# E84 Final Project

## Introduction

For our E84 final project, our group wanted to construct a buck converter. Buck converters are a type of DC-DC converter that decreases a DC voltage signal from a DC input signal [1]. The buck converter would have some DC input voltage, in this case a 5 V DC supplied by the power supply, and would "step down" and output a lower DC voltage. Using a buck converter is more efficient than a voltage divider since the divider only reaches lower voltages by dissipating energy. On the other hand, a buck converter is more efficient because it reaches a lower output voltage while maintaining most of the input energy via the inductor storing charge in the magnetic field [2,3].

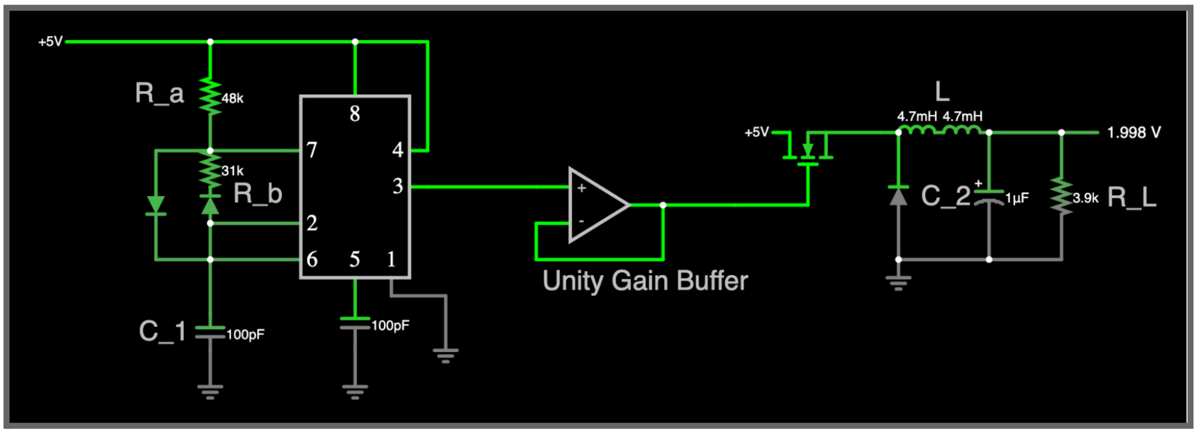


Figure 1. *Falstad Simulation of 555 Timer supplying a Square Wave to the Buck Converter*

We plan on stepping down a 5 V peak-peak source to about 2 V DC output. This was the intended goal because we wanted to simulate a potential sensor with an output that could be an input for a teensy unit with a maximum voltage capacity of 3.1 V. We chose an output voltage lower than 3.1 V to theoretically provide some "buffer" room that could account for any variation in the input voltage, like what may come from an external sensor.

## Materials

To construct the buck converter circuit, we used the following electrical components outlined in Table 1, which were sourced from the HMC Engineering Analog Lab.

Table 1. Electrical Components in Buck Converter Circuit

| Part | Value/Model | Quantity | Purpose |
|---|---|---|---|
| Inductor | 4.7 mH | 2 | Buck Converter |
| Capacitor | 100 pF | 2 | 555 Timer |
| | 0.1 μF | 3 | Decoupling Capacitor |
| | 1 μF | 1 | Buck Converter |

| | | | |
|---|---|---|---|
| Resistor | 3.9 kΩ | 1 | Buck Converter - R_L |
| | 47 kΩ | 1 | 555 Timer - R_a |
| | 30 kΩ | 1 | 555 Timer - R_b |
| | 1 kΩ | 2 | 555 Timer - R_a, R_b |
| Diode | IN4004 | 2 | 555 Timer |
| | | 1 | Buck Converter |
| 555 Timer | LMC 555 CMOS | 1 | 555 Timer - Square Wave Generator |
| Op-Amp | MCP 601 | 1 | Unity Gain Buffer |
| Mosfet | TN2106 N-Channel Enhancement-Mode Vertical DMOS FET | 1 | Buck Converter |

## Circuit Hardware Analysis

To construct the buck converter circuit, we can reference the Falstad simulation circuit diagram (see Figure 1). The buck converter will have three main parts: the 555 timer (see Figure 3), the unity gain buffer (see Figure 4), and the buck converter op-amp (see Figure 4). This circuit uses two breadboards, a power supply, and a variety of electrical components. We also used an oscilloscope to visualize the output of our circuit. The final breadboarded circuit should resemble the circuit shown in Figure 2.

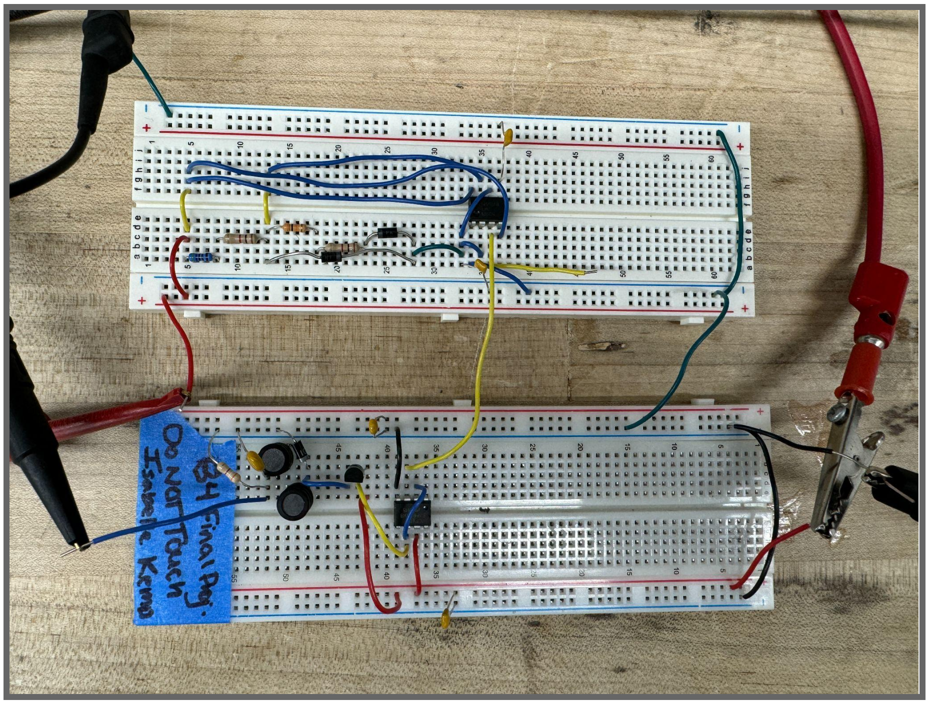


Figure 2. *Final Breadboard Setup of Buck Converter Circuit*

**555 Timer**

The 555 timer takes a DC input of 5 V and outputs a square wave with a specified duty cycle and frequency based on the resistors and capacitors attached to the LMC 555 CMOS Timer (8 Pins). The connections to each pin for the LMC 555 CMOS timer are as follows:

1. Pin 1 connects to ground.
2. Pin 2 connects to pin 6 to form a common node.
    a. An IN4004 diode also connects this node to pin 7 in series, where the negative terminal (anode) is connected to the common node between pin 2 and pin 6.
3. Pin 3 is the output of the 555 timer and should generate a square wave with a frequency and duty cycle of approximately 123 kHz and 75%. Pin 3 should also be the input to the unity gain buffer.
4. Pin 4 connects to pin 8 to form a common node.
5. Pin 5 connects to a 100 pF capacitor connected to ground.
6. Pin 6 should be connected to a common node with pin 2.
    a. This node should also be connected in series to a 100 pF capacitor connected to ground
7. Pin 7 should be connected in series with a 31 kΩ resistor, which is then connected to an IN4004 diode in series with the negative terminal (cathode). The negative terminal (anode) of the IN4004 diode is then connected to the common node of pin 2 and pin 6.
8. Pin 8 should be connected to a 5V source and also connected in series with a 48 kΩ resistor and pin 7.

The duty cycle and frequency of the generated square wave can be adjusted with the help of the following formulas [4]:

$$f = \frac{1.44}{(R_a + 2R_b)C_1}\ [Hz]$$

$$T_{High} = 0.693(R_a + R_b)C_1$$

$$T_{Low} = 0.693 \cdot R_b \cdot C_1$$

$$Duty\ Cycle = \frac{T_{High}}{T_{High} + T_{Low}} \cdot 100$$

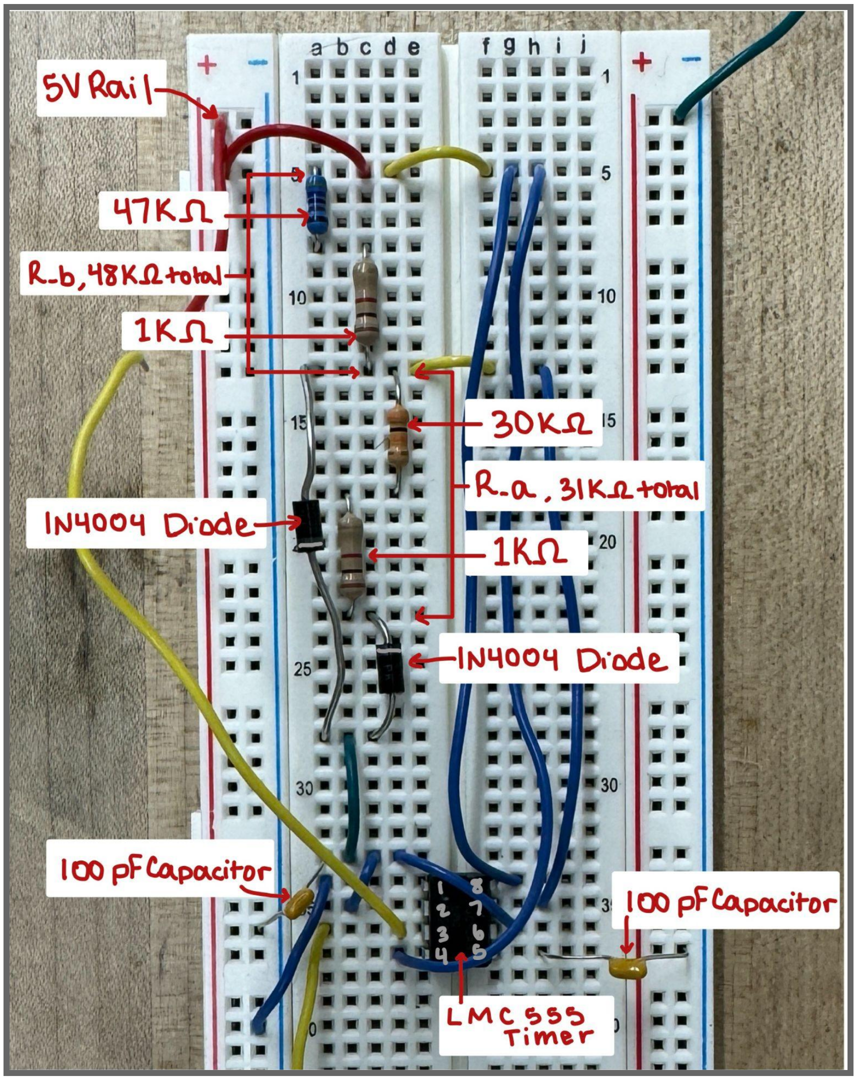


Figure 3. *555 Timer Breadboard Circuit*

**Unity Gain Buffer**

The purpose of the unity gain buffer is to isolate the buck converter from the 555 timer and to ensure that the square wave is not impacted by any unwanted loading.

The unity gain buffer takes the square wave from the 555 timer as the positive input to the MCP 601 Op-Amp and outputs the same square wave. The positive rail $V_{DD}$ is connected to 5 V while the negative rail $V_{SS}$ is connected to ground. The negative input is connected to the output, thus completing a negative feedback loop.

**Buck Converter**

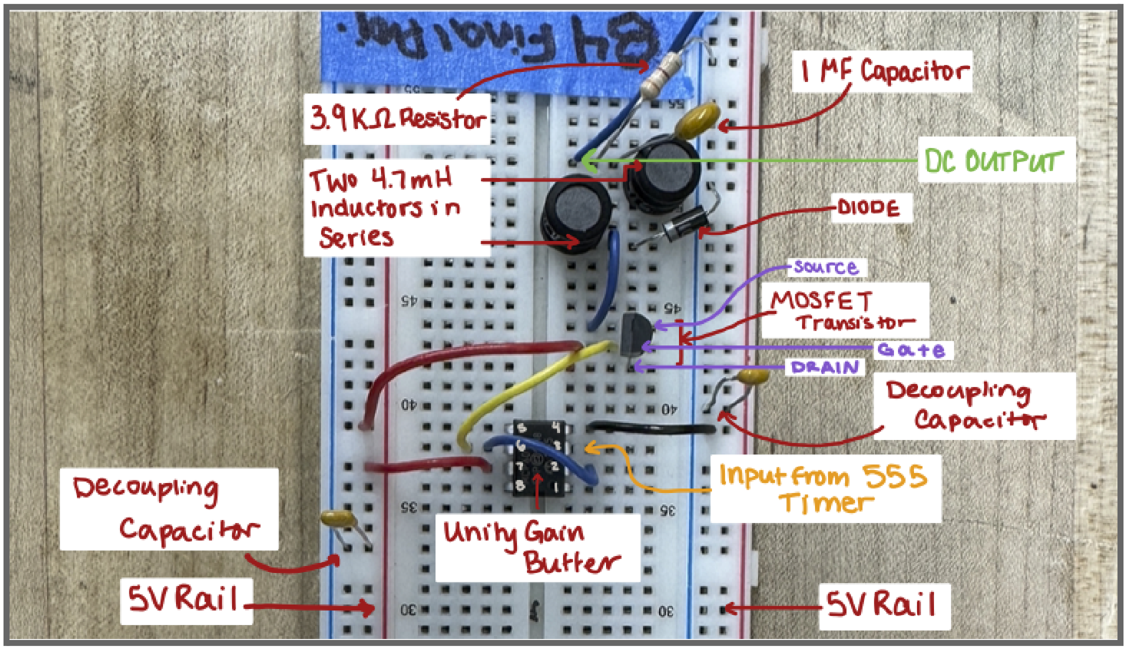


Figure 4. *Unity Gain Buffer and Buck Converter Breadboard Circuits*

The buck converter takes the output of the unity gain buffer, which emulates the square wave output of the 555 timer, as the input into the gate pin for the MOSFET. The drain pin for the MOSFET is connected to a 5 V source. The source pin then acts as the input for the remainder of the buck converter.

The source pin of the MOSFET is fed into a node that is connected with two 4.7 mH inductors (or another desired inductor value L) and an IN4004 diode, where the positive terminal (cathode) is connected to ground. The inductors are then connected in parallel with both a capacitor (C_2, 1 μF) and a resistor (R_L, 3.9 kΩ), both of which are also connected to ground. The final desired output voltage is read at the node where C_2, R_L, and L meet.

## Results

To test the buck converter, we visualized the output and input voltages using an oscilloscope. Figure 5 below shows the 5.0 V DC input that was supplied into the 555 timer and the ~2.0 V DC output from the buck converter. Figure 6 shows the output of the 555 timer and the input for the unity gain buffer: a 123.72 Hz and 76.01% duty cycle square wave.

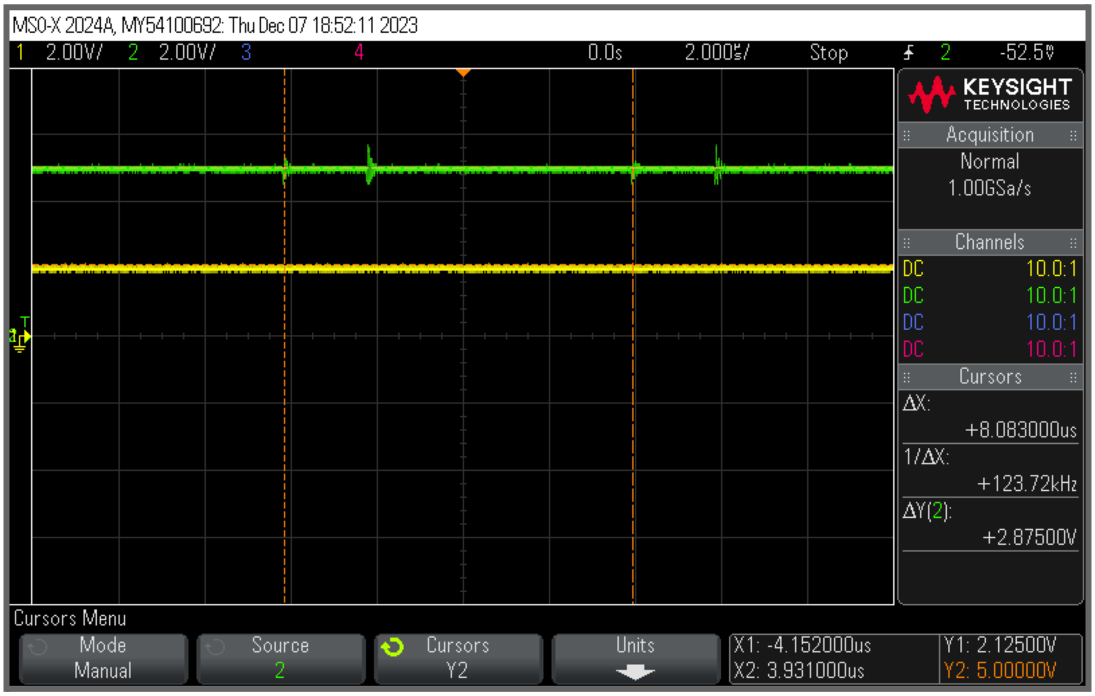


Figure 5. *Input (Green) and Output (Yellow) of Buck Converter Circuit*

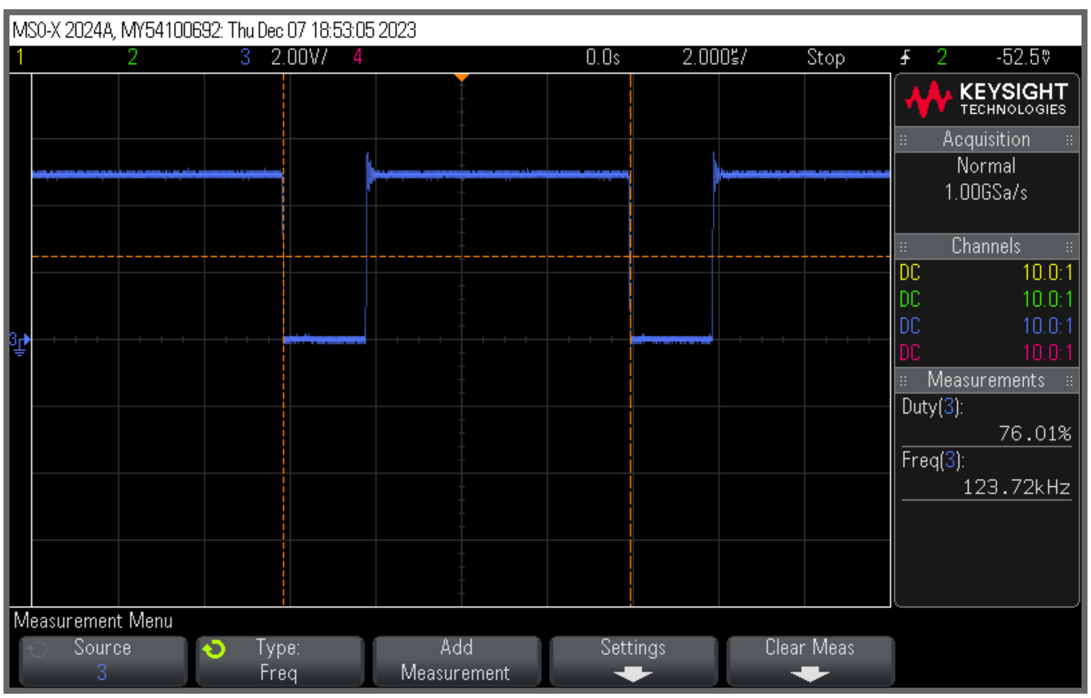


Figure 6. *Output Square Wave of 555 Timer and Input of Unity Gain Buffer*

## Conclusion

Overall, the general results of the buck converter matched the aforementioned calculations and matched performance expectations. These results match expectations much more closely than the original overall circuit design. The changes between the original circuit and the final circuit are listed in Table 2 below.

Table 2. Lessons Learned from Trial and Error

| Change/Lesson | Reason |
|---|---|
| The inductor value (L) was lowered from 0.1 H to two 4.7 mH in series. | Our group's expectation for readily available inductor values was not properly adjusted. The original reason for such a large inductor value was to decrease the inductor ripple current and to help stabilize the output voltage. This change also occurred because at high frequencies, the large inductor did not have enough time to discharge all of its energy stored in the magnetic field and thus lowered the output voltage below the initially expected values. |
| The original 555 timer used a TS555 timer while the final timer used a LMC 555 CMOS Timer | The LMC 555 CMOS had higher maximum values and previously our group planned on utilizing an input voltage of 10 V. This change in components ensured that we were not breaking any components by accidentally pushing them past their maximum rated parameters. |

## References

[1] “Power Supply Technology - Buck DC/DC Converters| Mouser Electronics.” Accessed: Dec. 07, 2023. [Online]. Available: https://www.mouser.com/applications/power-supply-topology-buck/.

[2] *Buck Converter*, (June 20, 2020). Accessed: Nov. 09, 2023. [Online Video]. Available: https://www.youtube.com/watch?v=rfChSvb8FX0.

[3] “DC to DC Buck Converter Tutorial & Diagram | Analog Devices.” Accessed: Nov. 09, 2023. [Online]. Available: https://www.analog.com/en/technical-articles/dc-to-dc-buck-converter-tutorial.html.

[4] “555 Timer Calculator | DigiKey Electronics.” Accessed: Dec. 07, 2023. [Online]. Available: https://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-555-timer.