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Section 007
Lab 11
Lab 11: Control Loops
April 8, 2021

Abstract

This report will cover the topics of open loop and closed loop control systems. In the report, we will cover the open loop vs closed loop control of a buck converter set to output 2.5V. This is done using an LMC555 PWM controlled square wave, a buck converter, an error amplifier, and a PI circuit.

This report will be found useful for those looking to implement a control system into a circuit that needs to be closely regulated and can correct the output very quickly.

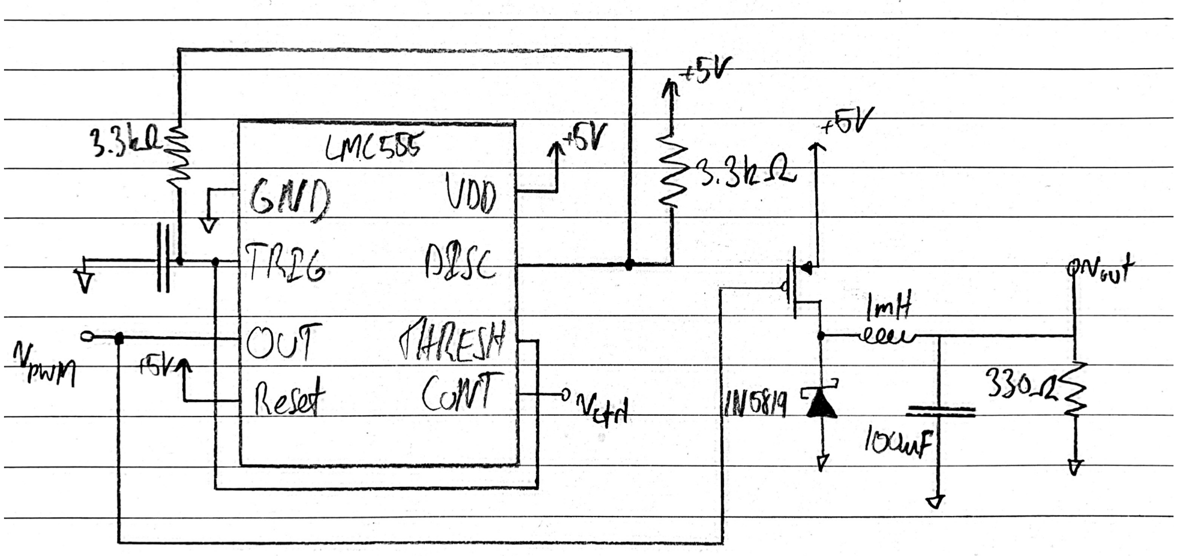
Task 11.4.1:
Objective

This section will demonstrate how to construct and test a buck regulator with pwm modulator control. This circuit is an example of open loop control.

Procedure

First, the AD2 was connected to a computer and wired up to the breadboard and the circuit shown below in figure 1 was constructed.

FIGURE 1



PWM modulation circuit wired to a buck converter

Next, the function generator was set to output a DC voltage, then wired to V_{ctrl}. Values of V_{out} were measured against different V_{ctrl} voltages, and then plotted to discover the relationship between the two. These steps were repeated for V_{cc} = 5V and 4V.

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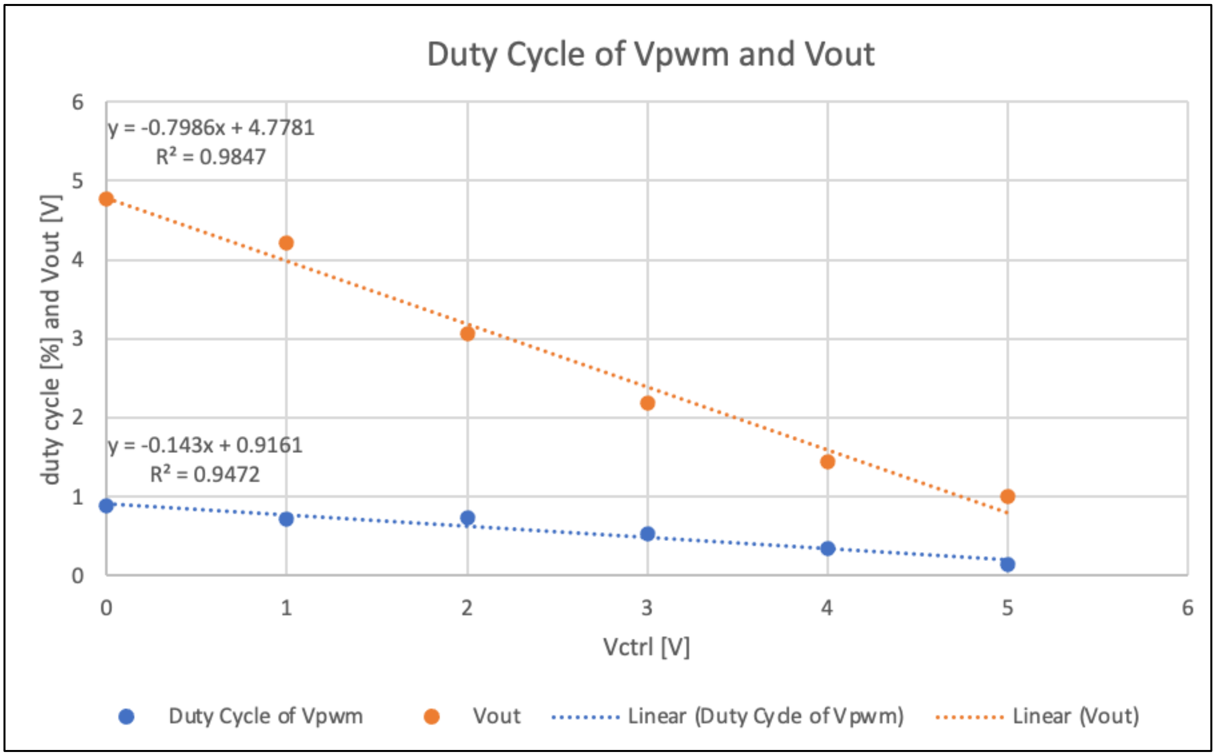
Results/Calculations

The graphical relationship between V_{ctrl}, the duty cycle of V_{pwm}, and V_{out} is shown below in figure 2.

FIGURE 2



Graph showing the relationship between V_{ctrl}, the duty cycle of V_{pwm}, and V_{out}

Here, we can see that both V_{out} and the duty cycle of V_{pwm} decrease as V_{ctrl} increases. They have an inverse relationship.

In order to obtain 2.5V on V_{out} when V_{cc} = 5V, V_{ctrl} must be approximately 2.64 V. The duty cycle at this point on V_{pwm} was measured to be 60.589%. It was found that V_{ctrl} must be 1.34 V when V_{cc} = 4V in order to get 2.5V on V_{out}, which has an 84.825% duty cycle on V_{pwm}.

When V_{cc} is lower, V_{pwm} must have a higher duty cycle in order to maintain a voltage of 2.5V. We also notice that the duty cycle of the LMC555 increases as the voltage increases, but that leads to a decrease of the duty cycle of the PMOS transistor, as it is active low.

This method of controlling the regulated output voltage is open loop, because the input to V_{ctrl} is determined before the circuit is powered and does not change with regards to the output of the circuit.

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Conclusions

This task was successful because we were able to correctly construct the circuit and determine the relationship between V_{ctrl}, the duty cycle of V_{pwm}, and V_{out}. We were also able to determine that this is an example of open loop control because V_{ctrl} is determined before the circuit is powered and is initially configured by making assumptions.

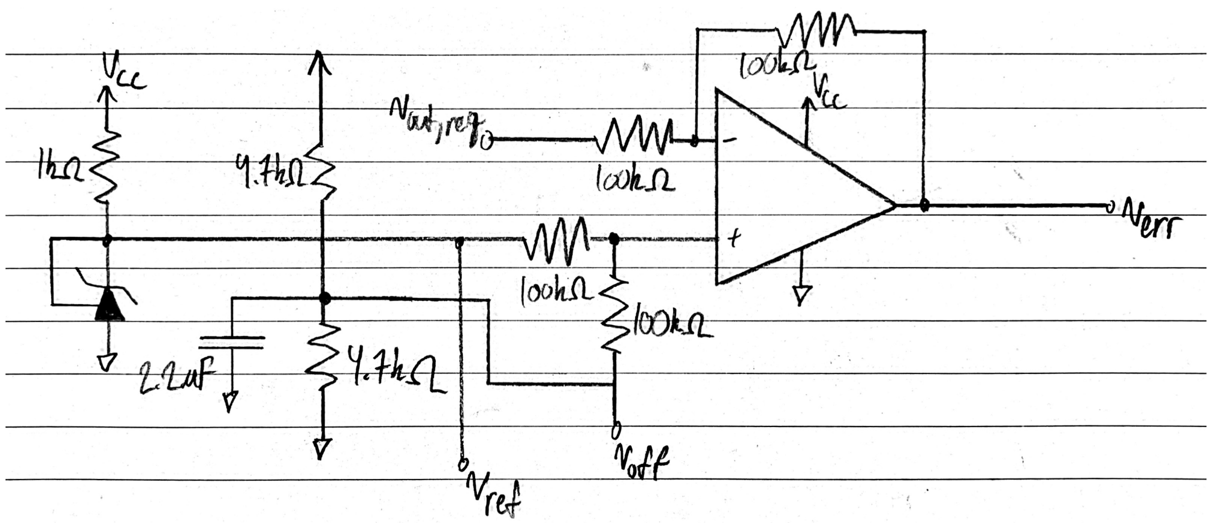
Task 11.4.2:
Objective

This section will demonstrate how to construct and test an error amplifier, specifically for a voltage of 2.5V.

Procedure

The circuit shown below in figure 3 was constructed, and $V_{out, reg}$ was connected to the function generator.

FIGURE 3



Error amplifier, which acts as a pwm modulation circuit

The function generator was swept from 1V to 4V while V_{cc} was first set to 5V and then 4V. The results of the sweep were recorded and plotted.

Results/Calculations

The plot showing V_{err} when $V_{out, reg}$ is swept from 1V to 4V while V_{cc} is 5V is shown below in figure 4.

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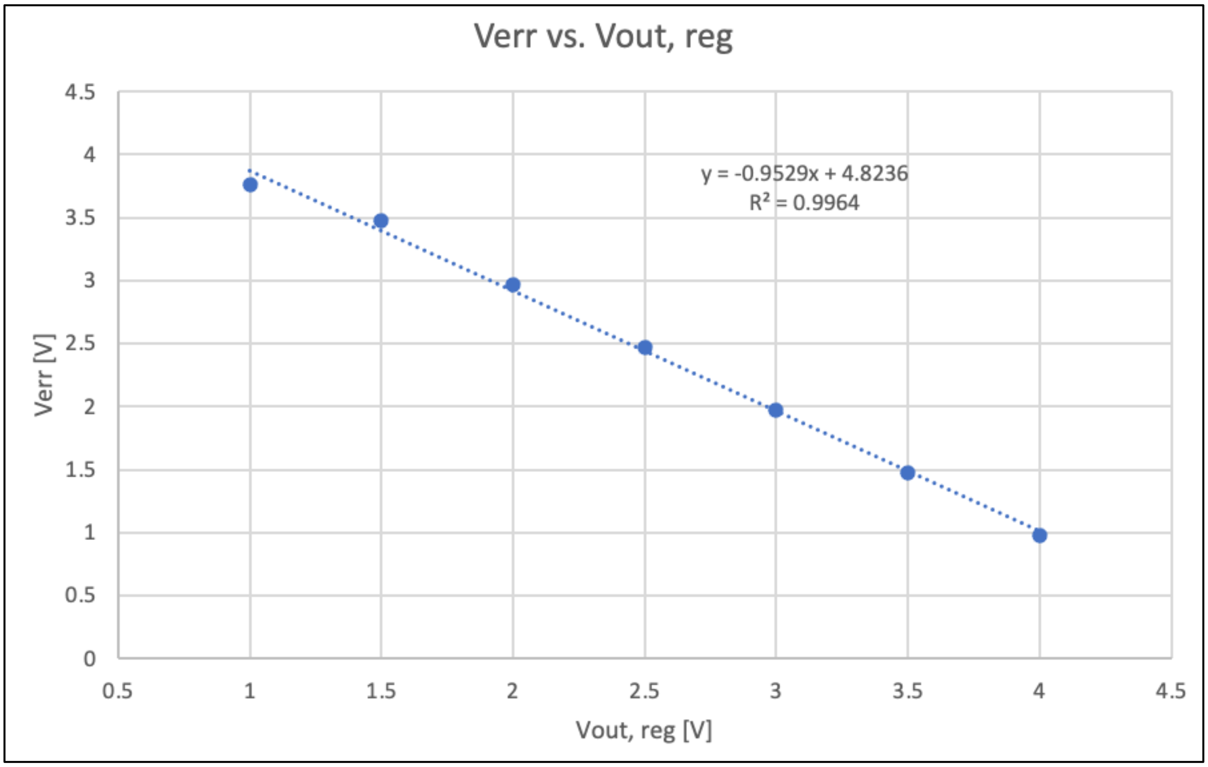
FIGURE 4

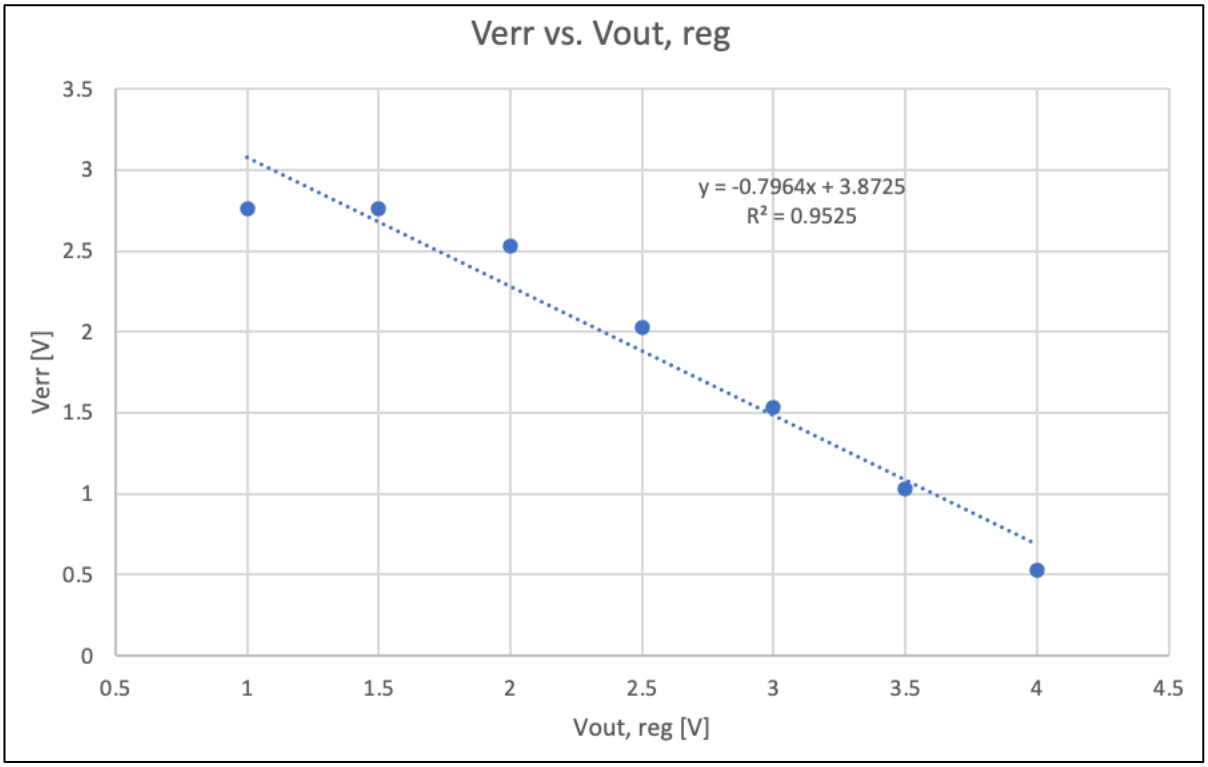


Plot of Verr vs. Vout, reg when Vout, reg varies from 1V to 4V. Vcc = 5V

Here we see that as $V_{out, reg}$ increases, V_{err} decreases. We also notice that $V_{out, reg}$ is 2.5V when V_{err} is the expected value of 2.5V.

Next, let's look at the plot showing V_{err} when $V_{out, reg}$ is swept from 1V to 4V while V_{cc} is 5V is shown below in figure 5.

FIGURE 5



Plot of Verr vs. Vout, reg when Vout, reg varies from 1V to 4V. Vcc = 4V

Here we see that as $V_{out,\ reg}$ increases, V_{err} decreases. We also notice that $V_{out,\ reg}$ is 2V when V_{err} is the expected value of 2.5V.

From these plots we can see that the error amplifier implements the correct equations as the error is 0 when $V_{out,\ reg}$ is half of V_{cc}.

Conclusions

This task was successful as we were able to correctly build and test the error amplifier part of the circuit. By sweeping the input, we were able to see that the output is generating the correct values, which we can then use to implement a closed feedback loop and control V_{out}.

Task 11.4.3:

Objective

This section will demonstrate how to construct a closed loop buck controller using the circuits built in the previous two tasks.

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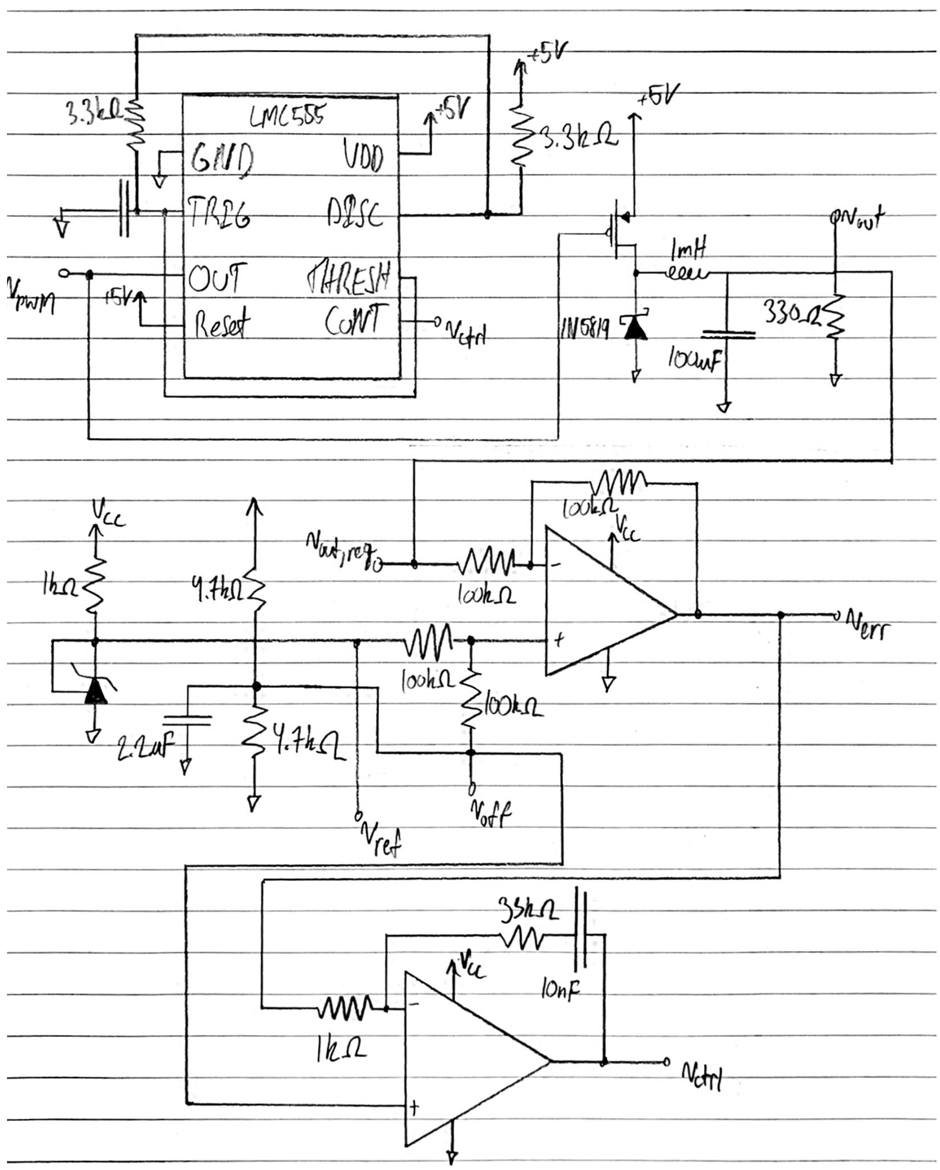
Procedure

First, the circuit shown below in figure 6 was constructed. Notice the buck converter and amplifier that was constructed in the previous two tasks.

FIGURE 6



Closed loop buck regulator controller

Next V_{cc} was swept from 4V to 5V, and V_{out} and V_{ctrl} were measured and plotted. This was done in order to distinguish a relationship between the variables.

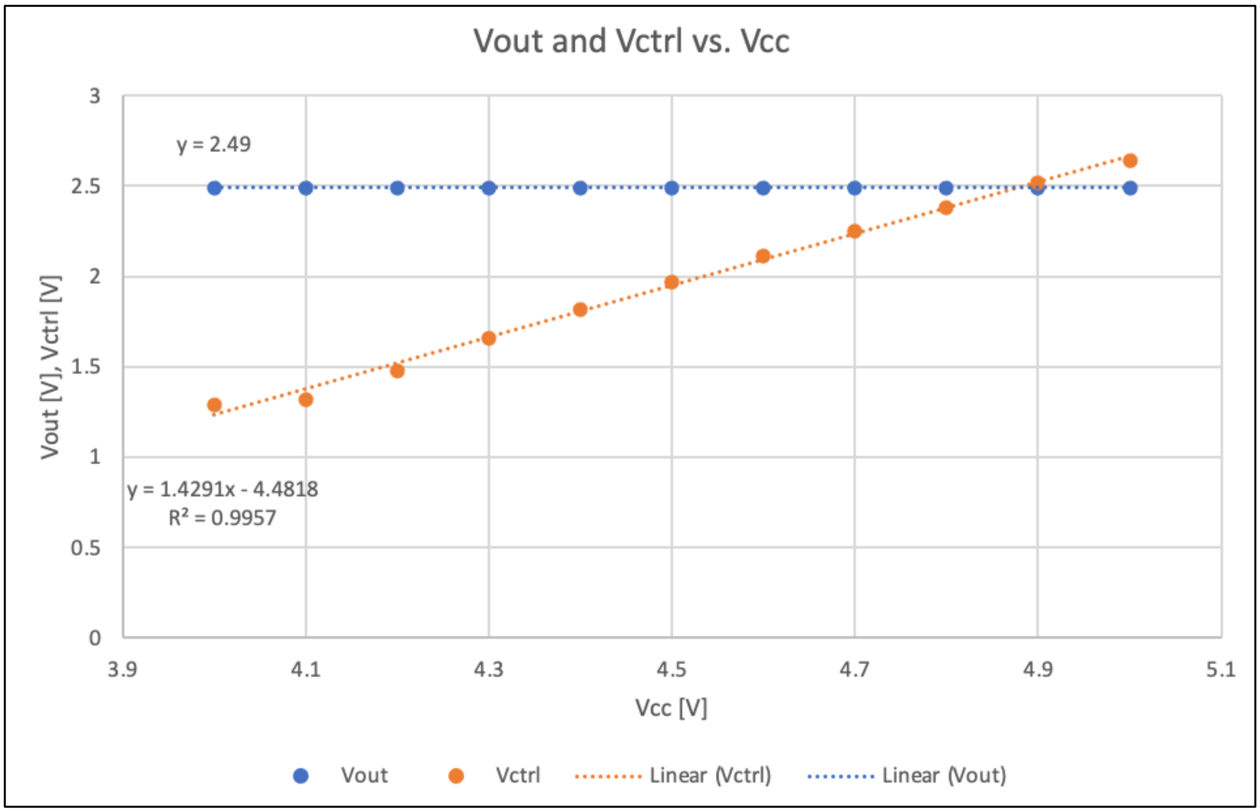
In order to see the closed loop control system in action, the next step captured V_{out} and V_{ctrl} during the startup sequence of the system.

Lastly, different elements of the system were swapped out in order to determine whether their specific values impacted the system. R_L was changed from 330 ohms to 150 ohms, and the 33K ohm resistor in the PI controller was changed to 2.2K ohms.

Results/Calculations

The results of sweeping V_{cc} from 4V to 5V are shown below in figure 7, where the values of V_{out} and V_{ctrl} are shown at each step.

FIGURE 7



Plot of Vout and Vctrl vs. Vcc as it is swept from 4V to 5V

Here, we can see that V_{out} stays at a consistent 2.49V no matter the voltage of V_{cc}. This means that V_{out} is independent of V_{cc}. This is because V_{ctrl} adjusts linearly as V_{cc} changes, which then drives the duty cycle higher or lower, depending on if the change in V_{cc} is higher or lower respectively.

Next, let's take a look at the boot up sequence of the circuit. Shown below in figure 8, we can see that both V_{out} and V_{ctrl} start at zero and adjust to their expected values when V_{cc} is at 5V.

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FIGURE 8

Boot up sequence of the circuit. Note the orange channel is Vout and the blue circuit is Vctrl

Here we see that both signals start at 0V, and then V_{ctrl} spikes and then adjusts for the value of V_{out}. V_{ctrl} then stays low, waiting for V_{out} to charge to 2.5V. Once V_{out} hits 2.5V and then goes slightly above, V_{ctrl} spikes in order to compensate for overshooting the desired target of 2.5V. We then see V_{ctrl} oscillate a bit, before V_{out} settles at 2.5V, and then both voltages are constant. Notice that this process happens in under 30ms, which is incredibly fast!

When changing R_L from 330 ohms to 150 ohms, we notice V_{ctrl} oscillates at a higher frequency and does not exactly settle. This phenomenon is shown below in figure 9.

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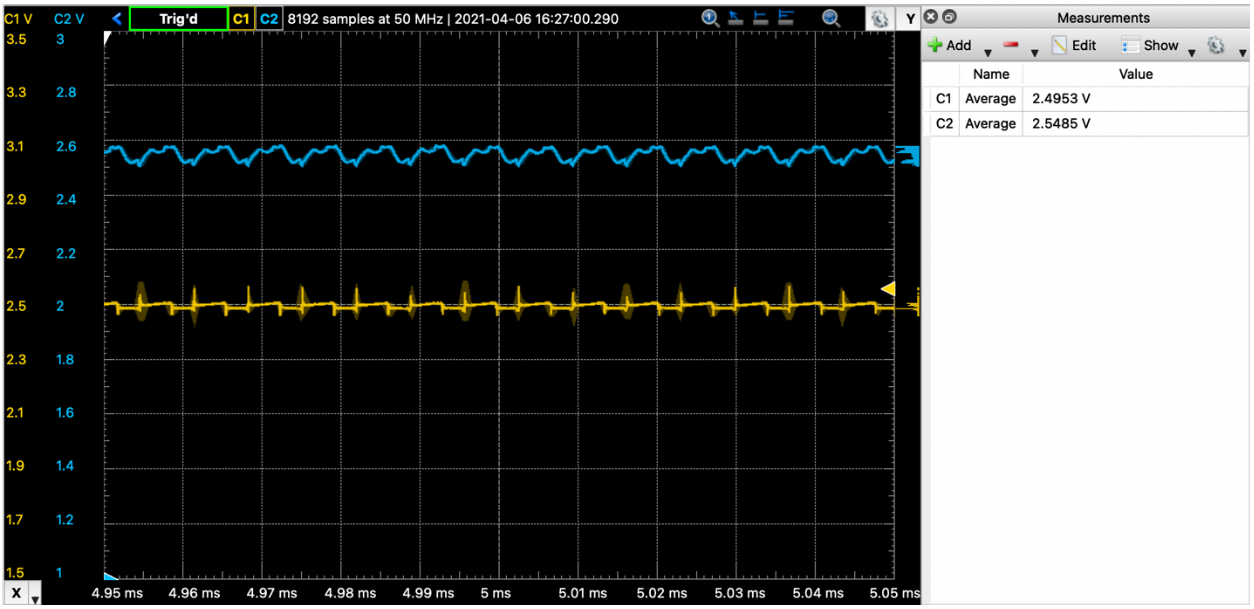
FIGURE 9



Oscillation of Vctrl when RL = 150 ohms

Here we see that V_{ctrl} oscillates, as it cannot settle on an exact value. This may be due to the fact that more current flows through R_L and therefore makes the exact voltage of V_{out} harder to control. In order to compensate for these faster changes, a smaller capacitor in the PI circuit would need to be used. We also notice that V_{ctrl}'s average value is now 2.5485V, which is a small change from 2.6482V when R_L is 330 ohms. This means that V_{ctrl} and R_L have a positive linear relationship.

Lastly, we can take a look at what happens to V_{ctrl} and V_{out} when we change the PI resistor from 33K ohms to 2.2K ohms.

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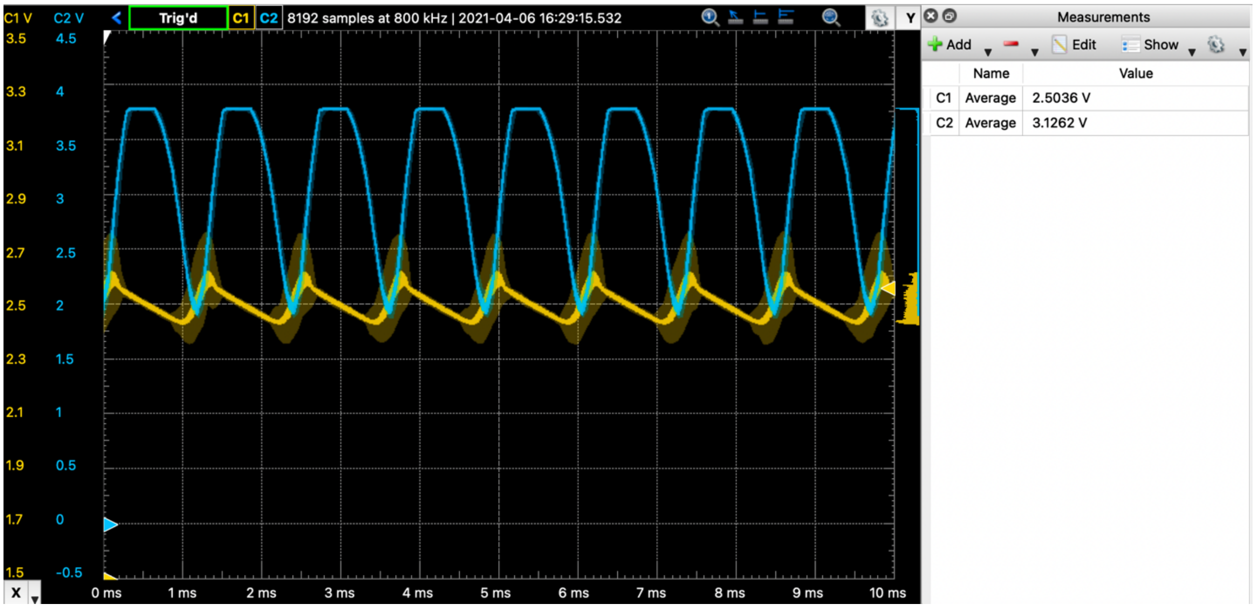
FIGURE 10



Oscillation that happens when the PI circuit does not have the right values for components. Note Vout is blue and Vctrl is orange

Here, we notice that V_{out}, although averaging at 2.5V, oscillates between 2V and 3.75V which means the power supply is not working correctly. This is because the PI circuit is not correctly implemented with the correct values. Because the PI circuit is not compensating correctly for incorrect output voltages, it oscillates infinitely and will never provide a stable 2.5V output.

Conclusions

This task was successful because we were able to accurately construct and measure characteristics of the circuit. We determined that V_{out} is able to maintain a stable voltage around 2.5V no matter the value of V_{cc}, so long as it lies between 4V and 5V. We also determined that changing R_L also changes the value of V_{ctrl} as they are positively related. Lastly, we were able to see what the output of V_{out} and V_{ctrl} look like when the PI circuit is not correctly implemented, such as having a resistor or capacitor with the wrong value.