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Experiment-04

Study of Half-Wave and Full-Wave Rectifier

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To build a half-wave rectifier circuit and understand its operating principle.
2. To build a full-wave rectifier circuit and understand its operating principle.

Equipments

1. p-n junction diode (1N4007) x 4
2. Resistor (10kΩ) - $\times$1
3. Capacitors (1μF, 4.7μF) – 1 each
4. Function Generator
5. Oscilloscope
6. Multimeter
7. Breadboard and Wires

Background Theory

Diodes are used to build rectifier circuits which convert the input sinusoidal voltage V_s to a unipolar output V_o. There are two types of rectifier circuits: (i) Half-wave rectifier and (ii) Full-wave rectifier.

Half-Wave (HW) Rectifier

The circuit of a half-wave rectifier is shown in the following figure:

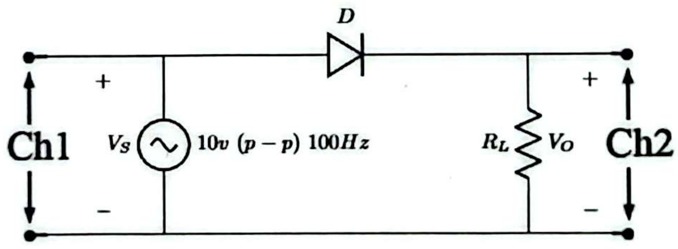


Figure 1: ***Half-Wave Rectifier***

Assuming ideal diode model,

For the period, $t = 0 \to T/2$, $V_S > 0$, Diode is ON and $V_O = V_S$

For the period, $t = T/2 \to T$, $V_S < 0$, Diode is OFF and $V_O = 0$

As only positive half cycle appears at the output and the negative half is blocked, the AC input voltage changes into a unidirectional DC voltage at the output. The process of removing half of the input signal to establish a dc level is aptly called half-wave rectification. Due to diode voltage drop, the actual output voltage will be approximately, $V_O = V_S - V_{D0}$. For, $V_S = V_m \sin \omega t$, DC voltage and current of a half wave rectifier are:

$$V_{dc} = \frac{V_m}{\pi} - \frac{V_{D0}}{2} \quad \text{and} \quad I_{dc} = \frac{V_{dc}}{R} = \frac{V_m/\pi - V_{D0}/2}{R}$$

where, V_m = peak input voltage, $V_{D0} \approx 0.7v$ for Silicon diodes. The following figures show the input and output wave shapes of a HW rectifier circuit:

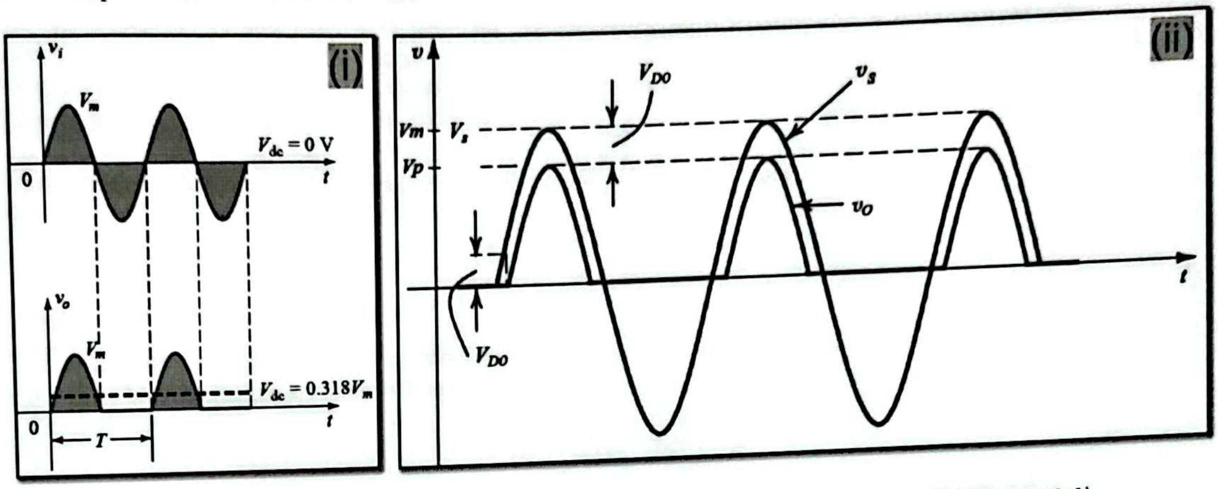


Figure 2: *(i) Assuming Ideal Diode (ii) Assuming Real Diode (CVD Model)*

HW Rectifier with Filter Capacitor

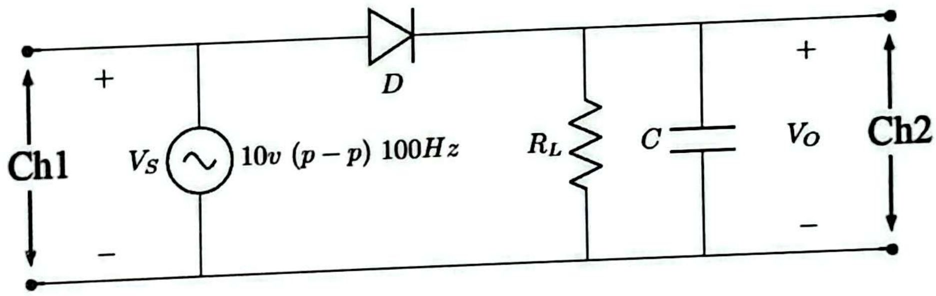


Figure 3: *Half-Wave Rectifier with Filter Capacitor*

Although the rectification stage makes the sine wave voltage to be positive, the rectifier's result is not as "flat" a DC value as we would like to have from a reliable voltage source, as you will measure in the lab. The capacitor is included to help smooth out the ripples that result in the output from the rectification stage.

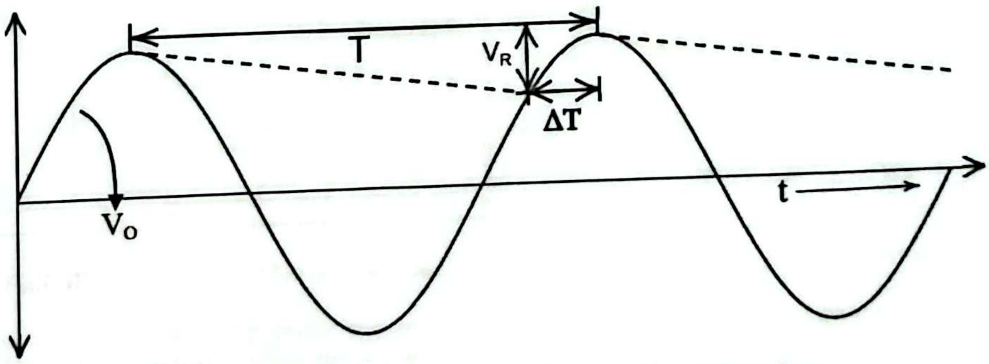


Figure 4: V_r *or* $V_{r(p-p)}$ *is the peak to peak ripple voltage*

Recall that the voltage across a capacitor cannot change instantaneously, but rather it requires a certain amount of time before it is fully charged. Initially, as the input voltage rises, diode turns on, and the capacitor starts charging. After the input voltage reaches its peak value, the capacitor gets charged to the peak input voltage. As the input voltage now starts decreasing below the peak value, the diode turns off, since the n-side is more positive than the p-side due to the voltage across the capacitor which does not change instantaneously. The stored charges on the capacitor will be released through R_L.

For $R_L C >> T$, it will take long time for the capacitor to discharge and the output terminal will maintain almost a dc voltage. Thus, large capacitance values help suppress the quickly changing voltage from the rectifier and result in a flatter DC value being supplied to the load. Typical power supply designs use relatively large capacitor values (greater than 1000 μF).

Peak Inverse Voltage(PIV): PIV is the maximum voltage that appears across the diode when it is reverse-biased.

$$PIV = V_m$$

Ripple Voltage and Ripple Factor

The output of a rectifier though unidirectional, contains periodically fluctuating components. The theoretical value for the peak-to-peak ripple voltage is given by,

$$V_{r(p-p)} = \frac{V_p}{fCR_L} = \frac{V_m - V_{D0}}{fCR_L}$$

Here, V_p = peak voltage of the rectified output, f = input frequency, and R_L is the resistance connected in parallel with C.

$$\text{Average value of the output wave, } V_{dc} = V_p - \frac{V_{r(p-p)}}{2}$$

$$\text{RMS value of the Ripple Voltage, } V_{r(rms)} = \frac{V_{r(p-p)}}{2\sqrt{3}}$$

A measure of the fluctuating components is given by the ripple factor r, which is defined as,

$$r = \frac{\text{rms value of alternating components of the output wave (multimeter in } AC)}{\text{average value of the output wave (multimeter in DC)}}$$

$$= \frac{V_{r-rms}}{V_{dc}}$$

Full-Wave (FW) Rectifier / Bridge Rectifier

The full-wave rectifier utilizes both halves of the input sinusoid. To provide a unipolar output,it inverts the negative halves of the sine wave. Figure-5 shows the circuit diagram, input and output waveform of Full-Wave Rectifier/Bridge Rectifier.

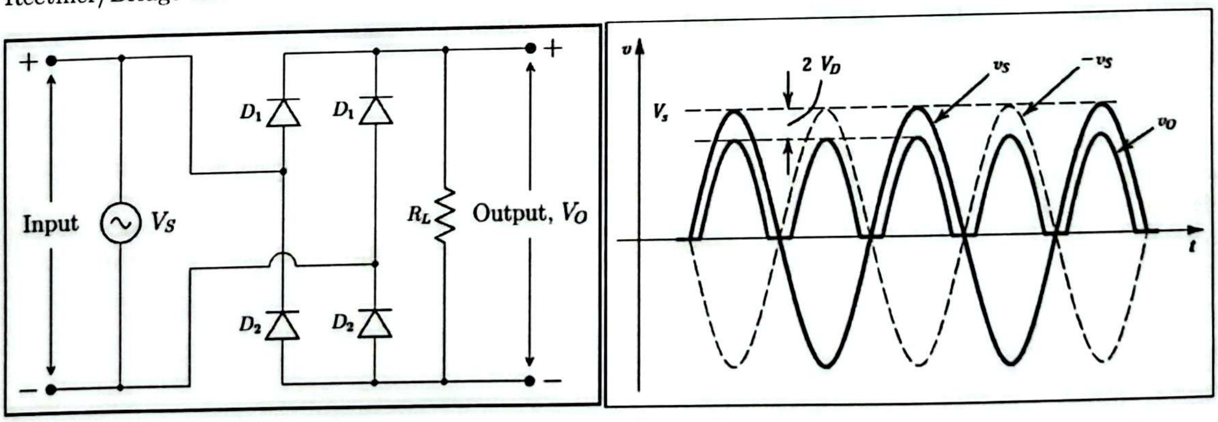


Figure 5: ***Full-Wave Rectifier Circuit without Capacitor and the Waveform of Input and Output***

In this case, constant voltage drop model was assumed. Peak inverse voltage across each diode and DC voltage in reverse-bias can be calculated using the following equations,

$$PIV = V_m - V_{D0}$$

$$V_{dc} = \frac{2V_m}{\pi} - 2V_{D0}$$

Full-Wave (FW) Rectifier with Capacitor

The pulsating nature of the output voltage produced by the rectifier circuits discussed above makes it unsuitable as a dc supply for electronic circuits. A simple way to reduce the variation of the output voltage is to place a capacitor across the load resistor. Figure-6 shows the circuit diagram and output waveform of Full-Wave Rectifier with Capacitor.

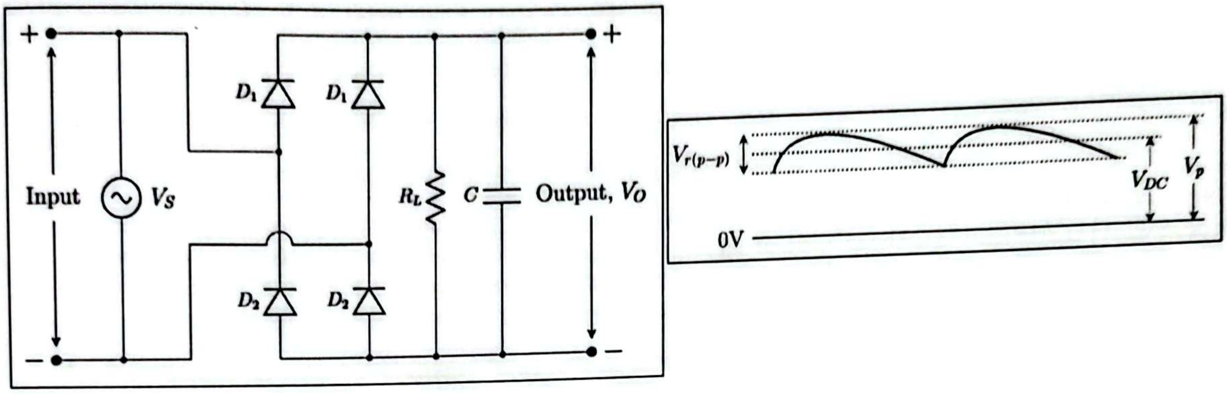


Figure 6: ***Full-Wave Rectifier Circuit with Capacitor and the Output Waveform***

Ripple Voltage and Ripple Factor

The output of a rectifier though unidirectional, contains periodically fluctuating components. The theoretical value for the peak-to-peak ripple voltage is given by,

$$V_{r(p-p)} = \frac{V_p}{2fCR_L} = \frac{V_m - 2V_{D0}}{2fCR_L}, \text{ for a FW rectifier circuit}$$

Here, V_p = peak voltage of the rectified output, f = input frequency, and R is the resistance connected in parallel with C.

$$\text{Average value of the output wave, } V_{dc} = V_p - \frac{V_{r(p-p)}}{2}$$

$$\text{RMS value of the Ripple Voltage, } V_{r-rms} = \frac{V_{r(p-p)}}{2\sqrt{3}}$$

A measure of the fluctuating components is given by the ripple factor r, which is defined as

$$r = \frac{\text{rms value of alternating components of the output wave (multimeter in AC mode)}}{\text{average value of the output wave (multimeter in DC mode)}}$$

$$= \frac{V_{r-rms}}{V_{dc}}$$

Larger ripple factor means the AC components of the output wave is larger compared to the DC components. Hence, there fluctuation in the output wave is large. Smaller ripple factor means the AC components of the output wave is smaller compared to the DC components. Hence, there fluctuation in the output wave is small. So, the lower the value of the ripple factor, the better the rectifier.

Task-01: HW Rectifier

Procedure

1. Construct circuit of ***Figure 1***. Observe V_S and V_O simultaneously on Channel 1 and Channel 2 of the oscilloscope respectively.
2. Capture the image of the input and output waveforms using your mobile camera.
3. Measure V_O with a multimeter in dc and ac mode to take data for the Data Sheet.
4. Connect 1μF capacitor across the resistor, $R_L = 10k\Omega$.
5. Capture the image of the input and output waveforms using your mobile camera.
6. Measure the peak voltage of the output, V_p and peak-to-peak ripple voltage $V_{r(p-p)}$ from the oscilloscope. To measure the peak and peak-to-peak the ripple voltages, go to the "***measure***" tab of the oscilloscope or switch on the cursors of the oscilloscope. This allows you to level your cursor horizontally with the peak or the ripple voltage and measure the values.
7. Again, measure V_O with a multimeter in dc and ac mode to take data for the Data Sheet. Calculate the ripple factor.
8. Replace 1μF Capacitor with 4.7μF and repeat steps 4-7.

Task-02: FW Rectifier

Procedure

1. Construct circuit of ***Figure 5***. Observe V_S and V_O separately on the oscilloscope [i.e. don't use both channels simultaneously, use only one channel].
2. Capture the image of the input and output waveforms using your mobile camera.
3. Measure V_O with a multimeter in dc and ac mode to take data for the Data Sheet.
4. Connect 1μF capacitor across the resistor, $R_L = 10k\Omega$.
5. Capture the image of the input and output waveforms using your mobile camera.
6. Measure the peak voltage of the output, V_p and peak-to-peak ripple voltage $V_{r(p-p)}$ from the oscilloscope. To measure the peak and the peak-to-peak ripple voltages, go to the "***measure***" tab of the oscilloscope or switch on the cursors of the oscilloscope. This allows you to level your cursor horizontally with the peak or the ripple voltage and measure the values.
7. Again, measure V_O with a multimeter in dc and ac mode and calculate the ripple factor.
8. Replace 1μF Capacitor with 4.7μF and repeat steps 4-7.

Data Sheet

Experimental Observation: HW Rectifier

1. **HW Rectifier without Capacitor:**
   Diode voltage, V_{D0} = $Input_{max}$ (oscilloscope) − $Output_{max}$ (oscilloscope) = 5.20 − 4.80 = 0.40 V
   Maximum output voltage, V_p (oscilloscope) = 4.80 V
   Average or DC output voltage, V_{dc} (multimeter in DC mode) = 1.46 V
   RMS or AC output voltage, V_{r-rms} (multimeter in AC mode) = 1.81 V

2. **HW Rectifier with 1μF Capacitor:**
   Diode voltage, V_{D0} = $Input_{max}$ (oscilloscope) − $Output_{max}$ (oscilloscope) = 5.00 − 4.80 = 0.20 V
   Maximum output voltage, V_p (oscilloscope) = 4.80 V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (oscilloscope) = 4.80 − 2.00 = 2.80 V
   Average or DC value of the ripple voltage, V_{dc} (multimeter in DC mode) = 3.3 V
   RMS or AC value of the ripple voltage, V_{r-rms} (multimeter in AC mode) = 0.8 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.8/3.3 = 0.2424

3. **HW Rectifier with 4.7μF Capacitor:**
   Diode voltage, V_{D0} = $Input_{max}$ (oscilloscope) − $Output_{max}$ (oscilloscope) = 5.00 − 4.80 = 0.20 V
   Maximum output voltage, V_p (oscilloscope) = 4.80 V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (oscilloscope) = 4.80 − 3.80 = 1.00 V
   Average or DC value of the ripple voltage, V_{dc} (multimeter in DC mode) = 4.15 V
   RMS or AC value of the ripple voltage, V_{r-rms} (multimeter in AC mode) = 0.223 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.223/4.15 = 0.0537

Theoretical Calculation: HW Rectifier

1. **HW Rectifier Without Capacitor:**
   Maximum output voltage, V_p (see the experimental observation) = 4.80 V
   Maximum input voltage, V_m = 5.00 V
   Diode voltage, V_{D0} (see the experimental observation) = 0.40 V
   DC output voltage of the rectifier, $V_{dc} = \frac{V_m}{\pi} - \frac{V_{D0}}{2}$ = 1.3915 V
   RMS or AC output voltage, $V_{r-rms} = \frac{V_p}{2}$ = 2.40 V

2. **HW Rectifier With 1μF Capacitor:**
   Maximum output voltage, V_p (see the experimental observation) = 4.80 V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (see the experimental observation)= 2.80 V
   DC value of the ripple voltage, $V_{dc} = V_p - \frac{V_{r(p-p)}}{2}$ = 3.40 V
   RMS value of the ripple voltage, $V_{r-rms} = \frac{V_{r(p-p)}}{2\sqrt{3}}$ = 0.8083 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.2377

3. **HW Rectifier with 4.7μF Capacitor:**
   Maximum output voltage, V_p (see the experimental observation) = 4.80 V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (see the experimental observation) = 1.00 V
   DC value of the ripple voltage, $V_{dc} = V_p - \frac{V_{r(p-p)}}{2}$ = 4.30 V
   RMS value of the ripple voltage, $V_{r-rms} = \frac{V_{r(p-p)}}{2\sqrt{3}}$ = 0.2887 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.06714

Experimental Observation: FW Rectifier

1. **FW Rectifier without Capacitor:**
   Diode voltage, $V_{D0} = \frac{\text{Input}_{max}\text{(oscilloscope)} - \text{Output}_{max}\text{(oscilloscope)}}{2} = \frac{(5.20 - 4.00)}{2} = 0.60V$
   Maximum output voltage, V_p (oscilloscope) = 4.00 V
   Average or DC output voltage, V_{dc} (multimeter in DC mode) = 2.391 V
   RMS or AC output voltage, V_{r-rms} (multimeter in AC mode) = 1.412 V

2. **FW Rectifier with 1μF Capacitor:**
   Diode voltage, $V_{D0} = \frac{\text{Input}_{max}\text{(oscilloscope)} - \text{Output}_{max}\text{(oscilloscope)}}{2} = \frac{(5.20 - 4.08)}{2} = 0.56V$
   Maximum output voltage, V_p (oscilloscope) = 4.08 V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (oscilloscope) = (4.08 - 2.64) = 1.44V
   Average or DC value of the ripple voltage, V_{dc} (multimeter in DC mode) = 3.5 V
   RMS or AC value of the ripple voltage, V_{r-rms} (multimeter in AC mode) = 0.38 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.38/3.5 = 0.1086

3. **FW Rectifier with 4.7μF Capacitor:**
   Diode voltage, $V_{D0} = \frac{\text{Input}_{max}\text{(oscilloscope)} - \text{Output}_{max}\text{(oscilloscope)}}{2} = \frac{(5.20 - 4.00)}{2} = 0.6V$
   Maximum output voltage, V_p (oscilloscope) = 4.00V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (oscilloscope) = 4.00 - 3.44 = 0.56V
   Average or DC value of the ripple voltage, V_{dc} (multimeter in DC mode) = 3.77V
   RMS or AC value of the ripple voltage, V_{r-rms} (multimeter in AC mode) = 0.094V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.094/3.77 = 0.025

Theoretical Calculation: FW Rectifier

1. **FW Rectifier without Capacitor:**
   Maximum output voltage, V_p (see the experimental observation) = 4.00 V
   Maximum input voltage, V_m = 5.00 V
   Diode voltage, V_{D0} (see the experimental observation) = 0.60 V
   DC output voltage of the rectifier, $V_{dc} = \frac{2V_m}{\pi} - 2V_{D0}$ = 1.983 V
   RMS or AC output voltage, $V_{r-rms} = \frac{V_p}{\sqrt{2}}$ = 2.83 V

2. **FW Rectifier with 1μF Capacitor:**
   Maximum output voltage, V_p (see the experimental observation) = 4.08V
   Peak to peak ripple voltage, $V_{r(p-p)}$ (see the experimental observation) = 1.44V
   DC value of the ripple voltage, $V_{dc} = V_p - \frac{V_{r(p-p)}}{2}$ = 3.36 V
   RMS value of the ripple voltage, $V_{r-rms} = \frac{V_{r(p-p)}}{2\sqrt{3}}$ = 0.4157 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.124

3. **FW Rectifier with 4.7μF Capacitor:**
   Maximum output voltage, V_p (see the experimental observation) = 4.00V
   Peak to peak ripple voltage, V_p (see the experimental observation) = 0.56V
   DC value of the ripple voltage, $V_{dc} = V_p - \frac{V_{r(p-p)}}{2}$ = 3.72 V
   RMS value of the ripple voltage, $V_{r-rms} = \frac{V_{r(p-p)}}{2\sqrt{3}}$ = 0.162 V
   Ripple factor, $r = V_{r-rms}/V_{dc}$ = 0.0435

Table for Comparison

		Experimental Observation			Theoretical Calculation		
	C(μF)	V_{r-rms} (V)	V_{dc} (V)	Ripple Factor, r	V_{r-rms} (V)	V_{dc} (V)	Ripple Factor, r
HW	1	0.8	3.3	0.2424	0.8083	3.40	0.2377
	4.7	0.223	4.15	0.0537	0.2887	4.30	0.06714
FW	1	0.38	3.5	0.1086	0.4157	3.36	0.124
	4.7	0.094	3.77	0.025	0.162	3.72	0.0435

10.08.25

Signature of the lab faculty

Report Submission Guidelines

1. Attach the signed Data Sheet (if any)
2. Attach the captured images (if any)
3. Answer the questions in the "Test Your Understanding" section
4. Add a brief Discussion regarding the experiment. For the Discussion part of the lab report, you should include the answers of the following questions in your own words:
   - What did you learn from this experiment?
   - What challenges did you face and how did you overcome the challenges? (if any)
   - What mistakes did you make and how did you correct the mistakes? (if any)
   - How will this experiment help you in future experiments of this course?

Test Your Understanding

Answer the following questions:

1. Which capacitor acts as a better filter? Explain briefly.
   Answer:
   The 4.7 μF acts as a better filter than the 1 μF capacitor. The more the capacitance is, the more it will store charges. Thus, it will take longer time discharging. Large capacitance value help suppress the quickly changing voltage from the rectifier resulting in a flatter DC value being supplied. Thus, 4.7μF capacitor produces a smaller ripple and more constant DC output, making it a better filter.

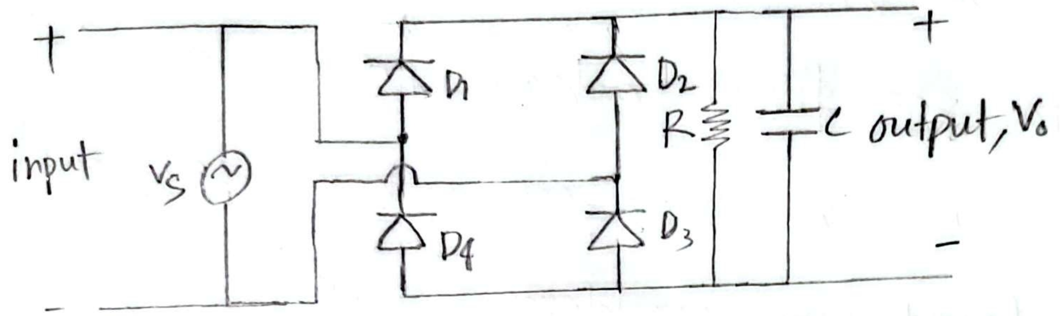
2. Which of the two rectifiers is better? Which quantity is calculated for this purpose? Explain briefly.
   Answer:
   The full wave rectifier is better if we consider the ripple factor.

   The ripple factor gives us the measure of the fluctuating components of the rectifier. A lower ripple factor means the fewer fluctuation. So, we can say that the lower the ripple factor the

the rectifier. From the comparison table, we can see that, the full wave rectifier has lower ripple factor compare to Half wave. So, we can say that, the Full wave rectifier is better if ripple factor is considered.

3. **Why can't you see the input and output using both channels of the oscilloscope simultaneously in Task-02?**
Answer:

A full-wave rectifier circuit looks like,



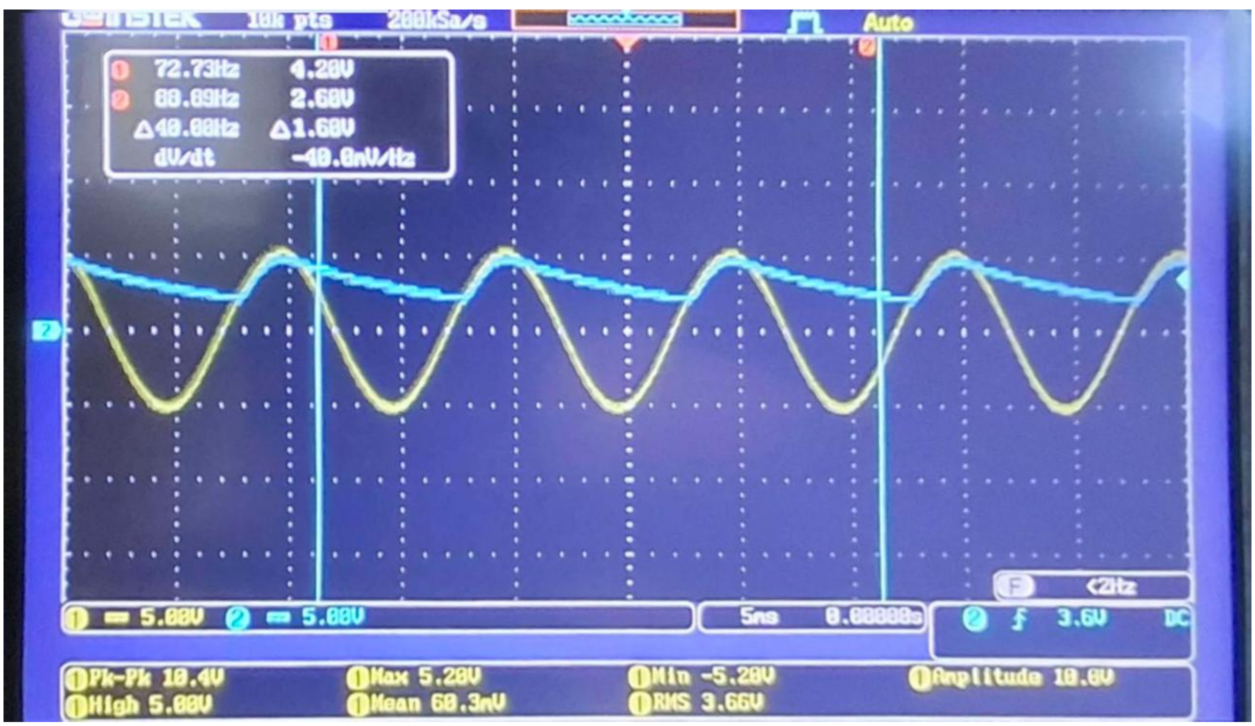
In this circuit, we can see that, output node is not referenced to the same ground as the input node. However, in oscilloscope, two channel's negative node is internally shorted, so they share a common ground. So, if we connet ch-1 to the input and ch-2 to the output, their ground will get shorted. Consequently, this will change the circuit structure and we won't get our desired curve.

Discussion:

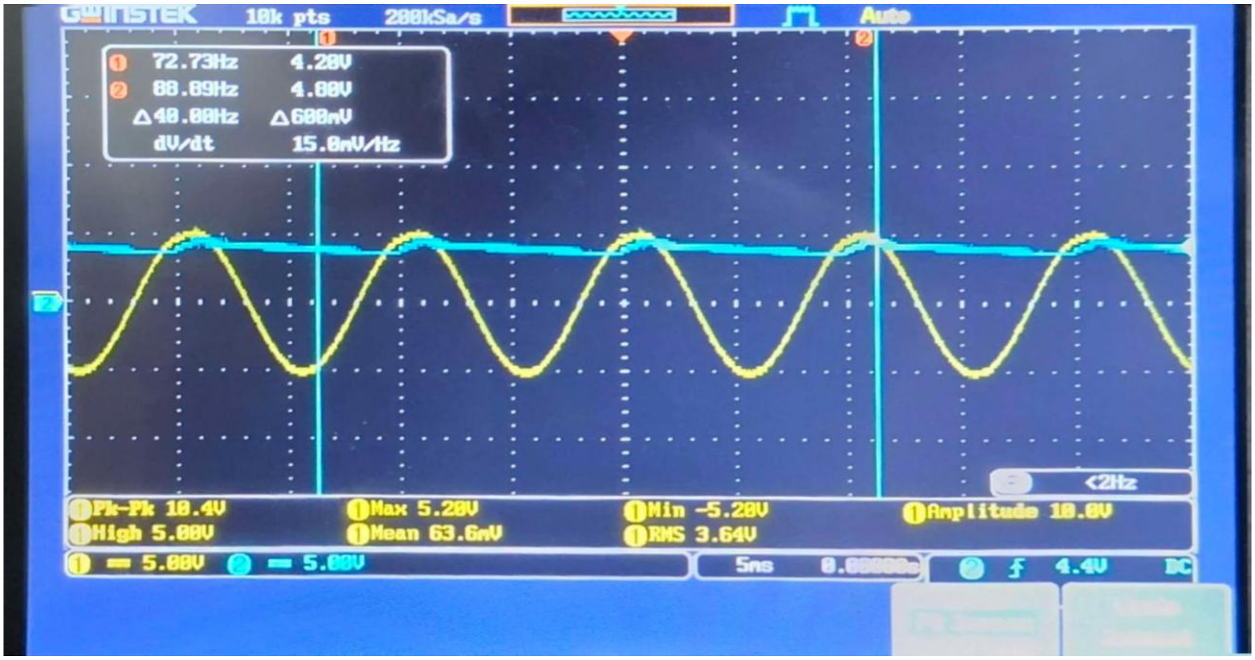
In this experiment, we got to learn about rectifiers which we only learned in our theory classes. We used half-wave and full-wave rectifiers practically and got to see their behaviour under different circumstances such as with or without capacitor. we initially faced some problems understanding the circuit structure of Half and full wave rectifiers. However, sir explained the circuit to us and we built the circuit. Then initially we took all the data and captured the necessary images. We though made mistakes. When we were capturing the images, they all look the same particularly the full wave output with 1 μF and 4.7 μF. But later, we adjusted the scalling and took the picture. Those pictures came out better than the previous ones. Finally, we learned many interesting things about rectifiers about their structures, how they behave etc. I believe this will help us in our future.

Input and output for Half-Wave rectifier without capacitor:

Input and output for Half-Wave rectifier with 1µF capacitor:

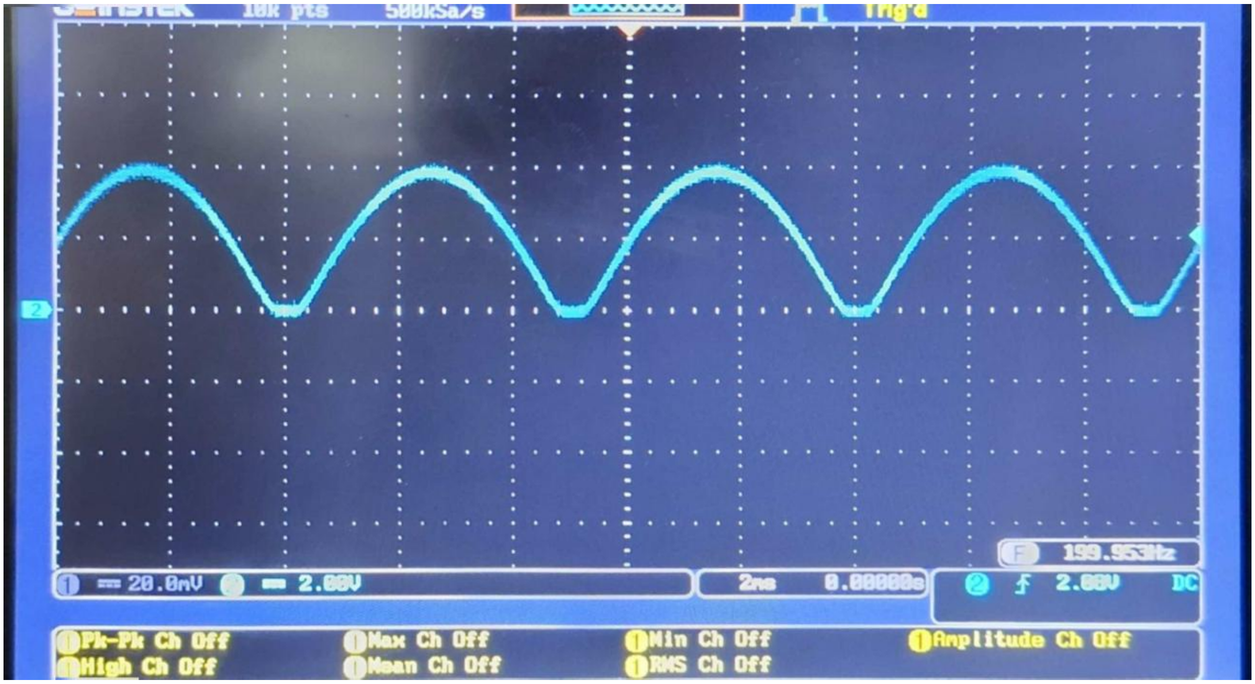


Input and output for Half-Wave rectifier with 4.7µF capacitor:

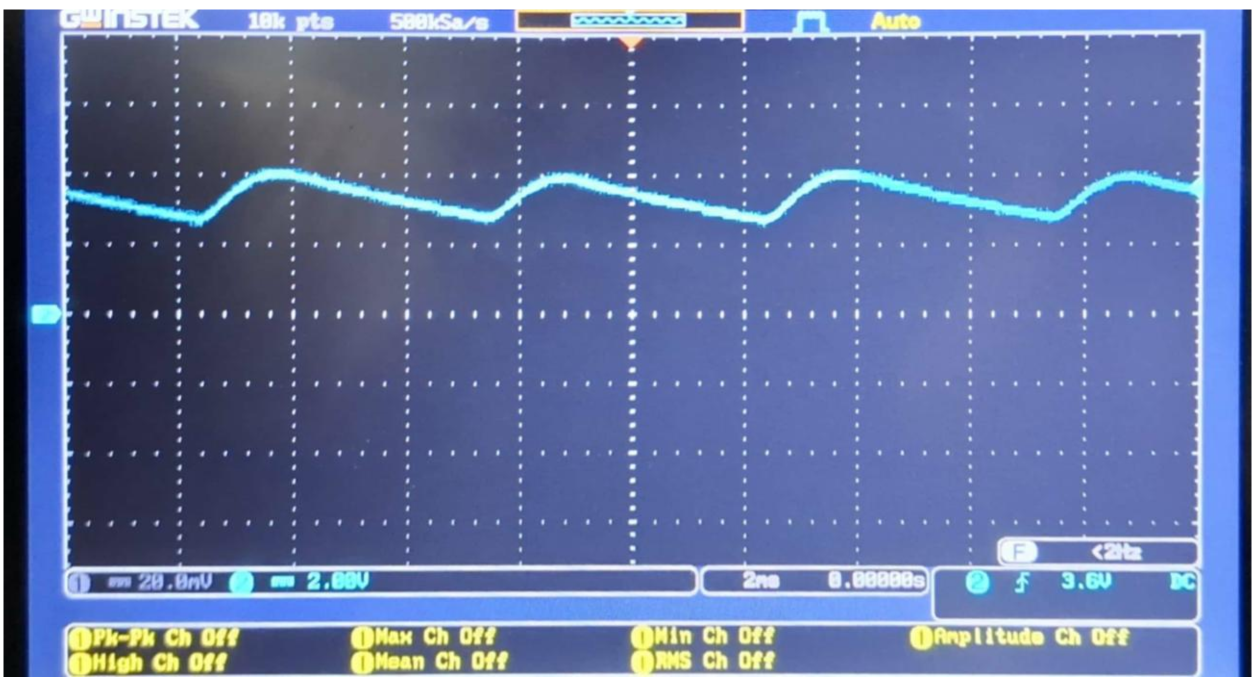


Input for Full-Wave rectifier without capacitor and 1µF and 4.7µF capacitor:

Output for Full-Wave rectifier without capacitor:



Output for Full-Wave rectifier with 1µF capacitor:



Output for Full-Wave rectifier with 4.7µF capacitor: