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CECS 311 Section 01
Lab 2
Due 2020-03-12

Introduction

In this lab, we were tasked with creating a 5 V DC power source from a 120 V AC mains power source. This feat involves many steps to accomplish, as 120 V AC and 5 V DC are very different. First, it was necessary to use a step-down transformer in order to convert the 120 V into something that is usable and won't fry our electronics. Second, it was necessary to rectify the voltage waveform from the transformer into a waveform that only deals with positive voltage, as all digital circuits rely on a steady, unchanging positive voltage to be able to function. Next, a capacitor is added in parallel in order to smooth the waveform to something resembling DC voltage. Lastly, a voltage regulator (specifically the 7805) was used in order to give the voltage an even straighter curve.

This lab was a mix of simulation and physical implementation. The results are detailed below.

1 AC Voltage Setup

The first step was to set up the simulator (LTspice IV) in order to accurately simulate the physical circuit that we would be making in the future. This involves setting up the main voltage source to act as mains power, or power that comes out of an outlet. This is defined as 120 V_{RMS} AC at 60 Hz with a series resistance of 100 µΩ. Below is a screenshot of the output.

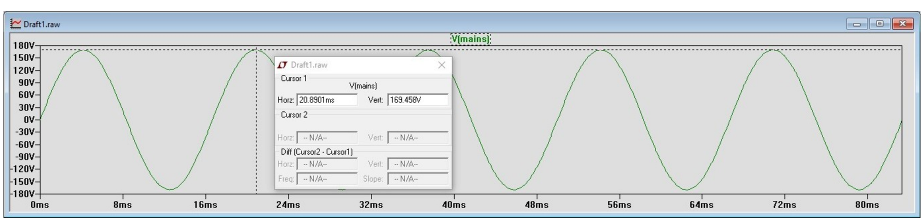

Figure 1: 120 V AC output.

2 Transformer Measurement

To measure the output of the transformer, we used an oscilloscope, which displays measured voltage with respect to time. Below is a picture of the output gotten from measuring the transformer.

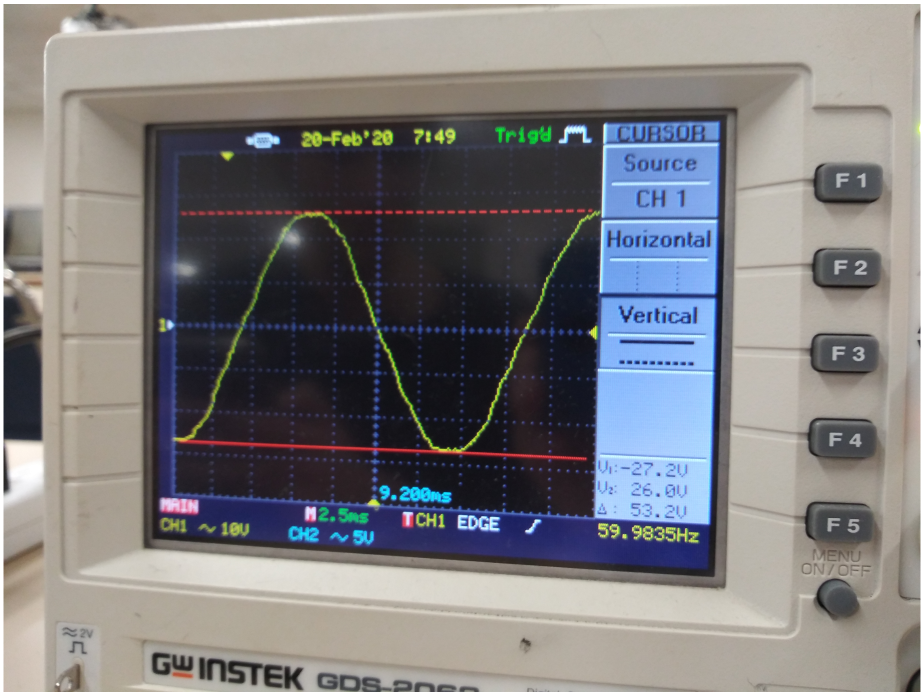

Figure 2: Transformer output.

The peak–peak measurement of this output is 53.2 V, and therefore the peak measure is 53.2 V/2 = 26.6 V. Therefore, the expected turns ratio of the transformer is given by

$$r = \frac{V_p}{V_s} = \frac{170\,\mathrm{V}}{26.6\,\mathrm{V}} \approx 6.4 : 1$$

3 Transformer Modeling

The next step is to model our given transformer in the simulator. Since the turns ratio of the transformer is 6.4 : 1, it is tempting to give the values 64 µH and 10 µH to the primary and secondary windings inductors, respectively. However, doing this gives an unexpected result: when the peak values for the primary and secondary windings are measured, they give approximately 169.17 V and 66.8702 V, respectively, giving a turns ratio of 169.17 V/66.8702 V ≈ 2.53 : 1, which is not our desired result. It is also evident that this result is incorrect because the output of the transformer is 26.6 V, but the simulation outputted a value much higher than this of 66.8702 V. There is a difference in peak voltage of −40.2702 V and a difference in peak–peak voltage of −80.5404 V.

It turns out that the relationship between the ratio of the primary and secondary voltages and the primary and secondary inductance values are given by the following equation:

$$\frac{V_p}{V_s} = \sqrt{\frac{L_p}{L_s}} \Rightarrow \frac{L_p}{L_s} = \left(\frac{V_p}{V_s}\right)^2 \tag{1}$$

where V_p is the voltage applied to the primary windings, V_s is the voltage induced by the secondary windings, L_p is the amount of inductance of the primary windings (in henries), and L_s is the amount of inductance of the secondary windings (in henries).

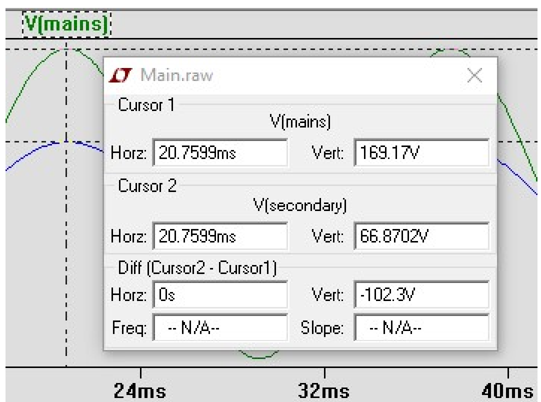

Figure 3: Test 1 of transformer. Incorrect results.

This means that to get our turns ratio, we must square our desired voltage ratio of 6.4 : 1 giving a turns ratio of $L_p/L_s = (6.4 : 1)^2 = 40.96 : 1$. Using values of $(L_p, L_s) = (4096\,\mu\text{H}, 100\,\mu\text{H})$, we achieve an output of 26.5264 V.

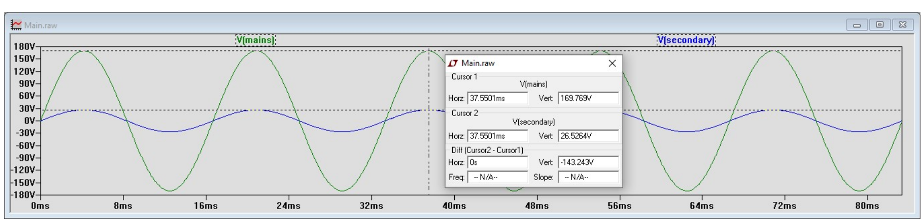

Figure 4: Test 2 of transformer. Correct results.

4 Full-Wave Bridge Rectifier Simulation

In order to get current to only flow in one direction, it is necessary to construct a full-wave bridge rectifier. This is done by placing four diodes in the circuit in a clever manner such that the voltage outputted by the diodes is only positive as opposed to the positive and negative sine wave that is outputted by the AC power source. In this example, we will be using `1N4001` rectifier diodes. Adding the bridge circuit to the output of the transformer in Section 3 and a 100 Ω load resistor to the output of the bridge circuit, we have the following:

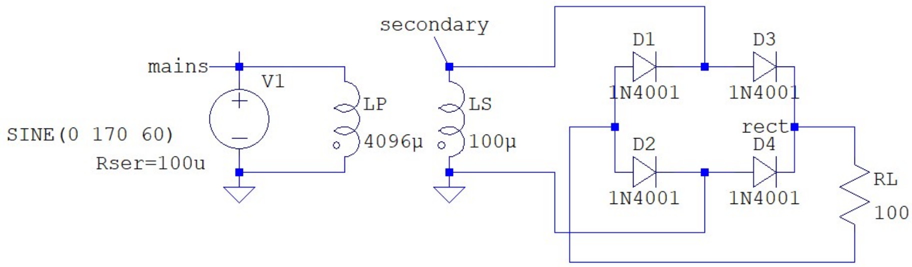

Figure 5: Full-wave bridge rectifier circuit.

The following is the output of this circuit with `V(mains)` and `V(secondary)` as reference.

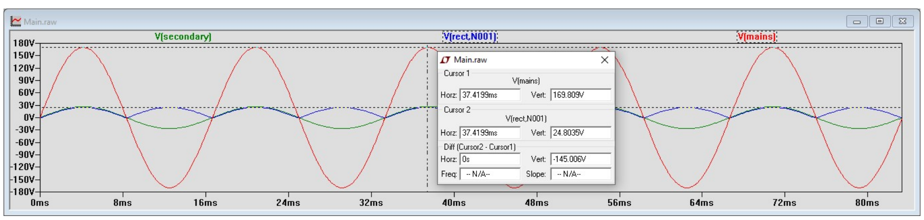

Figure 6: Full-wave bridge rectifier circuit output.

From Figure 4, the peak output of the secondary windings is 26.5264 V. The peak output of the full-wave bridge rectifier is 24.8035 V. This value is reasonable because the theoretical peak voltage of the rectifier is

$$V_{\text{rect},P} = V_{\text{in},P} - 1.4\,\text{V}$$

where $V_{\text{rect},P}$ is the peak voltage of the rectifier, $V_{\text{in},P}$ is the peak voltage of the input to the rectifier (in this case the secondary windings of the transformer), and 1.4 V is double the forward voltage of a silicon diode—this is because the current has to go through two diodes on both alternations of AC. Plugging in $V_{\text{in},P} = 26.5264\,\text{V}$, $V_{\text{rect},P} = 24.1264\,\text{V}$, which is close to the measured value of 24.8035 V from Figure 6.

The frequency of the secondary windings is the same as the frequency of the primary windings and therefore the same as mains power, which is by definition 60 Hz. This is because all a transformer does is reduce the peak–peak voltage, and does not affect the frequency of the sine wave. This can be seen in Figure 4.

The frequency of the output of the full-wave bridge rectifier, however, is double that of the frequency of the secondary windings at 120 Hz. This is because the rectifier has two periods in the time it takes for the secondary windings to have one.

5 Physical Full-Wave Bridge Rectifier

The circuit above was recreated physically using `1N4001` diodes and the given transformer. Below is the oscilloscope measurement of the circuit.

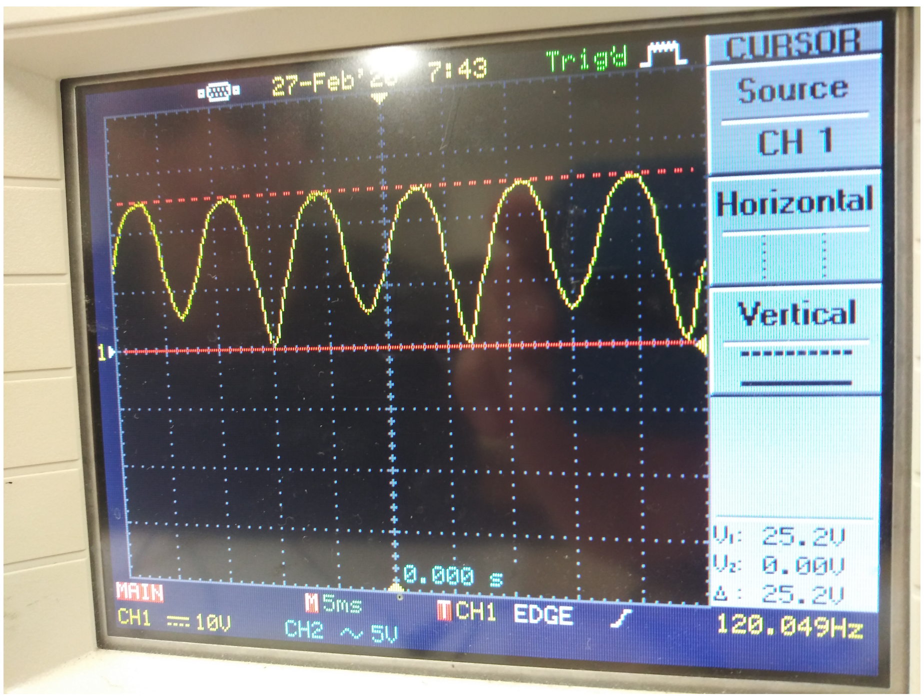

Figure 7: Oscilloscope output from full-wave bridge rectifier.

There is a small problem with the output of this circuit, and that is that half of the periods do not touch 0 V. This is likely due to a problem with the transformer, but if this flaw is ignored, then the output looks exactly like the simulated output in Figure 6; that is, the signal bounces up and down without going into the negative voltage region.

As it can be seen in the measurement of the oscilloscope output, the measured frequency of the rectifier is 120.049 Hz, which corroborates with the calculated and expected 120 Hz. The peak voltage of this circuit is 25.2 V, which is close to the expected 24.8025 V measured in Figure 6. In this case, the peak voltage is the same as the peak–peak voltage because the signal does not dip down below 0 V.

For comparison's sake, the oscilloscope output from Figure 2 of the secondary windings are compiled here. The measured frequency is 59.9835 Hz, close to the expected 60 Hz. the peak–peak voltage is 53.2 V, which makes the peak voltage $53.2\,\text{V}/2 = 26.6\,\text{V}$.

6 Adding a Capacitor

To smooth out the waveform to something resembling DC voltage, it is necessary to add a capacitor in parallel. Doing so will make a flatter curve. Below is the output of the voltage across a 100 Ω load resistor with a 2200 µF capacitor in parallel with it.

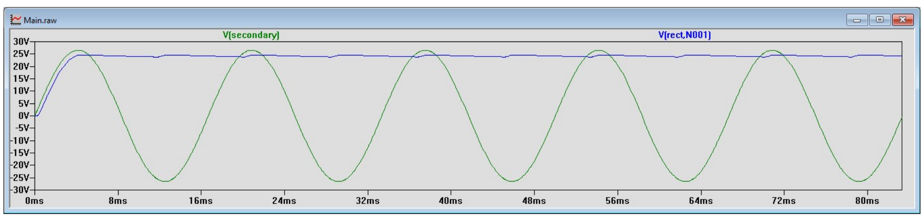

Figure 8: Output with capacitor in parallel.

As it is evident, the signal is not exactly a straight line. The highest voltage is 24.5654 V and the lowest voltage is 23.9123 V, which makes the ripple voltage $V_{\text{ripple}} = 24.5654\,\text{V} - 23.9123\,\text{V} = 653.1\,\text{mV}$. The ripple voltage is given by

$$V_{\text{rip}} = \frac{I}{2fC} = \frac{V_p}{2fRC}$$

where I is the current going through the load resistance, f is the frequency of the input voltage, C is the capacitance of the capacitor in parallel with the load resistance, V_p is the peak input voltage, and R is the resistance of the load resistor. Inputting the known values for the right side of the equation, we have the following:

$$V_{\text{rip}} = \frac{V_p}{2fRC} = \frac{26.2\,\text{V}}{2 \cdot 100\,\Omega \cdot 2200\,\text{mF}} \approx 992.4\,\text{mV}$$

There is a 339.3 mV difference between the calculated value and the measured value, which is a 34.2% error.

7 Adding a Capacitor (Physical)