University of Calgary

Schulich School of Engineering

Department of Electrical and Computer Engineering

ENEL 476 – Electromagnetic Waves and Applications

Final Examination

Winter Session 2013
April 22 (8 am to 11 am)

3 hours
Closed book

Student name: _____

EXAMINATION RULES AND REGULATIONS

STUDENT IDENTIFICATION

Each candidate must sign the Seating List confirming presence at the examination. All candidates for final examinations are required to place their University of Calgary I.D. cards on their desks for the duration of the examination. (Students writing mid-term tests can also be asked to provide identity proof.) Students without an I.D. card who can produce an acceptable alternative I.D., e.g., one with a printed name and photograph, are allowed to write the examination.

A student without acceptable I.D. will be required to complete an Identification Form. The form indicates that there is no guarantee that the examination paper will be graded if any discrepancies in identification are discovered after verification with the student's file. A Student who refuses to produce identification or who refuses to complete and sign the Identification Form is not permitted to write the examination.

EXAMINATION RULES

(1) Students late in arriving will not normally be admitted after one-half hour of the examination time has passed.

(2) No candidate will be permitted to leave the examination room until one-half hour has elapsed after the opening of the examination, nor during the last 15 minutes of the examination. All candidates remaining during the last 15 minutes of the examination period must remain at their desks until their papers have been collected by an invigilator.

(3) All inquiries and requests must be addressed to supervisors only.

(4) Candidates are strictly cautioned against:
- (a) speaking to other candidates or communicating with them under any circumstances whatsoever;
- (b) bringing into the examination room any textbook, notebook or document not authorized by the examiner;
- (c) making use of calculators, cameras, cell-phones, computers, headsets, pagers, PDA's, or any device not authorized by the examiner;
- (d) leaving answer papers exposed to view;
- (e) attempting to read other student's examination papers.

The penalty for violation of these rules is suspension or expulsion or such other penalty as may be determined.

(5) Candidates are requested to write on both sides of the page, unless the examiner has asked that the left hand page be reserved for rough drafts or calculations.

(6) Discarded matter is to be struck out and not removed by mutilation of the examination answer book.

(7) Candidates are cautioned against writing on their examination paper any matter extraneous to the actual answering of the question set.

(8) The candidate is to write his/her name on each answer book as directed and is to number each book.

(9) During the examination a candidate must report to a supervisor before leaving the examination room.

(10) Candidates must stop writing when the signal is given. Answer books must be handed to the supervisor-in-charge promptly. Failure to comply with this regulation will be cause for rejection of an answer paper.

(11) If during the course of an examination a student becomes ill or receives word of a domestic affliction, the student should report at once to the supervisor, hand in the unfinished paper and request that it be cancelled. If physical and/or emotional ill health is the cause, the student must report at once to a physician/counsellor so that subsequent application for a deferred examination is supported by a completed Physician/Counsellor Statement form. Students can consult professionals at University Health Services or University Counselling Services during normal working hours or consult their physician/counsellor in the community.
Once an examination has been handed in for marking a student cannot request that the examination be cancelled for whatever reason. Such a request will be denied. Retroactive withdrawals will also not be considered.

(12) Smoking during examinations is strictly prohibited.

Instructions

1. This is a closed book exam. No texts or notes are allowed.
2. Show as much of your reasoning as time permits. Write your answers in the examination booklets.
3. A programmable calculator is permitted.
4. Formulas and Smith Charts are provided at the end of the question pages.
5. Hand in all pages. If you detach any pages(s), write your name and UCID number on the detached page(s).
6. If you write anything you do not want marked, put a large X through it and write "Rough work" beside it.

1. (20 marks)

Consider a lossless transmission line with capacitance per unit length of C=15 pF/m and impedance of Z_o=300 Ω. The frequency of operation corresponds to $\omega=10^8$ rad/s.

a) Find the inductance per unit length (L). (2 marks)

b) Find the phase constant, β.(2 marks)

c) Find the wavelength, λ. Consider a 20-m length of line. How many wavelengths does 20-m represent? (3 marks)

d) Is the line distortionless? (3 marks)

A load is attached to the end of 20-m of line. The impedance of the load is

Z_L=440-j265 Ω.

e) Using the appropriate equation, calculate the reflection coefficient, Γ_L. (3 marks)

f) What is the standing wave ratio, s? (2 marks)

g) Using the appropriate equation, calculate the input impedance looking into the 20-m line terminated by the load (Z_{in}). (5 marks)

2. (20 marks)

A transmission line with $Z_o=50\ \Omega$ is terminated with a load of $Z_L=170\text{-}j20\ \Omega$. The frequency of operation is f=2 GHz and the phase velocity on the line is $v_p=0.8c$ where c is the speed of light in free space. Use the Smith chart to solve the following questions. Summarize your results on the question paper.

a) Find the reflection coefficient, Γ_L. (4 marks)

b) Find the standing wave ratio, s. (2 marks)

c) Find the distance to the first voltage maximum, $V_{max.}$ (2 marks)

d) Design a quarter-wavelength transformer to match the load to the line. Give the location from the load, length and impedance of the $\lambda/4$ transformer. (4 marks)

e) Design a shunt stub tuner with a shorted stub to match the line to the load. Indicate the location of the stub, and the length of the stub. (8 marks)

3. (20 marks)

An electric field is propagating in seawater (ε_r=72, μ_r=1, σ=5 S/m). The electric field is oriented in the y direction and the wave propagates in the z-direction. The field has amplitude at z=0 of 2.0 V/m. The frequency is 1 MHz.

a) Calculate the attenuation coefficient, α. (3 marks)

b) Calculate the phase constant, β. (1 mark)

c) Find an expression to describe the instantaneous electric field, $\mathbf{E}(z,t)$. (5 marks)

d) Express the electric field in phasor form, $\mathbf{E}_s(z)$. (4 marks)

e) Find the intrinsic impedance of the medium, η. (2 marks)

f) Find an expression to describe the instantaneous magnetic field, $\mathbf{H}(z,t)$. (3 marks)

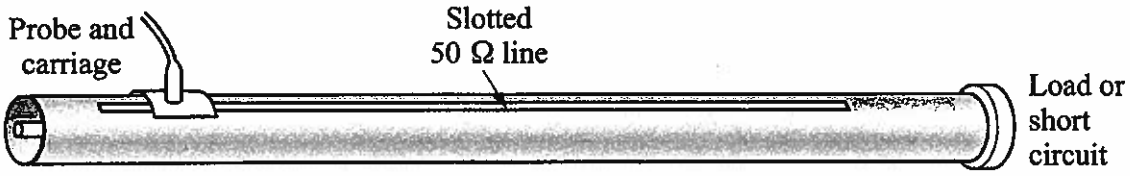
g) What would be different if the frequency of interest was 1 kHz? (2 marks)

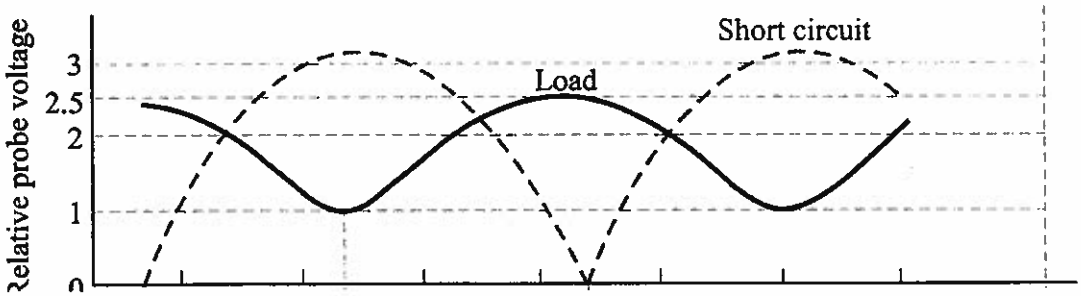
4. (40 marks)

You would like to design a system to detect sub-surface reflections.

You have an antenna available that operates at 100 MHz, however the impedance is unknown. You decided to use a slotted line to characterize with unknown impedance. The velocity of propagation on the line is the same as in free space.

You collect a set of measurements with the antenna attached, then collect a second set of measurements with a short attached. The resulting measurements are shown in the figure below. The separation between minima with the short attached is 1.5 m. With the load attached, the location of the minimum shifts by 50 cm.





a) Find the standing wave ratio with the antenna attached to the slotted line (s). (3 marks)

b) Find the wavelength, λ. (2 marks)

c) Using the Smith chart, find the unknown impedance of the antenna. (5 marks)

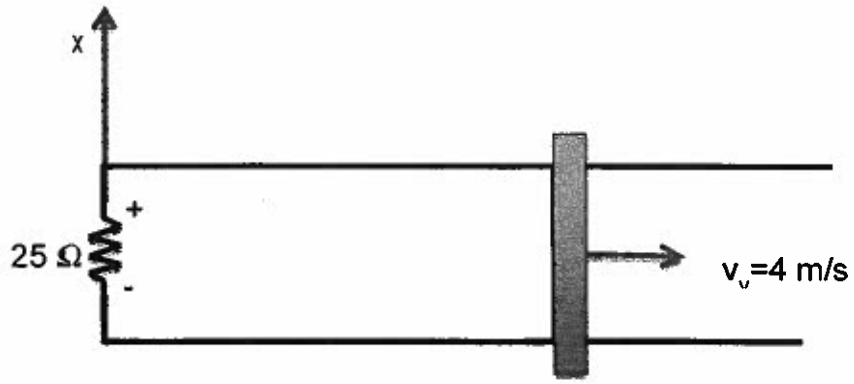
d) You decide to attach the antenna to a boom such that it is positioned several meters above the ground. You decide to model the field traveling from the antenna to the ground as a uniform plane wave. You estimate that the incident electric field has amplitude of 10 V/m. The wave propagates in the –z direction, and the electric field is oriented in the +y direction. Find an expression for the instantaneous electric field ($\mathbf{E}^{inc}(z,t)$). (5 marks)

e) You want to figure out how much of the incident field is reflected from the interface between the air (ε_o, μ_o) and ground (ε_r=2.4, μ_r=1, σ=0.02 S/m). Calculate the reflection coefficient (Γ). Find expressions for the reflected and transmitted electric fields ($\mathbf{E}^{refl}(z,t)$, $\mathbf{E}^{trans}(z,t)$). (22 marks)

f) You are aiming to detect buried objects. Find an expression for the Poynting vector of the transmitted field ($\mathbf{P}_{avg}(z)$. What is the time-averaged power density at a depth of 1 m? (3 marks)

5. (10 marks)

Consider a bar sliding on a set of parallel rails, as shown in the figure below. The separation between the bars in the x-direction is 20 cm. At time t=0, assume that the bar is at y=0.



The rails and bars are placed in a magnetic field with flux density

$$\mathbf{B}=(4.0\,\mathbf{a}_x + 3.0\,\mathbf{a}_z)\ \text{mWb/m}^2$$

Find the induced current. Indicate the direction of current flow.

Name	
Q1	
Q2	
Q3	
Q4	
Q5	
Total	