PHYSICAL COMPUTING 4: ANALOG INPUT & RESISTIVE SENSORS

CSE 599 Prototyping Interactive Systems | Lecture 5 | April 15

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DESIGN USE BUILD

MAKEABILITY LAB

PAUL G. ALLEN SCHOOL
OF COMPUTER SCIENCE & ENGINEERING

UNIVERSITY of WASHINGTON

PHYSICAL COMPUTING 4

TODAY'S LEARNING GOALS

Working with **analog input?**

What is **a knob/trim potentiometer** and how to use it?

What is **a slide potentiometer** and how to use it?

What are **variable resistive sensors** and how to use them?

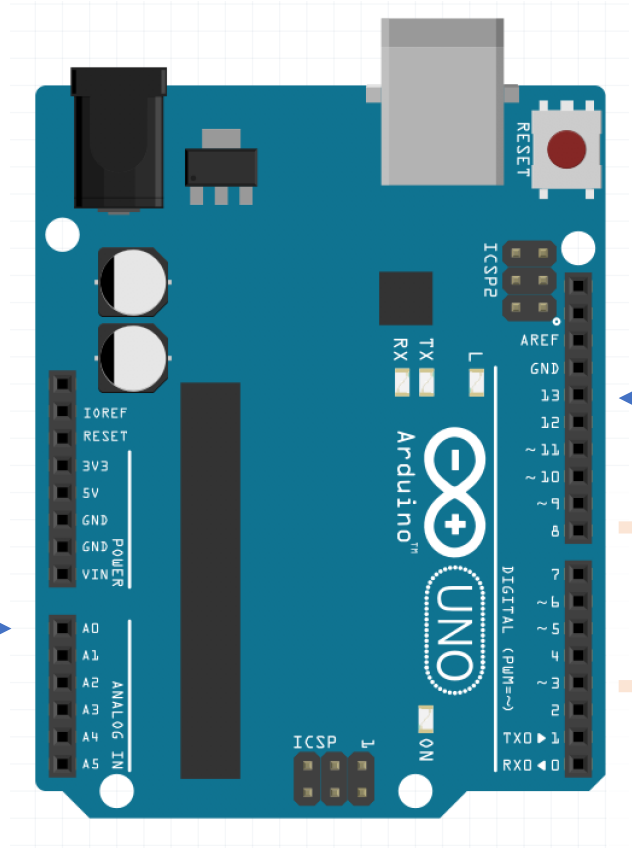
Understanding the **importance of voltage dividers** when working with analog input (and the relevancy of Ohm's law!)

DIGITAL AND ANALOG OUTPUT

Now we are going to switch from talking about output to talking about input

Analog Input on A0

Reads in any value between 0V or 5V using the analogRead function. In this case, the value of a photocell



Digital Input on pin 13

Reads in a digital input signal (anything below 2.5V converted to LOW, anything above 2.5V converted to HIGH). In this case, the value of switch.

Digital Output on pin 8

Writes out 0V or 5V using digitalWrite function. In this case, turning on and off an LED.

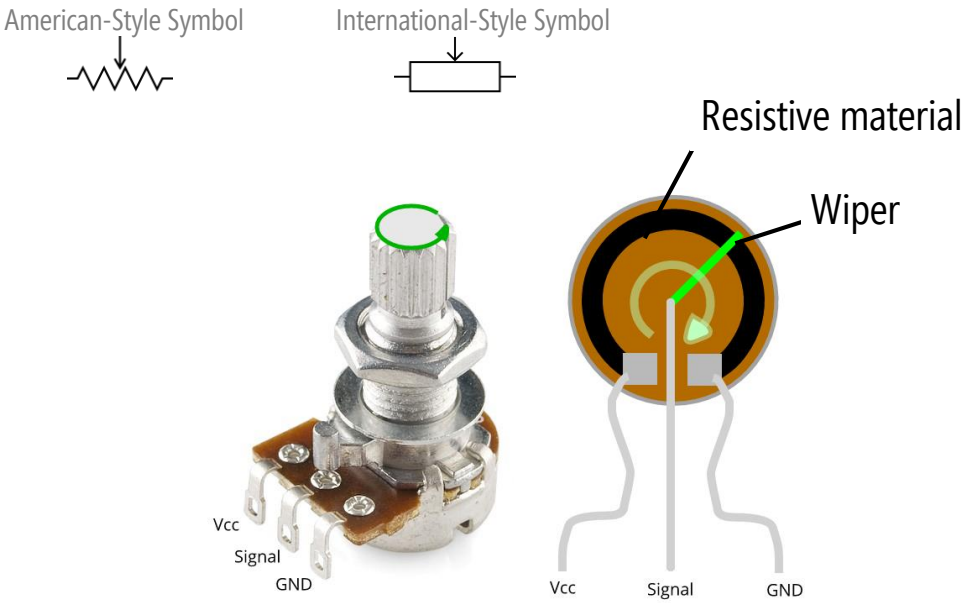
Analog Output on pin 3

Writes out any value between 0V or 5V using analogWrite function. In this case, vibrating a motor (where strength of vibration proportional to voltage). Only pins with a tilde ~ can be analog outputs.

REVISITING POTENTIOMETERS

VARIABLE RESISTORS

WHAT IS A POTENTIOMETER?



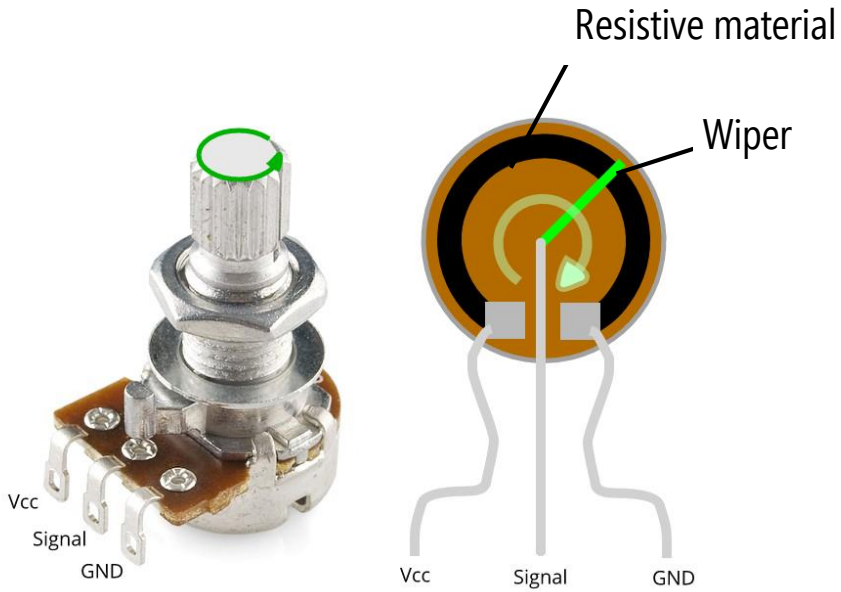
A three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider

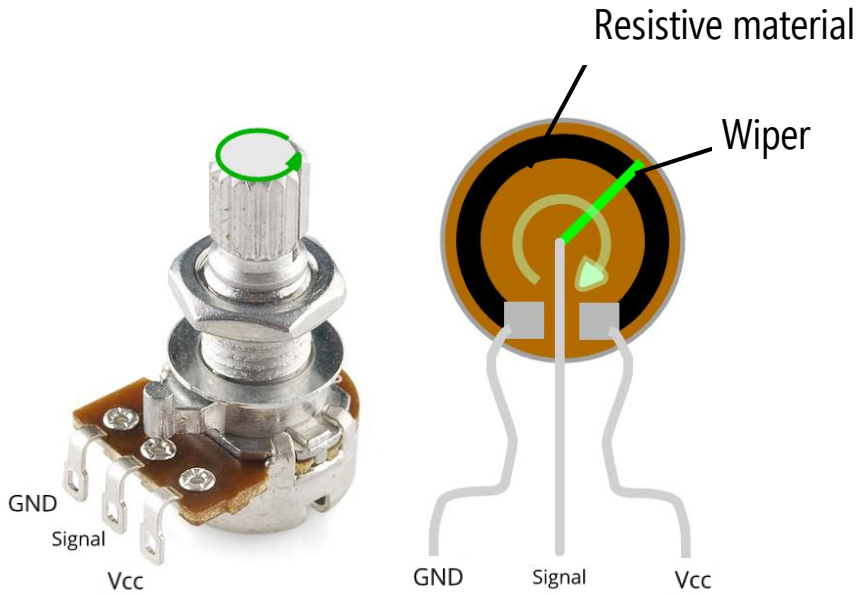
If only two terminals are used, the potentiometer acts as a **rheostat** or a two-terminal variable resistor

Source: https://en.wikipedia.org/wiki/Potentiometer

VARIABLE RESISTORS

POTENTIOMETERS CAN BE HOOKED UP IN EITHER ORIENTATION





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VARIABLE RESISTORS

POTENTIOMETER KNOBS

Source: https://en.wikipedia.org/wiki/Potentiometer

POTENTIOMETERS

INSIDE A POTENTIOMETER

Source: https://youtu.be/rUkrpqEmXb8

CTS EP086 500k

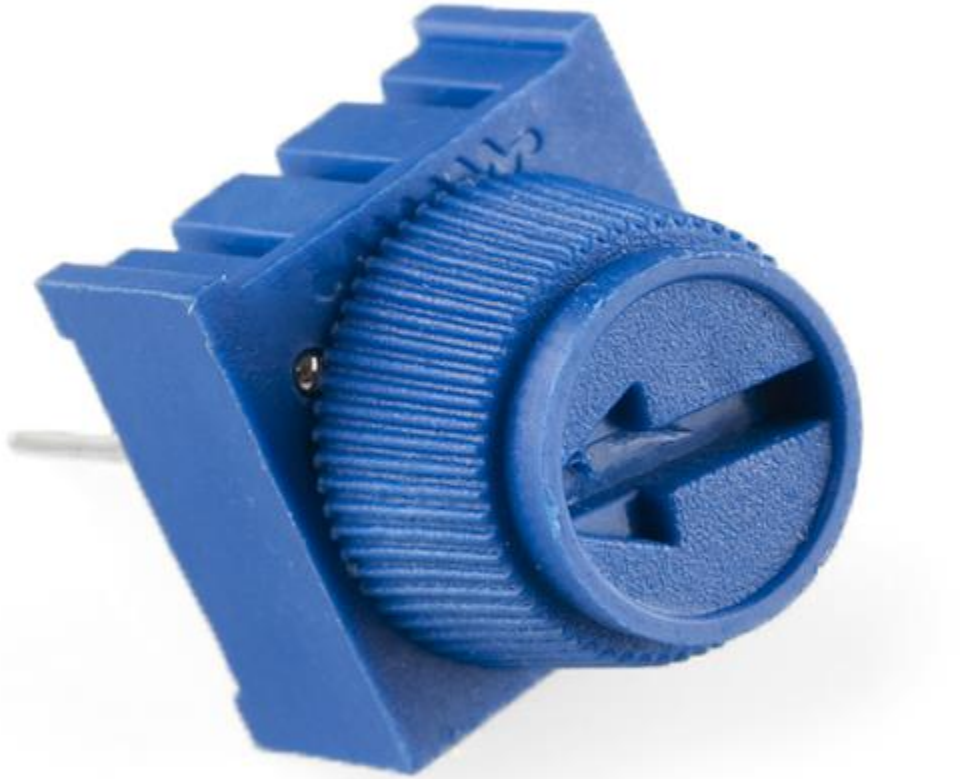
POTENTIOMETERS

LINEAR VS. EXPONENTIAL RESISTANCE

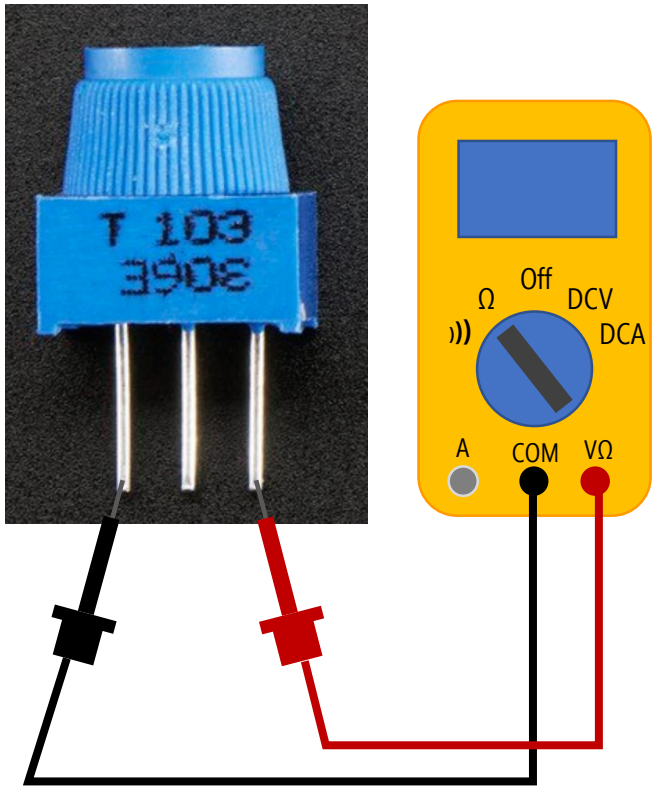
Source: https://youtu.be/rUkrpqEmXb8

VARIABLE RESISTORS

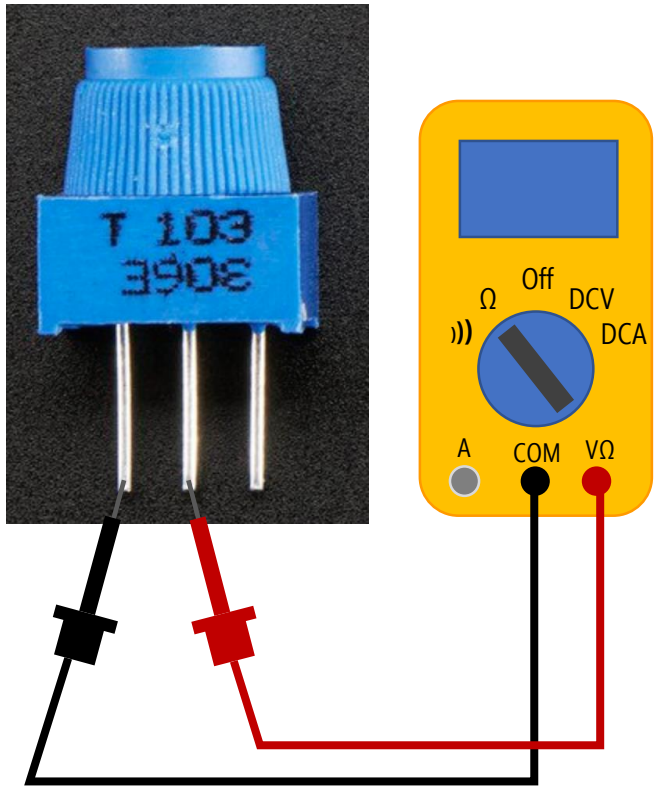
BREADBOARD-FRIENDLY TRIMPOT



ACTIVITY: EXPLORE THE POT WITH A MULTIMETER

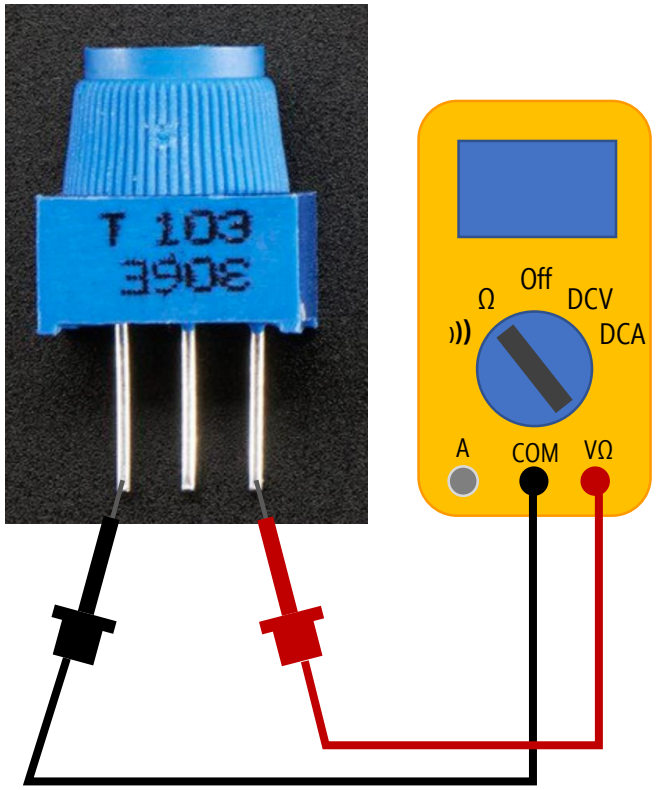


Hook up the **two outer legs** to the multimeter. What happens when you turn the knob?



Hook up the **middle** and an **outer leg** to the multimeter. What happens when you turn the knob?

ACTIVITY: EXPLORE THE POT WITH A MULTIMETER



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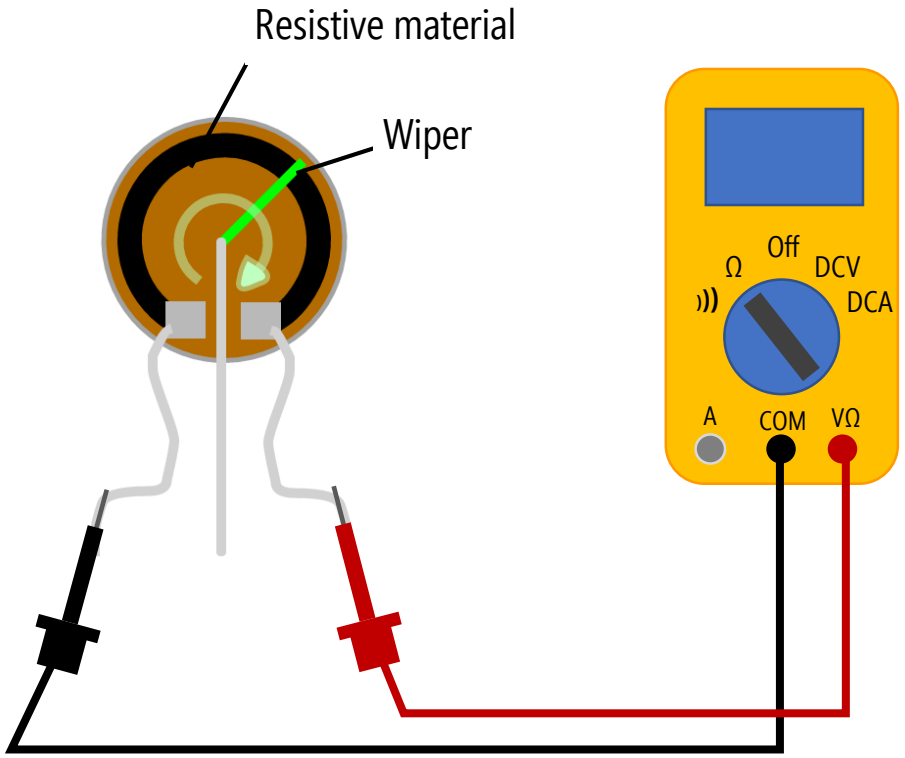
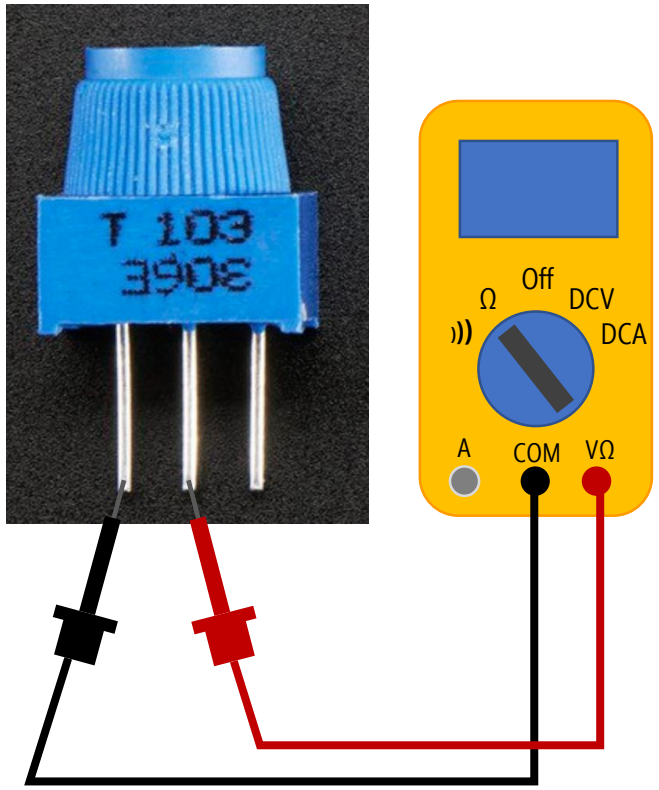


Answer: Nothing! The multimeter will always read the full max resistance of the potentiometer since you are measuring

ACTIVITY: EXPLORE THE POT WITH A MULTIMETER



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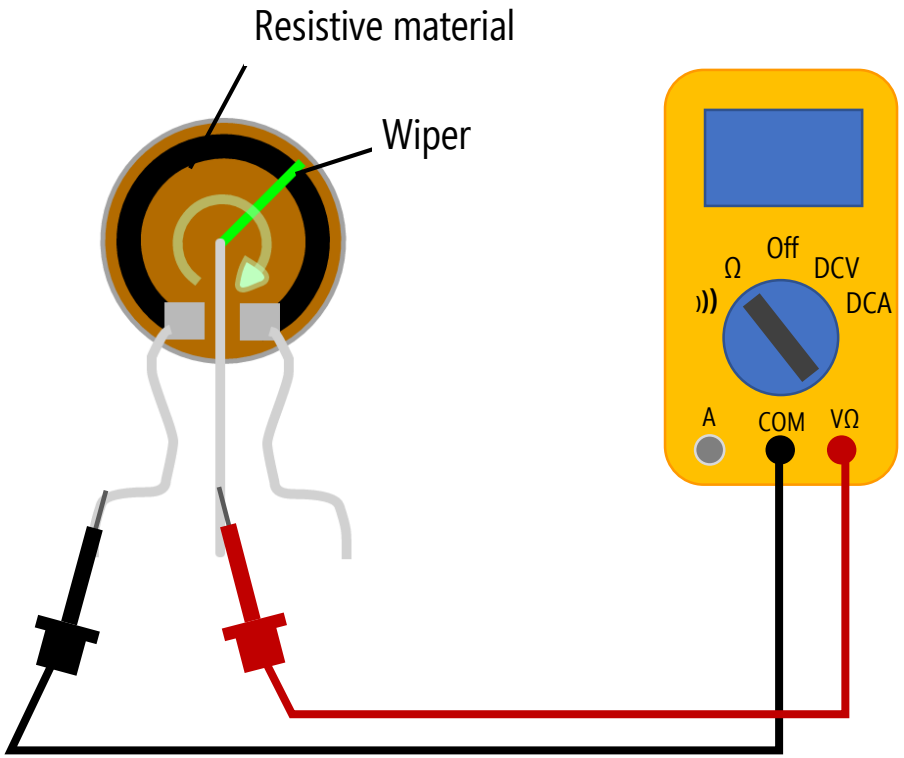
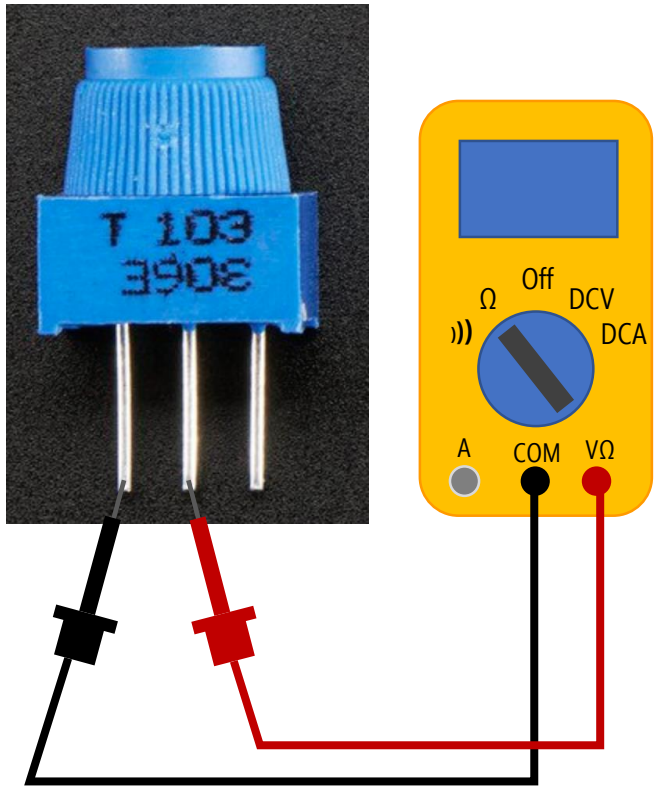
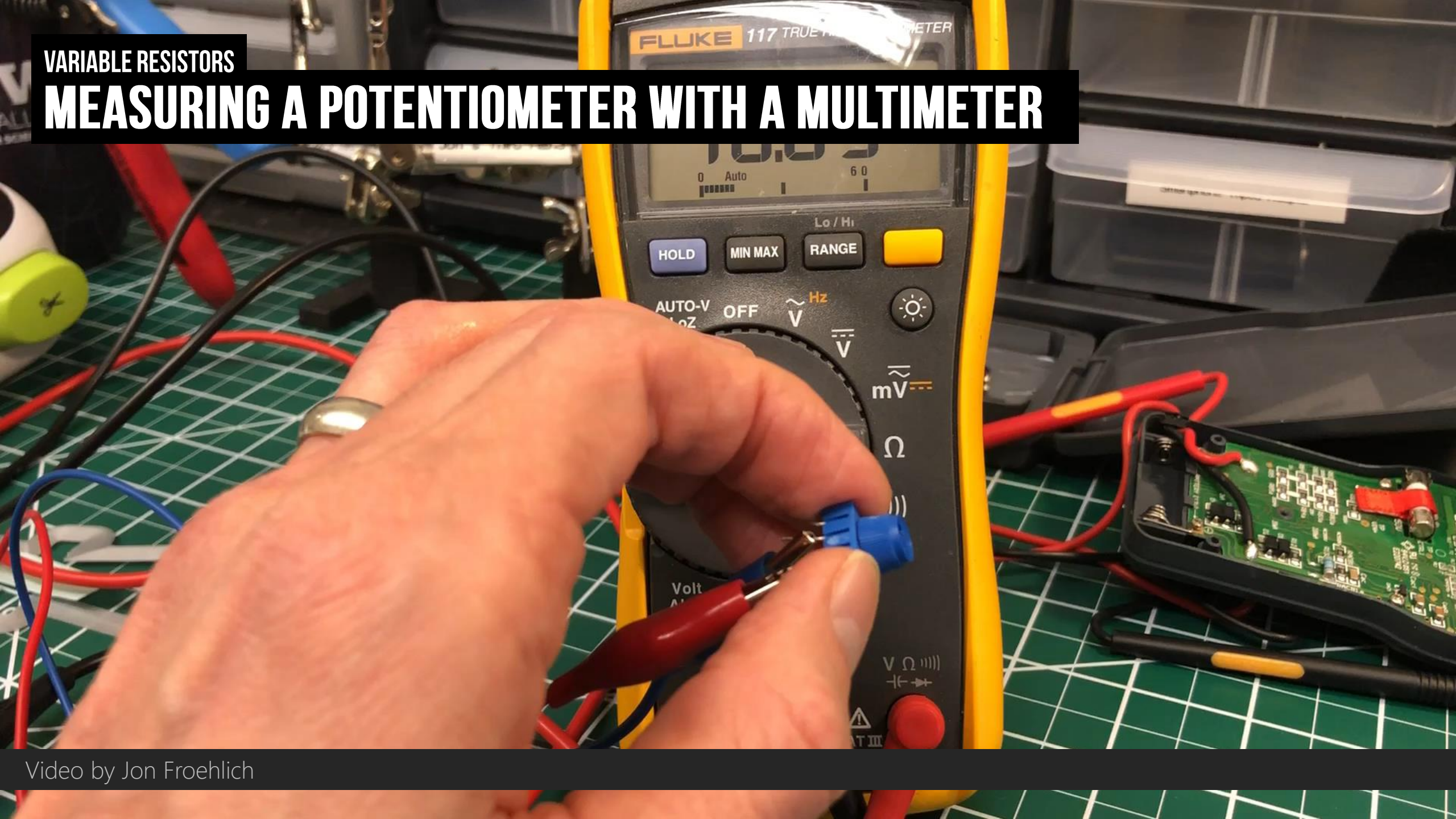




Answer: You'll see the resistance change based on the position of the knob. In this case, 0Ω with the knob all the way to the left, 5K Ω in middle, and 10KΩ with knob all the way to the right

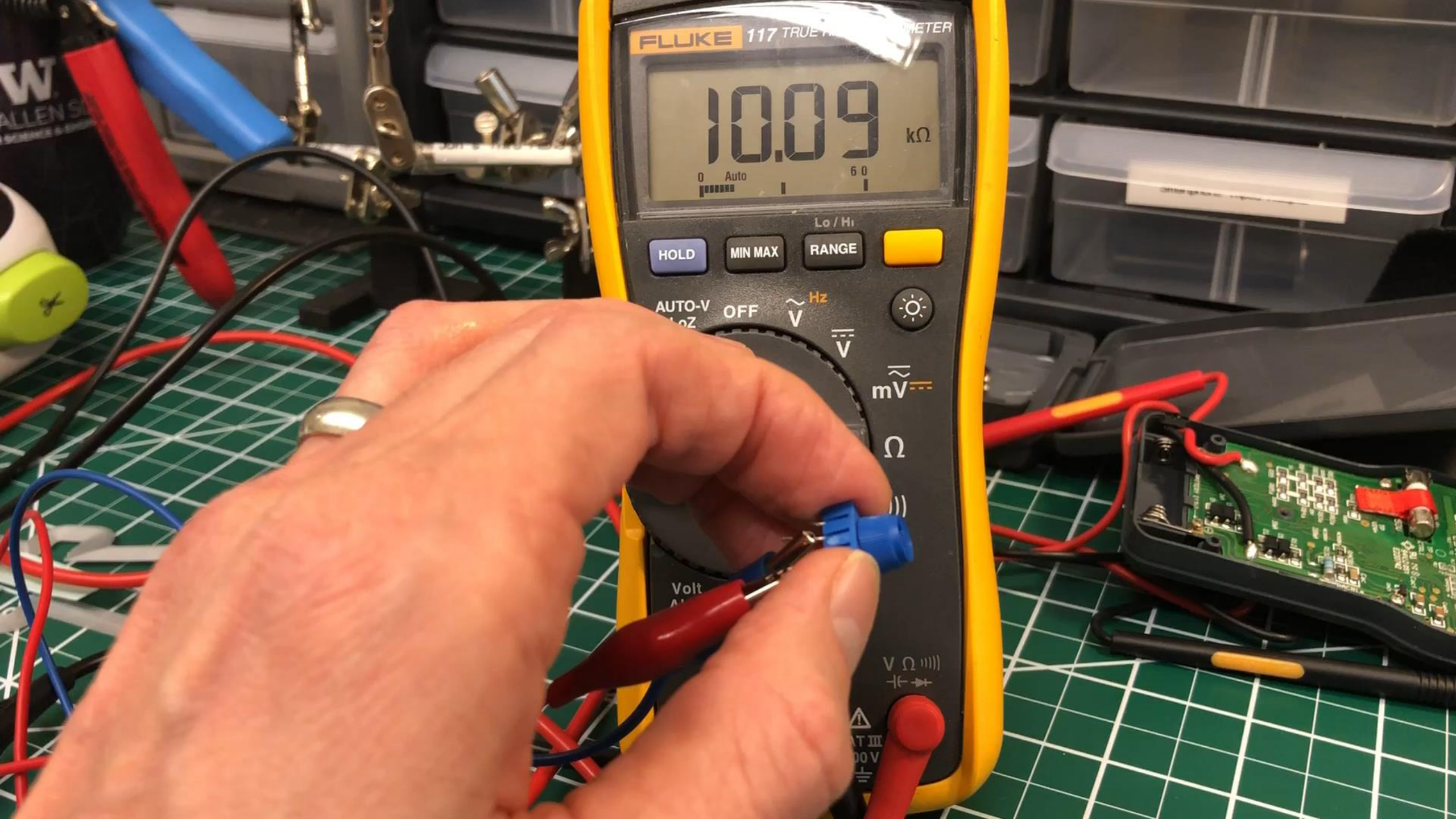
Hook up the **middle** and an **outer leg** to the multimeter. What happens when you turn the knob?



VARIABLE RESISTORS

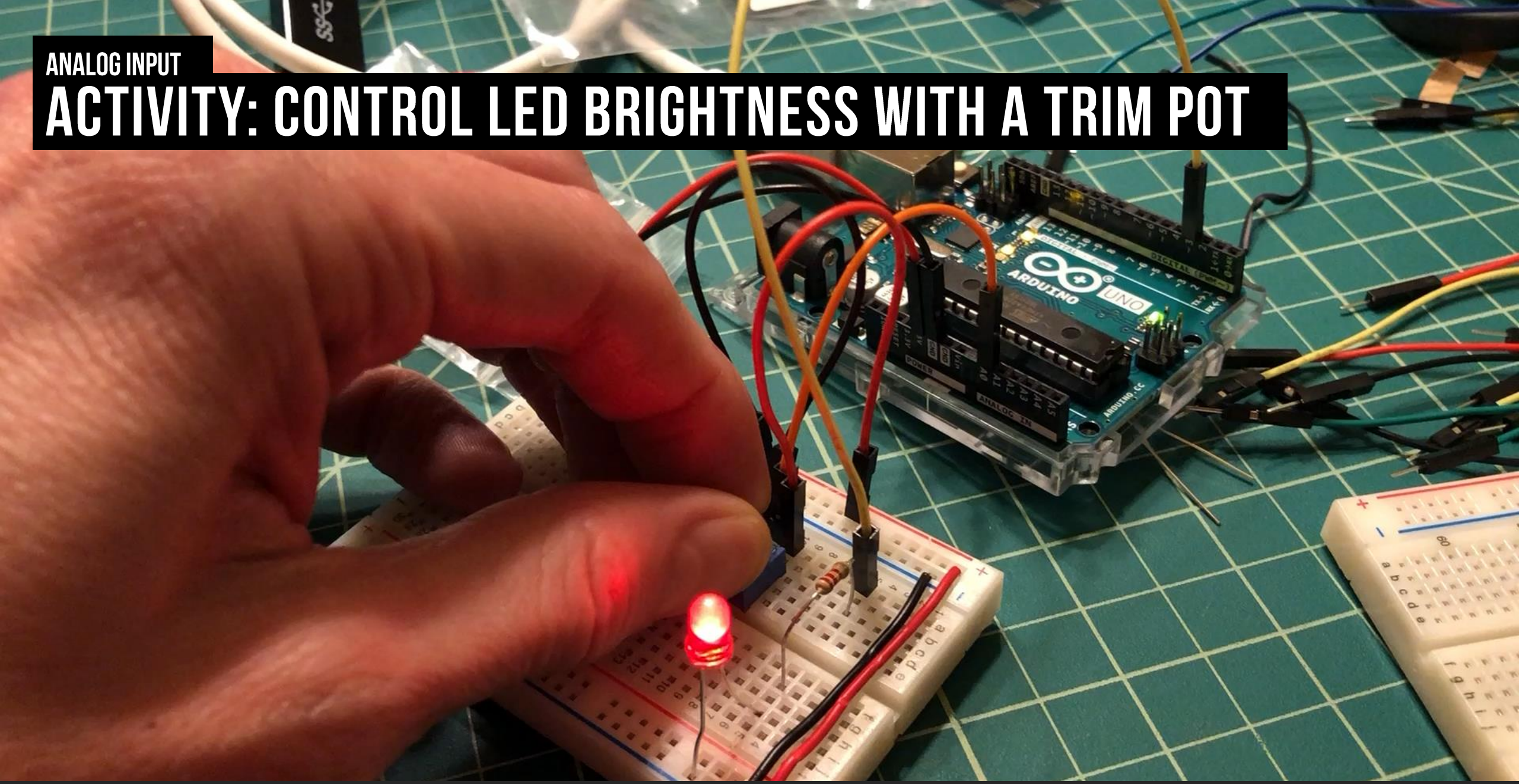
MEASURING A POTENTIOMETER WITH A MULTIMETER

Video by Jon Froehlich


FLUKE
10.09
kΩ
HOLD
MIN MAX
RANGE
Lo / Hi
AUTO-V
OFF
Hz
mV
Ω

ANALOG INPUT

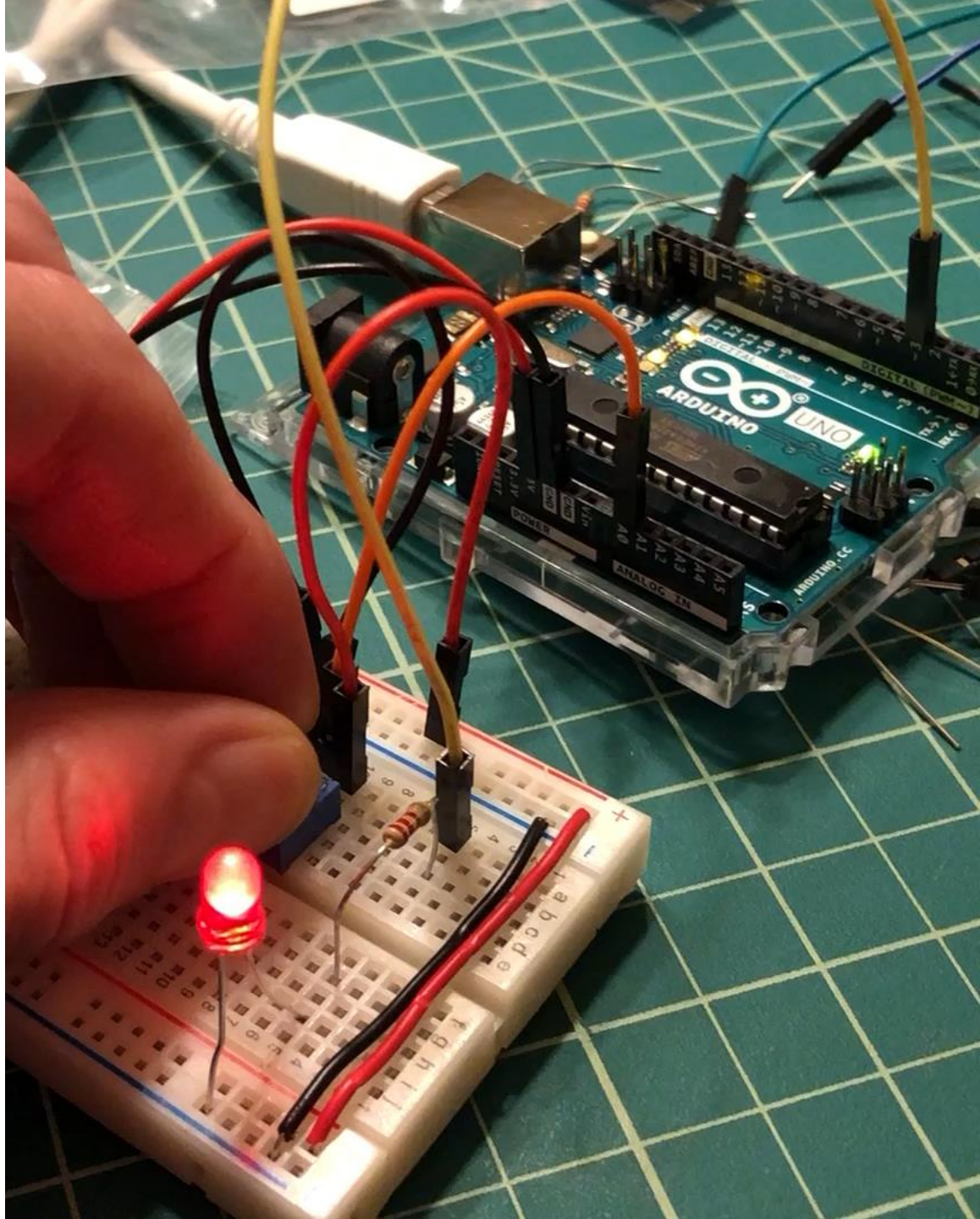
ACTIVITY: CONTROL LED BRIGHTNESS WITH A TRIM POT



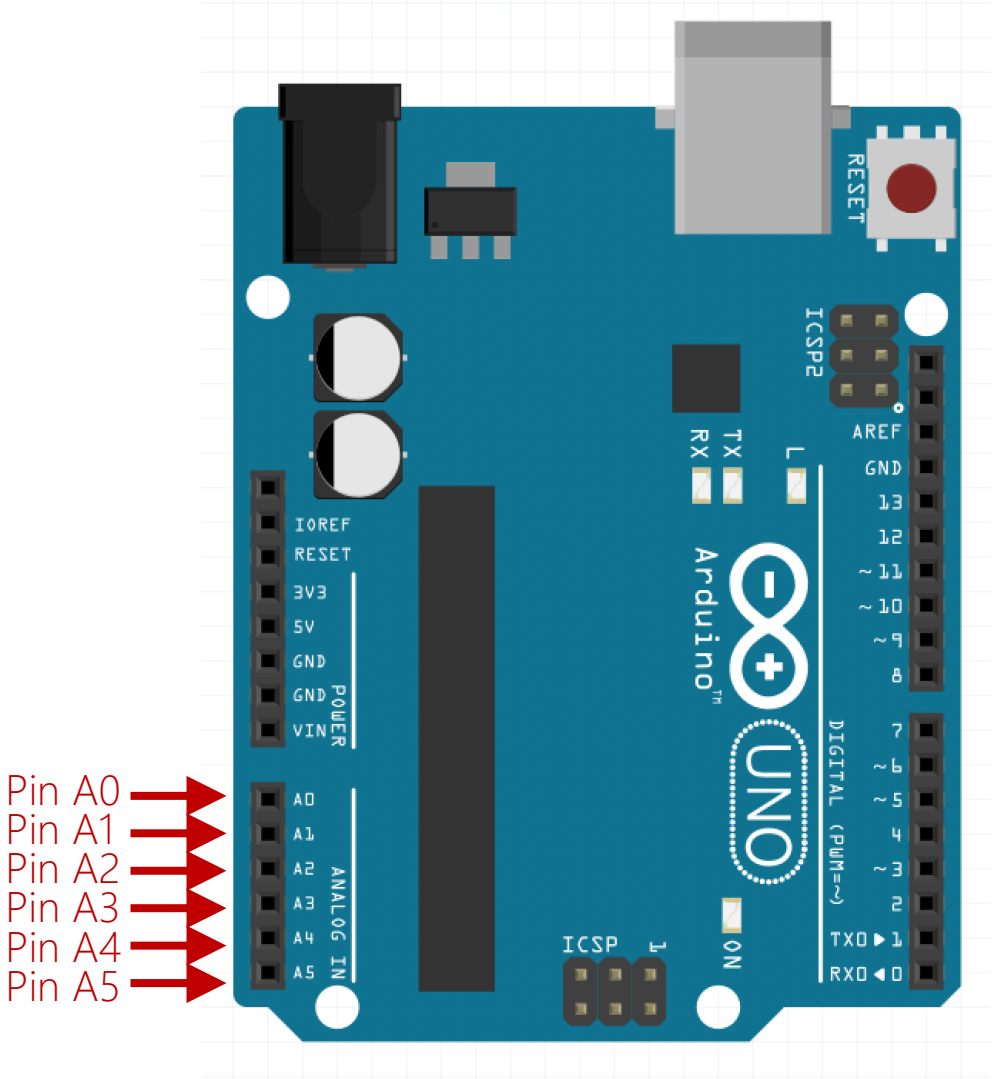
Video by Jon Froehlich

ACTIVITY: CONTROL LED BRIGHTNESS WITH TRIMPOT

Design circuit + software to read the potentiometer value on A0 and proportionally set the brightness of an LED on D3

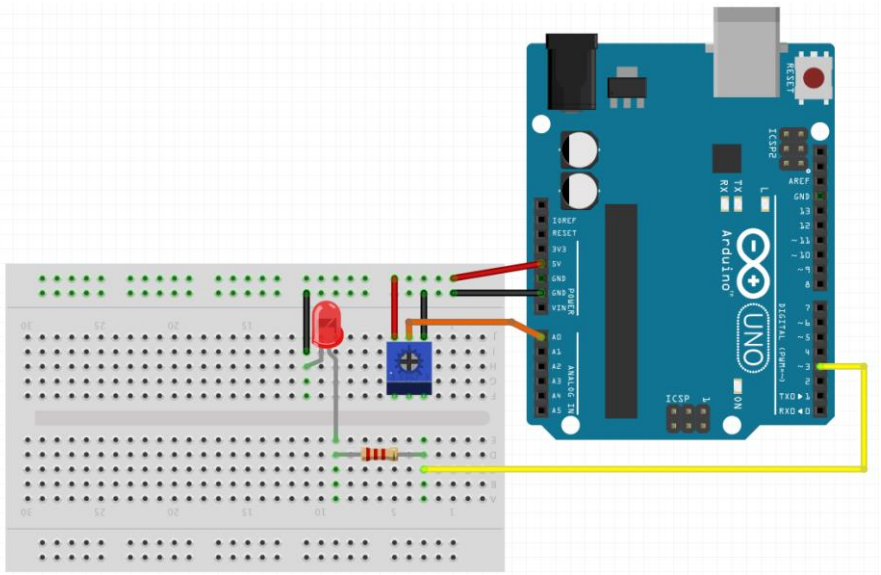


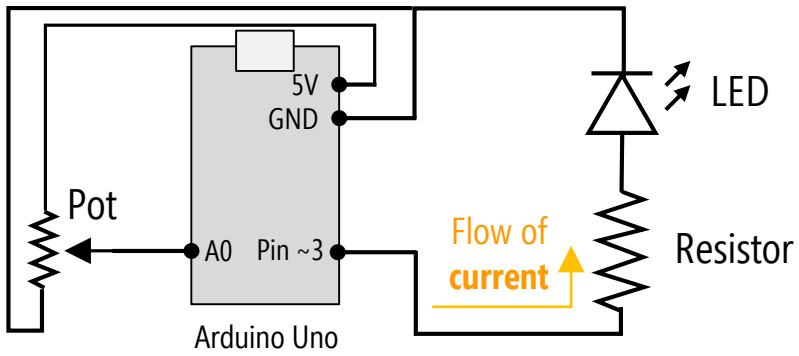
UNO AND LEONARDO BOARDS HAVE SIX ANALOG INPUTS



ACTIVITY: CONTROL LED BRIGHTNESS WITH POTENTIOMETER

Circuit: Fade LED on/off via pot value





Code: Fade LED on/off via pot value

TrimpotLED

```
// The Arduino Uno ADC is 10 bits (thus, 0 - 1023 values)
#define MAX_ANALOG_INPUT_VAL 1023

const int LED_OUTPUT_PIN = 3;
const int POT_INPUT_PIN = A0;

void setup() {
  pinMode(LED_OUTPUT_PIN, OUTPUT);
  Serial.begin(9600);
}

void loop() {

  // read the potentiometer value
  int potVal = analogRead(POT_INPUT_PIN);

  // the analogRead on the Arduino Uno goes from 0 to 1023. We need to remap
  // this value to the smaller range (0-255) since the analogWrite function can
  // only write out 0-255 (a byte--2^8). The map function provides a linear
  // mapping to do this (however, a better way would likely be some sort of
  // non-linear mapping given that perceived LED brightness is not linear with current,
  // perhaps logarithmic)
  int ledVal = map(potVal, 0, MAX_ANALOG_INPUT_VAL, 0, 255);

  // print the raw pot value and the converted led value
  Serial.print(potVal);
  Serial.print(",");
  Serial.println(ledVal);

  // write out the LED value. This value is translated to voltage by:
  // voltageVal = max_voltage * val/255 or voltageVal = 3.3V * val/255 in
  // the case of the RedBear Duo
  analogWrite(LED_OUTPUT_PIN, ledVal);

  delay(100);
}
```

ANALOG INPUT

int analogRead()

Reads the voltage from the specified analog pin & returns an integer (0 – 1023)

Syntax

`analogRead(pin)`

Parameters

`pin`: the analog pin to read from

Returns

An integer between 0 and 1023 (inclusive).

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// The Arduino Uno ADC is 10 bits (thus, 0 - 1023 values)
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const int LED_OUTPUT_PIN = 3;
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https://www.arduino.cc/reference/en/language/functions/analog-io/analogread/

ANALOG INPUT

int analogRead()

Reads the voltage value from the specified analog pin and returns it as an integer (0 – 1023)

Syntax

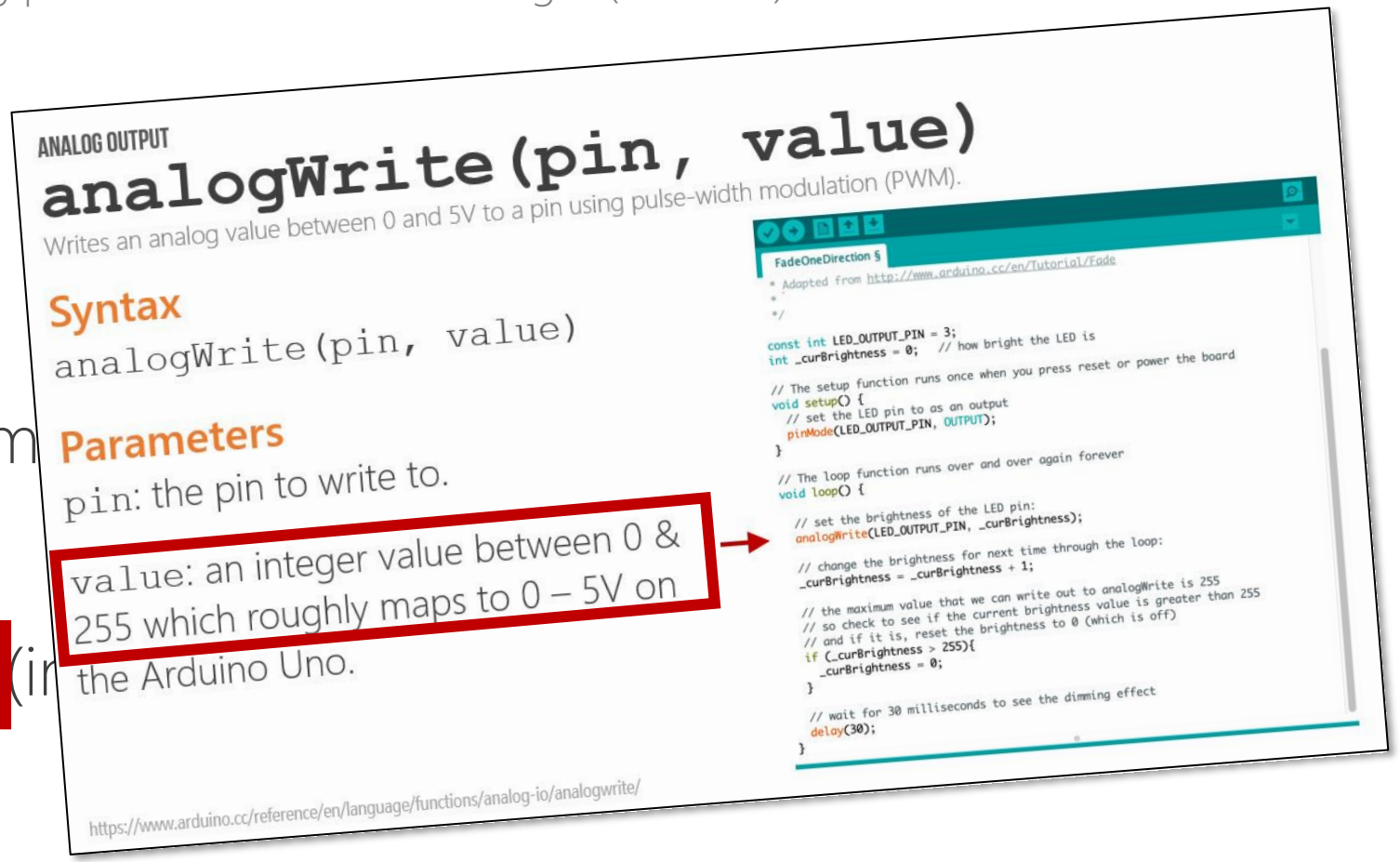
`analogRead(pin)`

Parameters

`pin`: the analog pin to read from

Returns

An integer between 0 and 1023 (in



https://www.arduino.cc/reference/en/language/functions/analog-io/analogread/

HELPER FUNCTION

map(value, fromLow, fromHigh, toLow, toHigh)

Remaps a number from one range to another. Warning: it does not constrain values to be within the range.

Syntax

`map(value, fromLow, fromHigh, toLow, toHigh)`

Parameters

`value`: the number to map

`fromLow`: the lower bound of the value's current range

`fromHigh`: the upper bound of the value's current range

`toLow`: the lower bound of the value's target range

`toHigh`: the upper bound of the value's target range

Returns

The mapped value

TrimpotLED

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https://www.arduino.cc/reference/en/language/functions/math/map/

ANALOG INPUT

`int analogRead()`

Reads the voltage value from the specified analog pin and returns it as an integer (0 – 1023)

ATmega microcontroller uses a **10-bit analog-to-digital-convert** (so, input voltages are mapped to 0-1023)

On a Uno or Leonardo, this yields a **resolution of 0.0049 volts** (5 volts / 1024 units)

The reading freq is about **~10,000Hz**

Reference > Language > Functions > Analog io > Analogread

analogRead()

[Analog I/O]

Description

Reads the value from the specified analog pin. Arduino boards contain a multichannel, 10-bit analog to digital converter. This means that it will map input voltages between 0 and the operating voltage(5V or 3.3V) into integer values between 0 and 1023. On an Arduino UNO, for example, this yields a resolution between readings of: 5 volts / 1024 units or, 0.0049 volts (4.9 mV) per unit. See the table below for the usable pins, operating voltage and maximum resolution for some Arduino boards.

The input range can be changed using analogReference(), while the resolution can be changed (only for Zero, Due and MKR boards) using analogReadResolution().

On ATmega based boards (UNO, Nano, Mini, Mega), it takes about 100 microseconds (0.0001 s) to read an analog input, so the maximum reading rate is about 10,000 times a second.

https://www.arduino.cc/reference/en/language/functions/analog-io/analogread/

`int analogRead():Tips/Warnings`

If the analog **input pin is not connected** to anything, the value returned by analogRead() will fluctuate based on a number of factors (*e.g.*, the values of the other analog inputs, how close your hand is to the board, *etc.*). Try it! ☺

https://www.arduino.cc/reference/en/language/functions/analog-io/analogread/; https://github.com/firmata/arduino/issues/334; http://forum.arduino.cc/index.php?topic=69675.0

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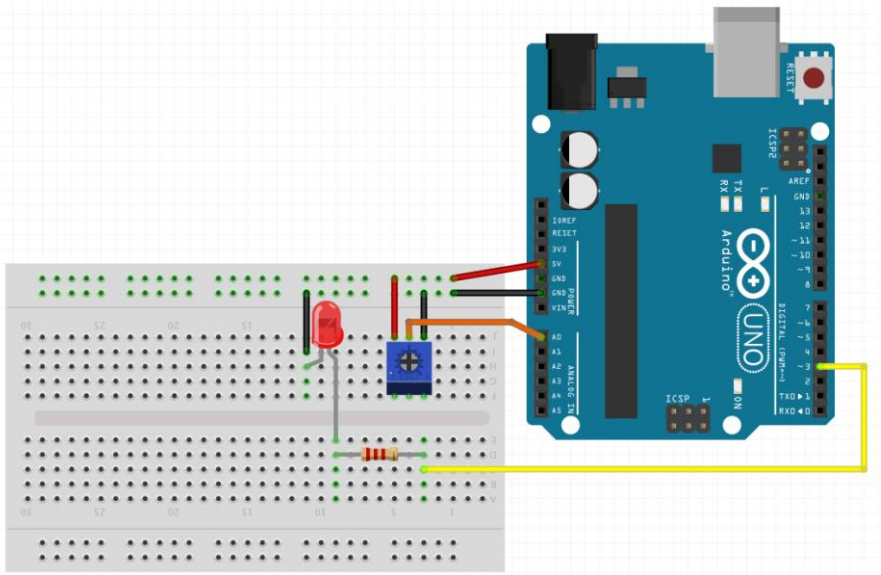
If you **execute multiple, consecutive** analogReads() **across different pins**, you might get noisy values. Instead:

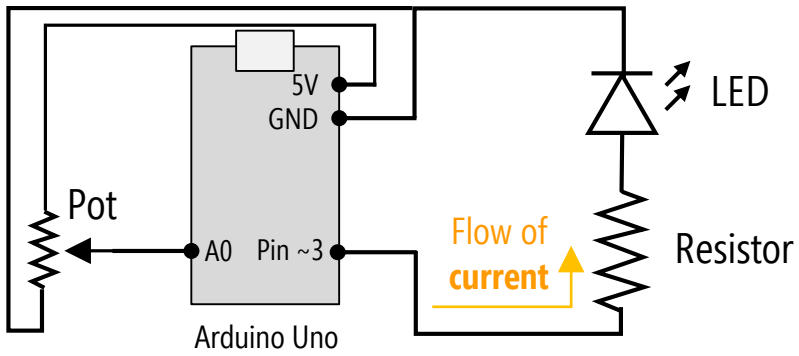
- add a couple of ms delay between measurements on different pins
- perform two analogRead() on the same pin, dump the 1st & keep the 2nd

https://www.arduino.cc/reference/en/language/functions/analog-io/analogread/; https://github.com/firmata/arduino/issues/334; http://forum.arduino.cc/index.php?topic=69675.0

ACTIVITY: CONTROL LED BRIGHTNESS WITH POTENTIOMETER

Circuit: Fade LED on/off via pot value





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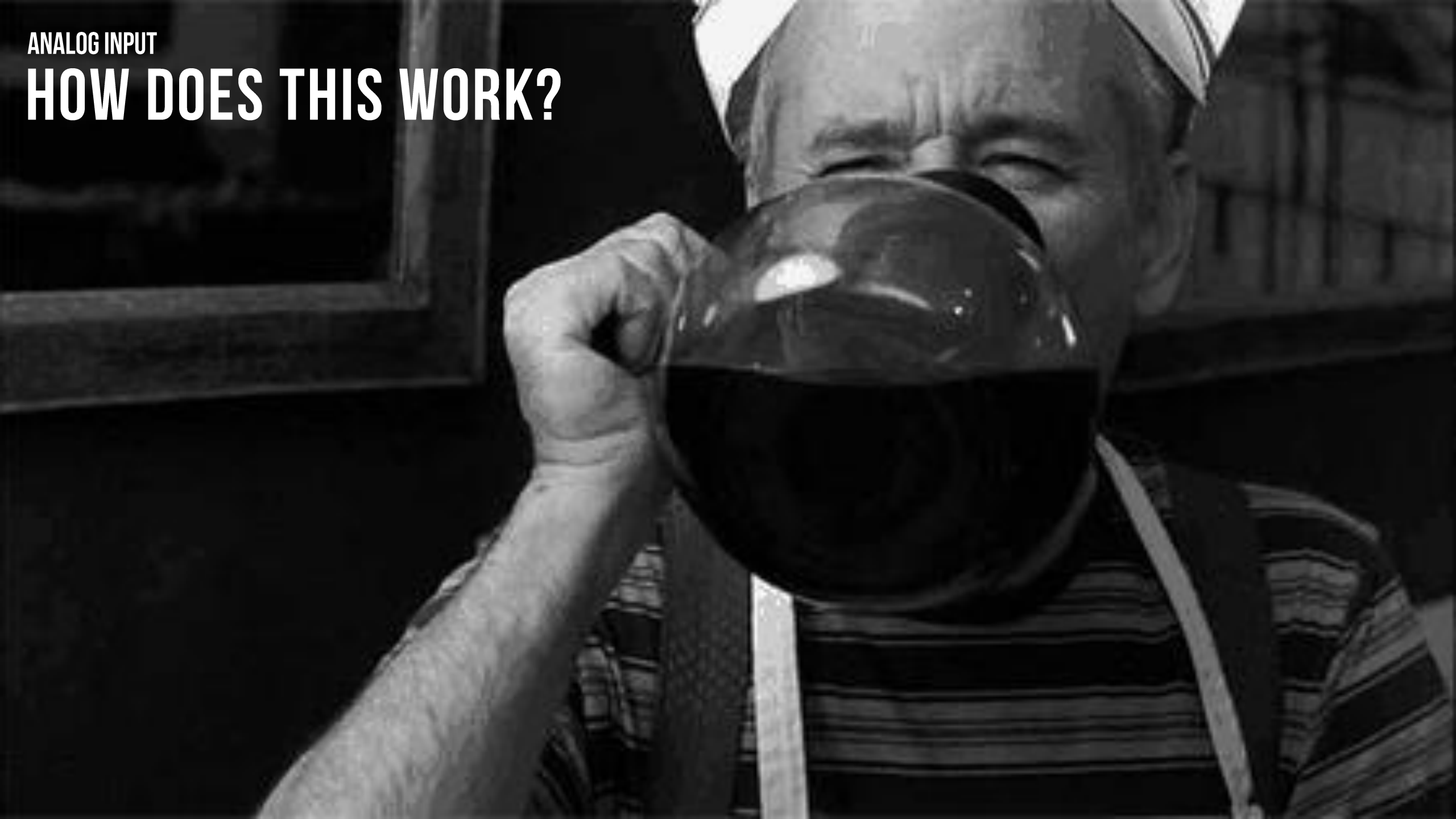
ANALOG INPUT

HOW DOES THIS WORK?



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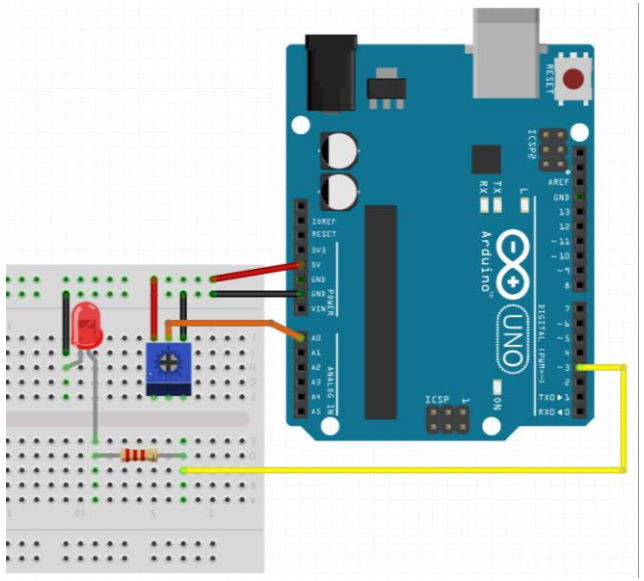
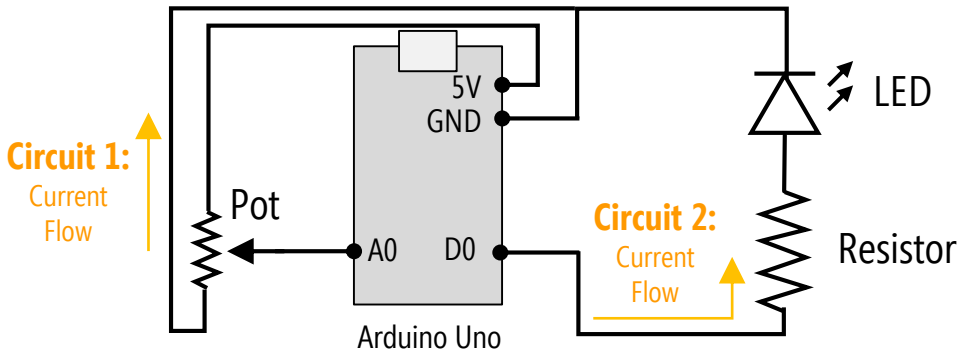
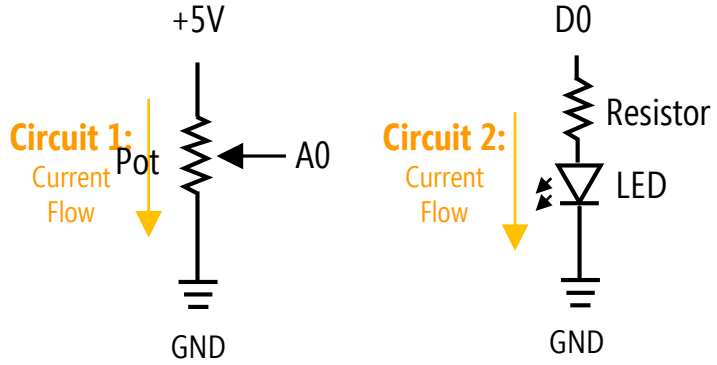


Let's redraw our circuit into an equivalent but simpler representation



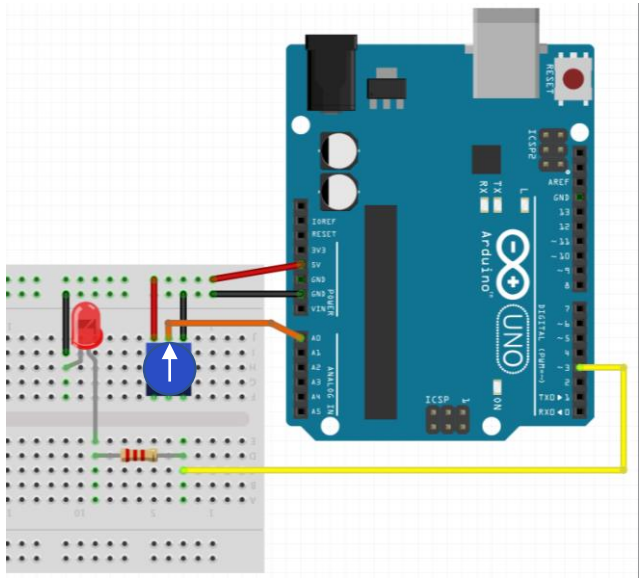
Schematic Representation 1



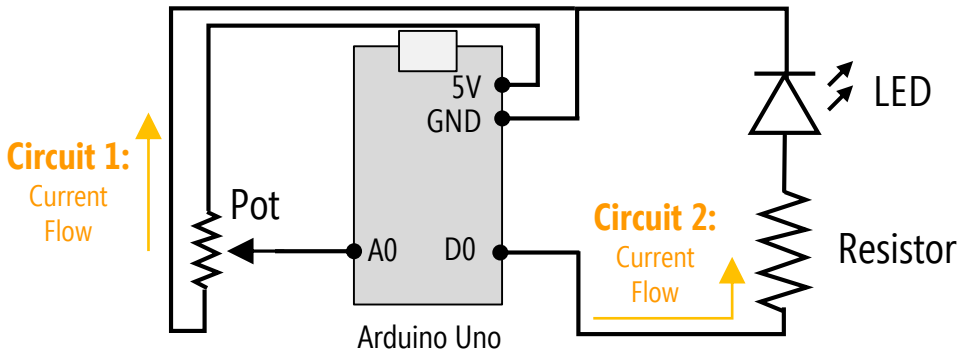
Schematic Representation 2

ANALOG INPUT

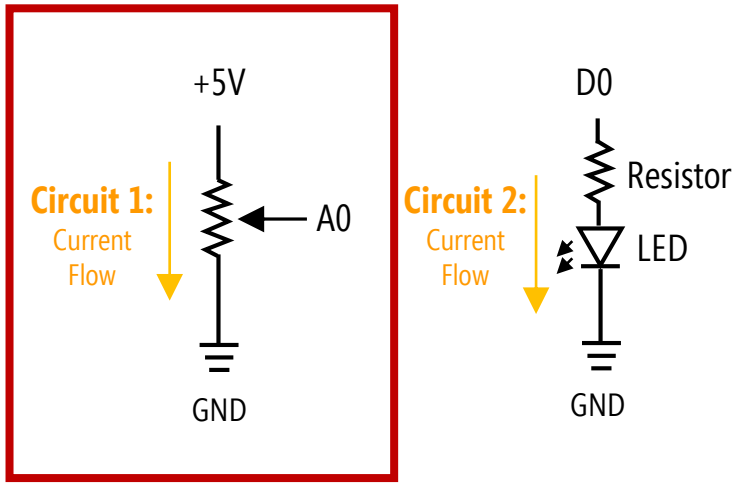
HOW DOES THIS WORK?



Let's redraw our circuit into an equivalent but simpler representation



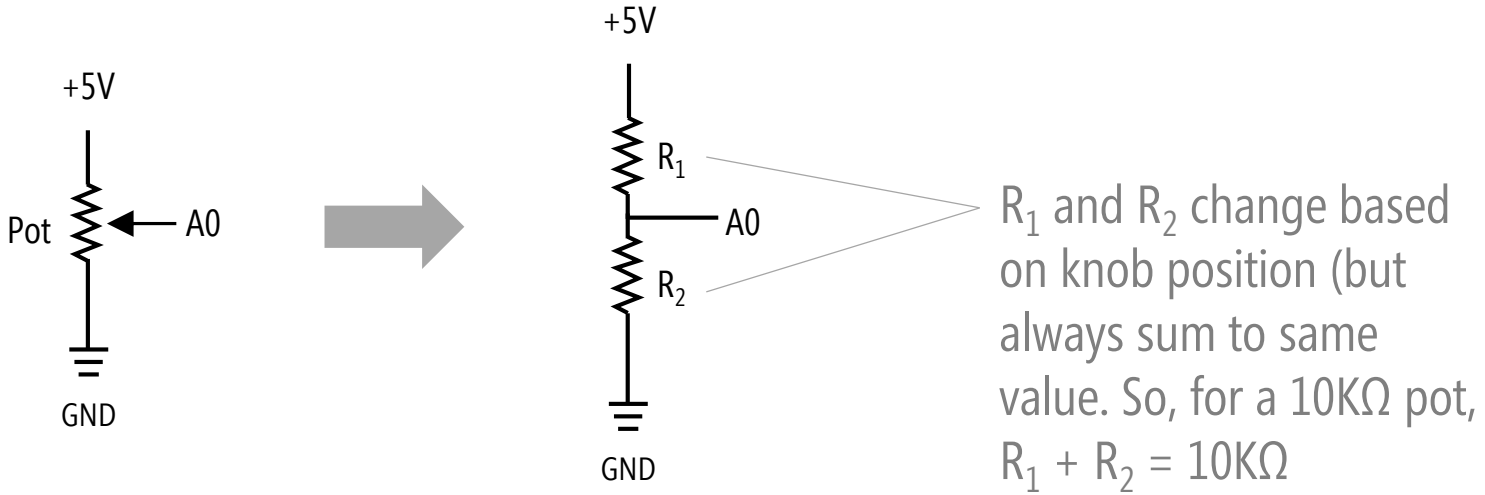
Schematic Representation 1



Schematic Representation 2

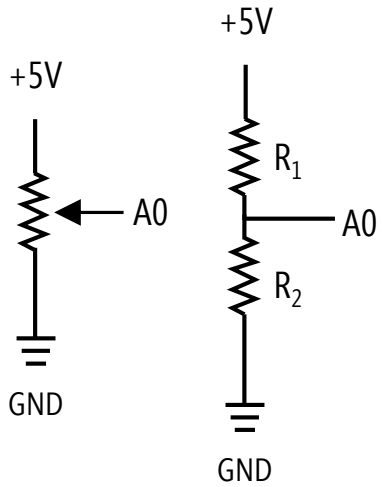
HOW DOES THIS WORK?

Another way to think about the potentiometer



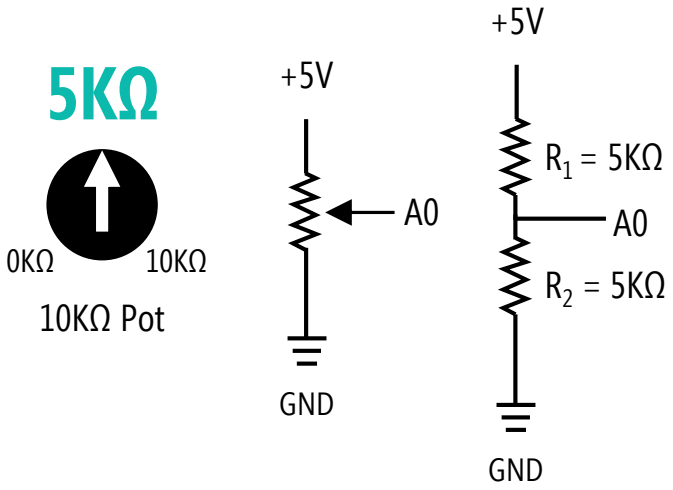
R_1 and R_2 change based on knob position (but always sum to same value. So, for a 10KΩ pot, $R_1 + R_2 = 10K\Omega$

WHAT IF THE POT IS SET TO 5KΩ?



ANALOG INPUT

WHAT IF THE POT IS SET TO 5KΩ?



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{5{,}000\Omega + 5{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

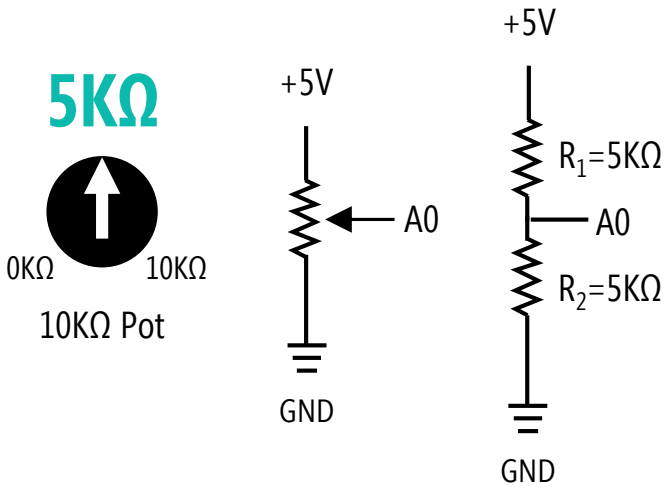
$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 5{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 2.5V$$

ANALOG INPUT

WHAT IF THE POT IS SET TO 5KΩ?



What is A0 equal to?

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$$Current = I = \frac{5V - 0V}{5{,}000\Omega + 5{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

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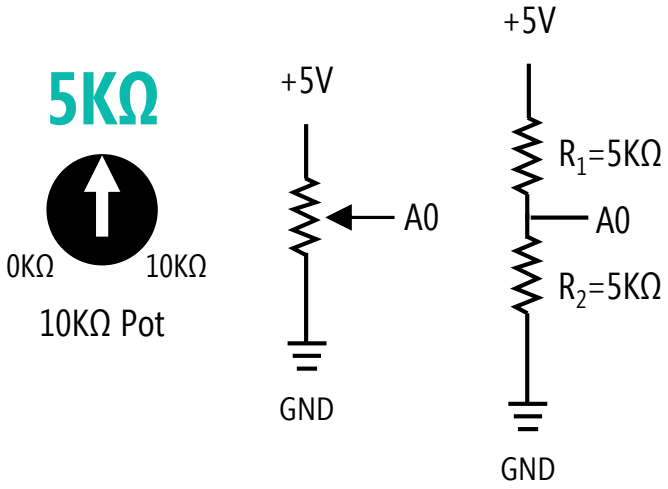
$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 5{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 2.5V$$

analogRead(A0) would return 512

ANALOG INPUT

WHAT IF THE POT IS SET TO 5KΩ?



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{5{,}000\Omega + 5{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

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$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 5{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 2.5V$$

Why? Recall that the minimum and maximum analogRead values are 0 and 1023 respectively on the Uno. Thus:

$$\frac{2.5V}{5V} = \frac{x}{1023}$$

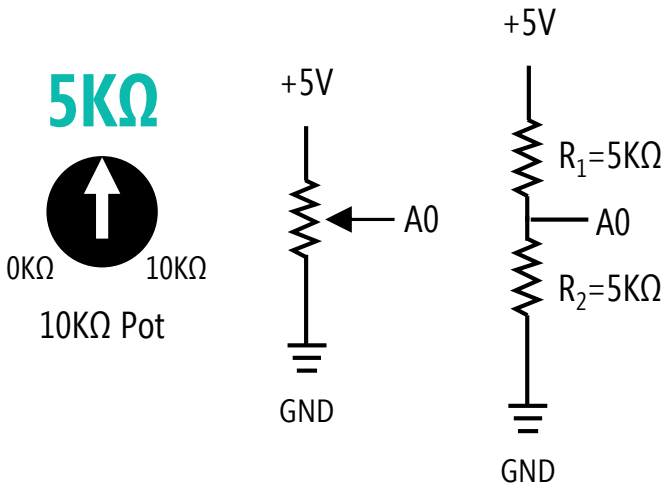
$$0.5 = \frac{x}{1023}$$

$$x = 0.5 * 1023 = 511.5$$

analogRead(A0) would return 512

ANALOG INPUT

WHAT IF THE POT IS SET TO 5KΩ?



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{5{,}000\Omega + 5{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 5{,}000\Omega)$$

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Why? Recall that the minimum and maximum analogRead values are 0 & 1023 respectively on the Uno. Thus:

$$\frac{2.5V}{5V} = \frac{x}{1023}$$

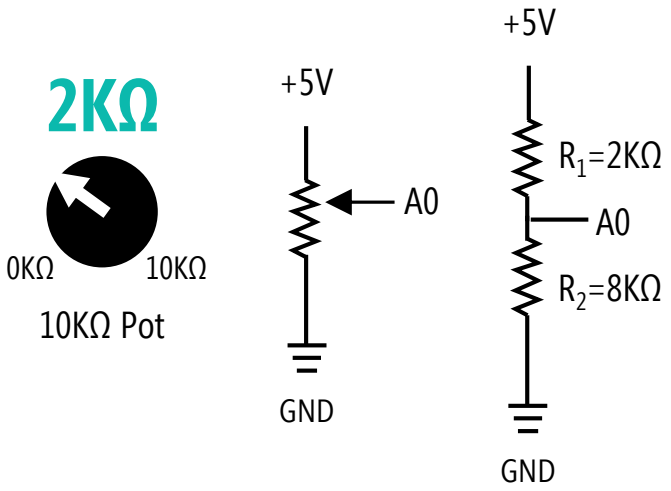
$$0.5 = \frac{x}{1023}$$

$$x = 0.5 * 1023 = 511.5$$

analogRead(A0) would return 512

ANALOG INPUT

WHAT IF THE POT IS SET TO 2KΩ?



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{2{,}000\Omega + 8{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

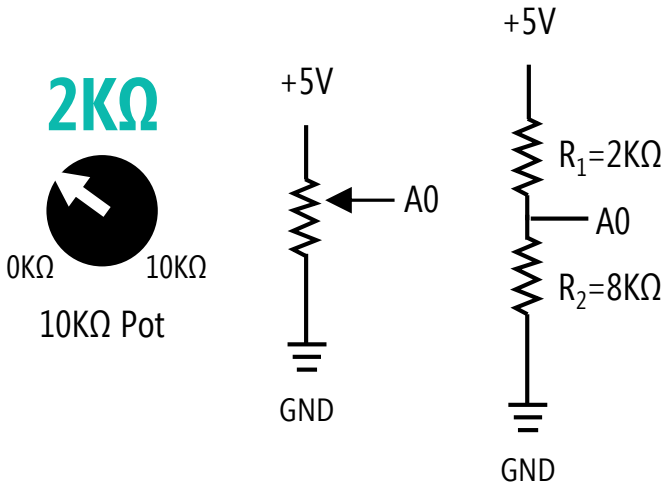
$$\boldsymbol{Voltage = V = I * R}$$

$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 2{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 4V$$

WHAT IF THE POT IS SET TO 2KΩ?



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{2{,}000\Omega + 8{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

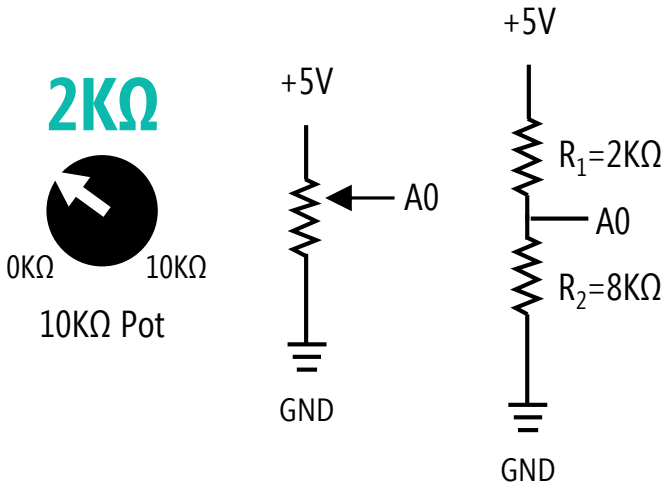
$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 2{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 4V$$

analogRead(A0) would return 818

ANALOG INPUT

WHAT IF THE POT IS SET TO 2KΩ?



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{2{,}000\Omega + 8{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 2{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 4V$$

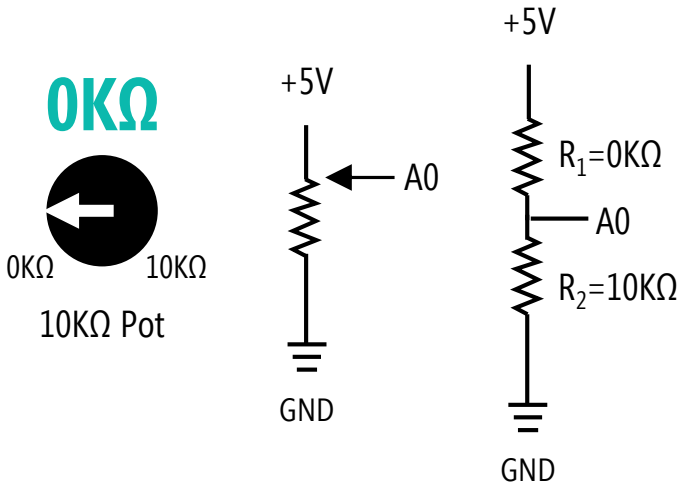
$$\frac{4V}{5V} = \frac{x}{1023}$$

$$0.8 = \frac{x}{1023}$$

$$x = 0.8 * 1023 = 818.4$$

analogRead(A0) would return **818**

WHAT IF THE POT IS SET TO 0KΩ



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{2{,}000\Omega + 8{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

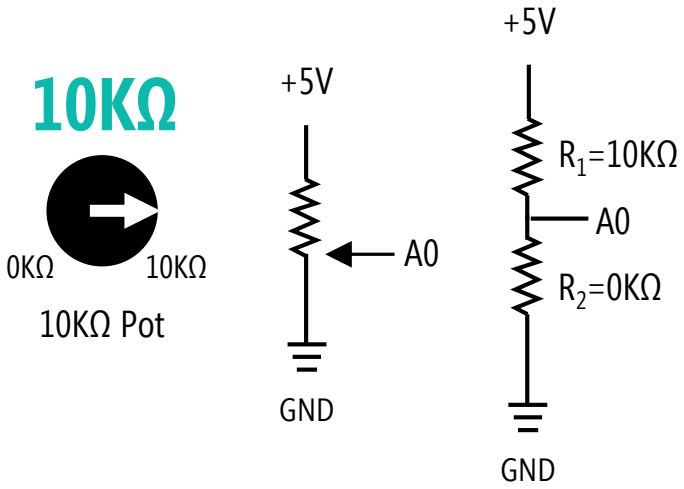
$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 0\Omega)$$

$$Voltage_{A0} = V_{A0} = 5V$$

analogRead(A0) would return **1023**

WHAT IF THE POT IS SET TO 10KΩ



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{2{,}000\Omega + 8{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

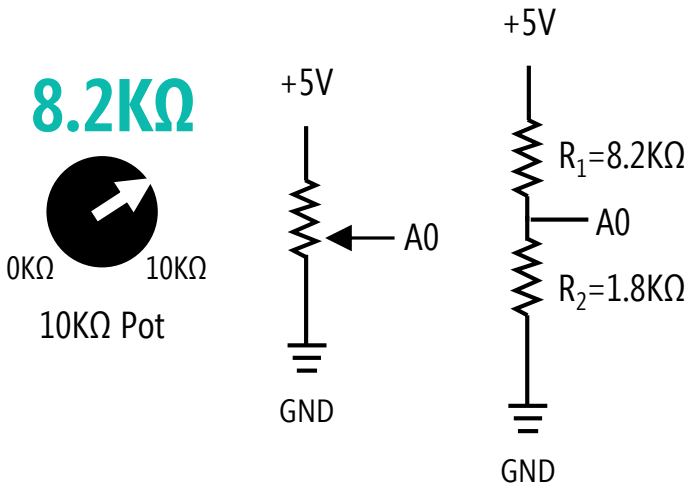
$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 10{,}000\Omega)$$

$$Voltage_{A0} = V_{A0} = 0V$$

analogRead(A0) would return **0**

ANALOG INPUT

WHAT IF THE POT IS SET TO 8.2KΩ



What is A0 equal to?

$$\boldsymbol{Current = I = \frac{V_{high\ potential} - V_{low\ potential}}{R}}$$

$$Current = I = \frac{5V - 0V}{2{,}000\Omega + 8{,}000\Omega}$$

$$Current = I = 0.0005A = 0.5mA$$

$$\boldsymbol{Voltage = V = I * R}$$

$$Voltage_{A0} = V_{A0} = 5V - V_{R1}$$

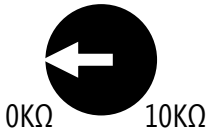
$$Voltage_{A0} = V_{A0} = 5V - (0.0005A * 8{,}200\Omega)$$

$$Voltage_{A0} = V_{A0} = 0.9V$$

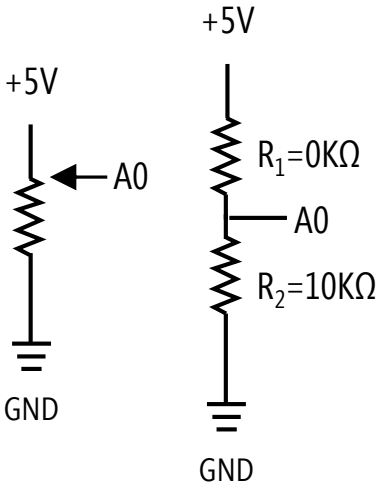
analogRead(A0) would return **184**

LET'S LOOK AT SOME VALUES ALL TOGETHER

0KΩ



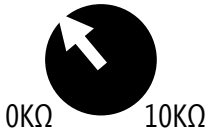
10KΩ Pot



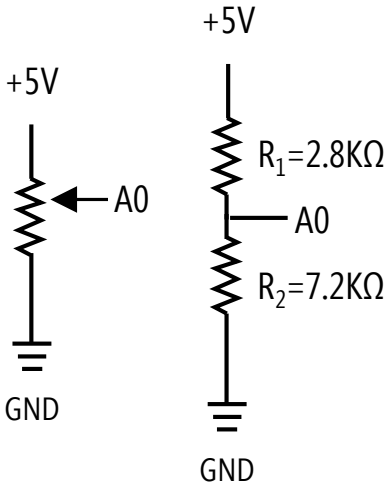
$Voltage_{A0} = V_{A0} = \mathbf{5V}$

analogRead(A0) returns **1023**

2.8KΩ



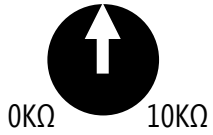
10KΩ Pot



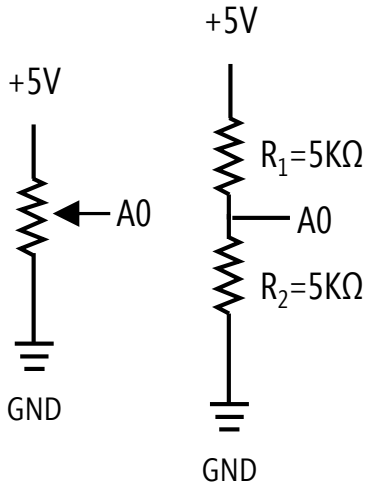
$Voltage_{A0} = V_{A0} = \mathbf{3.6V}$

analogRead(A0) returns **737**

5KΩ



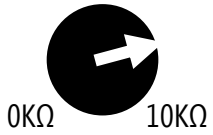
10KΩ Pot



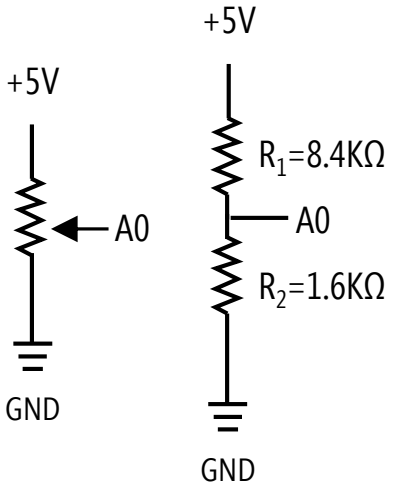
$Voltage_{A0} = V_{A0} = \mathbf{2.5V}$

analogRead(A0) returns **512**

8.4KΩ



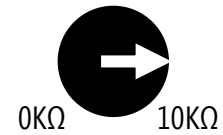
10KΩ Pot



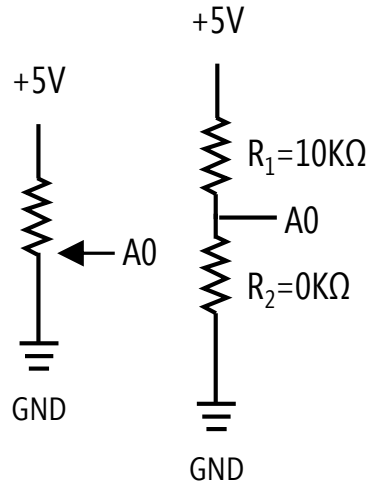
$Voltage_{A0} = V_{A0} = \mathbf{0.8V}$

analogRead(A0) returns **164**

10KΩ



10KΩ Pot



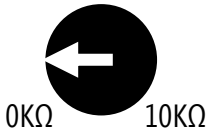
$Voltage_{A0} = V_{A0} = \mathbf{0V}$

analogRead(A0) returns **0**

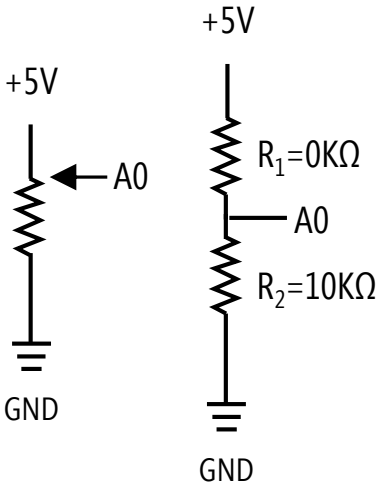
ANALOG INPUT

LET'S LOOK AT SOME VALUES ALL TOGETHER

0KΩ



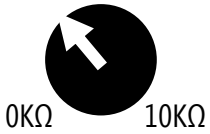
10KΩ Pot



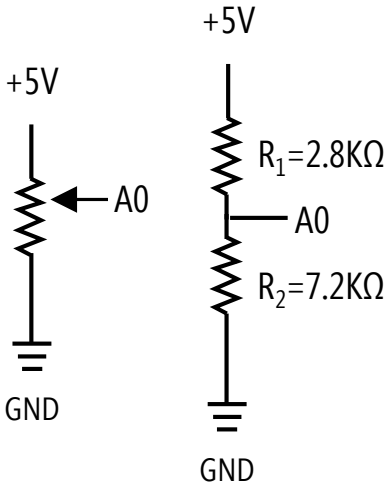
$Voltage_{A0} = V_{A0} = \mathbf{5V}$

analogRead(A0) returns **1023**

2.8KΩ



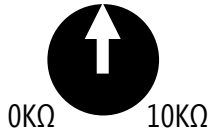
10KΩ Pot



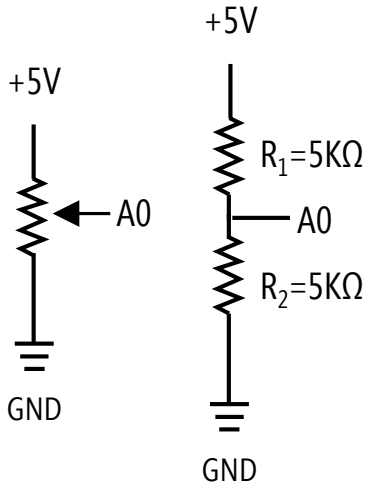
$Voltage_{A0} = V_{A0} = \mathbf{3.6V}$

analogRead(A0) returns **737**

5KΩ



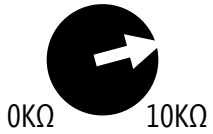
10KΩ Pot



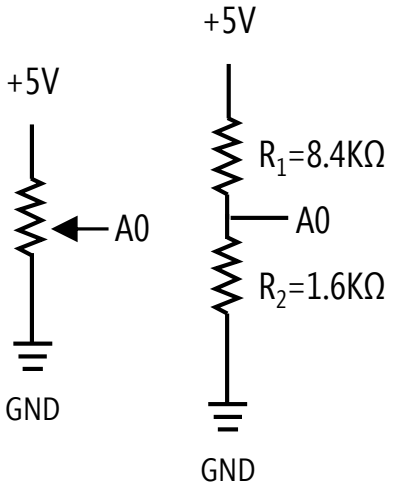
$Voltage_{A0} = V_{A0} = \mathbf{2.5V}$

analogRead(A0) returns **512**

8.4KΩ



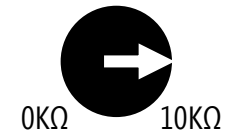
10KΩ Pot



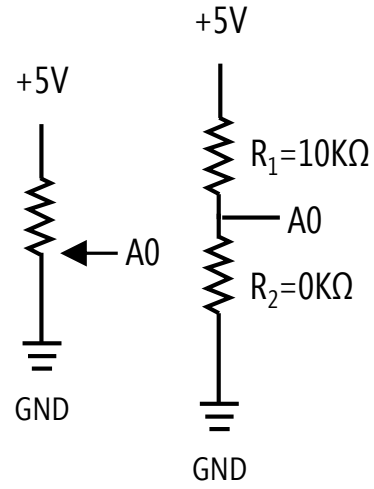
$Voltage_{A0} = V_{A0} = \mathbf{0.8V}$

analogRead(A0) returns **164**

10KΩ



10KΩ Pot



$Voltage_{A0} = V_{A0} = \mathbf{0V}$

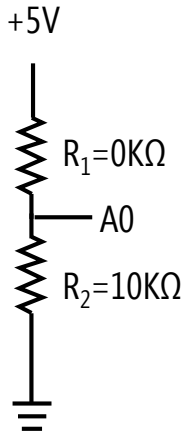
analogRead(A0) returns **0**

As R_1 grows big with respect to R_2, V_{A0} drops to zero

ANALOG INPUT

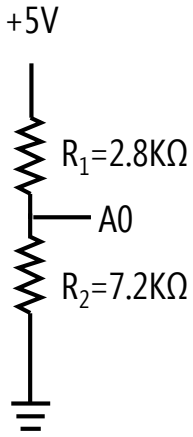
THIS TYPE OF CIRCUIT IS CALLED A "VOLTAGE DIVIDER"

It's called a voltage divider because the voltage drops are divided across two resistors. A voltage divider is one of the primary ways that we configure our circuits to read sensor data with Arduino.



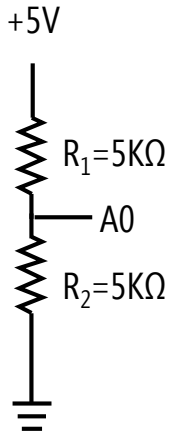
$Voltage_{A0} = V_{A0} = \mathbf{5V}$

analogRead(A0) returns **1023**



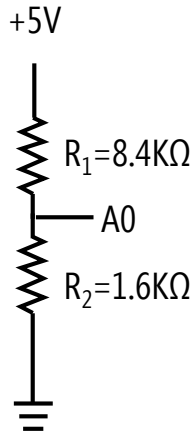
$Voltage_{A0} = V_{A0} = \mathbf{3.6V}$

analogRead(A0) returns **737**



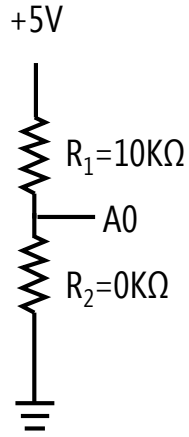
$Voltage_{A0} = V_{A0} = \mathbf{2.5V}$

analogRead(A0) returns **512**



$Voltage_{A0} = V_{A0} = \mathbf{0.8V}$

analogRead(A0) returns **164**

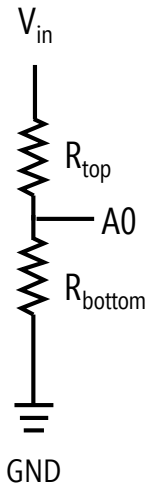


$Voltage_{A0} = V_{A0} = \mathbf{0V}$

analogRead(A0) returns **0**

ANALOG INPUT

VOLTAGE DIVIDER EQUATION



$$Voltage_{A0} = V_{A0} = V_{in} * \frac{R_{bottom}}{(R_{top} + R_{bottom})}$$

Note that it's the **ratio** between the two resistors that's important.

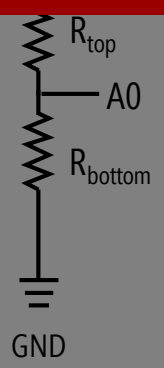
As R_{bottom} grows large with respect to R_{top}, V_{A0} grows proportionally large

Similarly, as R_{top} grows large with respect to $R_{bottom,}$ V_{A0} grows proportionally small

ANALOG INPUT

VOLTAGE DIVIDER EQUATION

We covered this in our **1st Physical Computing** Lecture

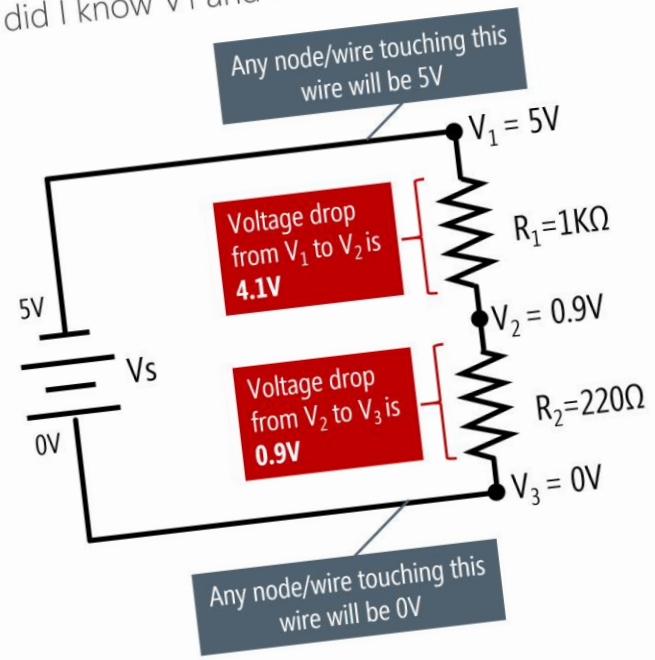


$Voltag$

SERIES VS. PARALLEL RESISTANCE

OHM'S LAW EXERCISE: SOLVE FOR V1, V2, AND V3

How did I know V1 and V3?



This basic circuit is called a **voltage divider** because it "splits" or "divides" voltages across nodes.

It is one of the **most common** (and useful) circuit configurations when working with microcontrollers

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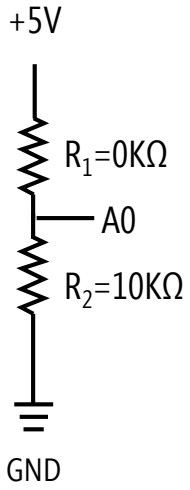
rge

rge with

respect to R_{bottom}, V_{A0} grows proportionally small

ANALOG INPUT

APPLYING THE "VOLTAGE DIVIDER" EQUATION



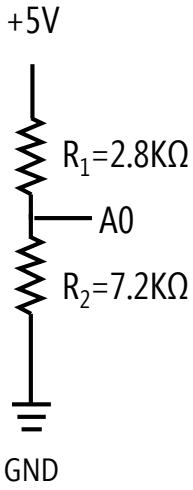
$$V_{A0} = V_{in} * \frac{R_{bottom}}{(R_{top} + R_{bottom})}$$

$$V_{A0} = 5V * \frac{10{,}000\Omega}{(0\Omega + 10{,}000\Omega)}$$

$$V_{A0} = 5V * 1$$

$$V_{A0} = \mathbf{5V}$$

analogRead(A0) returns **1023**



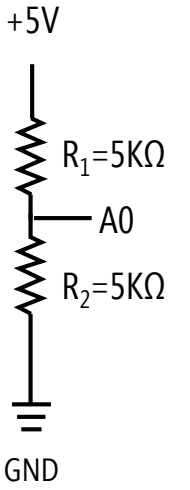
$$V_{A0} = V_{in} * \frac{R_{bottom}}{(R_{top} + R_{bottom})}$$

$$V_{A0} = 5V * \frac{7{,}200\Omega}{(2{,}800\Omega + 7{,}200\Omega)}$$

$$V_{A0} = 5V * 0.72$$

$$V_{A0} = \mathbf{3.6V}$$

analogRead(A0) returns **737**



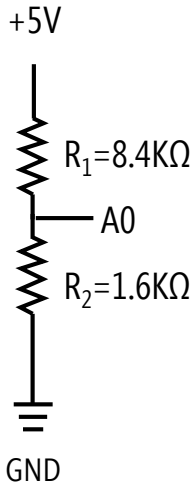
$$V_{A0} = V_{in} * \frac{R_{bottom}}{(R_{top} + R_{bottom})}$$

$$V_{A0} = 5V * \frac{5{,}000\Omega}{(5{,}000\Omega + 5{,}000\Omega)}$$

$$V_{A0} = 5V * 0.5$$

$$V_{A0} = \mathbf{2.5V}$$

analogRead(A0) returns **512**



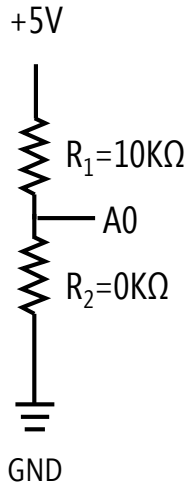
$$V_{A0} = V_{in} * \frac{R_{bottom}}{(R_{top} + R_{bottom})}$$

$$V_{A0} = 5V * \frac{1{,}600\Omega}{(8{,}400\Omega + 1{,}600\Omega)}$$

$$V_{A0} = 5V * 0.16$$

$$V_{A0} = \mathbf{0.8V}$$

analogRead(A0) returns **164**



$$V_{A0} = V_{in} * \frac{R_{bottom}}{(R_{top} + R_{bottom})}$$

$$V_{A0} = 5V * \frac{0\Omega}{(10{,}000\Omega + 0\Omega)}$$

$$V_{A0} = 5V * 0$$

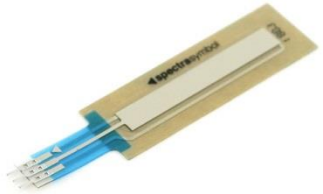
$$V_{A0} = \mathbf{0V}$$

analogRead(A0) returns **0**

VARIABLE RESISTORS

LOTS OF DIFFERENT KINDS OF VARIABLE RESISTORS

Potentiometer 10k; $0.95*



Touch Membrane Potentiometer; $12.95

Photocell (aka photodetector or photo resistor); $1.50

Thermistor 10k; $0.75

Force Resistive Sensor 0.5”; $6.95

Flex Sensor 4.5”; $12.95

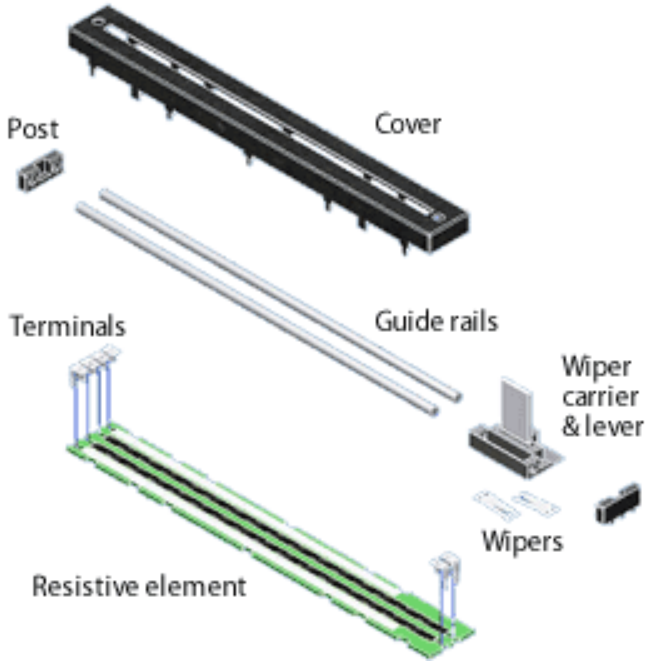
*Note: Prices are from Sparkfun.com; parts are cheaper in bulk and often cheaper from Digikey.com

SLIDE POTENTIOMETERS

Slide potentiometers on an audio mixing board in a music studio

VARIABLE RESISTORS

SLIDE POTENTIOMETERS



Very similar to a **traditional (rotating) potentiometer** but the resistive material is laid out in a straight line

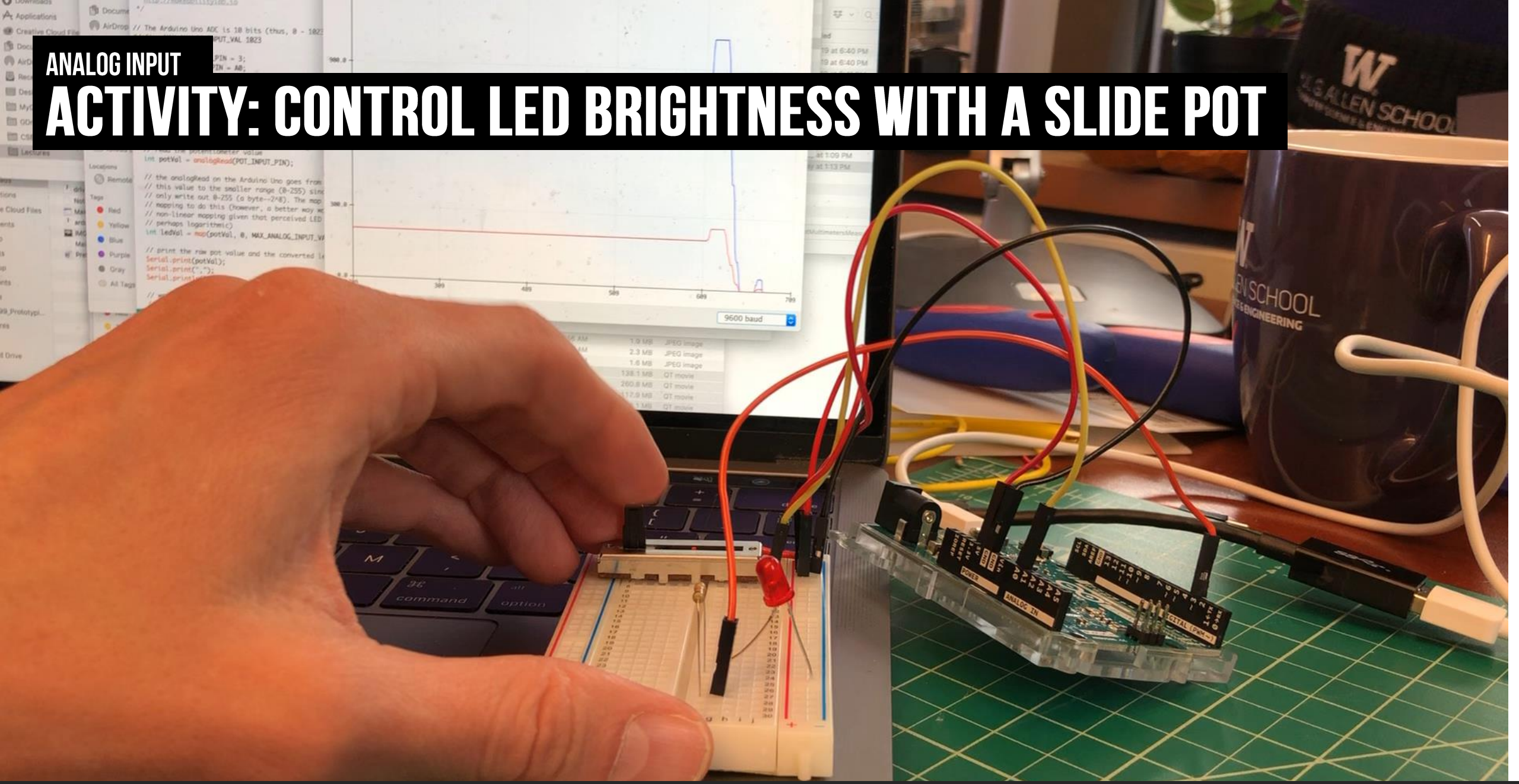
Can have linear taper, exponential taper, etc.

Comes in different sizes

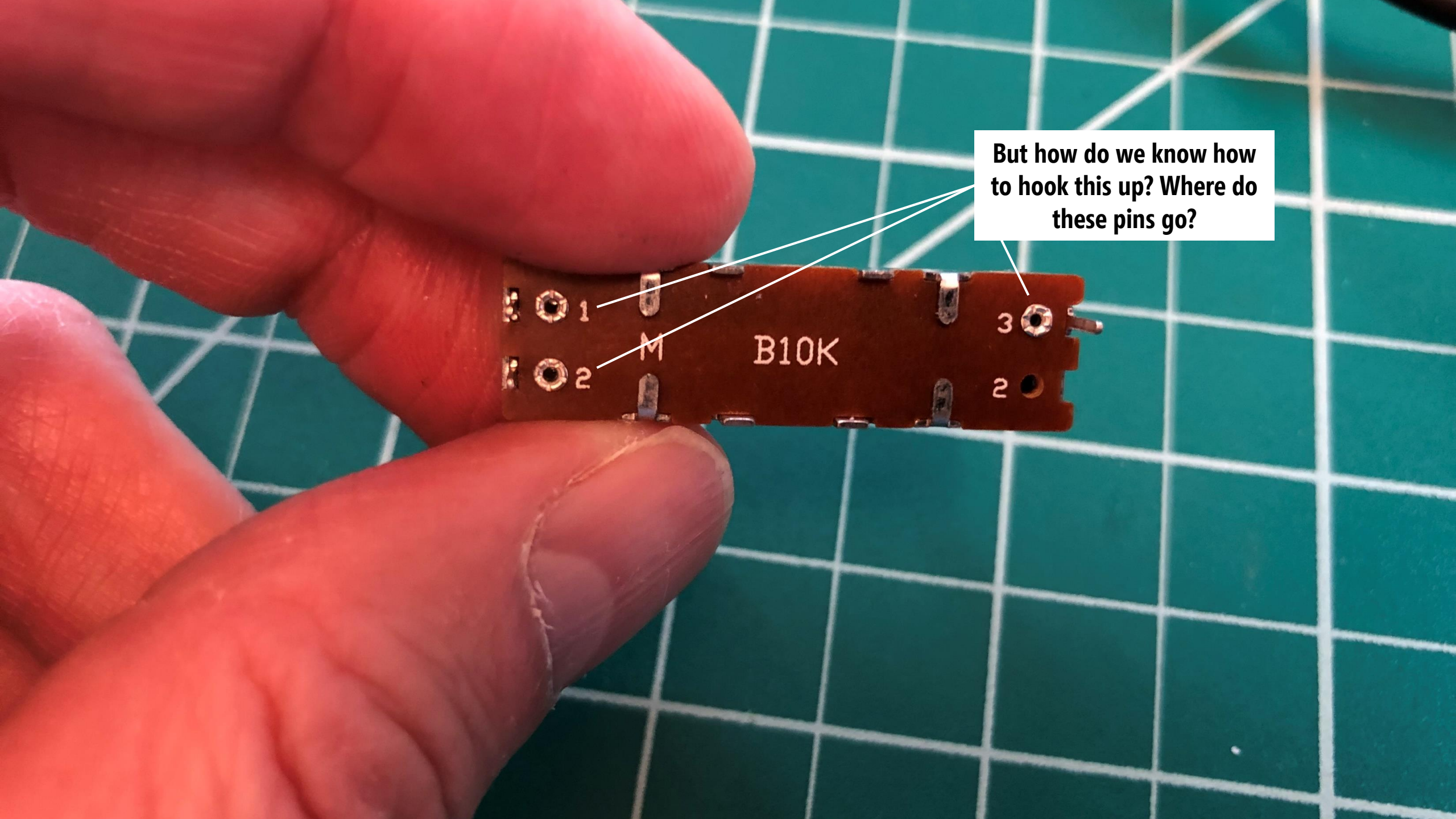
Source: https://www.sparkfun.com/products/11620

ANALOG INPUT

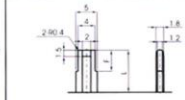
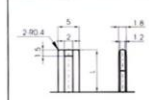
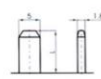
ACTIVITY: CONTROL LED BRIGHTNESS WITH A SLIDE POT



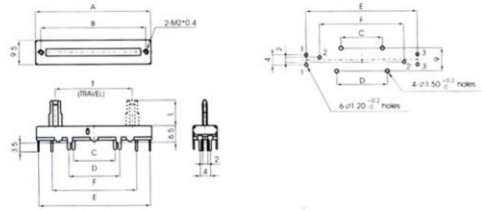
Video by Jon Froehlich


But how do we know how to hook this up? Where do these pins go?
1
2
M
B10K
3
2

LEVER TYPE

MATERIAL	Insulated lever			
LEVER TYPE	C	CA	B	
DIMENSIONS				
LENGTH(L)	X 1 2 3 5 6 7 L 10 12.5 15 18 20 0 F 5 5 5 5 5 5	X 4 8 L 5 10	X 9 L 10	

P.C.B. MOUNTING HOLE DETAIL



MODEL	T	A	B	C	D	E	F
C1531	15	30	26			28.5	18
C2031	20	35	31	6.2	9.8	33.5	23
C3031	30	45	41	16.2	19.8	43.5	33
C4531	45	60	56			58.5	48

Electrical characteristics:電氣的性能 :

Total resistance 總阻值	5K Ω ~2M Ω						
Total resistance tolerance 總阻偏差	± 20% more than 1M Ω ± 30%						
Resistance taper 阻值規律	A, B, C, D, K, W, RD						
Insulation resistance 絶緣電阻	100M Ω min. at 250V DC.						
Withstand voltage 耐電壓	AC 300V (1 minute)						
Rated power 額定功率 (W)	Taper \ Travel		15 mm	20 mm	30 mm	45 mm	
	B	Single	0.05	0.1	0.2	0.25	
		Dual	0.025	0.05	0.1	0.125	
	Except B (B 以外)	Single	0.025	0.05	0.1	0.125	
		Dual	0.012	0.025	0.05	0.06	
Max. operating voltage(AC V) 最高使用電壓	B	Single	100	200	200	200	
	Except B (B 以外)	Dual	50	150	150	150	
Residual resistance 殘留阻值	Total resistance 總阻值		10K Ω	50K Ω	100K Ω	200K Ω	500K Ω	1M Ω
	Between terminals 1-2 端子 1-2 間		10 Ω	10 Ω	10 Ω	20 Ω	20 Ω	20 Ω
	Between terminals 2-3 端子 2-3 間		10 Ω	10 Ω	20 Ω	20 Ω	50 Ω	50 Ω

Durability:耐久的性能:

Slidinglife 滑動壽命	15,000 cycles

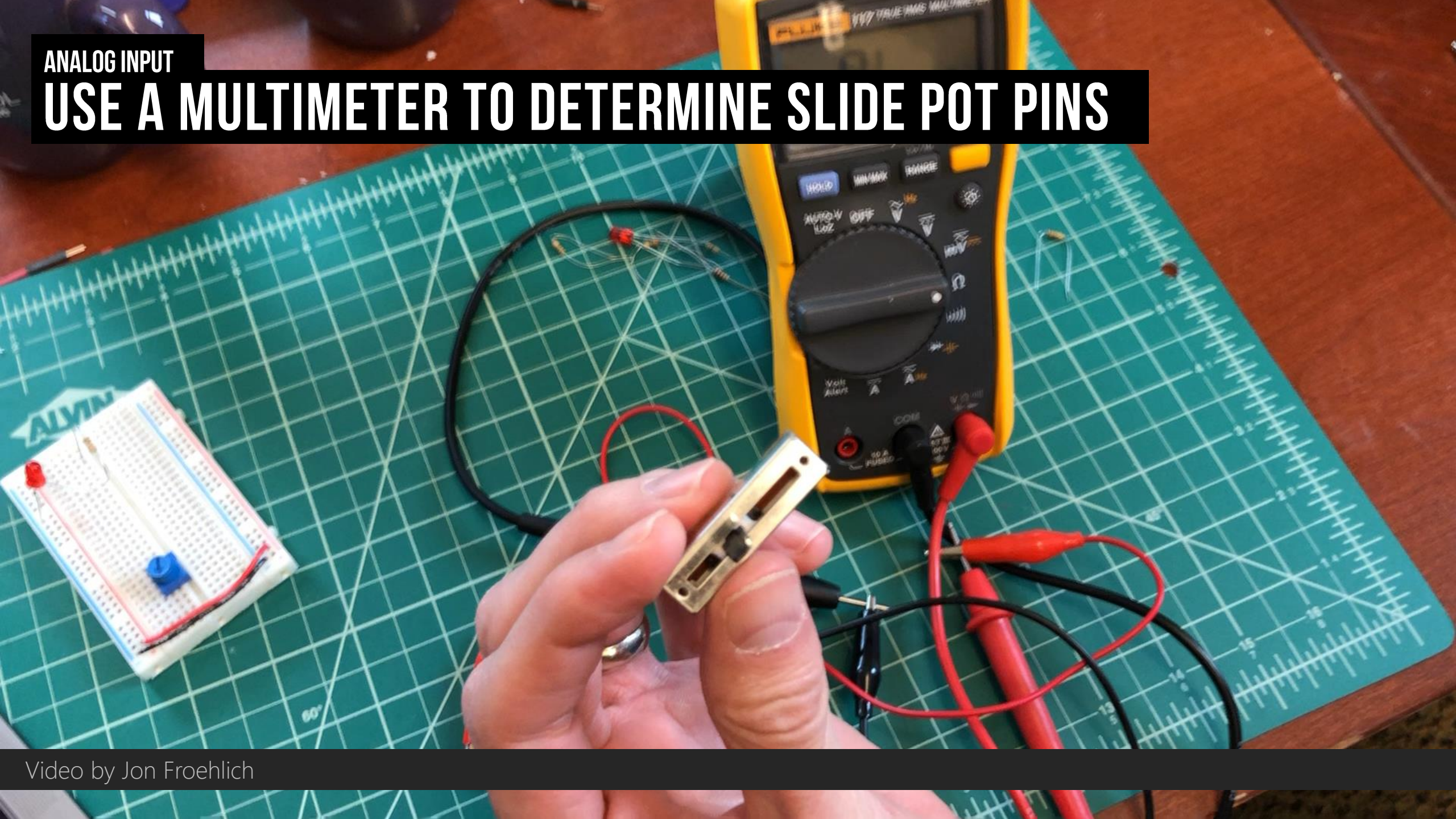
Mechanical characteristics:機械的性能 :

Operating force 滑動力	0.2 ~ 2N (20 ~ 200gf)
Stopper strength 止擋强度	50N (5kgf) measuring point = 5mm
Lever wobble 柄的晃動	2 (2*L) / 20 mm max. (L: Lever length both side) L:兩側柄長
Bendingmoment 瞬間彎曲	25mN.m (250gf.cm)

Push pull strength 軸推拉强度	30N (3kgf)
Click slip - out force C.C. 脱出力	0.2 ~ 2N (20 ~ 200gf)
Lever deviation 柄的偏心量	0.5 max. (one side) 单側

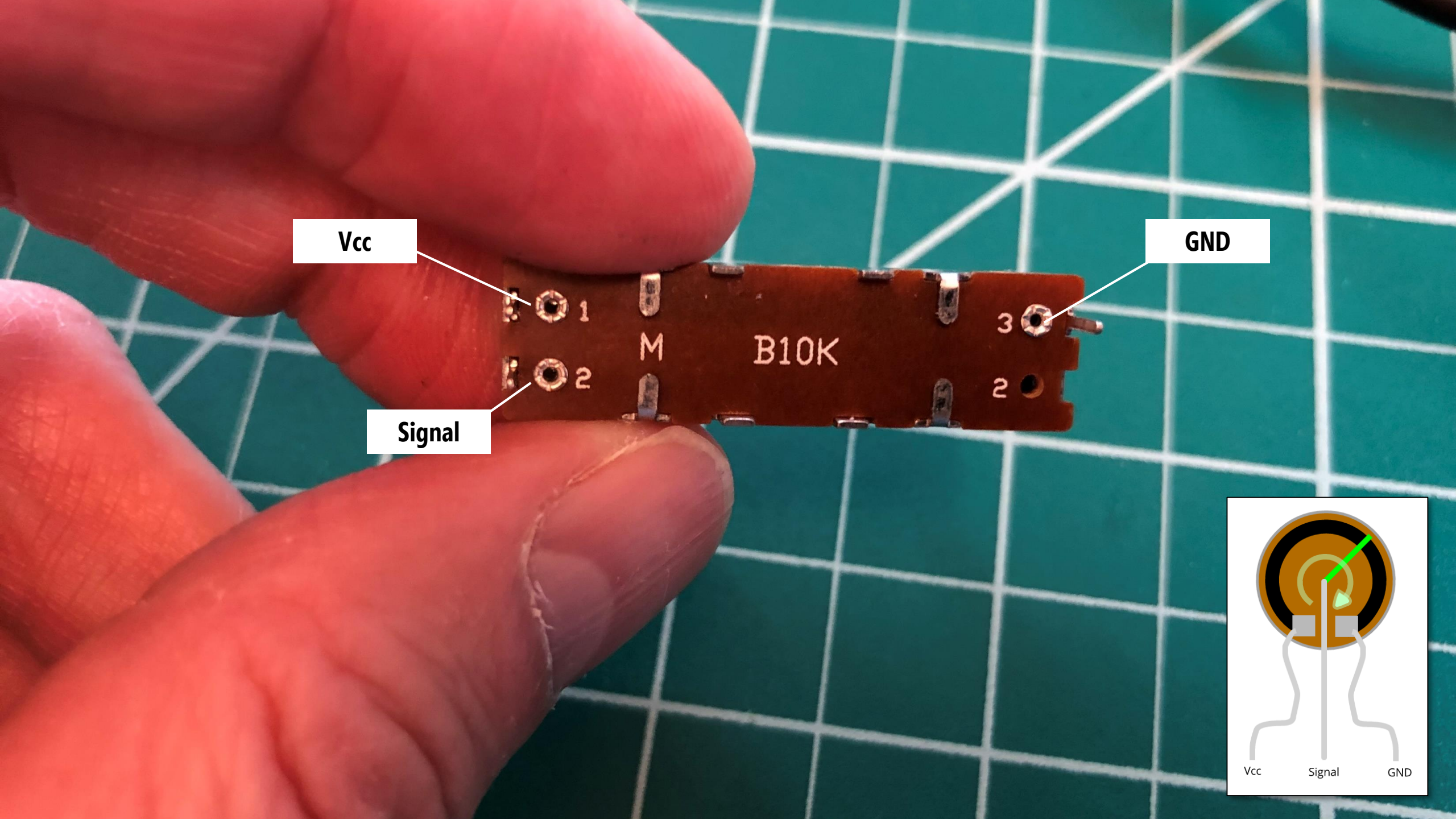
ANALOG INPUT

USE A MULTIMETER TO DETERMINE SLIDE POT PINS



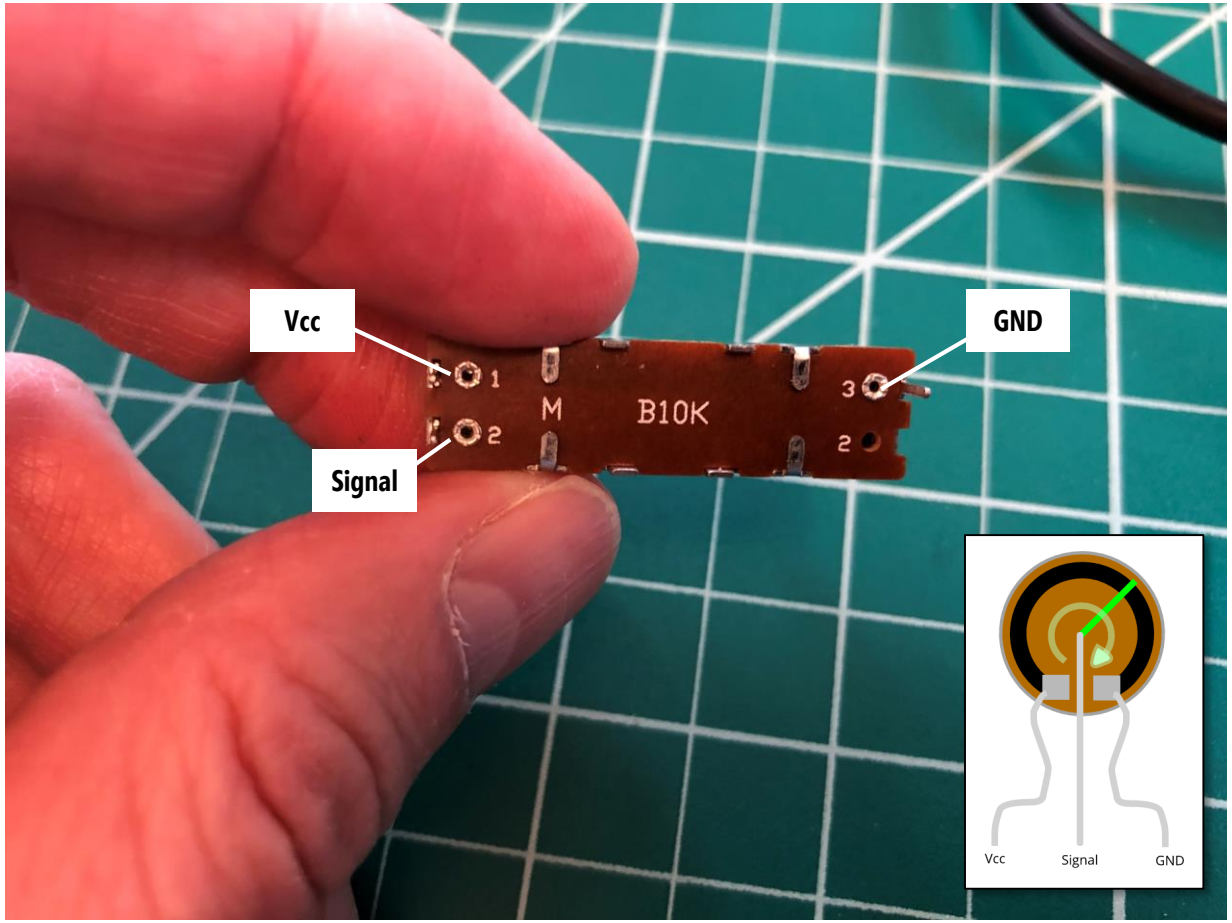
Video by Jon Froehlich

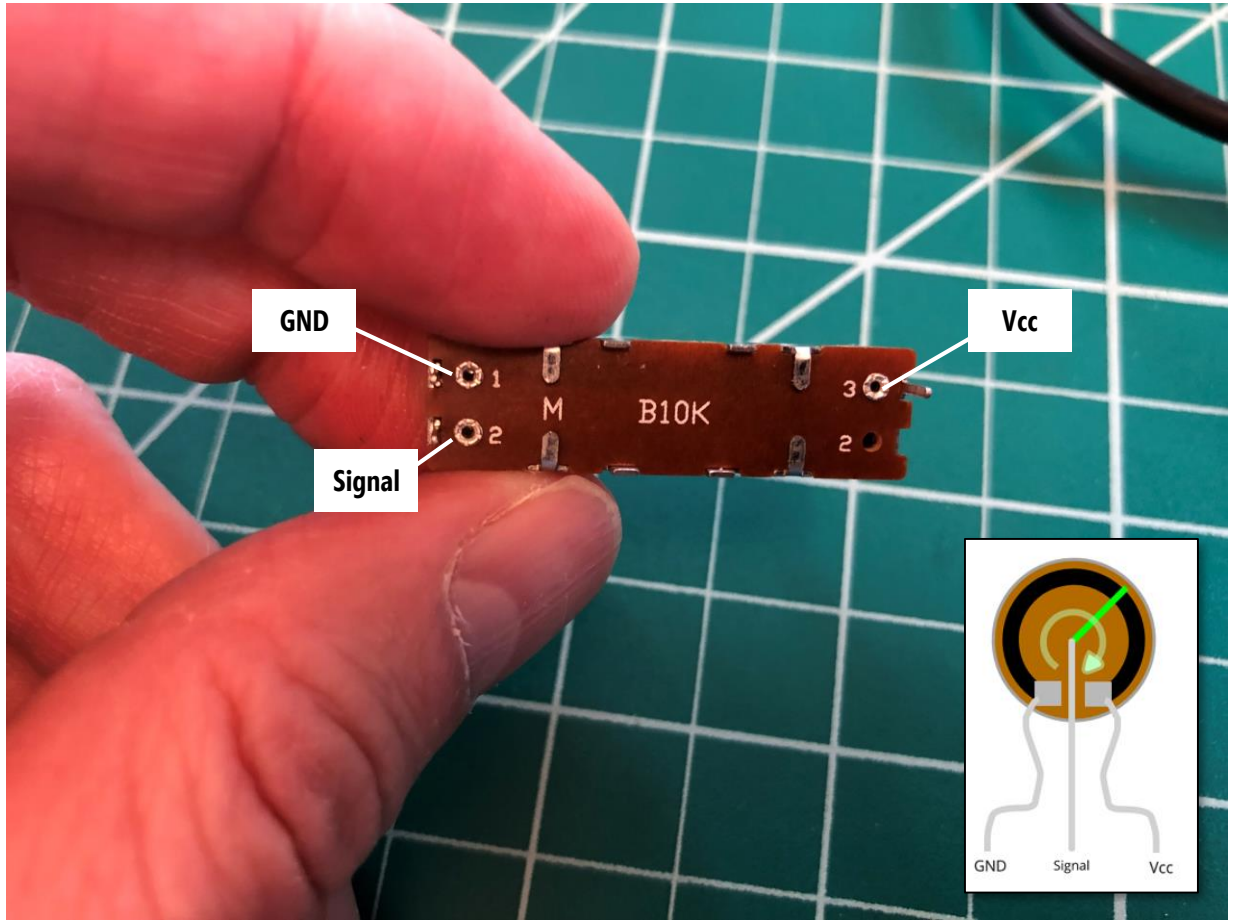

FLUKE
HOLD
MIN/MAX
RANGE
OFF
COM
10 A FUSED


Vcc
GND
Signal
1
2
M
B10K
3
2
Vcc
Signal
GND

SLIDE POTENTIOMETERS

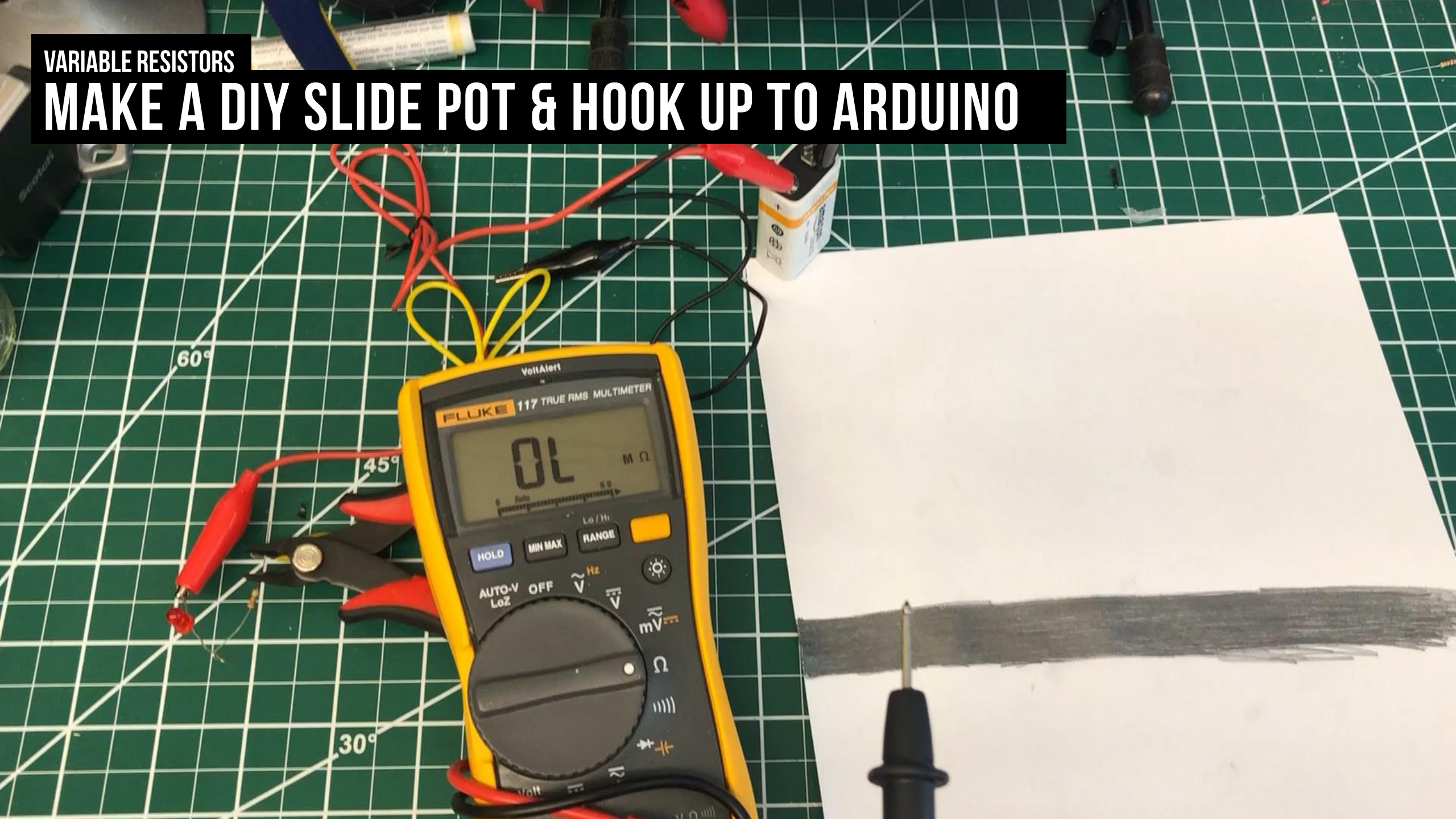
REMEMBER: EITHER ORIENTATION WORKS!





VARIABLE RESISTORS

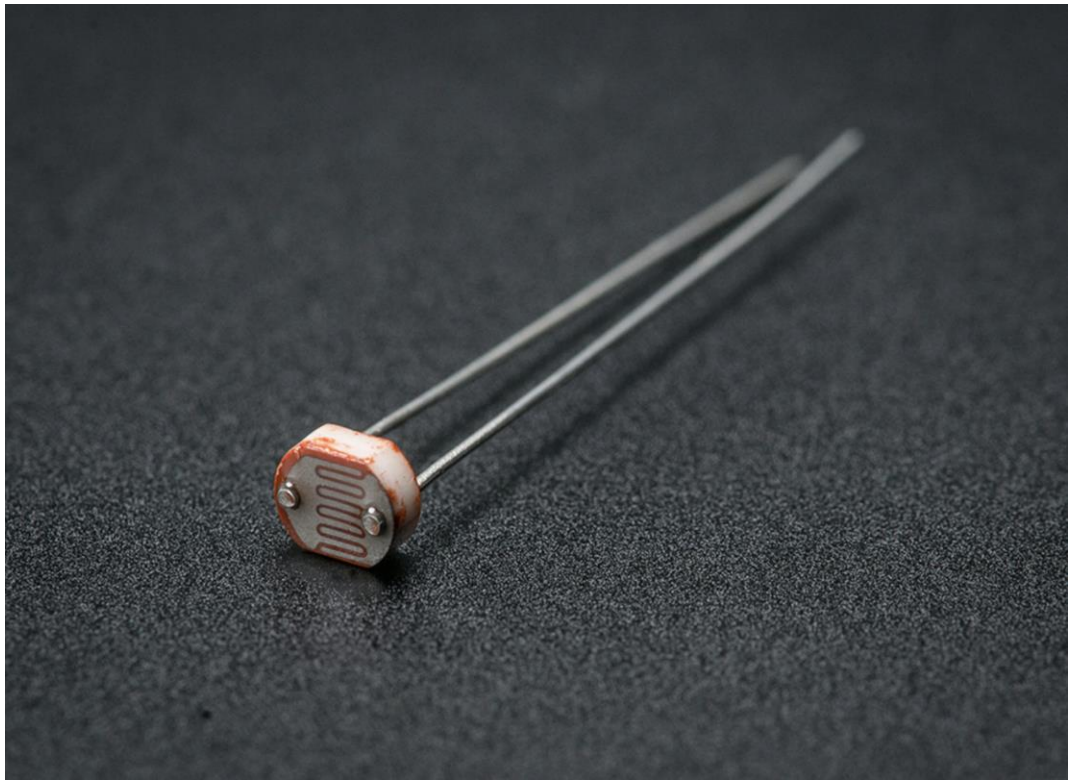
MAKE A DIY SLIDE POT & HOOK UP TO ARDUINO



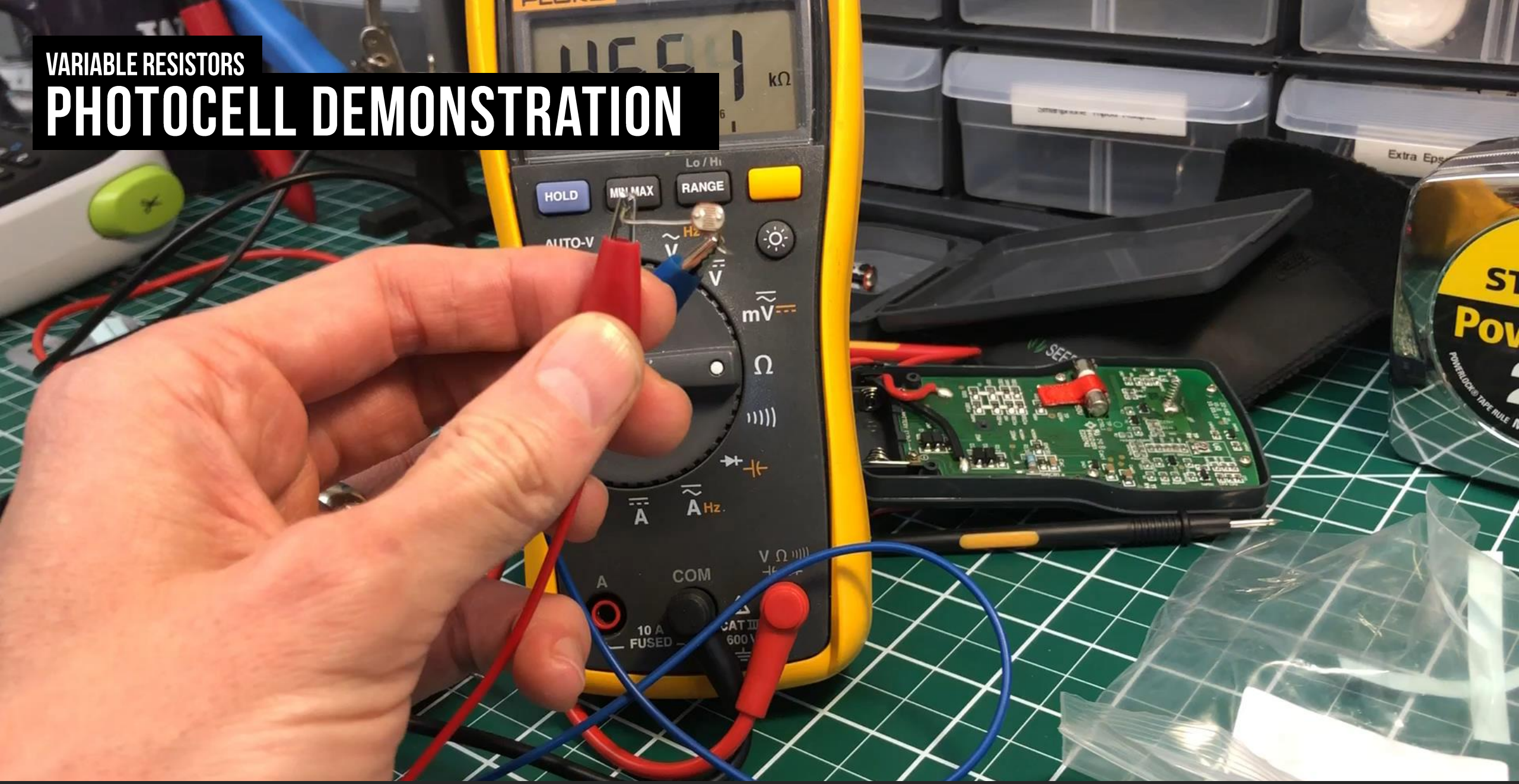
PHOTORESISTORS AND HOW TO USE THEM

ANALOG INPUT

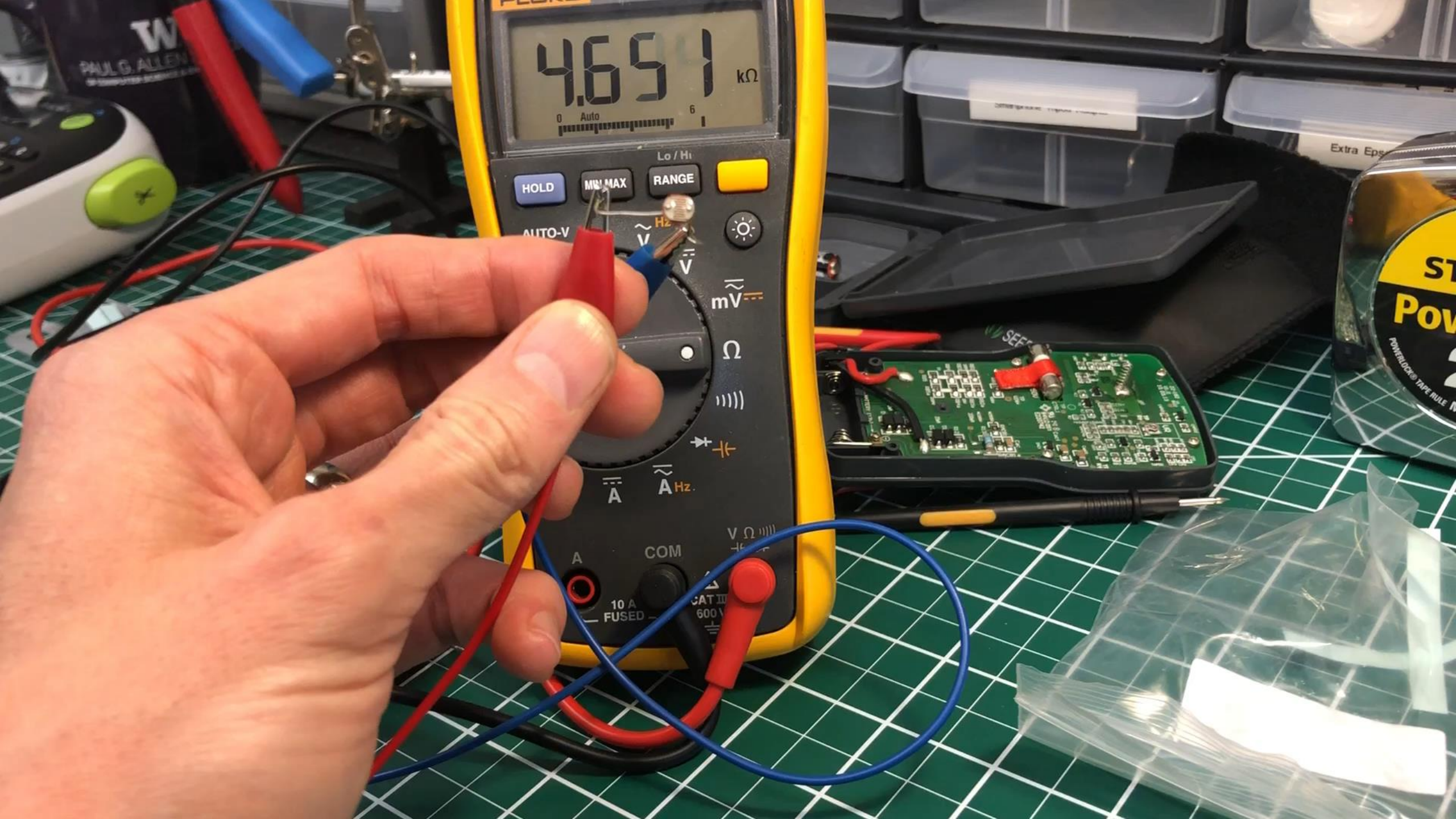
THE PHOTOSENSITIVE RESISTOR



Photosensitive resistors or photocells **change their resistance based** on **light levels**. When light levels go up, resistance goes down.



Video by Jon Froehlich

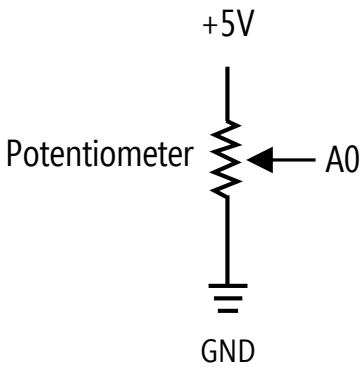

4.651
kΩ
0 Auto 6
Lo / Hi
HOLD
MIN MAX
RANGE
AUTO-V
mV
Ω
A
A Hz
V Ω
A
COM
10 A
FUSED
CAT III
600 V

VARIABLE RESISTORS

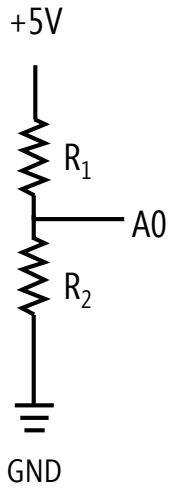
PHOTOCELLS ARE EVERYWHERE!


Melissa & Doug
~crafted by hand~
SOUND PUZZLE
FIRE TRUCK
COUNTY
FIRE DEPT
6
9-1-1

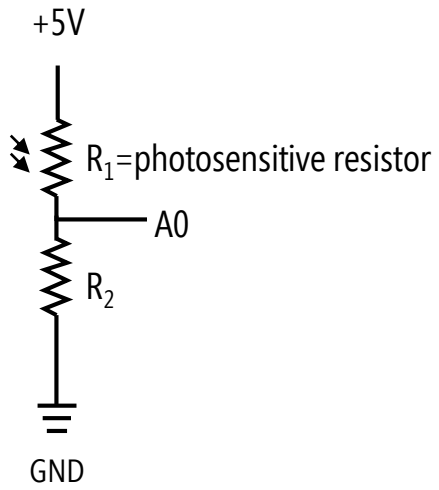
REPLACE POT WITH PHOTOSENSITIVE RESISTOR



Potentiometer
input circuit

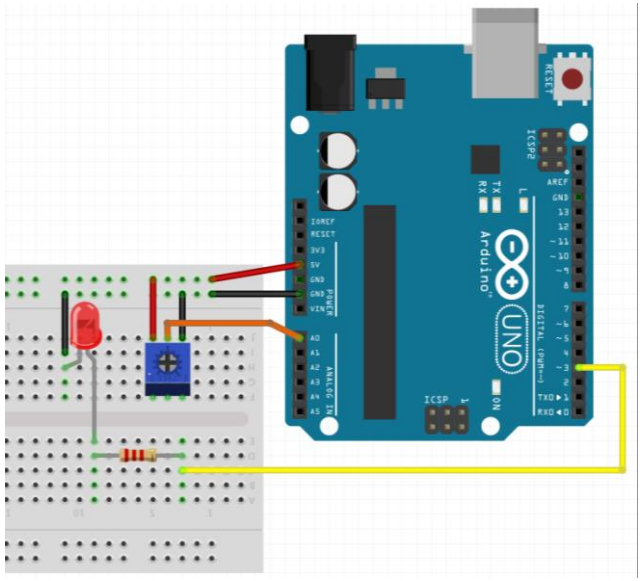


Potentiometer
input circuit is, by
design, a voltage divider

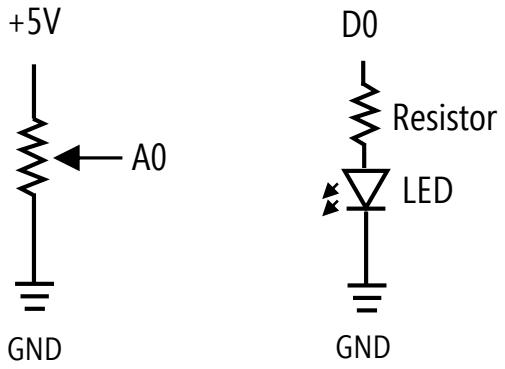


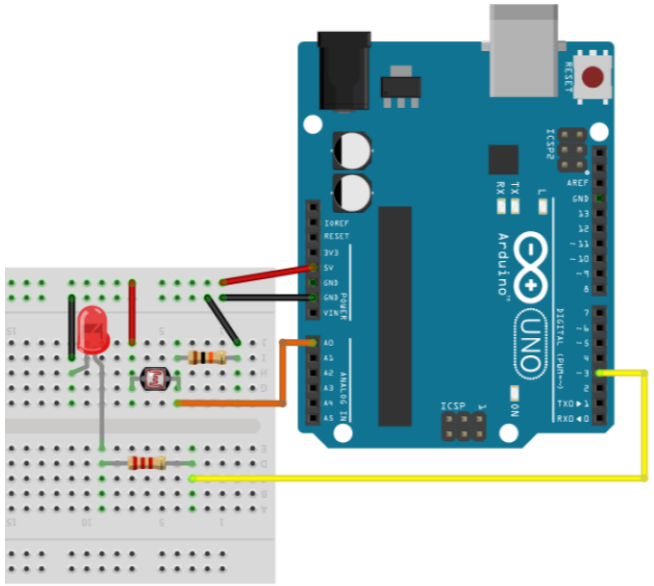
Let's make a similar
circuit but with a
photosensitive resistor

REPLACE POT WITH PHOTOSENSITIVE RESISTOR

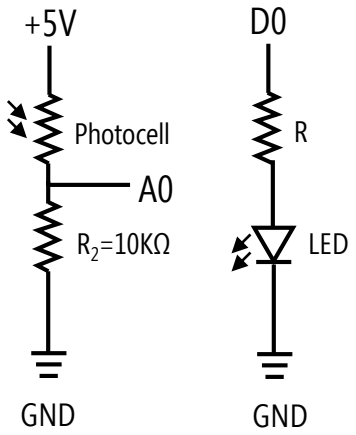


Old Circuit with Potentiometer



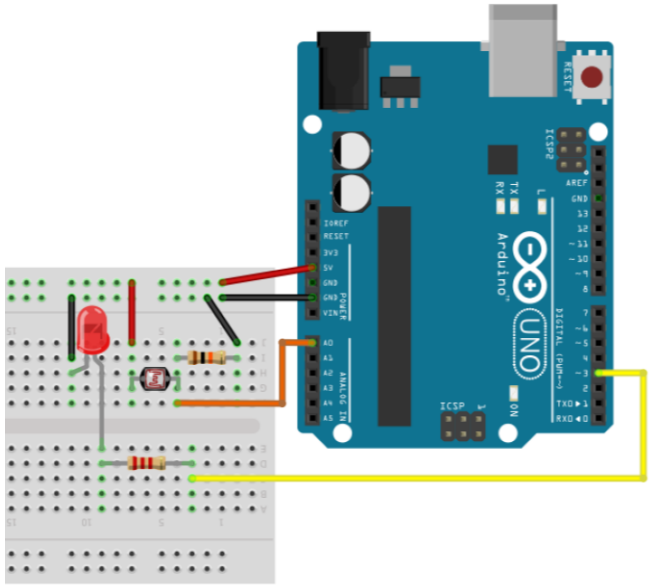


New Circuit with Photocell

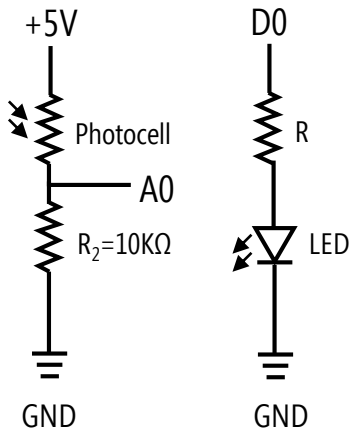


ANALOG INPUT

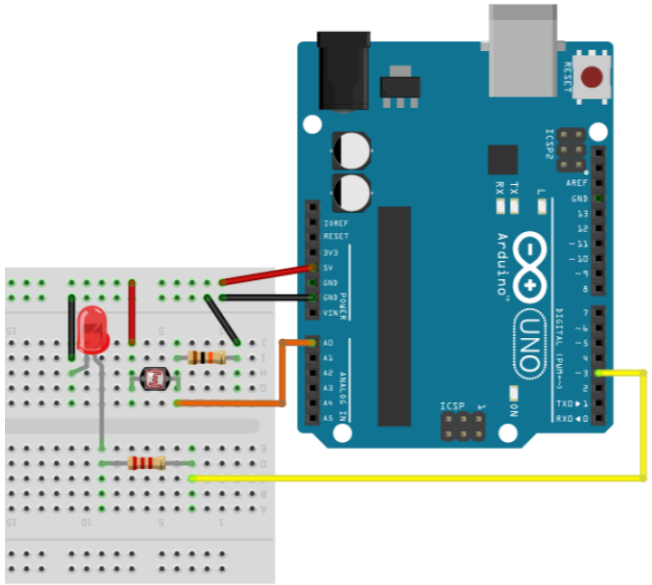
PHOTOCELL HOOKUP DIAGRAM



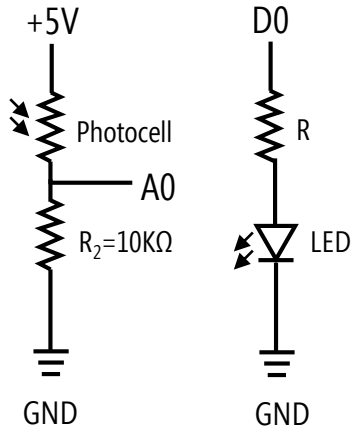
Correct Circuit with Photocell

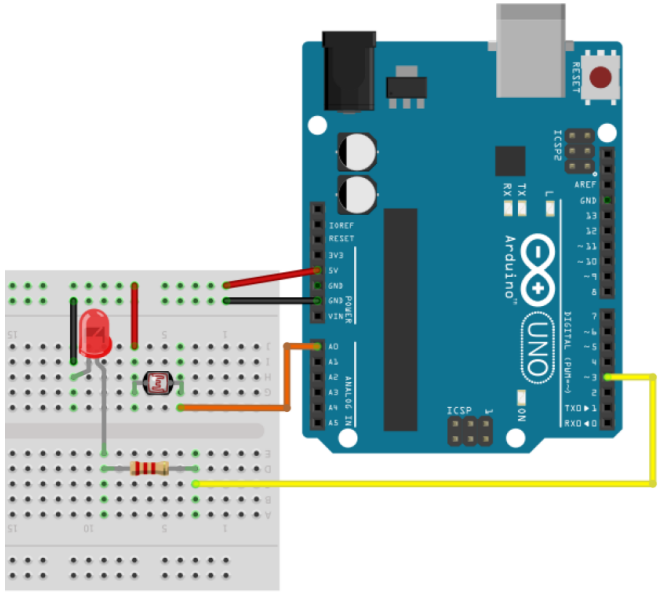


WHY CAN'T WE DO THIS?

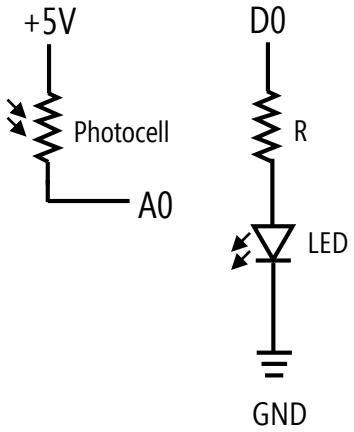


Correct Circuit with Photocell

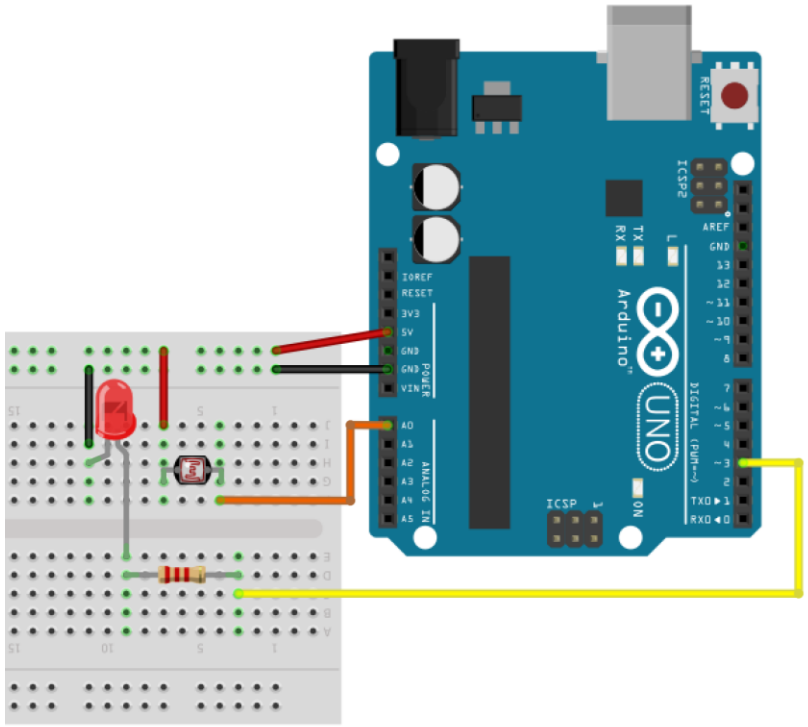




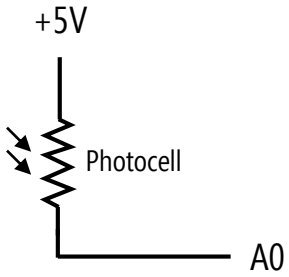
Incorrect Circuit with Photocell



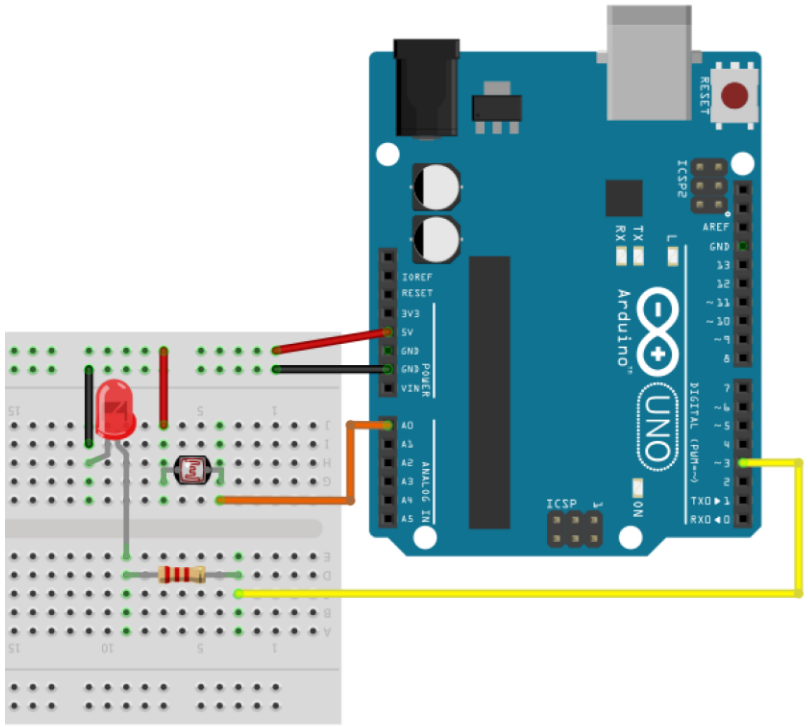
WHY CAN'T WE JUST DO THIS?



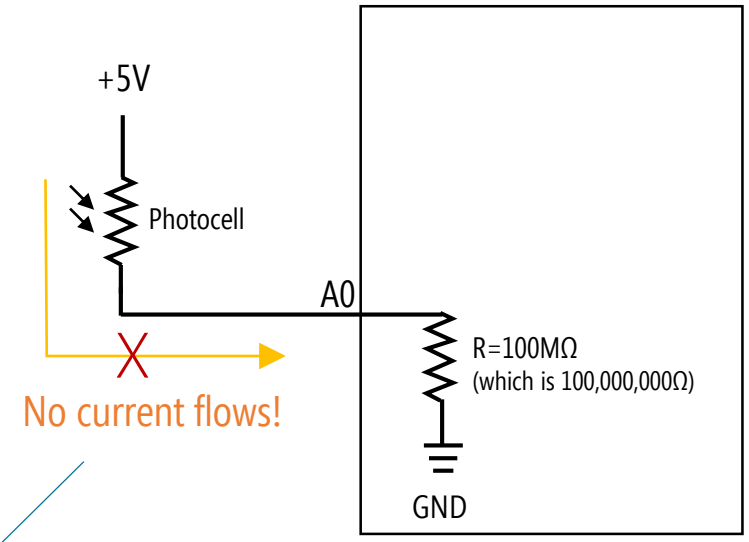
What's wrong with this circuit?



WHY CAN'T WE JUST DO THIS?



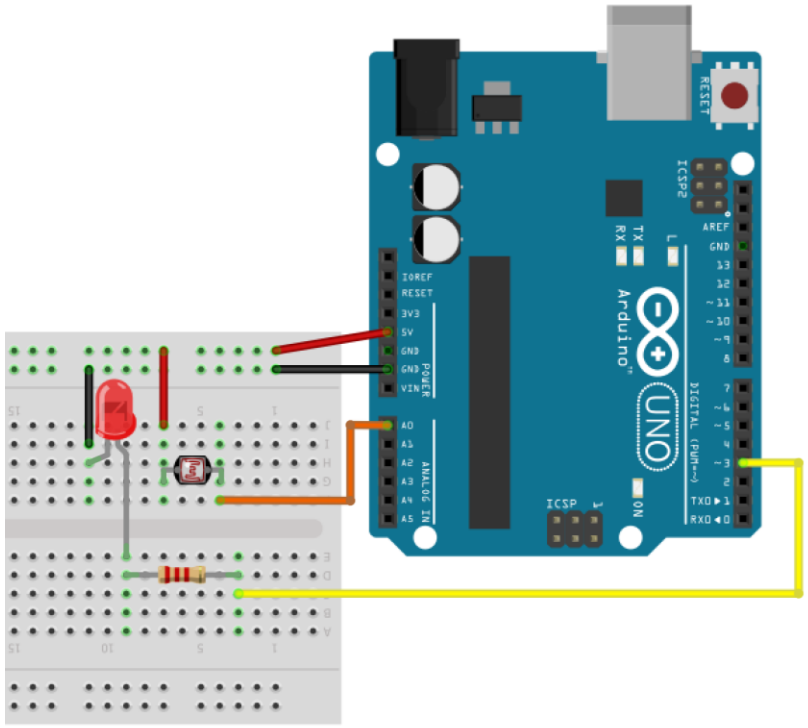
What's wrong with this circuit?



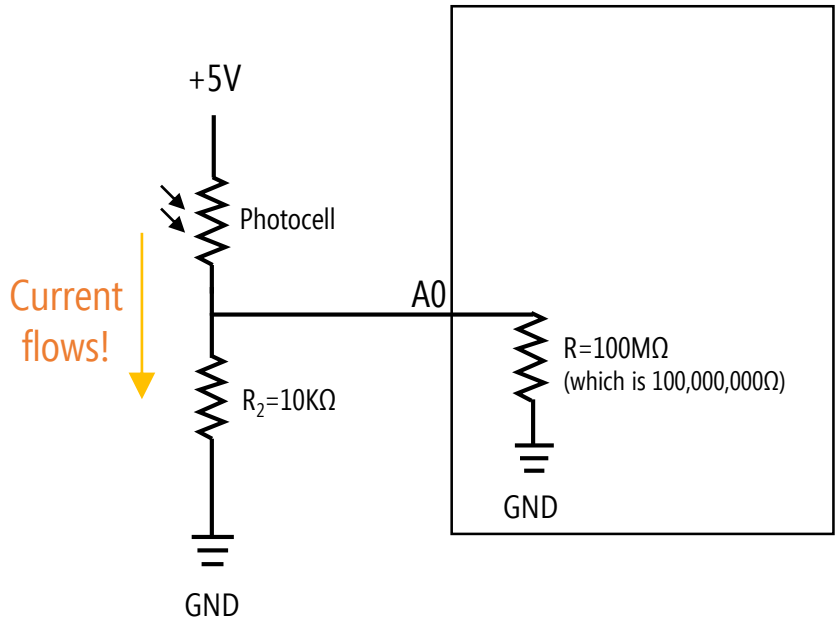
1. No current flows into the input pin because of extremely high resistance in the microcontroller

2. Microcontrollers **read changes in voltage** & not resistance or current

WHY CAN'T WE JUST DO THIS?

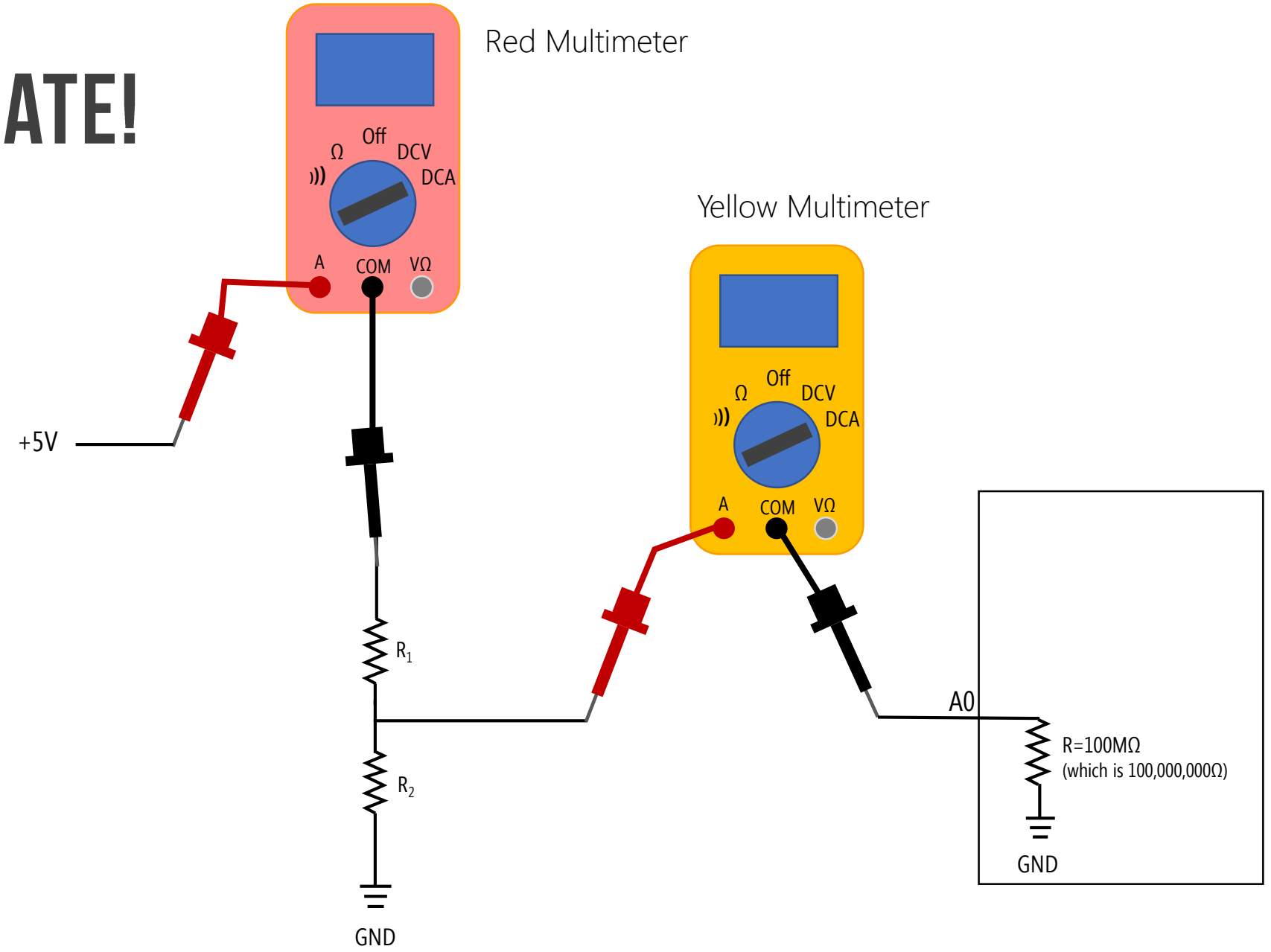


The correct circuit design



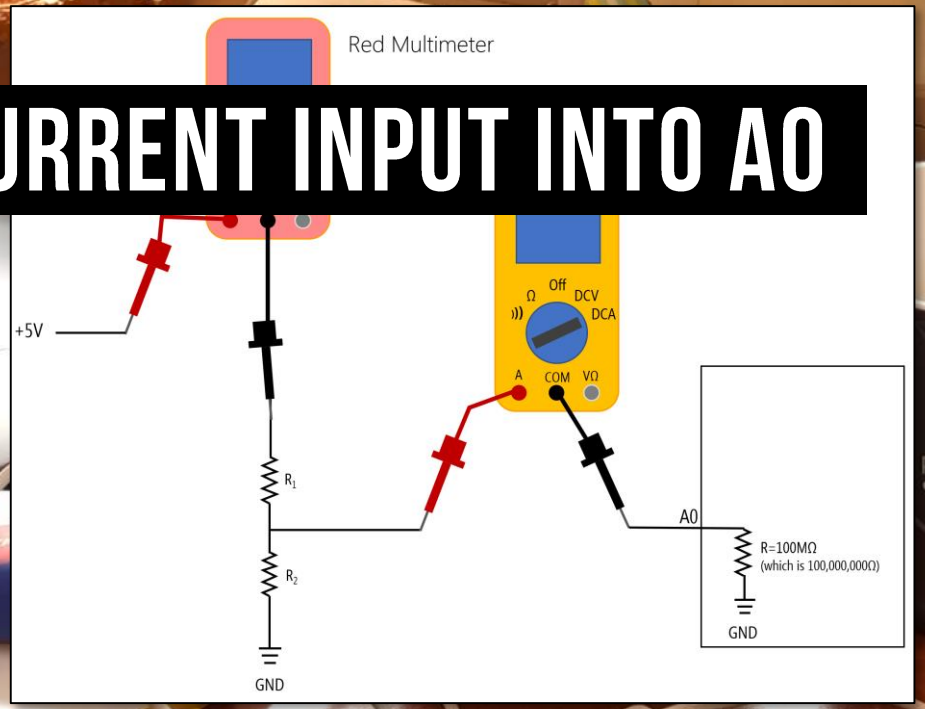
ANALOG INPUT

LET'S INVESTIGATE!

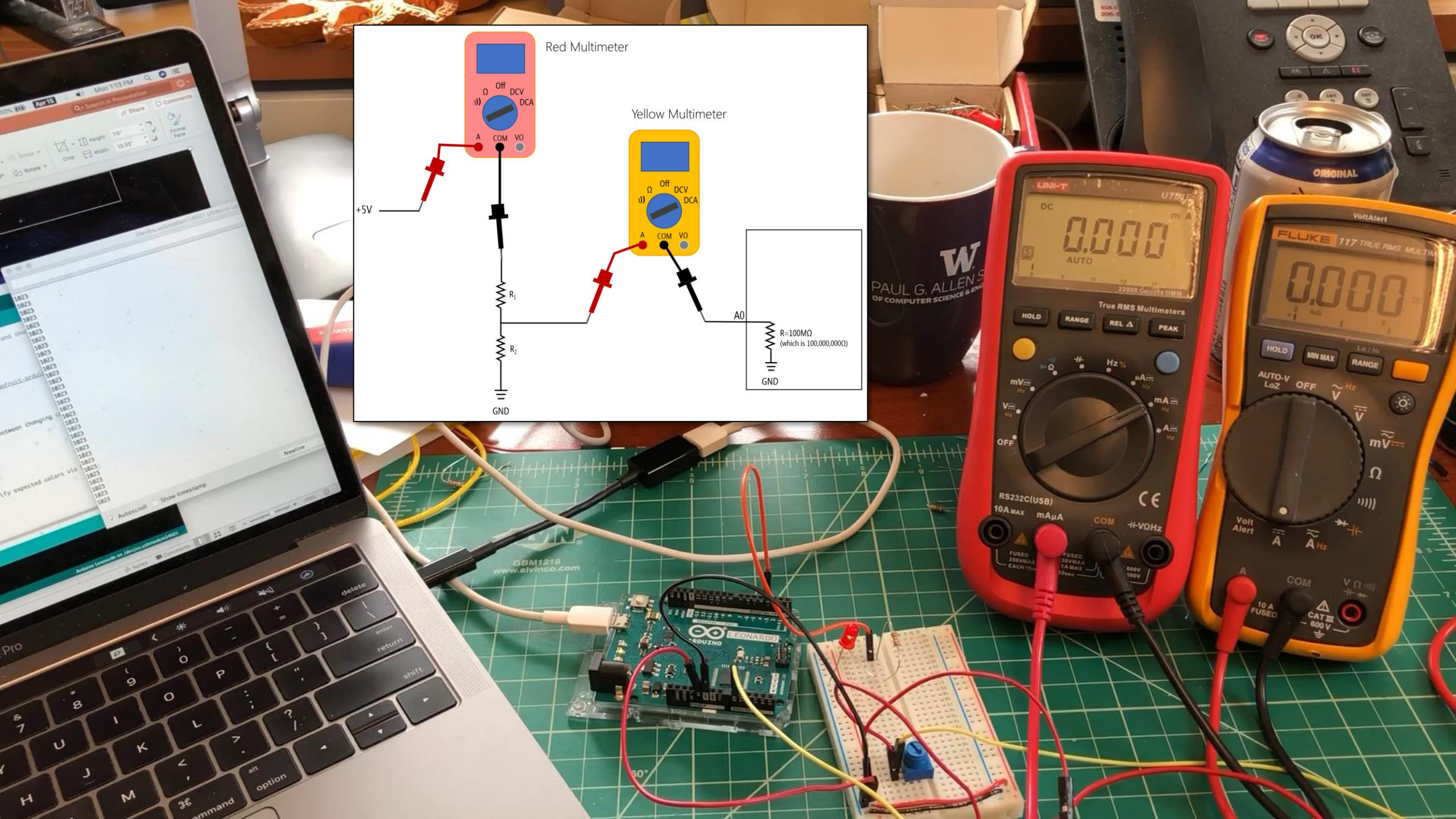


ANALOG INPUT

MEASURING CURRENT INPUT INTO A0

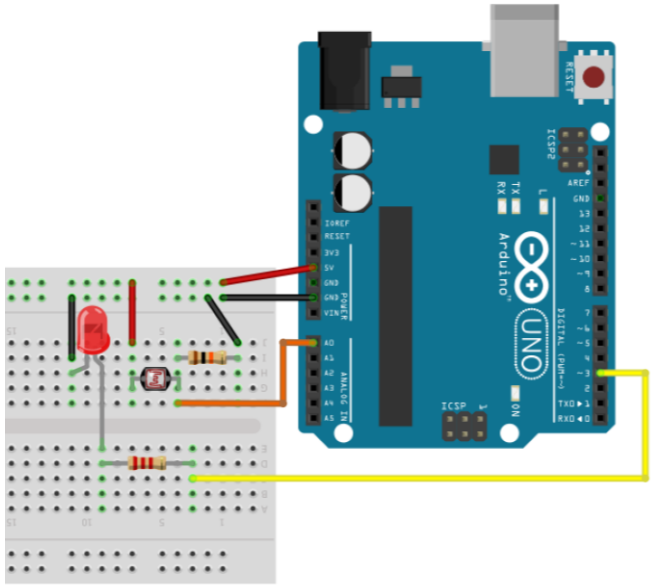


Video by Jon Froehlich

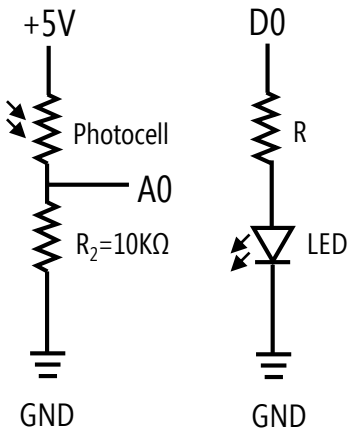

Red Multimeter
Off
Ω
DCV
DCA
A
COM
VΩ
+5V
R1
R2
GND
Yellow Multimeter
Off
Ω
DCV
DCA
A
COM
VΩ
A0
R=100MΩ
(which is 100,000,000Ω)
GND

ANALOG INPUT

HOOKING UP PHOTOCELL



Correct Circuit with Photocell

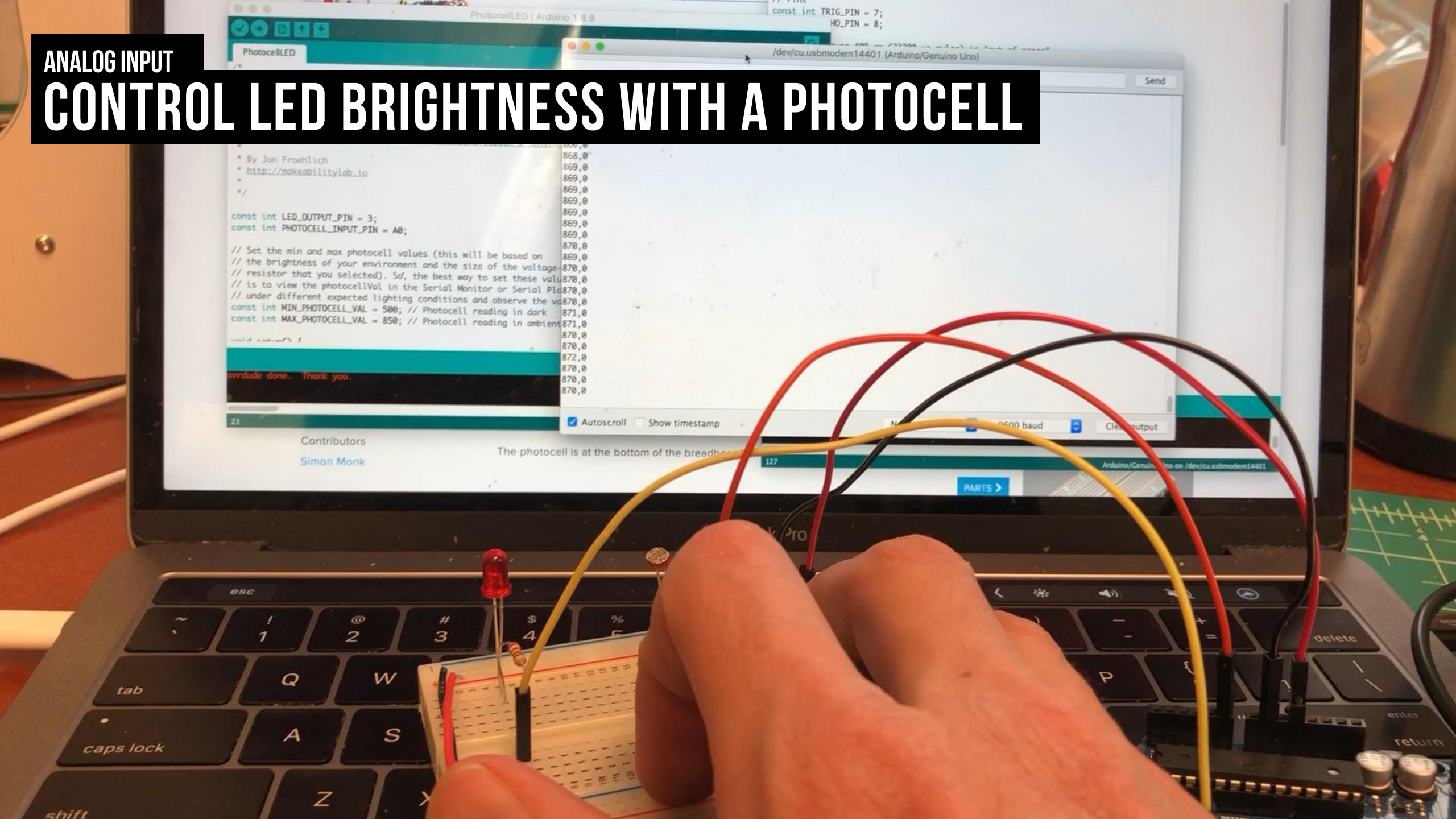


PhotocellLED

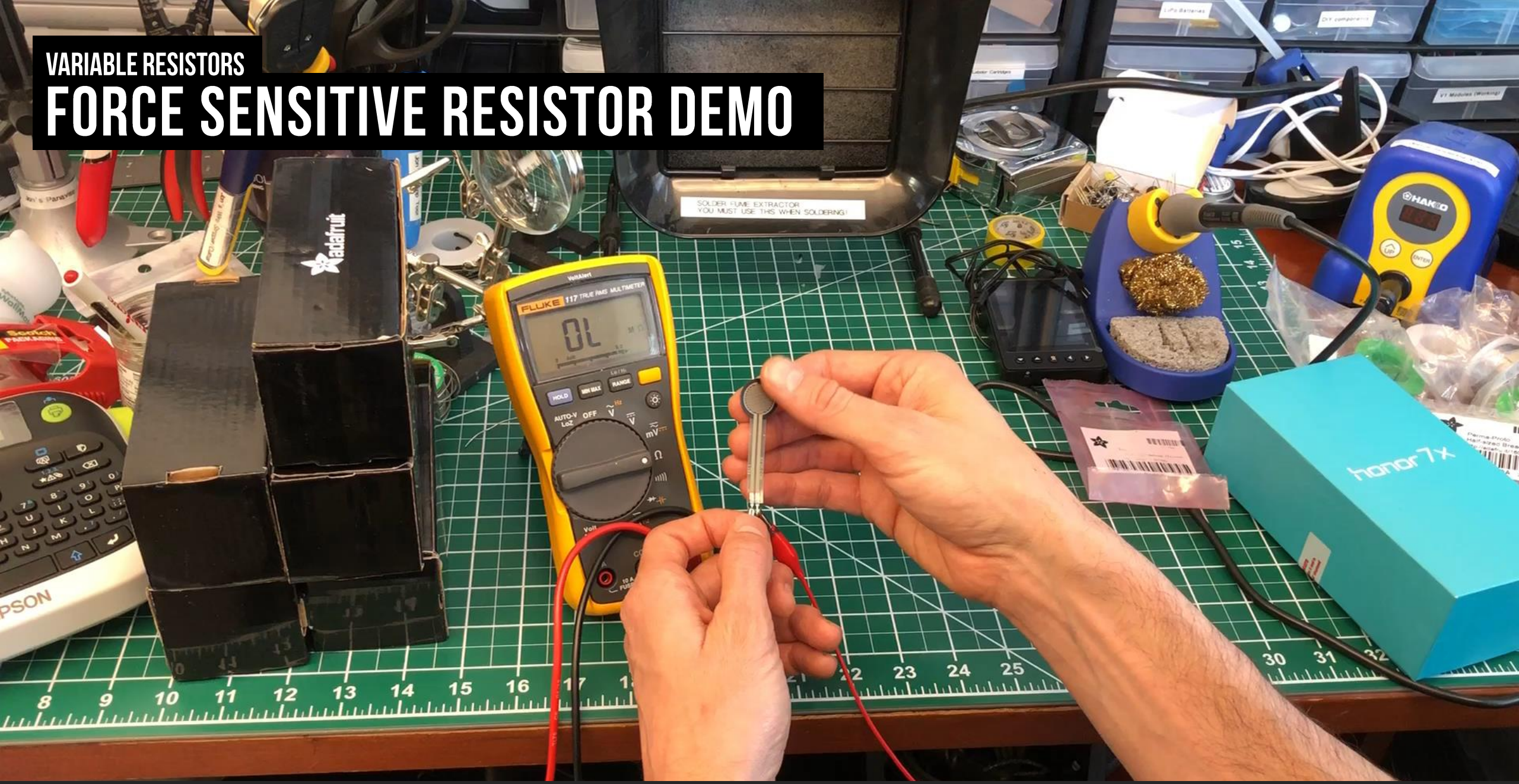
```
const int LED_OUTPUT_PIN = 3;
const int PHOTOCELL_INPUT_PIN = A0;

// Set the min and max photocell values (this will be based on
// the brightness of your environment and the size of the voltage-divider
// resistor that you selected). So, the best way to set these values
// is to view the photocellVal in the Serial Monitor or Serial Plotter
// under different expected lighting conditions and observe the values
const int MIN_PHOTOCELL_VAL = 150; // Photocell reading in dark
const int MAX_PHOTOCELL_VAL = 1023; // Photocell reading in ambient light

void setup() {
  pinMode(LED_OUTPUT_PIN, OUTPUT);
  pinMode(PHOTOCELL_INPUT_PIN, INPUT);
  Serial.begin(9600);
}

void loop() {

  // Read the photo-sensitive resistor value. If you have the photocell resistor hooked
  // up as Rtop in the voltage divider (that is, one leg of the photocell is connected to 5V),
  // then higher values correspond to brightness. If you ahve the photocell hooked up as Rbottom
  // in the voltage divider (that is, one leg of the photocell is connected to GND), then
  // higher values correspond to darkness.
  int photocellVal = analogRead(PHOTOCELL_INPUT_PIN);

  // Remap the value for output.
  int ledVal = map(photocellVal, MIN_PHOTOCELL_VAL, MAX_PHOTOCELL_VAL, 0, 255);

  // The map function does not constrain output outside of the provided range
  // so, we need to make sure that things are within range for the led
  ledVal = constrain(ledVal, 0, 255);

  // We want to invert the LED (it should be brighter when environment is darker)
  // This assumes the photocell is Rtop in the voltage divider
  ledVal = 255 - ledVal;

  // Print the raw photocell value and the converted led value (e,g., for Serial Plotter)
  Serial.print(photocellVal);
  Serial.print(",");
  Serial.println(ledVal);

  // Write out the LED value.
  analogWrite(LED_OUTPUT_PIN, ledVal);

  delay(100);
}
```

ANALOG INPUT

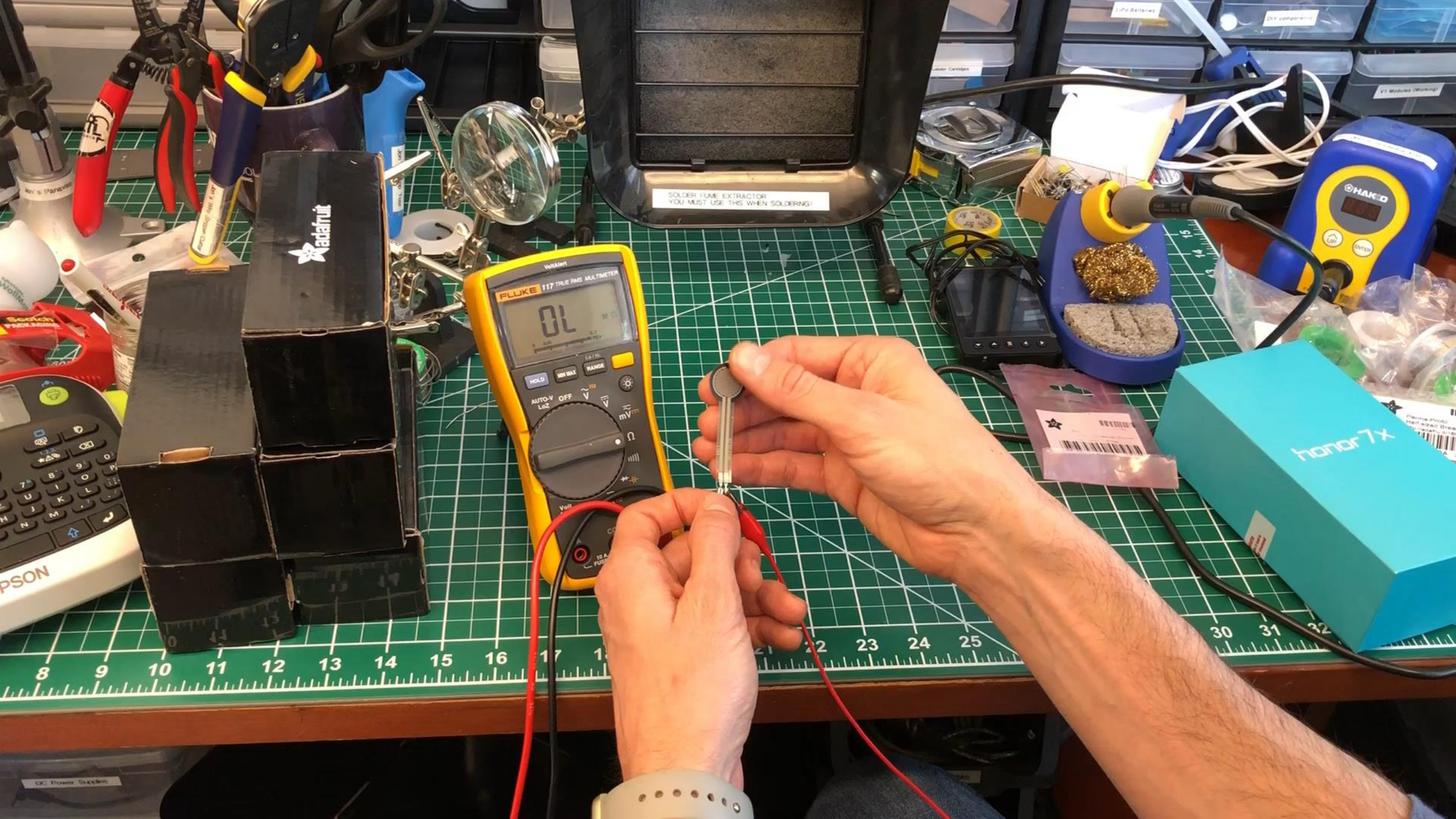
CONTROL LED BRIGHTNESS WITH A PHOTOCELL




FORCE SENSITIVE RESISTORS (FSRS)



Video by Jon Froehlich


SOLDER FUME EXTRACTOR
YOU MUST USE THIS WHEN SOLDERING!
FLUKE 117 TRUE RMS MULTIMETER
OL
HOLD
MIN MAX
RANGE
AUTO-V
OFF
HAKKO
honor 7x

VARIABLE RESISTORS

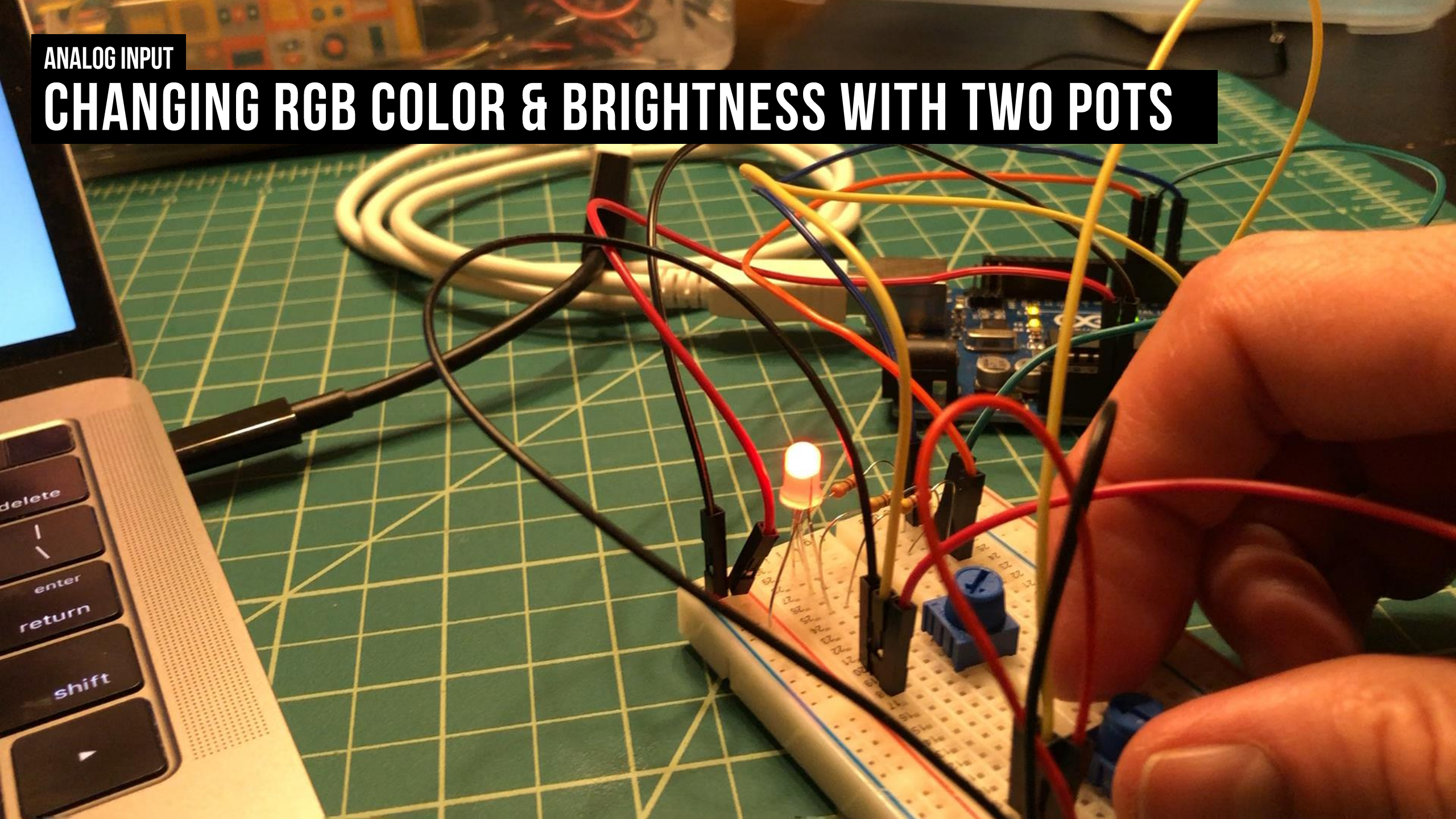
ACTIVITY: FORCE SENSITIVE RESISTOR

Replace your photocell with an FSR

Experiment!

ANALOG INPUT

CHANGING RGB COLOR & BRIGHTNESS WITH TWO POTS



PHYSICAL COMPUTING 4

TODAY'S LEARNING GOALS

Working with **analog input?**

What is **a knob/trim potentiometer** and how to use it?

What is **a slide potentiometer** and how to use it?

What are **variable resistive sensors** and how to use them?

Understanding the **importance of voltage dividers** when working with analog input (and the relevancy of Ohm's law!)

PHYSICAL COMPUTING 4: ANALOG INPUT & RESISTIVE SENSORS

CSE 599 Prototyping Interactive Systems | Lecture 5 | April 15

Jon Froehlich • Jasper O'Leary (TA)

DESIGN USE BUILD

MAKEABILITY LAB

PAUL G. ALLEN SCHOOL
OF COMPUTER SCIENCE & ENGINEERING

UNIVERSITY of WASHINGTON