

EE320L Electronics I

Laboratory

Laboratory Exercise #5

Clipping and Clamping Circuits

By

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Objective:

The purpose of this lab is to understand the operation of clipping and clamping circuits and their applications.

Equipment Used:

Power Supply

Oscilloscope

Function Generator

Breadboard

Jumper Wires

TL082 or LF412 Dual JFET Input Operational Amplifiers

10x Scope Probes

Various Resistors and Capacitors

Background:

Clipping and Clamping Circuits

Diodes, despite being two terminals devices have more uses than it may seem. While the application most commonly associated with diodes is rectification for power supplies and radio frequency detection, diodes are also used for clipping and clamping signals. Clipping is simply bounding a signal to limited amplitude. Clamping is shifting the center of an AC signal to a different value. Both of these operations can be implemented with a diode and a few passive components. Active versions of these circuits are implemented with op-amps. As is commonly the case, using op-amps allows the performance of a circuit to approach theoretical ideals. Clipping and clamping circuits find widespread use in audio and video circuitry.

A brief digression into the types of diodes is important for designing clipping and clamping circuits. Diodes can be classified based on their material type, application and structure. Most diodes today are made out of silicon. These diodes have a forward voltage drop of around 0.6V. In the past, germanium diodes were more common and had a forward voltage drop of 0.3V. They can still be purchased if one looks hard enough. The intended application is what sets diodes made from the same material apart. Diodes are either intended for power rectification or small-signal operation. Power rectifier diodes are relatively large, slow and have small forward voltage drops near the minimum for a particular material type. Small signal diodes are fast, have slightly higher forward voltages and higher series resistances. These diodes are used for RF and fast switching applications. One can use either power or small-signal diodes in clipping and clamping circuits depending on the user's forward voltage and speed requirements. Finally diodes can be classified by structure. Schottky and zener diodes are classifications based on structure. A schottky diode layers a semiconductor and a metal which results in a very low forward voltage of 0.2-0.3V. A zener diode uses doping to achieve a low precisely set reverse breakdown voltage compared to normal diodes. Zeners have breakdown voltages from 3.3V to 100V. All these different diodes enable creativity with clipping and clamping circuits.

Clipping a signal is done to prevent its amplitude from exceeding a certain limit. An example of a signal and its clipped version is shown below in fig. 1. Notice that anything exceeding the set limit is “clipped” off. This is where the word clipping comes from. Changing the point at which clipping occurs results in fig. 2.

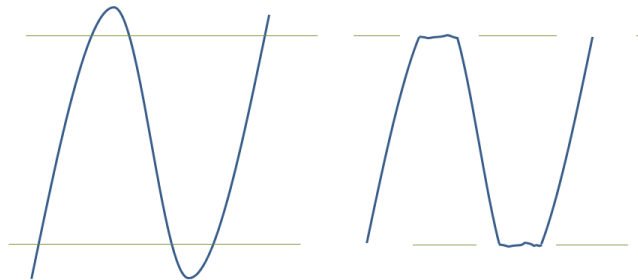


Figure 1 Clipping

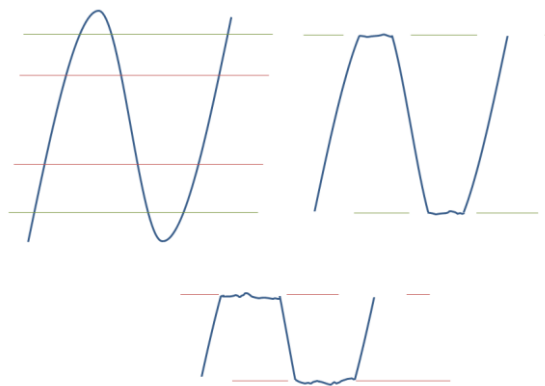


Figure 2 Clipping Points

Looking at these waveforms, two effects of clipping are apparent. The amplitude of the waveform is reduced and the shape is changed. Two immediately apparent applications of clipping circuits are input protection and square wave generation. Some sensitive circuits can be damaged if large signals are applied to them. Clipping can be used to protect these circuits by limiting the signal amplitude. If a sine wave is clipped significantly the resulting waveform looks like a square wave. This forms a rudimentary sine wave to square wave converter.

Clipping circuits are implemented with diodes in various configurations and rely on their unidirectional current conduction property. Recall that all diodes have a particular **forward voltage** beyond which the diode conducts significant current. If a signal is applied across a diode and is large enough to forward bias the diode then the diode will conduct current and limit the signal's amplitude to the forward voltage of the diode. Since most AC signals are symmetrical in the positive and negative directions two diodes are used in an anti-parallel combination. A simple clipper circuit is shown in fig. 3. The output of the circuit is shown in fig. 4. The input signals are 0.5V, 1V and 1.5V. Notice how a small input signal of 0.5V (blue trace) has its

amplitude and shape preserved. As the input signal exceeds the diodes turn-on voltage of 0.6 the waveforms become more clipped.

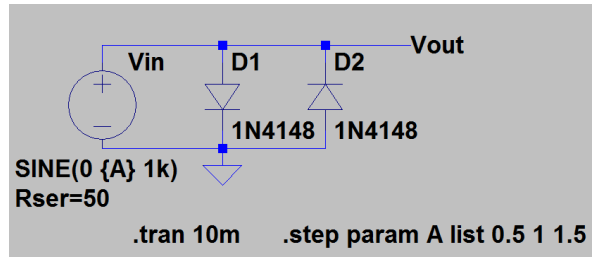


Figure 3 Simple Clipping Circuit

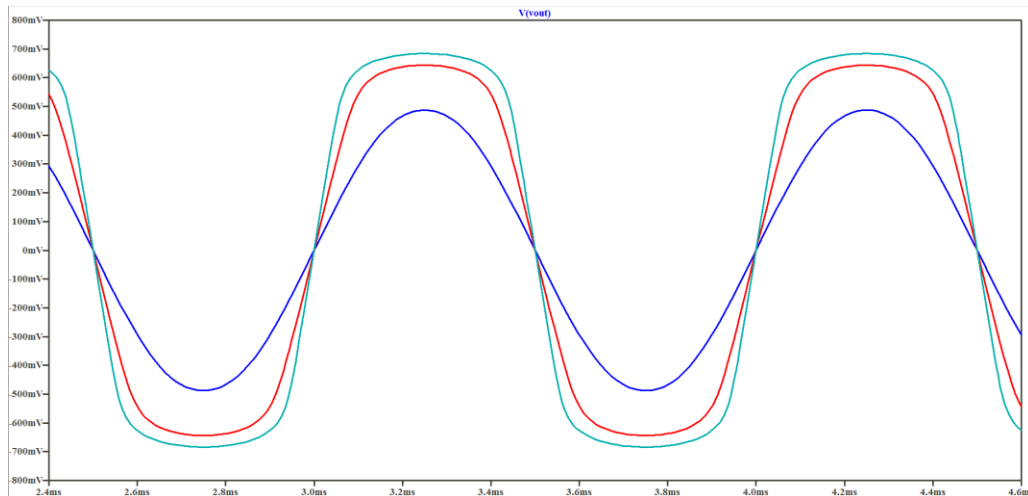


Figure 4 Output with 0.5V, 1V and 1.5V Input

In the previous circuit the signal amplitude was limited to around 0.7V. This is a result of the physical properties of the diode. If different diodes were used, then the amplitude will be limited to different values. Fig. 5 shows a zener diode based clipper. In this circuit the diodes are “back to back” in series instead of parallel. If zener diodes were placed in parallel then the circuit would behave as if it had normal diodes connected since the forward voltage drop of a zener is the same as a normal diode. Placing them in series gives the clipper circuit an amplitude limit of $V_{limit} = \pm V_z + V_f$, where V_z is the zener voltage of the diode and V_f is the forward voltage diode drop. The output of the clipper for 3, 5 and 7 volts is shown in fig. 6. The zener diodes used are 4.7V which results in $V_{limit} = \pm V_z + V_f = 4.7V + 0.6V = 5.1V$.

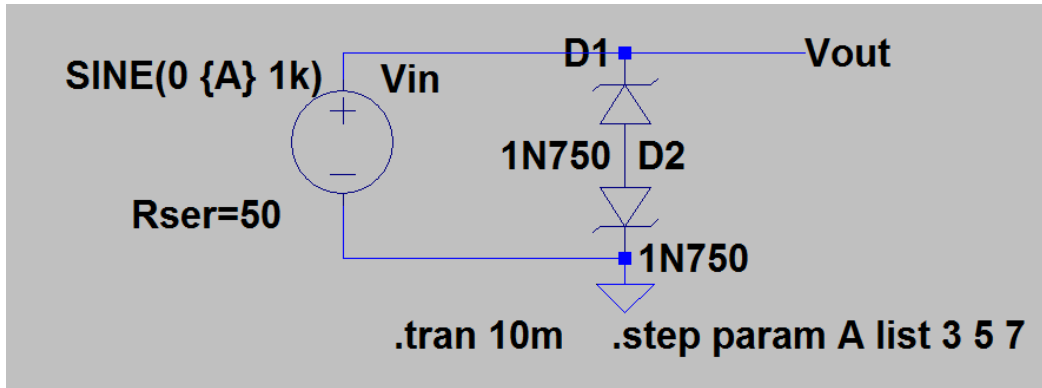


Figure 5 Zener Diode Clipper

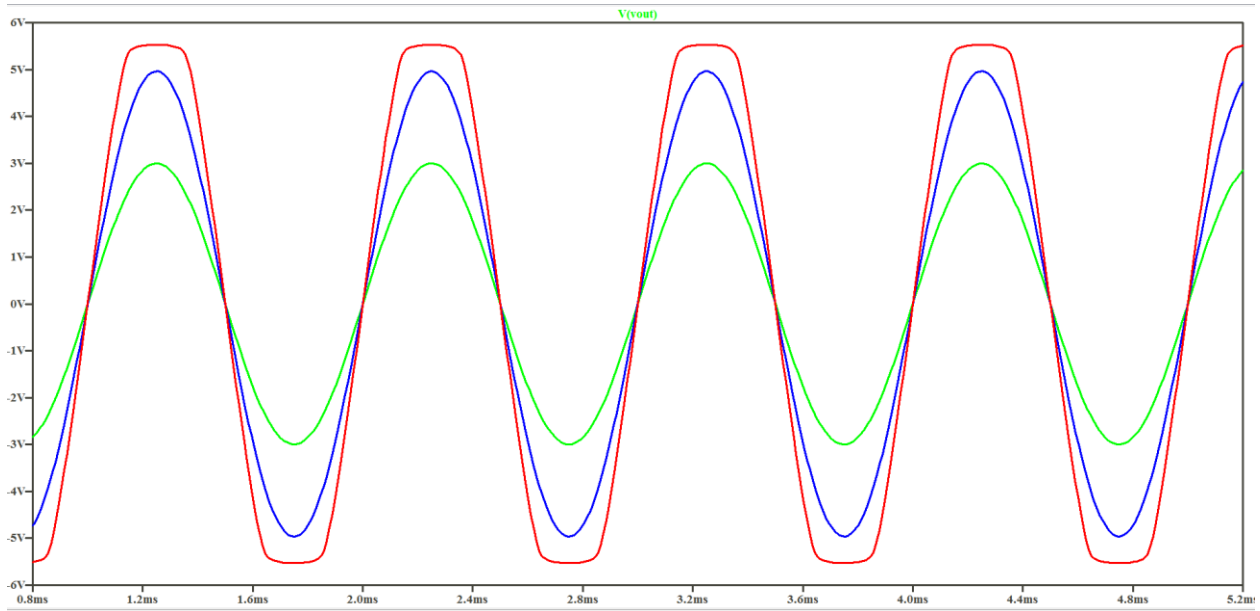


Figure 6 Output with 3V, 5V and 7V Input

Clamping circuits are simple yet their operation can be hard to understand. A clamping circuit is used to “clamp” a signal to a fixed DC level. This is also known as “DC restoration.” This term dates back to the first television receivers which needed to restore a transmitted signal to a reference value to set the black level. A simple clamping circuit is shown below in fig. 7. The capacitor separates the voltage source from the load and the diode sets the clamping voltage level. The input and output of the circuit is shown in fig. 8. The input signal is a 5V sine wave. The output signal is the sine wave shifted so that the negative excursion of the sine wave is now at 0V minus a diode drop (0.6), or -0.6V.

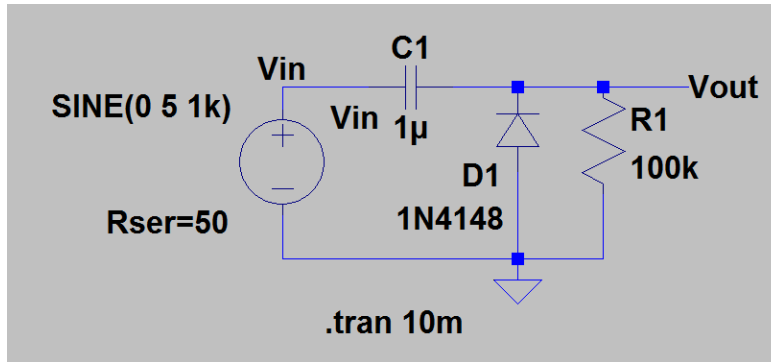


Figure 7 Simple Clamping Circuit

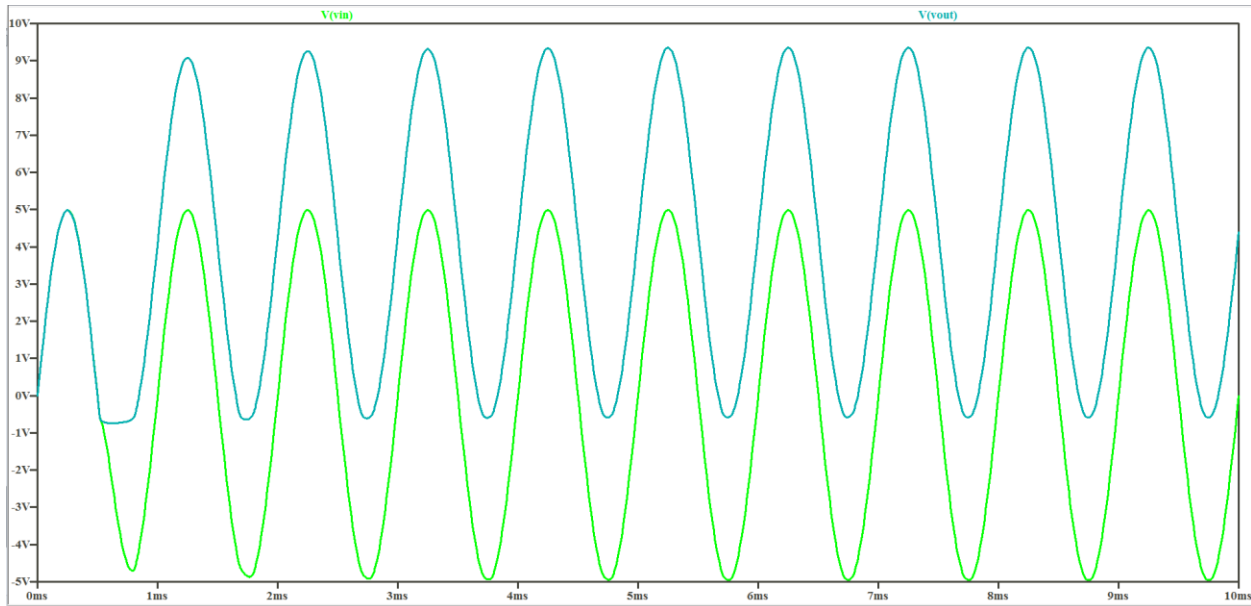


Figure 8 Input(green) and Output(teal)

To understand how this circuit works a more detailed plot is required shown in fig. 9. This plot adds two additional traces to fig. 8. The red trace shows the current through the diode and the blue trace shows the voltage across the capacitor. At the start of the simulation it can be seen that the output voltage (teal) tracks the input voltage (green) exactly until the voltage gets below the forward bias voltage of the diode which in this case is -0.6V . At this moment, current begins to flow through the diode as shown by the first red spike. As current flows, the capacitor's voltage charges up to the peak level of the input signal. Once the capacitor is charged, the peak level of the signal becomes the new center point for the signal. Once the capacitor is fully charged current only flows through the diode when the resistor discharges the capacitor enough to cause the diode to forward bias again and conduct. It is important to not load down this circuit too much for optimal performance. Note that switching the polarity of the diode will cause the signal to be shifted by the negative peak level of the signal. If a different DC level is desired, a separate DC supply can be added between the diode and ground.

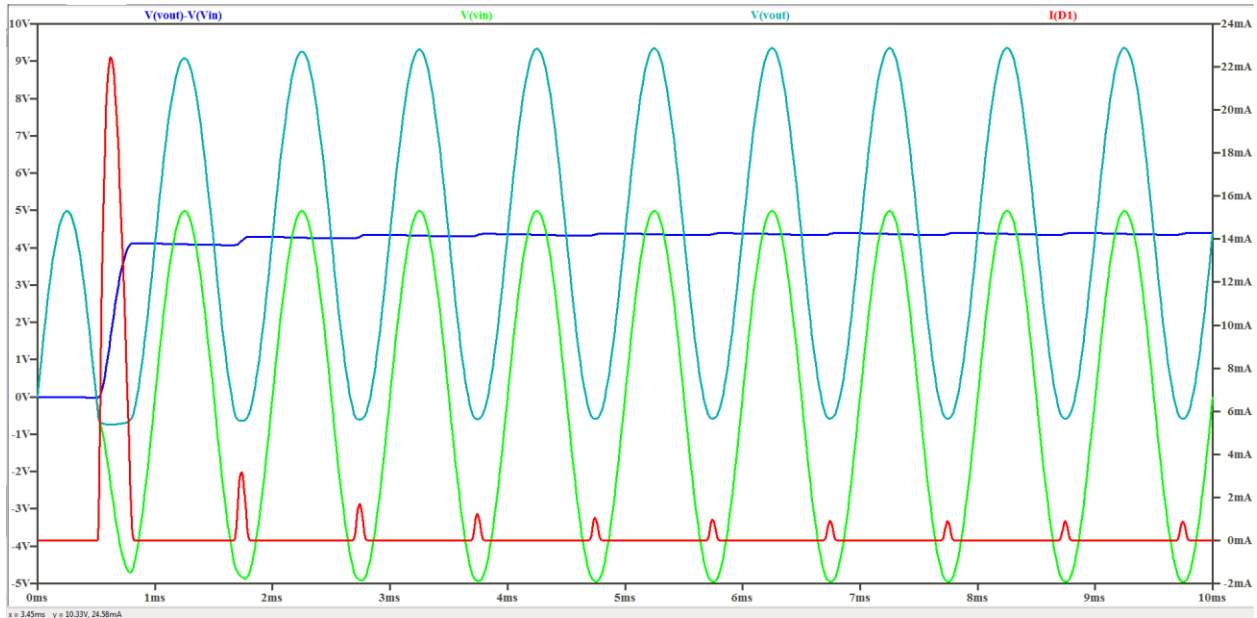


Figure 9 Capacitor Voltage (Blue), Input Voltage (Green), Output Voltage (Teal), and Diode Current (Red)

While these clipping and clamping circuits are useful, they can be improved through the use of op-amps. An op-amp based clipper is shown in fig. 10. This circuit is very straightforward to understand. It is the basic inverting amplifier topology but with back to back zener diodes added to the feedback path. The gain of the op-amp is $-\frac{R_f}{R_{in}} = \frac{200k}{10k} = 20$ as expected but the zener diodes limit the amplitude of the signal to $V_z + V_f = 4.7 + 0.6 = 5.1V$. Looking at the output this is not the case. We can see that the output is clipping at 3.6V (0.3V input). The reason for this is that diodes do conduct some current below their forward voltage/breakdown. This current conduction results in an earlier onset of clipping. Notice that the peaks of the clipped signal are rounded and not as square as the simple clipper circuit. This characteristic can be used to implement a “soft-clipping” function.

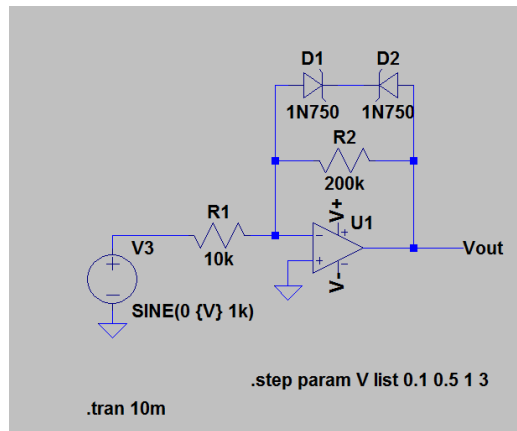


Figure 10 Op-Amp Clipper Circuit

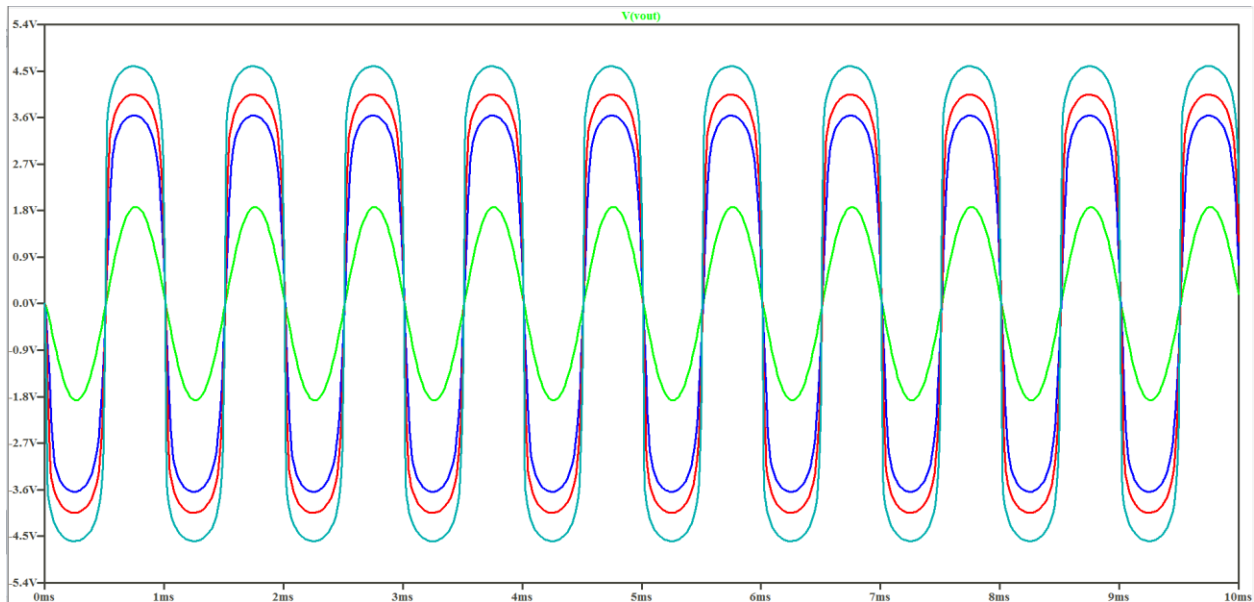


Figure 11 Output with 0.1V, 0.5V, 1V and 3V input

The use of an op-amp to implement a clamper circuit is where the very high gain of an op-amp is beneficial. The op-amp clamper circuit is shown in fig. 12. This circuit encloses the diode within the feedback loop of the op-amp. This causes the forward voltage drop of the diode to be divided by the gain of the amplifier. Since the gain of an op-amp is in the millions, the voltage drop is negligible at the output. The op-amps maximum output voltage does drop by the forward voltage drop of the diode however. The resistor is used to set the input impedance of the circuit. The desired DC level can be applied to the non-inverting terminal of the op-amp. In fig. 12, the level applied is zero volts. The input and output can be seen in fig. 13. The output is shifted by exactly the peak value of the signal without the influence of the diode.

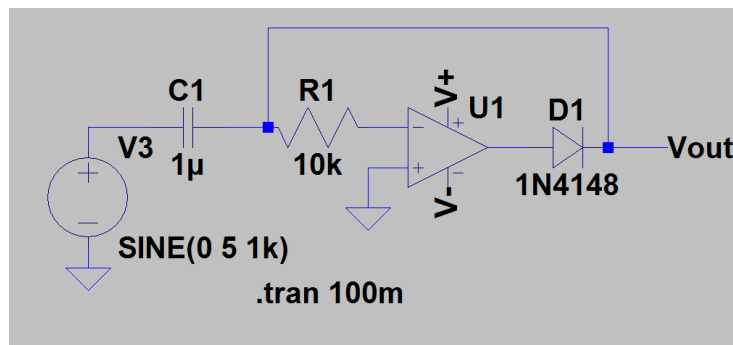


Figure 12 Op-Amp Based Clamper

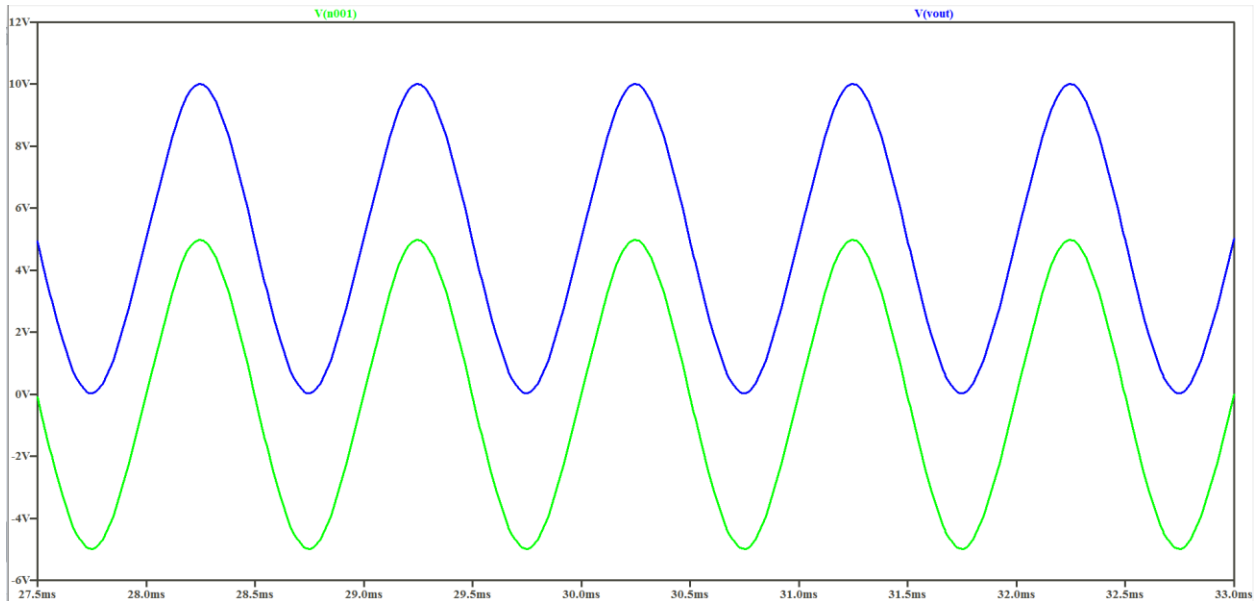


Figure 13 Input (Green) and Output (Blue)

Prelabs:

Prelab 1: Simulate a Simple Clipper Circuit.

Draw the circuit as shown below in fig. 14 in LTSpice. Set the diode models to be 1N4148 as shown in the schematic. These are the most common small signal diodes. To select the diode model right click on the body of the diode and click on “Pick New Diode” then select “1N4148”. The voltage source is set to be a 1V 1 KHz sine wave and has a series resistance of 50 ohms. Do not forget to set the series resistance. If the series resistance is zero then the clipper circuit will not work because the voltage source will “overpower” the diodes and force the voltage to be whatever it is set to. Right clicking on the voltage source lets you set its properties. Notice that the field to enter series resistance is highlighted in green in fig. 15. Also note that the Rload is simply the expected input impedance of the stage after the clipper. Since this is most likely to be a voltage amplifier it will have fairly high input impedance. Finally, run a transient simulation of 10mS duration. The output is shown in fig. 16.

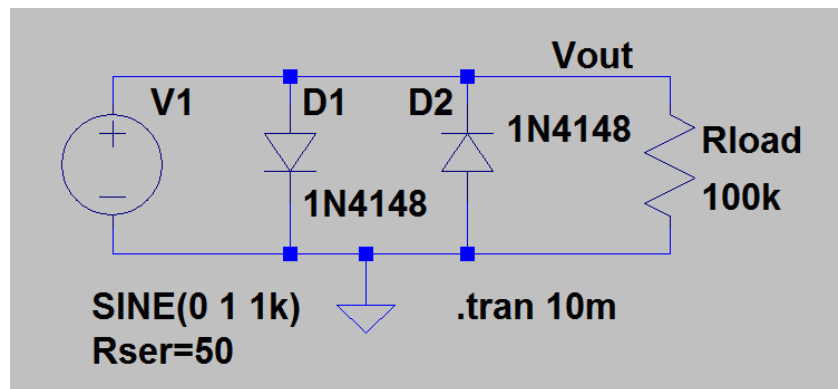


Figure 14 Simple Diode Clipper

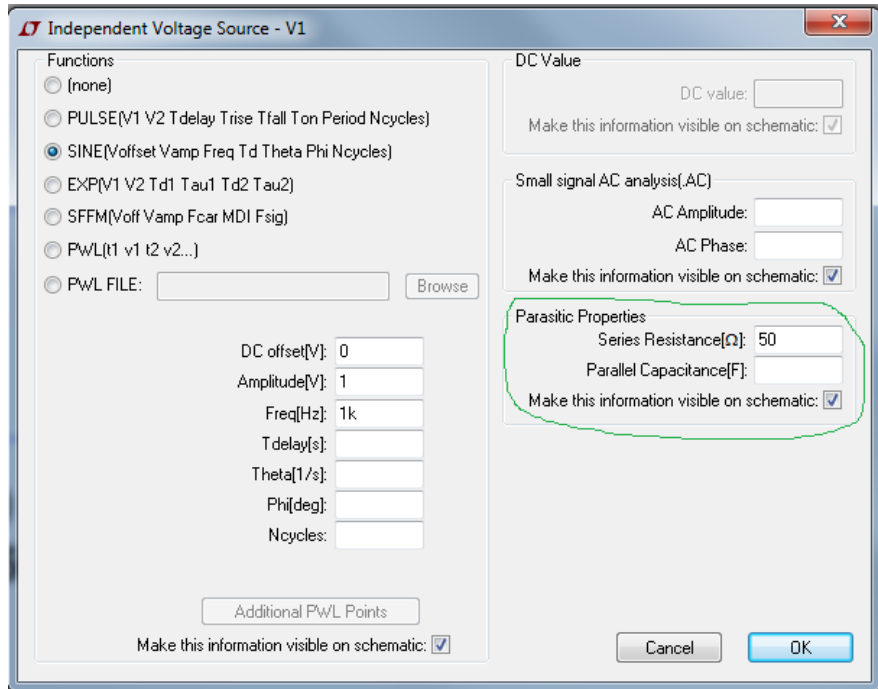


Figure 15 Editing Series Resistance

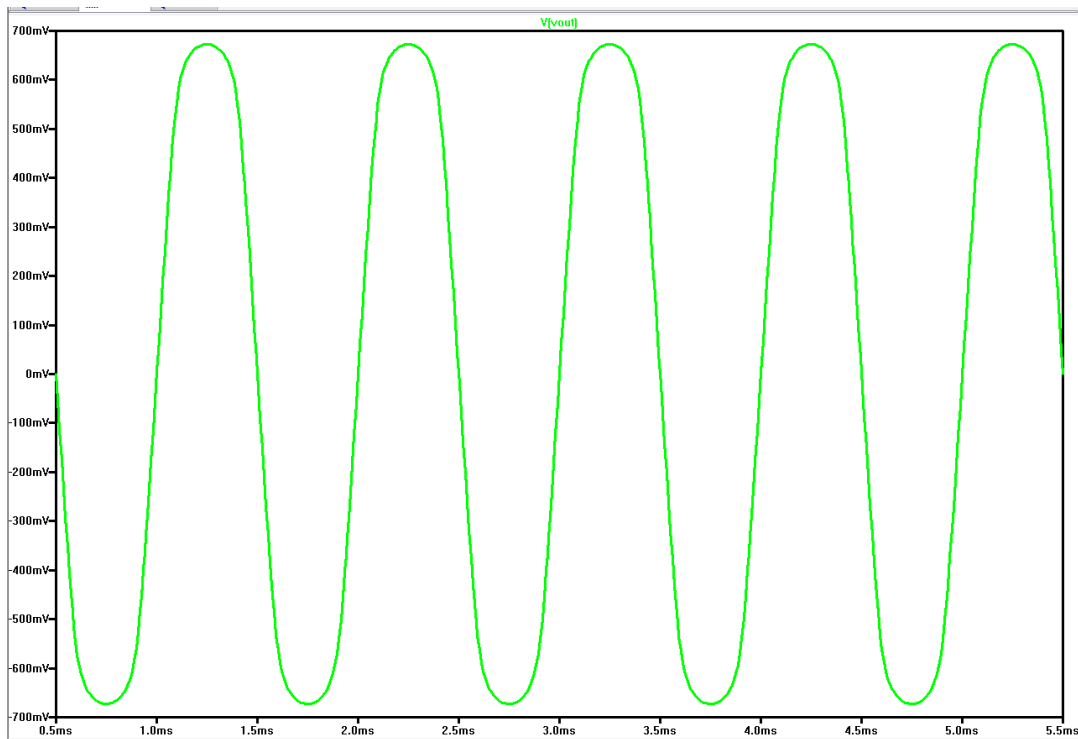


Figure 16 Output

Prelab 2: Simulate a Series Zener Clipper Circuit.

Draw the circuit as shown below in fig. 17 in LTSpice. The zener diode symbol is appropriately called “zener” in the component selection menu. It is only a symbol though and using the normal diode symbol is fine too but won’t indicate to someone reading the schematic that the diode is a zener diode. Right click on the diodes and set them to “1N750”. One thing that is different in this schematic is that the voltage source is set to “{V}”. In the amplitude field enter “{V}”. This is done so that we can run a transient analysis for a few different values of amplitude to see how the circuit responds to different inputs all on the same graph. This makes nice looking plots and reduces tedium. Enter a .op statement “.step param V list 1 3 5 7 9”. This statement runs the transient analysis for each value listed for the parameter V in curly brackets. The output is shown in fig. 18. Right clicking on the graph and clicking on “select steps” lets you pick which values to display and is useful if your graph is too cluttered.

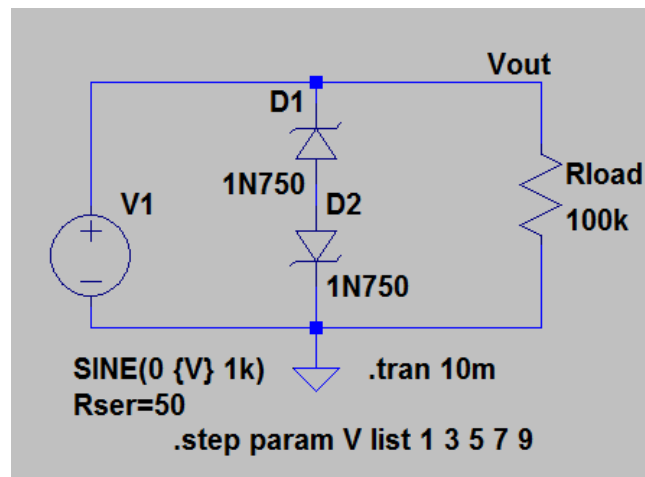


Figure 17 Zener Clipper

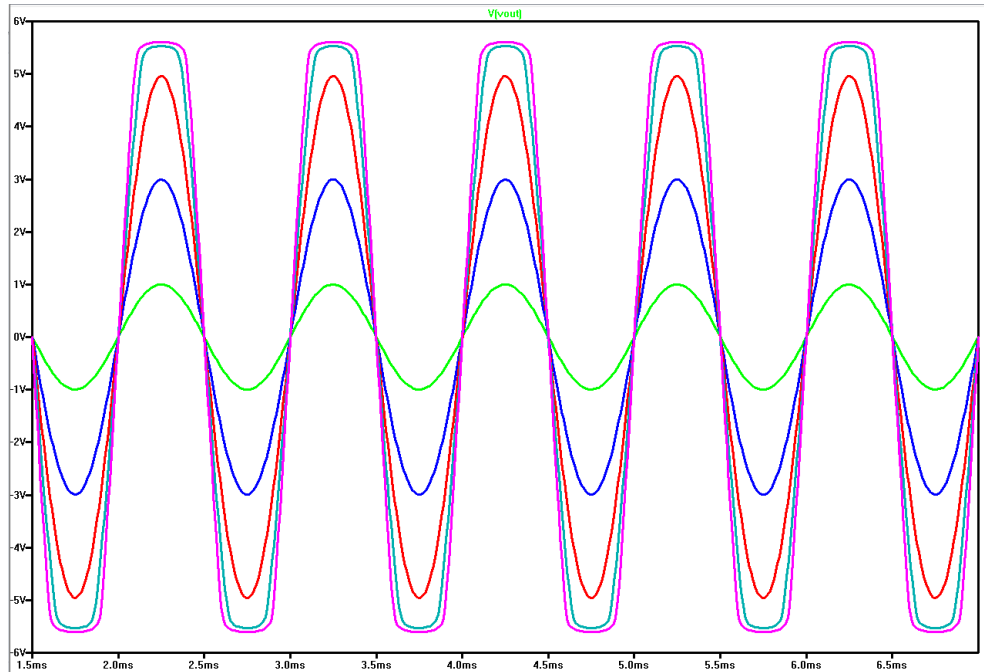


Figure 18 Outputs with 1V, 3V, 5V, 7V and 9V inputs.

Prelab 3: Simulate a Simple Clamper Circuit

Draw the circuit exactly as shown below in fig. 19. At this point the schematic should be self-explanatory. The output of the circuit is shown in fig. 20. Notice how the capacitor takes the first few cycles to charge up. The output is shifted up to the DC level minus the diode drop of 0.6V.

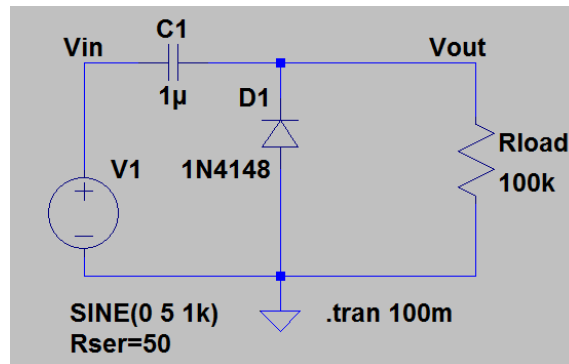


Figure 19 Simple Clamper

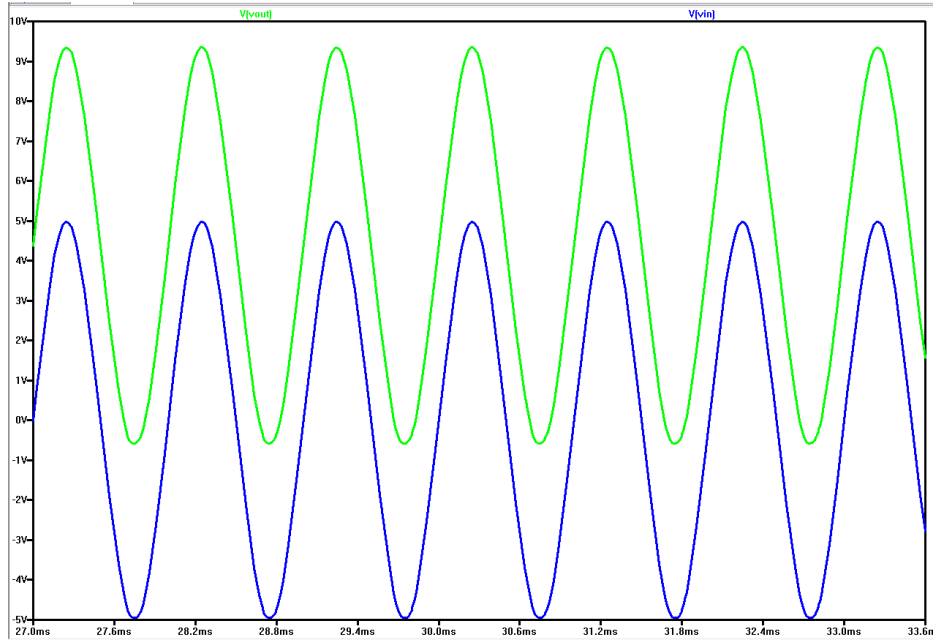


Figure 20 Output of Simple Clamper

Prelab 4: Simulate an Op-Amp Clipper

Draw and simulate the circuit shown below in fig. 21. Use a universal op-amp. Be sure to enclose the voltage value of the input source in curly brackets for the parameter step to work properly. Run a transient analysis of 10mS for 0.1V, 0.5V, 1V and 3V inputs. You should get the output shown in fig. 22.

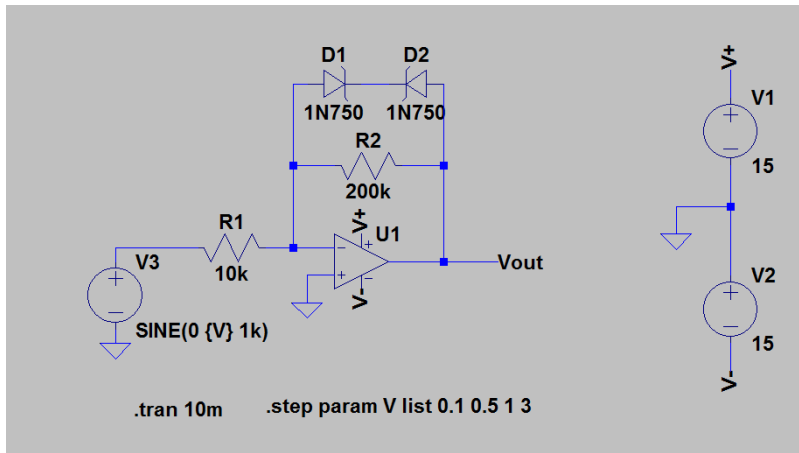


Figure 21 Op-Amp Clipper

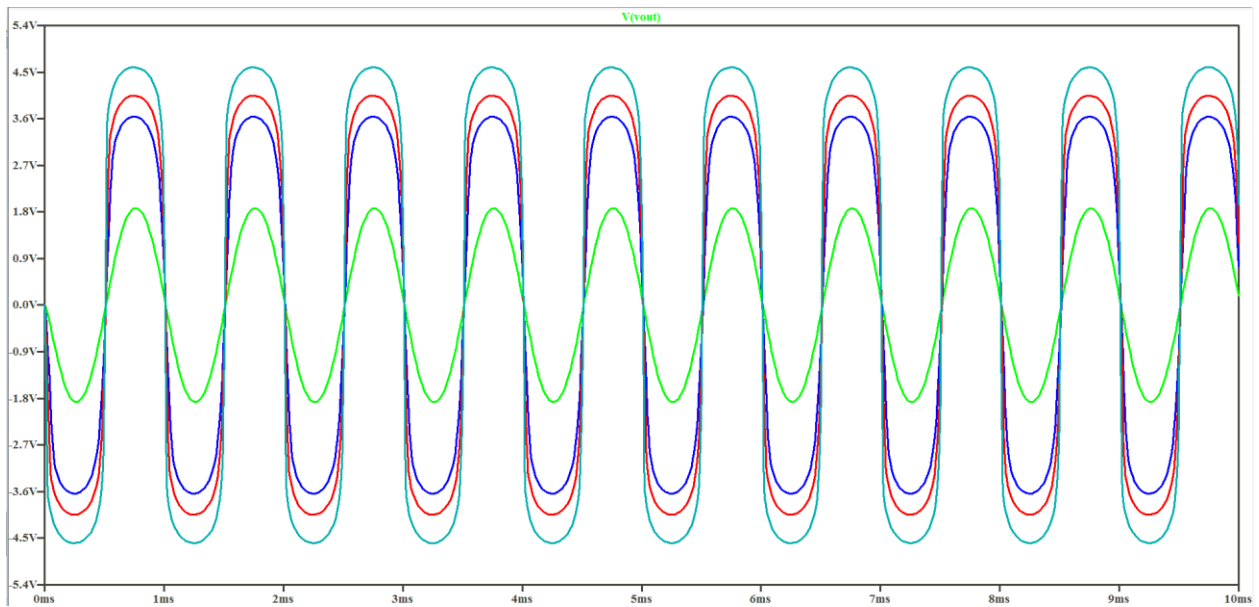


Figure 22 Outputs with 0.1V, 0.5V, 1V and 3V Inputs

Prelab 5: Simulate an Op-Amp Clamper

On the same schematic as prelab 4 draw an op-amp based clamper circuit as shown in fig. 23. Run a transient analysis for this simulation. You should get the output shown in fig. 24. Next, combine the clipper and clamper circuits as shown in fig. 25. If you're having trouble, delete the voltage input for the clamper and connect the output from the clipper to the input of the clamper. Then run a 10mS transient analysis with stepped parameters of 0.1, 0.5, 1 and 3V inputs. The output is shown in fig. 26.

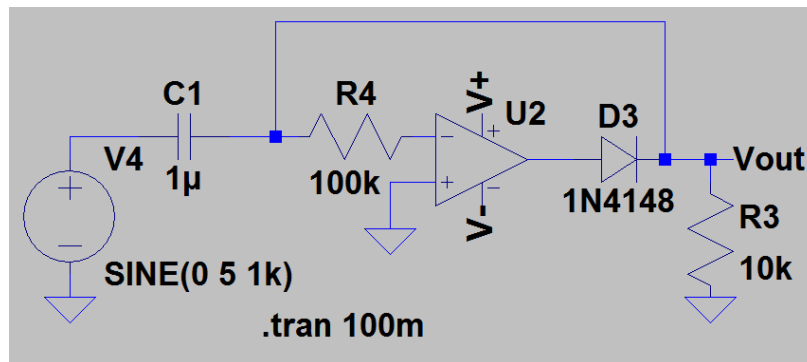


Figure 23 Op-Amp Clamper

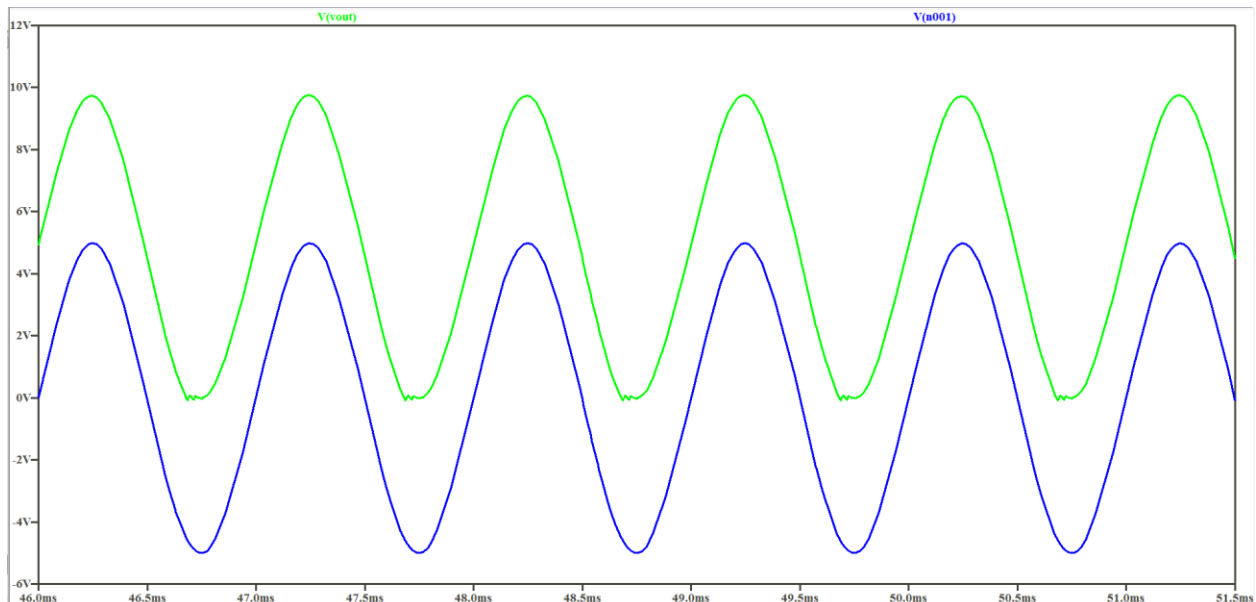


Figure 24 Output of Op-Amp Clamper

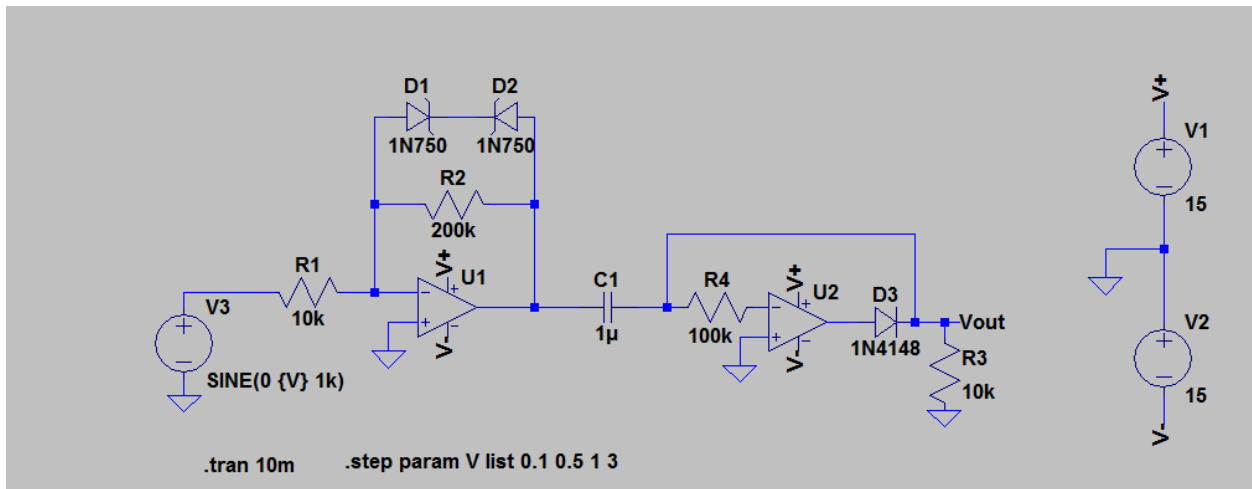


Figure 25 Combined Op-Amp Clipper and Clamper Circuit

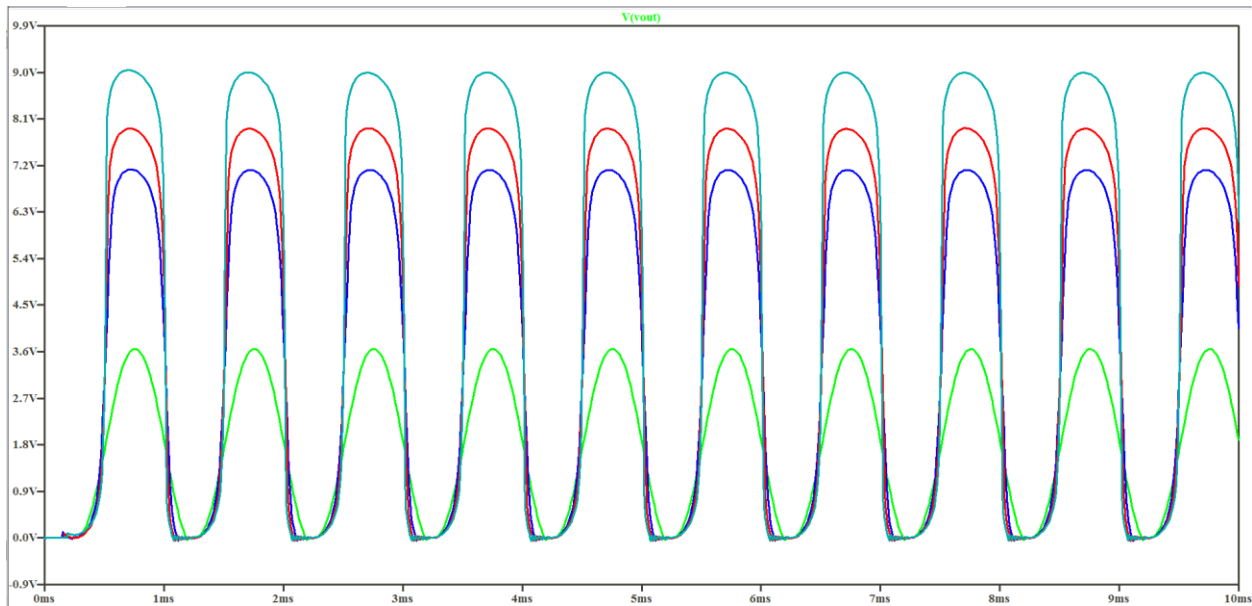


Figure 26 Output with 0.1V, 0.5V, 1V and 3V Inputs.

Prelab Deliverables:

- 1). Submit screenshots of each prelab's schematic and simulation output.
- 2). Email the .asc file (LTspice file format) of your prelab to your TA.

Laboratory Experiments:

Experiment 1:

Construct the simple diode clipper circuit as shown in prelab 1. Find the point at which it begins to clip the input signal. Take a picture of the clipped waveform.

Experiment 2:

Construct the zener diode clipper circuit as shown in prelab 2. Find the point at which it begins to clip the input signal. Take a picture of the clipped waveform.

Experiment 3:

Construct the simple clamper circuit as shown in prelab 3. Compare the input and the clamped output waveforms. Take a picture of these waveforms.

Experiment 4:

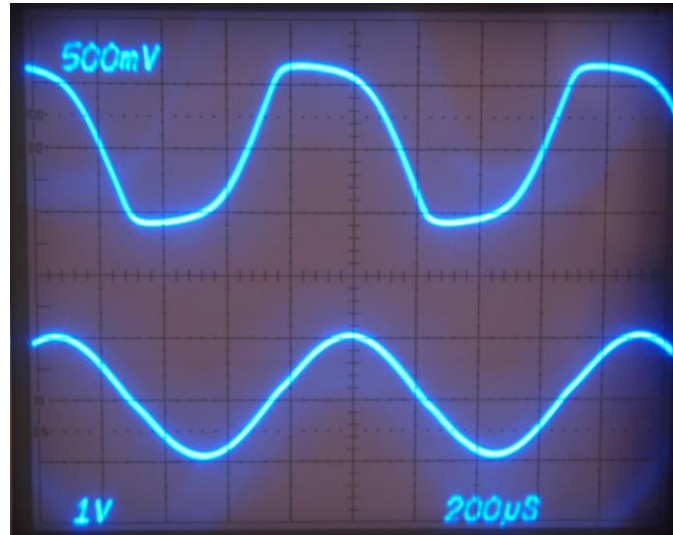
Construct the op-amp based clipper circuit as shown in prelab 4. Find the point at which the signal begins to clip significantly. Compare the input and clipped output waveforms. Take a picture of these waveforms.

Experiment 5:

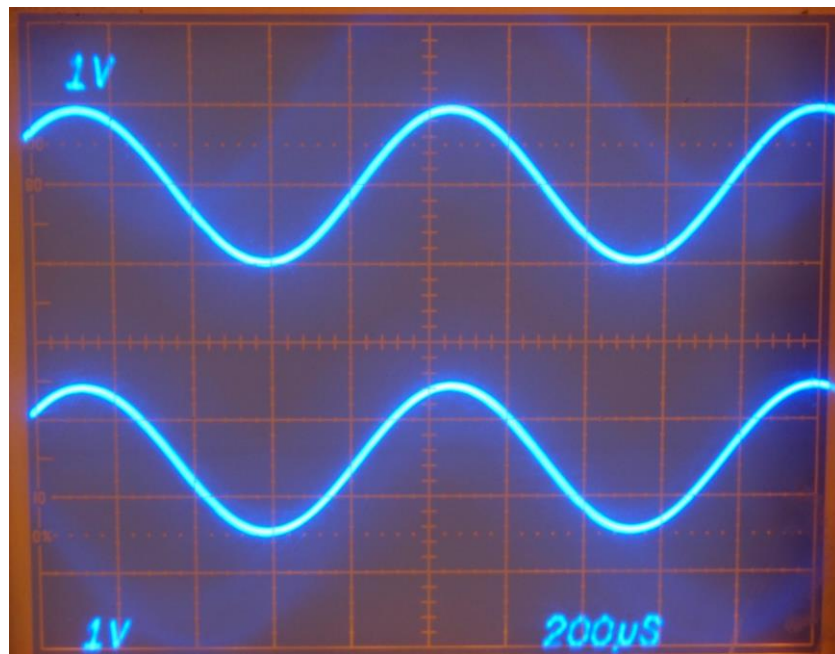
Construct the op-amp based clamper circuit as shown in prelab 5. Compare the input and the clamped output waveforms. Next combine the op-amp clipper and clamper circuits and compare input and output waveforms. Take a picture of these waveforms.

Useful Pictures:

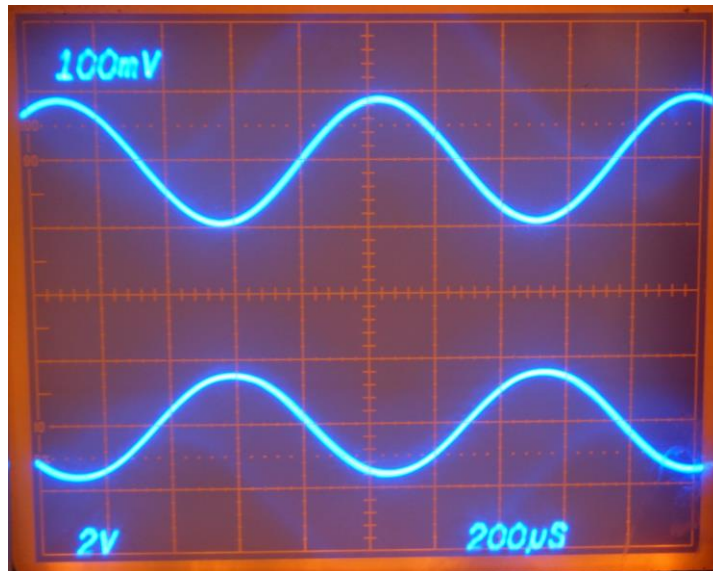
Here are some useful pictures of the waveforms of the real circuits (zener clipper not pictured) that can help guide you.



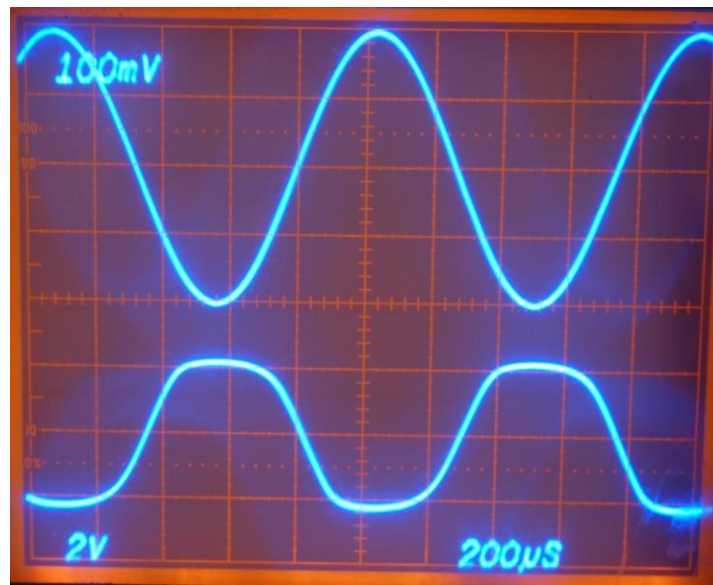
Input (bottom) and output (top) of simple clipper circuit. 1x probes used (do not use 1x probes). A capacitor was used to separate input and output, you do not need to show the input waveform.



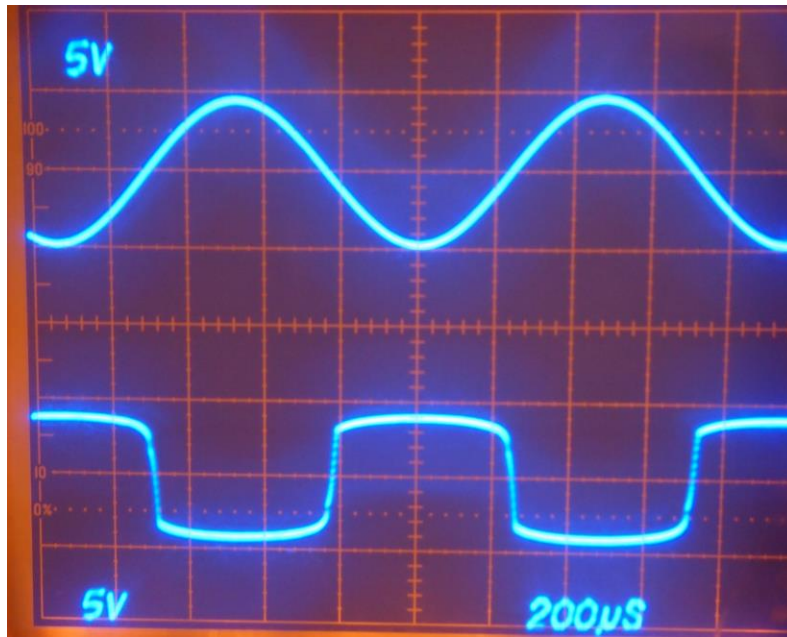
Input(top) and output(bottom) of simple clamper circuit. Notice how the bottom waveform is shifted up. 1x probes were used.



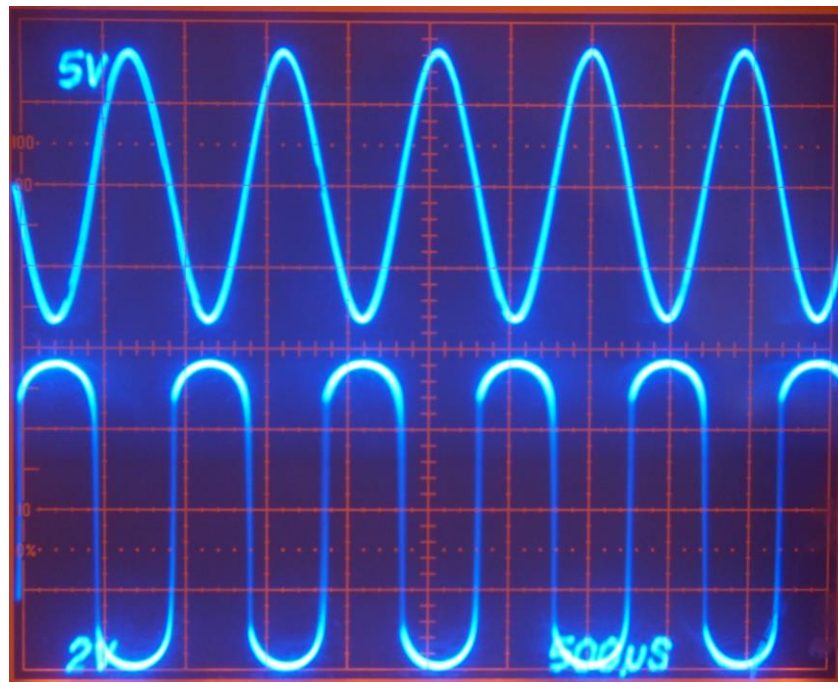
Input (top) and output (bottom) for op-amp clipper circuit. Input signal level of 200mV P-P causes no clipping.



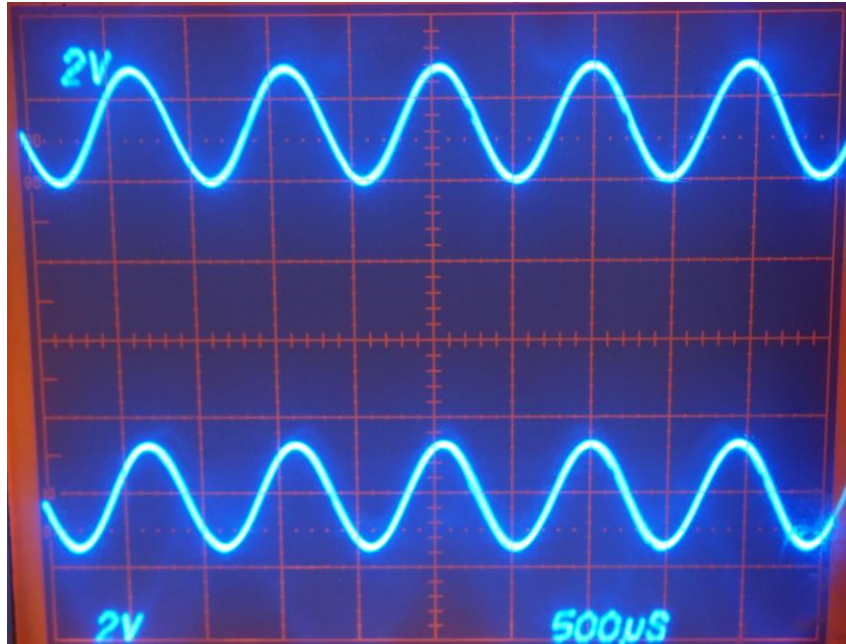
Input (top) and output (bottom) for op-amp clipper circuit. Input signal level of 400mV P-P causes clipping.



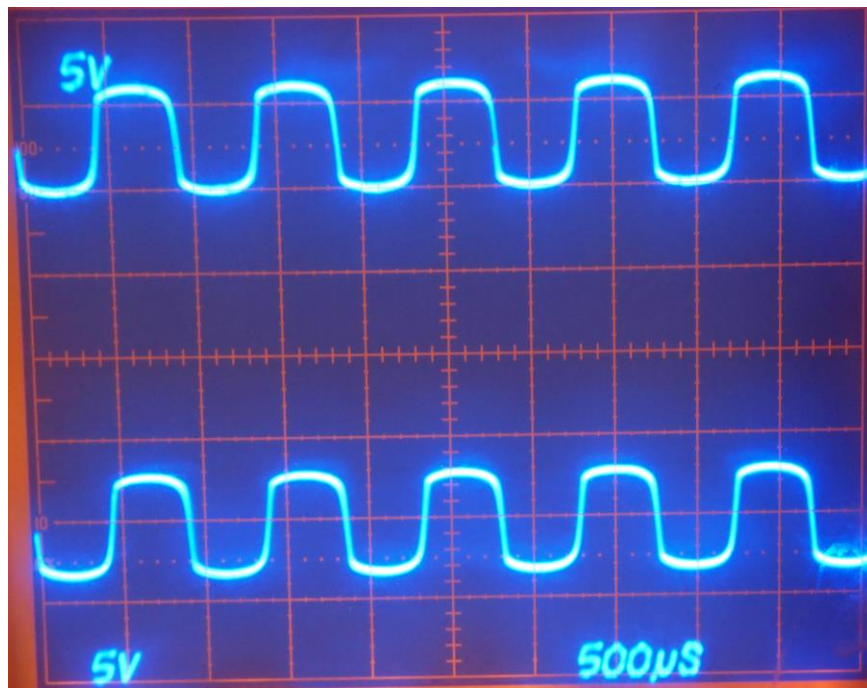
Input (top) and output (bottom) for op-amp clipper circuit. Input signal level of 10V P-P causes severe clipping and shows the limit of the clipper circuit.



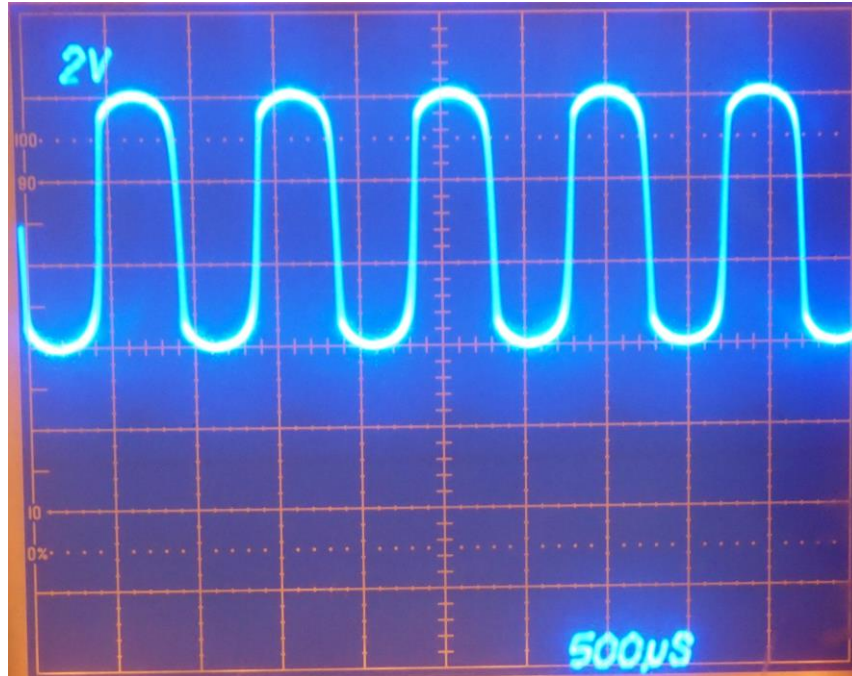
Input (top) and output (bottom) for op-amp clipper circuit. Same as above but zoomed out to show the curved tops of the clipped signal.



Input (bottom) and output (top) for op-amp clamper circuit. Notice level shift for top waveform.



Output from op-amp clipper circuit (bottom) and output from op-amp clamper circuit (top). Notice clipped waveform is clamped to ground level.



Nice picture of output of combined circuit showing both clipping and clamping.

Postlab Deliverables and Questions:

1. Submit a picture of your breadboard with your circuit on it.
2. Submit all required waveform pictures as described in the experiments.
3. Questions:
 - a. Why is it important to keep the load resistance for the simple clipping and clamping circuits as high as possible? (hint: think about the loading effect)
 - b. Why do diodes have reverse leakage current? How are the leakage current and forward voltage drop affected by temperature? How could this change the performance of the circuits built in this lab?
 - c. Do some research and describe what “DC restoration” was used for. Are there any modern applications for clamper circuits?