Supplementary information for Lab 2: Quadrature Encoders; Pull-up and Pull-down Resistors

Important: This is **NOT** a lab description. This is **NOT** a prelab description. This is supplementary information meant to provide additional understanding. There are **no** homework assignments in any ECE 206 supplementary document. Students **must** read the main lab descriptions and complete their prelabs by the assigned deadlines. All prelabs are described in the lab description documents.

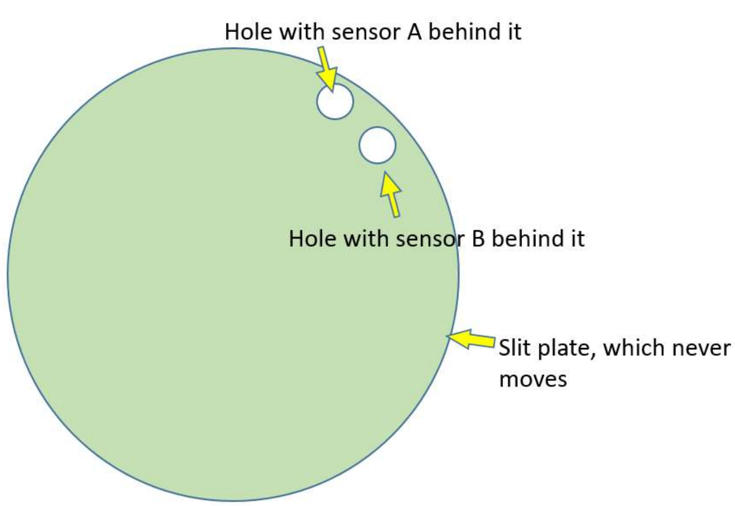
Advice for the Prelab to Lab 2:

Some students become confused by the drawing for Prelab 2. Here is a simplified version of the situation.

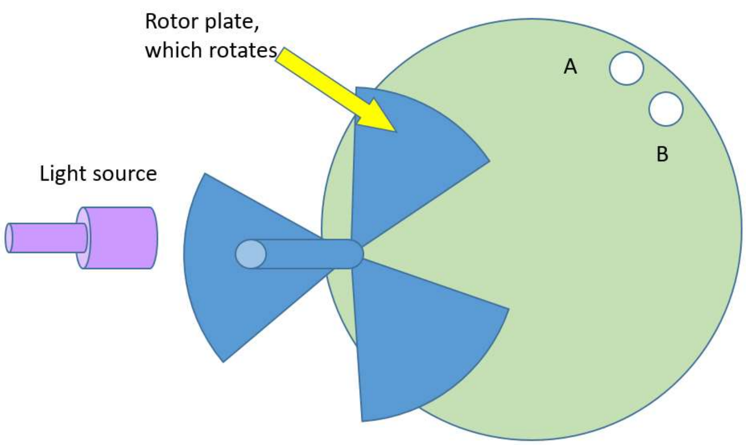
Simplifications:

1. Instead of LED emission diodes, I drew a flashlight. This does not change anything significant.
2. Instead of hundreds of slits in the rotor plate, I drew three slits. This just means there will be less transitions per wheel rotation. This does not change anything significant.
3. Phase Z slit and sensor is not shown because we are not reading the waveform for Phase Z anyway.

First, we have the slit plate and the sensors behind it. The sensors are phototransistors. When the phototransistor for A has light shining on it, A is HIGH. When the phototransistor for A has a shadow over it, A is LOW. The same is true for the sensors for B. The slit plate only allows light to reach the phototransistors if the light is shining directly on the holes in it. If light is not shining on the holes in it, then the phototransistors just see shadow.

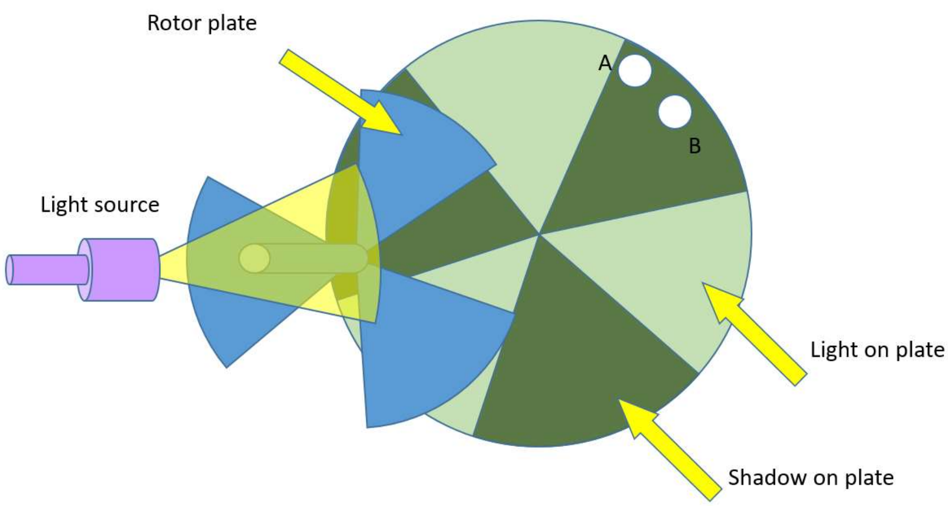


Next, we have the light source and the rotor plate.



The rotor plate is attached to a rotating shaft. It can turn clockwise or counter-clockwise. The light source does not move.

Finally, take a look at the diagram below:



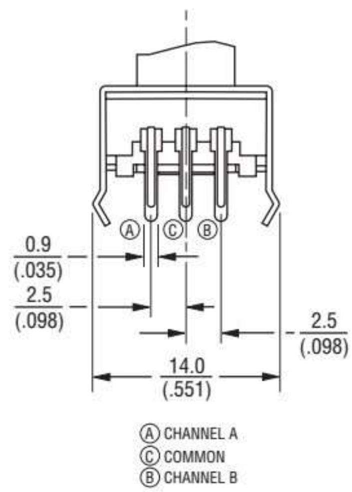
As the shaft turns, the rotor plate with it. As the rotor plate turns, the shadow that it casts on the slit plate also rotates. Sometimes the shadow will be over both A and B at the same time, and they will both read LOW. Sometimes it will be over just A, or just B, and one will be HIGH while the other is LOW. Sometimes, both A and B will see light at the same time, and they will both be HIGH.

In the prelab, you need to understand that the pattern of transitions between high and low contains enough information to track the rotation of the shaft.

One part of the plot that many students seem to miss is that a phase number has been assigned to each of the four possibilities. When both A and B are low, that is called Phase 1 on the chart. When A is high and B is low, that is called Phase 2 on the chart, etc. When you re-draw the chart to show the opposite direction rotation, keep this in mind!

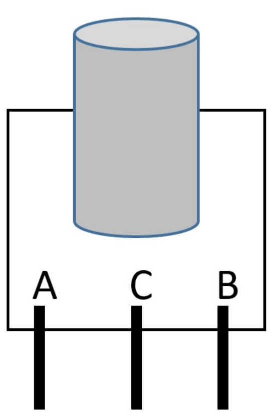
Understanding the Encoder

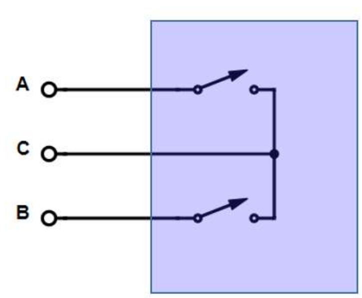
In the lab description you see the following diagram:



This is NOT an electrical diagram. It is a mechanical drawing of the dial encoder. It gives a label for which pin is Channel A, which pin is Channel B, and which pin is the Common pin.

Your encoder has no light source. It has no photodiodes. So how does it work? Inside the encoder, there are two switches. One switch makes connections between pin A and pin C. The other switch makes connections between pin B and pin C. That is why pin C is called "Common" – it is common to both switches. By reading whether each switch is OPEN or CLOSED, you can track the movement of the encoder the same way as you could track the movement of the rotating shaft in the prelab.

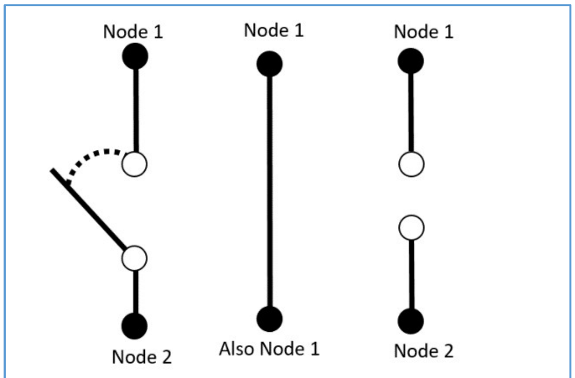




<u>Reading the position of a switch</u>

Note: Some students have a lot of trouble with understanding the techniques described in this section. If you are at all confused, PLEASE, come to office hours!

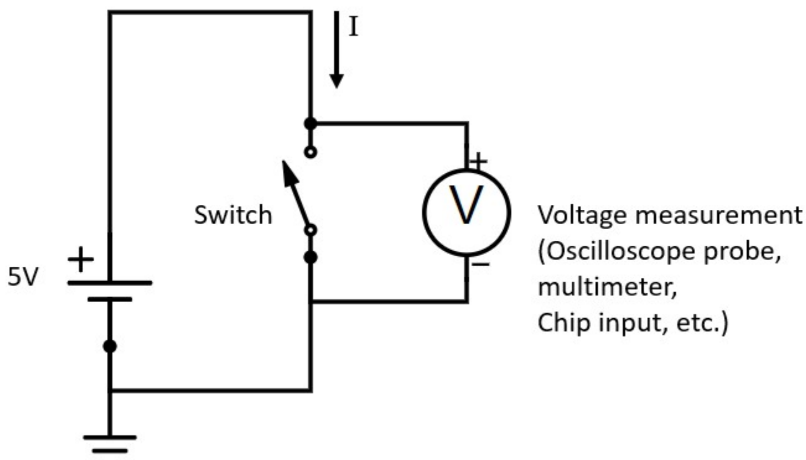
Below are the schematic symbols for a switch, a wire, and an open disconnect between two points. When a switch is CLOSED, it behaves like a wire between two points. When it is OPEN, it behaves like an open disconnect between two points. All points on an ideal wire have the same voltage, and are considered to be the same node.



Schematic symbols for a switch, a wire, and an open disconnect

So, how can one determine the state of a switch?

Circuit #1: What NOT to do



In this diagram, someone has wired a DC voltage supply (such as a battery or your bench power supply) directly to a switch, with nothing in between them. The volt meter is reading the voltage across the switch. When the switch is open, everything is fine – There will be no current flowing, so the voltage measured across the switch will be equal to the voltage of the DC power supply.

What happens when the switch is closed? The switch will cause a short circuit between the two terminals of the DC power supply. **This is bad.** Why is it bad? We offer two explanations: physical, and mathematical.

Physical explanation of why this is wrong:
When the switch closes, it's the same thing as putting a wire directly across the DC terminals. In designing circuits, we say that wires have approximately 0Ω of resistance. However, all DC circuits **must** obey Ohm's Law. $V = IR$. We have a 5 volt power supply. If resistance were truly 0Ω, then current would have to be infinite. In reality, the resistance isn't 0Ω, but it is very tiny, and so you will have a very large current demand. What happens depends on the physical properties of your circuit. Your voltmeter will always show you *some* value, but it won't be a reliable, engineered value of 5V or 0V like the other circuits you will read about below. This circuit is a bad plan. Do not do this.

If you are using a bench power supply, it will have a programmed maximum current limit. You will see the power supply hit the maximum current output, and then it will reduce the voltage so that $\frac{V}{R} = I \leq maximum\ current\ setting$. This is a safety feature. If you ever see your bench power supply suddenly reduce its voltage output, you are probably triggering this safety feature, and you should check for a short circuit.

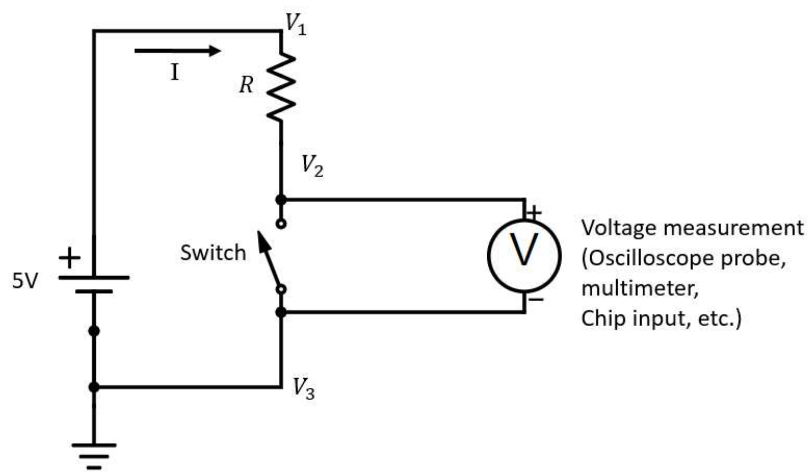
If you are using a battery, then the battery will output as much current as it possibly can, and due to internal resistance, both the battery and the wires in your circuit will become very hot. This can cause the battery to **explode** or start a **fire**.

Mathematical explanation of why this is wrong:
We say that all points in a circuit connected by the same wire are at the same voltage. So drawing a schematic with a short circuit across the DC power supply is saying the circuit must satisfy the condition $5V = 0V$. Because 5 does not equal 0, this is a mathematical absurdity, and doomed to fail.

Behavior of Circuit 1	
Condition	**Result**
Switch is OPEN	Measure V_2
Switch is CLOSED	BAD. UNDEFFINED BEHAVIOR. POSSIBLE FIRE.

Circuit #2: Using a pull-up resistor

Look at the circuit below:



No matter what position the switch is in, the voltage supply never has its positive and negative terminals shorted together. This is a good start. We will read the voltage difference across the switch.

When the switch is CLOSED:
V_3 is located at ground, so $V_3 = 0V$.
The switch creates a short, so $V_2 = V_3 = 0V$.
V_1 is located at the positive terminal of the DC power supply, so $V_1 = 0V + 5V = 5V$.

$$I = \frac{V_1 - V_2}{R} = \frac{5V - 0}{R} = \frac{5V}{R}$$

The voltage across the resistor follows Ohm's law. $V_{across\ resistor} = I * R = \left(\frac{5V}{R}\right) * R = 5V$.
The voltage measurement probe is reading $V_2 - V_3 = 0V - 0V = 0V$.

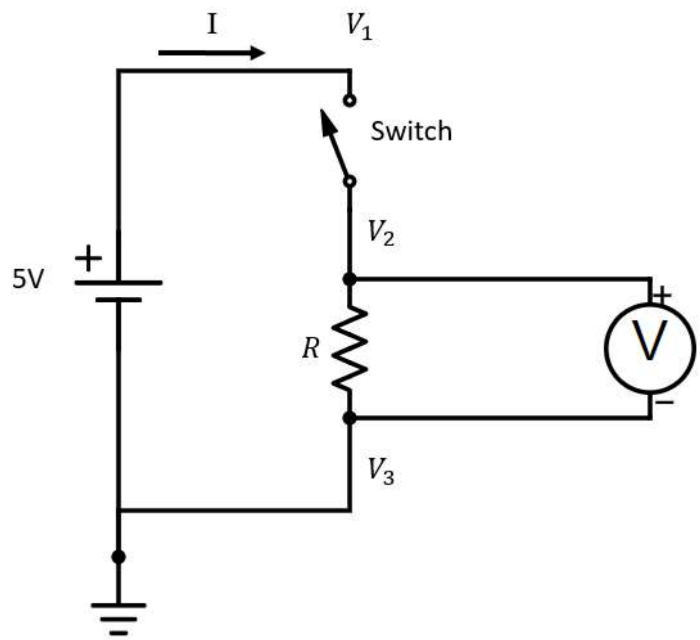
When the switch is OPEN:
V_3 is located at ground, so $V_3 = 0V$.
V_1 is located at the positive terminal of the DC power supply, so $V_1 = 0V + 5V = 5V$.
There is no path for current to flow through, so $I = 0A$.
There is no current, so $V_{across\ resistor} = I * R = (0A) * R = 0V$.
$V_2 = V_1 - V_{across\ resistor} = V_1 - 0 = V_1 = 5V$.
The measurement probe is reading $V_2 - V_3 = 5V - 0V = 5V$.

Behavior of Circuit 2: Pull-up resistor	
Condition	**Result**
Switch is OPEN	Measure 5 volts
Switch is CLOSED	Measure 0 volts.

The switch is connected to a resistor that brings the voltage up when the switch is open, but allows the switch to force the voltage to 0V when the switch is closed. We say that the switch is connected to a **Pull-up resistor.**

Circuit #3: Using a Pull-down resistor

Look at the circuit below. It uses a pull-down resistor:



What's the difference? This time, the resistor is between the switch and ground. That is why it is called a pull-down resistor: the resistor connected to ground pulls V_2 down to 0V when the switch is not directly shorting V_2 to a different voltage. In the last circuit, the resistor was between the switch and a high voltage.

You are encouraged to derive the behavior of the circuit yourself. However, here is a table for your reference:

Behavior of switch-measuring circuits with 5V DC power supply			
Condition	**No resistor**	**Pull-Up Resistor**	**Pull-down Resistor**
Switch is OPEN	5V	5V	0V
Switch is CLOSED	SHORT CIRCUIT. BAD.	0V	5V

Now, based on what you've learned here, you should be able to design a circuit that can read from your encoder. The voltage measurement device you use in Lab 2 will be the oscilloscope. The black leads of each oscilloscope probe should ALWAYS be connected to the ground of your circuit.