

BIOS and Embedded Systems

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EECS 373

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Overview

- What is the BIOS?
- What does it do?
- Why is it necessary?
- Can it be used in embedded systems?
- Embedded BIOS

What is the BIOS?

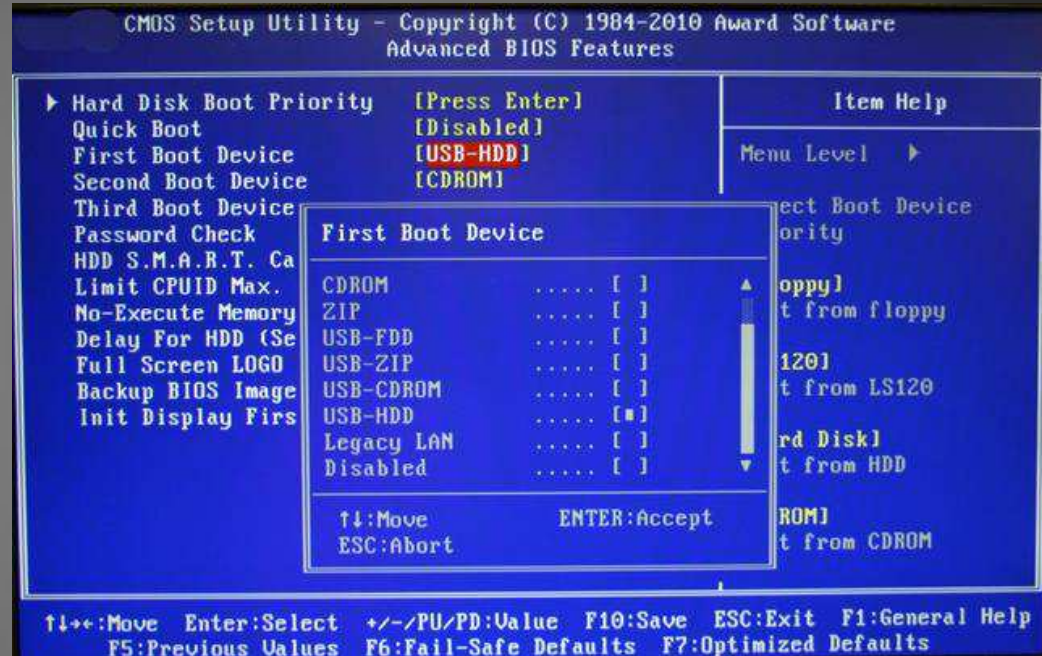
- BIOS stands for Basic Input/Output System.
- Low-level software (lower than the OS) that provides link between hardware and software in a PC.
- Invented in 1975 for the CP/M operating system.
- Found in IBM PC compatible computers (pretty much all PCs today).
- Located in ROM (old days) or flash memory (nowadays) on the motherboard rather than disk.



Source: <http://www.ecomputerz.com/american-megatrends-bios.html>

What does it do?

- First software that runs on system power-up, before OS.
 - Performs POST and other hardware checks.
 - Allows user to change system configuration settings (which are saved in another chip on the motherboard).
 - Initialises device drivers (hardware interrupt handlers).
 - Initiates OS boot process.
 - Provides routines to access system hardware.



Source: <https://commons.wikimedia.org/wiki/File:Bios-configuration-orden-arranque.png>

Why is it necessary?

- Need to load OS into main memory, but OS in disk.
 - BIOS initiates OS load from disk to memory.
- BIOS is abstraction layer under OS, hides most hardware details.

Can it be used in embedded systems?

- BIOS widespread on PCs; can it be used in embedded systems?
 - Yes, if the embedded system uses x86 architecture.
- BIOS-related issues:
 - Long BIOS start-up time (as long as 13 seconds).
 - Many BIOS implementations rigidly geared towards a PC, not embedded systems.

Embedded BIOS

- One solution for embedded is Embedded Bios with StrongFrame Technology, from Phoenix Technologies.
 - Built with configurability and extendibility in mind.
 - Easy to modify for desired application.
 - System hardware already known; can eliminate checks for...
 - Mouse and keyboard.
 - Video subsystem.
 - Hard disk.
 - ✓ Gives faster boot time.

References

- *Upgrading and Repairing PCs*, 22nd Edition, by Scott Mueller.
- <http://www.pcguide.com/ref/mbsys/bios/index.htm>
- <https://www.pddnet.com/article/2010/01/embedded-bios-increases-x86-leverage>

Embedded Systems in Advanced Prosthetics

AARON CLAUSSEN

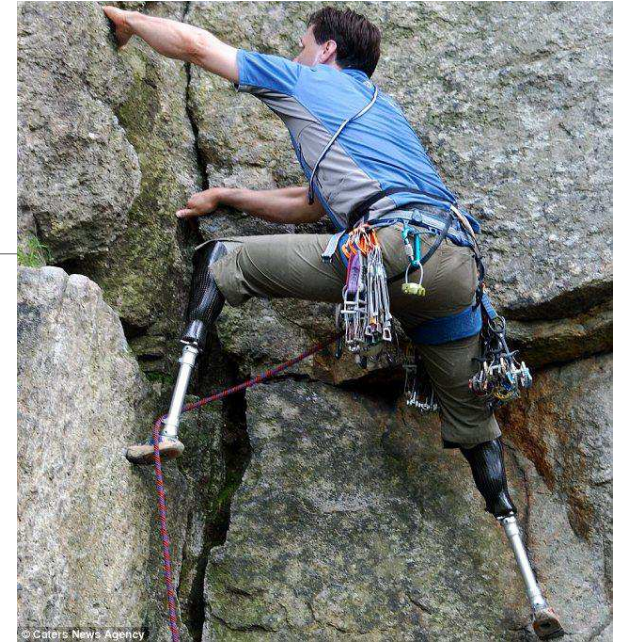
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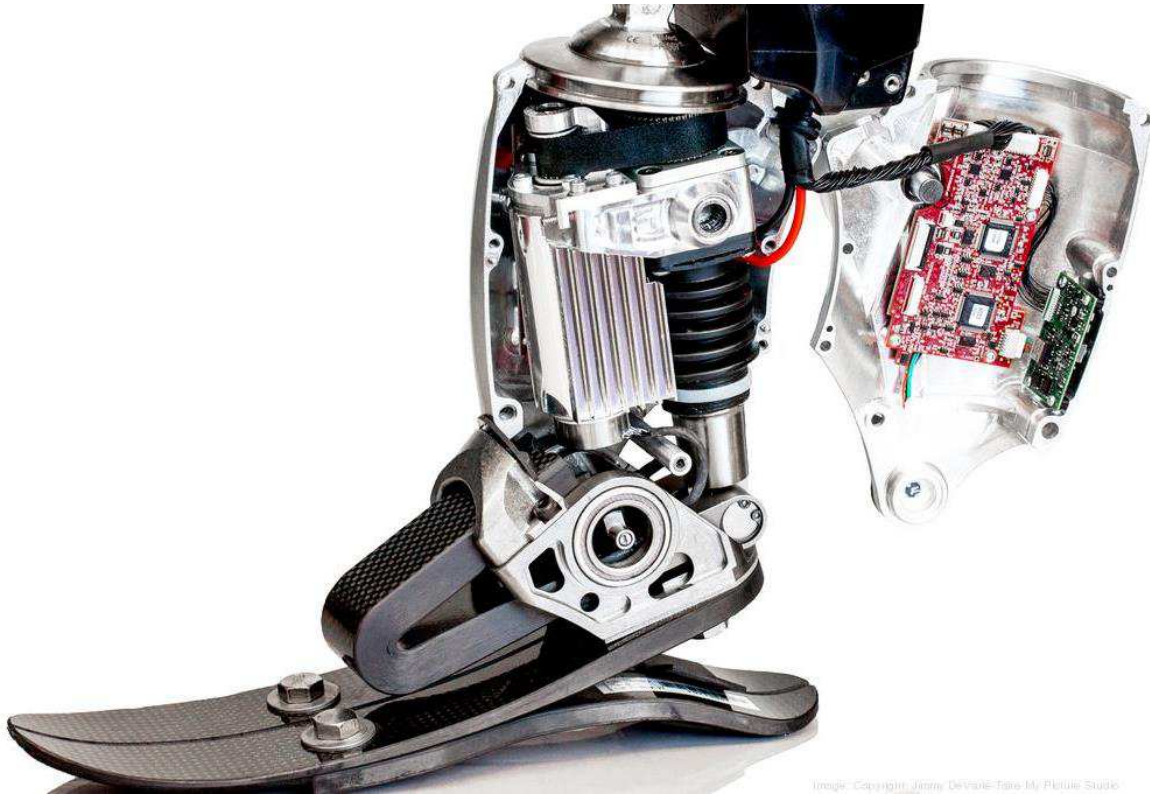
Background

Hugh Herr

- Mechanical engineer, biophysicist, and rock climber
- Double amputee due to frostbite during a climb
- Designer of his own specialized prosthetic legs
- Head of MIT Media Lab's Biomechatronics group



BiOM Ankle-Foot Prosthesis



Simulates work done at ankle during walking

Sensors track position, motion, phase of stepping process

Microprocessors control springs and motors to deliver proper force and torque

Significance

Walking with prosthetics now feels more natural

- Quicker rehabilitation
- Reduced risk of consequential afflictions
- Restored ability for users

References

https://www.ted.com/talks/hugh_herr_the_new_bionics_that_let_us_run_climb_and_dance/transcript?language=en

<https://dam-prod.media.mit.edu/x/files/wp-content/uploads/sites/3/2013/07/au-weber-herr-2007-IEEE-biomech-design-of-PAFP.pdf>

https://en.wikipedia.org/wiki/Hugh_Herr

<http://www.bostonmagazine.com/health/article/2013/11/26/prosthetics-research-boston-biom-ankle-prosthetic/>

<http://www.dailymail.co.uk/news/article-2181527/Who-Says-I-Cant-climber-scales-200ft-cliff-despite-having-legs--false-limbs-falling-halfway-up.html>

<http://www.bizjournals.com/boston/blog/startups/2014/12/bedford-bionics-maker-biom-may-go-public-but-not.html>

Questions?

RFID

NEAL TATUM

Radio Frequency Identification

Up to 1000's of items

Possibility of >100m range

Instant data

- Manufacturer
- Product details
- Location of items
- Supply count



Types of RFID

Active Tags

- Requires internal battery
- Read/Write
- Partner w/ other technology/sensors
- Larger signal range
- Expensive
- Larger in size

Passive Tags

- Powered by the reader
- Smaller, lighter
- Unlimited lifetime
- Low signal range
- Typically less data
- Cheaper

Passive RFID

Reader, antenna, tags

Reader sends RF signal

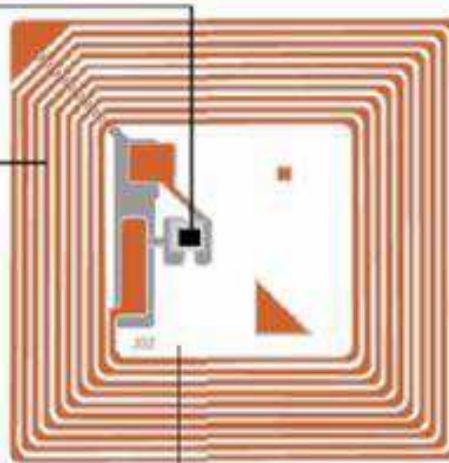
Tag antenna -> power -> tag IC -> antenna

Reader receives data -> processor/database



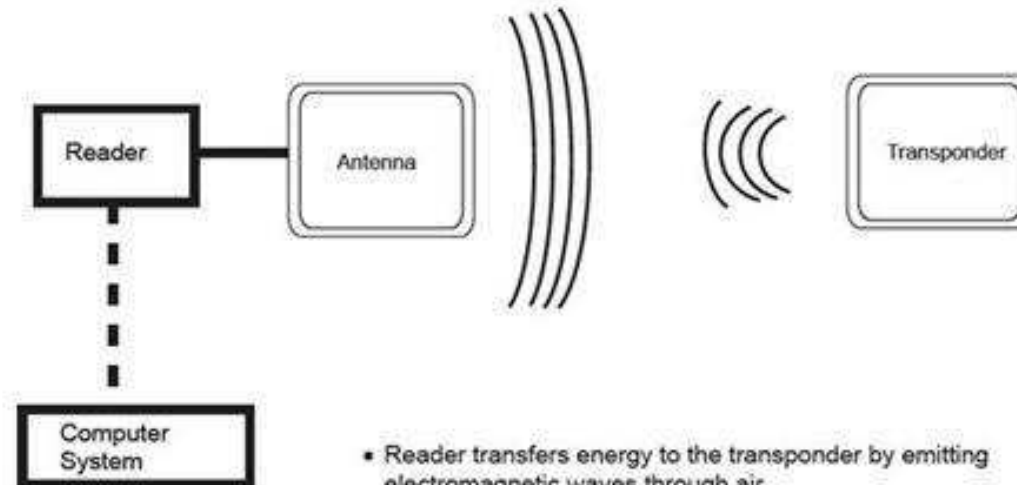
RFID tags are made up of three parts:*

1. **Chip:** holds information about the physical object to which the tag is attached
2. **Antenna:** transmits information to a reader (e.g., handheld, warehouse portal, store shelf) using radio waves
3. **Packaging:** encases the chip and antenna so that tag can be attached to physical object



System is comprised of 3 components:

1. Chip
2. Reader
3. Database



- Reader transfers energy to the transponder by emitting electromagnetic waves through air.
- Transponder uses RF energy to charge up.
- Transponder receives command/data signal and responds accordingly
- Reader receives transponder response and process accordingly ie. sent to a host computer or external devices through its control lines.

Information on the tag



* Hexidecimal Number where A-F=10-15

Current Real World Examples

Item inventory

- Location
- Condition
- Count

Animal identification

Credit cards

Toll Tags

Attendance Tracking

Race Timing

Access Control

Kiosks / Library-like systems



Future of RFID

Grocery store example

Pantry/refrigerator example

Printed directly on products

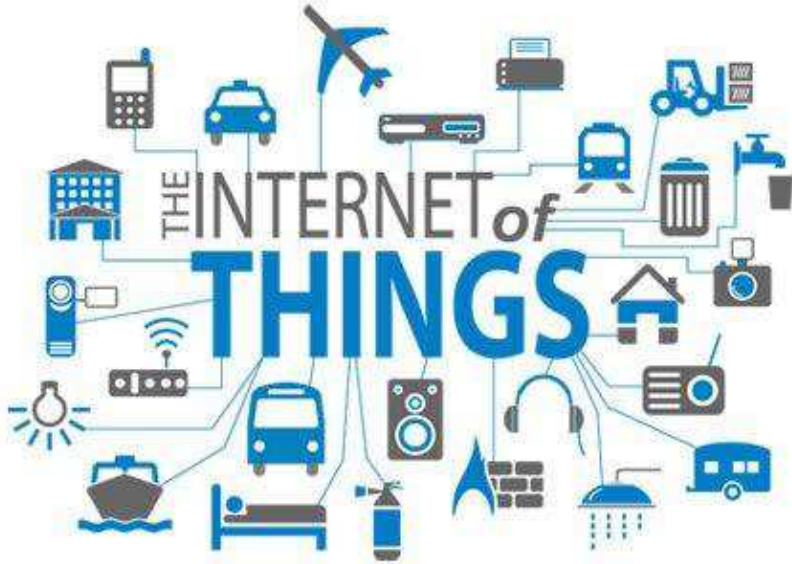
People are RFID tagged

RFID will play a huge role in embedded systems

Internet of Things

— Aidan Connolly —

Introduction



- Interconnectivity of physical devices with embedded systems
- Integration of the digital and physical worlds

Origins

“The Internet of Things, or IoT, is the integration of people, processes and technology with connectable devices and sensors to enable remote monitoring, status, manipulation and evaluation of trends of such devices.”

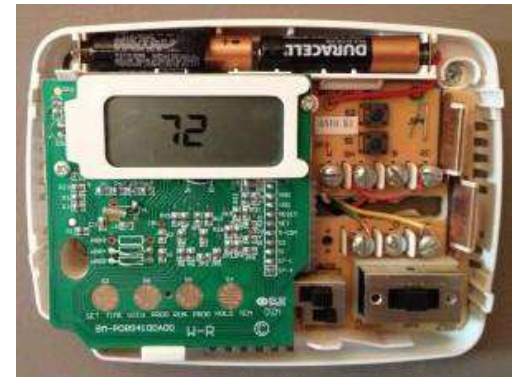
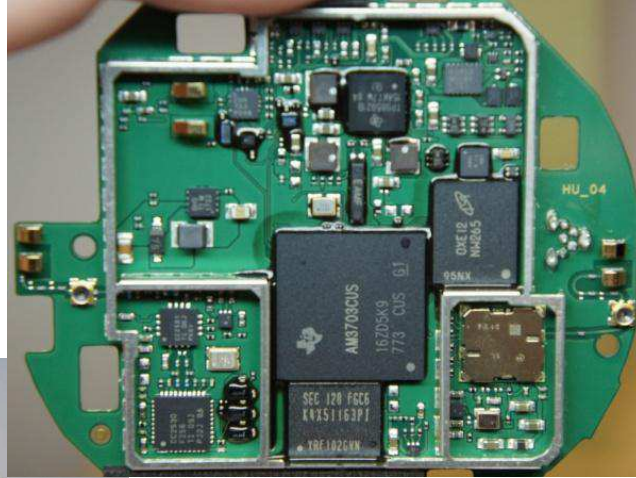
- Peter T. Lewis to the FCC, 1985

Modern Consumer Example - Nest Thermostat



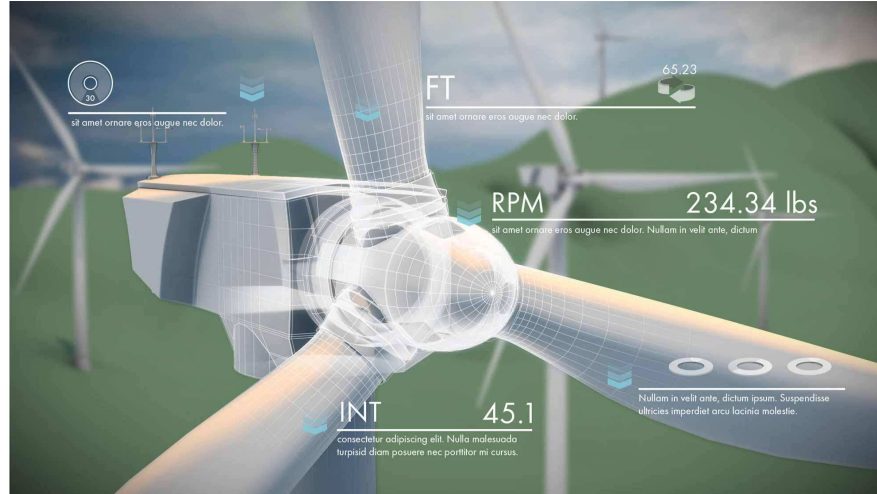
- Self-learning, wifi enabled thermostat
- Optimizes HVAC to conserve energy
- Nest can remotely push updates

Nest Teardown



Another IoT Application - Industrial

- IoT's impact is not limited to consumers
- General Electric's industrial software platform
 - "The world's first industrial internet platform"
 - GE and Intel partnership to bring IoT to the industrial world



Energy Scavenging

KC Bruner





What is energy scavenging?

Energy scavenging is the process by which energy is derived and captured from external sources (e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy) [5]

Energy Scavenging in embedded systems

Energy scavenging results in small quantities of power.

-> Not exactly useful for power hungry circuits.

Low power circuits -> Energy scavenging is incredibly useful, having the potential provide adequate power to run the device Indefinitely.

Can make active circuit elements into passive circuit elements, reducing the number of wires running from your main power source.

Where does energy scavenging shine? Sensors.

Piezoelectric

Basic idea: Applying a force to the material generates will generate an electrical current (and vice versa). [3]

This force can from from things like human motion, acoustic noise, and low frequency seismic vibrations. [5]

Energy produced is generally ~mW

Availability is limited, and fairly expensive.

Piezo Systems, Inc -> Energy harvesting kit for \$660

Triboelectric

Basic idea:

Two sheets of dissimilar materials; an electron donor and an electron acceptor.

Materials touch -> electrons flow from donor to acceptor.

After materials are separated -> one sheet holds an electrical charge isolated by the gap between them.

Connecting a load to electrodes placed at outer edges results in current flow equalizing the charges. [3]

Wide ranging implications for new types of sensors.

Brief search for availability yielded no results.

Thermoelectric Generation

Basic idea: Thermal gradient between two dissimilar conductors results in a voltage.

Solid state device

Efficiency is generally very low : $\sim 0.001 - 0.1$

-> For embedded applications, on the lower end

Potential to turn active cooling elements into passive elements [4]

Available at a reasonable price

-> 4 different TEGs on digikey, some for $\sim \$20$

Solar

Widely available, cheap (112 different items on digikey alone)

Can generate power both indoors and outdoors, depending on the solar cell

Power generated ranges from $\sim 15\mu\text{W}$ - 5W

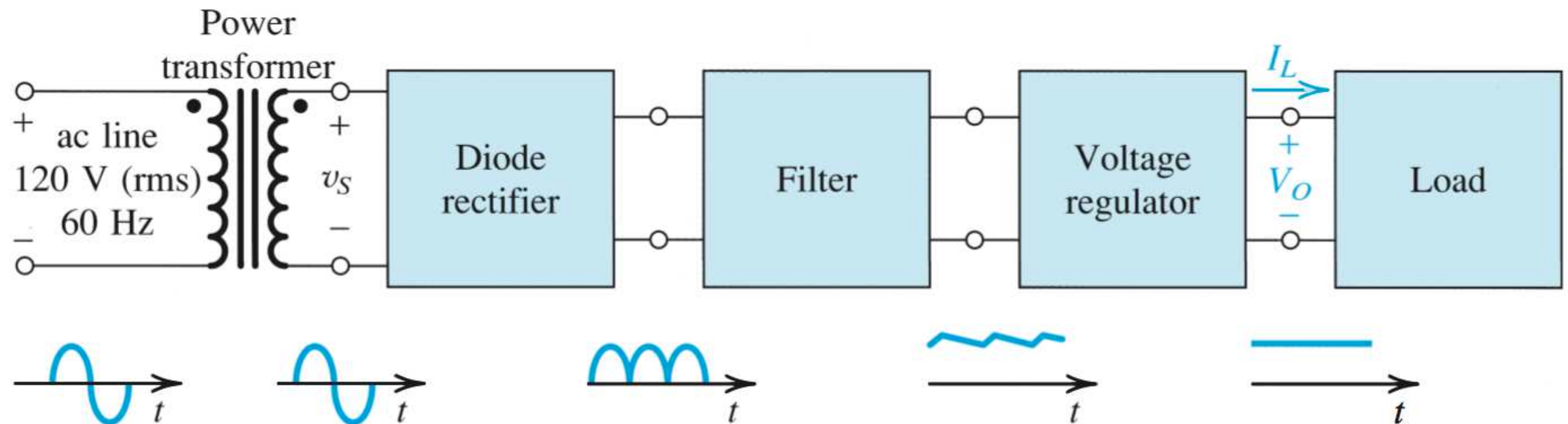
As small as 8.8mm^2

- [1] A. Poor, *Three Technologies for Harvesting Ambient Energy*, IEEE, Mar. 2015. [Online]. Available:
<http://spectrum.ieee.org/consumer-electronics/gadgets/three-technologies-for-harvesting-ambient-energy> [Accessed: 20 Mar. 2017]
- [2] W. Jung et al., *High Output Piezo/Triboelectric Hybrid Generator*, Macmillan Publishers, Mar. 2015. [Online]. Available: <http://www.nature.com/articles/srep09309#s1> [Accessed: 20 Mar. 2017].
- [3] J. Toon, *Harvesting Electricity: Triboelectric Generators Capture Wasted Power*, Georgia Institute of Technology, Dec. 2013. [Online]. Available:
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- [4] O. Sullivan et al., “On-Chip Power Generation Using Ultrathin Thermoelectric Generators,” *Journal of Electronic Packaging*, vol. 137, no. 1, Mar. 2015, pp. 1-7. [Online]. Available:
http://minds.gatech.edu/Publications/Papers_2014/Owen_JEP_2014.pdf [Accessed: 20 Mar. 2017].
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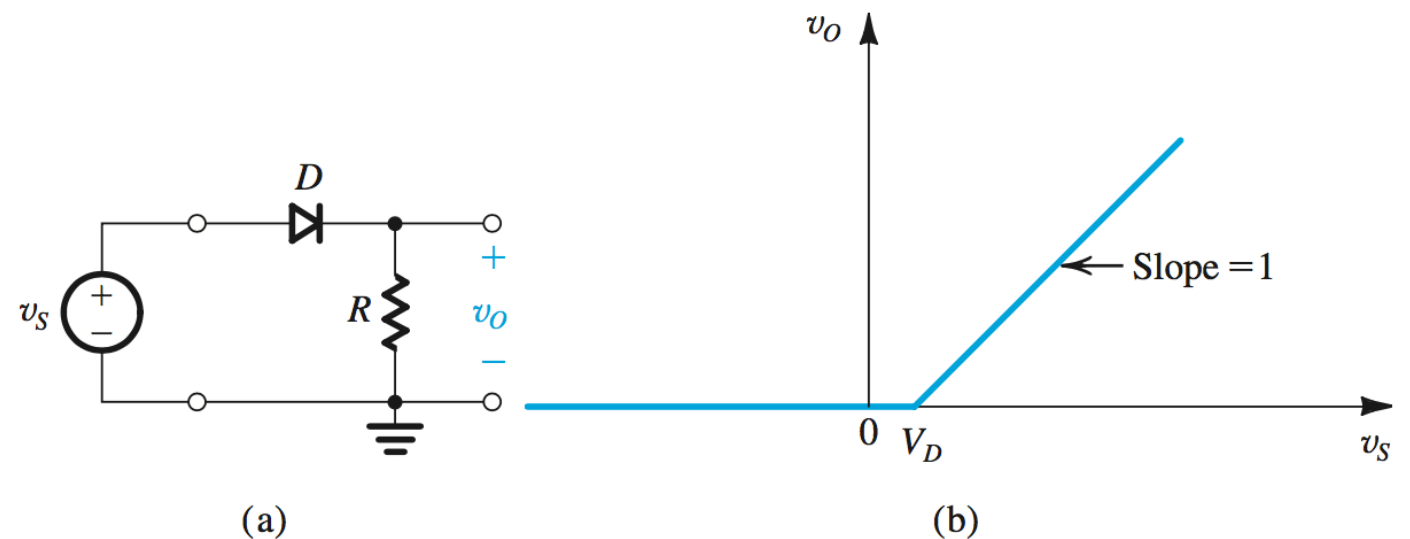
Rectifier Circuits

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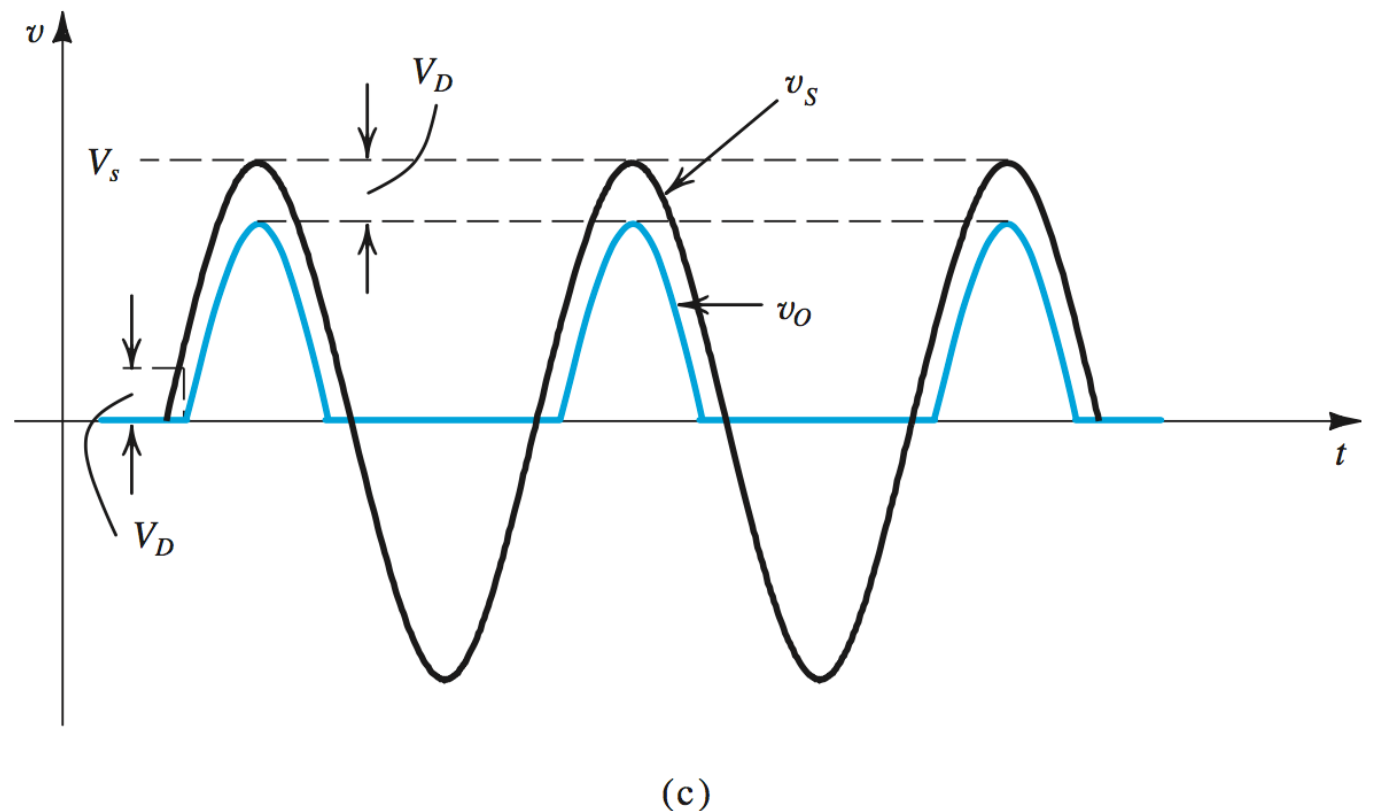
Block diagram of a DC power supply



Half-wave rectifier

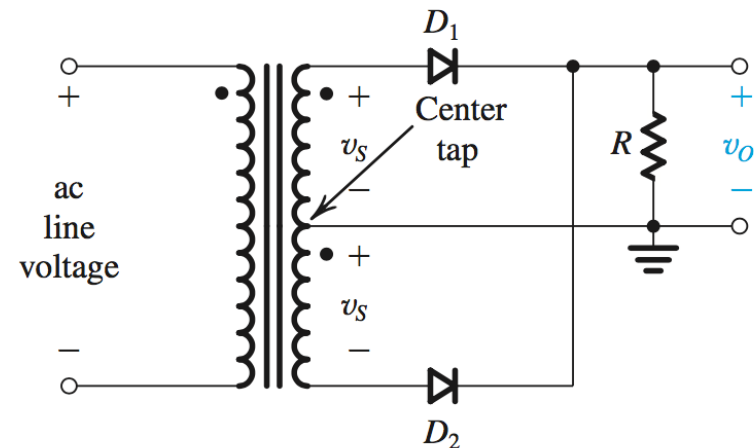


- Using constant-voltage-drop model for the diode.
- Peak Inverse Voltage (PIV) = V_S

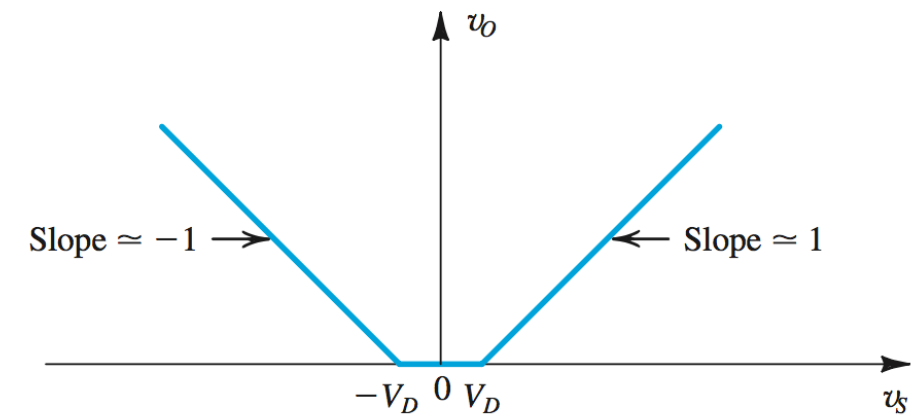


Full-wave rectifier

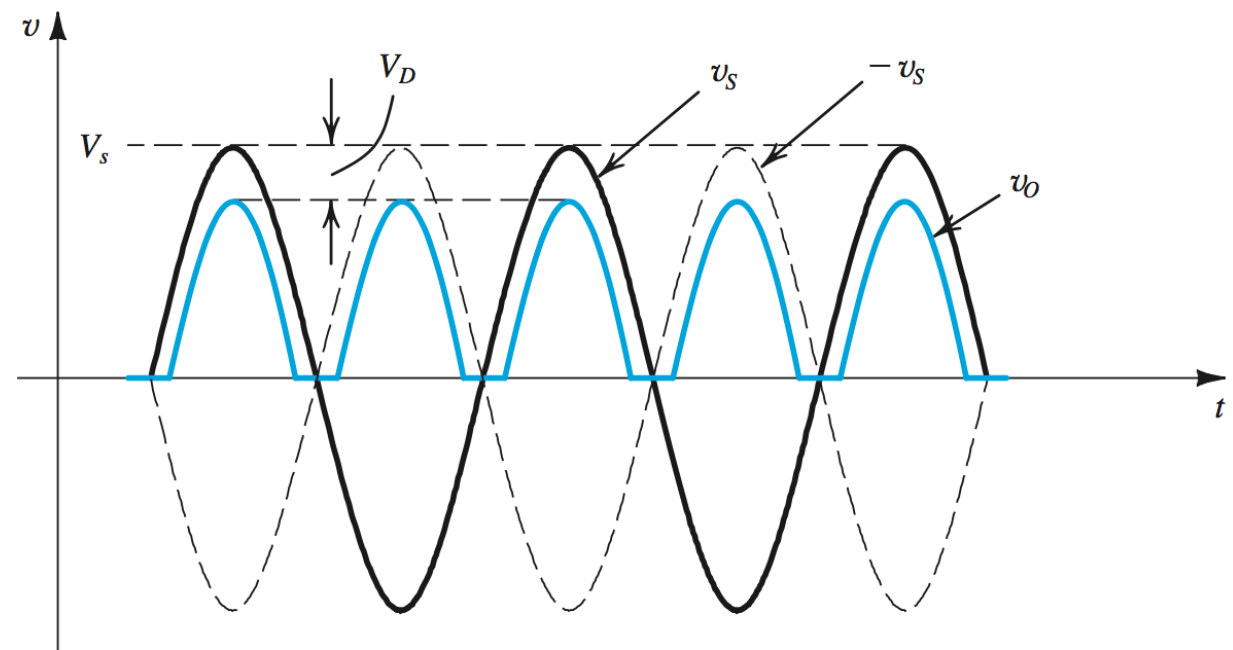
- Need a center-tapped winding.
- More “energetic” than half-wave.
- $PIV = 2V_s - V_D$



(a)



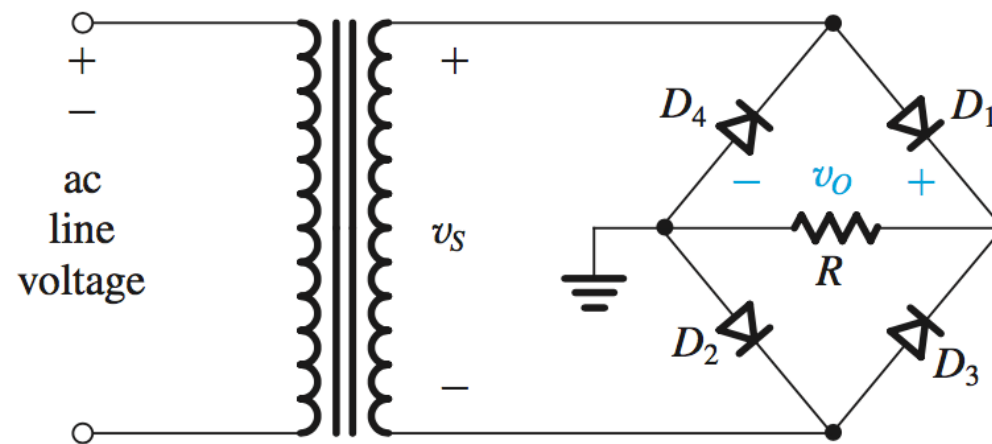
(b)



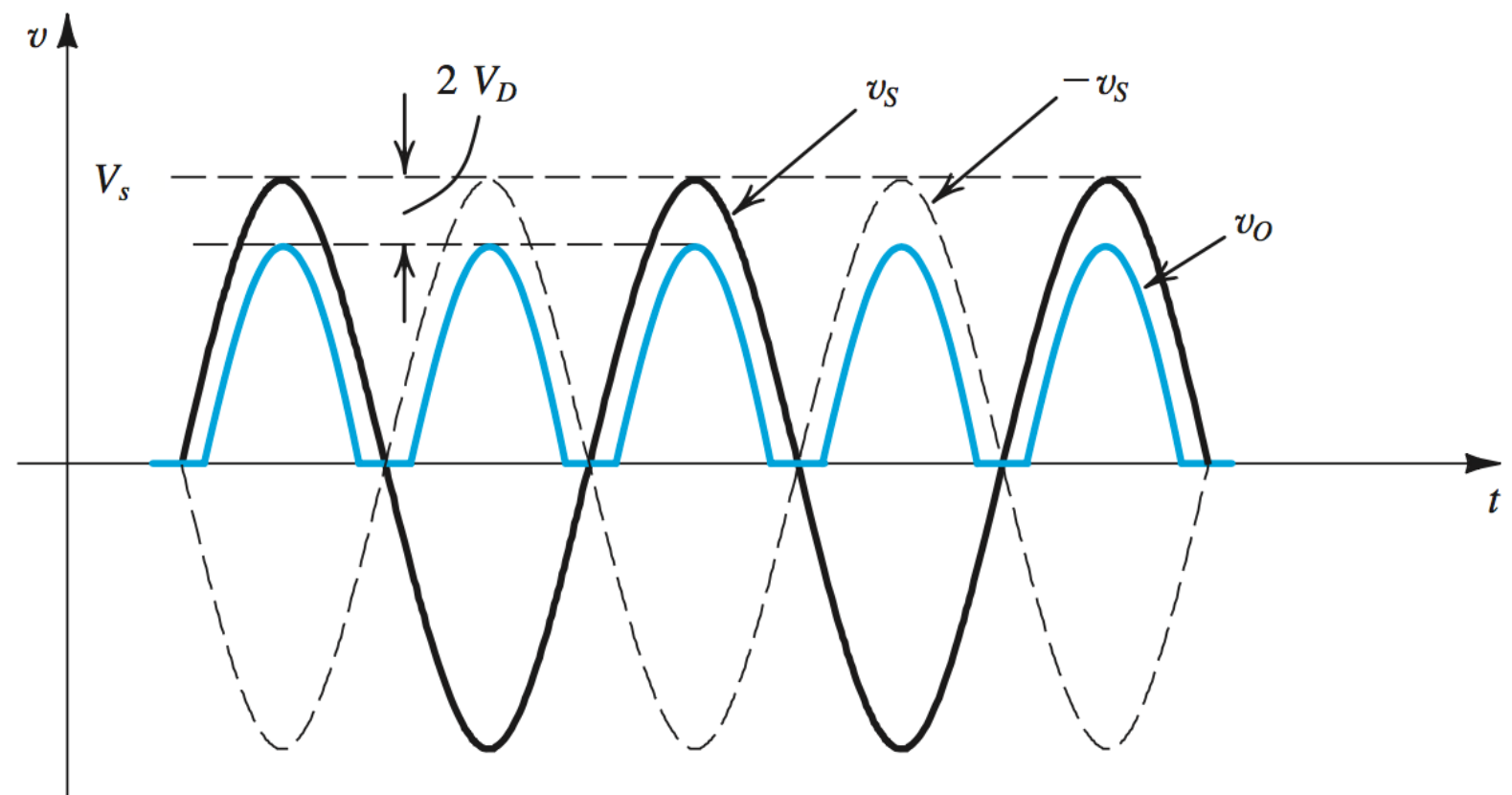
(c)

The bridge rectifier

- Configuration similar to Wheatstone bridge.
- No need of center-tap.
- Only half as many turns as center-tapped rectifier.
- Require 4 diodes (cheap).
- $PIV = V_s - V_D$

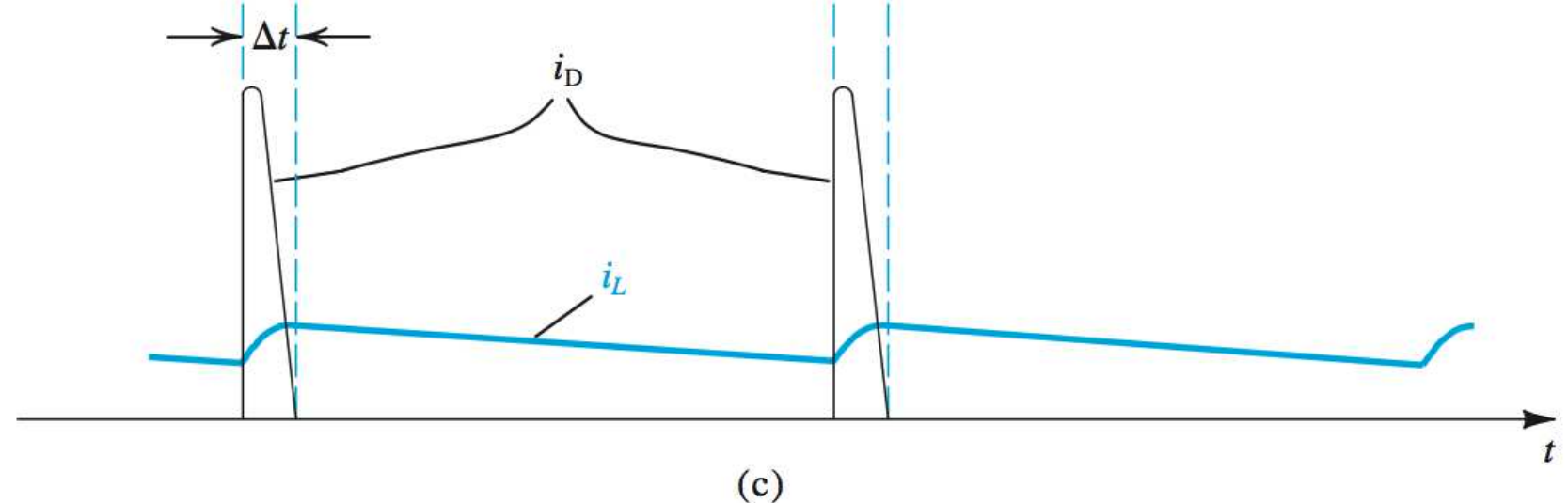
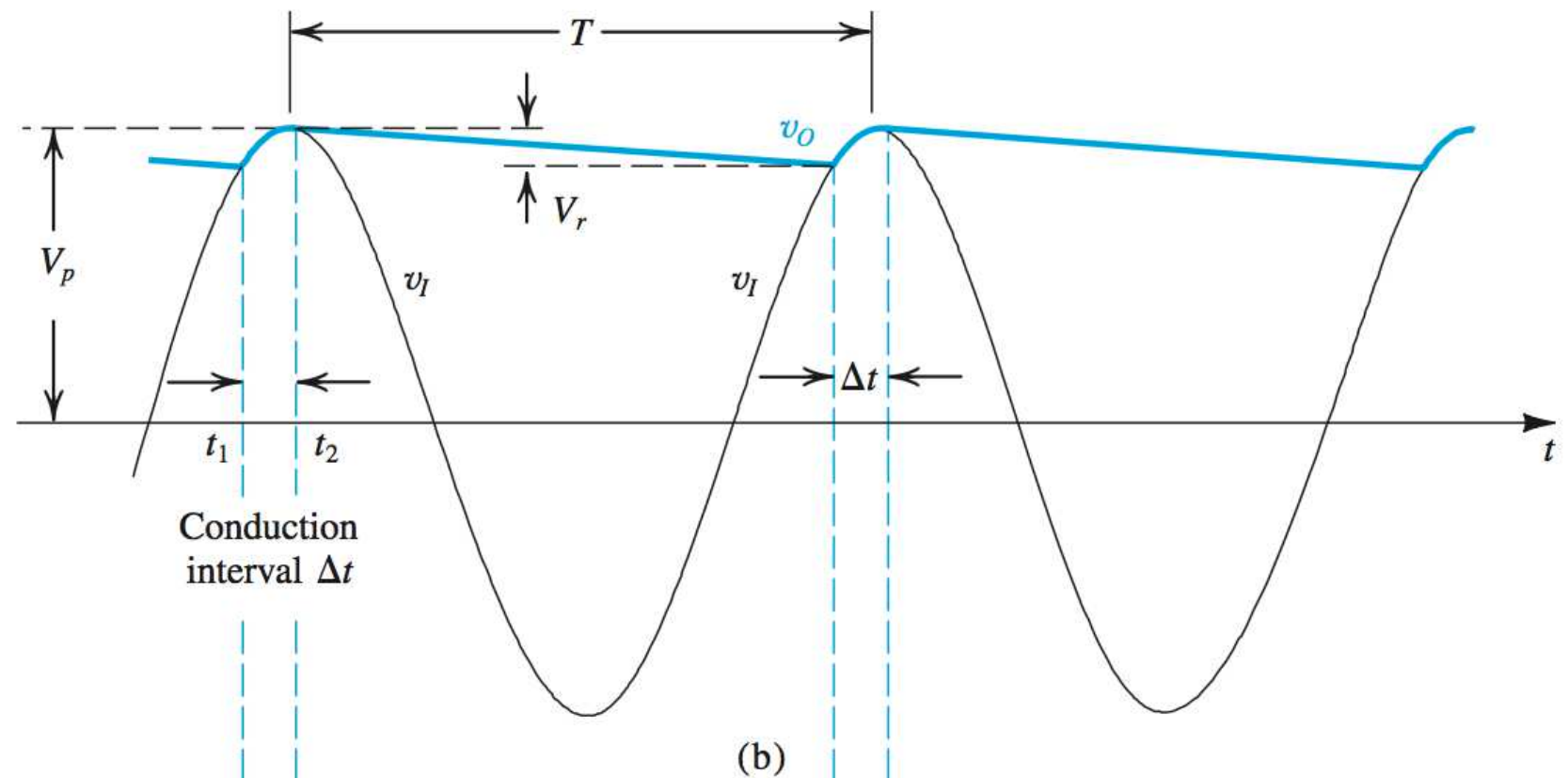
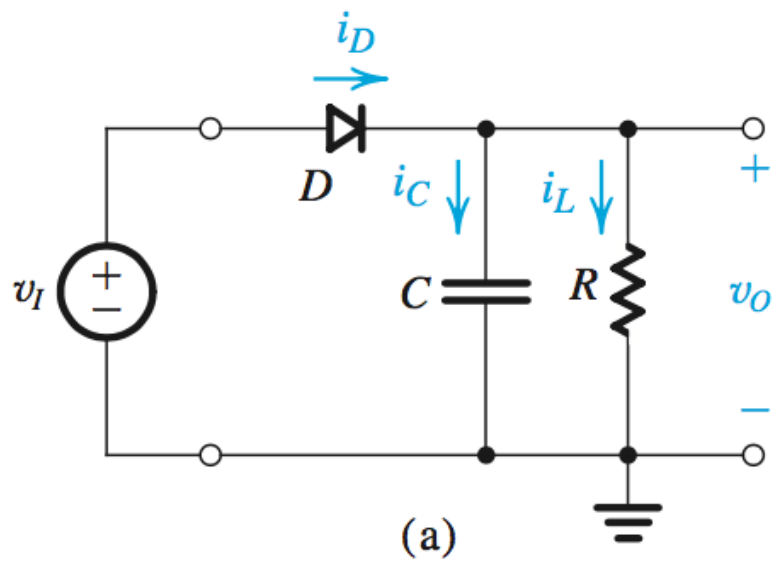


(a)



(b)

The peak rectifier



- Add a filter capacitor.
- $CR \gg T$

Reference

- Adel S. Sedra, Kenneth C. Smith, Microelectronic Circuits, 7th edition. Oxford University Press.

Bad USB

Christopher Niemann

21 March, 2017

Outline

- What is it
- How it works
- Fixes

What is Bad USB?

Exploit of hardware oversight in USB devices

Became well-known in 2014

Extraordinarily hard to detect by anti-virus programs

How does Bad USB work?

Computers don't trust external software, but do trust external firmware

By reprogramming a USB's firmware, can add malicious code

Trick OS into thinking that USB is an HID (Human Interface Device)

Effects of the Payload

Attacker can emulate keyboard, mouse, etc.

The limit is the attacker's imagination



Image source: <http://i.imgur.com/rWwBace.jpg>

Fixes for Bad USB

Prevent firmware changes altogether

Force firmware updates to be signed, authenticated by manufacturer

Tamper-proofing USB devices

Questions?

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đv ٧ ٨ ٩ ١٠ ١١ ١٢ ١٣ ١٤ ١٥ ١٦ ١٧ ١٨ ١٩ ٢٠ ٢١ ٢٢ ٢٣ ٢٤ ٢٥ ٢٦ ٢٧ ٢٨ ٢٩ ٣٠ ٣١ ٣٢ ٣٣ ٣٤ ٣٥ ٣٦ ٣٧ ٣٨ ٣٩ ٤٠ ٤١ ٤٢ ٤٣ ٤٤ ٤٥ ٤٦ ٤٧ ٤٨ ٤٩ ٥٠ ٥١ ٥٢ ٥٣ ٥٤ ٥٥ ٥٦ ٥٧ ٥٨ ٥٩ ٦٠ ٦١ ٦٢ ٦٣ ٦٤ ٦٥ ٦٦ ٦٧ ٦٨ ٦٩ ٧٠ ٧١ ٧٢ ٧٣ ٧٤ ٧٥ ٧٦ ٧٧ ٧٨ ٧٩ ٨٠ ٨١ ٨٢ ٨٣ ٨٤ ٨٥ ٨٦ ٨٧ ٨٨ ٨٩ ٩٠ ٩١ ٩٢ ٩٣ ٩٤ ٩٥ ٩٦ ٩٧ ٩٨ ٩٩ ١٠٠ ١٠١ ١٠٢ ١٠٣ ١٠٤ ١٠٥ ١٠٦ ١٠٧ ١٠٨ ١٠٩ ١١٠ ١١١ ١١٢ ١١٣ ١١٤ ١١٥ ١١٦ ١١٧ ١١٨ ١١٩ ١٢٠ ١٢١ ١٢٢ ١٢٣ ١٢٤ ١٢٥ ١٢٦ ١٢٧ ١٢٨ ١٢٩ ١٣٠ ١٣١ ١٣٢ ١٣٣ ١٣٤ ١٣٥ ١٣٦ ١٣٧ ١٣٨ ١٣٩ ١٤٠ ١٤١ ١٤٢ ١٤٣ ١٤٤ ١٤٥ ١٤٦ ١٤٧ ١٤٨ ١٤٩ ١٥٠ ١٥١ ١٥٢ ١٥٣ ١٥٤ ١٥٥ ١٥٦ ١٥٧ ١٥٨ ١٥٩ ١٦٠ ١٦١ ١٦٢ ١٦٣ ١٦٤ ١٦٥ ١٦٦ ١٦٧ ١٦٨ ١٦٩ ١٧٠ ١٧١ ١٧٢ ١٧٣ ١٧٤ ١٧٥ ١٧٦ ١٧٧ ١٧٨ ١٧٩ ١٨٠ ١٨١ ١٨٢ ١٨٣ ١٨٤ ١٨٥ ١٨٦ ١٨٧ ١٨٨ ١٨٩ ١٩٠ ١٩١ ١٩٢ ١٩٣ ١٩٤ ١٩٥ ١٩٦ ١٩٧ ١٩٨ ١٩٩ ٢٠٠ ٢٠١ ٢٠٢ ٢٠٣ ٢٠٤ ٢٠٥ ٢٠٦ ٢٠٧ ٢٠٨ ٢٠٩ ٢١٠ ٢١١ ٢١٢ ٢١٣ ٢١٤ ٢١٥ ٢١٦ ٢١٧ ٢١٨ ٢١٩ ٢٢٠ ٢٢١ ٢٢٢ ٢٢٣ ٢٢٤ ٢٢٥ ٢٢٦ ٢٢٧ ٢٢٨ ٢٢٩ ٢٣٠ ٢٣١ ٢٣٢ ٢٣٣ ٢٣٤ ٢٣٥ ٢٣٦ ٢٣٧ ٢٣٨ ٢٣٩ ٢٤٠ ٢٤١ ٢٤٢ ٢٤٣ ٢٤٤ ٢٤٥ ٢٤٦ ٢٤٧ ٢٤٨ ٢٤٩ ٢٥٠ ٢٥١ ٢٥٢ ٢٥٣ ٢٥٤ ٢٥٥ ٢٥٦ ٢٥٧ ٢٥٨ ٢٥٩ ٢٦٠ ٢٦١ ٢٦٢ ٢٦٣ ٢٦٤ ٢٦٥ ٢٦٦ ٢٦٧ ٢٦٨ ٢٦٩ ٢٧٠ ٢٧١ ٢٧٢ ٢٧٣ ٢٧٤ ٢٧٥ ٢٧٦ ٢٧٧ ٢٧٨ ٢٧٩ ٢٨٠ ٢٨١ ٢٨٢ ٢٨٣ ٢٨٤ ٢٨٥ ٢٨٦ ٢٨٧ ٢٨٨ ٢٨٩ ٢٩٠ ٢٩١ ٢٩٢ ٢٩٣ ٢٩٤ ٢٩٥ ٢٩٦ ٢٩٧ ٢٩٨ ٢٩٩ ٣٠٠ ٣٠١ ٣٠٢ ٣٠٣ ٣٠٤ ٣٠٥ ٣٠٦ ٣٠٧ ٣٠٨ ٣٠٩ ٣١٠ ٣١١ ٣١٢ ٣١٣ ٣١٤ ٣١٥ ٣١٦ ٣١٧ ٣١٨ ٣١٩ ٣٢٠ ٣٢١ ٣٢٢ ٣٢٣ ٣٢٤ ٣٢٥ ٣٢٦ ٣٢٧ ٣٢٨ ٣٢٩ ٣٣٠ ٣٣١ ٣٣٢ ٣٣٣ ٣٣٤ ٣٣٥ ٣٣٦ ٣٣٧ ٣٣٨ ٣٣٩ ٣٤٠ ٣٤١ ٣٤٢ ٣٤٣ ٣٤٤ ٣٤٥ ٣٤٦ ٣٤٧ ٣٤٨ ٣٤٩ ٣٥٠ ٣٥١ ٣٥٢ ٣٥٣ ٣٥٤ ٣٥٥ ٣٥٦ ٣٥٧ ٣٥٨ ٣٥٩ ٣٦٠ ٣٦١ ٣٦٢ ٣٦٣ ٣٦٤ ٣٦٥ ٣٦٦ ٣٦٧ ٣٦٨ ٣٦٩ ٣٧٠ ٣٧١ ٣٧٢ ٣٧٣ ٣٧٤ ٣٧٥ ٣٧٦ ٣٧٧ ٣٧٨ ٣٧٩ ٣٨٠ ٣٨١ ٣٨٢ ٣٨٣ ٣٨٤ ٣٨٥ ٣٨٦ ٣٨٧ ٣٨٨ ٣٨٩ ٣٩٠ ٣٩١ ٣٩٢ ٣٩٣ ٣٩٤ ٣٩٥ ٣٩٦ ٣٩٧ ٣٩٨ ٣٩٩ ٤٠٠ ٤٠١ ٤٠٢ ٤٠٣ ٤٠٤ ٤٠٥ ٤٠٦ ٤٠٧ ٤٠٨ ٤٠٩ ٤١٠ ٤١١ ٤١٢ ٤١٣ ٤١٤ ٤١٥ ٤١٦ ٤١٧ ٤١٨ ٤١٩ ٤٢٠ ٤٢١ ٤٢٢ ٤٢٣ ٤٢٤ ٤٢٥ ٤٢٦ ٤٢٧ ٤٢٨ ٤٢٩ ٤٣٠ ٤٣١ ٤٣٢ ٤٣٣ ٤٣٤ ٤٣٥ ٤٣٦ ٤٣٧ ٤٣٨ ٤٣٩ ٤٤٠ ٤٤١ ٤٤٢ ٤٤٣ ٤٤٤ ٤٤٥ ٤٤٦ ٤٤٧ ٤٤٨ ٤٤٩ ٤٥٠ ٤٥١ ٤٥٢ ٤٥٣ ٤٥٤ ٤٥٥ ٤٥٦ ٤٥٧ ٤٥٨ ٤٥٩ ٤٦٠ ٤٦١ ٤٦٢ ٤٦٣ ٤٦٤ ٤٦٥ ٤٦٦ ٤٦٧ ٤٦٨ ٤٦٩ ٤٧٠ ٤٧١ ٤٧٢ ٤٧٣ ٤٧٤ ٤٧٥ ٤٧٦ ٤٧٧ ٤٧٨ ٤٧٩ ٤٨٠ ٤٨١ ٤٨٢ ٤٨٣ ٤٨٤ ٤٨٥ ٤٨٦ ٤٨٧ ٤٨٨ ٤٨٩ ٤٩٠ ٤٩١ ٤٩٢ ٤٩٣ ٤٩٤ ٤٩٥ ٤٩٦ ٤٩٧ ٤٩٨ ٤٩٩ ٥٠٠ ٥٠١ ٥٠٢ ٥٠٣ ٥٠٤ ٥٠٥ ٥٠٦ ٥٠٧ ٥٠٨ ٥٠٩ ٥١٠ ٥١١ ٥١٢ ٥١٣ ٥١٤ ٥١٥ ٥١٦ ٥١٧ ٥١٨ ٥١٩ ٥٢٠ ٥٢١ ٥٢٢ ٥٢٣ ٥٢٤ ٥٢٥ ٥٢٦ ٥٢٧ ٥٢٨ ٥٢٩ ٥٣٠ ٥٣١ ٥٣٢ ٥٣٣ ٥٣٤ ٥٣٥ ٥٣٦ ٥٣٧ ٥٣٨ ٥٣٩ ٥٤٠ ٥٤١ ٥٤٢ ٥٤٣ ٥٤٤ ٥٤٥ ٥٤٦ ٥٤٧ ٥٤٨ ٥٤٩ ٥٥٠ ٥٥١ ٥٥٢ ٥٥٣ ٥٥٤ ٥٥٥ ٥٥٦ ٥٥٧ ٥٥٨ ٥٥٩ ٥٦٠ ٥٦١ ٥٦٢ ٥٦٣ ٥٦٤ ٥٦٥ ٥٦٦ ٥٦٧ ٥٦٨ ٥٦٩ ٥٧٠ ٥٧١ ٥٧٢ ٥٧٣ ٥٧٤ ٥٧٥ ٥٧٦ ٥٧٧ ٥٧٨ ٥٧٩ ٥٨٠ ٥٨١ ٥٨٢ ٥٨٣ ٥٨٤ ٥٨٥ ٥٨٦ ٥٨٧ ٥٨٨ ٥٨٩ ٥٩٠ ٥٩١ ٥٩٢ ٥٩٣ ٥٩٤ ٥٩٥ ٥٩٦ ٥٩٧ ٥٩٨ ٥٩٩ ٦٠٠ ٦٠١ ٦٠٢ ٦٠٣ ٦٠٤ ٦٠٥ ٦٠٦ ٦٠٧ ٦٠٨ ٦٠٩ ٦١٠ ٦١١ ٦١٢ ٦١٣ ٦١

$$\delta \left\{ \begin{array}{l} \uparrow \downarrow \\ \uparrow \downarrow \end{array} \right. \frac{1}{B} \frac{1}{3}$$

$\partial_a \text{IX} \rightleftharpoons \text{D}_\mu \text{X} \rightarrow \text{ГТДХ} \rightleftharpoons \text{УП} \frac{1}{2}$

ŏ¹ т ↑↑ (ГД) 1/2 → 1/2 ГД ГД ↑↑ ДА ↑↑

$$\partial / \partial x^{\alpha} \rightarrow \partial_{\alpha} = \frac{1}{c} \frac{\partial}{\partial t}, \quad \text{for } \alpha = 0$$

đ a IX 6 = 4 4 6 7 1 X I 4 6 7 7 7 7

[illegible]

94I i% / IXIIX3 %IXCpI

đ t l5 / IXIIX399/ { 33E↑↑

đ D0↑↑ 4↑ %4↑↑ 0↑↑↑ OT↑↑↑ IX↑↑↑ IXI 4X↑↑ 0 4I 0↑↑ IXI↑ IX4↑↑ I

đ 4I i% I↑ 4IIXI↑↑ 4IXI↑↑
4ro4IXI/3IX44IXI↑ IXI↑↑ 4 4=

đ / IXI↑↑ 4X↑ I↑↑OTO 4I i% I↑ 4IIXI

đ 4↑↑4IX↑ 44IXIXI↑↑ 4X↑

đ a 400↑ OT↑400↑ 4IXI↑ I4%IXI↑ IX↑↑ 4I↑

đ {4I i% 4↑ 4↑↑IXI↑ 4↑↑ 4 4=

```
//roll acts on x, pitch acts on y, thrust acts on z
save pose and setpoints from state struct
for each roll, pitch, and thrust
    error = pose - setpoint
    accumulated error += trapezoidal integrated
    error
    if the error is outside of the saturation bounds
        , saturate
    if reset error flag is set, clear accumulated
    error
    errordot = 0 - posedot //0 is desired velocity
    run errordot through tenth order FIR filter (
        simple moving average)
    output = error * KP + accumulated error * KI +
        errordot * KD
    output+=1500+trim bias
    pass to channels structure to go to Blocks
end
```

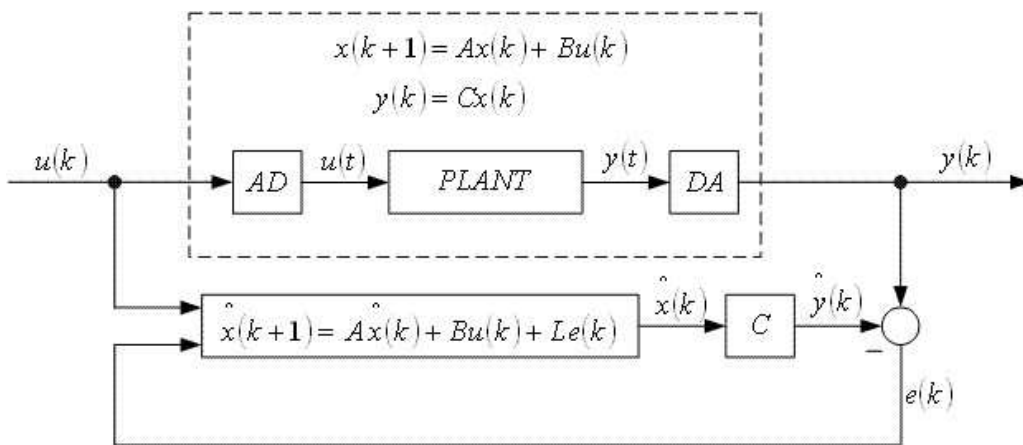
9.4.1.1. The Kalman Filter

What is the Kalman Filter?

It is a recursive algorithm that estimates the state of a system from a series of measurements.

It is used in many applications, including navigation, robotics, and control systems.

It is a type of state estimator that uses a model of the system and a series of measurements to estimate the state.



```

for each predicted state in model
  apply model to each predicted state
  add input to each predicted state
  add error to each predicted state
  collect measurements from actual system state
  calculate error in estimation and measurement
  feed error back
  use state estimation to choose control input
end
    
```

94IiXB bLQELQXII! 1/8IXQDρI

 $\delta\{\Uparrow \Downarrow \Uparrow \Downarrow \Uparrow \Downarrow \Uparrow \Downarrow \}$

ð / ЦЩДр ¼вх≠X5↑т дIXII↑↑д↑GEX I Ц↑CIXI≠X5 I Ц≡II×гт Ц ¼в ↑IX
 ItЦ↑↑т OCTд↑¼

ð9↵¹ t½vd0⇐⊥b ixX0IXIb↑IXI ⊔dт½b↑IXIT↑↑

[illegible]

Db/ 94IixB □ 9wh{t 73hα4 1B{ 4↑

đt ↑IX↑LI LI↑LI↑1/2↑GI 1/2↑IX↑ix↑IXLIot↑oto IXG ILIXI

ø! ддт ↕ ↕ ↕ IX IX L O IX T ↕ ↕ O L L ↕ I L E II ↕ IX T ↕ ↕ O L L

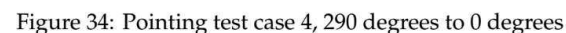
[illegible]

$\delta Y_{\text{L}} / Y_{\text{L}}$ $\text{C}_{\text{H}_2\text{O}}$ C_{CO_2} C_{CH_4} C_{N_2} C_{NH_3}

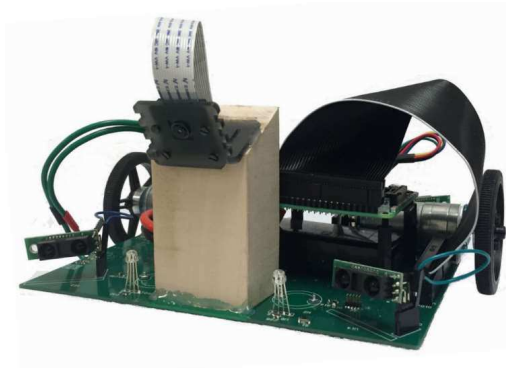
øt l5 dIX↑↑IX%↑ ↻T↕ T↑↑IX GHT↕↕GI Lto CDE½
CDB OT↕OTO CDE½ ↑IXET IT↑LT HPIXix↕↕



$\partial \text{Cl}(\frac{1}{2})^{\uparrow}$ IIXOT $\Downarrow \uparrow$ LQGE $\Downarrow \uparrow$ %
 LiX $\uparrow\uparrow$



øt l5 dIX↑↑IX%b↑IXΠoQ↑ΠΠT ΠΠb ΠΠE1/8 ↑IXV3T↑↑IXCET Π↑ΠT IIXIX
IX↑ix↑



v 5 ↑↑IX↑

đ{IX↑↑

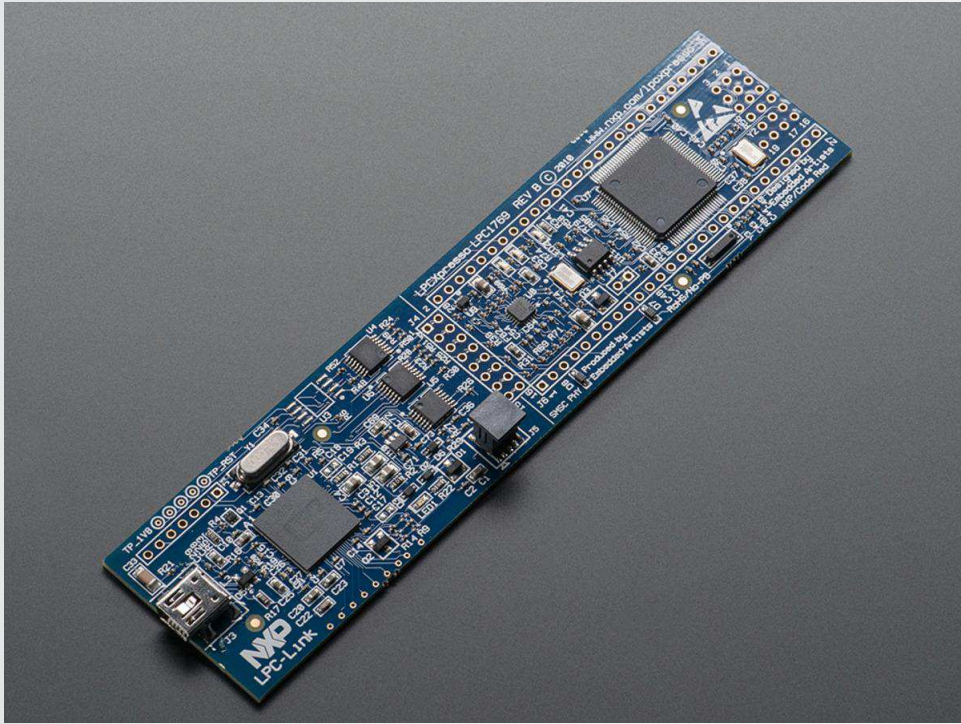
đ Đ↑↑ix o ⅃ Π×GAix o ⅃IXE ⅃×GAU ⅃I ⅃PK ⅃↑

đ 99/ { めう ⅃⅃↑ IXIWX IX↑ Y ⅃I ⅃⅃C ⅃↑ ΠX↑

đ Đ↑↑ix o ⅃ Π×GAix o ⅃IXE ⅃×GAU ⅃↑ ⅃↑×IX↑↑↑↑

đ! 9wh{t めめ ↑⇒I ixIX↑ h r ↑↑↑↑ ⅃⅃ Y ⅃I ⅃⅃C ⅃↑ ΠX↑

đ Đ↑↑ix o ⅃ Π×GAix o ⅃IXE ⅃×GAU ⅃↑× ⅃⅃⅃× ⅃IX↑↑I



LPC1769 LPCXpresso

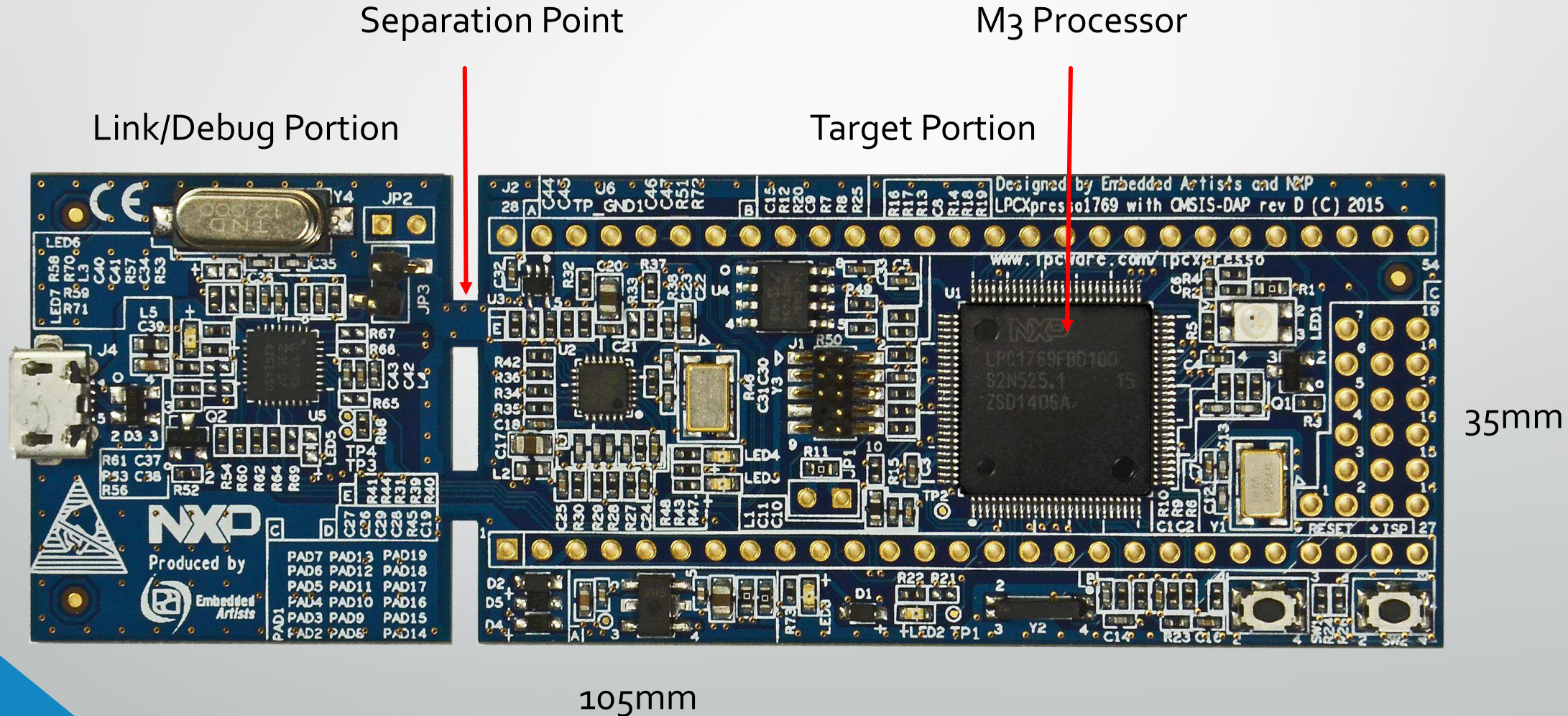
Samuel Habbo-Gavin

Why use this board?

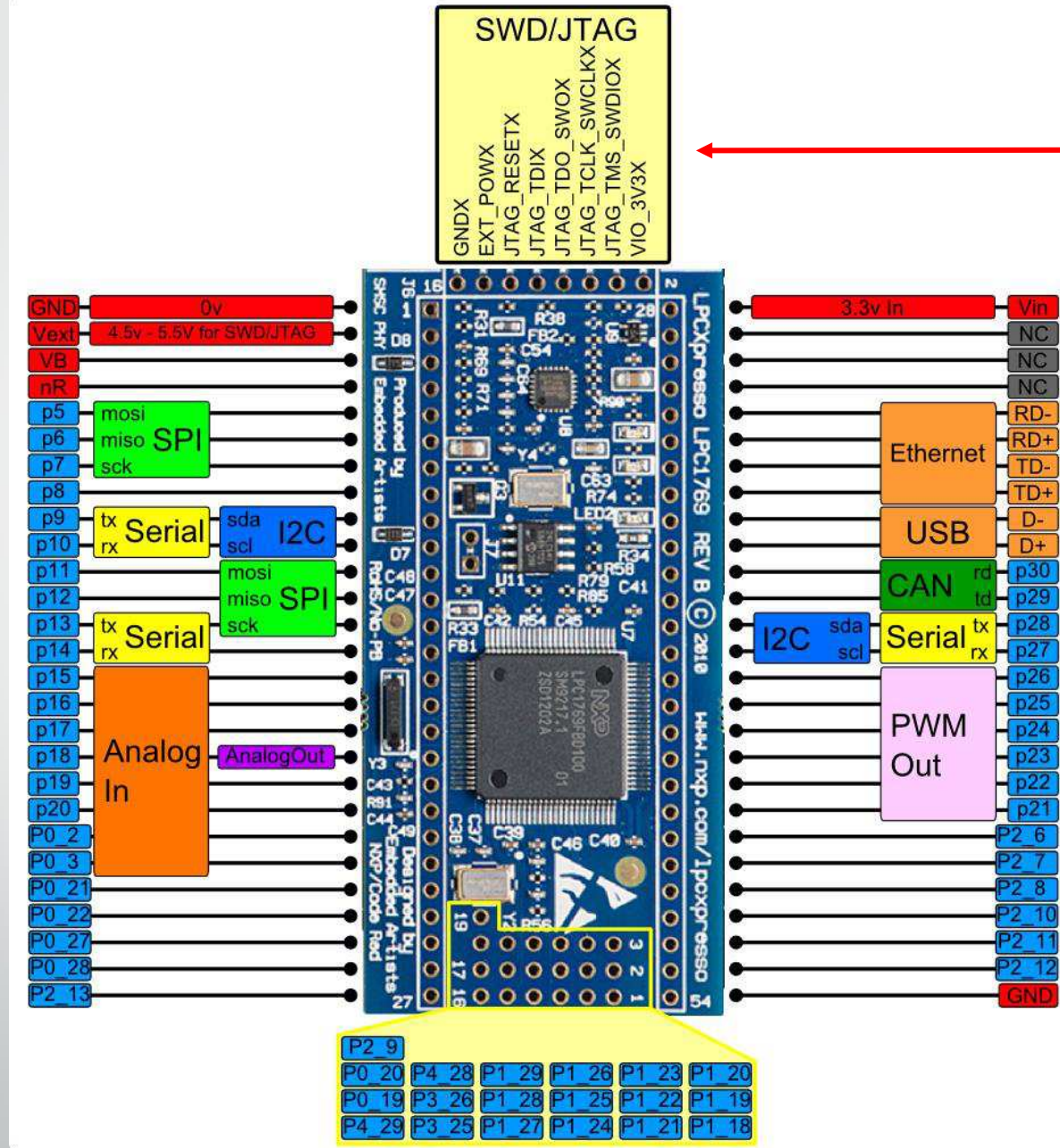
- LCPXpresso is smaller than the SmartFusion board
- Low power consumption
- Uses a similar Eclipse based IDE
- Cortex M3 processor

Board Layout

Note: No FPGA



Pin Layout



Outdated Debug Pins

Process for using LPCXpresso

- Use Eclipse-based IDE to program the board
- Debug the system using built in debugger
- Permanently remove debugging portion
- Power and run the target portion
- LPC Link2 Debugger Hardware needed after separation

References

Board:

https://www.embeddedartists.com/products/lpcxpresso/lpc1769_cmsis_xpr.php

IDE:

<http://www.nxp.com/products/software-and-tools/software-development-tools/software-tools/lpc-microcontroller-utilities/lpcxpresso-ide-v8.2.2:LPCXPRESSO?tid=vanLPCXPRESSO>

Images:

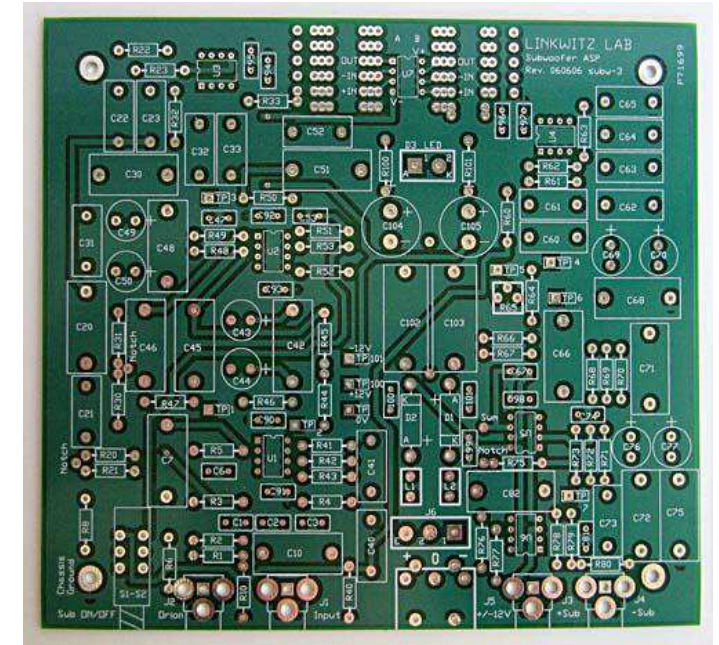
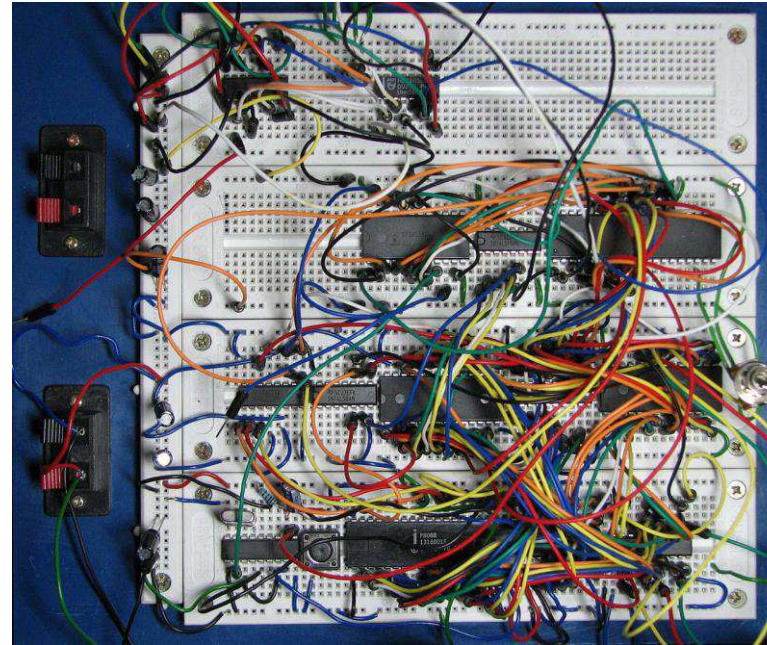
<https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=oahUKEwjPp9mL5ubSAhXCKiYKHbOpBwsQjRwIBw&url=https%3A%2F%2Fdeveloper.mbed.org%2Fusers%2Fnameless129%2Fnotebook%2Flpcxpresso-lpc1769-pinout%2F&psig=AFQjCNHGPPql1EQoKZPYfNq9fH-KFUrtQ&ust=1490158217228545>

Paper Circuits

Qihan Sun

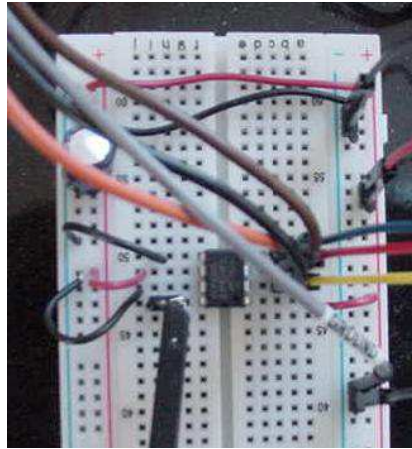
What we have learned

- Breadboard-based prototyping
 - Fast to build
 - Rework easily
 - Cheap
 - Not so scalable
- PCB-based prototyping
 - Slow to manufacture
 - In-place rework is nearly impossible
 - Expensive
 - Clean layout, scalable

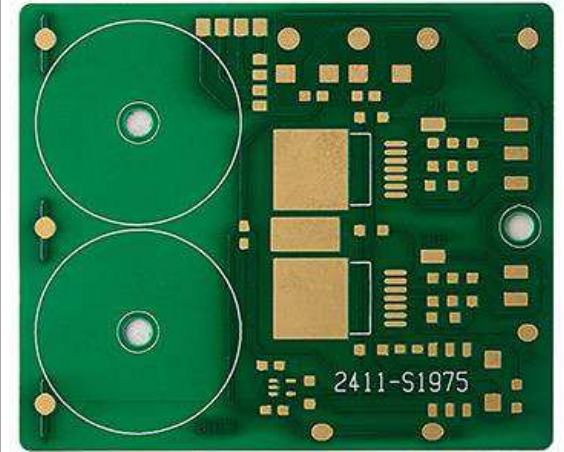


Something in between

Breadboard-based
prototyping

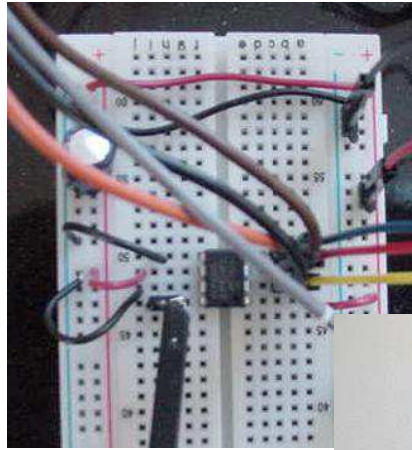


PCB-based
prototyping



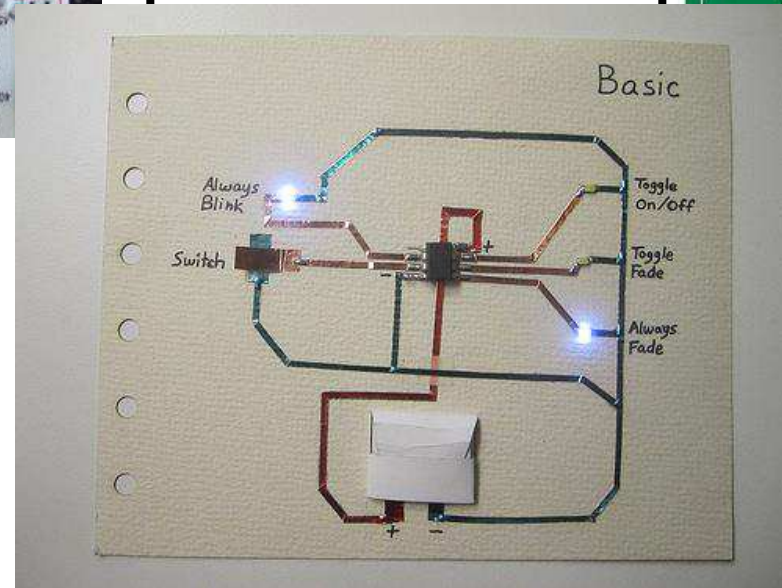
Paper circuits

Breadboard-based prototyping

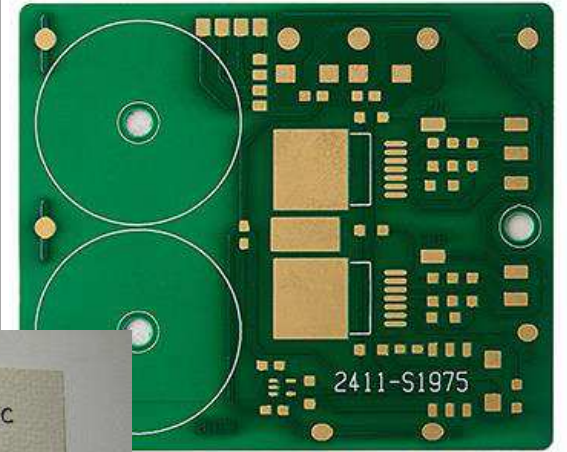


Paper circuits

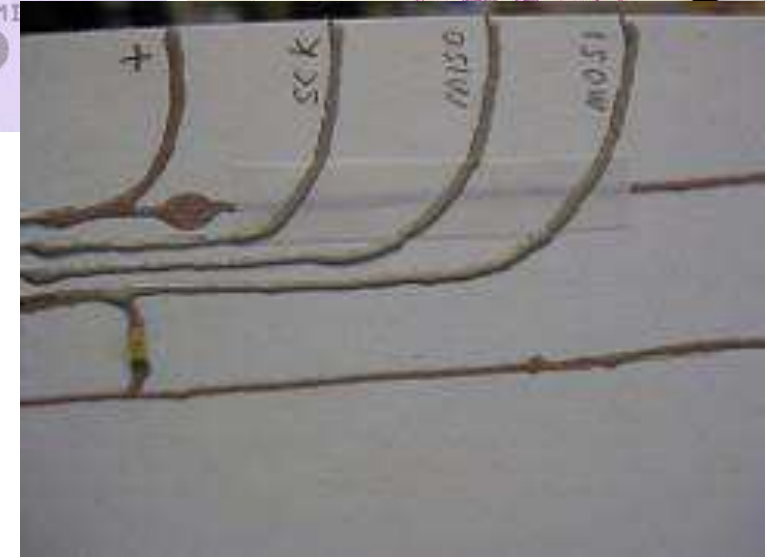
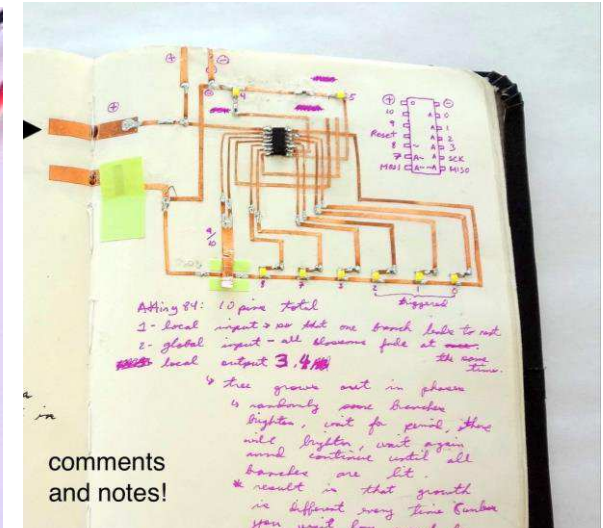
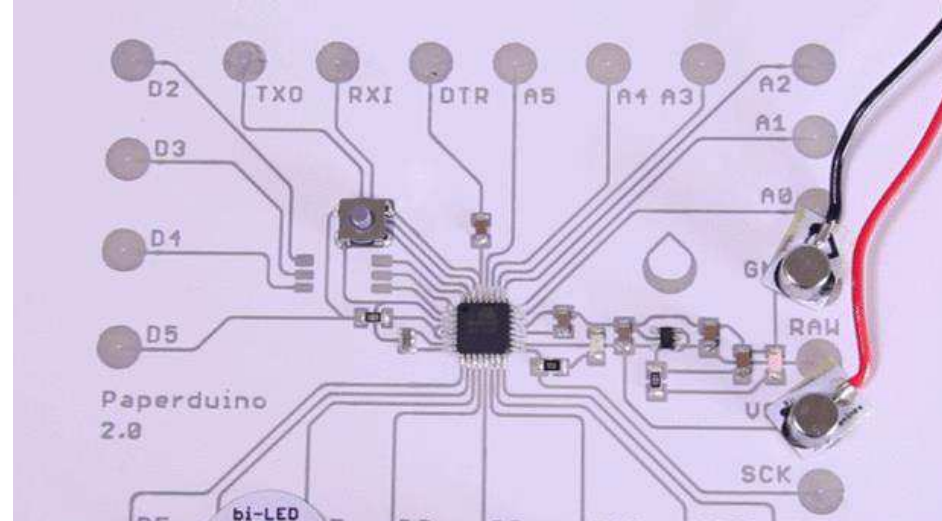
- Moderate build time
- Moderate rework effort
- Moderate price
- Moderate scalability



PCB-based prototyping



Paper circuits



<http://www.instructables.com/id/Paperduino-20-with-Circuit-Scribe/> http://technolgie.com/circuit_sketchbook/
<https://www.kickstarter.com/projects/electroninks/circuit-scribe-draw-circuits-instantly>
<http://highlowtech.org/wiki/pmwiki.php?n=Main.PaperCircuits>

Comparison

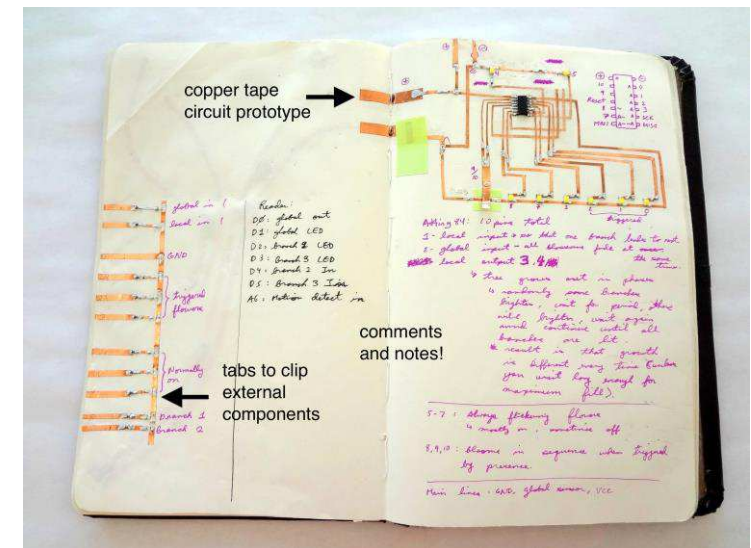
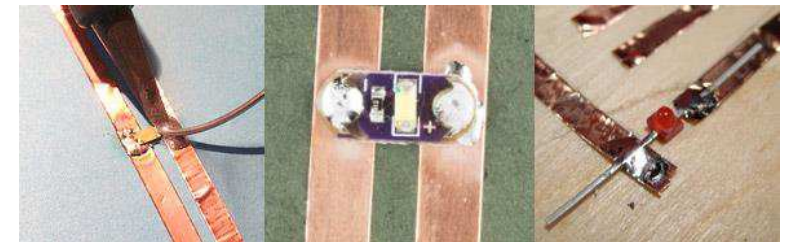
	Breadboard	Paper circuits	PCB
Build time	Minutes	Hours	Hours (soldering only)
Rework time	Seconds to Minutes	Minutes to Hours	Days (including time waiting for the new PCB)
Price	10\$ for the board 2\$ for wires	\$3 for tape \$10 for paint \$20 for ink	Depend on layers of board Usually starts at \$10
Scalability	Lowest, could be messy	Moderate, equivalent as single/double-layer PCB	Highest, machine manufactured, multi-layer available
Extras	Lots of resources immediately available in lab	Low-profile, flexible circuits achievable	Routing tool available, milling technique

Building paper circuits

- Conductive tape
- Conductive paint
- Conductive ink

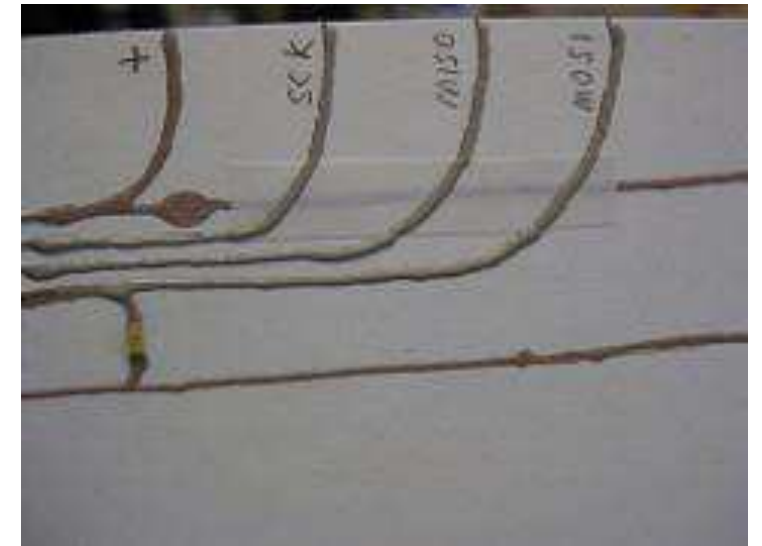
Conductive tape

- Pro
 - No dry time
 - Solderable
 - Cheapest
- Con
 - Only straight line possible
 - Fixed trace width



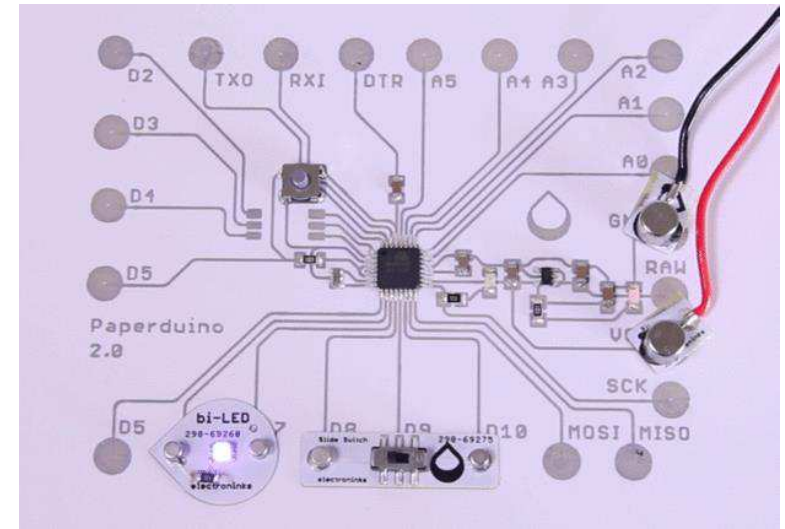
Conductive paint

- Pro
 - Easy to draw smooth lines
 - Can used as cold solder joint to attach components to traces
 - Layer more paint on existing trace to easy fix connection
- Con
 - Not conductive until fully dry
 - Copper based paints could oxidize and lost conductivity
 - Could crack when under strain



Conductive ink

- Pro
 - Fast dry time
 - Precise lines
 - Machine drawing possible
- Con
 - Components attachment could be tricky
 - Higher price



Q&A

References: <https://learn.sparkfun.com/tutorials/the-great-big-guide-to-paper-circuits/all>

<https://en.wikipedia.org/wiki/Breadboard>

<http://eecs.umich.edu/courses/eecs373/lectures/l11.pdf>

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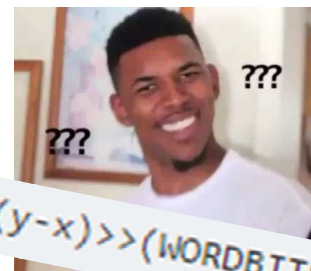
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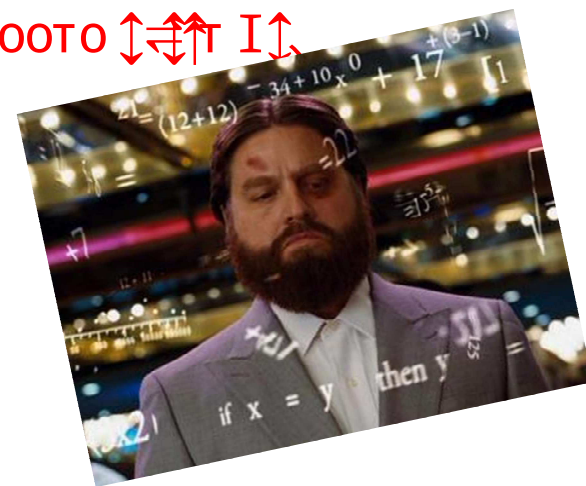
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$$\delta \{ \uparrow \text{IX} \uparrow \uparrow \text{LI} \uparrow \uparrow \text{ET} \uparrow \uparrow \text{TE} \text{GI} \text{ix} \text{V} \text{X} \text{LI} \uparrow \uparrow \text{IX} \text{LI} \text{GI} \uparrow \text{LI} \text{LI} \rho \uparrow \uparrow \text{LI} \uparrow \uparrow \text{ET} \uparrow \uparrow \text{I} \text{LI} \uparrow \text{LI} \uparrow \}$$

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P

The number of cycles required for a pipeline refill. This ranges from 1 to 3 depending on the alignment and width of the target instruction, and whether the processor manages to speculate the address early.

Branch	Conditional	B<cc> <label>	1 or 1 + Pd
	Unconditional	B <label>	1 + P
	With link	BL <label>	1 + P
	With exchange	BX Rm	1 + P
	With link and exchange	BLX Rm	1 + P
	Branch if zero	CBZ Rn, <label>	1 or 1 + Pd
	Branch if non-zero	CBNZ Rn, <label>	1 or 1 + Pd
	Byte table branch	TBB [Rn, Rm]	2 + P
	Halfword table branch	TBH [Rn, Rm, LSL#1]	2 + P

{IX↗дт↕ ЦБ дХХ3ПЫХ

ǒ 𐀀 𐀁𐀂𐀃𐀄𐀅𐀆𐀇𐀈𐀉𐀊𐀋𐀌𐀍𐀎𐀏𐀐𐀑𐀒𐀓𐀔𐀕𐀖𐀗𐀘𐀙𐀚𐀛𐀜𐀝𐀞𐀟𐀠𐀡𐀢𐀣𐀤𐀥𐀦𐀧𐀨𐀩𐀪𐀫𐀬𐀭𐀮𐀯𐀰𐀱𐀲𐀳𐀴𐀵𐀶𐀷𐀸𐀹𐀺𐀻𐀼𐀽𐀾𐀿𐁀𐁁𐁂𐁃𐁄𐁅𐁆𐁇𐁈𐁉𐁊𐁋𐁌𐁍𐁎𐁏𐁐𐁑𐁒𐁓𐁔𐁕𐁖𐁗𐁘𐁙𐁚𐁛𐁜𐁝𐁞𐁟𐁠𐁡𐁢𐁣𐁤𐁥𐁦𐁧𐁨𐁩𐁪𐁫𐁬𐁭𐁮𐁯𐁰𐁱𐁲𐁳𐁴𐁵𐁶𐁷𐁸𐁹𐁺𐁻𐁼𐁽𐁾𐁿𐂀𐂁𐂂𐂃𐂄𐂅𐂆𐂇𐂈𐂉𐂊𐂋𐂌𐂍𐂎𐂏𐂐𐂑𐂒𐂓𐂔𐂕𐂖𐂗𐂘𐂙𐂚𐂛𐂜𐂝𐂞𐂟𐂠𐂡𐂢𐂣𐂤𐂥𐂦𐂧𐂨𐂩𐂪𐂫𐂬𐂭𐂮𐂯𐂰𐂱𐂲𐂳𐂴𐂵𐂶𐂷𐂸𐂹𐂺𐂻𐂼𐂽𐂾𐂿𐃀𐃁𐃂𐃃𐃄𐃅𐃆𐃇𐃈𐃉𐃊𐃋𐃌𐃍𐃎𐃏𐃐𐃑𐃒𐃓𐃔𐃕𐃖𐃗𐃘𐃙𐃚𐃛𐃜𐃝𐃞𐃟𐃠𐃡𐃢𐃣𐃤𐃥𐃦𐃧𐃨𐃩𐃪𐃫𐃬𐃭𐃮𐃯𐃰𐃱𐃲𐃳𐃴𐃵𐃶𐃷𐃸𐃹𐃺𐃻𐃼𐃽𐃾𐃿𐄀𐄁𐄂𐄃𐄄𐄅𐄆𐄇𐄈𐄉𐄊𐄋𐄌𐄍𐄎𐄏𐄐𐄑𐄒𐄓𐄔𐄕𐄖𐄗𐄘𐄙𐄚𐄛𐄜𐄝𐄞𐄟𐄠𐄡𐄢𐄣𐄤𐄥𐄦𐄧𐄨𐄩𐄪𐄫𐄬𐄭𐄮𐄯𐄰𐄱𐄲𐄳𐄴𐄵𐄶𐄷𐄸𐄹𐄺𐄻𐄼𐄽𐄾𐄿𐅀𐅁𐅂𐅃𐅄𐅅𐅆𐅇𐅈𐅉𐅊𐅋𐅌𐅍𐅎𐅏𐅐𐅑𐅒𐅓𐅔𐅕𐅖𐅗𐅘𐅙𐅚𐅛𐅜𐅝𐅞𐅟𐅠𐅡𐅢𐅣𐅤𐅥𐅦𐅧𐅨𐅩𐅪𐅫𐅬𐅭𐅮𐅯𐅰𐅱𐅲𐅳𐅴𐅵𐅶𐅷𐅸𐅹𐅺𐅻𐅼𐅽𐅾𐅿𐆀𐆁𐆂𐆃𐆄𐆅𐆆𐆇𐆈𐆉𐆊𐆋𐆌𐆍𐆎𐆏𐆐𐆑𐆒𐆓𐆔𐆕𐆖𐆗𐆘𐆙𐆚𐆛𐆜𐆝𐆞𐆟𐆠𐆡𐆢𐆣𐆤𐆥𐆦𐆧𐆨𐆩𐆪𐆫𐆬𐆭𐆮𐆯𐆰𐆱𐆲𐆳𐆴𐆵𐆶𐆷𐆸𐆹𐆺𐆻𐆼𐆽𐆾𐆿𐇀𐇁𐇂𐇃𐇄𐇅𐇆𐇇𐇈𐇉𐇊𐇋𐇌𐇍𐇎𐇏𐇐𐇑𐇒𐇓𐇔𐇕𐇖𐇗𐇘𐇙𐇚𐇛𐇜𐇝𐇞𐇟𐇠𐇡𐇢𐇣𐇤𐇥𐇦𐇧𐇨𐇩𐇪𐇫𐇬𐇭𐇮𐇯𐇰𐇱𐇲𐇳𐇴𐇵𐇶𐇷𐇸𐇹𐇺𐇻𐇼𐇽𐇾𐇿𐈀𐈁𐈂𐈃𐈄𐈅𐈆𐈇𐈈𐈉𐈊𐈋𐈌𐈍𐈎𐈏𐈐𐈑𐈒𐈓𐈔𐈕𐈖𐈗𐈘𐈙𐈚𐈛𐈜𐈝𐈞𐈟𐈠𐈡𐈢𐈣𐈤𐈥𐈦𐈧𐈨𐈩𐈪𐈫𐈬𐈭𐈮𐈯𐈰𐈱𐈲𐈳𐈴𐈵𐈶𐈷𐈸𐈹𐈺𐈻𐈼𐈽𐈾𐈿𐉀𐉁𐉂𐉃𐉄𐉅𐉆𐉇𐉈𐉉𐉊𐉋𐉌𐉍𐉎𐉏𐉐𐉑𐉒𐉓𐉔𐉕𐉖𐉗𐉘𐉙𐉚𐉛𐉜𐉝𐉞𐉟𐉠𐉡𐉢𐉣𐉤𐉥𐉦𐉧𐉨𐉩𐉪𐉫𐉬𐉭𐉮𐉯𐉰𐉱𐉲𐉳𐉴𐉵𐉶𐉷𐉸𐉹𐉺𐉻𐉼𐉽𐉾𐉿𐊀𐊁𐊂𐊃𐊄𐊅𐊆𐊇𐊈𐊉𐊊𐊋𐊌𐊍𐊎𐊏𐊐𐊑𐊒𐊓𐊔𐊕𐊖𐊗𐊘𐊙𐊚𐊛𐊜𐊝𐊞𐊟𐊠𐊡𐊢𐊣𐊤𐊥𐊦𐊧𐊨𐊩𐊪𐊫𐊬𐊭𐊮𐊯𐊰𐊱𐊲𐊳𐊴𐊵𐊶𐊷𐊸𐊹𐊺𐊻𐊼𐊽𐊾𐊿𐋀𐋁𐋂𐋃𐋄𐋅𐋆𐋇𐋈𐋉𐋊𐋋𐋌𐋍𐋎𐋏𐋐𐋑𐋒𐋓𐋔𐋕𐋖𐋗𐋘𐋙𐋚𐋛𐋜𐋝𐋞𐋟𐋠𐋡𐋢𐋣𐋤𐋥𐋦𐋧𐋨𐋩𐋪𐋫𐋬𐋭𐋮𐋯𐋰𐋱𐋲𐋳𐋴𐋵𐋶𐋷𐋸𐋹𐋺𐋻𐋼𐋽𐋾𐋿𐌀𐌁𐌂𐌃𐌄𐌅𐌆𐌇𐌈𐌉𐌊𐌋𐌌𐌍𐌎𐌏𐌐𐌑𐌒𐌓𐌔𐌕𐌖𐌗𐌘𐌙𐌚𐌛𐌜𐌝𐌞𐌟𐌠𐌡𐌢𐌣𐌤𐌥𐌦𐌧𐌨𐌩𐌪𐌫𐌬𐌭𐌮𐌯𐌰𐌱𐌲𐌳𐌴𐌵𐌶𐌷𐌸𐌹𐌺𐌻𐌼𐌽𐌾𐌿𐍀𐍁𐍂𐍃𐍄𐍅𐍆𐍇𐍈𐍉𐍊𐍋𐍌𐍍𐍎𐍏𐍐𐍑𐍒𐍓𐍔𐍕𐍖𐍗𐍘𐍙𐍚𐍛𐍜𐍝𐍞𐍟𐍠𐍡𐍢𐍣𐍤𐍥𐍦𐍧𐍨𐍩𐍪𐍫𐍬𐍭𐍮𐍯𐍰𐍱𐍲𐍳𐍴𐍵𐍶𐍷𐍸𐍹𐍺𐍻𐍼𐍽𐍾𐍿𐎀𐎁𐎂𐎃𐎄𐎅𐎆𐎇𐎈𐎉𐎊𐎋𐎌𐎍𐎎𐎏𐎐𐎑𐎒𐎓𐎔𐎕𐎖𐎗𐎘𐎙𐎚𐎛𐎜𐎝𐎞𐎟𐎠𐎡𐎢𐎣𐎤𐎥𐎦𐎧𐎨𐎩𐎪𐎫𐎬𐎭𐎮𐎯𐎰𐎱𐎲𐎳𐎴𐎵𐎶𐎷𐎸𐎹𐎺𐎻𐎼𐎽𐎾𐎿𐏀𐏁𐏂𐏃𐏄𐏅𐏆𐏇𐏈𐏉𐏊𐏋𐏌𐏍𐏎𐏏𐏐𐏑𐏒𐏓𐏔𐏕𐏖𐏗𐏘𐏙𐏚𐏛𐏜𐏝𐏞𐏟𐏠𐏡𐏢𐏣𐏤𐏥𐏦𐏧𐏨𐏩𐏪𐏫𐏬𐏭𐏮𐏯𐏰𐏱𐏲𐏳𐏴𐏵𐏶𐏷𐏸𐏹𐏺𐏻𐏼𐏽𐏾𐏿𐐀𐐁𐐂𐐃𐐄𐐅𐐆𐐇𐐈𐐉𐐊𐐋𐐌𐐍𐐎𐐏𐐐𐐑𐐒𐐓𐐔𐐕𐐖𐐗𐐘𐐙𐐚𐐛𐐜𐐝𐐞𐐟𐐠𐐡𐐢𐐣𐐤𐐥𐐦𐐧𐐨𐐩𐐪𐐫𐐬𐐭𐐮𐐯𐐰𐐱𐐲𐐳𐐴𐐵𐐶𐐷𐐸𐐹𐐺𐐻𐐼𐐽𐐾𐐿𐑀𐑁𐑂𐑃𐑄𐑅𐑆𐑇𐑈𐑉𐑊𐑋𐑌𐑍𐑎𐑏𐑐𐑑𐑒𐑓𐑔𐑕𐑖𐑗𐑘𐑙𐑚𐑛𐑜𐑝𐑞𐑟𐑠𐑡𐑢𐑣𐑤𐑥𐑦𐑧𐑨𐑩𐑪𐑫𐑬𐑭𐑮𐑯𐑰𐑱𐑲𐑳𐑴𐑵𐑶𐑷𐑸𐑹𐑺𐑻𐑼𐑽𐑾𐑿𐒀𐒁𐒂𐒃𐒄𐒅𐒆𐒇𐒈𐒉𐒊𐒋𐒌𐒍𐒎𐒏𐒐𐒑𐒒𐒓𐒔𐒕𐒖𐒗𐒘𐒙𐒚𐒛𐒜𐒝𐒞𐒟𐒠𐒡𐒢𐒣𐒤𐒥𐒦𐒧𐒨𐒩𐒪𐒫𐒬𐒭𐒮𐒯𐒰𐒱𐒲𐒳𐒴𐒵𐒶𐒷𐒸𐒹𐒺𐒻𐒼𐒽𐒾𐒿𐓀𐓁𐓂𐓃𐓄𐓅𐓆𐓇𐓈𐓉𐓊𐓋𐓌𐓍𐓎𐓏𐓐𐓑𐓒𐓓𐓔𐓕𐓖𐓗𐓘𐓙𐓚𐓛𐓜𐓝𐓞𐓟𐓠𐓡𐓢𐓣𐓤𐓥𐓦𐓧𐓨𐓩𐓪𐓫𐓬𐓭𐓮𐓯𐓰𐓱𐓲𐓳𐓴𐓵𐓶𐓷𐓸𐓹𐓺𐓻𐓼𐓽𐓾𐓿𐔀𐔁𐔂𐔃𐔄𐔅𐔆𐔇𐔈𐔉𐔊𐔋𐔌𐔍𐔎𐔏𐔐𐔑𐔒𐔓𐔔𐔕𐔖𐔗𐔘𐔙𐔚𐔛𐔜𐔝𐔞𐔟𐔠𐔡𐔢𐔣𐔤𐔥𐔦𐔧𐔨𐔩𐔪𐔫𐔬𐔭𐔮𐔯𐔰𐔱𐔲𐔳𐔴𐔵𐔶𐔷𐔸𐔹𐔺𐔻𐔼𐔽𐔾𐔿𐕀𐕁𐕂𐕃𐕄𐕅𐕆𐕇𐕈𐕉𐕊𐕋𐕌𐕍𐕎𐕏𐕐𐕑𐕒𐕓𐕔𐕕𐕖𐕗𐕘𐕙𐕚𐕛𐕜𐕝𐕞𐕟𐕠𐕡𐕢𐕣𐕤𐕥𐕦𐕧𐕨𐕩𐕪𐕫𐕬𐕭𐕮𐕯𐕰𐕱𐕲𐕳𐕴𐕵𐕶𐕷𐕸𐕹𐕺𐕻𐕼𐕽𐕾𐕿𐖀𐖁𐖂𐖃𐖄𐖅𐖆𐖇𐖈𐖉𐖊𐖋𐖌𐖍𐖎𐖏𐖐𐖑𐖒𐖓𐖔𐖕𐖖𐖗𐖘𐖙𐖚𐖛𐖜𐖝𐖞𐖟𐖠𐖡𐖢𐖣𐖤𐖥𐖦𐖧𐖨𐖩𐖪𐖫𐖬𐖭𐖮𐖯𐖰𐖱𐖲𐖳𐖴𐖵𐖶𐖷𐖸𐖹𐖺𐖻𐖼𐖽𐖾𐖿𐗀𐗁𐗂𐗃𐗄𐗅𐗆𐗇𐗈𐗉𐗊𐗋𐗌𐗍𐗎𐗏𐗐𐗑𐗒𐗓𐗔𐗕𐗖𐗗𐗘𐗙𐗚𐗛𐗜𐗝𐗞𐗟𐗠𐗡𐗢𐗣𐗤𐗥𐗦𐗧𐗨𐗩𐗪𐗫𐗬𐗭𐗮𐗯𐗰𐗱𐗲𐗳𐗴𐗵𐗶𐗷𐗸𐗹𐗺𐗻𐗼𐗽𐗾𐗿𐘀𐘁𐘂𐘃𐘄𐘅𐘆𐘇𐘈𐘉𐘊𐘋𐘌𐘍𐘎𐘏𐘐𐘑𐘒𐘓𐘔𐘕𐘖𐘗𐘘𐘙𐘚𐘛𐘜𐘝𐘞𐘟𐘠𐘡𐘢𐘣𐘤𐘥𐘦𐘧𐘨𐘩𐘪𐘫𐘬𐘭𐘮𐘯𐘰𐘱𐘲𐘳𐘴𐘵𐘶𐘷𐘸𐘹𐘺𐘻𐘼𐘽𐘾𐘿𐙀𐙁𐙂𐙃𐙄𐙅𐙆𐙇𐙈𐙉𐙊𐙋𐙌𐙍𐙎𐙏𐙐𐙑𐙒𐙓𐙔𐙕𐙖𐙗𐙘𐙙𐙚𐙛𐙜𐙝𐙞𐙟𐙠𐙡𐙢𐙣𐙤𐙥𐙦𐙧𐙨𐙩𐙪𐙫𐙬𐙭𐙮𐙯𐙰𐙱𐙲𐙳𐙴𐙵𐙶𐙷𐙸𐙹𐙺𐙻𐙼𐙽𐙾𐙿𐚀𐚁𐚂𐚃𐚄𐚅𐚆𐚇𐚈𐚉𐚊𐚋𐚌𐚍𐚎𐚏𐚐𐚑𐚒𐚓𐚔𐚕𐚖𐚗𐚘𐚙𐚚𐚛𐚜𐚝𐚞𐚟𐚠𐚡𐚢𐚣𐚤𐚥𐚦𐚧𐚨𐚩𐚪𐚫𐚬𐚭𐚮𐚯𐚰𐚱𐚲𐚳𐚴𐚵𐚶𐚷𐚸𐚹𐚺𐚻𐚼𐚽𐚾𐚿𐛀𐛁𐛂𐛃𐛄𐛅𐛆𐛇𐛈𐛉𐛊𐛋𐛌𐛍𐛎𐛏𐛐𐛑𐛒𐛓𐛔𐛕𐛖𐛗𐛘𐛙𐛚𐛛𐛜𐛝𐛞𐛟𐛠𐛡𐛢𐛣𐛤𐛥𐛦𐛧𐛨𐛩𐛪𐛫𐛬𐛭𐛮𐛯𐛰𐛱𐛲𐛳𐛴𐛵𐛶𐛷𐛸𐛹𐛺𐛻𐛼𐛽𐛾𐛿𐜀𐜁𐜂𐜃𐜄𐜅𐜆𐜇𐜈𐜉𐜊𐜋𐜌𐜍𐜎𐜏𐜐𐜑𐜒𐜓𐜔𐜕𐜖𐜗𐜘𐜙𐜚𐜛𐜜𐜝𐜞𐜟𐜠𐜡𐜢𐜣𐜤𐜥𐜦𐜧𐜨𐜩𐜪𐜫𐜬𐜭𐜮𐜯𐜰𐜱𐜲𐜳𐜴𐜵𐜶𐜷𐜸𐜹𐜺𐜻𐜼𐜽𐜾𐜿𐝀𐝁𐝂𐝃𐝄𐝅𐝆𐝇𐝈𐝉𐝊𐝋𐝌𐝍𐝎𐝏𐝐𐝑𐝒𐝓𐝔𐝕𐝖𐝗𐝘𐝙𐝚𐝛𐝜𐝝𐝞𐝟𐝠𐝡𐝢𐝣𐝤𐝥𐝦𐝧𐝨𐝩𐝪𐝫𐝬𐝭𐝮𐝯𐝰𐝱𐝲𐝳𐝴𐝵𐝶𐝷𐝸𐝹𐝺𐝻𐝼𐝽𐝾𐝿𐞀𐞁𐞂𐞃𐞄𐞅𐞆𐞇𐞈𐞉𐞊𐞋𐞌𐞍𐞎𐞏𐞐𐞑𐞒𐞓𐞔𐞕𐞖𐞗𐞘𐞙𐞚𐞛𐞜𐞝𐞞𐞟𐞠𐞡𐞢𐞣𐞤𐞥𐞦𐞧𐞨𐞩𐞪𐞫𐞬𐞭𐞮𐞯𐞰𐞱𐞲𐞳𐞴𐞵𐞶𐞷𐞸𐞹𐞺𐞻𐞼𐞽𐞾𐞿𐟀𐟁𐟂𐟃𐟄𐟅𐟆𐟇𐟈𐟉𐟊𐟋𐟌𐟍𐟎𐟏𐟐𐟑𐟒𐟓𐟔𐟕𐟖𐟗𐟘𐟙𐟚𐟛𐟜𐟝𐟞𐟟𐟠𐟡𐟢𐟣𐟤𐟥𐟦𐟧𐟨𐟩𐟪𐟫𐟬𐟭𐟮𐟯𐟰𐟱𐟲𐟳𐟴𐟵𐟶𐟷𐟸𐟹𐟺𐟻𐟼𐟽𐟾𐟿𐠀𐠁𐠂𐠃𐠄𐠅𐠆𐠇𐠈𐠉𐠊𐠋𐠌𐠍𐠎𐠏𐠐𐠑𐠒𐠓𐠔𐠕𐠖𐠗𐠘𐠙𐠚𐠛𐠜𐠝𐠞𐠟𐠠𐠡𐠢𐠣𐠤𐠥𐠦𐠧𐠨𐠩𐠪𐠫𐠬𐠭𐠮𐠯𐠰𐠱𐠲𐠳𐠴𐠵𐠶𐠷𐠸𐠹𐠺𐠻𐠼𐠽𐠾𐠿𐡀𐡁𐡂𐡃𐡄𐡅𐡆𐡇𐡈𐡉𐡊𐡋𐡌𐡍𐡎𐡏𐡐𐡑𐡒𐡓𐡔𐡕𐡖𐡗𐡘𐡙𐡚𐡛𐡜𐡝𐡞𐡟𐡠𐡡𐡢𐡣𐡤𐡥𐡦𐡧𐡨𐡩𐡪𐡫𐡬𐡭𐡮𐡯𐡰𐡱𐡲𐡳𐡴𐡵𐡶𐡷𐡸𐡹𐡺𐡻𐡼𐡽𐡾𐡿𐢀𐢁𐢂𐢃𐢄𐢅𐢆𐢇𐢈𐢉𐢊𐢋𐢌𐢍𐢎𐢏𐢐𐢑𐢒𐢓𐢔𐢕𐢖𐢗𐢘𐢙𐢚𐢛𐢜𐢝𐢞𐢟𐢠𐢡𐢢𐢣𐢤𐢥𐢦𐢧𐢨𐢩𐢪𐢫𐢬𐢭𐢮𐢯𐢰𐢱𐢲𐢳𐢴𐢵𐢶𐢷𐢸𐢹𐢺𐢻𐢼𐢽𐢾𐢿𐣀𐣁𐣂𐣃𐣄𐣅𐣆𐣇𐣈𐣉𐣊𐣋𐣌𐣍𐣎𐣏𐣐𐣑𐣒𐣓𐣔𐣕𐣖𐣗𐣘𐣙𐣚𐣛𐣜𐣝𐣞𐣟𐣠𐣡𐣢𐣣𐣤𐣥𐣦𐣧𐣨𐣩𐣪𐣫𐣬𐣭𐣮𐣯𐣰𐣱𐣲𐣳𐣴𐣵𐣶𐣷𐣸𐣹𐣺𐣻𐣼𐣽𐣾𐣿𐤀𐤁𐤂𐤃𐤄𐤅𐤆𐤇𐤈𐤉𐤊𐤋𐤌𐤍𐤎𐤏𐤐𐤑𐤒𐤓𐤔𐤕𐤖𐤗𐤘𐤙𐤚𐤛𐤜𐤝𐤞𐤟𐤠𐤡𐤢𐤣𐤤𐤥𐤦𐤧𐤨𐤩𐤪𐤫𐤬𐤭𐤮𐤯𐤰𐤱𐤲𐤳𐤴𐤵𐤶𐤷𐤸𐤹𐤺𐤻𐤼𐤽𐤾𐤿𐥀𐥁𐥂𐥃𐥄𐥅𐥆𐥇𐥈𐥉𐥊𐥋𐥌𐥍𐥎𐥏𐥐𐥑𐥒𐥓𐥔𐥕𐥖𐥗𐥘𐥙𐥚𐥛𐥜𐥝𐥞𐥟𐥠𐥡𐥢𐥣𐥤𐥥𐥦𐥧𐥨𐥩𐥪𐥫𐥬𐥭𐥮𐥯𐥰𐥱𐥲𐥳𐥴𐥵𐥶𐥷𐥸𐥹𐥺𐥻𐥼𐥽𐥾𐥿𐦀𐦁𐦂𐦃𐦄𐦅𐦆𐦇𐦈𐦉𐦊𐦋𐦌𐦍𐦎𐦏𐦐𐦑𐦒𐦓𐦔𐦕𐦖𐦗𐦘𐦙𐦚𐦛𐦜𐦝𐦞𐦟𐦠𐦡𐦢𐦣𐦤𐦥𐦦𐦧𐦨𐦩𐦪𐦫𐦬𐦭𐦮𐦯𐦰𐦱𐦲𐦳𐦴𐦵𐦶𐦷𐦸𐦹𐦺𐦻𐦼𐦽𐦾𐦿𐧀𐧁𐧂𐧃𐧄𐧅𐧆𐧇𐧈𐧉𐧊𐧋𐧌𐧍𐧎𐧏𐧐𐧑𐧒𐧓𐧔𐧕𐧖𐧗𐧘𐧙𐧚𐧛𐧜𐧝𐧞𐧟𐧠𐧡𐧢𐧣𐧤𐧥𐧦𐧧𐧨𐧩𐧪𐧫𐧬𐧭𐧮𐧯𐧰𐧱𐧲𐧳𐧴𐧵𐧶𐧷𐧸𐧹𐧺𐧻𐧼𐧽𐧾𐧿𐨀𐨁𐨂𐨃𐨄𐨅𐨆𐨇𐨈𐨉𐨊𐨋𐨌𐨍𐨎𐨏𐨐𐨑𐨒𐨓𐨔𐨕𐨖𐨗𐨘𐨙𐨚𐨛𐨜𐨝𐨞𐨟𐨠𐨡𐨢𐨣𐨤𐨥𐨦𐨧𐨨𐨩𐨪𐨫𐨬𐨭𐨮𐨯𐨰𐨱𐨲𐨳𐨴𐨵𐨶𐨷𐨹𐨺𐨸𐨻𐨼𐨽𐨾𐨿𐩀𐩁𐩂𐩃𐩄𐩅𐩆𐩇𐩈𐩉𐩊𐩋𐩌𐩍𐩎𐩏𐩐𐩑𐩒𐩓𐩔𐩕𐩖𐩗𐩘𐩙𐩚𐩛𐩜𐩝𐩞𐩟𐩠𐩡𐩢𐩣𐩤𐩥𐩦𐩧𐩨𐩩𐩪𐩫𐩬𐩭𐩮𐩯𐩰𐩱𐩲𐩳𐩴𐩵𐩶𐩷𐩸𐩹𐩺𐩻𐩼𐩽𐩾𐩿𐪀𐪁𐪂𐪃𐪄𐪅𐪆𐪇𐪈𐪉𐪊𐪋𐪌𐪍𐪎𐪏𐪐𐪑𐪒𐪓𐪔𐪕𐪖𐪗𐪘𐪙𐪚𐪛𐪜𐪝𐪞𐪟𐪠𐪡𐪢𐪣𐪤𐪥𐪦𐪧𐪨𐪩𐪪𐪫𐪬𐪭𐪮𐪯𐪰𐪱𐪲𐪳𐪴𐪵𐪶𐪷𐪸𐪹𐪺𐪻𐪼𐪽𐪾𐪿𐫀𐫁𐫂𐫃𐫄𐫅𐫆𐫇𐫈𐫉𐫊𐫋𐫌𐫍𐫎𐫏𐫐𐫑𐫒𐫓𐫔𐫕𐫖𐫗𐫘𐫙𐫚𐫛𐫜𐫝𐫞𐫟𐫠𐫡𐫢𐫣𐫤𐫦𐫥𐫧𐫨𐫩𐫪𐫫𐫬𐫭𐫮𐫯𐫰𐫱𐫲𐫳𐫴𐫵𐫶𐫷𐫸𐫹𐫺𐫻𐫼𐫽𐫾𐫿𐬀𐬁𐬂𐬃𐬄𐬅𐬆𐬇𐬈𐬉𐬊𐬋𐬌𐬍𐬎𐬏𐬐𐬑𐬒𐬓𐬔𐬕𐬖𐬗𐬘𐬙𐬚𐬛𐬜𐬝𐬞𐬟𐬠𐬡𐬢𐬣𐬤𐬥𐬦𐬧𐬨𐬩𐬪𐬫𐬬𐬭𐬮𐬯𐬰𐬱𐬲𐬳𐬴𐬵𐬶𐬷𐬸𐬹𐬺𐬻𐬼𐬽𐬾𐬿𐭀𐭁𐭂𐭃𐭄𐭅𐭆𐭇𐭈𐭉𐭊𐭋𐭌𐭍𐭎𐭏𐭐𐭑𐭒𐭓𐭔𐭕𐭖𐭗𐭘𐭙𐭚𐭛𐭜𐭝𐭞𐭟𐭠𐭡𐭢𐭣𐭤𐭥𐭦𐭧𐭨𐭩𐭪𐭫𐭬𐭭𐭮𐭯𐭰𐭱𐭲𐭳𐭴𐭵𐭶𐭷𐭸𐭹𐭺𐭻𐭼𐭽𐭾𐭿𐮀𐮁𐮂𐮃𐮄𐮅𐮆𐮇𐮈𐮉𐮊𐮋𐮌𐮍𐮎𐮏𐮐𐮑𐮒𐮓𐮔𐮕𐮖𐮗𐮘𐮙𐮚𐮛𐮜𐮝𐮞𐮟𐮠𐮡𐮢𐮣𐮤𐮥𐮦𐮧𐮨𐮩𐮪𐮫𐮬𐮭𐮮𐮯𐮰𐮱𐮲𐮳𐮴𐮵𐮶𐮷𐮸𐮹𐮺𐮻𐮼𐮽𐮾𐮿𐯀𐯁𐯂𐯃𐯄𐯅𐯆𐯇𐯈𐯉𐯊𐯋𐯌𐯍𐯎𐯏𐯐𐯑𐯒𐯓𐯔𐯕𐯖𐯗𐯘𐯙𐯚𐯛𐯜𐯝𐯞𐯟𐯠𐯡𐯢𐯣𐯤𐯥𐯦𐯧𐯨𐯩𐯪𐯫𐯬𐯭𐯮𐯯𐯰𐯱𐯲𐯳𐯴𐯵𐯶𐯷𐯸𐯹𐯺𐯻𐯼𐯽𐯾𐯿𐰀𐰁𐰂𐰃

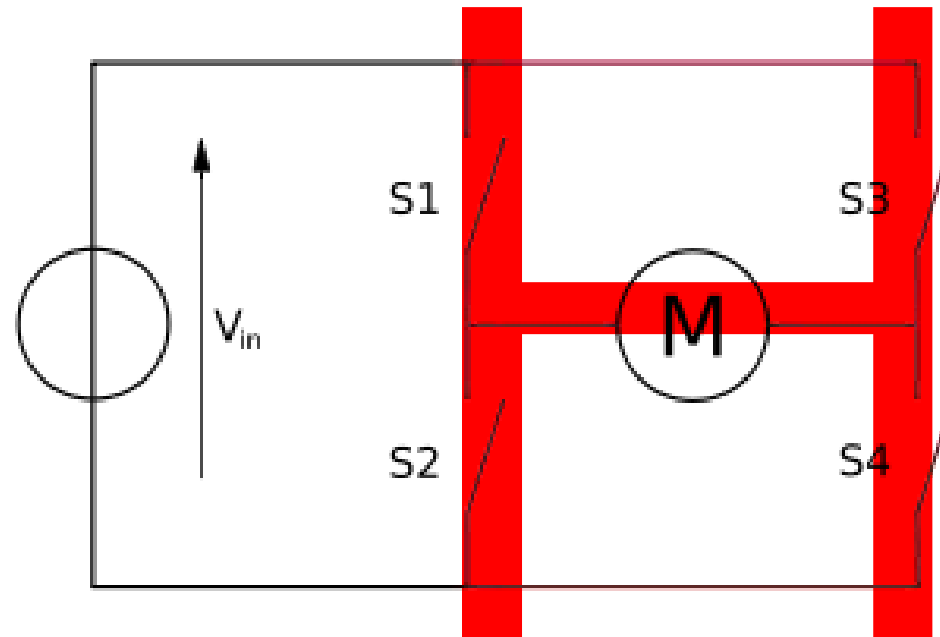
H Bridge DC Motor Driver

Yuan Yao

yaoyua@umich.edu

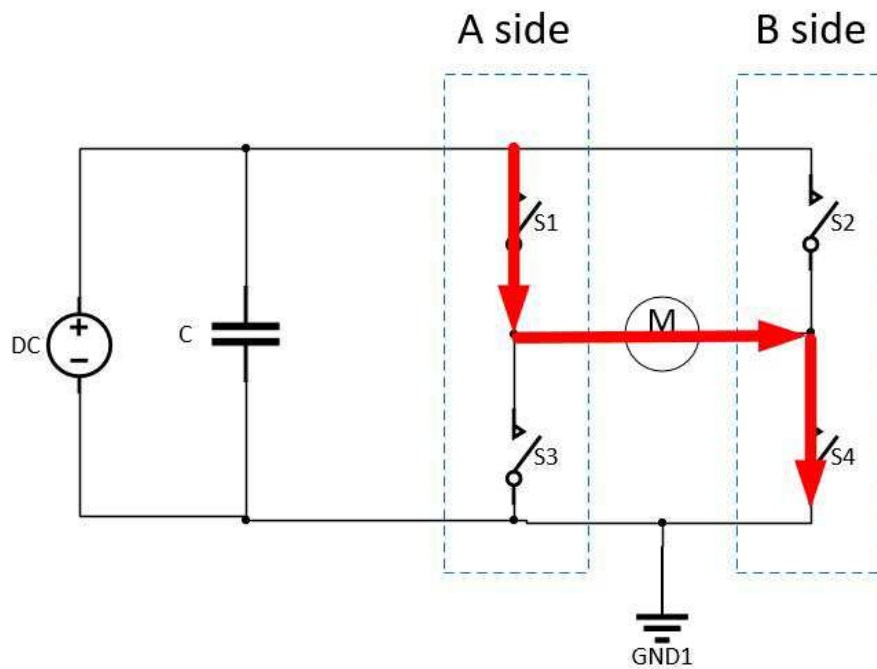
Working Principle

- A circuit that can control the direction and speed of a dc motor.

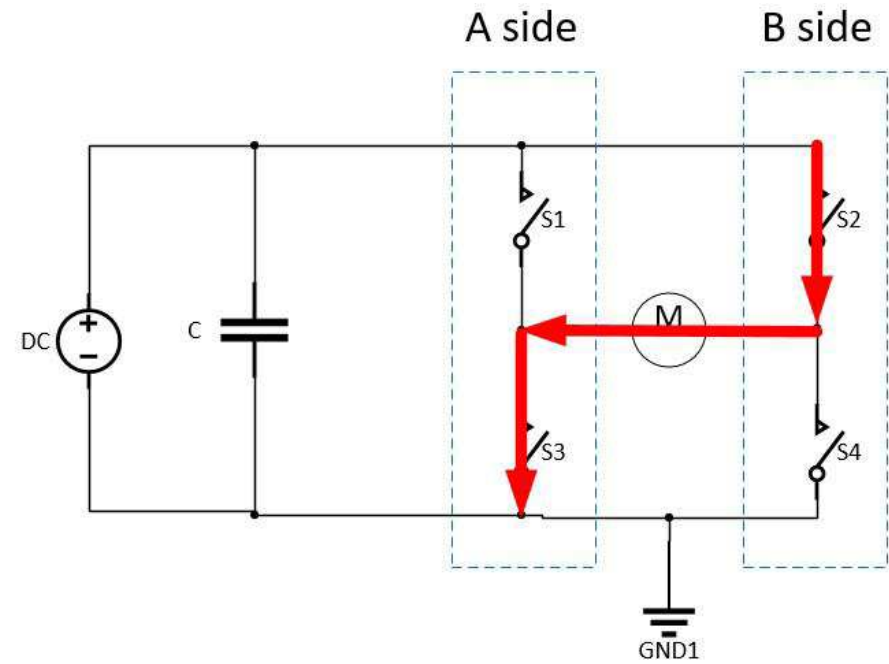


Simple H bridge configuration

Operation: Rotate

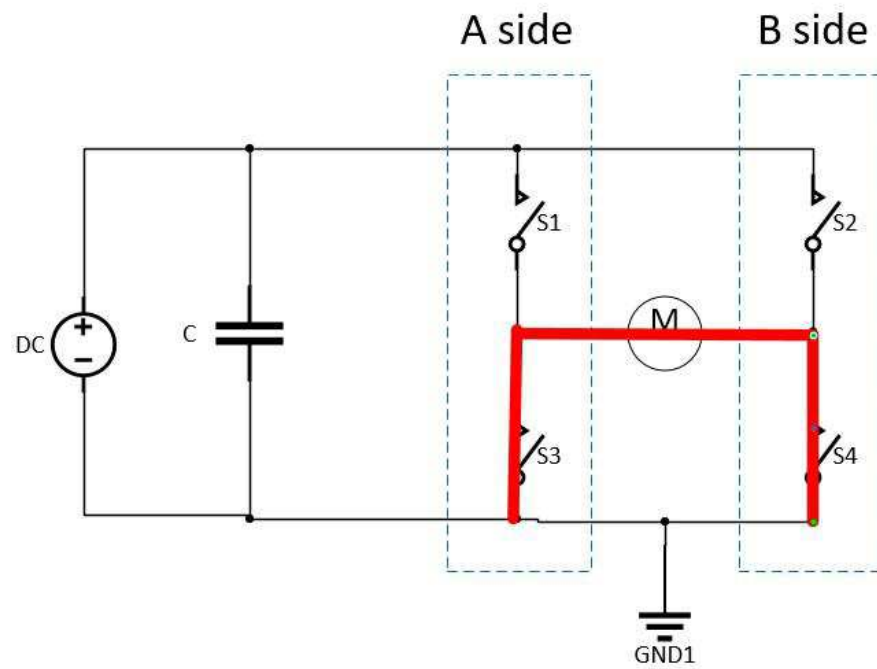


Rotate Right

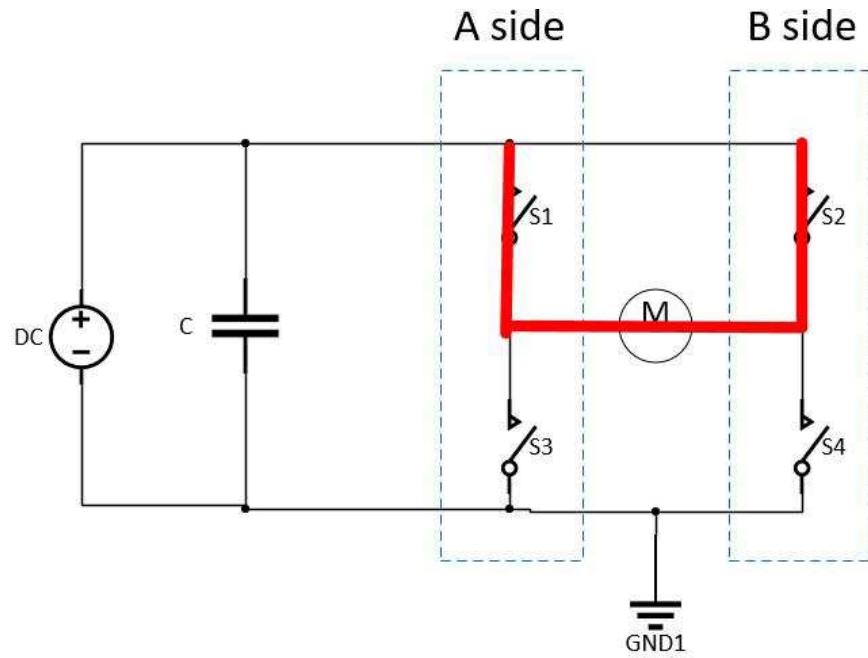


Rotate Left

Operation: Brake

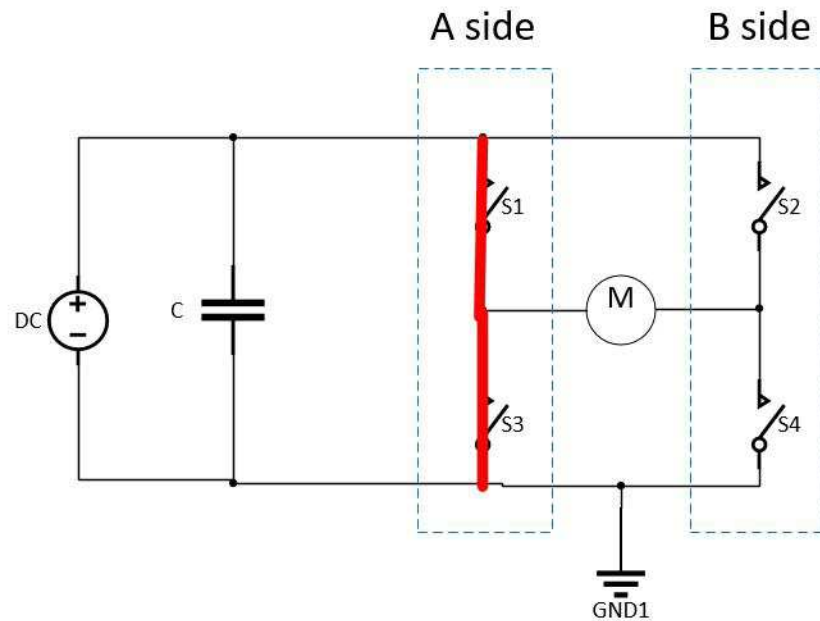


Brake Operation 1

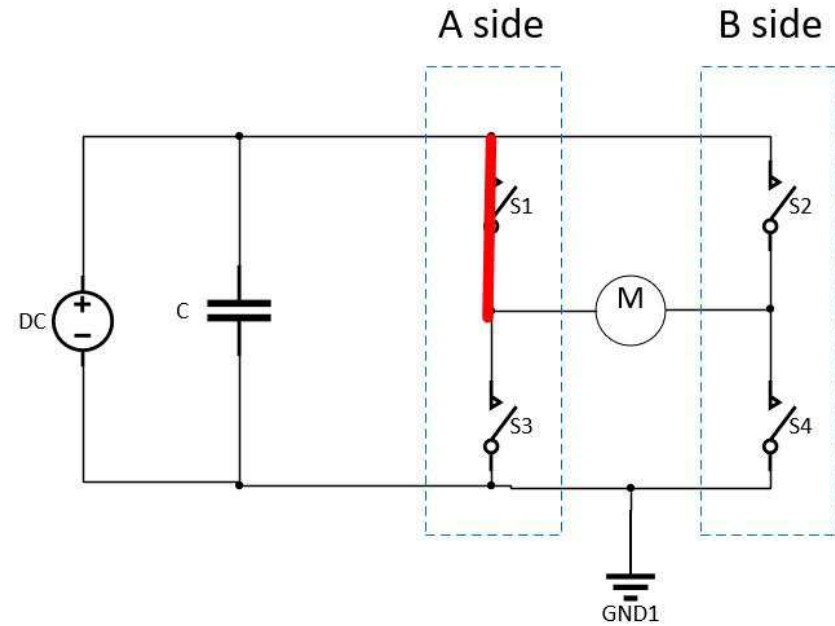


Brake Operation 2

Operation: Others

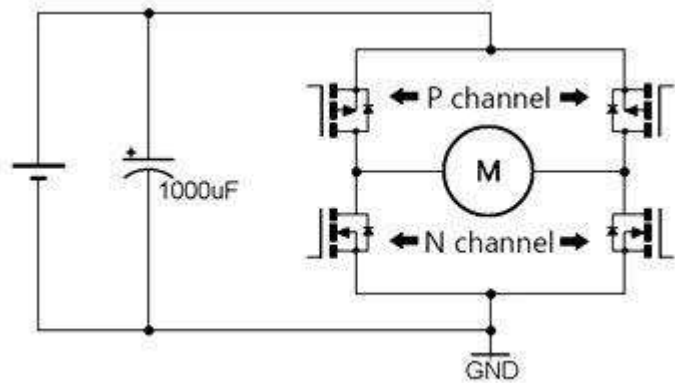


Short Circuit

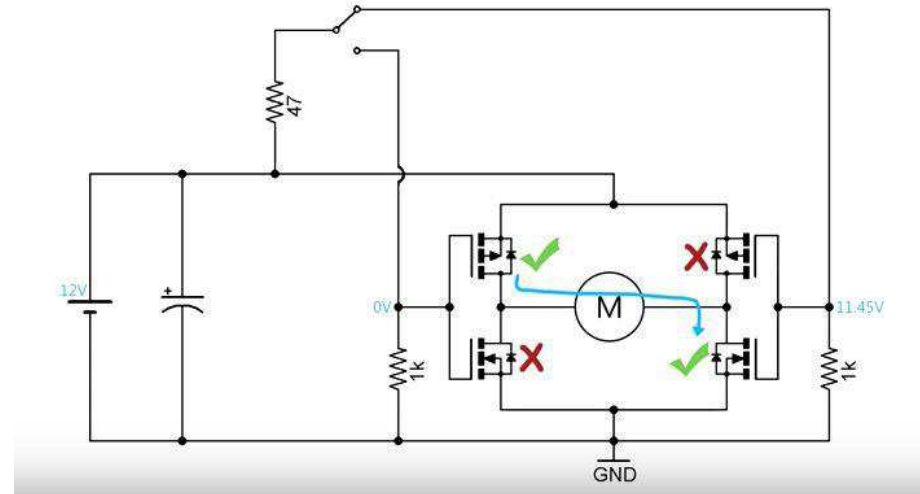


Motor Coast

Short Circuit Avoidance



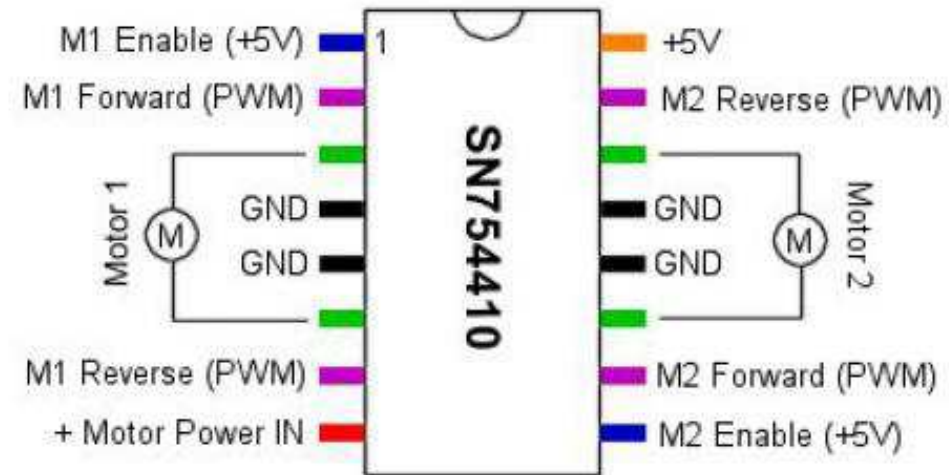
Original Circuit



Protective Circuit

Real H Bridge driver usage

- Common Component
 - SN754410
 - L293D



SN754410

Reference

- https://en.wikipedia.org/wiki/H_bridge
- <https://www.youtube.com/watch?v=iYafyPZ15g8>
- <http://www.hobbytronics.co.uk/h-bridge-driver-sn754410>

Q & A

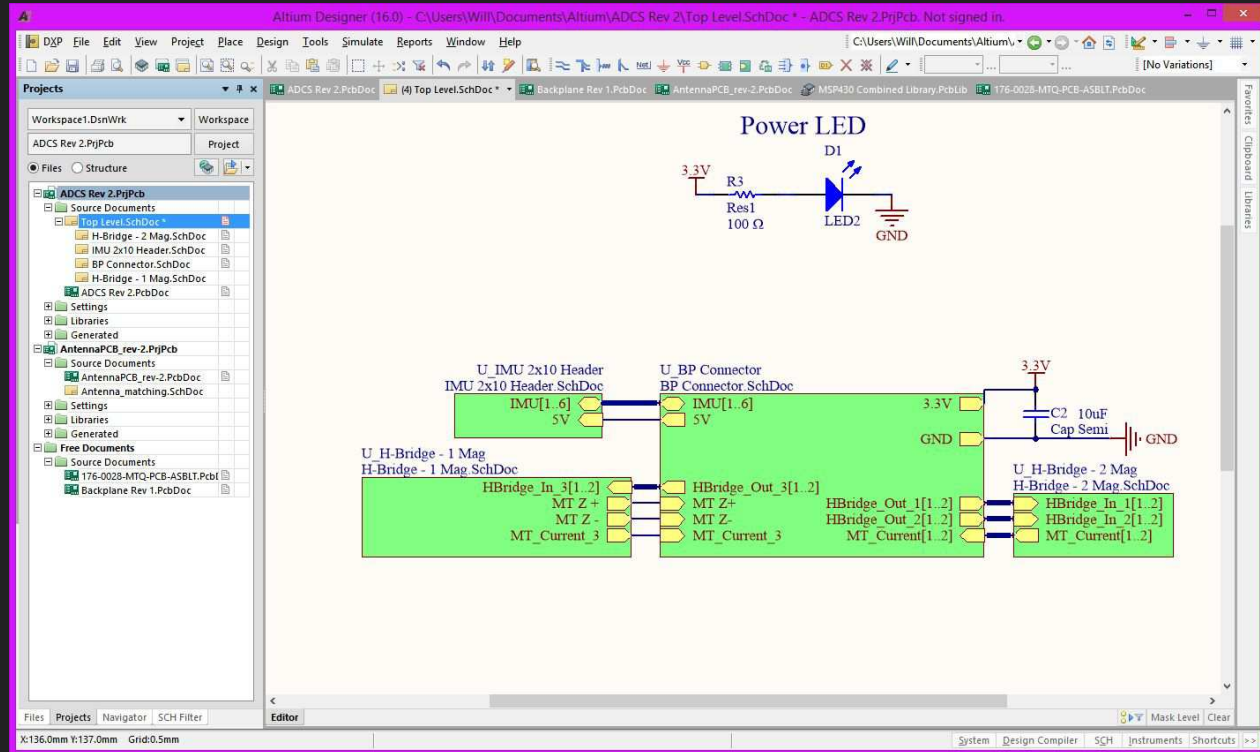
Altium Designer



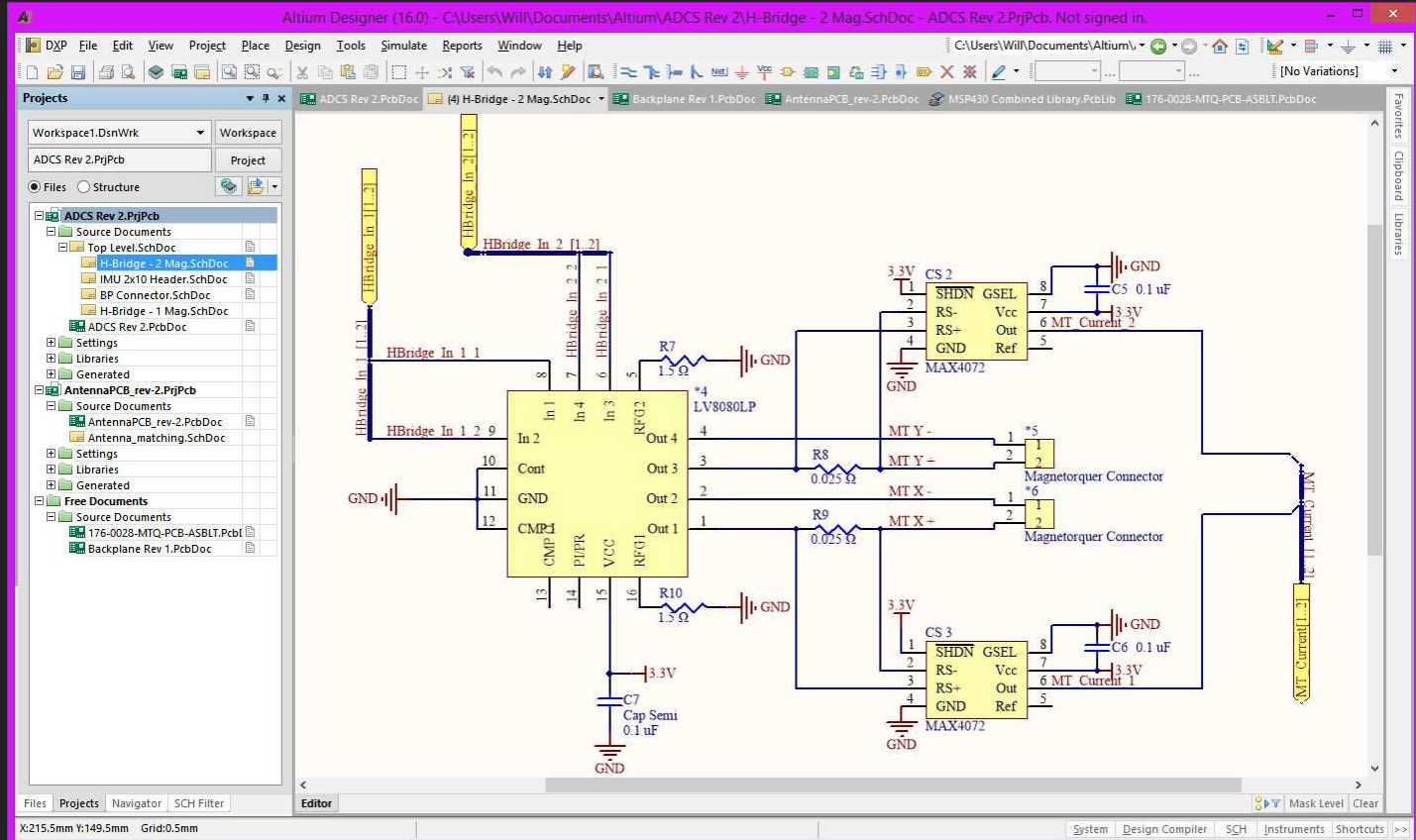
Will Howren

Welcome to Altium

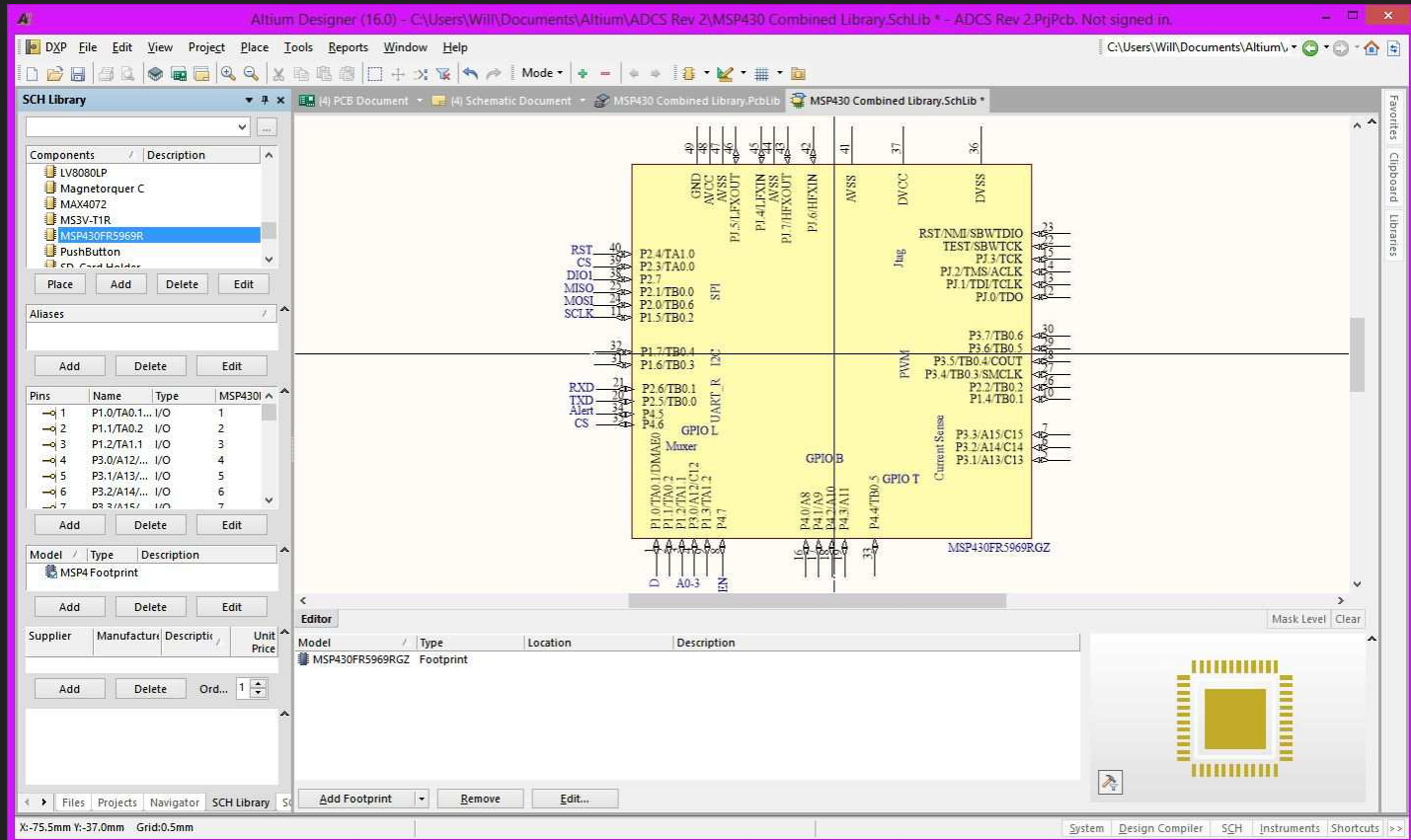
- Schematic capture
- PCB Design and Layout
- FPGA Design



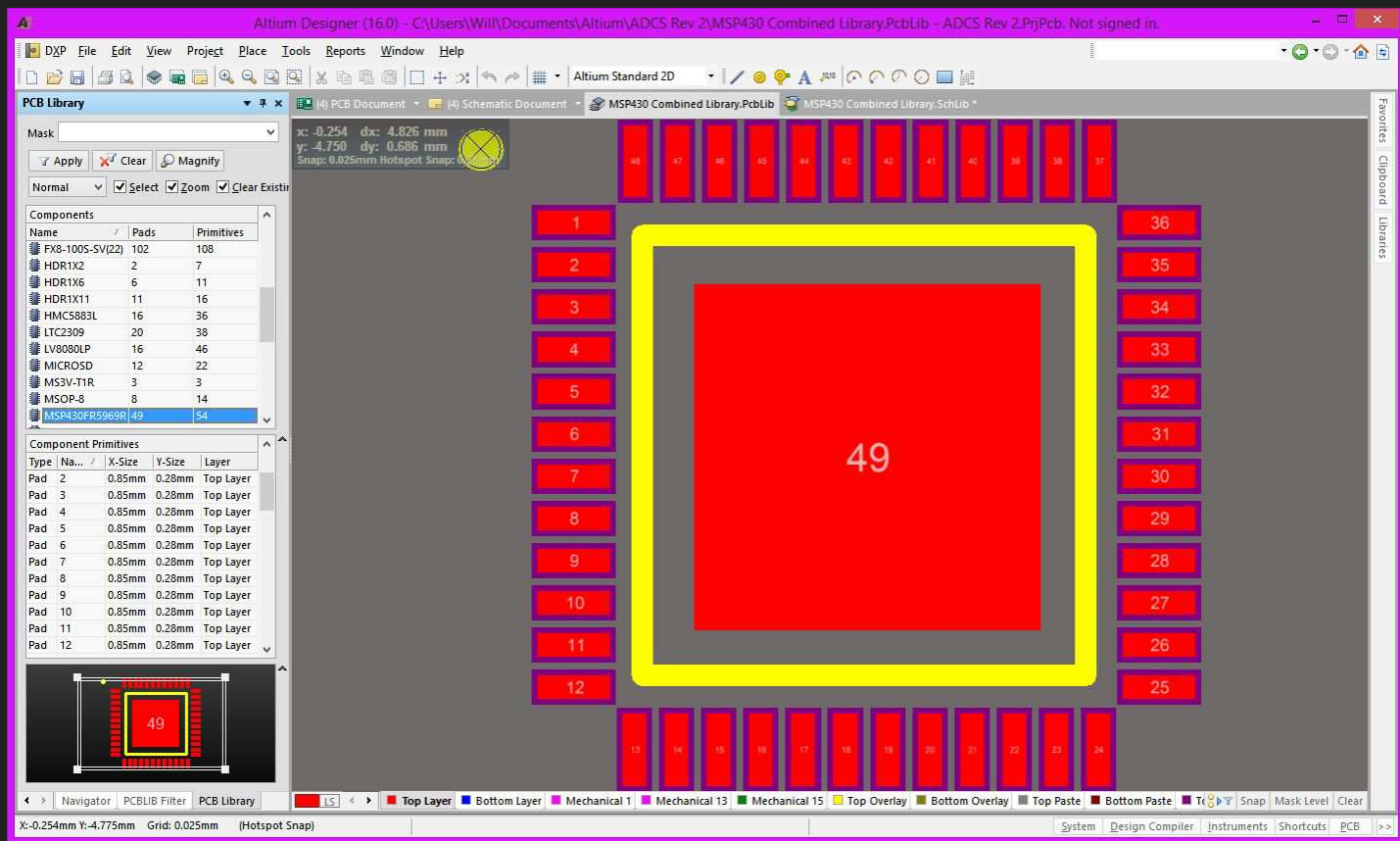
Schematic Capture



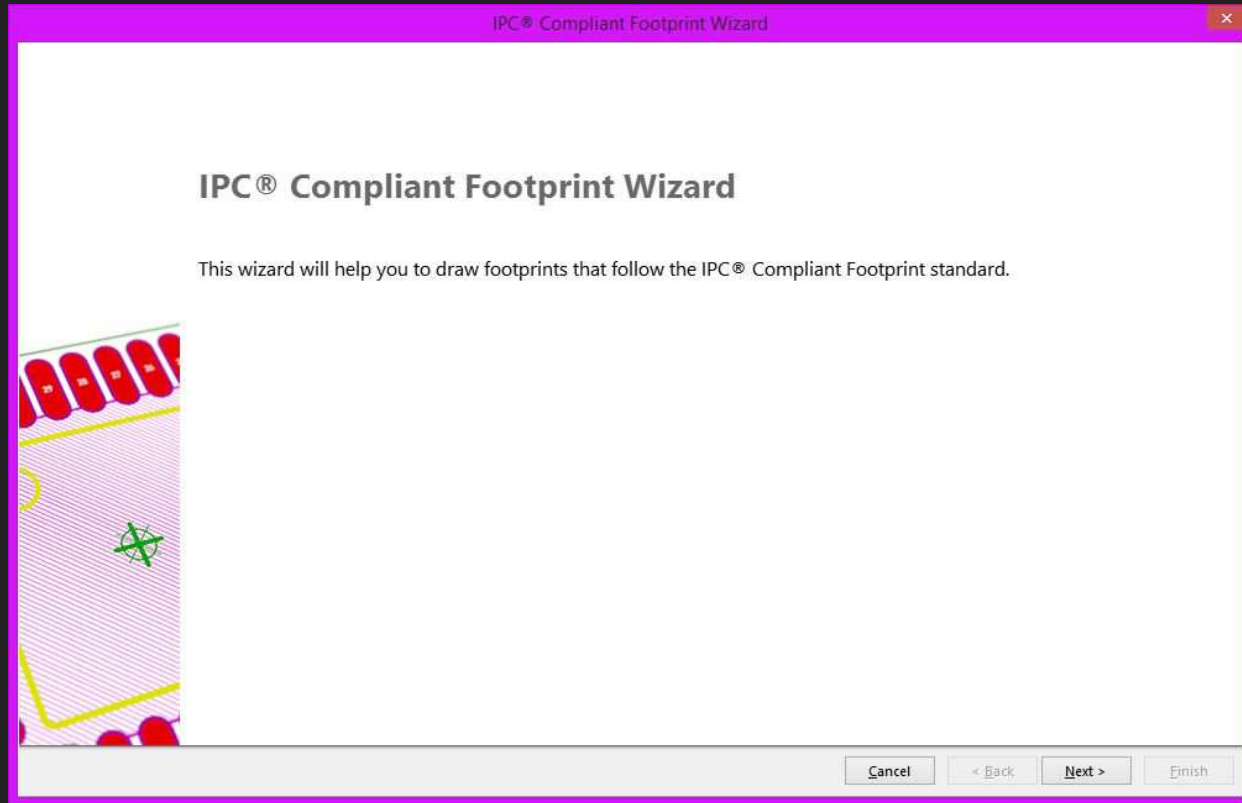
Component Entry



Component Footprint



Footprint Wizard



Footprint Wizard

IPC® Compliant Footprint Wizard

Select Component Type

Select the family of components you wish to create.

Component Types

Name	Description	Included Packages
LGA	Land Grid Array	LGA
MELF	MELF Components, 2-Pins	Diode, Resistor
MOLDED	Molded Components, 2-Pins	Capacitor, Inductor, Diode
PLCC	Plastic Leaded Chip Carrier, Square - J Leads	PLCC
PQFN	Pullback Quad Flat No-Lead	PQFN
PQFP	Plastic Quad Flat Pack	PQFP, PQFP Exposed Pad
PSON	Pullback Small Outline No-Lead	PSON
QFN	Quad Flat No-Lead	QFN, LLP
QFN-2ROW	Quad Flat No-Lead, 2 Rows, Square	Double Row QFN
SODFL	Small Outline Diode, Flat Lead	SODFL
SOIC	Small Outline Integrated Package, 1.27mm Pitch - Gullwing Leads	SOIC, SOIC Exposed Pad
SOJ	Small Outline Package - J Leads	SOJ
SON	Small Outline Non-lead	SON, SON Exposed Pad
SOP/TSOP	Small Outline Package - Gullwing Leads	SOP, TSOP, TSSOP
SOT143/343	Small Outline Transistor	SOT143, SOT343
SOT223	Small Outline Transistor	SOT223
SOT23	Small Outline Transistor	3-Leads, 5-Leads, 6-Leads
SOT89	Small Outline Transistor	SOT89
SOTFL	Small Outline Transistor, Flat Lead	3-Leads, 5-Leads, 6-Leads
WIRE WOUND	Precision Wire Wound Inductor, 2-Pins	Inductor

The selected component is SOP/TSOP. This will allow you to generate SOP, TSOP, TSSOP packages, including those packages with exposed pads.



NOTE: All wizard measurement dimensions are required to be entered as metric (mm) units.

Cancel

< Back

Next >

Finish

Footprint Wizard

IPC® Compliant Footprint Wizard

SOP/TSOP Package Dimensions

Enter the required package values.

Overall Dimensions

Width Range (H)	Minimum	9.97mm
	Maximum	10.63mm
Maximum Height (A)		2.65mm
Minimum standoff height (A1)		0.1mm
Body width range (E)	Minimum	7.4mm
	Maximum	7.6mm
Body length range (D)	Minimum	10.1mm
	Maximum	10.5mm

Pin Information

Number of pins		16
Lead Width Range (B)	Minimum	0.31mm
	Maximum	0.51mm
Lead Length Range (L)	Minimum	0.4mm
	Maximum	1.27mm
Pitch (e)		1.27mm

Preview

☐ Generate STEP Model Preview

Cancel

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Next >

Finish

Footprint Wizard

IPC® Compliant Footprint Wizard

SOP/TSOP Footprint Dimensions

The footprint dimensions can now be inferred from the package dimensions.
You can review and modify them here.

The footprint has 16 pads and a pitch (P) of 1.27mm. You can modify here the calculated dimensions of the footprint.

☒ Use calculated footprint values

Pad Dimensions

X

0.6mm

Y

1.9mm

Pads are trimmed to prevent from extending under body

Pad Spacing

C

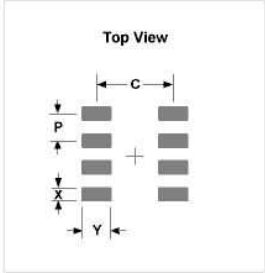
9.5mm

Pad Shape

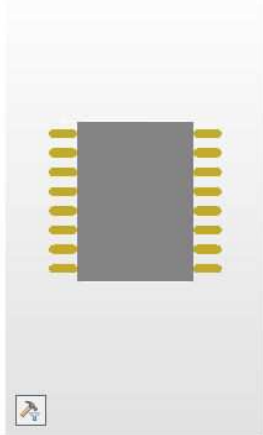
☒ Rounded

☐ Rectangular

Top View



Preview



☐ Generate STEP Model Preview

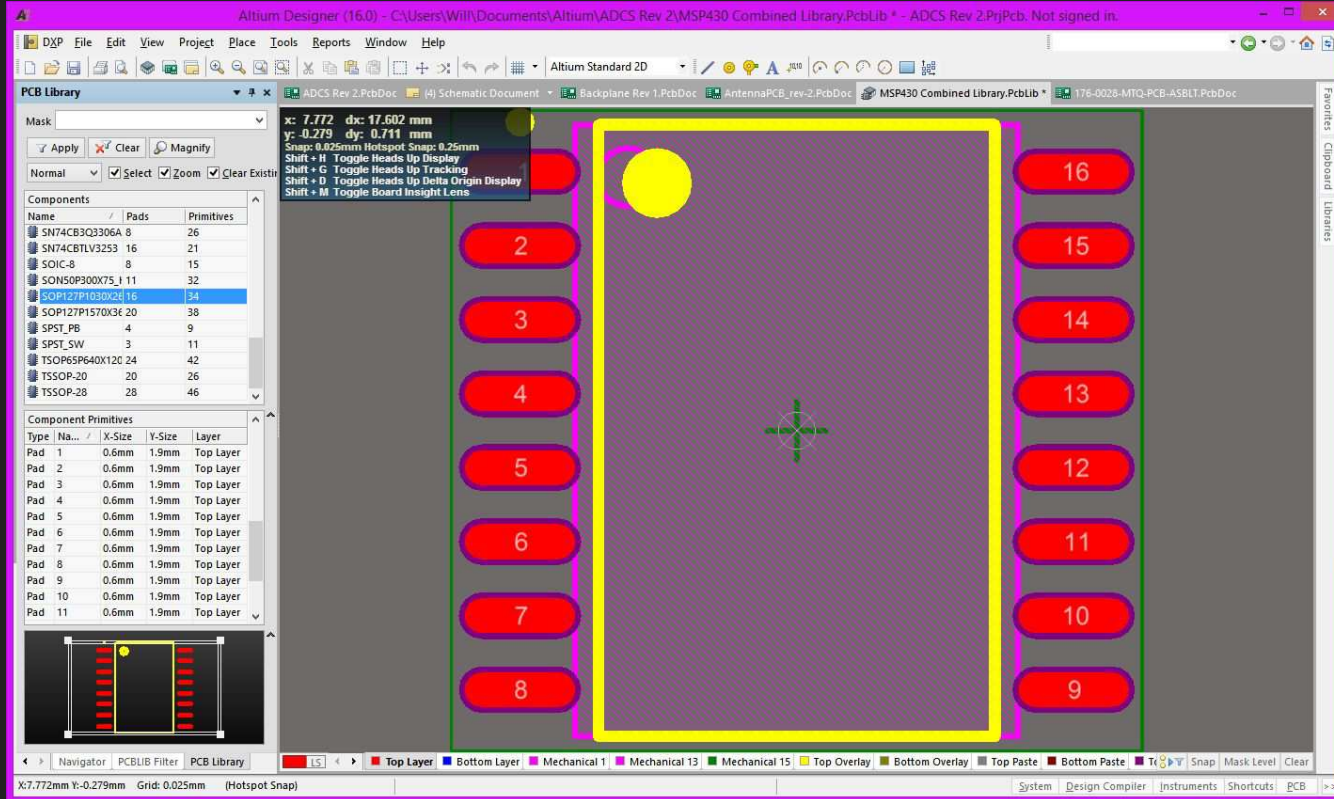
Cancel

< Back

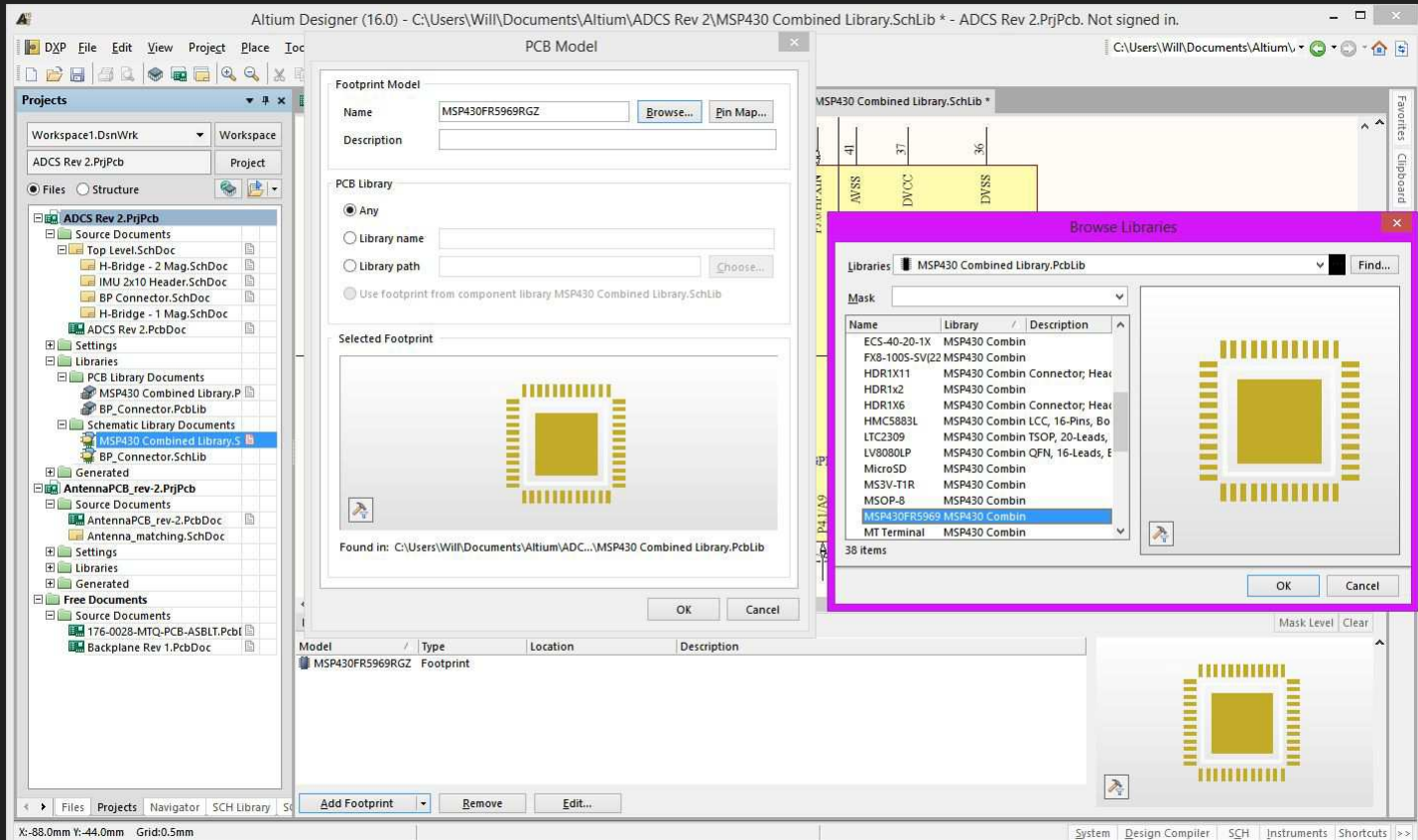
Next >

Finish

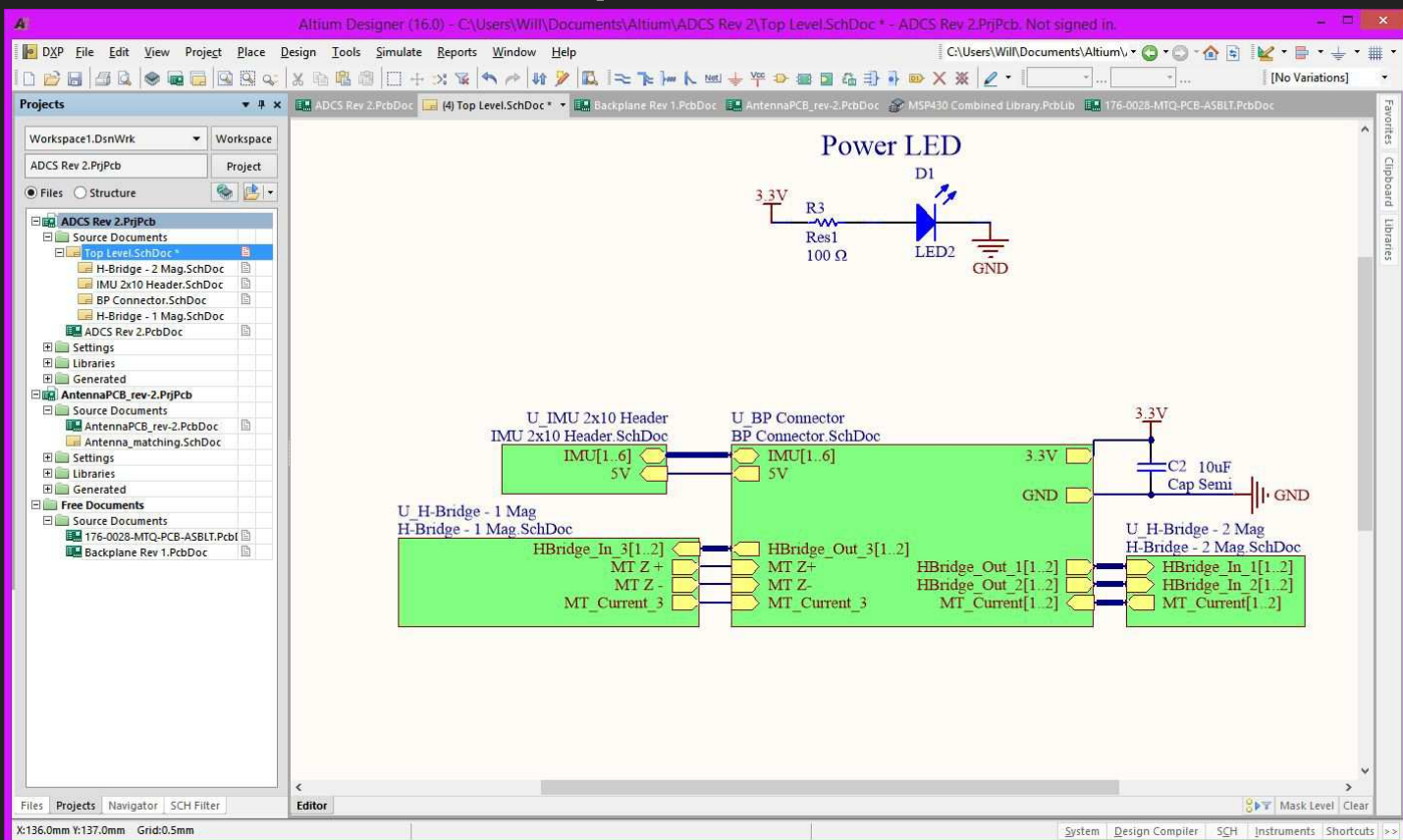
Footprint Wizard



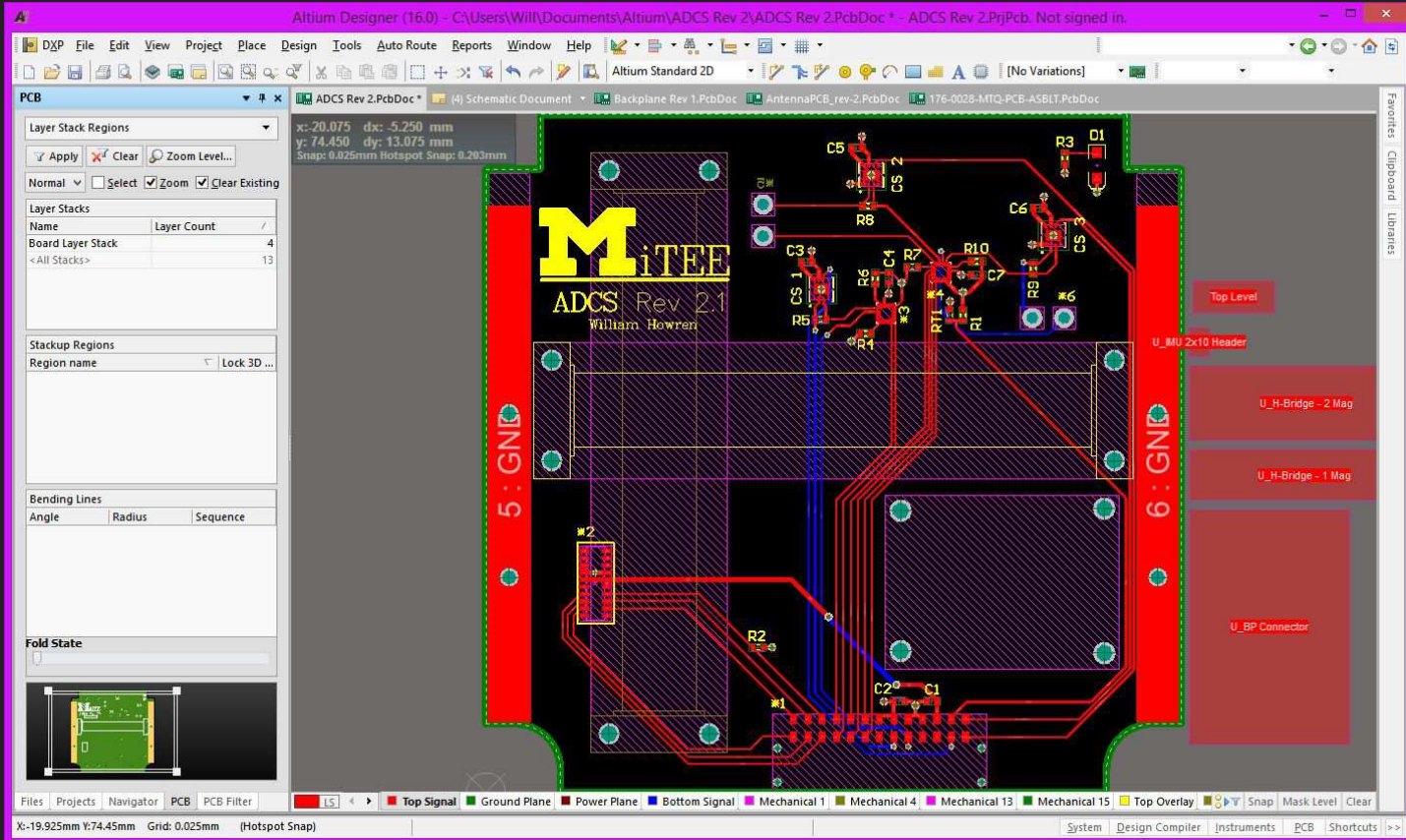
Attaching a Footprint



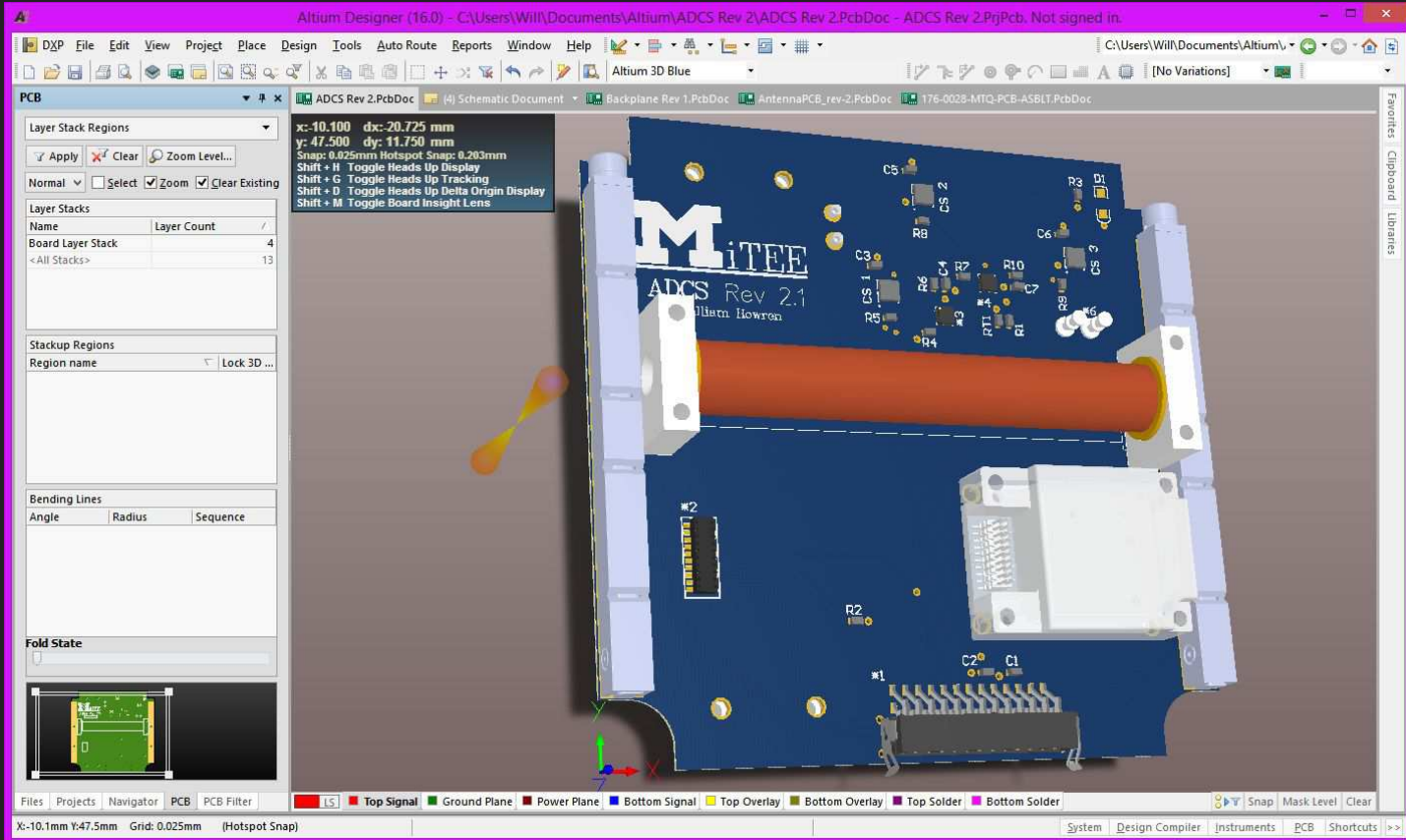
Top Level



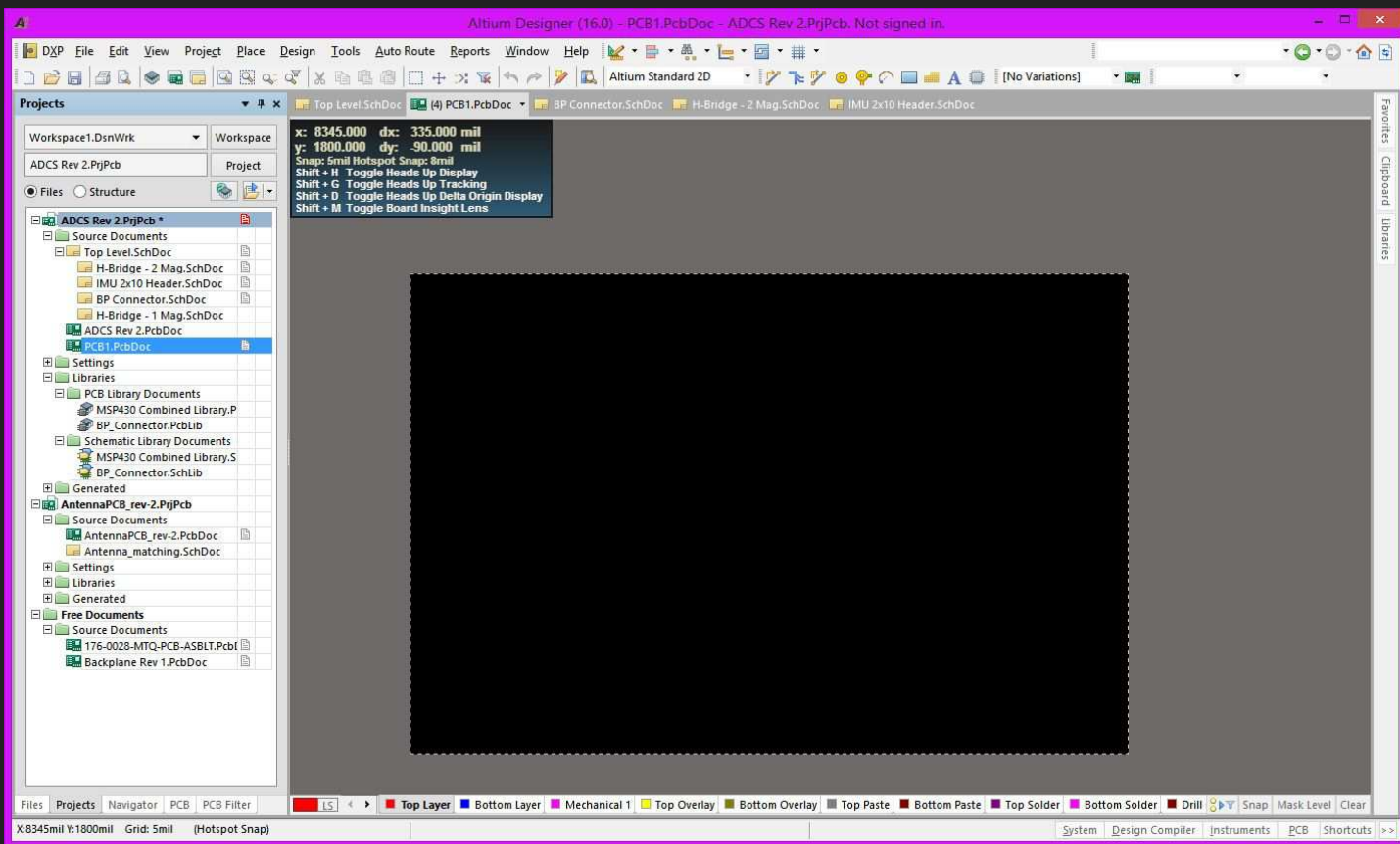
PCB Layout Editor



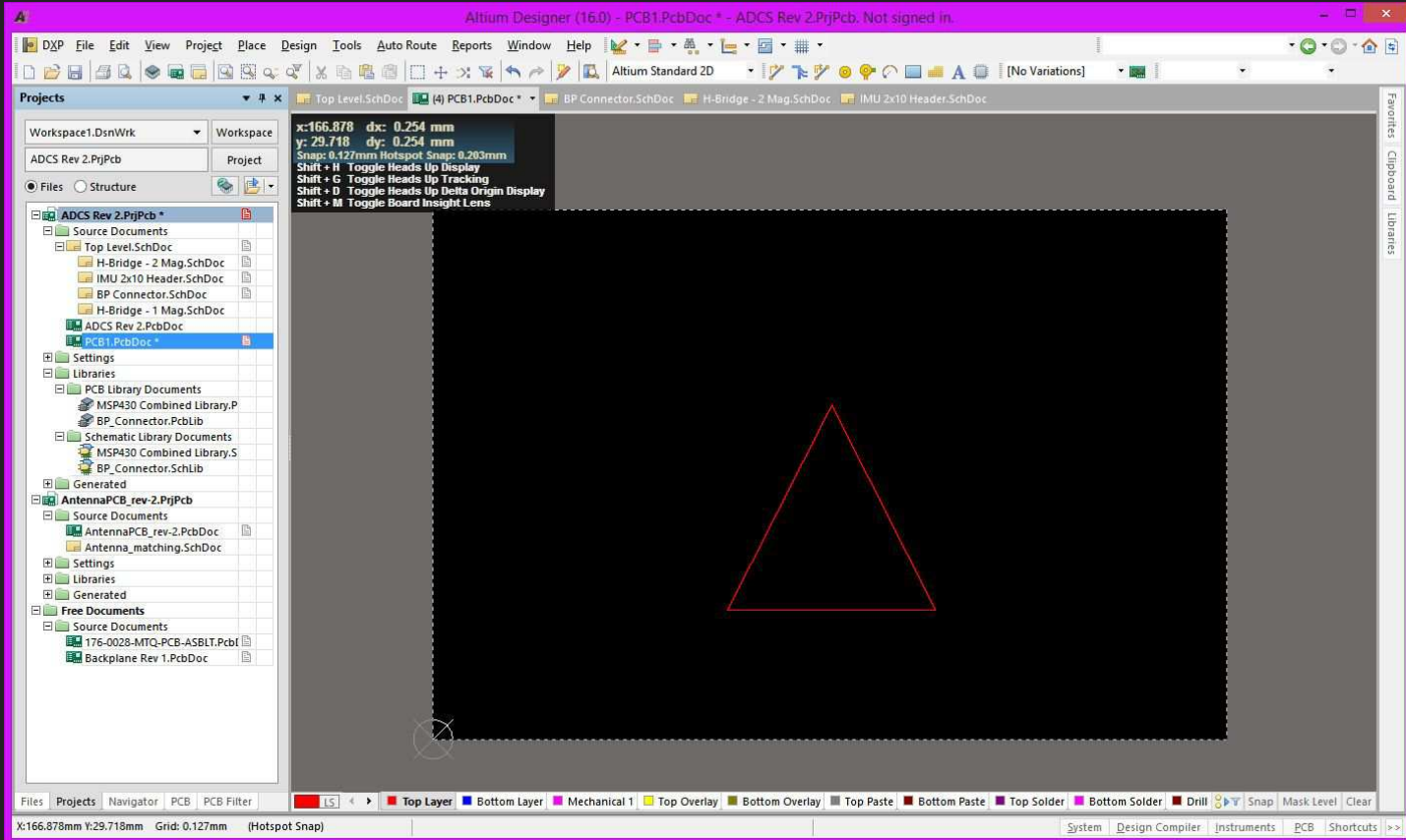
PCB Layout Editor



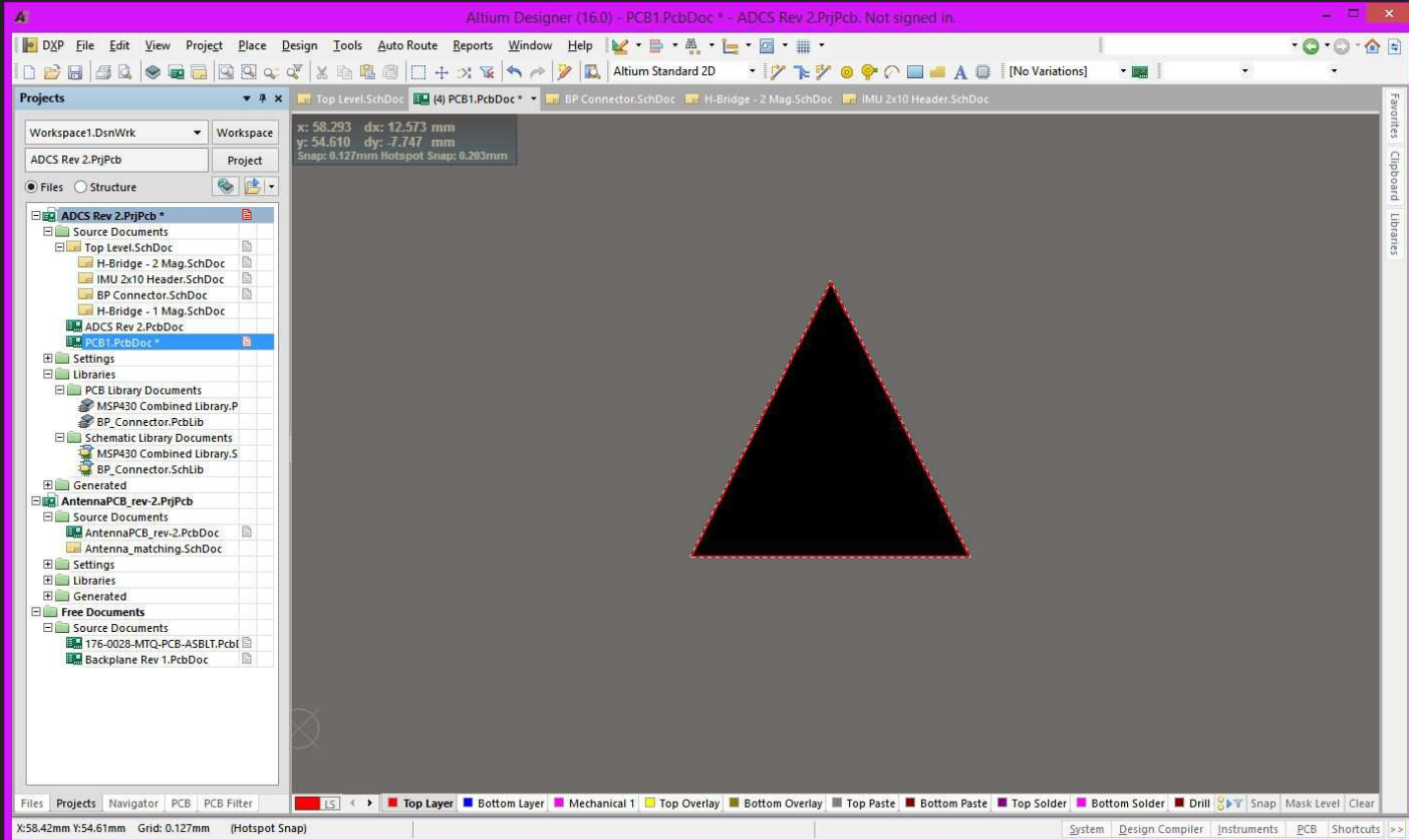
Blank PCB



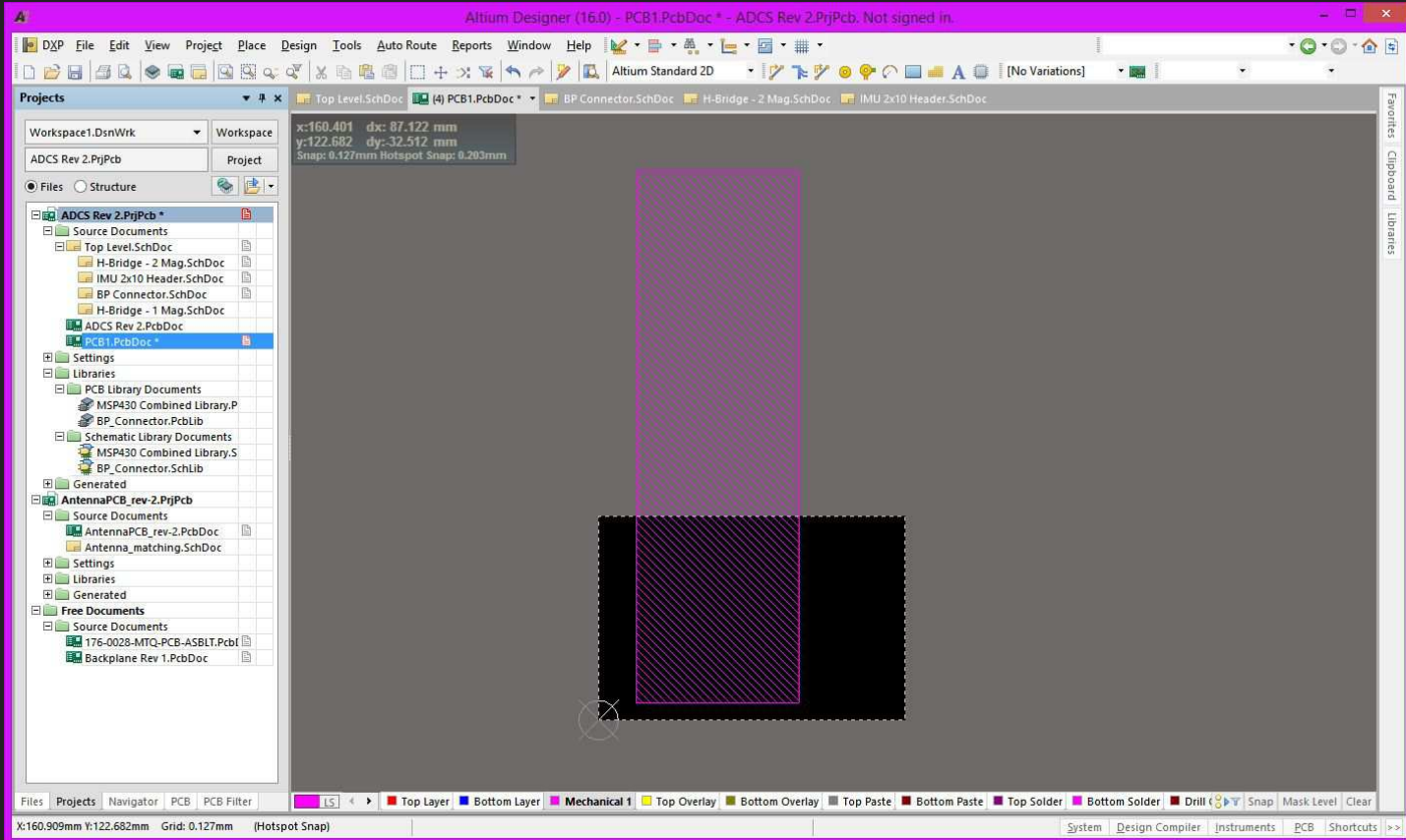
Defining the Board Shape



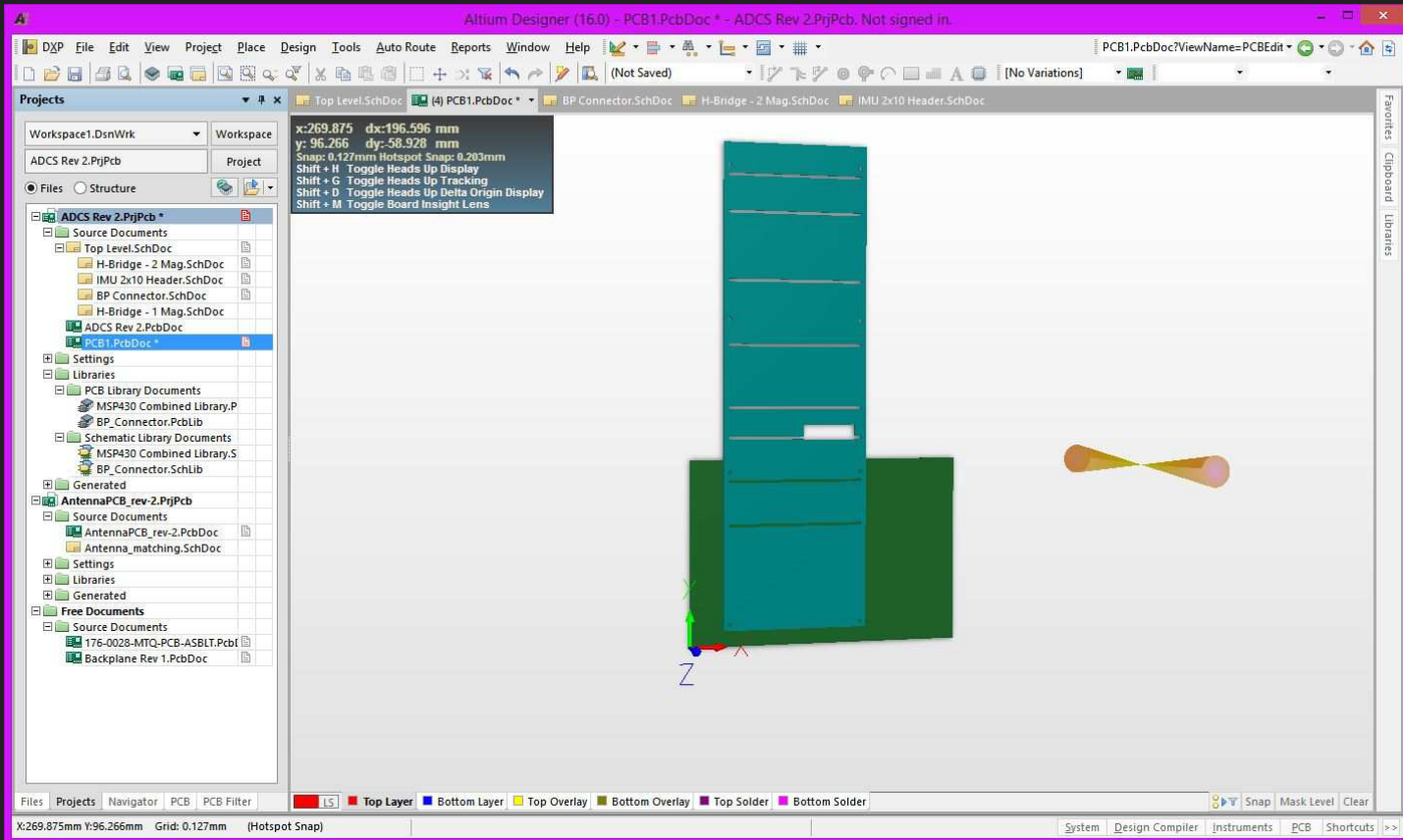
Defining the Board Shape



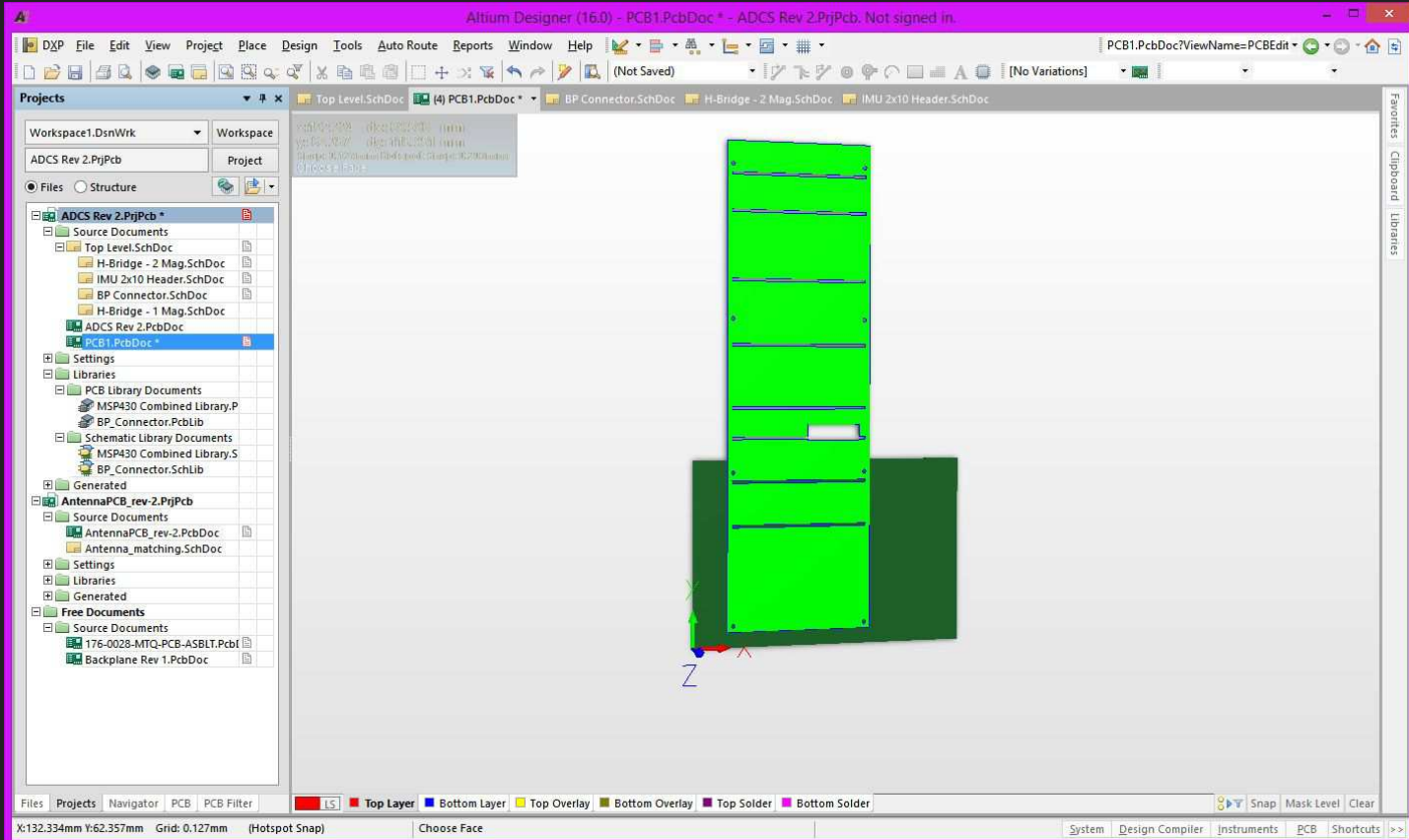
Defining the Board Shape



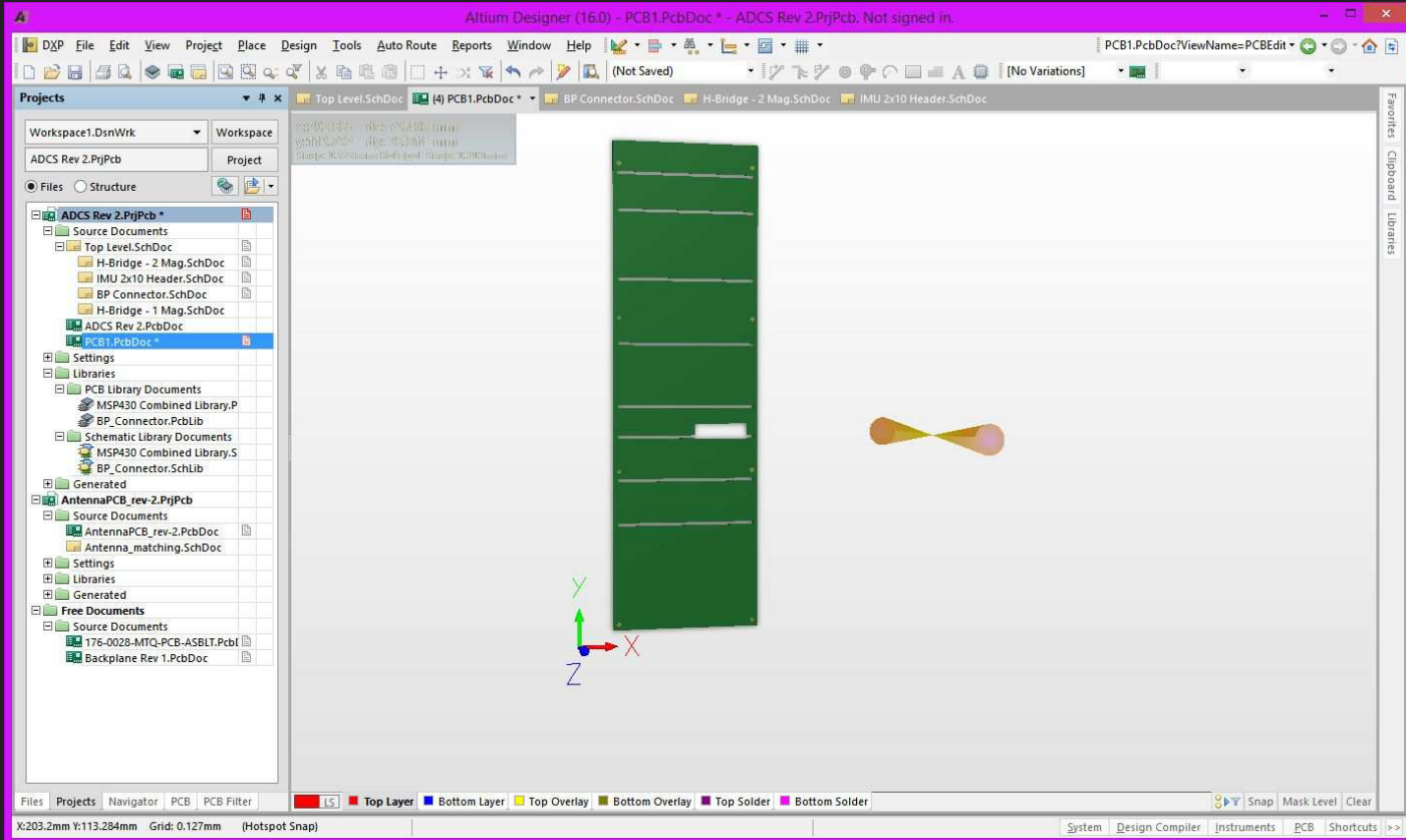
Defining the Board Shape



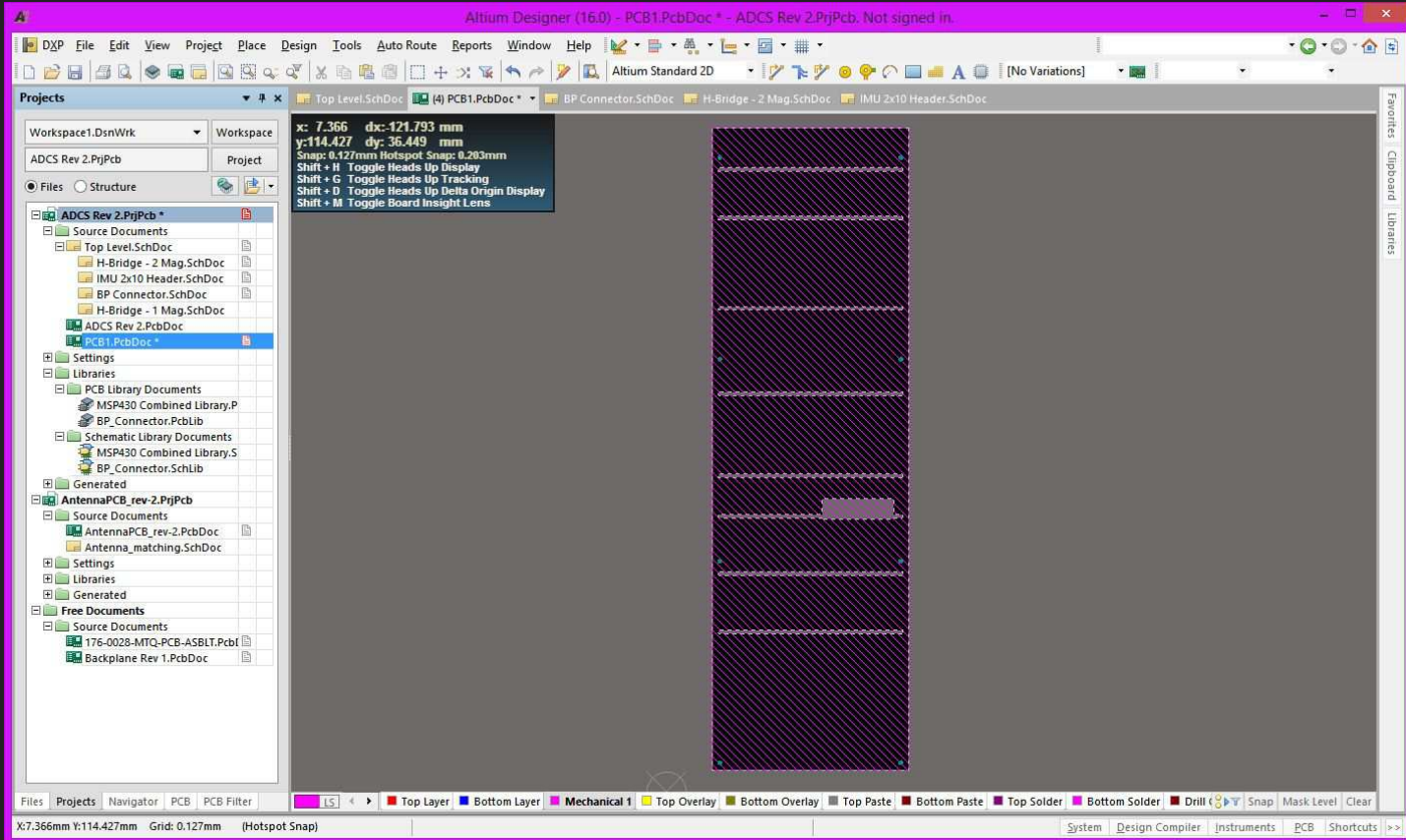
Defining the Board Shape



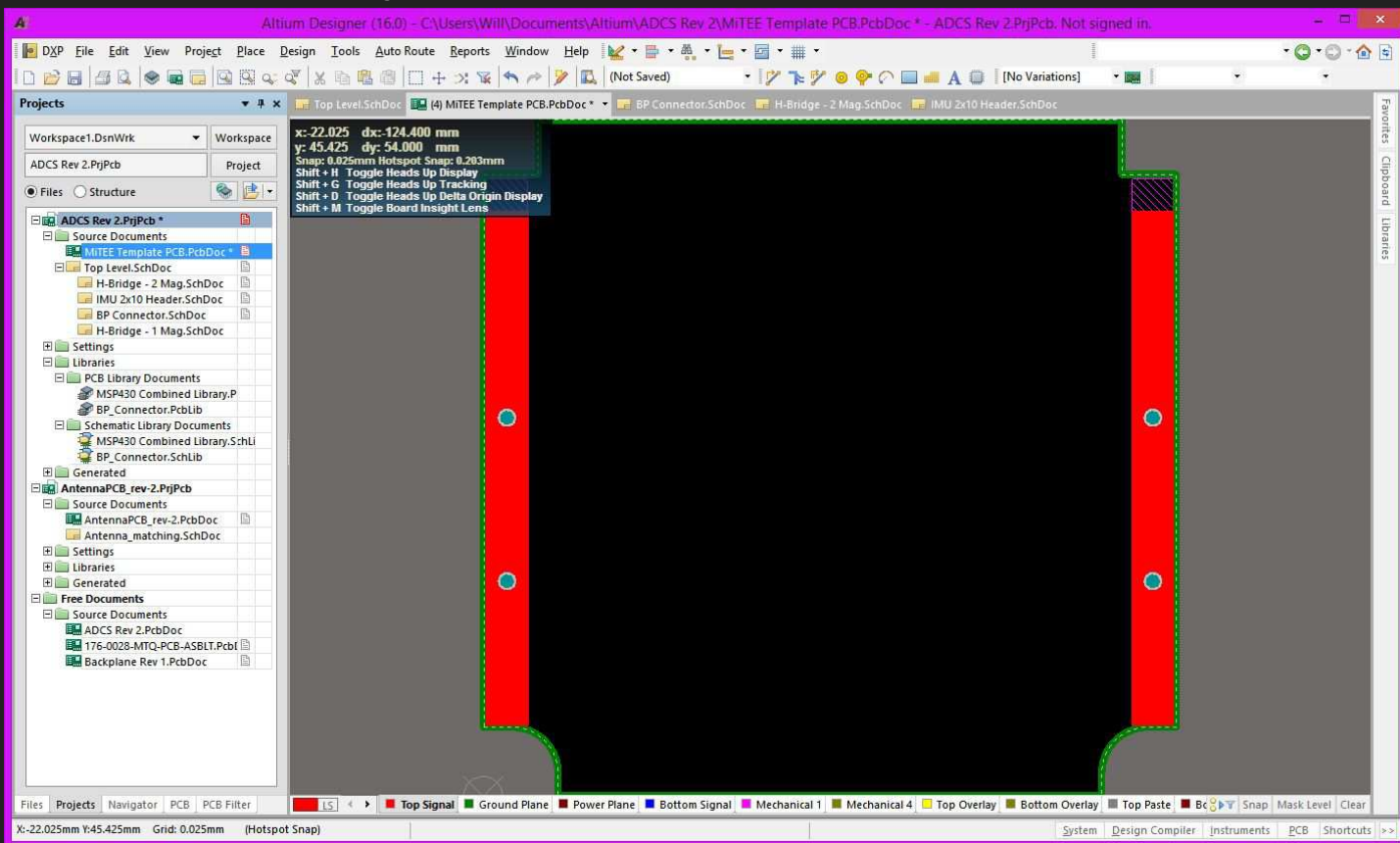
Defining the Board Shape



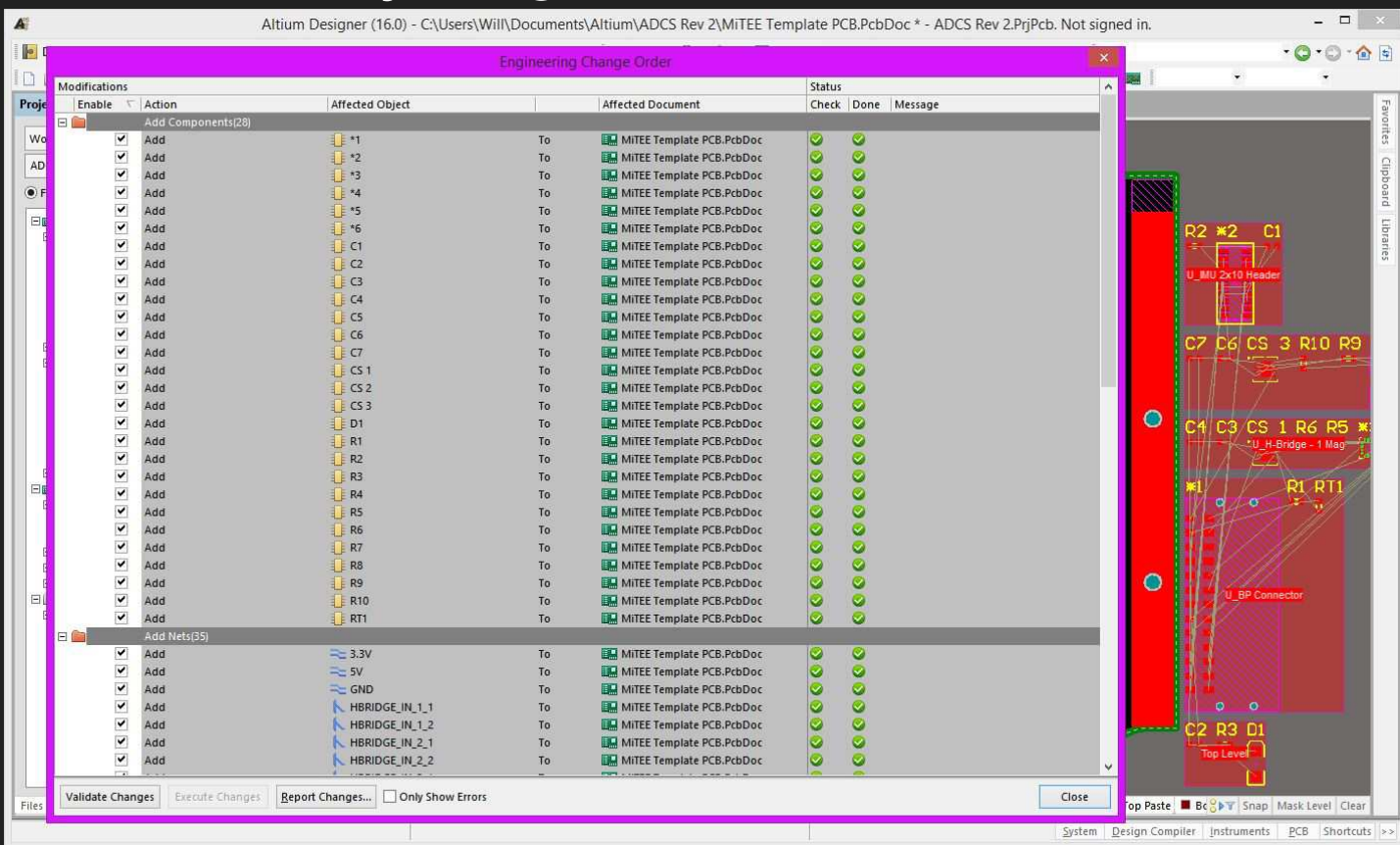
Defining the Board Shape



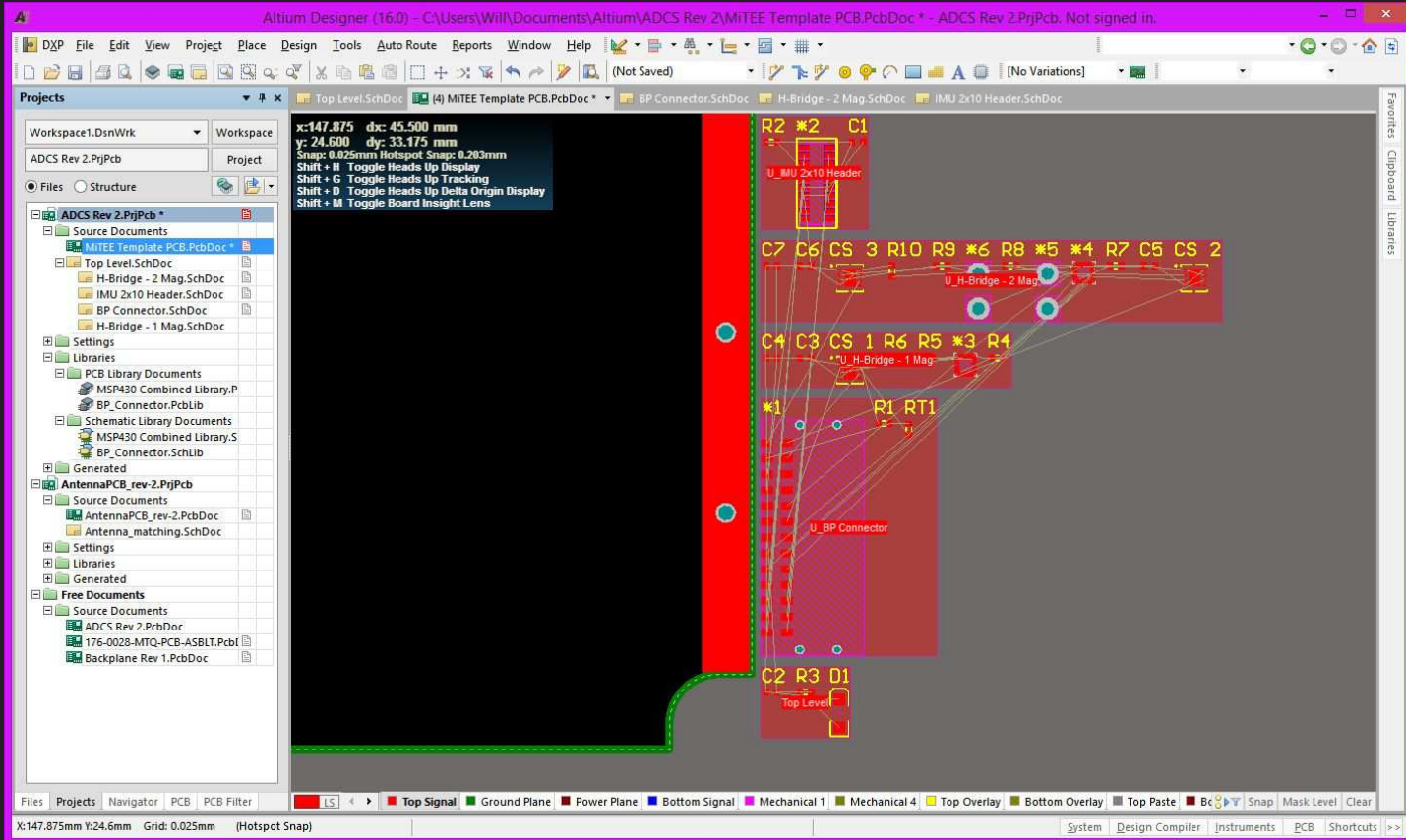
Laying Out the PCB



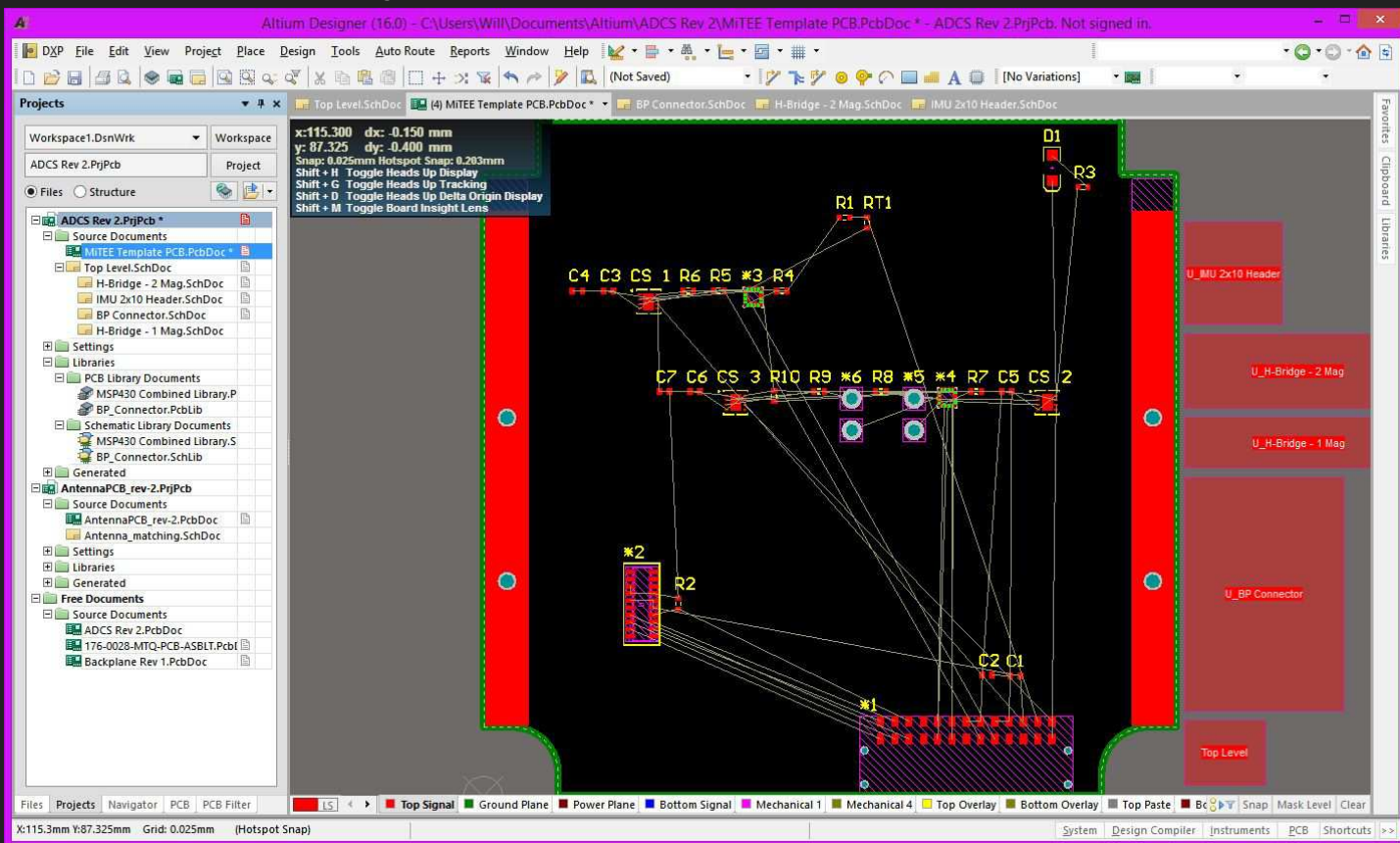
Laying Out the PCB



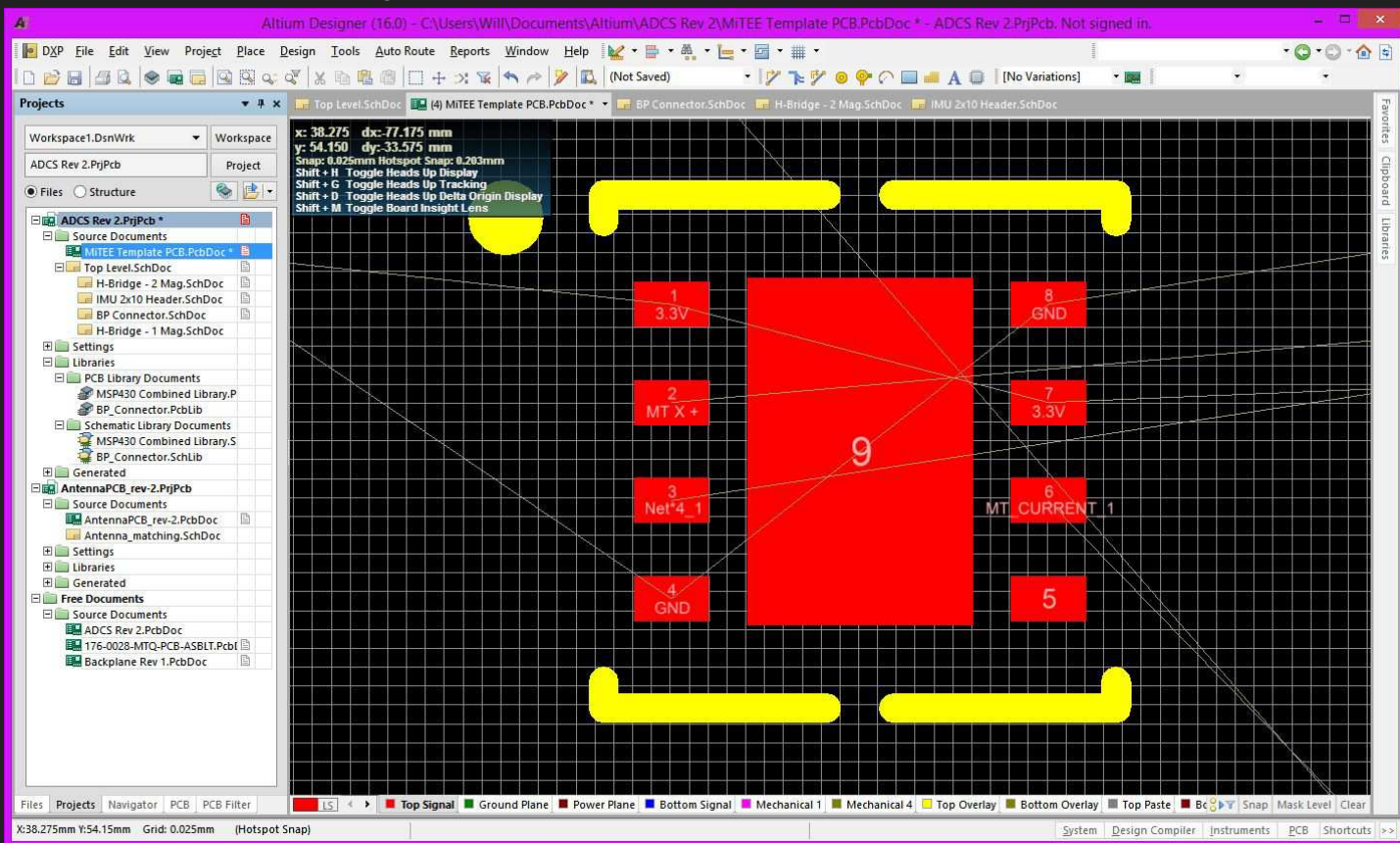
Laying Out the PCB



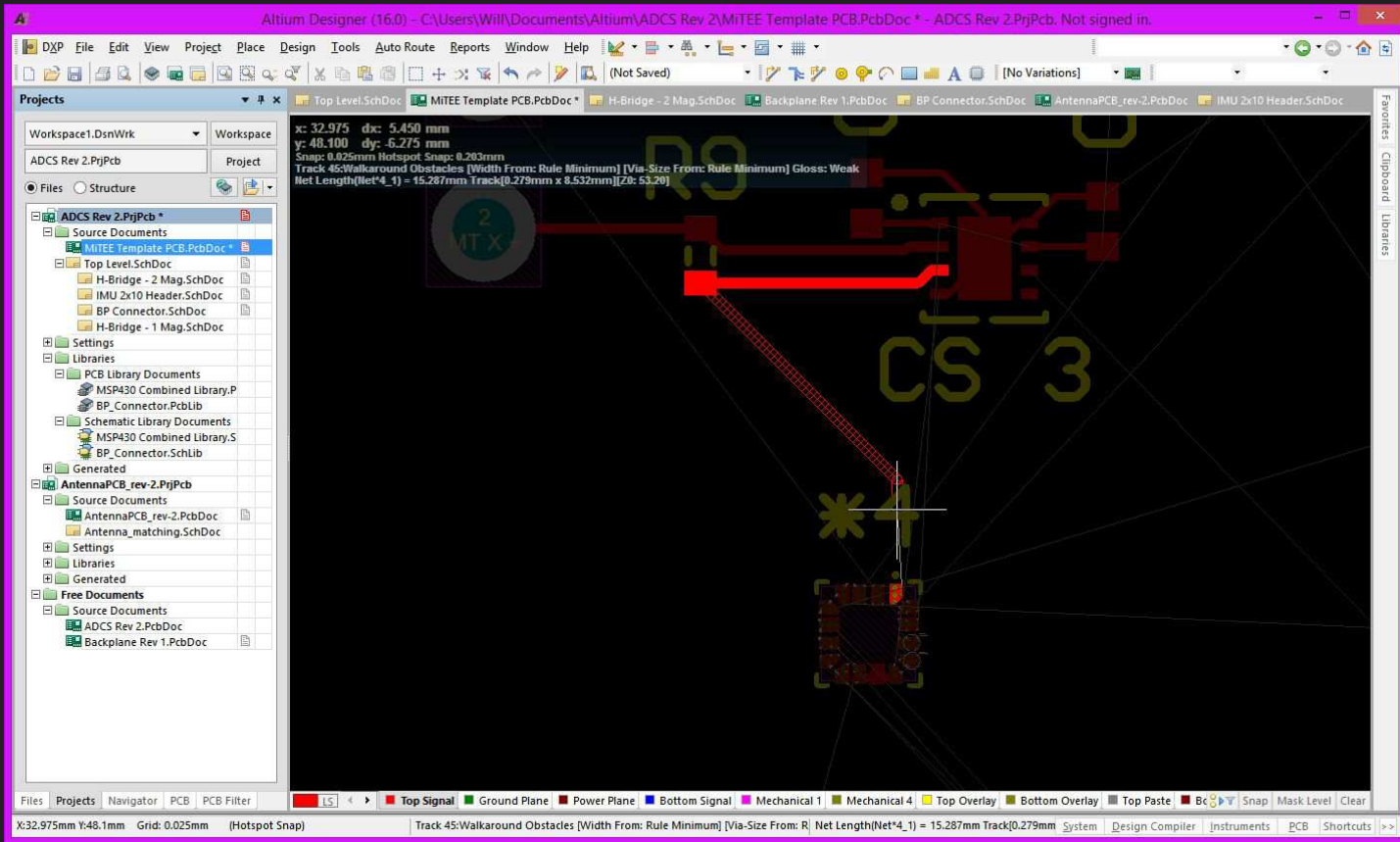
Laying Out the PCB



Laying Out the PCB



Laying Out the PCB



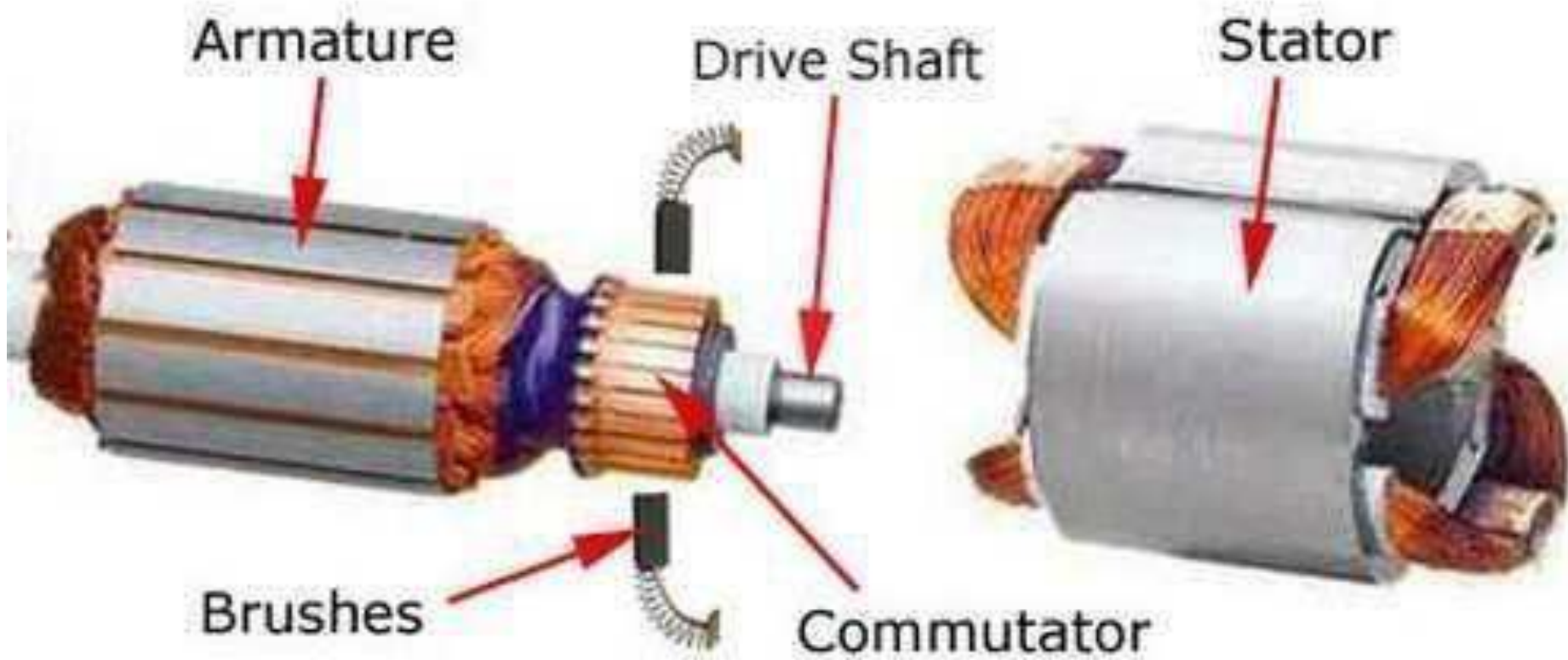
Final Thoughts

- Quirky
- Expensive
- Powerful

Dealing with brushed DC Motor noise

Daniel Bole
dgbole@umich.edu

Source of the noise



Adding capacitors

- Between positive and negative terminal and between each terminal and motor casing
- Generally recommended value of $0.1\mu\text{F}$
- Acts as a short at high frequencies



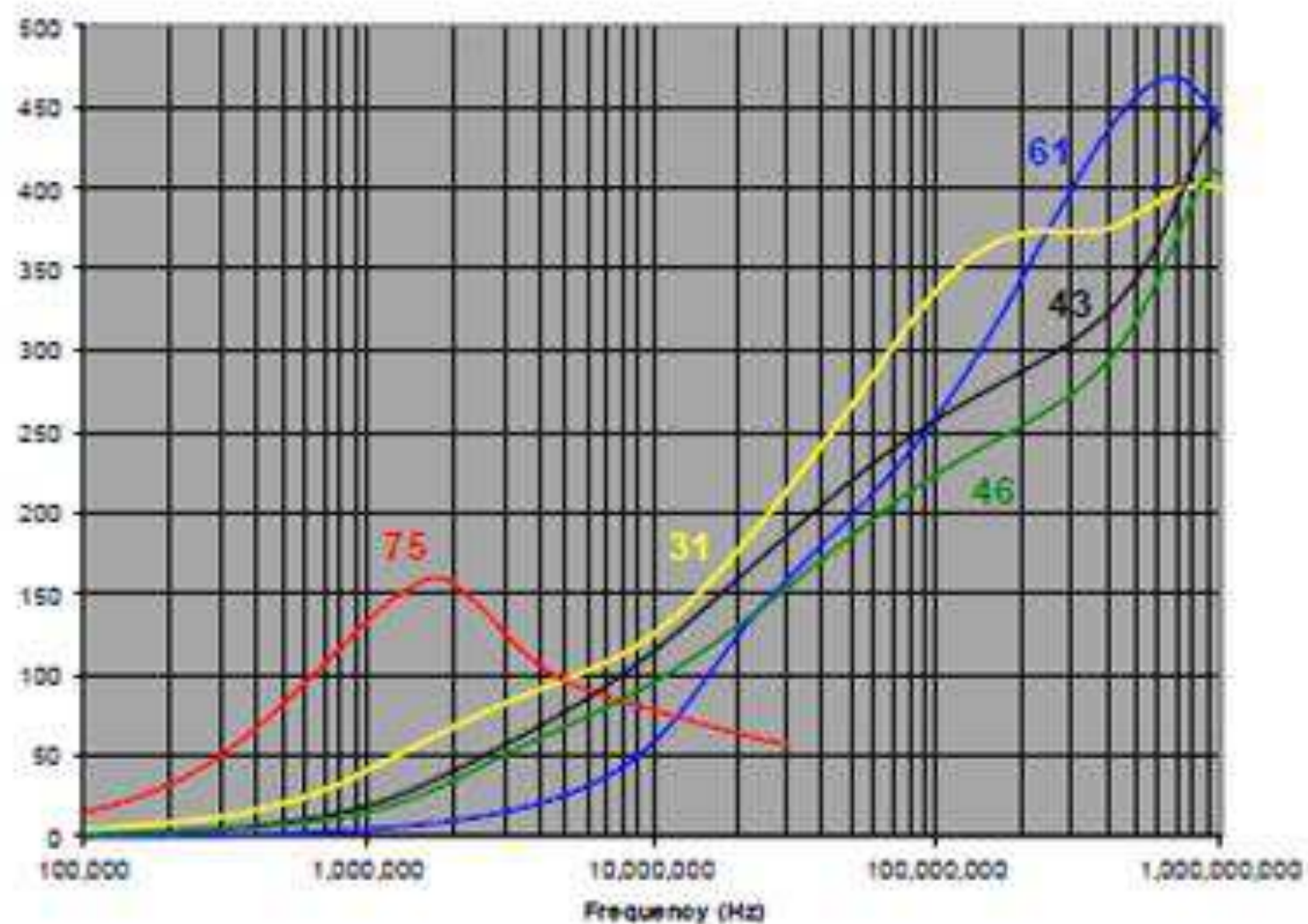
What if capacitors don't work?

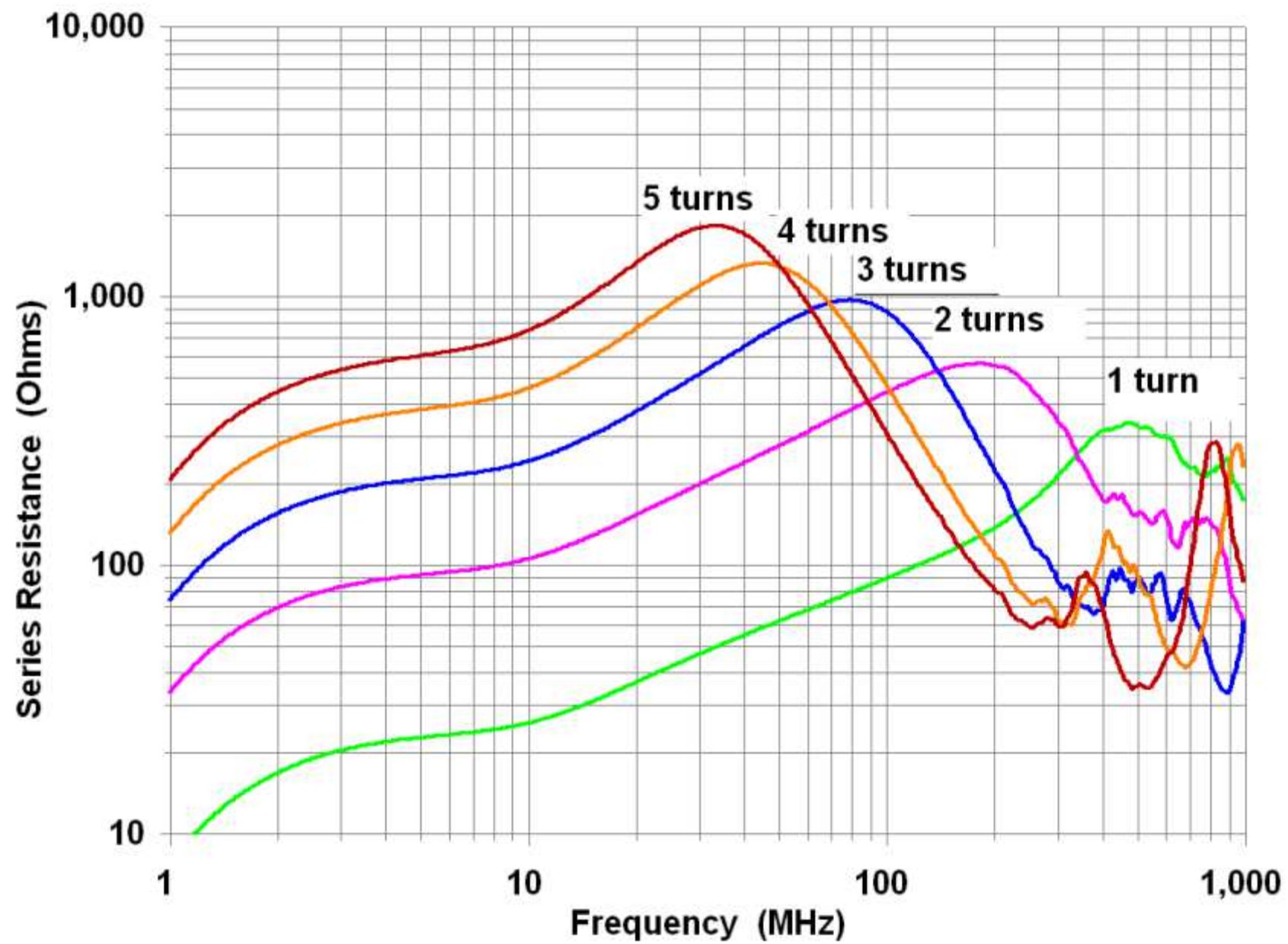
- Adding a ferrite choke acts as a resistor at high frequencies
- Many types of ferrite with different frequency response
- Easy to add to existing motors



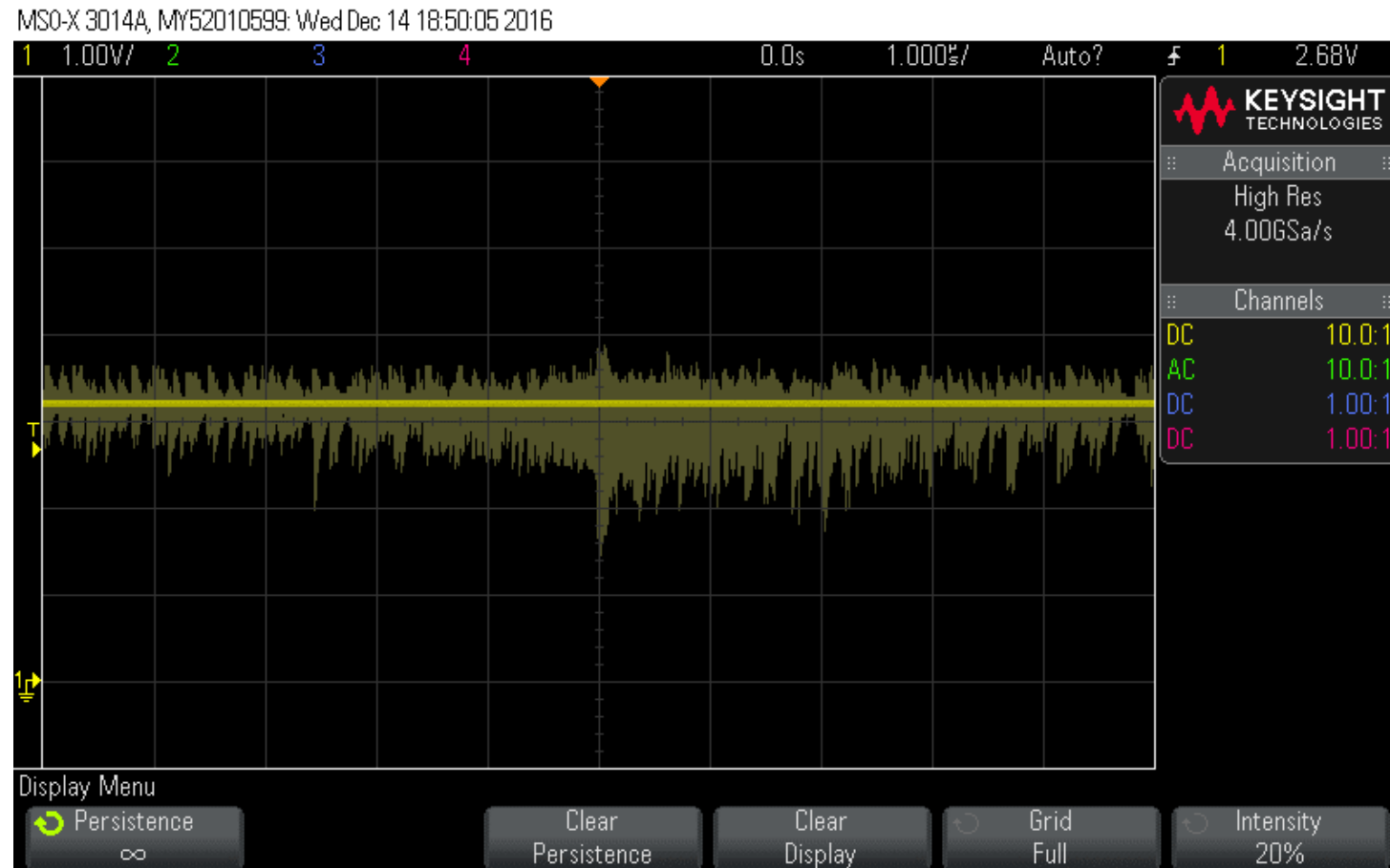
Impedance (ohms)

26-540002 size 14.3OD x 6.35ID x 28.6Length (mm)

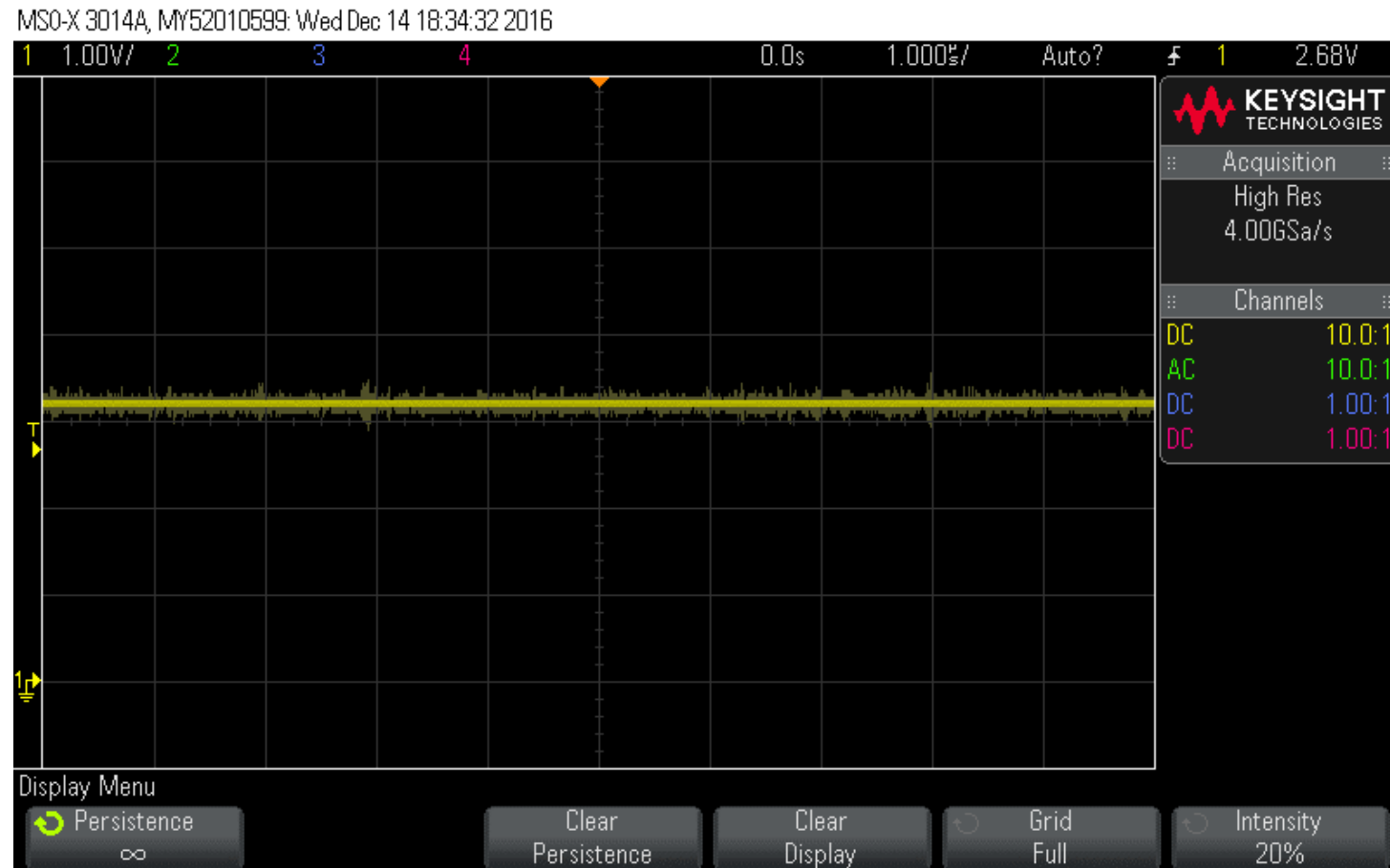




Brushed DC motor no ferrite choke



Brushed DC motor with ferrite choke



Questions?