Name: ____________________

GTID: ____________________

ECE 3065: Electromagnetics
TEST 1 (Spring 2004)

- Please read all instructions before continuing with the test.

- This is a **closed** notes, **closed** book, **closed** friend, **open** mind test. On your desk you should only have writing instruments, a calculator, and a compass+ruler for working Smith chart problems.

- Show all work. (It helps me give partial credit.) Work all problems in the spaces below the problem statement. If you need more room, use the back of the page. DO NOT use or attach extra sheets of paper for work.

- Work intelligently – read through the exam and do the easiest problems first. Save the hard ones for last.

- All necessary mathematical formulas are included either in the problem statements or the last few pages of this test.

- You have 75 minutes to complete this examination. When I announce a "last call" for examination papers, I will leave the room in 5 minutes. The fact that I do not have your examination in my possession will not stop me.

- I will not grade your examination if you fail to 1) put your name and GTID number in the upper left-hand blanks on this page or 2) sign the blank below acknowledging the terms of this test and the honor code policy.

- Have a nice day!

Pledge Signature: ____

I acknowledge the above terms for taking this examination. I have neither given nor received unauthorized help on this test. I have followed the Georgia Tech honor code in preparing and submitting the test.

1. **Short Answer Section (24 points)**

   (a) ________________

   If the intrinsic impedance of a medium is complex, then we know that medium is $\boxed{\textit{Answer}}$.

   (b) ________________

   If you are trying to match a transmission line with input impedance of 1000Ω to a load of 10Ω, you need a quarter-wavelength termination of impedance $\boxed{\textit{Answer}}$.

   (c) __________ (1) __________ (2) __________ (3) __________ (4)

   A simple medium has the following four properties: $\boxed{\textit{Answer 1}}$, $\boxed{\textit{Answer 2}}$, $\boxed{\textit{Answer 3}}$, and $\boxed{\textit{Answer 4}}$.

   (d) ________________

   Snell's law and Fresnel reflection coefficients are derived by enforcing the $\boxed{\textit{Answer}}$ conditions on plane wave fields at the dielectric interface.

   (e) __________ (1) __________ (2) __________ (3) __________ (4)

   A transmission line will have a VSWR of $+\infty$ if it terminates in either one of 4 types of loads (circuit elements): $\boxed{\textit{Answer 1}}$, $\boxed{\textit{Answer 2}}$, $\boxed{\textit{Answer 3}}$, or $\boxed{\textit{Answer 4}}$.

   (f) ________________

   $\boxed{\textit{Answer}}$ is an example of an application that relies on the principle of total reflection.

Optional Survey Question: When did you take ECE 3025 and who was your instructor?

Year: __________ Semester: __________ Instructor: __________

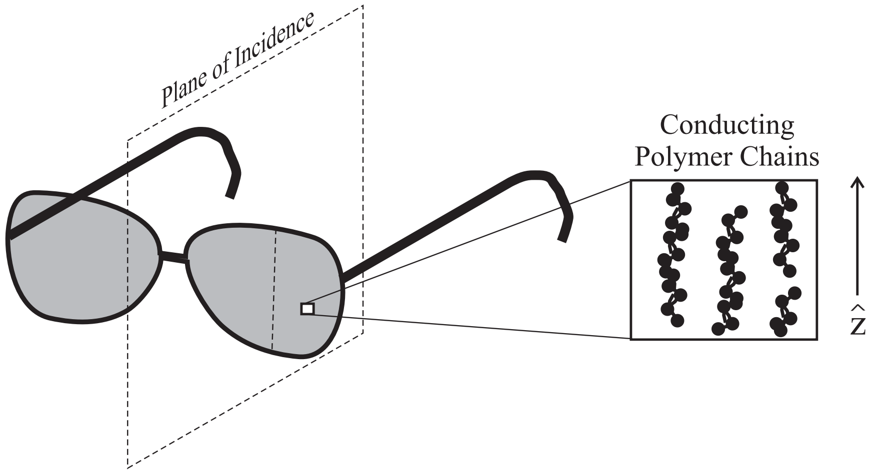
2. **Descriptive Answer Section (16 points)**
Write a **concise** answer to each question in the spaces provided beneath each problem statement. **Note:** Correct answers that are extremely verbose will be penalized.

(a) **Glare (8 points):** *Glare* occurs when smooth surfaces such as water, glass, or metal reflect the light from the overhead sun directly into a person's eyes. Below are two sketches for $\perp$ and $\parallel$ reflection coefficients corresponding to different relative perimittivities in the transmitted medium and air in the incident medium. Based on these graphs, which polarization (vertical or horizontal with respect to an observer) should be dominant in the reflected wave? Assume that there are equal polarization components in the incident wave.

(b) **Polarizing Sunglasses (8 points):** To reduce glare, we use *polarizing sunglasses*, with lenses that contain conducting polymer chains aligned in the vertical direction. These polymer chains allow conductivity in the presence of z-polarized electric fields (along the length of the chains), but not for x or y polarizations. Thus, we say that the conductivity is *anisotropic*, and we can relate $\vec{E}$ and $\vec{J}$ through a matrix:

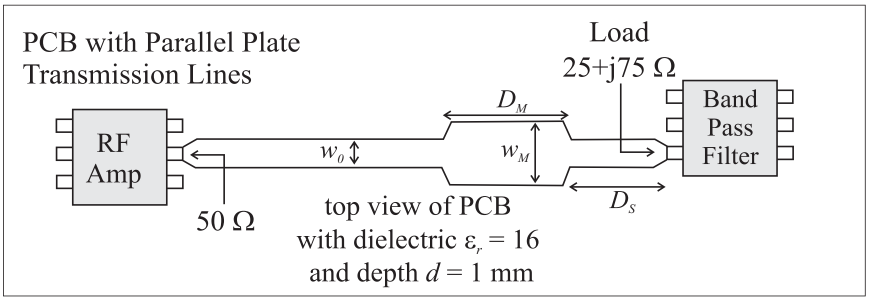
$$\vec{J} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_z \end{bmatrix} \vec{E}$$

Below is the diagram for polarizing sun glasses. Using this as a reference point, write a *short* explanation describing the operation of the polarizing sun glasses. What type of waves are propagating in the air and through the lenses and why? Which type of incident polarization do the glasses block?



3. **Splice Match:**

Below is a schematic for a high-frequency parallel-plate transmission line that connects two RF components. The parallel-plate transmission line consists of a 1mm-thick dielectric layer sandwiched between two striplines of equal length (no ground plane like the microstrip). The initial width of the line is $w_0 = 0.53$mm to achieve a 50Ω impedance. You place a section of parallel-plate line with a different width w_m. Calculate the appropriate values for the matching trace width w_m (in mm), and the line lengths D_m and D_s (in wavelengths). Be sure to use the attached Smith Chart to show your work. (**30 points**)



4. **Circular-Polarized Radio Wave:** A right-hand circularly polarized wave is incident upon a dielectric surface at a grazing angle (θ_i is close to 90°). The equation for its electric field is

$$\tilde{\vec{\mathrm{E}}}_i(\vec{\mathrm{r}}) = \frac{E_i}{\sqrt{2}}(\cos\theta_i\hat{\mathrm{x}} - \sin\theta_i\hat{\mathrm{z}} + j\hat{\mathrm{y}})\exp(-jk[\sin\theta_i\hat{\mathrm{x}} + \cos\theta_i\hat{\mathrm{z}}]\cdot\vec{\mathrm{r}})$$

(a) Make the grazing assumption for reflection coefficients and write the equation describing the reflected electric field, $\tilde{\vec{\mathrm{E}}}_r(\vec{\mathrm{r}})$. (**15 points**)

(b) What is the total electric field (incident plus reflected) on the $z = 0$ plane? (**15 points**)

Cheat Sheet

Electrical Properties of Common Transmission Lines

	L (H/m)	C (F/m)	Impedance, Z_0	v_p
Parallel Plate	$\frac{\mu d}{w}$	$\frac{\epsilon w}{d}$	$\frac{d}{w}\sqrt{\frac{\mu}{\epsilon}}$	$\frac{1}{\sqrt{\mu\epsilon}}$
Coaxial Cable	$\frac{\mu}{2\pi}\ln\left(\frac{b}{a}\right)$	$\frac{2\pi\epsilon}{\ln\left(\frac{b}{a}\right)}$	$\frac{1}{2\pi}\ln\left(\frac{b}{a}\right)\sqrt{\frac{\mu}{\epsilon}}$	$\frac{1}{\sqrt{\mu\epsilon}}$
Stripline	$\frac{Z_0}{v_p}$	$\frac{1}{v_p Z_0}$	$\frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon_{\text{eff}}}}\ln\left(\frac{8b}{a}+\frac{a}{4b}\right)$ $a < b$ $\sqrt{\frac{\mu}{\epsilon_{\text{eff}}}}\frac{1}{1.393+\frac{a}{b}+\frac{2}{3}\ln\left(\frac{a}{b}+\frac{13}{9}\right)}$ $a > b$	$\frac{1}{\sqrt{\mu\epsilon_{\text{eff}}}}$

$^*\epsilon_{\text{eff}} = \epsilon_0\left[\frac{\epsilon_r+1}{2}+\frac{\epsilon_r-1}{2}\frac{1}{\sqrt{1+12b/a}}\right]$ $\quad \epsilon_0 = 8.85\times10^{-12}$ F/m $\quad \mu_0 = 4\pi\times10^{-7}$H/m

$$\lambda f = v_p \qquad \omega = 2\pi f \qquad \beta = \frac{2\pi}{\lambda} \qquad D = Tv_p$$

Reflection: $\Gamma_{L,G} = \dfrac{Z_{L,G}-Z_0}{Z_{L,G}+Z_0}$ $\qquad$ Transmission: $1+\Gamma_{L,G}$

Phasor Transform: $A\cos(2\pi ft+\phi) \longrightarrow A\exp(j\phi)$

Reverse Transform: $\tilde{x} \longrightarrow \text{Real}\left\{\tilde{x}\exp(j2\pi ft)\right\}$

$$v(z) = V^+\exp(-\gamma z) + V^-\exp(+\gamma z)$$

$$i(z) = \frac{V^+}{Z_0}\exp(-\gamma z) - \frac{V^-}{Z_0}\exp(+\gamma z)$$

$$\gamma = \alpha + j\beta = \sqrt{(R+j\omega L)(G+j\omega C)}$$

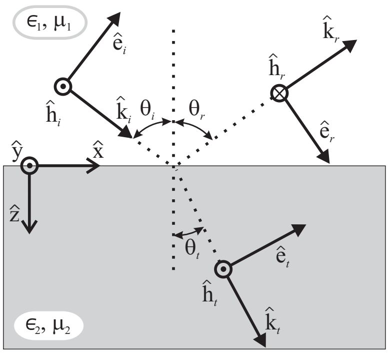
$$Z_{in} = Z_0\frac{Z_L + jZ_0\tan\beta D}{Z_0 + jZ_L\tan\beta D}$$

Quarter Wave Match: $Z_M = \sqrt{Z_0 Z_L}$

$$VSWR = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{1+|\Gamma_L|}{1-|\Gamma_L|}$$

Fresnel Reflection Coefficients for a Dielectric Interface

$\parallel$ Polarization



$$\Gamma_\parallel = \frac{\eta_1 \cos\theta_i - \eta_2 \cos\theta_t}{\eta_1 \cos\theta_i + \eta_2 \cos\theta_t}$$

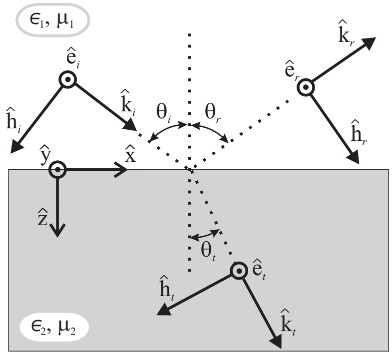
$$\tau_\parallel = \frac{2\eta_2 \cos\theta_i}{\eta_1 \cos\theta_i + \eta_2 \cos\theta_t} = \frac{\cos\theta_i}{\cos\theta_t}\left(1 + \Gamma_\parallel\right)$$

$$\begin{aligned} \hat{\mathrm{k}}_i &= \sin\theta_i \hat{\mathrm{x}} + \cos\theta_i \hat{\mathrm{z}} \\ \hat{\mathrm{e}}_i &= \cos\theta_i \hat{\mathrm{x}} - \sin\theta_i \hat{\mathrm{z}} \\ \hat{\mathrm{h}}_i &= \hat{\mathrm{y}} \end{aligned}$$

$$\begin{aligned} \hat{\mathrm{k}}_r &= \sin\theta_r \hat{\mathrm{x}} - \cos\theta_r \hat{\mathrm{z}} \\ \hat{\mathrm{e}}_r &= \cos\theta_r \hat{\mathrm{x}} + \sin\theta_r \hat{\mathrm{z}} \\ \hat{\mathrm{h}}_r &= -\hat{\mathrm{y}} \end{aligned}$$

$$\begin{aligned} \hat{\mathrm{k}}_t &= \sin\theta_t \hat{\mathrm{x}} + \cos\theta_t \hat{\mathrm{z}} \\ \hat{\mathrm{e}}_t &= \cos\theta_t \hat{\mathrm{x}} - \sin\theta_t \hat{\mathrm{z}} \\ \hat{\mathrm{h}}_t &= \hat{\mathrm{y}} \end{aligned}$$

$\perp$ Polarization



$$\Gamma_\perp = \frac{\eta_2 \cos\theta_i - \eta_1 \cos\theta_t}{\eta_2 \cos\theta_i + \eta_1 \cos\theta_t}$$

$$\tau_\perp = \frac{2\eta_2 \cos\theta_i}{\eta_2 \cos\theta_i + \eta_1 \cos\theta_t} = 1 + \Gamma_\perp$$

$$\begin{aligned} \hat{\mathrm{k}}_i &= \sin\theta_i \hat{\mathrm{x}} + \cos\theta_i \hat{\mathrm{z}} \\ \hat{\mathrm{e}}_i &= \hat{\mathrm{y}} \\ \hat{\mathrm{h}}_i &= -\cos\theta_i \hat{\mathrm{x}} + \sin\theta_i \hat{\mathrm{z}} \end{aligned}$$

$$\begin{aligned} \hat{\mathrm{k}}_r &= \sin\theta_r \hat{\mathrm{x}} - \cos\theta_r \hat{\mathrm{z}} \\ \hat{\mathrm{e}}_r &= \hat{\mathrm{y}} \\ \hat{\mathrm{h}}_r &= \cos\theta_r \hat{\mathrm{x}} + \sin\theta_r \hat{\mathrm{z}} \end{aligned}$$

$$\begin{aligned} \hat{\mathrm{k}}_t &= \sin\theta_t \hat{\mathrm{x}} + \cos\theta_t \hat{\mathrm{z}} \\ \hat{\mathrm{e}}_t &= \hat{\mathrm{y}} \\ \hat{\mathrm{h}}_t &= -\cos\theta_t \hat{\mathrm{x}} + \sin\theta_t \hat{\mathrm{z}} \end{aligned}$$

General Plane Wave Solution

$$\vec{\mathsf{E}}_\diamond(\vec{\mathrm{r}}) = E_\diamond \, \hat{\mathrm{e}}_\diamond \, \exp\left(j\left[\phi - k\hat{\mathrm{k}}_\diamond \cdot \vec{\mathrm{r}}\right]\right) \qquad \vec{\mathsf{H}}_\diamond(\vec{\mathrm{r}}) = \frac{E_\diamond}{\eta} \hat{\mathrm{h}}_\diamond \exp\left(j\left[\phi - k\hat{\mathrm{k}}_\diamond \cdot \vec{\mathrm{r}}\right]\right)$$

$\vec{\mathrm{r}} = x\hat{\mathrm{x}} + y\hat{\mathrm{y}} + z\hat{\mathrm{z}}$ $\quad \eta = \sqrt{\frac{\mu}{\epsilon}}$ $\quad k = \frac{2\pi}{\lambda} = \frac{2\pi f}{v_p}$ $\quad \diamond \rightarrow i$ (incident) **or** r (reflected) **or** t (transmitted)

Snell's Law of Reflection

$$\theta_i = \theta_r$$

Snell's Law of Refraction

$$\frac{\sin\theta_i}{v_{p1}} = \frac{\sin\theta_t}{v_{p2}} \quad \text{where } v_p = \frac{1}{\sqrt{\epsilon\mu}}$$

Physical Quantities

θ_i	angle of incidence	E	electric field amplitude (V/m)
θ_r	angle of reflection	$\Gamma_{\parallel,\perp}$	reflection coefficient ($\frac{E_r}{E_i}$)
θ_t	angle of transmission	$\tau_{\parallel,\perp}$	transmission coefficient ($\frac{E_t}{E_i}$)
$\hat{\mathrm{e}}$	electric field polarization	η	intrinsic impedance (Ω, Ohms)
$\hat{\mathrm{h}}$	magnetic field polarization	v_p	velocity of propagation (m/s)
$\hat{\mathrm{k}}$	direction of propagation	k	wavenumber (radians/m)
μ	magnetic permeability (H/m)	λ	wavelength (m)
ϵ	electric permittivity (F/m)	f	frequency (Hz)