Digital Electronics 101

An introductory course on Electronics, C++ and Arduino-like platforms

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What are Electronics?

Fundamental Notions and Laws in Electronics

There are three main notions to be understood in electronics:

- **Current aka I** (SI: Ampere): The ordered flow of electrons, therefore electrical charge per time unit
- **Electrical Tension or Potential Difference aka U** (SI: Volt): The tension applied on said electrons, therefore energy per charge
- **Resistance aka R** (SI: Ohm): The resistance of a medium to the electron flow

Ohm's Law

We can describe the resistance as the tension we have to "apply" to push the electron flow establishing an equality-**Ohm's Law:**

$$R = \frac{U}{I}$$

Or in a funnier way:

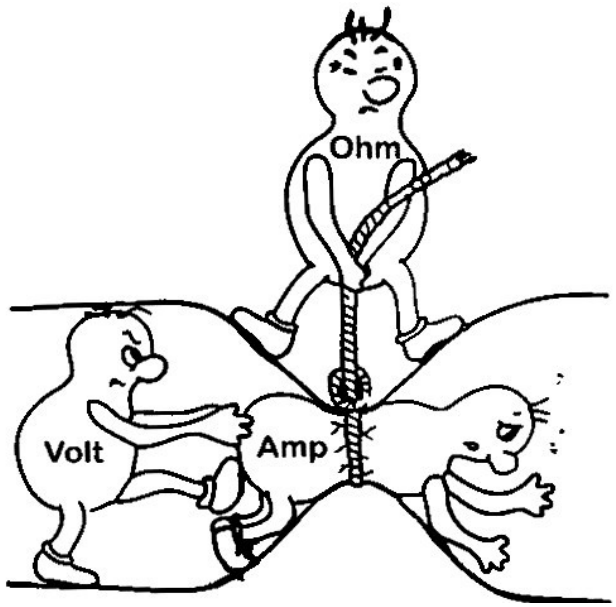


Figure 1: Ohm's Law

Kirchhoff's Voltage Law

The sum of all potential diferences in a loop is zero!

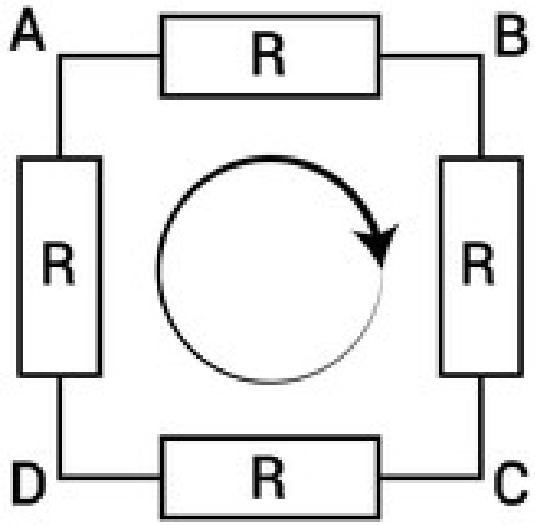


Figure 2: Kirchhoff's Voltage Law

Kirchhoff's Current Law

There can be no residual current in a node!

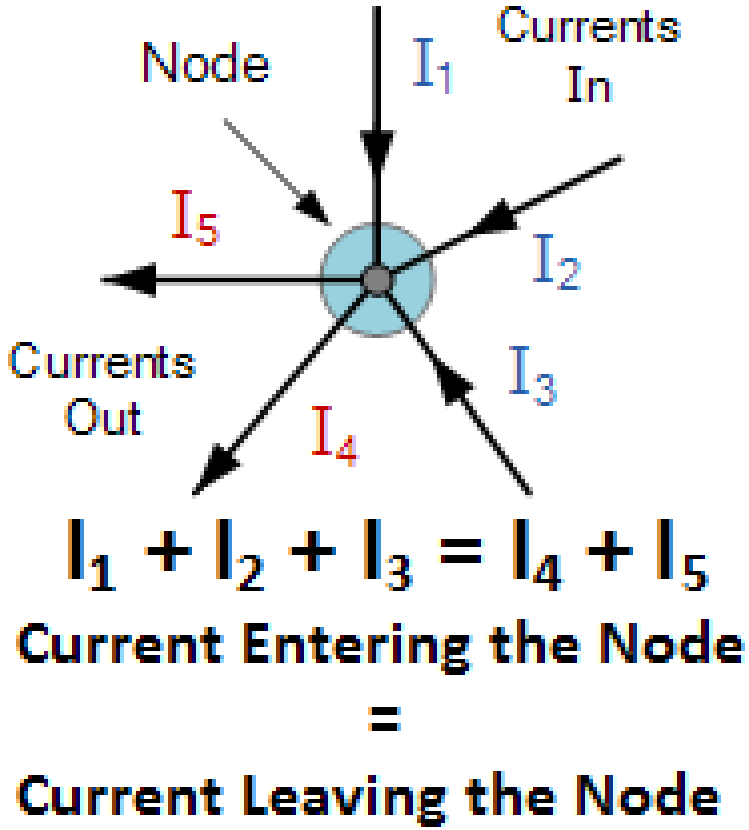


Figure 3: Kirchhoff's Current Law

Additional Notions and Fundamentals

Then we can also add some additional notions

- **Power**(SI: Watt): Rate of transference of electrical energy through a circuit, using the definition of Electrical Tension and current:

$$P = U \times I$$

Breadboards and PCBs I

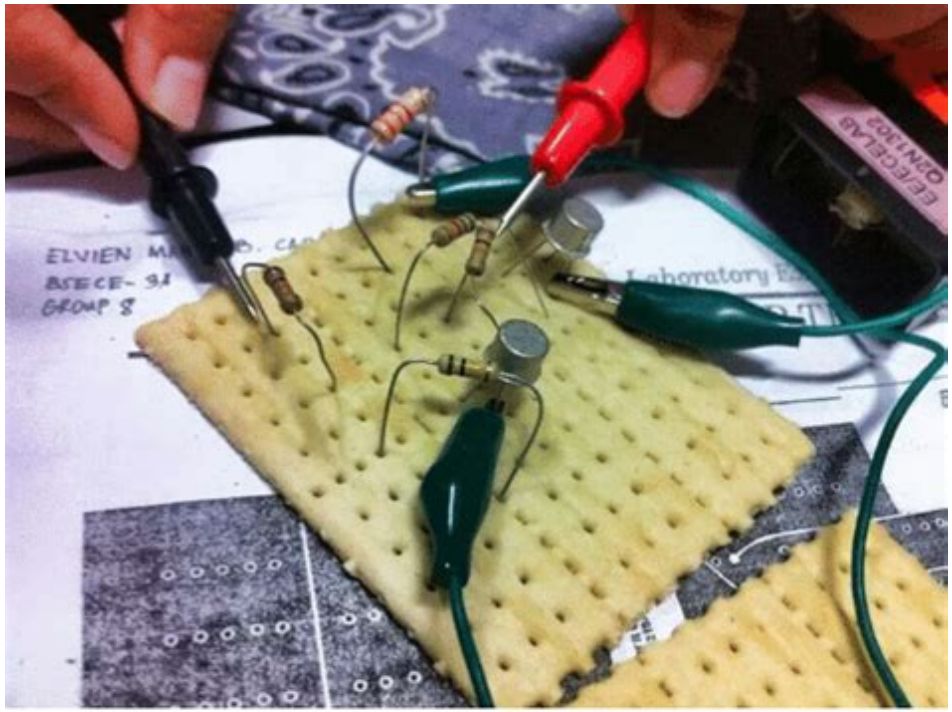


Figure 4: A BREADboard!

Breadboards and PCBs II

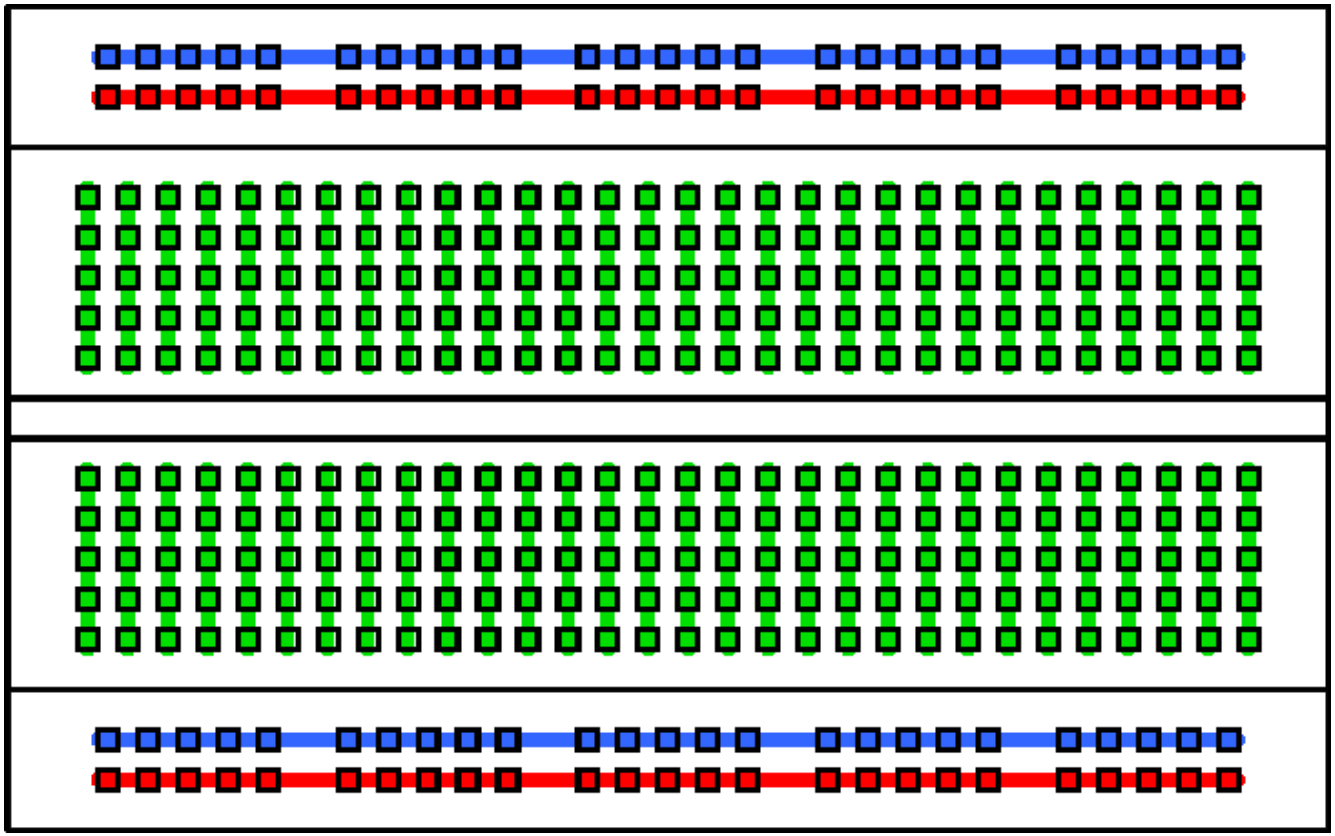


Figure 5: An actual breadboard

Breadboards and PCBs III

After testing our circuit in a breadboard, we might have a very complex and not portable weave of wires and components...

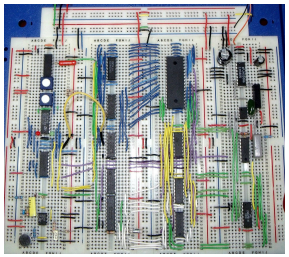


Figure 6: A very confusing weave of wires

We can then use some software tools (like KiCAD) to help us create a PCB schematic.After that we can send it to a manufacturer or do it ourselves!

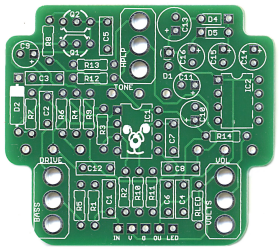


Figure 7: A printable circuit board

Power sources

The most fundamental devices are power sources. They supply (active component) a given tension to our circuit through the conversion of an x type of energy (chemical, mechanical, etc.) into electrical energy.

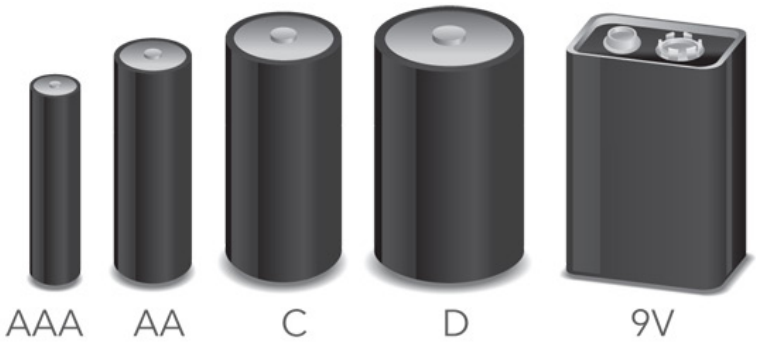


Figure 8: Batteries - A conversion device of chemical into electrical energy

Resistors

Another fundamental component. Depending on the resistor type they introduce a fixed or variable resistance (R) into our circuits. They are unpolarized.

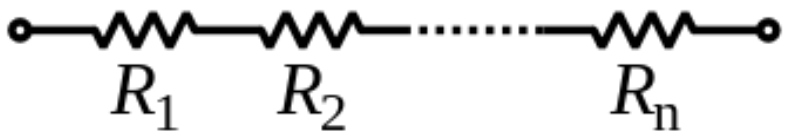


Figure 9: Series association: $R_{\text{eq}} = R_1 + R_2 + \cdots + R_n$

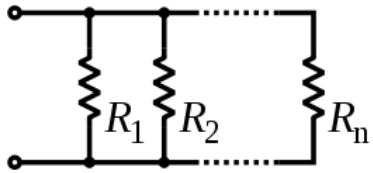
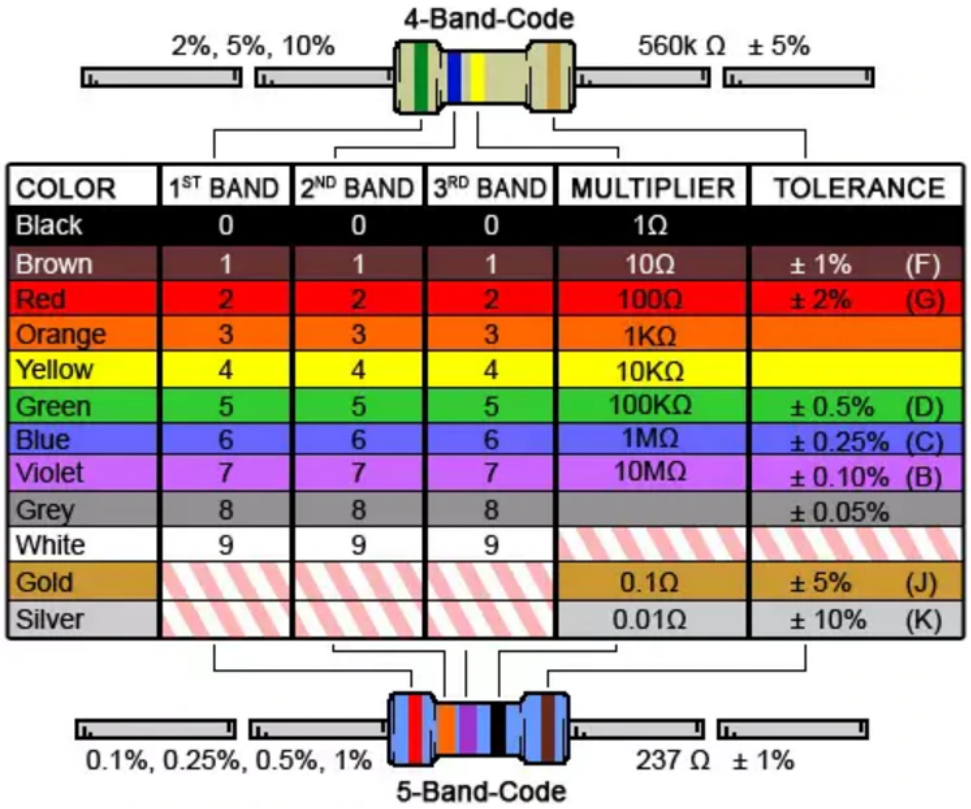


Figure 10: Paralel association: $\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$

Resistors II



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

Figure 11: How to read a resistor

Toggle Components

They toggle the loop where they are placed, opening or closing said loop.

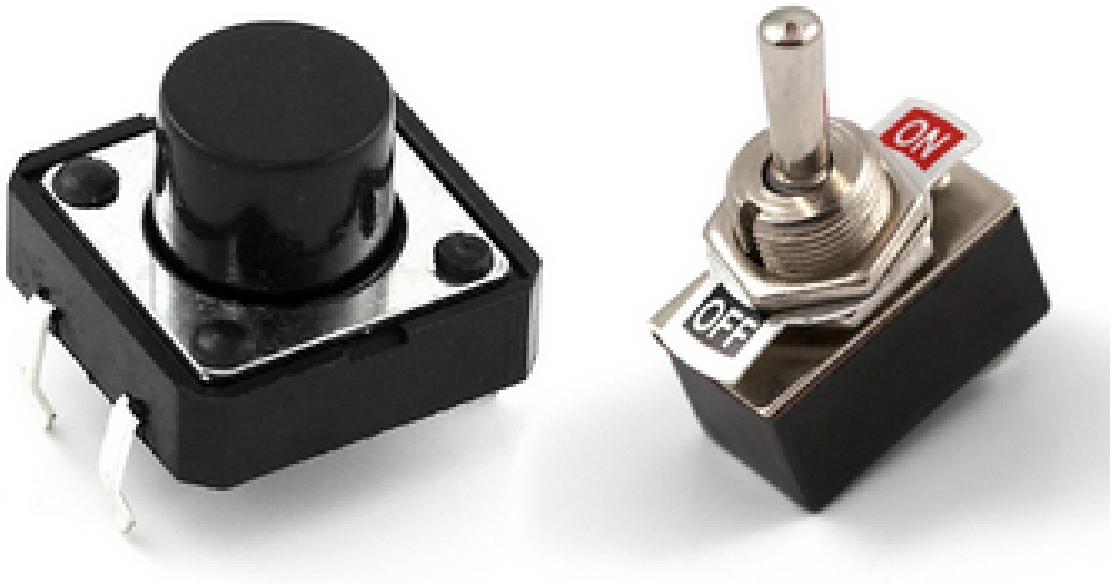


Figure 12: A press button and a toggle switch

Capacitors in a DC circuit

Capacitors are components with relevant capacitance.

- **Capacitance**(SI: Farad): The ability of a material to store electrical charge. In a DC circuit:

$$C = \frac{q}{U}$$

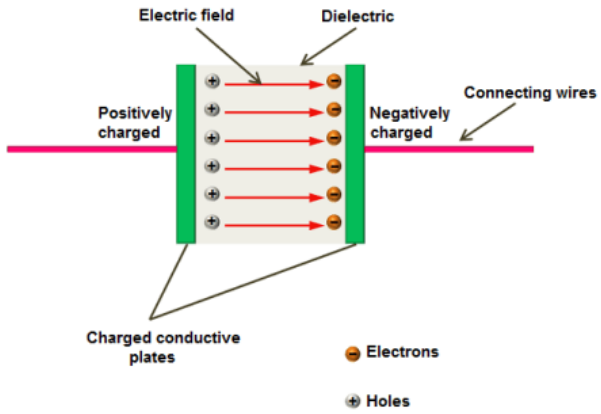


Figure 13: A capacitor schematic

Why is this relevant?. . . .

A pratical example - the RC circuit

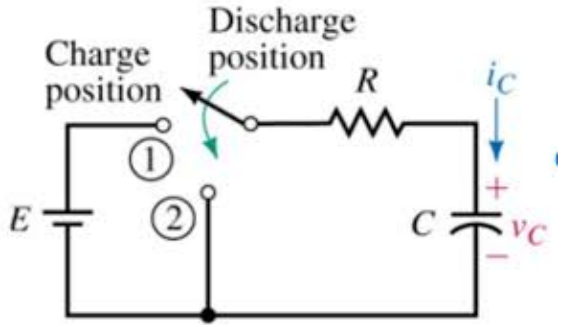


Figure 14: A resistor-capacitor circuit

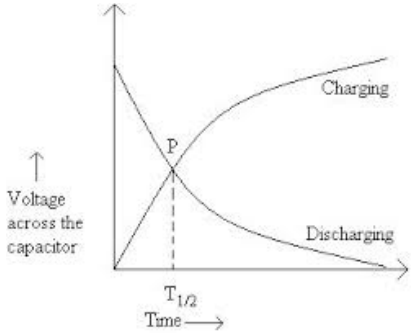


Figure 15: The capacitor's charge and discharge graphs with $\tau = RC$

And capacitors have many more appliances such as filtering, shielding, etc.

Diodes

Diodes are components that limit the flow of electrical current in a single orientation. Nowadays most diodes are composed of semiconductors in a p-n junction, which is also the material basis for another important component, the **transistor**.

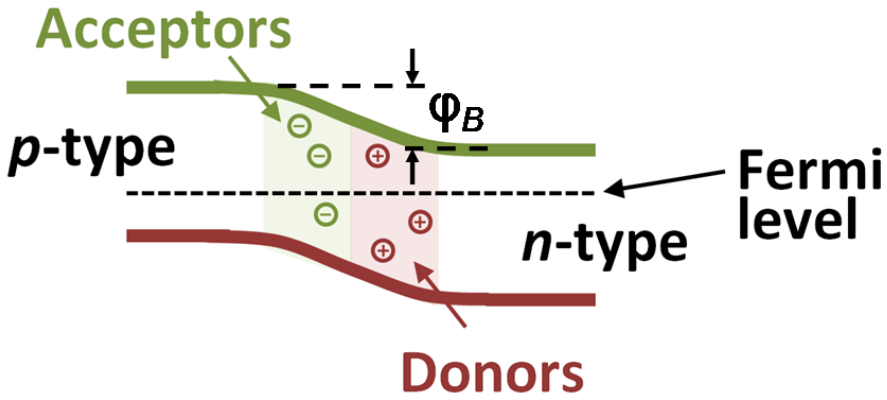


Figure 16: P-N junction

Diodes have a limited use in DC circuits, however we can use them to protect other components from inverted polarity, to construct diode logic gates, etc., or...

LEDs

Arguably the most used diodes in DC circuits.

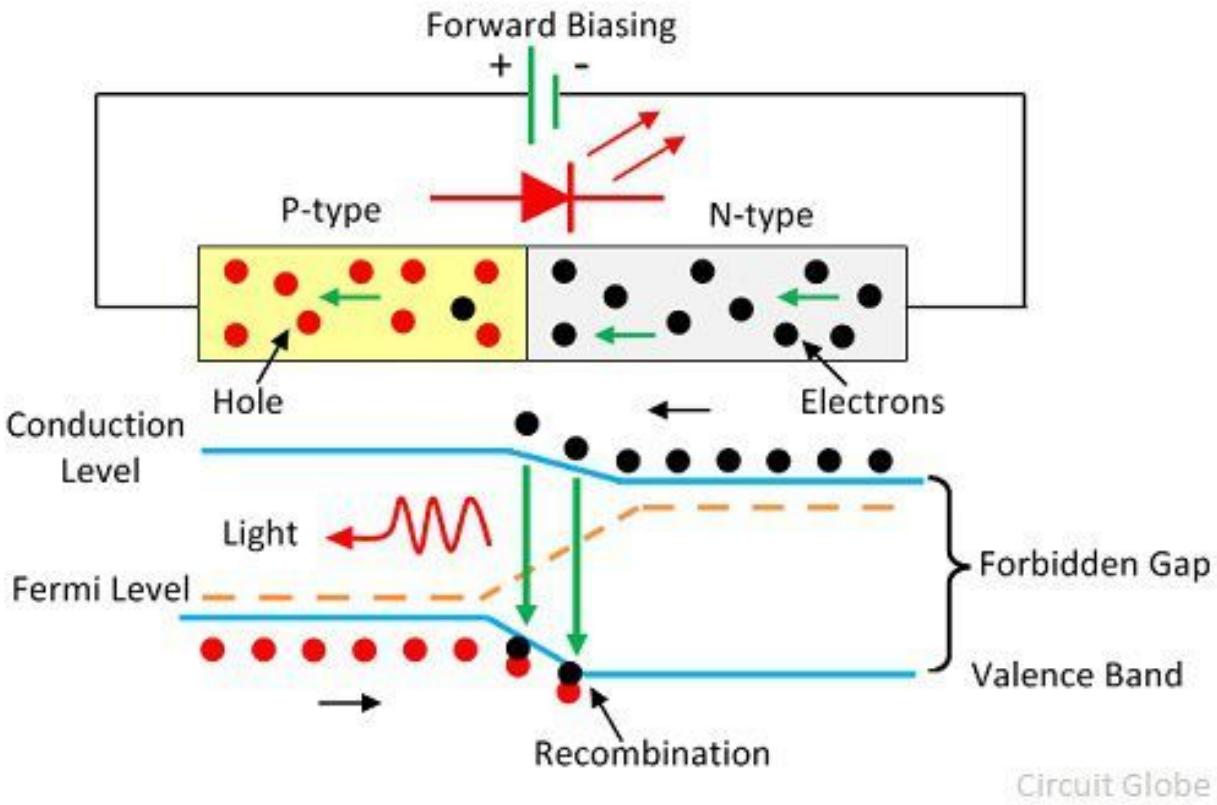


Figure 17: The inner workings of a LED

Integrated Circuits

Integrated circuits have a miriad of functions from amp-ops, to integrated diodes, to timers and even logic gates. They are composed of tiny MOSFE transistors.

Figure 18: The Signetic's 555 timer IC

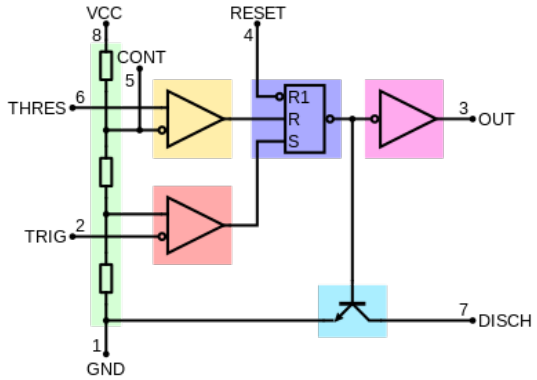


Figure 19: Logic diagram of the 555 timer

Integrated Circuits II

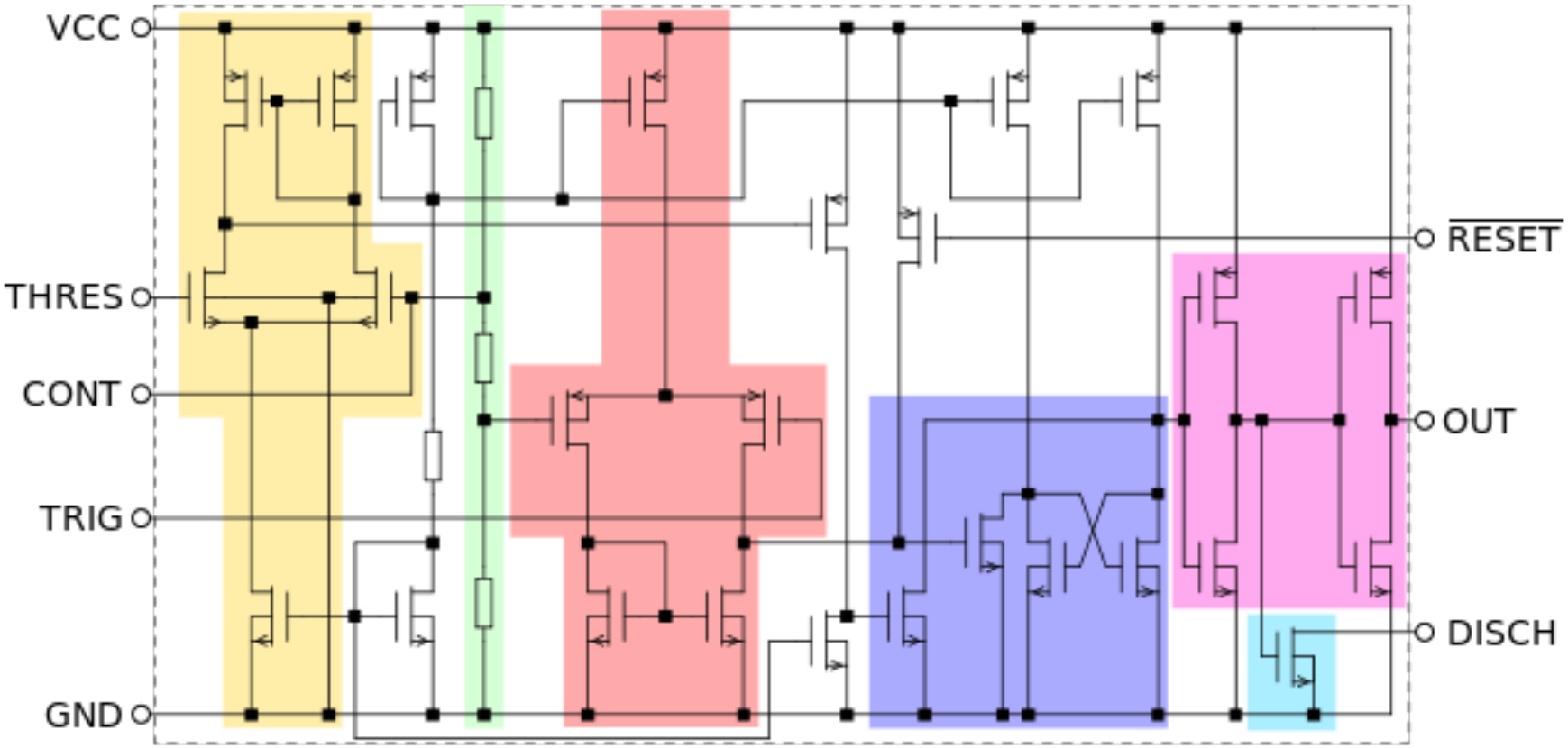


Figure 20: CMOS diagram of the 555 timer

Arduino

Arduino boards are microcontrollers under a CC-BY-SA license.

They allow the integration of digital and analogic control, UART bus communication, etc. into electronic circuits, expanding their potential.

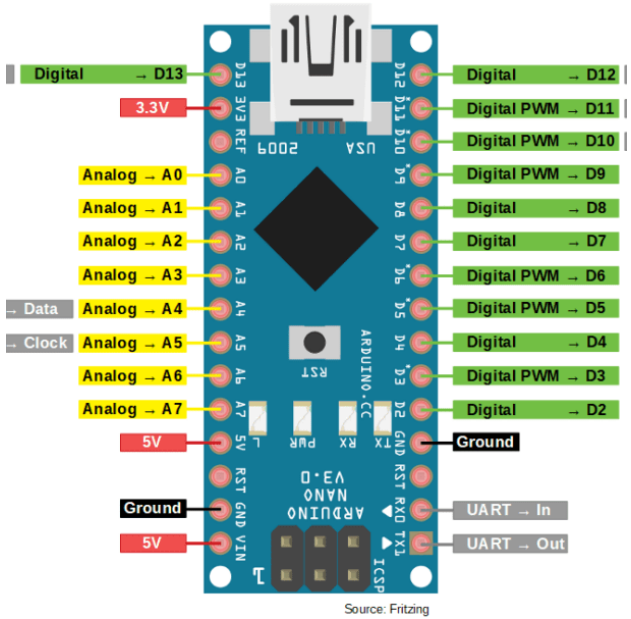


Figure 21: Arduino Nano pinout

Arduino IDE

The Arduino IDE, is an integrated development enviroment under LGPL.

It allows serial communication with a Arduino board, compilation of .ino files (based on C++) and flashing of said binaries into a Arduino Board. Recently a 2.0 version of the IDE has been released.

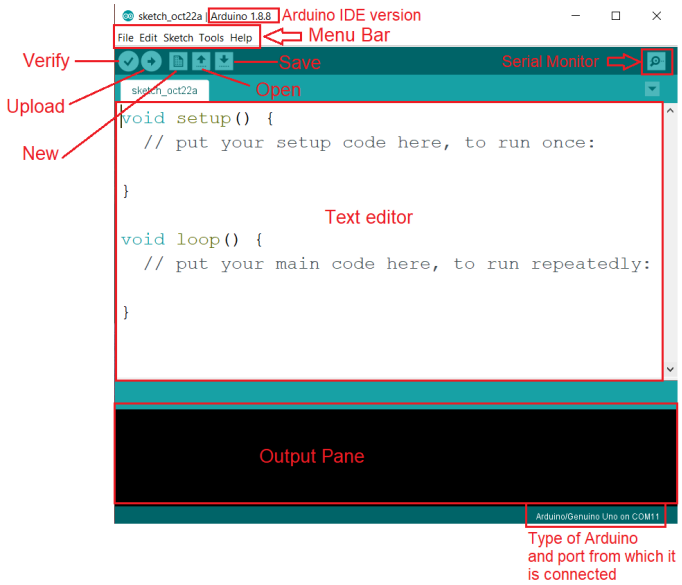


Figure 22: Arduino IDE

C++ vs Python

- C++ is compiled, while Python is interpreted.
- Statements end with a semicolon (;), brackets are used to define block of code, instead of indentation.
- Variables are statically typed, instead of dynamically typed.
- Lower level, closer to the hardware, allows for more control.

Variables

Python

```python
foo = 1
bar = 3.1415 # sample text
baz = True
```

C++

```cpp
int foo = 1;
float bar = 3.1415; // sample text
bool baz = true;
```

Functions

Python

```python
def add(a, b):
    return a + b
```

C++

```cpp
int add(int a, int b) {
    return a + b;
}
```

Conditional Statements

Python

```python
if bar > 0:
    return bar
elif bar < 0:
    return -bar
else:
    return 0
```

C++

```cpp
if (bar > 0) {
    return bar;
} else if (bar < 0) {
    return -bar;
} else {
    return 0;
}
```

While Loops

Python

```python
foo = 0
while foo < 10:
    foo += 1
    # do something
```

C++

```cpp
int foo = 0;
while (foo < 10) {
    foo += 1;
    // do something
}
```

For Loops

Python

```python
for foo in range(10):
    # do something
```

C++

```cpp
for (int foo = 0; foo < 10; foo += 1) {
    // do something
}
```

Controlling your Arduino with C++

Program Structure

```
void setup() {
    // code here runs once, when the board is powered on
}

void loop() {
    // code here runs repeatedly, forever
}
```

Serial

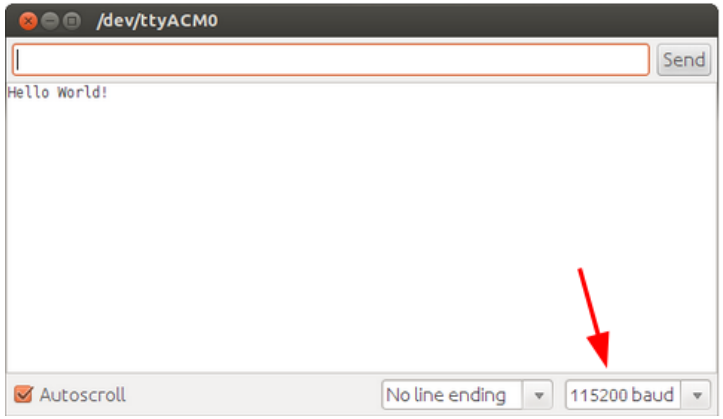


Figure 23: Serial Monitor

```
void setup() {
    Serial.begin(9600);
}

void loop() {
    Serial.println("Hello World!");
}
```

Delay

```
int secondsElapsed;

void setup() {
    Serial.begin(9600);
    secondsElapsed = 0; // start at 0
}

void loop() {
    Serial.print(secondsElapsed);
    Serial.println(" seconds have passed");
    secondsElapsed += 1;
    delay(1000); // wait for a second before repeating
}
```

Figure 24: It's always time for a JoJo reference

```
0 seconds have passed
1 seconds have passed
2 seconds have passed
3 seconds have passed
4 seconds have passed
5 seconds have passed
(...)
```

IO functions

- `pinMode(pin, mode)`: sets the mode of a pin to either `INPUT` or `OUTPUT`.
- `digitalWrite(pin, value)`: sets the value of a pin to either `HIGH` or `LOW`.
- `digitalRead(pin)`: returns the value of a pin, either `HIGH` or `LOW`.
- `analogWrite(pin, value)`: sets the value of a pin to a value between 0 and 255.
- `analogRead(pin)`: returns the value of a pin, between 0 and 1023.

LED Blink

```
void setup() {
    pinMode(13, OUTPUT); // set pin 13 as output
}

void loop() {
    digitalWrite(13, HIGH); // turn on the LED
    delay(1000); // wait for a second
    digitalWrite(13, LOW); // turn off the LED
    delay(1000); // wait for a second
}
```

Button

```
void setup() {
    pinMode(2, INPUT); // set pin 2 as input
    Serial.begin(9600);
}

void loop() {
    if (digitalRead(2) == HIGH) {
        Serial.println("Button pressed");
    }
}
```

Project