LEDs
Basic prototyping skills (Part 2)

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ITP, Fall, 2018
Idea presentation
LED is

Light-emitting Diode

A little device converts electrical current to light.
Parts of an LED

- Epoxy lens/case
- Wire bond
- Reflective cavity
- Semiconductor die
- Leadframe
- Anvil
- Post
- Flat spot
Gold wires
RGB LED
How it's made

https://www.youtube.com/watch?v=eGqKcVrGlic
Polarity

[Diagram of a light-emitting diode (LED) showing polarity with an anode (positive) and a cathode (negative).]
Review: LED symbols

It's Diode! Not LED!
Turn on the LED
LED characteristic

LED is a diode.

Too much current will kill it.
Review of some physics

Ohm's Law

\[ I = \frac{V}{R} \]

Electric current = Voltage / Resistance
Take a look at a real LED

This is example of red LED

This graph shows how much current will flow through LED at certain voltage.

For most LED look like this, don’t use more than 20mA.
Why Arduino pin hasn’t burn my LED?

You may connect to LED to Arduino directly. Both of them may survive.

But it is not a good practice.
Wait...
Let’s test
Take a look at ATMega328p (UNO’s core)

When Arduino is trying to supply more current, voltage on that pin will drop.

As a result the current and voltage of Arduino and LED will match.
Benefits of using a resistor

It will limit current at desired level.

Resistor is not sensitive to heat.
Problem of not using a resistor

LED only uses around 2~3V.

Arduino Uno uses 5V.

So the extra voltage will be applied to Arduino and generate heat.

If you connect too many leds, Arduino may overheat.
Choose a proper resistor

\[ I = \frac{V}{R} \]

\[ R = \frac{V}{I} = \frac{3.3 \text{V}}{5 \text{mA}} = 660 \text{ ohm} \]

\[ R_{\text{resistor}} = 660 \text{ ohm} - R_{\text{LED}} \]

What's the resistance of an LED?
The resistance of LED

Not constant.

Do NOT try to measure an LED’s resistance with a multimeter.
Common misunderstanding: Ohm’s law is always true

Ohm's law is an **empirical law** relating the voltage $V$ across an element to the current $I$ through it:

$$I \propto V$$

This law is not always true:

- false for diodes, batteries, and other devices whose conductance is not constant. → **non-ohmic parts**
- true for wires and resistors (assuming that other conditions, including temperature, are held constant). → **ohmic parts**
Review: Ohm’s law

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship:

\[ I = \frac{V}{R}, \]
Opt.1: Accurate way to calculate

If we want 5mA through LED

Resistor follows Ohm’s law:
I=V/R

Resistor and LED are in series:
VR+VLED=3.3V
Opt.1: Accurate way to calculate

From the graph, we know the voltage drop on LED will be 1.95V with 5mA current.

\[ V_R = V_{LED} = 3.3V - 1.95V = 1.35V \]

\[ R_{resistor} = \frac{V}{I} = \frac{1.35V}{5mA} = 270 \text{ ohm} \]
Opt.2: Quick way to calculate

We can read the forward voltage and assume the voltage drop is always 2.1V

This is an approximation to accelerate calculation
Opt.2: Quick way to calculate

In simplified model:

We have $(3.3V-2.1V) = 1.2V$ voltage on resistor.

And the resistor we need is $1.2V/5mA = 240$ ohm

Pretty close.
Question

if I have a resistor, how to know if it will work with my LED?

eg. a green LED and 200 ohm resistor:

We will have 3.3V-2.1V=1.2V on resistor

Current in circuit will be 1.2V/200 ohm=6mA < 20mA

It is safe. It is up to your application if it is right brightness.
**Voltage drop on LEDs**

LED with color on red side of rainbow has lower forward voltage

<table>
<thead>
<tr>
<th>LED Color</th>
<th>Forward Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>2.0</td>
</tr>
<tr>
<td>Yellow</td>
<td>2.1</td>
</tr>
<tr>
<td>Green</td>
<td>2.1</td>
</tr>
<tr>
<td>Blue</td>
<td>3.5</td>
</tr>
<tr>
<td>White</td>
<td>3.5</td>
</tr>
<tr>
<td>Warm- White</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Quiz

With white LED and 220 ohm resistor in kit on 5V Arduino, how much current you get?

Write Down your answer.
**Hands on**

Connect LED and resistor between 11 and GND.

```cpp
void setup() {
    pinMode(11, OUTPUT);
    digitalWrite(11, HIGH);
}

void loop() {
}
```

Use multimeter to measure current. See if it matches your calculation.
Why White and Blue LED so similar

Blue LED + yellow phosphor = White LED

White light can be produced by combining the wavelengths of yellow and blue light only. Sir Isaac Newton discovered this effect when performing colour-matching experiments in the early 1700s.
How to test if LED works.

Use diode function in multimeter.

Connect Red probe to anode (Positive) of LED
Connect Black probe to cathode (Negative) of LED

You should see LED have a dim light. Also you should see voltage drop on LED. If you are using a low-end meter, you may not get a reading.
LED Brightness Control
Flicker fusion

If a LED flickers fast enough, it looks steady.

AnalogWrite on Arduino has a cycle of 490Hz
Review: AnalogWrite

Most low-cost microcontroller can not output other than High or Low.

But it can output a square wave to mimic analog value.
Review: Duty cycle

Duty cycle is ratio between pulse and period

When LED looks steady, duty cycle affects brightness.
Physical and perceived brightness

Steven’s Power law

\[ S = c \cdot I^n \]

Sensing level = \( c \cdot \text{Brightness}^{0.33} \)
Physical and perceived brightness

you will need 8 times candle for double brightness
Look up table

<table>
<thead>
<tr>
<th>Perceived Brightness level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linearized PWM value</td>
<td>0.25</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td>Corrected PWM value</td>
<td>0.015</td>
<td>0.125</td>
<td>0.422</td>
<td>1</td>
</tr>
</tbody>
</table>

For example: $\frac{1}{4}$ of brightness

Linearized PWM value = $\frac{1}{4} = 0.25$

Corrected PWM value = $\frac{1}{4} \times \frac{1}{4} \times \frac{1}{4} = 0.015$
You can check the code on github

https://github.com/DeqingSun/Prototyping-Electronic-Devices/blob/master/class04/Arduino_01_brightness/Arduino_01_brightness.ino
Use Array in Arduino
Use array and loop can reduce code size

```cpp
bool useCorrectedPWM = true;
int LEDpin = 11;

void setup() {
}

void loop() {
  if (useCorrectedPWM) {
    analogWrite(LEDpin, 155);
    delay(125);
    analogWrite(LEDpin, 31);
    delay(125);
    analogWrite(LEDpin, 47);
    delay(125);
    analogWrite(LEDpin, 63);
    delay(125);
    analogWrite(LEDpin, 79);
    delay(125);
    analogWrite(LEDpin, 95);
    delay(125);
    analogWrite(LEDpin, 111);
    delay(125);
    analogWrite(LEDpin, 127);
    delay(125);
    analogWrite(LEDpin, 143);
    delay(125);
    analogWrite(LEDpin, 159);
    delay(125);
    analogWrite(LEDpin, 175);
    delay(125);
    analogWrite(LEDpin, 191);
    delay(125);
    analogWrite(LEDpin, 207);
    delay(125);
    analogWrite(LEDpin, 223);
    delay(125);
    analogWrite(LEDpin, 239);
    delay(125);
    analogWrite(LEDpin, 255);
    delay(125);
  }

  uint8_t ledBrightnessPower[16] = {1, 1, 2, 4, 8, 13, 21, 32, 45, 65, 97, 145, 233, 377, 625, 1025};

  void setup() {
  }

  void loop() {
    for (uint8_t i = 0; i < 16; i++) {
      analogWrite(LEDpin, ledBrightnessPower[i]);
      delay(125);
    }
  }
```
How array is processed in Arduino

Arduino Chip (Uno)

Data Memory
(RAM, 2KB)

Program Memory
(Flash, 32KB, Read only)

CPU

Arduino _02_brightness_array

```c
int LEDpin = 11;

uint8_t ledBrightnessPower[16] = {1, 1, 2, 4, 8, 13, 21, 32, 45};

void setup() {
}

void loop() {
    for (uint8_t i = 0; i < 16; i++) {
        analogWrite(LEDpin, ledBrightnessPower[i]);
        delay(125);
    }
}
```
Put array in program memory

1. Use pgmspace library for this feature
2. Add "const" and "PROGMEM"
3. Use "pgm_read_byte" to fetch value from program memory
Example, if you want to build a music box

Your melody data is large and won’t change

You can store them in program memory
Keep String in program space

F() syntax can be used to avoid spending RAM on Strings

```
Serial.println("This string will be stored in flash memory");
```
Will take 43 bytes of data memory

```
Serial.println(F("This string will be stored in flash memory"));
```
Will take 0 bytes of data memory
Mounting LED
Use LED holder for LED on panel
Light guide of LED
Diffuser, the secret of making great LED project

Triangle Attractor by Micah Scott

Ecstatic Epiphany by Micah Scott
2 methods

Diffusive materials

Reflective cavities
2 common structures of diffusive materials

Matte surface
- Scatter on the surface
- p95

Light diffusing beads
- Scatter through the material
Diffusive materials: Acrylic

Advantages:
Superior optical properties
- highest light transmission
- easy to fabricate
- UV stable for outdoor use
Diffusive materials: Acrylic

Widely used in:
- Commercial lighting fixtures
- Point-of-purchase displays
- Back-lit signs
Diffusive materials: Acrylic

Disadvantages:
- Easy to leave scratches
- Easy to break
- Not flexible
- Is flammable
Diffusive materials: Polycarbonate

Advantages:
- Increased toughness
- More durable than acrylic
- Good flammability characteristics
- Flexibility and formability
Diffusive materials: Polycarbonate

Widely used in:
- Lighting fixtures
- Automotive instrument panels
- Film industry
Quiz: what’s the diffuser material?
Translucent acrylic
Quiz: what’s the diffuser material?
Case study: Triangle Attractor

By Micah Scott
Case study: Ecstatic Epiphany

By Micah Scott
Where to buy

Canal Plastic Center
https://www.canalplastic.com/

Acrylite
http://www.acrylite.net/product/acrylite/en/Pages/default.aspx

B&H
https://www.bhphotovideo.com/

Inventables
https://www.inventables.com/technologies/light-diffuser-films
Be creative!
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10 min break
LED Cube
Build a 2*2*2 cube
Test every LED before soldering

You never know if anyone put a bad LED back on shelf.

Test before you solder.
Schematic

Connect top layer to pin12
Connect bottom layer to pin11

Connect 4 anode pins to Arduino’s pin 2,3,4,5
Bend Led’s legs
Bend Anode leg
Repeat until you have 4 bended Leds
smaller jig on bigger jig, place leds
Bend legs sideways to etched lines, solder
Trim legs & solder wire between top 2 Leds
Test four LEDs to see if they work.
Make another set of Led. Place Led on jig
Build support structure and place 2nd layer
Solder anodes together
Bend Cathodes and solder wires to extend
Plug cube to breadboard
We will talk about the code next class
Wrap Up
Next Class

Ways to light up multiple LEDs:
- Matrix
- Charlieplexing
- Smart LED

Bring:
- your 2*2*2 LED cube
- Arduino board
- a breadboard
- a multimeter