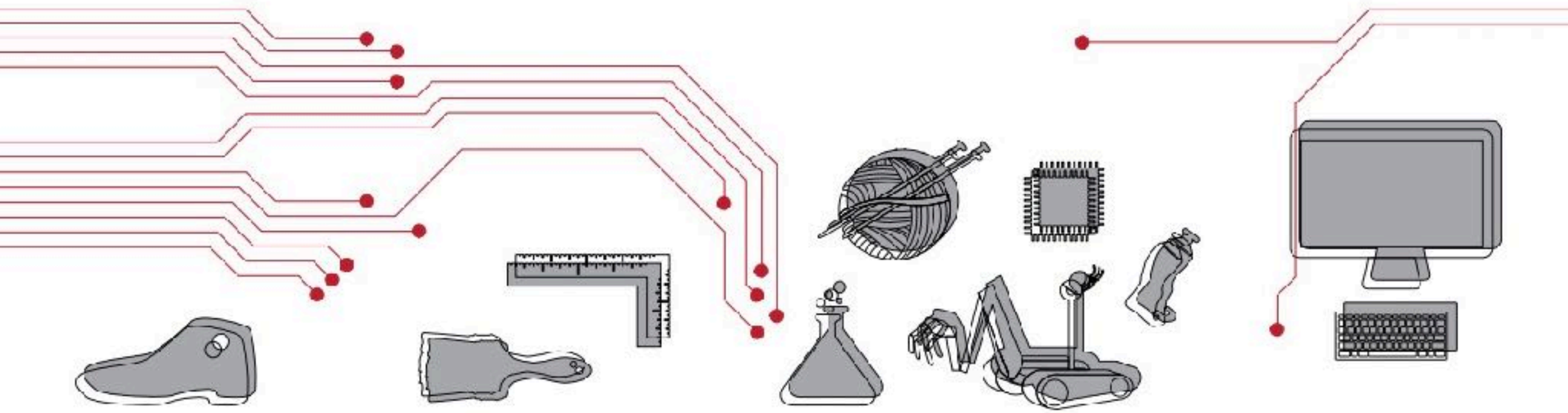
Introduction to Electronics and Microcontrollers

MAKE santa fe

Paul Sakion



Welcome

- Your Email - Experiences Good/Bad - Interests - Projects

- My Background: Electrical engineer with interests that include robotics, microcontrollers, internet of things, sensors, and 3D printers.

- Self Balancing robot demo

- "Grunt-bot" demo

Class Overview

- Modern electronics brings together many technologies: computers, microcontrollers, breadboards, sensors, motors, LEDs, displays, WiFi, Bluetooth, etc.

- Even knowing what to search for can be difficult: ESP32/ ESP8266, Arduino, PWM, Neopixels, MicroPython?

- For example, "What motor do I need to do X?" - DC, AC, stepper, servos?

- This class is a practical introduction for Makers with "just enough" electronics theory

Basic Safety

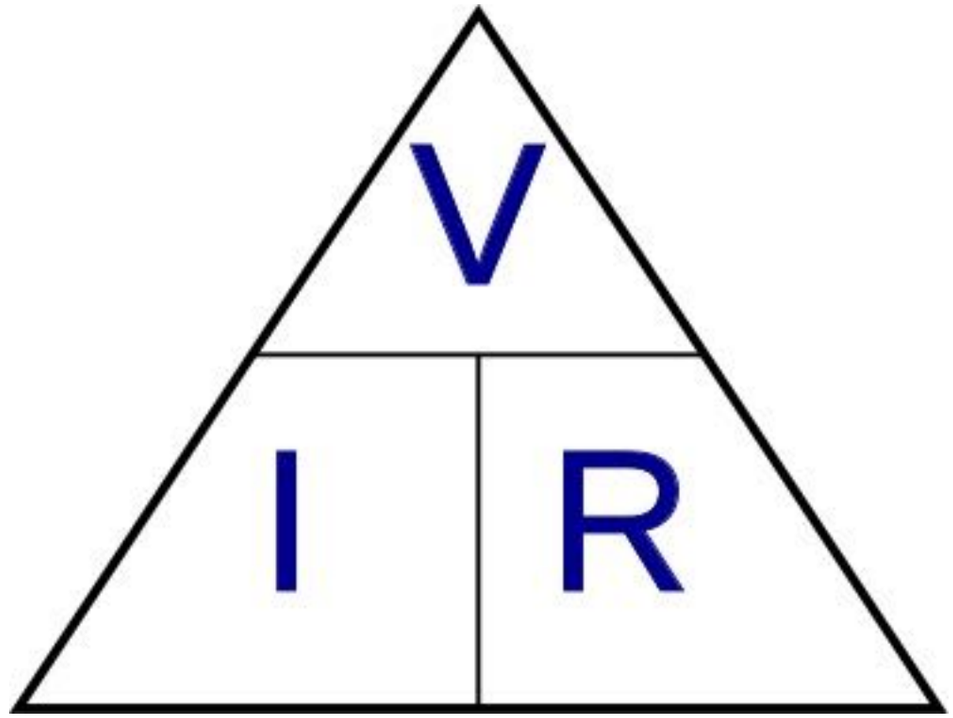
- One hand rule, buddy rule, capacitors, hot components
- Static grounding / Power ratings / Wire sizes / Batteries

Voltage

- Electrical “pressure”
- Like distance - measured between points
- Direct Current - Battery, DC “wall wart,” USB port, DC power supply
- Alternating Current - Power outlet, AC power supply

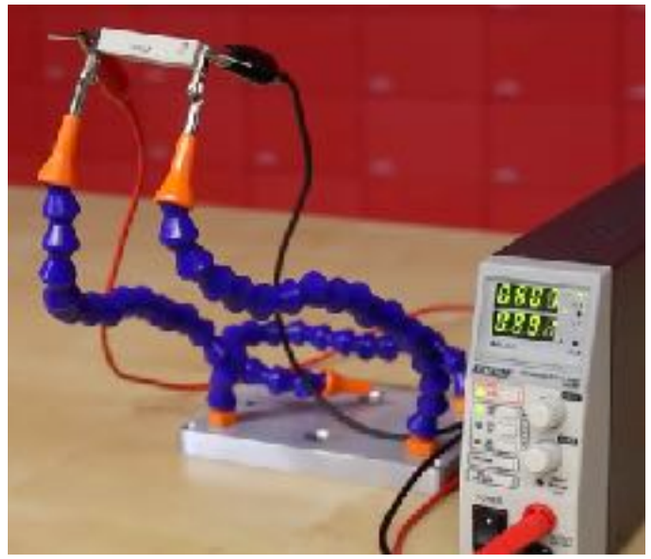
Voltage, Current, and Resistance in a Circuit

- Voltage is electrical pressure
- Current is the flow in amps (I)
- Resistance is the friction in ohms
- Related to each other by Ohm's Law V = I R



Power: Watts (P = V I)

- Work done by the flow of electrons (current) by pressure (voltage)
- 100W incandescent / 10W LED
- 1500W hair dryer plugged into 120V / 15A circuit
- Power rating of components
- Summary Video



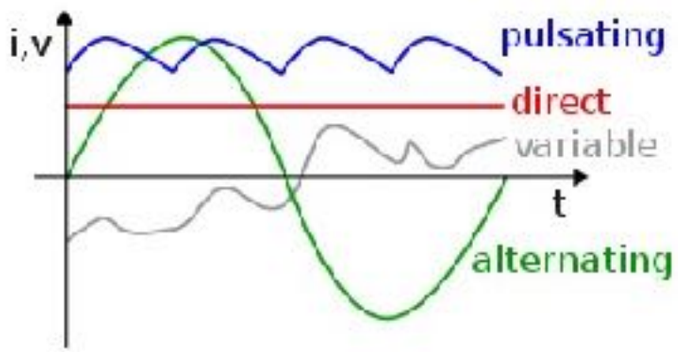
SparkFun Video

Watt Meter to measure power consumption

Frequency

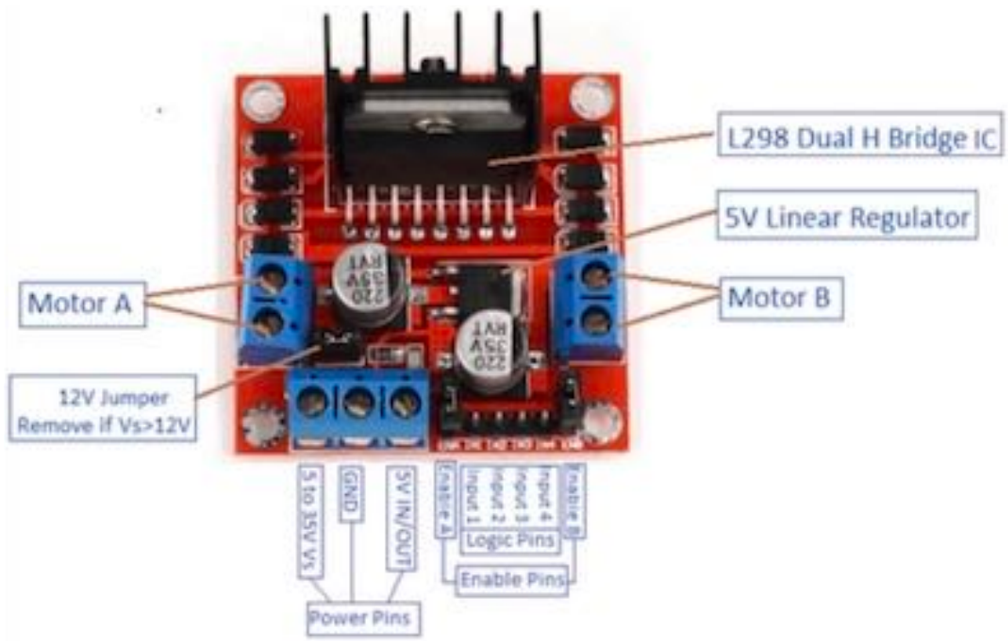
- Change in voltage over time in Hertz - cycles / second
- Wall socket (USA) is 60 Hz / 120v (thanks to Tesla / Edison)
- Computer microprocessors ~ 4.6 GHz
- Electromagnetic - 2.4 GHz (microwaves) / 5 GHz / 300 GHz
- Wavelength - 10E8 (c) / frequency (“mmwaves” = 300 GHz)

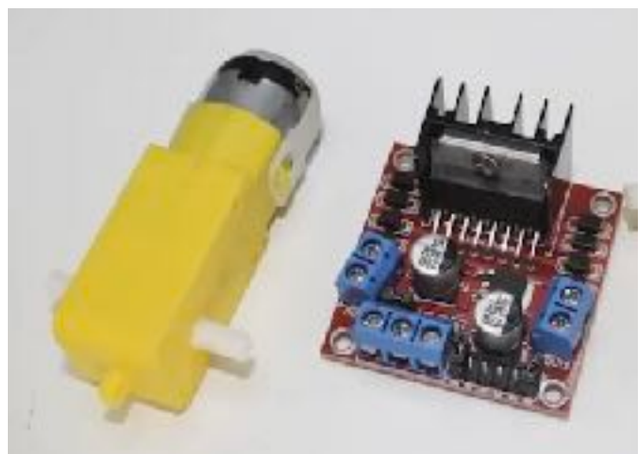
Alternating current (green curve). The horizontal axis measures time; the vertical, current or



Troubleshooting

- Requires a systematic approach
- Break down and simply the problem by isolating parts
- Review the specs, confirm inputs, confirm outputs
- Test power to motor / test motor / test connections





Modern Electronics

- Microcontrollers, breadboards, LEDs, sensors, motors (DC, AC, stepper, servos), displays, WiFi, Bluetooth

- CircuitLab / TinkerCad

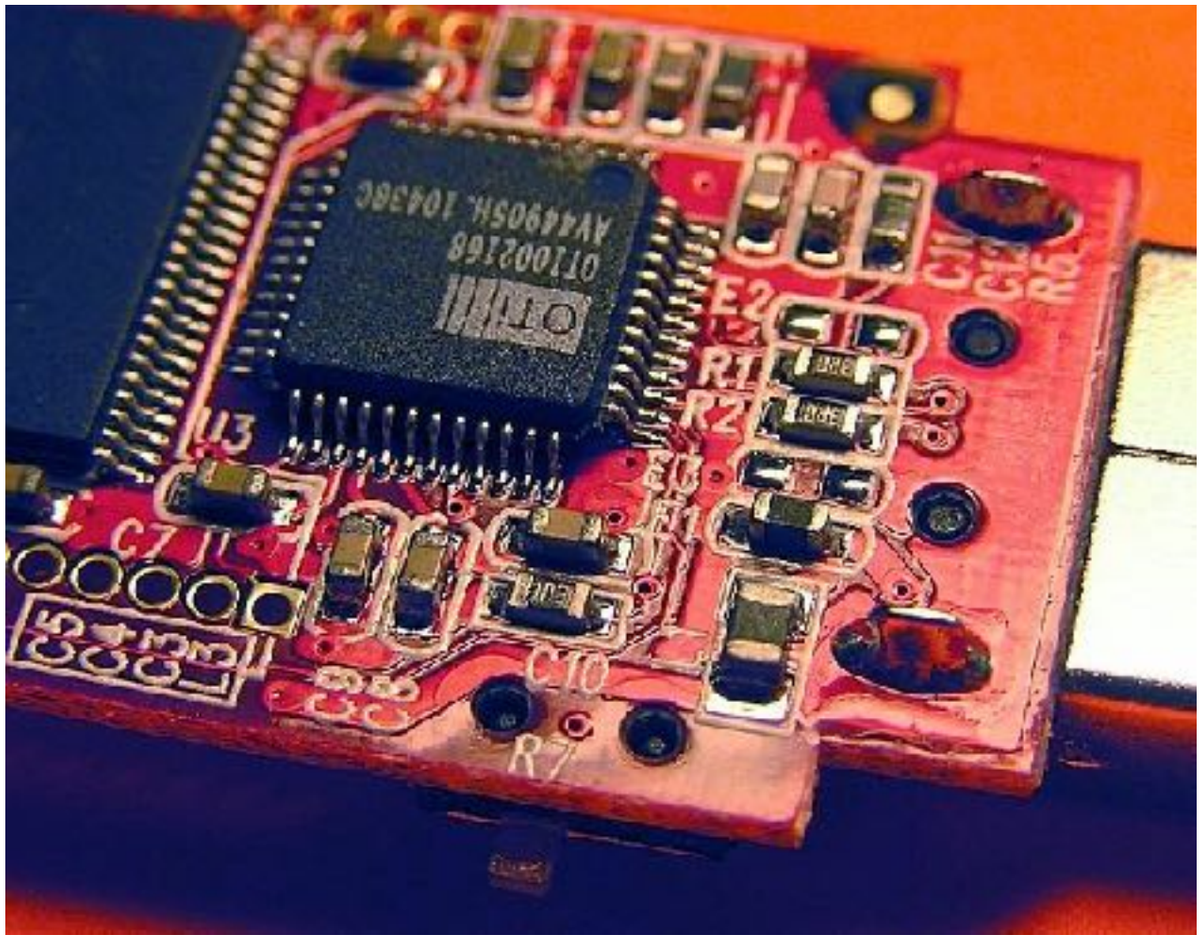
- Demo of Multimeter

- Demo of Power Supply

- Explanation of Oscilloscope

The Circuit Board

- All those little specks are electronic parts
- Resistors, capacitors, inductors, integrated circuits
- Connected by "wires" embedded in the "circuit board"



Microcontrollers

- Arduino / ESP32 - Open-source hardware / software electronics platforms intended for anyone making interactive projects (Arduino "cookbook")

- Raspberry Pi - A credit card sized computer that can be used to learn coding and to build electronics projects, also works like a desktop PC (beginner's kit / "cookbook" / Sparkfun guide)

- Micro:bit - An open-source hardware designed for education. It has a processor, several sensors, Bluetooth / USB, 25 LEDs, two buttons, and can be powered by either USB or an external battery pack

Inputs and Outputs

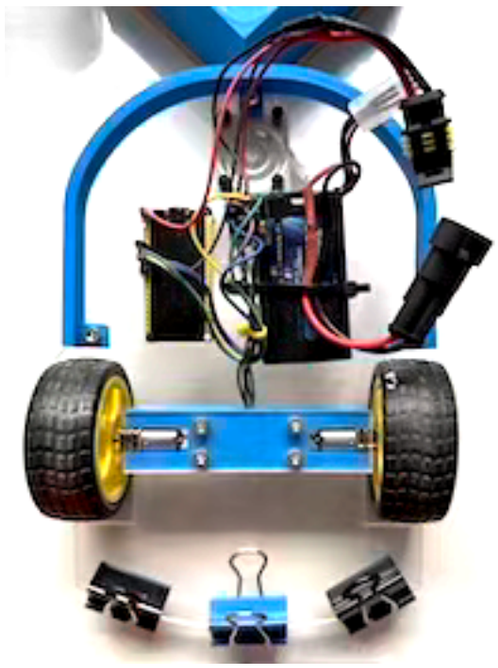
- Sensors - Thousands of types including temperature, pressure, humidity, light, microphones, cameras, movement, speed, distance, switches

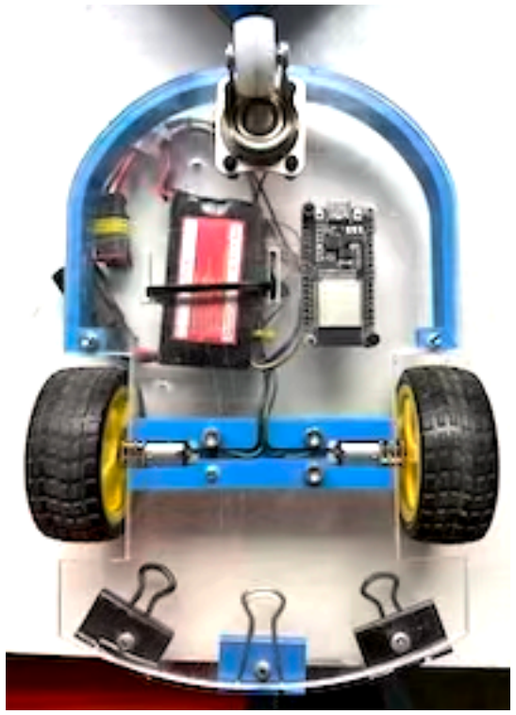
- Indicators - LEDs, buzzers, speakers, displays

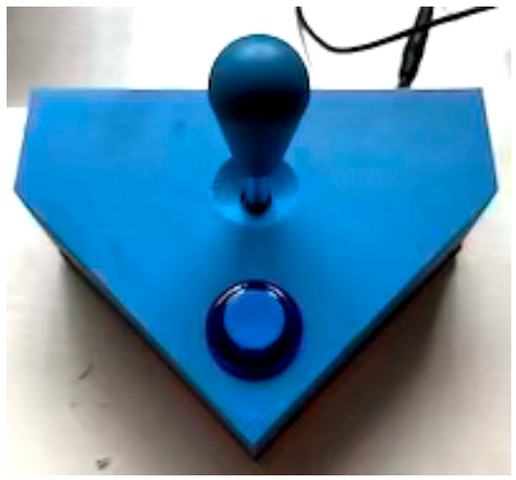
- DC Motors - Servos (airplane flaps / car steering), Stepper (precise movement), "Brushed" DC (requires motor controller), "Brushless" DC (drones, requires an "ESC" Electronic Speed Controller)

Andrew's Car

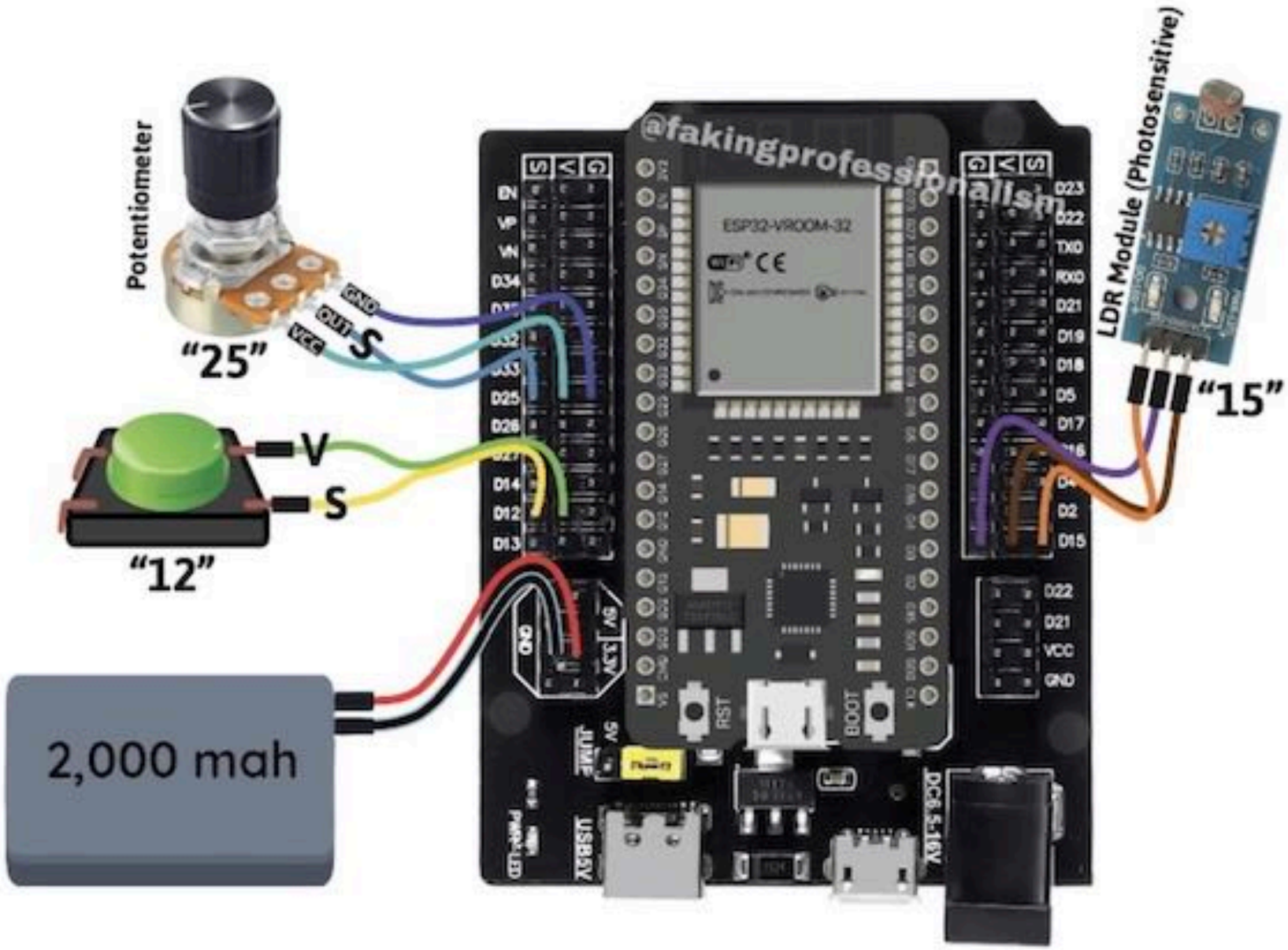
- Made from microcontroller, motors, battery, motor driver
- 3D printed or laser cut body
- Purchased wheels, joystick, etc.



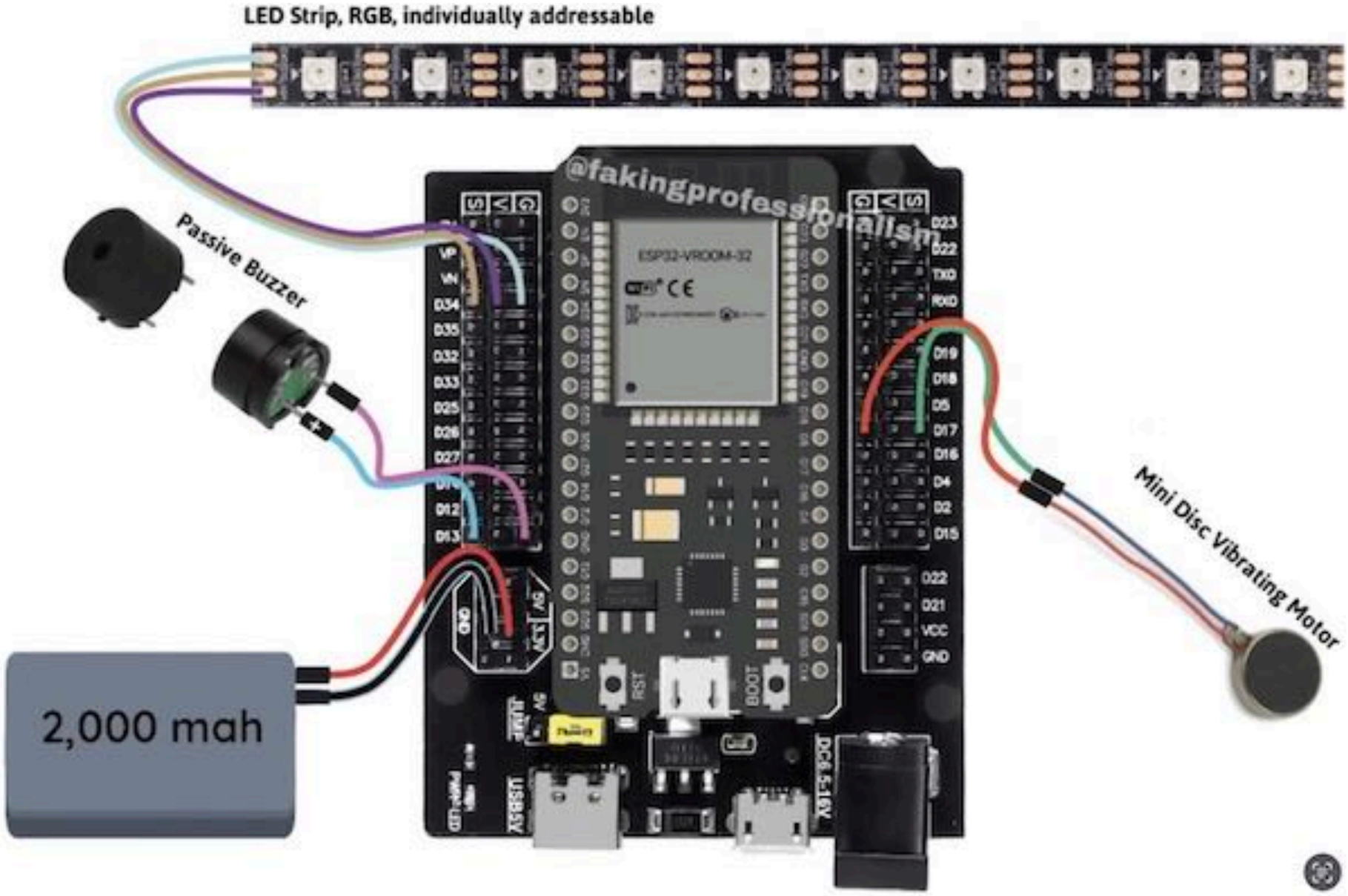




Inputs

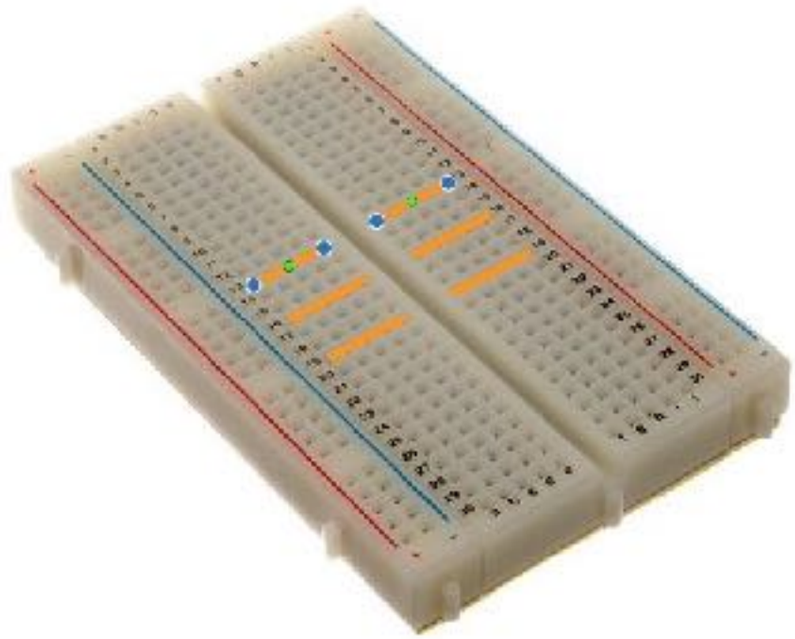

Potentiometer
"25"
GND
OUT
VCC
S
V
S
"12"
2,000 mah
@fakingprofessionalism
ESP32-VROOM-32
LDR Module (Photosensitive)
"15"
EN
VP
VN
D34
D25
D26
D14
D12
D13
D23
D22
TXD
RXD
D21
D19
D18
D5
D17
D2
D15
D22
D21
VCC
GND
RST
BOOT
JUMP
USB5V
DC6.5-16V

Outputs


LED Strip, RGB, individually addressable
Passive Buzzer
2,000 mah
Mini Disc Vibrating Motor
@fakingprofessionalism
ESP32-VROOM-32
VP
VN
D34
D35
D32
D33
D25
D26
D27
D14
D12
D13
GND
5V
RST
BOOT
D23
D22
TXD
RXD
D19
D18
D5
D17
D16
D4
D2
D15
D22
D21
VCC
GND
USB5V
DC6.5-12V

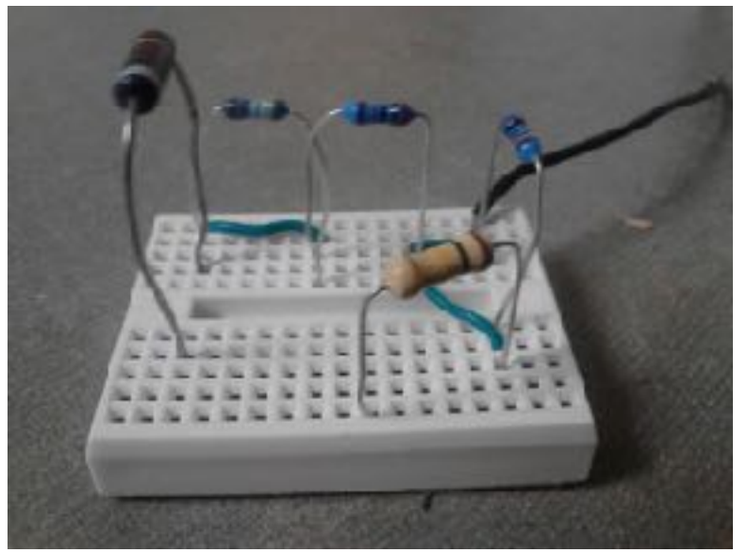
Building Circuits

- "Breadboards" - No soldering



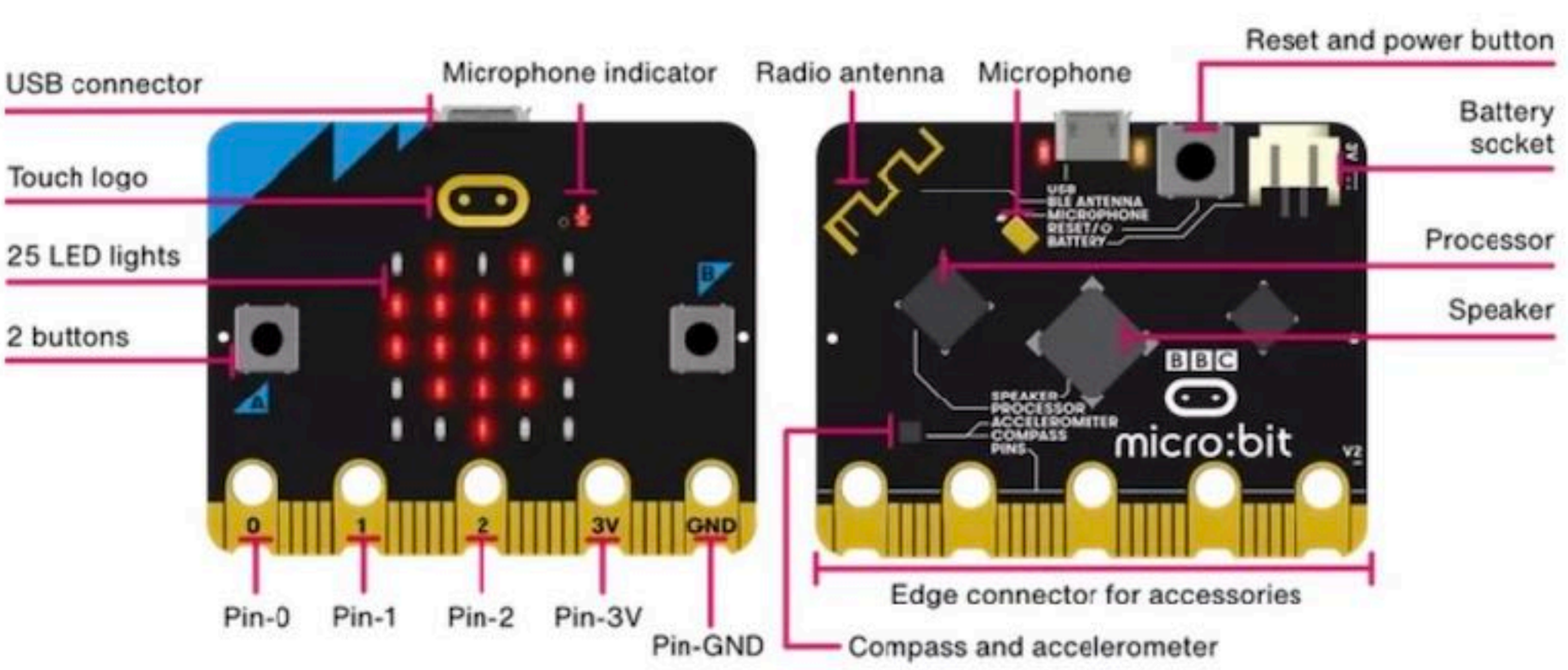
- Printed Circuit Boards (PCBs) - As low as $2 for 5 but requires design skills (KiCad) and soldering skills

- An expert level example



Micro:bit Microcontroller

- Micro:bit - Open-source hardware with a processor, several sensors, Bluetooth/USB, 25 LEDs, two buttons, powered by USB or external battery pack (buy at Amazon)



MicroBlocks Programming

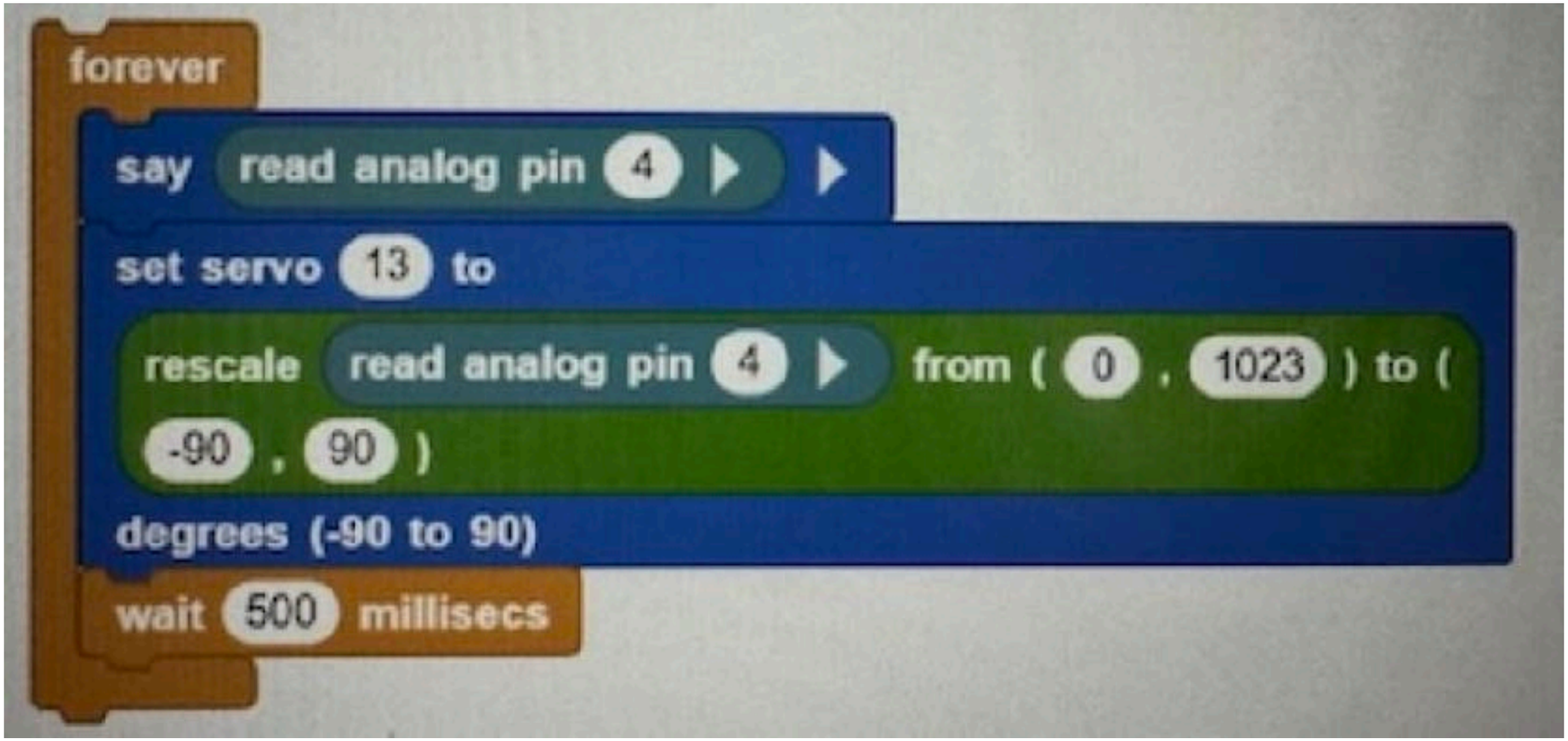
- Easy way to get started with real-time programming
- Update firmware first
- Command, reporter, C-Blocks, HAT-blocks, Categories
- Using Libraries and the Help System
- Play with reporters to explore the IDE and micro:bit
- The “Hello World” of microcontroller - Blink!

MicroBlocks Programming

- Load LED DISPLAY library
- Display a letter/number on LED
- Display longer text and numbers on LED
- Display icon pictures selected from the menu
- Program button A / B: display text, picture, animation
- Discover the ENCODED information - everything is a number

MicroBlocks Programming

- Control a servo with a joystick using the ESP32



Picobricks

- An electronic development board which is designed for use in Maker projects. Several sensor modules are included: Display, Neopixels, temperature, presence, relay, keyboard, motor drivers, communications, gesture, light, and potentiometer (buy at Robotistan)

Picobricks Overview

- Explore hardware features: Display, RGB LEDs, Temp/Humidity sensor, Passive IR (PIR) sensor, Relay, Motor module, Gesture sensor, LDR Light sensor, Potentiometer, Touchkey sensor

- PicoBricks Library: blocks and functionalities

- Learn about basic operational principles and use of the modules:

- Display: bitmap images, print information and graphics

- RGB LEDS: how colors are made, use as indicators or display images on TV, cell phone

- Temp/humidity sensor: monitor the environment, activate AC/ Heating/Watering (greenhouse / home automation applications)

Picobricks Sensors

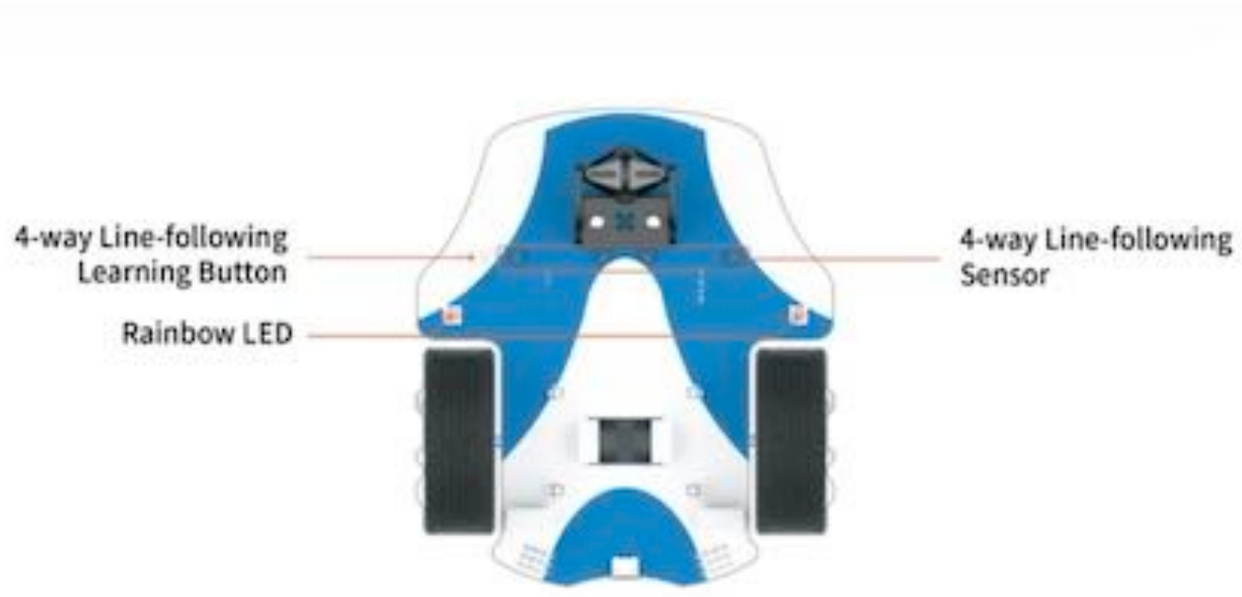
- PIR sensor: detect motion in area, use to build alarm systems, monitor activity
- Relay: turn power on/off, use to control devices, motors, lights, appliances
- Motor module: DC / Servos, cars, robots, open/close entrances
- Gesture sensor: detect hand motions nearby, use to control activities remotely
- LDR Light sensor: detect light levels, use to control lights or window shades
- Potentiometer: turn to change, use for input for sound, light, temp, etc control
- Touch Key sensor: activates when touch is detected, use for control of anything you can think of or play music/games

Picobricks Extra Credit

- Let’s make a letter and display it on the screen: first with micro:bit, then on TFT
- TFT display: text in various sizes, geometric shapes
- What’s with all the blinking going on the TFT display, how do we get rid of it?
- Program the pot to control TFT brightness using backlight
- RGB colors (0-255): primary colors and combination colors
- Program NEOPixels for desired patterns, colors, movements
- Program to display temp/humidity on the TFT screen
- Explore displaying values in multiple lines, in various sizes
- Program the PIR sensor to alert for motion and sound an alarm
- Motor module: make motors and servos move
- Program hand movements to control micro:bit or other modules, display pictures
- Program LDR light sensor to dim/brighten TFT display
- Program to plot potentiometer values, rescale values to change (for example): size, volume, brightness, etc.
- Use a touch key sensor to play musical notes and display the note names on the TFT Display. Make the note play duration controlled by the user (HINT: need sensor input)
- Display multiple sensor values on the TFT and update them in real-time Eg: temp, potentiometer, Light sensor, etc.
- Design and implement a system with sensor detection and corresponding action. Eg: Alarm system, Appliance use automation, turn on/off motors, etc.
- Design a mini broadcast system based on Radio that transmits messages, pictures, sensor values over different channels. Users will tune into the channel and receive the information.
- Use joystick to remotely control a servo over Wifi (requires two micro:bit controllers)

Cutebot Pro Car Kit

- A programmable robot with a 4-way infrared line-following sensor, an encoder motor, the LED rainbow light, an ultrasonic sensor, and other devices (buy at Elecfreaks)



Cutebot Overview

- Hardware features: Chassis, power switch, battery, encoder motors, micro:bit slot, distance sensor, IR sensor, Headlights (LEDs), NEOPixel Lights, Line tracking sensors, Calibration button, Expansion ports
- Basics of Robotics 3C's: communication, command, and control.
- Communication: IR Remote control, Radio Control
- Command: manipulating the car using library commands that are preprogrammed, getting telemetry information from the sensors
- Control: maneuvering the car in various ways: by motor power %, by distance, by wheel rotation, programming responses to sensor data, acting on external events.
- What is a Control LOOP? What is programmed versus continuous control?
- What is a Line tracking sensor, how does it work?
- What is an Encoder and why do we need it?
- How do DC motors work?
- What are minimal car controls that we need to successfully maneuver the car?
- What is an IR Remote Controller, how does it work?

Cutebot Projects

- Program car movements: forward, backward, turns in place
- Program turns by rotation angles forward and backwards
- Program car movements monitoring sensor values: distance, speed, obstacles
- “Extra Credit” Activities
  - Program a script to detect lines
  - Program a control script using IR Remote for car control
  - Program displays for telemetry information display
  - Program obstacle avoidance using the Sonar distance sensor
  - Program the car to follow the track
  - Program a control script using Radio for car control
  - Pretty the car movements by using the Headlights, NEOPixels, and Sounds

MicroPython

- Python designed to work under constrained conditions like those found in microcontrollers / embedded systems

- Includes modules to access low-level hardware like GPIO

- Several steps required before it can be used with a microcontroller (firmware, Thonny IDE, etc.)

- Tutorials are available and AI can be used to write code

Arduino

- Web based Arduino code editor (IDE) where you can write code, access libraries, and upload to board (ESP32 and other boards as well)

- Tutorials are available and a language reference

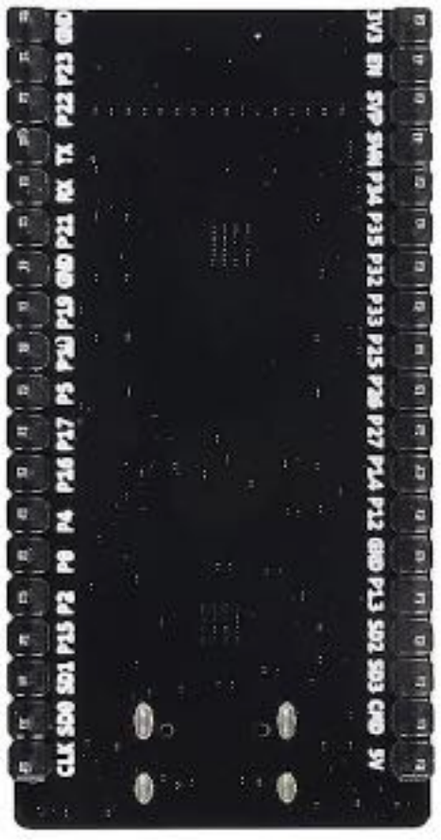
- The Arduino “Cookbook”

- Many kits are available online: Elegoo for example. For less than $50 get Arduino, temperature/humidity, distance, joystick, infrared, and other misc parts.

ESP32 Microcontroller

- Best to buy with breakout board - Guide to choosing
- Input 5-14V 19 mA (3.3V internally) Bluetooth and WiFi

ESP32 "38 pin"



ESP32 "30 pin"

Analog Components

- Capacitor - Stores energy in an electric field (like a tiny tank). Two conductive plates separated by an insulator.

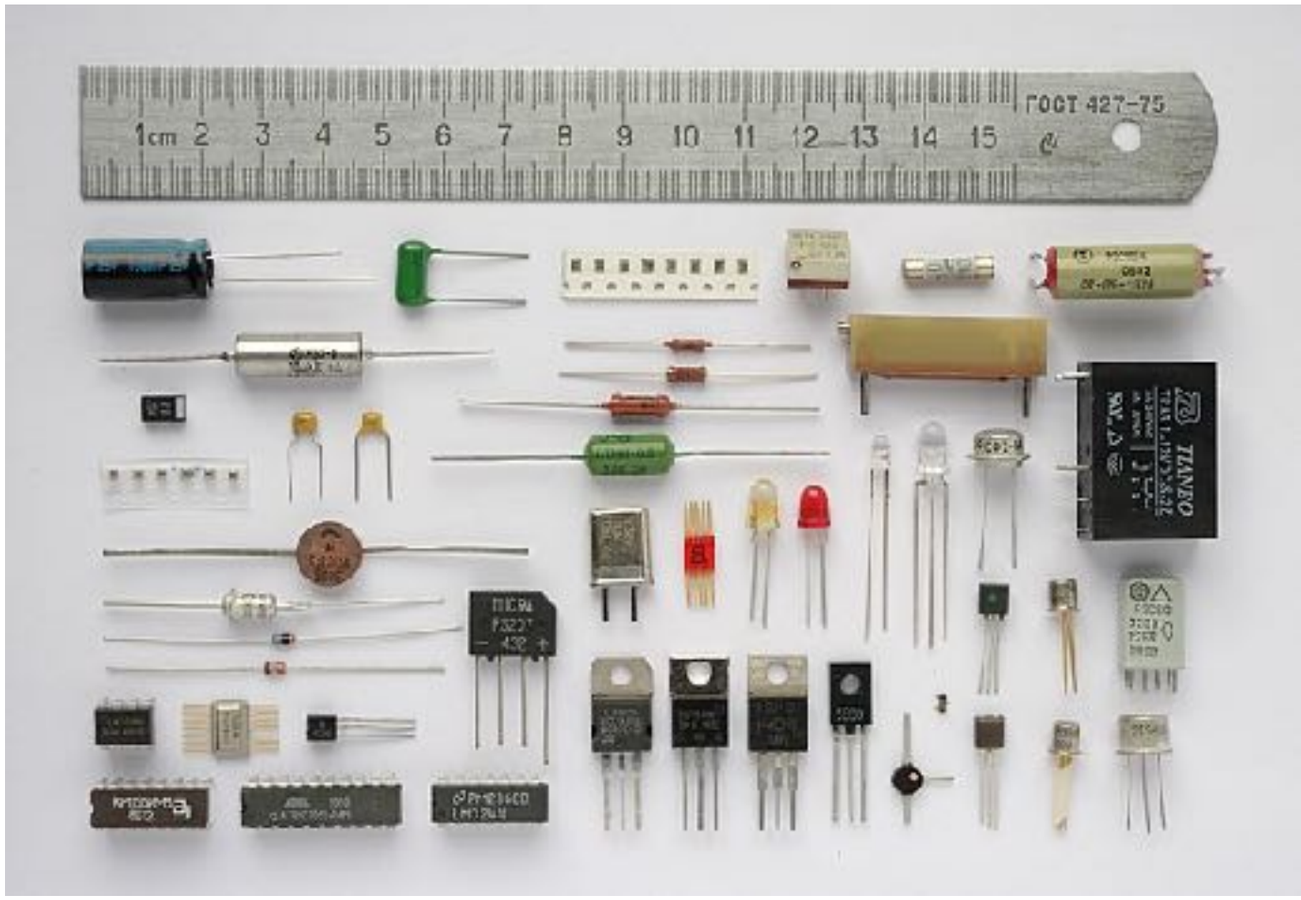
- Inductor - Stores energy in a magnetic field (like a tiny water wheel connected to a mass). A coil of wire.

- Resistor - Resists the flow of electrons like a thinner piece of pipe. A wire with resistive material (carbon, etc.)

- Lots of YouTube Videos

Other Components

- Diode - Allows current to flow only in one direction
- Transformer - Two inductors coupled by a magnetic field
- Relay - Electrical switch
- Transistor - Semiconductor used to amplify or switch
- Integrated Circuits (ICs)

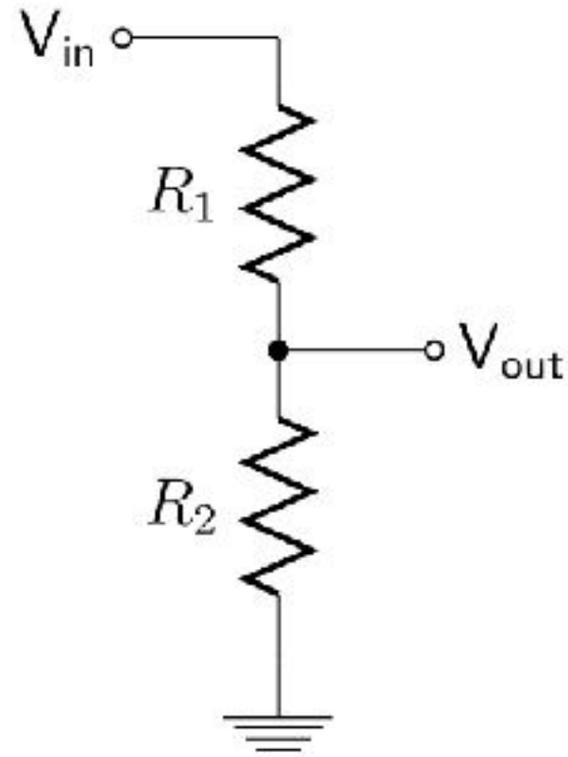


Circuits

- Series and parallel circuits - <u>There is a difference</u> for calculating voltage, current, resistance, capacitance, and inductance

- Analog Circuits - Current or voltage vary continuously with time

- Digital Circuit - Voltages are assigned to discrete values (ex. 0=0v / 1=3.3 or 5v) to represent logical and numeric values

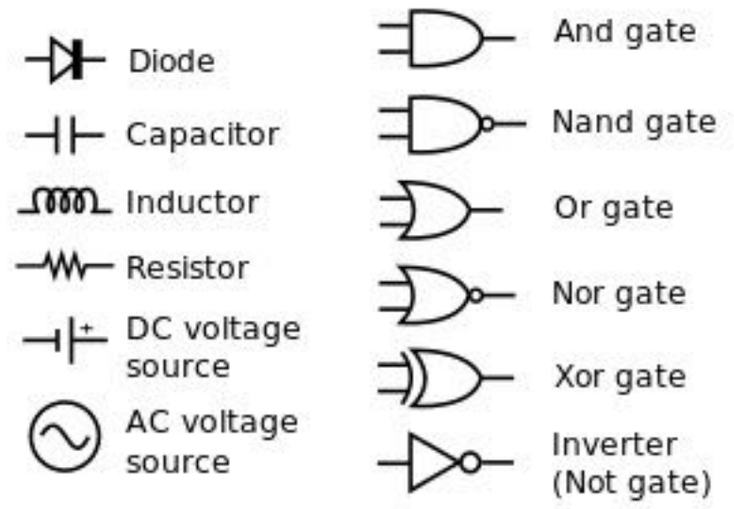


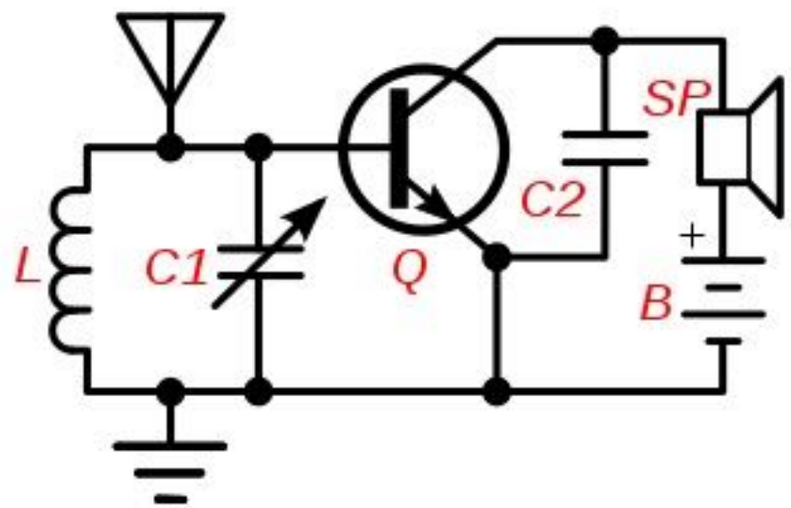
$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}}$$

Schematics

- A simplified summary: Read upper left to bottom right

- The long version: The radio signal from the antenna is applied to a tuned circuit so the radio station at that frequency is passed on to the transistor and signals at other frequencies are routed to ground. The transistor both amplifies and rectifies the amplitude modulated (AM) radio signal. Since the base-emitter junction acts as a diode it conducts only on the positive half-cycles of the carrier wave, blocking the negative half cycles, rectifying the carrier to extract the audio modulation signal from the radio wave. The collector current is an amplified copy of the base current, consisting of pulses of current with amplitude proportional to the audio modulation. The capacitor functions as a lowpass filter, smoothing the current, removing the radio frequency pulses leaving the audio signal, which is converted into sound waves by the speaker.





USB-C Power

- Unlike USB-A, the voltage can vary and be "negotiated"
- Standard voltage steps are 5 V, 9 V, 15 V, 20 V, and 28V
- Formal name is USB-C Power Delivery

- Qualcomm has a proprietary standard - "QC"
- Experimental boards: HUSB238 and ZY12PDN
- A more complete guide can be found here and a video

Solar Powered Systems

- Several factors - wattage, temperature, type, orientation...
- Mono-crystalline - higher efficiency / cost than poly
- 400-watt panel can produce about 1,600 watts / day
- 200 watts - Adequate for basic needs
- 400-700 watts - can power a range of small appliances
- 1400 watts - Running a small air conditioner for 12 hours

Solar Systems

- <u>Semi DIY</u> $600 - 200 Watts 12 Volt/24 Volt Mono-crystalline Solar Panels with 30A PWM Charge Controller and 100aH LiFePO4 Battery

- <u>Solar "Generator"</u> $1000 - 200W Solar Panel,1070Wh LiFePO4 Battery,1500W AC/100W USB-C Output

Batteries

- Lithium Ion (Li-ion) - Good general rechargeable, usually cylindrical. Found in phones, laptops, flashlights, etc.

- Lithium Polymer (LiPo) - Higher discharge rate, usually rectangular or "pouch" shaped

- Lithium Iron Phosphate (LiFePO4) - Heavier, 0%-100% every day, 2000+ charge cycles (vs 500), less risk of thermal runaway, good for solar battery systems

Basis	Lithium Ion	Lithium Polymer
Ageing	Loses actual charging capacity over time	Retains charging capacity better than Lithium =ion
Energy Density	High Energy density	Low as compared to lithium ion
Conversion Rate	The capacity to convert battery into actual power 85-95%	75- 85%
Safety	More Volatile as compared to lithium polymer	More safety. Less chance of explosion
Cost	Cheaper	Slightly Expensive(+30%)
Weight	Heavier	Light Weight
Charging duration	Longer Charge	Comparatively Shorter

Single Analog LEDs

- One color for each LED and need a current limiting resistor

- Very inexpensive - 100 for $5

- Also: Analog LED strips (which are different from digital LEDs on next slide)

- An excellent guide

WS2812B / NeoPixels

- Digital - each “programmed” separately
- Requires microcontroller (5 volts!): “LEDring.ino”
- Many colors, shapes, and sizes - including "wearable"
- Super guide / Technical guide
- Adafruit wearable kits
  (and here and here)

Wireless LED Control

- “A fast and feature-rich implementation of an ESP8266/ESP32-WROOM32 web server to control NeoPixel (WS2812B, WS2811, SK6812)”

- WiFi (no Bluetooth)

- WLED project website. Installation website

Wemos D1 Mini

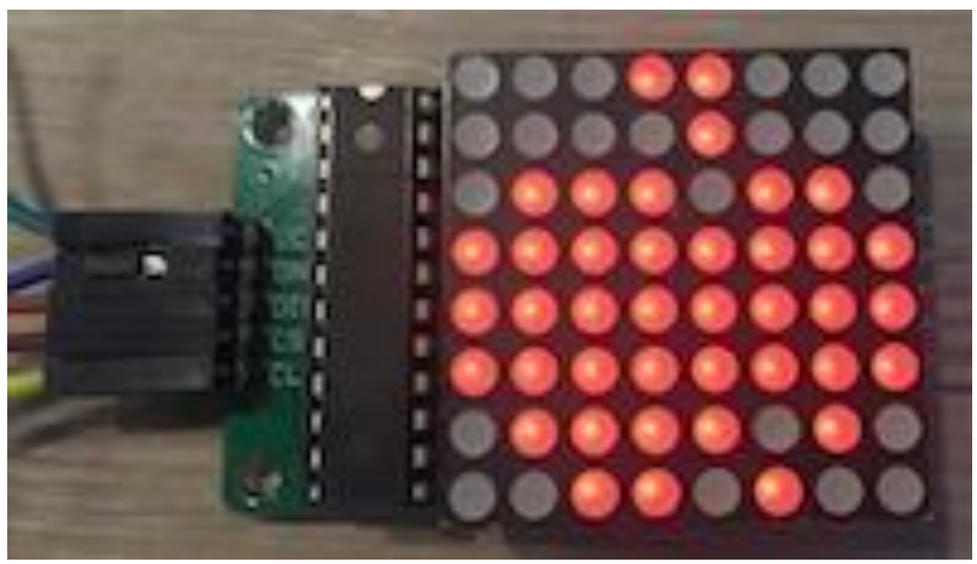
- Smallest microcontroller compatible with MicroBlocks
- Includes WiFi (can control wearables)
- 0.1A @ 5V = 0.5W - 12Wh = 24 hrs
- 11 digital IO: PWM / I2C
- 1 analog input - 3.2V max

Circuit Playground

- A small USB ring with ten NeoPixels from Adafruit ($25)
- Also includes motion, temperature, light, and sound sensors as well as a speaker, push buttons, USB/battery connector, Bluetooth, and more (see guide)
- Many project examples at Adafruit.com

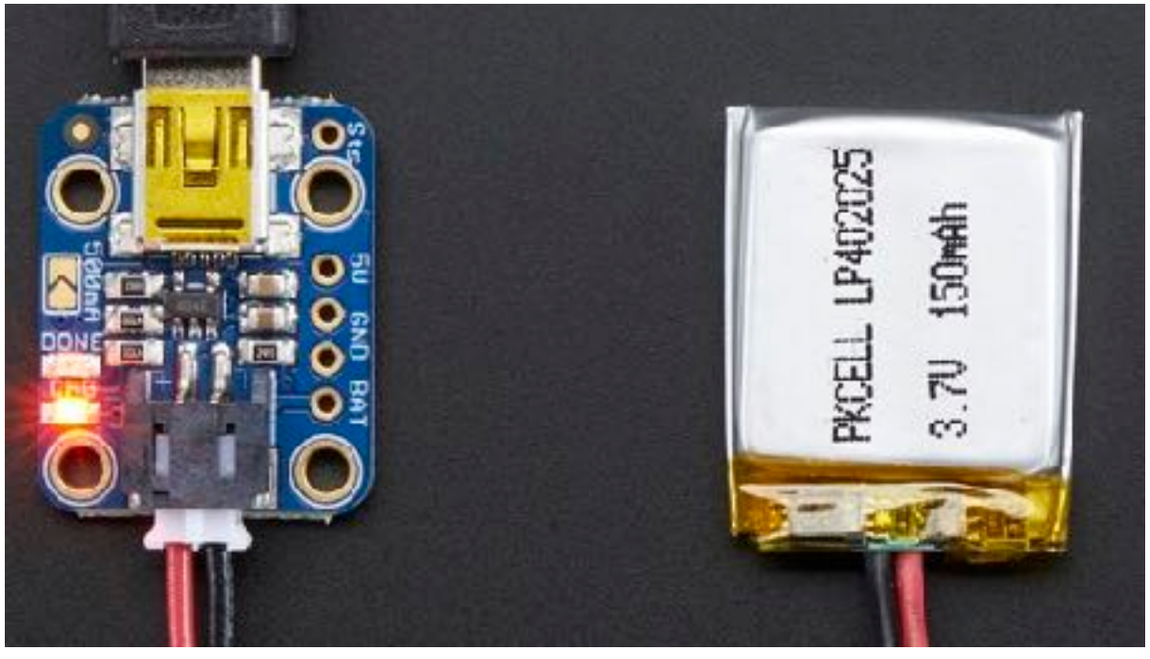
Matrix LEDs

- Requires microcontroller - “MAX7219LED.ino”
- Larger sizes (but requires larger power supplies)
- Text styles: scrolling, wipe, dissolve, mesh, etc.
- Usage guide. Arduino guide.



Miscellaneous

- "Noods" - Flexible LEDs "Noodles" - Guide
- Special Purpose Controllers - "Proffieboard" for lightsabers
- Small Lithium Polymer (LiPo) are good (3.7V * 2Ah = 7.4Wh)



Robotics Projects

- Commercial: Boston Dynamics, Curiosity Rover
- Controllers, sensors, motors, etc. (simple and advanced kits)
- 3D printed robot or made with the laser cutter
- DIY self balancing robot

Entertainment Projects

- Retro Gaming with Raspberry Pi
- "RetroPie"
- Arduino Photo Booth

Reddit user GuzziGuy

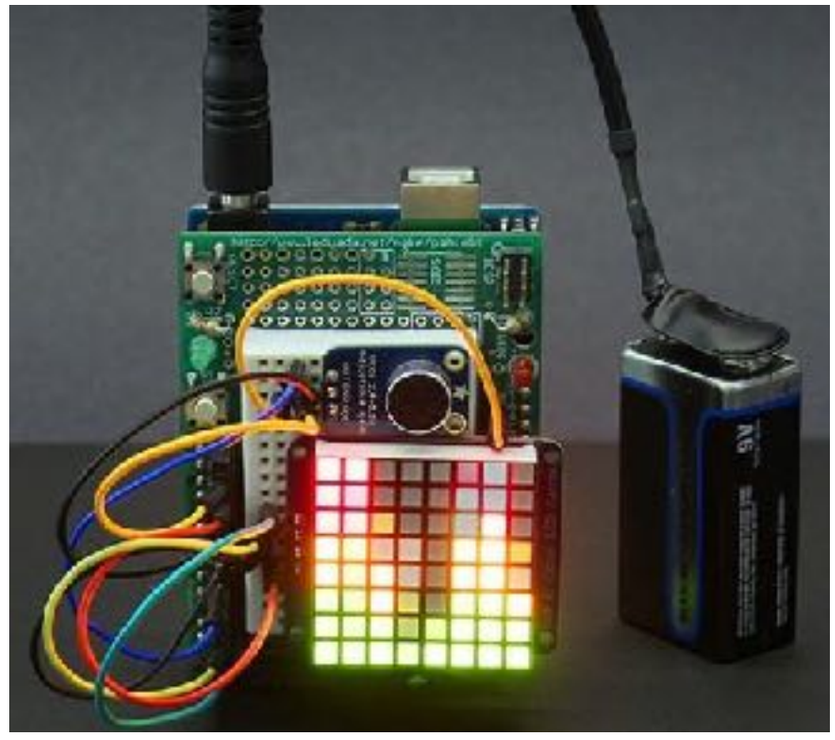
Home Automation

- Monitoring
- DIY Home Automation
- Lighting, thermostats, locks, motion detectors, cameras, doorbells, etc.

Music Projects

- Piccolo Arduino Music Visualizer
- Making Music With Synthfonio

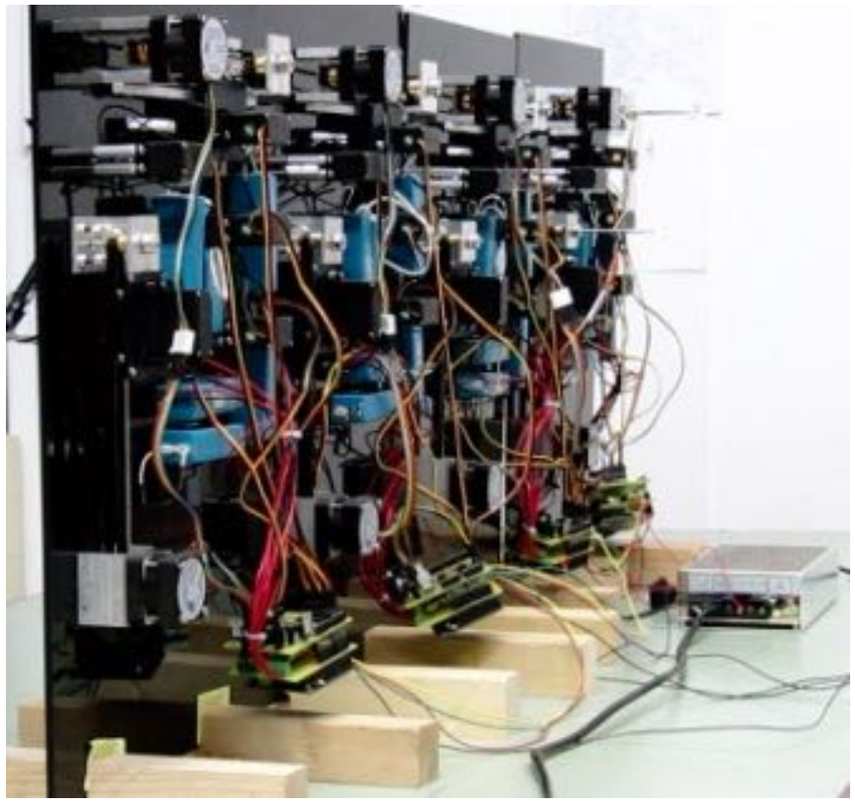
Franco Molina Video



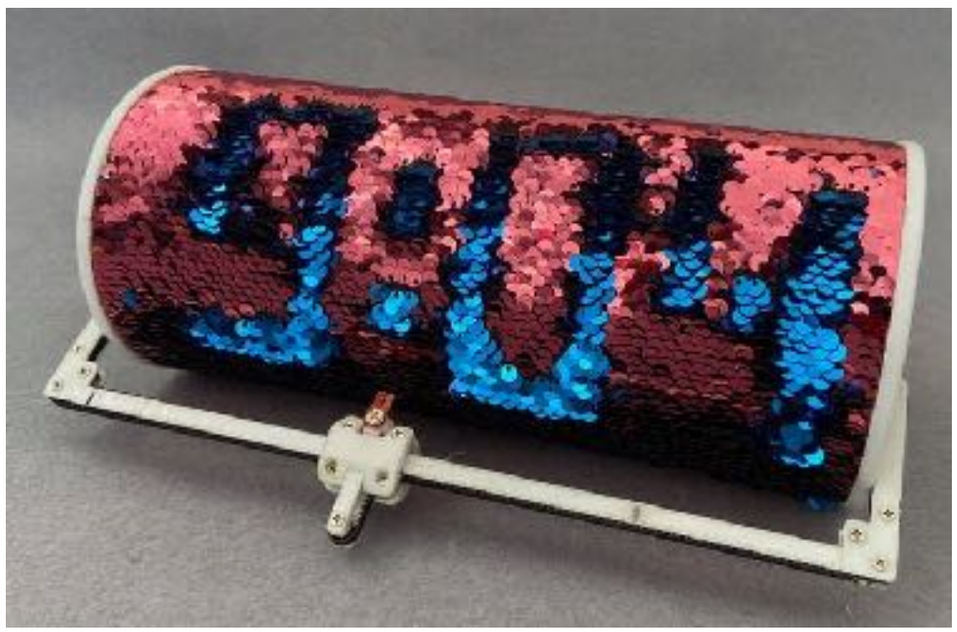
Adafruit Video

Art Projects

- Meow Wolf Behind the Scenes
- Interactive Art - Virtual Peephole



Four Letters Words Project - Video



Sequino and Video

Miscellaneous Projects

- Computer Vision - OpenCV / Resources / Bouncer
- 3D scanner to "copy" 3D objects
- DAKboard - Display for photos, calendar, news, etc.
- YouTube channel of DIY Perks

Where To Go From Here?

- Sparkfun - Engineering Essentials
- Hackspace - Free Maker Books
- Adafruit - General and IoT Guides
- Arduino - Project Hub (over 5,500 projects)
- Raspberry Pi - PiMyLifeUp (Arduino, Linux, Electronics)
- More complex circuit simulation. More projects.
- And as always… YouTube (10 hour+ playlist)

Links From Class

- MicroBlocks website
- Micro:bit bare board
- Micro:bit motor driver board
- Less expensive Cutebot Pro Robot Car
- PicoBricks (unfortunately over $100)
- Raspberry Pi Pico W board