EEP 592

Applied Electromagnetics:
How the Force of Maxwell's Equations Drives Circuit Theory and the Rest of Life

Winter 2024

This is arguably the most fundamental course you will take, if you take it.

In it, you'll learn how four tiny equations, together with vector calculus and its fundamental theorems, completely describe the force that drives charge through all electronic systems—and incidentally also drives virtually every phenomenon we encounter in life. The exceptions? Falling bodies, astronomical motion, toilets, and the tides. That's about it—up to quantization, anyway, which is negligible in a vast range of settings. This course is about the force that drives our discipline and also, on the length scales we inhabit, essentially all of life.

If you press hard in this course, you will end up clear about some fundamental matters. How and why circuit theory works. When it doesn't. What Kirchhoff's Voltage and Current Laws in truth are, and when they fail. What exactly inductance is. What capacitance is. Why circuit theory is in the process-- in your generation, as operating frequency and circuit area swiftly rise-- of completely falling apart for high-speed systems even on-chip. Why the basic phenomena of life work as they do. Stuff like that.

Oh, and you will also end up being an anomalous electrical engineer: one who knows exactly what voltage is. If you push hard for clarity in this class, you'll likely find this stuff thrilling. At a minimum it will make you weird.

To understand the broad sweep of matters described above, we focus on the behavior of waves of electromagnetic force propagating through both circuits and unguided media. We emphasize the roots of these waves in Maxwell's Equations; their necessary manifestations as waves of voltage and current ripping along wires and circuits; their quite puzzling complete absence from electronic circuit theory; and the fundamental implications of these waves for high-speed electronic systems and for the rest of life.

It is critical that you develop not just facility with the formalism—the math—of these voltage, current, and electromagnetic-force waves, but also ***physical intuition*** for them—an ability to ***visualize the fields*** and their dynamic dance. This will result in a gut-level intuitive grasp of the broad sweep of phenomena at the very foundation of electrical engineering—and life—over which every electrical engineer should feel the pleasure of mastery.

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Office hours: Monday, 7:00-8:30 pm via Zoom

TA: TBA
Office hours: TBA

Lectures: Thursdays. 6:00-9:50 pm, Room: TBA.

Textbook: None required. The class lectures are self-sufficient and contain all course material.
Note: If you're rusty on e.g. waves or phasors, or if you'd like to fill out your understanding with a textbook, a reference like Ulaby or Griffiths (below) would make sense.

Recommended references on Electromagnetics:
F. T. Ulaby and U. Ravaioli, *Fundamentals of Applied Electromagnetics*, Pearson Prentice-Hall. All editions (2007-2020) are equally good. (Elementary and brief).
David J. Griffiths, *Introduction to Electrodynamics*, Cambridge, 2017.

Course format

This course consists of a mathematical and intuitive description of the electromagnetic force, and of how it drives circuit theory and life. Lectures take place at the board and projection screen. A significant part of the lecture material is not to my knowledge covered in textbooks or elsewhere.

This has a simple, unavoidable consequence. <u>You must attend lectures</u>. And in class, you must take <u>meticulous notes</u>, to accompany lecture slides, both of which you'll need to study at length until all is crystal clear.

It's been proven empirically that there's no other way. There are no lecture notes, no video recordings, nothing to bail you out later. You need to come to class.

If the above isn't your firm plan, or if, realistically, there's a significant chance you'll have trouble adhering to it, don't enroll in this class.

Requisite knowledge

At the outset of the class, you should be very comfortable with the following piece of math:

- **<u>Phasor analysis.</u>** (EE215, EE233, EE242)

  Throughout the course we'll be making use of complex-valued functions F to represent real sinusoidal functions through the usual expedient of choosing F so that $\mathrm{Re}(Fe^{j\omega t})$ equals the real-valued function of interest. You've no doubt seen this for a long time. Which, of course, is not necessarily to imply that you profoundly get what's going on or find it comfortable.

  If it makes you queasy to represent real sinusoidal functions like voltages using complex functions like those above, you must attack this queasiness and remove it immediately. In this case, first read a brief intro to phasors (e.g. the relevant sections of Ulaby's chapter 1) and think hard about what a phasor representation is. Should this fail, seek prompt help from the instructor or TA. In most portions of this course, almost everything's a phasor, so you need to be crystal-clear about how and why they work. Anyway, they offer a shockingly clear view of a large swath of the world.

You should also feel ready and energized, with the intructor's help in lectures, to quickly learn or relearn the piece of math that's most crucial to describing the EM force:

- **<u>Vector calculus</u>**. Including gradient, divergence, curl, line- and surface-integrals, and the three fundamental theorems of vector calculus that interweave them all. (This is the content of UW MATH324).

  I don't care whether you can write out a vector function's curl in spherical coordinates. Doesn't matter. Even your ability to rapidly compute divergence and curl doesn't matter much. What *is* critical is that you have a rock-solid ***intuitive feel*** for divergence and curl—a clear picture of what vector fields with nonzero divergence and curl look like. Gut-level, visual understanding is the point.

  You can begin to tell whether you have this by checking to see whether you have an *intuitive, visual feel* for the fundamental theorems—especially the Divergence Theorem and Stokes' Theorem. Forget moving symbols around. Can you intuitively ***see*** that they must be true? If so, you're good.

> If not, you doubtless have company. Vector calculus is not usually learned in a visual, intuitive way. And even when it is, it often evaporates.
>
> We will quickly recapitulate the central elements of intuitive vector calculus in lectures around the mid-point of the course. If, after that, you're still feeling tentative, seek help from the instructor. An intuitive grasp of vector calculus is the key tool for understanding EM force and how it undergirds circuit theory.

Homework

Assigned weekly on Fridays.
Due via electronic submission before the beginning of lecture on the following Thursday.
Late homework is not accepted.

Joint-work policy: Homework will be done and submitted *individually*, not in groups.

You're welcome to collaborate with others to learn how to do things, but the work you submit must be your own creation and must not be your recording of work done collectively.

Ok: Discussing lectures and general approaches to subject-matter and to problems.
Not Ok: Doing homework assignments jointly or making any use of work that is not your own.

Because learning E&M depends so crucially on homework, violations of this policy will be punished harshly.

Exams

The in-class midterm will cover the basic material of the course.
The final exam, held during finals week, will cover everything, with uniform emphasis over the whole quarter.

The exams offer little opportunity to calculate quantities only dimly understood. Instead, they focus on probing the extent to which you have pushed hard to digest the *meanings of central quantities*, the *fundamental behavior of waves of voltage and current*, and the *dance of the propagating force fields that lie beneath them*. They test your *deep intuitive picture* of how fields and waves work, and how they generate the chief phenomena of electrical engineering. They also test your understanding of the subject's logic and the means by which its major results are proved.

Logic matters. Derivations do too. Intuition is key.

To get a better idea of this and of what's generally expected, I'll provide practice exams as the time approaches.

Exams are closed-book, with calculator allowed.
You can bring two pages of notes (both sides ok) to the midterm, and six pages (both sides ok) to the final.

Grades

Course grades will be based on: Homework (30%). Midterm exam (35%). Final exam (35%).

Grading policy

Homework and exam answers must include a full account of their origins. A numerically correct answer is *wrong* if it does not include a *clear, well-articulated account of the thinking* that yielded it. Well-thought-out wrong answers, on the other hand, receive significant credit.

In both homework and exams, the key is deep, intuitive understanding of the EM force and the logic by which it drives circuit theory. That is the focus of grading. Numbers in general matter little.

Policy on Exam absences

Occasionally circumstances conspire against taking an exam at the appointed time. Some reasonable excuses include childbirth, presenting a paper at a technical conference, military duty, jury duty. If you can alert the instructor in advance, many things can be accommodated. The critical thing is to contact the instructor early.

Grading Disputes

On occasion you may disagree with a grade. And we do occasionally make mistakes. But remember that fairness is created above all by consistency; if the grader is uniformly demanding of all, then there is no problem.

Should there be a specific grading issue you'd like to have re-examined, here is the process:

1. You must request the re-grade within one week of the day on which the work was returned.
2. You must submit the re-grade request in writing; we won't process requests live.
3. You must be willing to risk losing two points by asking for a re-grade. If your grade is not changed upon re-examination, you'll lose two points. If it is changed, the points will be refunded.