18-100: Intro to Electrical and Computer Engineering

LAB05: 555 Lab

Writeup Due: Thursday, March 3, 2022 at 10 PM ET

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Note that while you may work with other students on completing the lab, this writeup is to be completed alone. Do not exchange or copy measurements, plots, code, calculations, or answer in the lab writeup.

Your lab grade will consist of two components:

1. Answers to all lab questions in your lab handout. The questions consist of measurements taken during the lab activities, calculations on those measurements and questions on the lab material.
2. A demonstration of your working lab circuits and conceptual understanding of the material. These demos are scheduled on an individual basis with your group TA.

Question:	1	2	3	Total
Points:	20	15	25	60
Score:				

Lab Outline

This lab aims to demonstrate how RC circuits can be used to construct timing circuits. Students will then use these timing circuits to control various different output devices.

1. LED Flasher
2. Speaker Circuit
3. Servo Controller

Equipment Required

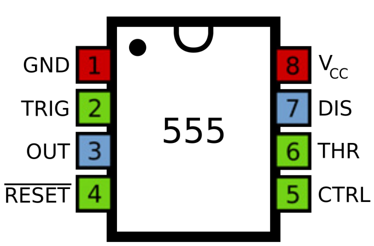
- Breadboard
- Power Supply
- Digital Multimeter with Probes
- ADAM2000 + Scopy {`Oscilloscope`}
- Oscilloscope Probes
- Wire Strippers
- Diagonal Cutters
- Pliers

Bill of Materials

1x 100Ω Resistor
1x 470Ω Resistor
6x 1kΩ Resistor
2x 2.2kΩ Resistor
2x 10kΩ Resistor
2x 100kΩ Resistor
1x 10kΩ Potentiometer (`B10K`, Box 2)
2x 20kΩ Potentiometer (`B20K`, Box 2)
1x 50kΩ Potentiometer (`B50K`, Box 2)

4x 103 10nF Ceramic Capacitor (Box 2)
3x 104 100nF Ceramic Capacitor (Box 2)
6x 10μF Electrolytic Capacitor (Box 2)
4x SE555P Timer IC (Box 1)
1x LED (Box 1)
1x 8Ω Speaker (Bag 4)
1x Pushbutton (Box 2)
2x n-MOSFET (ZVN3306A, Box 1)
2x 9g Servo Motors + Pan-Tilt Parts Kit (Bag 4)

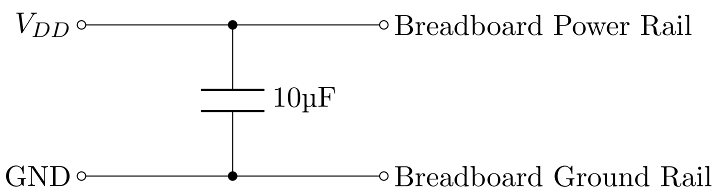
Pinouts

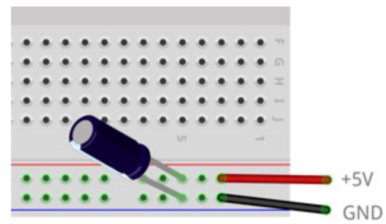


555 Timer Pinout

Decoupling Capacitors

Decoupling capacitors are placed in parallel with the circuit, and store excess input voltage while also providing their stored power if the input voltage decreases. This helps reduce noise in the circuit by smoothing out in the input voltage. They provide the opposite function from coupling capacitors by absorbing AC inputs and letting DC inputs travel to the rest of the circuit. When connected from the input voltage to ground, decoupling capacitors also protect components from high-frequency inputs, as the high frequency means the capacitor will have a low impedance, and let the current flow through it to ground.





⚠ **Note: You must include this capacitor across your power rails! Circuits may not function correctly without it.**

Connecting the Speaker

Similar to the Glucose Strip in Lab 4, connect your speaker to the breadboard in the following manner using the binding posts and the micrograbber cables:

Figure 2: Speaker Connections

The positive terminal of the speaker is marked with red paint. The unmarked terminal should be connected to ground.

1. LED Flasher

The *555 Timer* revolutionized timing circuits when it was released in 1972, and remains today one of the most popular ICs ever manufactured due to its stability and its ease of use. In this lab, we're going to look at the 555 as an *astable oscillator*, a circuit that oscillates between a high and a low state ($\sim$ 3V and $\sim$ 0V respectively).

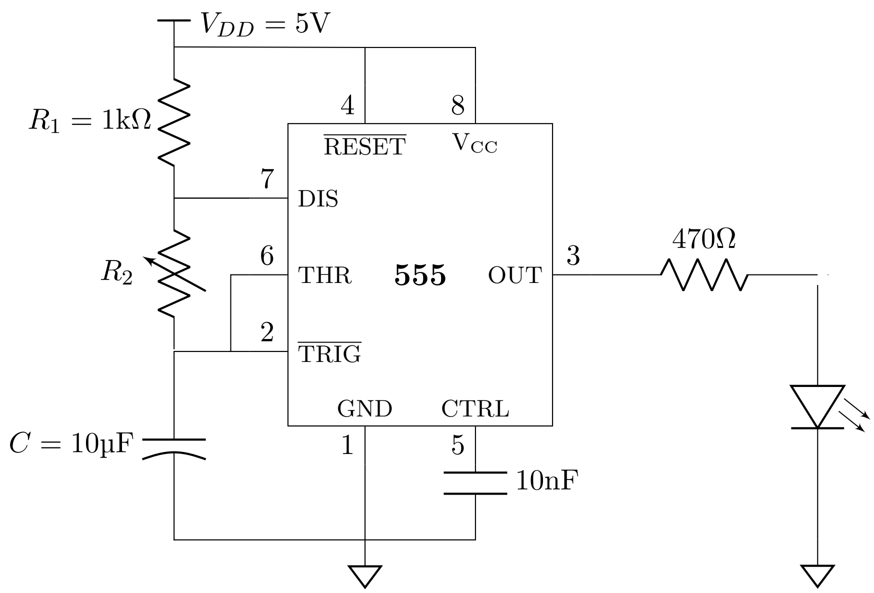


Figure 3: 555 Timer Signal Source, LED Output

1 pts

1.1 R_2 is a variable resistance formed by a 10kΩ potentiometer and a 1kΩ resistor in series. For the rest of this section we will treat this is as one value. Calculate the minimum and maximum values for R_2 formed by the 1kΩ and the 10kΩ potentiometer.

Minimum = 1 kΩ **Maximum** = 11 kΩ

Build the above circuit (Figure 3) on a breadboard. We've provided a diagram below to help you get started.

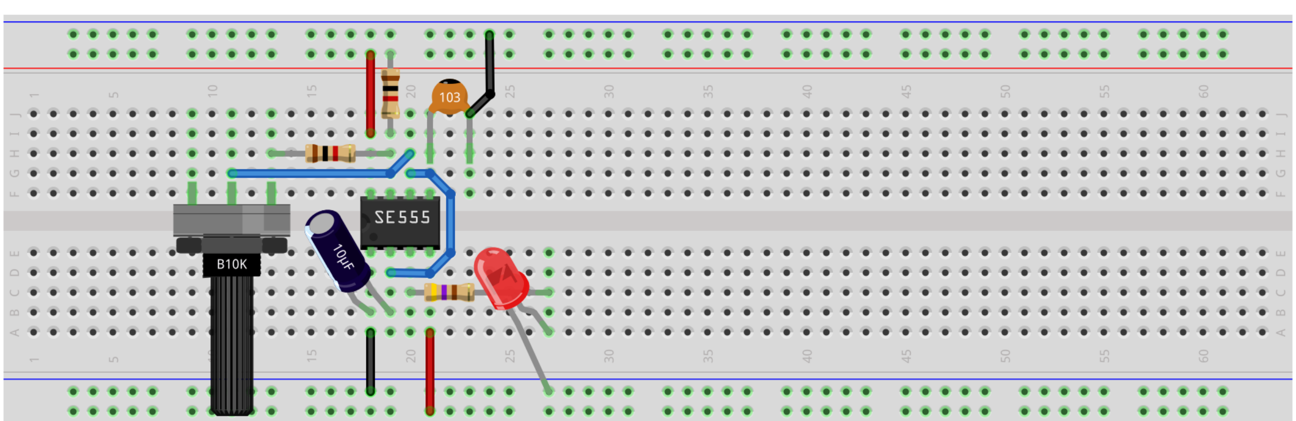


Figure 4: 555 Timer Circuit on a Breadboard

2 pts

1.2 Power on the circuit and turn the potentiometer to its highest resistance. (If you set up the circuit as indicated in Figure 4, this should be all the way to the left). Slowly turn the potentiometer to decrease its resistance until it is zero (all the way to the right). What do you observe? Describe the circuit's initial and final states with respect to *frequency*.

As you increase the resistance of the potentiometer the frequency of the output decreases.
when the resistance is decreased, frequency of the circuit's output increases.

The LED may have appeared to stop blinking but, in actuality, it's just turning on and off faster than the human eye can perceive! Using the oscilloscope, we can see this oscillation.

Connect probes to `CH1`, `CH2` on the ADALM2000 Adapter Board. Make sure the switch on the probe is set to 1X and the jumper on the Adapter Board is set to "DC". Connect the `CH1` probe across the output pin of the 555 timer as shown below. Connect the `CH2` probe across the 10μF capacitor as shown below:

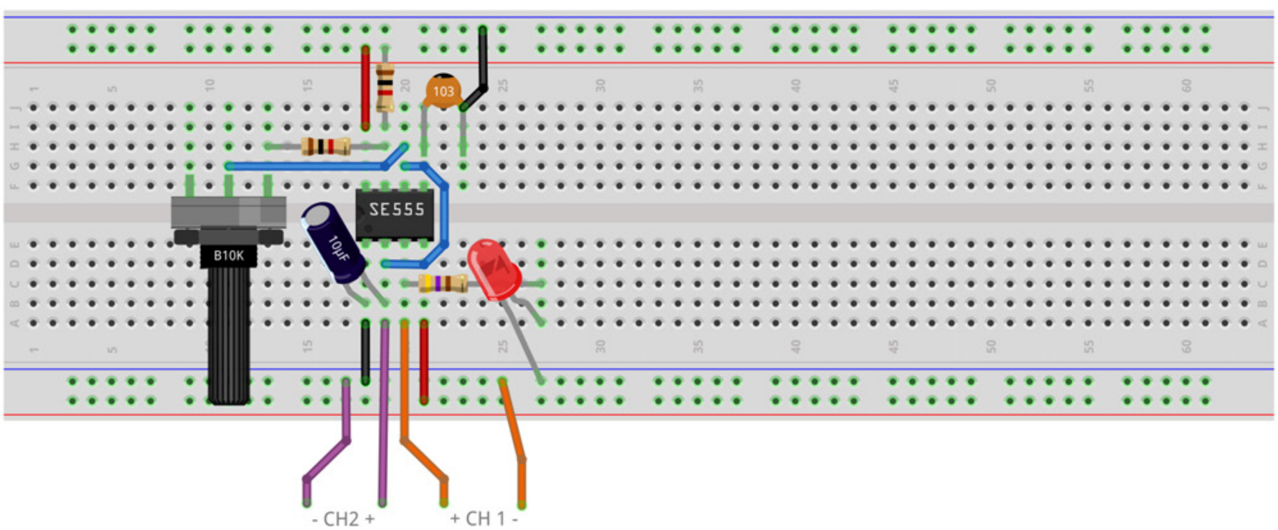


Figure 5: Oscilloscope Probes on 555 Output and Capacitor

1 pts

1.3 Measure the frequency and period across the output of the 555 (`CH1`).

Frequency = 49.7 Hz **Period** = 20.1 ms

1 pts

1.4 Using the cursors, measure the low output voltage (V_{OL}) and high output voltage (V_{OH}). (`CH1`)

V_{OL} = -0.3 V V_{OH} = 3.8 V

1 pts

1.5 Using the same methodology as in Question 1.4, find V_{min} and V_{max} for the voltage across the capacitor.

V_{min} = 1.61 V V_{max} = 3.16 V

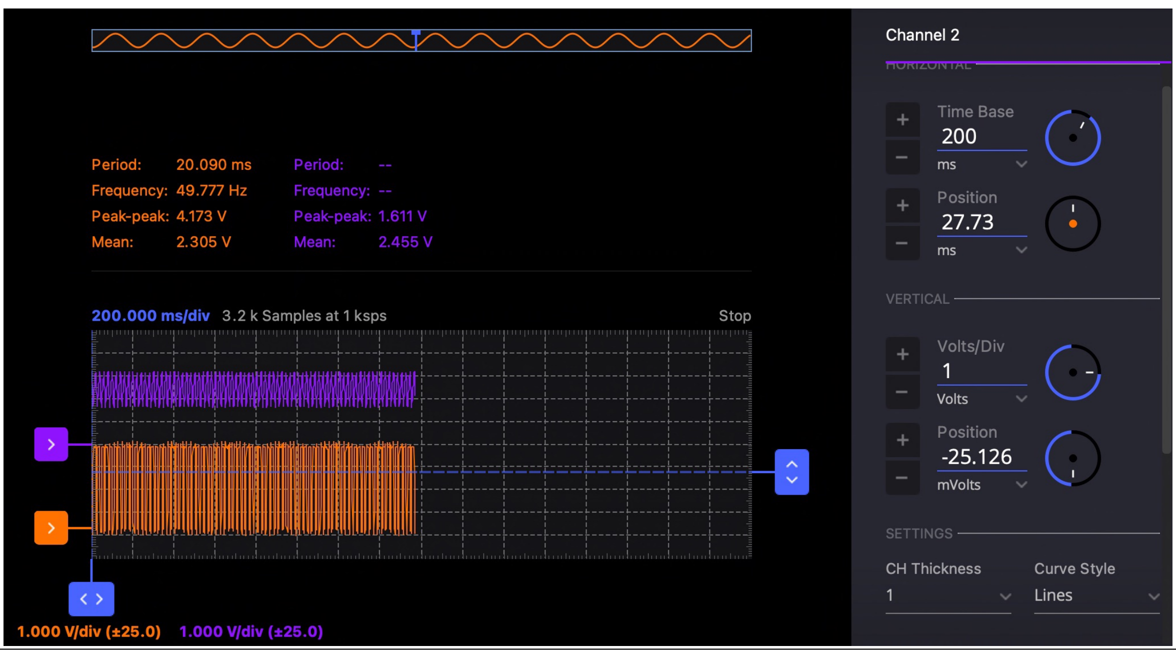
2 pts

1.6 Approximately, what fraction of V_{CC} are V_{min} and V_{max}? How do these values correspond to when the 555 output transitions from high to low?

Vmin is about $\frac{1}{3}$ of V_{cc} and Vmax is about $\frac{2}{3}$.

3 pts

1.7 Paste a screenshot of your oscilloscope window in the box below. **List your Time Base and Voltage Scale used below).**



Time Base = 2000.0 µs/div **Voltage Scale** = 1 V/div

While the wave you see on your oscilloscope may look like it is on/off the same amount of time, the t_L and t_H (time low/high) are actually different and depend on the resistors/capacitors used in your circuit.

The high time (t_H) and low time (t_L) can be calculated using the formulas below:

$$t_H = 0.693 * (R_1 + R_2) * C \quad (1)$$

$$t_L = 0.693 * R_2 * C \quad (2)$$

The sum of the high and low time is the period of the signal (T). Its inverse is the frequency (f).

$$T = \frac{1}{f} = t_L + t_H \tag{3}$$

2 pts

1.8 Calculate the t_H and t_L for the 555 Timer LED Flasher for when the potentiometer is at its max value (11kΩ) and min value (1kΩ). (Use $R_1 = 1\text{k}\Omega$ and $C = 10\mu\text{F}$)

$\boldsymbol{R_2 = 1k\Omega}$	$\boldsymbol{R_2 = 11k\Omega}$
$t_L = 0.693 \cdot 1k\Omega \cdot 10\mu F$	$t_L = 0.693 \cdot 11k\Omega \cdot 10\mu F$
$= 6.93$ ms	$= 7.6$ ms
$t_H = 0.693 (2k\Omega) \cdot 10\,\mu F$	$t_H = 0.693 (12k\Omega)(10\mu F) =$
$t_H =$ 13.8 ms $t_L =$ 6.93 ms	$t_H =$ 83.16 ms $t_L =$ 76.23 ms

In *astable* mode, the 555 timer generates a square wave. This means that the output voltage is a periodic pulse that alternates between the V_{CC} value and 0 volts.

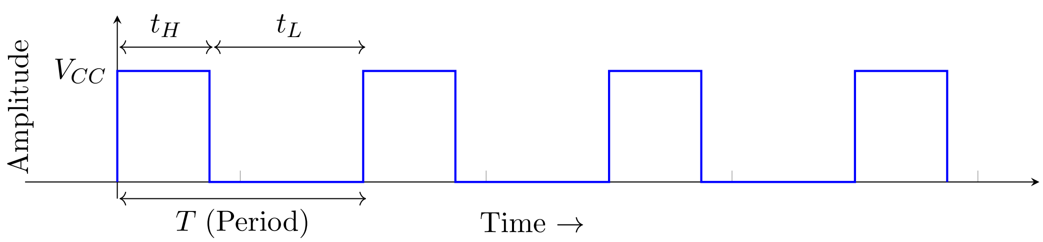


Figure 6: A Pulse-Train Wave Oscillating between V_{CC} and 0 V (33% Duty Cycle)

In Figure 6, the signal is either high (at V_{CC}) or low (at 0V). The percentage of time that the signal is high for is called the *duty cycle*. We represent this quantity with the following equation:

$$\text{Duty Cycle (D)} = \frac{t_H}{T} \times 100\% \tag{4}$$

2 pts

1.9 Using Equation 4, calculate the duty cycle for the 555 LED Flasher circuit.

$D_{1k} =$ 65.5 % $D_{11k} =$ 54.4 %

5 pts

1.10 Be prepared to demonstrate your working 555 LED Flasher circuit as well as answer a few questions relating to its operation.

⚠ **Do NOT take your circuit apart yet! You will need it for lab checkoff!**

2. 555 Audio Synthesizer

In the previous section, we've seen how we can use a 555 Timer to create oscillating signals. We've also seen how some of those signals can go beyond our ability to visually perceive them (e.g. the LED blinking faster than we can see). In this section, we'll see how can we take even faster oscillations and use them to produce sounds.

Build the 555-based signal source with the speaker in Figure 7 on breadboard.

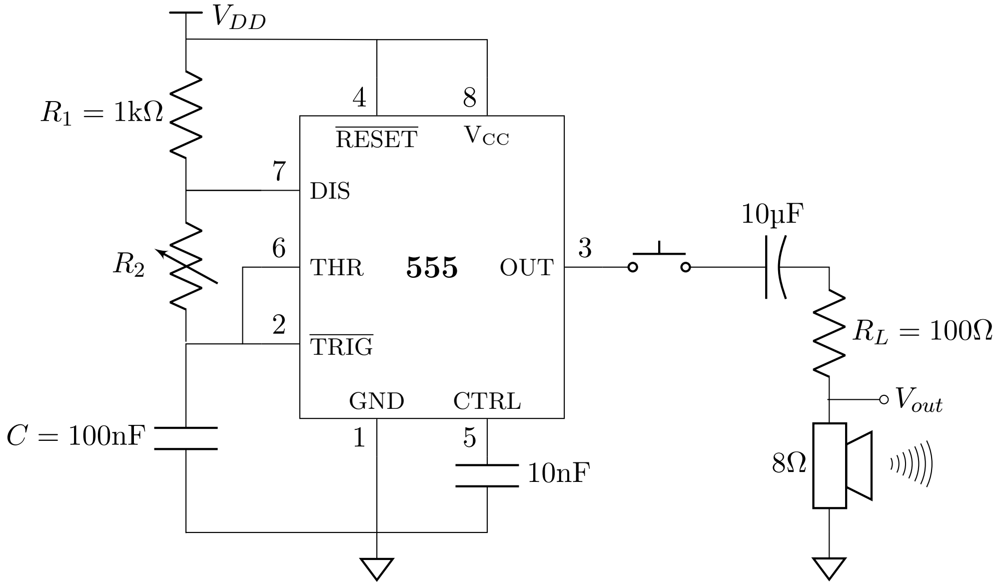
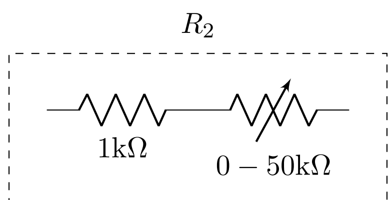


Figure 7: 555 Timer Signal Source with Speaker

R_2 is comprised of a 1kΩ resistor and a 50kΩ potentiometer (B50k) in series. Make sure you have a 10µF decoupling capacitor between your power and ground rails. R_L is a current-limiting resistor to reduce the volume of the speaker. Use the binding posts on the breadboard and the banana-micrograbber cables to connect the speaker to the circuit. This is shown in more detail in the Introduction section.



1 pts **2.1** Based on the behavior of the circuit, as you increase the resistance the pitch:

☐ **Increases** ☒ **Decreases** ☐ **Stays the same**

1 pts **2.2** Calculate the minimum and maximum frequencies produced by the circuit.

min: $T = 2(0.693 \cdot 1k\Omega \cdot 100nF) =$

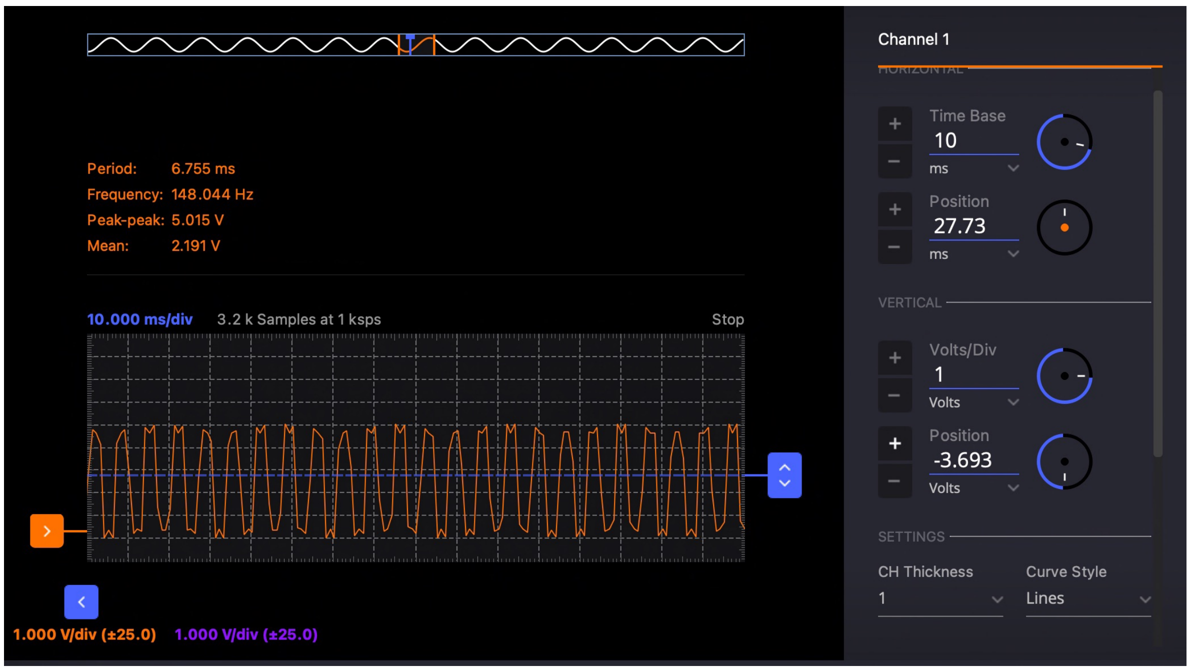
max $T = (0.693 \cdot 1k\Omega \cdot 100nF) + (0.693 \cdot 51k\Omega \cdot 100nF)$

$f_{min} =$ 277.5 Hz $f_{max} =$ 7.22 kHz

Connect CH1 of the ADALM2000 to the output of the 555 timer (pin 3) when the button is not pressed (i.e. when the output of the 555 timer is not loaded by the speaker). Run the oscilloscope. Enable measurements for CH1 (make sure to include: frequency and peak-to-peak voltage).

3 pts

2.3 Paste a screenshot of your oscilloscope window in the box below. Make sure the measurements and cursors are visible. (Note: *If you have difficulties inserting your image into the PDF, simply append them as an extra page to the END of your lab packet and mark the given box. Do NOT insert between pages.*)



Time Base = 10000 µs/div **Voltage Scale** = 1 V/div

10 pts

2.4 Be prepared to demonstrate your functioning 555 Timer loudspeaker circuit and answer questions relating to the operation of the 555 timer.

⚠ **Do NOT take your circuit apart yet! You will need it for lab checkoff!**

3. 555 Servo Controller

In this section, you will build two 555 circuits to drive two servomotors (a servomotor is a motor with a built-in position calculator). You will then use these two motors to move a pan-tilt robotic assembly.

Servo Motor Control

A servomotor is controlled using *pulse-width modulation*. PWM works by sending a train of pulses of varying widths to convey information or to control power usage (this will be covered in more detail later in the semester). When an electrical signal of a certain width is sent to the servomotor, it will turn to the position corresponding to the width of the pulse.

Our servomotor has three pins: `VCC` – connected to the 5V rail (red), `GND` – connected to ground (brown), and a `PWM` – our PWM input pin (orange).

For example, to turn the servomotor to its neutral position (90°), a pulse width of about 1.5ms is needed. To turn to 180°, a pulse width should be about $2ms$. And a pulse width of about 1ms should be applied to turn a servomotor to 0° A pulse width between 1ms and 2ms will turn a servomotor to an angle between $-90°$ and $+90°$.

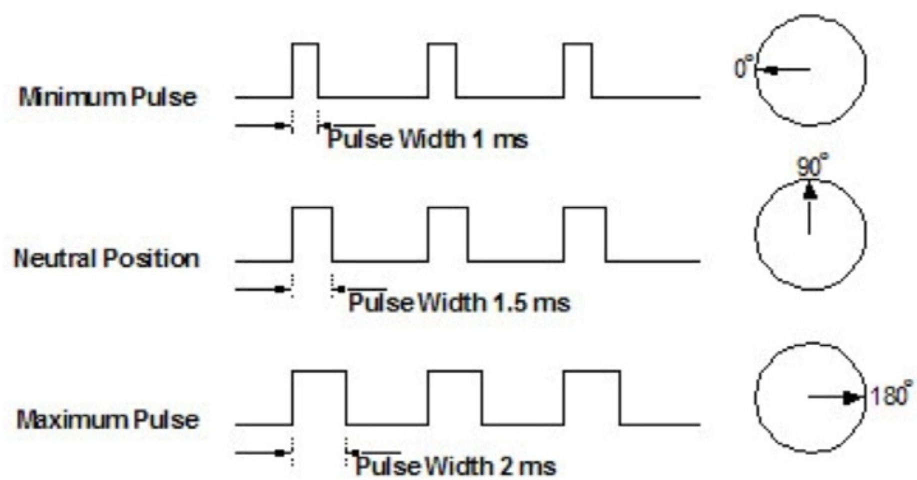


Figure 8: Servo PWM Control

You will build two 555 circuits similar to the ones you have built in this lab so far to produce signals with different pulse widths. This time, you will select the appropriate resistance and capacitance values to produced signals with the desired pulse widths.

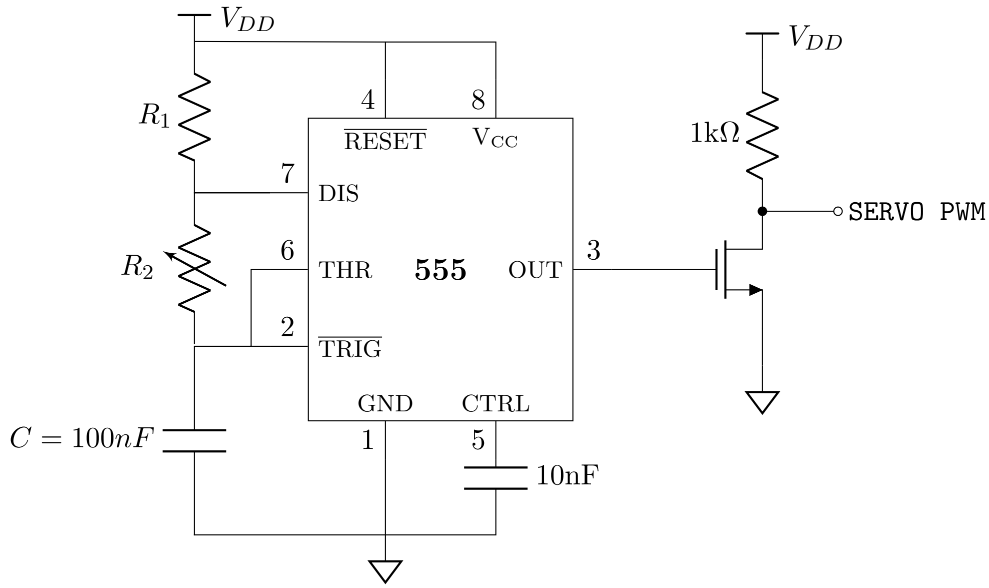


Figure 9: 555 Timer Signal Source with Servomotor

3 pts

3.1 Connect an NMOS inverter to the output of the 555 timer in order to invert the output (since the minimum duty cycle of the 555 is 50%). Thus, t_L produced by the 555 will become t_H (and vice versa). Use the equations below for your calculations:

$$t_L = 0.693 * (R_1 + R_2) * C \quad (5)$$

$$t_H = 0.693 * R_2 * C \quad (6)$$

What $\tau = R_2 * C$ time constants produce pulse widths (t_H) of 1ms, 1.5ms, and 2ms?

$$\tau = \frac{t_H}{0.693}$$

$t_H = 1.0ms$ $\tau =$ 0.001443 s

$t_H = 1.5ms$ $\tau =$ 0.002165 s

$t_H = 2.0ms$ $\tau =$ 0.002886 s

3 pts

3.2 Fix C to be 100nF. Calculate R_2 values that result in approximate pulse widths (t_H) of 1ms, 1.5ms, and 2ms:

$R_2 = \frac{T}{C}$

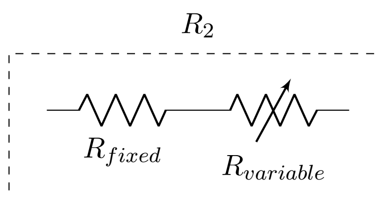
$t_H = 1.0ms$ $R_2 =$ 14.430 $k\Omega$

$t_H = 1.5ms$ $R_2 =$ 21.645 $k\Omega$

$t_H = 2.0ms$ $R_2 =$ 28.86 $k\Omega$

1 pts

3.3 Since we want to produce different pulse widths, R_2 should be a variable resistance. To do this, you will need to connect a potentiometer and a resistor in series, like you did for the previous circuits.



Select resistance values for the resistor and potentiometer that make up R_2.

$R_{fixed} =$ 10 $k\Omega$ $R_{variable} =$ 20 $k\Omega$

(Note: you will not be able to perfectly fit R_2 to the range calculated in the previous section. It is okay to be off by as much as 50% - this just changes how the potentiometer's rotation range maps to the servomotor's range of motion. You may also make R_{fixed} out of multiple resistors. You also do not have much of a choice for $R_{variable}$, since you only have four potentiometers to choose from, and two of them are in use with the previous circuits.)

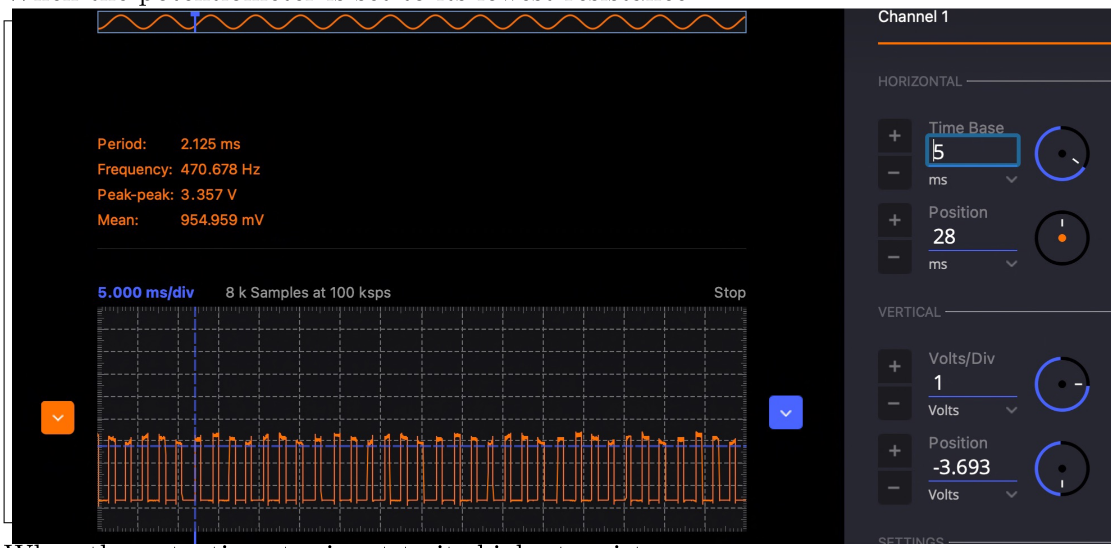
Now build two 555 circuits with $R_1 = 100\text{k}\Omega$, $C = 100\text{nF}$ and the R_2 you calculated in the previous sections. Try to control the servomotors by turning the potentiometers.

> ⚠ **You cannot power this circuit with the ADALM.**
> **You must use the breadboard power supply or a benchtop supply.**

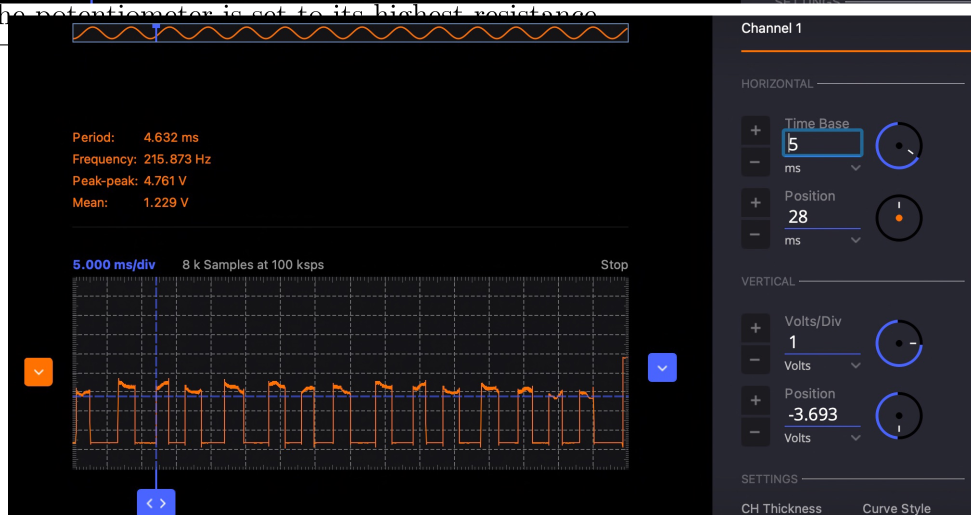
8 pts

3.4 Measure the PWM input signal of the servos for one circuit using your oscilloscope. Paste a screenshot of your measurements in the following scenarios:

i. When the potentiometer is set to its lowest resistance



ii. When the potentiometer is set to its highest resistance



Time Base = 5000 µs/div **Voltage Scale** = 1 V/div

10 pts

3.5 Be prepared to demonstrate your functioning 555 Timer servomotor circuits and answer questions relating to the operation of the 555 timer.

> ⚠ **Do NOT take your circuit apart yet! You will need it for lab checkoff!**