**Circuits**

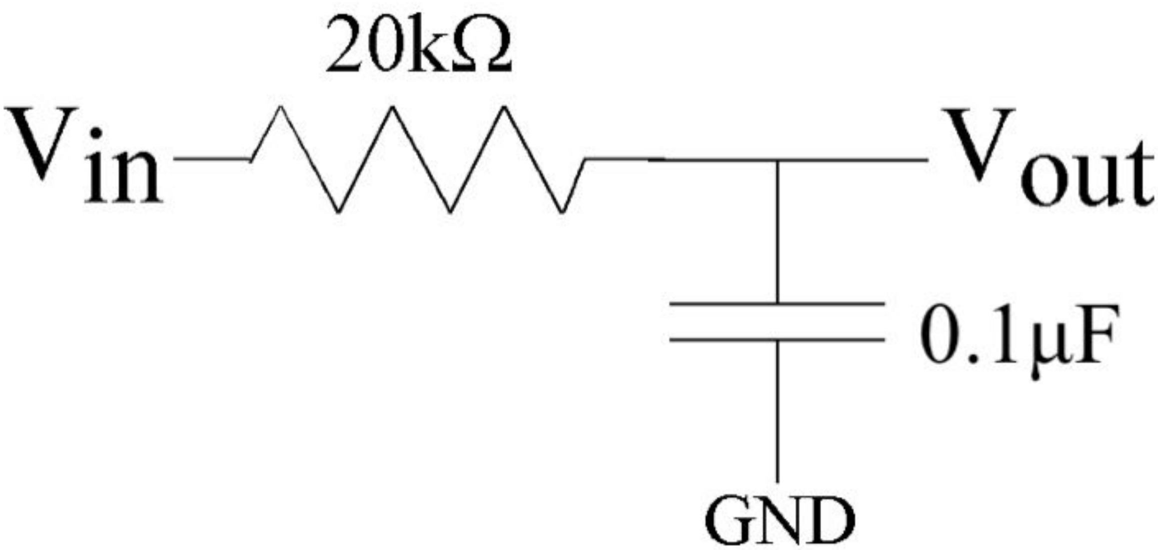


*Figure 1*. First circuit constructed.

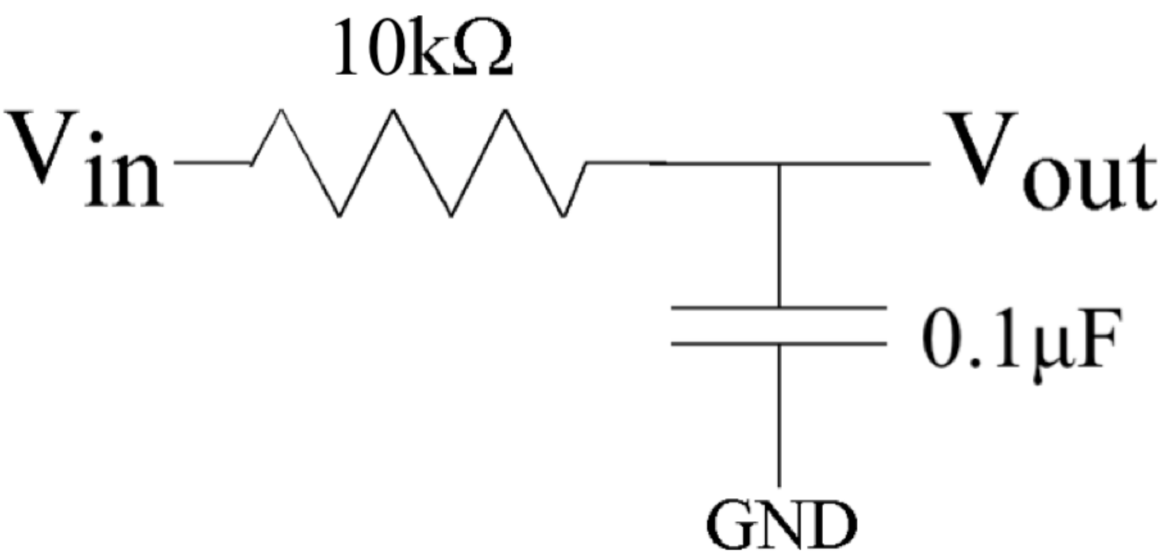


*Figure 2*. Second circuit constructed, replacing the 20kΩ resistor with a 10kΩ resistor.

# Circuit Behavior

## Voltage Output for Sweep

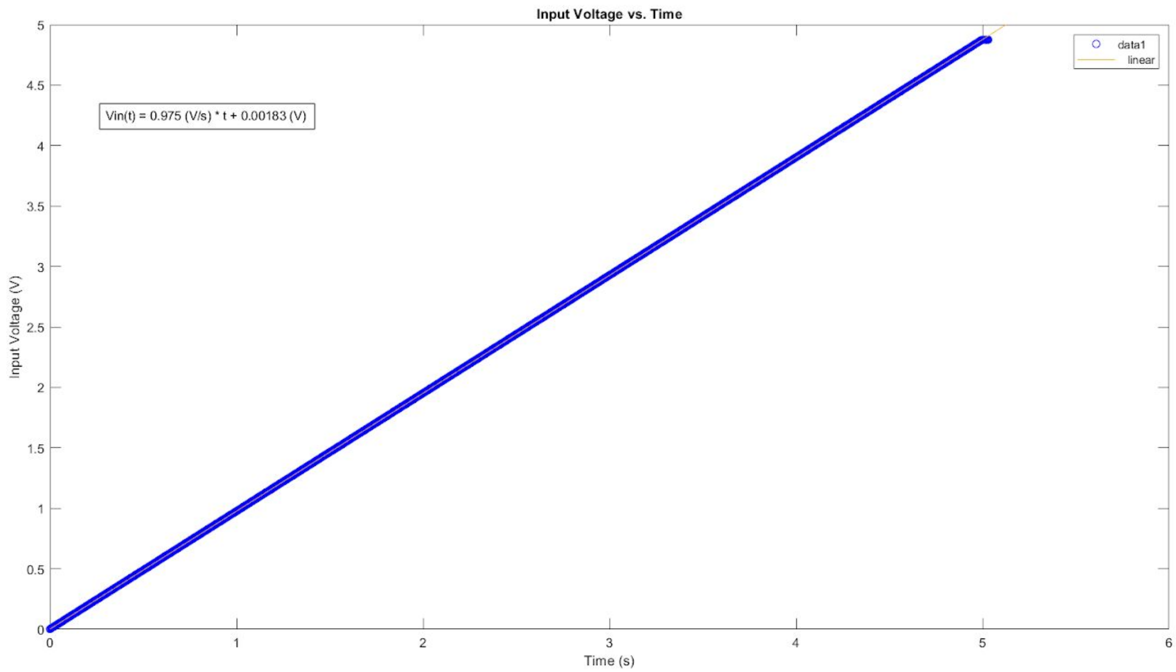


*Figure 3*. Input sweep voltage as a function of time outputted from the MyDAQ.

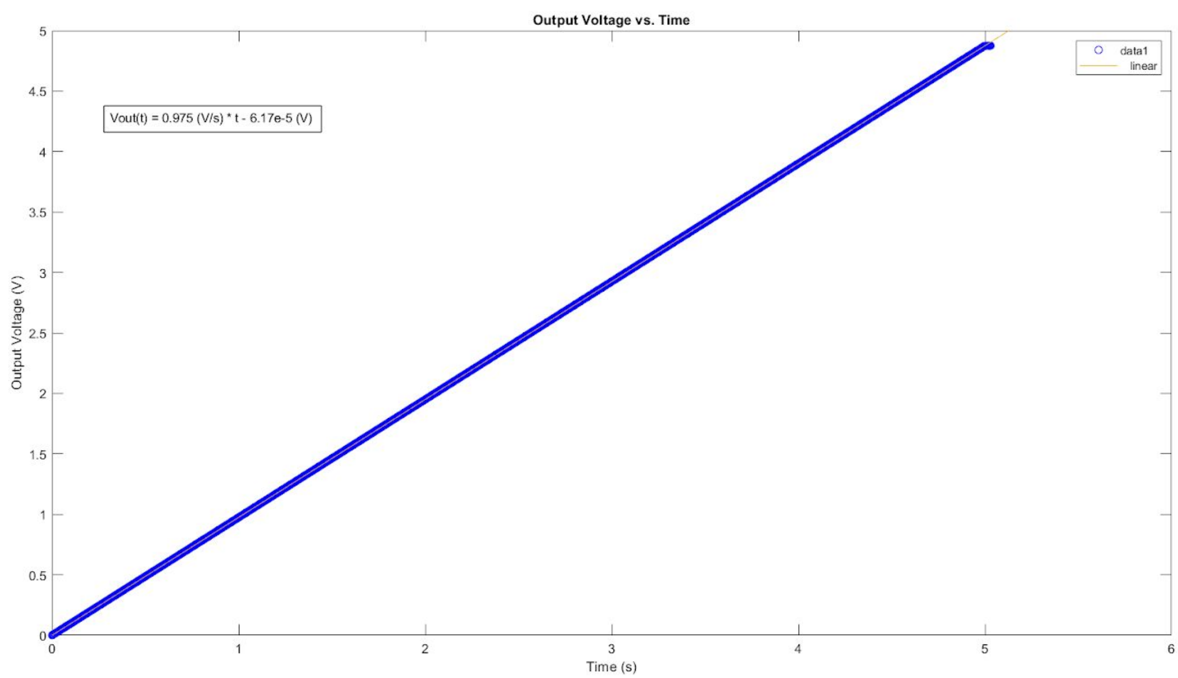

*Figure 4*. Output voltage as a function of time plotted alongside a curve fit for the output voltage function, for the input sweep voltage for the first circuit.

The expected response of the circuit for the voltage sweep input should be a matching voltage output, with no offset and a identical slope to that of the input. However, we saw in Figure 4 the output voltage had a slope of 0.975 V/s with a $6.17 \times 10^{-5}$ V offset. In comparison in Figure 3, the input voltage had a slope of 0.975 V/s with a 0.00183 V offset. The slopes are identical, as they should be, but the offsets are not. The offset for the input could result from the curve fit of electrical noise in the measurement device and the sweep not perfectly going from 0 volts to 5 volts. In addition, there would be electrical noise in the measurement device with a small voltage input going into the circuit, leading to the differing offset in the output.

**RC Time Constant for Exponential Increase for First Circuit**

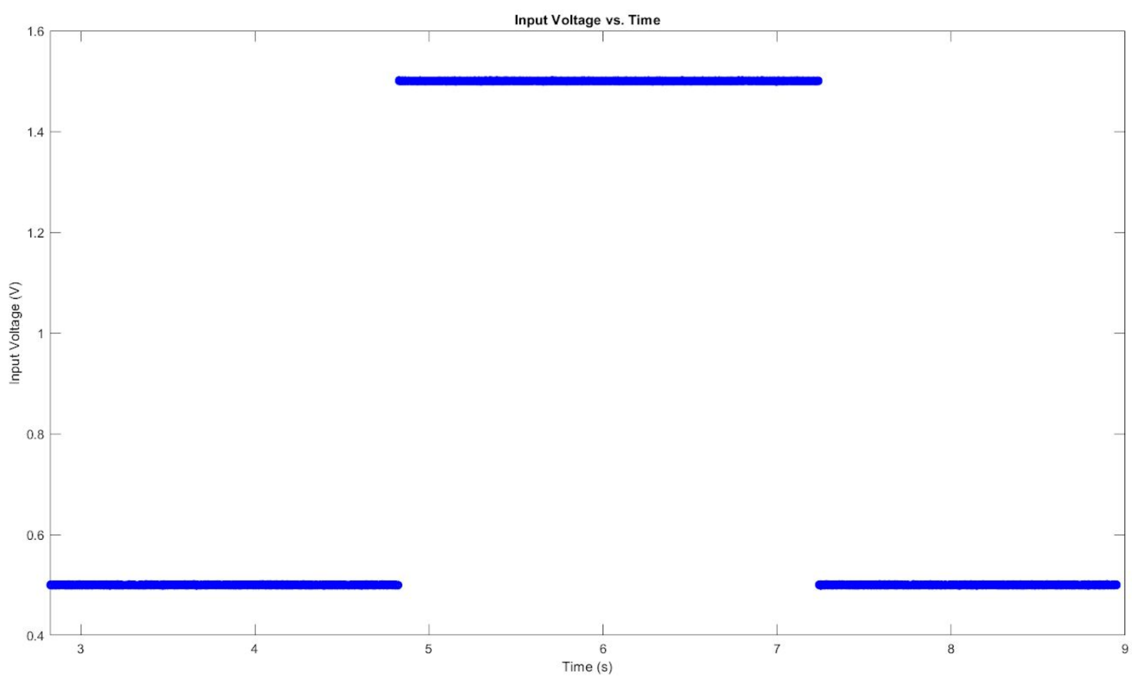


*Figure 5*. Input step voltage as a function of time outputted from the MyDAQ.

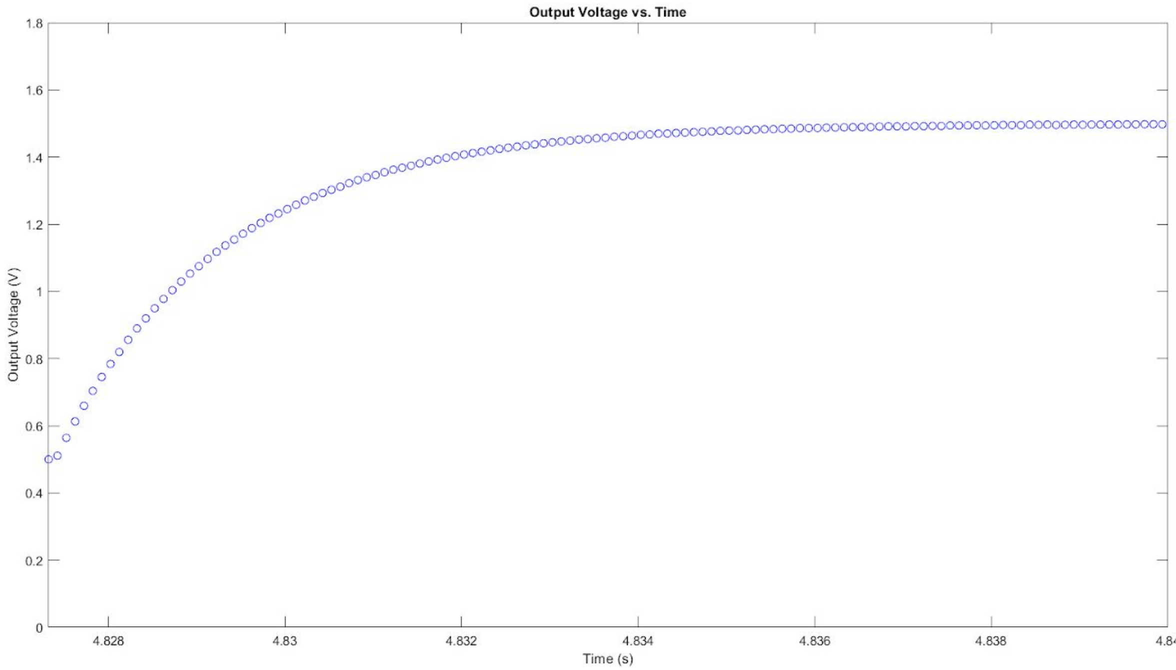


*Figure 6*. Output voltage as a function of time, for the input step up voltage for the first circuit.

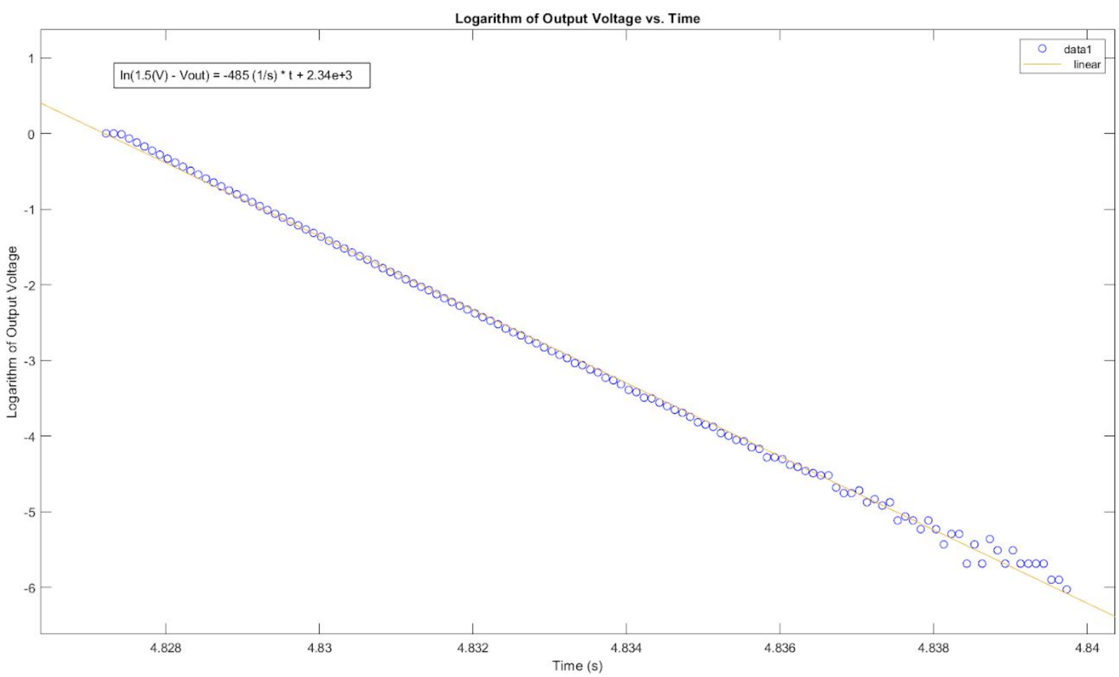


*Figure 7.* Log of output voltage as a function of time plotted alongside a curve fit for the log of output voltage function, for the input step up voltage for the first circuit.

The expected response of the first circuit to the voltage step up part of Figure 5 should be an exponential increase from the low voltage of 0.5 volts to 1.5 volts following the following equation, $1.5\ V\ -\ e^{-\frac{t}{\tau}}\ V$ . The output, seen in Figure 6, was the predicated exponential increase and the log of the output, seen in Figure 7, was linear as expected with some additional noise at the end. The noise at the end of the line could be due to the diminishing changes in the exponential increase being smaller than the electrical noise in the measurement device. That is, as the change in the voltage decreases, the noise becomes more significant. Calculating the time constant using the following equation, $\tau = \frac{-1}{m}$ where $m$ is the slope of the curve fit line, we obtain $\tau$ as 0.00206 seconds.

**RC Time Constant for Exponential Decrease for First Circuit**

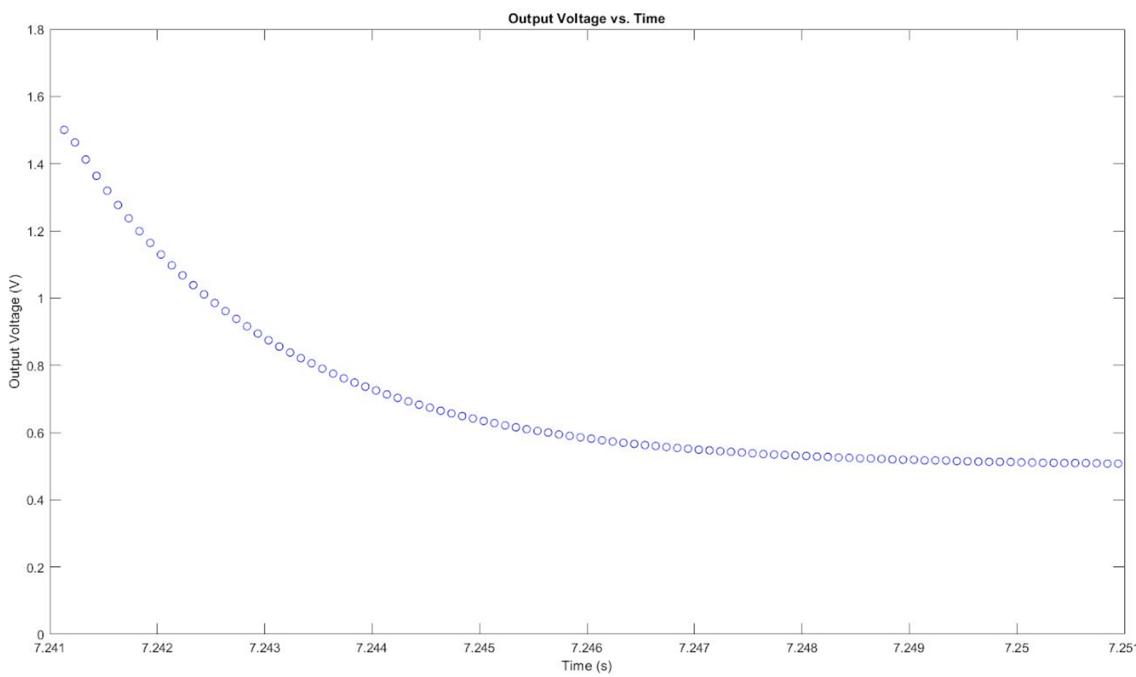


*Figure 8*. Output voltage as a function of time, for the input step down voltage for the first circuit.

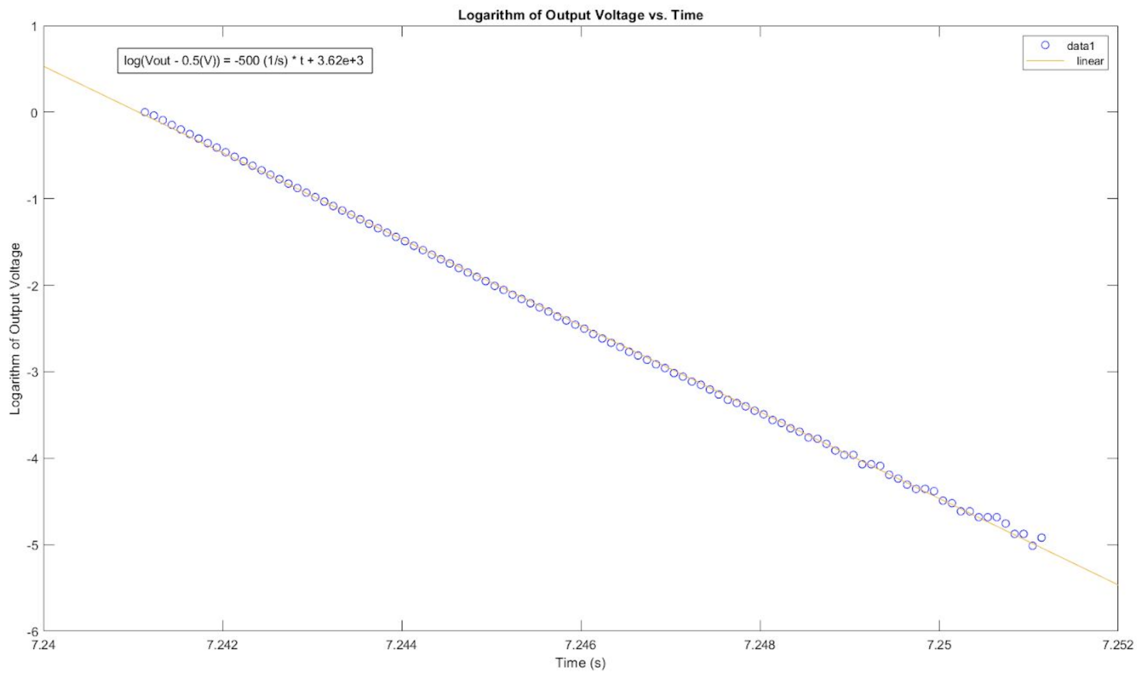


*Figure 9*. Log of output voltage as a function of time plotted alongside a curve fit for the output voltage function, for the input step down voltage for the first circuit.

The expected response of the first circuit to the voltage step down part of Figure 5 should be an exponential decrease from the high voltage of 1.5 volts to 0.5 volts following the equation $1.5\ V - e^{-\frac{t}{\tau}}\ V$. The output, seen in Figure 8, was the predicated exponential decrease and the log of the output, seen in Figure 9, was linear as expected with some additional noise at the end. The noise at the end of the line could once again be due to the diminishing changes in the exponential decrease being smaller than the electrical noise in the measurement device. Like before, as the change in the voltage decreases, the noise becomes more significant. Calculating the time constant using the following equation, $\tau = \frac{-1}{m}$ where $m$ is the slope of the curve fit line, we obtain $\tau$ as 0.002 seconds.

**RC Time Constant Behavior for First Circuit**

The time constants for the two steps for the first circuit are expected to agree, and closely match the theoretical value of $\tau$, derived from $\tau = RC$, and equal 0.002 seconds. The time constant, for the physical resistor and capacitor, should be 0.00194 seconds which itself is a 3% deviation from the theoretical. However we saw the two $\tau$ experimentally measured values as 0.00206 seconds and 0.002 seconds, with a 3% deviation and 0% deviation from the theoretical value for the exponential increasing and exponential decreasing data respectively. Those two values themselves differ by 3%. The likely cause of the differing values is electrical noise, physical component differences and the data sampling leading to an analysis that yields differing values for $\tau$. The deviation was low, indicating that the measurements were good with low error.

**RC Time Constant for Exponential Increase for Second Circuit**

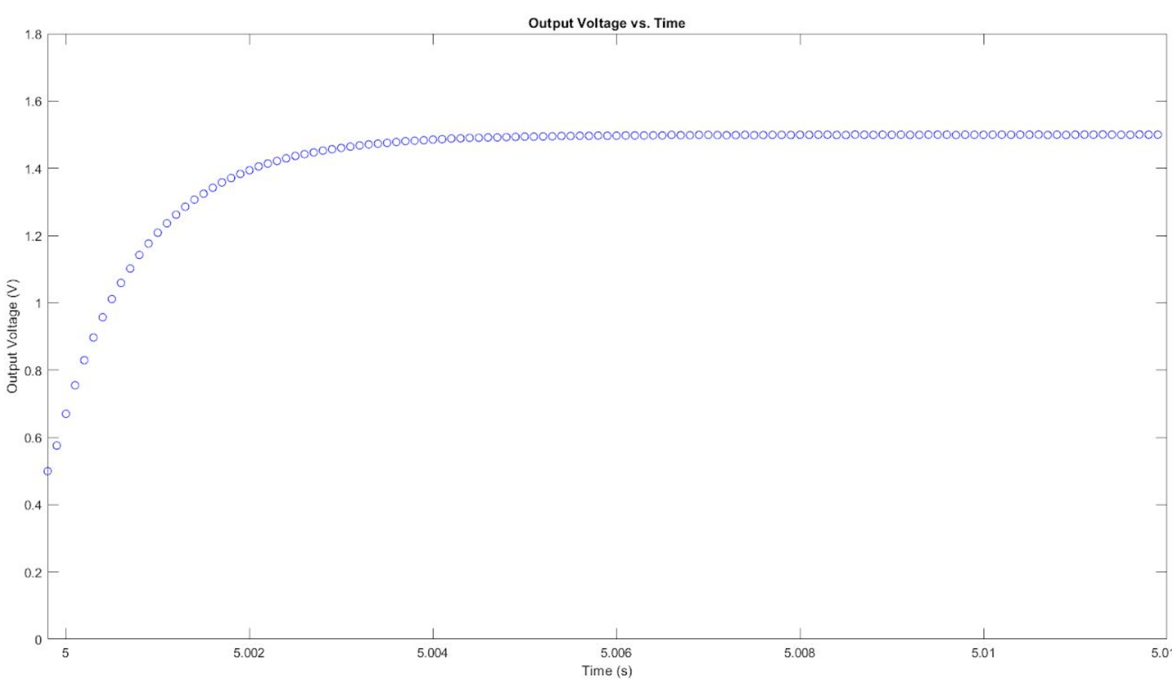

*Figure 10*. Output voltage as a function of time, for the input step up voltage for the second circuit.

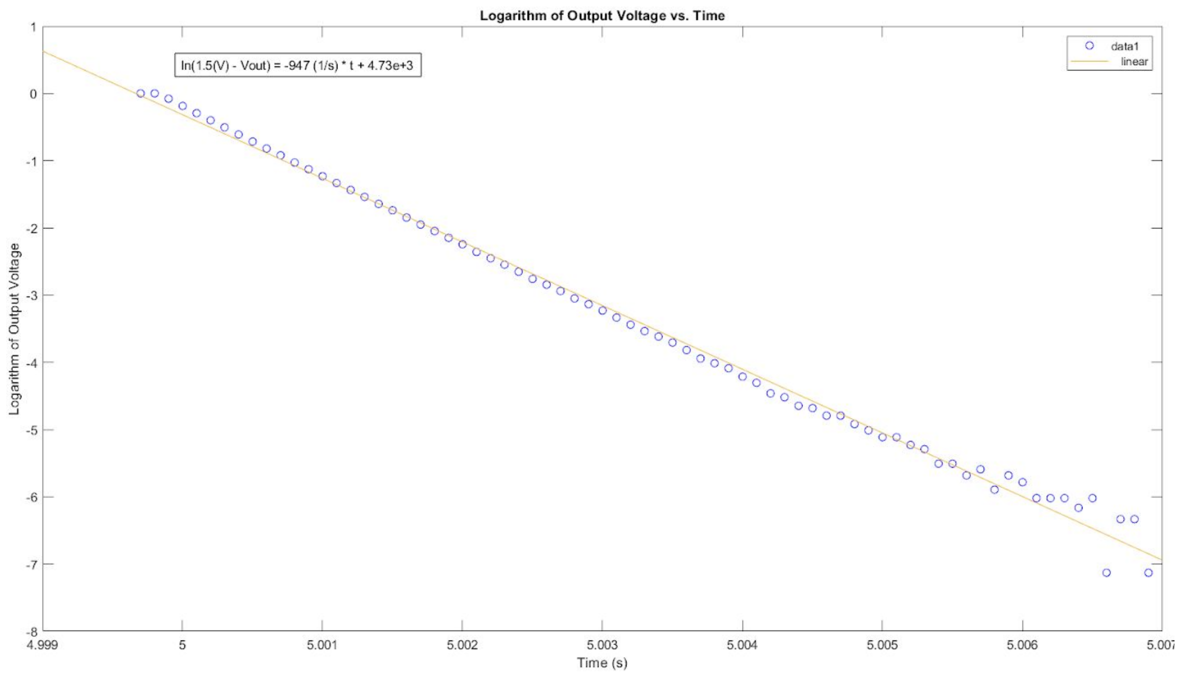


*Figure 11*. Log of output voltage as a function of time plotted alongside a curve fit for the output voltage function, for the input step up voltage for the second circuit.

The expected response of the second circuit to the voltage step up part of Figure 5 should be an exponential increase from the low voltage of 0.5 volts to 1.5 volts following the following equation, $1.5\ V - e^{-\frac{t}{\tau}}\ V$. The output, seen in Figure 10, was the predicated exponential increase and the log of the output, seen in Figure 11, was linear as expected with some additional noise at the end. The noise at the end of the line could be due to the diminishing changes in the exponential increase being smaller than the electrical noise in the measurement device. That is, as the change in the voltage decreases, the noise becomes more significant. Calculating the time constant using the following equation, $\tau = \frac{-1}{m}$ where $m$ is the slope of the curve fit line, we obtain $\tau$ as 0.00106 seconds.

**RC Time Constant for Exponential Decrease for Second Circuit**

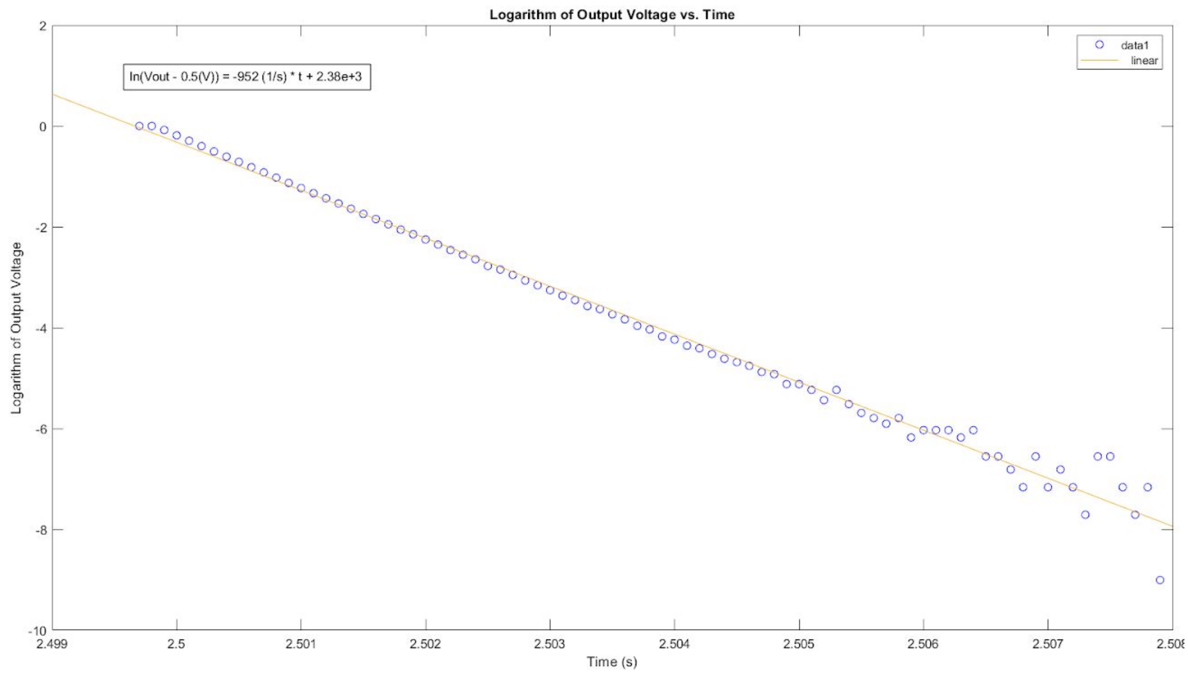


*Figure 12*. Output voltage as a function of time, for the input step down voltage for the second circuit.

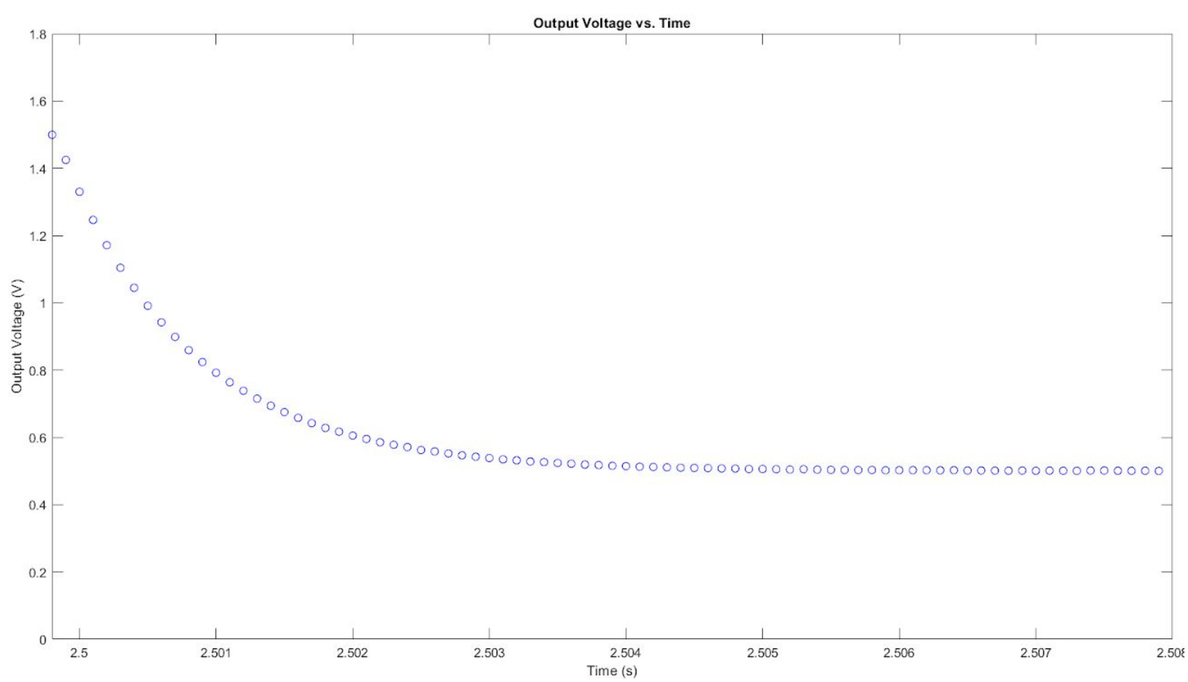

*Figure 13*. Log of output voltage as a function of time plotted alongside a curve fit for the output voltage function, for the input step down voltage for the second circuit.

The expected response of the second circuit to the voltage step down part of Figure 5 should be an exponential decrease from the high voltage of 1.5 volts to 0.5 volts following the following equation, $1.5\ V\ -\ e^{-\frac{t}{\tau}}\ V$ . The output, seen in Figure 12, was the predicated exponential decrease and the log of the output, seen in Figure 13, was linear as expected with some additional noise at the end. The noise at the end of the line could be due to the diminishing changes in the exponential decrease being smaller than the electrical noise in the measurement device. That is, as the change in the voltage decreases, the noise becomes more significant. Calculating the time constant using the following equation, $\tau = \frac{-1}{m}$ where $m$ is the slope of the curve fit line, we obtain $\tau$ as 0.00105 seconds.

**RC Time Constant Behavior for Second Circuit**

The time constants for the two steps for the first circuit are expected to agree, and closely match the theoretical value of $\tau$ , derived from $\tau = RC$ , and equal 0.001 seconds. The time constant, for the physical components mentioned below, should be 0.000967 seconds which itself is a 3.3% deviation from the theoretical. However we saw the two $\tau$ experimentally measured values as 0.00106 seconds and 0.00105 seconds, with a 5% deviation and 6% deviation from the theoretical value for the exponential increasing and exponential decreasing data respectively. Those two measured values themselves differ by 0.9%. The likely cause of the differing values is electrical noise, physical component differences and the data sampling leading to an analysis that yields differing values for $\tau$ . The deviation was low, indicating that the measurements were good with low error.

**Frequency Response for First Circuit**

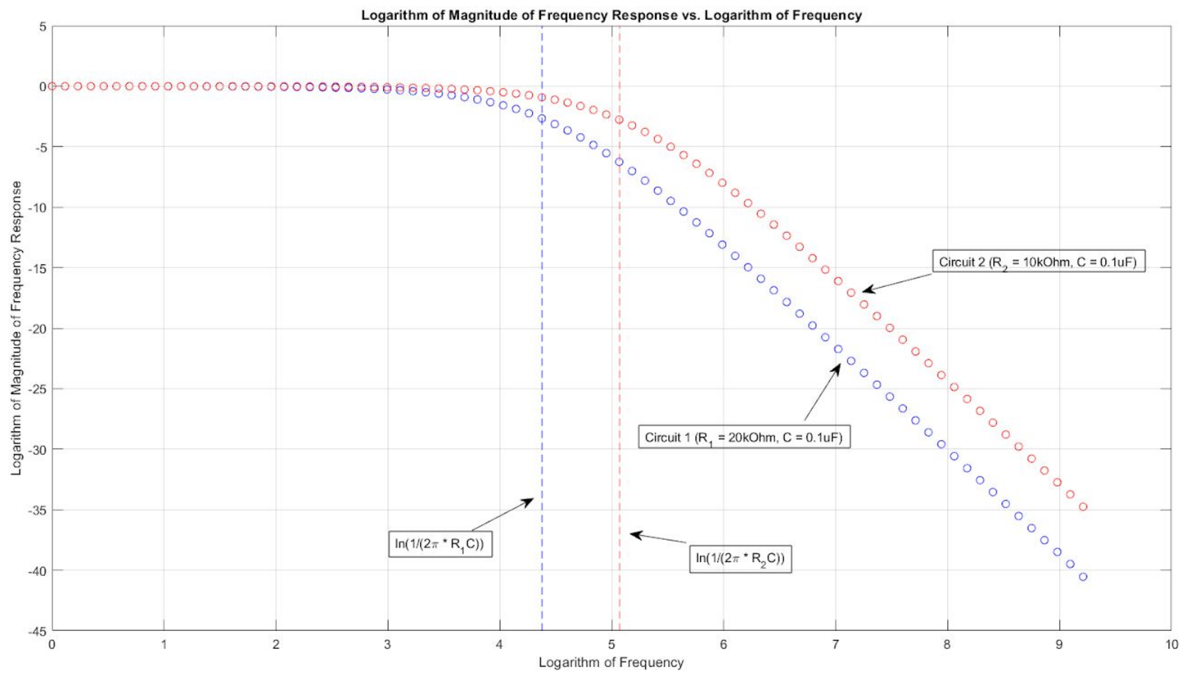


*Figure 14*. Log of voltage output as a function of log of frequency for the each circuit alongside the other.

The frequency response of the first circuit (a low-pass filter), with the log-log plot blue part of Figure 14, had the intended shape with a relatively flat region followed by a steady drop in the gain once the cutoff frequency was reached. The theoretical behavior can be characterized by the frequency found using the following $\frac{1}{2\pi\tau}$ where $\tau$ is the time constant, which should produce behavior like a filter with following cutoff frequency of 79.577 hz. Using the actual time constant from the measured resistor and capacitor, the cutoff frequency was actually 82.039 hz. The predictions match what can be seen from the graph with the drop off occurring relatively close to the log of 82.039 hz.

**Frequency Response for Second Circuit**

The frequency response of the second circuit (a low-pass filter), with the log-log plot red part of Figure 14, had the intended shape with a relatively flat region followed by a steady drop in the gain once the cutoff frequency was reached. The theoretical behavior can be characterized by the frequency found using the following $\frac{1}{2\pi\tau}$ where $\tau$ is the time constant, which should produce behavior like a filter with following cutoff frequency of 159.154 hz. Using the actual time constant from the measured resistor and capacitor, the cutoff frequency was actually 164.586 hz. The predictions match what can be seen from the graph with the drop off occurring relatively close to the log of 164.586 hz.

**Comparison of Frequency Responses**

Quantitatively, the lines indicating the cutoff frequencies should be separated by very close to $ln(2)$, which comes from the fact that the two circuits have cutoff frequencies differing by a factor of 2. This difference is represented as a horizontal shift of the lines in the plot of the log of frequency. Qualitatively, the larger time constant of the second circuit and the larger cutoff frequency that goes with it means the second circuit sees a drop in the gain at a later point in the frequency sweep than the first circuit.

## Physical Resistors and Capacitor

**Resistor Measurements**

The resistors were measured as the first 20kΩ being 19.8kΩ and second 10kΩ being 9.86kΩ.

**Theoretical Resistances**

The resistors would theoretically be as follows: the first resistor equalling 20kΩ with a tolerance of ± 5% and the second equalling 10kΩ with a tolerance of ± 5%. Both actual resistor values are within the 5% tolerance, with the first having a 1% deviation and the second having a 1.4% deviation from the ideal values, which could result from the process of manufacturing producing resistors that are binned into batches with poorer resistors having a larger tolerance range.

**Capacitor Measurement**

The 0.1μF capacitor was measured to be 0.0981μF.

**Theoretical Capacitance**

The capacitor would theoretically equal 0.1μF with a tolerance of ± 20%. The actual capacitors value is within the 20% tolerance with it having a 1.9% deviation from the ideal values, which could result from the process of manufacturing producing ceramic capacitors that are binned into batches with poorer capacitors having a larger tolerance range.