# Discover Electrical Engineering FPOP
Some Documentation for the 2025 DEE FPOP

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August 24, 2025

This document contains schedules, correspondence, outlines for chalk talks, and more — all for the 2025 Discover Electrical Engineering first-year pre-orientation program, which was sponsored by the MIT Department of Electrical Engineering and Computer Science.

## Contents

# 1 Schedule

## 1.1 Tuesday, August 19, 2025

| | | |
|---|---|---|
| 5:00 p.m. | Kick-Off Barbecue | Kresge |

## 1.2 Wednesday, August 20, 2025

| | | |
|---|---|---|
| 9:00 a.m. | Breakfast | 34-401 |
| 9:30 a.m. | Introductions and Community Building | 34-401 |
| 10:30 a.m. | Electrical Engineering at MIT | 34-401 |
| 11:30 a.m. | EECS Faculty and Instructor Talks | 34-401 |
| 1:00 p.m. | Lunch | 34-401 |
| 1:30 p.m. | Makerspace Tour | Metropolis |
| 2:30 p.m. | DIY Loudspeakers | 34-501 |
| 4:00 p.m. | Campus Scavenger Hunt | around MIT |
| 5:00 p.m. | Rain: Pizza Party (Stayed inside. Played “mafia.”) | 34-401 |

## 1.3 Thursday, August 21, 2025

| | | |
|---|---|---|
| 9:00 a.m. | Breakfast | 34-401 |
| 10:00 a.m. | Discussion with Prof. Sam Coday and Prof. Tess Smidt | 34-401 |
| 11:00 a.m. | Chalk Talk #1 | 34-501 |
| 12:00 p.m. | Laboratory Project #1 | 34-501 |
| 1:00 p.m. | Lunch with EECS Community | 34-401 |
| 2:00 p.m. | Chalk Talk #2 | 34-501 |
| 3:00 p.m. | Laboratory Project #2 | 34-501 |
| 5:00 p.m. | Harvard Square (Take the One Bus.) | Cambridge |

### 1.4 Friday, August 22, 2025

| | | |
|---|---|---|
| 9:00 a.m. | Breakfast | 34-401 |
| 10:00 a.m. | Undergraduate Panel | 34-401 |
| 11:00 a.m. | Chalk Talk #3 | 34-501 |
| 12:00 p.m. | Laboratory Project #3 | 34-501 |
| 1:00 p.m. | Lunch with EECS Community | 34-401 |
| 2:00 p.m. | Chalk Talk #4 | 34-501 |
| 3:00 p.m. | Laboratory Project #4 | 34-501 |
| 5:00 p.m. | Boston Common (Take the Red Line or walk.) | Boston |

### 1.5 Saturday, August 23, 2025

| | | |
|---|---|---|
| 10:00 a.m. | Brunch | 34-401 |
| 11:00 a.m. | Kahoot! | 34-401 |
| 11:30 a.m. | Design Project | 34-501 |
| 2:30 p.m. | Surveys and Ice Cream Sundaes | 34-401 |
| 3:00 p.m. | Group Photograph | Killian Court |

## 2 Staff

| **Name** | **Role** |
|---|---|
| Acevedo, Anthony | Counselor |
| Clark, Colin | Coordinator |
| Farag, Fadi | Counselor |
| Jin, Bernard | Counselor |
| Li, Cynthia | Counselor |
| Li, Jason | Counselor |
| Morgan, Riley | Counselor |
| Piety, Joshua | Counselor |
| Reid, Ellen | EECS Undergraduate Office |
| Roesler, Titus | Coordinator |
| Vela, Alonso | Counselor |

# 3 List of Guests

## 3.1 Wednesday, August 20

### 3.1.1 Electrical Engineering at MIT @ 10:30 a.m.

| **Name** | **Titles** |
|---|---|
| Han, Ruonan | Professor and EECS Undergraduate Laboratory Officer |
| LaCurts, Katrina | Lecturer and EECS Undergraduate Officer |
| Liu, Luqiao | Professor and EE Curriculum Chair |

### 3.1.2 Demonstrations @ 11:30 a.m.

| **Name** | **Role** | **Information** |
|---|---|---|
| Chen, Kevin | Professor | Soft and Micro Robotics Laboratory |
| White, Jacob | Professor | 6.4800: Biomedical Imaging with MRI |
| Steinmeyer, Joe | Lecturer | embedded systems, FPGA, SOC, . . . |

## 3.2 Thursday, August 21

### 3.2.1 Discussion with Prof. Coday and Prof. Smidt @ 10:00 a.m.

| **Name** | **Role** | **Group** |
|---|---|---|
| Coday, Sam | Professor | Coday Research Group |
| Smidt, Tess | Professor | Atomic Architects Group |

### 3.2.2 Lunch with EECS Community @ 1:00 p.m.

| **Name** | **Role** | **Information** |
|---|---|---|
| Hartz, Adam | Lecturer | educational technology |
| Notatos, Jelena | Professor | Photonics and Electronics Research Group |
| Rau, Mark | Professor | music technology |
| Shen, Shen | Lecturer | machine learning |

## 3.3 Friday, August 22

### 3.3.1 Undergraduate Panel @ 10:00 a.m.

| Name | Role |
|---|---|
| Clark, Colin | Undergraduate |
| Kothnur, Nithya | Undergraduate |
| Lin, Allison | Undergraduate |
| Lu, Ruth | Undergraduate |
| Vu, Will | Undergraduate |
| Zheng, Reng | Undergraduate |

### 3.3.2 Lunch with EECS Community @ 1:00 p.m.

| Name | Role | Information |
|---|---|---|
| Foland, Lexi | Undergraduate | robotics |
| Griffin, Joe | Doctoral Student | communications (demo) |
| Hom, Gim | Lecturer | electrical engineering (videos) |
| You, Sixian | Professor | Computational Biophotonics |

# 4 Counselor Checklist

## 4.1 Schedule

| Date | Start at | End at | Meet at | Hours | Cumulative |
|---|---|---|---|---|---|
| Tuesday, August 19 | 5:00 p.m. | 7:00 p.m. | Kresge | 2 | 2 |
| Wednesday, August 20 | 9:00 a.m. | 8:00 p.m. | 34-401 | 11 | 13 |
| Thursday, August 21 | 9:00 a.m. | 8:00 p.m. | 34-401 | 11 | 24 |
| Friday, August 22 | 9:00 a.m. | 8:00 p.m. | 34-401 | 11 | 35 |
| Saturday, August 23 | 10:00 a.m. | 3:00 p.m. | 34-401 | 5 | 40 |

We expect counselors to show up for all times listed in the table above. Counselors are permitted to work additional hours, but EECS will not compensate counselors for more than 40 hours of work — no exceptions! Counselors should expect to dedicate Tuesday, August 19, through Saturday, August 23, to the FPOP. Do not plan to juggle multiple commitments during this time.

## 4.2 Responsibilities

We expect counselors to

1. organize a campus-wide scavenger hunt for first-years on Wednesday, August 20;
2. prepare on-campus evening social activities in case of rain;
3. socialize with and facilitate discussions amongst first-years, especially during meal-times;
4. help first-years during labs;
5. accompany groups of first-years on the evening excursions; and
6. assist with other tasks as needed.

During chalk talks, Colin and the counselors will prepare for labs in 34-501.

Counselors will accompany first-years on evening excursions. Colin and Titus will stay on campus to prepare for the next day.

## 4.3 Campus Scavenger Hunt

Counselors are in charge of organizing a campus scavenger hunt for Wednesday, August 20.

1. Arrange first-years into groups.
2. Give each group a possibly-cryptic list of and/or things to find on campus.
3. Instruct the groups to take a selfie at as many places and/or things as they can find in the allotted time.
4. At the end of the allotted time, first-years must return to 34-401.
5. Counselors will award points to teams based on how many places and/or things they photographed.
6. Deduct points for returning late.

Counselors should complete this task before the FPOP starts in mid-August. Below is a list of what we expect.

1. Make a possibly-cryptic list of places and/or things for first-years to find on campus. (Don't make this impossible. They're new to MIT.) Counselors will need to provide copies of this list to first-years, either in print or online.
2. Split the first-years into groups. (We'll provide a list of first-years closer to mid-August. This shouldn't take long.)

3. Determine a scoring system. For instance, selfies of some places and/or things could be worth more points than others.
4. Decide on a spokesperson to explain the activity and announce the winning team(s) at the end.

### 4.4 Evening Activities for Rainy Days

If it's raining in the evening, counselors will take charge of on-campus evening activities. We'll have access to 34-401 after hours.

Prepare a few social activities that require little to no set-up. (For example, you could play charades, mafia, sardines, tag, truth or dare, twenty questions. Be responsible, though.) Do what you see fit to get the first-years socializing.

## 5 Welcome Letter

Hello, prospective electrical engineers!

We're excited to welcome you all to MIT on Tuesday, August 19, when the evening FPOP barbecue kicks off our week all about electrical engineering. Please plan to move into your residence hall before 4:00 p.m. The FPOP barbecue will begin at 5:00 p.m. on Kresge Oval. (https://whereis.mit.edu/ is a useful online map.) The DEE FPOP runs from 5:00 p.m. on Tuesday, August 19, through the afternoon on Saturday, August 23. We expect you to show up for all activities — other first-years were turned away to make room for you in this FPOP.

Now, a bit about our program: We're going to get you all modeling, analyzing, and designing real-world systems from day one. We want to *empower* you from the get-go — without overwhelming you by cramming a degree's worth of work into a week. Whether you're already set on studying electrical engineering or sitting on the fence, this program has something for you. Please don't worry about being left behind: We assume absolutely no prior engineering experience and will bring you all up to speed.

On top of that, we'll have professors giving talks and demonstrations during the day and trips throughout Cambridge and Boston in the evening. You'll be too busy having fun to feel homesick!

Building a community where everyone belongs is our number-one priority for this FPOP. Engineering is not just for a bunch of solder-fume-sniffers who spend all day in the basement and/or garage. We want to emphasize that engineering has a spot for everyone. By the end of the FPOP, we hope you'll see yourself as an electrical engineer, too!

A few logistics: We'll provide three meals a day for Wednesday, Thursday, and Friday. You'll have the option to pack a dinner to go or to purchase dinner with your own funds on our evening excursions. On Saturday, we'll provide brunch. Bring closed-toe shoes to wear when we're working with lab equipment.

With that said, we hope that you're as excited for this FPOP as we are. See you Tuesday, August 19!

Best regards,

Titus (on behalf of the DEE FPOP counselors and coordinators)

# 6 Discord Invitation

Hello again, prospective electrical engineers!

With just over two weeks until the FPOP barbecue, I hope you are as excited as we are for DEE! We're still putting the finishing touches on the labs, chalk talks, and tours we have planned, but in the meantime, we'd love to have you join our DEE Discord server. We chose to use Discord this year as it's quite a common platform at MIT. Rest assured, even if this will be your first time using Discord, it won't be a wasted effort once you arrive on campus.

In the server, we'll be sharing important announcements and updates leading up to and including the week of the FPOP, including a mandatory online safety training, so keep your notifications enabled. Beyond the administrative doom and gloom, however, we hope to have a place to ask questions, share your favorite EE memes, and meet your fellow FPOP friends and DEE counselors. Click here (or — if it's not showing), but don't hesitate to respond to this email if something's not right.

We can't wait to see you on August 19 and look forward to talking with y'all in the server until then. Again, don't hesitate to email — with any comments or concerns that you wouldn't want to share publicly. Titus and I are the only two on the list, a fact that you can verify here: — (another useful website at MIT).

Cheers,

Colin (on behalf of the DEE FPOP counselors and coordinators)

# 7 Discussion with Prof. Coday and Prof. Smidt

*Thursday, August 21, 2025*

## 7.1 Introduction

Folks, we're joined now by Professors Sam Coday and Tess Smidt. Thank you for joining us at the Discover Electrical Engineering FPOP. Our intention was to assemble a panel of four to five faculty members, but we came up a bit short today. Well, we'll adapt. Think of this like an EECS talk show, rather than a formal academic panel.

We have with us approximately 30 first-years, many of them interested in studying electrical engineering. I'm sure they're all eager to hear anything and everything you two have to say.

Before I ask any questions, I'd like to give you each an opportunity to introduce yourselves. Tell us your name, what you research, and what you teach. Use names, not numbers, please.

## 7.2 Moderator Questions

### 7.2.1 Background

What sparked your interest in science and engineering? Was there a particular class, project, or person who inspired you?

How did you choose your undergraduate major? What other fields did you consider?

Please describe your academic journey. What was your path from undergrad to professor?

What's the biggest difference between being an undergraduate student and a faculty member?

Have you had a mentor (e.g., a professor) who has made a big impact on you? What did they teach you? (Do you have any academic or personal role models? Please elaborate.)

Could you share a story about a time you failed a class, or a project didn't work out? What did you learn from that experience?

### 7.2.2 Research

Could you give us an overview of your research? What problems are you trying to solve?

What's the most exciting development happening in your specific area of research right now?

Looking ahead, what do you see as the next big thing or challenge in your field of research?

If you had unlimited funding and resources, what's one "moonshot" project you would work on?

How can an undergraduate student get involved in research with a faculty member? What's the best way for them to approach someone like you?

### 7.2.3 Teaching

What are classes you've taught? Tell us about them.

If you had the time and resources to design a brand-new course, what would it be? Why?

If you had to teach a course on a non-EECS topic, what would it be?

How do you approach teaching? Do you have a teaching philosophy? Describe your style of teaching.

What's one skill you think is absolutely essential for an MIT student to develop?

#### 7.2.4 Miscellaneous

What do you do for fun?

What's the last book you read or the last movie you watched?

What's your go-to "pump-up" song?

If you weren't a professor, what do you think you'd be doing for a living?

If you could have any superpower, what would it be? Why?

What's a piece of advice you wish you had received when you were a first-year student?

### 7.3 First-Year Town Hall

Let's now turn over the questioning to our first-year students.

...

Sam and Tess, thank you for your time. It's been a pleasure to have you here.

Folks, let's give them a hand.

## 8 Chalk Talk #1: Lumped Element Abstraction

*Thursday, August 21, 2025*

### 8.1 From Continuum Physics to Discrete Building Blocks

Electromagnetism may seem magical. In many ways, it is. That need not deter us from understanding what's going on under the hood, however. The purpose of these chalk talks is not to prepare you to complete a problem set or ace an exam. Rather, the purpose of these chalk talks is to impart some level of understanding and intuition that you can draw upon to make informed design decisions when you're in the lab. These are the highlights, not the full story.

It's only appropriate that we begin with the fundamental underlying physics. So, we confront Maxwell's equations. Maxwell's equations — given here in differential form — are a set of partial differential equations that govern all classical electromagnetic phenomena:

$$\begin{aligned}
\nabla \cdot \mathbf{D} &= \rho && \text{(Gauss's law for electric fields)} \\
\nabla \cdot \mathbf{B} &= 0 && \text{(Gauss's law for magnetic fields)} \\
\nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} && \text{(Faraday's law of induction)} \\
\nabla \times \mathbf{H} &= \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} && \text{(Ampère's law, as amended by Maxwell)}
\end{aligned}$$

where $\mathbf{E}$ denotes the electric field intensity (volts per meter), $\mathbf{H}$ denotes the magnetic field intensity (amperes per meter), $\mathbf{D} = \epsilon_0 \mathbf{E}$ denotes the electric flux density (coulombs per square meter), $\mathbf{B} = \mu_0 \mathbf{H}$ denotes the magnetic flux density (webers per square meter, or teslas), $\rho$ denotes the volume charge density (coulombs per cubic meter), and $\mathbf{J}$ denotes the electric current density (amperes per cubic meter). Here, $\epsilon_0$ and $\mu_0$ denote the permittivity and permeability of vacuum, respectively. Furthermore, we write $\nabla \cdot \mathbf{F}$ and $\nabla \times \mathbf{F}$ to denote the divergence and curl of a vector field $\mathbf{F}$, respectively.[1]

Our objective as engineers, however, is not to slog through solving partial differential equations. We would much rather have a set of simple building blocks from which we can construct complex devices. To circumvent the need to work directly with Maxwell's equations, we will employ an enormously useful abstraction — the lumped-element abstraction.

With the lumped-element abstraction, we abstract away the details unnecessary for the task at hand. We are left with a set of simpler rules which we may use to design practical devices. To illustrate the utility of this abstraction, let's consider an analogy in mechanics. (The fact that we are working with electromagnetism may make concepts seem more intimidating than they ought to be.)

$$\text{FORCE } \mathbf{F} \rightarrow \boxed{\text{MASS } m}$$

If you apply a force $\mathbf{F}$ to a block of mass $m$, what will the acceleration $\mathbf{a}$ be? Reflexively, you say, $\mathbf{F} = m\mathbf{a}$! Per Newton's second law, $\mathbf{a} = \mathbf{F}/m$ must be the acceleration. In applying Newton's second law, however, you implicitly modeled the block as a point-mass, ignoring, for instance, the block's shape and where the force was applied.[2]

Even Newton's laws are approximations. Newton's laws break down when applied to particles moving at the speed of light — hence, the theory of relativity — and when applied to very small particles — hence, quantum mechanics. Nonetheless, Newton's laws serve as useful approximations for a wide variety of practical engineering applications. British statistician George E. P. Box (1919 – 2013) is often attributed with the saying, "All models are wrong, but some are useful." Certainly, no engineer would dispute the usefulness of Newton's laws.

Now, let us return to electromagnetism.

We want
1. a set of simple building blocks we can use to construct complex devices, and
2. a set of rules for building practical devices from these simple building blocks.

Using the lumped-element abstraction, we will abstract away the electric fields, magnetic fields, and the like. We will build circuits out of simple building blocks, like voltage sources, current sources, resistors, capacitors, and inductors. Instead of slogging through Maxwell's equations, we will characterize each simple building block by how it relates voltage $v$ and current $i$. We will call this the constitutive relation, or $i$-$v$ characteristic, of the element. To

[1] Orfanidis, Sophocles J. *Electromagnetic Waves and Antennas.* 2016. Rutgers University, `https://ece.rutgers.edu/orfanidis`.

[2] Agarwal, Anant, and Jeffrey H. Lang. *Circuits and Electronics.* Spring 2007. Massachusetts Institute of Technology: MIT OpenCouseWare, `https://ocw.mit.edu/`. License: Creative Commons BY-NC-SA.

understand how to combine simple building blocks to construct a complex device, we will use Kirchhoff's laws, which tell us how voltage and current are conserved in a circuit.

> So, we have
> 1. discrete elements, each defined by how they relate voltage $v$ and current $i$, and
> 2. Kirchhoff's laws, which tell us how voltage and current are conserved in a circuit.

## 8.2 Constitutive Relations and Kirchhoff's Laws

### 8.2.1 Constitutive Relations

Now, let's look at the lumped elements we'll use to build circuits to perform practical tasks. Each element is defined by its constitutive relation — how it relates voltage and current. An element some of you may be familiar with is the resistor. A resistor with resistance $R$ ohms relates voltage $v$ and current $i$ though Ohm's law.

$$v = Ri \qquad \text{(Ohm's law)}$$

That is, the voltage drop across a resistor, $v$, is proportional to the current flowing through the resistor, $i$.

Another element we'll work with is the capacitor. A capacitor stores energy in the form of an electrical field. A capacitor with capacitance $C$ relates voltage $v$ and current $i$ through a first-order differential equation. In differential form, this constitutive relation is

$$i(t) = C\frac{dv(t)}{dt} \tag{1}$$

or, in integral form,

$$v(t) = v(t_0) + \frac{1}{C}\int_{t_0}^{t} i(t)\,dt, \tag{2}$$

where $t_0$ denotes some arbitrary starting time. Unlike a resistor, a capacitor possesses some semblance of memory: The voltage at time $t$ depends on the current that flows through the capacitor from time $t_0$ to time $t$. Contrast this with a resistor, where the voltage at time $t$ depends only on the current at time $t$.

The inductor is similar to the capacitor. Like a capacitor, an inductor stores energy. The inductor, however, stores energy in the form of a magnetic field, rather than an electrical field. An inductor with inductance $L$ relates voltage $v$ and current $i$ through a first-order differential equation. In differential form, this constitutive relation is

$$v(t) = L\frac{di(t)}{dt} \tag{3}$$

or, in integral form,

$$i(t) = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(t)\,dt, \tag{4}$$

where $t_0$ again denotes some arbitrary starting time. Like a capacitor, an inductor possesses some semblance of memory: The current at time $t$ depends on the voltage that drops across the inductor from time $t_0$ to time $t$.

Notice that the constitutive relation for a resistor is an algebraic equation relating voltage $v$ and current $i$. The constitutive relations for capacitors and inductors, however, are differential equations relating voltage $v$ and current $i$. For now, we will focus on resistors. Consequently, we will need only algebra to analyze and design circuits with resistors. Later on, in order to work with capacitors and inductors without first taking a course in differential equations, we will learn how to turn differential equations into algebraic equations.

Lastly, let me introduce sources. Voltage source supplies voltage. We might model a battery as a voltage source. The constitutive relation for a voltage source that supplies, say, $V_0$ volts, is $v = V_0$, with no constraint placed on the current $i$. No matter how much current is flowing, a voltage source will supply $V_0$ volts.

Likewise, a current source supplies current. The constitutive relation for a current source that supplies, say, $I_0$ amps, is $i = I_0$, with no constraint placed on the voltage $v$. No matter the voltage drop, a current source will supply $I_0$ amps.

**Summary**

1. Elements are defined by constitutive relations between voltage $v$ and current $i$.
2. A resistor relates voltage and current through Ohm's law: $v = Ri$.
3. The constitutive relations for capacitors and inductors are differential equations.
4. Voltage sources supply voltage, and current sources supply current.

### 8.2.2 Kirchhoff's Laws

So far, we have looked at a set of simple building blocks we can use to construct complex devices. Each building block is defined by a constitutive relation. Now, we need a set of rules for building practical devices from these simple building blocks. These rules are Kirchhoff's voltage law and Kirchhoff's current law — in short, KVL and KCL, respectively. Kirchhoff's laws tell us how voltage and current are conserved in a circuit.

Kirchhoff's voltage law summarizes how voltage is conserved in a circuit: There cannot be any net voltage drop around any closed loop in the circuit. Said another way, the voltage drops around any closed loop in the circuit must sum to zero.

$$\sum_{n \in \text{loop}} v_n = 0 \tag{KVL}$$

Kirchhoff's current law summarizes how current is conserved in a circuit: There cannot be any net current flowing into or out of around any node in the circuit. Said another way, the currents flowing into or out of any node in the circuit must sum to zero.

$$\sum_{n \in \text{node}} i_n = 0 \tag{KCL}$$

The current that flows into a node must flow out of a node.

Constitutive relations and Kirchhoff's laws are all we need to analyze and design circuits. Let's apply them in an example.

### 8.2.3 Example: Voltage Divider

Suppose that I connect a voltage source that supplies $V_0$ volts to two resistors in series. The resistors have resistances $R_1$ and $R_2$ ohms, respectively. We'll refer to them as resistor $R_1$ and resistor $R_2$. Let's determine the voltage drops across $R_1$ and $R_2$.

First, write out the constitutive relations: $v_{\text{in}} = V_0$, $v_1 = R_1 i_1$, and $v_2 = R_2 i_2$. The resistors are connected in series, so the same current must flow through both resistors. To highlight this, let's write $i = i_1 = i_2$. So, $v_1 = R_1 i$ and $v_2 = R_2 i$.

Now that we've written out the constitutive relations, let's apply Kirchhoff's voltage law:

$$V_0 - v_1 - v_2 = 0, \tag{5}$$

or

$$V_0 = v_1 + v_2 = R_1 i + R_2 i = (R_1 + R_2) i. \tag{6}$$

Next, we solve for $i$.

$$i = \frac{V_0}{R_1 + R_2} \tag{7}$$

Finally, we substitute this result back in the constitutive relations for $R_1$ and $R_2$ to solve for the voltage drops across those resistors.

$$v_1 = R_1 i = R_1 \frac{V_0}{R_1 + R_2} = \left(\frac{R_1}{R_1 + R_2}\right) V_0 \tag{8}$$

$$v_2 = R_2 i = R_2 \frac{V_0}{R_1 + R_2} = \left(\frac{R_2}{R_1 + R_2}\right) V_0 \tag{9}$$

Some fraction of the voltage drops across $R_1$, and the remaining voltage drops across $R_2$. This simple circuit is called a voltage divider. The input voltage, $v_{\text{in}} = V_0$, is divided up among the resistors, in some sense.

From a more abstract input-output perspective,

$$v_{\text{in}} \to \boxed{\text{CIRCUIT}} \to v_1 = \left(\frac{R_1}{R_1 + R_2}\right) v_{\text{in}}$$

and

$$v_{\text{in}} \to \boxed{\text{CIRCUIT}} \to v_2 = \left(\frac{R_2}{R_1 + R_2}\right) v_{\text{in}}.$$

We approached this as a problem of analysis: Given a circuit, determine the voltage drop across each element and the current flowing through each element. In another context, we could have approached this as a design problem: Given a set of specifications, design a circuit to meet those specifications. Analysis and design are "two sides of the same coin."

## 8.3 Circuit Simplifications

### 8.3.1 Example: Voltage Divider with Many Resistors in Series

Suppose that I connect a voltage source that supplies $V_0$ volts to many resistors — $N$ resistors, let's say — in series. The resistors have resistances $R_1$, $R_2$, …, $R_N$ ohms, respectively. Let's determine the voltage drops across resistor $R_N$.

We could start by writing out the constitutive relations:

$$v_n = R_n i_n \tag{10}$$

for $n = 1, 2, \ldots, N$. The resistors are connected in series, so the same current must flow through all resistors. To highlight this, let's write $i = i_1 = i_2 = \cdots = i_N$. So,

$$v_n = R_n i \tag{11}$$

for $n = 1, 2, \ldots, N$. Next, we apply KVL:

$$V_0 - \sum_{n=1}^{N} v_n = 0, \tag{12}$$

or

$$V_0 = \sum_{n=1}^{N} v_n = \sum_{n=1}^{N} R_n i = (R_1 + R_2 + \cdots + R_N)i. \tag{13}$$

We solve for $i$:

$$i = \frac{V_0}{R_1 + R_2 + \cdots + R_N}. \tag{14}$$

Using our expression for $i$, we determine the voltage drop across resistor $R_N$:

$$v_N = R_N i = R_N \frac{V_0}{R_1 + R_2 + \cdots + R_N} = \left(\frac{R_N}{R_1 + R_2 + \cdots + R_N}\right) V_0. \tag{15}$$

Is there a simpler way we could have gone about deriving this result, though? Let's look at simplifications we can make in our circuit analysis.

### 8.3.2 Resistors in Series and Resistors in Parallel

If we connect many resistors in series, we effectively have a "more resistive" resistor. To be more precise, for resistors $R_1$, $R_2$, …, $R_N$ connected in series, the effective resistance is

$$R_{\text{eff}} = R_1 + R_2 + \cdots + R_N. \tag{16}$$

Think back to the voltage divider example with resistors $R_1$, $R_2$, …, $R_N$. If we make the definition $R_{\text{eff}} = R_1 + R_2 + \cdots + R_{N-1}$, then we may apply the result we derived for the simpler two-resistor voltage divider:

$$v_N = \left(\frac{R_N}{R_{\text{eff}} + R_N}\right) V_0. \tag{17}$$

Using simplifications, we may derive results through pattern-matching rather than algebra.

We may also connect resistors in parallel. For resistors $R_1$, $R_2$, …, $R_N$ connected in parallel, the effective resistance is

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N} \tag{18}$$

or, in terms of conductance,

$$G_{\text{eff}} = G_1 + G_2 + \cdots + G_N, \tag{19}$$

where $G_n = 1/R_n$ for $n = 1, 2, \ldots, N$. Think of the result like this: Voltage and current will always take the "path of least resistance." Voltage and current will divide themselves up so as to dissipate the least amount of energy across all the resistors combined in parallel.

### 8.3.3 Example: Current Divider

Let's work through an example. Suppose that I connect a voltage source that supplies $V_0$ volts to resistors $R_1$ and $R_2$, which are connected in parallel. Let's determine the voltages $v_1$ and $v_2$.

First, we write out the constitutive relations: $v_1 = R_1 i_1$ and $v_2 = R_2 i_2$. Unlike in previous examples, there is no reason to assume that the same current flows through both branches. More current ought to flow through the resistor with the lesser resistance. However, recognize that the voltage source imposes a constraint: The voltage drop across each branch must be $V_0$ volts. So, we write $v_1 = V_0 = R_1 i_1$ and $v_2 = V_0 = R_2 i_2$.

Next, we apply KVL:

$$v_1 - v_2 = 0, \tag{20}$$

or

$$\begin{aligned} v_1 &= v_2 & (21)\\ V_0 &= V_0 & (22)\\ R_1 i_1 &= R_2 i_2, & (23) \end{aligned}$$

from which we observe that

$$i_2 = \left(\frac{R_1}{R_2}\right) i_i. \tag{24}$$

If $R_1 > R_2$, then more current will flow through resistor $R_2$. If $R_1 < R_2$, then more current will flow through resistor $R_1$. More current flows through the resistor with the lesser resistance. This seems reasonable. (Sanity checks are always good!) We still need to determine expressions for the branch currents $i_1$ and $i_2$, though.

From KCL, we know that current must be conserved in a circuit. If $i$ amps flows out of the voltage source, then the currents flowing through each branch must sum to $i$ amps. That is,

$$i = i_1 + i_2. \tag{25}$$

We can determine $i$ using Ohm's law:

$$i = \frac{V_0}{R_{\text{eff}}} \tag{26}$$

where

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2}, \tag{27}$$

or

$$R_{\text{eff}} = \frac{R_1 R_2}{R_1 + R_2}. \tag{28}$$

In this case,

$$i = V_0 \frac{R_1 + R_2}{R_1 R_2}. \tag{29}$$

Now, let's determine $i$ in terms of $i_1$ and $i_2$. Using our earlier result for $i_2$, we write

$$i = i_1 + i_2 = i_1 + \left(\frac{R_1}{R_2}\right) i_1 = \left(\frac{R_2}{R_2}\right) i_1 + \left(\frac{R_1}{R_2}\right) i_1 = \left(\frac{R_1 + R_2}{R_2}\right) i_1. \tag{30}$$

Finally, we substitute this expression back into our result from Ohm's law:

$$i_1 = \frac{V_0}{R_1} \tag{31}$$

or

$$i_1 = \left(\frac{R_2}{R_1 + R_2}\right) i. \tag{32}$$

It is straightforward to derive that

$$i_2 = \frac{V_0}{R_2} \tag{33}$$

or

$$i_2 = \left(\frac{R_1}{R_1 + R_2}\right) i. \tag{34}$$

Moreover, an analogous result holds for $N$ resistors combined in parallel.

We'll call this circuit a current divider. Current is divided up between the branches.

## 8.4 Lessons Learned

So, there you have it. We covered a lot of ground in this chalk talk. Let me summarize what we discussed.

1. The **lumped-element abstraction** provides us a means to construct complex devices out of simple building blocks.

2. Each element is defined how it relates voltage $v$ and current $i$. We call this the element's **constitutive relation**, or $i$-$v$ characteristic.

3. **Kirchhoff's laws** describe how voltage and current are conserved in a circuit.
4. A **voltage divider** supplies a fraction of the input voltage at the output. A **current divider** supplies a fraction of the input current at the output.
5. We may replace a set of resistors connected in series or in parallel with a single resistor with the **effective resistance**.

Using what you've just learned, you can now analyze and design circuits composed of sources and resistors. In the next chalk talks, we'll discuss additional circuit elements, like capacitors, inductors, and operational amplifiers, so that you can use these elements in more complex circuits. We'll also discuss new methods of analyzing circuits. For now, though, let's take a five-minute break before starting our next project.

## 8.5 Summary of Results

**Constitutive Relation for a Resistor (Ohm's Law)**

$$v(t) = R\,i(t) \text{ for all time } t$$

**Constitutive Relation for a Capacitor**

$$i(t) = C\frac{dv(t)}{dt} \quad \text{or} \quad v(t) = v(t_0) + \frac{1}{C}\int_{t_0}^{t} i(t)\,dt$$

**Constitutive Relation for an Inductor**

$$v(t) = L\frac{di(t)}{dt} \quad \text{or} \quad i(t) = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(t)\,dt$$

**Kirchhoff's Voltage Law (KVL) and Kirchoff's Current Law (KCL)**

$$\textbf{KVL:} \sum_{\text{loop}} v_n = 0 \qquad \textbf{KCL:} \sum_{\text{node}} i_n = 0$$

**Resistors in Series**

$$R_{\text{eff}} = R_1 + R_2 + \cdots + R_N$$

**Resistors in Parallel**

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$$

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2} \quad \text{or} \quad R_{\text{eff}} = \frac{R_1 R_2}{R_1 + R_2}$$

**Voltage Divider**

$$v_1 = \left(\frac{R_1}{R_1 + R_2}\right) v_{\text{in}} \qquad v_2 = \left(\frac{R_2}{R_1 + R_2}\right) v_{\text{in}}$$

**Current Divider**

$$i_1 = \frac{v_{\text{in}}}{R_1} = \left(\frac{R_2}{R_1 + R_2}\right) i_{\text{in}} \qquad i_2 = \frac{v_{\text{in}}}{R_2} = \left(\frac{R_1}{R_1 + R_2}\right) i_{\text{in}}$$

# 9 Chalk Talk #2: Operational Amplifiers

*Thursday, August 21, 2025*

I began with a brief review of the material discussed in the first chalk talk. Following this, I motivated the need to enforce modularity in circuit design. I did so with an example: I determined that the output voltage dropped when a load was connected.

As a solution, I introduce the operational amplifier, or op-amp. Rather than examining the innards of an op-amp or even giving, say, a voltage-controlled voltage source model of an ideal op-amp, I examined the use of ideal op-amps in two contexts. First, I noted the use of op-amps as buffers. Second, I used op-amps to construct a non-inverting amplifier.

# 10 Undergraduate Panel

*Friday, August 22, 2025*

I moderated a panel of six undergraduates — five with an EECS affiliation and one affiliated with MechE. I referred to the list of questions I prepared for the discussion with Prof. Sam Coday and Prof. Tess Smidt, though I modified the questions somewhat to aim them at the undergraduates on the panel. Near the end, I opened the floor to questions from first-years.

# 11 Chalk Talk #3: Fourier Transform

*Friday, August 22, 2025*

I began with a digital signal processing demonstration. I loaded in a clip of audio and showed both time-domain and frequency-domain plots. (In the case of the latter, I showed a plot of the magnitude of the Fourier transform.) I demonstrated through audio and visuals the effect of low-pass and high-pass filtering.

Following this demonstration, I began the third chalk talk with a brief review of the material discussed in the first two chalk talks. From the first chalk talk, I recalled that the constitutive relations for capacitors and inductors involved differential equations. I, however, am not interested in solving differential equations at the moment. One particularly useful property of the Fourier transform that we will eventually use is the "differentiation property" — that differentiation (with respect to time) in the time domain is equivalent to multiplication by a frequency-dependent factor in the frequency domain. Of course, there are numerous other uses of and reasons why one ought to learn about the Fourier transform.

There is one perspective of the Fourier transform that I like to use when introducing it to a general yet technically-inclined audience: The Fourier transform is a measurement of similarity between a signal and sinusoids — sinusoids that span a range of different fundamental frequencies. The method we use to measure similarity is an inner product — but I don't use that terminology.

While the basis functions (again, not called as such to keep the terminology to a minimum) are initially real-valued sinusoids, I introduce complex numbers and Euler's formula in order to formulate the Fourier transform in the usual form with complex exponentials as the basis functions.

At the end, I emphasize that, no matter how gnarly the mathematics may appear, the Fourier transform is fundamentally simple: We measure the similarity between a signal and a sinusoid at a fixed frequency. When we vary that frequency over a range, we can determine the "amount of signal" per frequency. This yields the Fourier transform of the signal, which is a function of frequency, rather than a function of time.

# 12 Chalk Talk #4: Frequency Response and Filtering

*Friday, August 22, 2025*

I began the fourth and final chalk talk as I did the previous three chalk talks — by discussing the material covered in prior chalk talks. I returned the constitutive relations for capacitors and inductors, which relate voltage and current through differential equations. Having learned about the Fourier transform, we may now analyze circuits in the frequency domain in addition to the time domain. In the frequency domain, the constitutive relations for capacitors and inductors become algebraic equations.