Name: ______________________________

GTID: ______________________________

# ECE 3025: Electromagnetics

## TEST 1 (Fall 2009)

- Please read all instructions before continuing with the test.
- This is a **closed** notes, **closed** book, **closed** calculator, **closed** friend, **open** mind test. You should only have writing instruments on your desk when you take this test. If I find anything on your desk (excluding the test itself, writing instruments, and life-or-death medication) I will turn you in for an honor code violation. I am serious.
- 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 80 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!

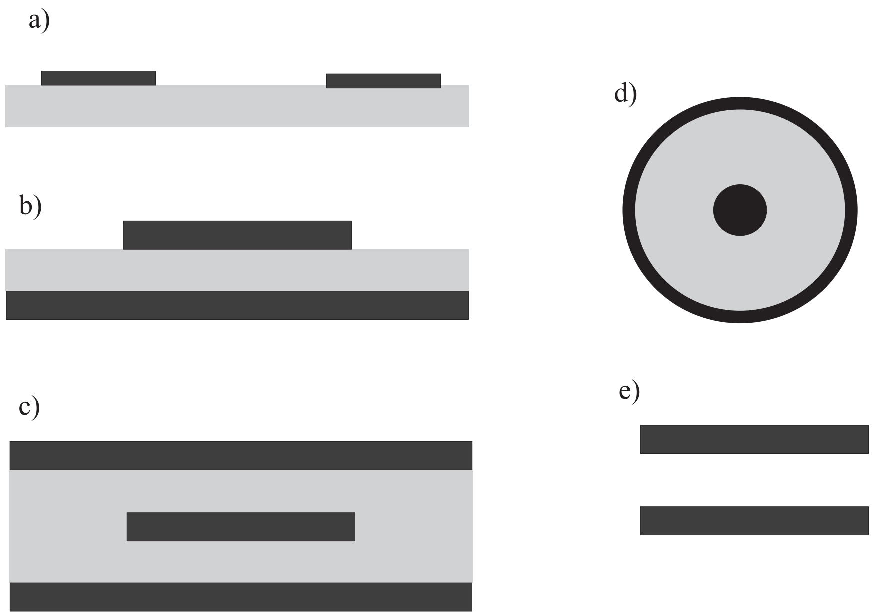
Pledge Signature: ____________________________________________

*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) a) ________ b) ________ c) ________ d) ________ e) ________

Identify the name we use for each of the transmission line cross section geometries illustrated below (dark is metal, gray is dielectric):




(b) ____________

When a transmission line fans-out to $N$ lines (in parallel) with identical input impedance, the forward-looking reflection coefficient is $\boxed{\textit{Answer}}$.

(c) ____________

When a transmission line fans-out to $N$ lines (in series) with identical input impedance, the forward-looking reflection coefficient is $\boxed{\textit{Answer}}$.

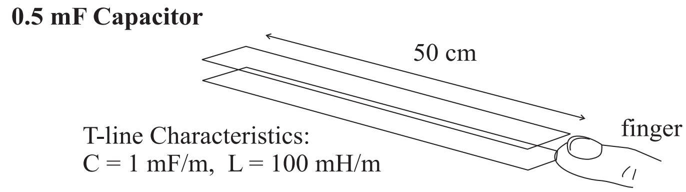
(d) ____________

True or False: Under steady-state time-harmonic excitation, a useful equivalent circuit for a transmission line is two short circuit pathways.

(e) ____________

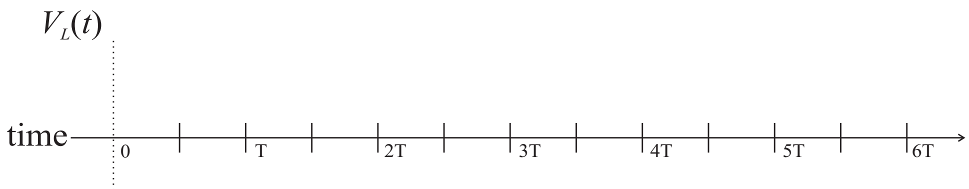
A short circuit load appears to be a $\boxed{\textit{Answer}}$ from the source side of a $\lambda/4$-length transmission line under sinusoidal excitation.

(2) **Discharge of a Long Capacitor:** As a practical joke, you charge up a long, skinny parallel-plate capacitor to 200 V and leave it in your friend's sock drawer. While charged, your friend begins rummaging for socks and touches his $190\Omega$ finger to the end of the capacitor, which can be modeled as a transmission line with intrinsic impedance of $Z_0 = 10\Omega$:

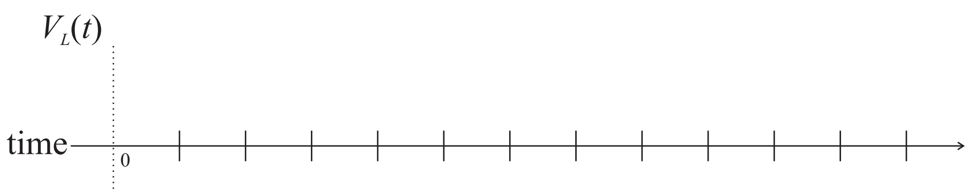



Answer the following questions based on this scenario. (**25 points**)

(a) Sketch the total voltage across the finger as a function of time in the graph below. You do not need to label amplitudes. (**10 points**)



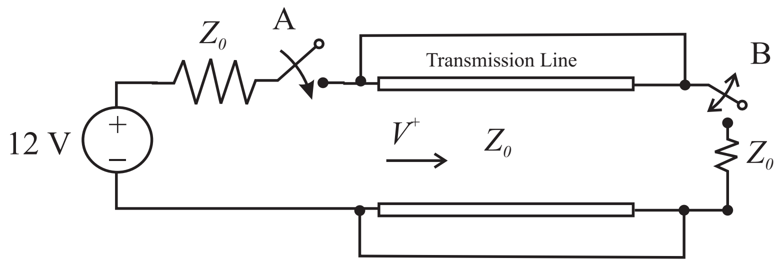

(b) If the capacitor was modeled as a single lumped-parameter circuit (a resistive finger in parallel with a charged capacitor) sketch what the transient would look like. (**10 points**)




(c) Under what condition(s) would the transient graph in part (a) resemble the transient graph in part (b)? (**5 points**)

(d) (**Bonus +5 Points**): Show mathematically how the voltage transient in (b) becomes equivalent to the voltage transient in (a) under certain conditions and identify which conditions lead to this (in terms of $C$, $L$, $Z_0$, $D$, and/or $T$). No partial credit. Do not attempt this unless the rest of the test has been completed to your satisfaction.

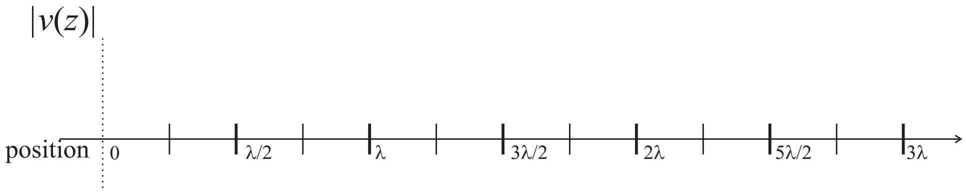
(3) **T-line Sequence Problem:** Below is a transmission line circuit. Fill out the state table for $V^+$ as the circuit is sequentially switched under the following conditions. Note: $V^+$ is measured at the *start* of the transmission line. Assume ideal circuit components. (**22 points**)

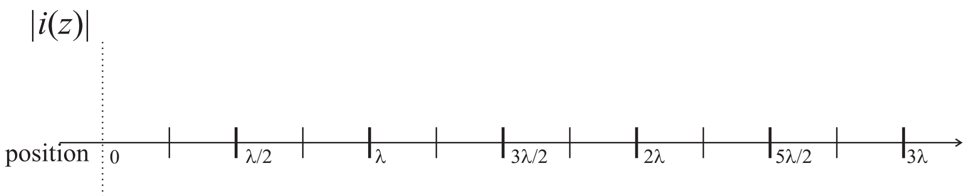



| | $V^+$ | Condition |
|---|---|---|
| State 0 | | Both switches are open and the t-line is discharged |
| State 1 | | Immediately after switch A is closed |
| State 2 | | Switch A has been closed for a while |
| State 3 | | Immediately after switch A is opened |
| State 4 | | Switch A has been open for a while |
| State 5 | | Immediately after switch B is closed |
| State 6 | | Switch B has been closed for a while |
| State 7 | | Immediately after switch A is closed |
| State 8 | | Switch A has been closed for a while |
| State 9 | | Immediately after switch B is opened |
| State 10 | | Switch B has been opened for a while |

(4) **Sinusoidal T-lines:** Answer the following questions based on time-harmonic estimation of a transmission line connected to a load $R_L$. (**35 points**)

(a) Sketch the total voltage and total current across a $3\lambda$-length transmission line if the peak voltage is 10V and the VSWR is 2. The load is purely resistive and $R_L > Z_0$. Label voltage amplitudes (peaks and nulls) on the graph. (**15 points**)




(b) On your graph above, draw arrows pointing to the locations along $z$ that would result in the *highest* possible Thevenin equivalent input impedance for the remaining section of transmission line. Place a circle around all of the locations along $z$ that would likewise result in the lowest possible Thevenin equivalent input impedance. (**5 points**)

(c) Based on the information of part (a), solve for $R_L$ in terms of $Z_0$. (**10 points**)

(d) Would the VSWR increase or decrease if the load was replaced with an inductor? Explain why. (**5 points**)

# Formula Sheet

$$\frac{\partial^2 v(z,t)}{\partial z^2} = LC\frac{\partial^2 v(z,t)}{\partial t^2} \qquad \frac{\partial^2 i(z,t)}{\partial z^2} = LC\frac{\partial^2 i(z,t)}{\partial t^2} \qquad Z_0 = \sqrt{\frac{L}{C}} \qquad v_p = \frac{1}{\sqrt{LC}}$$

$$\lambda f = v_p \qquad \omega = 2\pi f \qquad \beta = \frac{2\pi}{\lambda} \qquad \text{Reflection: } \Gamma_{L,G} = \frac{Z_{L,G} - Z_0}{Z_{L,G} + Z_0} \qquad \text{Transmission: } 1 + \Gamma_{L,G}$$

$$\text{Phasor Transform: } A\cos(2\pi f t + \phi) \longrightarrow A\exp(j\phi)$$

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

$$v(z,t) = V^+ f\left(t - \tfrac{z}{v_p}\right) + V^- g\left(t + \tfrac{z}{v_p}\right) \qquad \tilde{v}(z) = V^+\exp(-j\beta z) + V^-\exp(+j\beta z)$$

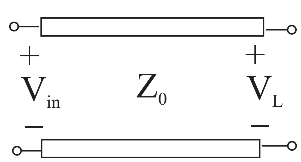
$$i(z,t) = \tfrac{V^+}{Z_0} f\left(t - \tfrac{z}{v_p}\right) - \tfrac{V^-}{Z_0} g\left(t + \tfrac{z}{v_p}\right) \qquad \tilde{i}(z) = \tfrac{V^+}{Z_0}\exp(-j\beta z) - \tfrac{V^-}{Z_0}\exp(+j\beta z)$$

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

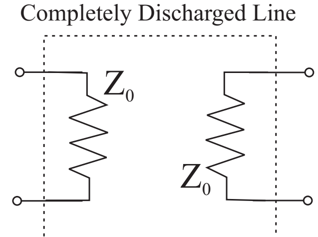
$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|}$$

$$V^+ = \frac{V_L + I_L Z_0}{2} \qquad V^- = \frac{V_L - I_L Z_0}{2}$$

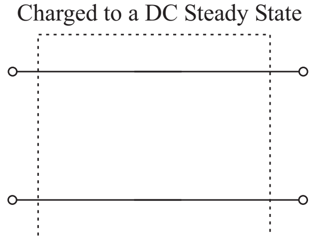
**Useful Equivalent Circuits for T-lines**



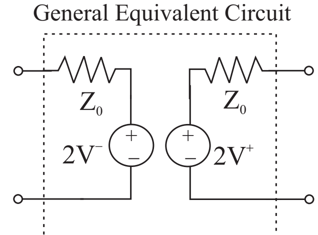

Completely Discharged Line




Charged to a DC Steady State



General Equivalent Circuit




$$\mu = \mu_r\mu_0 \qquad \mu_0 = 4\pi\times 10^{-7}\ \text{H/m} \qquad \epsilon = \epsilon_r\epsilon_0 \qquad \epsilon_0 = 8.854\times 10^{-12}\ \text{F/m}$$

$$\text{Time Constant: } \tau = RC$$