Electronics Lab

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Section 1

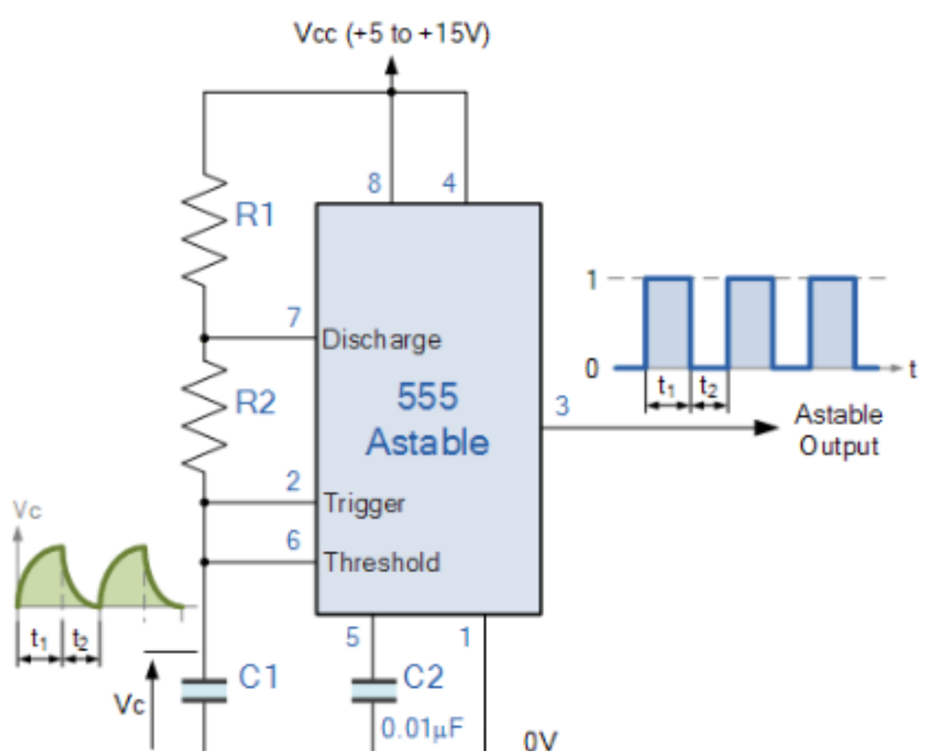
The objective of this lab was to create a breadboard circuit to create and manipulate a signal using a 555 timer, a voltage divider, an op-amp, and a hi-pass filter. This lab utilizes concepts from Electromagnetic Theory extensively, including Ohm's Law, behavior of capacitors in series/parallel, and circuits. Measurements were carried out with a Tektronix TDS1002B Oscilliscope and a Fluke Multimeter.
A breakdown by section:

Section 1: 555 Timer

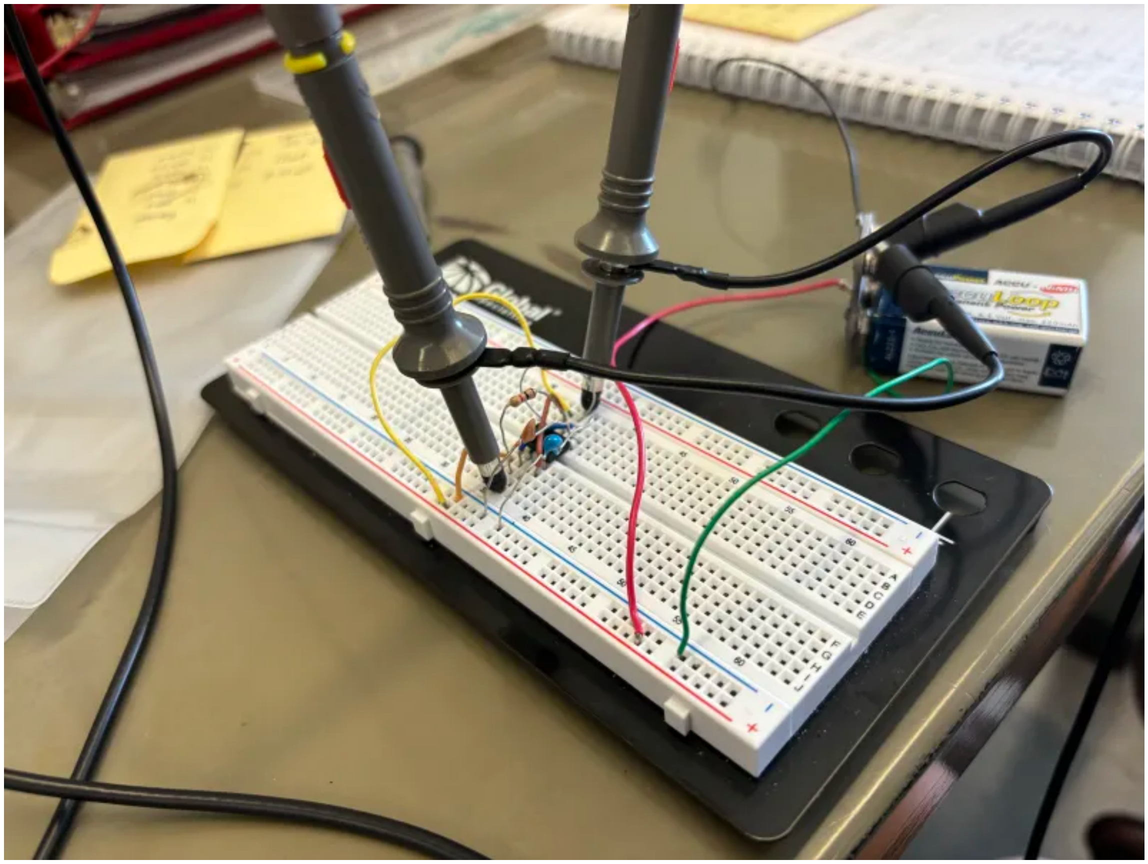
Objective: Use Oscilliscope to observe the behavior of a Texas Instruments 555 timer integrated circuit.

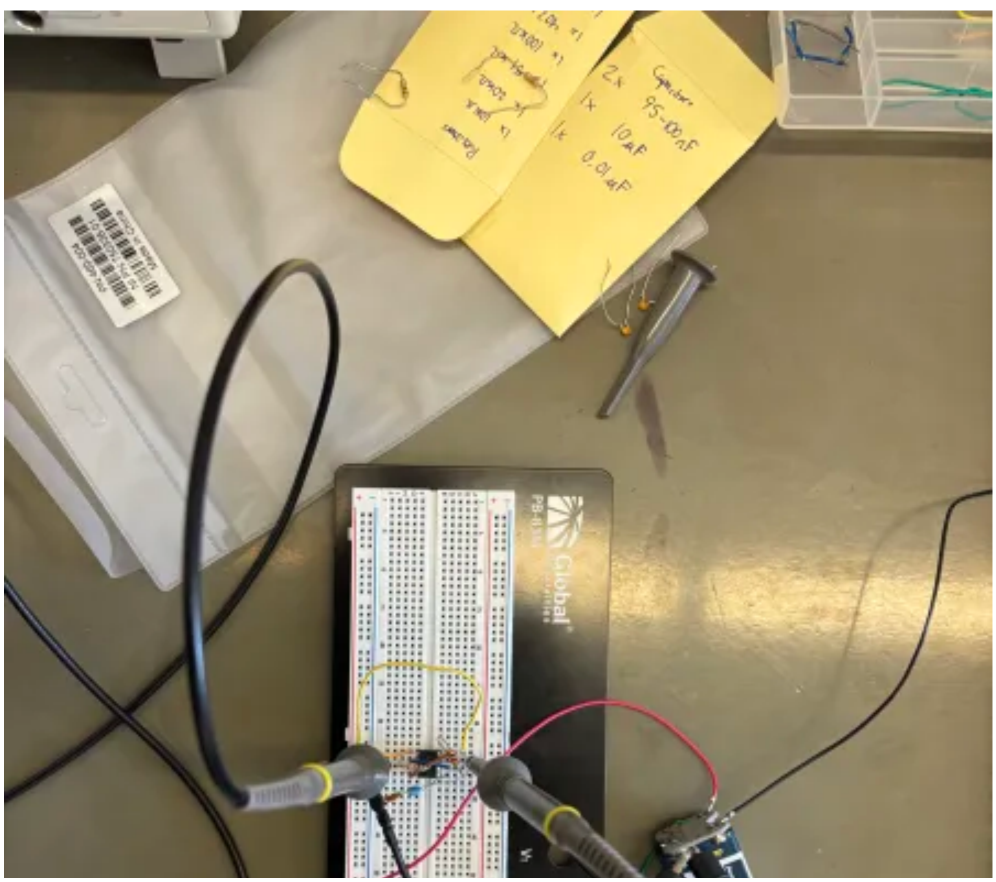
Equipment: Tektronix Oscilliscope, Breadboard, Jumper Cables, TI 555 timer IC, 9v battery, 9v battery harness, 4 different resistors, 2 capacitors

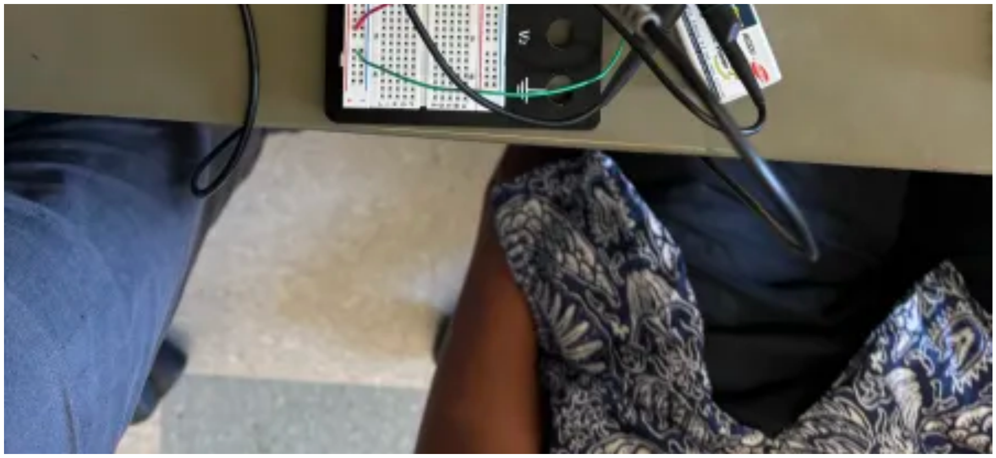
Procedure:Assemble breadboad according to below diagram. Use first set of resistors. Energize circuit with 9v battery and harness, and take measurements with oscilliscope. Repeat measurements with 4 distinct combinations of resistors.



Below are pictures of the experimental setup:







In [6]:
```
import numpy as np
import pandas as pandas
import matplotlib.pyplot as plt
#Resistor Values
resistor1 = 985 #ohms
resistor2 = 1968 #ohms
resistor3 = 9770 #ohms
resistor4 = 26640 #ohms
capacitor1 = 0.00000914 #farad
capacitor2 = 1 * 10**-8 #farad
```

Above we defined the resistor and capacitor values. These values were verrified with the multimeter, which has a listed tolerance of ± 0.9 % for our resistor ranges and ± 1.9 % for our capacitor range. We will use these values to compute the theoretical period and frequency produced by the 555 timer.
The configuration by trial is listed below
Trial 1: R1 = resistor 1; R2 = resistor 2
Trial 2: R1 = resistor 2; R2 = resistor 1
Trial 3: R1 = resistor 3; R2 = resistor 4
Trial 4: R1 = resistor 4; R2 = resistor 1

Analysis

The formula to compute the period T is given below:

$$T = 0.693 \cdot (R_1 + R_2) \cdot C_1 + 0.693 \cdot R_2 \cdot C_1$$

In [7]:
```
period1 = 0.693 * (resistor1 + resistor2) * capacitor1 + 0.693
period2 = 0.693 * (resistor2 + resistor1) * capacitor1 + 0.693
period3 = 0.693 * (resistor3 + resistor4) * capacitor1 + 0.693
period4 = 0.693 * (resistor4 + resistor1) * capacitor1 + 0.693
print( "Period 1:", period1, "\nPeriod 2:", period2,"\nPeriod 3
```

```
Period 1: 0.031169712420000002
Period 2: 0.02494337076
Period 3: 0.39935996100000004
Period 4: 0.1812163122
```

Error Analysis and propagation for each theoretical period:

$$

T_{1}= 0.0311697124[

$$\Delta T = \sqrt{\left(\frac{\partial T}{\partial R}\Delta R\right)^2 + \left(\frac{\partial T}{\partial r}\Delta r\right)^2 + \left(\frac{\partial T}{\partial c}\Delta c\right)^2}$$
$$= \sqrt{((c * 693/1000)\cdot \Delta R)^2 + ((c * 693/500)\cdot \Delta r)^2 + (((2 * r + R) * 693$$
$$= 0.0005927819$$
$$= 5.927819 \times 10^{-4}$$
$$= 6 \times 10^{-4}$$

$$

$$T_1 = (3.12 \pm 0.06) \times 10^{-2}$$

$$\Delta T = \sqrt{\left(\frac{\partial T}{\partial R}\Delta R\right)^2 + \left(\frac{\partial T}{\partial r}\Delta r\right)^2 + \left(\frac{\partial T}{\partial c}\Delta c\right)^2}$$
$$T_2 = 0.0249433708 \qquad = \sqrt{((c * 693/1000)\cdot \Delta R)^2 + ((c * 693/500)\cdot \Delta r)^2 +$$
$$= 0.0004742521$$
$$= 4.742521 \times 10^{-4}$$
$$= 5 \times 10^{-4}$$
$$T_2 = (2.49 \pm 0.05) \times 10^{-2}$$

$$\Delta T = \sqrt{\left(\frac{\partial T}{\partial R}\Delta R\right)^2 + \left(\frac{\partial T}{\partial r}\Delta r\right)^2 + \left(\frac{\partial T}{\partial c}\Delta c\right)^2}$$

$$T_3 = 0.399359961 \quad = \sqrt{((c * 693/1000) \cdot \Delta R)^2 + ((c * 693/500) \cdot \Delta r)^2 + }$$

$$= 0.0075955924$$

$$= 7.5955924 \times 10^{-3}$$

$$= 8 \times 10^{-3}$$

$$T_3 = (3.99 \pm 0.08) \times 10^{-1}$$

$$\Delta T = \sqrt{\left(\frac{\partial T}{\partial R}\Delta R\right)^2 + \left(\frac{\partial T}{\partial r}\Delta r\right)^2 + \left(\frac{\partial T}{\partial c}\Delta c\right)^2}$$

$$T_4 = 0.1812163122 \quad = \sqrt{((c * 693/1000) \cdot \Delta R)^2 + ((c * 693/500) \cdot \Delta r)^2 + }$$

$$= 0.0034472648$$

$$= 3.4472648 \times 10^{-3}$$

$$= 3 \times 10^{-3}$$

$$T_4 = (1.81 \pm 0.03) \times 10^{-1}$$

Above is our computed theoretical values of the period for the various resistor combinations. Next we will analyze the experimental data from each result using pandas and numpy to experimentally verrify our results.

In [8]:

```
def analyze_square_wave(data):
    """
    Analyzes a square wave and returns its period.
    Parameters:
    data (np.array): A 2D array with time in the first column a
    Returns:
    float: The period of the square wave in seconds.
    """
    # Extract time and voltage
    time = data[:, 0]
    voltage = data[:, 1]

    # Find the indices where the square wave changes from low t
    crossings = np.where(np.diff(voltage) > 1)[0]
    if len(crossings) < 2:
        raise ValueError("Not enough transitions to determine t


    # Calculate the time difference between consecutive transit
    transition_times = time[crossings]
    periods = np.diff(transition_times)

    # The period of the square wave is twice the average time b
    period = np.mean(periods)

    return period


trial1 = np.array(pandas.read_csv('/home/admin/Documents/School
trial2 = np.array(pandas.read_csv('/home/admin/Documents/School
trial3 = np.array(pandas.read_csv('/home/admin/Documents/School
trial4 = np.array(pandas.read_csv('/home/admin/Documents/School

eperiod1 = analyze_square_wave(trial1)
eperiod2 = analyze_square_wave(trial2)
eperiod3 = analyze_square_wave(trial3)
eperiod4 = analyze_square_wave(trial4)

print( "Experimental Values:\n"  "Period 1:", eperiod1, "\nPeri
```

```
Experimental Values:
Period 1: 0.024669999999999997
Period 2: 0.018783333333333332
Period 3: 0.31085714285714283
Period 4: 0.03603636363636364
```

Conclusions

For block 1, our experimental period measurements appeared to be consistently less then the theoretical values.

Section 2: Voltage Divider

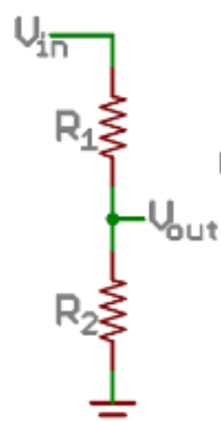
Objective:

Create and use a voltage divider for use in section 3, the Op-Amp circuit. Utilize previous circuits knowledge and analyze voltage divider theoretically and experimentally.

Equipment:

Resistors, Multimeter, Osciliscope, Jumper Cables, 555 Timer circuit from section 1, 9v battery and harness.

Procedure:



Perform calculations to determine theoretical voltage attenuation given certian resistors value. Target for voltage attenuation is 10x. Use breadboard, resistors, and jumpers to create circuit outlined in diagram above. Apply voltage and use multimeter to verrify the calculated voltage attenuation is accurate.

Beginning with the target attenuation (10x), we can calculate the ratio of resistance we need.

$$

V_(out) = \frac{R_2}{R_1+R_2} \cdot V_(in)

$$

Rearrange to solve for attenuation

$$\frac{V_{out}}{V_{in}} = \frac{1}{10} = 0.1 = \frac{R_2}{R_1 + R_2}$$

Rearrange this to solve for the required resistance

$$0.1R_1 + 0.1R_2 = R_2$$
$$R_1 = 9R_2$$

This is the required ratio between our two resistors.

Experimentally measured resistance of the resistors: | | R1 | R2 | |------------|------------|------------| | Resistance | 19.89 +- 0.9% kohm | 2.189 +- 0.9% kohm |

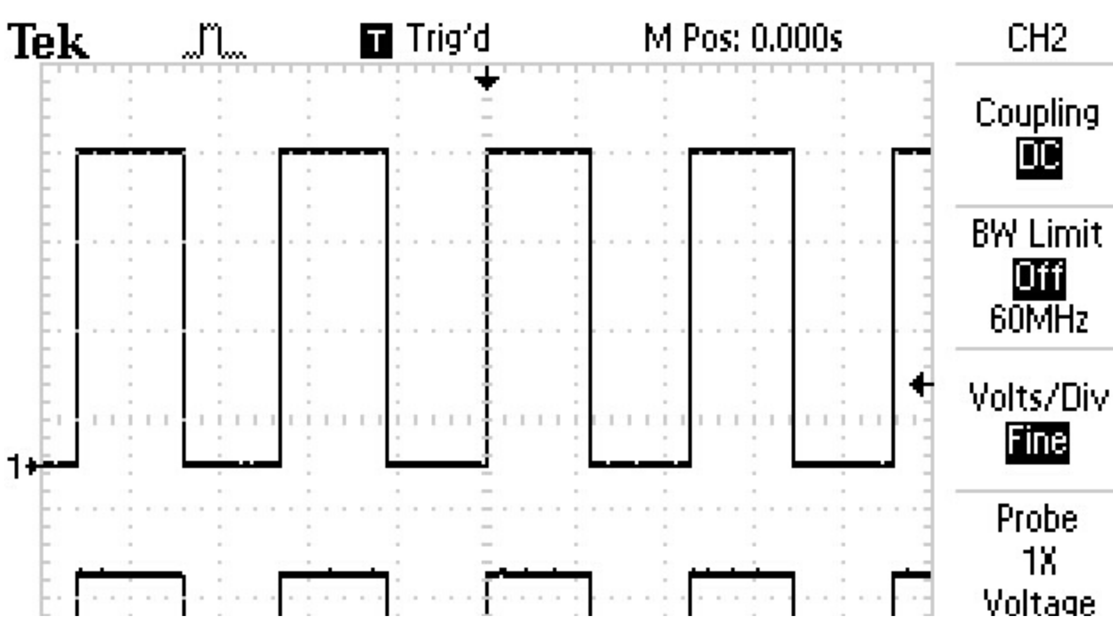
Given these resistance values, we can calculate the theoretical voltage attenuation with the measured resistance.

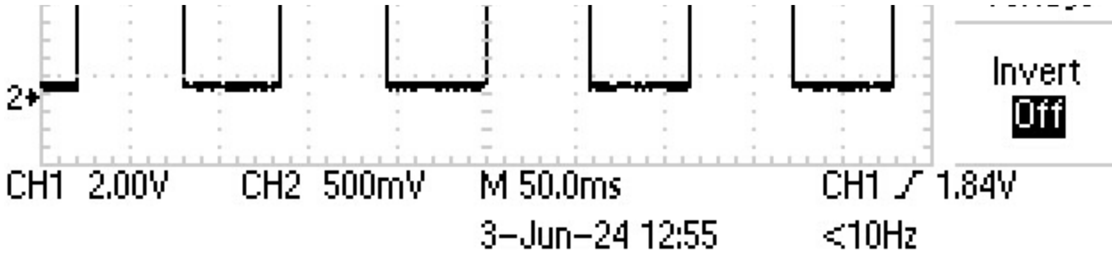
$$\frac{2.189 \text{ k}\Omega}{2.189 \text{ k}\Omega + 19.89 \text{ k}\Omega} = 0.991 \sim 0.1$$

Performing Error Propagation on the results:

$$\Delta a = \sqrt{\left(\frac{\partial a}{\partial R}\Delta R\right)^2 + \left(\frac{\partial a}{\partial r}\Delta r\right)^2}$$

$$a = 0.09914398 \qquad = \sqrt{\left(\left(-(r/(R+r)^2)\right) \cdot \Delta R\right)^2 + \left(\left(R/(R+r)^2\right) \cdot \Delta r\right)^2}$$
$$= 0.0011367874$$
$$= 1.1367874 \times 10^{-3}$$
$$= 1 \times 10^{-3}$$
$$a = (9.9 \pm 0.1) \times 10^{-2}$$





Results:

Above is the Oscilloscope reading for V_{in} and V_{out}, with V_{in} on channel 1 and V_{out} on channel 2. You can clearly see the attenuation, however, the scaling on channel 2 was increased relative to channel 1 to retain clarity. Measurements of V_{out} with a steady power supply yielded an experimental V_{out} of 0.951 volts, with a V_{in} of 9.60 volts.

Analysis:

Looking at these results, we can easily calculate the experimentally measured attenuation. With a V_{in} of 9.60 and a V_{out} of 0.951, gain is calculated by:

$$\frac{V_{out}}{V_{in}} = \frac{0.951 \text{ volts}}{0.960 \text{ volts}} = 0.0991 \sim 0.1$$

As seen here, the experimental value matched the theorized value for our measured resistances to the extent of the accuracy of our measuring equipment.

Conclusions:

This experiment verified that the experimentally measured attenuation matched the theoretically calculated attenuation to the highest accuracy we could measure with our lab equipment. We were not able to perfectly match our goal of 10x attenuation due to a lack of properly matched resistors.

Section 3

Objective:

The objective of this portion of the lab is to use an Operational amplifier, or Op-Amp integrated circuit to create an inverting amplifier and "reverse" the previous attenuation performed with the voltage divider and testing if the theoretically calculated amplification values are in line with the experimentally measured and verified values.

Equipment:

T-I Op-amp chip, breadboard, circuits from Section 1 and 2, oscilloscope, multi-meter, pair of resistors to yield desired gain and 9v power supply.

Procedure:

First begin by calculating the appropriate gain while taking care to ensure that the amplifier is not being pushed beyond its limits. Since section 2 yielded an attenuation of $\sim$ 10x, the operational amplifier circuit has to have a less then 10x gain. To achieve this, a pair of resistors has to follow the following relation:

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

Where R_f and R_{in} are labeled in the diagram below

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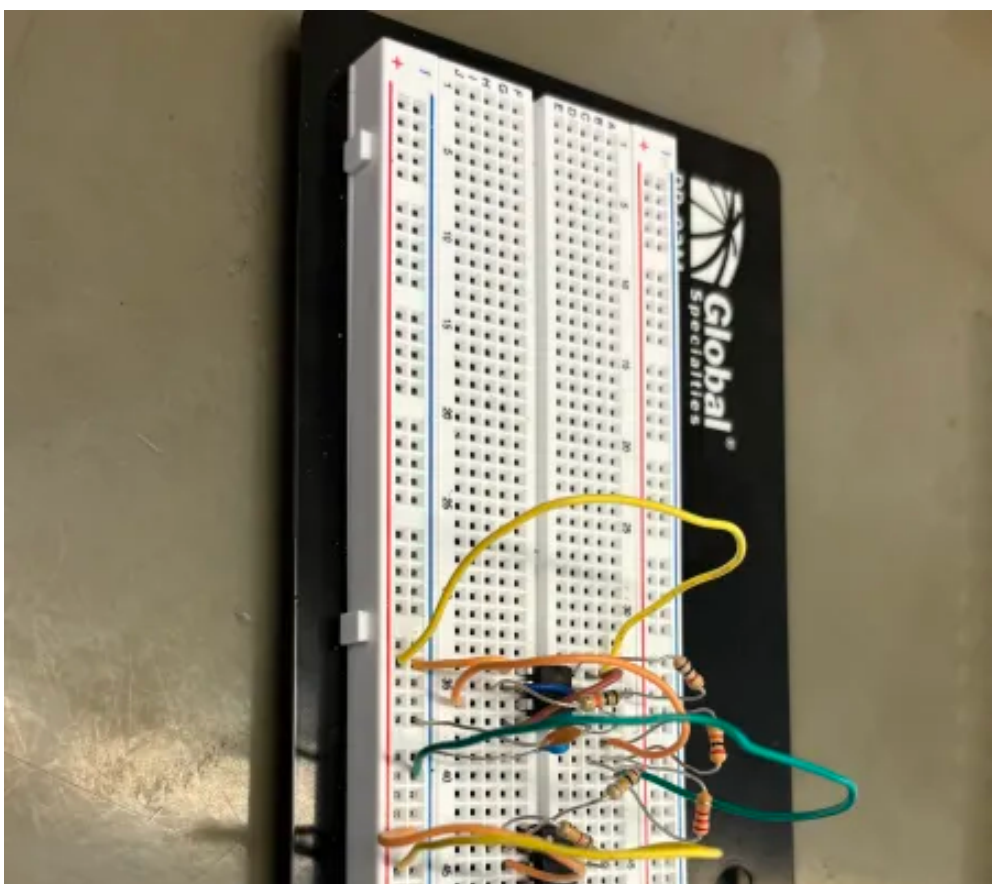
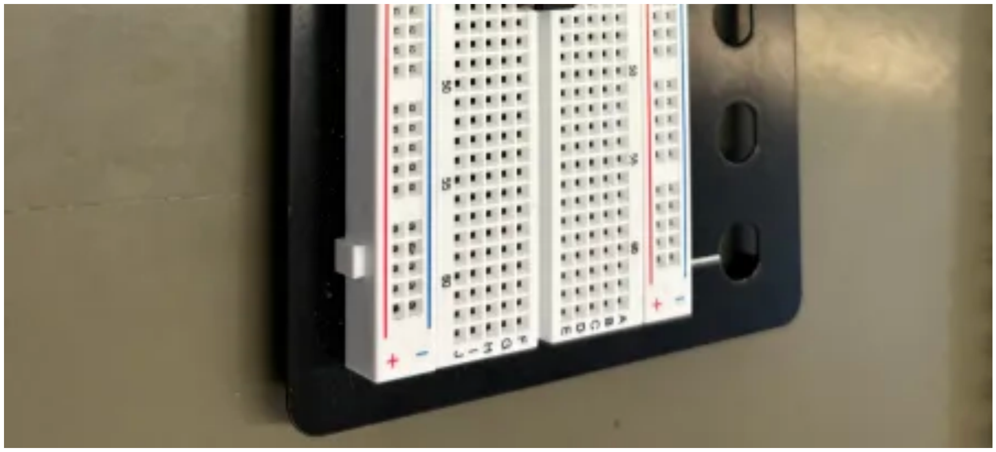
After computing the theoretical gain from the resistors, we can proceed to compute the experimental gain. Using the oscilloscope or DMM to measure the gain produced from the inverting Op-Amp circuit.

Data

Picture of the Op-Amp circuit (Top IC) and 555 Timer circuit (Bottom IC)





Our measured resistor values:

	R_f	R_{in}
Resistance	830 $\pm$ 0.9% $k\Omega$	98.7 $\pm$ 0.9% $k\Omega$

Using equation for inverting Op-Amp gain:

$$\text{Gain } = -\frac{R_f}{R_{in}}$$

We can plug in our measured values to calculate gain and uncertainty in gain

$$g = 8.4093211753[$$

$$\begin{aligned}
\Delta g &= \sqrt{\left(\frac{\partial g}{\partial r_f}\Delta r_f\right)^2 + \left(\frac{\partial g}{\partial r_i}\Delta r_i\right)^2} \\
&= \sqrt{\left((1/r_i)\cdot \Delta r_f\right)^2 + \left(\left(-(r_f/r_i^2)\right)\cdot \Delta r_i\right)^2} \\
&= 0.1070331845 \\
&= 1.070331845 \times 10^{-1} \\
&= 1 \times 10^{-1}
\end{aligned}$$

Computed Gain:

$$g = 8.4 \pm 0.1$$

Results with constant 9v signal:

$$\begin{aligned}
&V_{in} = 9.98 \pm 0.5\% \text{ V} \\
&V_{out} \text{ from voltage divider } = 0.927 \pm 0.5\% \text{ V} \\
&V_{out} \text{ from Op-Amp} = 7.79 \pm 0.5\% \text{ V}
\end{aligned}$$

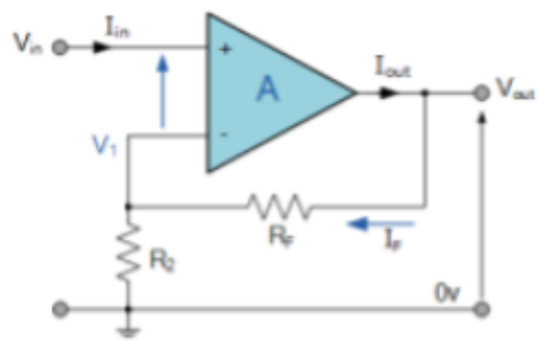
Calculated gain and uncertainty from experimental voltage measurements

$$g = 8.4034519957 \qquad \begin{aligned} \Delta g &= \sqrt{\left(\frac{\partial g}{\partial v_o}\Delta v_o\right)^2 + \left(\frac{\partial g}{\partial v_i}\Delta v_i\right)^2} \\ &= \sqrt{((1/v_i)\cdot \Delta v_o)^2 + \left(\left(-(v_o/v_i^2)\right)\cdot \Delta v_i\right)^2} \\ &= 0.0594213789 \\ &= 5.94213789 \times 10^{-2} \\ &= 6 \times 10^{-2} \\ & g = 8.4 \pm 0.06 \end{aligned}$$

Conclusion:

The theoretical and experimental gain and uncertainty produced from the inverting Op-Amp correlated very closely, both within the uncertainties of each other. This evidence verifies the operation of the inverting Op-Amp circuit being regulated by the equations stated above.

Analytical Design Problem:



Given this non-inverting amplifier circuit, we need to find how to calculate the gain based on values of R_2 and R_F. We can accomplish this using the golden rules:

1. The voltage across R_2 and R_f in series is equivalent to V_{out}.
2. Using the voltage divider equation we can find V_1, the potential between R_f and R_2. In the below equation, V_{in} is V_{out} from the op-amp and V_{out} is V_1 $$

V_{out} = \frac{R_{2}}{R_f+R_{2}} \cdot V_{in}

3. V_{in} to the op-amp is always kept the same as V_{1} due to golden rule #1. We can r

V_{in} = \frac{R_{2}}{R_f+R_{2}} \cdot V_{out}

$$4. Rewrite to solve for \$ \frac{V_{out}}{V_{in}} \$$$

\frac{R_{f}+R_{2}}{R_{2}} = \frac{V_{out}}{V_{in}} = 1 + \frac{R_{f}}{R_{2}} $$

This is in agreeance with the given value from the assignment description. Using golden rule #1 we were able to derive the gain from the circuit design by treating it as a potential divider in reverse.

Section 4

Objective:

The objective of this section was to combine passive elements such as capacitors and inductors to create a low-pass frequency filter. This will build upon the previous sections, using the amplified signal from section 3 as an input.

Equipment:

Previously built circuits, capacitors, resistors, multi-meter, oscilloscope, jumper wires, 9v power supply.

Procedure:

To create and test this low pass filter, we need to combine a resistor and a capacitor in the diagram shown below:

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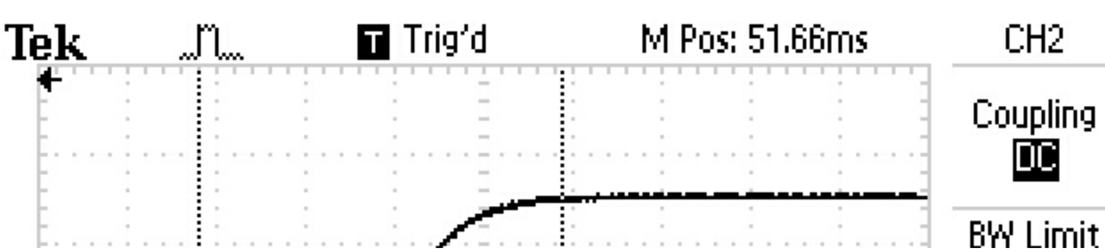
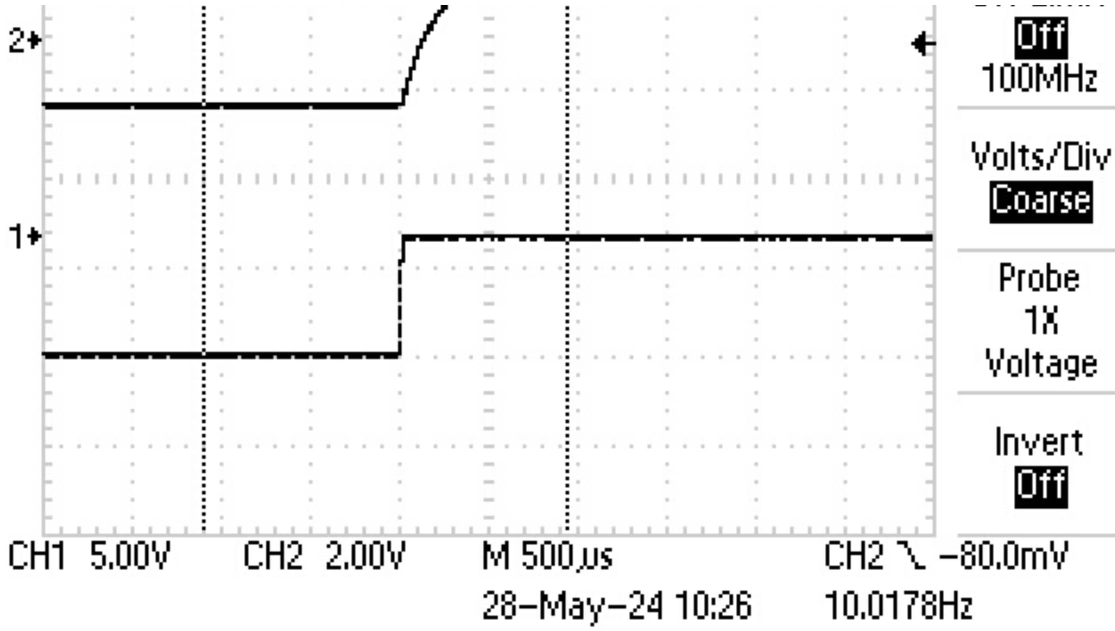
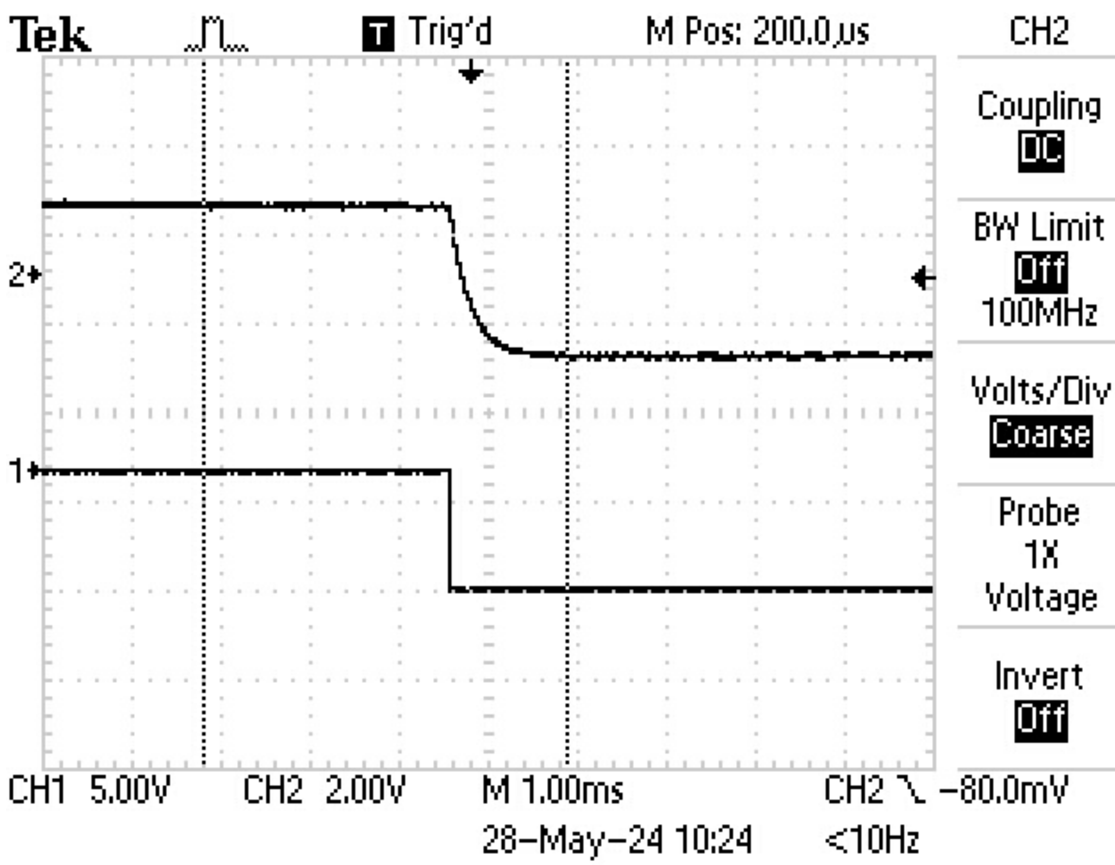
The problem gives us values to use for the capacitor and resistor, 47 nF and 4.7 $k\Omega$ respectively. We will first calculate the theoretical voltage attenuation at 100Hz and 10kHz. After performing these calculations, we next must experimentally verify them. However, we are not given a 47 nF capacitor, but we have 95 nF capacitors. We can combine 2 95 nF capacitors in series to achieve our desired capacitance.

Using these components and building the circuit, the next step is to connect the output of section 3 into the V_{in} of the low pass filter. Next, we are to test the circuit with a 100Hz signal and a 10kHz signal. Finally, we will take measurements and compare this to our theoretical findings.

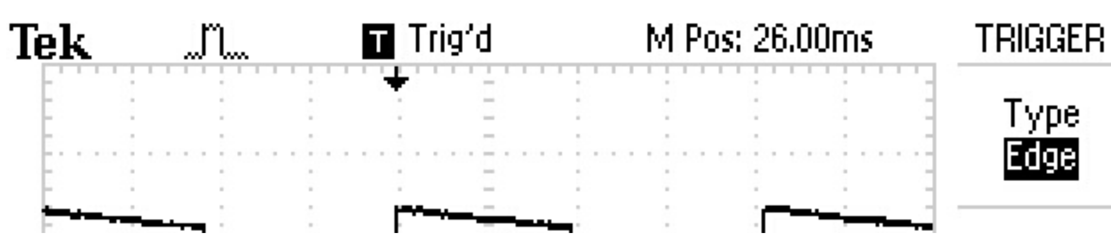
Data:

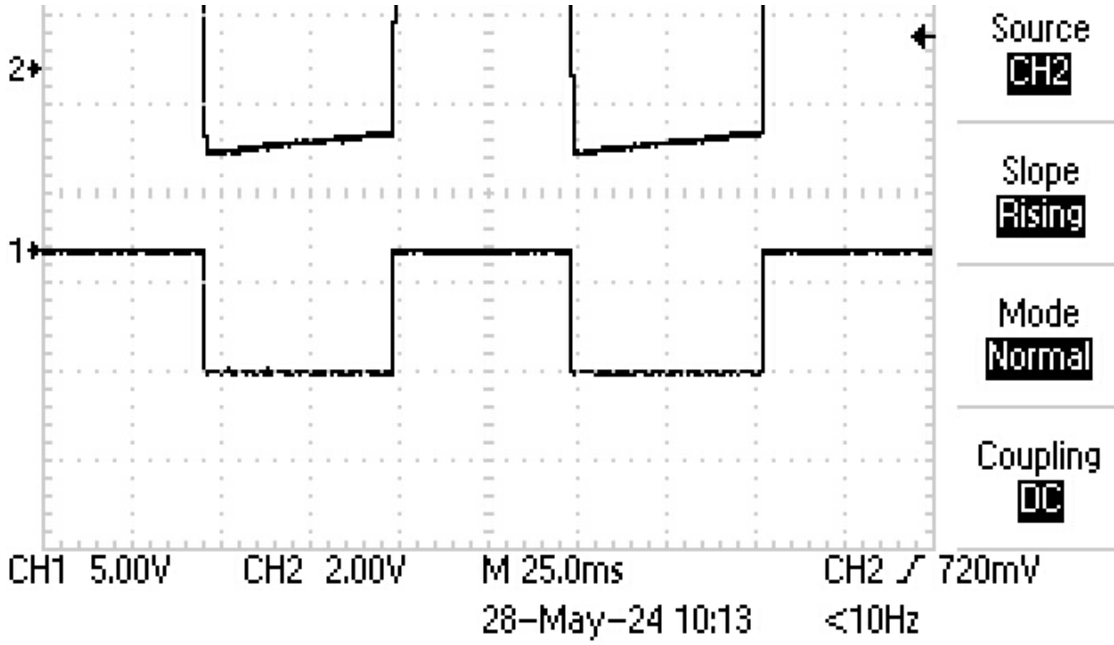






This above photo shows the rising and falling edges of the waveform. You can see how the square wave is separated and the lower frequency components are passed while the higher frequency components are attenuated out.





The above photo shows both the rising and falling edges, with a few wave cycles. This photo shows, in less detail, the attenuation of the higher frequency components of the square wave. This correlates with the diagrams presented in the lab instructions as well.

Conclusions:

The low pass filter functioned as expected, resulting in expected attenuation of higher frequency components of the square wave.