California Polytechnic State University – San Luis Obispo
Electrical Engineering Department
EE 346-01 Semiconductor Device Electronic Laboratory – **Winter 2019**
Location: 020-0149, Tuesdays 8:10 AM – 11:00 AM
Instructor: Siddharth Vyas
Experiment # 4
Experiment Title: Diode Circuits
Work Station # 6
Date of Experiment: January 29, 2019
Lab Report by: Victor Delaplaine, Derek Iwashimizu

Introduction:

The objective of this lab was to apply our knowledge of diode characteristics to analyze and measure the response of diode circuits. In this experiment we assembled a diode based clipper, clamp, half-wave and full wave rectifier. After getting the experimental data needed we then observed the prelab measurements with our experimental data.

Materials:

- 1 x 33120A Function Generator
- 1 x Oscilloscope
- 1 x TPS 4000 Dual Power Supply
- 1 x E3640A Power Supply
- 1 x 34401A Digital Multimeter
- 4 x IN4001 Diodes
- 1 x 15 kΩ Resistor (15.281kΩ)measured
- 1 x 68 kΩ Resistor (66.98kΩ)measured
- 1 x 150 kΩ Resistor (150.5kΩ)measured
- 1 x 2.2 kΩ, ½ W Resistor (2270Ω)measured
- 1 x 0.1 µF Capacitor
- 4 x Banana to Grabber
- 1 x BNC to Banana
- 1 x Breadboard
- 1 x BNC to BNC
- 1 x BNC T
- 4 x Banana to Banana
- 1 x Bag of Short Leads

Procedure:

First part of the lab is to construct the circuit shown in figure 1, and then capture the experiment signals using the oscilloscope for vo(t) and vi(t). Then changing the two sources that are 1.5 to 4.5 and then record the same data. These signals captured will be compared to the prelab ones. For part two one will assemble the clamping circuit shown in Figure 2 with C=0.1uF, R=68k Ω using the function generator as the source vi(t) set it to square wave 10vpp. Then capture the experiment vi, and vo on the oscilloscope and compare to the prelab. After this do the same procedure but for R=2.2,15 and 150k Ω. Then one will repeat part two only having the diode flipped. Part three is to construct the half-wave rectifier shown in figure 4, using the oscilloscope measure the signal vo and vi and then repeat for R=2.2k,150k Ω. In each value of R one will record the DC voltage across vo. Part four is a subset of part three only now connecting a .1uF capacitor in parallel with 150k Ω doing the same procedure as part three only now measuring the RMS ac ripple voltage across the load resistor using the multimeter. Part five coniststs of contstructing the circuit in Figure 7, using the same procedure from part five. Repeat this for R=2.2k Ω. Finally one will place a .1uF capacitor across the resistor shown in Figure 8, and record the vo(t) waveform on the oscilloscope, DC voltage and RMS ac ripple voltage on the multimeter for R = 150k, 2.2k.

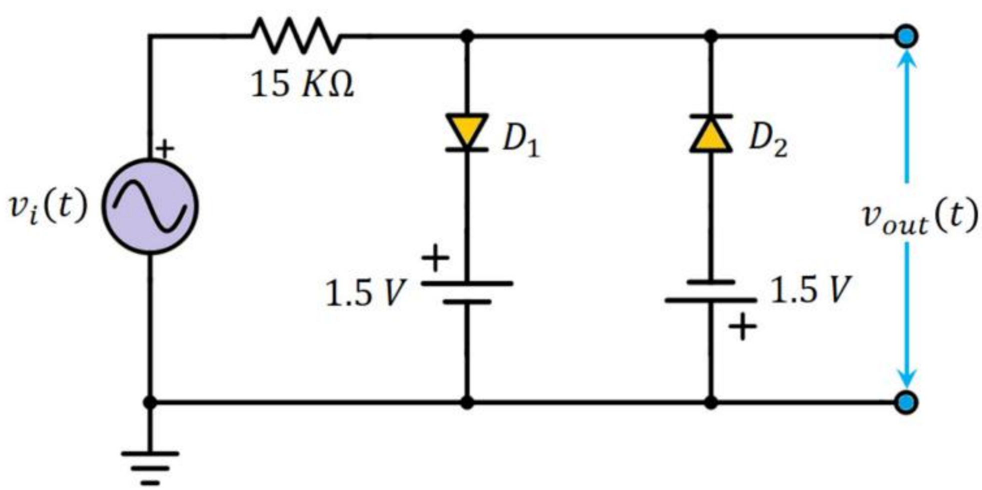

Figure 1: Clipping Circuit, with vi(t) = 5 sin6280t V

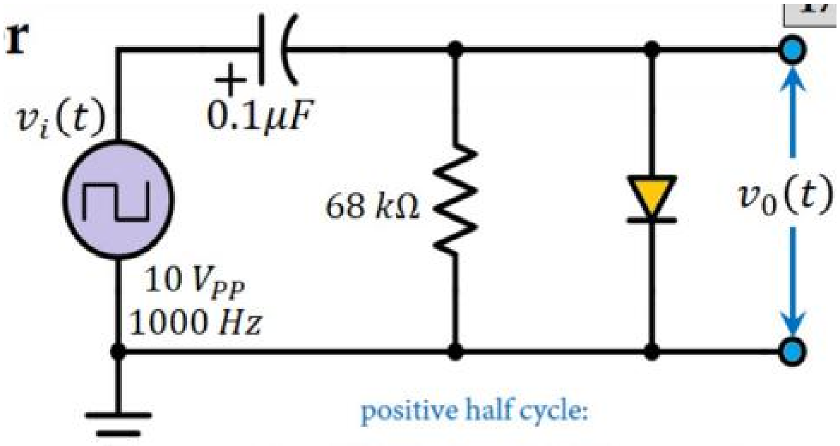

Figure 2: Clamping circuit (pos. half cycle), with vi a square wave of 10 Vpp and 1000Hz

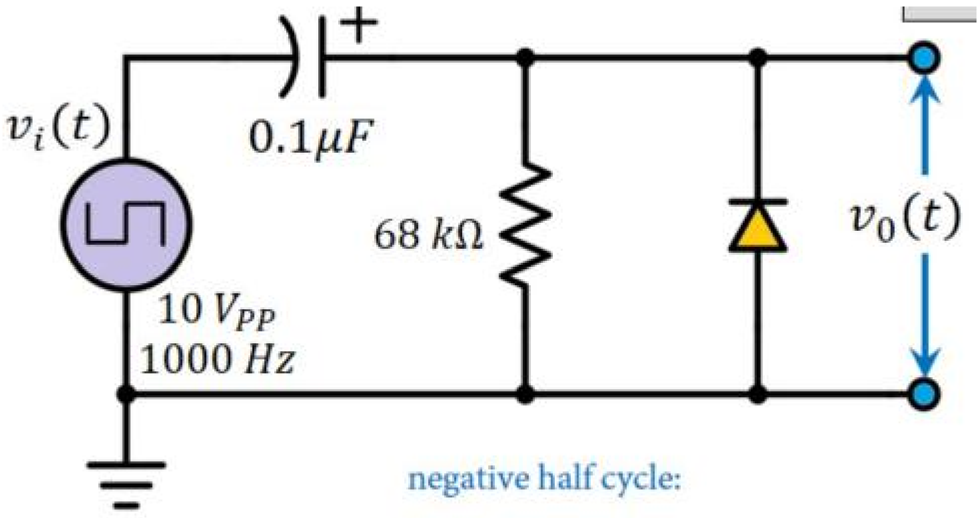

Figure 3: Clamping circuit (neg. half cycle), with vi a square wave of 10 Vpp and 1000Hz

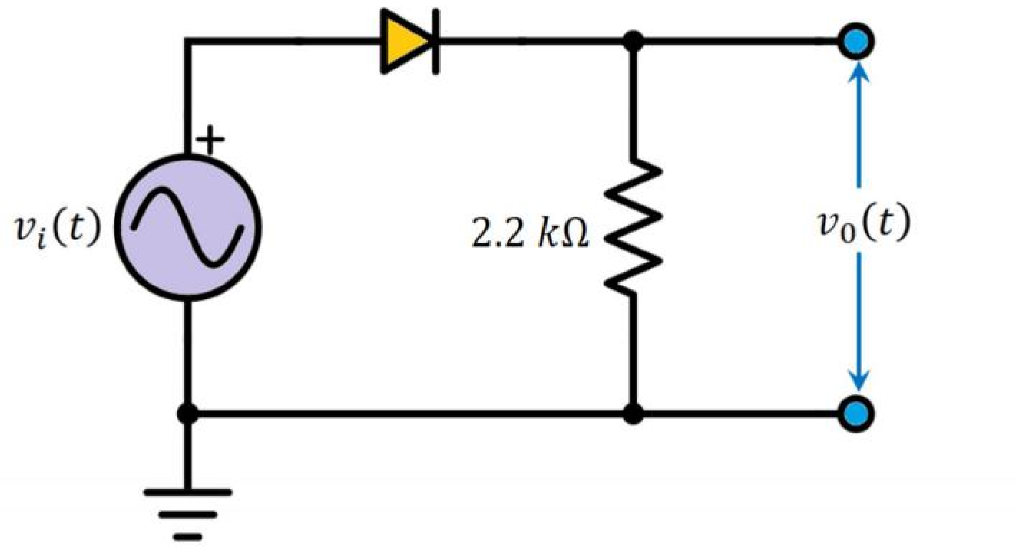

Figure 4: Half - wave rectifier with R = 2.2k Ω, vi(t) = 10 sin(120 π t)V

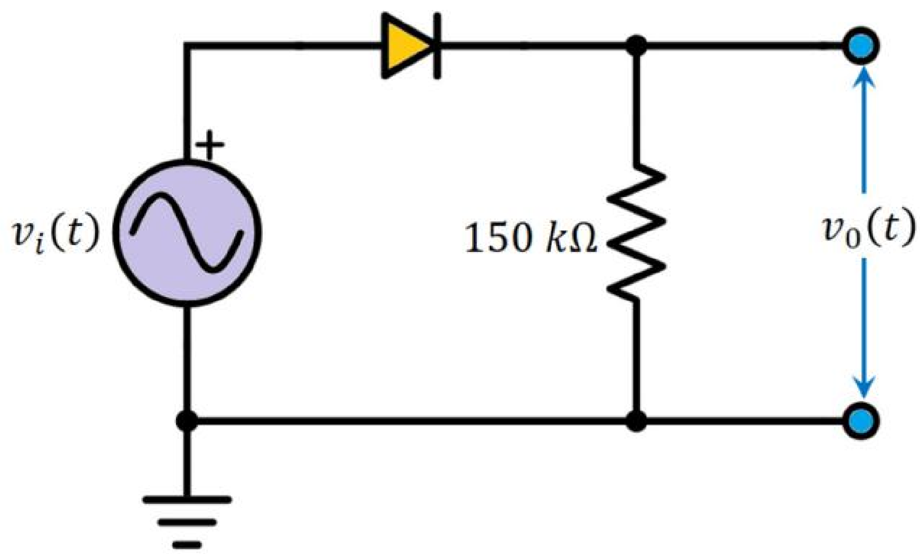

Figure 5: Half - wave rectifier with R = 150k Ω, vi(t) = 10 sin(120 π t)V

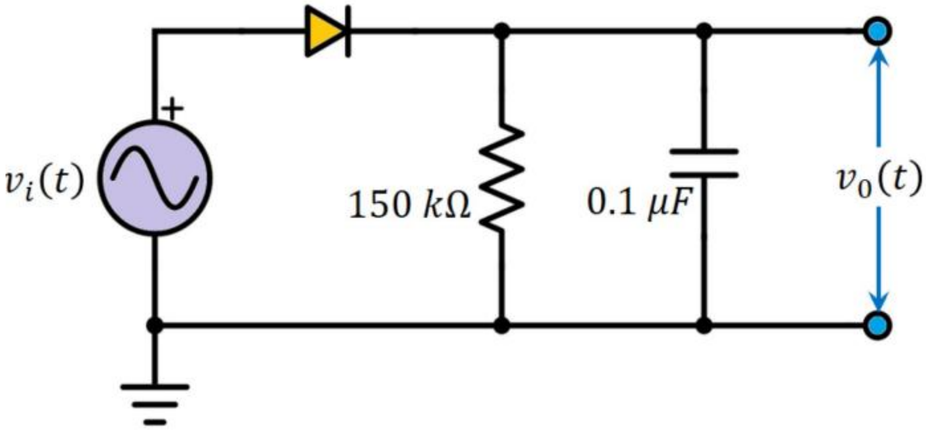

Figure 6: Half - wave rectifier with R = 150k Ω and .1uF Capacitor in parallel, vi(t) = 10 sin(120 π t)V

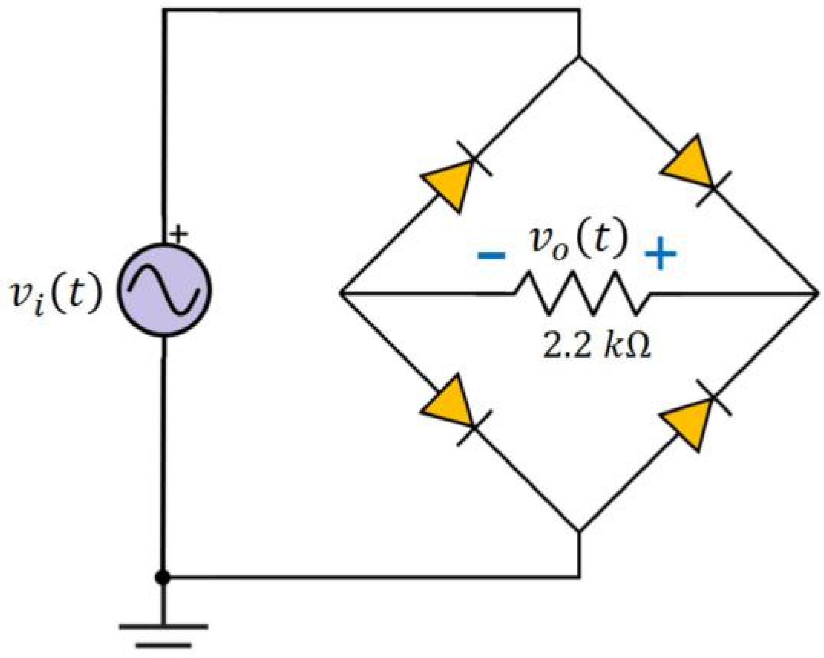

Figure 7: bridge rectifier with R = 2.2k Ω, vi(t) = 10 sin(120 π t)V

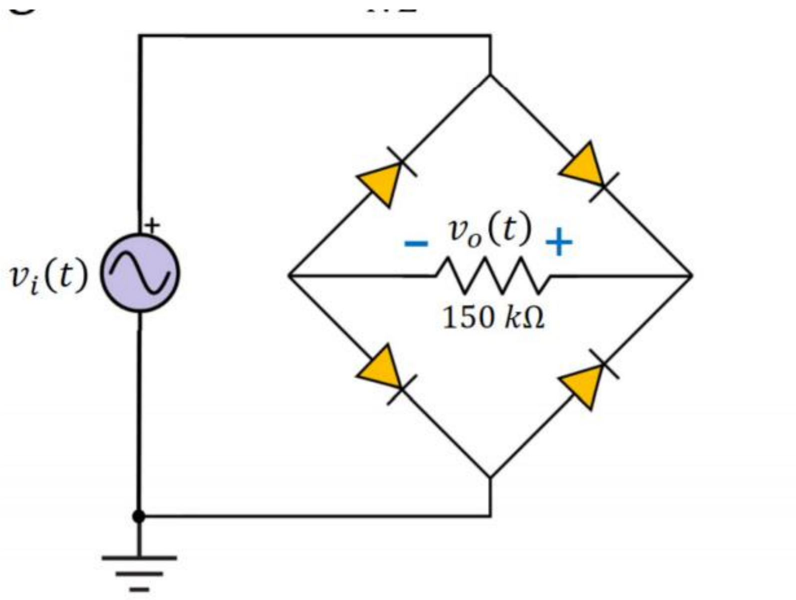

Figure 8: bridge rectifier with R = 150k Ω, vi(t) = 10 sin(120 π t)V

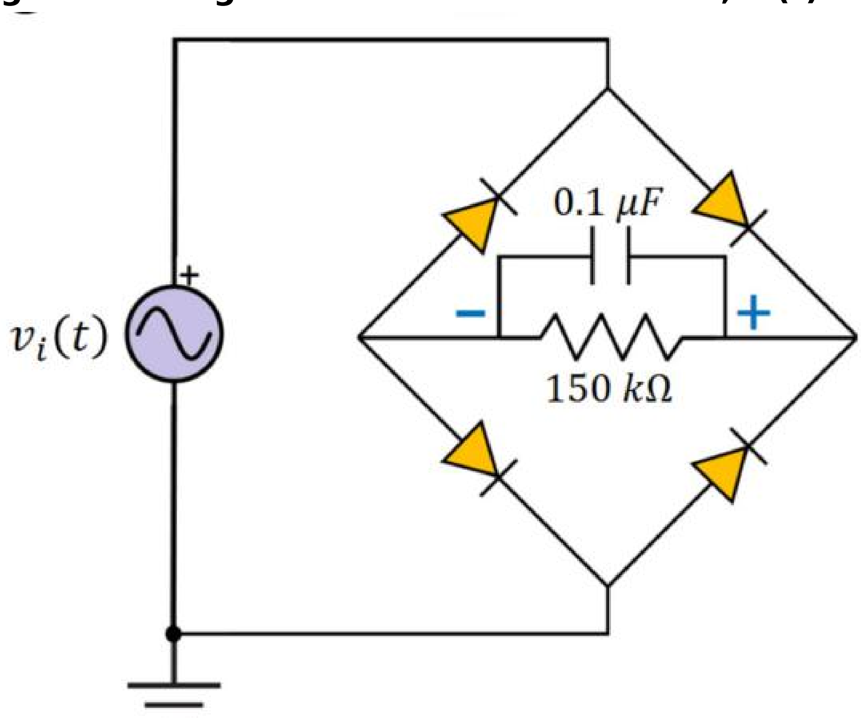

Figure 9: bridge rectifier with R =150k Ω and parallel cap of .1uF, vi(t) = 10 sin(120 π t)V

Data and Observation:

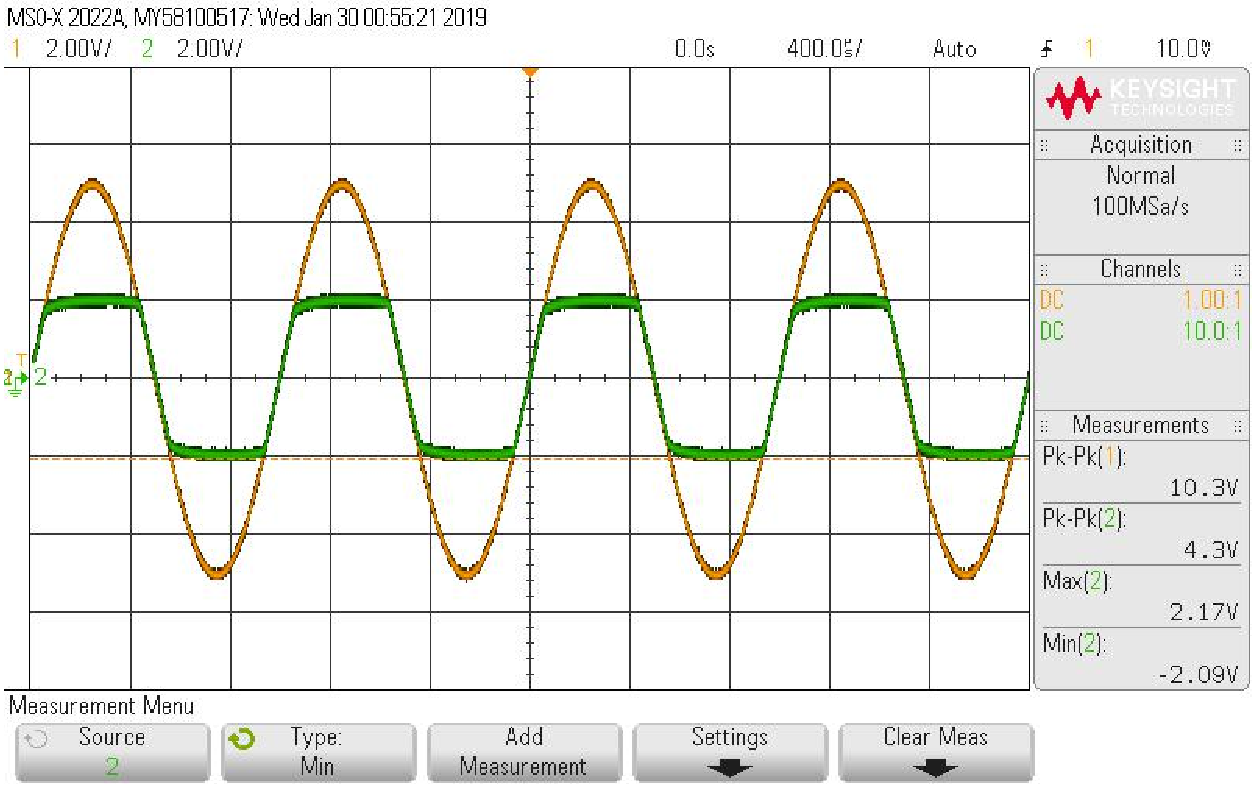

Figure 10: Clipping circuit, Vi(t)- orange, Vo(t) - green for V1=V2=1.5V(experimental)

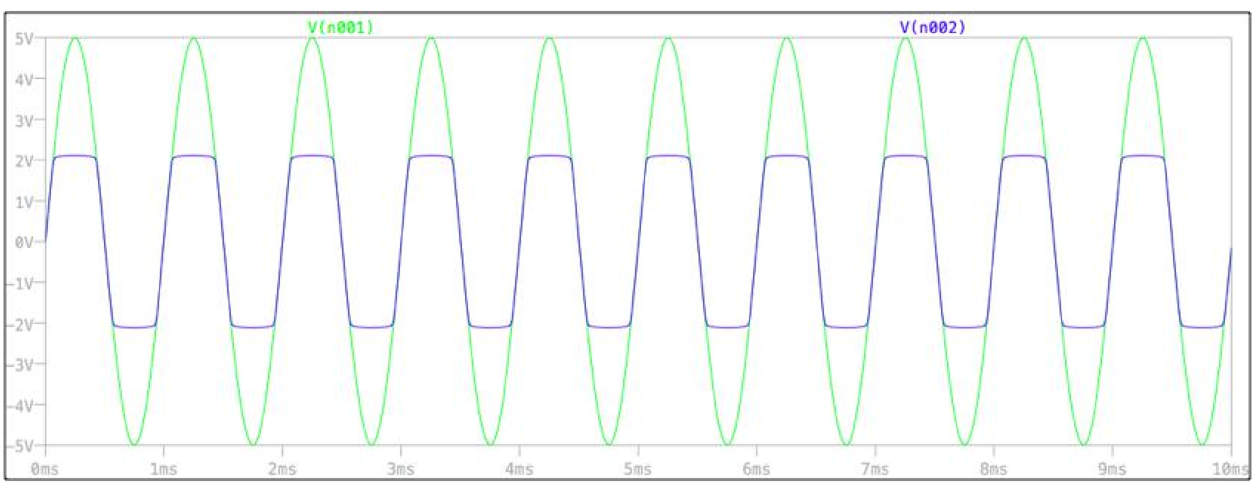

Figure 11: Clipping circuit, Vi(t)- green, Vo(t) - blue V1=V2=1.5V (prelab)

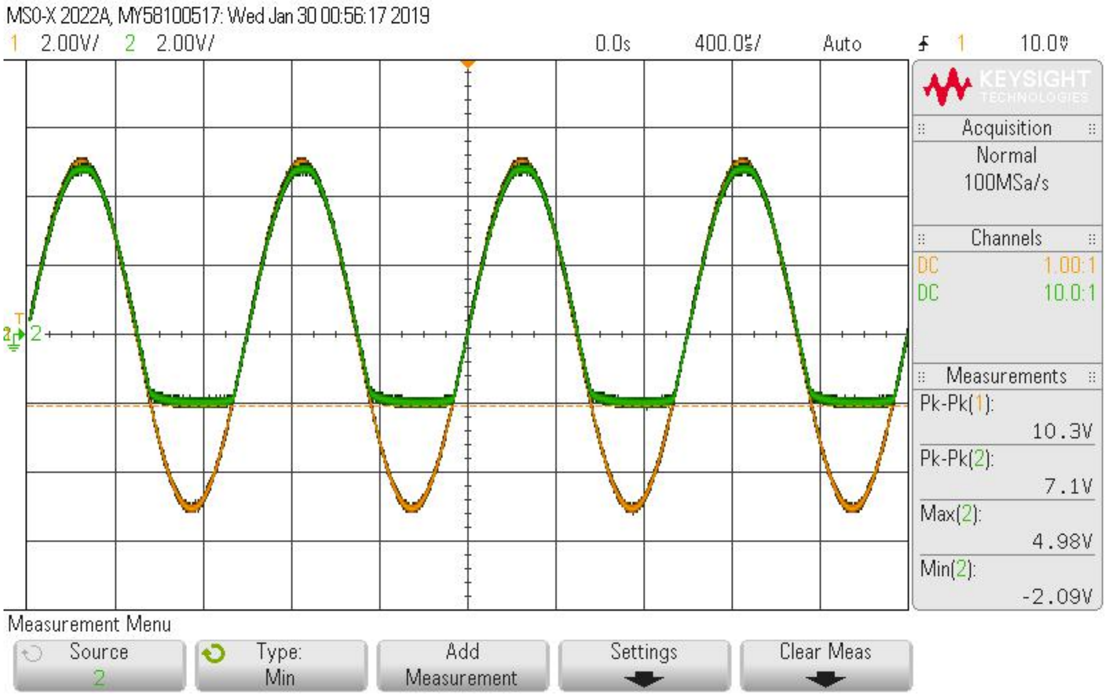

Figure 12: Clipping circuit, Vi(t)- orange, Vo(t) - green for V1=V2 = 4.5V(experimental)

Figure 13: Positive clamping circuit, Vi(t)- orange, Vo(t) - green for R =$68k\Omega$(experimental)

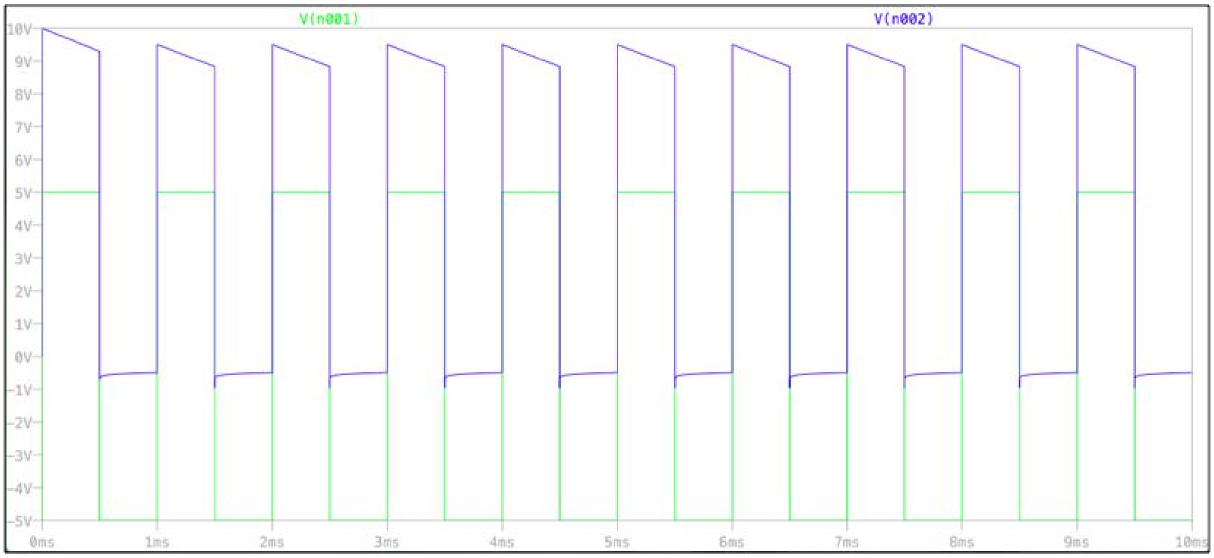

Figure 14: Positive clamping circuit, Vi(t)- green, Vo(t) - blue for R =$68k\Omega$(prelab)

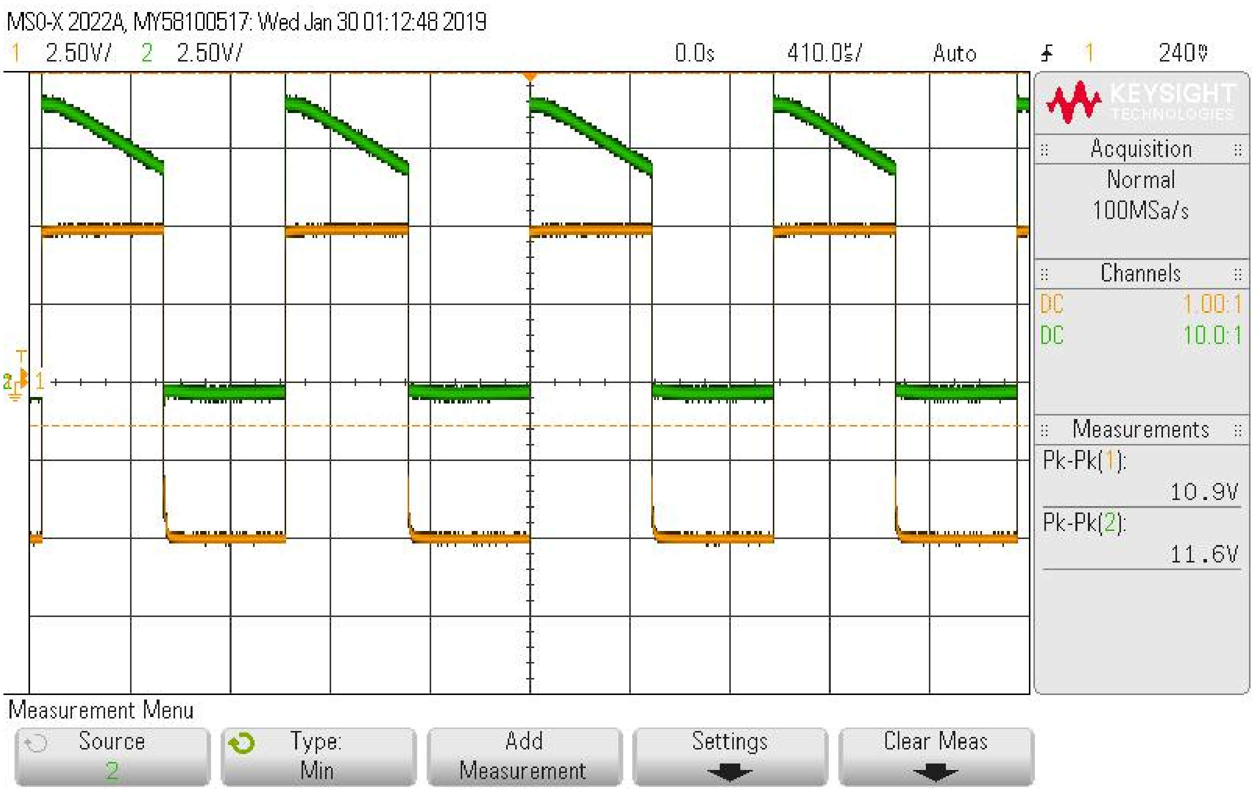

Figure 15: Positive clamping circuit, Vi(t)- orange, Vo(t) - green for R =$15k\Omega$(experimental)

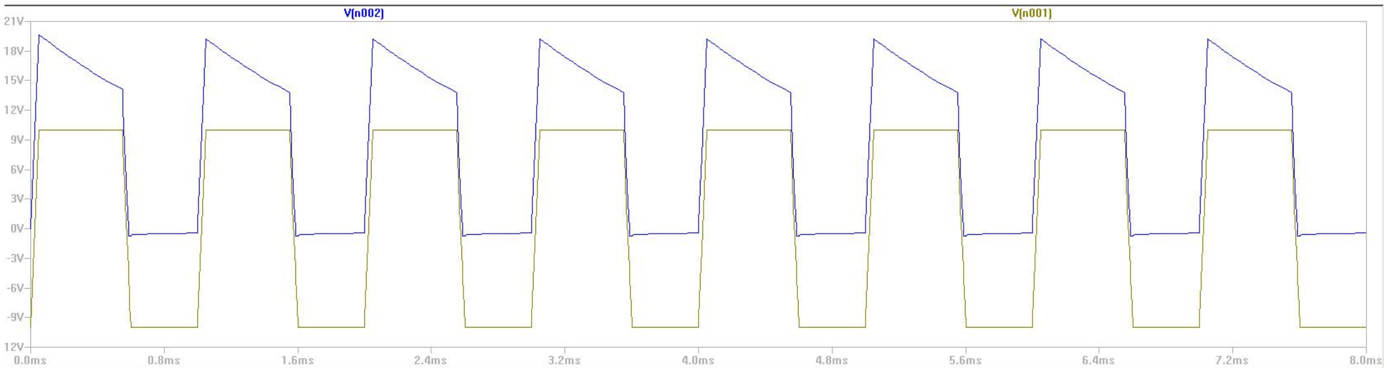

Figure 16: Positive clamping circuit, Vi(t)- green, Vo(t) - blue for R =$15k\Omega$(prelab)

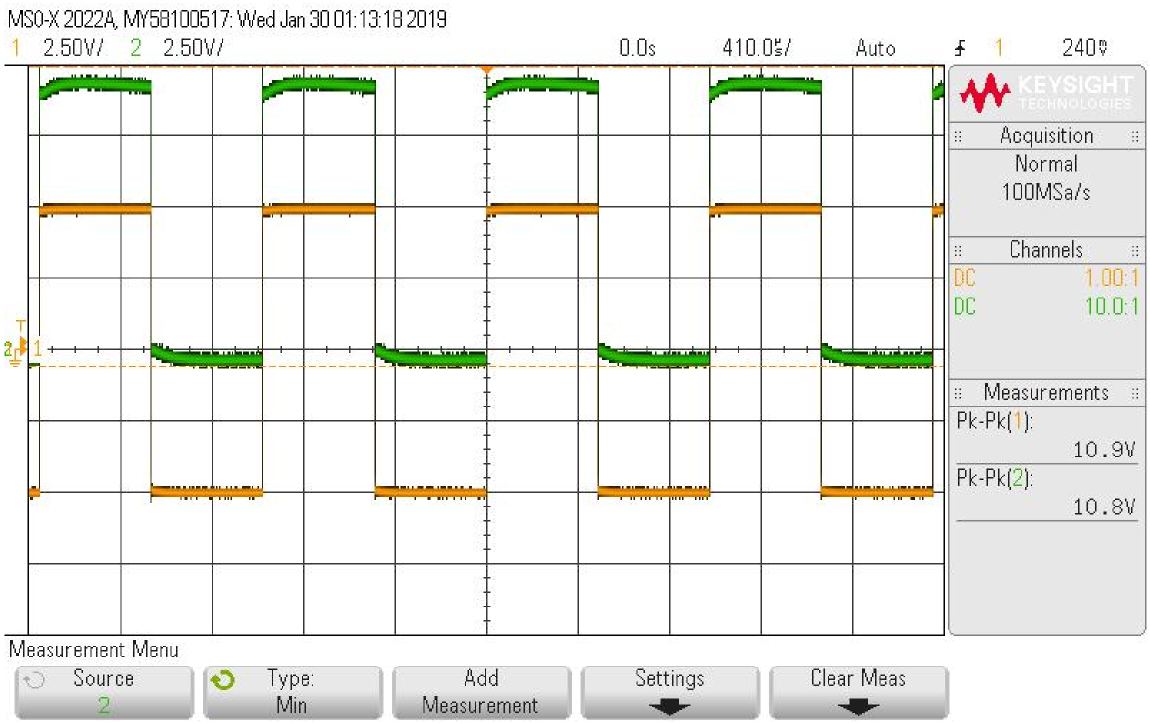

Figure 17: Positive clamping circuit, Vi(t)- orange, Vo(t) - green for R =$150k\Omega$(experimental)

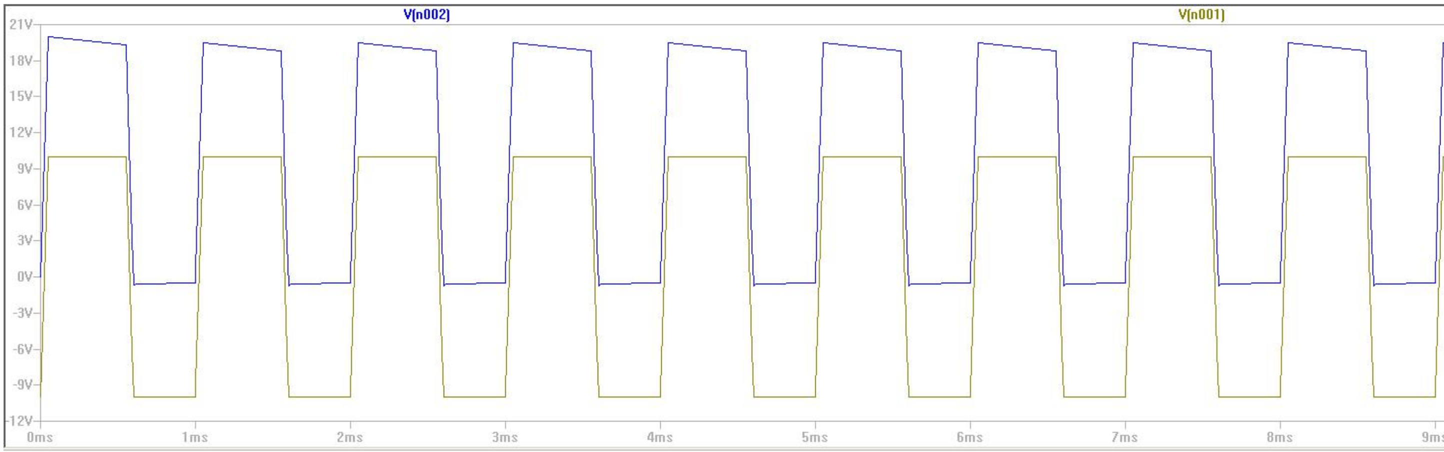

Figure 18: Positive clamping circuit, Vi(t)- green, Vo(t) - blue for R =$150k\Omega$(prelab)

Figure 19: Positive clamping circuit, Vi(t)- orange, Vo(t) - green for R =$2.2k\Omega$(experimental)

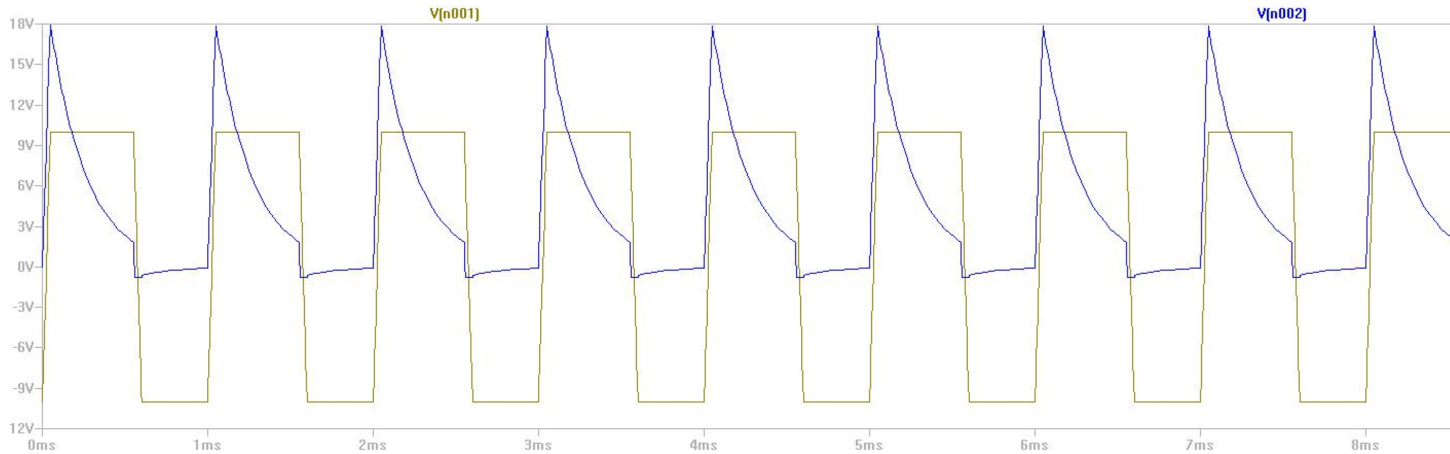

Figure 20: Positive clamping circuit, Vi(t)- green, Vo(t) - blue for R =$2.2k\Omega$(prelab)

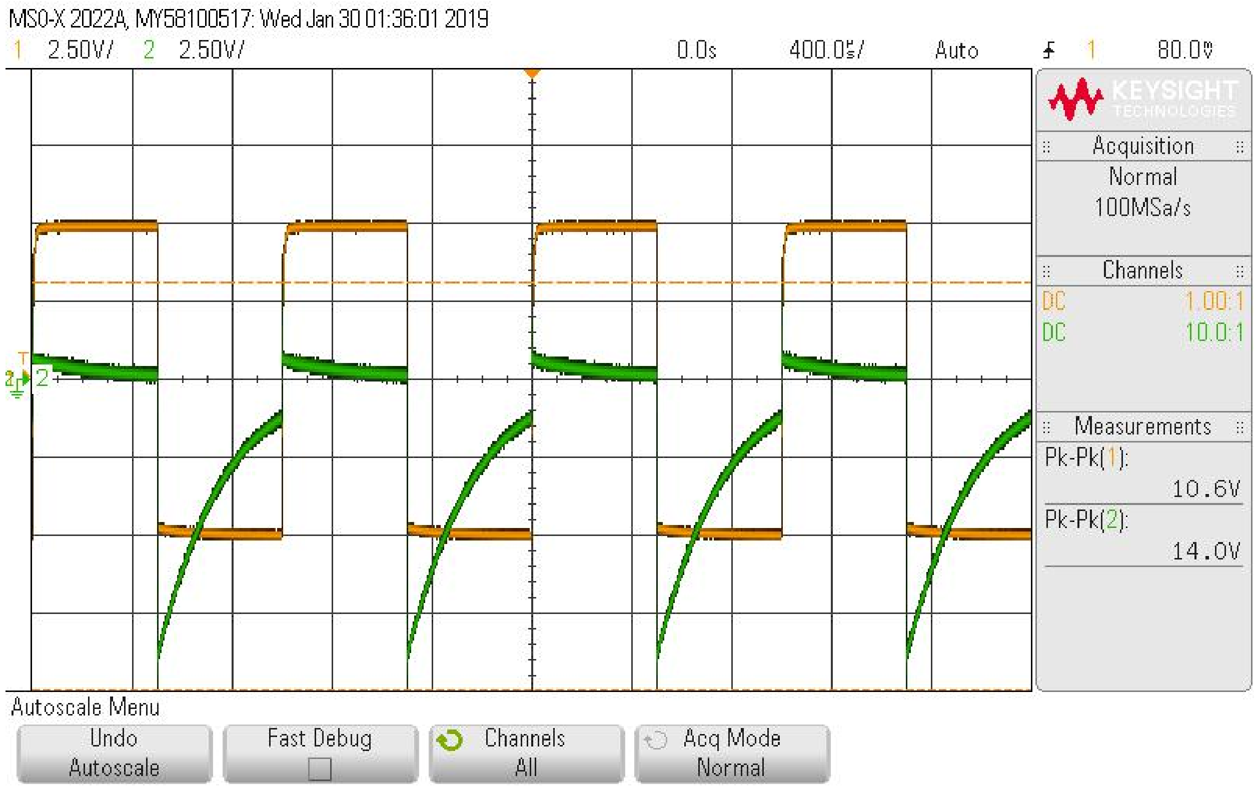

Figure 18: Negative clamping circuit, Vi(t)- orange, Vo(t) - green for R =$2.2k\Omega$(experimental)

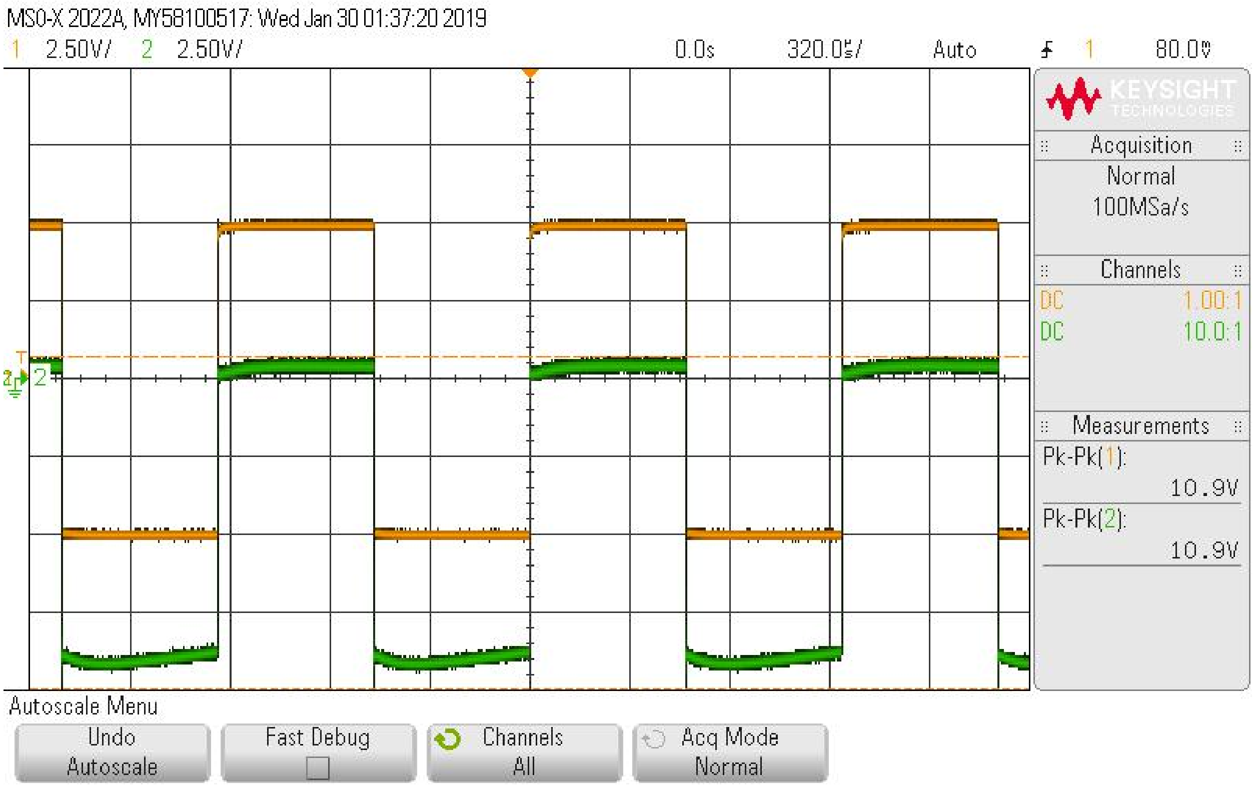

Figure 19: Negative clamping circuit, Vi(t)- orange, Vo(t) - green for R =$68k\Omega$(experimental)

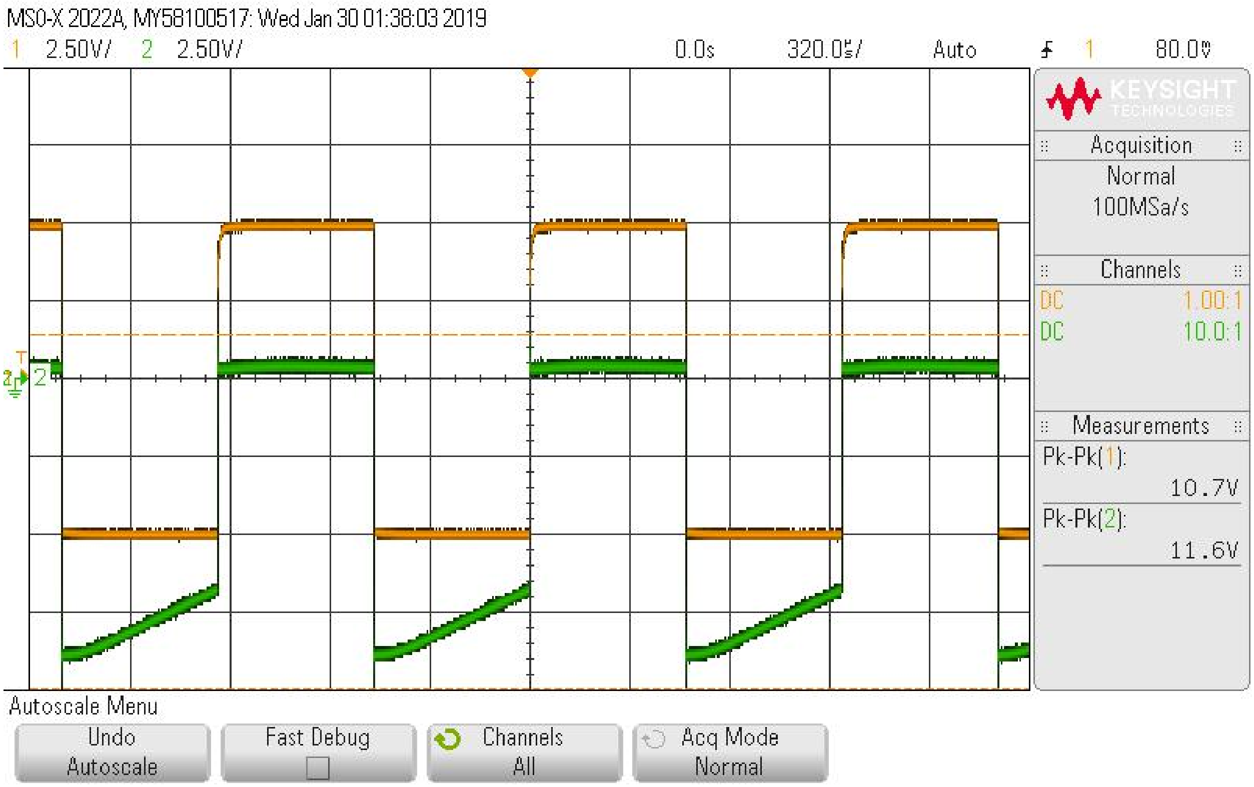

Figure 20: Negative clamping circuit, Vi(t)- orange, Vo(t) - green for R =$15k\Omega$(experimental)

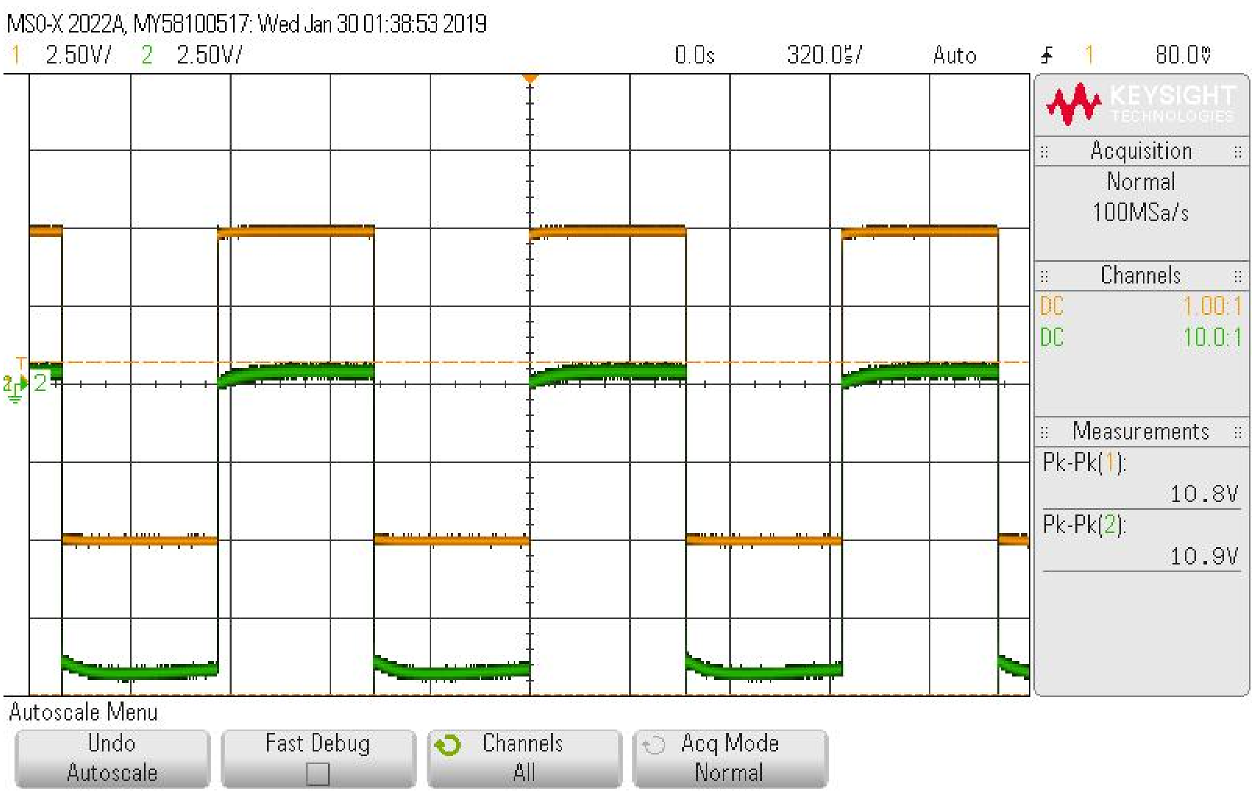

Figure 21: Negative clamping circuit, Vi(t)- orange, Vo(t) - green for R =$150k\Omega$(experimental)

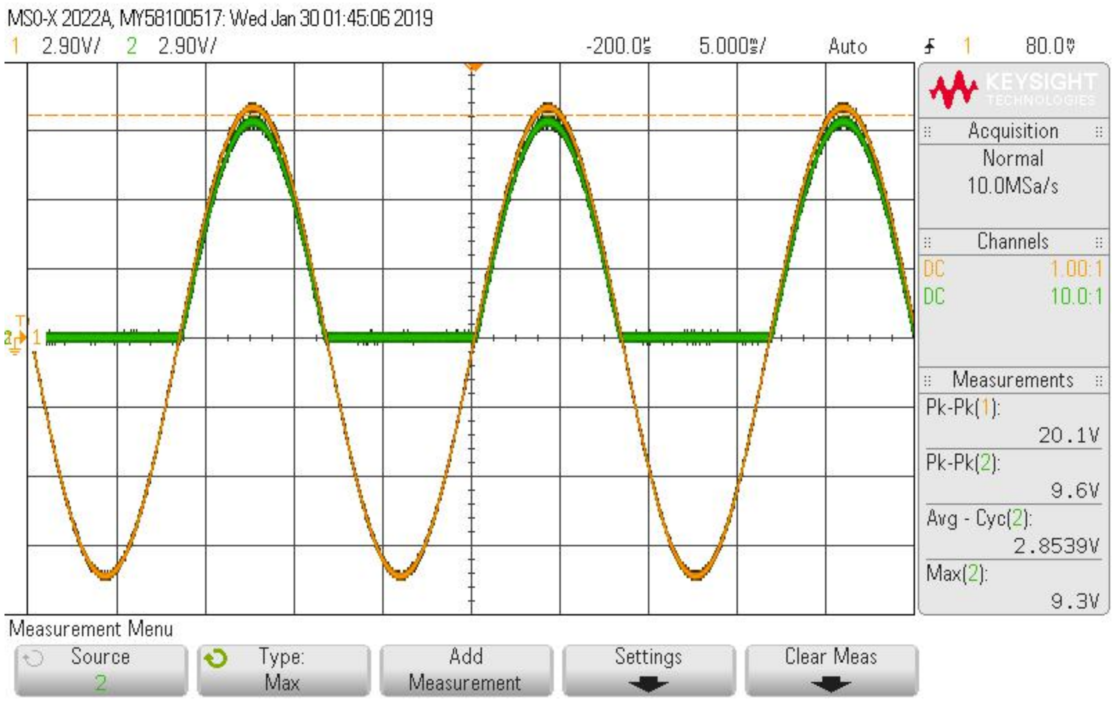

Figure 22: Half wave - rectifier, Vi(t)- orange, Vo(t) - green for R =$2.2k\Omega$(experimental)

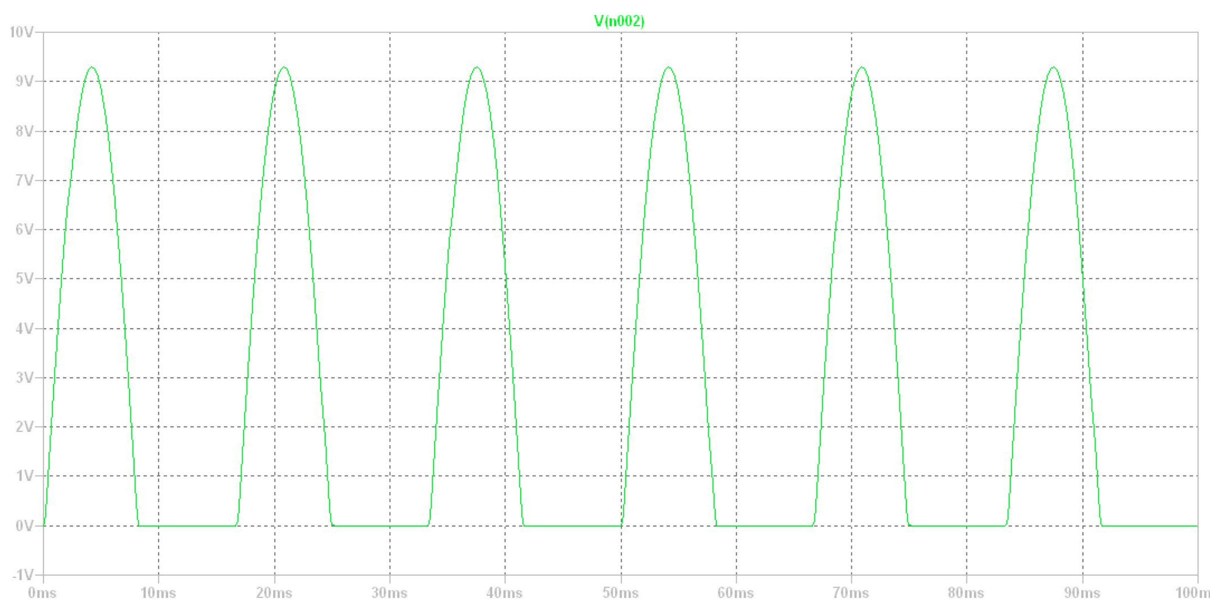

Figure 23: Full wave - rectifier,Vo(t) - green for R =$2.2k\Omega$(Prelab)

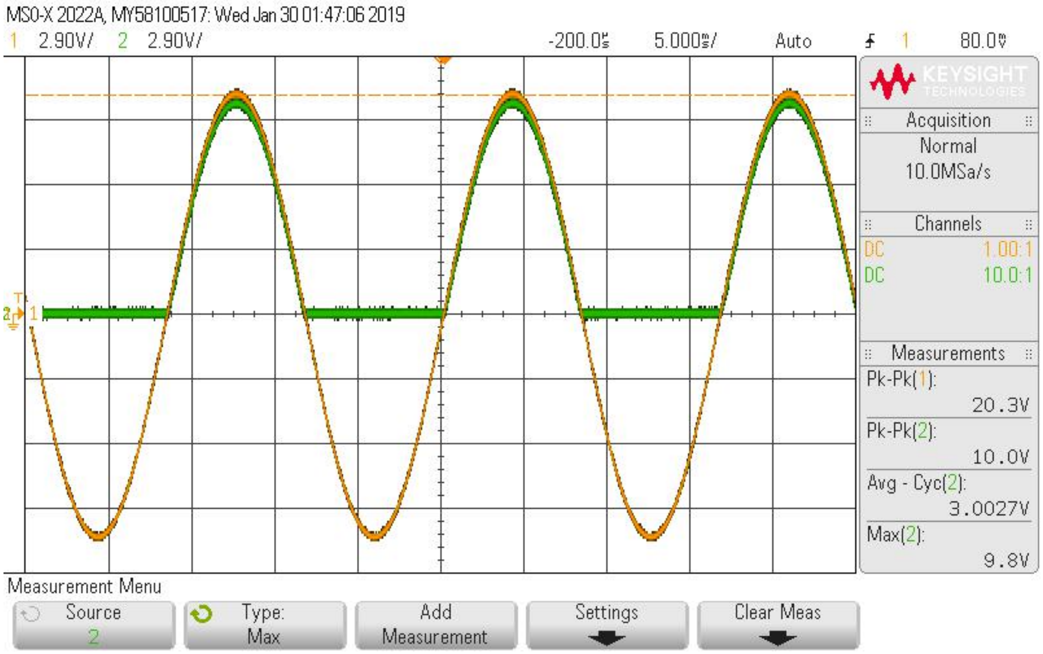

Figure 24: Half wave - rectifier, Vi(t)- orange, Vo(t) - green for R =$150k\Omega$(experimental)

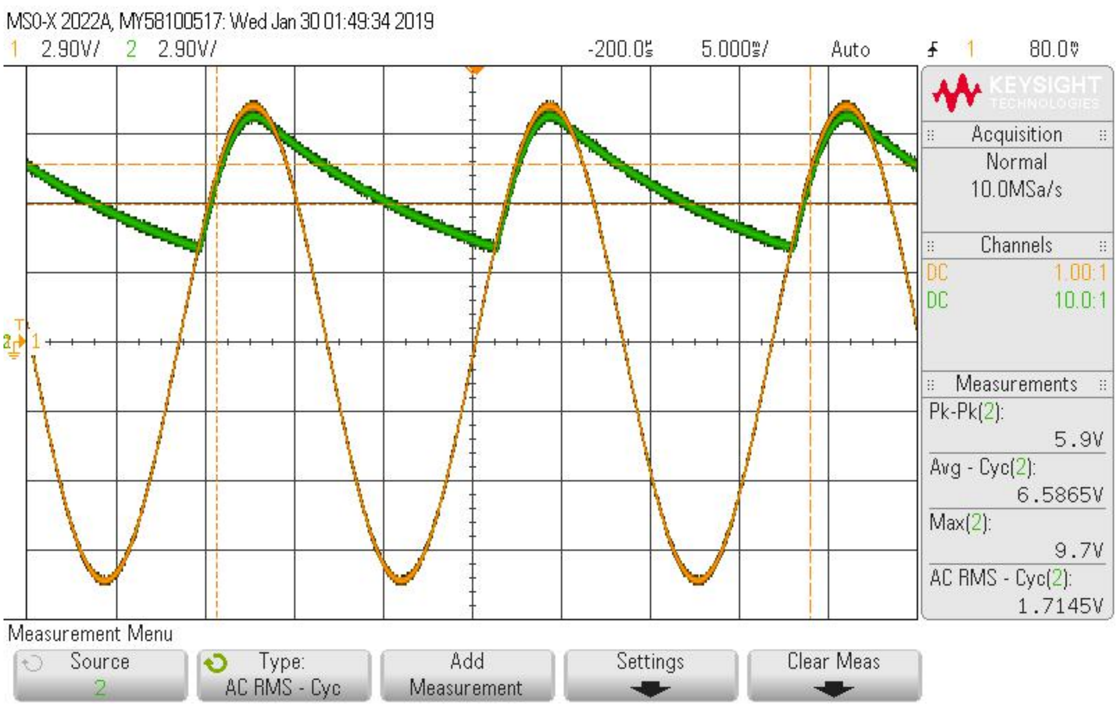

Figure 25: Half wave - rectifier, Vi(t)- orange, Vo(t) - green for R =$150k\Omega$ with .1uF in parallel(experimental)

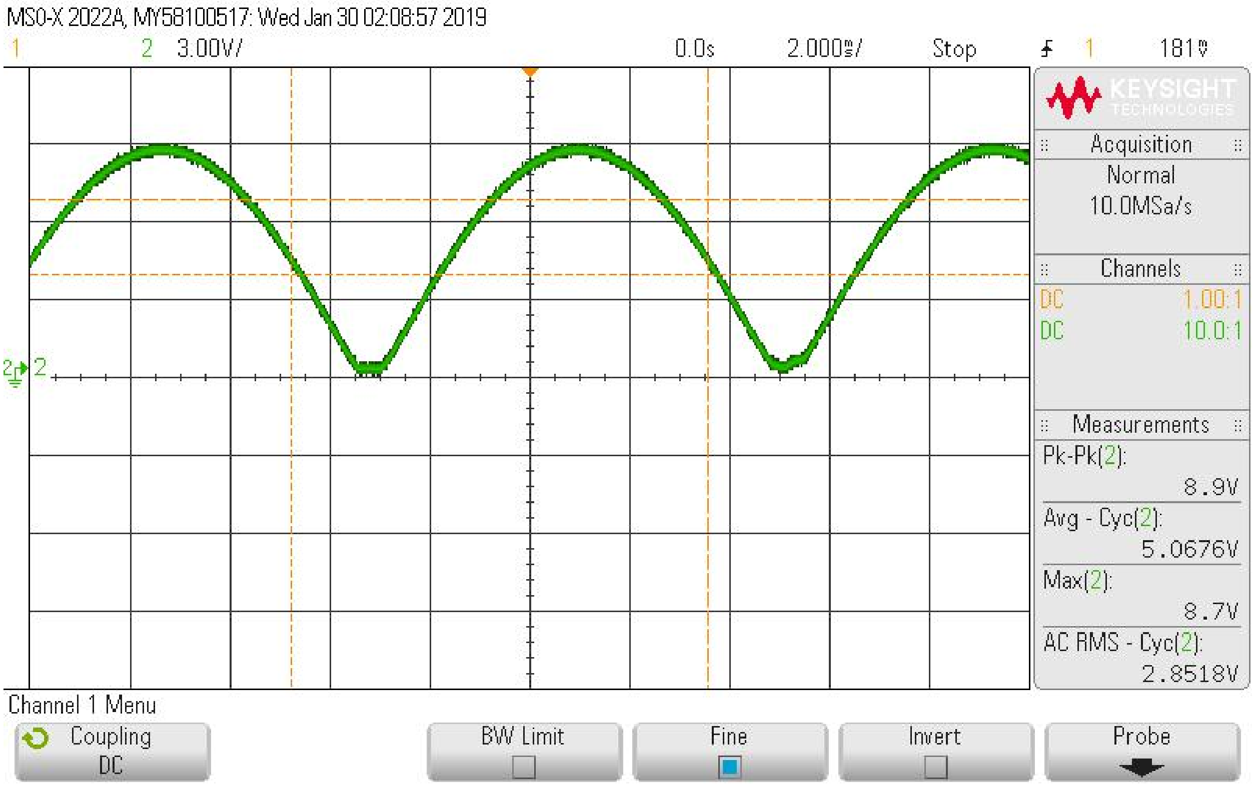

Figure 26: Bridge rectifier, Vo(t) - green for R =$2.2k\Omega$(experimental)

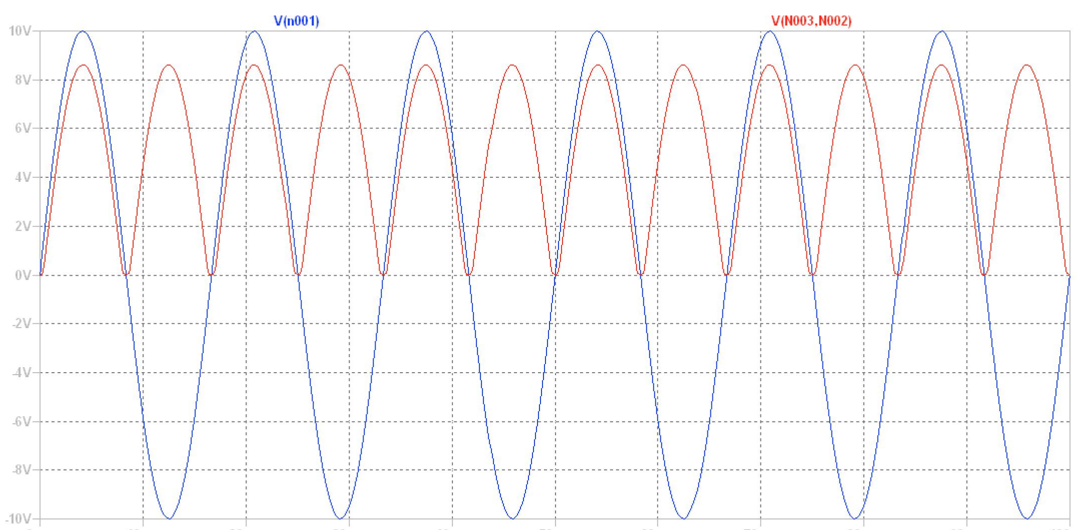

Figure 26: Bridge rectifier, Vo(t) - red and vi(t) blue for R =$2.2k\Omega$(Prelab)

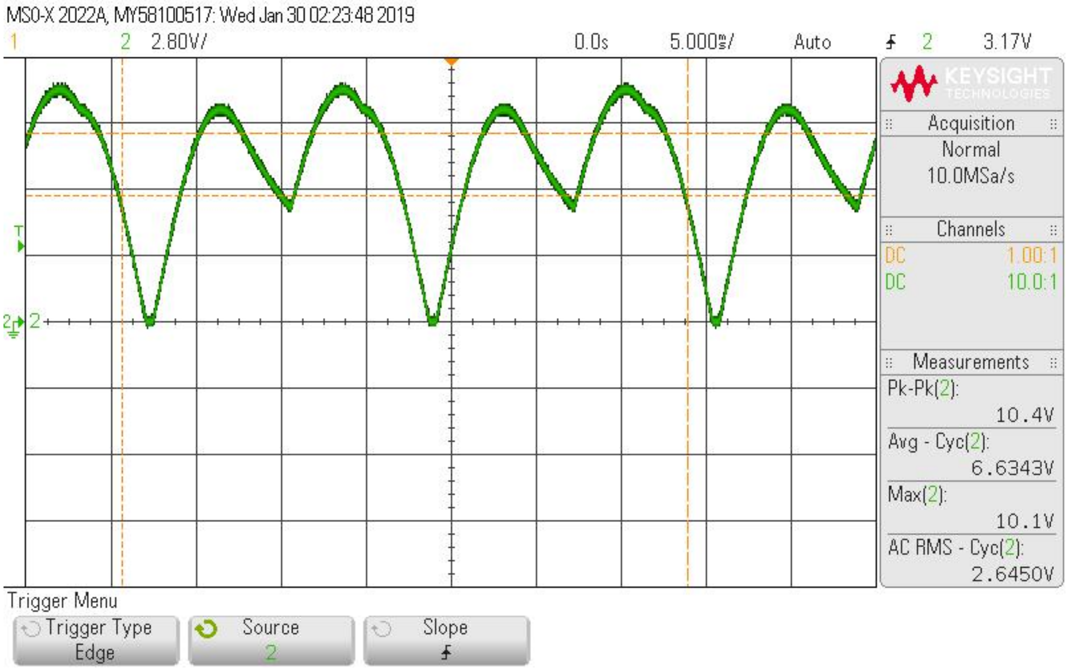

Figure 26: Bridge rectifier, Vo(t) - green for R =$150k\Omega$(experimental)

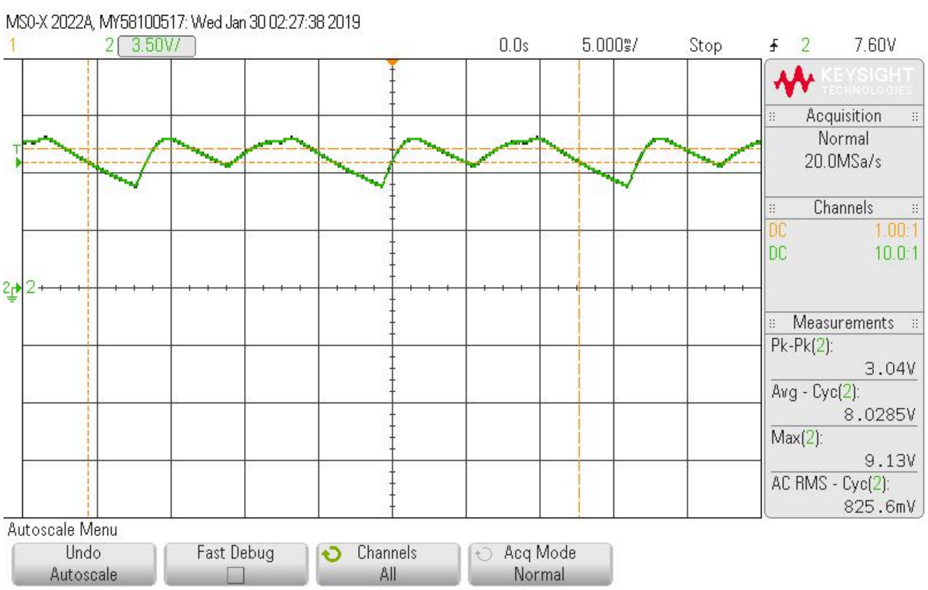

Figure 26: Bridge rectifier, Vo(t) - green for R =$150k\Omega$ with .1uF in parallel(experimental)

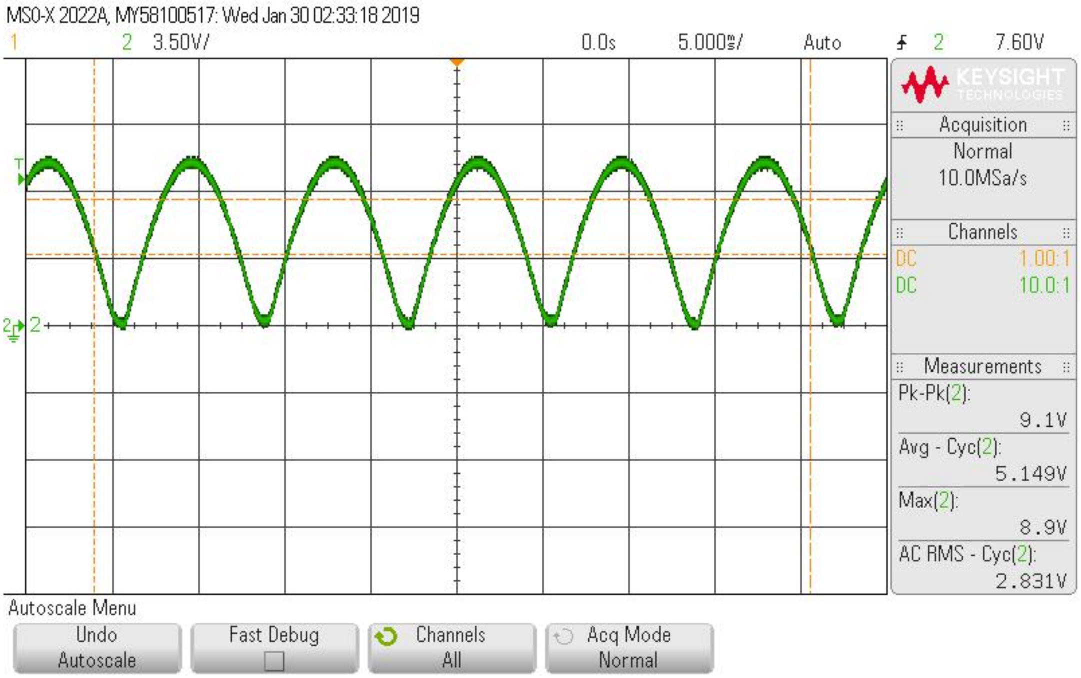

Figure 27: Bridge rectifier, Vo(t) - green for R =$2.2k\Omega$ with .1uF in parallel(experimental)

Table 1: Measured vs. Nominal Resistance Values

Nominal Resistance (Ω)	Measured Resistance (Ω)	Relative Difference (Ω)
15k	14.72 K	.32
68k	67k	1k
150k	147.5k	2.5k
2.2k (2.330k)	2.294k	.6k

Table 2: Measured resistances, and corresponding dc voltage for half-wave rectifier

Nominal Resistance (Ω)	DC output voltage (V)	AC RMS Ripple voltage (V)
150k	2.956	-

150k (parallel with .1uF)	6.55	1.67
2.2k (2.330k)	2.804	-

Table 3: Measured resistances, and corresponding dc voltage for full-wave rectifier

Nominal Resistance (Ω)	DC output voltage (V)	AC RMS Ripple voltage (V)
150k	6.6	-
150k (parallel with .1uF)	7.98	.766
2.2k (parallel with .1uF)	5.06	2.767
2.2k	6.58	-

Calculations:

Equations:

$$V_{FL} = \frac{V_{odc}}{l_{int}+R_{FL}} * R_{FL}$$ **[eqn.1]**

$$V_{NL} = \frac{V_{odc}}{l_{int}+R_{FL}} * R_{FL}$$ **[eqn.2]**

1. Using the no-load (open circuit) and full load dc output voltage measurements from Part 9 and 10, calculate the percent voltage regulation of the half-wave rectifier. Define voltage regulation as the no-load voltage minus the full-load voltage divided by the full-load voltage. Consider the 150 kΩ case no load and the 2.2 kΩ case full load.

1. Voltage regulation for the half-wave rectifier:

$VR = \frac{V_{no}-V_{full}}{V_{full}}$*100% = $\frac{2.956-2.804}{2.804}$*100% = 5.42%

2. Similarly, find the voltage regulation of the bridge rectifier from the data in parts 12-15. Compare the voltage regulation with and without the filter capacitor.

$VR = \frac{V_{no} - V_{full}}{V_{full}}$ * 100% = $\frac{6.6 - 6.58}{6.58} * 100\%$ = 0.304%

Voltage regulation for the bridge rectifier with the filter capacitor:

$VR = \frac{V_{no} - V_{full}}{V_{full}} *$ 100% = $\frac{7.98 - 5.06}{5.06} * 100\%$ =57.7%

3. Determine the internal resistance, r_{int}, of the rectifier based on the same data used to find the voltage regulation.

$$r_{int} = \frac{R_{FL}(\frac{V_{NL}}{V_{FL}} - 1)}{1 - \frac{V_{NL}R_{FL}}{V_{FL}R_{NL}}}$$

Half-Wave Rectifier

$r_{int} = 2200\Omega * (\frac{2.956}{2.804} - 1)/(1 - \frac{2.946*2200}{2.804*150000})$=121.1Ω

Full-Wave Rectifier

$r_{int} = 2200\Omega * (\frac{6.6}{5.04} - 1)/(1 - \frac{6.6*2200}{5.04*150000})$=694.3Ω

Full-Wave Rectifier without filter

$r_{int} = 2200\Omega * (\frac{7.98}{5.06} - 1)/(1 - \frac{7.98*2200}{5.06*150000})$=1279Ω

4. If the diodes were ideal:

   a. What dc output should the half-wave rectifier produce?

If the diodes were ideal, the dc output voltage of the half-wave rectifier would be the average of the voltage of the sine wave input over half of a period. With a 10V peak sine wave, the dc output voltage is as follows:

$$V_{DC} = \frac{1}{\pi}\int_0^{\pi} 10\sin(t)dt = \frac{10}{\pi} = 3.183V$$

b. What dc output voltage should the bridge rectifier produce?

The bridge rectifier keeps both portions of the wave, so the dc output of the bridge is just twice that of the dc output of the half-wave rectifier**.** With a 10V peak sine wave, the dc output voltage is as follows

$$V_{DC} = \frac{2}{\pi}\int_0^{\pi} 10\sin(t)dt = \frac{20}{\pi} = 6.366V$$

Questions

1. For what significant reason might the theoretical and experimental waveshapes of $V_o(t)$ in the clipper circuit be different?

Potentially the most significant reason is because in theoretical model, a standard diode is assumed. The diodes we are working with are not ideal and might differ even from the standard. They do require some turn on voltage which could differ from what LTspice assumed for the diodes, and there is a saturation current which might also be different. This will cause the experimental waveshapes to slightly differ from the theoretical plots. However, as seen from our measurements and plotted functions even if the diode is not quite ideal, it matches the theoretical behavior quite accurately. Of course there are other factor such as the resistors differing slightly from their nominal voltage and other small factors that arise from the lab setup, but the most fundamental difference between the theoretical setup and experimental setup is the idea of an standard versus real-world diode.

3. How would the normal operation of the clipper change, if the 15 kΩ current limiting resistance were replaced by a short circuit.

If the resistor were replaced with a short, this would make the node at the junction between D_1 and D_2 of the clipping circuit equal to the input voltage directly. There would no longer be any clipping behavior; the output voltage would just be equal to the input voltage as the devices would not be functioning as intended. The resistor is necessary to keep the clipper circuit functioning as necessary.

5. What relationship between RC and the period of the input waveform allows the clamper to perform effectively?

The relationship between RC and the period of the input waveform in the clamper circuit is that when the the input square wave is dropped to zero volts. The transient term of the output waveform drops off as well. Based on RC determines the correlation of Vi(t) and Vo(t), the greater the RC values the more vi(t) correlates to vo(t) and vice versa, this is because the capacitor has less time to discharge with bigger RC values.

7. a.) Consider that one diode in the bridge rectifier fails shorted. Explain how the normal circuit operation changes. Does some element overload? Does the output change?

If one diode in the bridge rectifier circuit fails to shorten on let's say the positive half cycle of the input voltage. The output will change be zero, because both of the diodes are acting as open circuits thus when there is no current there is no voltage across the resistor.

b.) Repeat part 7a, if this diode fails as an open circuit, the more likely the failure mode.

If one of the diodes fails as an open circuit then you will have two shorts across the resistor which is dangerous because both sides have the same potential. Most likely you will burn the resistor and fail, and you might get a spark.

9. Why is the bridge rectifier preferred over the half-wave rectifier?

The bridge rectifier is is preferred over the half-wave rectifier because the period of time the voltage across the resistor is zero is less than if we were to use a half-wave rectifier.

Sustainability:

This experiment was all about the different circuit configurations that can be created with the use of diodes. Diodes are everywhere in the world, from voltage rectifiers to convert AC to DC, or just simply lighting using LEDs.

The application of rectifiers are extremely useful in terms of sustainability because instead of requiring an entirely different DC power source, rectifiers make use of the AC sources already around us to convert AC to a practical DC voltage. The application of a rectifier can be something as simple as plugging in your phone charger which has a built in rectifier, or it can be something like signal demodulation which is useful for radio signals and working with electronics where the negative voltage is not needed.

Of course there is the argument that diodes and really any electronic are harmful towards the environment. This can be evident in just our typical lab setup. The lab only confirmed our suspicions of what we observed in LTspice; to help with sustainability the lab could have just been simulated in LTspice. However, ultimately the applications of the diodes create a sense of sustainability in a world so heavily reliant on electronics just by working with the power we have and converting the power into a useful state.

Conclusion:

This experiment allowed us to apply our understanding of diodes towards practical applications, analyze the difference between our experimental values with our theoretically calculated values, and come up with explanations for those differences. In the clipping circuit, we could see that our experimental graphs were almost identical to our theoretical graphs we made from the prelab. We also observed that altering the additional DC voltage sources changes the amount of clipping on the input voltage; an example would be increasing V_1 increases the max positive input voltage. In the clamping circuit, we saw that our experimental graphs did not appear to be the same as our simulated graphs, but the difference can be attributed to the shift in our experimental scale to fit the input and output on the same screen as well as a 5V DC offset in the simulation. At low resistances in the clamping circuit, the voltage takes a steep drop. But, as the resistance increases, the output voltage observed fits more similarly to the input voltage. Also, reversing the diode only changes the range of voltage from 0 to 10V to 0 to -10V. In the half-wave rectifier, we observed that the circuit rejects negative current and prevents the circuit from outputting the exact input voltage, due to the implied voltage drop from the diode which prevents the output from reaching it's maximum. Our measured DC voltage and theoretical DC voltage differed with a decent amount of percent error, but this error can be attributed to the inaccuracy of our multimeter since we had to restart it whenever we wanted to take a measurement.

Generally, with the addition of a capacitor in parallel with the resistor in the rectifier circuits, we observed that the output voltage decreased as the capacitor discharged and it never reached 0V. Also, whenever resistance values increased, the output signal stabilized and mirrored the input voltage with slight differences. Additionally, when the resistance, in which the voltage is being measured across, is small, there will be more inaccuracy in measurements. Overall, our results were relatively consistent with our theoretical data and this lab allowed us to implement different diode circuits to observe their behavior under certain circumstances.