Lecture 01 - SYSTEM DESIGN

How do we begin designing PCBs?

Outline

- Course Overview
- What is a PCB?
- Introduction to System Design
- System Parameters
- Modelling the System
- Course Project
- Summary
- Radio Primer

Course Overview

Topics

- Understanding the design-for-manufacturing process at both the system and component level
- Devising basic circuit topologies for common device applications
- Applying SPICE-level simulations to electronic circuits
- Independently converting an electronic system into a design schematic
- Efficiently creating a printed circuit board (PCB) layout from a design schematic
- Analyzing component datasheets
- Understanding real-world device limitations when selecting components
- Using industry-standard electronic design automation (EDA) tools (e.g. Altium, KiCAD, LTSpice)
- Understanding the PCB fabrication process
- Assembling complex PCBs by hand with surface-mount and through-hole technologies

Course Overview

THE ART AND SCIENCE of PCB DESIGN

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Course Numbers:
- 6.S092 (U)
- EC.S03 (U)

Preregister! Ends today!

Prerequisite:
Recommend having taken 6.200 or 2.678/2.679

Lectures:
- MWF 10-11 @ 2-190
- Lecture recordings on pcb.mit.edu
- Lecture quiz released at 11AM and due EOD

Recitations:
- MWF 11-12 @ 2-190
- Optional; provides further in-depth look and practice problems
- Notes posted on website

Labs:
- TTh 9-12, 12-3 @ 38-500
- Bring laptop and computer mouse
- Lab assignments due before next lab

Fill out lab section preference form!

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Software:
- Altium Designer (Windows-only) or KiCAD
- LTspice
- Install before lab; see pcb.mit.edu

Website:
- pcb.mit.edu
- Piazza

Lecturers:
- Will Vu
- Noah Haefner
- Deepta Gupta

Lab Assistants:
- Sean Boerhout
- Jeewoo Kang
- Claudius Tewari
- Jake Li
- Nerissa Wong

We're a bit budget/staff-limited, so your patience with us is highly appreciated!

Course Overview

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This course is made possible via gracious support from:

MIT Edgerton Center

MIT EECS

Course Sponsor: **Joe Steinmeyer**

Course Overview

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Grading:
1. Do lecture quizzes
2. Attend labs

As long as you complete all labs/revisions, you'll pass

For late-arrivals:
- Be sure to complete labs/lecture quizzes on-time remotely

Questions:
Please ask away!
- During lab/OH
- Piazza

Both questions relating course and general PCB/electronics questions

What I want to know:
- Field/interests (e.g., electric vehicles, clean energy, high-speed devices)
- What do you want to do with PCB design skills?
- What PCB/electronic skills do you want to gain?

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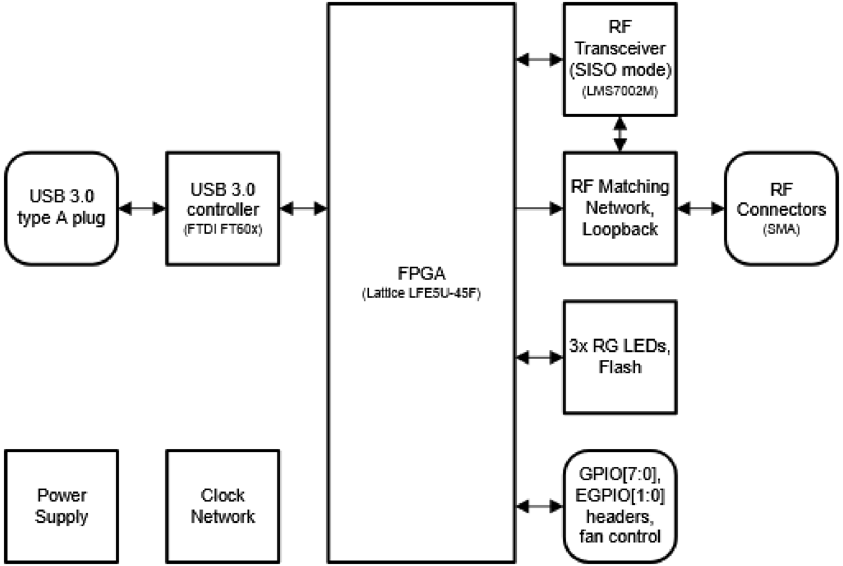
Course Overview

Fill out lab section preference form!

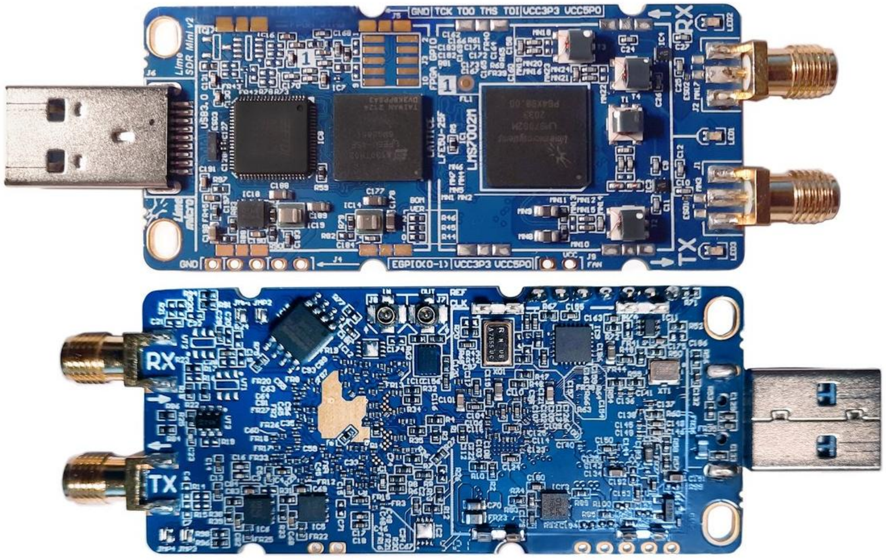
- **Definitive way for staff knowing you are in the course**

What is a PCB?

Software Defined Radio



LimeSDR Mini 2.0

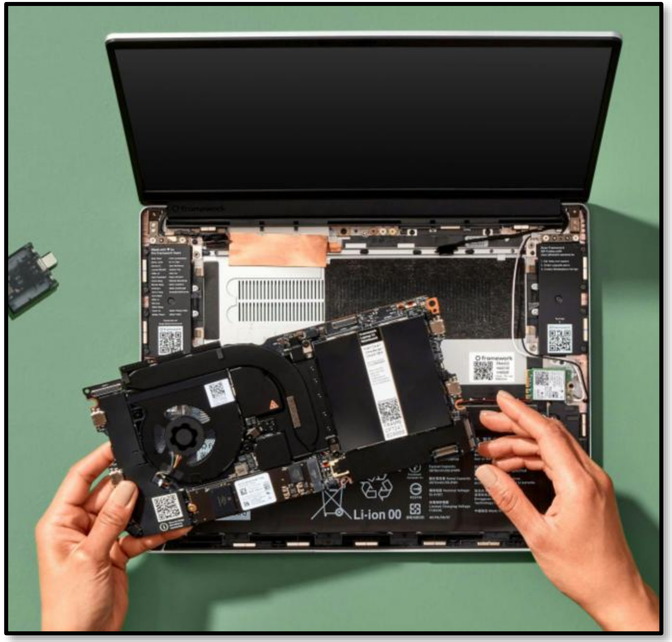


www.crowdsupply.com/lime-micro/limesdr-mini-2

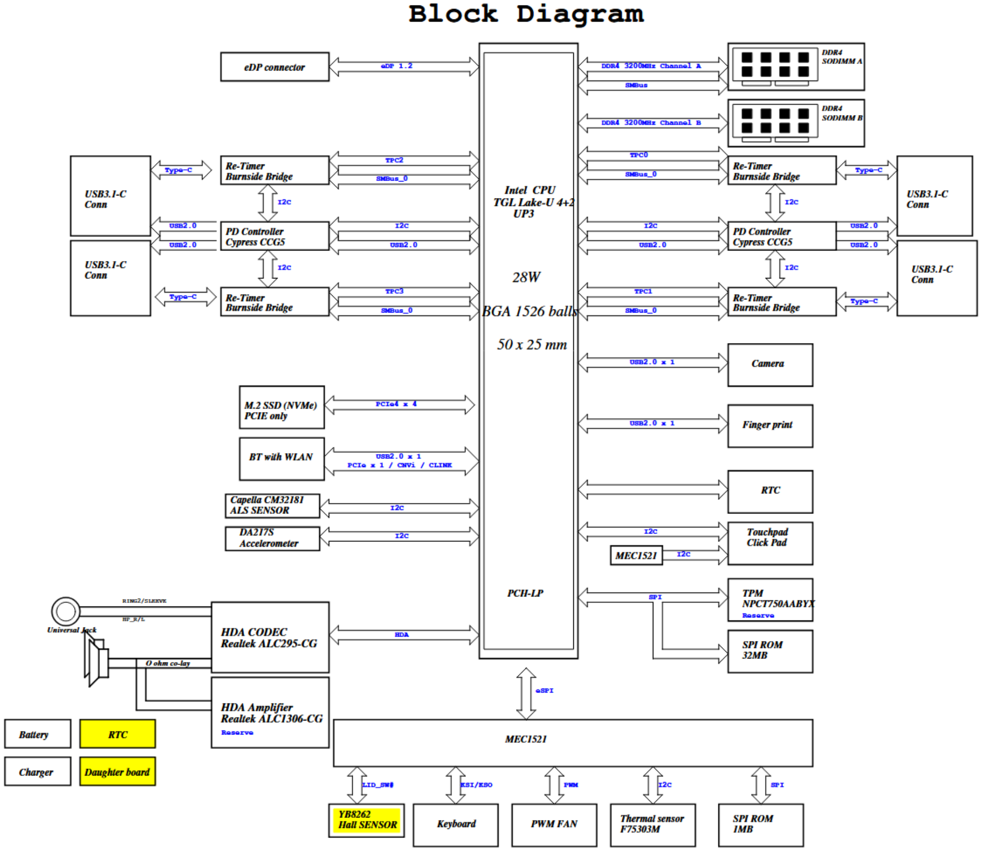
What is a PCB?

Laptop Motherboard

Framework Laptop 13



frame.work/laptop13



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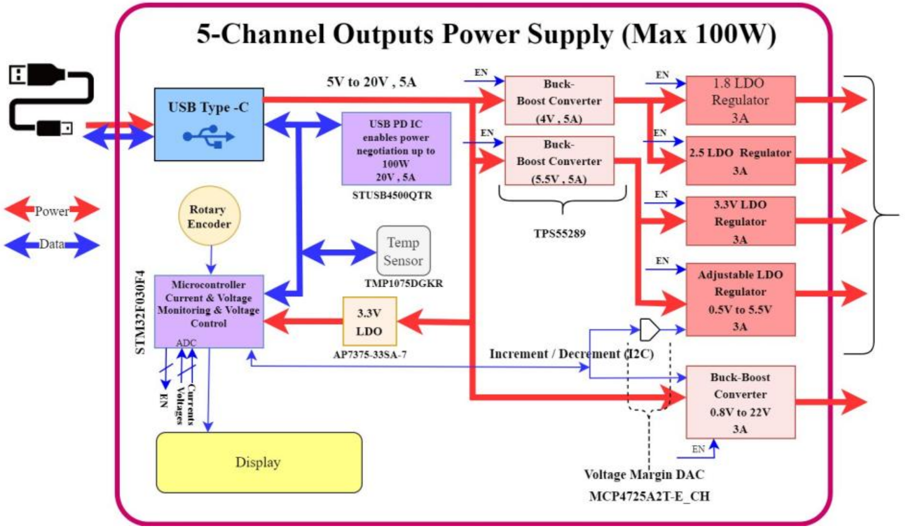
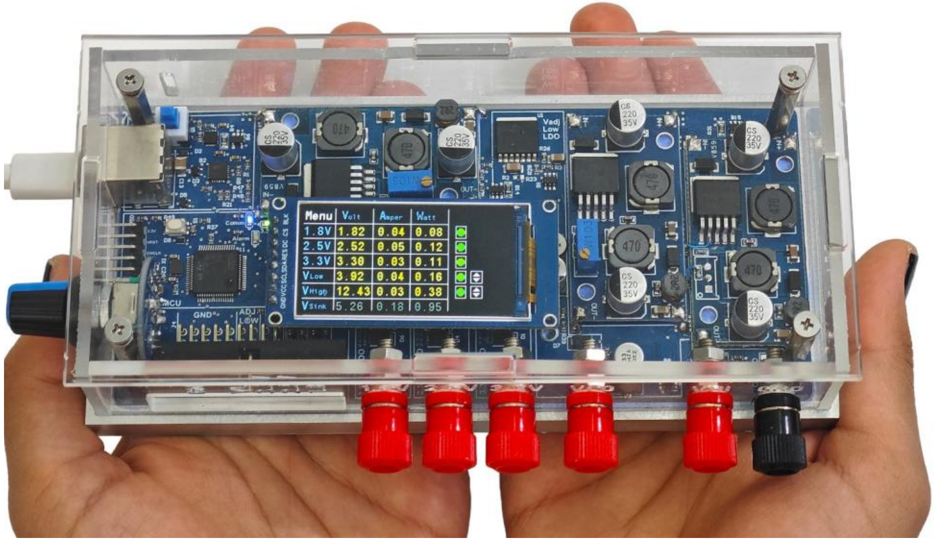
What is a PCB?

Power Supply

BenchVolt PD



BenchVolt PD

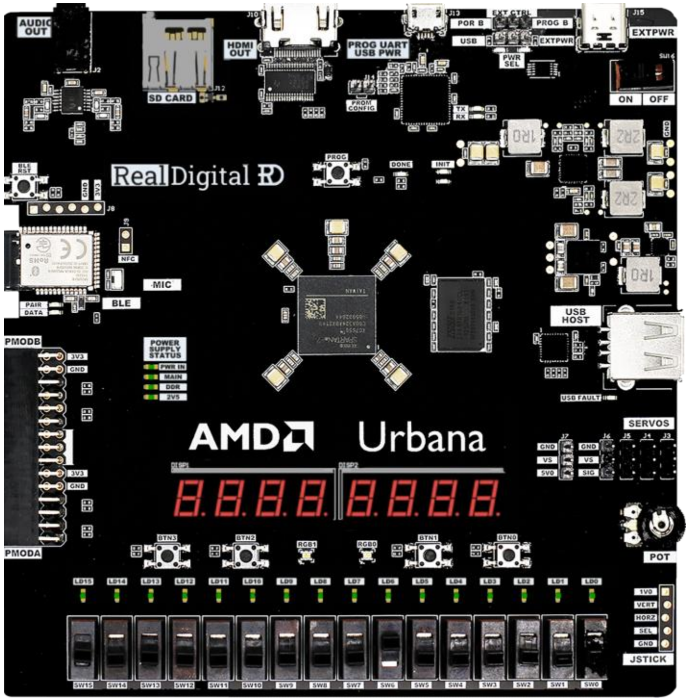


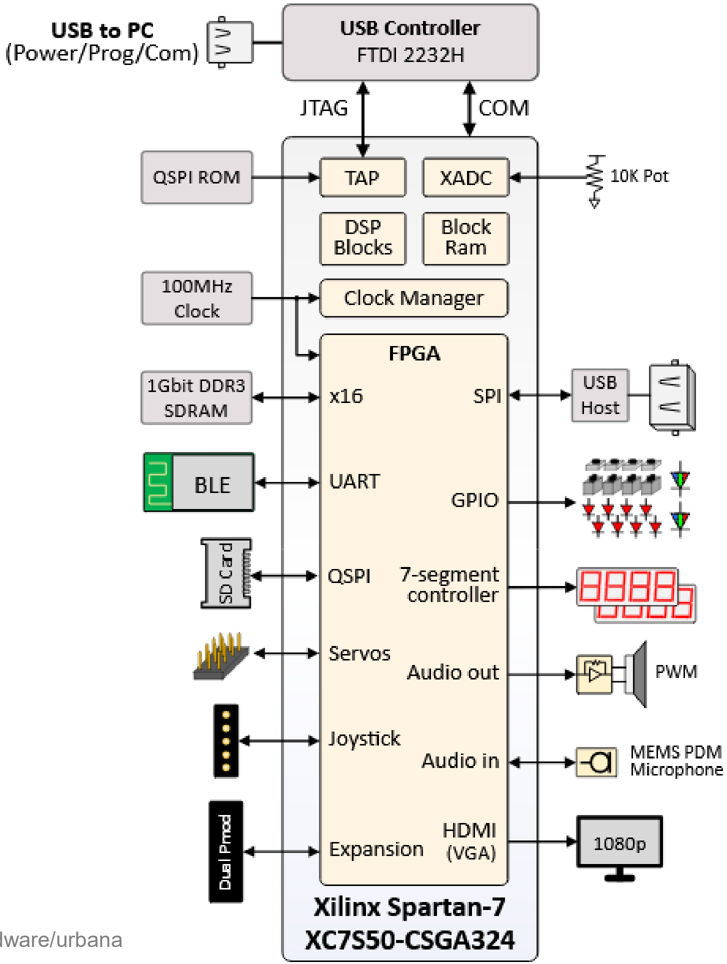
www.crowdsupply.com/fusionxvision/benchvolt-pd

What is a PCB?

FPGA Development

Urbana Board





www.realdigital.org/hardware/urbana

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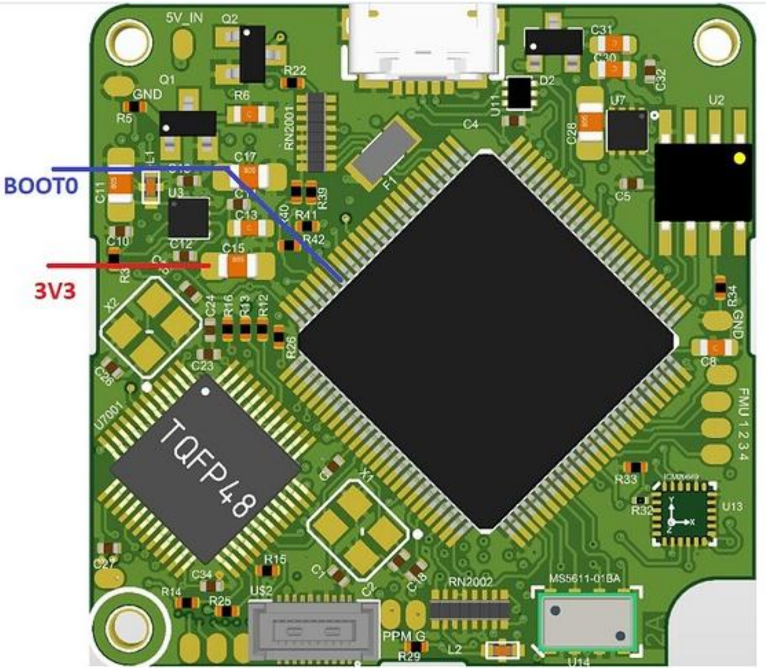
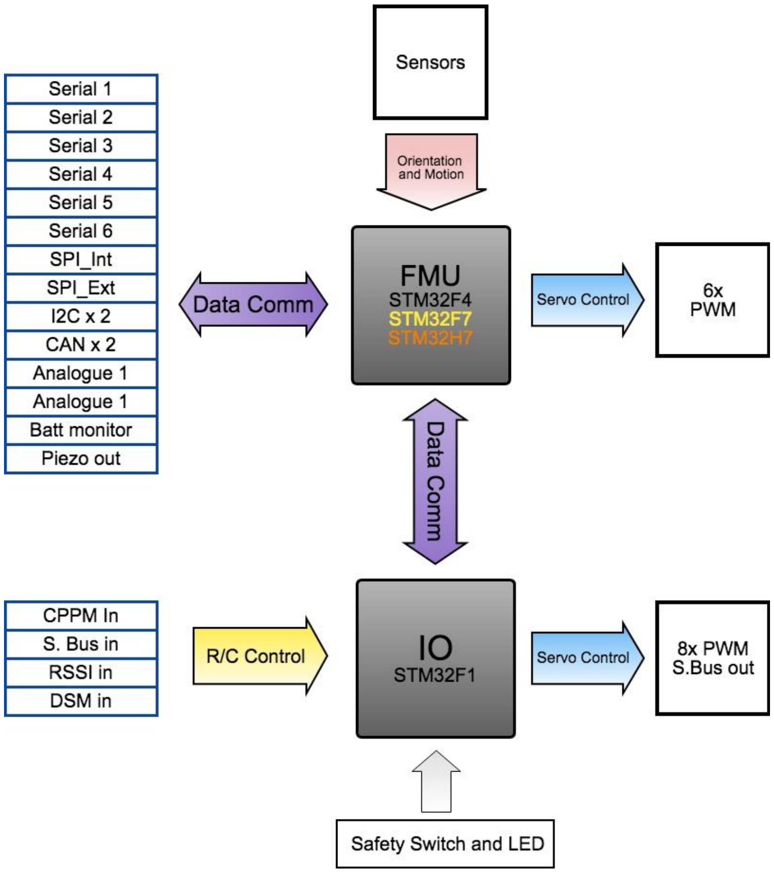
What is a PCB?

Flight Controller

Cube





www.cubepilot.com

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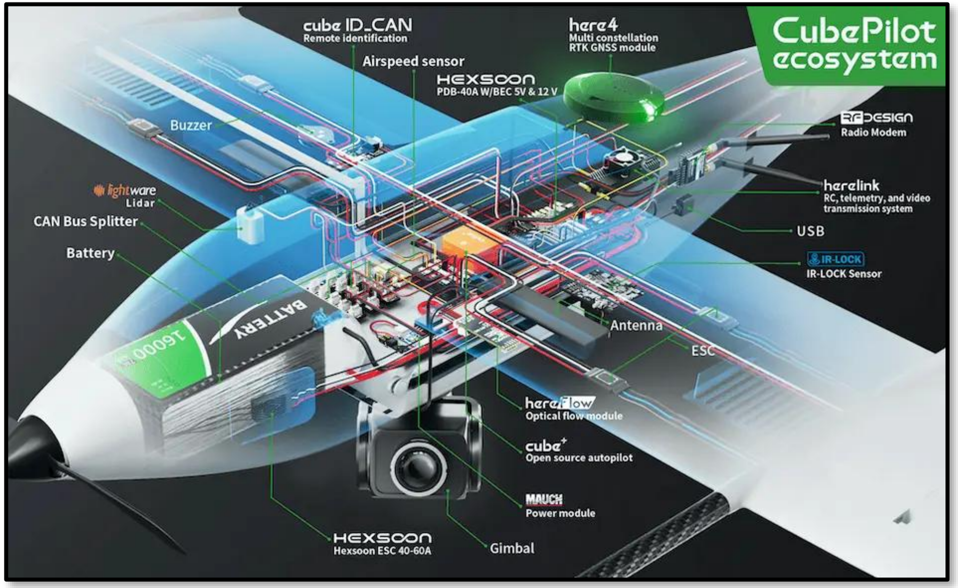
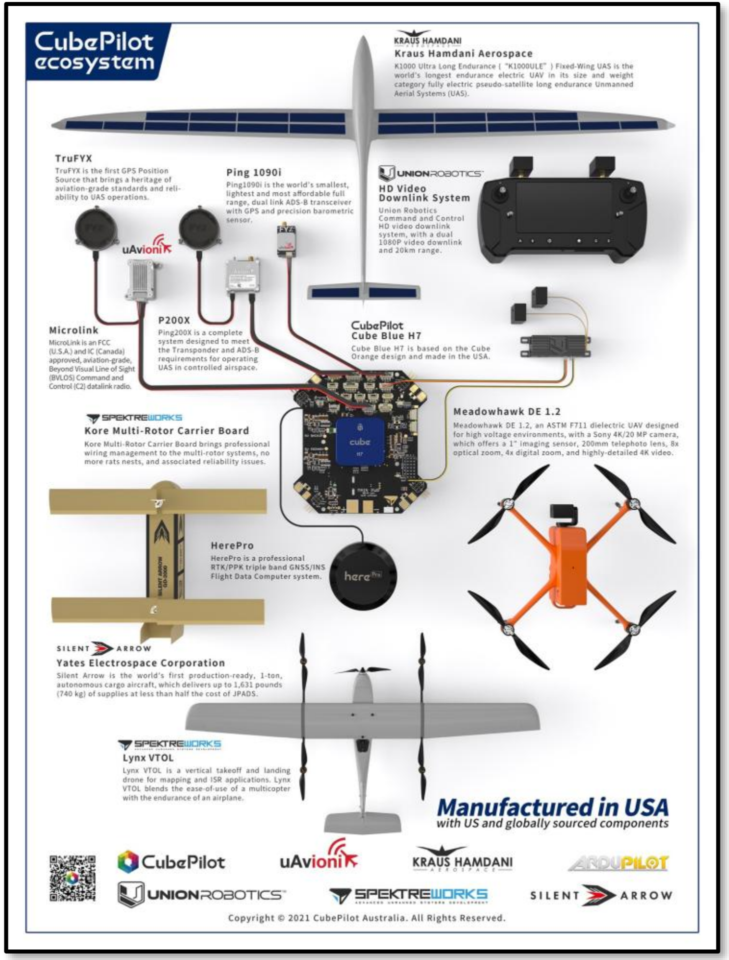
What is a PCB?

Flight Controller





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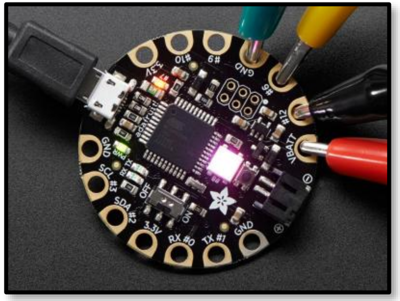
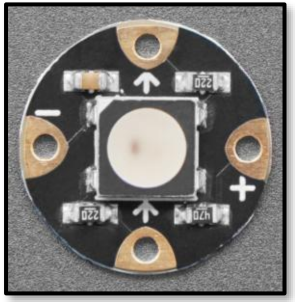
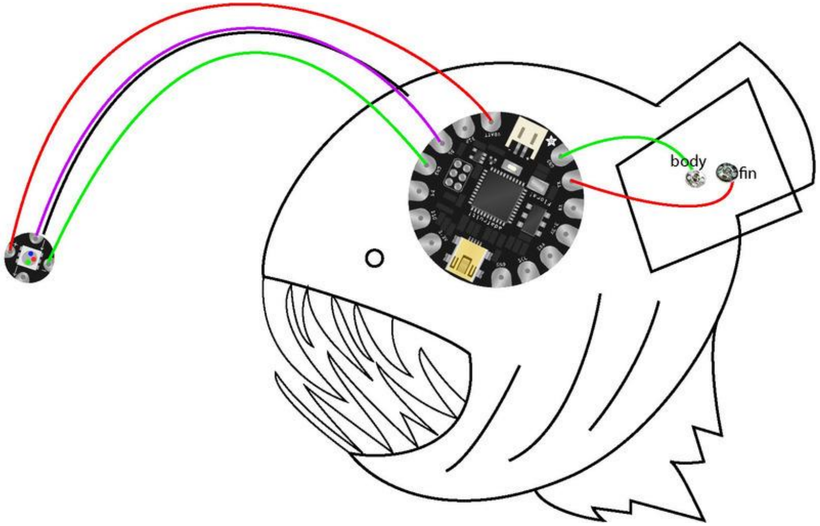
What is a PCB?

Wearables







Light-Up Angler Fish Embroidery

learn.adafruit.com/light-up-angler-fish-embroidery/overview

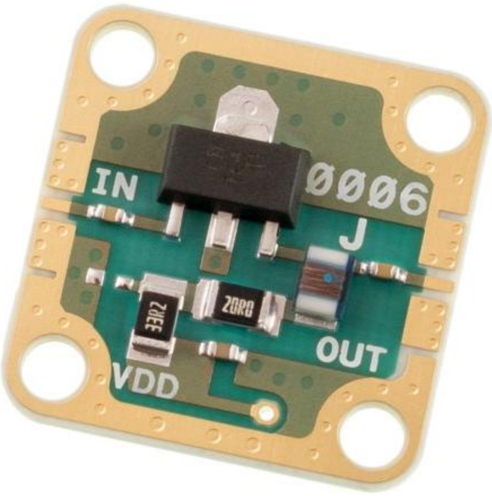
What is a PCB?

RF/Microwave Components

Microwave Power Combiner

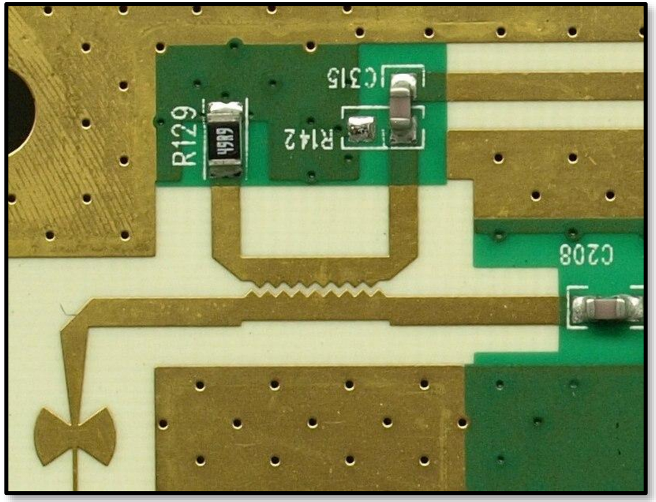
knowlescapacitors.com/Products/Microwave-Products/Power-Dividers

Microwave Amplifier



quanticxmw.com

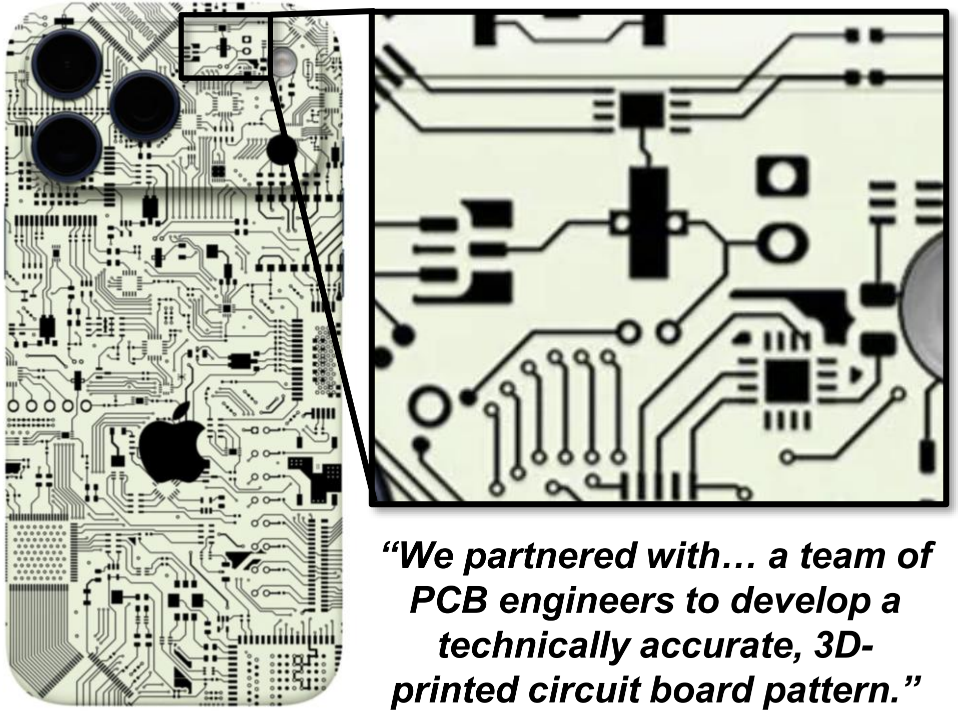
Microwave Coupler



en.wikipedia.org/wiki/Slow-wave_coupler

What is a PCB?

Invalid PCBs



“We partnered with… a team of PCB engineers to develop a technically accurate, 3D-printed circuit board pattern.”

dbrand.com/shop/limited-edition/circuit-board

digital.microwavejournal.com

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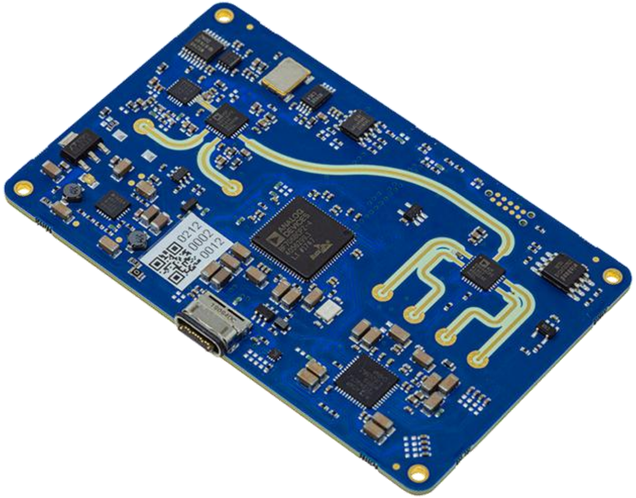
System Design

System Design

Introduction

Printed Circuit Boards are medium for fabricating electronic devices

PCB Design



Before we start design PCBs, we first need to design electronic devices

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System Design

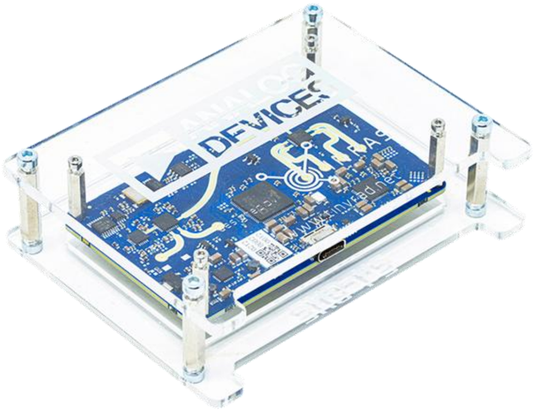
Introduction

With any electronic system, we're seeking to solve a problem

Radio Astronomy

Or it could be your…

- UROP
- Class project
- Thesis
- Personal pursuit



Radar Education Platform

Driver Assistance

Terminal Missile Defense

System Design

Introduction

The unique constraints provided by PCBs makes it a Design For Manufacturing (DFM) process

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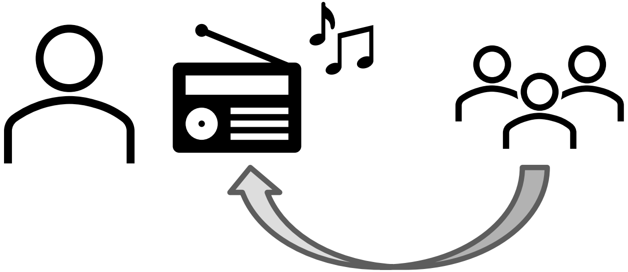
As we continue, let's use an example…

Me
(your boss)



You
(PCB engineer)

Create an FM radio receiver

- Identify Problem
- Devise Solution
- Identify System Parameters
- Create/Model System
- Design PCB! → Fabrication → Test/Debug

Repeat as needed

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System Design

Defining System Parameters

After devising a solution (our electronic system), we need metrics to design/measure it by

Electrical Performance

How well the device operates

- Speed/clock rate
- Output power
- Latency
- Resolution
- Accuracy
- Power consumption

Defined by the problem-to-be-solved

Form Factor

How the user interacts with the device

- Size
- Weight
- Control interfaces
- Training requirement

Defined by the end-user

Manufacturability

How the device is built

- Cost
- Procurement speed
- Fabrication constraints
- Assembly constraints
- COTS or custom
- Export restrictions

Defined by PCB fab/assembly capabilities

COTS – Commercial Off The Shelf

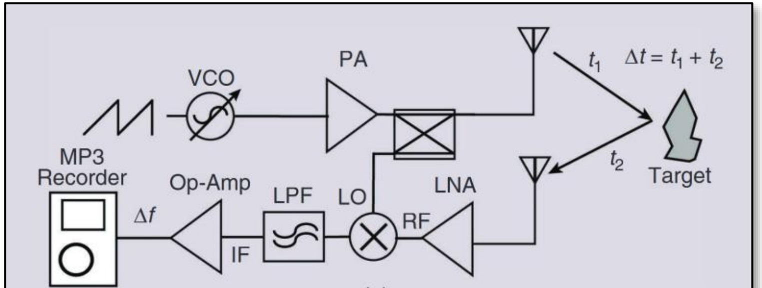
System Design

Modelling the System

[1] M. Dwye and D. S. Ricketts, "The North Carolina State University Rabbit Radar: Build a Frequency-Modulated Continuous-Wave Radar in a Day [Application Notes]," *IEEE Microwave Magazine*, vol. 21, no. 5, Institute of Electrical and Electronics Engineers Inc., pp. 136–145, May 01, 2020. doi: 10.1109/MMM.2020.2971184.

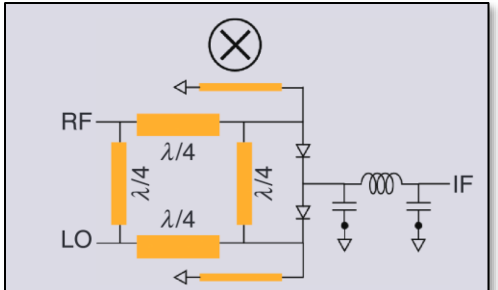
NC State Rabbit Radar [1]

2-words, 3-syllables: ***Block Diagrams!***

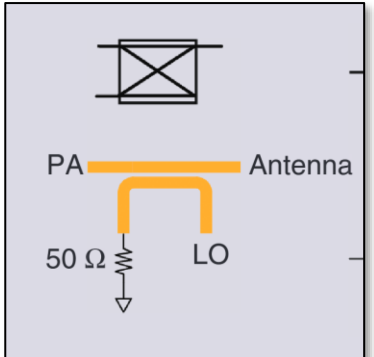


(a)

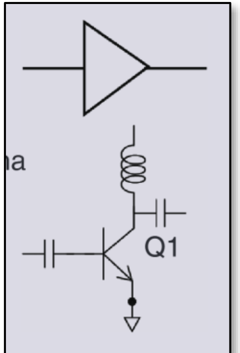
Abstract the electrical system into lumped components and use circuit interconnections to show the flow of information/power/electrons



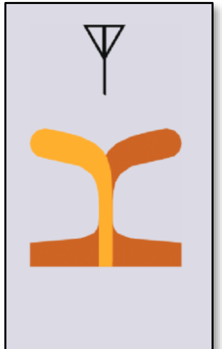
(c)



(d)



(e)

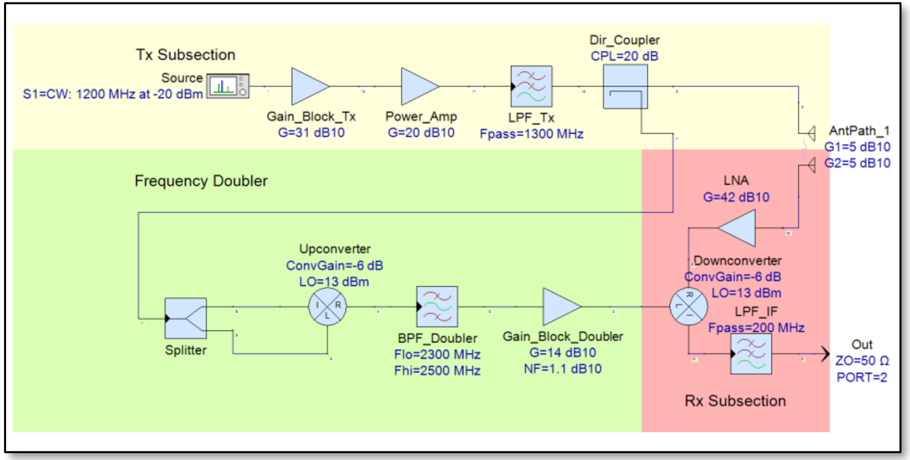


(f)

Breakdown the system into individual components

System Design

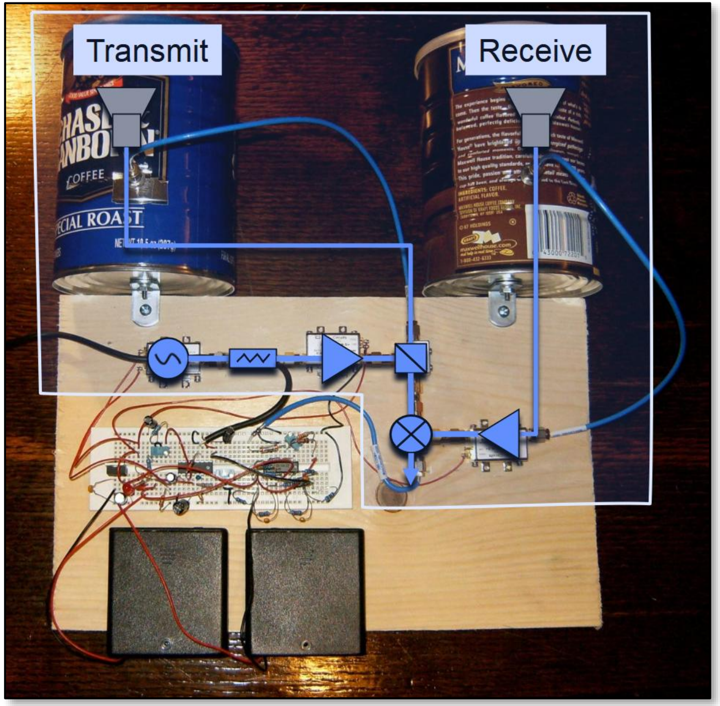
Modelling the System



Using our block diagrams we can perform simulations at various levels:

1. **System level**
2. **Circuit level**
3. **Component level**

Block diagrams help explain system functionality at a high level



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System Design

Course Project

Recall our example...?

Identify Problem ✓

Devise Solution ✓

Identify System Parameters ✓

Create/Model System ✓

FM radio receiver

Course Project!

Throughout IAP you'll be guided through the

1. System design,
2. Circuit design,
3. PCB design, and
4. Fabrication/assembly

of the course project!

Later topics

Design PCB! → Fabrication → Test/Debug

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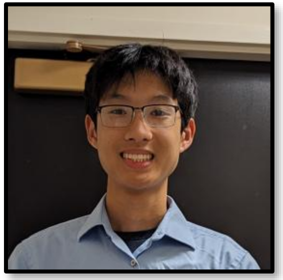
Course Project

Identify Problem



Solution: Radio!

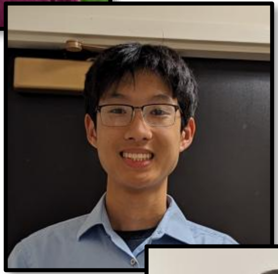
- **Who doesn't like listening to tunes?**
- **No Spotify subscription required**
- **Multiple can be made**

***Major problem*: instructors are majorly bored**

Course Project

Identify Problem

I need to be listening to the Top-40 hits on WXKS 107.9 FM!



I don’t how to use anything analog…

I’m bringing this to my weekly jam sessions in the park!

Requirements

- Receive FM radio broadcasts

- Digital tune/volume control
- Digital tune/volume display

- Portable
- Battery-operated
- Stereo speaker output

- Mass-produceable
- Cheap

Course Project

Devise Solution

Requirements

- Receive FM radio broadcasts

- Digital tune/volume control
- Digital tune/volume display

- Portable
- Battery-operated
- Stereo speaker output

- Mass-produceable
- Cheap

Solutions

- FM radio receiver chip?
- FM radio amplifier?

- Microcontroller control?
- Seven-segment display?
- Digital button control?

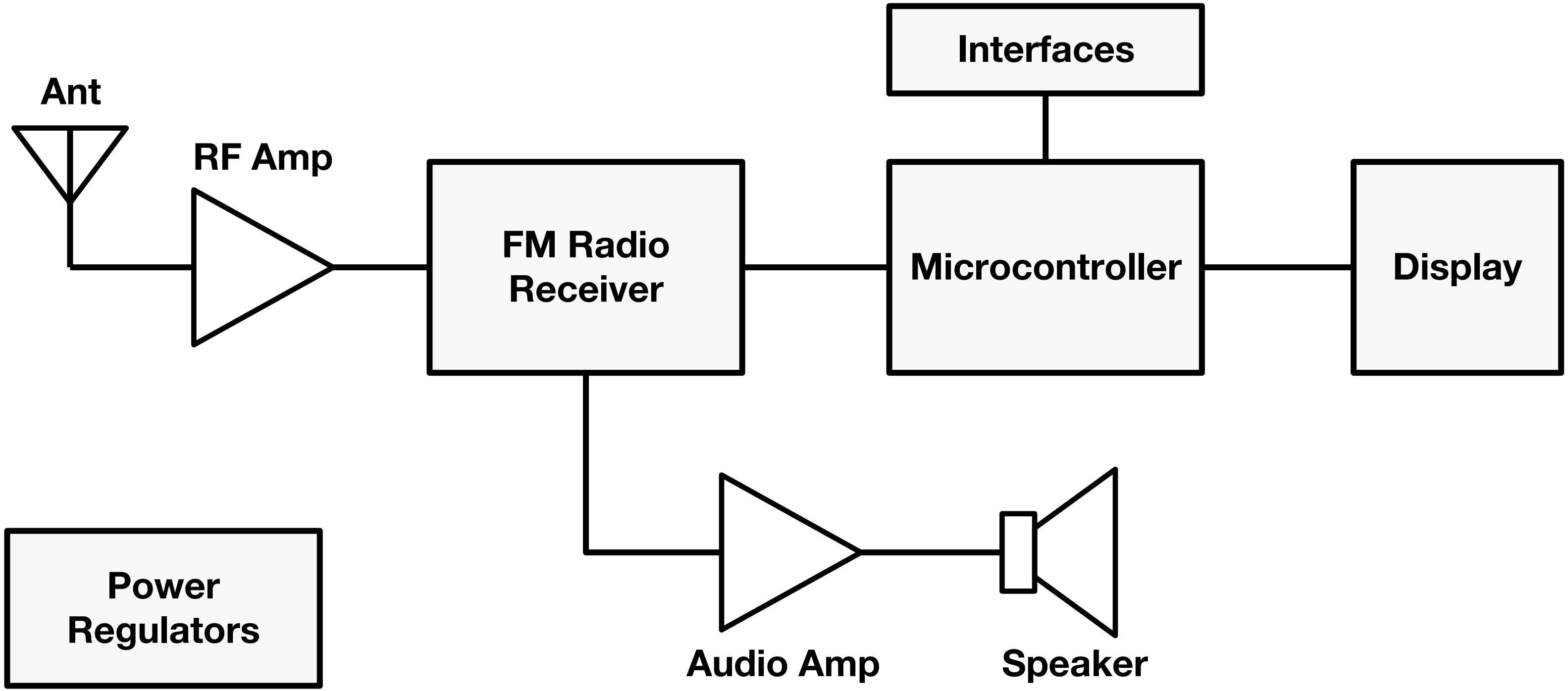
- Battery input?
- Attachable external antenna?
- External speaker output?
- Dual speaker drivers?

- PCB format?
- Surface mount components?

***Next time*: figure out the components needed!**

Course Project

Block Diagram



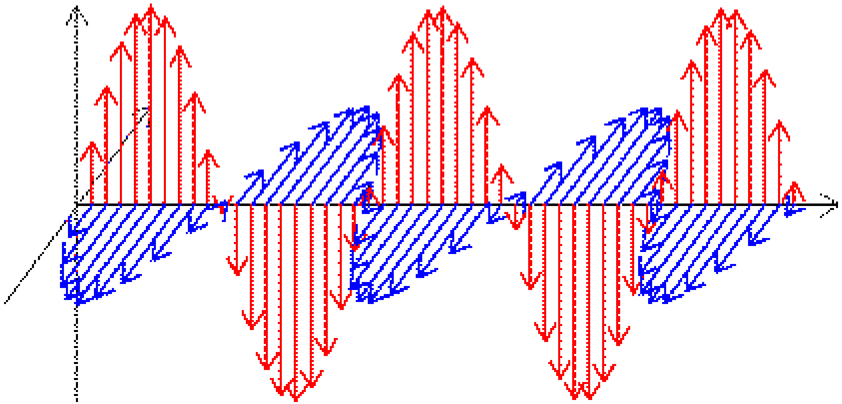
Summary

- System design consists of crucial steps we must take before designing any PCB
- After determining a problem, we can devise an electronic system to solve it
- We must define system parameters by which to quantify our device/system's performance
- We must model our system using block diagrams to create abstractions to aide with design, simulation, and documentation
- Course project will be designing an FM radio receiver

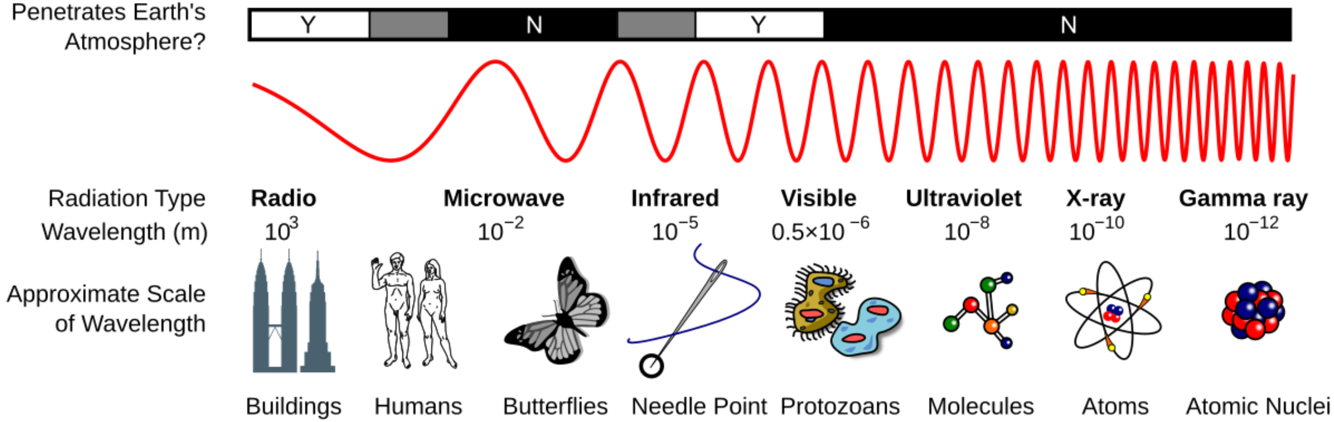
Radio Primer

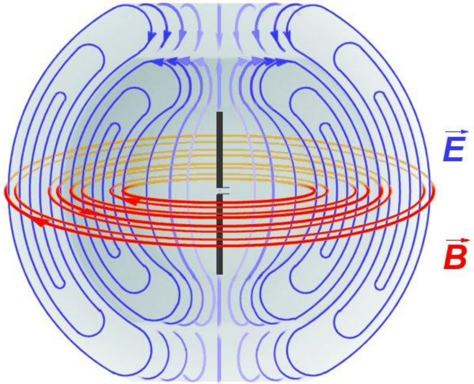
Radio Basics

Fundamentals



Radios communicate information via propagation of electromagnetic waves at radio frequencies (RF)





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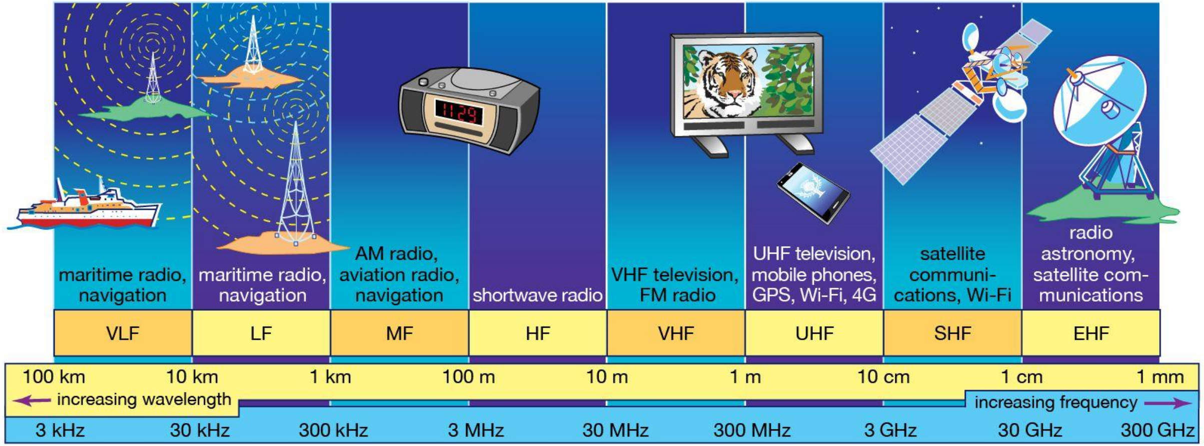
Radio Basics

Fundamentals

Electromagnetic waves at radio frequencies (RF) have good propagation characteristics over free-space

- **Approximately 3 kHz to 3 GHz**



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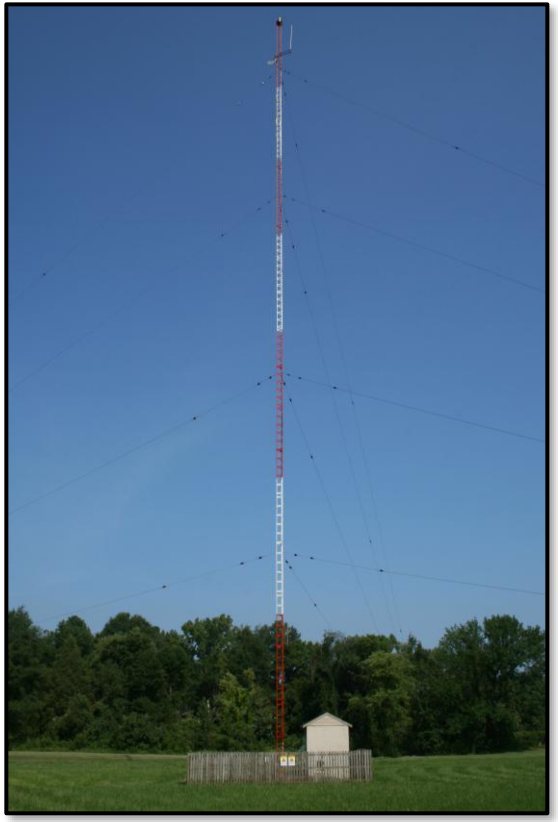
Sending information over RF allows it to be communicated over far distances

Radio Basics

Antennas

Radio waves can be received using an antenna

- **Antenna converts electromagnetic wave into voltages/currents in a circuit**
- **Antenna can be as simple as a length of wire**
- **Antenna/aperture size proportional to radio wavelength**



Radio Basics

Modulation

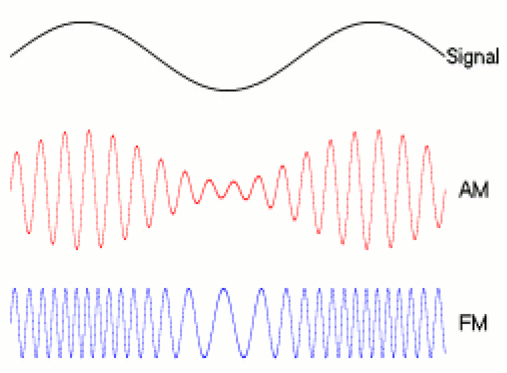
To send information over RF, a radio wave at some *carrier frequency* is modulated with information

Radio modulation involves encoding information into the properties of the radio wave:

1. **Amplitude**
2. **Frequency**
3. **Instantaneous Phase**

FM broadcast radio carrier frequency: ~100 MHz

AM broadcast radio carrier frequency: ~1 MHz



Transmission of broadcast audio signals will typically use these simple modulations

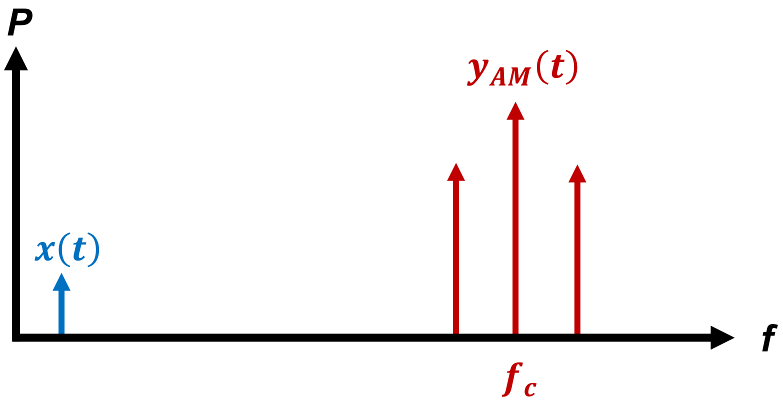
Radio Basics

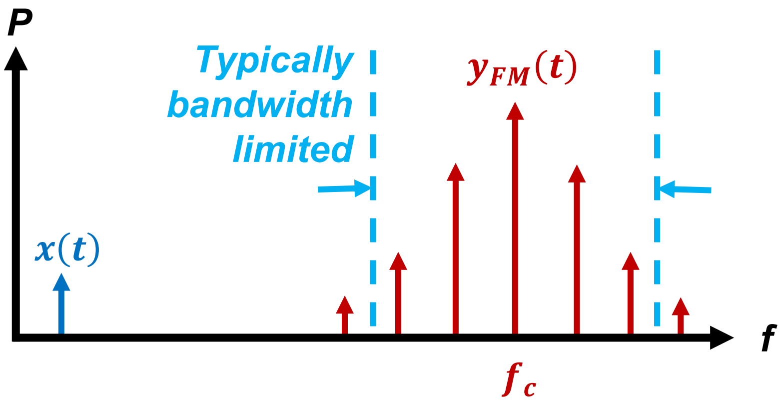
Modulation

Given some (low-frequency) audio signal $x(t)$ and a modulation index m:

$$y_{AM}(t) = \left(1 + mx(t)\right) \cdot A\cos(2\pi f_c t + \phi)$$

$$y_{FM}(t) = A\cos\left(2\pi f_c t + \phi + m\int_{-\infty}^{t} x(t)\ dt\right)$$





Amplitude modulation shifts the audio spectrum up to the carrier frequency

Frequency modulation creates an infinitely-wide spectra from the audio spectra

Radio Basics

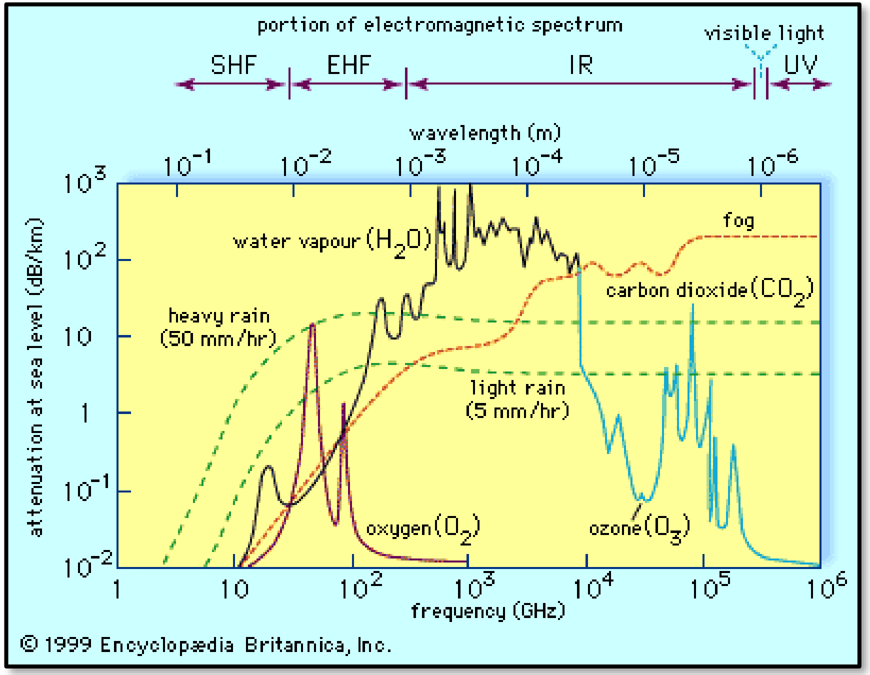
AM versus FM

AM characteristics:

- **Simple to modulate/demodulate**
- **Narrower bandwidth required**
- **More susceptible to interference**

FM characteristics:

- **Complicated to demodulate**
- **Wider bandwidth required**
- **Resilient to interference**



Lab Preference Form

PCB EDA Tools

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Altium Designer®

- More professional/enterprise
- Closed-source/expensive
- Advanced features
- Student license available

KiCad

- Better for personal projects/work
- Open-source/free
- Very customizable – lots of community support and extensions

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Questions?

- ❑ Make sure you are registered for the course
- ❑ Fill out lab preferences form ASAP (lab sections released tonight)
- ❑ Complete Lecture Quiz 01 (pcb.mit.edu/schedule), due midnight today
- ❑ Complete required software setup (pcb.mit.edu/schedule) before lab tomorrow
- ❑ Optional recitation following lecture in 2-190