## 1. Introduction

A Buck Converter (also referred to as a Step-Down Converter) is a topology used in electronics that converts, or steps down, a higher input voltage to a lower output voltage. Buck Converters are found in a wide variety of different applications from consumer electronics such as laptops and smartphones all the way to solar and wind energy systems to control output voltage of energy-harvesting equipment. A Buck Converter's main advantage comes from its simplicity, granting efficient voltage conversion with only a small amount of components. This project will be looking at the inner machinations of the Buck Converter, and the components that lie within that allow it to operate.

## 2. Background Information

Components Used:

- 1 x 2kΩ Resistor
- 1 x 5kΩ Resistor
- 1 x 2.7nF Capacitor
- 1 x 116μF Capacitor
- 1 x 9.7nF Capacitor
- 1 x 2.2mH Inductor
- 1 x 555 Timer
- 1 x 2N7000 Transistor
- 1 x 1N4004 Diode
- 1 x Red LED

Our project is divided into two main segments. One section of our breadboard is reserved entirely for our 555 Timer circuit. This will be the device that generates the PWM for our buck converter. This section utilizes the two resistors and one capacitor, and is also supplied with its own DC voltage of around 9v in order to make sure it runs properly. Though a 555 Timer is not always required for a Buck Converter, we implemented one due to its simplicity and its function in the switching element for our transistor.

The second section of our board is our actual Buck Converter circuit. In this section, we have another DC voltage of 12v that will be stepped down in our desired 4-5v output. This section of our project utilizes our diode, LED, inductor, and another capacitor to function properly. The transistor between the two circuits on our breadboard is where we define our midpoint, and it is our transistor that acts as our switch, keeping our voltage consistently at the 4-5v output.

## 3. Schematics and Simulations

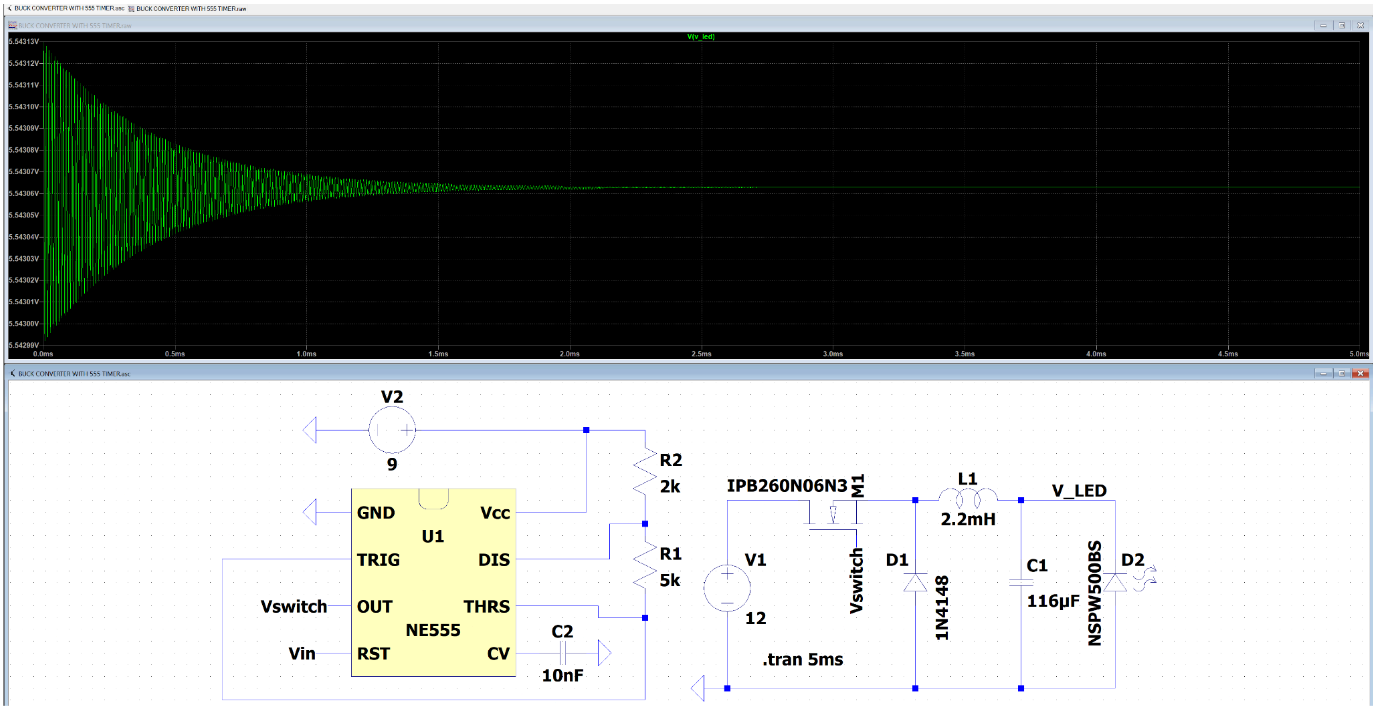


Figure 1: LTSpice Schematic and Waveform of 555 Timer and Buck Converter

555 timer calcs

$R_1 = 2k$
$R_2 = 5k$
$C = 10nF$

Time High:

$T_H = 0.7(R_1 + R_2)(C)$

$0.7(2000 + 5000)(10 \times 10^{-9})$

$T_H = (49 \times 10^{-6})s$

or

$49 \mu s$

The time spent active

Time low:

$T_L = 0.7(R_2)(C)$

$0.7(5000)(10 \times 10^{-9})$

$35 \mu s$

Time spent off

Frequency:

$$f = \frac{1.4}{(R_1 + 2R_2)C} = \frac{1.4}{(2000 + 2(5000))(10 \times 10^{-9})} \approx 11.6kHz$$

Period: $T_H + T_L = 49 \mu s + 35 \mu s = 84 \mu s$

Duty Cycle:

$$\frac{\text{on time}}{\text{Period}} = \frac{T_H}{T_H + T_L} = \frac{49}{49 + 35} \approx 58.5\%$$

Figure 2: Calculations for 555 Timer Circuit and Buck Converter

For our project, doing everything at once would've been a very demanding task, so we decided to split the circuit up into two "sections." As seen in Figure 1, the 555 Timer was its own separate circuit as it would make our simulations much more readable and allowed us to get a better sense of what was going on within our circuit. The 555 Timer was generating the PWM in order for the entire circuit to work, so getting this section of the circuit to work first was crucial. With the 555 Timer circuit working, we then move onto the actual Buck Converter circuit. The PWM generated from the 555 would allow the Buck to do its job and convert the 12v input voltage down into the 5v output voltage seen in the figure. With both sections of our circuit working as intended, we can now put them together as a whole and complete the entire Buck Converter circuit.

Figure 2 showcases mostly the calculations for the 555 Timer. The main calculation to note here is our duty cycle, which was by far the most difficult calculation to nail. A duty cycle in the 50% range is very important to have, as anything too high or too low would cause the Buck to not function properly. This is also reflected in our high and low times, which also lie in that 50% sweet spot. The frequency of our 555 Timer was also of utmost importance as this would affect our PWM control, pulse generation, and any noise and stability that may be present. For our project, we wanted to keep our frequency between 10kHz to 50kHz, which would allow our Buck to operate properly. Aside from these calculations, the rest of the components were acquired mostly using trial and error. We based these values on what was available to us in the lab and eventually settled on the resistor, capacitor, and inductor values seen within the circuit schematic.

**4. Results & Demonstration**

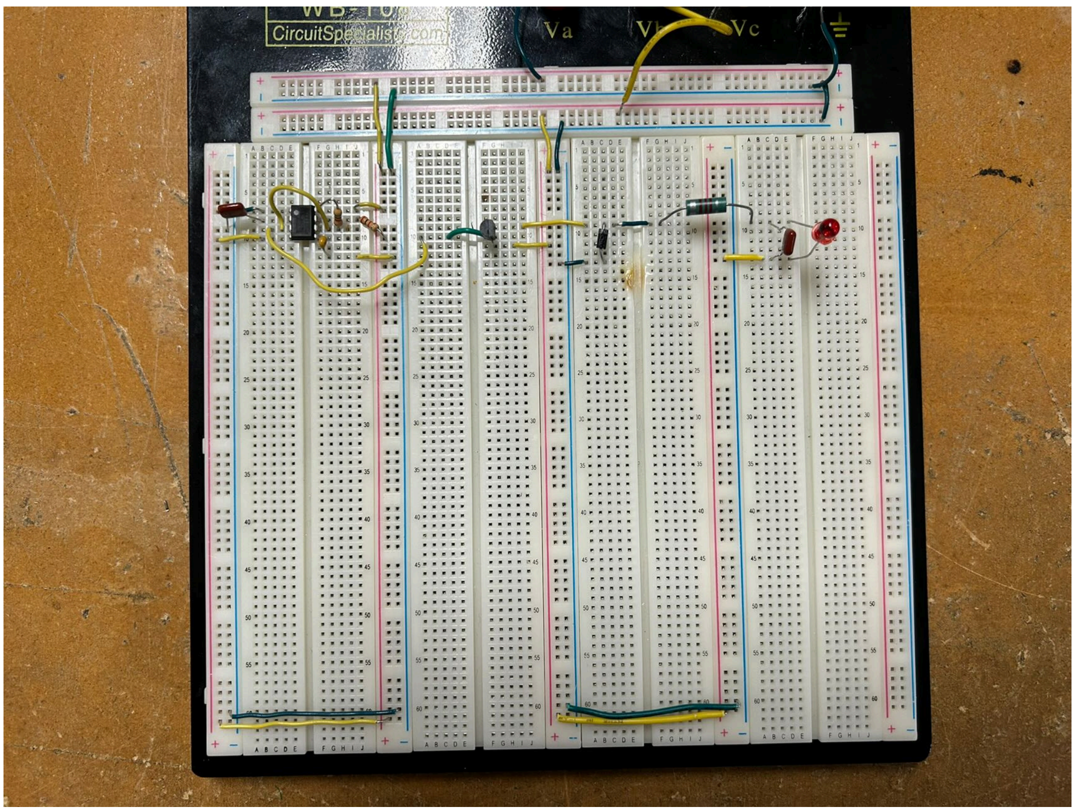

Figure 3: Circuit on Breadboard with no Voltage Applied

Figure 3 above showcases the Buck Converter circuit with no voltage applied to it. As previously mentioned, it made it much easier for us to think of the entire schematic as two sections, and this is visible from the breadboard circuit above. On the left is our 555 Timer circuit utilizing the two resistors, two capacitors, and of course the actual 555 Timer. The 9v supplied into this circuit would allow the 555 Timer to generate the PWM needed for the Buck Converter. As we move towards the right, our transistor acts as sort of our "midpoint" that bridges the two sections. This acts as our switch to keep the output voltage down to around 4-5v. Past that is the rest of our Buck Converter which includes our inductor, another capacitor, and finally the LED which takes the place of where a normal load resistor would be found.

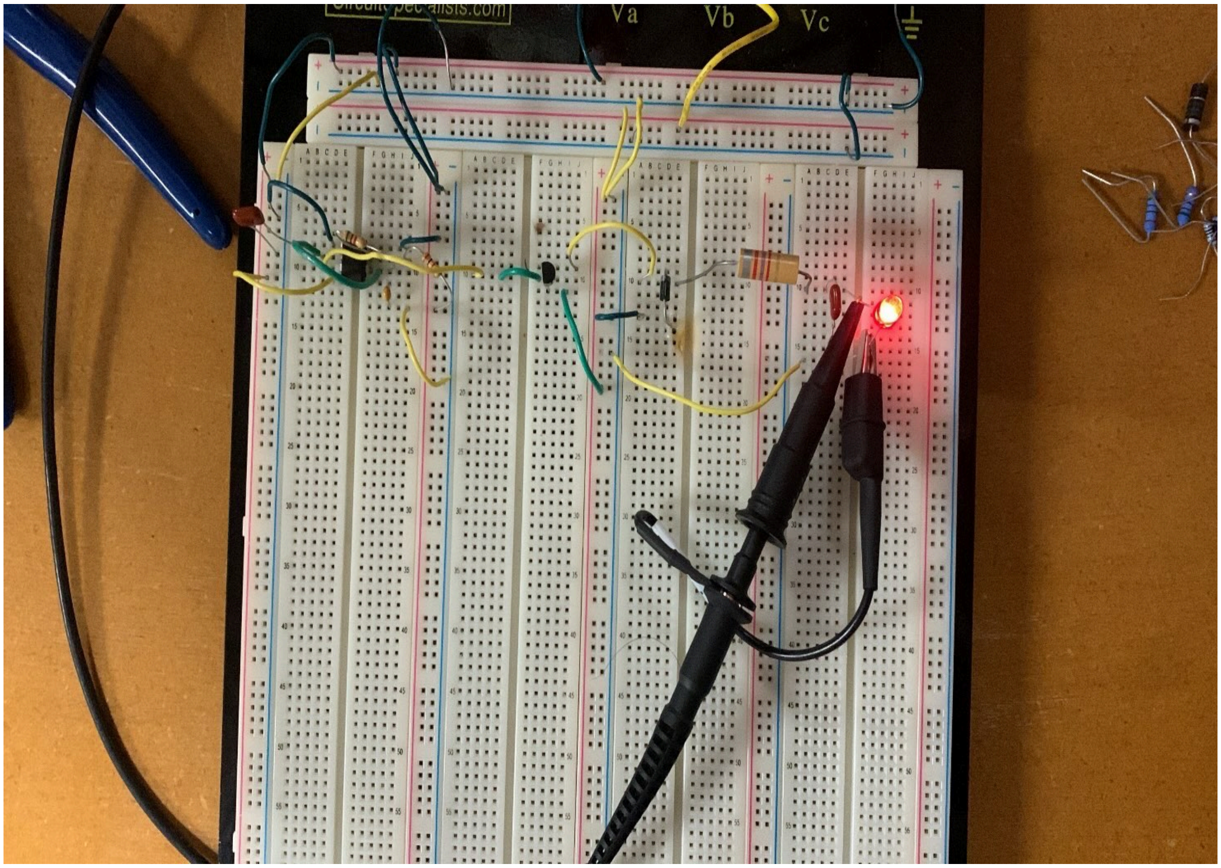


Figure 4: Buck Converter with 12v Input Voltage

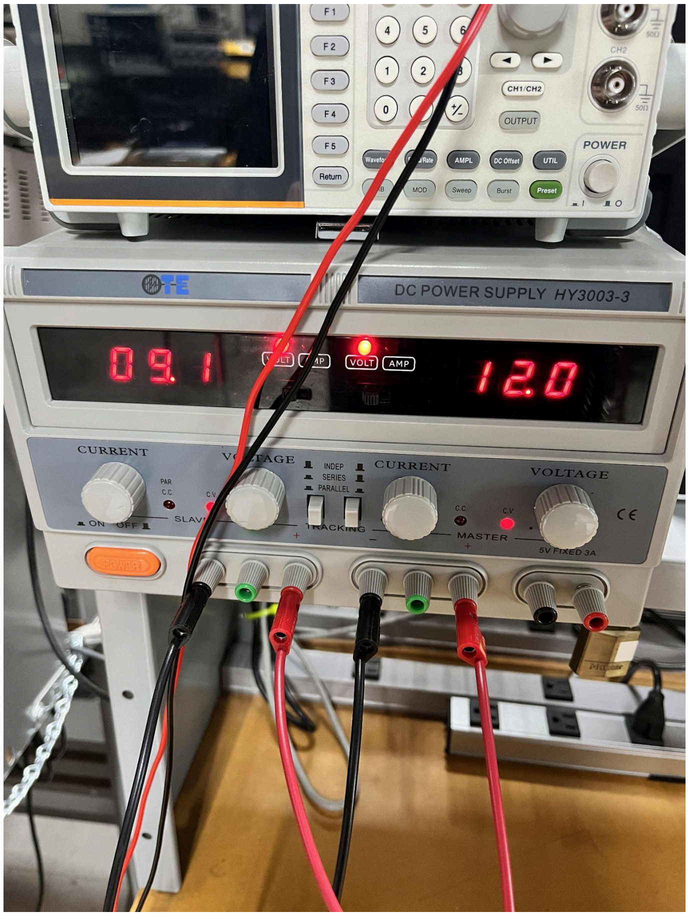


Figure 5: Input Voltage for 555 Timer (9v) and Buck Converter (12v)

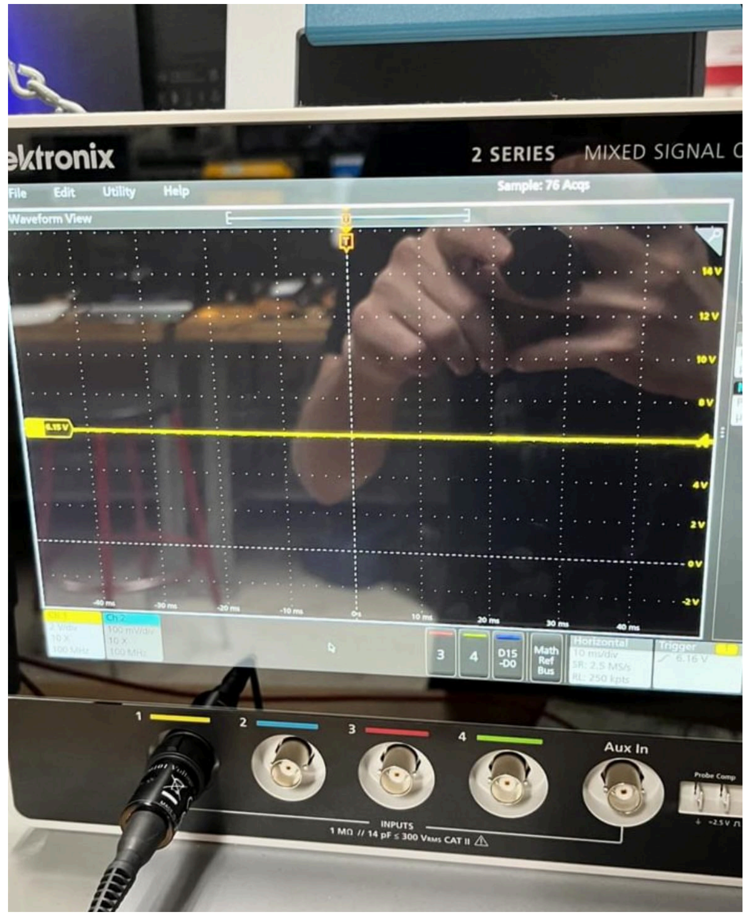


Figure 6: Stepped Down Voltage from Buck Converter

Now with 12v being supplied to the circuit, we can immediately see the results of our Buck Converter. First of all, the LED is lit up and working properly. Even without any sort of device reading, we know immediately that our 12v input seen in Figure 5 is being brought down to a proper voltage with the LED not being blown. Typically, a normal LED can withstand up to about 4-5v. Red LEDs have a voltage drop of around 1.8 to 3.3 volts. Had the full 12v passed through, even with the voltage drop, the LED more than likely would have blown, signifying an incorrect circuit. In addition, the oscilloscope in Figure 6 shows the DC voltage value probing the LED, which is showing our expected value of around 4-5v being sent through the LED.

## 5. Problems Encountered

Problems arose the further we progressed into the project. A big one was the wiring for the 555 Timer. We decided that getting the circuitry down for this circuit should be a priority since without it, the rest of the circuit would not function whatsoever. Figuring out how to properly wire the 555 Timer to the rest of the circuit proved to be a challenge, but was overcome with just a little more research. The duty cycle calculation was another big problem, as we needed this to be in our range if we wanted the circuit to function properly. Thankfully, with the help of online resources we managed to get around this and get our desired duty cycle. Implementing our diode also gave us a little bit of trouble, however since we were already a bit familiar with diodes, some trial and error would get us past the issue. The last problems we faced were mainly miniscule wiring issues. In the first prototype of our circuit, our transistor and diodes were connected in reverse, meaning nothing would show on the oscilloscope when we would measure it. However, flipping these components would then get the circuit to operate as intended and give us the results we expected.

## 6. Conclusions

Buck Converters are an extremely important piece of technology used in many different applications and disciplines. They allow for a high input voltage to be brought down to a much more manageable level in order to operate devices all over, from portable devices all the way to automotive systems. This project took an in-depth look into the internals of a Buck Converter and the components that allow it to operate, hence the name "DIY" Buck Converter. Normally, Buck Converters are already pre-built, so it would be unconventional to make your own unless required for a very specific application. Breaking it down into its internal components, we can see how each individual device interacts with one another in order to bring about the entire schematic as a whole. Understanding how these circuits work allows us to view its behavior more in-depth, as well as get a better understanding of the bigger devices and circuits in which a Buck Converter may be found.