Alex Gieson
Section 007
Lab 10
Lab 10: Switching Circuits: DC Voltage Regulation
March 31, 2021

Abstract

This report will cover different converters, including the buck converter, boost converter, and inverted boost converter. Converters are circuits that can have a high voltage output using lower voltage inputs. It does this using a special configuration of a diode, capacitor, inductor, and transistor, and includes a resistor for the load.

This lab will go over constructing and building the different types of converters, as well as measuring their different characteristics, including power consumption. In the last task, we will put the boost converter and inverted boost converter to the test by using them to power an inverting amplifier with 10V on the positive input and -10V on the negative input.

Task 10.5.1:

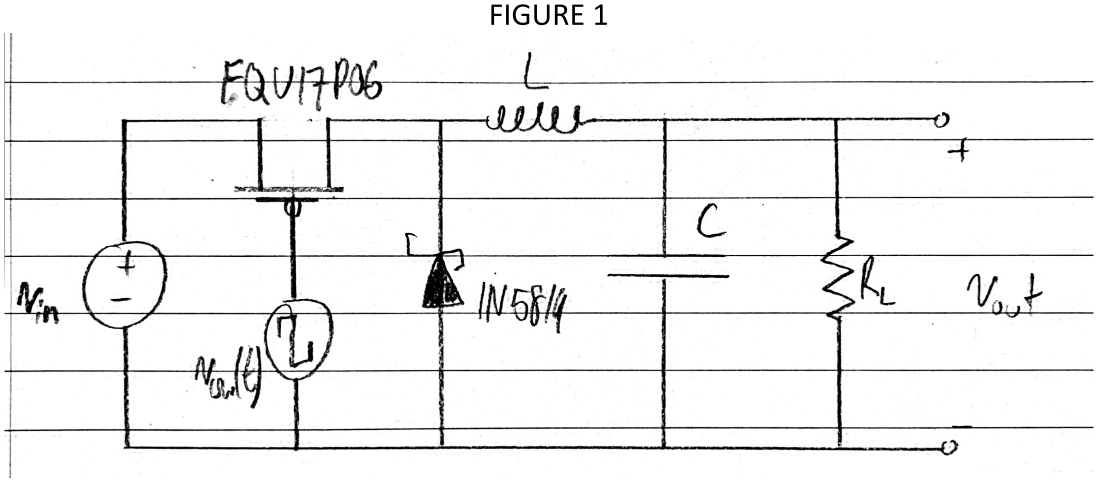
Objective

This section will demonstrate how to build and measure the characteristics of a Buck converter.

Procedure

First, the theoretical V_{out} of the circuit shown below in figure 1 was calculated to be 2.5V.

FIGURE 1



A Buck converter circuit (L = 1mH, C = 10muF, RL = 330 ohms, Vin = 5V, Vsw is a -5V to 5V 50% duty cycle square wave)

Next the circuit shown in figure 1 was constructed and the peak-to-peak voltage as well as the average of the output were measured and compared to the calculated values. Then the efficiency of the circuit was measured using the voltage and current readings from the power supply. Lastly, V_{out} was plotted against the duty cycle of V_{sw} in order to discover the relationship between the two.

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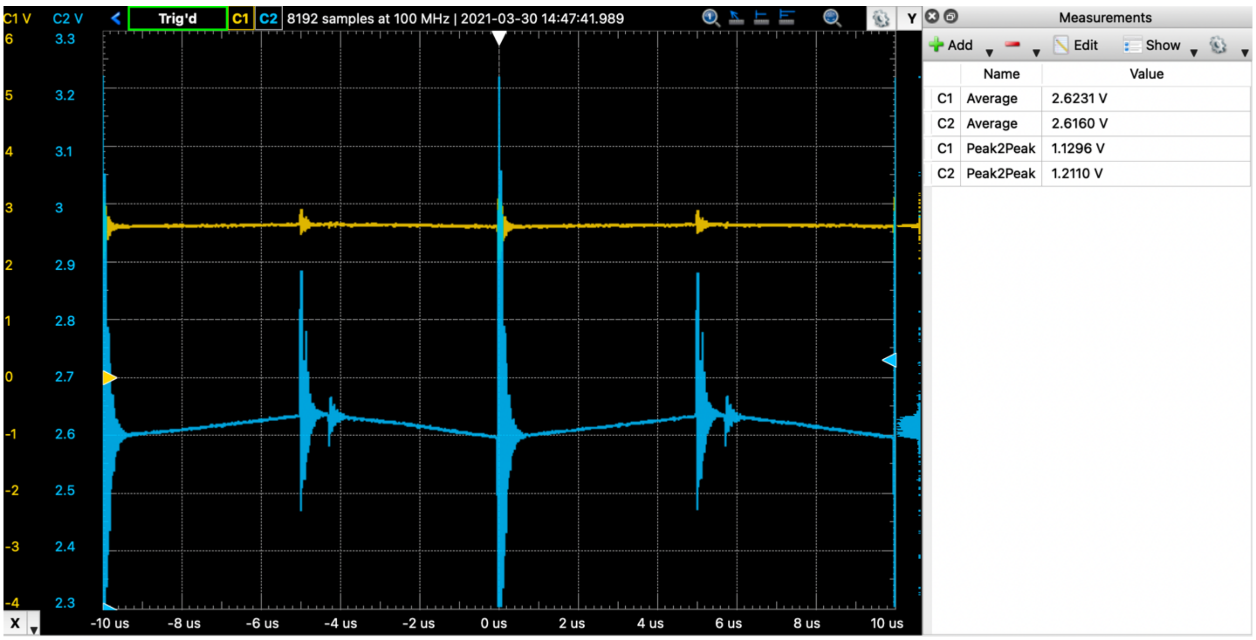
Results/Calculations

Measuring V_{out} on the oscilloscope is shown below in figure 2. Notice V_{out} is on channel 1 and 2, channel 1 being 1V/div while channel 2 is 100mV/div.

FIGURE 2



Oscilloscope screenshot showing Vout of the circuit in 2 different scales

Here, we can see that the average value of the waveform is about 2.616 V, which is very close to our expected value of 2.5V that we calculated. This gives us a percent error of 4.64%.

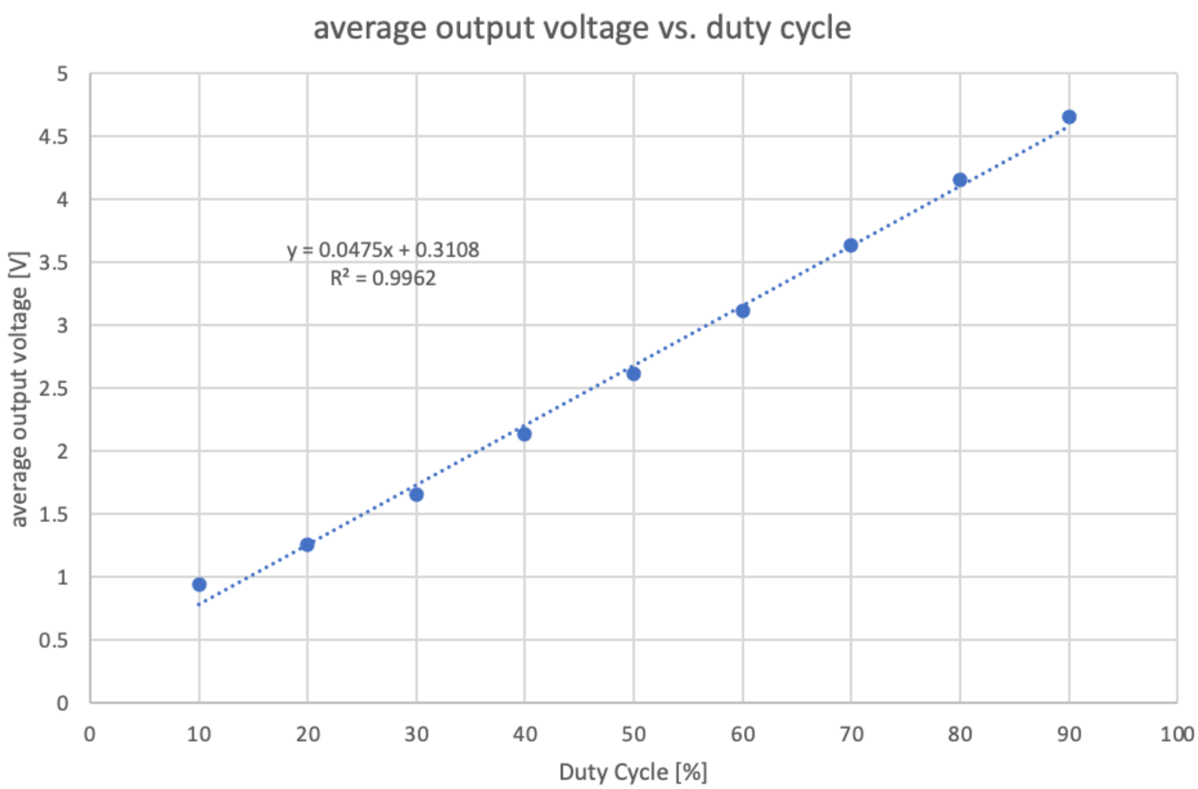
The power efficiency is calculated as follows:

$$\frac{\frac{{V_{out}}^2}{R_{out}}}{I_{in}V_{in}} = \frac{\frac{2.616^2}{330}}{0.4073 * 5.008} = \frac{0.0207377}{2.0397584} = 0.01016676556\,W$$

As we can see, the power consumption is very low, which makes the circuit very efficient!

Looking at the plot of V_{out} vs duty cycle below in figure 3, we can see that there is a linear relationship between the two.

FIGURE 3



Plot showing the relationship between the average output voltage and the duty cycle of the input waveform

We can see that there is a clear linear relationship between the output voltage and duty cycle of the wave, especially due to the high r squared value of 0.9962, meaning that the trendline is a very good fit for the data.

Conclusions

This task was successful as we were able to build the circuit correctly and test the output voltage against our expected value to get a percent error of 4.64%. Additionally, we were able to calculate that the buck converter is very efficient because it uses very little power to operate. Lastly, we were able to determine that there is a linear relationship between the output voltage and the duty cycle of the input waveform.

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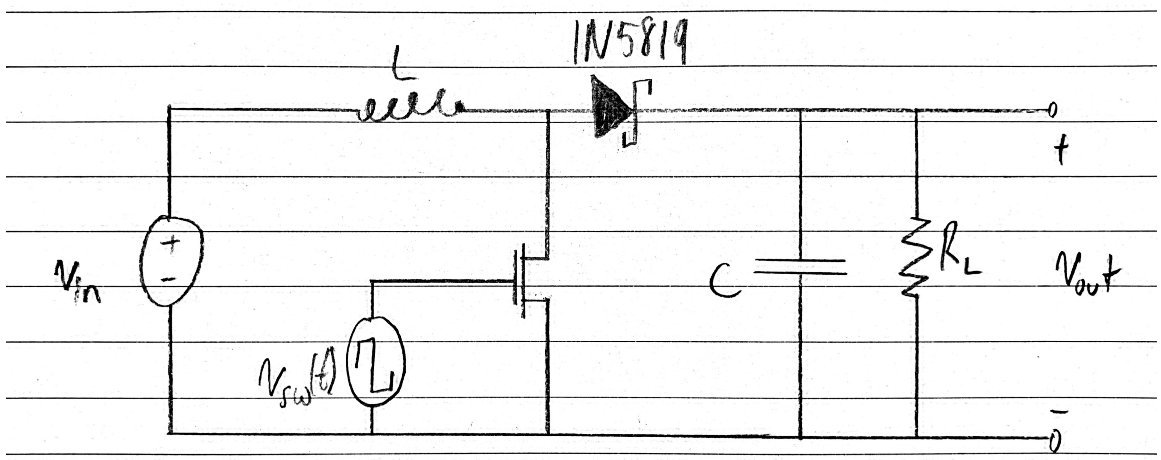
Task 10.5.2:
Objective

This section will demonstrate how to build and measure the characteristics of a boost converter.

Procedure

First, the duty cycle needed to obtain a V_{out} of 10 V was calculated to be 50% for the circuit shown below in figure 4.

FIGURE 4



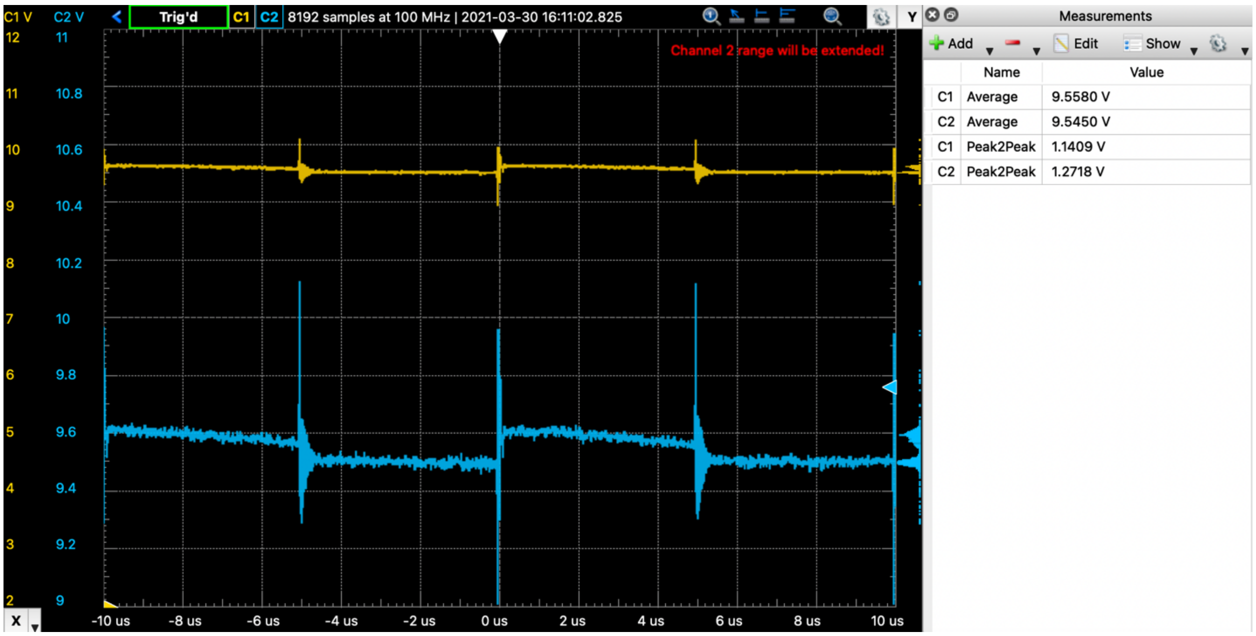
A boost converter circuit (L = 1mH, C = 10muF, RL = 680 ohms, Vin = 5V, Vsw is a 0V to 5V 50% duty cycle square wave)

Next the circuit was constructed, and the peak-to-peak voltage and average voltage were recorded, including screenshots of the oscilloscope. Lastly, the efficiency of the conversion was calculated.

Results/Calculations

Measuring V_{out} on the oscilloscope is shown below in figure 5. Notice V_{out} is on channel 1 and 2, channel 1 being 1V/div while channel 2 is 100mV/div.

FIGURE 5



Oscilloscope screenshot showing Vout of the circuit in 2 different scales

Here we can see that the average value is about 9.545V, which is close to the 10V that it should be. This leaves us with a 4.55% error.

The power efficiency is calculated as follows:

$$\frac{\frac{{V_{out}}^2}{R_{out}}}{I_{in}V_{in}} = \frac{\frac{9.545^2}{680}}{0.4073 * 5.008} = \frac{0.13398}{2.0397584} = 0.0656847\ W$$

As we can see, the power consumption is very low, which makes the circuit very efficient!

Conclusions

This task was successful as we were able to build the circuit correctly and test the output voltage against our expected value to get a percent error of 4.55%. Additionally, we were able to calculate that the boost converter is efficient as it uses very little power to operate. In this lab, the buck converter is much more efficient, although the output voltage was much lower.

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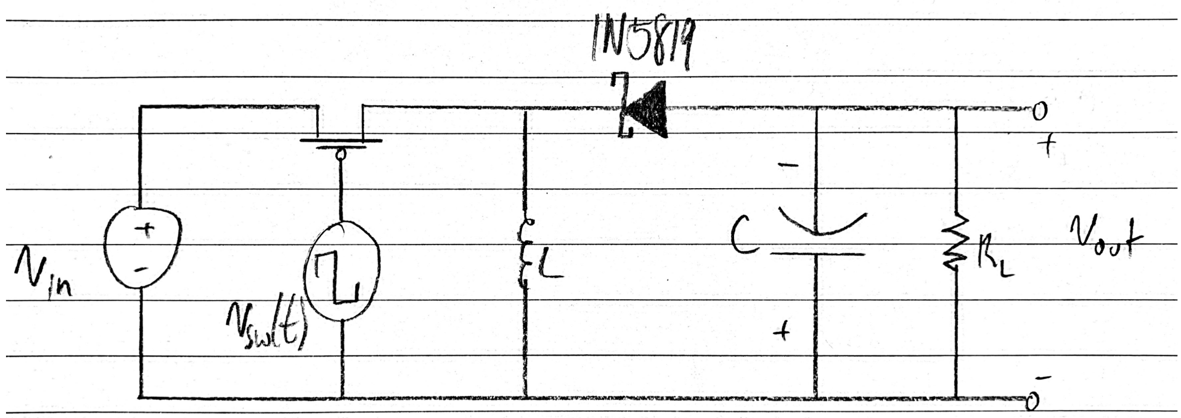
Task 10.5.3:
Objective

This section will demonstrate how to build and measure the characteristics of an inverting boost converter.

Procedure

First, the duty cycle needed to obtain a V_{out} of -10 V was calculated to be 33.3% for the circuit shown below in figure 6.

FIGURE 6



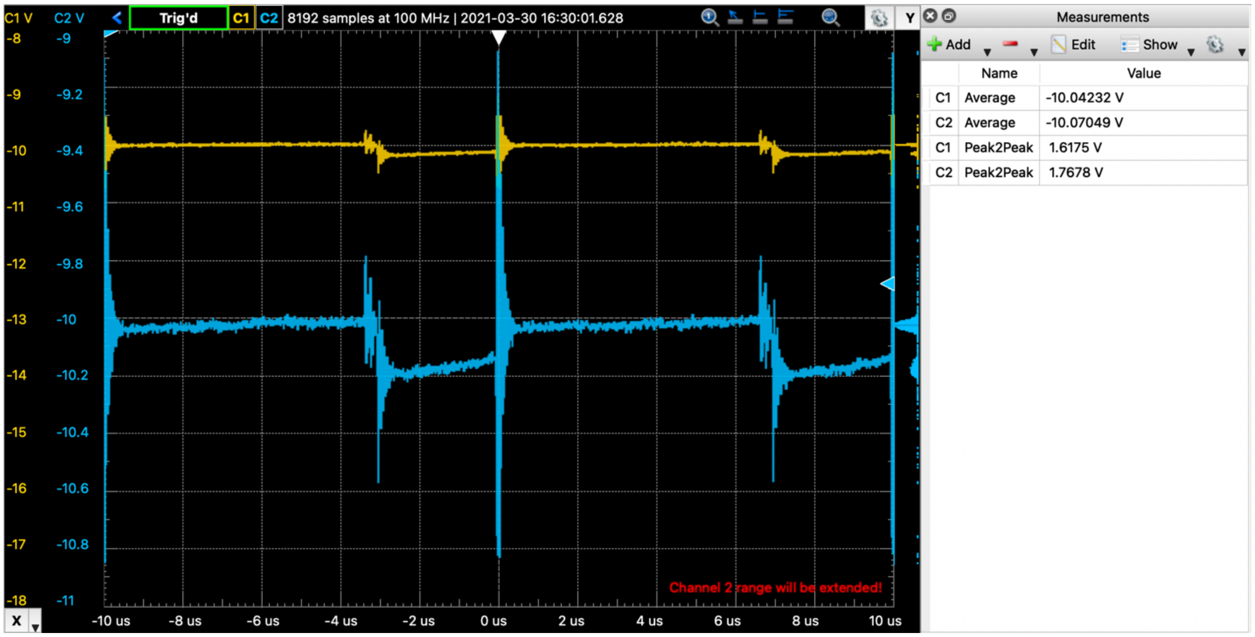
A boost converter circuit (L = 1mH, C = 10muF, RL = 680 ohms, Vin = 5V, Vsw is a -5V to 5V 50% duty cycle square wave)

Next the circuit was constructed, and the peak-to-peak voltage and average voltage were recorded, including screenshots of the oscilloscope. Lastly, the efficiency of the conversion was calculated.

Results/Calculations

Measuring V_{out} on the oscilloscope is shown below in figure 7. Notice V_{out} is on channel 1 and 2, channel 1 being 1V/div while channel 2 is 100mV/div.

FIGURE 7



Oscilloscope screenshot showing Vout of the circuit in 2 different scales

Here we can see that the average value is about -10.07049V, which is close to the 10V that it should be. This leaves us with a 0.7049% error.

The power efficiency is calculated as follows:

$$\frac{\frac{{V_{out}}^2}{R_{out}}}{I_{in}V_{in}} = \frac{\frac{10.07049^2}{680}}{0.4298 * 5.008} = \frac{0.1491393659}{2.1524384} = 0.069288564\, W$$

As we can see, the power consumption is very low, which makes the circuit very efficient!

Conclusions

This task was successful as we were able to build the circuit correctly and test the output voltage against our expected value to get a percent error of 0.7049%. Additionally, we were able to calculate that the inverted boost converter is efficient as it uses very little power to operate. This circuit is nearly as efficient as the boost converter. This discrepancy could be due to the fact that the measuring devices we are using are not incredibly accurate.

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Task 10.5.4:

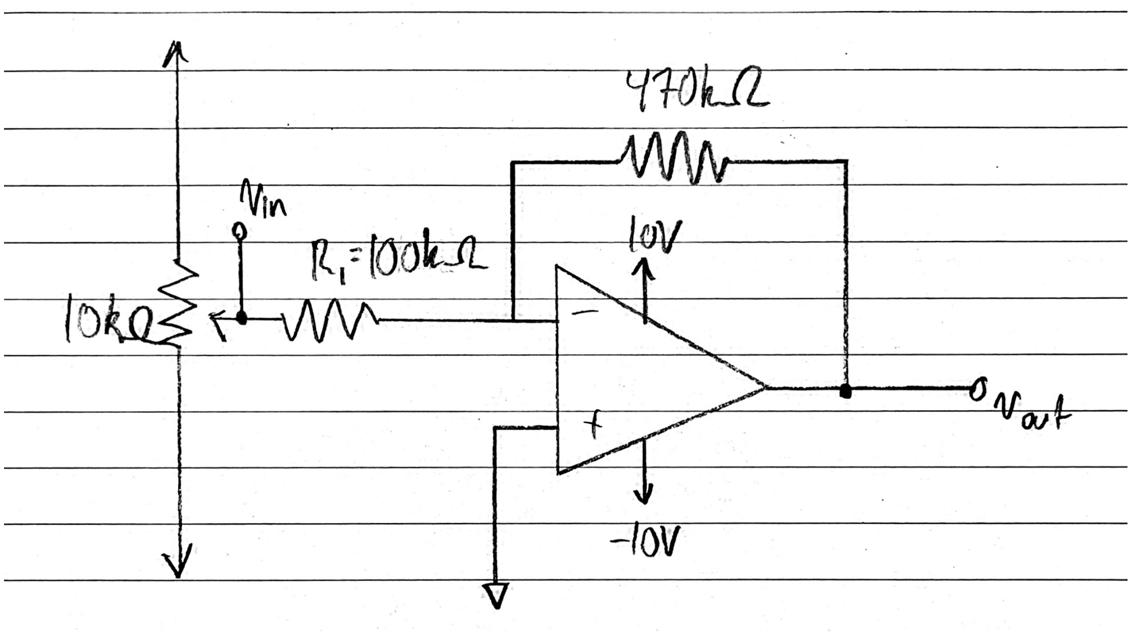
Objective

This section will demonstrate how to design a dual rail power supply that can drive an inverting op amp circuit.

Procedure

Using the boost circuit and inverted boost circuit from the previous two tasks, we can drive an op amp with -10V and 10V by wiring the circuit as shown below in figure 8.

FIGURE 8



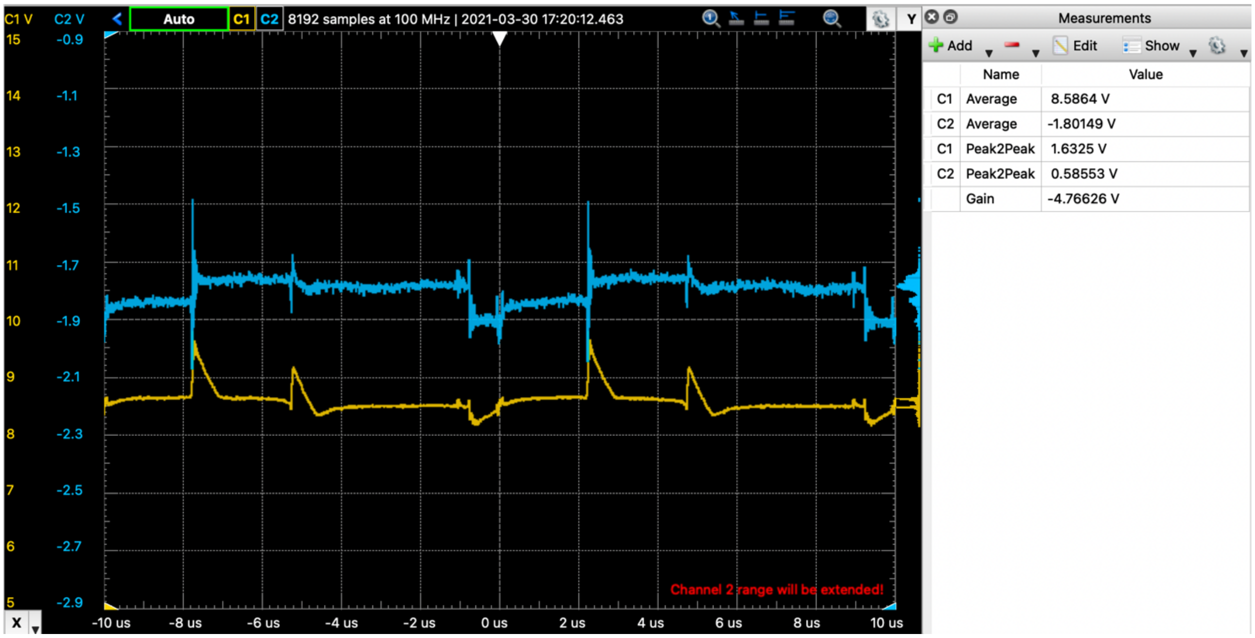
An inverting amplifier circuit

The resistor values were picked in order to give the amplifier a gain of -4.7, they are shown above in figure 8. After adjusting the duty cycles of the waves to get as close to -10V and 10V as possible, V_{in} and V_{out} were measured and plotted against each other in order to distinguish the relationship between the two.

Results/Calculations

In order to get as close to 10V and -10V as possible, the duty cycles were changed to be 52% and 33% on the boost converter and inverted boost converter respectively. Measuring the gain of the operational amplifier in the oscilloscope gives us the following values in the measurement window

FIGURE 9



Oscilloscope screenshot showing the input and output of the op amp. Most notably it shows the gain in the top right corner

As we can see, the measured gain of the op amp is -4.76626, which is quite close to the expected -4.7. This leaves us with a 1.41% error!

Next, we can take a look at the V_{in} and V_{out} values while changing the potentiometer, which are shown below.

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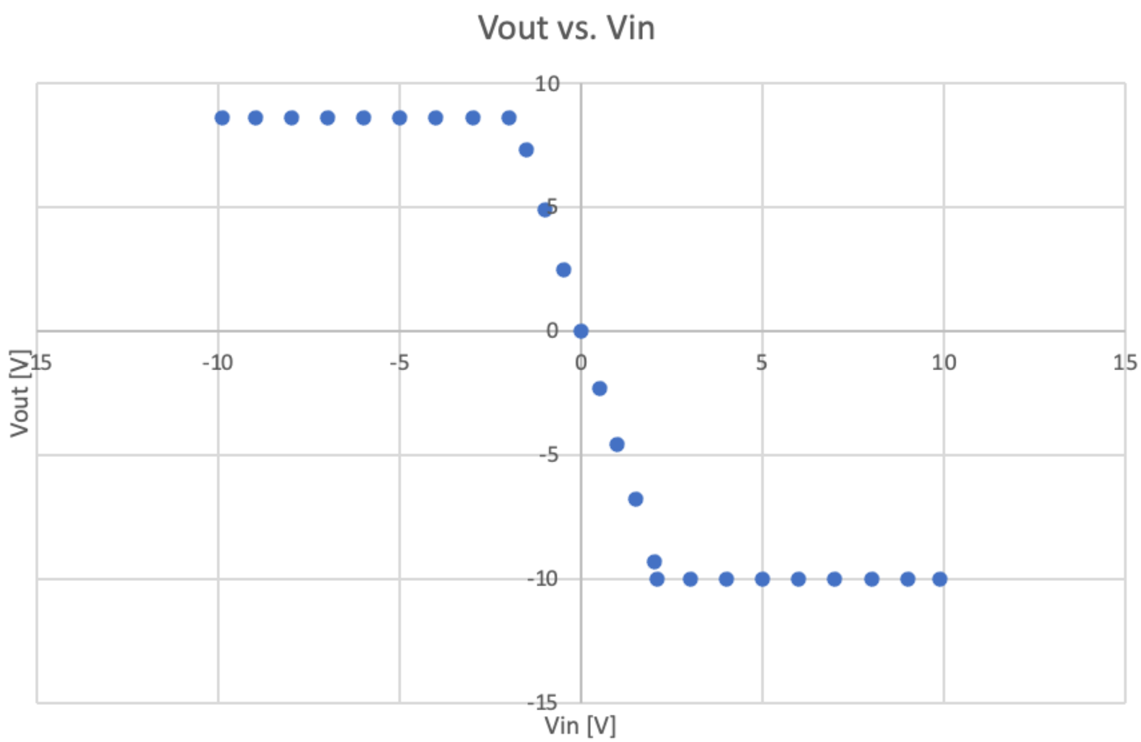
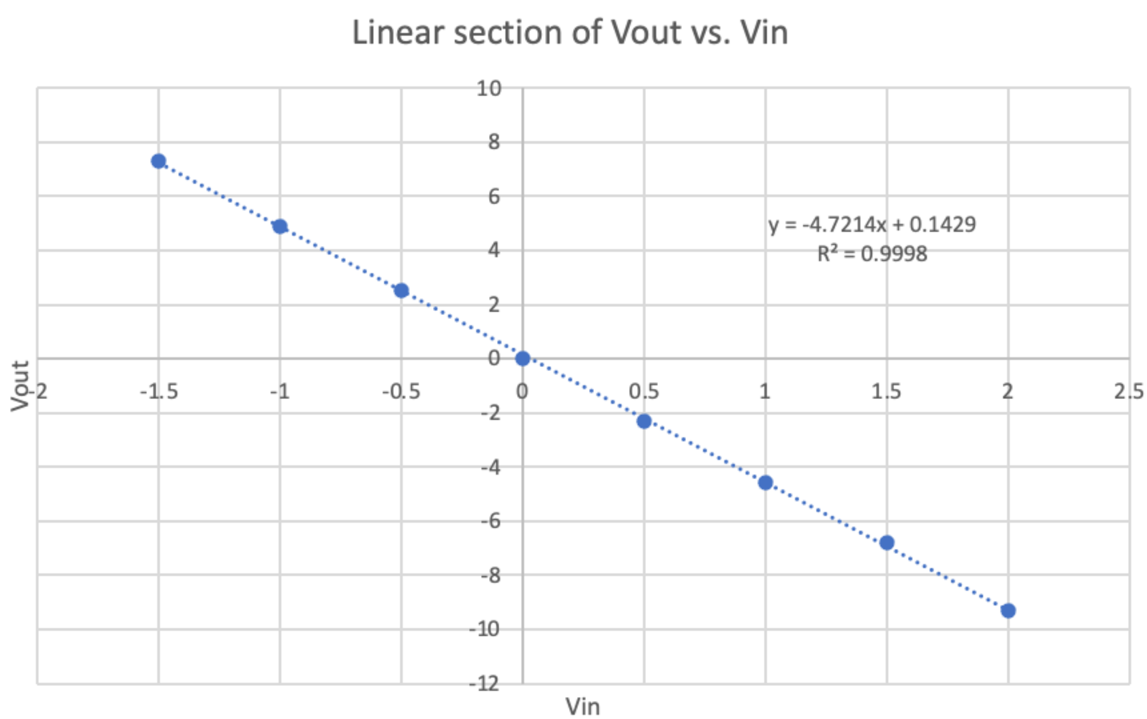
FIGURE 10



Vin vs. Vout of the op amp

Here, we can clearly see that the op amp has cutoffs at 10V and -10V, which is what we would expect. We can also take a look at the linear section of the graph even further:

FIGURE 11



Linear section of Vin vs. Vout

Shown on the graph, we can see that the slope of the line is -4.7214, which would be equal to the gain of the op amp. This gives us an even better gain value with a percent error of 0.455%!

Conclusions

This task was successful because we were able to build the op amp with the gain being within 0.455% of the expected gain. Additionally, we were able to adequately power it with 10V and -10V, which is clearly seen in figure 10 as the extreme y values are 10V and -10V.