Lab # 2a: Study of Normal and Zener Diode Characteristics

Objectives:

i) To study and plot the forward and reverse bias characteristics of a normal diode and to determine the threshold voltage, static and dynamic resistance.
ii) To study and plot forward and reverse bias characteristics of a zener diode and to determine the threshold and zener break-down voltage.

Overview:

A diode is a nonlinear circuit element. The symbol of a diode and a real commercial diode is shown in Fig. 1. Generally there is a band marked at its cathode for its identification. There exists another type of diode known as zener diode, which has a heavily doped PN junction.

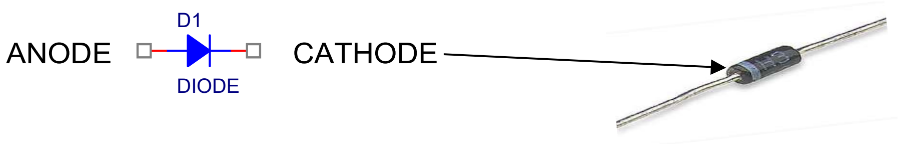


Fig. 1

The theoretical equation for the diode current I_D is

$$I_D = I_S\left[\exp\left(\frac{V_D}{nV_T}\right)-1\right]$$

where V_D is the diode voltage drop, I_S is the saturation current, n is the emission coefficient, and V_T = kT/q (≈ 0.026V at T=300K) is the thermal voltage. The emission coefficient accounts for recombinations of electrons and holes in the depletion region, which tend to decrease the current. For discrete diodes, it has the value n is 2.

The I~V characteristic of an ideal diode is shown in Fig. 2-a. Under forward biased condition of a real PN junction diode, the P-side is connected to the positive and N-side is connected to the negative terminal of the power supply. This reduces the potential barrier. As a result current flows from P to N-type in forward direction. When the applied voltage is more than the barrier potential, the resistance is small (ideally 0) and the current increases rapidly. This point is called the *Knee-point* or *turn-on voltage* or *threshold voltage* (Fig. 2-b). This voltage is about 0.3 volts for Ge diodes and 0.7 volts for Si diodes.

Under reverse biased condition, the P-side of the junction diode is connected to the negative and N-side is connected to the positive terminal of the power supply. This increases the potential barrier due to which no current should flow ideally. But in practice, the minority carriers can travel down the potential barrier to give very small current. This is called as the *reverse saturation current*. This current is about 2-20 μA for Ge diodes and 2-20 nA for Si diodes (the values might differ for diodes of different makes).

However, if the reverse bias is made too high, the current through the PN junction increases abruptly. The voltage at which this phenomenon occurs is known as the *break-down or reverse voltage* and the mechanism involved depends on the construction of the diode. In conventional diodes with a lightly doped junction, application of higher reverse voltage leads to large number of carriers produced by collision of thermally generated electrons and the phenomenon is called *avalanche breakdown*. When the reverse bias exceeds this breakdown voltage, a conventional diode is subject to high current. Unless this current is limited by external circuitry, the diode will be permanently damaged. If the junction is heavily doped with narrow depletion layers, break-down occurs when the reverse voltage is strong enough to rupture the covalent bonds generating large number of electron-hole pairs. This phenomenon is called *zener breakdown*.

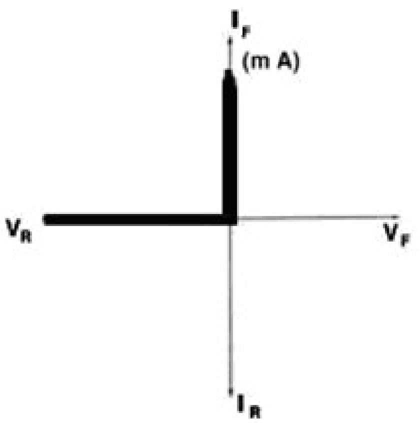


Fig. 2 (a)

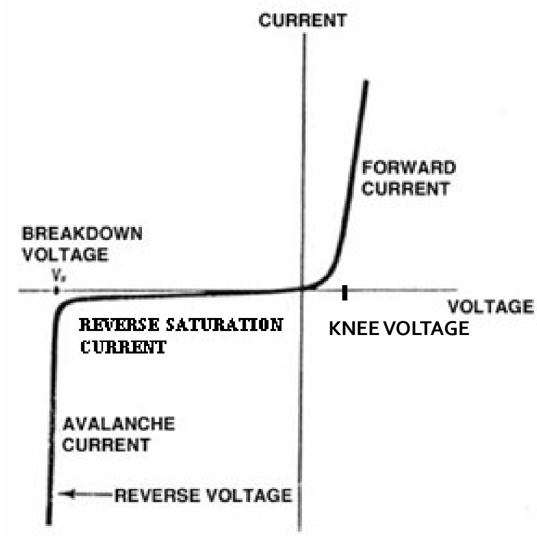


Fig. 2 (b)

Zener diode:

It is a reverse biased heavily doped PN junction diode generally operated in zener breakdown region. Zener voltage is the reverse voltage above which there is a controlled *breakdown* which does not damage the diode. The voltage drop across the diode remains constant at zener voltage no matter how high the reverse bias voltage is. The forward characteristic of a zener diode is similar to a normal diode. The symbol of a zener diode is shown in Figure 3.

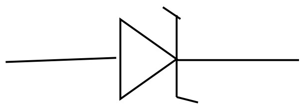


Fig. 3

Static and Dynamic Resistance:

At a given operating point, the static and dynamic resistance of a diode can be determined from its characteristics as shown in Fig. 4. The *static or dc resistance*, R_D, of the diode at the operating point (the point where the load line intersects the diode characteristics), Q, is simply the quotient of the corresponding levels of V_D and I_D. The dc resistance levels at the knee and below will be greater than the resistance levels obtained for the vertical rise section of the characteristics.

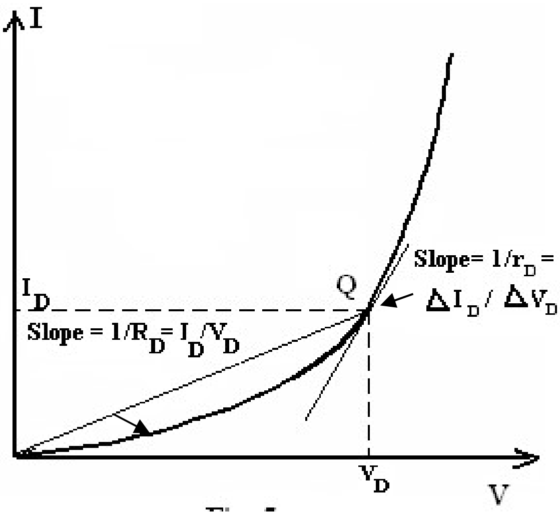


Fig. 4

$$R_D = V_D/I_D$$

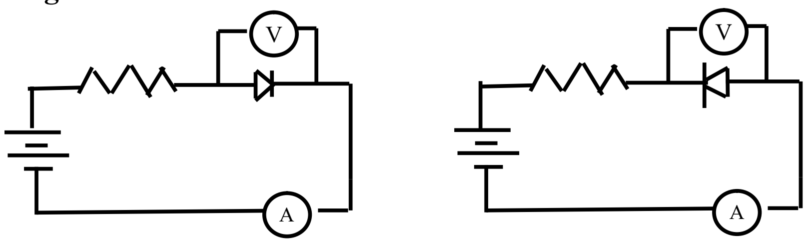
The diode circuits generally operate with varying inputs, which will move the instantaneous operating point up and down a region of the characteristics and defines a specific change in current and voltage. *Dynamic or ac Resistance*, r_d, is defined as the quotient of this change in voltage and change in current around the dc operating point.

$$r_d = \Delta V_D / \Delta I_D$$

Components/Equipments:

(i) Junction diodes (Si,Ge), (ii) Zener diode, (iii) A current limiting Resistor (1kΩ), (iv) D.C. Power supply, (iv) 2 multimeters and (vi) Breadboard, (vii) Connecting wires

Circuit Diagram:



Forward Biasing   Reverse Biasing

Procedure:

Before you proceed, identify the p and n-side of the diode in order to connect properly in forward and reverse bias mode.

(i) Forward and reverse bias characteristics of a normal diode:

Forward Bias characteristics:

1. Assemble the circuit on your breadboard as shown in Fig 1(a). Connect to the 0-30V dc power supply.
2. Switch on the power supply. Slowly increase the supply voltage in steps of 0.1 Volt using the fine adjustment knob and note down the corresponding readings of diode current. When you find the change in current is larger (which means you have already crossed the threshold point!), increase the supply voltage in steps of 0.5 to note down current.
3. Using multimeters in appropriate modes, measure voltage drop across the diode and the current in the circuit. Switch off the supply after taking sufficient readings.
4. Plot the I~V characteristics and estimate the threshold voltage.
5. Choose two operating points below and above the threshold point and determine the static and dynamic resistance at each of the points.

Reverse Bias characteristics:

1. Assemble the circuit on your breadboard as shown in Fig 1(b). Connect to the 0-30V dc power supply.
2. Switch on the supply. Increase the supply voltage in steps of 0.5 Volt to note down the diode current.
3. Use multimeters for voltage and current measurements. Keep in mind that magnitude of current flowing in the circuit will be very small, so choose current range properly. Switch off the supply after taking sufficient readings.
4. Plot the I~V characteristics on the same graph sheet and estimate the reverse saturation current.

(ii) Forward and reverse bias characteristics of a zener diode:

Forward Bias characteristics:

1. Assemble the circuit on your breadboard as shown in Fig 1(a). Use a zener diode this time in your circuit and repeat steps 2-4 of forward bias characteristics of normal diode.

Reverse Bias characteristics:

1. Assemble the circuit on your breadboard with the zener diode, as shown in Fig 1(b). Keep in mind that initially the magnitude of current flowing in the circuit will be very small.
2. Switch on the power supply. Increase the supply voltage in steps of 0.5 Volt and note down the corresponding readings of diode current. When you find the change in current is larger (which means you have already crossed the break-down point!), using the fine adjustment knob increase the supply voltage in steps of 0.1 to note down diode current.
3. Plot the I~V characteristics on the same graph sheet and estimate the threshold and break-down voltages.

Observation:

Code Number of Diode: (i) normal diode: _______ (Si)

_______ (Ge)

(ii) Zener Diode: _______

Table (i) For normal Diode (Si)

Obs. No.	Forward Biasing			Reverse biasing		
	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (mA)	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (μA)
1						

(ii) For normal Diode (Ge)

Same as Table (i)

(iii) For zener Diode:

Obs. No.	Forward Biasing			Reverse biasing		
	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (mA)	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (μA)
1						

Graphs:

Plot I~V characteristics for both the diodes and estimate the required parameters.

Discussions/Results:

i) Describe the behavior of the I~V curve for each diode.

ii) Threshold voltage for normal diode is ______V (What type of a diode it is, Si/Ge?)

Static resistance = ------, Dynamic resistance = ------ at operating point Q.

iii) Threshold voltage for Zener diode = --------

Zener Break-down voltage = -------

Precautions:

LAB#2b: HALF-WAVE RECTIFIER CIRCUIT WITHOUT AND WITH FILTER

Objectives:

1. To construct a half-wave rectifier circuit and analyze its output.
2. To analyze the rectifier output using a capacitor in shunt as a filter.

Overview:

The process of converting an alternating current into direct current is known as rectification. The unidirectional conduction property of semiconductor diodes (junction diodes) is used for rectification. Rectifiers are of two types: (a) Half wave rectifier and (b) Full wave rectifier. In a half-wave rectifier circuit (Fig. 1), during the positive half-cycle of the input, the diode is forward biased and conducts. Current flows through the load and a voltage is developed across it. During the negative half-cycle, it is reverse bias and does not conduct. Therefore, in the negative half cycle of the supply, no current flows in the load resistor as no voltage appears across it. Thus the dc voltage across the load is sinusoidal for the first half cycle only and a pure a.c. input signal is converted into a unidirectional pulsating output signal.

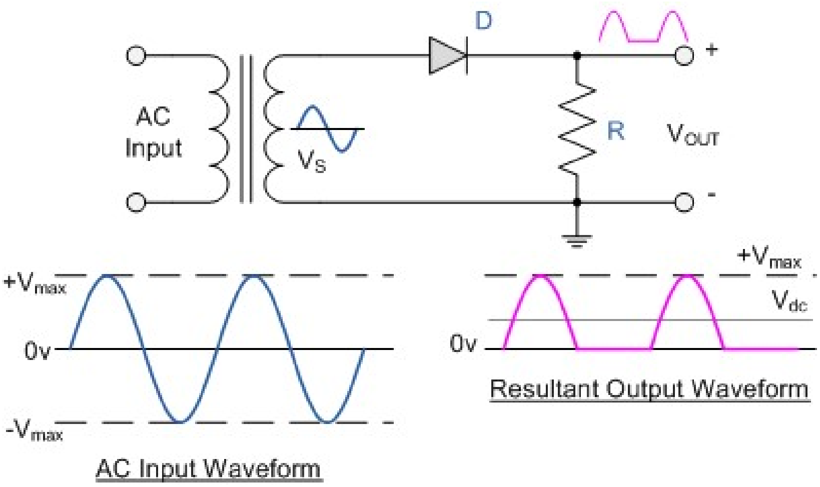


Fig.1: Half-wave rectifier circuit

Since the diode conducts only in one half-cycle (0-π), it can be verified that the d.c. component in the output is V_{max}/π, where V_{max} is the peak value of the voltage. Thus,

$$V_{dc} = \frac{V_{max}}{\pi} = 0.318V_{max}$$

The current flowing through the resistor, $I_{dc} = \frac{V_{dc}}{R}$ and power consumed by the load, $P = I_{dc}{}^{2}R$.

Ripple factor:

As the voltage across the load resistor is only present during the positive half of the cycle, the resultant voltage is "ON" and "OFF" during every cycle resulting in a low average dc value. This variation on the rectified waveform is called "**Ripple**" and is an undesirable feature. The ripple factor is a measure of purity of the d.c. output of a rectifier and is defined as

$$r = \left.\frac{V_{ac}}{V_{dc}}\right|_{output} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{\left(\frac{0.5}{0.318}\right)^2 - 1} = 1.21$$

In case of a half-wave rectifier $V_{rms} = V_{max}/2 = 0.5V_{max}$. (How?)

Rectification Efficiency:

Rectification efficiency, η, is a measure of the percentage of total a.c. power input converted to useful d.c. power output.

$$\begin{aligned}\eta &= d.c.power\ delivered\ to\ load / a.c.power\ at\ input \\ &= V_{dc}I_{dc} / V_{ac}\,I_{ac} \\ &= \frac{I_{dc}^2 R}{I_{ac}{}^{2}/(r_d + R)} = \frac{(0.318V_{max})^2}{(0.5V_{max})^2\left(1+\frac{r_d}{R}\right)} = \frac{0.405}{\left(1+\frac{r_d}{R}\right)}\end{aligned}$$

Here r_d is the forward resistance of diode. Under the assumption of no diode loss (r_d<<), the rectification efficiency in case of a half-wave rectifier is approximately 40.5%.

Filters:

The output of a rectifier gives a pulsating d.c. signal (Fig.1) because of presence of some a.c. components whose frequency is equal to that of the a.c. supply frequency. Very often when rectifying an alternating voltage we wish to produce a "steady" direct voltage free from any voltage variations or ripple. Filter circuits are used to smoothen the output. Various filter circuits are available such as shunt capacitor, series inductor, choke input LC filter and π-filter etc. Here we will use a simple **shunt capacitor** filter circuit (Fig. 2). Since a capacitor is open to d.c. and offers low impedance path to a.c. current, putting a capacitor across the output will make the d.c. component to pass through the load resulting in small ripple voltage.

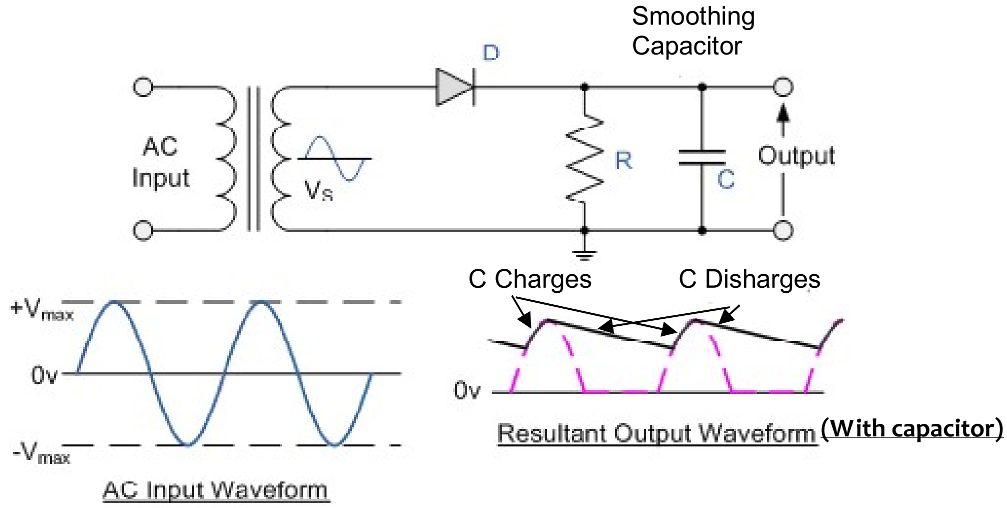


Fig.2: Half-wave rectifier circuit with capacitor filter

The working of the capacitor can be understood in the following manner. When the rectifier output voltage is increasing, the capacitor charges to the peak voltage $V_{m.}$ Just past the positive peak the rectifier output voltage tries to fall. As the source voltage decreases below V_m , the capacitor will try to send the current back to diode making it reverse biased. Thus the diode separates/disconnects the source from the load and hence the capacitor will discharge through the load until the source voltage becomes more than the capacitor voltage. The diode again starts conducting and the capacitor is again charged to the peak value V_m and the process continues. Although in the output waveform the discharging of capacitor is shown as a straight line for simplicity, the decay is actually the normal exponential decay of any capacitor discharging through a load resistor. The extent to which the capacitor voltage drops depends on the capacitance and the amount of current drawn by the load; these two factors effectively form the RC time constant for voltage decay. A proper combination of large capacitance and small load resistance can give out a steady output.

Circuit components/Equipments:

(i) A step-down transformer, (ii) A junction diode, (iii) 3 Load resistors, (iv) 3 Electrolytic Capacitors, (v) Oscilloscope, (vi) Multimeters, (vii) Connecting wires, (viii) Breadboard.

Circuit Diagram: (As shown in Figs. 1 and 2)

Procedure:

i) Configure the half-wave rectifier circuit as shown in the circuit diagram. Note down all the values of the components being used.

ii) Connect the primary side of the transformer to the a.c. Mains and secondary to the input of the circuit.

iii) Measure the input a.c. voltage (V_{ac}) and current (I_{ac}) and the output a.c. (V_{ac}), d.c. (V_{dc}) voltages using multimeter for at least 3 values of load resistor (Be careful to choose proper settings of multimeter for ac and dc measurement).

iv) Multiply the V_{ac} at the input by $\sqrt{2}$ to get the peak value and calculate V_{dc} using the formula $V_{dc} = V_{max}/\pi$. Compare this value with the measured V_{dc} at the output.

v) Feed the input and output (in DC coupling mode) to the two channels of oscilloscope. We will use oscilloscope here only to trace the output waveform. Save the data for each measurement using SAVE/LOAD or STORAGE button of the oscilloscope.

vi) Calculate the ripple factor and efficiency.

vii) Connect an electrolytic capacitor (with –ve terminal connected to ground) across the output for each load resistor and measure the output a.c. and d.c. voltages once again and calculate the ripple factor. Trace the input and output waveforms in oscilloscope and notice the change.

viii) Repeat the above measurement foe all values of capacitors and study the output.

Observations:

1. Code number of diode = ________
2. Input Voltage: V_{ac} = _________ Volt

Table(I): Half wave rectifier w/o filter

Sl. No	Load R (kΩ)	Input Current I_{ac} (mA)	Output Voltage			Ripple Factor *r*	Efficiency η $(V^2_{dc}/R)/V_{ac}I_{ac}$ (%)
			V_{ac} (Volt)	V_{dc} (Volt)	V_{max}/π (Volt)		
1							
2							
3							

Table(II): Half wave rectifier with filter (C = ____ μF) (Make separate tables for each capacitor)

Sl. No	Load R (kΩ)	Output Voltage		Ripple Factor r
		V_{ac} (Volt)	V_{dc} (Volt)	
1				
2				
3				

(III) Input and output waveforms:

Waveforms without Filter:

R = ______ **Input** **Output**

(Paste data here)

Waveforms with Capacitor Filter: C = ______ μF

R = ______ **Input** **Output**

(Paste data here)

Discussions:

Precautions:

LAB#3a: FULL-WAVE BRIDGE RECTIFIER CIRCUIT WITHOUT AND WITH FILTER

Objectives:

1. To construct a full-wave bridge rectifier circuit and analyze its output.
2. To analyze the rectifier output using a capacitor in shunt as a filter.

Overview:

As you have seen already a half-wave rectifier circuit is unsuitable to applications which need a "steady and smooth" dc supply voltage. One method to improve on this is to use every half-cycle of the input voltage instead of every other half-cycle. The circuit which allows us to do this is called a Full-wave Rectifier. Here, unidirectional current flows in the output for both the cycles of input signal and rectifies it. The rectification can be done either by a center tap full wave rectifier (using two diodes) or a full wave bridge rectifier (using four diodes). In this experiment we will study a full wave bridge rectifier.

The Full-wave Bridge Rectifier

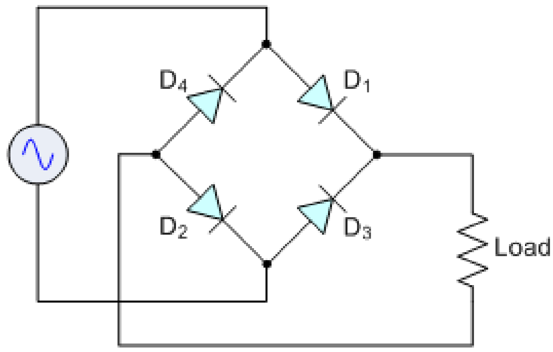


Fig. 1: Full-wave Bridge Rectifier

Another type of circuit that produces the same output as a full-wave rectifier is that of the Bridge Rectifier (Fig. 1). This type of single phase rectifier uses 4 individual rectifying diodes connected in a "bridged" configuration to produce the desired output but does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown in figure. The 4 diodes labeled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below (Fig. 2). During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch of as they are now reverse biased. The current flowing through the load is the same direction as before.

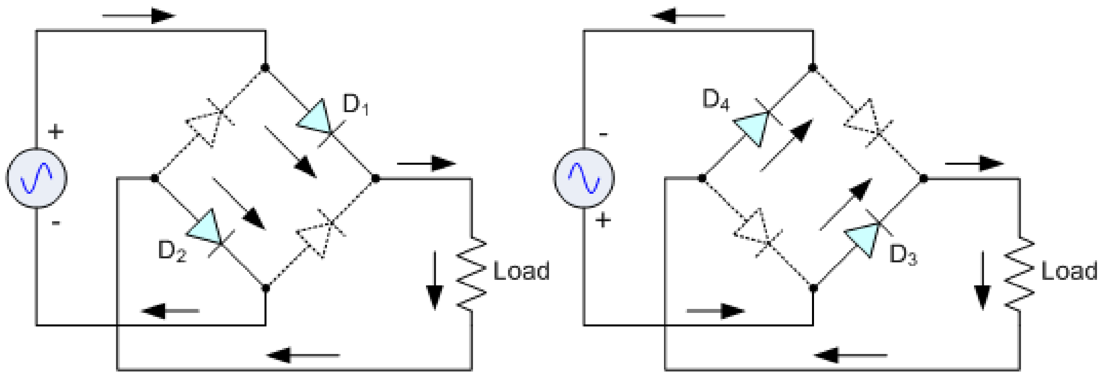


Fig. 2: Working of Full-wave bridge rectifier

As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional during both the half cycles. Thus, the average dc output voltage across the load resistor is double that of a half-wave rectifier circuit, assuming no losses.

$$V_{dc} = \frac{2V_{max}}{\pi} = 0.637V_{max}$$

Ripple factor:

As mentioned in the previous lab the ripple factor is a measure of purity of the d.c. output of a rectifier and is defined as

$$r = \frac{V_{ac}(output)}{V_{dc}(output)} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{\left(\frac{0.707}{0.637}\right)^2 - 1} = 0.48$$

In case of a full-wave rectifier $V_{rms} = V_{max}/\sqrt{2} = 0.707V_{max}$. The ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply).

Rectification Efficiency:

Rectification efficiency, η, is given by

$$\eta = d.c.power\ delivered\ to\ load / a.c.power\ at\ input$$
$$= V_{dc} I_{dc} / V_{ac} I_{ac}$$
$$= \frac{V_{dc}^2 / R_L}{V_s^2 / (r_d + R_L)} = \frac{(0.637 V_{max})^2}{(0.707 V_{max})^2 \left(1 + \frac{r_d}{R_L}\right)} = \frac{0.811}{\left(1 + \frac{r_d}{R_L}\right)}$$

where r_d is the forward resistance of diode. Under the assumption of no diode loss (r_d<<), the rectification efficiency in case of a full-wave rectifier is approximately 81.1%, which is twice the value for a half-wave rectifier.

Filter:

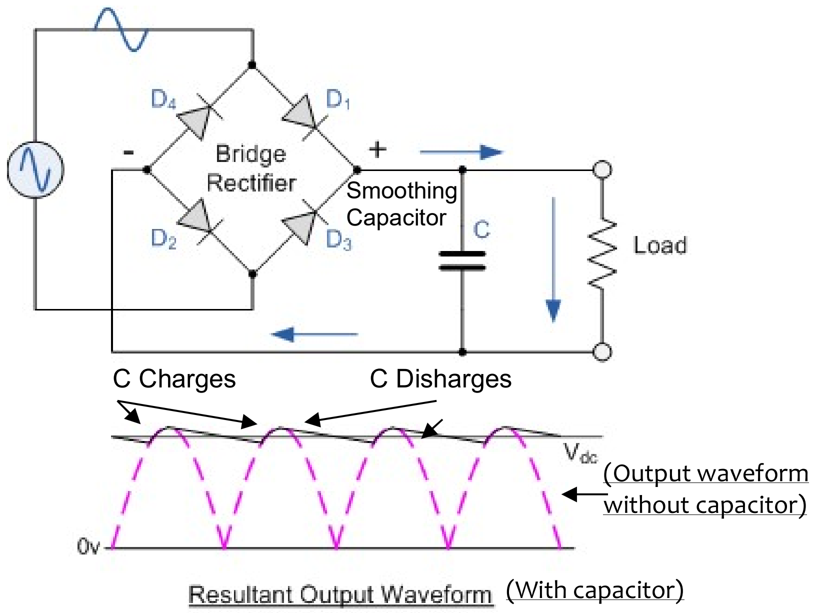


Fig.3: Full-wave rectifier circuit with capacitor filter

The full-wave rectifier circuit with capacitor filter is shown in Fig. 3. The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth dc output voltage. The detailed description of its filtering action is already explained in half-wave rectifier handout. Two important parameters to consider when choosing a suitable a capacitor are its *working voltage*, which must be higher than the no-load output value of the rectifier and its *capacitance value*, which determines the amount of ripple that will appear superimposed on top of the dc voltage.

Apart from rectification efficiency, the main advantages of a full-wave bridge rectifier is that it has a smaller ac ripple value for a given load and a smaller smoothing capacitor than an equivalent half-wave rectifier. The amount of ripple voltage that is superimposed on top of the dc supply voltage by the diodes can be virtually eliminated by adding other improved filters such as a pi-filter.

Circuit components/Equipments:

(i) A step-down transformer, (ii) 4 junction diodes, (iii) 3 Load resistors, (iv) Capacitor, (v) Oscilloscope, (vi) Multimeters, (vii) Connecting wires, (viii) Breadboard.

Circuit Diagram: (As shown in Fig. 1 and 3)

Procedure:

i) Configure the full-wave rectifier circuit as shown in the circuit diagram. Note down all the values of the components being used.
ii) Connect the primary side of the transformer to the a.c. Mains and secondary to the input of the circuit.
iii) Measure the input a.c. voltage (V_{ac}) and current (I_{ac}) and the output a.c. (V_{ac}) and d.c. (V_{dc}) voltages using multimeter for at least 3 values of load resistor (Be careful to choose proper settings of multimeter for ac and dc measurement).
iv) Feed the input and output to the oscilloscope (we will use oscilloscope here only to trace the output waveform) and save the data for each measurement. MEASURE THE INPUT AND OUTPUT VOLTAGES SEPARATELY.
v) Multiply the V_{ac} at the input by $\sqrt{2}$ to get the peak value and calculate V_{dc} Using the formula $V_{dc} = 2V_{max}/ \pi$. Compare this value with the measured V_{dc} at the output.

vi) Calculate the ripple factor and efficiency.

vii) Connect the capacitor across the output for each load resistor. Measure the output a.c. and d.c. voltages once again and calculate the ripple factor. Trace the input and output waveforms in oscilloscope and notice the change. (If time permits you could also use different values of capacitors and study the output)

Observations:

1. Code number of diode = ________
2. Input Voltage: V_{ac} = _________ Volt

Table(I): Full-wave rectifier w/o filter

Sl. No	Load R_L (kΩ)	Input Current I_{ac} (mA)	Output Voltage			Ripple Factor r	Efficiency η $(V_{dc}^2/R_L)/V_{ac}I_{ac}$ (%)
			V_{ac} (Volt)	V_{dc} (Volt)	$2V_{max}/\pi$ (Volt)		
1							
2							
3							

Table(II): Full-wave rectifier with filter (C = ____ μF)

Sl. No	Load R_L (kΩ)	Output Voltage		Ripple Factor r
		V_{ac} (Volt)	V_{dc} (Volt)	
1				
2				
3				

(III) Input and output waveforms:

Waveforms without Filter:

R_L = ______

Input **Output**

(Paste data here)

Waveforms with Capacitor Filter:

R_L = ______

Input **Output**

(Paste data here)

Discussions:

Precautions:
