University of Calgary

Schulich School of Engineering

Department of Electrical and Computer Engineering

ENEL 476 – Electromagnetic Waves and Applications

Final Examination

Winter Session 2015

April 22, 2015 at 8 am in KN Gold

Instructor: Dr. E. Fear

3 hours

Closed book; Calculators Permitted

15 pages

Question	Mark
1	15
2	25
3	30
4	20
5	8
6	12
Total	110

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.

RO 94-01

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 (15 marks).

A shunt stub tuner has been designed with the stub located 9 mm from the load. The stub is terminated in an open circuit and has length of 4 mm. The frequency of operation is 10 GHz and the velocity of wave propagation on the transmission line is 1×10^8 m/s. The impedance of the line is 60 Ω. For parts c-f, show your work clearly on a Smith Chart.

a) What is the wavelength? (2 marks)

b) What are the stub length and location in terms of wavelength? (2 marks)

c) What is the input admittance of the stub? (3 marks)

d) What is the normalized input admittance of the line at the location where the stub is attached? (2 marks)

e) What is the normalized admittance of the unknown load? (3 marks)

f) What is the impedance of the unknown load? (3 marks)

Question 2 (25 marks).

A distortionless transmission line has R=5 Ω/m, L=20 μH/m, C=30 nF/m and is operated at 10 MHz.

Calculate the following quantities:

a) G (2 marks)

b) the impedance of the line, Z_o (2 marks)

c) the attenuation of the line, α (2 marks)

d) the phase constant of the line, β (2 marks)

e) the wavelength on the line, λ (1 mark)

A load of Z_L=30-j40 Ω is attached to 6 cm of the transmission line.

f) Using the appropriate equation, find Z_{in} for the section of transmission line terminated by the load. If you were not able to solve the first part of the question, use Z_o=50 Ω. (2 marks)

Solve the following sections of the question using a Smith Chart.

g) Plot the load (Z_L=30-j40 Ω) on the Smith Chart. (2 marks)

h) Find the reflection coefficient. (3 marks)

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

j) Find the shortest distance from the load to a voltage maximum. (2 marks)

k) Find Z_{in} at a distance of 6 cm from the line. Does this agree with the result that you found in part f)? Explain any discrepancies. (5 marks)

Question 3 (30 marks).

At a sufficient distance from an antenna, the fields radiated by the antenna may be represented using a uniform plane wave. Assume that the fields are traveling in a source-free region of free space ($\varepsilon=\varepsilon_o$, $\mu=\mu_o$, $\sigma=0$). The electric field is given by:

$$\mathbf{E}(x,t)=100\cos(6\times10^9 t-\beta x)\,\mathbf{a}_y \text{ V/m}$$

Find the:

a) frequency (f) (2 marks)

b) wavelength (λ) (2 marks)

c) phase constant (β) (2 marks)

d) magnetic field ($\mathbf{H}(x,t)$) (2 marks)

The antenna system is being used for thru-wall inspection (i.e. waves travel through a wall and detect objects on the other side). The wall has $\varepsilon_r=3$, $\sigma=0.01$ S/m and $\mu_r=1$. Given that the wave is normally incident on the wall, find the:

e) attenuation coefficient (α) (2 marks)

f) phase constant (β) (2 marks)

g) intrinsic impedance (η) (3 marks)

h) reflection coefficient (Γ) (3 marks)

i) transmission coefficient (T) (3 marks)

j) velocity at which the wave travels in the wall (2 marks)

k) For the incident field given above, find expressions for the reflected electric ($\mathbf{E}^r(x,t)$) and magnetic ($\mathbf{H}^r(x,t)$) fields. (3 marks)

l) For the incident field given above, find expressions for the transmitted electric ($\mathbf{E}(x,t)$) and magnetic ($\mathbf{H}(x,t)$) fields associated with the wave traveling in the wall. (4 marks)

Question 4 (20 marks).

Electromagnetic heating of oil sands has been proposed as a method to aid in extraction. Assume that bitumen has the following properties at 10 MHz: ε_r=20, σ=0.5 S/m, μ_r=1. The fields used during heating may be modeled with uniform plane waves.

Assume that the electric field in bitumen has amplitude of 100 kV/m at the surface of the bitumen. The field is propagating in the –z direction and oriented in the x direction.

a) If the properties of the bitumen do not change with frequency, what is the frequency at which bitumen may be considered a good conductor? (2 marks)

b) Find the attenuation constant (α) (1 mark)

c) Find the phase constant (β) (1 mark)

d) Find the intrinsic impedance (η) (2 marks)

e) Write expressions for the electric field of the uniform plane wave in time and phasor forms ($\mathbf{E}(z,t)$ and $\mathbf{E}_s(z)$). Specify the relevant quantities (e.g. frequency). (5 marks)

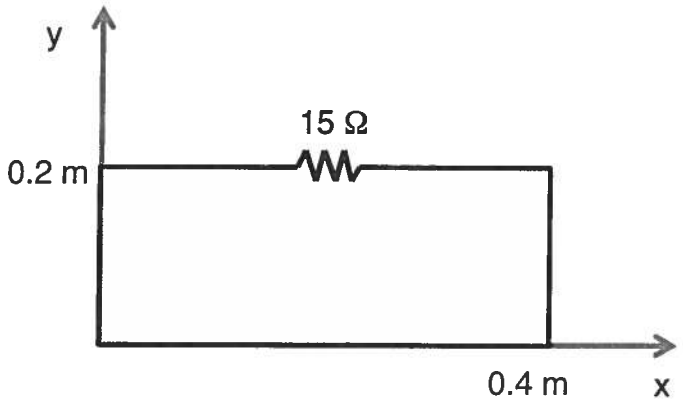
f) Write an expression for the magnetic field of the uniform plane wave ($\mathbf{H}(z,t)$). (4 marks)

g) Write an expression for the Poyting vector. If significant heating occurs where the power is 25% of its initial value, over what depths does significant heating occur? Does the proposed frequency provide good results? If not, suggest a modification to the approach. (5 marks)

Question 5 (8 marks).

Consider the loop containing a resistor as shown below. The loop is placed in a magnetic flux density described by:

$$\mathbf{B}=-20\cos(100\pi t-\pi/3)\mathbf{a}_z \text{ mWb/m}^2$$



a) Find the EMF (V_{emf}) (4.5 marks).

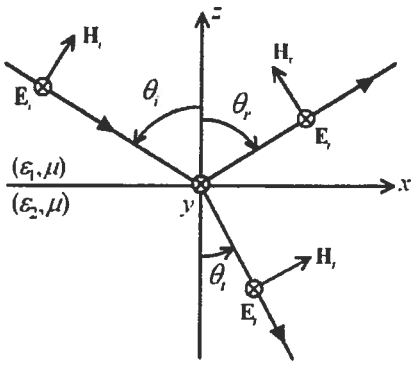
b) Calculate the induced current in the loop. Indicate the direction of current flow during the first quarter period on the figure above. (3.5 marks)

Question 6 (12 marks; 2 marks each part).

1. A transmission line of impedance Z_o=75 Ω is terminated by a load with Z_L=100-j30 Ω. If the incident power is 10 mW, the power at the load is:

   a) 0.5 mW
   b) 7.8 mW
   c) 9.5 mW
   d) 10.5 mW

2. Region 1 is free space, while region 2 is a lossless dielectric with $\varepsilon_2=4\varepsilon_o$. For the wave shown in the figure below, the angle of incidence (θ_i) is 50^0.



   The angle of transmission (θ_t) is:

   a) 11.0°
   b) 22.5°
   c) 90°

   The reflection coefficient is:

   a) -0.13
   b) -0.16
   c) -0.48
   d) -0.51

3. You want to match a 100 Ω load to a 50 Ω line using a quarter-wave transformer. The frequency is 1 GHz and the velocity of wave travel on the transmission line is 0.75 c.

   The impedance of the quarter-wavelength section is:

   a) 50 Ω
   b) 66.7 Ω
   c) 70.7 Ω
   d) 100 Ω

   The length of the quarter-wavelength section is:

   a) 5.6 cm
   b) 7.5 cm
   c) 11.25 cm
   d) 15.0 cm

4. What is the polarization of the wave described by:

$$\mathbf{E}(z,t)=15\cos(2\pi x10^{9}t-10z)\mathbf{a}_x+20\cos(2\pi x10^{9}t-10z)\mathbf{a}_y$$

   a) Linear
   b) Elliptical
   c) Circular