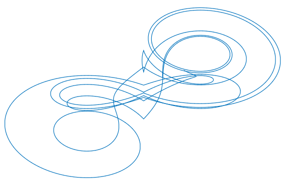
PHYS 222: Fundamentals of Engineering Design

Broadly applicable mathematical, computational, and experimental skills strategically selected to be mutually reinforcing with a small but diverse set of engineering topics.



"A little known secret is that a physicist is one of the most employable people in the marketplace — a physicist is a trained problem solver. How many times have you heard a person in a workplace say, 'I wasn't trained for this!' That's an impossible reaction from a physicist, who would say, instead, 'Cool.'" — Neil deGrasse Tyson

Engineering is vast. Even a single engineering discipline, such as electrical engineering, is vast, a subject for a lifetime of study. **This course is a "super fun pack" of five engineering skills and three engineering topics.** The skills and topics were not selected at random. Instead, the chosen skills and topics are mutually reinforcing, like the stones in an archway. **All five skills will be illustrated through all three topics:**

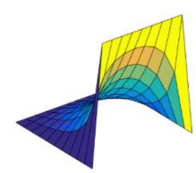
- We will use **Fourier series** to analytically solve problems in **heat conduction**, **circuit analysis**, and **semiconductor physics**.

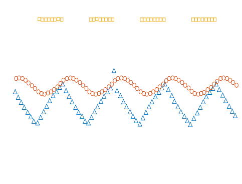
$$T(x,t) = \sum_{n=1}^{\infty} A_n \sin\left(\frac{n\pi x}{L}\right) \exp\left[-\alpha\left(\frac{n\pi}{L}\right)^2 t\right]$$

- We will use **Laplace transforms** to analytically solve problems in **heat conduction**, **circuit analysis**, and **semiconductor physics**.

$$\overline{V}_{out}(s) = \frac{A}{(1+sRC)}$$

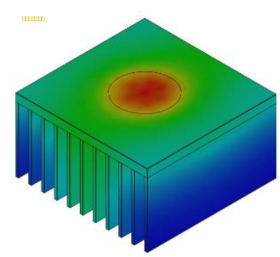
- We will use **finite difference approximations** to numerically solve problems in **heat conduction**, **circuit analysis**, and **semiconductor physics**.





- We will use the **Arduino microcontroller** to do experiments in **heat conduction**, **circuit analysis**, and **semiconductor physics**.

- We will use the **FreeCAD** software to create three-dimensional models of objects discussed in **heat conduction**, **circuit analysis**, and **semiconductor physics**.



Fourier series, **Laplace transforms**, **finite difference approximations**, and proficiency with the **Arduino microcontroller** and **FreeCAD** are broadly applicable skills. Problems in heat conduction, circuit analysis, and semiconductor physics are just a small sampling of the problems that can be solved using the skills that you'll learn in this course. By the end of the course, I think you'll be amazed at your ability to solve problems analytically, computationally, and experimentally.

The course is divided into three units:

1. **Design of Heat Fins**: Heat conduction, Fourier series, and finite difference approximations.
2. **Design of Amplifiers**: Op amps, circuit analysis, and Laplace transforms.
3. **Design of Solar Cells**: Semiconductor physics and further applications of Fourier series, Laplace transforms, finite difference approximations, Arduino, and FreeCAD!

Texts:

For your convenience, I provide 88 pages of typed lecture notes. The primary references are also ebooks that you can access for free:

- Chapters 2, 4, and 5 from Lienhard and Lienhard, *A Heat Transfer Textbook*, 5^{th} ed., 2020. Free ebook: http://web.mit.edu/lienhard/www/ahtt.html.
- Chapters 10, 11, 13, 15, 16, and 18 from Santiago, *Circuit Analysis for Dummies*, 2013. Ebook accessible through Emory libraries.
- Chapters 3 and 4 from Honsberg and Bowden, Photovoltaics Education Website. Free ebook: https://www.pveducation.org/.

I think the material is sufficiently complicated that you'll benefit from both attending the lectures and reading the typed lecture notes (maybe skim them before the lecture, and review afterward).

Grading:

- 45% Tests (15×3 tests)
- 30% Lab reports (5% $\times$ 6 reports)
- 10% FreeCAD exercises (2% $\times$ 5 exercises)
- 15% Final project (10% written report, 5% degree of difficulty)

Lab (and final project) reports: Clearly, correctly, and thoroughly explain what your data means and how you got it. You may work with a lab partner.

FreeCAD exercises: Submit the images you generate and brief explanatory text. You may work with a lab partner.

Joint lab reports: You and your lab partner **may** submit joint lab reports (and final project report, and FreeCAD submissions). If your lab partner submits a report with your name on it, you don't have to submit it. I encourage you to submit joint reports to lighten the workload. Engineering is about making things easier.

Problem sets: Ungraded but strongly recommended as preparation for tests. Solutions are provided.

Final project: Imitation is a great way to learn, so you can replicate a project you find online, as long as you cite your sources, and you thoroughly explain how it works. You can elevate the degree of difficulty by one or more of the following:

- Pick a project that requires advanced mathematical or computational skill.
- Pick a project that requires laborious construction or troubleshooting in the lab.
- Pick a project that you partially or entirely design yourself (not imitating someone else's).

	Topic	**Lab activity**	**Problem Set**	**Due**
Jan 18	Fourier's law	Smith Ch. 1	1	
Jan 23	1D heat equation	Smith Ch. 2	3	
Jan 25	Lumped capacity	Smith Ch. 5.1, 5.2	2	**FreeCAD 1**
Jan 30	Heat fin	Lab 1	4	
Feb 1	T(x,t): Fourier series	Lab 1	5	**FreeCAD 2**
Feb 6	$T_{steady}(x) + T_{transient}(x,t)$	Lab 1	6	
Feb 8	Finite difference approx.	Lab 2	7	**Lab 1**
Feb 13	T(r)	Lab 2	8	
Feb 15	T(x,y)		9	**Lab 2**
Feb 20	**Test 1**			
Feb 22	Op amps	Lab 3	10	**FreeCAD 3**
Feb 27	RC circuits	Lab 3	15	
Feb 29	Frequency response (gain)	Lab 4	11	**Lab 3**
Mar 5	Laplace transforms	Lab 4	12	
Mar 7	Transfer functions	Lab 4	13	**FreeCAD 4**
Mar 19	Shortcut to T(s)	Lab 4	14	
Mar 21	Chaos in electronics		16	**Lab 4**
Mar 26	**Test 2**			
Mar 28	Semiconductors	Lab 5	17	
Apr 2	Generation, recombination	Lab 5	18	**FreeCAD 5**
Apr 4	Diffusion equation	Lab 5	19	
Apr 9	Nonhomogeneous dif. eqs.	Lab 6	20	**Lab 5**
Apr 11	Surface recombination	Lab 6	21	
Apr 16	p-n junction	Lab 6	22	
Apr 18	**Test 3**			
Apr 23	Solar cells	Final project	23	**Lab 6**
Apr 25		Final project		
May 7				**Final project**