ELE404_Lab_3_Bridge_Rectifier

June 16, 2020 6:05 AM

Ryerson University

Department of Electrical & Computer Engineering

ELE 404

Bridge Rectifier

Introduction

An important property of a diode is that it allows the current to flow in only one direction. This property is utilized for conversion of AC to DC in circuits that are known as *rectifiers*. This lab studies an important member of the family of rectifiers, that is, the so-called ***Bridge Rectifier***.

For manual calculations, assume the on-state voltage drop of a diode (e.g., 1N4148) to be 0.7 V.

Pre-lab Assignment

P1. For the bridge rectifier of **Figure 1**, derive the v_S-v_O transfer characteristic for a source voltage range of $\boldsymbol{-8\,V \leq v_S \leq +8\,V}$, assuming that the diodes are **1N4148** diodes and R_L is considerably larger than R_{int} (e.g., $R_L \geq 10R_{int}$). Present the characteristic curve as **Graph P1**.

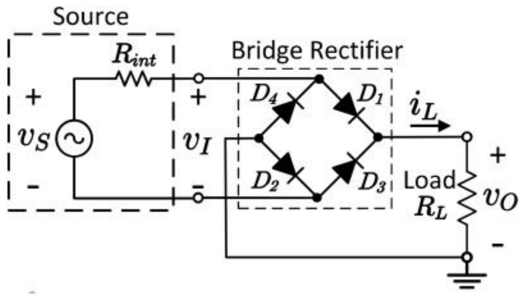
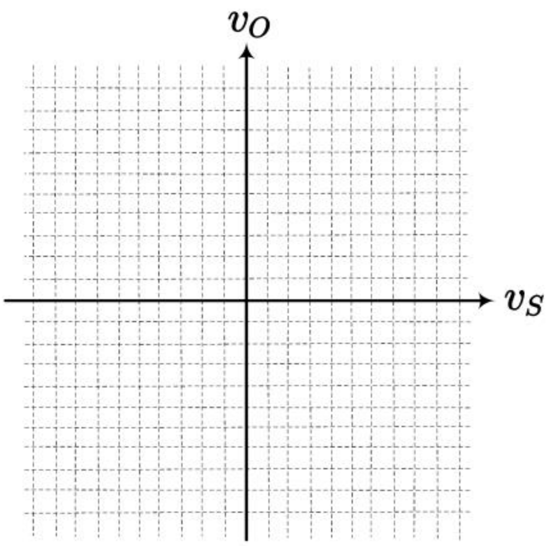
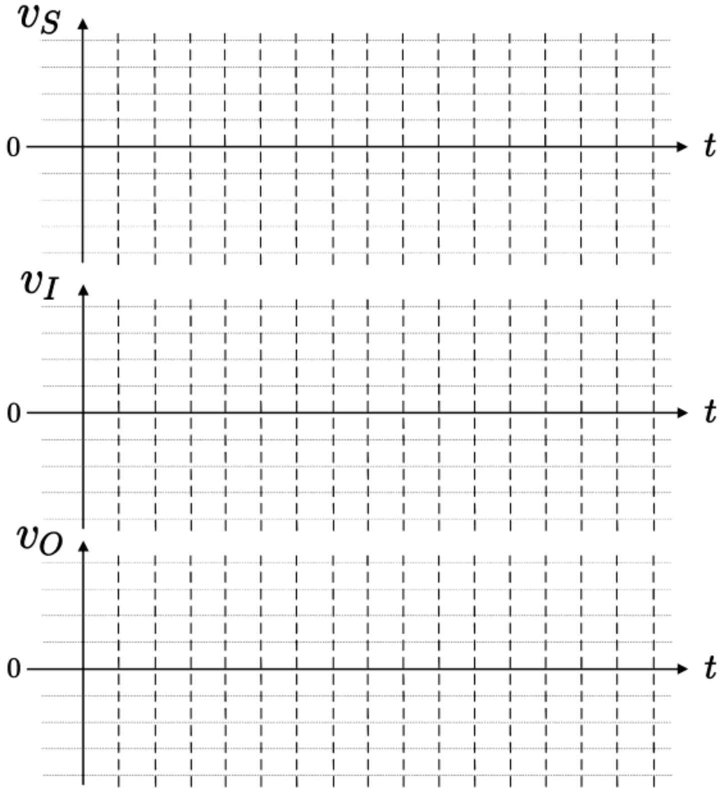


Figure 1. Bridge rectifier with a resistive load.

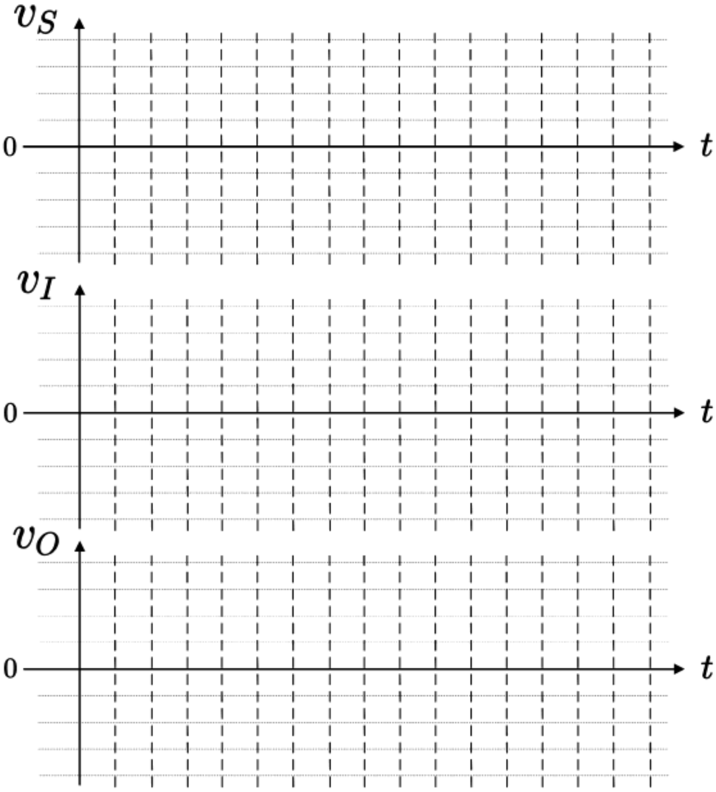


Graph P1. Transfer characteristic of the bridge rectifier of Figure 1.

P2. Assuming **1N4148** diodes, a **500-Hz symmetrical sinusoidal source voltage v_S with a magnitude of 16 V peak-to-peak**, and a source internal resistance of $\boldsymbol{R_{int}} = \mathbf{50\ \Omega}$, simulate the bridge rectifier of **Figure 1** with $\boldsymbol{R_L} = \mathbf{1\ k\Omega}$, and capture the waveforms of the source voltage v_S, input voltage v_I, and output voltage v_O, for about three cycles. Present the input and output voltage waveforms as **Graph P2(a).** Repeat the simulation with $\boldsymbol{R_L} = \mathbf{270\ \Omega}$ and present the voltage waveforms as **Graph P2(b)**.



Graph P2(a). Source, input, and output voltage waveforms of the bridge rectifier of Figure 1, with 1N4148 diodes and $\boldsymbol{R_L} = \mathbf{1\ k\Omega}$.



Graph P2(b). Source, input, and output voltage waveforms of the bridge rectifier of Figure 1, with 1N4148 diodes and $R_L = 270\ \Omega$.

P3. Consider the circuit of **Figure 2** and repeat the simulation of **Step P2** for it (with $R_L = 1\ k\Omega$, while the other parameters remain unchanged). Note that the circuit of **Figure 2** is the same circuit as that of **Figure 1,** but with a major difference: **The ground of the circuit (denoted by symbol ⏚) is shorted to the negative terminal of the source**. Capture the waveforms of v_I, v_O, and i_{D4}(i.e., the current of D_4) for about three cycles, as **Graph P3.**

If the current probe utility of your software of choice does not offer plotting capability, you can insert a small resistance (e.g., 0.1 Ω in value) in series with D_4 and probe the voltage drop across the resistor. The current waveform will then be a scaled version of the probed voltage waveform, and the scale factor is the reciprocal of the series resistance.

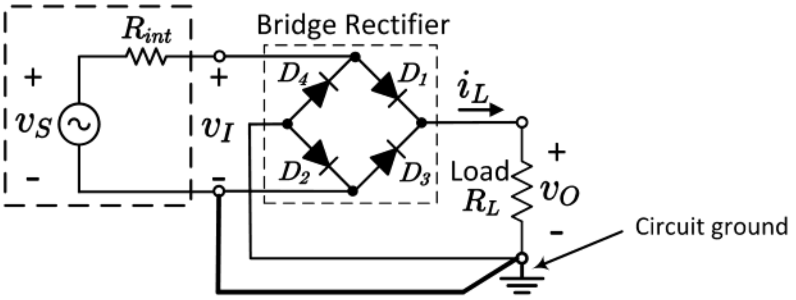
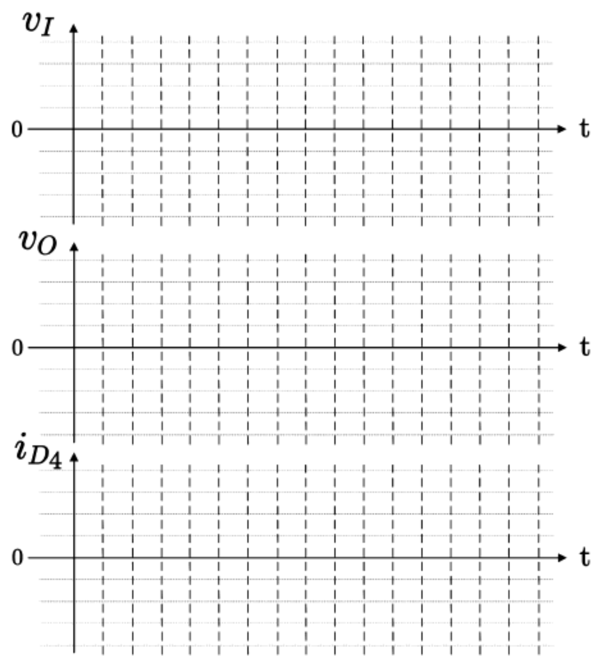


Figure 2. Bridge rectifier in which the circuit ground is shorted to the negative terminal of the source.



Graph P3. Waveforms of v_I, v_O, and i_{D4}, in the circuit of Figure 2.

P4. Consider the circuit of **Figure 3**, which is a bridge rectifier with a smoothing capacitor. Assume that the diodes are **1N4148** diodes, v_S has **a 500-Hz symmetrical sinusoidal waveform with a magnitude of 16 V peak-to-peak**, $\boldsymbol{C = 1\ \mu F}$. Then, calculate the average (DC) and peak-to-peak ripple of the output voltage, assuming that $\boldsymbol{R_L = 5.6\ k\Omega}$. For this exercise, ignore the source resistance (i.e., consider R_{int} to be a short link). Show all the work. Complete **Table P4**.

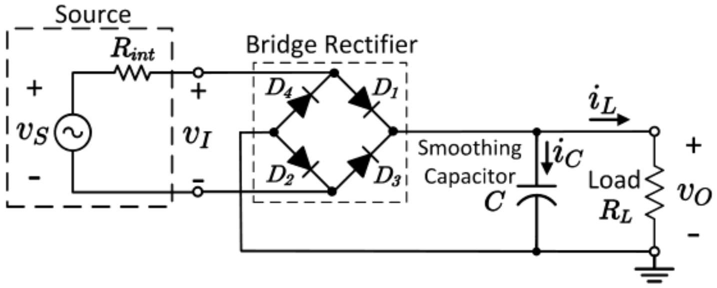


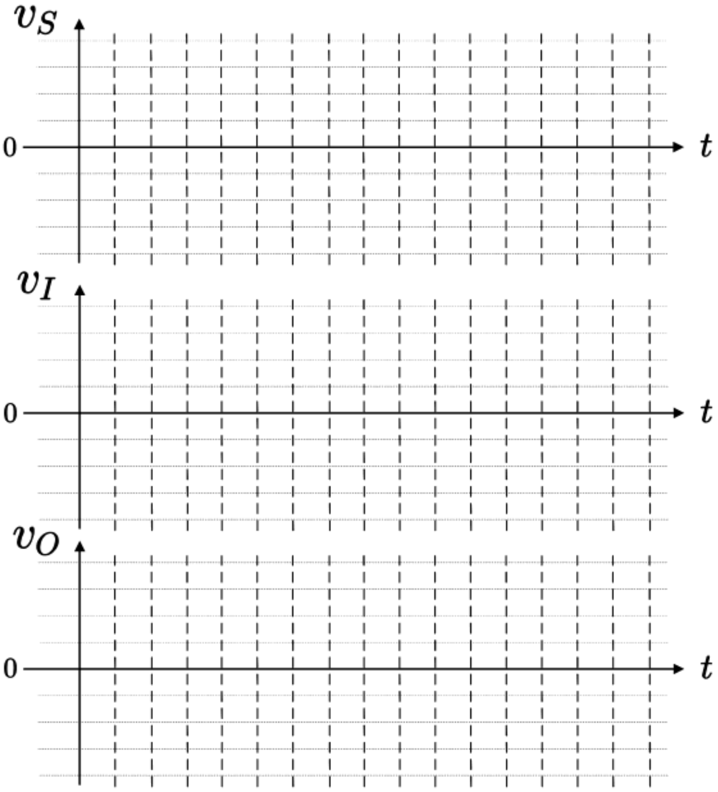
Figure 3. Bridge rectifier with smoothing capacitor.

Table P4. DC output voltage and peak-to-peak ripple

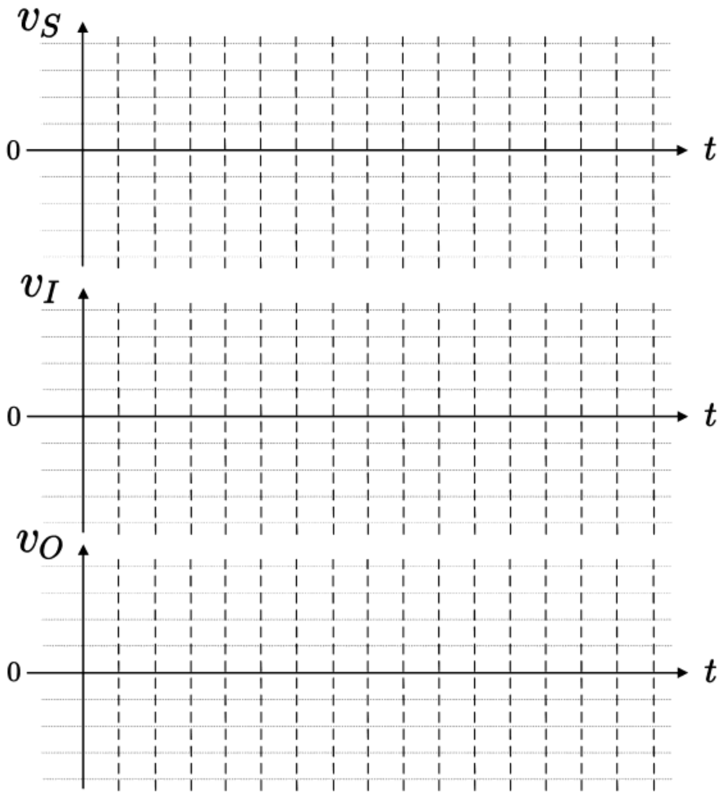
$\overline{v_O}$ $[V]$	V_r $[V]$

Then, assuming $R_{int} = 50\ \Omega$, simulate the circuit with $R_L = 5.6\ k\Omega$ and capture the source, input, and output voltage waveforms for about three cycles. Present the waveforms as **Graph P4(a)**.

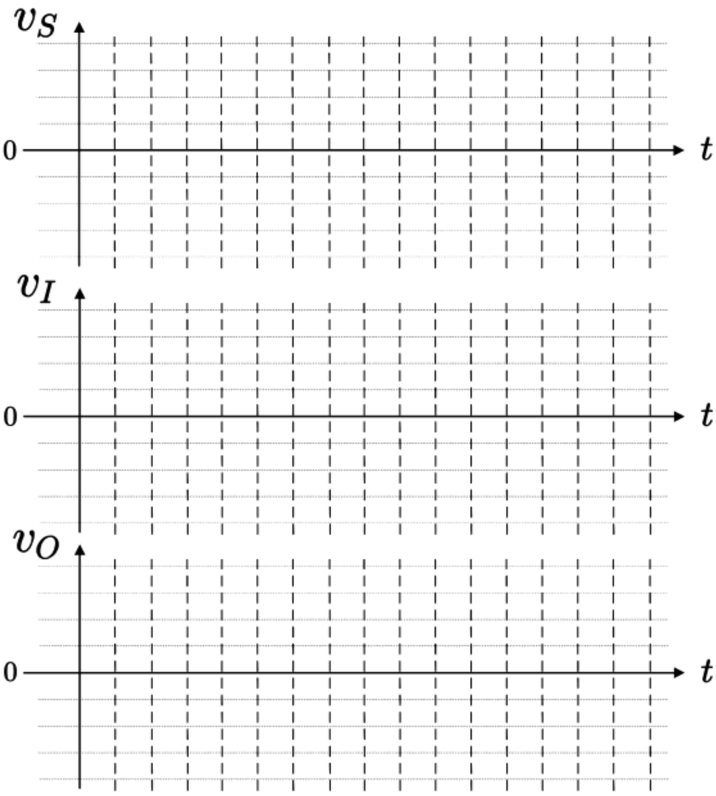
Repeat the simulation with $R_L = 56\ k\Omega$ and $R_L = 560\ \Omega$. Save the waveforms as **Graph P4(b)** and **Graph P4(c)**, respectively.



Graph P4(a). Source, input, and output voltage waveforms for the bridge rectifier with smoothing capacitor of Figure 3, with $R_{int} = 50\ \Omega$ and $R_L = 5.6\ k\Omega$.



Graph P4(b). Source, input, and output voltage waveforms for the bridge rectifier with smoothing capacitor of Figure 3, with $R_{int} = 50\ \Omega$ and $R_L = 56\ k\Omega$.



Graph P4(c). Source, input, and output voltage waveforms for the bridge rectifier with smoothing capacitor of Figure 3, with $\mathbf{R_{int} = 50\ \Omega}$ and $\mathbf{R_L = 560\ \Omega}$.

Experiments and Results

NOT REQUIRED

~~E1.~~ Construct the bridge rectifier of **Figure 4**, in which the source is your bench-top signal generator, and diodes D_1 through D_4 **are four red light-emitting diodes (LEDs)** from your lab kit. As the load, use the series connection of **a green LED, i.e., D_5**, and a 1-kΩ resistor, i.e., R (refer to Appendix "Useful Tips—LEDs" for advice on how to orient an LED).

Next, set the signal generator to produce a small symmetrical sinusoidal signal with a frequency of about **0.5-Hz**. Then, gradually increase the signal magnitude until the LEDs start to glow. Observe and note down the blinking pattern of the five LEDs. Also, observe the blinking frequency of the green LED relative to that of the red LEDs.

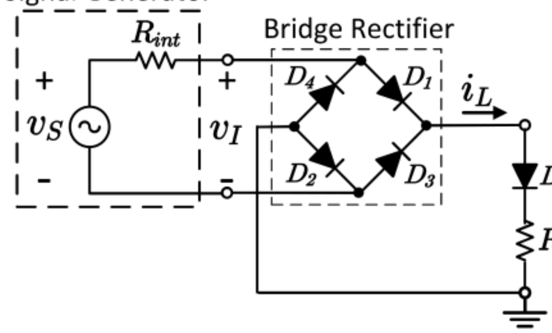


Figure 4. Bridge rectifier using LEDs.

E2. Turn off the signal generator and replace the four red LEDs with **1N4148** diodes. Also, replace the green LED with a wire such that only the 1-kΩ resistor is left as the load R_L. Now assume that you want to monitor the output voltage, v_O, of the bridge rectifier. Since **the oscilloscope and the signal generator share a common ground** (through the ground wiring of the power system), connection of the oscilloscope's ground probe to the negative terminal of the output port of your circuit (i.e., to the ground of your circuit, ⏚), as shown in **Figure 5**, is problematic (what is the problem? You simulated such a scenario in **Step P3**). Therefore, v_O must be monitored differentially, i.e., using two probes, as shown in **Figure 6**.

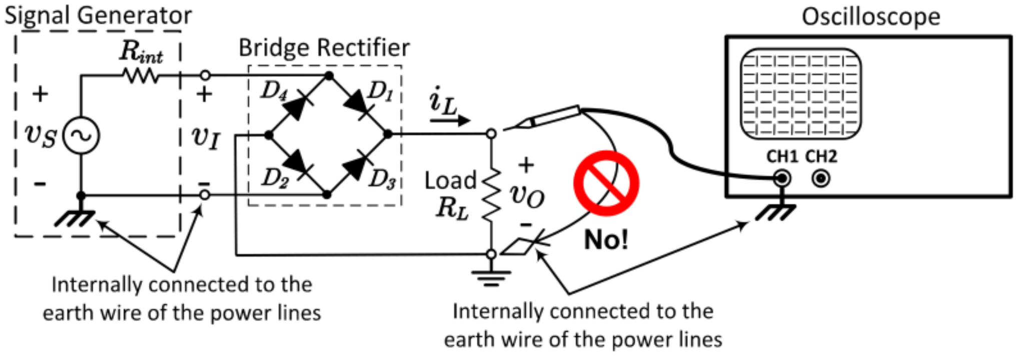


Figure 4. Single-ended monitoring of the output voltage in a bridge rectifier. **Avoid it!**

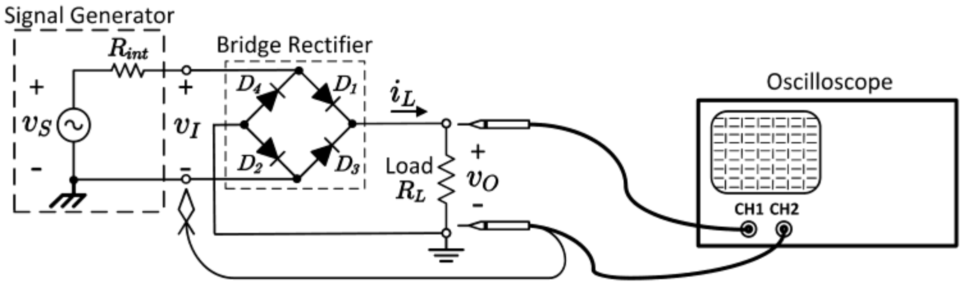


Figure 5. Differential monitoring of the output voltage waveform in the bridge rectifier.

To differentially monitor v_O, set the oscilloscope in the **Math Mode**, and subtract the signal of **Channel 2** from that of **Channel 1**. Make sure that **both channels** are **in the DC coupling mode**, have the **same voltage per division gains**, and have the **same signal attenuation settings (1:1 or 1:10) on their probes**. With the signal generator not yet connected to the circuit, set the signal generator to produce a symmetrical **500-Hz sinusoidal waveform with a magnitude of about 16 V peak-to-peak** (this will be your v_S. Why?). **You can use your bench-top multimeter in the AC voltage measurement mode, to both confirm the frequency and magnitude of v_S. The magnitude on the meter should read about 5.6 V rms)**. Connect the signal generator to the circuit. Capture the waveform of v_O for about three to four cycles, and save it as **Graph E2**.

E3. Disconnect the signal generator (do not change its frequency or magnitude setting), and supplement the circuit of **Figure 5** by adding a **1-μF** polyester capacitor across the output terminals, as shown in **Figure 6**. With $\boldsymbol{R_L = 5.6\,k\Omega}$, connect the signal generator and capture the waveform of v_O (differentially) for about three cycles and save the waveform as **Graph E3(a)**. Next, set both oscilloscope input channels in the **AC-coupled mode**, increase their the voltage per division gains sensibly (make sure that both channels have the same volt per division gains), and capture the fluctuating component (i.e., ripple) of v_O. Save the waveform as **Graph E3(b)** for three cycles. From the captured waveform, note down the peak-to-peak output voltage ripple of the rectifier. Also, use your bench-top multimeter in the DC voltage measurement mode and measure the DC output voltage. Record the results in **Table E3**.

Table E3. dc output voltage and peak-to-peak ripple

$\overline{v_O}$ [V]	V_r [V]

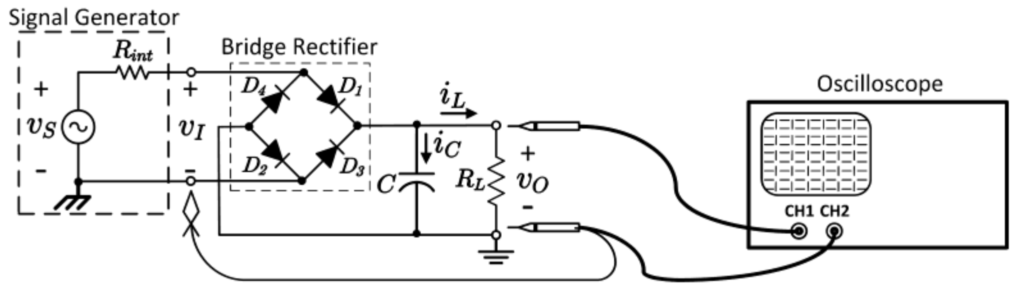


Figure 6. Bridge rectifier with smoothing capacitor.

Conclusions and Remarks

C1. Which set of waveforms in **Step P2** (i.e., **Graph P2(a)** or **Graph P2(b)**) better agree with the manually-derived transfer characteristic of **Graph P1** and why? What is the most consequential source of disagreement in this specific case? What are the sources of error, in general?

C2. Draw two equivalent circuits for the bridge rectifier of **Figure 2:** one for $v_S > 0.7\ V$ and the other one for $v_S < -0.7\ V$. Thus, replace the *on* diodes with a 0.7-V battery, and the *off* diodes with an open link. Based on the two equivalent circuits, derive expressions for the current of diode D_4, corresponding to each of the two aforementioned input voltage conditions. Then, check your expressions by your simulated waveforms of **Graph P3**, and comment. Based on your analysis and simulation results, comment of the effect of the short link between the ground of the circuit and the negative terminal of the source, in the bridge rectifier. What would happen if the source could supply a lot of current?

X NOT REQUIRED

C3. In **Step E1** you took note of the blinking pattern and frequencies of the LEDs. What did the pattern represent? How was the blinking frequency of the green LED related to that of the red LEDs? Explain the reason.

C4. Comment on the agreement between **Graph P2(a)** and **Graph E2**. Comment on discrepancies, if any.

X NOT REQUIRED

C5. Comment on the agreement between **Graph P4(a)** and **Graph E3**. Also, compare **Table P4** (calculated DC and ripple voltage values) with **Table E3** (measured DC and ripple voltage values). Comment on discrepancies, if any.

C6. Based on the results of **Step P4**, comment on the effect of load on the resemblance of the (actual) output voltage of a bridge rectifier to a perfect DC waveform. Comment on the value of each of the three loads, in view of the capacitance of the smoothing capacitor and half-period of the source voltage, and based on that justify the corresponding output voltage waveforms.

Appendix: Useful Tips – LEDs

LEDs (Light-Emitting Diodes) behave electrically just like ordinary diodes with the difference that they have a much larger forward voltage drop than the typical 0.7 V (e.g., 2.2 V for a green LED, 1.8 V for a red LED, etc.). This is due to the larger band-gap that LEDs have, such that when an electron and a hole recombine, a photon of a particular wavelength (corresponding to a color) is released. The intensity of the produced light is then proportional to the current passing through the LED. When an LED is used in a circuit, it typically requires a series resistor to limit its current. Otherwise, the LED heats up excessively and burns out quickly.

Orienting an LED is straightforward: the flat edge on the rim of the LED corresponds to the stripe (i.e., cathode) on a conventional diode. Thus, the lead opposite to the flat edge will be the anode. To verify the polarity, put the multimeter into "continuity testing" mode and touch the probes to the LED's leads. In the reverse bias, nothing will happen and the multimeter will report an open circuit. In the forward bias, the multimeter will show a value that is about the same as the forward voltage drop of the LED, and the LED glows faintly due to the small amount of current that the multimeter drives through it.

NOTE: *LEDs are not designed to work in reverse bias conditions. LEDs are usually either in forward bias or off. They tend to have a relatively low (~5V) breakdown voltage. This means that care needs to be taken when applying a reverse bias to an LED, since it is easy to enter the breakdown region and excessively heat up the LED. However, the current supplied by the signal generator is quite small so there should be little risk of damaging the LED in this lab.*

TA Copy of Results

Table E3. DC output voltage and peak-to-peak ripple

$\overline{v_O}$ $[V]$	V_r $[V]$

	Partner's Name	Pre-Lab (out of 20)	Set-Up (out of 10)	Data Collection (out of 10)	Participation (out of 5)
1					
2					

TA Copy