

Hello!

Welcome to ES 152: Circuits, Devices, and Transduction.

This course is focused on gaining intuition for the *art* of circuit design - focusing primarily on the building blocks of analog circuits. As much as we think of circuits as a rigorous technology, the precise manipulation of electrons traveling within materials and devices in the physical world is truly an art form. We can only hope to begin to wield it. ES 152 aims to give you the tools you'll need to craft circuits for applications you've thought of but could never implement. The goal is that a student who does well in this course will gain the fundamental skills needed to begin exploring advanced circuit topics in industry or academia.

Classroom

Weekly classes will be held in SEC 2.118 on Mondays and Wednesdays from 2:15 - 3:00 pm. This is a totally bizarro classroom that I have never taught in before. But it looks pretty nice actually because the display screen isn't made up of a bunch of smaller screens that make my slides look less pretty (like in SEC 1.402), so that's something to be happy about!

Lab Sets

Gaining an intuitive feel for circuit design is a long and arduous process. You'll employ various skillsets and tools, from analytical problem solving, circuit simulators, bench-top measurements, video walkthroughs, and whatever else you can scramble together the night before a deadline. We'll use all of that in ES 152. You might love it, you might hate it, you might look back on it fondly, you might erase it from your memory with disdain. Hopefully you'll gain some friends along the way. Lab Sets are designed to guide you through this dynamic process, and will consist of multiple sections that you'll gain experience with each week. Each Design Lab consists of the following:

1. **Analytical problems** to help with theoretical understanding
2. **Circuit simulations** to verify your results, help you manipulate complex circuit interactions, and build your intuition (if used correctly)
3. **In-Lab design component**, using the beautiful resources in our new lab in SEC to build physical circuits that interact with the real world

Templates will be provided for each Lab Set for you to work though. The skills you learn in the Lab Sets will enable you to complete the Final Lab Project.

Lab

Our beautiful lab, in SEC 1.110/1.111, decked out with new oscilloscopes, function generators, power supplies, soldering stations, you name it!

Believe it or not, it can be fun to be in lab! Or maybe I'm just a total nerd. At least here it LOOKS like we're having fun :) (this is ES 152 from 2 years ago).

Aaaaand last year's class. If you make it through to the end of class (I know you can do it!), you will be required to wear your favorite outfit for the class photo.

You'll be working in here at one of the following lab sessions each week:

- Thursdays, 3:45 am - 6:30 pm
- Fridays, 2:15 - 5:00 pm

Midterm + Final

We'll have a midterm, a final lab project, and a final exam. Both the midterm and final exam will be 48-hour take-home test; you'll be able to use a wide range of resources to complete them, since that's how you'll likely be solving problems in the "real world" (I've never had a boss who told me to design a circuit without looking at the internet or any textbooks). The only difference here is that you won't be able to talk to your friends :)

Final Lab Project

The final lab project will involve the design of a complex mixed signal CMOS circuit. We'll talk more about it in class.

Grading

There are 10 lab sets (+1 "hello world" lab set for gaining access to lab, picking up your lab kit, completing lab safety training, installing course software, and signing the academic integrity policy), each worth 500 points. The midterm, final exam, and final lab project are each worth some points too. The grading breakdown is shown in the following table. More details for the Lab Sets and Final Lab Project are in the sections below.

Total Points:

Category	Points	Fraction of Final Grade
Lab Sets 0-10	5,500 (500 each)	55%
Midterm	1,000	10%
Final exam	1,500	15%
Final Lab Project	1,000	10%
Class Attendance & Participation... come to class!	1,000	10%
Total	10,000	100%

As you can see, there are 10,000 total points, which should make it easy to track your performance throughout the semester. Your final grade is based on your total points (this class will not be graded on a curve). You™ll get an "A" with a score of 9,500 or above.

Specific Topics & Course Schedule

The class schedule is listed below. **Bold** entries indicate classes where we'll be covering new material. Some classes will be dedicated to review and problem solving sessions.

Week	Date	Class	Topics Covered
0	Sept. 4 (W)	0	Hello, Electric World
1	Sept. 9 (M)	1	Circuit Basics
	Sept. 11 (W)	2	Circuit Analysis
2	Sept. 16 (M)	3	Capacitor & Inductor Circuits, Part 1
	Sept. 18 (W)	4	Capacitor & Inductor Circuits, Part 2
3	Sept. 23 (M)	5	AC Analysis, Part 1
	Sept. 25 (W)	6	AC Analysis, Part 2
4	Sept. 30 (M)	7	Operational Amplifiers
	Oct. 2 (W)	8	Op Amp Circuits
5	Oct. 7 (M)	9	More Op Amp Circuits
	Oct. 9 (W)	10	Midterm Review
	Oct. 10-12 (Th-Sat)		Take-Home Midterm
6	Oct. 14 (M)		No class: Indigenous Peoples' Day
	Oct. 16 (W)	11	wtf is a Semiconductor? Part 1

7	Oct. 21 (M)	12	wtf is a Semiconductor? Part 2
	Oct. 23 (W)	13	PN Junction
8	Oct. 28 (M)	14	PN Junction / Diode
	Oct. 30 (W)	15	Small Signal Analysis
9	Nov. 4 (M)	16	MOSFET
	Nov. 6 (W)	17	MOSFET Circuits, Part 1
10	Nov. 11 (M)	18	MOSFET Circuits, Part 2
	Nov. 13 (M)	19	Op Amp Guts, Part 1
11	Nov. 18 (W)	20	Op Amp Guts, Part 2
	Nov. 20 (M)	21	Op Amp Guts, Part 3
12	Nov. 25 (M)	22	Intro to Digital VLSI Circuits
	Nov. 27 (W)		No Class: Thanksgiving Break
13 (last week of classes)	Dec. 2 (M)	23	Random Access Memory
	Dec. 4 (W)	24	Mystery Guest Lecture
Reading Week	Dec. 9 (M)	R1	[OPTIONAL] Final Project Q&A / Working Session #1
	Dec. 11 (W)	R2	[OPTIONAL] Final Project Q&A / Working Session #2
Finals Week	Dec. 16-18 (M-W)	F	Take-Home Final Exam

Lab Sets:

Number	Lab Set	Points
0	Hello, Beautiful Lab <i>Lab: Pick up your Lab Kit + Lab Safety Training</i>	500
1	Circuit Fundamentals <i>Lab: Talk to Your Circuit, Tell it Your Secrets</i>	500
2	AC & Transient Analysis <i>Lab: Your Circuit Feels Your Tender Touch</i>	500
3	Time & Frequency Domains <i>Lab: Welcome to the FREAK DOMAIN</i>	500
4	Op Amp Circuits <i>Lab: Give Your Circuit a Voice</i>	500
	No Lab Set due: Midterm	
5 & 6	WTF is a Semiconductor? <i>Lab: Measuring "Real" Semiconductor Devices</i>	1,000
7	MOSFETs <i>Lab: The Field-Effect Transistor, in All its Glory (and Some Diodes)</i>	500
8	CMOS Circuits <i>Lab: Gimme Gimme Gain, Gimme Gain, Gimme Gain</i>	500
9	Multi-Stage CMOS Amplifiers <i>Lab: Mystery Meat (AKA Op Amp Guts)</i>	500
	No Lab Set due: Thanksgiving break	
10	Very-Large-Scale Integrated (VLSI) Circuits <i>Lab: When Worlds Collide (Analog + Digital)</i>	500
Final Lab Project	You're a Circuit Designer <i>Lab: Eerie Circuit Captures Your Essence</i>	

Final Lab Project:

Deliverable	Due Date	Points
Final Lab Project Milestone <i>Memory Interface Circuits Working</i>	Beginning of reading week	500
Final Lab Project - Final Submission		

Submissions & "Late Days"

All Lab Sets and Final Lab Project deliverables will be submitted through canvas. While collaboration is encouraged (see the collaboration statement below), each student must submit their own unique submission for each graded assignment.

- Weekly Lab Sets are due on Mondays before class (at noon, so you can still get to class on time :).
- Each student can submit up to two "Late Lab Sets", which grants an extension up until the upcoming Friday at 11:59 pm (after that, we will post Lab Set solutions and can no longer accept submissions)
- There won't be any "dropped" Lab Sets, since you'll need skills learned from each one to complete the Final Project (and for the rest of your lives as engineers).

Course Staff, Contact, and Office Hours

Please do not hesitate to contact us at any time with questions! You'll likely have many small questions as you work through the analytical problems, circuit simulations, and building circuits in lab. We've also set up a slack channel (gain access to it here on canvas), which will be helpful for answering questions quickly. For more in-depth questions, come to weekly scheduled office hours or email us to set up an appointment.

- Prof. Gage Hills (ghills@seas.harvard.edu): Office Hours in SEC 5.415 on Fridays, 11:00 am - noon (or by appointment)

Graduate student TFs:

- TomHenry Reagan
- Patrick Pariseau

Undergraduate TF:

- Elsa Oreen

Active Learning Lab:

- Champa Gururaj
- Leo Gomez

Evening Design Parties (EDP) / EE MEGA OFFICE HOURS

This was a great way to informally work on assignments together (which we started doing in CS 148/248 in spring '22, and also did in ES 152 the last couple years). We'll be keeping the ball rolling this semester each Wednesday evening in SEC. Here's a picture of Andrew from one of the early EDPs, king of his lab.

Textbooks

There are two useful textbooks for this class, both of which are available in free or inexpensive ebook formats. These books are NOT REQUIRED, but I will often point to certain chapters that you might find useful for additional explanations. If you're concerned about the costs of the textbooks, come talk to me and we can chat about options.

- **Introduction to Electric Circuits (9th Edition)**
By James A. Svoboda & Richard C. Dorf

- **Microelectronic Circuits (7th Edition)**
By Sedra & Smith

There are multiple options for ordering or renting copies of the textbooks. While deciding where to order to the textbooks, you may be able to preview some of the pages online (there are some example links in the Lab Set 0 slides, which is available in the Assignments section of canvas).

Pre-requisites

Please contact Prof. Gage Hills if you have questions about the following pre-requisites:

- **MATH 1A (Introduction to Calculus)** – pre-requisite
- **MATH 1B (Integration, Series and Differential Equations)** – pre-requisite
- **At least** one of the following **co-requisites** (or consent of instructor, see Recommended Background section below)
 - **PHYSICI 12B (Electromagnetism and Quantum Physics from an Analytic, Numerical and Experimental Perspective)**
 - **PHYSICS 15B (Introductory Electromagnetism)**
 - **APPHY 50B (Physics as a Foundation for Science and Engineering, Part II)**
- **ES 50 (Introduction to Electrical Engineering)** – another good pre-requisite (but not required)
- Familiarity in a circuits lab environment is a plus, or you can pick up these skills along the way (e.g., using lab equipment like oscilloscopes, power supplies, function generators, or other equipment you'll find in the lab in SEC 1.110)
- Familiarity with programming languages is a plus, such as python, Matlab, Mathematica, etc., for data analysis, optimization, and visualizing/plotting results
- Thirst for delicious knowledge

Recommended Background

Math – Calculus and with some basic exposure to differential equations and linear algebra.

Physics – Newtonian mechanics and with some exposure to the topics of electrostatics, magnetostatics, and electromagnetic fields (Maxwell's Equations).

Self Assessment Quiz

If you're still wondering about your pre-reqs... wonder no more! We've created a quick "self-assessment quiz" that will help you figure out if ES 152 is right for you. The quiz is optional and we won't grade it - its for your own benefit. Many of the questions are labeled as "we don't expect you to know," i.e., if you can answer all of those ones then ES 152 will probably be too easy for you. On the other hand, if you're struggling with all of the questions labeled "there's a good chance you know," then you might think about taking ES 152 in another semester once you've completed some more pre-reqs. The first slide of the quiz is shown below, and you can access the full version in the Assignments section.

Collaboration

Discussion and the exchange of ideas are essential to doing academic work. For assignments in this course, students are encouraged to consult with classmates on problem sets and lab assignments. However, after discussions with peers, each student should write up their own submissions to ensure that they are able to work through the problems themselves, and that their submissions are the result of their own efforts. For problem sets and lab assignments, students should also include a list of classmates with whom they collaborated.

At the same time that you submit Lab Set 0, you should also sign and submit the ES 152 Academic Integrity Policy, available in the Assignments section.

Inclusion and Belonging

The ES 152 teaching staff believes that diversity of thoughts, backgrounds, perspectives, and experiences are valuable for learning and for improving our community and our society as a whole. We respect our students' identities, including but not limited to race, gender, class, sexuality, socioeconomic status, religion, and ability. We strive to create a learning environment where every student belongs and feels welcome and valued. We value your feedback in accomplishing this goal. If something is said by anyone in class or in a meeting that makes you uncomfortable, or if there is course material that feels insensitive, please talk to me or TFs about it, even if anonymously.

Semester-at-a-Glance

See the calendar below for all events related to this course (expected timeline subject to change! lol).