University of Calgary

Schulich School of Engineering

Department of Electrical and Computer Engineering

ENEL 476 – Electromagnetic Waves and Applications

Final Examination

Winter Session 2014

April 24, 2014 at 8 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 memoranda not authorized by the examiner;

(c) making use of calculators and/or portable computing machines not authorized by the instructor;

(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 in their answer book 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) A candidate must report to a supervisor before leaving the examination room.

(10) Answer books must be handed to the supervisor-in-charge promptly when the signal is given. 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.

Should a student write an examination, hand in the paper for marking, and later report extenuating circumstances to support a request for cancellation of the paper and for another examination, such a request will be denied.

(12) Smoking during examinations is strictly prohibited.

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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) Calculators are permitted.
(4) Formulas 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.

Question 1. (17 marks)

Consider a uniform plane wave propagating in a lossy dielectric medium. The lossy medium is characterized by σ=1 S/m, $\varepsilon=9\varepsilon_o$ and μ_o.

a) Find an expression for the ratio between conduction and displacement current. At what frequency would you expect the material to be a good conductor? (2 marks)

Consider a frequency of 600 MHz.

b) Calculate the attenuation constant (α) and phase constant (β). (4 marks)

The amplitude of the electric field is 10 V/m at y=0, the wave propagates in the -y direction and the electric field is oriented in the +x direction.

c) Write an expression for the electric field in time-domain form ($\mathbf{E}(y,t)$). (5 marks)

d) Write an expression for the electric field in phasor form ($\mathbf{E}_s(y)$). (1 mark)

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

f) Find an expression for the magnetic field in phasor form ($\mathbf{H}_s(y)$). (3 marks)

Question 2 (21 marks)

A ground penetrating radar system is modeled as a uniform plane wave in free space impinging on the ground at normal incidence. The incident electric field (in free space, so properties are ε_o, μ_o, σ=0) is given by:

$$\mathbf{E}^i(x,t)=10\cos(10^9 t-3.3x)\mathbf{a}_y \quad \text{V/m}$$

a) Find the wavelength. (2 marks)

The ground has properties of ε_r=4, μ_r=1, and σ=0.1 S/m.

b) Calculate the reflection (Γ) and transmission (T) coefficients. (6 marks)

c) Find an expression for the reflected electric field ($\mathbf{E}^r(x,t)$). (3 marks)

d) Find an expression for the transmitted electric ($\mathbf{E}^t(x,t)$) and magnetic fields ($\mathbf{H}^t(x,t)$). (7 marks)

e) Calculate the time-averaged Poynting vector ($\mathbf{P}_{av}(x)$) for the transmitted field. Given a required power density of 1 mW/m^2 at depths of up to 1 m for detection of landmines, will these fields be sufficient for detection? (3 marks)

Question 3 (20 marks)

A load of impedance Z_L=30-j60 Ω is attached to a transmission line with 75 Ω characteristic impedance (Z_o=75 Ω). The frequency of operation is 5 GHz and the wavelength on the line is 6 cm. Use the Smith Chart to solve the following questions.

a) Find the reflection coefficient at the load (Γ). (3 marks)

b) Find the standing wave ratio (s). Verify with the appropriate equation (3 marks)

c) Find the input impedance Z_{in} for a line of length of 5.0 cm attached to the load. (5 marks)

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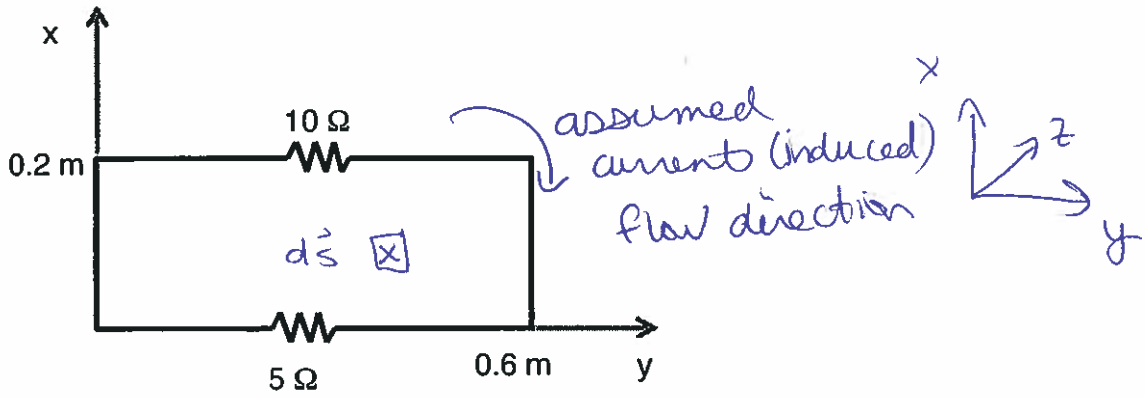
Question 4 (12 marks)

Consider the loop containing two resistors below. The loop is placed in a magnetic flux density described by:

$$\mathbf{B}=25\cos(35\pi t-2y)\mathbf{a}_z \text{ mWb/m}^2$$



a) Find the induced current in the loop. (9 marks)

b) Indicate the direction of initial induced current flow ~~during the first quarter period~~ on the figure above. Describe how this satisfies Lenz's law. (3 marks)

a) $I=\frac{V_{emf}}{R} \Rightarrow V_{emf}=$ $-\frac{d\Phi}{dt}$ ← transformer

$-\int \frac{\partial \vec{B}}{\partial t}\cdot d\vec{s}$

$\Phi=\int \vec{B}\cdot d\vec{s}$

$\Phi=\int_0^{0.6}\int_0^{0.2}(25)(\cos(35\pi t-2y)\,dx\,dy$

$V_{emf}=87.5\pi\left[\cos(35\pi t-1.2)-\cos(35\pi t)\right]$

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d) Find the admittance of the load (Y_L). (3 marks)

e) Find the distance from the load to the first voltage minimum. (2 marks)

f) Find the shortest distance to a purely resistive load. (2 marks)

g) Indicate the locations of the short and open on the Smith chart (2 marks).

Question 5. (20 marks)

An antenna is to be connected to a transmission line with 100 Ω impedance (Z_o=100 Ω).

A slotted line is used to characterize the antenna behaviour. With a short attached, the voltage minima are located at 2, 5 and 8 cm. With the antenna attached, these minima shift to 2.5, 5.5 and 8.5 cm. The standing wave ratio is 4. The velocity of propagation is 0.8c (where c=3x10^8 m/s).

a) Find the operating frequency. (2 marks)

b) Find the impedance of the antenna. (4 marks)

c) Design a quarter-wavelength transformer to match the antenna to the transmission line. Indicate the location relative to the load, the length of line assuming velocity of propagation is 0.8c, and the impedance of the quarter-wavelength section of line. (6 marks)

d) Design a shunt stub tuner to match the antenna to the line. Select the shorted stub with the minimum length. (8 marks)

Question 6. (10 marks; 2 marks each)

Part 1

A coaxial line has R=6 Ω/m, L=3 μH/m, G=8 mS/m and C=4 nF/m.
The frequency of operation is 1 MHz. Which of the following sets of parameters describe the coaxial line?

A. Z_o=27.4 Ω, α=0.22 Np/m and β=0.022 rad/m

B. Z_o=27.4 Ω, α =0.22 Np/m and β =0.69 rad/m

C. Z_o=274 Ω, α =2.2 Np/m and β =0.22 rad/m

D. Z_o=0.0365 Ω, α =3.5 nNp/m, β =1.38 Mrad/m

Part 2

Is the coaxial line described in the previous question distortionless?

A. Yes

B. No

Part 3

Consider a parallel plate capacitor that is connected to a 10 V generator operating at 10 MHz. The capacitor is filled with a material having relative permittivity of 2.5 (ε_r=2.5). For a plate separation of 0.25 mm and plate area of 2 cm^2, the maximum value of the total displacement current is:

A. 55.6 mA
B. 22.2 mA
C. 9 mA
D. 0.35 nA

Part 4:

An electric field in phasor form is described as:

$$\mathbf{E}_s = 40e^{j10z}\,\mathbf{a}_x + 60e^{j10z}\,\mathbf{a}_y \text{ V/m}$$

The polarization of the wave is:

A. Right elliptical
B. Left elliptical
C. Right circular
D. Linear

Part 5:

A 50 Ω transmission line is half of a wavelength in length. If the transmission line is terminated with a load of Z_L=10-j30 Ω, then the impedance looking into the line terminated by the load is:

A. Not possible to calculate.
B. Z_{in}=10+j30 Ω
C. Z_{in}=30-j10 Ω
D. Z_{in}=10-j30 Ω

Question	Mark
1	17
2	21
3	20
4	12
5	20
6	10
Total	