\right)$
skin-depth / penetration depth ~ distance till ⇒ Wave Amp = $\left(\frac{1}{e}\right)$(wave amp)

Lossless: $V_p = \frac{1}{\sqrt{\mu\varepsilon}}$; $k = \omega\sqrt{\varepsilon\mu}$ ← wave num.
↳ $\lambda = V_p/f = \frac{2\pi}{k} = \frac{2\pi V_p}{\omega} = \frac{2\pi}{\omega\sqrt{\mu\varepsilon}}$
$\eta = \frac{\omega\mu}{k} = \sqrt{\mu/\varepsilon} = \frac{k}{\omega\varepsilon}$ ↦ for pwr... if S.F. vol ⇒ $J = \sigma E$

Lossy: $\varepsilon_c = \frac{\sigma + j\omega\varepsilon}{j\omega}$; $\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$
↳ $\gamma = jk_c$, $k_c = \omega\sqrt{\mu\varepsilon}\sqrt{\left(1 - j\frac{\sigma}{\omega\varepsilon}\right)} = \alpha + jB$
$\overset{-}{\alpha}, \overset{+}{B} = \omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1 + \left(\frac{\sigma}{\omega\mu}\right)^2} \mp 1\right]}$
$\eta = \frac{j\omega\mu}{\gamma} = \frac{j\omega\mu}{\sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}} = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$
$V_p = \frac{\omega}{B}$; $\lambda = \frac{2\pi}{B}$
high loss → $\delta = 1/\alpha$
$P = E\times H$ $\vec{P}$ $\vec{H}$ $\vec{E}$

Chapter 13 (ref)

normal incidence $\rightarrow \theta_i = \theta_r = \theta_t = 0 \Rightarrow E_i = \hat{x} E_{i1} e^{-\gamma_1 z}$ (+z propagation), $E_r = \hat{x} E_{r1} e^{+\gamma_1 z}$ (reflected), $\gamma_i = \alpha_i + j\beta_1$ (transmitted) $\rightarrow H_1 = \hat{y}\left(E_{i1} e^{-\gamma_1 z} - E_{r1} e^{+\gamma_1 z}\right)\frac{1}{\eta_1}$



reflection coeff $\rightarrow \Gamma = \frac{E_{r1}}{E_{i1}}$; $E_r = \hat{x}\Gamma E_{i1} e^{+\gamma_1 z}$

transmission coeff $\rightarrow T = \frac{E_t}{E_{i1}}$; $E_t = \hat{x} T E_{i1} e^{-\gamma_2 z}$

$\rightarrow E_i + E_r = E_2 \equiv E_{i1} + \Gamma E_{i1} = T E_{i1}$

$H_i + H_r = H_2 \equiv (E_{i1} - \Gamma E_{i1})\frac{1}{\eta_1} = (T E_{i1})\frac{1}{\eta_2}$

$\rightarrow 1 + \Gamma = T$; $\frac{1}{\eta_1} - \frac{\Gamma}{\eta_1} = \frac{T}{\eta_2}$ $\rightarrow \Gamma = \frac{\eta_2 - \eta_1}{\eta_1 + \eta_2}$; $T = \frac{2\eta_2}{\eta_1 + \eta_2}$

gen. case $\rightarrow E_{1z} = \hat{x} E_{i1}\left(Te^{-\gamma_1 z} - \Gamma j 2\sin(j\gamma_1 z)\right)$; $E_{2z} = \hat{x} T E_{i1} e^{-\gamma_2 z}$ & $H_1(z) = \hat{y}\frac{E_{i1}}{\eta_1}\left(Te^{-\gamma_1 z} - \Gamma 2\cos(j\gamma_1 z)\right)$; $H_2(z) = \hat{y} T \frac{E_{i1}}{\eta_2} e^{-\gamma_2 z}$

normal incidence w/ conductor $\Rightarrow T = 0$ & $\Gamma = -1 \rightarrow E_1(z) = \hat{x} j 2E_{i1}\sin(\beta_1 z)$, $H_1(z) = \hat{y} 2\frac{E_{i1}}{\eta_1}\cos(\beta_1 z)$ — $P_{av1} = \frac{1}{2}\mathrm{Re}\{\vec{E}_1(z) \times \vec{H}_1(z)^*\}$

$E_1(z,t) = -\hat{x} 2E_{i1}\sin(\beta_1 z)\sin(\omega t)$ /// $E_2(z) = \hat{x} T E_{i1} e^{-\gamma_2 z}$ $H_2(z) = \hat{y} T\left(\frac{1}{\eta_0}\right) E_{i1} e^{-\gamma_2 z}$

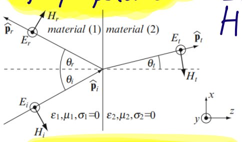
$\Gamma = \frac{1 + j - \sigma_2\delta_2\eta_2}{1 + j + \sigma_2\delta_2\eta_2}$; $T = \frac{2(1+j)}{\sigma_2\delta_2\eta_2 + (1+j)}$; $\alpha = \beta = \sqrt{\pi f \mu \sigma}$ $\delta = \frac{1}{\alpha} = \frac{1}{\sqrt{\pi f \mu \sigma}}$

oblique Incidence perp. polariz. $\rightarrow E_i(x,z) = \hat{y} E_{i1} e^{-j\beta_1(x\sin(\theta_i) \pm z\cos(\theta_i))}$ (make -ve for H_r & E_r)

$H_i(x,z) = \frac{E_{i1}}{\eta_1}\left(-\hat{x}\cos\theta_i + \hat{z}\sin\theta_i\right) e^{-j\beta_1(x\sin(\theta_i) \pm z\cos(\theta_i))}$

$\rightarrow \omega\sqrt{\varepsilon_1\mu_1}\sin\theta_i = \omega\sqrt{\varepsilon_2\mu_2}\sin\theta_t$

$(\sin\theta_t / \sin\theta_i) = n_1/n_2 = v_{p2}/v_{p1}$



$\Gamma_\perp = \frac{E_{r1}}{E_{i1}} = \frac{\eta_2\cos\theta_i - \eta_1\cos\theta_t}{\eta_2\cos\theta_i + \eta_1\cos\theta_t}$ $T_\perp = \frac{E_{t2}}{E_{i1}} = \frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_i + \eta_1\cos\theta_t}$ $\rightarrow$ **Perpendicular polarization**

Parallel polarization $\rightarrow E_i(x,z) = E_{i1}(\hat{x}\cos\theta_i - \hat{z}\sin\theta_i) e^{-j\beta_1(x\sin\theta_i + z\cos\theta_i)}$ & $H_i(x,z) = \hat{y}\frac{E_{i1}}{\eta_1} e^{-j\beta(x\sin\theta_i + z\cos\theta_i)}$

$\rightarrow E_r(x,z) = E_{i1}(-\hat{x}\cos\theta_i - z\sin\theta_i) e^{-j\beta(x\sin\theta_i - z\cos\theta_i)}$ & $H_r(x,z) = \hat{y}(E_{i1}/\eta_1) e^{-j\beta(x\sin\theta_i - z\cos\theta_i)}$

$\rightarrow E_t(x,z) = E_{1t}(\hat{x}\cos(\theta_t) - \hat{y}\sin(\theta_t)) e^{-j\beta(x\sin\theta_t + z\cos\theta_t)}$ & $H_t(x,z) = \hat{y}(E_{1t}/\eta_2) e^{-j\beta(x\sin\theta_t + z\cos\theta_t)}$

$\Gamma_\parallel = -\frac{E_{r1}}{E_{i1}} = \frac{\eta_2\cos\theta_t - \eta_1\sin\theta_i}{\eta_2\cos\theta_t + \eta_1\sin\theta_i}$ $T_\parallel = \frac{E_{t2}}{E_{i1}} = \frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_t + \eta_1\cos\theta_i}$ $\rightarrow E_{i1}\cos(\theta_i) - E_{r1}\cos(\theta_i) = E_{t2}\cos(\theta_t)$

$E_{i1}/\eta_1 + E_{r1}/\eta_1 = E_{t2}/\eta_2$

Brewsters angle (zero polarization, perfect transmission & ref = 0)

parallel $\parallel$ $\eta_1\cos(\theta_t) = \eta_2\cos(\theta_i) \rightarrow \sin(\theta_b) = \sqrt{\frac{\varepsilon_2(\mu_2\varepsilon_1 - \mu_1\varepsilon_2)}{\mu_1(\varepsilon_1^2 - \varepsilon_2^2)}}$

perpendicular $\perp$ $\eta_2\cos\theta_i = \eta_1\sin\theta_t \rightarrow \sin(\theta_b) = \sqrt{\frac{\mu_2(\varepsilon_1\mu_2 - \varepsilon_2\mu_1)}{\varepsilon_1(\mu_2^2 - \mu_1^2)}}$

total int ref. $\Rightarrow \Gamma = -1$ $T = 1$ at $\theta_t = 90 \Rightarrow \sin\theta_t = \sqrt{\frac{\mu_1\varepsilon_1}{\mu_2\varepsilon_2}}\sin\theta_i$