Lab 11 - Rectifying Circuits

Objectives

Voltage conversion circuits are ubiquitous in everyday life. Common AC adapters are used to convert the 60 Hz, 120 Volt AC voltage into a more convenient DC electrical voltage that can power small electronic components. In this lab, you will experiment with AC rectifying circuits, which use a network of diodes to convert an AC voltage supply into a DC supply.

Rectifying circuits are also used in analog signal processing, in applications such as AM demodulation or envelope detection. In the second part of this lab, you will build an op-amp circuit that uses diodes to rectify (take the absolute value of) an input voltage.

Laboratory Equipment

In this lab you will use the following test and measurement instruments:

- Waveform generator
- Oscilloscope
- (optional) - DMM, for measuring component values

In addition to the resistors, capacitors and op-amps, in this lab you will use diodes -- two-terminal circuit elements that inhibit current flow in the reverse direction.

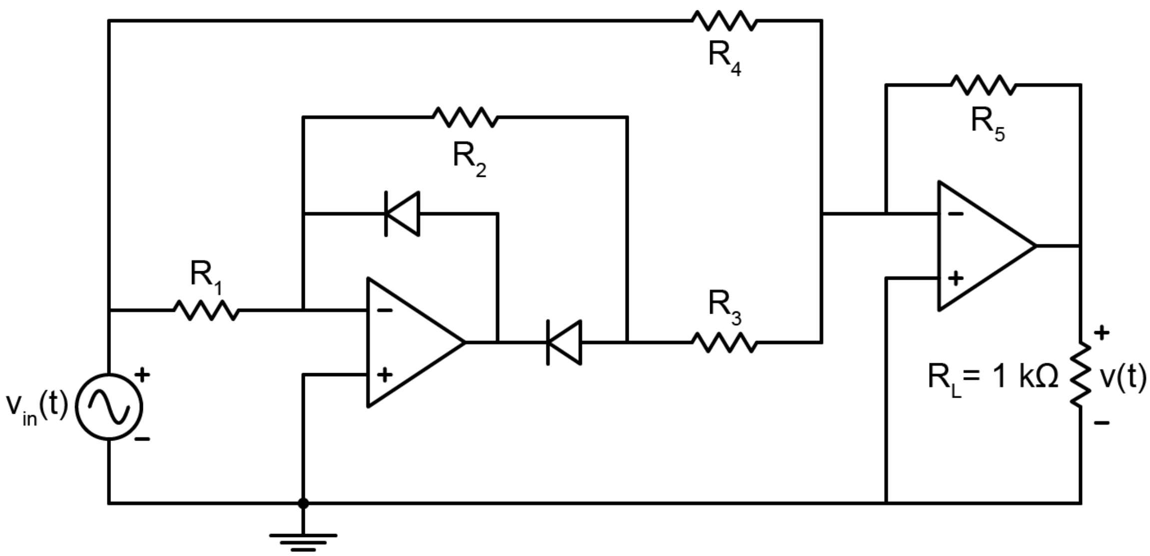
Pre-lab Preparation

Watch the following 18-minute video, which explains the operating principle of the precision full-wave rectifier circuit:

https://www.youtube.com/watch?v=5HweBajP-5g

After watching the video, choose the values of R1… R5 in the following full-wave rectifier circuit in order to meet the following constraints:

- $v(t) = |v_{in}(t)|$
- Do not use any resistors that are smaller than 1 kΩ
- Assume op-amp rail voltages of +5V and –5V.
- Your circuit must work for peak-to-peak amplitudes up to 8 Vp-p



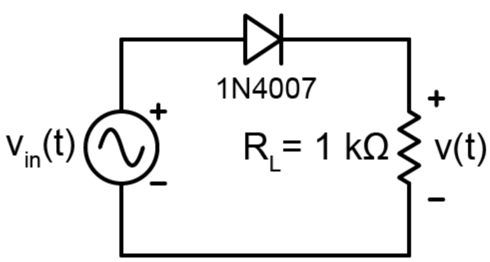
Simulate your circuit in PSpice and make a plot of the output voltage when the input voltage is a sinusoidal voltage with amplitude 8 Vpp and frequency 440 Hz. Submit a screenshot of your schematic, showing your design, and a simulation showing the input and rectified output.

Instructions

Half Wave Rectifier

In this portion of the lab, you will build and test an AC half-wave voltage rectifier and examine how adding a filtering component affects its output.

Build the following unfiltered half-wave rectifier using the 1n4007 diode and a 1kΩ load resistance:

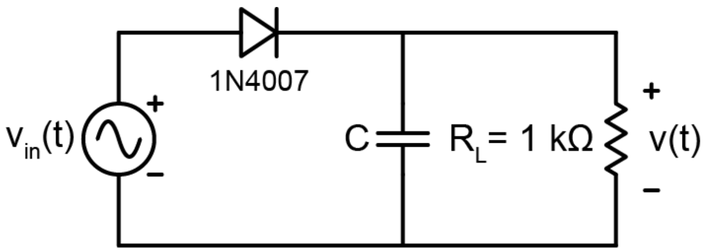


Use the function generator to provide a sinusoidal input signal $v_{in}(t)$ with the following properties:

- Waveform: Sinusoidal
- Offset voltage: 0 V
- Frequency: 60 Hz, 440 Hz
- Amplitude: 4 Vp-p
- [in-person labs]: Function generator load impedance: High

Measure and record both the input $v_{in}(t)$ and the output signal v(t) across the 1 kΩ load resistor, for both 60 Hz and 440 Hz input frequencies.

Next, insert a filtering capacitor in parallel with the load resistor, as shown below:

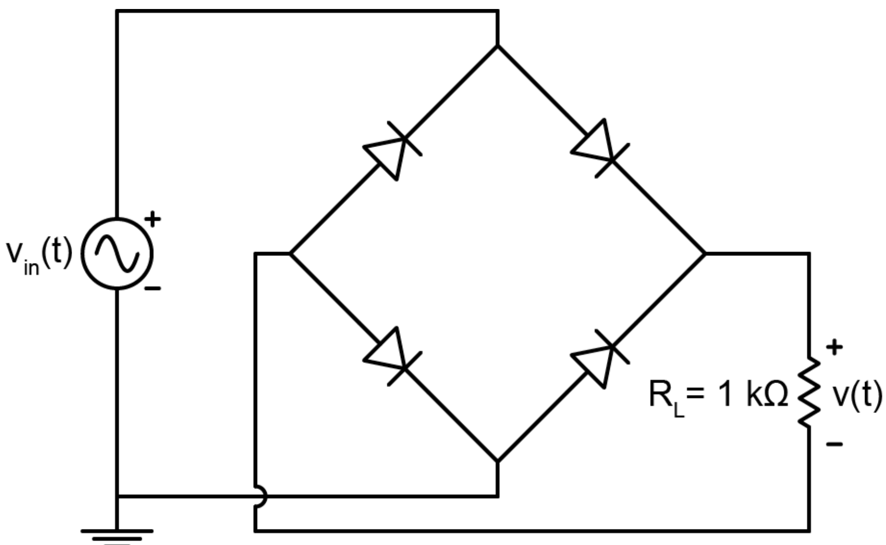


The role of the filter is to smooth out the ripple in the output voltage, thereby making the output voltage closer to an ideal DC source. Again, measure and record the output waveform v(t), for capacitance values of C = 1 μF, 22 μF, and 220 μF.

Full Wave Rectifier

In this portion of the lab, you will build and test an AC full-wave voltage rectifier, how adding a filtering component affects its output, and how it compares to the half-wave rectifier.

Build the following unfiltered full-wave rectifier using four 1N4007 diodes and a 1kΩ load resistance:



Note: In this circuit, the input signal $v_{in}(t)$ and output signal v(t) do not share a common ground connection. (I.e., the rectified output signal is “floating”.)

[Keysight Scopes] Because the channels on the benchtop oscilloscopes share a common ground with the function generator, you cannot directly measure the output voltage v(t) with a single oscilloscope channel. Instead, you will need to probe both sides of the input and use the oscilloscope’s math function to compute the difference.

[ADALM2000]: If you are using the ADALM2000 at home, you can simply use the differential voltage measurements “1+” and “1–” to directly probe v(t) without using math or subtraction, but you must make sure that the “1-” lead is not grounded.

As before, use the function generator to provide the sinusoidal 8 Vp-p input signal $v_{in}(t)$ at either 60 Hz or 440 Hz. Measure both the input voltage and output voltage v(t).

Again, try inserting a filtering capacitor in parallel with the load resistor, and record the smoothed output waveforms. (Take note of exactly which capacitor you used.)

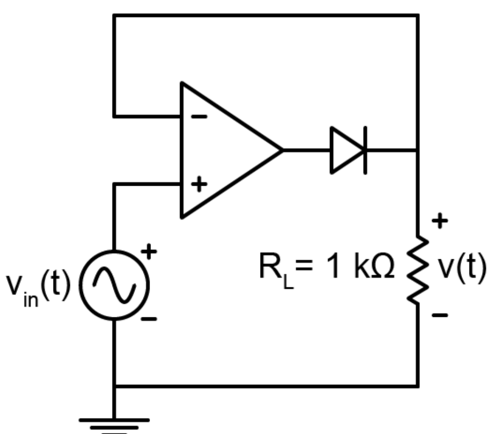
Precision Half Wave Rectifier

One of the drawbacks to the passive rectifying circuits considered in the preceding example is that there is a small but noticeable voltage drop across the diode (typically about 0.7 V), even when the diode is in the “ON” state. As a result, the rectified output voltage amplitude is smaller than the input amplitude. (For AC power circuits, where the amplitudes are 100-250 VAC, this voltage drop is negligible.)

However, rectifying circuits are also used in low-voltage, signal processing applications (such as envelope detection and AM demodulation). In these cases the diode voltage drop is undesirable and cannot be ignored. This limitation can be overcome by using operational amplifiers with diodes.

The following circuit, which is called a “superdiode” circuit, is essential a buffer amplifier, with a diode that restricts the polarity of the output voltage.

Build the following superdiode circuit, using the same sinusoidal input signal $v_{in}(t)$ considered in the earlier examples:



Measure and record the output voltage v(t) for both 60 Hz and 440 Hz input voltages.

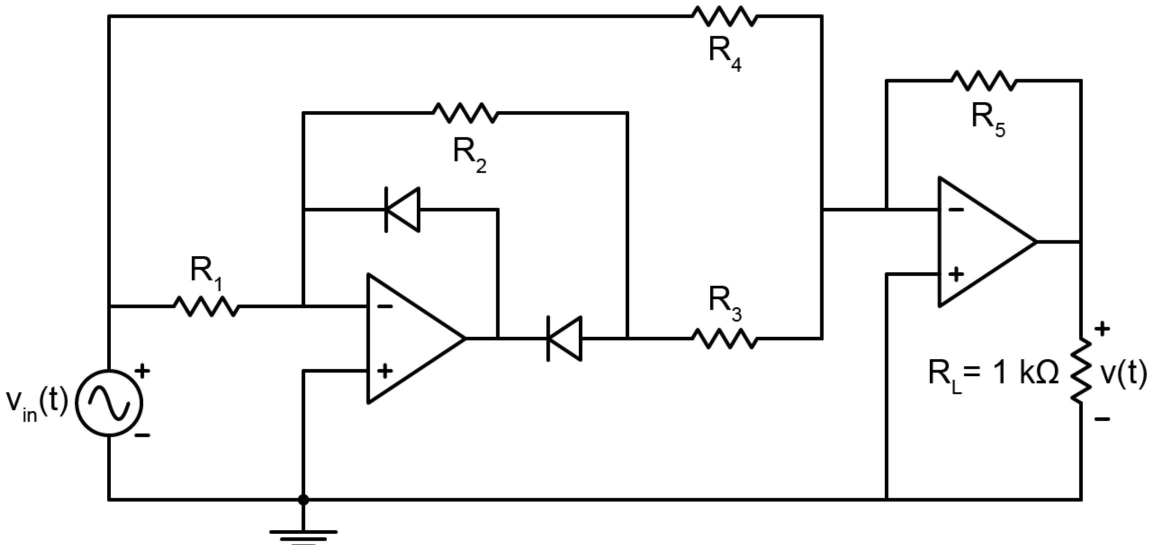
One problem with the superdiode rectifier is that when the input voltage is negative, the op-amp saturates at the negative rail. While this negative voltage never makes it to the output (because of the reverse-biased diode), the op-amp can exhibit an undesirable glitch/transient when $v_{in}(t)$

becomes positive again. Demonstrate this by measuring the voltage difference across the input terminals.

Precision Full Wave Rectifier

The precision half wave rectifier can be extended to provide full-wave rectification (you can think of this as an absolute value circuit.) The precision full-wave rectifier circuit consists of an inverting half-wave rectifier and a summing amplifier.

Build the full-wave precision rectifier circuit that you designed and simulated for the pre-lab:



Measure and record the following three voltages for 60 Hz and 440 Hz frequencies:

- $v_{in}(t)$, the input sinusoidal voltage
- $v_{half}(t)$, the intermediate output of the half-wave rectifier (just after the second diode)
- v(t), the fully rectified output waveform.

Post-lab Analysis

Generate a lab report following the sample report available in Appendix A. Mention any difficulties encountered during the lab. Describe any results that were unexpected and try to account for the origin of these results (i.e. explain what happened). In ADDITION, answer the following questions:

Half Wave Rectifier

- Make a plot (using Matlab, Excel, or any other program of your choice) the 60 Hz input voltage along with of all 60 Hz outputs (filtered and unfiltered) on a single graph.
- Repeat for the 1000 Hz case.
- Explain how adding the filter capacitance has altered the output.

- Explain how the half-wave rectifier could be used to convert AC to DC voltage and its limitations.

Full Wave Rectifier

- Make a plot (using Matlab, Excel, or any other program of your choice) of all 60 Hz input and outputs (filtered and unfiltered) on a single graph, and another with all 1kHz input and outputs.
- Explain how adding the filter capacitance has altered the output.
- Compare the outputs of the half-wave and full-wave rectifiers. How do their responses to the filter capacitance differ? Which one provides a more DC-like output?

Precision Half Wave Rectifier

- How does the op-amp rectifier differ from the passive diode-based rectifier considered earlier?

Precision Full Wave Rectifier

- Plot, on the same time-axis, the three voltages $v_{in}(t)$, $v_{half}(t)$, and the summing amplifier output v(t) at 60 Hz.
- Repeat for the three 440 Hz waveforms.
- How does the performance of the precision full wave rectifier compare to the passive bridge rectifier considered earlier?
- Use your PSpice simulation to determine the maximum sinusoidal voltage amplitude that can be rectified without distorting the waveform.
- Use your PSpice simulation to determine the maximum AC frequency that can be rectified without distorting the waveform.