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 $-8V \leq v_S \leq +8V$, assuming that the diodes are 1N4148 diodes and R_L is considerably larger than R_{int} (e.g., $R_L \geq 10R_{int}$). Draw the characteristic curve and label it Graph P1.

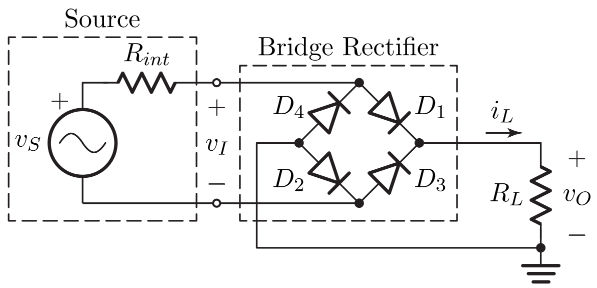

Figure 1: Bridge rectifier with a resistive load.

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

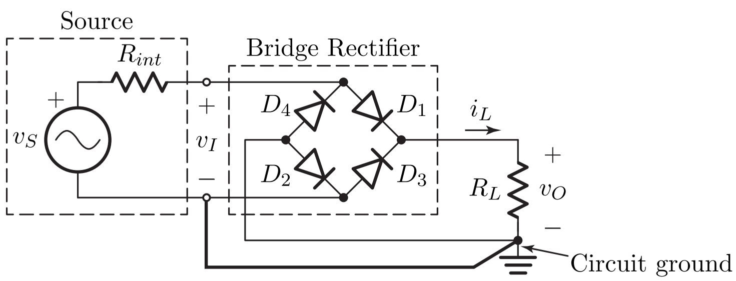

Figure 2: Bridge rectifier in which the circuit ground is shorted to the negative terminal of the source.

P3. Consider the circuit of Figure 2 and repeat the simulation of Step P2 for it (with $R_L = 1k\Omega$ 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 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., 0.1Ω in value) in series with 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.

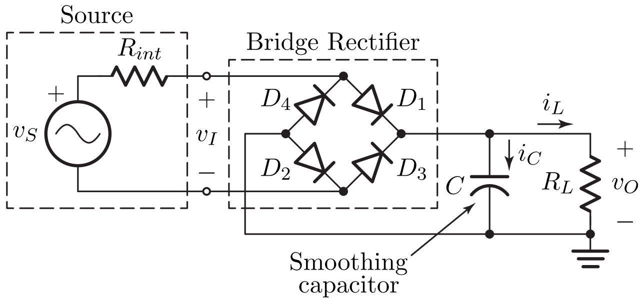

Figure 3: Bridge rectifier with smoothing capacitor.

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 $16V$ peak-to-peak, and $C = 1\mu F$. Then, calculate the average (DC) and peak-to-peak ripple of the output voltage assuming that $R_L = 5.6k\Omega$. For this exercise, ignore the source resistance (i.e., consider R_{int} to be a short link). Show all the work. Complete Table 1.

Table 1: 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 $R_L = 5.6k\Omega$ and capture the source, input, and output voltage waveforms for approximately three cycles. Present the waveforms as Graph P4(a). Repeat the simulation with $R_L = 56k\Omega$ and $R_L = 560\Omega$. Present the wavefroms as Graph P4(b) and Graph P4(c), respectively.

Experiment and Results

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 $1-k\Omega$ resistor, i.e., R. Refer to the appendix 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 LEDs. Also, observe the blinking frequency of the green LED relative to that of the red LEDs.

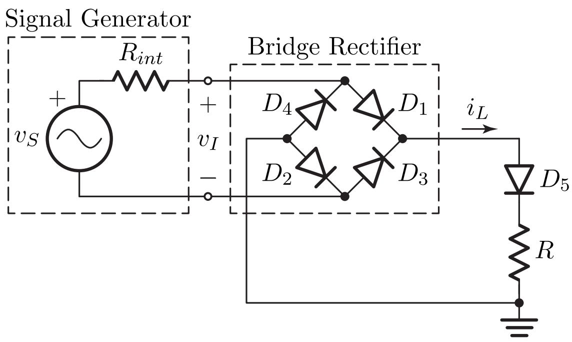

Figure 4: Bridge rectifier using LEDs.

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 $1-k\Omega$ 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 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 the 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.

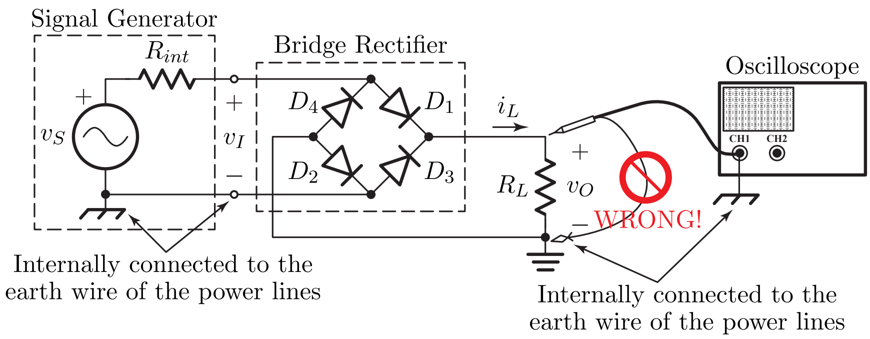

Figure 5: Single-ended monitoring of the output voltage in a bridge rectifier. AVOID IT!

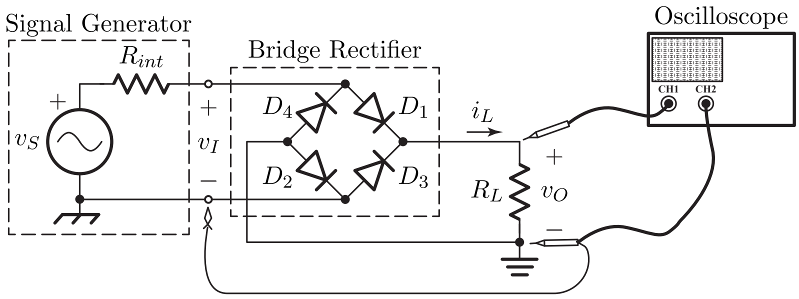

Figure 6: Differential monitoring of the output voltage waveform in the bridge rectifier.

To differentially monitor v_O, set the oscilloscope to the Math Mode, and subtract the signal of Channel 2 from that of Channel 1. Make sure that both signals are in 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 magntiude of about $16V$ peak-to-peak (this will be your v_S). You can use your bench-top multimeter in the AC voltage measurement mode to confirm the magnitude of v_S. The magnitude of the meter should read approximately $5.6V$ rms. Connect the signal generator to the circuit. Capture the waveform of v_O for about 3 to 4 cycles and present 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 $1-\mu F$ polyester capacitor across the output terminals, as shown in Figure 6. With $R_L = 5.6k\Omega$, connect the signal generator and capture the waveform of v_O (differentially) for about three cycles and present the waveform as Graph E3(a). Next, set both oscilloscope input channels in the AC-coupled mode, increase their voltage per division gains sensibly (make sure that they have the same gain), and capture the fluctuating component (i.e., ripple) of v_O. Present the waveform as Graph E3(b). 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 2.

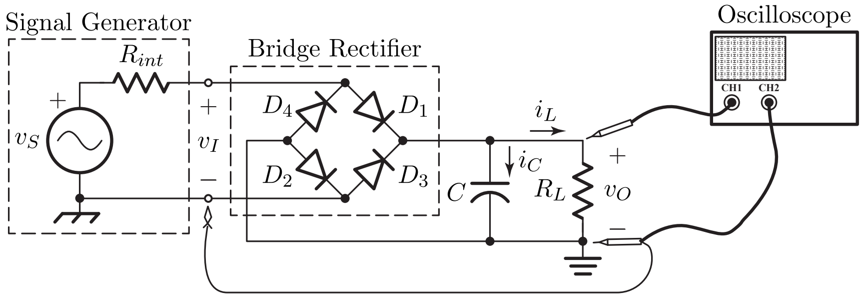

Figure 7: Bridge rectifier with smoothing capacitor.

Table 2: DC output voltage and peak-to-peak ripple.

$\overline{v_O}(V)$	$V_r(V)$

Conclusion

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 $v_S > 0.7V$ and the other one for $v_S < -0.7V$. 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?

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.

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 halfperiod 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 3: DC output voltage and peak-to-peak ripple.

$\overline{v_O}(V)$	$V_r(V)$

Student Name	Pre-lab (/20)	Set-up (/10)	Data Collection (/10)	Participation (/5)