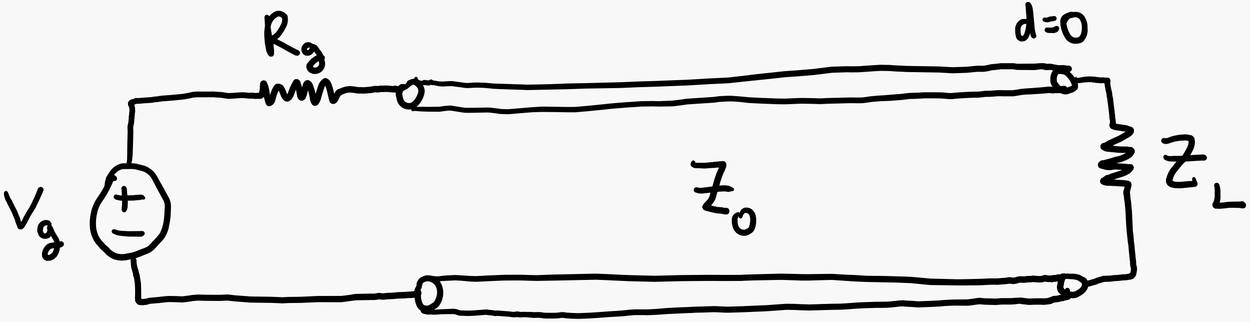
ECE329: Tutorial Session 13

December 3rd, 2024

Resonance



What if $Z_L = 0$?

What if $Z_L = \infty$?

Resonance

Type	Input	Output	T.L. Length
Series	Short	Short	$\frac{n\lambda}{2}$, n integer
Series	Short	Open	$\frac{n\lambda}{4}$, n odd integer
Parallel	Open	Short	$\frac{n\lambda}{4}$, n odd integer
Parallel	Open	Open	$\frac{n\lambda}{2}$, n integer

Problem 1: Resonance

Length of TL: 3m. $v = c$.
Load is shorted.

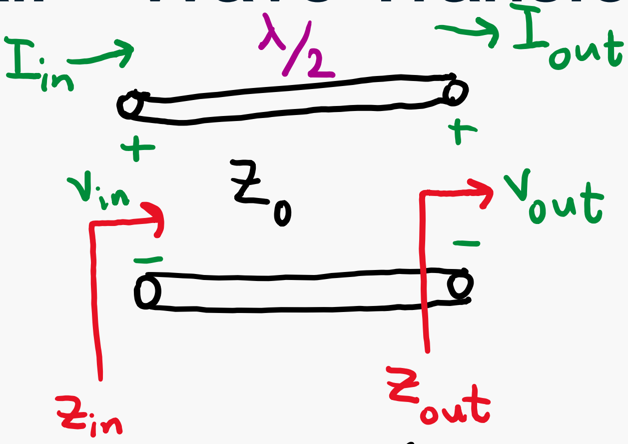
What input frequencies make Z_{in} equivalent to a short circuit?
What input frequencies make Z_{in} equivalent to an open circuit?

Problem 2: Resonance

$v = c.f = 3 * 10^8$ Hz.
Load is open circuit.

What lengths of TL make Z_{in} equivalent to a short circuit?
What lengths of TL make Z_{in} equivalent to an open circuit?

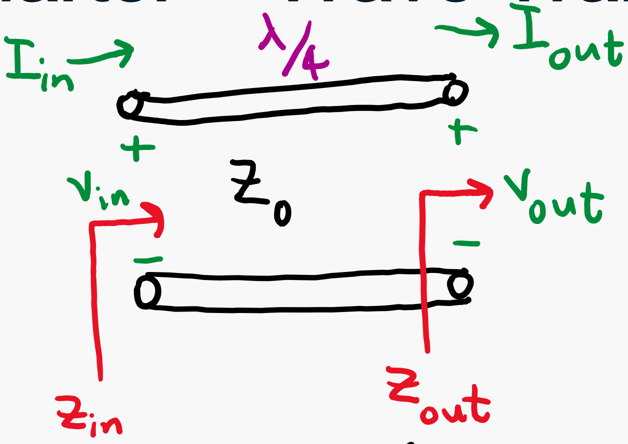
Last Week: Half -Wave Transformer



Allows you to 'crawl' up (or down) a TL in $\frac{\lambda}{2}$ steps.

$$V_{in} = -V_{out}$$
$$I_{in} = -I_{out}$$
$$Z_{in} = Z_{out}$$

Last Week: Quarter-Wave Transformer



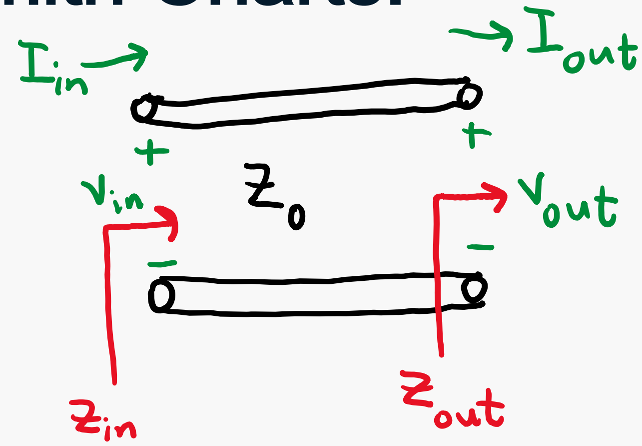
Allows you to 'crawl' up (or down) a TL in $\frac{\lambda}{4}$ steps.

$$V_{in} = jI_{out}Z_0$$

$$I_{in} = \frac{jV_{out}}{Z_0}$$

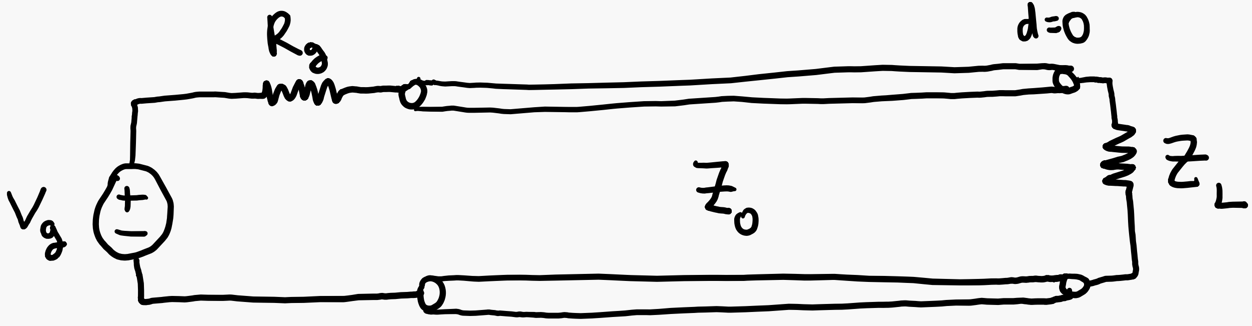
$$Z_{in} = \frac{Z_0^2}{Z_{out}}$$

This Week: Smith Charts!

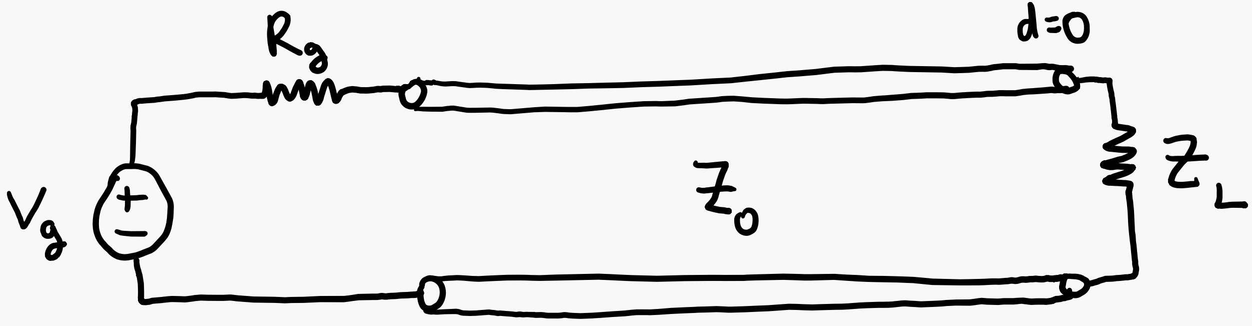


Allows you to ‘crawl’ up (or down) any TL of any length!

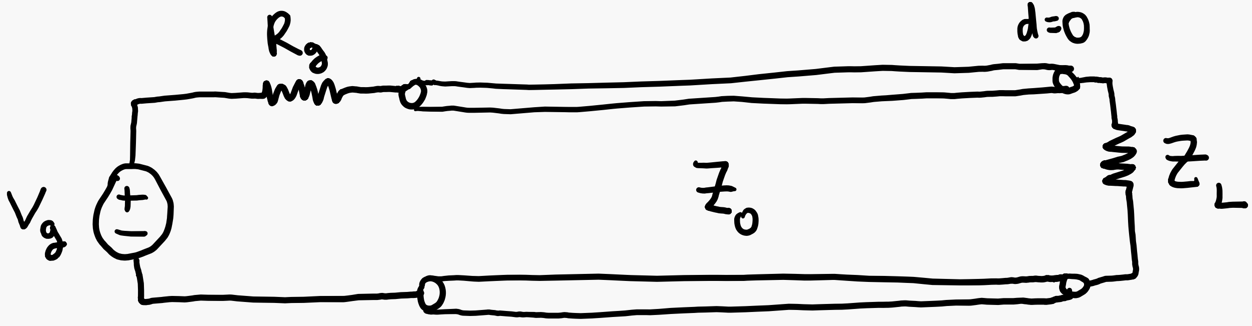
Smith Charts: Intro



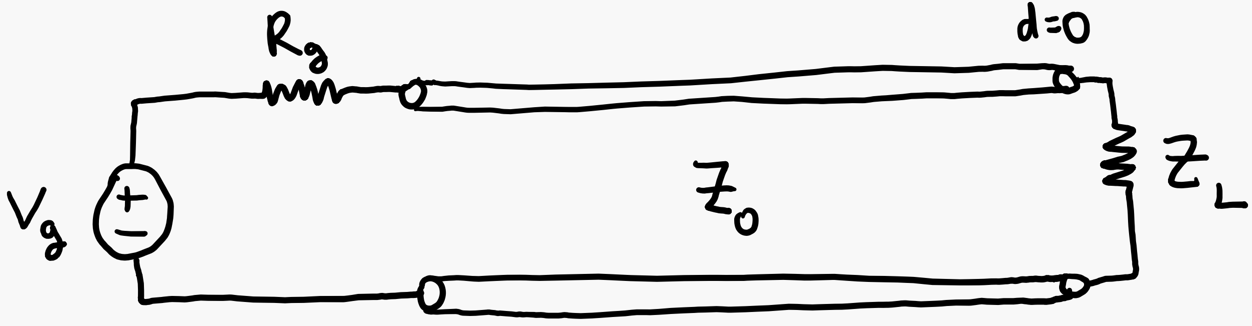
Smith Charts: Intro



Smith Charts: Intro



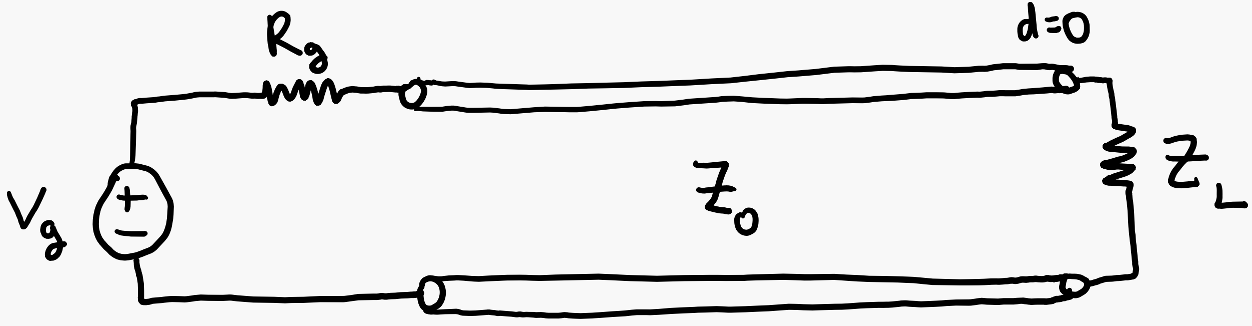
Smith Charts: Intro



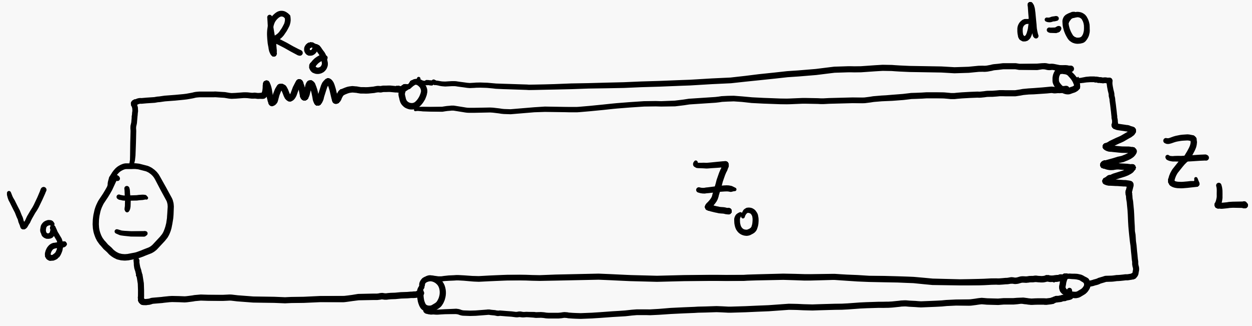
Problem 3

Eric protests – ”I thought the ratio between the voltage and current on the transmission line was always the characteristic impedance of the transmission line, namely Z_0!”
Is Eric wrong?

Smith Charts: Intro



Smith Charts: Intro



Problem 4: Pivotal Point 1

What does the origin of the Smith Chart correspond to in terms of Γ?
What does the origin of the Smith Chart correspond to in terms of z?
What does the origin of the Smith Chart correspond to as a load?

Problem 4: Pivotal Point 2

What does the leftmost point of the Smith Chart correspond to in terms of Γ?
What does the leftmost point of the Smith Chart correspond to in terms of z?
What does the leftmost point of the Smith Chart correspond to as a load?

Problem 4: Pivotal Point 3

What does the rightmost point of the Smith Chart correspond to in terms of Γ?
What does the rightmost point of the Smith Chart correspond to in terms of z?
What does the rightmost point of the Smith Chart correspond to as a load?

Problem 5: Devious Details 1

Evan tells you that at the load end of the transmission line he's at angle 0 on the Smith Chart. He then walks 3 meters toward the input and asks what angle we're at now.

What information are you missing to solve this problem?

Why is it important?

Problem 5: Devious Details 2

Evan starts at the load and walks $\lambda/2$ distance towards the input. How many degrees did he walkthrough on the Smith Chart? Why?

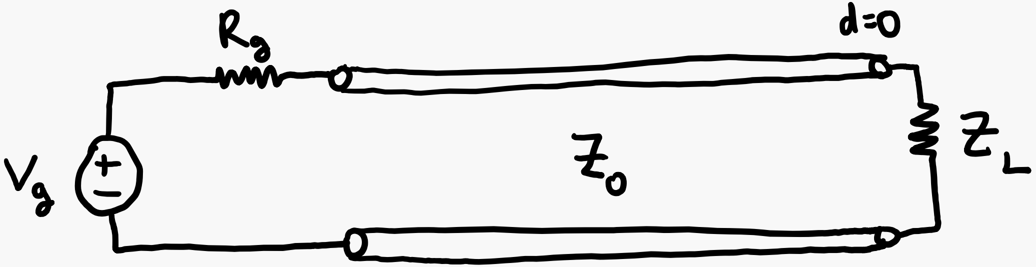
Problem 5: Devious Details 3

Sasha receives a transmission line problem with some load impedance and some intrinsic impedance. She first normalizes the load impedance, enters it on the Smith Chart, and then draws a constant Γ circle that passes through the origin and the point she drew.

Why did she do each of these three steps?

Problem 5: Devious Details 4

Eric finds the input impedance of some transmission line setup. He enters it on the Smith Chart and finds the phase and magnitude of Γ at that point. What is the significance of this Γ?



Problem 5: Devious Details 5

When travelling towards the source Sasha always rotates clockwise along the Smith Chart. Why?

If Sasha instead travels towards the load, then which direction should she rotate?

Problem 5: Devious Details 6

Does the Smith Chart yield steady state solutions, transient solutions, or both?

Problem 4: Example Smith Chart

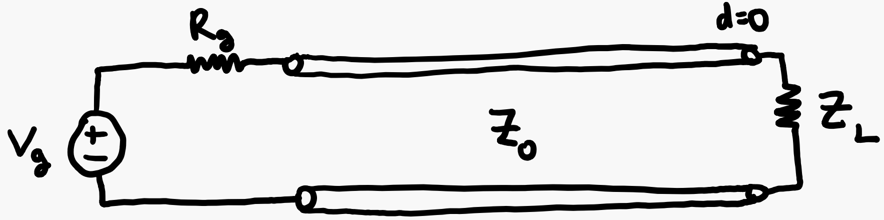
TL length = 5m.

$v = c$, $f = 100\text{MHz}$.

$Z_L = 150 + j150\Omega$, $Z_0 = 50\Omega$, $R_g = 25\Omega$.

$V_g = 10e^{\frac{j\pi}{4}}$ V

Find Γ_L, Z_{in}, V_{in}, I_{in}. How would you find $V(0)$?



Midterm 1 equations, in one place

$$\vec{F} = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}\hat{r}$$

$$\vec{F} = q_1\vec{E} + q_1(\vec{v}_1 \times \vec{B})$$

$$\vec{E} = \frac{q_2}{4\pi\epsilon_0 r^2}\hat{r}$$

$$\epsilon \oiint \vec{E} \cdot d\vec{S} = Q_{\text{enclosed}}$$

$$\oiint \vec{D} \cdot d\vec{S} = Q_{\text{enclosed}}$$

$$\iiint \rho dV = Q_{\text{enclosed}}$$

$$\oiint \vec{B} \cdot d\vec{S} = 0$$

$$I = \oiint \vec{J} \cdot d\vec{S} = -\frac{\partial Q_{\text{enclosed}}}{\partial t}$$

$$\nabla \times \vec{E} = 0$$

$$\vec{E} = -\nabla V$$

$$\oint \vec{E} \cdot d\vec{l} = 0$$

$$V_{ab} = V(b) - V(a) = -\int_a^b \vec{E} \cdot d\vec{l}$$

$$\hat{n} \cdot (\vec{D}_1 - \vec{D}_2) = \rho_s$$

$$\hat{n} \times (\vec{E}_1 - \vec{E}_2) = 0$$

$$\hat{n} \cdot (\vec{P}_1 - \vec{P}_2) = -\rho_{b,s}$$

$$\epsilon = \epsilon_0(1 + \chi_e)$$

$$\vec{P} = \epsilon_0 \chi_e \vec{E}$$

$$\vec{D} = \epsilon_0\vec{E} + \vec{P} = \epsilon\vec{E}$$

$$\vec{J} = \sigma\vec{E}$$

$$\rho_b = -\nabla \cdot \vec{P}$$

$$\nabla \cdot \epsilon_0 \vec{E} = \rho_f + \rho_b$$

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

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

$$-\nabla^2 V = \frac{\rho}{\epsilon}$$

$$\oiint \vec{D} \cdot d\vec{S} = \iiint \nabla \cdot \vec{D} dV$$

$$\oint \vec{E} \cdot d\vec{l} = \iint (\nabla \times \vec{E}) \cdot d\vec{S}$$

$$\int_a^b \nabla V \cdot d\vec{l} = V(b) - V(a)$$

Midterm 2 equations, in one place

$$\vec{B} = \frac{\mu I}{2\pi r}\hat{\phi}$$

$$d\vec{B} = \frac{\mu I d\vec{\ell} \times \hat{r}}{4\pi r^2}$$

$$\oint_C \vec{H} \cdot d\vec{\ell} = \iint_S \vec{J} \cdot d\vec{S}$$

$$\oint_C \vec{B} \cdot d\vec{\ell} = \mu I_{\text{encl}}$$

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

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

$$\Psi = \iint_s \vec{B} \cdot d\vec{S}$$

$$-\frac{d}{dt}\iint_s \vec{B} \cdot d\vec{S} = \oint_c \vec{E} \cdot d\vec{l}$$

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

$$\oint_c \vec{E} \cdot d\vec{l} = \varepsilon$$

$$\varepsilon = \frac{W}{q} = \oint_C \frac{\vec{F}}{q} \cdot d\vec{l}$$

$$\Psi = LI$$

$$\varepsilon = IR$$

$$v = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\mu\epsilon}}$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\eta = \frac{\sqrt{\mu}}{\sqrt{\epsilon}}$$

$$\beta = \omega\sqrt{\mu\epsilon}$$

$$\nabla^2 \vec{E} = \mu\epsilon\frac{\partial^2 \vec{E}}{\partial t^2}$$

$$\vec{S} = \vec{E} \times \vec{H}$$

$$\tilde{S} = \tilde{E} \times \tilde{H}^*$$

$$<\vec{S}> = \frac{1}{2}\text{Re}\{\tilde{E} \times \tilde{H}^*\}$$

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

$$Q = CV$$

$$G = \frac{\sigma}{\epsilon}C \qquad R = \frac{1}{G}$$

$$\vec{J}_b = \frac{\partial \vec{P}}{\partial t} + \nabla \times \vec{M}$$

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$$

$$\vec{M} = \chi_m \vec{H}$$

$$\vec{B} = \mu_0\mu_r\vec{H} = \mu\vec{H}$$

$$A\cos(\omega t - \beta x)\hat{z} \leftrightarrow Ae^{-j\beta x}\hat{z}$$

$$\hat{n} \cdot (\vec{B}_1 - \vec{B}_2) = 0$$

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

$$\hat{n} \times (\vec{M}_1 - \vec{M}_2) = \vec{J}_{b,s}$$

Midterm 3 equations, in one place

Waves:

	Condition	β	α	$\lvert\eta\rvert$	τ	$\lambda = \frac{2\pi}{\beta}$	$\delta = \frac{1}{\alpha}$
Perfect dielectric	$\sigma = 0$	$\omega\sqrt{\epsilon\mu}$	0	$\sqrt{\frac{\mu}{\epsilon}}$	0	$\frac{2\pi}{\omega\sqrt{\epsilon\mu}}$	∞
Imperfect dielectric	$\frac{\sigma}{\omega\epsilon} \ll 1$	$\sim \omega\sqrt{\epsilon\mu}$	$\beta\frac{1}{2}\frac{\sigma}{\omega\epsilon} = \frac{\sigma}{2}\sqrt{\frac{\mu}{\epsilon}}$	$\sim \sqrt{\frac{\mu}{\epsilon}}$	$\sim \frac{\sigma}{2\omega\epsilon}$	$\sim \frac{2\pi}{\omega\sqrt{\epsilon\mu}}$	$\frac{2}{\sigma}\sqrt{\frac{\epsilon}{\mu}}$
Good conductor	$\frac{\sigma}{\omega\epsilon} \gg 1$	$\sim \sqrt{\pi f\mu\sigma}$	$\sim \sqrt{\pi f\mu\sigma}$	$\sqrt{\frac{\omega\mu}{\sigma}}$	$45°$	$\sim \frac{2\pi}{\sqrt{\pi f\mu\sigma}}$	$\sim \frac{1}{\sqrt{\pi f\mu\sigma}}$
Perfect conductor	$\sigma = \infty$	∞	∞	0	-	0	0

$$\Gamma = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \qquad \tau = \frac{2\eta_2}{\eta_2 + \eta_1} = 1 + \Gamma$$

$$v = \frac{\omega}{\beta} = \lambda f$$

$$\nabla^2 \tilde{E} = (j\omega\mu)(\sigma + j\omega\epsilon)\tilde{E}$$

TLs:

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

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

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

$$\Gamma_{jk} = \frac{Z_k - Z_j}{Z_k + Z_j}$$

$$\tau_{jk} = 1 + \Gamma_{jk}$$

Half-wave:

$$V_{in} = -V_{out}$$

$$I_{in} = -I_{out}$$

$$Z_{in} = Z_{out}$$

Quarter-wave:

$$V_{in} = jI_{out}Z_0$$

$$I_{in} = \frac{jV_{out}}{Z_0}$$

$$Z_{in} = \frac{Z_0^2}{Z_{out}}$$

$$\cos(\theta) = \frac{e^{j\theta} + e^{-j\theta}}{2}$$

$$\sin(\theta) = \frac{e^{j\theta} - e^{-j\theta}}{2j}$$

Final exam equations, in one place

$$V(d) = V^+ e^{j\beta d}(1 + \Gamma_L e^{-j2\beta d})$$

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

$$z(d) = \frac{1 + \Gamma(\mathrm{d})}{1 - \Gamma(\mathrm{d})}$$

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

$$z(d) = \frac{Z(d)}{Z_0}$$

Resonance:

Type	Input	Output	T.L. Length
Series	Short	Short	$\frac{n\lambda}{2}$, n integer
Series	Short	Open	$\frac{n\lambda}{4}$, n odd integer
Parallel	Open	Short	$\frac{n\lambda}{4}$, n odd integer
Parallel	Open	Open	$\frac{n\lambda}{2}$, n integer

Units

Charge Q: C
Current I: A
Electric field strength $\vec{E}$: N/C or V/m
Electric flux density $\vec{D}$: C/m^2
Polarization field $\vec{P}$: C/m^2
Electric potential V: V
Capacitance C: F
Magnetic flux density $\vec{B}$: T or Wb/m^2
Magnetic field strength $\vec{H}$: A/m
Magnetic flux Ψ: Wb
Electromotive force ε: V
Inductance L: H

Electric permittivity ϵ: F/m
Magnetic permeability μ: H/m
Conductivity σ: Si/m

Charge density ρ: C/m^3
Surface charge density ρ_S: C/m^2
Current density $\vec{J}$: A/m^2

Intrinsic impedance η: Ohm
Wave number β: rad/m

Characteristic impedance Z: Ohm

Office Hours

Any questions?