Thomas Ranney, Saaif Ahmed

Laboratory 2: Diodes – Diode characteristics, Small-signal models, Diode circuits

Introduction:

This lab dives deep into diodes and their real characteristics. We cover their expected actions, popular use cases, and immediate effect. We then assess their real characteristics such as power draw, small signal resistance, and breakdown voltage. We take it a step further by analyzing their effect on circuit efficiency and expected values. From our tests we determine if the values found match simulation, analysis, and spec sheet values.

Exercise 2.1: Standard diode characteristics

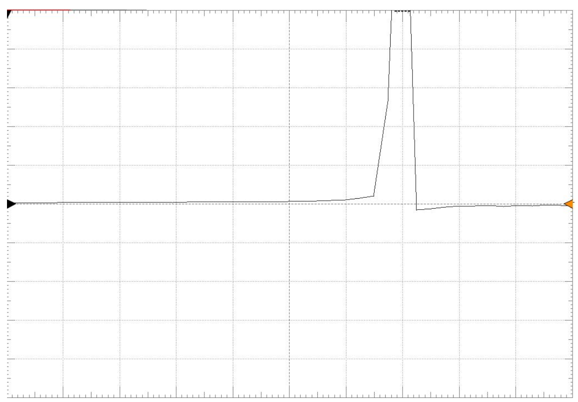

Figure 2.1.1 I vs V plot for the basic diode circuit built in Exercise 2.1 input voltage is set to a 100Hz triangle wave with a maximum value of 2V and a minimum value of -2V

The turn on voltage as shown in figure 2.1.1 is approximately .7 V.

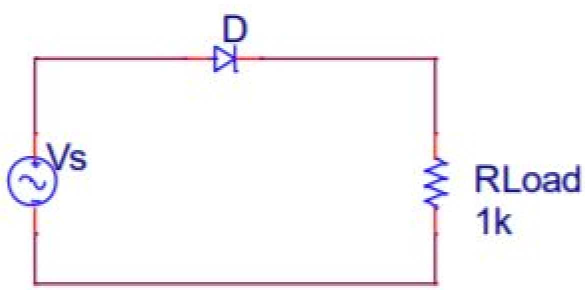

Figure 2.1.2 Half Rectifier Circuit for exercise 2.2.1

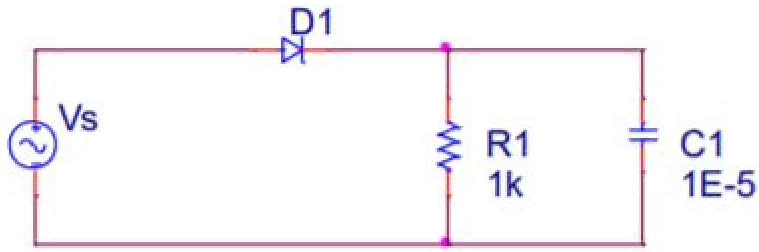

Figure 2.1.3 Half Rectifier Circuit with Smoothing Capacitor for Exercise 2.2.2

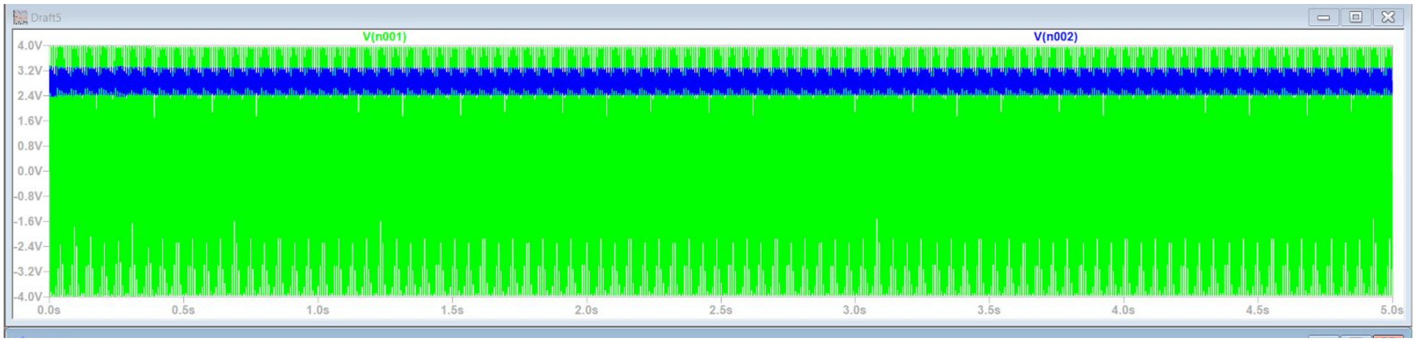

Figure 2.1.4 Source Voltage in Green and Voltage across load resistor in blue

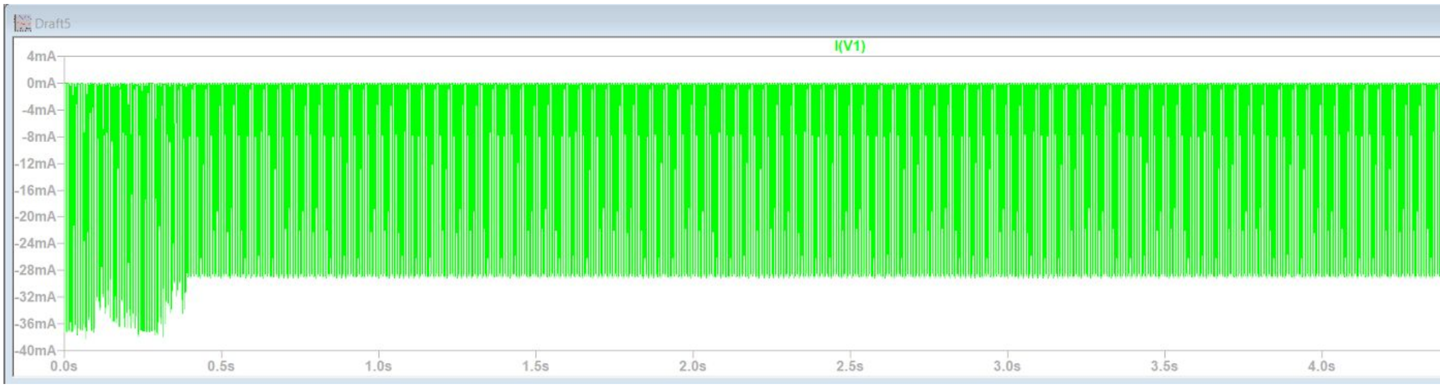

Figure 2.1.5 Source Current

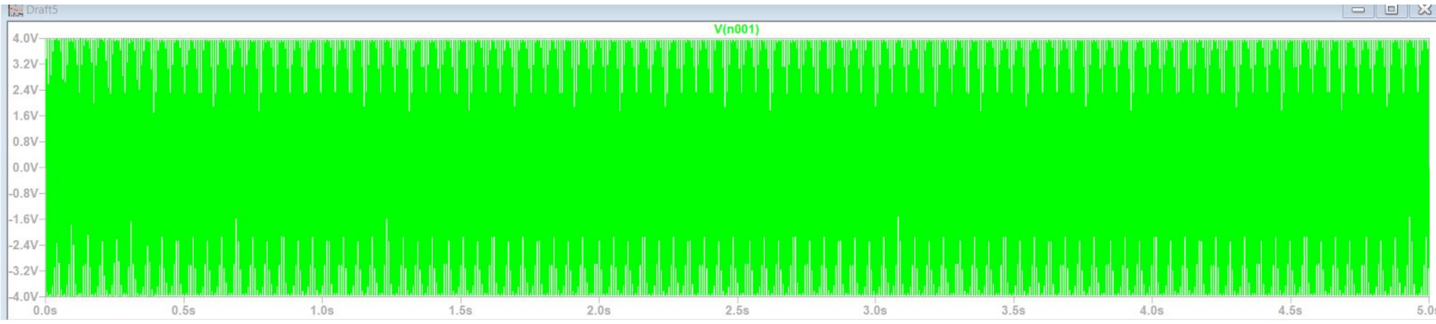

Figure 2.1.6 Source Voltage

Exercise 2.2: Rectifier Circuits

Half Wave Rectifier with Discovery Board:

Input (Yellow) Vs. Output (Blue):

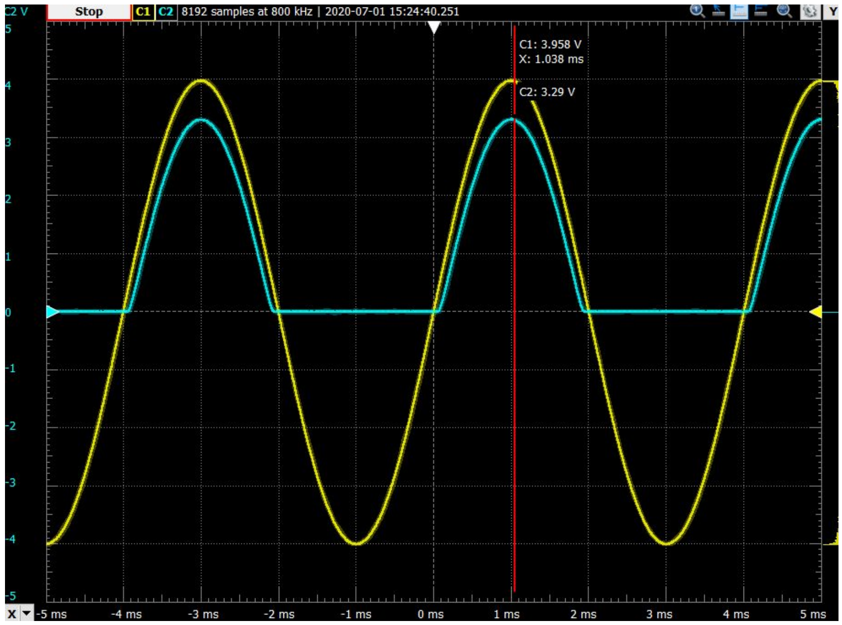

Figure 2.2.1 Input and Output Voltage

We expect the voltage across the load to be positive for half of the period of the input, and we expect the peak voltage across the load to be $V_{Load} = V_{input} - V_D$. Plugging values we get $V_{Load} = 4V - 0.7V = 3.3V$. Which exactly matches our output as shown above. This is consistent with Exercise 2.1

Half Wave Rectifier + Smoothing Capacitor with Discovery Board

Input (Yellow) Vs. Output (Blue):

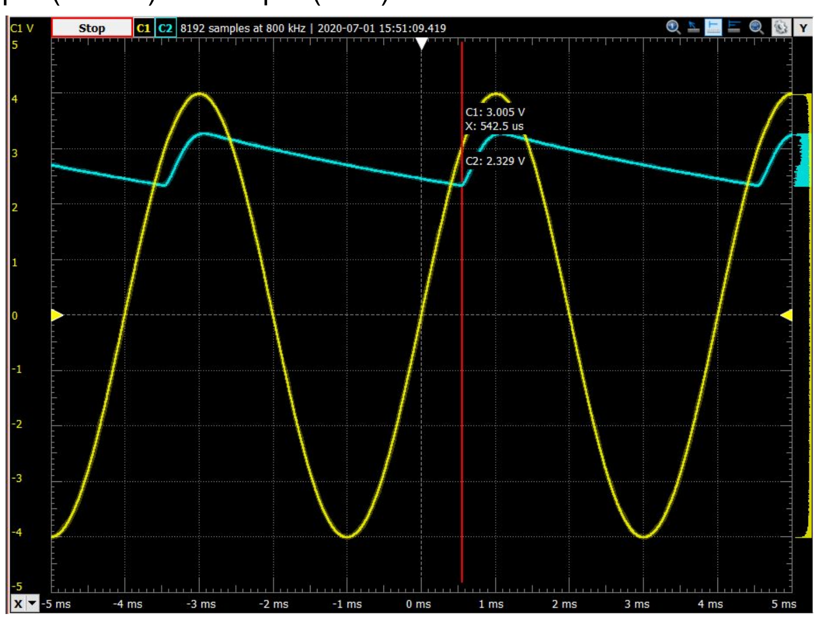

Figure 2.2.2 Half Wave Rectifier with Capacitor on Discovery Board

Measure $V_{ripple} = 3.3 - 2.32 = 0.98V$

Theoretically $V_{ripple} = \frac{V_{peak}}{f*R*C} = 1.32V$

The theoretically is higher than the measured Ripple Voltage.

LTSpice of a Half Wave Rectifier:

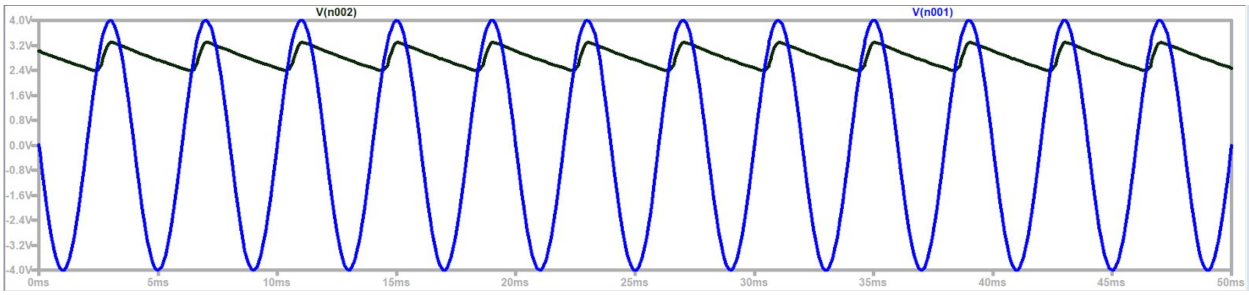

Figure 2.2.3 half wave rectifier on LT spice

The black is the voltage across the load.

Load Voltage = 3.3V

Ripple Voltage = 0.9V

$P_{RL} = \frac{V_{Avg}^{\ 2}}{R_l} = 0.00812$ is the average power consumed at the load

Thus the energy consumed is $E = P * T = 0.00812 * \frac{1}{250} = 3.25 * 10^{-5}$

The voltage drop across the diode when it is on is the on voltage or $0.7V$.

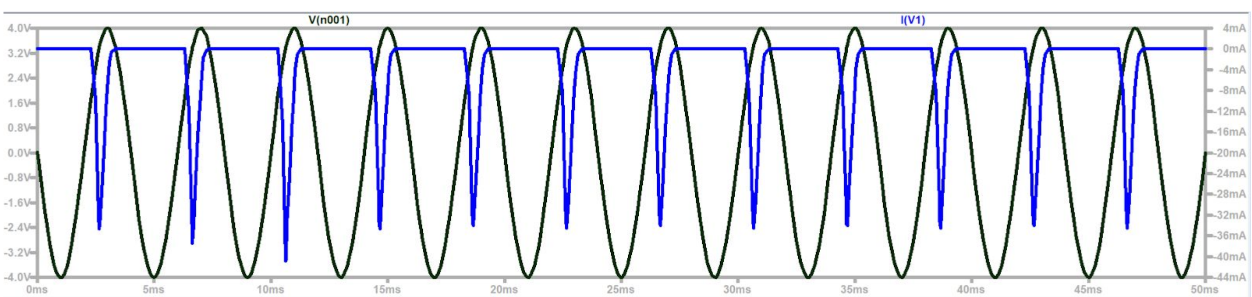

Figure 2.2.4 Source voltage vs Source current

The black line is the source voltage. The blue is the current through the source.

$\Delta t = 5.694 * 10^{-4}$

Source Power: $I_{s_{avg}} * V_S * \frac{\Delta t}{T} = (\frac{1}{2}C\omega^2 V_o \Delta t + \frac{V_{avg}}{1000}) * 4V * \frac{\Delta t}{T} = 0.01766$

Energy of the Source: $E_S = P_s * \Delta t = 1.0065 * 10^{-5}$

Diode Power : $I_{s_{avg}} * V_D * \frac{\Delta t}{T} = (\frac{1}{2}C\omega^2 V_o \Delta t + \frac{V_{avg}}{1000}) * 0.7V * \frac{\Delta t}{T} = 0.0031$

Energy of the Diode : $P_D * \Delta t = 1.76 * 10^{-6}$

Efficiency of the circuit: $100 * 0.00812/0.01766 = 45.98\%$

LTSpice of a Half Wave Rectifier with 40V Source:

Peak Voltage : $Vp = V_s - V_D = 39.3V$

Ripple Voltage: $V_{Rip} = V_P/fRC = 15.72V$

Load Voltage: $V_p - V_{rip}/2 = 31.44V$

Power of Load : $(V_{avg})^2/1000 = 0.988$

$\Delta t = 5.7 * 10^{-4}$

Source Power : $I_{S_{avg}} * V_S * \frac{\Delta t}{T} = (\frac{1}{2}C\omega^2 V_o \Delta t + \frac{V_{avg}}{1000}) * 40V * \frac{\Delta t}{T} = 1.7825$

Efficiency : $100 * 0.988/1.7825 = 55.45\%$

The efficiency of the circuit increased because the diode voltage is no longer a significant portion of the source voltage so the effects of the diode drop are not seen as much.

Discovery Board Full Wave Rectifier:

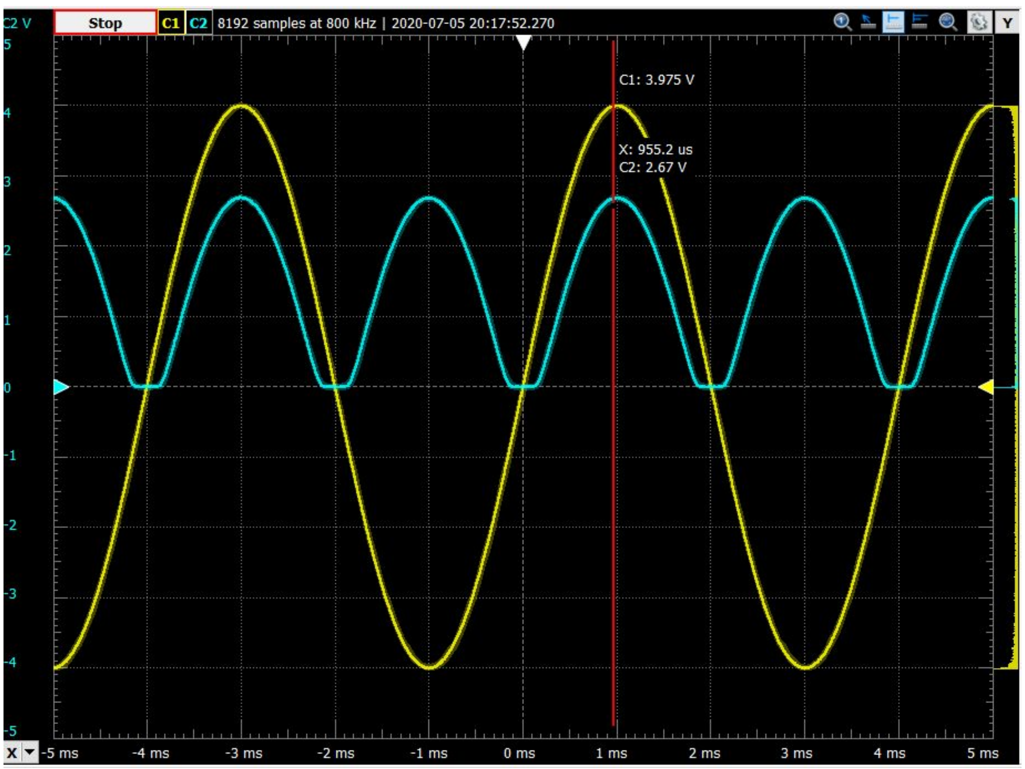

Figure 2.2.5 Full wave rectifier Discovery Board, input and output voltage

The Blue waveform is the output of the Full Wave rectifier. The output waveform is exactly as expected. The measured peak voltage is roughly 2.6V. This is consistent with expectations of the real diode.

Relative to the Half Wave rectifier the expectations are consistent. Isolating each “half” of the input waveform we see that there are 2 diodes in series with the resistor. This means 2 times the voltage drop of the diodes. 2*0.7V = 1.4V and 4V - 1.4V = 2.6V peak which is what we observe.

Discovery Board Full Wave Rectifier with Smoothing Cap:

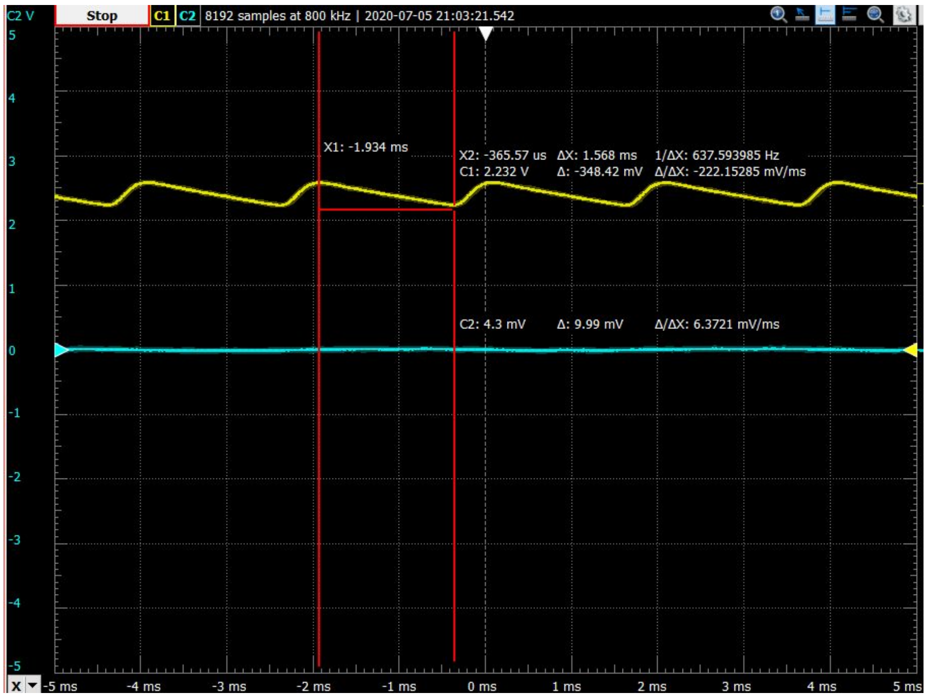

Figure 2.2.6 Full wave rectifier with capacitor

Measured Ripple Voltage: 0.35V

Measured Average Voltage: 2.425V

Theoretical Ripple Voltage: $\frac{2.6}{2*250*1000*10^{-5}} = 0.52$

Theoretical Average Voltage: $2.34V$

The measured values are larger than the theoretical values.

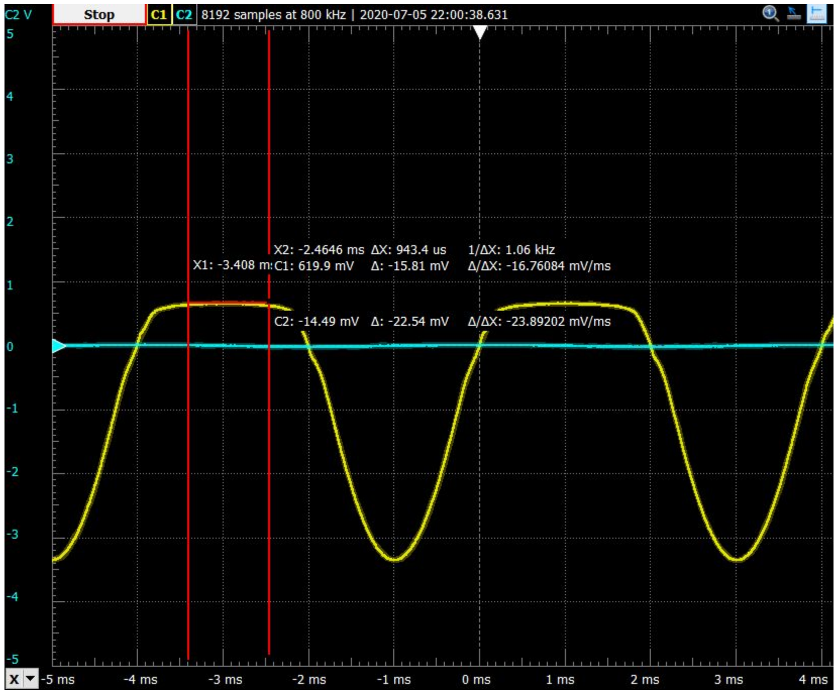

Figure 2.2.7 Voltage across diode

The on time of the diode is measured to be 0.943 ms.

Theoretical on time: 0.805 ms

The measured and calculated on-time are decently close in value. The difference is because of the Taylor series approximations we make to calculate on time.

With a 1 uF Cap:

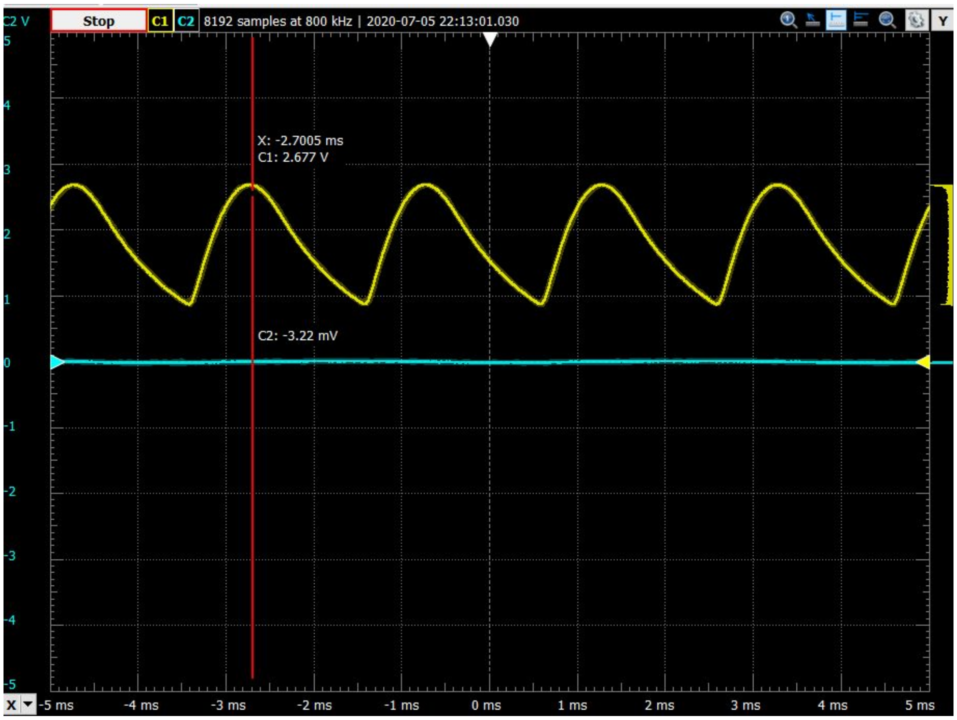

Figure 2.2.8 Voltage across diode with 1uF capacitor

With a 1uF the ripple voltage is much larger. This causes changes with the output waveform clearly. The output does not look like much of a stable DC output. The ripple voltage change causes lots of other changes such as conduction time for the diode.

Exercise 2.3: Diode Resistance and Small Signal Characteristics

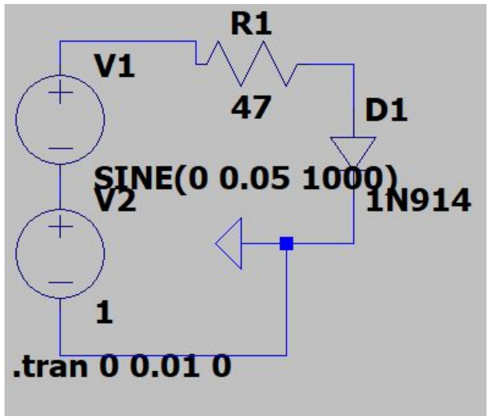

Figure 2.3.1 LT spice schematic for part 2.3

A)

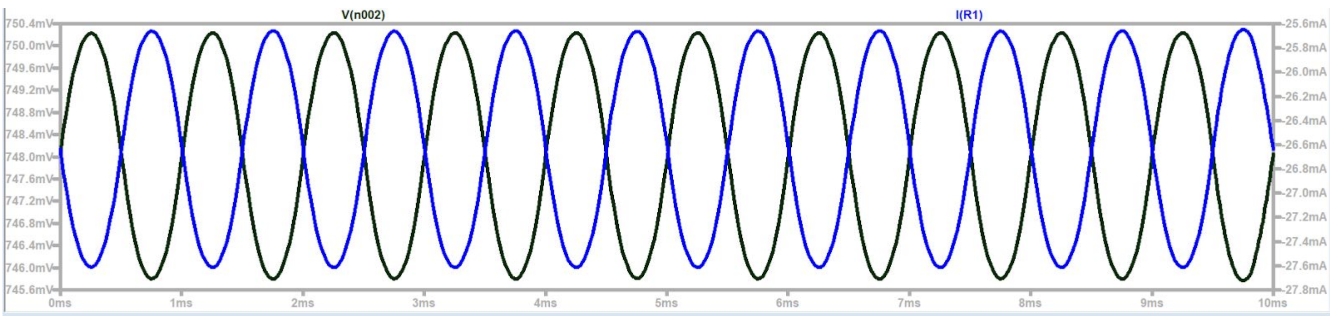

Figure 2.3.2 Source voltage and current through resistor

Using the iterative solution we make a guess of Vd.

$V_s - I_{R1}R_1 \ = \ 0.7498V = V_d$

From the iterative solution we get that the diode resistance is $2.2\ \Omega$

Using $r_D = \frac{V_{AC}}{I_{AC}} \ = \ \frac{4.44}{1.95} \ = \ 2.27\ \Omega$

The thermal voltage would cause most of the difference. The thermal voltage is not taken into account in the AC equation.

B)

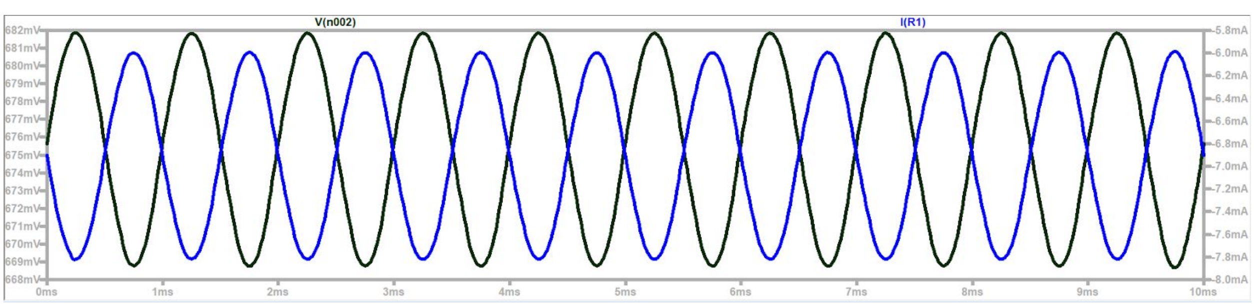

Figure 2.3.3 Source voltage and current through resistor

We make a guess of $V_D = 0.7V$

From the iterative solution we get that the diode resistance is $7\,\Omega$.

Using $r_D = \frac{V_{AC}}{I_{AC}} = \frac{13}{1.8} = 7.22\,\Omega$

There is a relative difference between the iterative and the AC analysis method, that is consistent in both parts.

The changes made to the small signal diode resistance are consistent with the change in the DC bias. They make the linear approximations we make for analysis.

C)

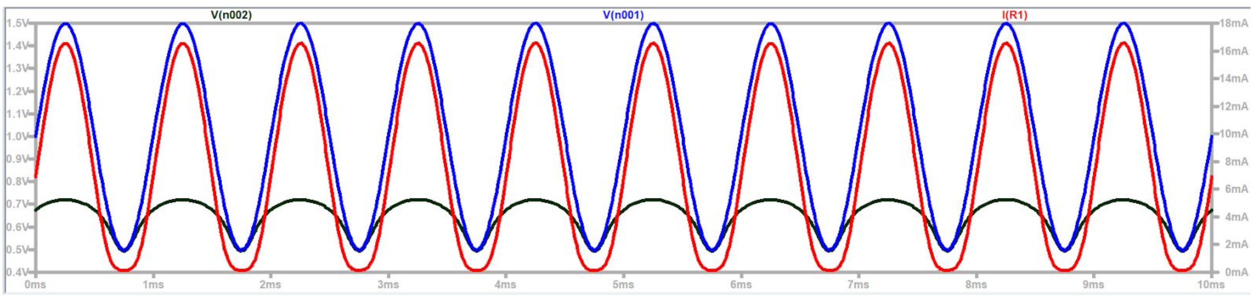

Figure 2.3.4 Source voltage , voltage across diode and current through resistor

Black line is the voltage across the diode.

The diode voltage is no longer sinusoidal because the AC component is a significant ratio of the DC bias. Due to the AC signal shutting off the diode at certain points, there would be no current flowing through the loop. Meaning that the voltage across it is not dropped by the resistor and is instead equal to the source voltage. As shown in the graph above.

D)

Analog Discovery: Input V1 = 2V + 50mV *sin(wt)

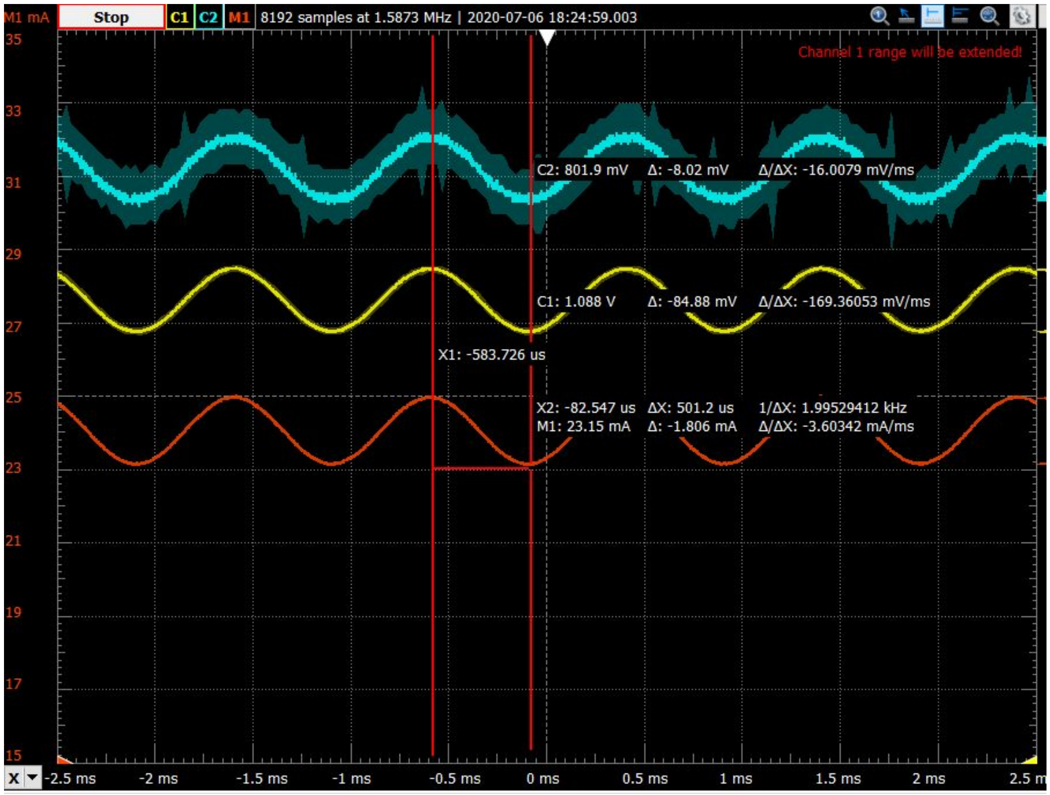

Figure 2.3.5 Diode Voltage in Blue, Resistor Voltage in Yellow, Resistor/Diode Current in Red

Using $r_D = V_{AC}/I_{AC} = 8\ mV\ /\ 1.8\ mA = 4.44\ \Omega$

Analog Discovery: Input V1 = 1V + 50mV * sin(wt)

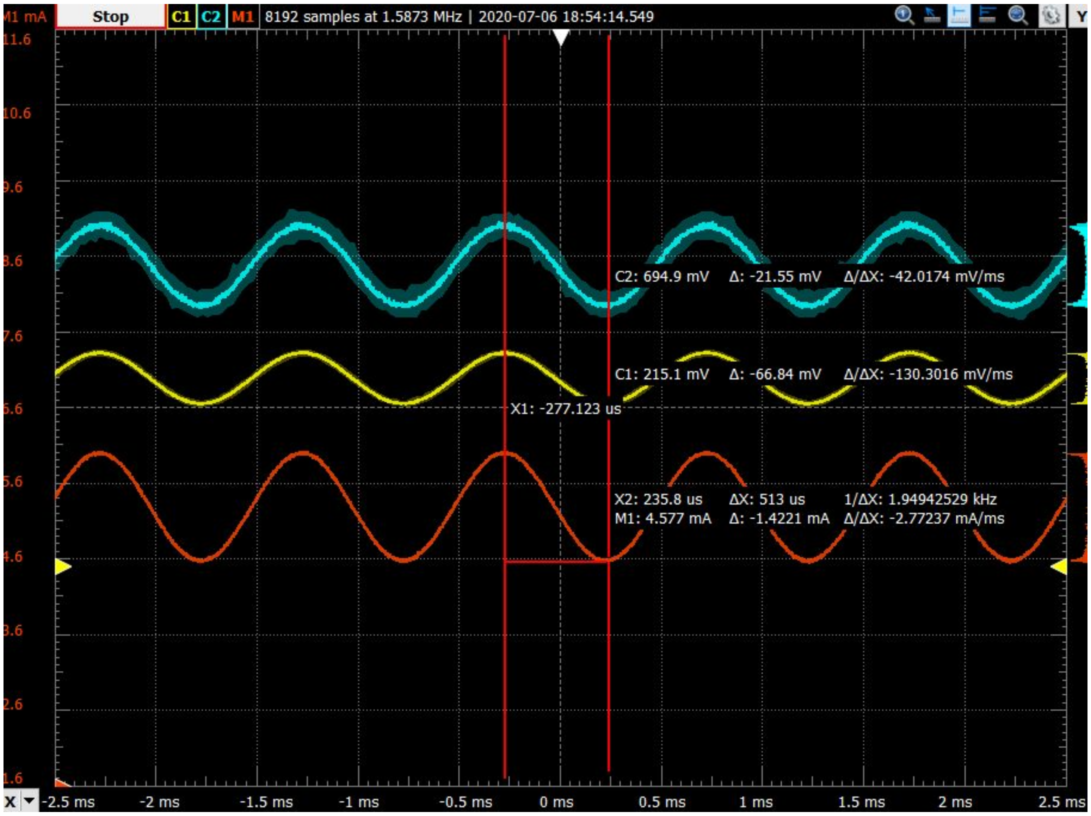

Figure 2.3.6 Diode Voltage in Blue, Resistor Voltage in Yellow, Resistor/Diode Current in Red

Using $r_D = V_{AC}/I_{AC} = 66\ mV\ /\ 1.4\ mA = 47.14\ \Omega$

The values have a similar trend of the lower DC offset creating a larger resistance. For Part A it was very close to the simulated value. For Part B it was decently off. The discrepancies can be attributed to noise from the Analog Discovery, imperfections and resistor tolerances of the diode itself, and thermals.

The value in the equation that attributes to off values is V Thermal. The thermal voltage changes with ambient temperature. And though it is simulated at room temperature, depending on weather, air conditioning, and other factors the thermal voltage of the diode is affected and thus it’s resistance is affected.

Exercise 2.4 Zener Diode Characteristics

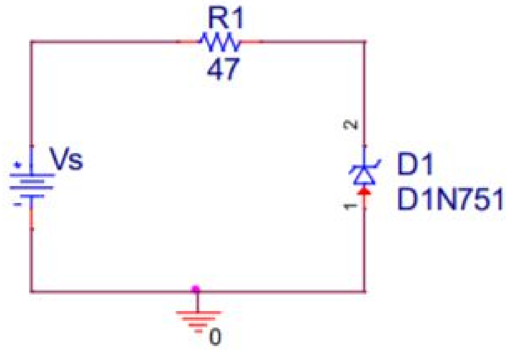

Figure 2.4.1 Circuit used in part 2.4 with the 1N751 diode

Figure 2.4.2 LT spice IV plot of Diode

The knee voltage is about .5 V , and the knee current is about 25 mA when the diode is in breakdown. Rz is about 45 ohms, close to the spec sheet value of 47.

At I = 5 mA, Vz = 225 mV. At I = 10 mA, Vz = 475 mV. Rz = 47 Ohms

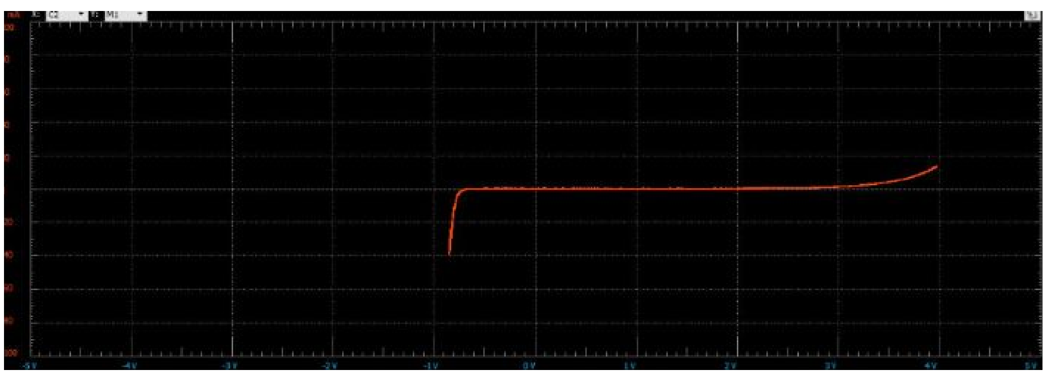

Figure 2.4.3 IV plot on discovery board

After linearizing the data, the zener resistance was about 46 ohms.

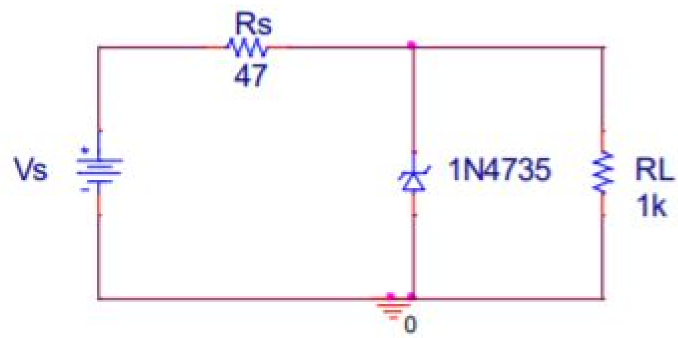

Figure 2.4.4 Circuit with added 1k load Resistor

Using the circuit above, and superposition, the Rz was calculated to be 45 ohms . This is reasonably close to our previous estimate of 46 and the spec sheet value of 47.

The zener diode drops out of regulation at about .55 volts, yes this is a reasonable value for the knee voltage.

Conclusion:

Diodes themselves are very powerful tools as they are able to automatically serve as a check valve for current flow. They have many uses such as protecting against reverse voltage, acting as voltage regulators, and AC to DC conversion. They have various flaws, the largest being the turn on voltage. In low voltage circuits, the diode on voltage could be a significant portion of the source voltage, resulting in less power delivered to the load. Another understated flaw is the diode’s tendency to change its resistance with ambient temperature. This can prove to be a substantial negative component of the circuit by altering values of current and voltage. However, diodes remain strong components that resolve many problems and have work around for their flaws.