ECEN 3410, Spring 2015, Zoya Popovic
Study Questions for Midterm and Final

The questions below are intended to be a guideline for studying this material and they should follow your class notes closely in terms of order and content. The material is, of course, in your textbooks or notes posted on the class web page, but not necessarily in the same order.

Maxwell’s equations:

1. Write Maxwell’s equations in integral form. Give names and units for all quantities.
2. Derive the point form of:
   a. Faraday’s law starting from the integral form. What does this law mean? What is the meaning of the negative sign?
   b. Maxwell-Ampere’s law from the integral form. What does this law mean? What currents exist and what are their unique features?
   c. Gauss’ laws for electric and magnetic fields. What do these mean?
3. How can we classify electromagnetic fields based on the time-dependence of these fields? Explain the unique features of these fields.
4. How do we convert time-domain forms into phasors? For a given phasor …. write down its time-domain form. When and why are phasors useful?
5. Write Maxwell’s equations in complex form.
6. What is the continuity equation? Write it in integral form and explain the meaning of the equation.
7. Starting from Maxwell’s equations, derive the boundary conditions for the tangential electric and magnetic field vectors at the boundary between two electrically dissimilar media.
8. Derive the boundary conditions for the normal electric flux density and magnetic induction (magnetic flux density) vectors at the boundary between two electrically dissimilar media.
9. What are the boundary conditions on a perfect electric conductor? Sketch the problem and show all relevant parameters.
10. Derive the Poynting theorem starting from Maxwell’s equations. What is the Poynting vector? Then, show expressions for a linear, time-invariant medium.
11. Write the Poynting theorem for isotropic, linear, time-invariant medium with all losses coming from the conduction currents. What is the physical meaning?

Plane waves:

12. What are electromagnetic waves? What are uniform plane waves? How are electromagnetic waves created?
13. Starting from Maxwell’s equations, derive the wave equation for electric fields in a homogeneous, time-invariant, linear, source free medium.
14. Derive the wave equation for magnetic fields in a homogeneous, time-invariant, linear, source free medium. Start from Maxwell’s equations.
15. Prove that the E- and H- vectors of a uniform plane wave are perpendicular to each other. Then, for an E-field oscillating in the x-direction and propagating along the z-axis, derive d’Alambert’s equations and show the time domain solutions.
16. Define wave impedance, phase coefficient, and velocity of a plane wave. What happens with these values if the permittivity of the medium is increased 4 times?
17. What is the approximate speed of light in fresh water? What about the wave impedance?
18. What is a transverse electromagnetic wave?
19. Define phase and group velocities and sketch a \( \omega-\beta \) diagram for these two.
20. What is dispersion? Derive the expression for the relationship between the phase and group velocities. What kinds of dispersion exist and where are they found?
21. Derive the E-field wave equation for uniform plane waves in phasor form.
22. Derive the H-field wave equation for uniform plane waves in phasor form.
23. What is the polarization of electromagnetic waves? What polarizations exist? What is the polarization sense?
24. How can you create circular polarization? What is the difference between left and right circular polarization? What is the difference between circular and linear polarizations?
25. If an x-component of the E-field varies as a sine function, and y-field component varies as a cosine function; assuming that the \( E_x = 0.7E_y \), what is the polarization of the resultant wave which propagates in the positive z-direction. For frequency \( f \), write the full expression in time domain for the electric field of a plane wave propagating in vacuum.
26. What is the skin effect? What is the physics of the skin effect? What is skin depth? Sketch the current distribution up to 5 skin depths inside the conductor with conductivity \( \sigma \).
27. If the skin depth for copper at 1kHz is 2.1mm, what is its value at 1GHz? Two metals, A and B, have their permittivities and conductivities relates as \( \mu_A = 1000 \mu_B \), and \( \sigma_A = 0.01 \sigma_B \), respectively. Which one will have a longer penetration depth?

**Plane-waves reflection and refraction:**

29. Write all the relationships you know between the angles, and propagation vectors for the case of oblique incidence on the boundary between two media. Assume you know the constitutive parameters of both media. Include a sketch and label all relevant parameters.
30. Determine the total electric field for the normal polarization. Write the time-domain form. Include a sketch and label all relevant parameters. What are the corresponding Fresnel coefficients?
31. Determine the total electric field for the parallel polarization. Write the time-domain form. Include a sketch and label all relevant parameters. What are the corresponding Fresnel coefficients?
32. What happens when a wave enters an optically (electrically) denser medium? Show it mathematically and explain the physics.
33. What happens when a wave enters an optically (electrically) less dense medium? Show it mathematically and explain the physics.
34. What is the critical angle? Derive the expression and provide a physical explanation.
35. How would you design a radome (cover for an antenna) to protect it from wind, but not affect the radiated wave? Give the relevant equations and explain the limitations of your approach/
36. How would you design a coating that maximizes the amount of the power from a red laser transmitted from air into glass? Give the relevant equations. Comment on the limitations of your anti-reflection coating and on how you would improve it if needed.
37. What types of polarizers are used in the optical frequency region, and why is a grid polarizer not practical in that frequency range?
38. Sketch a wire grid polarizer with an elliptically polarized incident wave. Write the equation for the incident E-field components along and perpendicular to the wires. Write the expression for
the reflected wave and the transmitted wave assuming a well-designed lossless polarizer. Do not forget to include a coordinate system in your figure.

Transmission lines:

39. What type of wave propagates in a coaxial cable? Derive the expressions for the electric field vector, magnetic field vector and Poynting vector.

40. Prove that in a coaxial line fed with a matched generator of voltage \( V \), with a current \( I \) flowing in the cable, the flux of the Poynting vector through the transverse cross-section equals the power \( VI \).

41. Derive the telegrapher equations and the voltage wave equation in a lossless coaxial line in time domain. What are the solutions of this equation and what do they mean?

42. Derive the telegrapher equations and the voltage wave equation in a lossless coaxial line for a time-harmonic generator. What are the solutions of this equation and what do they mean?

43. Repeat the above question for a lossy cable and comment on the sources of loss. How would you build a cable with the lowest loss?

44. Starting from the general expressions for the propagation coefficient for a lossy line, derive the approximate expression(s) for a line with low loss.

45. What type of wave exists on a transmission line terminated in a (a) matched load; (b) short circuit load; (c) open circuit; and (d) arbitrary mismatched load? Assume the line is fed by a time-harmonic matched generator on the other end. Explain and write the relevant equation(s).

46. Derive the input impedance of a (a) shorted and (b) open transmission line stub of length \( L \) and characteristic impedance \( Z \), fed by a time-harmonic generator at a frequency \( f \). Explain how you would make a (1) inductor and (b) capacitor from either of the stubs and comment on its limitations as a circuit element.

47. Why is it not practically possible to make a coaxial cable with a 500-ohm characteristic impedance? Can you make a 500-ohm two-wire line?

48. Explain how you can make a forward wave only on a transmission line.

49. Is the wavelength along a line greater or less that that in the same line filled with a dielectric? What is the answer if the dielectric has a relative permeability greater than one? Explain.

50. What are the SI units for the attenuation constant, phase constant, reflection coefficient and VSWR?

51. What is the magnitude of the reflection coefficient and the VSWR for which one half of the power of the incident wave is transferred to the load?

52. Why is the voltage at the termination \( Z \) of a transmission line of characteristic impedance \( Z_0 \) equal to \( V = 2ZV_+/(Z+Z_0) \)?

53. Can a resistive load of any resistance \( R \) be matched in practice to a transmission line of characteristic impedance \( Z_0 \)? Explain.

54. The formula for the characteristic impedance of a lossy line reduces to a real value if \( R' = G' = 0 \). Is there any other relationship between \( R' \) and \( G' \) for which the characteristic impedance is real?

55. Label the following on the Smith chart (this could be divided into 3 questions on the test):
   a. Short circuit, open circuit, matched load
   b. All impedances that are purely real and purely imaginary
   c. All impedances that have a real part equal to the characteristic impedance
   d. All impedances that have an imaginary part equal to the characteristic impedance
   e. All points that have a reflection coefficient of 0.5
   f. All points that have a VSWR of 3
   g. An impedance of 100+j50 ohms in a 50-ohm system
h. This impedance is connected to a section of 50-ohm line that is an eight of a wavelength long. Find and label the input impedance on the Smith chart.
i. The impedance from (g) is connected to a 100-ohm transmission line that is $3\lambda/8$ long. Find the normalized input impedance and de-normalize it.
j. The admittance corresponding to a 75-j125 ohms in a 50-ohm system

56. Using the Smith chart, determine the terminating impedance of a 70-ohm line if it was found experimentally that the complex voltage reflection coefficient is (a) 0.8; (b) $0.2\exp(-j\pi/4)$ and (c) $0.5\exp(j\pi/3)$.

57. A 10-m long coaxial transmission line is fed with a step-function at $t=0$. The coax is made with a dielectric of relative permittivity 2.2 and has a characteristic impedance of 50 ohms. Sketch the time-domain waveform at the end of the coax if it is (a) open circuited; (b) short circuited; (c) terminated in 25 ohms; (d) terminated in 100 ohms.

58. Sketch the electric and magnetic field lines of two microstrip lines, one with a substrate twice as thick as the other, but with the same relative permittivity. In which case is the TEM approximation more accurate? Explain.

59. Sketch the electric and magnetic field lines of two microstrip lines, one with a substrate with twice the relative permittivity and of the same thickness. In which case is the TEM approximation more accurate? Explain.

Midterm questions through 59.

Waveguides:

60. The wave impedance of a TEM wave is always real. Are the wave impedances of TE and TM models also always real? Explain.

61. What is the physical meaning of the coefficients $m$ and $n$ in the field components inside a rectangular waveguide for $TE_{mn}$ and $TM_{mn}$ modes?

62. What is the phase and group velocity in a rectangular waveguide in these three cases: (1) $f > f_c$; (2) $f = f_c$; and (3) $f < f_c$?

63. What are the parameters that determine the cutoff frequency in a rectangular waveguide?

64. A signal consisting of frequencies in the vicinity of a frequency $f_1$ propagates un-attenuated along a rectangular waveguide as a $TE_{10}$ mode, and a signal consisting of frequencies in the vicinity of a frequency $f_2$ propagates un-attenuated along the waveguide in the same mode. If $f_1 < f_2$, which is faster?

65. Describe all the steps in deriving the electric and magnetic fields for a rectangular waveguide. How many solutions are there? What are they called and how are they classified?

66. What is the dominant mode in a rectangular waveguide? Define and write down its main characteristics (propagation velocity, cutoff frequency, impedance).

67. Define the bandwidth of a rectangular waveguide if you want to use the dominant mode. For standard X-band waveguide, what is this bandwidth numerically?

68. Define the quality factor of a resonator and state how it is related to the bandwidth of the resonance.

69. What are typical values for Q-factors of a lumped-element circuit, coaxial resonator and waveguide resonator?
70. Derive the quality factor of a coaxial resonator with an inductance per unit length of \( L' \) and a resistance per unit length of \( R' \).

71. Explain the nature of the wave that exists in a grounded slab of dielectric of thickness \( D \), with air above the slab. Provide a sketch or equations to support your answer.

72. If a guiding structure is made with no metal walls (i.e. not like a coaxial line or metallic waveguide), what is the nature of the propagating wave guided by the structure and why?

73. How many modes can propagate in an optical fiber? Is there a dominant mode in the fiber and if yes, what does the field look like for this mode? What are the main advantages of optical fibers? Why are they not used at microwave frequencies?

**Antennas and propagation:**

74. Starting from reciprocity, derive the ratio of the directivity and effective area of an antenna. Is this true for all antennas, or are there assumptions in your derivation that are only valid for specific cases, and why?

75. Sketch the radiation pattern for a horizontal dipole (a) quarter wavelength and (b) half wavelength above ground. Repeat for vertical dipole.

76. What is the impedance of a quarter-wave grounded monopole if you know that the impedance of a half-wave dipole with no ground is \( 73 \Omega \)?

77. What is the directivity of the 300-m diameter Arecibo radio-telescope dish at 3GHz?