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EEE 419 – 01

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EEE 419 Experiment 1 Experimental Report

Introduction

The aim of the experiment is to design a Buck Converter that converts a negative voltage to a smaller negative voltage.

The design of the Buck Converter is completed and simulated through LTSpice as shown in figure 1.

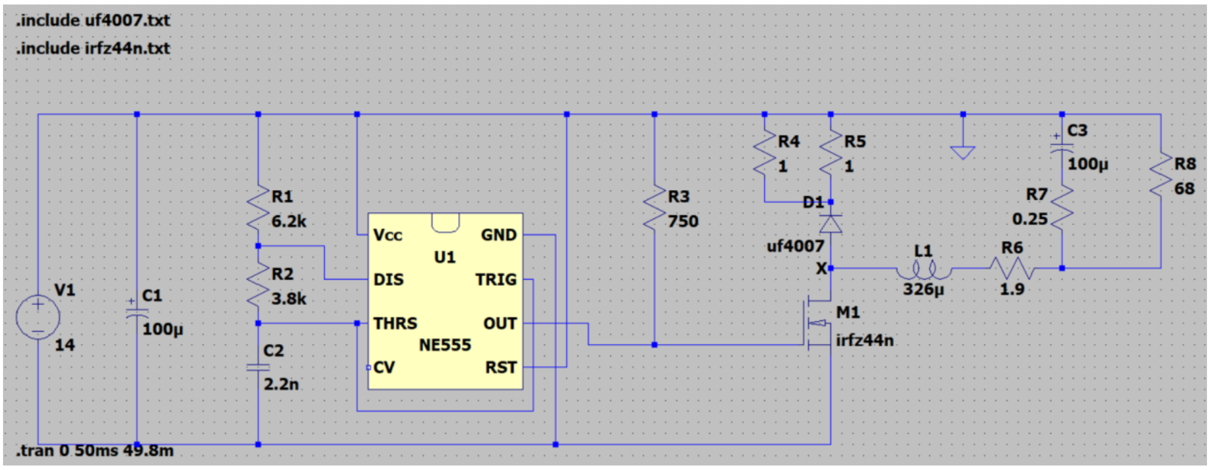

Figure 1: LTSpice Design of Buck Converter

The aim of this part is to conduct real-life implementation of Buck Converter on breadboard and observe the experimental results. Then these results will be compared to simulation results.

Implementation and Results

a) In this part, only NE555 circuit is implemented as shown in figure 2, including pull-up resistor at the output pin. In the design, pull-up resistor value is determined as 700Ω for 20mA current. However, to be able to use a single resistor and avoid connection issues, 680Ω is implemented on the breadboard as pull-up resistor.

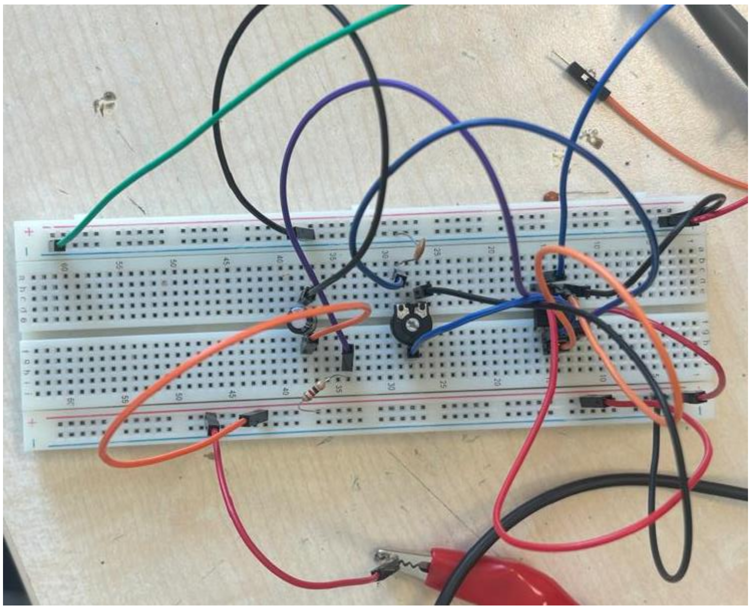

Figure 2: NE555 Circuit

The circuit is connected to 14V power supply, since V_d in the design was 14V. The expected output of the circuit in figure 2 is periodic negative pulse of magnitude varying between $-V_d$ and zero.

To make the observation, the oscilloscope probe's ground pin is connected to the output of NE555 and the other pin is connected to the same side with the negative pin of the power supply. The observed output is shown in figure 3.

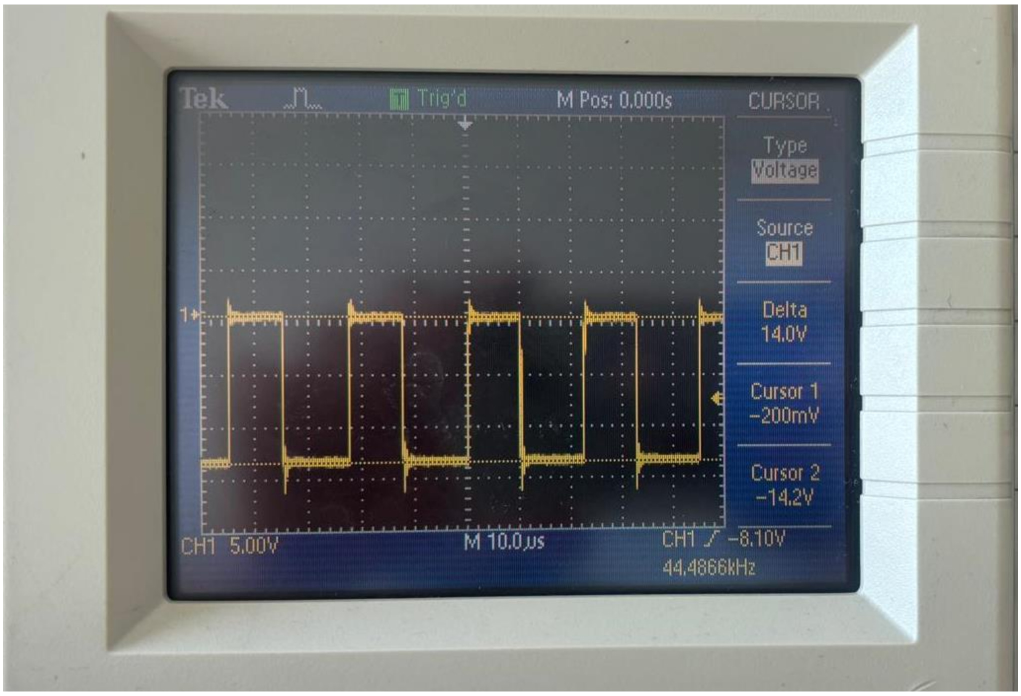

Figure 3: Output of NE555 Circuit

As shown in the figure 3, the output of the NE555 circuit is periodic negative pulse of magnitude varying between around -14V and 0V.

By using the time cursors, the T_s of the waveform is observed and set to required value, which is around 22.47μs, as shown in figure 4. From the observations, the duty cycle calculated as 0.678 as expected.

Figure 4: T_s of the Waveform

Hence it can be concluded that NE555 circuit capable of turning on MOSFET transistor fully.

b) The remaining components are implemented on the breadboard with 560Ω load resistor as shown in figure 5.

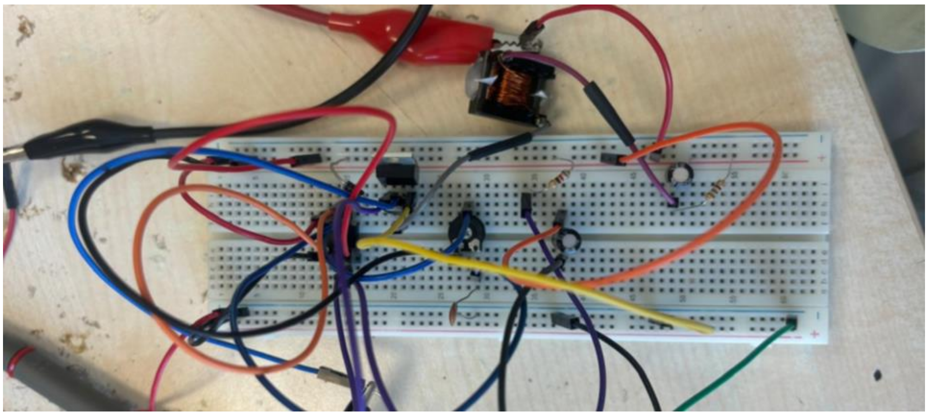

Figure 5: Complete Buck Converter Circuit with 560Ω Load Resistor

The expected output from this circuit is a voltage varies between 0.6V to -14V with oscillatory portion toward the end of the cycle. The oscilloscope probe is connected to the circuit and the output is observed as shown in figure 6.

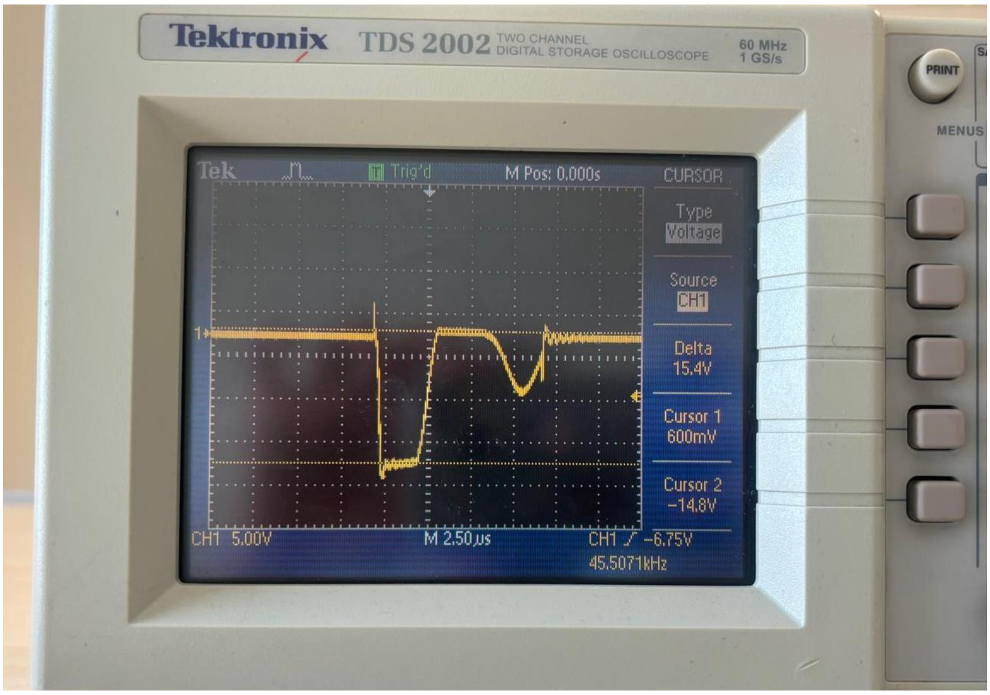

Figure 6: Output of the Negative Buck Converter with 560Ω Load Resistor

As shown in figure 6, output voltage varies between 0.6V to -14.8V, as expected.

From the previous calculations, it is known that when load resistor value is 560Ω, buck converter is in discontinuous mode which means that the inductor current falls to zero during each switching cycle because energy stored in the inductor is completely transferred to the load before the next switching period begins.

The voltage behavior of in discontinuous mode, v_X has three distinct phases within one switching cycle. In the first phase, when the MOSFET switch turns on, the input voltage applied across the inductor, so $-V_d \approx v_X$, which is around -14V. In the second phase, when the MOSFET switch turns off, the inductor tries to maintain its current flow by discharging its stored energy through the diode. Hence v_X rises to the diode's forward voltage drop which is equal to 0.6V. Since buck converter is in discontinuous mode, current of the inductor reaches zero and the circuit enters the zero-current state which is third phase. During this phase, no current flows through the inductor and the voltage v_X drops to zero until the next switching cycle starts.

The output voltage of this circuit is measured by multimeter and the value is found as -13.2V. This is nearly equal to -14V. Hence the circuit is qualified for the next implementations.

c) At the preliminary part, R_{L1} is chosen as 68Ω, so the required value is connected to the circuit and the output voltage is observed as shown in figure 7.

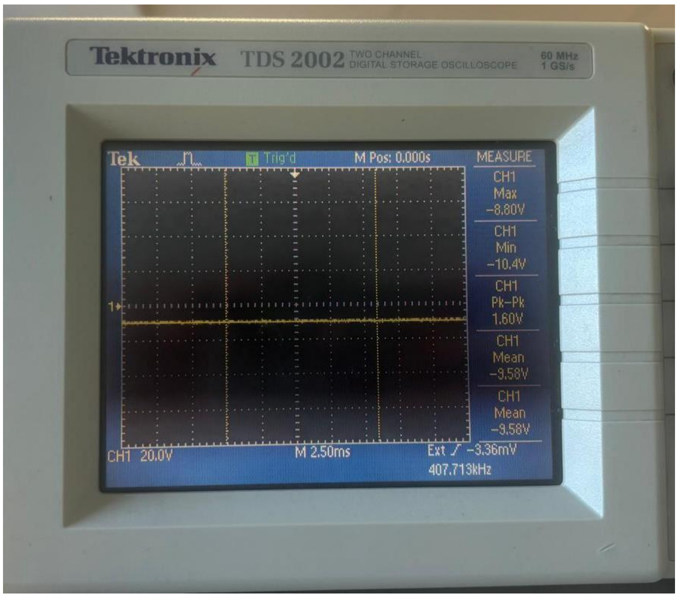

Figure 7: Output of the Negative Buck Converter with 68Ω Load Resistor

As can be seen from the output, the voltage value of the Buck Converter is -9.58V, which is very close to the required output.

By using the AC coupling, the ripple of the output voltage is observed as shown in figure 8.

Figure 8: The Ripple of the Output Voltage

Also, in the figure 8, it is shown that T_s value of the ripple is 21.20µs. This value was 21.40µs in the simulation. Hence the period of the ripple is quite close to the designed circuit.

The t_h value of the circuit was found as 5.86µs in the simulation, as shown in figure 9. The observed value of the same value is shown in figure 10, which is close to the simulated value.

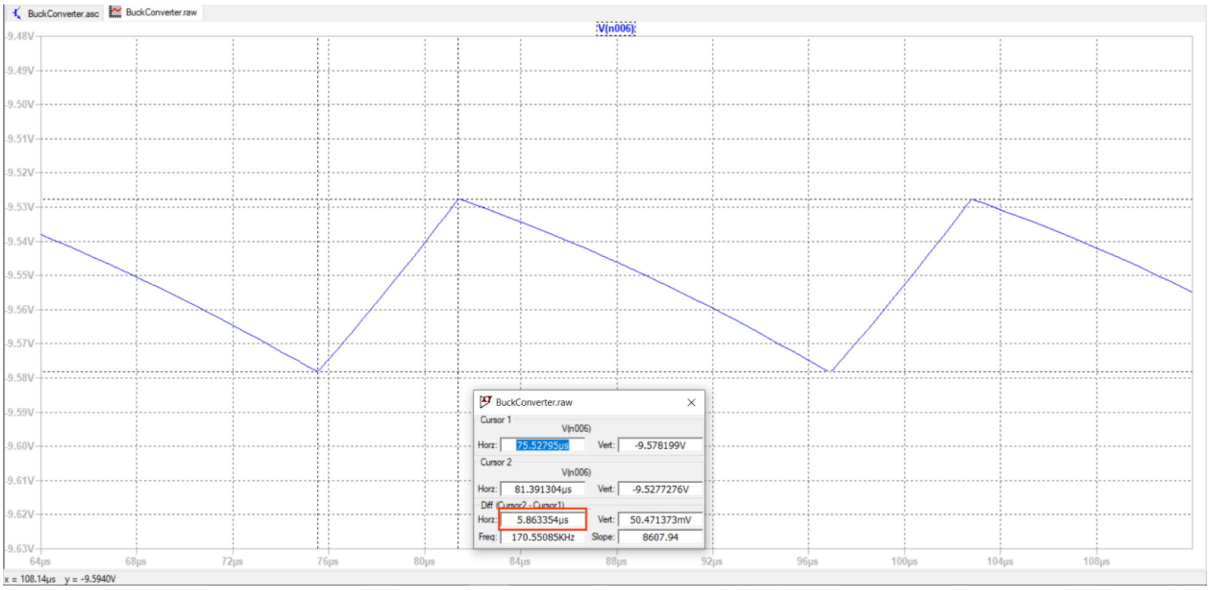

Figure 9: The Simulated Value of T_s - t_h

Figure 10: The Observed Value of T_s - t_h

The current through voltage source is observed on the power supply as shown in figure 11, which is 0.118A.

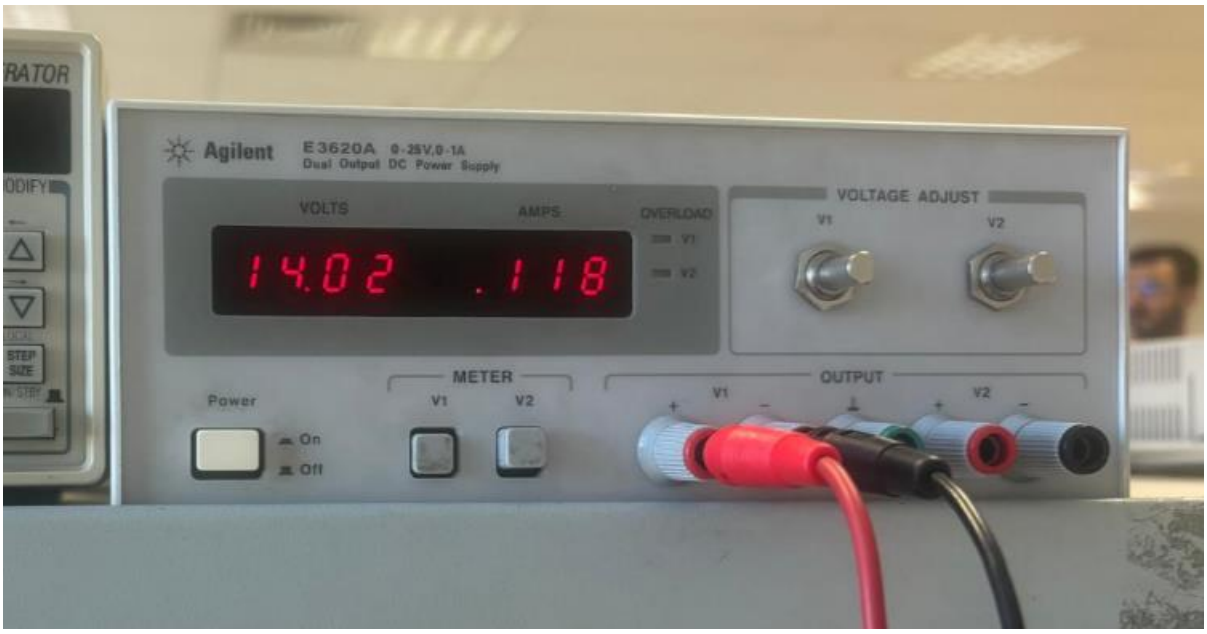

Figure 11: Power Supply Current

The ripple voltage is observed by using voltage cursors of the oscilloscope, as shown in figure 12. The ripple voltage value is found to be approximately 59.2mV, which is reasonably close to the simulation result, 50.2mV.

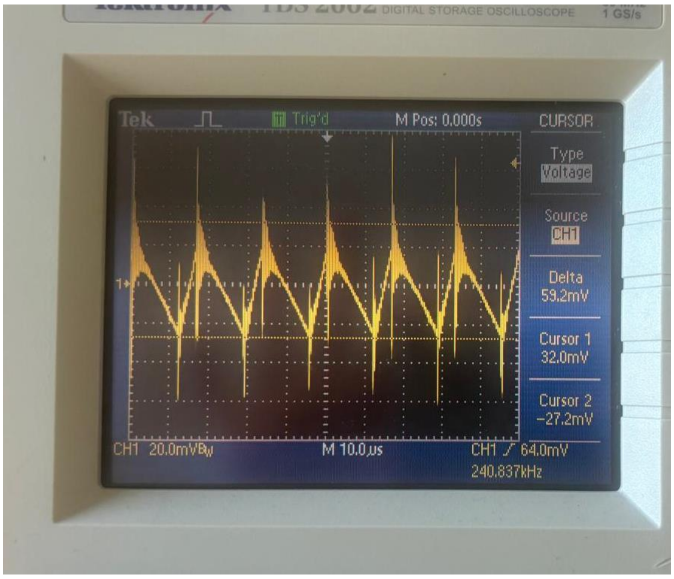

Figure 12: Ripple Voltage

From the preliminary part, the efficiency is calculated wrong, so the efficiency calculation of simulation results recalculated by using the power supply power. The simulated value is shown in figure 13.

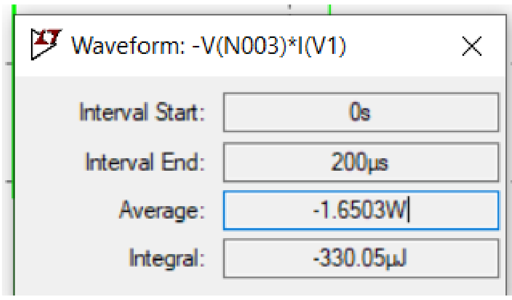

Figure 13: The Simulated Value of Power Supply Power

The efficiency of the simulated circuit is calculated and stated in Table 1.

The comparison preliminary and experimental results of the Negative Buck Converter with 68Ω Load Resistor is shown in Table 1.

	V_d	I_d	$R_L = R_{L1}$	D	V_o	η(%)	V_{ripple}
Preliminary	-14V	-107.7mA	68Ω	0.71	-9.54V	87.7%	50.2mV
Experiment	-14.02V	-0.118mA	68Ω	0.75	-9.58V	80.2%	59.2mV

Table 1: Comparison of Simulated (Preliminary) and Experimental Results

d) V_x value of the implemented circuit is shown in figure 14.

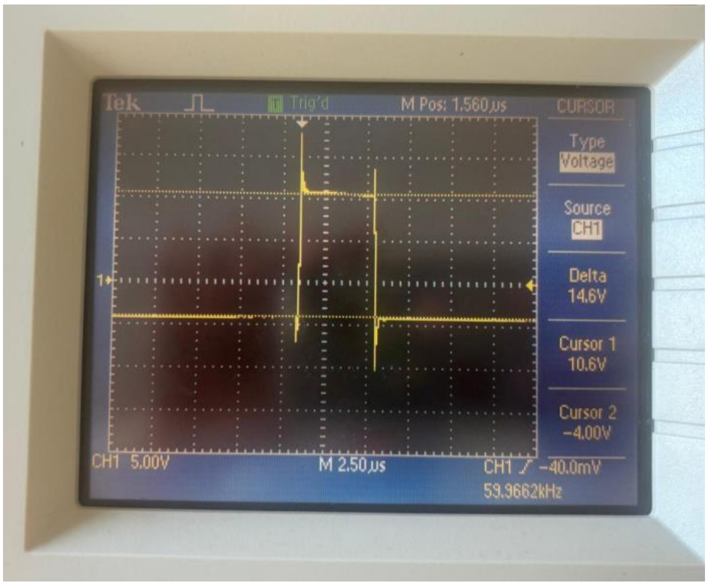

Figure 14: Vx Value of the Buck Converter

The value of the $v_R(t)$ which will be used to measure $i_D(t)$ is shown in figure 15.

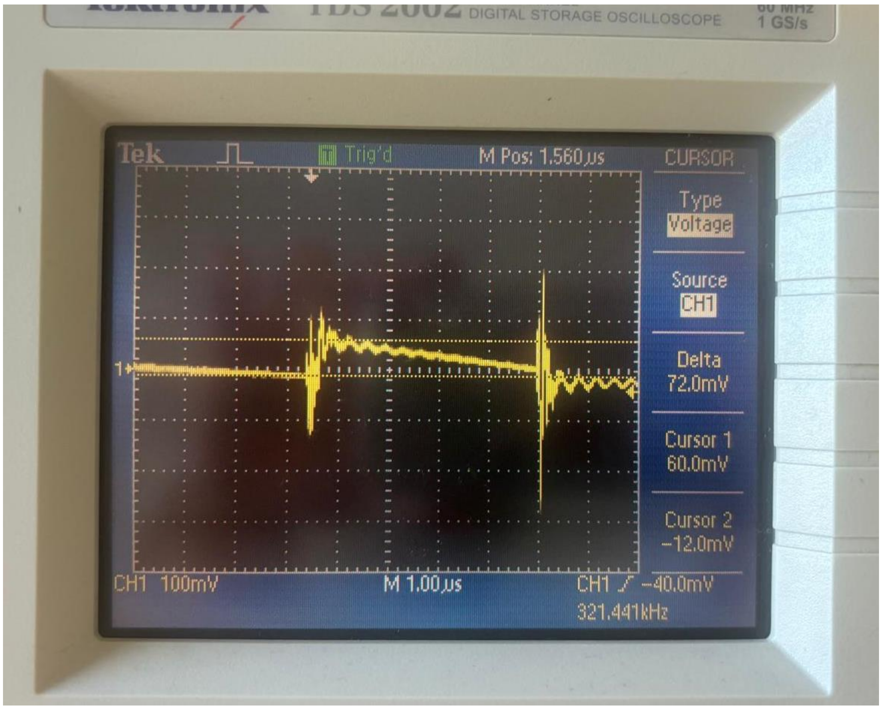

Figure 15: $v_R(t)$ Value of the Buck Converter

As shown in figure 15, the ripple of the $v_R(t)$ is 0.72mV. Since $i_D(t) = 2v_R(t)$, the ripple value of the diode current is 144mA. The simulated value of the diode current is approximately 181mA, as shown in figure 16.

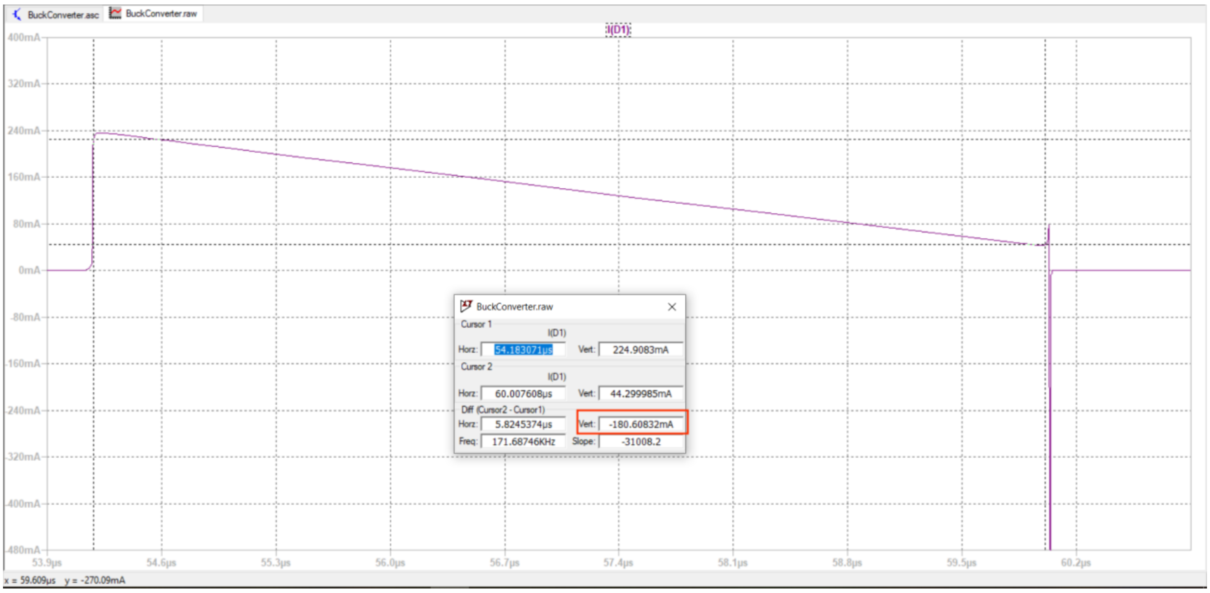

Figure 16: Simulated Ripple Value of Diode Current

e) The load resistance is replaced to R_{L2} which is chosen as 150Ω in preliminary part. The output voltage is observed as -10V, shown in figure 17.

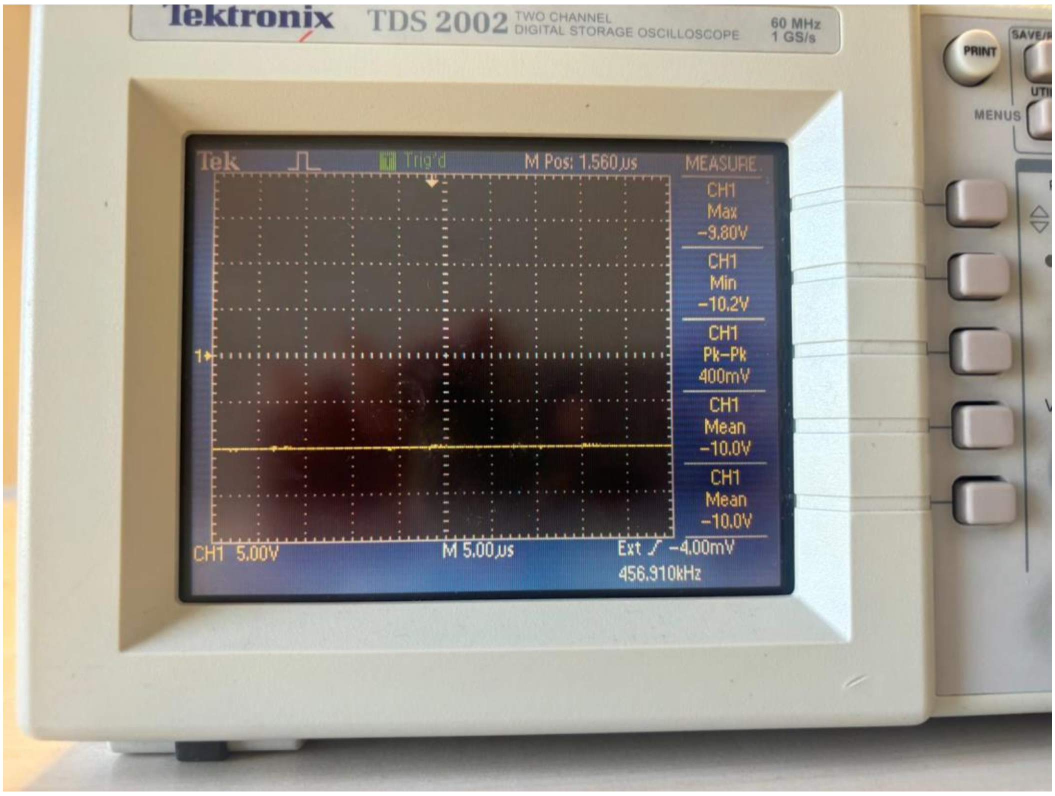

Figure 17: Output Voltage of the Buck Converter with 150Ω Load Resistance

The ripple of the output voltage is shown in figure 18, and the ripple voltage is found as 52.8mV.

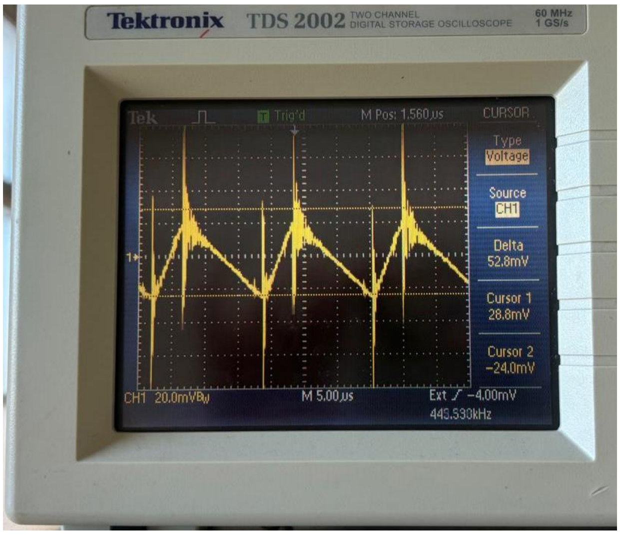

Figure 18: Ripple of the Output

Ts value of the ripple is shown in figure 19 and low-level duration is shown in figure 20.

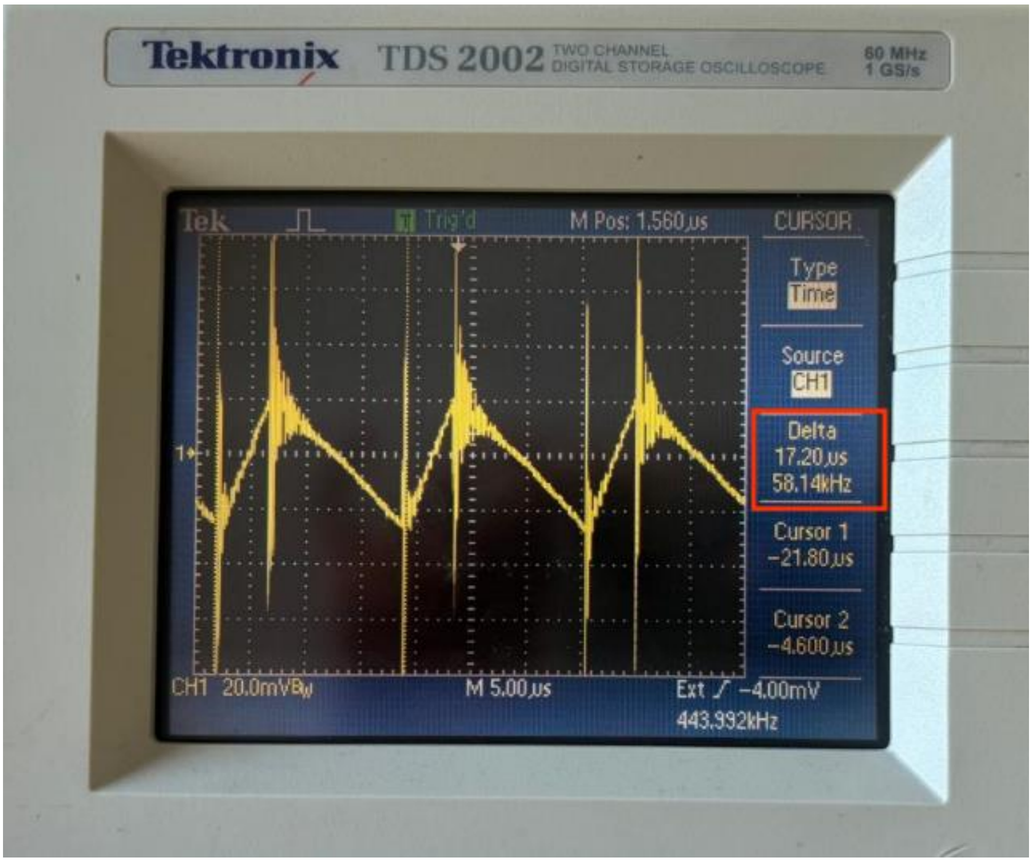

Figure 19: Ts of the Output Voltage

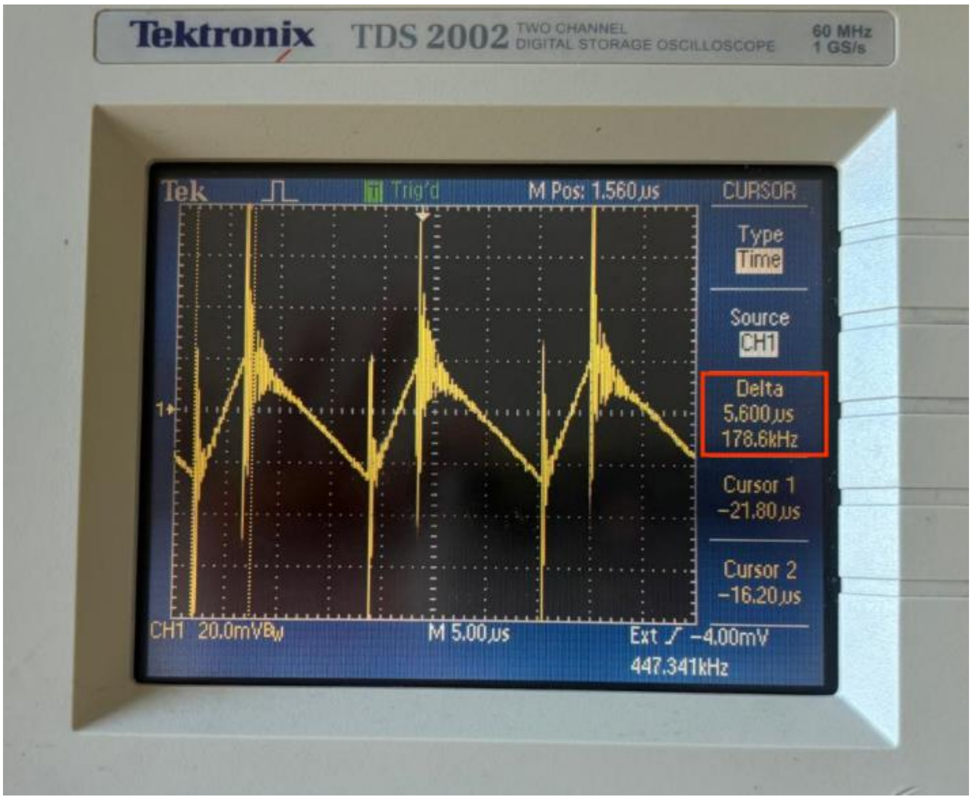

Figure 20: Low-Level Duration of the Ripple

With these results, the duty cycle is found to be 0.67. The comparison of the preliminary and experimental results is shown in Table 2.

	V_d	$R_L = R_{L2}$	D	V_o
Preliminary	14V	150Ω	0.52	-10.5V
Experiment	14.02V	150Ω	0.67	-10V

Table 2: Comparison of the Preliminary and Experiment Results

Since the load resistor value is more than R_{max}, the circuit is operating in discontinuous mode. Hence the inductor reaches zero during each cycle. As a result, the duty cycle is much shorter than a continuous case. When the results of the 150Ω load resistance is compared to the 560Ω, the results are closer to the continuous case for 150Ω. Hence it can be observed that the circuit begins to enter discontinuous mode. This situation increased the value of the output voltage; hence the converter begins to fail.

Conclusion

The experimental portion of the assignment successfully demonstrated the behavior of a Buck Converter in both continuous mode and discontinuous mode, as well as the effects of varying load resistance on the circuit's performance. By observing the voltage V_x and the output voltage V_o using an oscilloscope, the circuit's operation was confirmed.

When the load resistance was higher, the circuit operated in discontinuous mode, where the inductor current periodically reached zero. This caused the voltage waveform V_x to exhibit distinct zero-current periods, along with increased ripple in the output voltage. The results in this mode showed lower efficiency due to intermittent energy transfer.

On the other hand, with a lower load resistance, the circuit operated in continuous mode, where the inductor current remained above zero throughout the switching cycle. The output voltage was more stable with less ripple, confirming efficient energy transfer.

This experiment highlighted the importance of load resistance in determining the mode of operation, affecting both the stability of the output voltage and the overall efficiency of the converter. Through practical measurement and comparison with theoretical expectations, the assignment provided valuable insight into Buck Converter behavior under different operating conditions.