University of Jordan
School of Engineering
Electrical Engineering Department

EE 204
Electrical Engineering Lab

EXPERIMENT 8
DIODE APPLICATIONS

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DIODE APPLICATIONS

OBJECTIVE

Semiconductor diodes will be examined in this experiment. In particular, the properties of a typical diode will be investigated, including a plot of its *i-v* curve. In addition, common applications of diodes will be introduced, including half-wave rectifiers, full-wave rectifiers and AC-to-DC converters (envelope detectors).

DISCUSSION

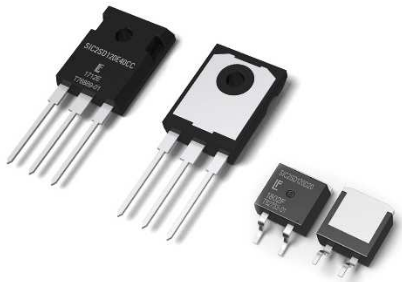
Diodes

A *semiconductor diode* (or just diode) is an electronic component that conducts current primarily in one direction. In other words, it has very low resistance in one direction, and almost infinite resistance in the other. A diode is typically built using a silicon p–n junction, though other materials such as germanium and gallium arsenide are also used.

The following figure shows some of the most common diodes used in practice. The light emitting diode (LED) and solar cell are some interesting types of diodes. In an LED, some of the energy of the electric current flowing through the diode is converted to light emitted from the LED, which makes it an efficient means of lighting homes and business. On the other hand, a light shined on a solar cell causes a current to flow through it, which allows renewable generation of electricity from the sun. Other interesting applications also exist for diodes. In this experiment, you will study half-wave rectifier and full-wave rectifier circuits, which attempt to convert an AC signal into a DC signal.


Rectifying diodes


Zener diodes


Schottky diode

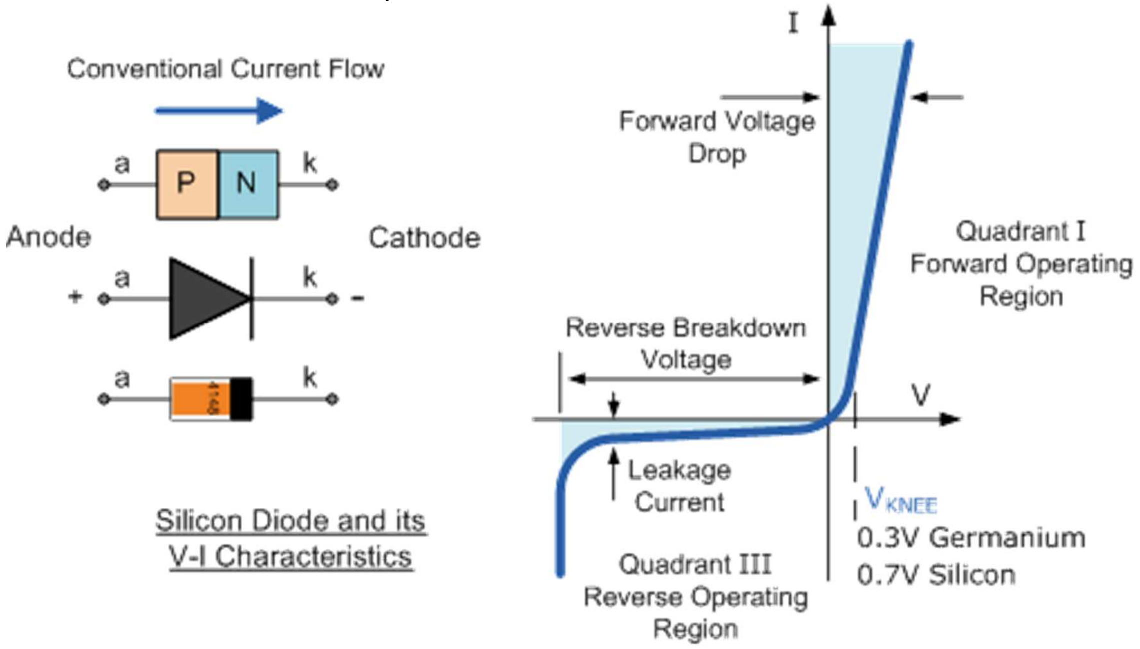

Gunn Diodes


Light emitting diodes (LED)

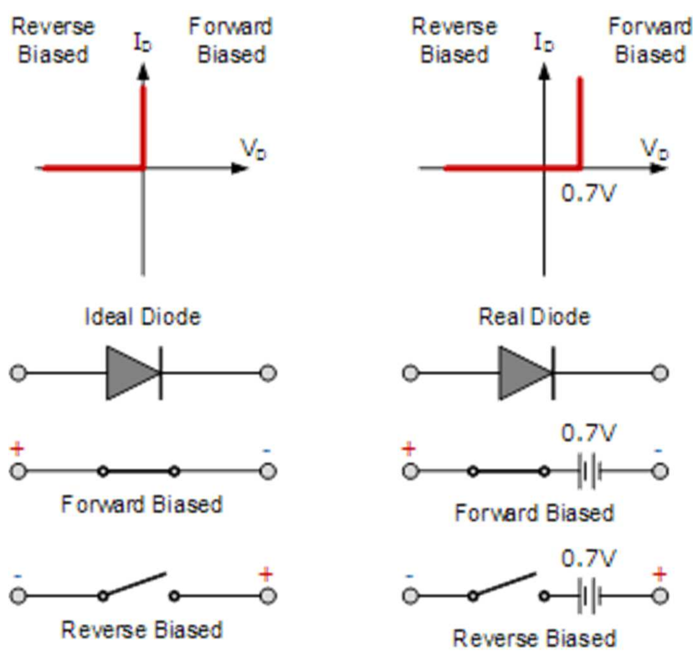

Solar cells and photodiodes

The diode p-junction is called the *anode* and its n-junction is called the *cathode*. In general, the cathode of a diode is marked by a solid line on the diode. When applying a positive voltage to the anode and negative voltage to the cathode of a diode, we say the diode is forward biased, and the diode conducts current. This is typically thought of as a closed switch (or short circuit). On the other hand, when the positive voltage is connected to the cathode (and the negative is connected to the anode), the diode is reverse biased, and it blocks current flow (i.e., it acts like an open circuit or an open switch).

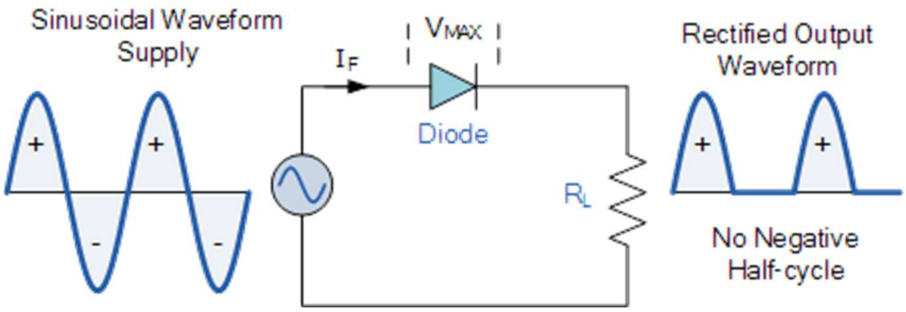
The characteristic curves (*i*-*v* curve) of a real diode is shown below. Notice that the diode starts conducting current after its forward bias voltage exceeds a certain *threshold* V_f (typically $V_f = 0.5 - 0.7$ V for silicon diodes and $V_f = 0.3$ V for germanium diodes).



When analyzing diodes, the real diode is usually replaced with a simpler model, which is an open or closed switch as shown below. The switch is closed when the diode is forward biased and open when the diode is reverse biased.

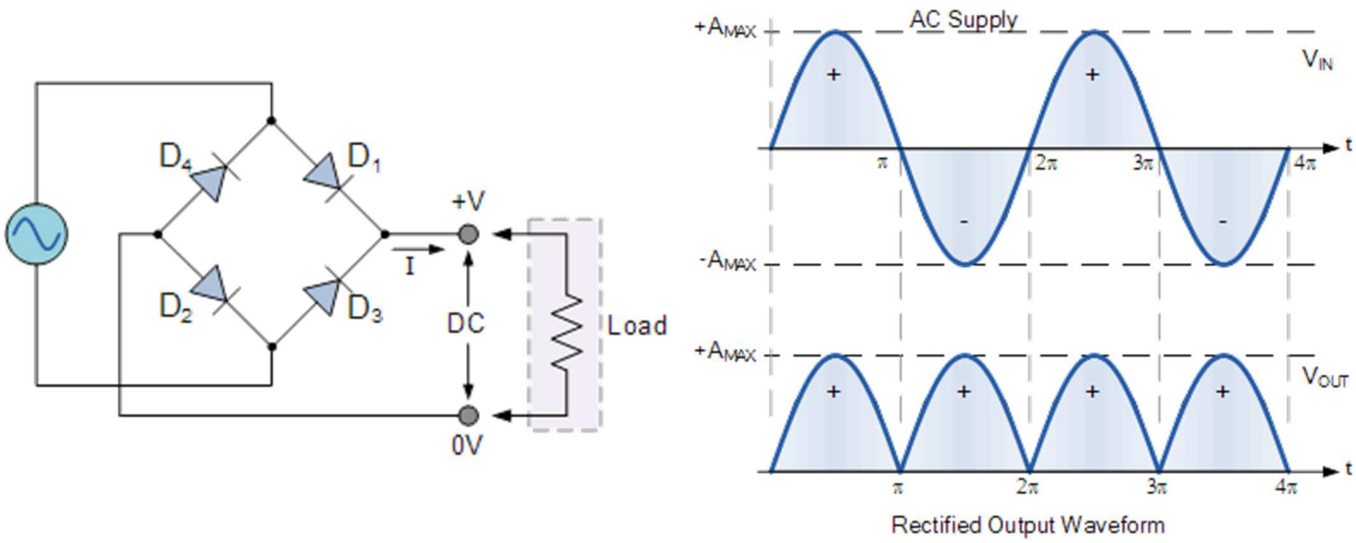


Half-Wave and Full-Wave Rectifiers
A rectifier circuit converts alternating current (AC) to direct current (DC). You probably can find one inside your hair dryer because it accepts an AC input but actually uses a DC motor inside. The simplest rectifier we can build is called a half-wave rectifier, where one diode is used as shown below.

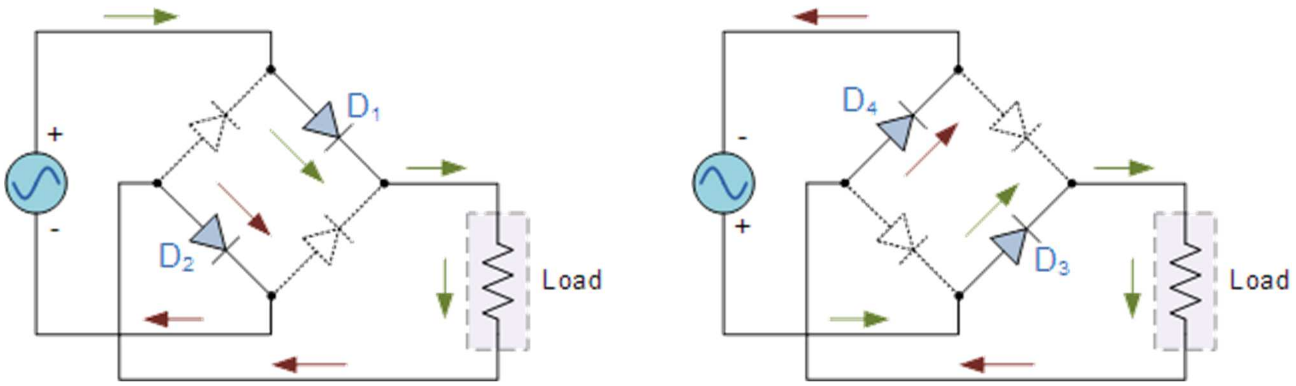


When the AC signal is applied across the diode, the diode will conduct during the positive half cycle (since it is forward biased) thus passing current to the load, while during the negative half cycle the diode will be reverse biased and hence will block the flow of current. The output signal becomes a unidirectional signal instead of an AC signal, which is closer to the desired DC output.

Sine only half of the input waveform reaches the output, this is very inefficient if used for power transfer. An alternative is to use a full-wave rectifier or bridge rectifier, which includes four diodes as shown below.



The diodes D1 to D4 are connected in a special way, so that during the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased. Hence, the current flows through the load resistor from top to bottom as shown below. During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 are off, forcing the current to flow through the load again is the same direction as before (see below).



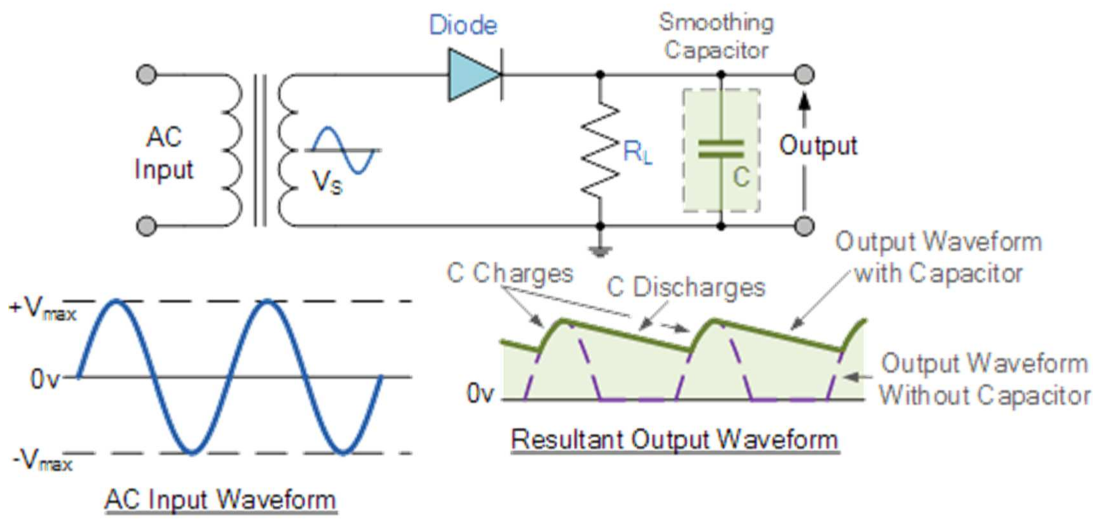
Since two cycles are produced by the full-wave rectifier (instead of just one), the average (DC) output voltage is higher for the full-wave rectifier compared to the half-wave rectifier. In addition, the output of the full-wave rectifier has much less ripple when combined with a capacitor (*see later*) than that of the half-wave rectifier. The output DC voltage of both rectifiers can be calculated with the following two ideal equations:

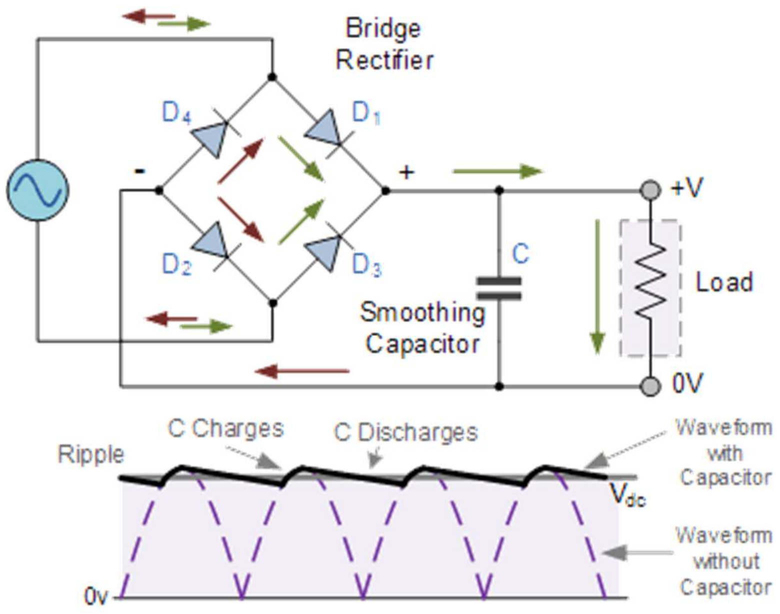
$$V_{dc} = \frac{V_{peak}}{\pi} \quad (half\ wave)$$

$$V_{dc} = \frac{2 \times V_{peak}}{\pi} \quad (full\ wave)$$

Rectifiers with Smoothing Capacitors

To produce a steady and constant DC voltage from the rectifier (with less voltage variations or ripple), we typically connect a large value *smoothing capacitor* across the output voltage terminals in parallel with the load resistor as shown below. The capacitor stores energy from the supply as the voltage approaches the peak value. After the peak ends, the capacitor supplies the current to the load and continues to do so until the capacitor voltage has fallen to the value of the now rising rectified voltage. At that point the rectifiers turn on again and delivers energy to the capacitor until peak voltage is again reached.





Resultant Output Waveform

It is important to note that there will still remain an amount of ripple where the voltage is not completely smoothed. If the time constant τ of both the resistor R and capacitor C, which is calculated as $\tau = R \times C$, is large in comparison to the period $T = 1/f$ of the input AC waveform, then the ripple becomes smaller.

PROCEDURE A – MULTIMETER DIODE TESTING

1. Turn on the digital multimeter (DMM) and select the *diode test* function. This mode measures the forward voltage of the diode if connected with proper polarity.

2. First, conduct the *forward bias* test, where the red multimeter lead (+ve) is connected to the anode terminal of the diode (+ve), and the black multimeter lead (COM) is connected to the cathode terminal of the diode (-ve). What is the reading on the multimeter screen?

. . . .

3. What does the above multimeter reading mean?

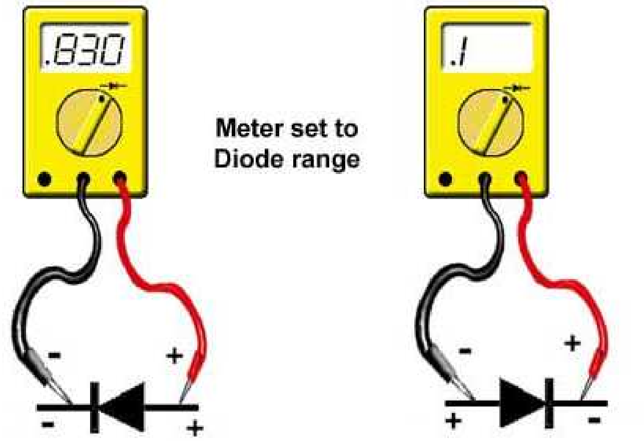
. . . .

4. Second, conduct the *reverse bias* test, where the red multimeter lead (+ve) is connected to the cathode terminal of the diode (-ve), and the black multimeter lead (COM) is connected to the anode terminal of the diode (+ve). What is the reading on the multimeter screen?

. . . .

5. What does the above multimeter reading mean?

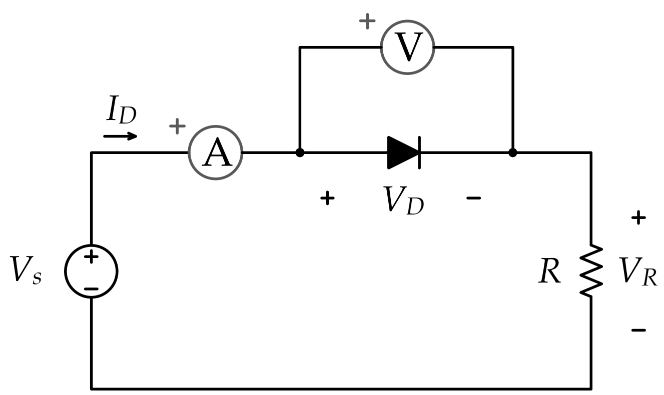
. . . .



Forward bias test Reverse bias test

PROCEDURE B – DIODE V-I CURVE

1. Construct the circuit shown below. Use an 1N4007 diode and R = 100 Ω. Pay attention to the polarity of diode as you connect it, so that it works in the forward bias region.



2. Set the DC supply output voltage controls to minimum then connect it to the circuit. Switch the DC supply ON, and set its voltage Vs to the values shown in Table 1. Verify this voltage using a voltmeter.

3. Set the ammeter to read DC current, and measure the current I_D in the diode. Remember that the ammeter must be connected in series and pay attention to the connection polarity. Record the values in Table 1.

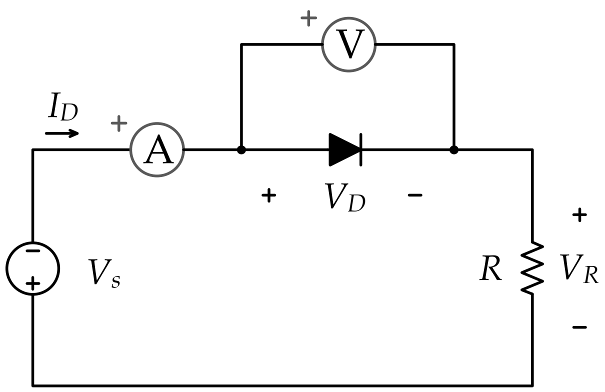
4. Set the voltmeter to read DC voltage, and pay attention to its polarity. Use the voltmeter to measure the diode voltage V_D and record the values in Table 1. Remember that the voltmeter should be connected in parallel with the diode.

5. Switch the DC supply OFF.

Table 1

V_S (V)	0.1	0.3	0.6	0.7	0.8	1	1.3	1.8	4.2	6.3
I_D (mA)										
V_D (V)										

6. Now flip the polarity of the DC power supply in your circuit to force the diode to work in the reverse bias region. This is shown the circuit below.



7. Set the DC supply output voltage controls to minimum. Switch the DC supply ON, and set its voltage Vs to the values shown in Table 2. Verify this voltage using a voltmeter.

8. Use the ammeter to measure the current I_D in the diode. Record the values in Table 2.

9. Use the voltmeter to measure the diode voltage V_D and record the values in Table 2.

Table 2

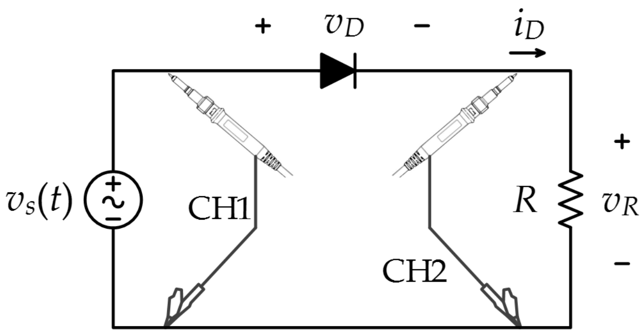
V_S (V)	**0.3**	**0.7**	**1**	**1.8**	**4.2**	**6.3**
I_D (mA)						
V_D (V)						

10. Using the *measured* values in Tables 1 and 2, plot (**by hand**) the following figure using the graph paper attached at the end of the report: $\boldsymbol{I_D}$ on the y-axis versus $\boldsymbol{V_D}$ on the x-axis for both the forward bias and reverse bias regions on the same figure.

11. For the above plot, state your conclusions under the plot?

PROCEDURE C – HALF-WAVE RECTIFIER (FILTERED VS. UNFILTERED)

1. Construct the circuit shown below. Use an 1N4007 diode and R = 1000 Ω (this is different than the previous 100 Ω resistor). Pay attention to the polarity of diode.



2. Set the function generator to produce a sinusoidal waveform (AC) with *frequency* of 500 Hz and *peak voltage* of $V_p = 10$ V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Set the oscilloscope Volt/Div and Time/Div so you can see about 2-3 full cycles of the input sinusoidal signal on CH1. Use the same Volt/Div setting for both CH1 and CH2. Write the settings you chose next to the oscilloscope plot below.

4. What is the difference between the signal you see on CH1 (input v_s) and the signal on CH2 (output v_R)?

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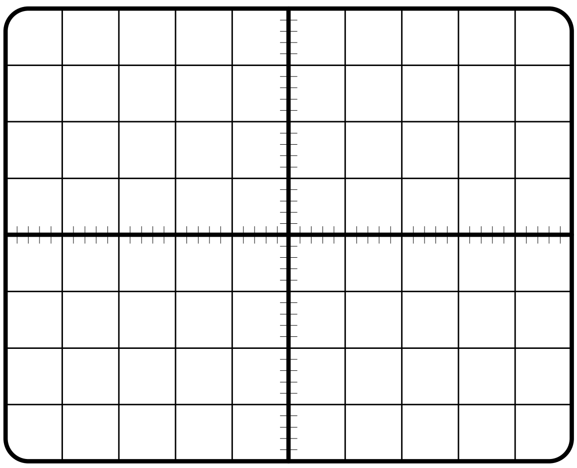
5. Draw the output signal v_R (CH2) you see on the oscilloscope screen below.



Volt/Div (CH2): ____________________

Time/Div: ____________________

Maximum value of v_R: ____________________ V

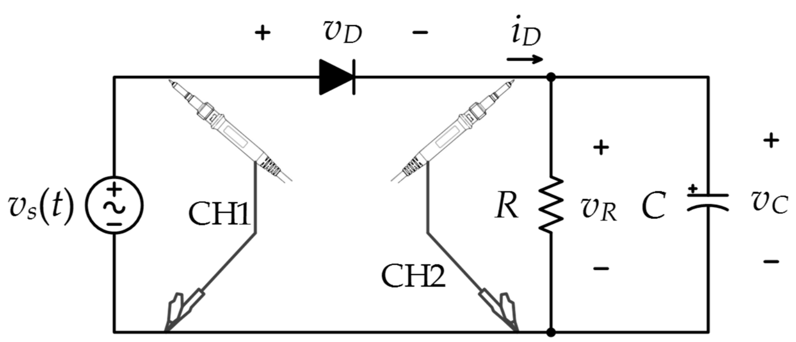
Minimum value of v_R: ____________________ V

Ripple of v_R (Max – Min): ________________ V

Average value of v_R: ____________________ V

6. Use the automatic measurement feature of the oscilloscope to measure the following quantities for the output rectified signal v_R (on CH2) and record them next to the plot above: maximum value of v_R, minimum value of v_R, the ripple of v_R (which is the maximum value minus the minimum value), and average (DC) value of v_R. If you forgot how to use automatic measurement on the oscilloscope, see experiment 6.

7. Now add a capacitor C = 1 μF to the above circuit in parallel with the load resistor, to produce the following circuit. Pay attention to the polarity of the electrolytic capacitor to avoid damaging it.

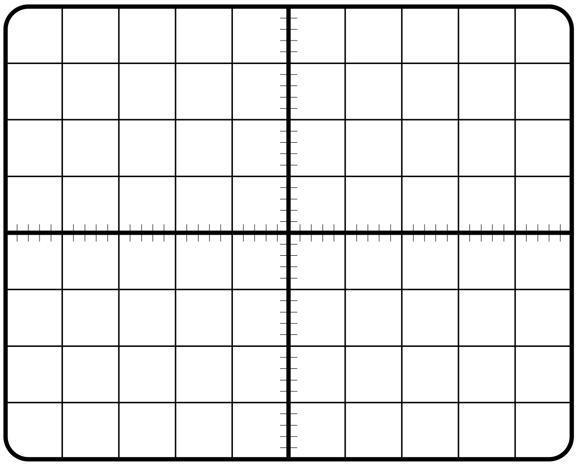


8. Make sure that the function generator is still producing a sinusoidal waveform (AC) with *frequency* of 500 Hz and *peak voltage* of V_p = 10 V. Maintain the same oscilloscope settings as earlier, and write such settings next to the oscilloscope plot below.

9. What has changed for the new output signal v_R (on CH2) compared to the earlier plot? Is the new output signal closer to a DC signal compared to the earlier output or not?

. . . .

10. Draw the output signal v_R (CH2) you see on the oscilloscope screen below.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value of v_R: __________________ V

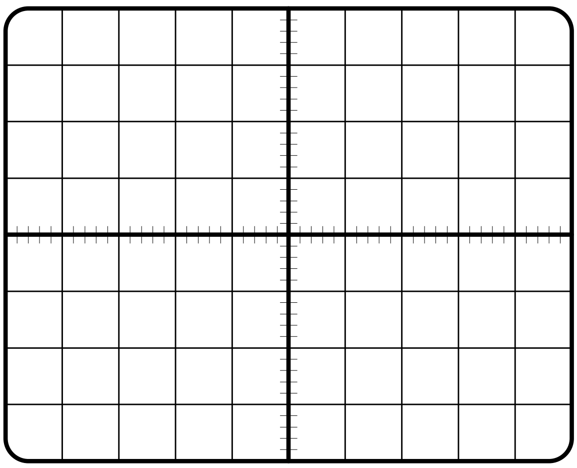
Minimum value of v_R: __________________ V

Ripple of v_R (Max – Min): _______________ V

Average value of v_R: ___________________ V

11. Use the automatic measurement feature of the oscilloscope to measure the following quantities for the new output signal v_R (on CH2) and record them next to the plot above: maximum, minimum, ripple and average value.

12. Keep the same above circuit connected but now use R = 1000 Ω and C = 2.2 μF. Draw the new output signal (CH2) you see on the oscilloscope screen below, along with making the appropriate measurements next to the plot.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value of v_R: __________________ V

Minimum value of v_R: __________________ V

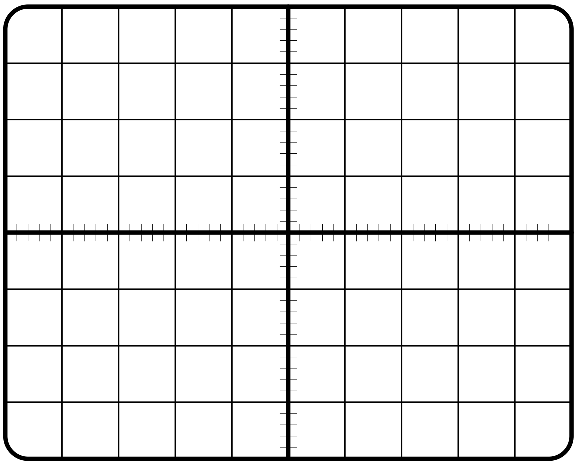
Ripple of v_R (Max – Min): _______________ V

Average value of v_R: ___________________ V

13. What has changed on the output signal v_R on CH2? Is that output closer to a DC signal compared to the earlier output or not?

. . . .

14. Using the same above circuit make sure you now use R = 4700 Ω and C = 2.2 μF. Draw the new output signal (CH2) you see on the oscilloscope screen below, along with making the appropriate measurements next to the plot.



Volt/Div (CH2): ____________________

Time/Div: ________________________

Maximum value of v_R: __________________ V

Minimum value of v_R: __________________ V

Ripple of v_R (Max – Min): ______________ V

Average value of v_R: __________________ V

15. Is there a difference between this signal and the one you obtained in step 12 above? State your conclusions?

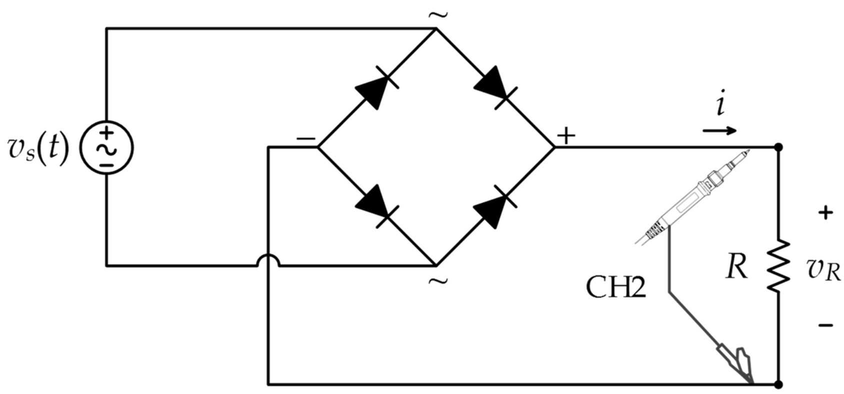
. . . .

16. What is the average value for a DC signal (not AC signal) that is V_s = 10 V?

. . . .

PROCEDURE D – FULL-WAVE RECTIFIER (FILTERED VS. UNFILTERED)

1. The circuit shown below will be constructed for you by the lab supervisor. It utilizes a diode bridge followed by R = 1000 Ω. Pay attention to the connection of the bridge terminals.



2. Set the function generator to produce a sinusoidal waveform (AC) with *frequency* of 500 Hz and *peak voltage* of V_p = 10 V.

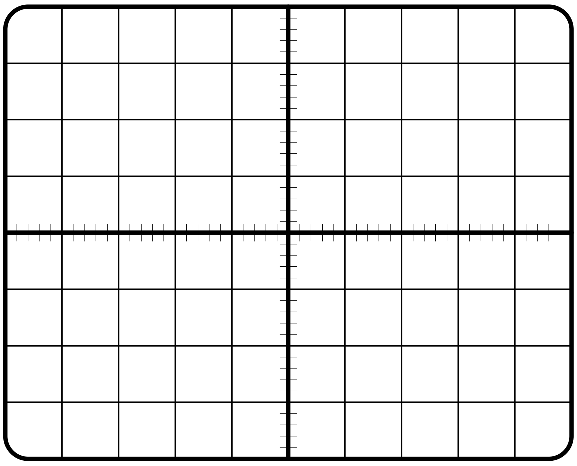
CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Set the oscilloscope Volt/Div and Time/Div so you can see about 2-3 full cycles of the input sinusoidal signal on CH1. Use the same Volt/Div setting for both CH1 and CH2. Write the settings you chose next to the oscilloscope plot below. **Be careful NOT** to connect both CH1 and CH2 simultaneously on the circuit since the grounds of both CH1 and CH2 are short circuited inside the oscilloscope, which will short the bottom left diode in the bridge. Rather first measure the input source using CH1 probe, then disconnect that probe completely from the circuit, and measure the output using CH2 probe.

4. What is the difference between the signal you see on CH1 (input v_s) and the signal on CH2 (output v_R)? How is that different than a half-wave rectifier output (*see* procedure C)?

. . . .

5. Draw the output signal v_R (CH2) you see on the oscilloscope screen below. You can use the **RUN/STOP button** on the oscilloscope to freeze CH2 if you have difficulty getting a stable signal due to triggering of the oscilloscope.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value of v_R: __________________ V

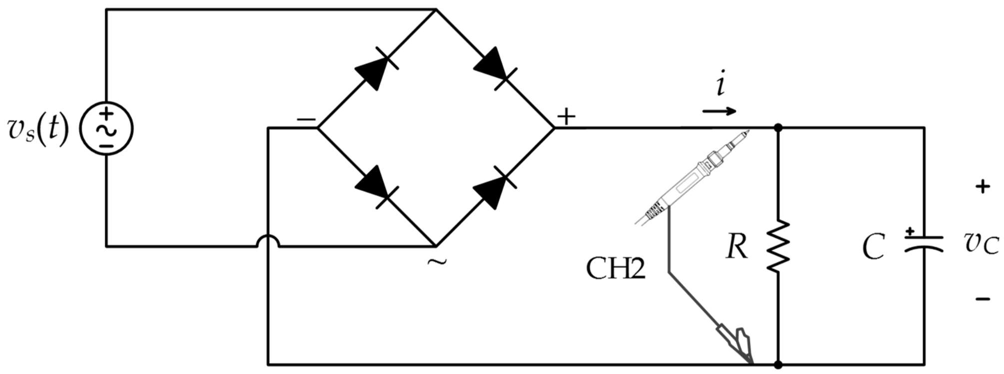
Minimum value of v_R: __________________ V

Ripple of v_R (Max – Min): _______________ V

Average value of v_R: ___________________ V

6. Use the automatic measurement feature of the oscilloscope to measure the following quantities for the output rectified signal v_R (on CH2) and record them next to the plot above: maximum value of v_R, minimum value of v_R, the ripple of v_R (which is the maximum value minus the minimum value), and average (DC) value of v_R.

7. Now add a capacitor C = 1 μF to the above circuit in parallel with the load resistor, to produce the following circuit. Pay attention to the polarity of the electrolytic capacitor to avoid damaging it.

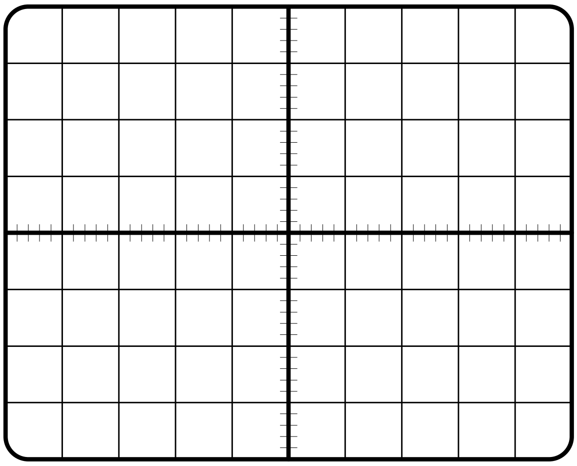


8. Make sure that the function generator is still producing a sinusoidal waveform (AC) with *frequency* of 500 Hz and *peak voltage* of V_p = 10 V. Maintain the same oscilloscope settings as earlier, and write such settings next to the oscilloscope plot below.

9. What has changed for the new output signal v_R (on CH2) compared to the earlier plot? Is the new output signal closer to a DC signal compared to the earlier output or not?

. . . .

10. Draw the output signal v_R (CH2) you see on the oscilloscope screen below.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value of v_R: __________________ V

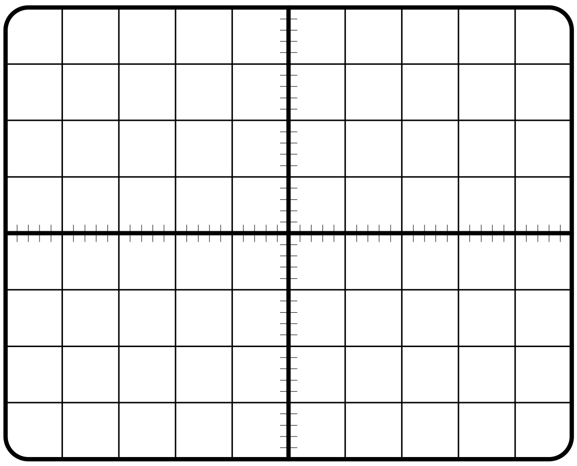
Minimum value of v_R: __________________ V

Ripple of v_R (Max – Min): _______________ V

Average value of v_R: ___________________ V

11. Use the automatic measurement feature of the oscilloscope to measure the following quantities for the new output signal v_R (on CH2) and record them next to the plot above: maximum, minimum, ripple and average value. You can use the **RUN/STOP button** on the oscilloscope to freeze CH2 if you have difficulty getting a stable signal due to triggering of the oscilloscope.

12. Keep the same above circuit connected but now use *R* = 1000 Ω and *C* = 2.2 μF. Draw the new output signal (CH2) you see on the oscilloscope screen below, along with making the appropriate measurements next to the plot.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value of v_R: __________________ V

Minimum value of v_R: __________________ V

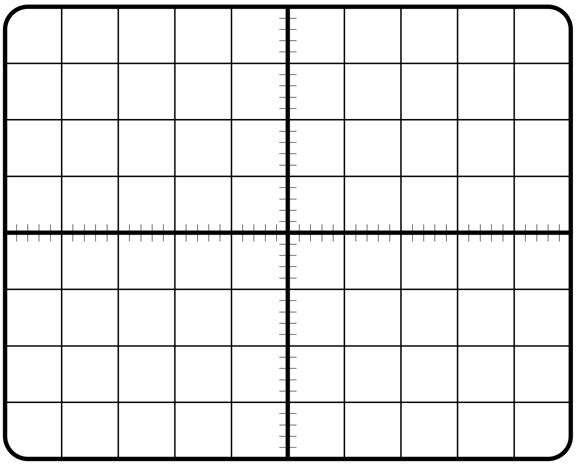
Ripple of v_R (Max – Min): _______________ V

Average value of v_R: ___________________ V

13. What has changed on the output signal v_R on CH2? Is that output closer to a DC signal compared to the earlier output or not?

. . . .

14. Using the same above circuit make sure you now use R = 4700 Ω and C = 2.2 μF. Draw the new output signal (CH2) you see on the oscilloscope screen below, along with making the appropriate measurements next to the plot.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value of v_R: __________________ V

Minimum value of v_R: __________________ V

Ripple of v_R (Max – Min): _______________ V

Average value of v_R: ___________________ V

15. Is there a difference between this signal and the one you obtained in step 12 above? State your conclusions?

. . . .

**** End ****