Fields and Waves I

Lecture 1

Introduction to Fields and Waves

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Materials from other sources are referenced where they are used.
Those listed as Ulaby are figures from Ulaby's textbook.

Overview

- Why study E&M?
- Standards-based grading
- Online course infrastructure
- Introduction to transmission lines
- Wrap-up

Why Study Electromagnetism (E&M)?

- Electromagnetism is, in a sense, the most **fundamental theory of electrical engineering**: the one that tells us how electric magnetic fields and related concepts (such current and voltage) actually work and relate to each other.
- This means that by understanding E&M, you will also understand **how electrical systems work at a fundamental level.**
- You will also understand the limits of other theories such as circuit theory - i.e. where these theories break down.

Why Study Electromagnetism (E&M)?

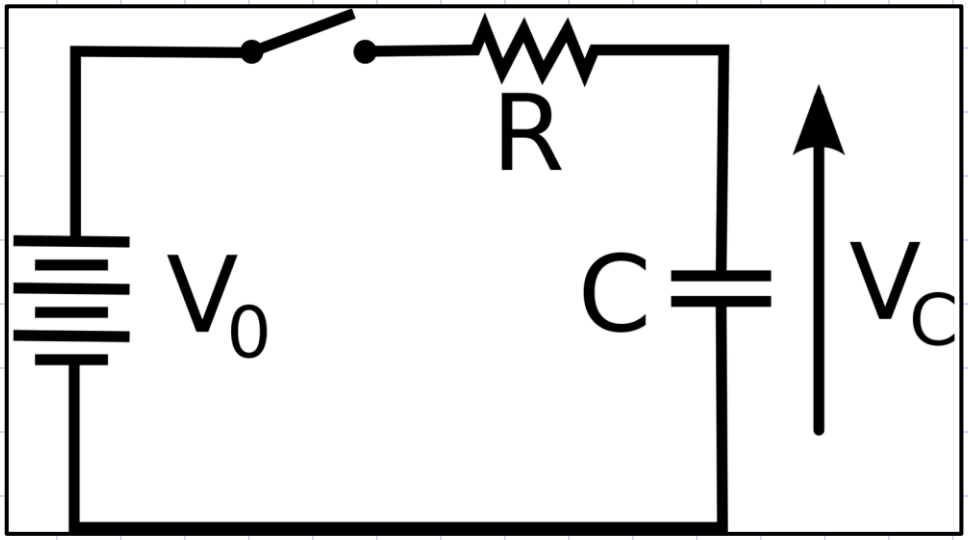
Relationship with Circuit Theory

Circuit theory uses simplified (lumped) models of components. The model, however, does not include:

- Details on how the components *actually work*
- Distributed properties (such as transmission lines)
- Electromagnetic waves (such as microwaves, radio waves, and optics)
- Noise

Why Study Electromagnetism (E&M)?

Relationship with Circuit Theory



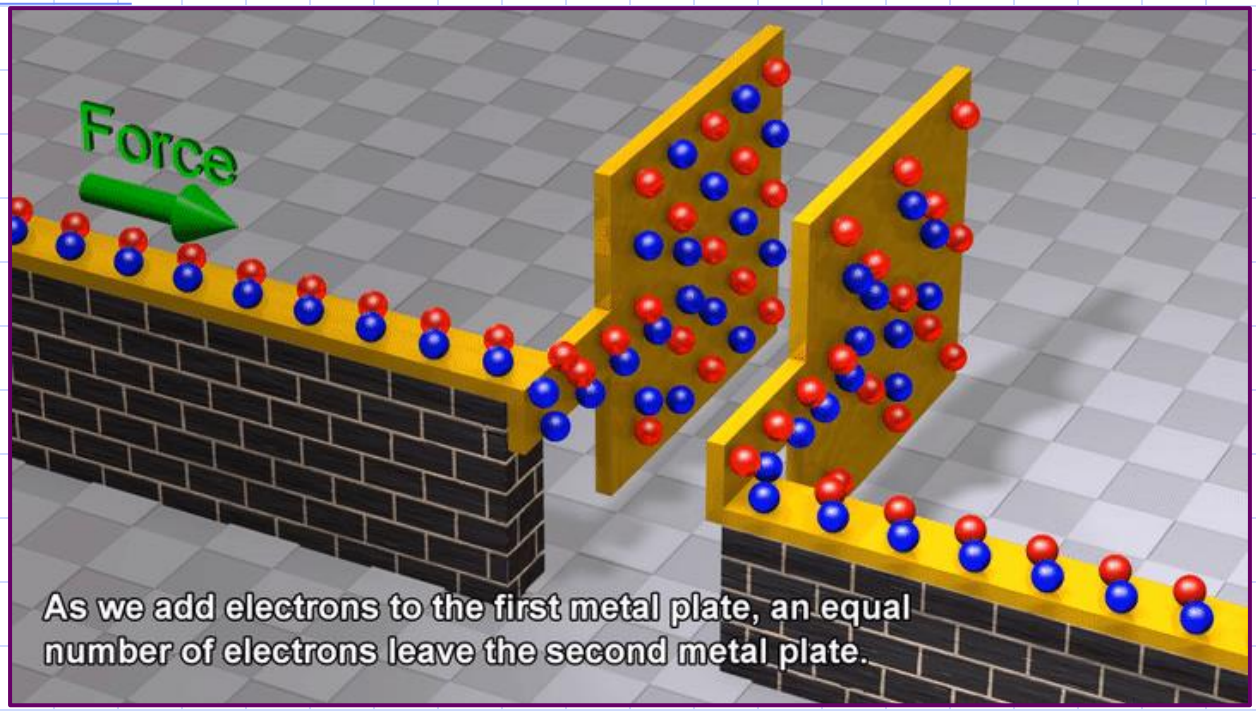
$$I(t) = \frac{V_0}{R} \cdot e^{\frac{-t}{\tau_0}}$$

$$V(t) = V_0 \left(1 - e^{\frac{-t}{\tau_0}}\right)$$

In circuit theory, you learn equations for the current and voltage behavior of a capacitor. But what are the physical phenomena that *cause* a capacitor to behave this way?

Why Study Electromagnetism (E&M)?

Relationship with Circuit Theory



Displacement current is the current that flows into and out of a capacitor, not due any connection between the two plates but due to the electric field between them.

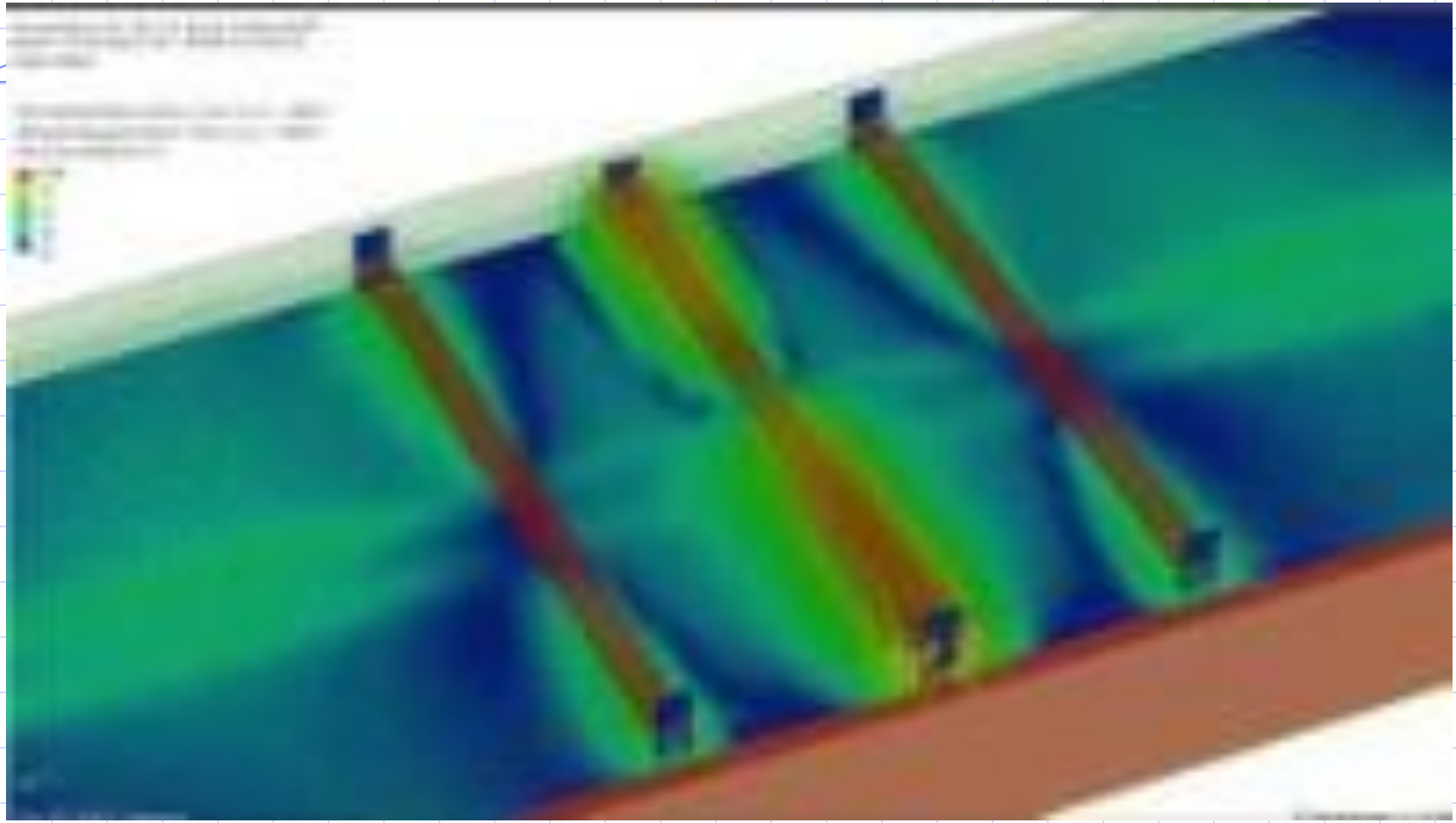
Why Study Electromagnetism (E&M)?

Relationship with Circuit Theory

Digital circuits typically process low-pass pulses having clock rates below **2 GHz.** Via pins provide electrical connections between the planes. Circuit operation is nominally not based upon electromagnetic wave effects.

- densely packed, multiple planes of metal traces providing flow paths for the signals
- DC power feeds
- ground returns

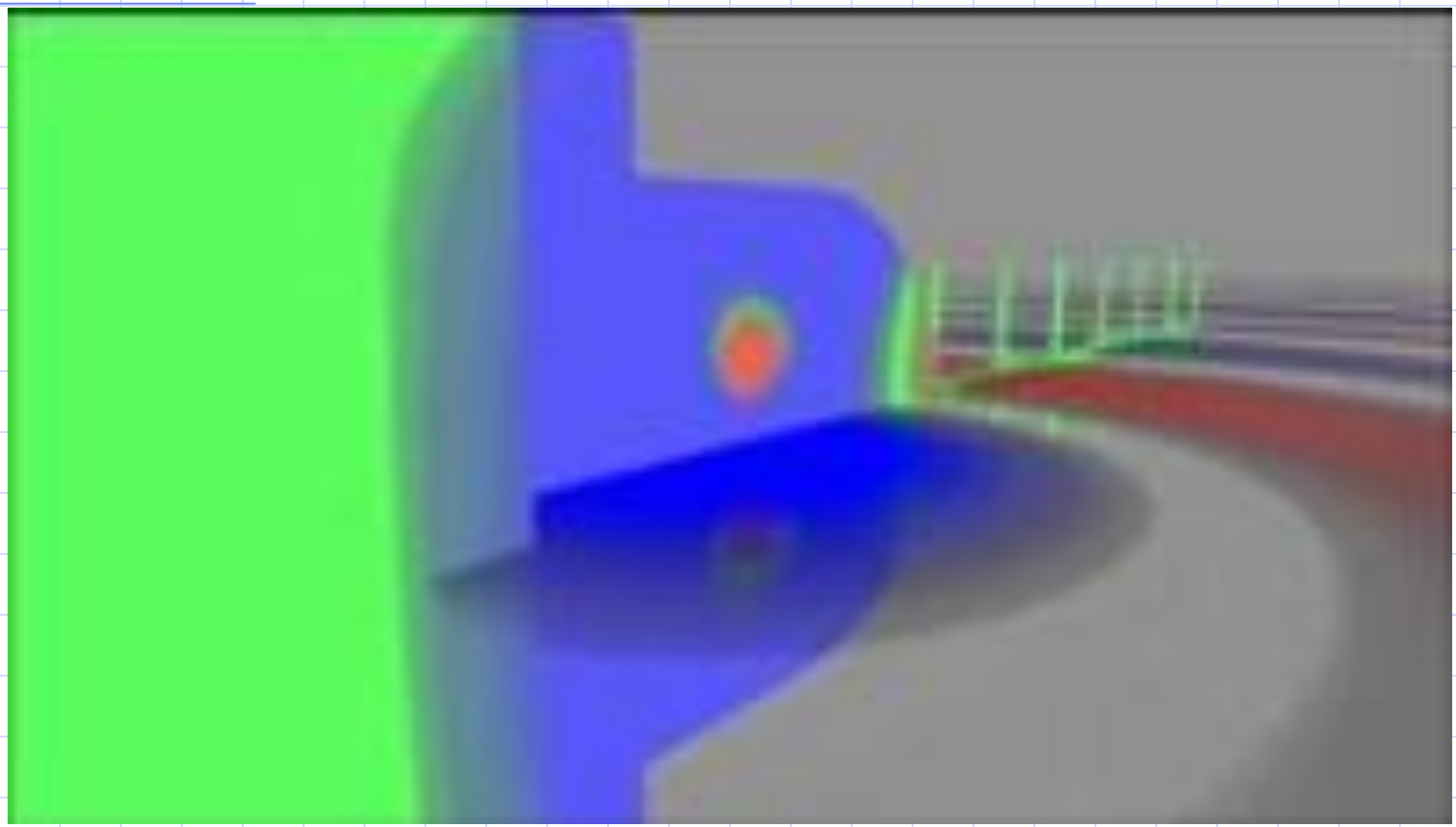
Kirchoff's current and voltage laws also fail in most **high-speed circuits**, which must be analyzed using E&M theory. Signal power flows are not confined to the intended metal wires or circuit paths.



Why Study Electromagnetism (E&M)?

Electromagnetic wave propagation devices, such as antennas, *fundamentally cannot be described* using traditional circuit theory.

They require us to take into account the geometry of the device, the materials and propagation media involved, and - most importantly - to think of electric phenomena as being composed of *waves*.



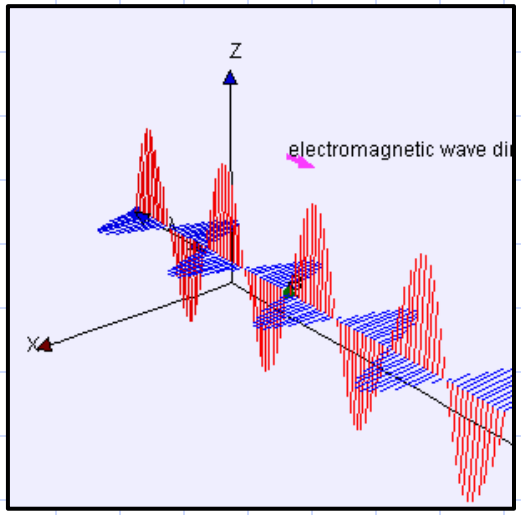
Why Study Electromagnetism (E&M)?

The "Waves" Part of Fields & Waves

Electromagnetic fields propagate as waves. They are governed by the electromagnetic wave equations, which are derived from Maxwell's Equations and can be written as:

$$\frac{\partial^2 \vec{E}}{\partial t^2} = c^2 \nabla^2 \vec{E} \qquad \frac{\partial^2 \vec{B}}{\partial t^2} = c^2 \nabla^2 \vec{B}$$

where **c** is the speed of light / EM waves. (Note that c depends on the medium the wave is propagating through!)



Source: https://en.wikipedia.org/wiki/Electromagnetic_radiation

Why Study Electromagnetism (E&M)?

The "Waves" Part of Fields & Waves

- For our purposes, a "wave" is anything that is governed by a wave equation (which takes this general form):

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

- Waves also have properties such as **wavelength, frequency, amplitude** and **velocity.**

Why Study Electromagnetism (E&M)?

Maxwell's Equations

$$\nabla . E = \frac{\rho}{\epsilon_0} \qquad (1) \qquad \text{Gauss' law}$$

$$\nabla . B = 0 \qquad (2) \qquad \text{Magnetic monopoles}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (3) \qquad \text{Faraday's law}$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad (4) \qquad \text{Ampere-Maxwell law}$$

These four equations *fundamentally describe all of electromagnetism.* The rest is a question of applications.

Why Study Electromagnetism (E&M)?

Maxwell's Equations

$$\nabla . E = \frac{\rho}{\epsilon_0}$$

Source: spectrumscientifics.wordpress.com

Gauss' Law: Electric charge gives rise to an electric field.

Why Study Electromagnetism (E&M)?

Maxwell's Equations

$$\nabla . B = 0$$

When they ask you where your magnetic monopoles are

Magnetic Monopoles: "Magnetic charges" don't exist.* Only electric charges do.

* except maybe in very esoteric branches of particle physics

Why Study Electromagnetism (E&M)?

Maxwell's Equations

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

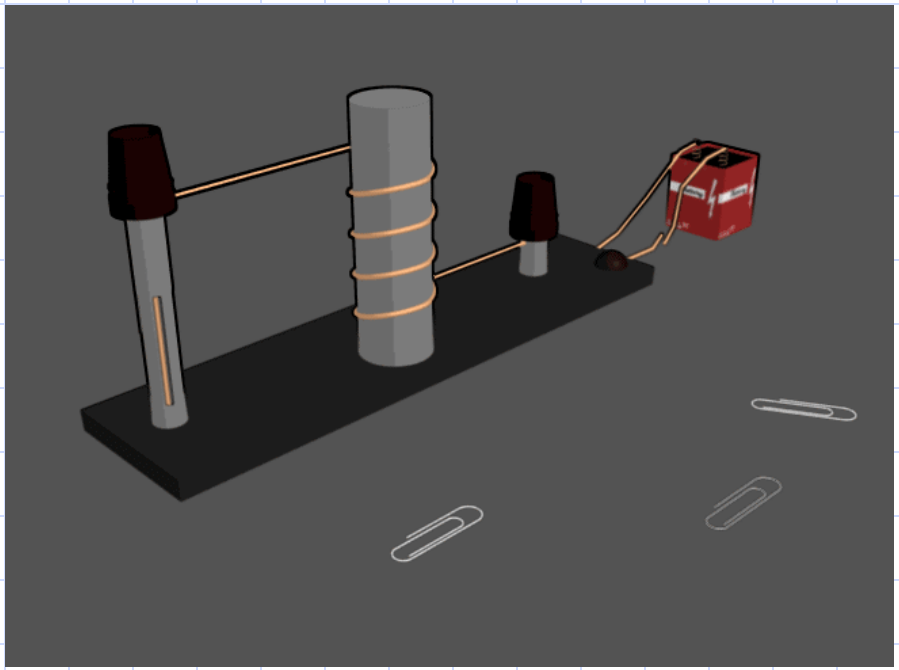
Source: Wikimedia Commons

Faraday's Law: Changing magnetic field gives rise to an electric field.

Why Study Electromagnetism (E&M)?

Maxwell's Equations

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$



Source: https://simple.wikipedia.org/wiki/Electromagnet

Ampere's Law: Current gives rise to a magnetic field.

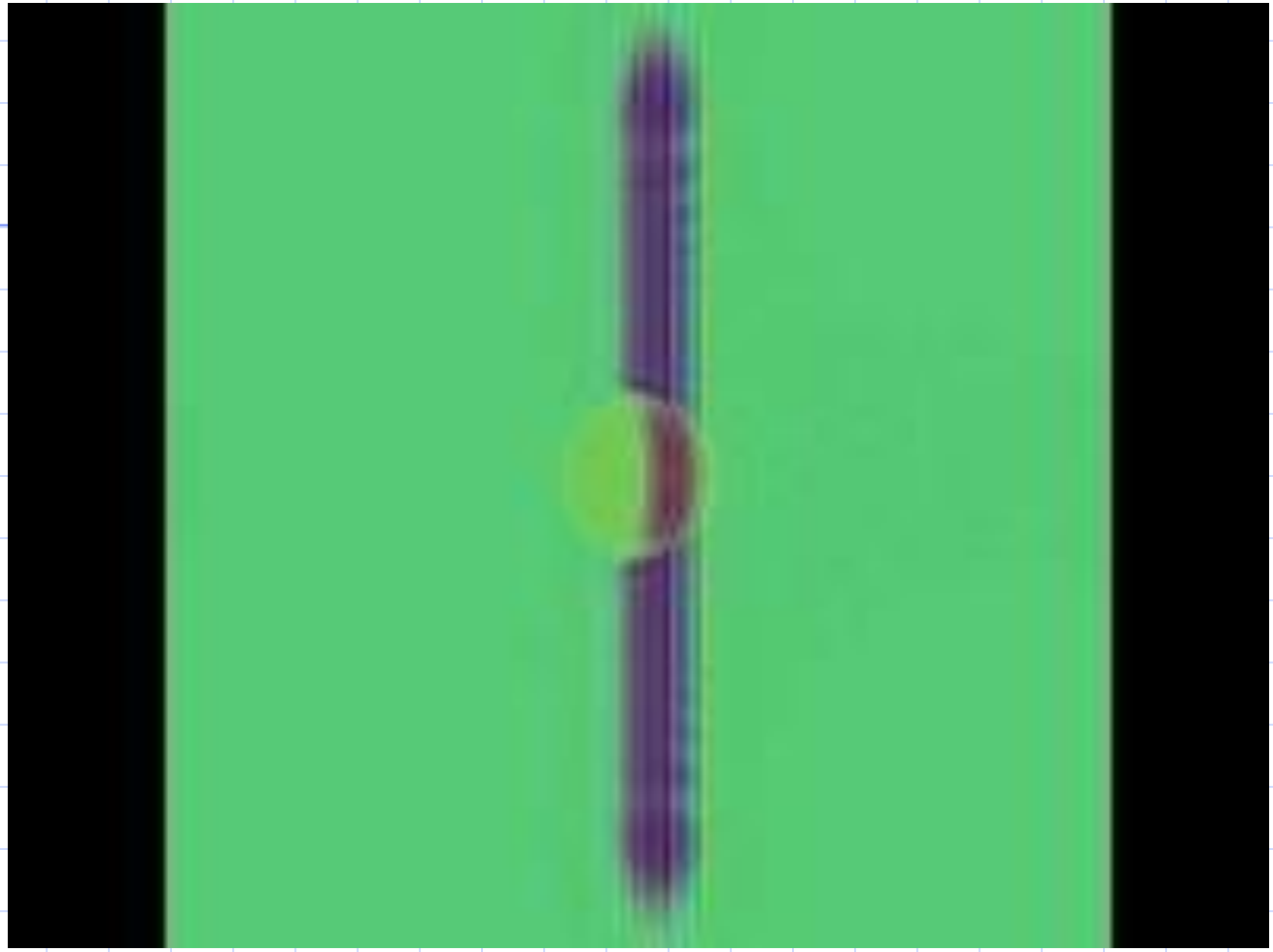
Why Study Electromagnetism (E&M)?

In Electrical Engineering Terms…

- When you have voltage (V), you have an electric field intensity (E).
- When you have current (I), you have a magnetic flux density (B).

Also:

- When you have change in B, you have a V.



Simulation of EM waves propagating through the air and hitting a sphere with water-like permittivity

Exercise 1

- Get to know your classmates.
- If you haven't joined Gradescope for the class, the code is: **2PJP78**
- Form a group of up to 4 (I will create breakout rooms) and do Lecture 1 Exercise 1 on Gradescope.
- **Only 1 of you needs to submit**, but include the names of everyone in your group.
- We'll reconvene in 10 minutes and share.

Standards-Based Grading (SBG)

- Fields and Waves will be taught using SBG this semester.
- This means that instead of giving you homework and exam grades, I will grade you **directly** on your demonstration of the class's Core Skills.
- Every unit of the Core Skills corresponds to one of the exams, and describes its content.
- You can check how you're doing on the Core Skills by viewing your Core Skill Progress Report on Gradescope.

Standards-Based Grading (SBG)

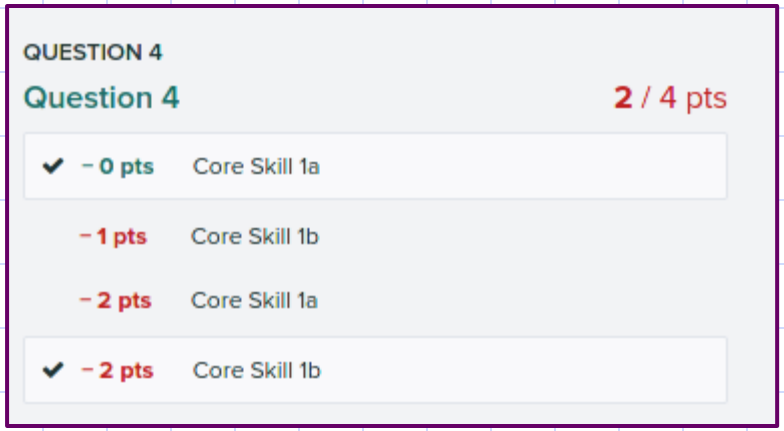
Core Skill Progress Report

1g	Calculate the input impedance of a lossless transmission line of arbitrary length and arbitrary load impedance.	0	
1h	Calculate the attenuation constant of a lossy transmission line based on a graph and / or the line parameters, or vice versa. Demonstrate an understanding of the physical meaning of the attenuation constant (such as using it to calculate the voltage amplitude at a particular point in the transmission line.)	0	
1i	Identify whether a transmission line is low-loss and calculate its characteristic impedance from its line parameters.	0	
1j	Understand the properties of a dispersionless transmission line and be able to apply the Heaviside condition to make a line dispersionless.	0	
1k	Be able to calculate the initial and long-term behavior of a short pulse or DC voltage propagating on a lossless transmission line.	0	
1l	Determine the amount of power transmitted to a load by a lossless or low-loss transmission line.	0	
Unit 1 Total:		0	0.00%

Standards-Based Grading (SBG)

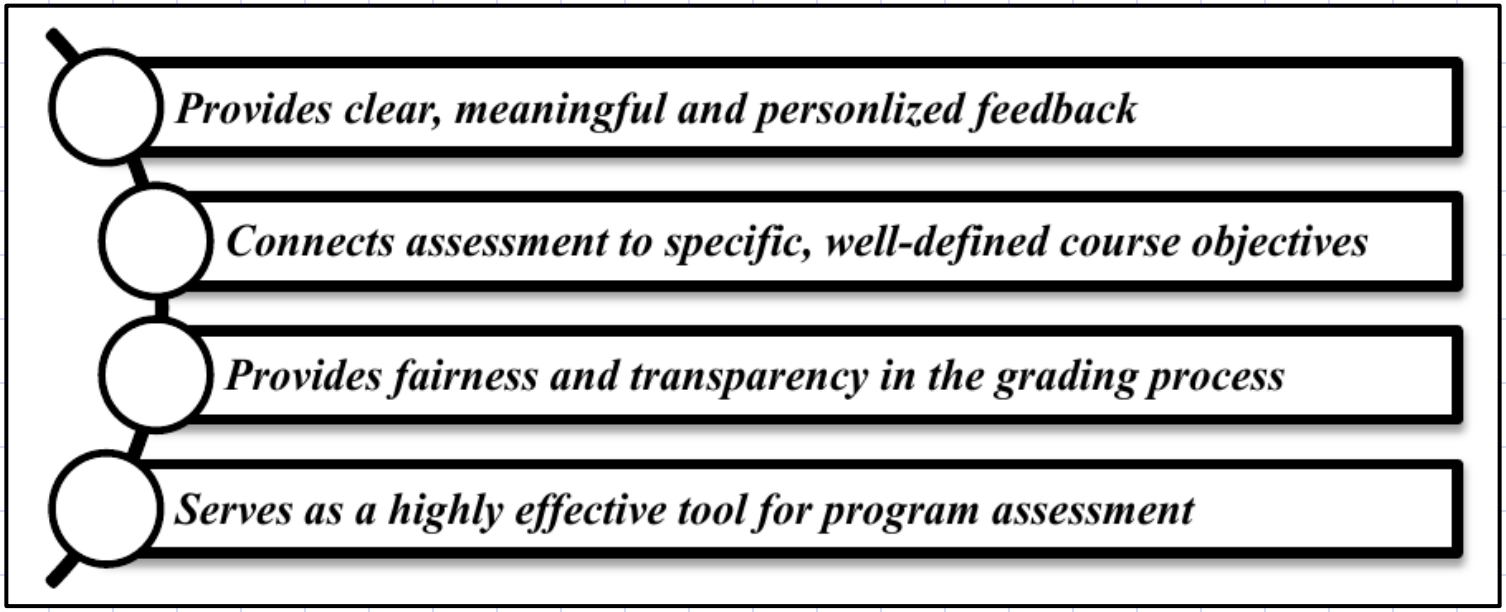
- When you take exams, your test feedback will describe what skills you demonstrated successfully on each problem, and to what degree
- **A fifth point will be added for units**

4 points	**Complete Mastery with Calculations.** Skill has been successfully demonstrated using a calculation for which the correct result was achieved.
3 points	**Mastery.** Skill has been successfully demonstrated. (small math errors will not prevent a student from earning a 3)
2 points	**Partial mastery.** Some understanding of the core skill was shown, but with some conceptual issues.
1 point	**Limited mastery.** Some basic understanding of the core skill was shown, but with major conceptual issues.
0 points	**No mastery.** Student has not yet demonstrated an understanding of this concept.



Standards-Based Grading (SBG)

Advantages of SBG



Siniawski MT, Carberry AR, Dionisio JDN. "Standards-based grading: An alternative to score-based assessment." In Proceedings of the 2012 ASEE PSW Section Conference; San Luis Obispo, California, April 19–21, 2012.

Standards-Based Grading (SBG)

- Your exam feedback will tell you exactly which skills you mastered and which you still need to master.
  - If many students are struggling with a concept, I will devote more class time to it.
  - You will have additional opportunities to demonstrate the skill by signing up for retests (link on website) or by doing the optional midterm or final.

Standards-Based Grading (SBG)

- Retests will take the form of a "Problem of the Week", revealed during the tests. The skills to be retested that week will be announced at the beginning of each week.
- You must request a retest at least 2 days in advance.
- The number of times you can test a topic is only limited by the number of testing slots we have in the semester.
- It doesn't matter when in the semester you master a Core Skill; the points will be the same.

Standards-Based Grading (SBG)

- Your progress on the class's Core Skills will be tracked as "Core Skill Progress" on Gradescope. This is a rubric that will show which core skills you've mastered, when you mastered them, and to what extent.
- I don't do extra credit in this class - instead, I offer multiple opportunities to show you've learned the Core Skills.
- Homeworks are a "Participation Plus" grade – you get full credit if you have the right idea.

Standards-Based Grading (SBG)

- On Wednesdays we will have Studio Sessions in which we do hands-on activities applying the theoretical concepts of the class.
- Some Studio Sessions will involve small activities:
  - One session/week long
  - Short write-up at the end for a participation grade
  - Remainder of the session is an open shop
  - Goal is to explore a Fields and Waves concept

Standards-Based Grading (SBG)

- Other Studio Sessions will involve larger activities:
  - Multiple sessions / weeks long
  - Formal graded lab report at the end of the sessions
  - Goal is to do engineering design work using Fields and Waves

Standards-Based Grading (SBG)

- Final grade will consist of:
  - Core Skills (67%)
  - Effort Grade (15%)
    - Attending lectures, exams, turning in homeworks
    - Attendance = completing in-class exercises
    - You may miss 2 days of lecture + 1 homework
  - Design and Integration Grade (18%)
    - Formal lab reports
    - Write-ups for one-session lab activities

Standards-Based Grading (SBG)

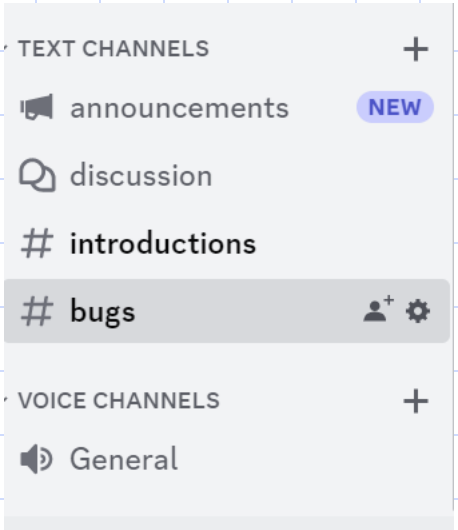
- This will be the **third** semester applying SBG to Fields and Waves. It's a work in progress!
- I welcome your constructive feedback and will collect it throughout the semester.

Standards-Based Grading (SBG)

- Any questions about SBG or other aspects of the course format?

Discord

- Will be used to help keep all of us (instructor, TAs, and students) connected in this hybrid instructional format (and adapt to its challenges as they come).
- Several different channels have been created for specific purposes.



Discord

- #announcements - A place for the TAs and I to communicate important information about the course. **This is not a place for students to ask questions.**
- #introductions - A place to introduce yourself as you join the server. **Please go do this ASAP and write your real name, pronouns, and email.**

Discord

- #discussion - A place to ask me, the TAs, or other students for help on your homework, quiz studying, or lab work. You can also tag specific topics in this channel due to the forum format.

  The TAs and I will monitor this channel closely during our office hours and also a bit throughout the day. If you ask a question after 8pm, don't expect a response until the following day unless a specific office hour is scheduled.

Discord

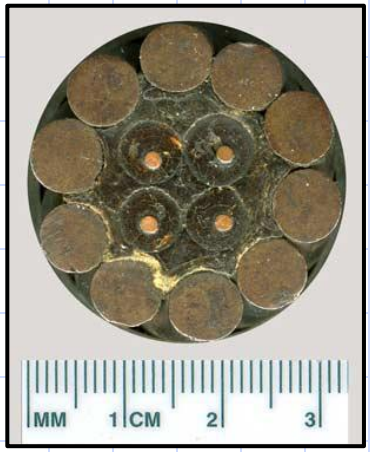
- #bugs - I make mistakes too! If you see an error in a homework, lecture, or other course document, post it here so I can correct it. (It needs to be a significant error, such as an incorrect symbol or missing minus sign.)

Transmission Lines

- Circuit theory was developed in the 18th and 19th centuries.
- One of the first practical applications was the telegraph (Francis Ronalds, 1816)
- Following this discovery, more and more long conductors were built for telegraphy

Transmission Lines

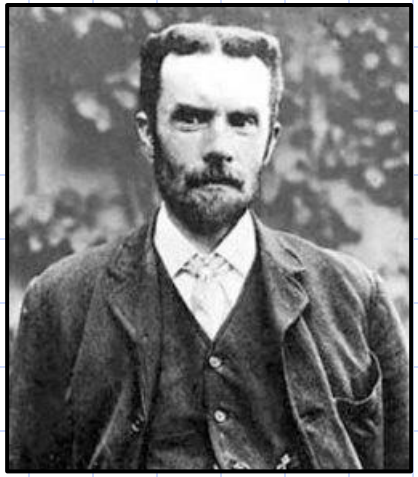
- As telegraphy expanded, there was demand for longer and longer cables
- First working undersea telegraph line was successfully laid across the English Channel in 1851. Other European undersea cables were then built, and the work of building a transatlantic cable began in the mid 1850s.
- These cables suffered from problems:
  - Voltage drop due to resistance
  - Signal delay
  - Signal distortion



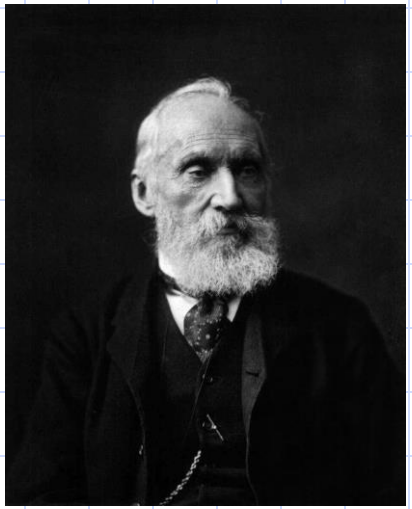
English Channel cable

Transmission Lines

- Several scientists and engineers worked to develop a formal electrical model of long conductors
- The equations that made up this model became known as the Telegrapher's Equations
- These equations allowed for intercontinental telegraph lines to develop, and they are used today for many new applications such as CPU microstrip lines



Oliver Heaviside



Lord Kelvin

Wrap-Up

- Syllabus is on the shared drive (read it!)
- Course schedule is on the website (and subject to change)
- Website is:
  - https://dylanrees.github.io/fields/
  - Or dylanrees.info and go to the ECSE 2100 tab

Wrap-Up

- Assignments will be submitted on Gradescope (except for Applied Core Skill Reports)
- Assignments due at 11:59pm on due date (see LMS / Discord for calendar)
- By default, I do not give credit for late assignments (but can make exceptions for special circumstances; please be proactive in communicating)

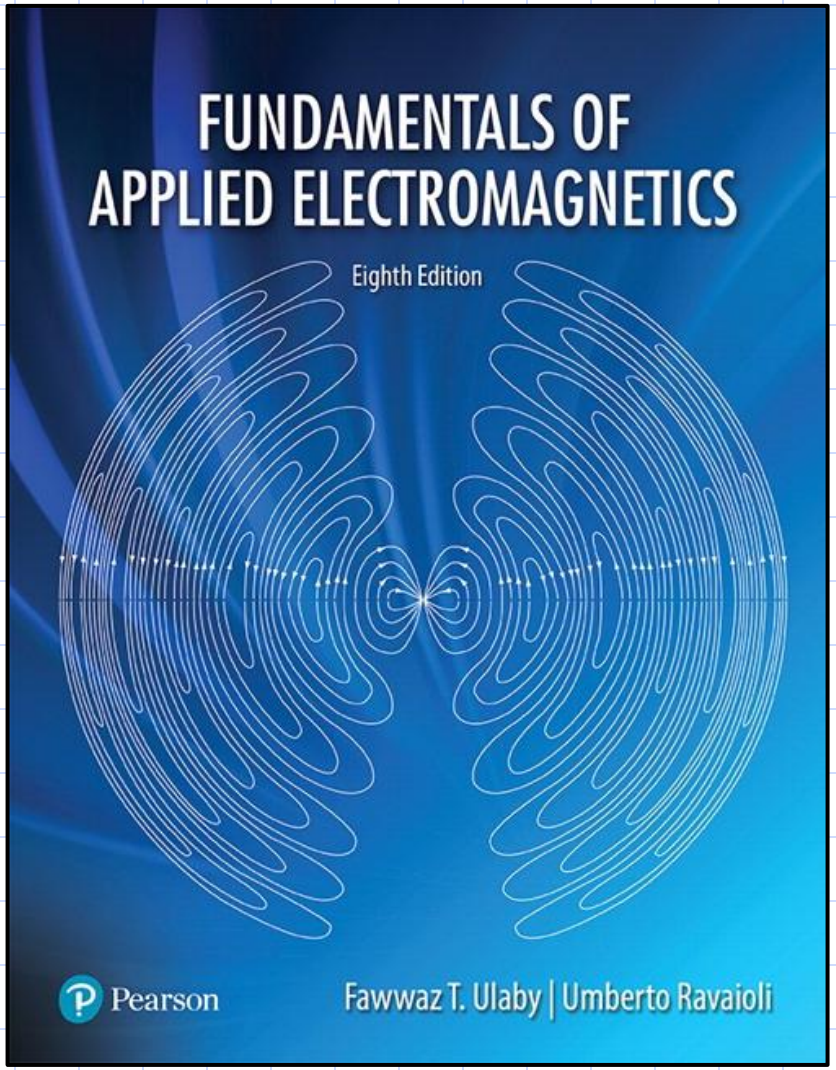
Wrap-Up

- Please go an Gradescope and find the Academic Integrity Policy + Digital Tools Acknowledgement, download, sign, and submit
- Please also fill out the survey on Gradescope
- Join the course Discord if you haven't already done so (link on website)

Wrap-Up

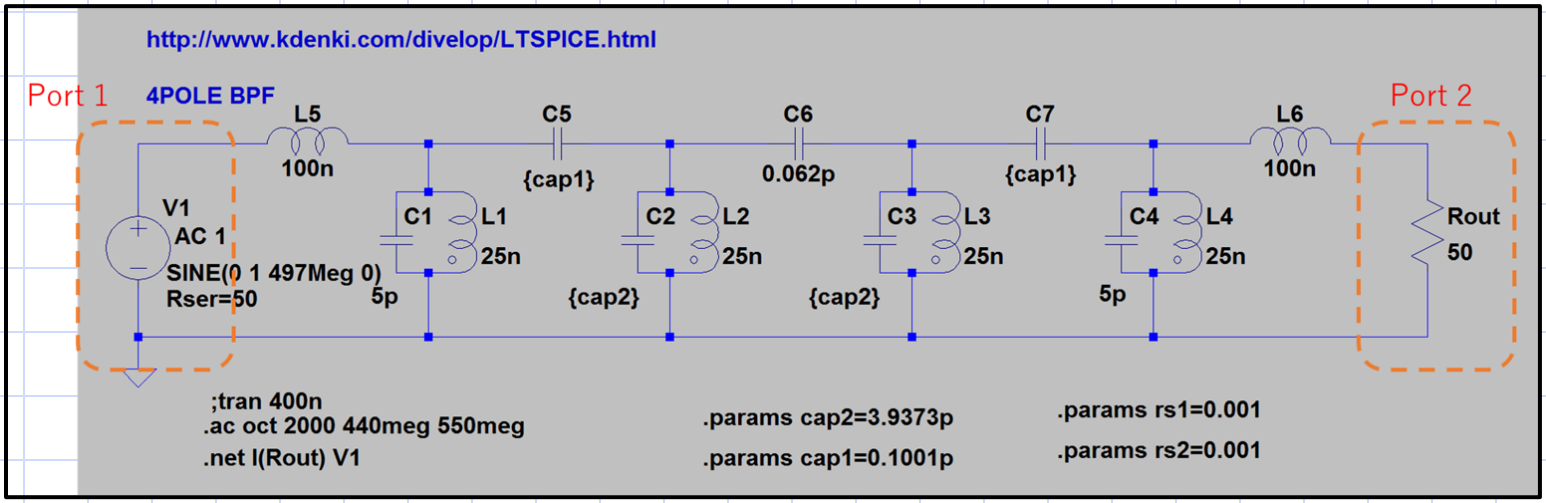
- Textbook is Ulaby, 8th edition
- There is a companion website with extra content:

https://em8e.eecs.umich.edu/



Wrap-Up

- Simulation will be done using LTSpice
- Download LTSpice and run some tutorials if you are not already familiar with it



Wrap-Up

- Begin reading Ulaby Ch. 2 sections 1-6
- Slides will always be accessible on the shared drive along with a recording of the lecture
- **No Wednesday lab this week.**
- **No in-person class on Thursday.** I will post a lecture on the shared drive for you to watch on your own time.