Creating I-V Curves and Load Line Calculation

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EE2002 Lab 003

March 6, 2006

Abstract

As an introduction to non-linear circuit devices, the electrical properties of both an incandescent lamp and silicon diode are investigated. Using a load-line analysis, the operating current is calculated and verified for the lamp. The silicon diodes are used in a variety of arrangements to produce different clipping circuits.

1 Introduction

In the world of electric circuit analysis, linear devices are wonderful. They permit the use of many important solution methods, such as Kirchhoff's two laws, the node-voltage and mesh-current methods, and the super-positioning principle. A system of linear devices is so well-behaved that man circuits can be reduced down to a Thevenin or Norton equivalent circuit, greatly simplifying subsequent calculations. Unfortunately, many common devices are classified as 'non-linear' devices. Unless simplifying assumptions are made, circuits involving these non-linear devices are much more difficult to analyze. For simple non-linear circuits, such as a light bulb or LED circuit, we can use a method known as 'load-line' analysis to find the circuit's operating parameters. For other non-linear devices, such as a silicon diode, we can use a function generator and oscilloscope to observe a circuit's effect on an input signal. Using the special, non-linear properties of these diodes, a number of interesting modifications can be performed on a signal, mostly in the way of clipping the input voltage at a specific level.

2 Experiments

2.1 Current Versus Voltage Relationship

The first step in conducting a load-line analysis is to obtain the raw current versus voltage relationship for the device in question, here, an incandescent lamp. The circuit was constructed as such:

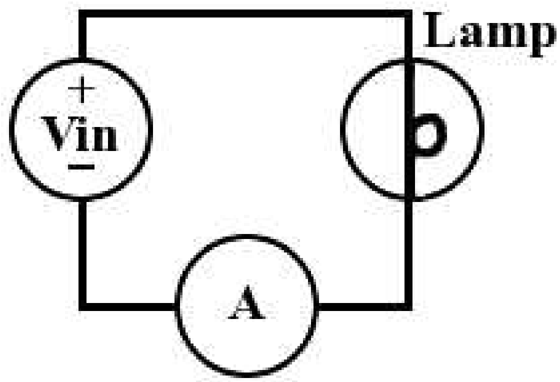
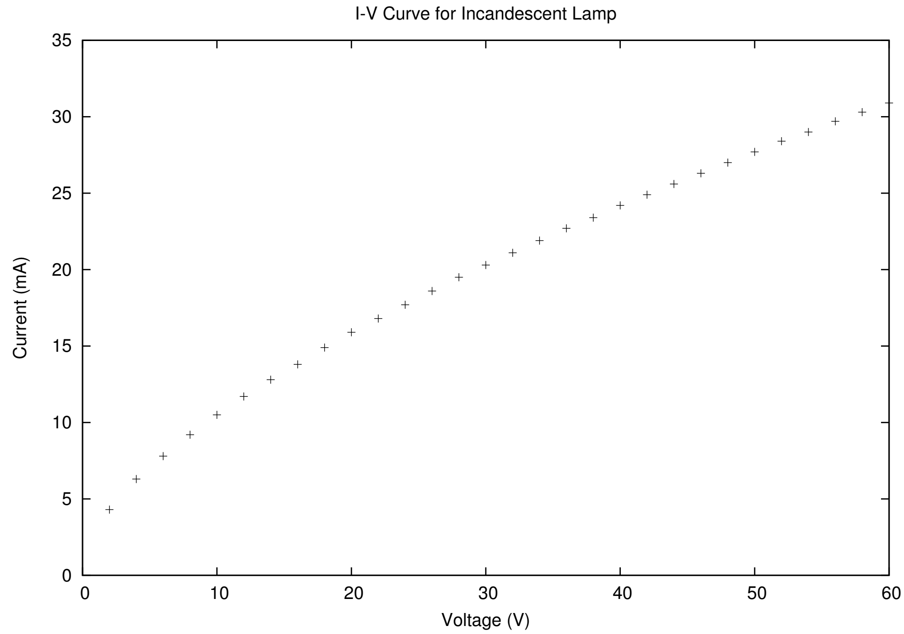


Figure 1: Circuit Schematic - Experiment 1

The voltage was varied in two volt increments between 2 and 60 volts. The measured current is summarized in the following table:

Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
2	4.3	32	21.1
4	6.3	34	21.9
6	7.8	36	22.7
8	9.2	38	23.4
10	10.5	40	24.2
12	11.7	42	24.9
14	12.8	44	25.6
16	13.8	46	26.3
18	14.9	48	27.0
20	15.9	50	27.7
22	16.8	52	28.4
24	17.7	54	29.0
26	18.6	56	29.7
28	19.5	58	30.3
30	20.3	60	30.9

A chart of the previous data is useful to observe the behavior of the device in response to various input voltages, and is included on the next page of this document. The current values appear to be levelling-off as the voltage continues to increase linearly. If this trend continues, the device will reach an upper-limit to the current it will allow. This chart is very important in calculating the load-line operating current and voltage. This is calculated in the next section.



2.2 Calculate Load-Line Operation

Using the data collected in the first part of this experiment, we will now calculate the load-line parameters for a lamp-resistor circuit. Here is a schematic drawing of the circuit:

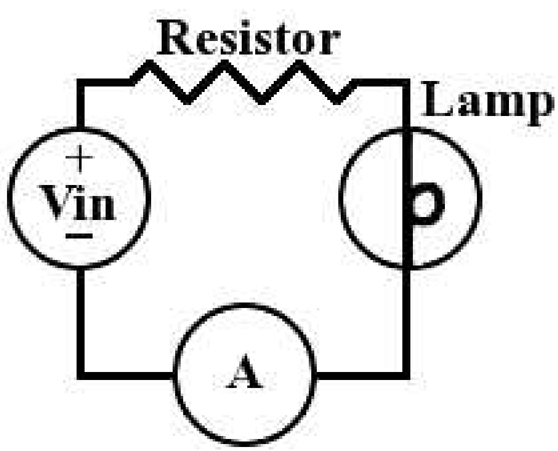
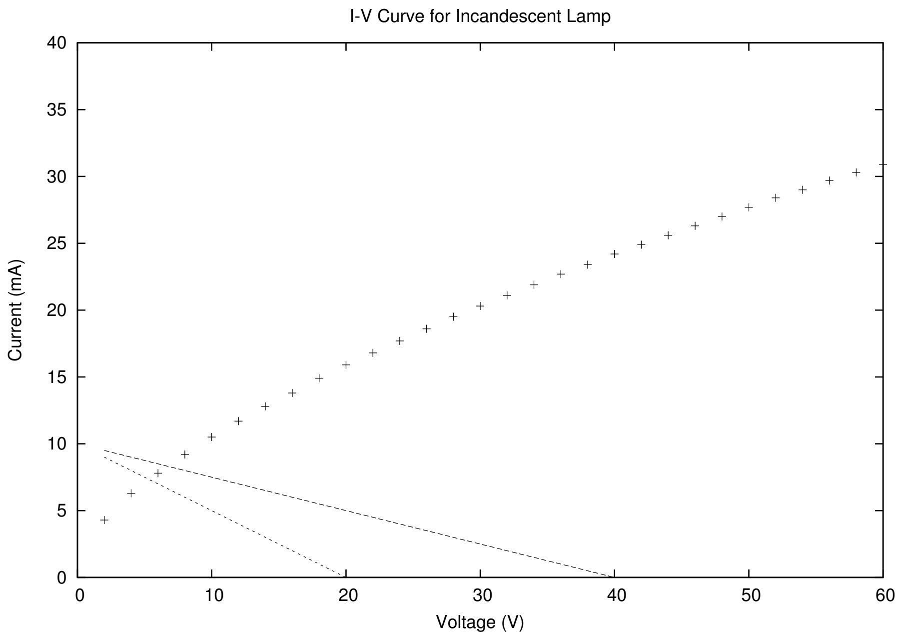


Figure 2: Circuit Schematic - Experiment 2

We are using two sets of resistance/voltage pairings for this part of the experiment. The two settings are:

Voltage	Resistance (Ω)
40.0	4,000
20.0	2,000

To find the load lines for each case, we need to find the maximum voltage, and the maximum current. For the 40V/4000Ω case, the maximum voltage is 40.0 volts, and the maximum current is 10mA. For the 20V/2000Ω case, the maximum voltage is 20.0 volts, and the maximum current is again 10mA. We draw two lines connection these points on the previous I-V characteristic chart, to produce:



In this previous chart, the upper, dashed line is the line for 40V/4000Ω, and the lower, dashed line is for 20V/2000Ω. The intersection of each of these lines with the I-V characteristic of the incandescent bulb predicts the operating point of each of these circuits. The results are summarized in this table:

Voltage (V)	Resistance (Ω)	Operating Voltage (V)	Operating Current (mA)
40.0	4,000	6.87	8.23
20.0	2,000	5.38	7.31

These calculations and predictions will be confirmed in the next section.

2.3 Verification of Load-Line Calculations

After construction the circuit according to the schematic in the previous section, we have measured the actual current passing through the circuit at the aforementioned voltages. The results are summarized in this table:

Circuit	Calculated		Measured		Error
	Voltage	Current	Voltage	Current	
40V 4,000Ω	6.87V	8.23mA	6.92V	8.31mA	0.84%
20V 2,000Ω	5.38V	7.31mA	5.43V	7.38mA	0.93%

The error was calculated as the arithmetic mean of the standard errors of the voltages and currents:

$$error = \frac{\left(\frac{V_{calc}+V_{exp}}{V_{exp}}\right) + \left(\frac{I_{calc}+I_{exp}}{I_{exp}}\right)}{2}$$

2.4 Silicon Diode Introduction

In this section, we constructed a circuit with the following schematic:

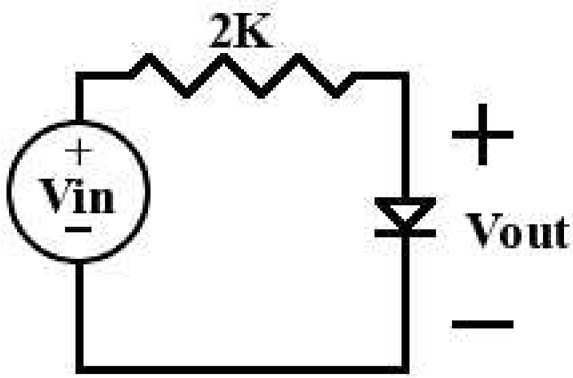


Figure 3: Circuit Schematic - Experiment 4

We utilized the function generator and oscilloscope to observe the changes this circuit produced on various input signals. For this part of the lab, we used a sine wave input signal. In the oscilloscope traces that follow in this document, the original, unmodified input signal is displayed on channel one, and the output from the circuit is displayed on channel two. In all cases, the original waveform can be identified easily, because the other waveform is obviously deformed by the circuit. Here, the input sine wave is being clipped when the positive voltage exceeds approximately 0.6 volts. This voltage is known as the diode's threshold voltage, which is the point in the I-V curve where the diode transitions from nearly infinite resistance to nearly zero resistance When the threshold voltage is reached in the forward direction across a diode of this type, the voltage across the diode will remain at the threshold voltage. In this circuit, when the input sine wave becomes greater than 0.6 volts, the diode enters into the 'active' region of operation, and behaves like a short circuit with a 0.6 volt drop across it.

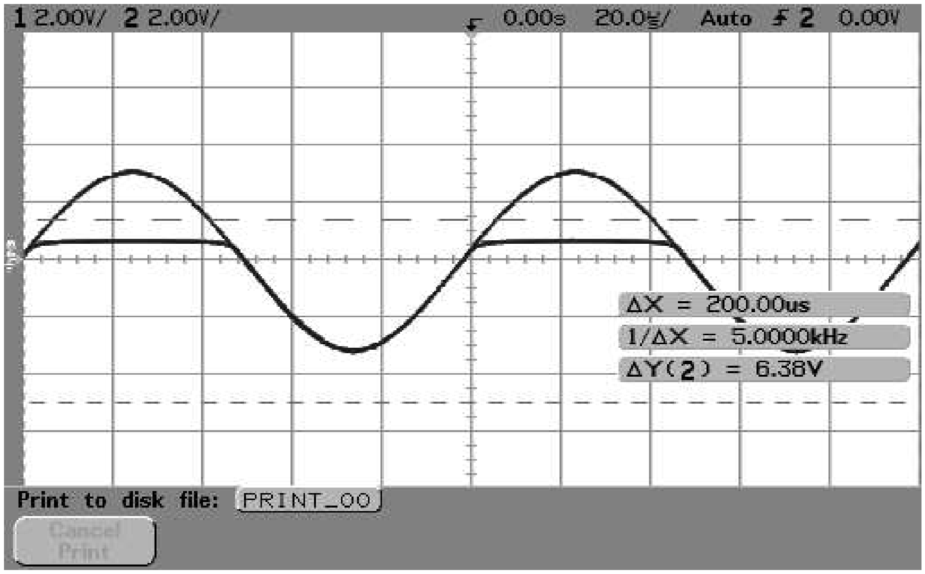


Figure 4: Oscilloscope Trace - Exp. 4: Clipping at 0.6 Volts

2.5 Clipping Negative Voltages

In this section, we are required to clip the input waveform at negative voltage. This can be easily accomplished by reversing the orientation of the diode. Now, when the input waveform is less than negative 0.6 volts, the diode will transition into the active mode operation region, and will conduct. The circuit schematic and oscilloscope trace are included here:

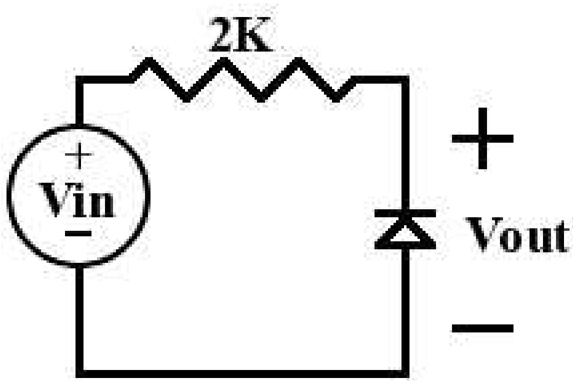


Figure 5: Circuit Schematic - Experiment 5

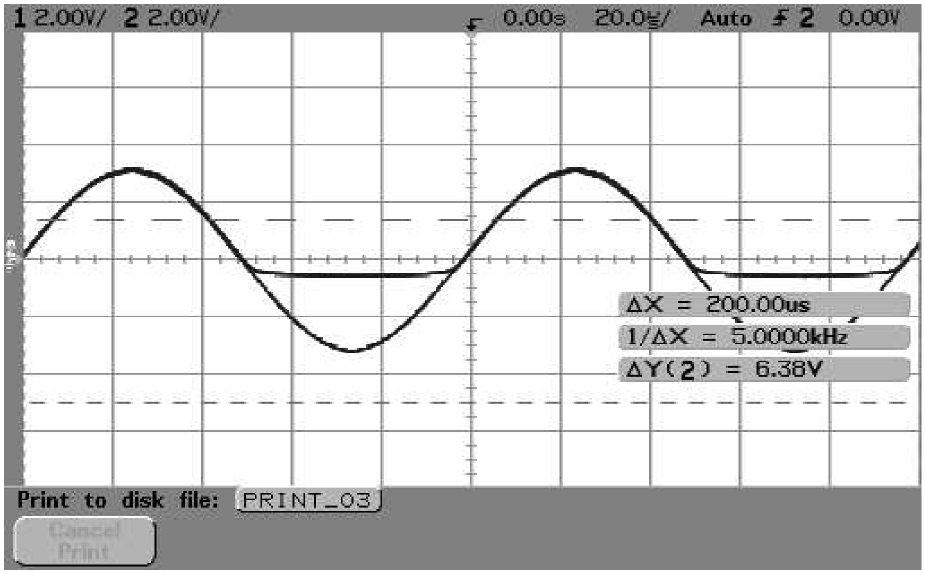


Figure 6: Oscilloscope Trace - Exp. 5: Clipping at -0.6 Volts

2.6 Clipping at 2 Volts

The 0.6 voltage used for clipping in the previous experiments was not chosen by anybody. It is rather a feature of the particular diodes we are using. To change the clipping voltages while using the same equipment requires a little creativity. To clip the input waveform at 2 volts instead of 0.6 volts requires us to put three diodes in series together. This will require a total voltage of approximately 1.8-2.1 volts to start all three diodes conducting. The circuit schematic and oscilloscope trace are included here.

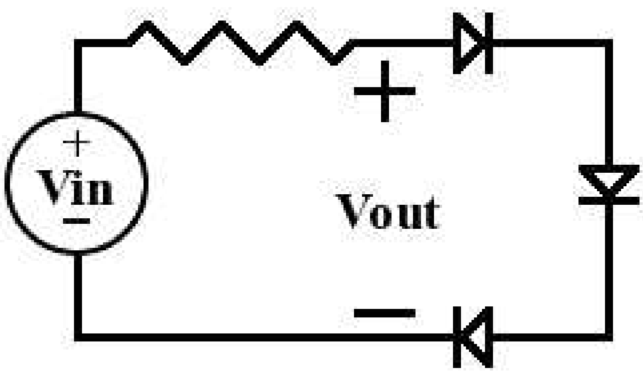


Figure 7: Circuit Schematic - Experiment 6

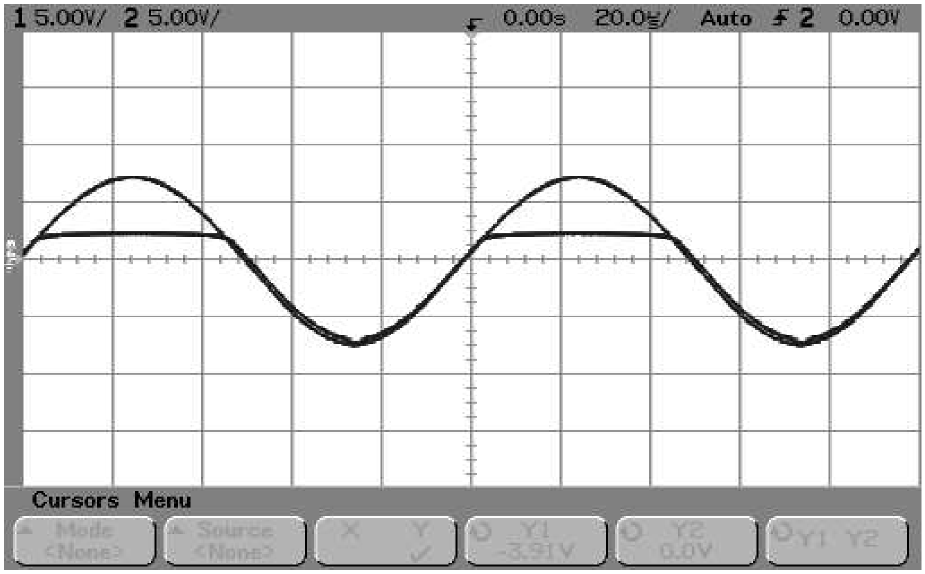


Figure 8: Oscilloscope Trace - Exp. 6: Clipping at +2 Volts

2.7 Clipping at ±2 Volts

In order to produce two clipping voltages, one negative and one positive, we have to add another path for the voltage to be clipped. Since we are still working with 2 volt clipping, we need three resistors in each path. If we connect one chain of diodes biased in on direction, say downward, and bias the other chain of diodes in the other direction, upwards, then the input waveform will be clipped if it exceeds either ±2 volts.

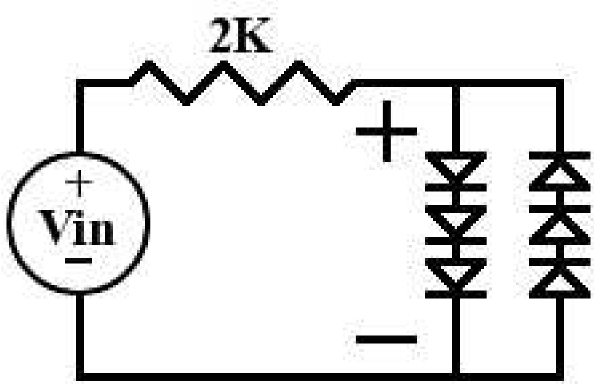


Figure 9: Circuit Schematic - Experiment 7

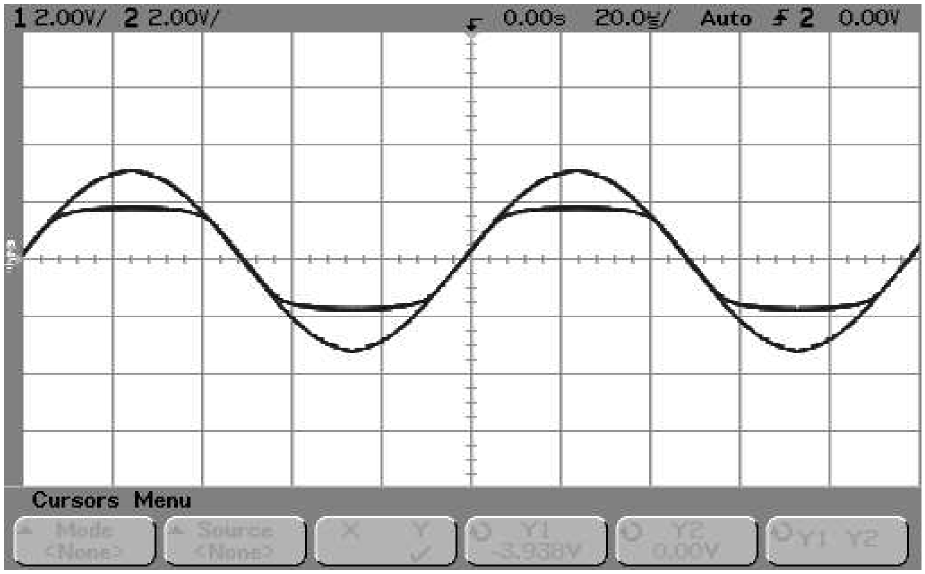


Figure 10: Oscilloscope Trace - Exp. 7: Clipping at ±2 Volts

2.8 Various Input Waveforms

For the remainder of the experiment, we applied various waveforms to the ±2 volt clipping circuit used first in section 7. The results are presented in a series of oscilloscope traces. The first waveform was a large amplitude sine wave. You can clearly see the cutoff caused by the diodes. The second waveform was from a square wave with a duty-cycle of approximately 20%. Again, you can see the cutoff region from the diodes. The third waveform was from a triangle wave with 50% duty. It is interesting to notice how the diodes create a crude sinewave from the triangle wave. The fourth waveform was created with a specialized saw-tooth waveform generator created in conjunction with another electrical engineering course dealing with microcontrollers. I created a rudimentary waveform generator with my microcontroller, and I happened to have it on hand when testing this part of the experiment. It produces a saw-tooth waveform, which is clipped just the same as any other waveform.

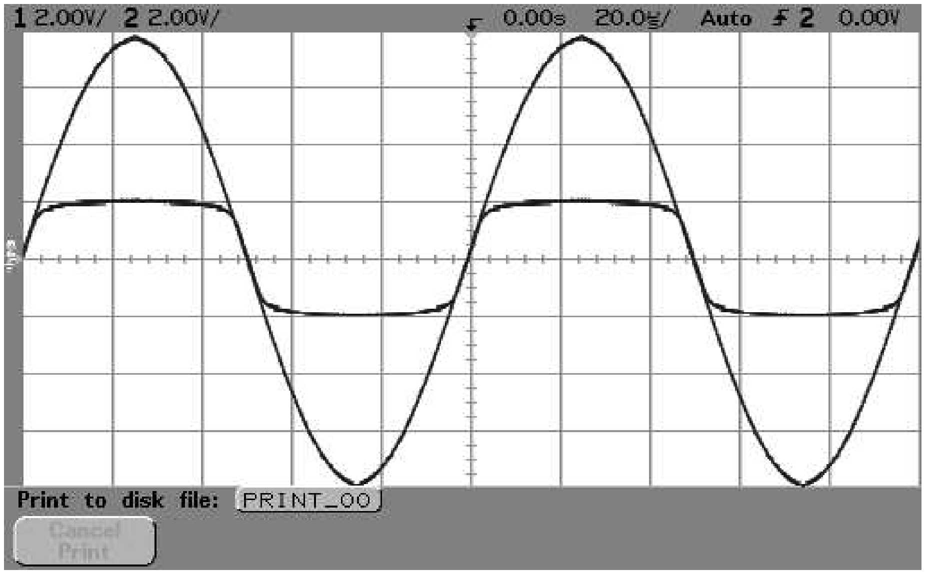


Figure 11: Oscilloscope Trace - Exp. 8: Large Sine Waveform

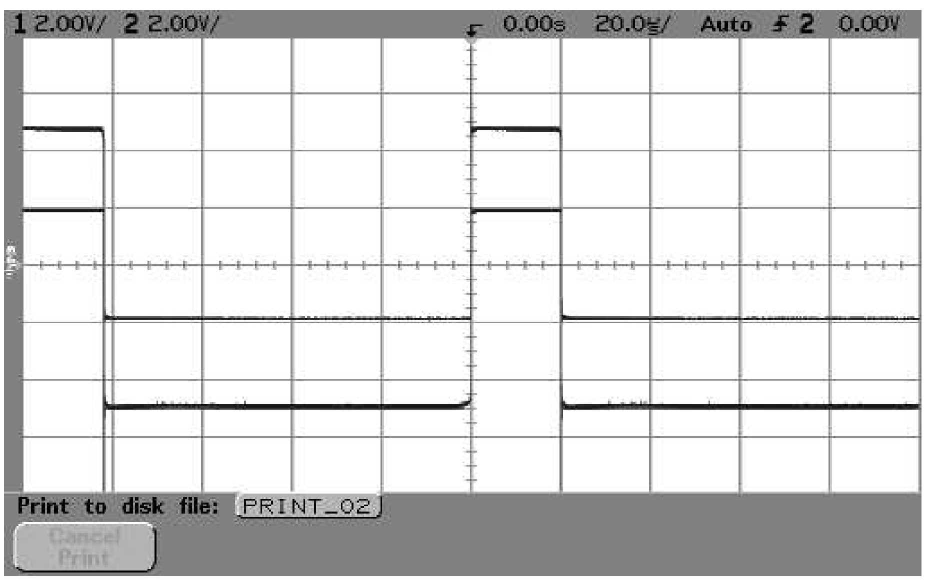


Figure 12: Oscilloscope Trace - Exp. 8: Square Waveform

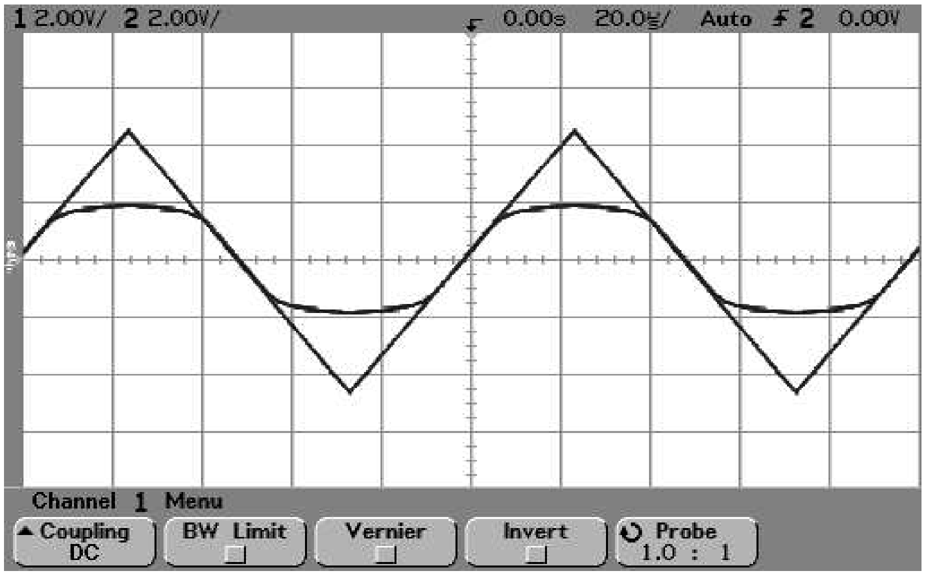


Figure 13: Oscilloscope Trace - Exp. 8: Triangle Waveform

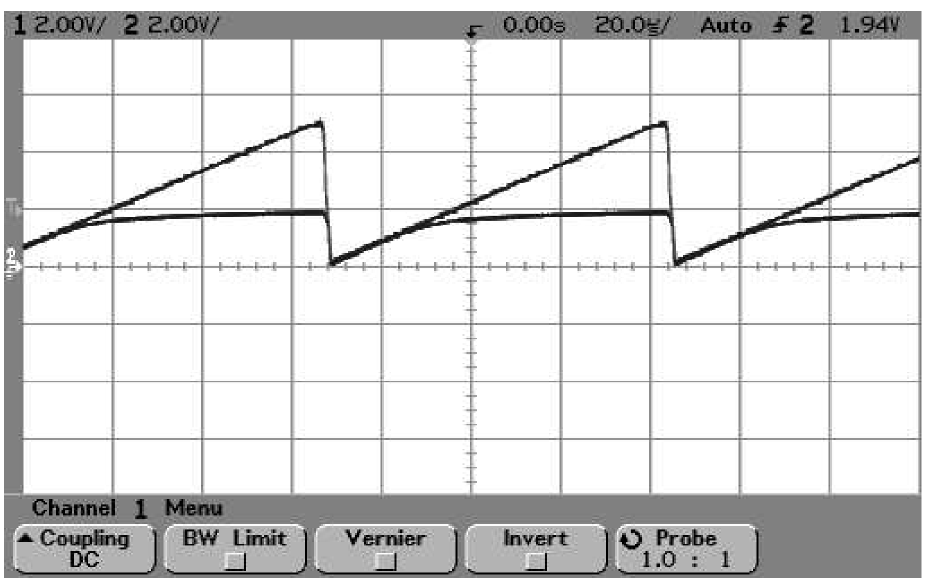


Figure 14: Oscilloscope Trace - Exp. 8: Sawtooth Waveform

3 Results and Conclusion

For the load-line analysis of the incandescent bulb, the analysis was a success. The predicted values for the voltage and current values were very close to the actual, experimentally measured values. The margins of error for each circuit were both less than 1%. The formula for the calculation of the error is printed in that section earlier in this document. The explanation of the theory behind load-line analysis is quite simple. When drawing the load-lines for the resistors, we know that since the resistor is a linear device, it will only operate at points along its line. We also know the same thing for the incandescent bulb, but it has a line of its own. Where these two lines intersect, that is the point of operation.

For the silicon diodes, we have successfully applied our very simple understanding of diode behavior to produce a number of useful circuits. For clipping circuits, we can easily obtain clipping voltages at any multiple of the single diode's threshold voltage, a property that was used in experiments 6, 7, and 8. For experiment 7 and 8, we used a dual-diode chain, one oriented inversely with respect to the other chain, to produce a circuit that was able to clip an input waveform on both the positive and negative sides. This is the expected result, based on the simple model of an ideal diode we have been using in lecture, with a threshold voltage between 0.6 and 0.7 volts. Since we are only considering the ideal diode model, we did not have to include any considerations of the dynamic resistance. Also, the waveforms we were using were relatively large in amplitude, especially when compared to the typical small-signal waveforms of small-signal analysis.