Φ	$C = sA$
E	$N/C = V/m$
B	$V \cdot s/m^2 = Wb/m^2 = T$
ρ	C/m^3
J	A/m^2

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$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}$ Laplacian

$E = -\frac{dV}{dr}$ charge inside conductor $= 0$

Laplace's eqn: $\rho = 0 \Rightarrow \nabla^2 V = 0$

poisson eqn: $\nabla^2 V = -\frac{\rho}{\epsilon_0}$ if ϵ_r indep. of position

Coulomb's:

$\vec{E}(\vec{r}) = \frac{Q}{4\pi\epsilon_0 r^2}\hat{r}$

$\vec{J} = \sigma\vec{E}$ Ohm's law

polarization $\vec{P} = N_d e d\hat{z} = N_d \vec{p}$

$\vec{D} = \epsilon_0 \vec{E}$ elect. field

disp. field

$\vec{D} = \epsilon\vec{E} = \epsilon_0\vec{E} + \vec{P}$ of a coaxial cable:

$\oint_S \vec{D} \cdot d\vec{S} = Q_V = \int_V \rho \, dV$

$C = \frac{2\pi}{\ln b/a}\epsilon L$ capacitance conductance $G = \frac{2\pi}{\ln b/a}\sigma L$

$\vec{v} = \frac{qt}{m}\vec{E}$ mobility

$\mu_0 = 4\pi \times 10^{-7}$ H/m

$\epsilon_0 \approx (36\pi \times 10^9)^{-1}$ F/m

$\vec{J} = Nq\vec{v}$ current density

susceptibility χ_e

$c = 3 \times 10^8$ m/s

Lorentz force $F = q(\vec{E} + \vec{v} \times \vec{B})$

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$E_{t1} = E_{t2}$, $(\vec{H}_1 - \vec{H}_2)_t = \vec{J}_s \times \hat{a}_n$, $\hat{a}_n \times (\vec{H}_1 - \vec{H}_2) = \vec{J}_s$

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Ampere's law: $\vec{B} = \frac{\mu_0 I}{2\pi r}\hat{\phi}$ $\mu_0 \vec{H} = \vec{B}$ $\oint \vec{H} \cdot d\vec{l} = \int_S \vec{J} \cdot d\vec{S}$

$I_c = \int_S \vec{J} \cdot d\vec{S}$ $\vec{J}(x,y,z) = \vec{J}_s(y,z)\,\delta(x - x_0)$

$\vec{F} = q\vec{v} \times \vec{B}$ $\oint_C \vec{B} \cdot d\vec{l} = \mu_0 I_c$ $\vec{J}(x,y,z) = \hat{z} I(z)\,\delta(x - x_0)\,\delta(y - y_0)$

Faraday's law $\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$, $\oint_C \vec{E} \cdot d\vec{l} = -\int_S \frac{\partial \vec{B}}{\partial t} \cdot d\vec{S} = -\frac{d}{dt}\int_S \vec{B} \cdot d\vec{S}$

$\Psi = \int_S \vec{B} \cdot d\vec{S}$, $\mathcal{E} = -\frac{d\Psi}{dt}$ (Faraday's law), $\mathcal{E} = -\frac{d\Psi}{dt} = \oint_C \vec{E} \cdot d\vec{l}$, $I = \frac{\mathcal{E}}{R}$, $\mathcal{E} = \oint_C (\vec{E} + \vec{v} \times \vec{B}) \cdot d\vec{l}$

Inductance $L = \frac{n\Psi}{I}$, $\mathcal{E} = -L\frac{dI}{dt}$, inductor of n loops

$\vec{B} = \mu_0 I N$

$L = \frac{n\Psi}{I} = N^2 \mu_0 A l$

$B \to z$ shorted coax

$B_\phi 2\pi r = \mu_0 I$, $L = \frac{\ln b/a}{2\pi}\mu_0 l$

$B_\phi = \frac{\mu_0 I}{2\pi r}$

$\Psi = l\frac{\mu_0}{2\pi}\ln\frac{b}{a} I$

$w = \frac{1}{2}\mu_0 \vec{H} \cdot \vec{H}$

$\int \frac{\partial \rho}{\partial t} dV = -\oint \vec{J} \cdot d\vec{S}$ Charge Conservation

$\frac{\partial \rho}{\partial t} = -\vec{\nabla} \cdot \vec{J}$

$\vec{D} = \epsilon\vec{E}$, $\vec{B} = \mu\vec{H}$

$\vec{\nabla} \cdot \vec{D} = \rho$ Gauss' law

$\vec{\nabla} \cdot \vec{B} = 0$ Ampere $\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$

$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ Faraday's law

$\hat{n} \cdot (\vec{D}^+ - \vec{D}^-) = \rho_s$

$\hat{n} \cdot (\vec{B}^+ - \vec{B}^-) = 0$

$\hat{n} \times (\vec{E}^+ - \vec{E}^-) = 0$

$\hat{n} \times (\vec{H}^+ - \vec{H}^-) = \vec{J}_s$

$\vec{H} = \mu_0^{-1}\vec{B} - \vec{M}$

$\vec{B} = \mu_0(1 + \chi_m)\vec{H} = \mu\vec{H}$

Diamagnetic $\chi_m < 0$ / $\chi_m > 0$ paramagnetic

ECE 329 Midterm 3 Notecard
Section X, Fall 2017

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

$\frac{|\vec{E}|}{|\vec{H}|} = \eta$ $\beta = \frac{\omega}{v} = \omega\sqrt{\mu\epsilon}$ wave number

wave frequency, wave speed

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

$\sin \to -j$, $\partial/\partial t \to j\omega$

$v = \lambda/T = \lambda f$

change of total electrical & mag energy density	energy transport	Joule heating power absorbed/unit vol

$\lambda = 2\pi/\beta$, $T = \frac{2\pi}{\omega} = \frac{1}{f}$, $= v_p/f$

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

$\vec{\nabla} \cdot \vec{B} = 0$

$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

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

$\vec{\nabla} \cdot \tilde{D} = \tilde{\rho}$

$\vec{\nabla} \cdot \tilde{B} = 0$

$\vec{\nabla} \times \tilde{E} = -j\omega\tilde{B}$

$\vec{\nabla} \times \tilde{H} = \tilde{J} + j\omega\tilde{D}$

$\tilde{D} = \epsilon\tilde{E}$, $\tilde{B} = \mu\tilde{H}$, $\tilde{J} = \sigma\tilde{E}$

Linear - one or 2 components (0/180°)
Circular - 2 comp. (90°), 2x power linear
Elliptical 2 components diff than (n of 0, 90, 180°) polarization
densities

$\delta \equiv 1/\alpha = \mathrm{Re}\{\sqrt{j\omega\mu(\sigma + j\omega\epsilon)}\}^{-1}$

$\delta \approx \sqrt{2/\mu\omega\sigma} = 1/\sqrt{\pi f\mu\sigma}$ Good conductor skin depth

Transmission Line $\mathcal{C} = \epsilon GF$

$\mathcal{L} = \mu/GF$

$Z_0 = \sqrt{\mathcal{L}/\mathcal{C}}$

$v = 1/\sqrt{\mathcal{L}\mathcal{C}}$

$\tau_g = \frac{Z_0}{R_g + Z_0}$

$\Gamma_L = \frac{R_L - Z_0}{R_L + Z_0}$

$\Gamma_G = \frac{R_g - Z_0}{R_g + Z_0}$

coax GF: $GF = \frac{2\pi}{\ln b/a}$

Wave reflection & transmission
Diff media w/ diff. properties $\to$ discontinuity

$\Gamma_{12} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}$, $\tau_2 = 1 + \Gamma_{12} = \frac{2\eta_2}{\eta_2 + \eta_1}$

perf cond: $\Gamma = -1$, $\tau = 0$

matched impedance: $\Gamma = 0$, $\tau = 1$

$\tilde{E}_i = \hat{x}E_0 e^{-j\beta_1 z}$ $\hat{n} \cdot (\vec{D}^+ - \vec{D}^-) = \rho_s$

$\tilde{H}_i = \hat{y}\frac{E_0}{\eta_1}e^{-j\beta_1 z}$ $\hat{n} \cdot (\vec{B}^+ - \vec{B}^-) = 0$

$\tilde{E}_r = \hat{x}\Gamma E_0 e^{j\beta_1 z}$ $\hat{n} \times (\vec{E}^+ - \vec{E}^-) = 0$

$\tilde{H}_r = -\hat{y}\frac{\Gamma E_0}{\eta_1}e^{j\beta_1 z}$ $\hat{n} \times (\vec{H}^+ - \vec{H}^-) = \vec{J}_s$

$\gamma = \sqrt{(j\omega\mu)(\sigma + j\omega\epsilon)}$

$\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}}$

$\gamma\eta = j\omega\mu$, $\frac{\gamma}{\eta} = \sigma + j\omega\epsilon$

Standing waves

$\vec{E} = \hat{x}2E_0\sin(\beta_1 z)\sin(\omega t)$

$\vec{H} = \hat{y}\frac{2E_0}{\eta_1}\cos(\beta_1 z)\cos(\omega t)$

$\tilde{E}_t = \hat{x}\tau E_0 e^{-\gamma_2 z}$

$\tilde{H}_t = \hat{y}\frac{\tau E_0}{\eta_2}e^{-\gamma_2 z}$

ECE 329 Final Note Sheet
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$\tilde{V}(z) = \tilde{V}^+ e^{-j\beta z} + \tilde{V}^- e^{j\beta z}$

$\tilde{I}(z) = \frac{\tilde{V}^+ e^{-j\beta z} - \tilde{V}^- e^{j\beta z}}{Z_0}$

$\tilde{V}(d) = V^+ e^{j\beta d} + V^- e^{-j\beta d}$

$\tilde{I}(d) = \frac{V^+ e^{j\beta d} - V^- e^{-j\beta d}}{Z_0}$

$\omega_0 = \frac{1}{\sqrt{LC}}$ $\beta = \frac{2\pi}{\lambda}$

$Z_L = R_L + jX_L$

load reflection coefficient

$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$

generalized reflection coefficient

$\Gamma(d) \equiv \Gamma_L e^{-j2\beta d}$

Line impedance

$Z(d) = \frac{V(d)}{I(d)} = Z_0\frac{1 + \Gamma(d)}{1 - \Gamma(d)}$

$\Gamma = \frac{Z - Z_0}{Z + Z_0}$ $\frac{Z}{Z_0} = \frac{1 + \Gamma}{1 - \Gamma} \equiv z$

$y(d) = \frac{1}{z(d)}$ $Y = \frac{y}{Z_0}$

Voltage Standing Wave Ratio (VSWR)

$VSWR = \frac{|V(d_{max})|}{|V(d_{min})|} = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|}$

$|\Gamma_L| = \frac{VSWR - 1}{VSWR + 1}$

$VSWR = \frac{1 + \Gamma(d_{max})}{1 - \Gamma(d_{min})}$

$z(d_{max}) = VSWR$

$P(d) = \frac{1}{2}\mathrm{Re}\{V(d)I^*(d)\}$
$= \frac{|V^+|^2 - |V^-|^2}{2Z_0}$

$z_{in} = \frac{z_q^2}{z_L}$

Smith Chart

Find $Z(\ell)$, $V(\ell)$ and $I(\ell)$ given Z_L & Z_0

1. Calculate $z_L = Z_L/Z_0$
2. Mark z_L on SC
3. center of SC to z_L is dist $|\Gamma_L|$
   $\angle\Gamma_L$ is measured CCW from Re axis
4. Find $z(\ell)$: rotate CW (toward generator) by $\theta = \ell(360/0.5\lambda)$
5. Calculate $Z(\ell) = z(\ell)Z_0$, $\Gamma(\ell) = |\Gamma_L|\angle\Gamma_L$
6. Use VDR: $V(\ell) = V_g[Z(\ell)/(Z_g + Z(\ell))]^{+\Theta}$
7. Calc V^+: $V(\ell) = V^+(e^{-j\beta\ell} + \Gamma_L e^{j\beta\ell})$
8. Calculate $V(\ell)$ for any ℓ by sub V^+ → (4)
9. $I(\ell) = V(\ell)/Z(\ell)$ at any given ℓ

Quarter Wave Transformer

1. Calculate $z_L = Z_L/Z_0$
2. Mark z_L on SC
3. Dist center SC → z_L is $|\Gamma_L|$, $\angle\Gamma_L$ is measured CCW from real axis
4. Draw circle centered on SC w/ $r = |\Gamma_L|$
5. z_L' point (intersection on real axis) (impedance is purely real)
6. Rotate toward generator (CW) $z_L \to z_L'$. Angle is dist d_1 of quarter-wave transformer from load in λ units
7. Impedance at d_1 is $Z(d_1) = Z_0 z_L'$
8. Characteristic impedance of quarter-wave transformer $Z_{q0} = \sqrt{Z_0 Z(d_1)}$

Calculate Z_L given VSWR

1. Calculate d_{min} or d_{max} using fact that on TL, 2 minima or 2 maxima are separated by 0.5λ
2. On SC, mark $z(d_{max}) = VSWR + j0$
   $z(d_{min}) = (1/VSWR) + j0$, as A, B, resp.
3. Radius = VSWR circle on SC thru A, B
4. start at pt B, rotate CCW (toward load) by dist d_{min} (in λ units). → pt C
   z_L of C read it.
5. Dist from center of SC to C is $|\Gamma_L|$ and angle $\angle\Gamma_L = -180° + d_{min}(360°/0.5\lambda)$
6. Solve for $|V^+|$ and $|V^-|$ using $|V_{max}| = |V^+| + |V^-|$, $|V_{min}| = |V^+| - |V^-|$
7. $VSWR = |V_{max}|/|V_{min}|$

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line	$\vec{E} = \hat{r}\dfrac{\lambda}{2\pi\epsilon_0 r}$	$\vec{\nabla}\times\vec{E} = 0 \Leftrightarrow$ curl-free
sheet	$\vec{E} = \hat{x}\dfrac{\rho_s}{2\epsilon_0}\,\mathrm{sgn}(x)$	gradient $\vec{\nabla}V\left(\dfrac{\partial V}{\partial x}, \dfrac{\partial V}{\partial y}, \dfrac{\partial V}{\partial z}\right) \ni \vec{E} = -\vec{\nabla}V$
slab	$\vec{E} = \hat{x}\dfrac{\rho x}{\epsilon_0}$	$V(b) - V(a) = -\int_a^b \vec{E}\cdot d\vec{l}$

$\vec{\nabla}\cdot\vec{D} = \rho$ divergence $\quad \oint_C \vec{E}\cdot d\vec{l} = \int \vec{\nabla}\times\vec{E}\, d\vec{S}$

$\dfrac{\partial D_x}{\partial x} + \dfrac{\partial D_y}{\partial y} + \dfrac{\partial D_z}{\partial z} = \rho \quad$ stoke's thm $\oint_C \vec{E}\cdot d\vec{l} = 0 \Leftrightarrow \vec{\nabla}\times\vec{E} = 0$

$\vec{\nabla}\times\vec{E} = 0$, $\vec{\nabla}\cdot\vec{D} = \rho$, $\vec{D} = \epsilon_0\vec{E}$

$\vec{\nabla} = \left(\dfrac{\partial}{\partial x}, \dfrac{\partial}{\partial y}, \dfrac{\partial}{\partial z}\right) \quad \vec{F} = Q\vec{E}$, $\vec{E} = -\nabla V$, parallel pl: $C = \epsilon_0\dfrac{A}{d}$

$\vec{\nabla}\times\vec{E} = \left(\dfrac{\partial}{\partial x}, \dfrac{\partial}{\partial y}, \dfrac{\partial}{\partial z}\right)\times(E_x, E_y, E_z) \quad \vec{D} = \hat{x}\,Q/A$, $Q = CV$

curl $= \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ E_x & E_y & E_z \end{vmatrix} = \hat{x}\left(\dfrac{\partial E_z}{\partial y} - \dfrac{\partial E_y}{\partial z}\right) - \hat{y}\left(\dfrac{\partial E_z}{\partial x} - \dfrac{\partial E_x}{\partial z}\right) + \hat{z}\left(\dfrac{\partial E_y}{\partial x} - \dfrac{\partial E_x}{\partial y}\right)$

TEM Wave Solns

$\vec{\nabla}^2\vec{E} = \dfrac{\partial^2\vec{E}}{\partial x^2} + \dfrac{\partial^2\vec{E}}{\partial y^2} + \dfrac{\partial^2\vec{E}}{\partial z^2} = \mu\epsilon\dfrac{\partial^2\vec{E}}{\partial t^2}$

$\vec{E}(\vec{r}, t) = \hat{x}E_x(z, t) \quad v = \dfrac{1}{\sqrt{\mu\epsilon}} \quad \hat{z} = \hat{E}\times\hat{H}$

$\dfrac{\partial^2 E_x}{\partial z^2} = \mu\epsilon\dfrac{\partial^2 E_x}{\partial t^2} \quad \eta = \sqrt{\dfrac{\mu}{\epsilon}}$ intrinsic impedance

$E_x = \cos(\omega(t \mp \frac{z}{v}))$ depend on z, t

$\vec{H} = \pm\hat{y}\sqrt{\dfrac{\epsilon}{\mu}}\cos(\omega(t \mp \frac{z}{v}))$ polarized in x

$\vec{E}^{\pm}\times\vec{H}^{\pm} \quad \vec{J}_s = \hat{x}f(t)$ on $z = 0$

$\vec{J}_s = \hat{x}J_x(t) \quad \vec{E}^{\pm} = -\hat{x}\dfrac{\eta f(t - \frac{z}{v})}{2}$

$\vec{H}^{\pm} = \mp\dfrac{f(t \mp \frac{z}{v})}{2}\quad z \gtrless 0$

$\vec{E}^-\times\vec{H}^-$

$\vec{E} = \hat{y}\cos(\omega(t \mp \frac{z}{v}))$ polarized in y

$\vec{H} = \mp\hat{x}\dfrac{\cos(\omega(t \mp \frac{z}{v}))}{\eta}$ dependant on z, t

$\nabla^2 V = \dfrac{\partial^2 V}{\partial x^2} + \dfrac{\partial^2 V}{\partial y^2} + \dfrac{\partial^2 V}{\partial z^2}$ Laplacian $\quad \vec{J} = \sigma\vec{E}$

curl $\vec{\nabla}\times\vec{E} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ E_x & E_y & E_z \end{vmatrix} = \hat{x}\left(\dfrac{\partial E_z}{\partial y} - \dfrac{\partial E_y}{\partial z}\right) - \hat{y}\left(\dfrac{\partial E_z}{\partial x} - \dfrac{\partial E_x}{\partial z}\right) + \hat{z}\left(\dfrac{\partial E_y}{\partial x} - \dfrac{\partial E_x}{\partial y}\right)$

divergence $\vec{\nabla}\cdot\vec{D} = \dfrac{\partial D_x}{\partial x} + \dfrac{\partial D_y}{\partial y} + \dfrac{\partial D_z}{\partial z}$

D_{n1}, D_{n2}, $+ + \rho_s + +$, $D_{n1} - D_{n2} = \rho_s$

$\mu_0 = 4\pi\times10^{-7}$ H/m

$\epsilon_0 = (36\pi\times10^{-9})^{-1}$ F/m

$c = 3\times10^8$ m/s $\quad \eta_0 = 120\pi\ \Omega$

$= 300$ m/µs

$\vec{E}$ antiparallel to $\vec{J}$

B_{n1}, B_{n2}, $B_{n1} = B_{n2}$

q	C = sA				
E	N/C = V/m				
B	V·s/m² = Wb/m² = T				
D	C/m²				
H	A/m	S	A/m²	L	H = Wb/A = VS/A
ρ	C/m³	ε	V		
J	A/m²	Ψ	Wb	C	F = As/V = C/V

$\nabla^2 V = \dfrac{\partial^2 V}{\partial x^2} + \dfrac{\partial^2 V}{\partial y^2} + \dfrac{\partial^2 V}{\partial z^2}$ Laplacian

curl $\vec{\nabla}\times\vec{E} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ E_x & E_y & E_z \end{vmatrix} = \hat{x}\left(\dfrac{\partial E_z}{\partial y} - \dfrac{\partial E_y}{\partial z}\right) - \hat{y}\left(\dfrac{\partial E_z}{\partial x} - \dfrac{\partial E_x}{\partial z}\right) + \hat{z}\left(\dfrac{\partial E_y}{\partial x} - \dfrac{\partial E_x}{\partial y}\right)$

divergence $\vec{\nabla}\cdot\vec{D} = \dfrac{\partial D_x}{\partial x} + \dfrac{\partial D_y}{\partial y} + \dfrac{\partial D_z}{\partial z}$

$V(z,t) = \tau_g \sum_{n=0}^{\infty} (\Gamma_L\Gamma_g)^n \delta(t - \frac{z}{v} - n\frac{2\ell}{v}) + \tau_g\Gamma_L \sum_{n=0}^{\infty} (\Gamma_L\Gamma_g)^n \delta(t + \frac{z}{v} - (n+1)\frac{2\ell}{v})$

$I(z,t) = \dfrac{\tau_g}{Z_0}\sum_{n=0}^{\infty} (\Gamma_L\Gamma_g)^n \delta(t - \frac{z}{v} - n\frac{2\ell}{v}) - \dfrac{\tau_g}{Z_0}\Gamma_L\sum_{n=0}^{\infty} (\Gamma_L\Gamma_g)^n \delta(t + \frac{z}{v} - (n+1)\frac{2\ell}{v})$

$\mu_0 = 4\pi\times10^{-7}$ H/m $\quad \tau = RC$

$\epsilon_0 = (36\pi\times10^{-9})^{-1}$ F/m $\quad \tau = L/R$

$c = 3\times10^8$ m/s $\quad \eta_0 = 120\pi\ \Omega \quad \eta = \sqrt{\dfrac{\mu}{\epsilon}}$

$= 300$ m/µs

$\vec{\nabla}^2\vec{E} = \dfrac{\partial^2\vec{E}}{\partial x^2} + \dfrac{\partial^2\vec{E}}{\partial y^2} + \dfrac{\partial^2\vec{E}}{\partial z^2} = \mu\epsilon\dfrac{\partial^2\vec{E}}{\partial t^2}$ TEM Wave solutions

GF = w/d parallel plate

GF = $\dfrac{\pi}{\cosh^{-1} D/2a}$ twin-lead

$E_x = E_0 e^{\mp\alpha z} e^{\mp j\beta z}$

$E_x = E_0 e^{\mp\alpha z}\cos(\omega t \mp \beta z)$

$\Gamma_{jk} = \dfrac{Z_k - Z_j}{Z_k + Z_j}$ $j \to k$

cos leads sin leads −cos leads −sin

parallel multi-line $Z_{eq} = \dfrac{RZ_2}{R + Z_2}$ KVL KCL

q	C = sA	L	H = Wb/A = V·s/A	$\lvert\vec{H}\rvert = \frac{\lvert J_s\rvert}{2}$ current sheet
E	N/C = V/m	C	F = A·s/V = C/V	
B	V·s/m² = Wb/m² = T	Ψ	Wb	
D	C/m²	P	W	α Np/m
H	A/m	V_p	m/s	β rad/m
ρ	C/m³	ω	rad/s	γ Np/m & rad/m
J	A/m²	f	Hz = s⁻¹	δ m $\quad E_x = \cos\omega(t \mp \frac{z}{v})$
S	W/m²	σ	S/m	ε F/m
ε	V	z	rad	
		λ	m	J A/m

E_{t1}, E_{t2}, $E_{t1} = E_{t2}$ $\quad J_s$, H_{t1}, H_{t2}, $(\vec{H}_1 - \vec{H}_2)_t = \vec{J}_s\times\hat{n}$

$\hat{n}\times(\vec{H}_1 - \vec{H}_2)_t = \vec{J}_s$

D_{n1}, $+ + \rho_s + +$, D_{n2}, $D_{n1} - D_{n2} = \rho_s$ $\quad B_{n1}$, B_{n2}, $B_{n1} = B_{n2}$

Impedance matching using stubs

1. Calculate $z_L = Z_L/Z_0$
2. Calculate $y_L = 1/z_L$
3. Mark y_L on SC
4. $|\Gamma_L|$, s dist to y_L ...
5. Draw circle of $r = |\Gamma_L|$
6. Rotate along circle from y_L toward gen. (CCW) until reach g = 1 circle.
   intersection: $y(d_1) = 1 + jX$
7. Rotated dist d_1 is dist from load to put stub
8. Admittance of stub $y_S = -jX$
9. For short circuit stub: Length of stub, locate $y = \infty$. Rotate on outermost circle ($r = 1$) toward gen (CW) until reach $y = -jX$
10. For open circuit stub: Length of stub, locate $y = 0$, rotate on outermost circle toward gen (CW) until $y = -jX$
11. Rotation dist in λ units is len of stub (d_s)