ECE 407 **ELECTROMAGNETIC COMPATIBILITY** Spring 2016

MWF 12:40-1:30 1300 EB

Instructor: Ed Rothwell
Office: 2214A Engineering Building
Phone: 355-5231
E-mail: rothwell@egr.msu.edu
Office Hours: 11:30-12:30 MWF, 2234 EB
Web site: http://www.egr.msu.edu/~rothwell

Text: Introduction to Electromagnetic Compatibility, Clayton R. Paul, John Wiley & Sons, New York, 2nd edition, 2006.
Course notes: Posted to http://www.egr.msu.edu/em/research/goali/notes/
Course web site: MSU Desire 2 Learn system (https://d2l.msu.edu)

Principal reference: Noise Reduction Techniques in Electronic Systems, Henry W. Ott, John Wiley & Sons, 1988.

Grading:

Exam 1	15%
Exam 2	15%
Exam 3	15%
Exam 4	15%
Project	15%
Lab	25%

Suggested References ----------

1. Handbook of Electromagnetic Compatibility, Reinaldo Perez, ed., Academic Press, 1995.
2. Principles and Techniques of Electromagnetic Compatibility, Christos Christopoulos, CRC Press, 1995.
3. EMC: Electromagnetic Theory to Practical Design, P.A. Chatterton and M.A. Houlden, John Wiley & Sons, 1992.
4. Electromagnetic Compatibility: Principles and Applications, David A. Weston, Marcel Dekker, Inc., 1991.
5. Grounding and Shielding Techniques in Instrumentation, Ralph Morrison, John Wiley & Sons, 1967.
6. EMI Suppression Handbook, William D. Kimmel and Daryl D. Gerke, Seven Mountains Scientific, Inc., 1998.
7. Principles of Electromagnetic Compatibility, Bernhard Keiser, Artech House, 1987.

Exam dates ----------
Exam 1: February 10
Exam 2: March 18
Exam 3: April 13
Exam 4: May 5, 12:45-2:45 pm

Other important dates ----------
1/15 Open add period ends – 8 p.m.
1/18 MLK holiday – **no class**
2/5 Last day to drop with refund – 8 p.m.
3/2 Last day to drop with no grade reported – 8 p.m.
3/7-3/11 Spring break
5/1 Design day – **no class**

University Policies

Accommodations for Students with Disabilities*:* Students with disabilities should contact the Resource Center for Persons with Disabilities to establish reasonable accommodations. For an appointment with a disability specialist, call 353-9642 (voice), 355-1293 (TTY), or visit https://www.rcpd.msu.edu/.

Academic Honesty*:* Information on academic honesty may be found at https://www.msu.edu/~ombud/academic-integrity/index.html. Note in particular that General Student Regulation 1.00 *PROTECTION OF SCHOLARSHIP AND GRADES* states

> The principles of truth and honesty are fundamental to the educational process and the academic integrity of the University; therefore, no student shall:
>
> 1.01 claim or submit the academic work of another as one's own.
> 1.02 procure, provide, accept or use any materials containing questions or answers to any examination or assignment without proper authorization.
> 1.03 complete or attempt to complete any assignment or examination for another individual without proper authorization.
> 1.04 allow any examination or assignment to be completed for oneself, in part or in total, by another without proper authorization.
> 1.05 alter, tamper with, appropriate, destroy or otherwise interfere with the research, resources, or other academic work of another person.
> 1.06 fabricate or falsify data or results.

Instructor Policies

Attendance policy: You are not required to attend lectures. However, I will take attendance approximately once per week on an unannounced day. If you have one or fewer absences on attendance day, you will be allowed to drop your lowest test grade. Illnesses (with a doctor's excuse) and other excused absences will be handled on a case-by-case basis.

Exam policy: If you must miss an exam, you must contact me **before** the day of the exam to make alternative arrangements. True emergencies will be dealt with on a case-by-case basis.

Policy on religious observances: If any exam, assignment or project conflicts with a religious observance, let me know **ahead of time** and we will make other arrangements.

Exam 1 Learning Objectives

1. **Decibel units**. Be able to convert ordinary units to decibel units (volts to dBμV, watts to dBm, etc), and vice versa. Understand the settings on an oscillator, and the effect of the internal impedance of the oscillator on the power delivered to a load. Understand how the loss in a transmission line affects the reading on an oscilloscope or power meter.
2. **Faraday's law**. Understand how to use Faraday's law to compute the voltage and current induced in a circuit. Understand how to do the integrals necessary to compute the flux and the derivatives necessary to compute the voltage. Be sure you understand the difference between peak and RMS quantities.
3. **Transmission lines.** Understand the relationship between voltage, current, and characteristic impedance. Understand how to find characteristic impedance and propagation constant. Know how to compute all the important quantities for a line with complex terminating impedance: reflection coefficient, SWR, input impedance, voltage, and power.

Exam 1 Schedule

Problem No.	Topic	Notes	Textbook	Exam Problems	Textbook problems	Completion date
1	Decibel units	2.2	1.5	2014: 1.1 2013: 1.1 2012: 1.1 2011: 1.1 2010: 1.1	1.5.2, 1.5.3, 1.5.7, 1.5.9, 1.5.11, 1.5.12	1.22.16
2	Faraday's Law	2.4, 2.5	B.2.1	2014: 1.2 2013: 1.2 2012: 1.2 2011: 1.2 2010: 1.2	B.2.2, B.2.8, B.2.10	1.27.16
3	Transmission Lines	2.6	4.5	2014: 1.3 2013: 1.3 2012: 1.3 2011: 1.4 2010: 1.4	4.5.5, 4.5.11	2.8.16
Exam 1						2.10.16

Exam 2 Learning Objectives

1. **Propagation of plane waves.** Understand how plane waves propagate in various media. Know the definitions of a good conductor and a good dielectric. Know the relationship between electric and magnetic fields and the direction of propagation. Be able to compute power, wavelength, phase velocity, intrinsic impedance, attenuation, and skin depth. Be sure to know the difference between formulas specialized for good conductors and those specialized for good dielectrics. Know how to use phasors.
2. **Fourier series**. Be able to compute the trigonometric and exponential Fourier series coefficients for a given waveform. Be sure to know the various properties of the Fourier coefficients (time shifting theorem, differentiation theorem, etc.) Understand harmonics and how to convert ordinary units to decibel units (volts to dBμV, watts to dBm, etc), and vice versa.
3. **Spectra of trapezoidal pulses.** Understand the spectrum of a trapezoidal pulse and how the spectrum depends on period, duty cycle, and risetime. Know how to compute the voltage level of any harmonic both by using the exact formula and by using the spectral bounds. Understand how to compute the voltage across a load (such as a logic gate) that is connected to a trapezoidal pulse generator (clock). Understand how to use the voltage divider rule.

Exam 2 Schedule

Problem No.	Topic	Notes	Textbook	Exam Problems	Textbook problems	Completion date
1	Propagation of Plane Waves	2.4, 2.8	1.4, 7.6, B.5, B.6	2014: 2.1 2013: 2.1 2012: 2.1 2011: 1.3 2010: 1.3	B.5.1, B.6.3, B.6.7	2.19.16
2	Fourier Series	3.0, 3.1, 3.2	3.1	2014: 2.2 2013: 2.2 2012: 2.2 2011: 2.1 2010: 2.1	3.1.1, 3.1.2, 3.1.8	2.29.16
3	Spectra of Trapezoidal Pulses	3.3	3.2	2014: 2.3 2013: 2.3 2012: 2.3 2011: 2.3 2010: 2.3	3.2.1, 3.2.3, 3.2.4	3.16.16
Exam 2						3.18.16

Exam 3 Learning Objectives

1. **Non-ideal behavior of circuit components.** Understand the equivalent circuits of resistors, capacitors, and inductors, and how to compute the impedance of these components at a given frequency. Know the meaning of resonance and how to compute resonant frequency. Know how to compute the internal inductance of a wire.
2. **Measurement of radiated emissions.** Know the CISPR and FCC rules for radiated emissions. Understand how radiated emissions are measured. Know the meaning of antenna factor and how to use it. Know how to convert the field measured at a certain distance to the field at a different distance.
3. **Conducted emissions.** Common and differential mode currents. Conducted emissions. LISN. Common mode chokes. Differential mode chokes. Conducted emission limits (FCC and CISPR). Conducted emission mitigation.

Exam 3 Schedule

Problem No.	Topic	Notes	Textbook	Exam Problems	Textbook problems	Completion date
1	Non-ideal Behavior of Circuit Components	5.1, 5.3	5.1, 5.4, 5.5, 5.6	2014: 3.1 2013: 3.1 2012: 3.1 2011: 2.2 2010: 2.2	5.1.4, 5.5.1, 5.6.1	3.30.16
2	Measurement of Radiated Emissions	8	2.1	2014: 3.2 2013: 3.2 2012: 3.2 2011: 2.4 2010: 2.4	2.1.5, 2.1.11	4.6.16
3	Conducted Emissions	8, 11	5.9, 6.1, 6.2	2014: 3.3 2013: 3.3 2012: 4.1 2011: 3.1 2010: 3.1		4.11.16
Exam 3						4.13.16

Exam 4 Learning Objectives

1. **Radiated emissions.** Common and differential mode currents. Estimated field produced by a pair of wires. Radiated emission limits (FCC and CISPR).
2. **Shielding.** Shielding effectiveness. Skin depth. Reflection. Absorption and attenuation.
3. **Measurement of common and differential mode currents**. Current probes. Transfer impedance.

Exam 4 Schedule

Problem No.	Topic	Notes	Textbook	Exam Problems	Textbook problems	Completion date
1	Radiated Emissions	8, 9.1, 9.2, 9.3	8.1	2014: 4.1 2013: 4.1 2012: 3.3 2011: 3.2 2010: 3.2	8.1.1, 8.1.2, 8.1.3, 8.1.7	4.18.16
2	Shielding	15	10.1, 10.2	2014: 4.2 2013: 4.2 2012: 4.2 2011: 3.4 2010: 3.4	10.2.4	4.22.16
3	Measurement of Common and Differential Mode Currents	9.4	8.1	2014: 4.3 2013: 4.3 2012: 4.3 2011: 3.3 2010: 3.3	8.1.5	4.27.16
Exam 4						5.5.16

ECE 407 Laboratory Policies

Spring 2016

Lab supervisor: Ed Rothwell

Lab instructor: Steve Hughey
E-mail: hugheyst@msu.edu
Office hours: TBD

Schedule: Section 1 Tu 11:30-2:20 2234 EB
Section 3 Tu 3:00-5:50 2234 EB

1. Grade breakdown. Your lab grade will be determined from the following breakdown:

   Reports 75%
   Performance 25%

   The lab instructor will award your performance grade based on his/her observations of your behavior during the lab period. If you are contributing to your group, then you will receive a full 25%. If you are just standing around doing nothing, you will receive 0%.

2. Make-ups. **ALL** labs must be completed for you to receive a course grade. **If you do not complete an experiment, you will receive a "0" for your course grade.** You must be present during lab to get credit. Make-up labs must be arranged either prior to the absence, or afterward with a doctor's excuse. Attendance will be taken during all labs.

3. Preparation. You are expected to be prepared before coming to lab. Read the lab before coming to class, complete the preliminary exercises, if any, and review any topics you are unsure of. There will NOT be a lecture during the lab period. The instructor will NOT answer questions during the lab period over topics you should know from the lab manual. The instructor's presence during the lab period is to oversee the lab and help you with any mechanical trouble you are having with the equipment. If you do not understand material from the manual, see the instructor **before** the lab period.

4. Data. All data must be taken in PEN. It must be signed and dated by the instructor before you leave the lab.

5. Lab reports. Lab reports are to be handed in at the beginning of the lab period immediately following the period during which the lab was completed. You will be graded on spelling, grammar, organization and writing style, as well as on content. Each group will turn in one report.

   All lab reports must be written using Microsoft Word. Following is a suggested outline, but

the lab instructor may choose to implement his or her own guidelines for the reports.

1. **Title page**. Title of lab, names of students, name of instructor, section number, date of lab, date of report (due date).

2. **Goals**. One paragraph outlining the goals of the lab.

3. **Accomplishments**. A summary of your accomplishments -- what you have learned during the lab. Discuss discoveries, difficulties, verifications of theory, etc. Relate these to the goals of the lab.

4. **Discussion**. A discussion of your results, which follow in the next section. You must refer to labeled tables and plots. Include answers to questions posed in the lab manual and discuss error, if appropriate. Include all calculations.

5. **Results**. Include your measured and calculated data. Your data must be in either a properly labeled table or graph, or both. When you refer to these, it must be by table or graph number. Every table and graph must be referred to at least once in the report. See the attached pages for examples of a table and graph. For small amounts of data, use a table. For large amounts of data, or when visualization is important, use a graph. Be sure to include units!

6. **Raw data**. Include at the end of your report the raw data you took in lab, including your instructor's signature. Label this data as APPENDIX 1: RAW DATA.

Parts 2 and 3 above are to get you to think about how the lab experience relates to the class material and how the information gained during the lab has helped your understanding of the class topics.

6. Discussion of error. When you discuss error you may, if you wish, blame the equipment. If you do, you must discuss both the source AND RANGE of the error. For example, if you can read a dial to within 5%, this range of error cannot completely explain a difference of 25% between theory and experiment, unless it is compounded. Remember, the most common cause of error is unfamiliarity with equipment.

7. Be nice. Please treat the equipment kindly. Be nice to sensitive things like connectors, switches and dials. To be safe, there will be no food or drink allowed in the lab.

EXAMPLE OF PROPERLY LABELED PLOT

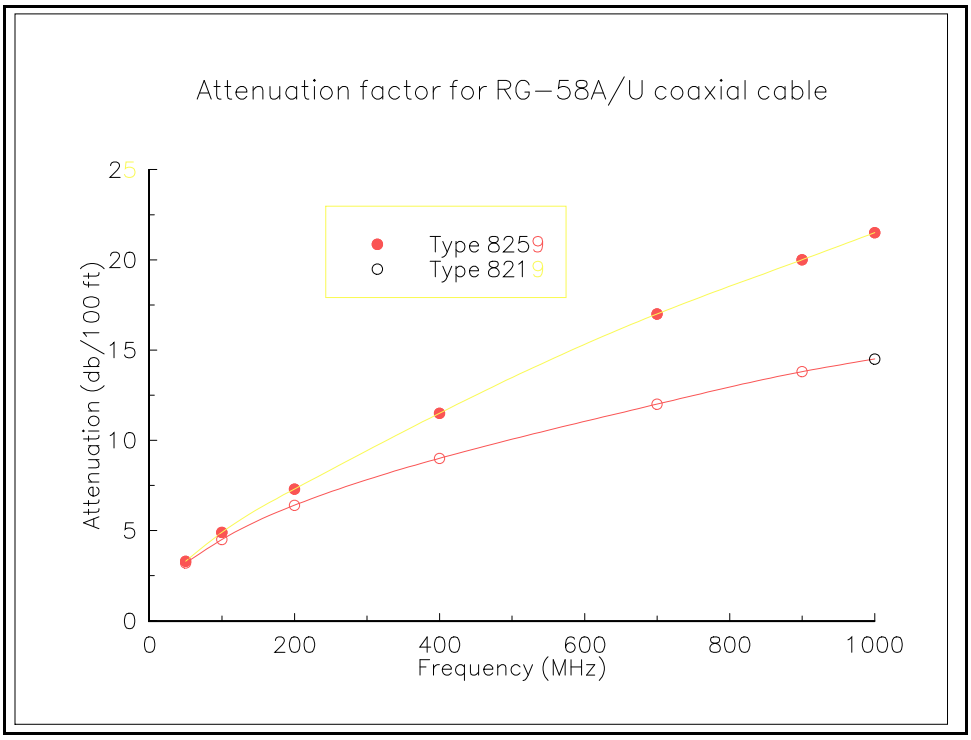

Figure 1. Attenuation factor for RG-58A/U coaxial cable.

EXAMPLE OF PROPERLY LABELED TABLE

Table 1. Properties of various soft ferromagnetic materials.

Material	Initial relative permeability	Coercive force (A/m)	Residual field (Wb/m^2)	Saturation field (Wb/m^2)	density (g/cm^3)
Commercial Iron	150-250	80	0.77	2.15	7.85
Pure iron	10k	4	0.2	2.15	7.85
Silicon-steel	900-1700	35-60	0.62-0.93	1.5-2.0	7.65
Siloctron	1.3k	8-24	1.4	1.5-2.0	7.65
Silicon-iron	400	40	1.2	1.5-2.0	7.65
Deltamax	400-1700	16-32	1.3-1.8	1.35-1.85	8.25
4-79 Mo Perm-Alloy	10k-40k	3-12	0.4-0.55	0.7-0.8	8.74
Supermalloy	50k-120k	0.2-4	0.4-0.55	0.65-0.75	8.77

ECE 407 LABORATORY SCHEDULE

Spring 2016

Note: This schedule is subject to change at the discretion of the ECE 407 instructor

Week	Experiment
01/11	No lab
01/18	No lab
01/25	Introduction to the 33250A Waveform Generator and the 54501A Oscilloscope
02/01	Transmission lines with transient excitation
02/08	--continue above experiment
02/15	Steady-state transmission lines
02/22	--continue above experiment
02/29	Introduction to the 4396B network analyzer
03/07	SPRING BREAK
03/14	--continue above experiment
03/21	Introduction to the 4396B spectrum analyzer
03/28	Signals and spectra
04/04	Non-ideal behavior of circuit components
04/11	Conducted emissions
04/18	Radiated emissions
04/25	Shielding

ECE 407 LABORATORY SAFETY CONSIDERATIONS

Spring 2016

This document addresses safety considerations for students participating in the ECE 407 laboratory. Students should review all safety material provided by previous lab supervisors and be aware of the health effects of electrical shock. This document describes specific potential hazards for ECE 407.

Protective eyewear

All students **must wear protective eyewear** (goggles or glasses) while performing measurements of any type in 2234 EB, or while working with tools of any type in 2234 EB (including soldering tools). Students **must wear protective eyewear** if any other student anywhere in the lab is working with tools of any type. Students attending office hours, working on computers, or participating in presentations do not need to wear protective eyewear as long as no one else in the lab is working with tools at the time.

First aid

An emergency first aid kit is located near the door in 2234 EB.

Fire extinguisher

A fire extinguisher is located in the hallway immediately adjacent to the door to 2234 EB.

Electrical Shock

Any time students use electrical equipment there is a possibility of electrical shock. In the ECE 407 lab there is little potential for shock since most equipment produces low-voltage, high-frequency signals. By using caution and common sense, a high level of electrical safety can be maintained. Whenever using electrical equipment of any kind, students should be on watch for frayed and broken plugs, wires, and connections. Any potential hazards should be **immediately reported to the lab instructor**.

Microwave Exposure

Several ECE 407 experiments involve using signals at microwave frequencies. Power levels employed are well below those which give rise to electromagnetic heating. However, the subtle physiological effects of microwave energy are still uncertain, and students should take care to minimize their exposure to microwave energy. The following guidelines should be sufficient to provide a safe environment.

1. Never look directly into the open end of a waveguide or transmission line.
2. Never radiate EM fields in the direction of yourself or other people.
3. Never perform measurements while anyone is inside the anechoic chamber.

Note that the measurement software has been written so that RF output is turned off at all times when measurements are not being performed. However, students must be aware of the presence of persons inside the anechoic chamber, and make sure that the measurement process is not initiated when the chamber is occupied.

If students have ANY questions regarding safety, they should immediately discuss them with their lab instructor.