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4/2/18

CE 3101 Lab Experiment 4

Abstract

In the field of consumer digital electronics, circuits that convert high AC voltage into a much lower DC voltage are essential. These types of devices can be found nearly anywhere where a digital logic circuit is used. In most scenarios, a converter can just be bought which will allow a DC electronic circuit to work, but building an AC to DC converter provides an invaluable experience that helps broaden understanding of electronics, while providing insight into the history of the consumer electronics industry. The AC to DC converter is made up of several different components that each satisfy a unique portion of the design. A transformer first steps down the voltage from the wall socket to a value much closer to the desired DC voltage. After the step down, the AC signal is then rectified so that it provides power during both the positive and negative portions of the sinusoidal signal. Next, a filter capacitor is used to hold the voltage at a near-constant value, allowing for a small amount of ripple voltage. Finally, a regulator is used to hold the DC voltage output constant, regardless of current pull and environmental thermal characteristics.

In this lab, the goal was to build the circuit described above. To do so, the transformer, diode rectifier, and filter capacitor portions of the circuit were designed, and then tested in PSPICE to verify correct behavior. Following successful verification of the design, the AC to DC converter was built one stage at a time, starting with the transformer (provided by the MSOE EECS tech department). After successful verification of each stage, the next stage of the design was completed. Note that the regulator was not designed or built in this lab; rather, an IC chip provided by the EECS tech department was used. During the build, different filter capacitors and load resistors were used so that the effects of each could be observed and analyzed. Upon completion of the experiment, an oscilloscope was used to verify correct design and implementation of the converter. Consequently, the lab was concluded to be successful with a high level of confidence in the findings of the experiment.

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Experiment

Design

To provide a constant 5V DC output voltage, with a secondary stepped-down voltage set at 12 VRMS, a ripple of 0.5V, a load resistance of 100 Ω, and diodes modeled after the DB101 full-wave bridge rectifier, the following design was constructed.

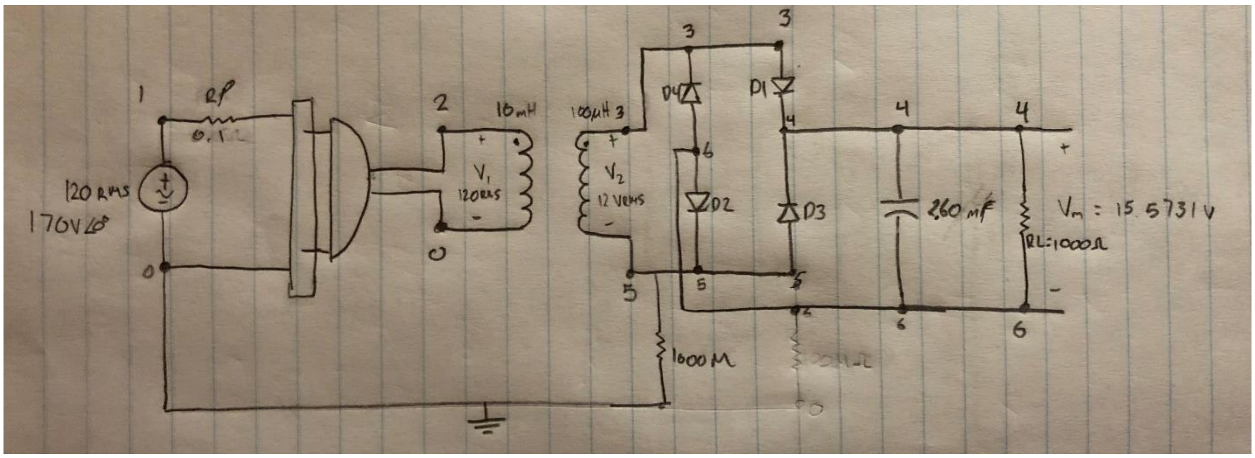

Figure 1 - Design of unregulated 5V power supply

To verify its behavior, it was simulated using PSPICE. The following trace illustrates the simulation results.

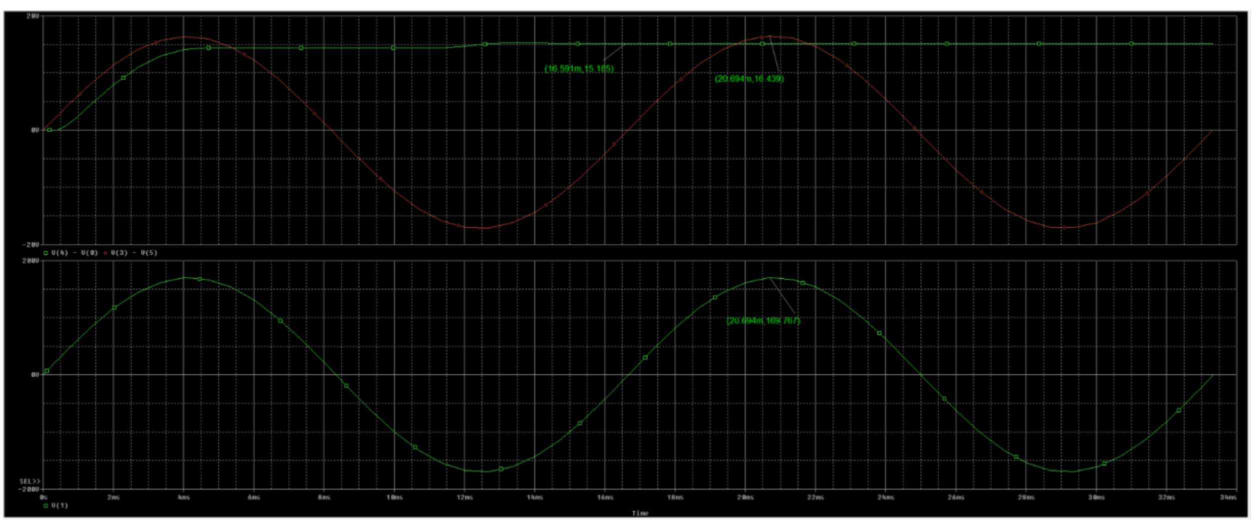

Figure 2 - PSPICE simulation of design circuit.

While the voltage measured across the load resistor (15.185 V) does not match the value derived in the design (15.573 V), it was close enough to provide verification of design. Its important to remember that the diodes and transformer model being used in the PSPICE simulation were only approximations, and do not perfectly model ideal components. With simulation results close to the values expected, and behavior that is consistent with the theoretical behavior of the design, it was declared safe to implement the designed circuit.

Transformer Verification

The first portion of the design implemented was the transformer. Since this was provided by the EECS tech department, only a simple verification of step down voltage was needed. A 10X oscilloscope was used to measure the output of the transformer as it was connected to US main. The transformer was expected to step voltage down to a value near 17 V, but variation was expected.The following image illustrates the findings.

Figure 3 - Oscilloscope view of stepped down voltage.

As expected, voltage was stepped down to a value closer to 17V, with slight variation. In reality, the implemented circuit would need to handle a secondary voltage of 19.8V.

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Full Bridge Rectifier

A full bridge rectifier chip was placed in the circuit implementation next, and its output was measured with the oscilloscope to verify that the secondary voltage was being successfully rectified. An image of the oscilloscope is attached below.

Figure 4 - Oscilloscope view of full bridge rectifier output

The oscilloscope verified that the negative portions of secondary voltage were being rectified so that the full period of secondary voltage was being used. The peak voltage dropped from 19.8V to 19.1V (0.7V) difference after going through rectification.

100 µF Capacitor

Initially, a 100 µf capacitor was used as the filter capacitor in the implemented circuit. This was different from the design, and as a result, a new ripple voltage would occur. This ripple voltage was calculated to be:

$$V_r = \frac{19.1V}{2*60Hz*100\Omega*100\mu F} = 15.92V$$

A 100Ω 5W resistor was added to the circuit so that the ripple voltage could be measured and compared against the calculated value. The results are shown below:

Figure 5 - Oscilloscope capture of ripple voltage with 100 uF filter capacitor.

The results were surprising at first – a ripple of almost 16V was expected, yet the measured ripple was only 7.4V. While this didn't seem to make sense at first glance, the reason for the severe discrepancy was due to the fact that the equation used to calculate ripple voltage only works for small amounts of ripple voltage. The equation used approximates a differential equation, and when the resulting ripple voltage approaches larger values, it begins to break down. If the actual ripple voltage calculation was needed for ripple voltage that large, the differential equation would be necessary, and the linear approximation would be inappropriate. While the ripple voltage was different than expected, the oscilloscope was able to verify that the load was causing a ripple voltage.

The minimum and maximum current experienced by the load resistor due to the ripple voltage were:

$$i_{\min} = \frac{10.6V}{100\Omega} = 106mA$$

$$i_{\max} = \frac{18.0V}{100\Omega} = 180mA$$

The minimum and maximum power experienced by the load resistor due to the ripple voltage were:

$$p_{\min} = 106mA * 10.6V = 1.12W$$

$$p_{\max} = 180mA * 18.0V = 3.24W$$

Actual Filter Capacitor

The filter calculation was redone according to the actual rectified maximum amplitude voltage. This resulted in a filter capacitor of:

$$C_F = \frac{19.1V}{2 * 60Hz * 100\Omega * 0.5V} = 3.18mF$$

With the actual rectified maximum amplitude voltage, the filter capacitor capacitance increased slightly from a design value of 2.60 µF to 3.18µF.

The 100 µF capacitor was replaced with 2 1500 µF capacitors in parallel to approximate the new filter capacitance. This resulted in the following ripple:

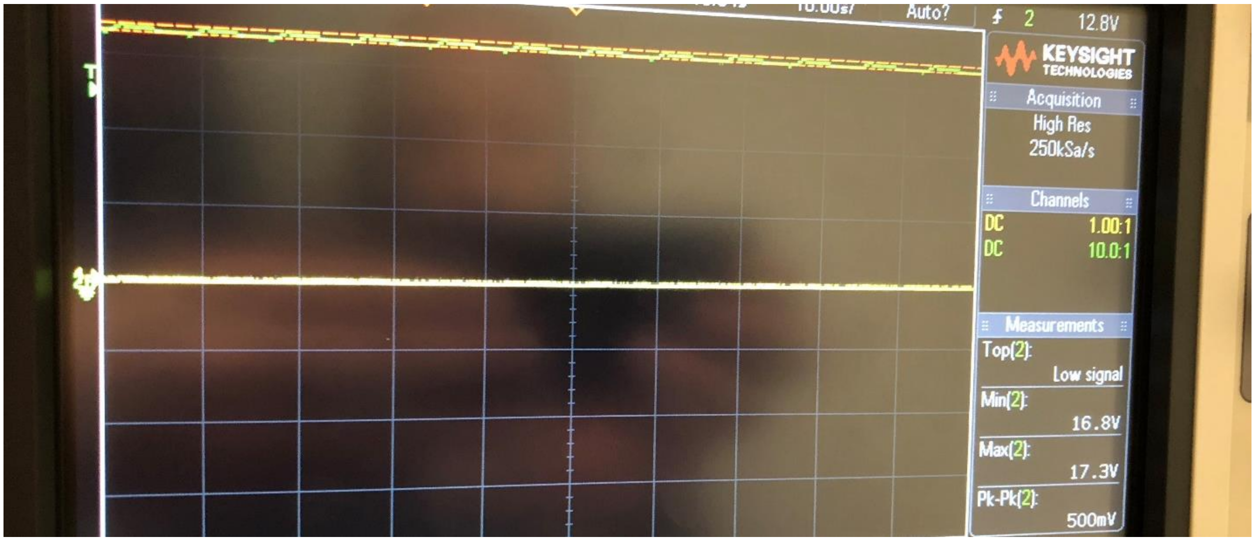

Figure 6 - Oscilloscope capture of ripple voltage for approximation of 3.18 mF capacitor.

When placing an approximation of the correct filter capacitor, a correct ripple voltage of 0.5 V is obtained. With this new ripple voltage,

The minimum and maximum current experienced by the load resistor due to the ripple voltage were:

$$i_{\min} = \frac{16.8V}{100\Omega} = 168mA$$

$$i_{\max} = \frac{17.3V}{100\Omega} = 173mA$$

The minimum and maximum power experienced by the load resistor due to the ripple voltage were:

$$p_{\min} = 168mA * 16.8V = 2.82W$$

$$p_{\max} = 173mA * 17.3V = 2.99W$$

7805 Regulator

Next, the 7805 regulator was placed in the circuit to finish the design. This component was expected to create a constant DC output of 5V. A load resistor was placed in the circuit of 100 Ω, and the following ripple was observed.

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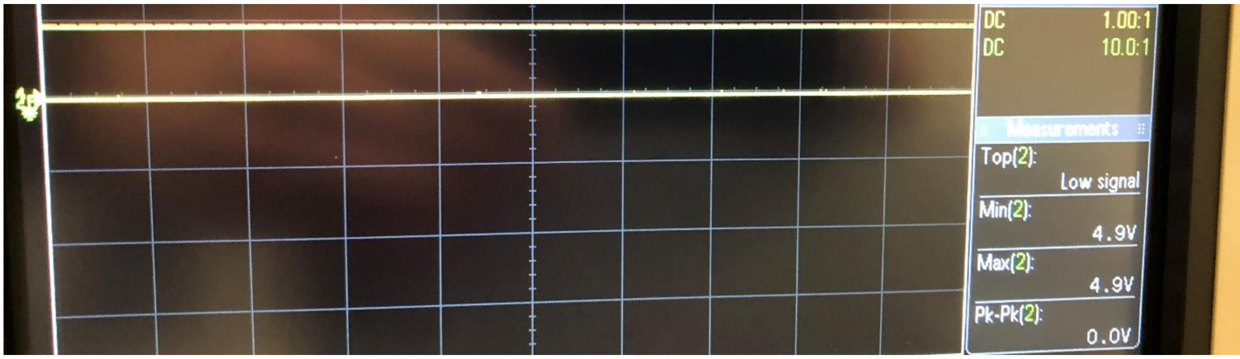

Figure 7 - Oscilloscope capture of regulator output.

As expected, a constant voltage was output from the regulator – the ripple was reduced to the point that the oscilloscope could not read it. Due to this, the load experiences the same minimum and maximum currents and powers. They were calculated to be:

The current experienced by the load resistor due to the ripple voltage were:

$$i_{\min} = \frac{4.9V}{100\Omega} = 49mA$$

The power experienced by the load resistor due to the ripple voltage were:

$$p_{\min} = 49mA * 4.9V = 0.24W$$

An ammeter was inserted into the circuit to verify the calculated current experienced by the load.

Figure 8 - Ammeter measurement for 100 Ohm load.

The current measured from the ammeter was really close to the expected value of 49mA, with minor differences most likely caused by minute differences between ideal components and physical components.

4.7 KΩ Load

To simulate a larger load, the 100 Ω load was swapped with a 4.7 KΩ load and the previous step was repeated. The oscilloscope showed a ripple voltage exactly the same as what was shown in the previous image of the ripple voltage for a 100 Ω load. The larger load did however, lead to a new current and power experienced by the load (again, because of a 0V ripple, the minimum and maximum currents and powers were identical, respectively).

The current experienced by the load resistor due to the ripple voltage were:

$$i_{\min} = \frac{4.9V}{4700\Omega} = 1.0mA$$

The power experienced by the load resistor due to the ripple voltage were:

$$p_{\min} = 1.0mA * 4.9V = 4.9mW$$

Again, an ammeter was inserted into the circuit to verify the current experienced by the load resistor.

Figure 9 - Ammeter measurement for 4700 Ohm load.

Again, just as with the 100 Ω load, the ammeter seemed to verify the calculations made for current experienced by the load. Similar to the 100 Ω load, small differences were observed, but were most likely due to differences between theoretical components and physical components.

Conclusion

In the end, this lab was extremely successful in fortifying theory taught in the classroom. Prior to this lab, only portions of the converter (such as half and full bridge rectifiers) had been implemented in lab, and most theory had only been simulated in PSPICE. While that provided a good theoretical understanding of the material, physical implementation of circuits usually deviates slightly from design. This is something that never happens in simulation, since components are typically modeled to a point that they appear almost as ideal. In this lab experiment however, design sacrifices had to be made, and this lab experiment helped teach how they can, and should be made. Additionally, it was helpful designing the full AC to DC converted step by step, verifying behavior at each point. Due to this, as well as the results of the circuit implementation, it would be reasonable to declare this experiment a success.