

Experiment No.1

Equipment Familiarization

Object

To be familiar with the laboratory equipment and functions of each one.

Theory

In this laboratory exercise, you will familiarize yourself with the usage of some of the most commonly used laboratory test and measurement equipment such as the multimeter, dc power supply, oscilloscope, signal/function generator and also the breadboard for test circuit construction.

- **Oscilloscope**

An oscilloscope, previously called an oscillograph, and informally known as a scope or o-scope, CRO (for cathode-ray oscilloscope), or DSO (for the more modern digital storage oscilloscope), is a type of electronic test instrument that allows observation of varying signal voltages, usually as a two-dimensional plot of one or more signals as a function of time. Other signals (such as sound or vibration) can be converted to voltages and displayed.





Oscilloscopes are used to observe the change of an electrical signal over time, such that voltage and time describe a shape which is continuously graphed against a calibrated scale. The observed waveform can be analyzed for such properties as amplitude, frequency, rise time, time interval, distortion and others. Modern digital instruments may calculate and display these properties directly. Originally, calculation of these values required manually measuring the waveform against the scales built into the screen of the instrument.

The oscilloscope can be adjusted so that repetitive signals can be observed as a continuous shape on the screen. A storage oscilloscope allows single events to be captured by the instrument and displayed for a relatively long time, allowing observation of events too fast to be directly perceptible.

Oscilloscopes are used in the sciences, medicine, engineering, automotive and the telecommunications industry. General-purpose instruments are used for maintenance of electronic equipment and laboratory work. Special-purpose oscilloscopes may be used for such purposes as analyzing an automotive ignition system or to display the waveform of the heartbeat as an electrocardiogram.

Early oscilloscopes used cathode ray tubes (CRTs) as their display element (hence they were commonly referred to as CROs) and linear amplifiers for signal processing. Storage oscilloscopes used special storage CRTs to maintain a steady display of a single brief signal. CROs were later largely superseded by digital storage oscilloscopes (DSOs) with thin panel displays, fast analog-to-digital converters and digital signal processors. DSOs without integrated displays (sometimes known as digitizers) are available at lower cost and use a general-purpose digital computer to process and display waveforms.

- **Function generator**

A function generator is usually a piece of electronic test equipment or software used to generate different types of electrical waveforms over a wide range of frequencies. Some of the most common waveforms produced by the function generator are the sine wave, square wave, triangular wave and sawtooth shapes.

These waveforms can be either repetitive or single-shot (which requires an internal or external trigger source). Integrated circuits used to generate waveforms may also be described as function generator ICs.



In addition to producing sine waves, function generators may typically produce other repetitive waveforms including sawtooth and triangular waveforms, square waves, and pulses. Another feature included on many function generators is the ability to add a DC offset.

Although function generators cover both audio and RF frequencies, they are usually not suitable for applications that need low distortion or stable frequency signals. When those traits are required, other signal generators would be more appropriate.

Some function generators can be phase-locked to an external signal source (which may be a frequency reference) or another function generator.

Function generators are used in the development, test and repair of electronic equipment. For example, they may be used as a signal source to test amplifiers or to introduce an error signal into a control loop. Function generators are primarily used for working with analog circuits, related pulse generators are primarily used for working with digital circuits.

• Digital multimeters

A digital multimeter (DMM) is a test tool used to measure two or more electrical values—principally voltage (volts), current (amps) and resistance (ohms). It is a standard diagnostic tool for technicians in the electrical/electronic industries.

long ago replaced needle-based analog meters due to their ability to measure with greater accuracy, reliability and increased impedance. Fluke introduced its first digital multimeter in 1977.

Digital multimeters combine the testing capabilities of single-task meters—the voltmeter (for measuring volts), ammeter (amps) and ohmmeter (ohms). Often, they include a number of additional specialized features or advanced options. Technicians with specific needs, therefore, can seek out a model targeted for particular tasks.



The face of a digital multimeter typically includes four components:

- Display: Where measurement readouts can be viewed.
- Buttons: For selecting various functions; the options vary by model.
- Dial (or rotary switch): For selecting primary measurement values (volts, amps, ohms).
- Input jacks: Where test leads are inserted.

- **Power supply**

A power supply is an electrical device that supplies electric power to an electrical load. The primary function of a power supply is to convert electric current from a source to the correct voltage, current, and frequency to power the load. As a result, power supplies are sometimes referred to as electric power converters. Some power supplies are separate standalone pieces of equipment,



while others are built into the load appliances that they power. Examples of the latter include power supplies found in desktop computers and consumer electronics devices. Other functions that power supplies may perform include limiting the current drawn by the load to safe levels, shutting off the current in the event of an electrical fault, power conditioning to prevent electronic noise or voltage surges on the input from reaching the load, power-factor correction, and storing energy so it can continue to power the load in the event of a temporary interruption in the source power (uninterruptible power supply).

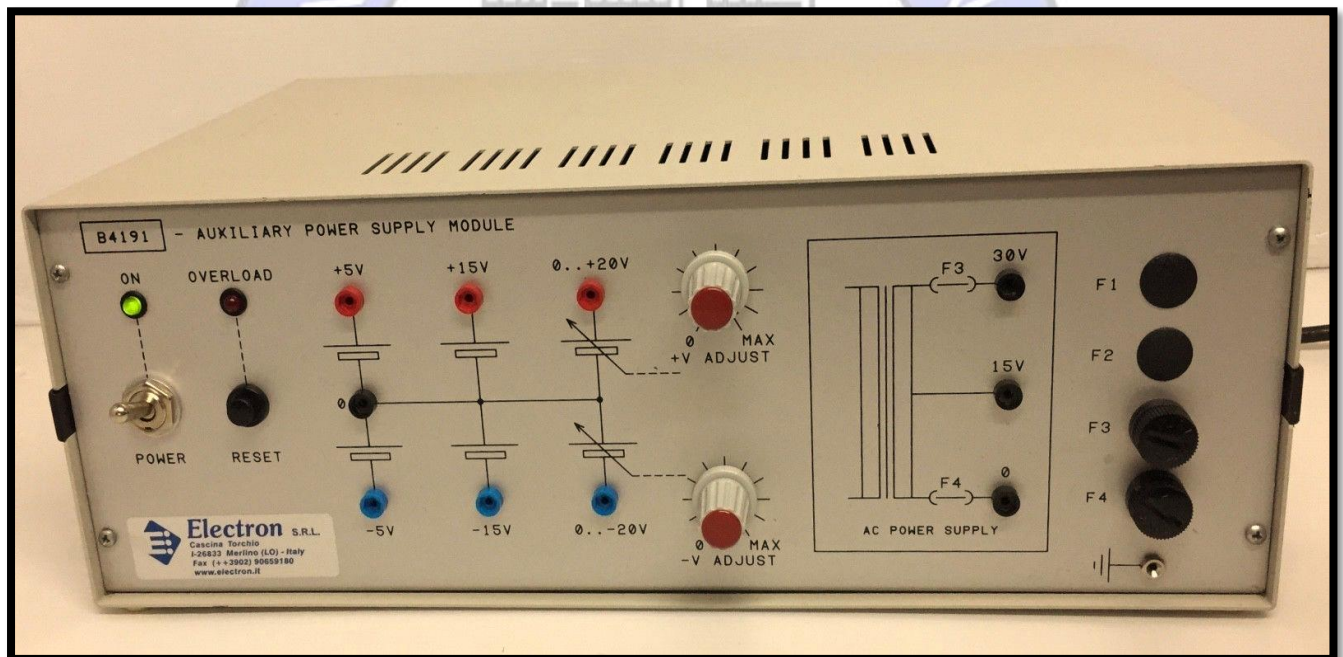
All power supplies have a power input connection, which receives energy in the form of electric current from a source, and one or more power output connections that deliver current to the load. The source power may come from the electric power grid, such as an electrical outlet, energy storage devices such as batteries or fuel cells, generators or alternators, solar power converters, or

another power supply. The input and output are usually hardwired circuit connections, though some power supplies employ wireless energy transfer to power their loads without wired connections. Some power supplies have other types of inputs and outputs as well, for functions such as external monitoring and control.

- **Auxiliary power supply**

Auxiliary power supply is electric power equipment that is provide an alternate source and that serves as backup for the primary power source at the station main bus or prescribed sub-bus.

An offline unit provides electrical isolation between the primary power source and the critical technical load whereas an online unit does not.



Discussion

1. What is the main purpose of Oscilloscope?
2. What is the main purpose of Digital multimeters?
3. What is the main purpose of Function generator?
4. What is the main purpose of Auxiliary power supply?



Experiment No.2

Diode Characteristics

Object

The purpose of this experiment is to measure and plot the forward and reverse IV characteristics of a silicon diode, and to measure the DC and AC (dynamic) resistances of the diode.

Required Parts and Equipment's

1. DC Power Supply
2. Digital Multimeters
3. Electronic Test Board (M50)
4. Function Generator
5. Dual-Channel Oscilloscope
6. Small Signal Silicon Diode 1N4001
7. Resistors, $R_1 = 470\Omega$, $R_2 = 1K\Omega$
8. Leads and BNC Adaptors

Theory

When a P-type and N-type semiconductor materials are effectively made on the same crystal base, a diode is formed. The P-type side of the diode is called the anode, and the N-type side is called the cathode. When the diode's anode is at a higher potential than the cathode, the diode is forward-biased, and current will flow through the diode from anode to cathode. On the other hand, if the anode is at a lower potential than the cathode, the diode is said to be reverse-biased, and only a very small reverse current flows from cathode to anode until breakdown occurs at a very high reverse voltage V_{BR} , and a successive current may flow in the reverse direction. The breakdown voltage V_{BR} is above 50V for typical diodes.

Unlike a resistor, in which the current is directly (linearly) proportional to the voltage across it, the diode is a nonlinear device. When the diode is forward-biased, a small voltage drop occurs across it. This voltage drop is called the barrier potential with an approximate value of 0.3V for germanium diodes, and 0.7V for silicon diodes.

Fig.1 presents the IV characteristics curve for a typical semiconductor diode. This characteristic curve can be approximately estimated in the forward-bias region from the equation:

$$I_D = I_S(e^{V_D/V_T} - 1)$$

Where:

I_D : is the diode current

V_D : is the diode voltage

I_S : is the diode reverse saturation current

V_T : is the thermal voltage, which is approximately 26 mV at room temperature

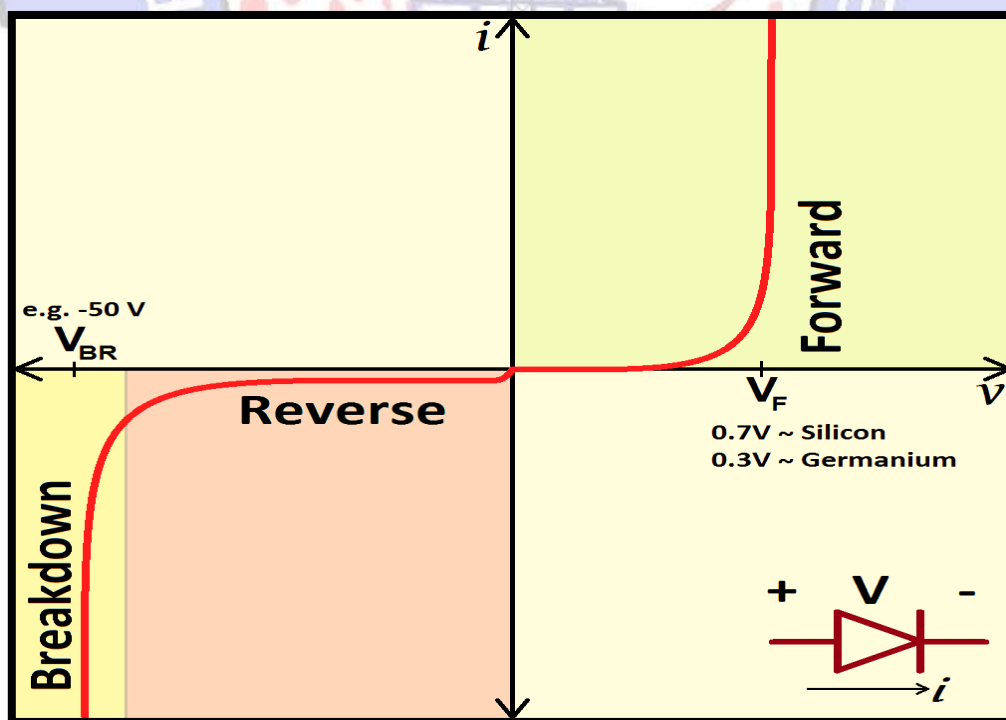


Figure 1: Diode IV Characteristics

The diode forward static (or DC) resistance at a particular DC operating point (Q) is given by:

$$R_{DC} = R_D = \frac{V_{DQ}}{I_{DQ}}$$

Where V_{DQ} is the diode bias voltage, and I_{DQ} is the diode operating current.

The diode dynamic (or AC) resistance can be found from the characteristic curve at the Q-Point as:

$$r_{ac} = r_d = \frac{\Delta V_D}{\Delta I_D}$$

Where ΔV_D is a small increment in diode voltage around V_{DQ} , and ΔI_D is a small increment in diode current around I_{DQ} as depicted in Fig.2.

The dynamic resistance depends on the operating point, and can be calculated approximately from the equation:

$$r_d = \frac{V_T}{I_{DQ}}$$

Where V_T is the thermal voltage, and I_{DQ} is the diode operating current.

Fig.2 shows the determination of the dynamic resistance graphically.

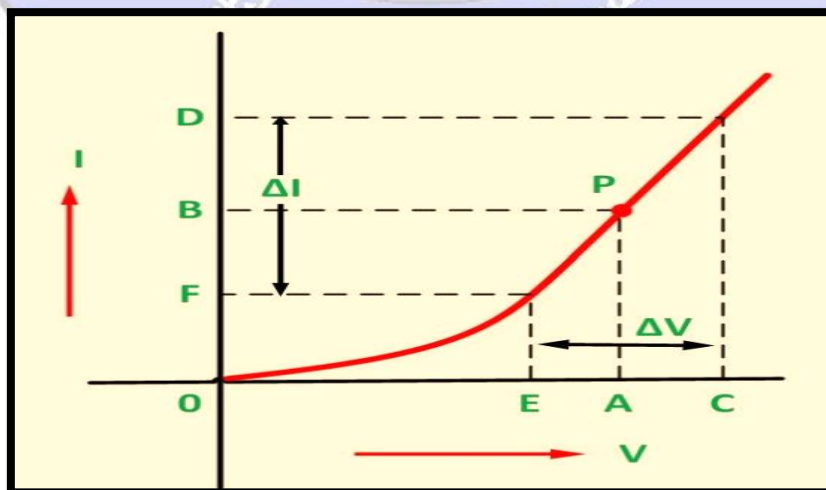


Figure 2: Graphical Determination of the Diode Dynamic Resistance

Procedure

1. Connect the diode circuit shown in Fig.3.

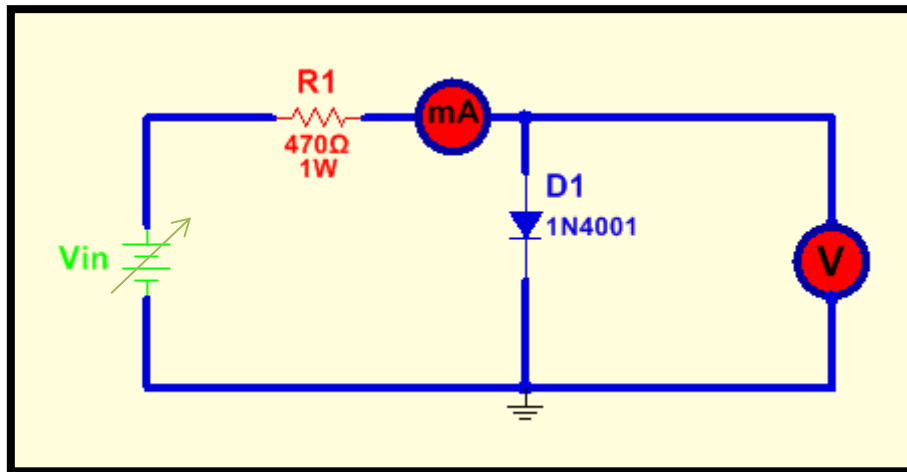


Figure 3: Diode Forward-Biased Circuit

2. Set the DC supply voltage V_{in} at 0V, and increase it gradually. Record diode voltage V_D and current I_D in each step according to Table 1 below.

Table 1: Recorded Data for the Forward-Biased Diode Circuit

I_D (mA)	V_D (V)
0	
0.5	
1	
2	
6	
10	
12	
18	
20	
22	

3. Connect the reverse-biased diode circuit shown in Fig.4. Set the DC power supply voltage V_{in} at 0V, and increase it gradually in several steps and record diode reverse voltage V_R and reverse current I_R as indicated in Table 2.

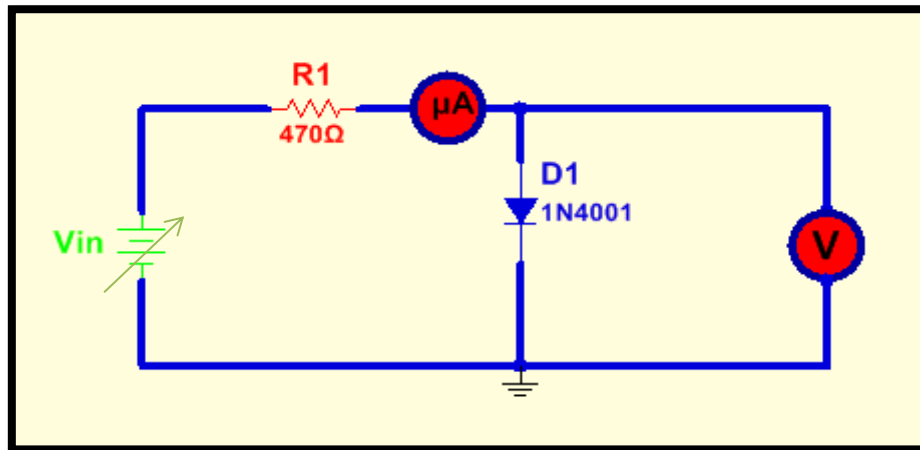
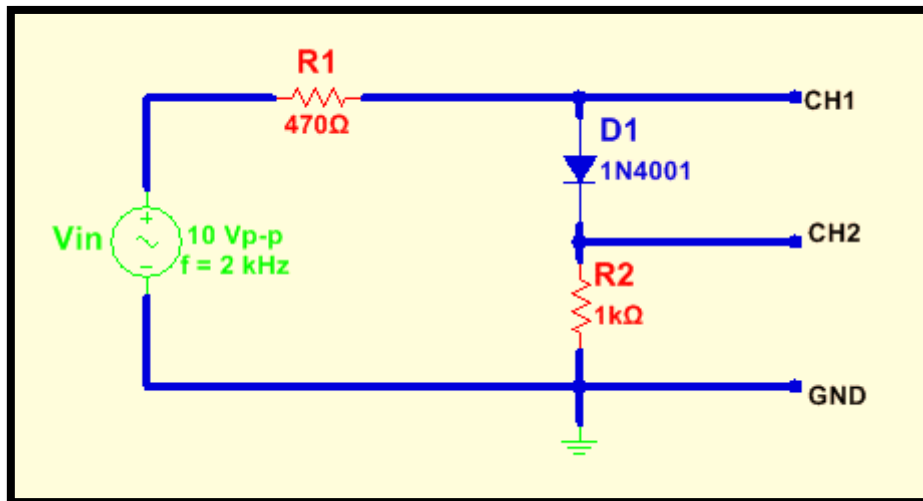


Figure 4: Diode Reverse-Biased Circuit

Table 2: Recorded Data for the Reverse-Biased Circuit

V_R (V)	I_R (μ A)
0	
5	
10	
15	
20	
25	

4. Connect the circuit shown in Fig.5 to display the diode characteristics on the oscilloscope. Set the oscilloscope in the X-Y mode and vary the vertical and horizontal sensitivities of the oscilloscope to obtain the proper display.



Sketch the resulting characteristic curve. Record the voltage scale for channel 1 (X-channel), and channel 2 (Y-channel) after fixing the scope in the X-Y mode. The X-channel represents the diode voltage, and the Y-channel represents the diode current with the current scale obtained as:

$$\text{Current sensitivity} = \frac{\text{Voltage sensitivity}}{10\Omega}$$

Calculations and Discussion

1. Plot the diode forward characteristics from the results obtained, and determine the cut in voltage V_γ from the sketch.
2. From the sketched characteristic curve determine the static resistance of the diode R_{DC}
3. at $I_{DQ} = 10\text{mA}$. Determine also the diode dynamic resistance at $I_{DQ} = 10\text{mA}$, and compare it with the theoretical value obtained from the equation.
4. Plot the diode reverse characteristic, and estimate an approximate value for the reverse saturation current I_S . From the results obtained in this experiment, compute the maximum power dissipated in the diode.
5. Explain how you could use an ohmmeter to identify the cathode of an unmarked diode.
6. Explain why a series resistor is necessary when a diode is forward-biased.



7. In a certain silicon diode, it was found that the diode current is 15mA when the diode voltage is 0.64V at room temperature. Determine the diode current when the voltage across it becomes 0.68V. Use the approximate diode characteristic equation.
8. From the approximate diode characteristic equation, derive an expression for the dynamic resistance r_d .





Experiment No.3

Diode Applications 1

Rectifier Circuit

Object

The purpose of this experiment is to demonstrate the operation of three different diode rectifier circuits which are the half-wave rectifier, center-tapped full-wave rectifier, and the bridge full-wave rectifier. In addition to that, the operation of a capacitor filter connected to the output of the rectifier will also be demonstrated.

Required Parts and Equipment's

1. Digital Multimeters
2. Electronic Test Board (M50)
3. Step-down center-tapped transformer (220V/12Vr.m. s)
4. Dual-Channel Oscilloscope
5. General purpose Silicon Diodes $[D_1, D_2, D_7, D_8]=1N4001$, $[D_3, D_4, D_5, D_6]=WL04$
6. Resistors, $R_1 = 1K\Omega$, $R_2 = 2K\Omega$
7. Capacitors $C_1 = 470\mu F, 25V$, $C_2 = 2200\mu F, 25V$, $C_3 = C_4 = 470\mu F, 63V$
8. Leads and BNC Adaptors

Theory

The rectifier is circuit that converts the AC input voltage into a pulsed waveform having an average (or DC) value. This waveform can then be filtered to remove the unwanted variations. Rectifiers are widely used in power supplies which provide the DC voltage necessary for electronic circuits. The three basic rectifier circuits are the half-wave, the center-tapped full wave, and the full-wave bridge rectifier circuits. The most important parameters for choosing diodes for these circuits are the maximum forward current, and the peak inverse voltage rating (PIV) of the diode. The peak inverse voltage is the maximum voltage the diode can withstand when it is reverse-biased. The amount of reverse voltage that appears across a diode depends on the type of circuit in which it is connected.

Some characteristics of the three rectifiers circuits will be investigated in this experiment.

▪ **Half-Wave Rectifier**

Figure 1 shows a schematic diagram of a transformer coupled half-wave rectifier circuit. The transformer is useful in electrically isolating the diode rectifier circuit from the 220V AC source, and also is used to step-down the input line voltage into a suitable value according to the turn's ratio.

The transformer's turns ratio is defined by:

$$n = \frac{V_{pr(r.m.s)}}{V_s(r.m.s)}$$

Where $V_{pr(r.m.s)}$ is the r.m.s value of the transformer primary winding voltage, and $V_s(r.m.s)$ is the r.m.s value of the transformer secondary winding voltage. In the circuit of Fig.1, $V_{pr(r.m.s)} = 220V$.

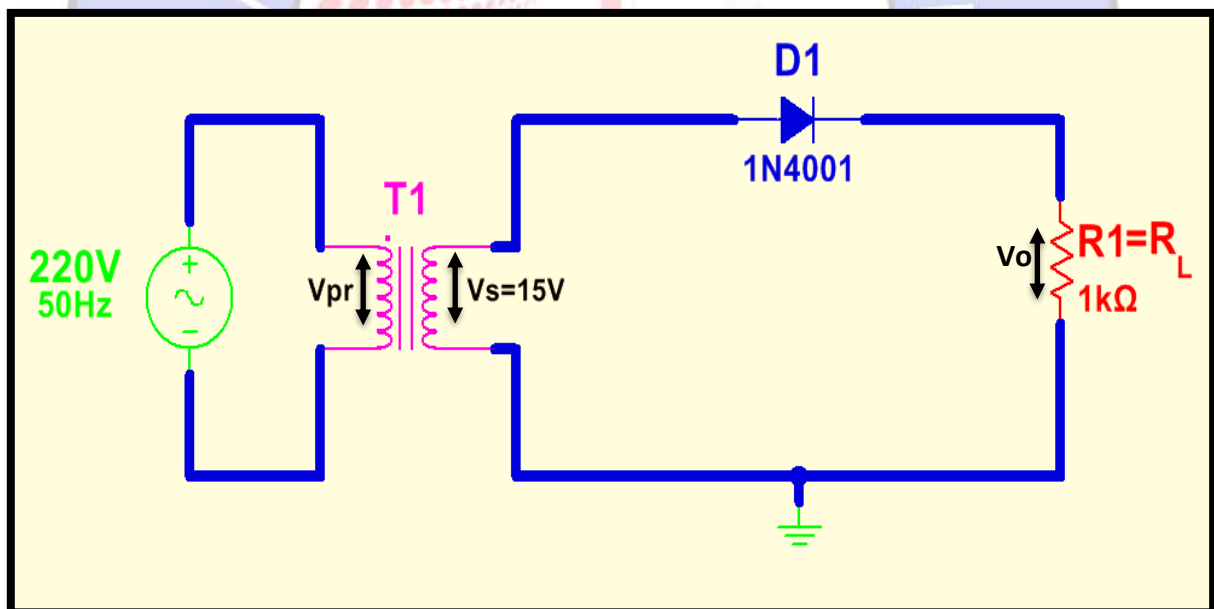


Figure 1: Half-Wave Rectifier with Transformer-Coupled Input Voltage

The peak value of the secondary winding voltage V_{sp} is related to the r.m.s value by the relation:

$$V_{sp} = \sqrt{2} V_s(r.m.s)$$

When the sinusoidal voltage across the secondary winding of the transformer goes positive, the diode is forward-biased and conducts current through the load resistor R_L . Thus, the output voltage across R_L has the same shape as the positive half-cycle of the input voltage.

When the secondary winding voltage goes negative during the second half of its cycle, the diode is reverse-biased. There is no current in this case, so the voltage across the load resistor is 0V. The net result is that only the positive half-cycles of the AC input voltage on the secondary winding appear across the load as shown in Fig.2. Since the output does not change polarity, it is a pulsating DC voltage with frequency equals to that of the input AC voltage.

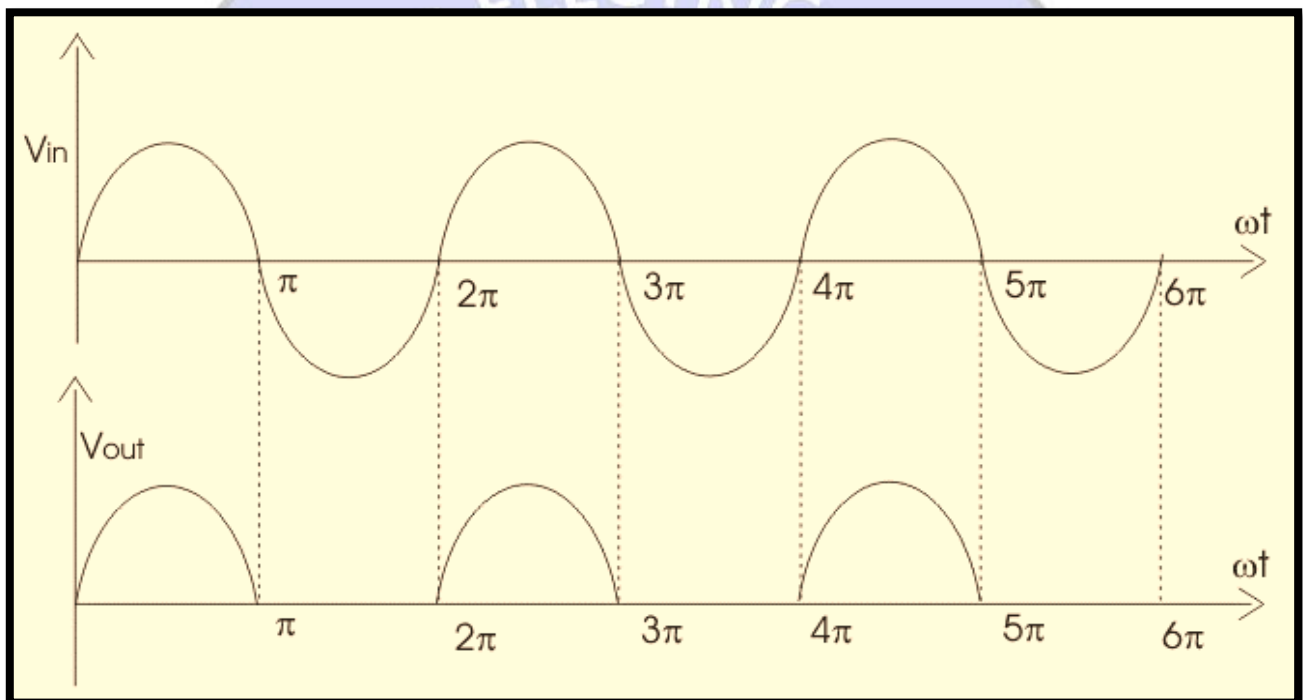


Figure 2: Waveforms of the Half-Wave Rectifier Circuit

When taking the voltage drop across the diode into account, the peak value of the output voltage is given by:

$$V_{op} = V_{sp} - 0.7$$

In equation (3), it was assumed that the voltage drop across the silicon diode is 0.7V when it conducts.

It can be verified that the average (or DC) value of the output voltage is given by:

$$V_{dc} = \frac{V_{op}}{\pi} = \frac{V_{sp} - 0.7}{\pi}$$

The peak inverse voltage (PIV) of the diode for this circuit equals the peak value of the secondary winding voltage:

$$PIV = V_{sp} = V_{op} + 0.7$$

▪ **Center-Tapped Full-Wave Rectifier**

The full-wave center-tapped rectifier uses two diodes connected to the secondary of a center tapped transformer as shown in Fig.3.

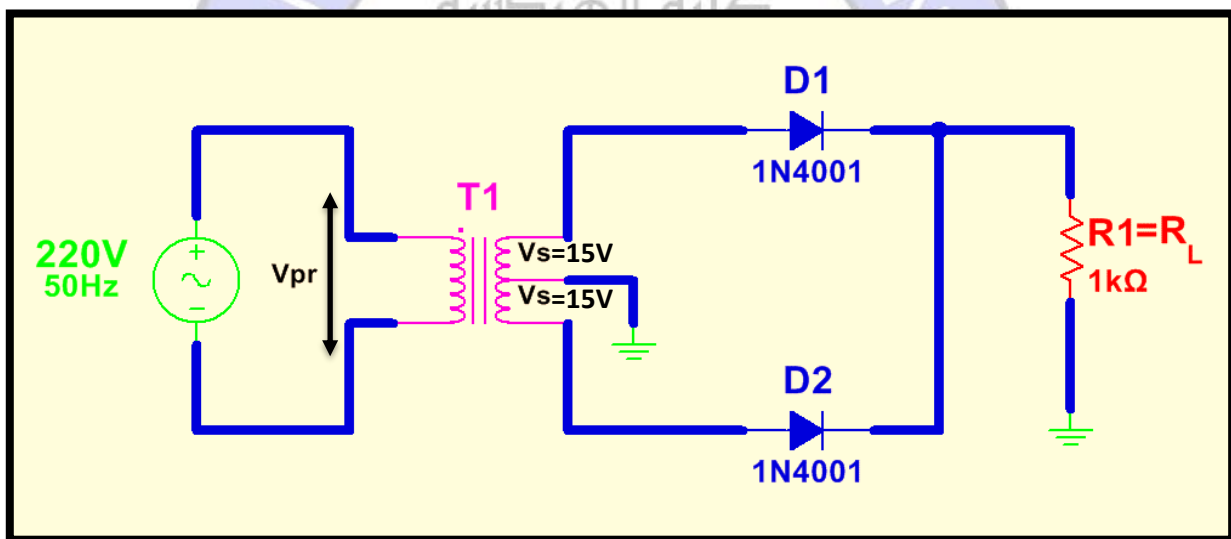


Figure 3: The Center-Tapped Full-Wave Rectifier Circuit

The Input voltage is coupled through the transformer to the center-tapped secondary. For the positive half cycle of the input signal, the polarities of the secondary winding voltages are shown in Fig.3. This makes the upper diode D_1 conducting and the lower diode D_2 to be reverse-biased. The current path is through D_1 and the load resistor R_L . For the negative half cycle of the input voltage, the voltage polarities on the secondary winding of the transformer will be reversed causing D_2 to conduct, while reverse-biasing D_1 . The current path is

through D_2 and R_L . Because the output current during both the positive and negative portions of the input cycle is in the same direction through the load, the output voltage developed across the load resistor is a full-wave rectified DC voltage as shown in Fig.4.

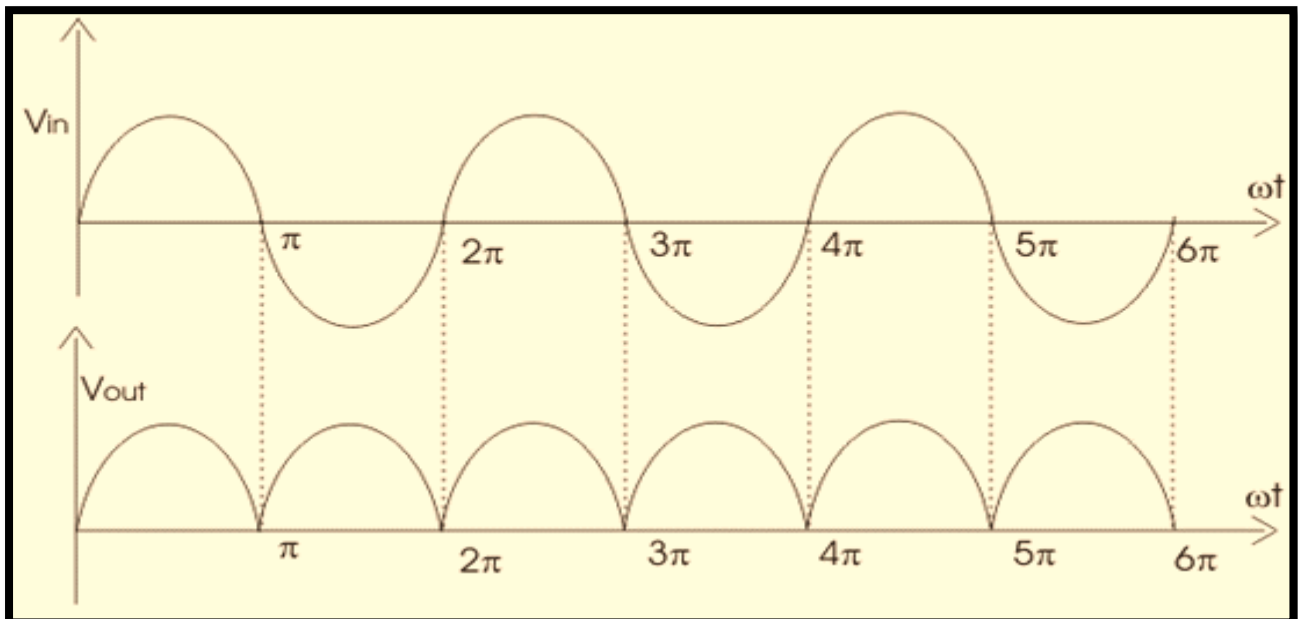


Figure 4: Waveforms of the Full-Wave Rectifier

The DC output voltage of the full-wave rectifier is given by:

$$V_{dc} = \frac{2V_{op}}{\pi} = \frac{2(V_{sp} - 0.7)}{\pi}$$

The peak inverse voltage (PIV) of each diode in this circuit is obtained as:

$$PIV = V_{sp} = V_{op} + 0.7$$

The frequency of the output voltage equals twice the line frequency as shown from the waveform of the output voltage.

▪ Full-Wave Bridge Rectifier

The full-wave bridge rectifier uses four diodes as shown in Fig.5. When the input cycle is positive, diodes D_5 and D_4 are forward biased and conduct current. A voltage is developed across R_L which looks like the positive half of the input cycle. During this time, diodes D_3 and D_6 are reverse-biased.

When the input cycle is negative, diodes D_3 and D_6 become forward-biased and conduct current in the same direction through R_L as during the positive half-cycle. During the negative half-cycle, D_4 and D_5 are reverse biased. A full-wave rectified output voltage appears across R_L as a result of this action.

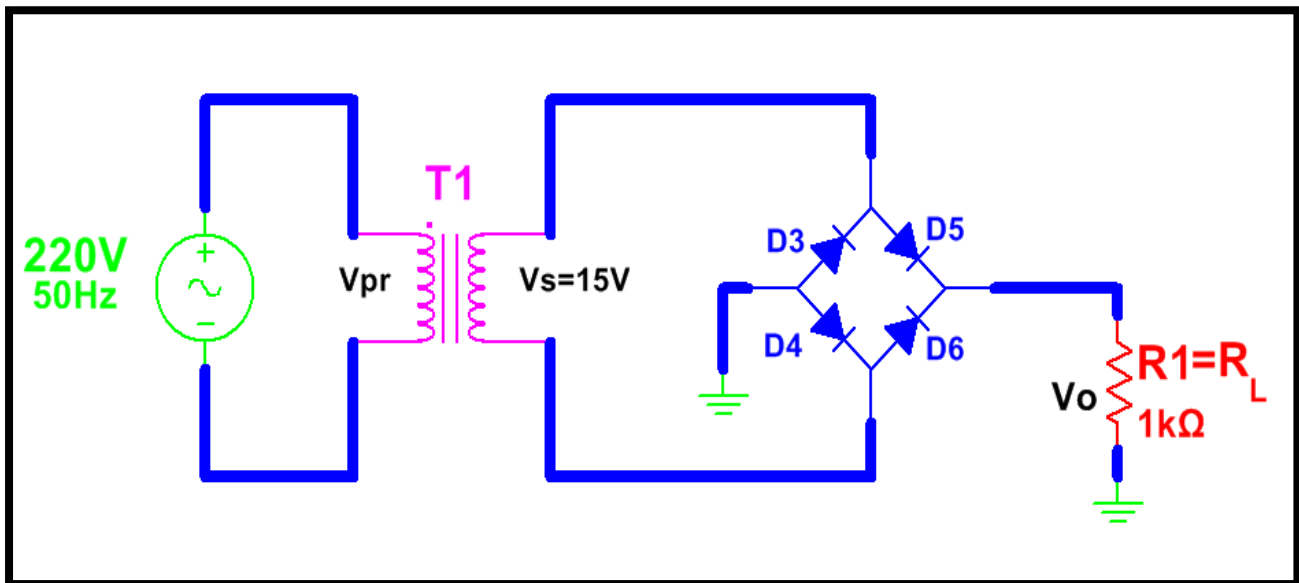


Figure 5: The Full-Wave Bridge Rectifier Circuit

In this circuit, two diodes are always in series with the load resistor during both the positive and negative half-cycles. If these diode drops are taken into account, the output peak voltage is:

$$V_{op} = V_{sp} - 1.4$$

The DC output voltage is given by:

$$V_{dc} = \frac{2V_{op}}{\pi} = \frac{2(V_{sp} - 1.4)}{\pi}$$

The peak inverse voltage of each diode in the circuit is given by:

$$PIV = V_{sp} - 0.7 = V_{op} + 0.7$$

▪ Capacitor Filter

As stated previously, the filter is used to reduce the ripples in the pulsating waveform of the rectifier. A half-wave rectifier with a capacitor filter is shown in Fig.6.

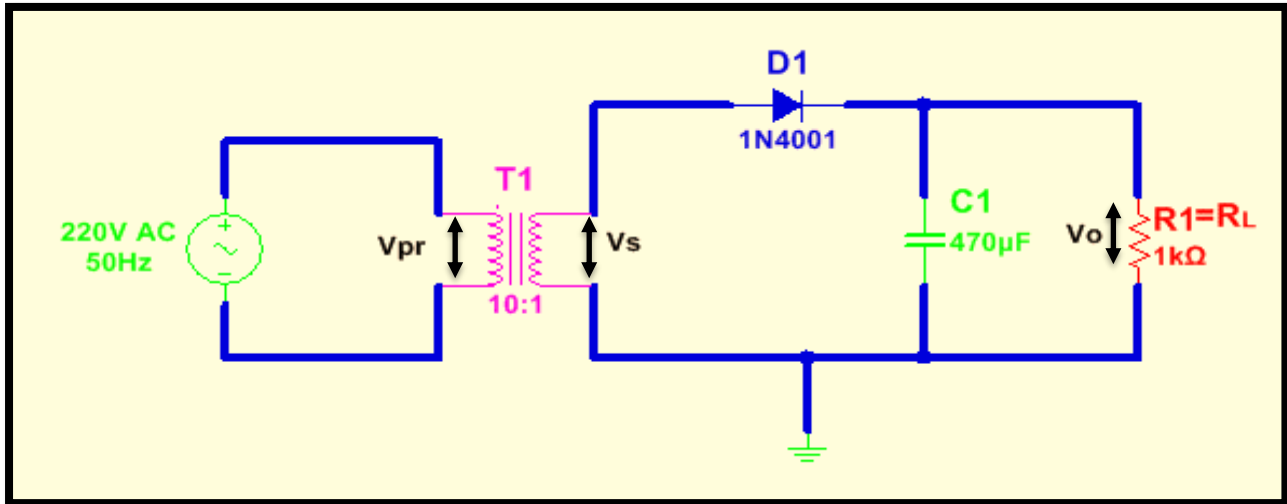


Figure 6: Half-Wave Rectifier with a Capacitor Filter

During the positive first quarter-cycle of the input signal, the diode is forward-biased, allowing the capacitor to charge to within 0.7V of the peak value of the secondary winding voltage. When the input begins to decrease below its peak, the capacitor retains its charge and the diode becomes reverse-biased because the cathode is more positive than the anode. During the remaining part of the cycle, the capacitor can discharge only through the load resistance at a rate determined by the $R_L C$ time constant, which is normally long compared to the period of the input signal. Figure 7 shows the output voltage of the filter circuit.

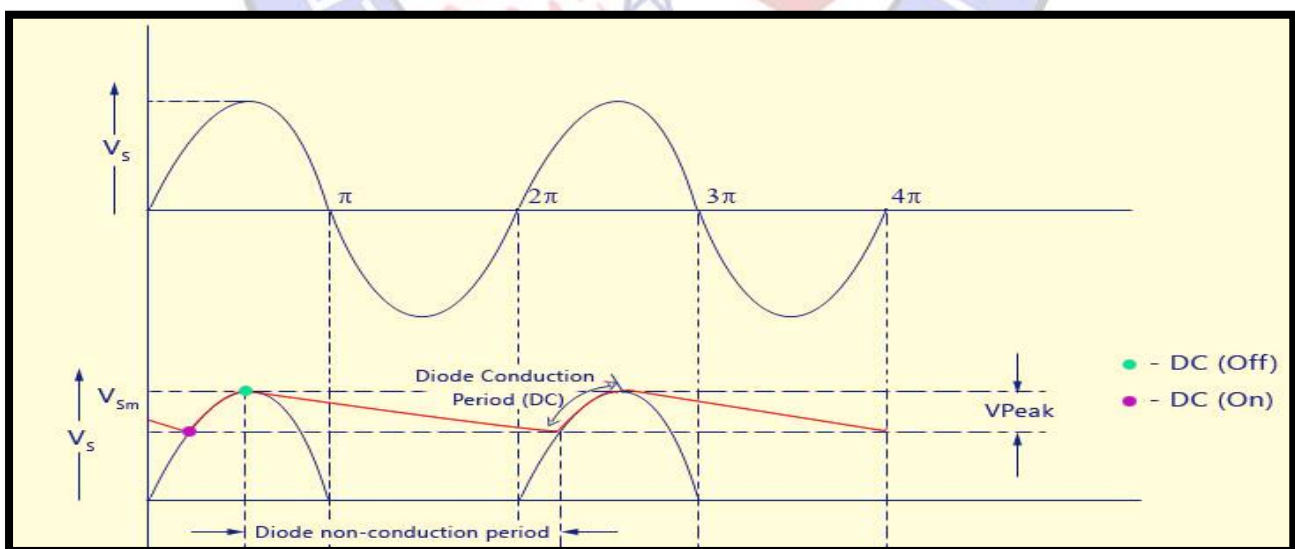


Figure 7: Output Waveform of the Capacitor Filter

Connected with the Half-Wave Rectifier



The variation in the capacitor voltage due to the charging and discharging is called the ripple voltage as illustrated in Fig.7. Generally, ripple is undesirable. Thus, the smaller the ripple, the better the filtering action.

For a half-wave rectified capacitor filter, the approximate value of the peak-to-peak ripple voltage is given by:

$$V_{r(pp)} \cong \left(\frac{1}{fR_L C} \right) V_{op}$$

Where f is the frequency of the input signal, and V_{op} is the measured peak value of the output waveform.

The DC voltage of the output waveform can be approximated by:

$$V_{dc} = V_{op} - \left(\frac{V_{r(pp)}}{2} \right)$$

Or,

$$V_{dc} \cong \left(1 - \frac{1}{2fR_L C} \right) V_{op}$$

For the full-wave rectifier, the output frequency is twice that of the half-wave rectifier. This makes a full-wave rectifier easier to filter because of the shorter time between peaks. The peak-to-peak ripple voltage for the full-wave rectified capacitor filter is given by:

$$V_{r(pp)} \cong \left(\frac{1}{fR_L C} \right) V_{op}$$

The DC voltage of the output waveform for the full-wave rectified capacitor filter can be approximated by:

$$V_{dc} \cong \left(1 - \frac{1}{4fR_L C} \right) V_{op}$$

The ripple factor is an indication of the effectiveness of the filter and is defined as:

$$r = \frac{V_{r(pp)}}{V_{dc}}$$

The lower the ripple factor, the better the filter. The ripple factor can be lowered by increasing the value of the filter capacitor or increasing the load resistance.

Procedure

1. Connect the half-wave rectifier circuit shown in Fig.8. Measure the DC output voltage, peak value of the secondary winding voltage, and the peak value of the output voltage as tabulated in Table 1. Sketch the output waveform.

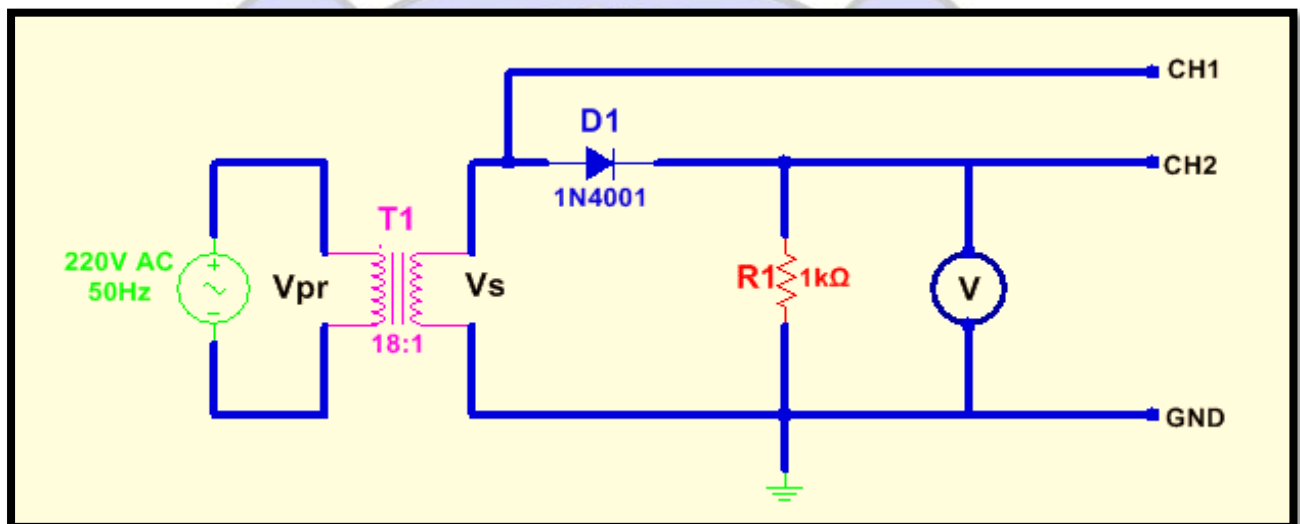


Figure 8: The Practical Half-Wave Rectifier Circuit

Quantity	Measured Value	Calculated Value
V_{sp}		
V_{op}		
V_{dc}		

Table 1: Recorded Data for the Half-wave Rectifier Circuit

2. Connect a capacitor filter at the output of the half-wave rectifier as shown in Fig.9, and measure the DC output voltage and peak-to-peak ripple voltage in the output.

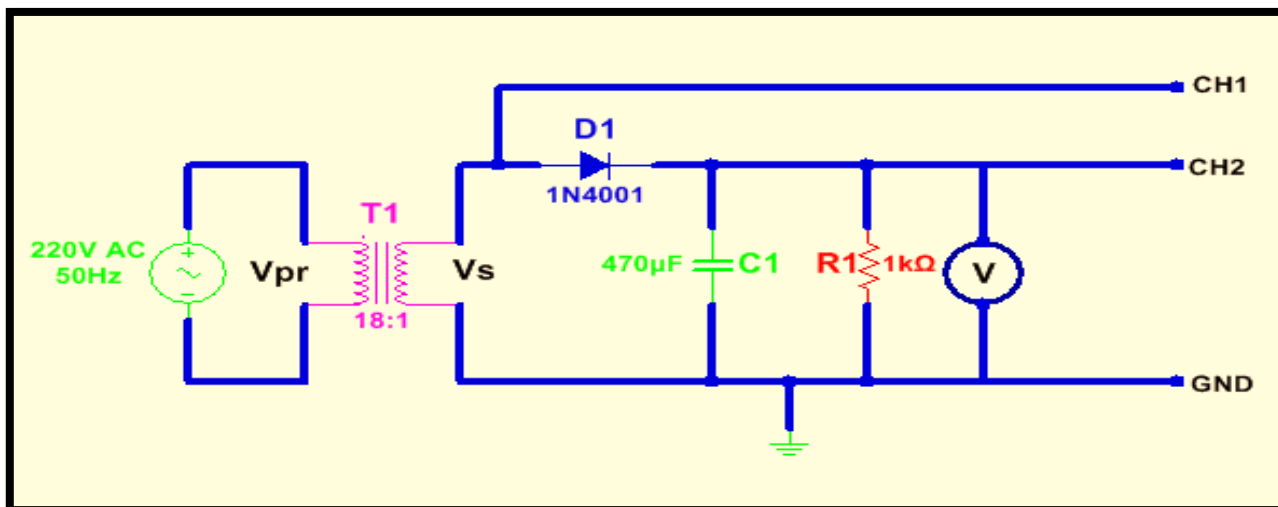


Figure 9: Practical Capacitor Filter Connected to the Half-Wave Rectifier

Quantity	Measured Value	Calculated Value
V_{dc}		
$V_{r(pp)}$		

- Repeat step 2 after replacing the filter capacitor with another one of value $10\mu\text{F}$.
- Connect the full-wave center-tapped transformer rectifier circuit shown in Fig.10. Measure the DC output voltage, peak value of the secondary winding voltage, and the peak value of the output voltage as tabulated in Table 3. Sketch the output waveform in this case.

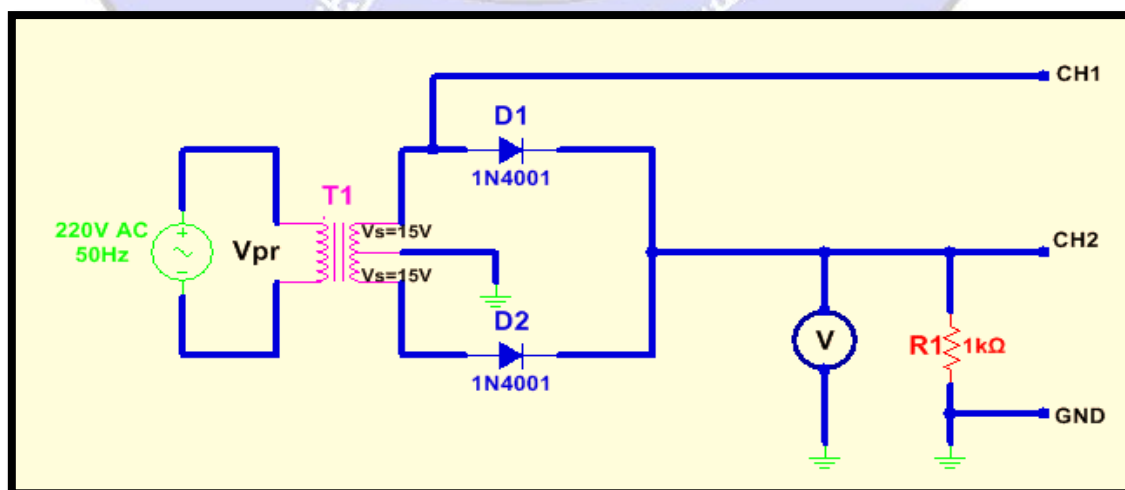


Figure 10: Practical Circuit for the Center-Tapped Full-Wave Rectifier



Quantity	Measured Value	Calculated Value
V_{sp}		
V_{op}		
V_{dc}		

Table 3: Recorded Data for the Center-Tapped Rectifier Circuit

- Connect a capacitor filter at the output of the full-wave rectifier as shown in Fig.11, and measure the DC output voltage and peak-to-peak ripple voltage at the output.

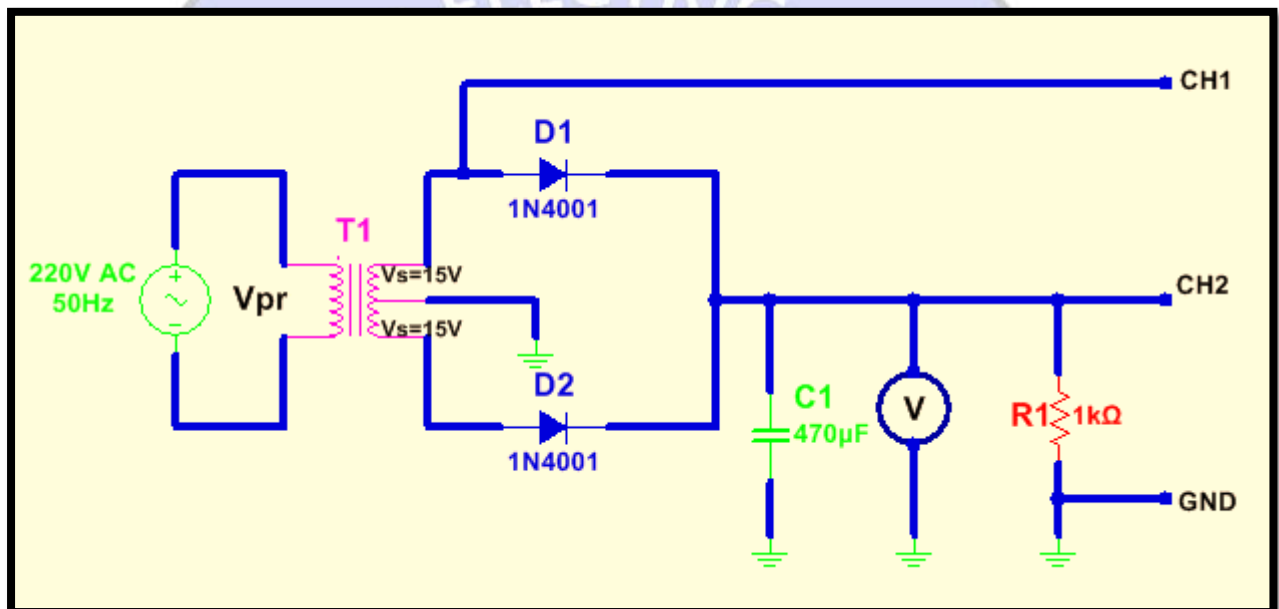


Figure 11: Practical Circuit for the Center-Tapped Full-Wave Rectifier with the Capacitor Filter

Quantity	Measured Value	Calculated Value
V_{dc}		
$V_{r(pp)}$		

- Replace the filter capacitor with another one of value $10\mu\text{F}$ and repeat step 5.

7. Connect the full-wave bridge rectifier circuit shown in Fig.12. Measure the DC output voltage, and the peak value of the output voltage as tabulated in Table 5. Sketch the output waveform in this case. It should be noted that the secondary winding waveform in this case is similar to that of the center-tapped full-wave rectifier.

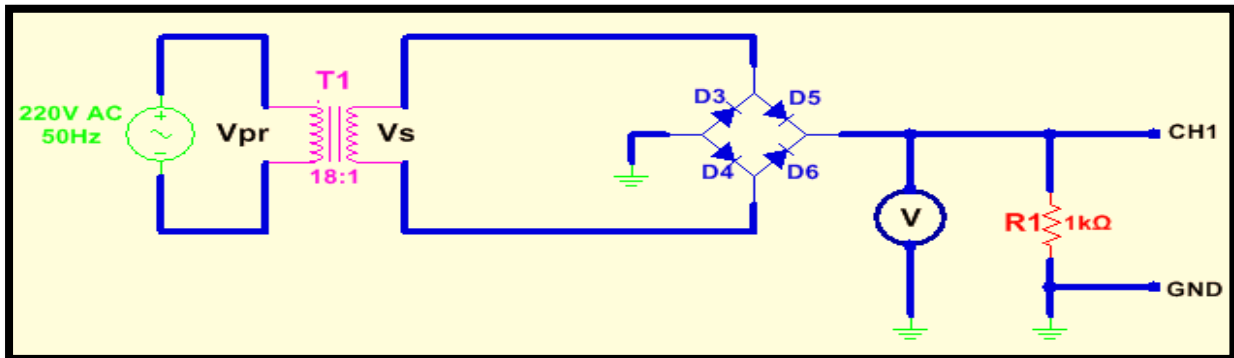


Figure 12: The Practical Full-Wave Bridge Rectifier Circuit

Quantity	Measured Value	Calculated Value
V_{op}		
V_{dc}		

Table 5: Recorded Data for the Full-Wave Bridge Rectifier Circuit

8. Connect a capacitor filter at the output of the full-wave bridge rectifier as shown in Fig.13, and measure the DC output voltage and peak-to-peak ripple voltage at the output.

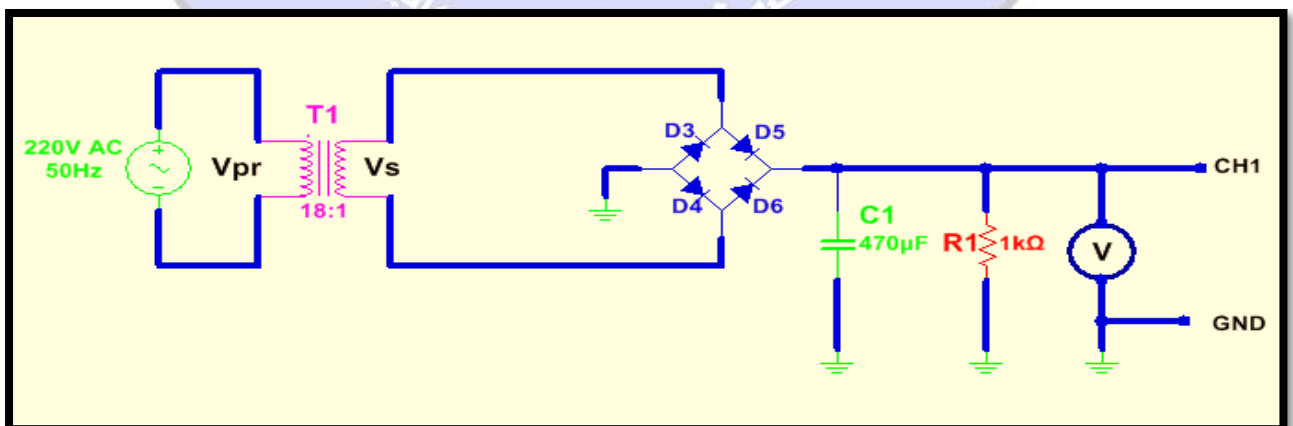


Figure 13: Practical Circuit for the Full-Wave Bridge Rectifier with the Capacitor Filter



Quantity	Measured Value	Calculated Value
V_{dc}		
$V_{r(pp)}$		

Table 6: Recorded Data for the Full-wave Bridge Rectifier and Filter Circuit

- Replace the filter capacitor with another one of value $10\mu\text{F}$ and repeat step 8.

Calculations and Discussion

- Calculate the theoretical output DC voltage of the half-wave rectifier circuit and compare it with measured value. For the capacitive filter, obtain the theoretical values of the DC output voltage and the ripple voltage and compare these values with the measured quantities. Determine also the practical and theoretical values of the ripple factor.
- Calculate the theoretical output DC voltage of the center-tapped full-wave rectifier circuit and compare it with measured value. For the capacitive filter, obtain the theoretical values of the DC output voltage and the ripple voltage and compare these values with the measured quantities. Determine also the practical and theoretical values of the ripple factor.
- Repeat the calculations for the full-wave bridge rectifier and filter circuit.
- Determine the peak inverse voltage (PIV) on each diode in the three rectifier circuits.
- If diode D4 in the bridge rectifier circuit of Figure 5 was removed or burned, explain the operation of the circuit in this case and sketch the predicted waveform of the output.
- Explain the effect of increasing the filter capacitance on the output voltage in the halfwave rectifier and filter circuit.
- Compare the DC output voltages of the three rectifier circuits. Which circuit has the highest output? On the other hand, which circuit has the lowest peak inverse voltage on each diode?



8. What value of filter capacitor is required to produce 1% ripple factor for a full-wave rectifier having a load resistance of $1.5k\Omega$? Assume that the peak value of the output voltage is 18V.





Experiment No.4

Diode Applications 1

Clipping and Clamping Circuits

Object

The purpose of this experiment is to demonstrate the operation of diode clipping and clamping circuits.

Required Parts and Equipment's

1. Function Generator
2. Electronic Test Board (M50)
3. Dual-Channel Oscilloscope
4. DC Power Supply
5. Silicon Diode 1N4001
6. Resistors, $R_1 = 1K\Omega$, $R_2 = 2K\Omega$
7. Leads and Adaptors

Theory

In addition to the use of diodes as rectifiers, there are a number of other interesting applications. For example, diodes are frequently used in applications such as wave-shaping, detectors, voltage multipliers, switching circuits, protection circuits, and mixers. In this experiment, we will investigate two widely used applications of diode circuits, namely diode clipping circuits and diode clamping circuits.

▪ **Half-Wave Rectifier**

Diode clipping circuits are wave-shaping circuits that are used to prevent signal voltages from going above or below certain levels. The clipping level may be either equal to the diode's barrier potential or made variable with a DC voltage source (or bias voltage). Because of this limiting capability, the clipper is also called a limiter.

There are, in general, two types of clipping circuits: parallel clippers and series clippers. In parallel clippers, the diode is connected in a branch parallel to the load, while in series clippers, the diode is connected in series with the load.

Fig.1 presents a simple diode clipping circuit. This circuit is known as the unbiased parallel diode clipper, and is used to clip or limit the positive part of the input voltage. As the input voltage goes positive, the diode becomes forward-biased. The anode of the diode in this case is at a potential of 0.7V with respect to the cathode. So, the output voltage will be limited to 0.7V when the input voltage exceeds this value. When the input voltage goes back below 0.7V, the diode is reverse-biased and appears as an open circuit. The output voltage will look like the negative part of the input voltage.

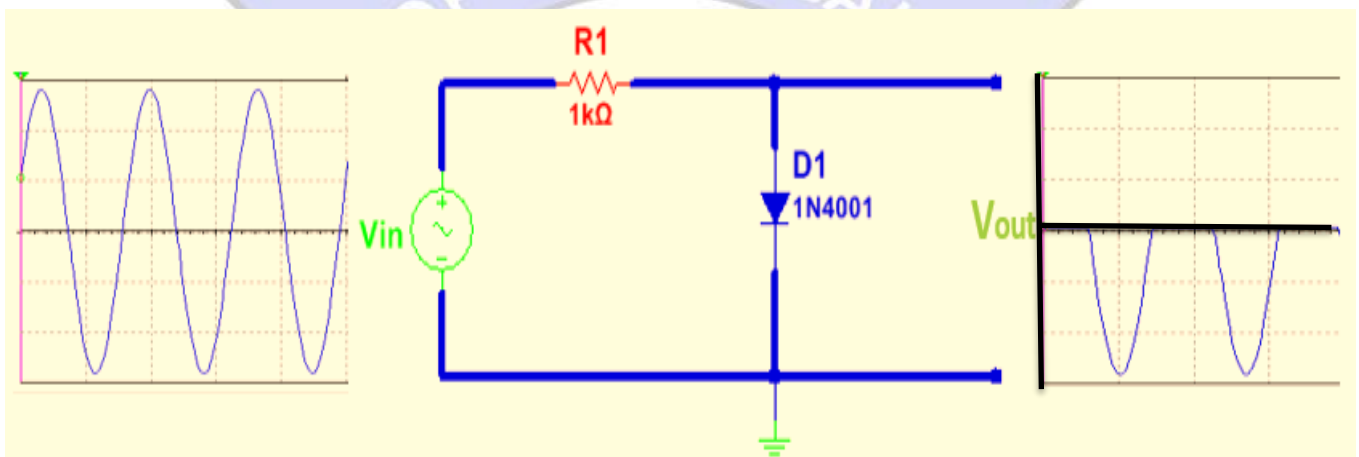


Figure 1: Simple Unbiased Parallel Diode Clipping Circuit

The level to which an AC voltage is limited can be adjusted by adding a bias voltage V_B in series with the diode as shown in Fig.2.

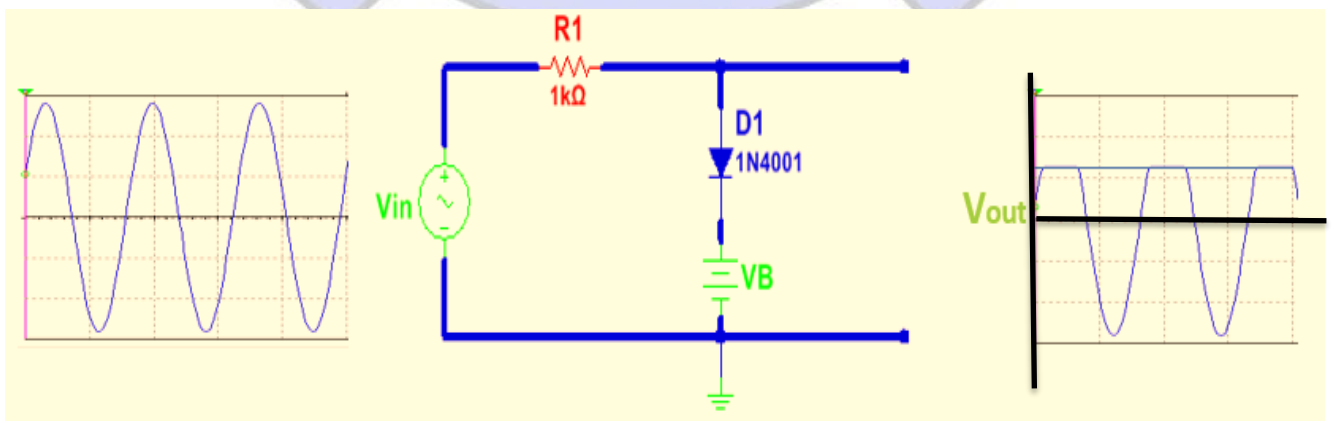


Figure 2: Biased Parallel Diode Clipping Circuit

In this circuit, the input voltage must equal $V_B + 0.7V$ before the diode will become forward biased and conduct. Once the diode begins to conduct, the output voltage is limited to $V_B + 0.7V$ so that all input voltage above this level is clipped off.

In Fig.3, a simple series diode clipping circuit is presented. Its action is actually similar to that of the half-wave rectifier.

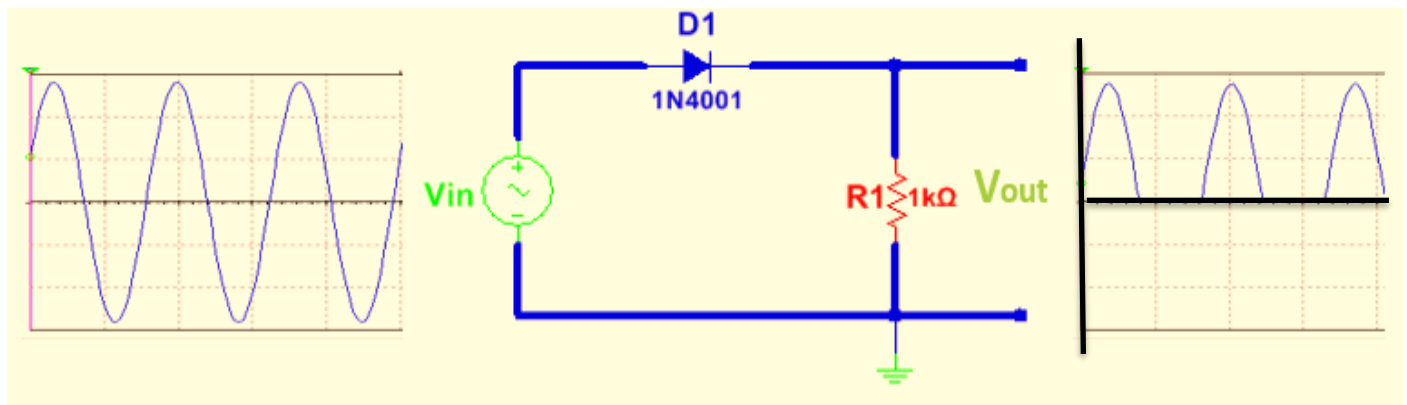


Figure 3: Simple Unbiased Series Diode Clipping Circuit

When the input signal goes positive and exceeds $0.7V$, the diode becomes forward-biased and the output voltage is $V_{in} - 0.7V$. When the input voltage becomes less than $0.7V$, the diode becomes reverse-biased and no current flows in the circuit resulting in zero output voltage. Fig.4 shows a biased series clipping circuit.

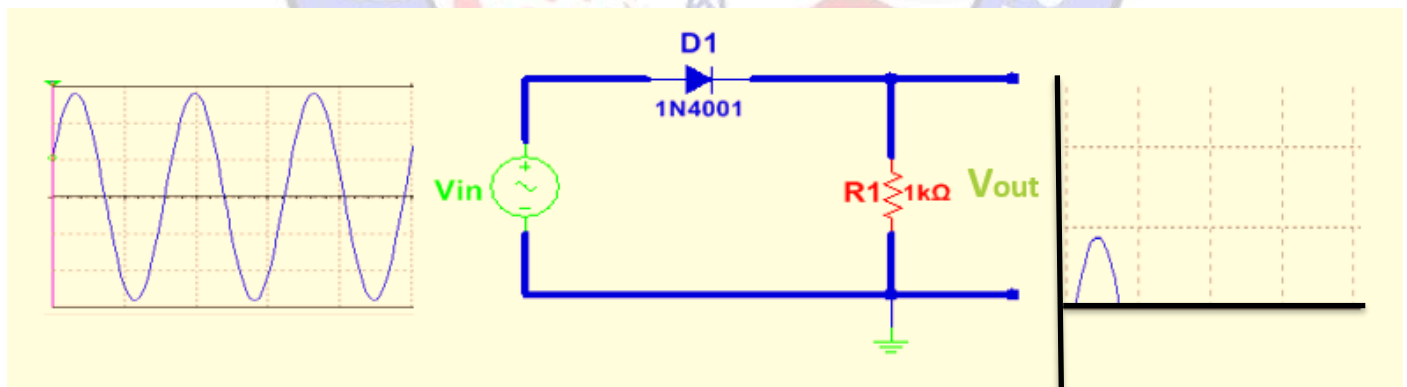


Figure 4: Biased Series Diode Clipping Circuit

When the input voltage is less than $V_B + 0.7V$, the diode does not conduct and no current flows through the load, and hence the output voltage will be $0V$. If the input signal becomes larger than $V_B + 0.7V$, the diode will conduct and the output voltage becomes $V_{in} - (V_B + 0.7)$. The output voltage waveform will be as shown in Fig.4.

▪ Clamping Circuits

Diode clamping circuits are used to shift the DC level of a waveform. If a signal has passed through a capacitor, the DC component is blocked. A clamping circuit can restore the DC level. For this reason, these circuits are sometimes called DC restorers. There are two kinds of clamping circuits, positive clampers and negative clampers.

Fig.5 shows a positive diode clamper that inserts a positive DC level in the output waveform.

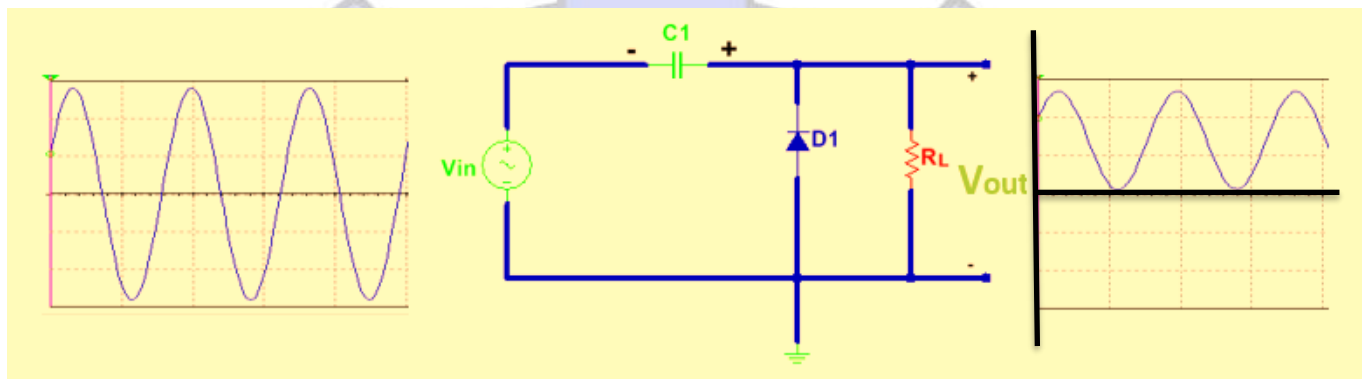


Figure 5: Unbiased Positive Clamping Circuit

During the negative half cycle, the diode conducts and the capacitor charges to V_p volts (assuming ideal diode). In the positive half cycle, the capacitor which was charged initially, discharges through the resistor by a time constant RLC . This happens only if RLC time constant is much less than half the time period of the waveform. Hence if RLC is larger than half the time period, it will not discharge through RL . Now C acts as a DC battery of V_p volt.

Hence during the positive half cycle, the diode is reverse biased by $(V_{in} + V_p)$ volts, which appears across it. The magnitude of RL and C must be chosen such that the time constant $\tau = RLC$ is large enough to ensure the voltage across the capacitor does not discharge significantly during the interval of the diode when it is non-conducting ($\tau \gg T$). So, for an acceptable approximation we have:

$$R_L \cdot C \cong 10T$$

Where T is the time period of the input signal.

Biased clamping circuits produce an output waveform which is clamped by a variable level defined by a bias voltage source connected in series with the diode. If a battery of value V_B is added to forward bias the diode of Fig.5 then the clamping level of the output waveform is raised from V_p to $V_p + V_B$ volts. Consider Fig.6, where a biased positive clamper circuit is presented. The capacitor gets charged to $V_p + V_B$ volts assuming an ideal diode. In the positive half cycle the same C acts as a battery of $V_p + V_B$ volts, and hence the output is $(V_{in} + V_p + V_B)$ volts.

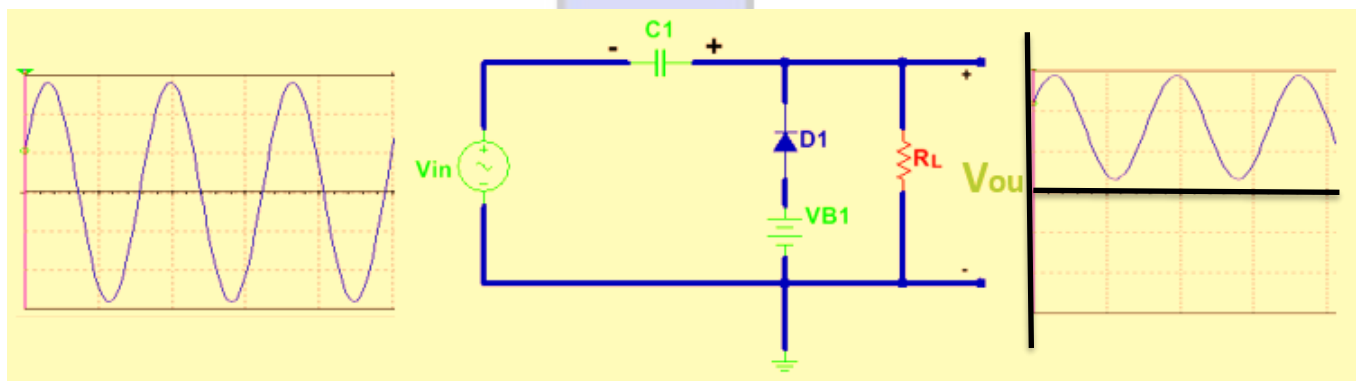


Figure 6: Biased Positive Clamping Circuit

Procedure

1. Connect the clipping circuit shown in Fig.7, and apply a 20Vpp sinusoidal input waveform with frequency of 1 kHz at the input. Display and sketch both input and output signals.

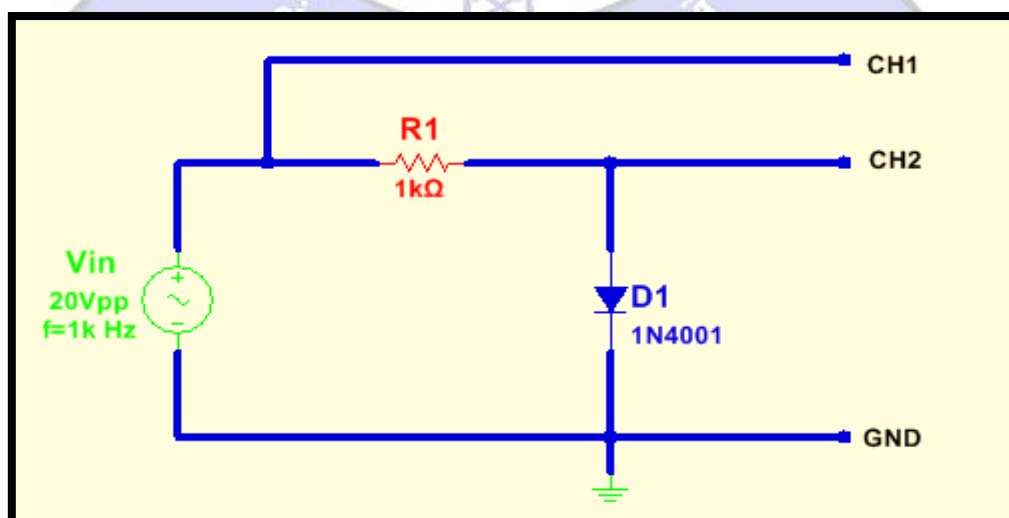


Figure 7: Practical Unbiased Parallel Clipping Circuit

2. Connect the biased parallel clipping circuit shown in Fig.8, and apply a 20Vpp sinusoidal input waveform with frequency of 1 kHz at the input. Display and sketch the input and the output waveforms.

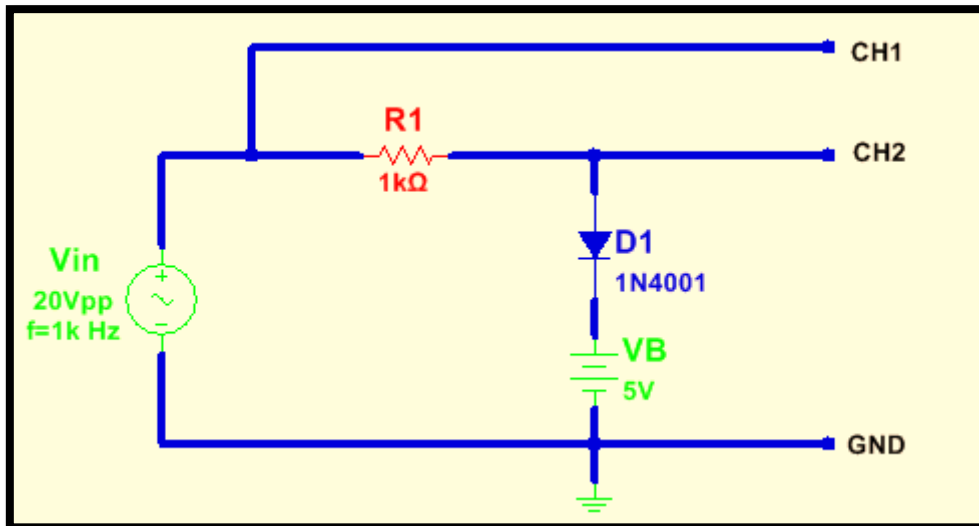


Figure 8: Practical Biased Parallel Clipping Circuit

3. Connect the series clipping circuit shown in Fig.9, and apply a 20Vpp sinusoidal input waveform with frequency of 1 kHz at the input. Display and sketch the input and the output waveforms.

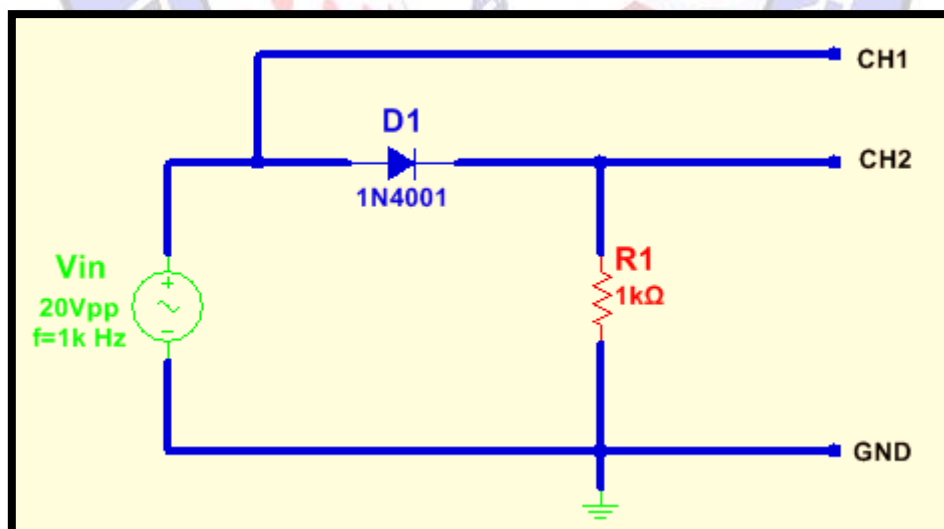


Figure 9: Practical Unbiased Series Clipping Circuit

4. Connect the biased series clipping circuit shown in Fig.10, and apply a 20Vpp sinusoidal input waveform with frequency of 1 kHz at the input. Display and sketch the input and the output waveforms.

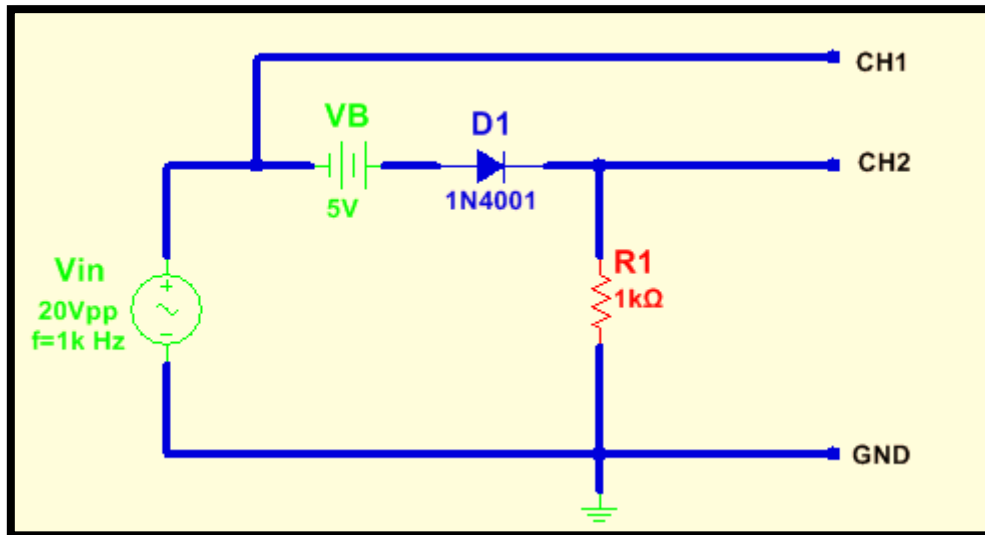


Figure 10: Practical Biased Series Clipping Circuit

5. Connect the clamping circuit shown in Fig.11, and apply a 10Vpp sinusoidal input waveform with frequency of 1 kHz at the input. Display and sketch the input and the output waveforms.

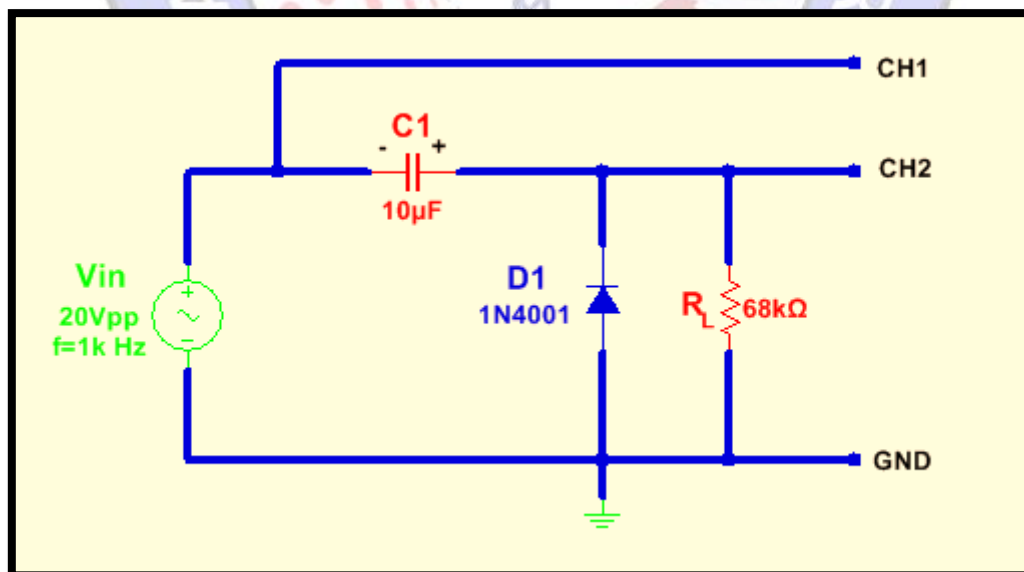


Figure 11: Practical Unbiased Positive Clamping Circuit

- Repeat step 5 after applying a square wave of 10Vpp amplitude and 1 kHz frequency.
- Connect the biased positive clamping circuit shown in Fig.12, and apply a 10Vpp sinusoidal input waveform with frequency of 1 kHz at the input. Display and sketch the input and the output waveforms.

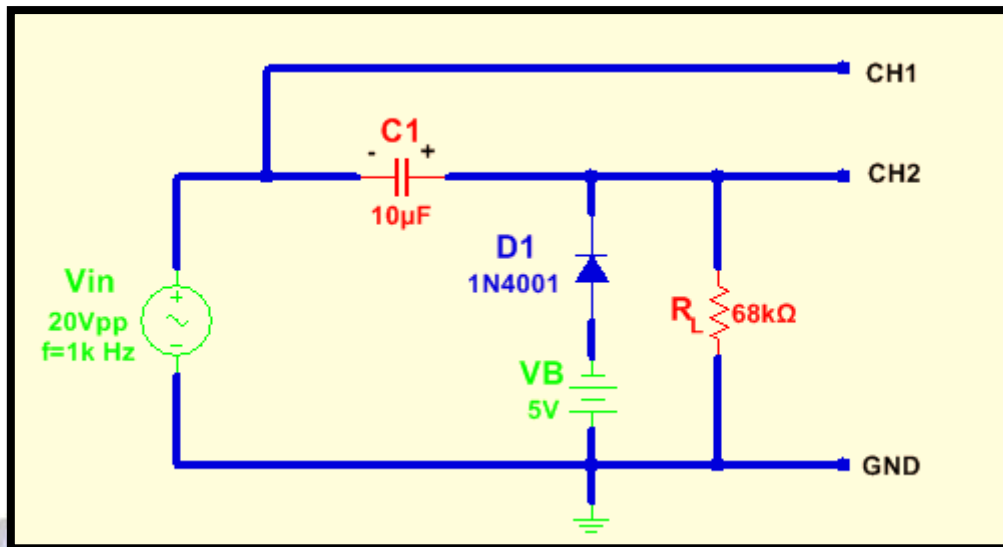


Figure 12: Practical Biased Positive Clamping Circuit

- Repeat step 7 after applying a square wave of 10Vpp amplitude and 1 kHz frequency.

Calculations and Discussion

- What is the effect of the diode voltage drop on the output of the clipping circuit in Fig.4? Compare the waveforms with those obtained when assuming ideal diodes.
- If the diode in the circuit of Fig.2 was reversed, then sketch the output waveform in this case and explain briefly the operation of the circuit.
- Design a clipping circuit that will limit the output voltage to 5V when applying an input sinusoidal waveform with a peak value of 10V. Assume available diodes with voltage drop of 0.5V. Sketch the output waveform of the circuit.
- Sketch the output waveform for the clipping circuit of Fig.1, if a load resistance R_L of value 1 kΩ is connected at the output terminals in parallel with the diode.
- Discuss how diode limiters and diode clampers differ in terms of their function.



6. Design a clamper circuit that shifts the DC level of an input sinusoidal waveform by +6V if the peak value of the input signal is 3V, and its frequency is 500 Hz. Assume diode voltage drop is 0.6V.
7. What is the effect of reducing the load resistor on the output of the clamper circuit shown in Fig.5 if the input signal is a square wave?
8. What is the difference between a positive clamper and a negative clamper? Explain with the aid of circuit diagrams and output waveforms.



Experiment No.5

Zener Diode Characteristics

Object

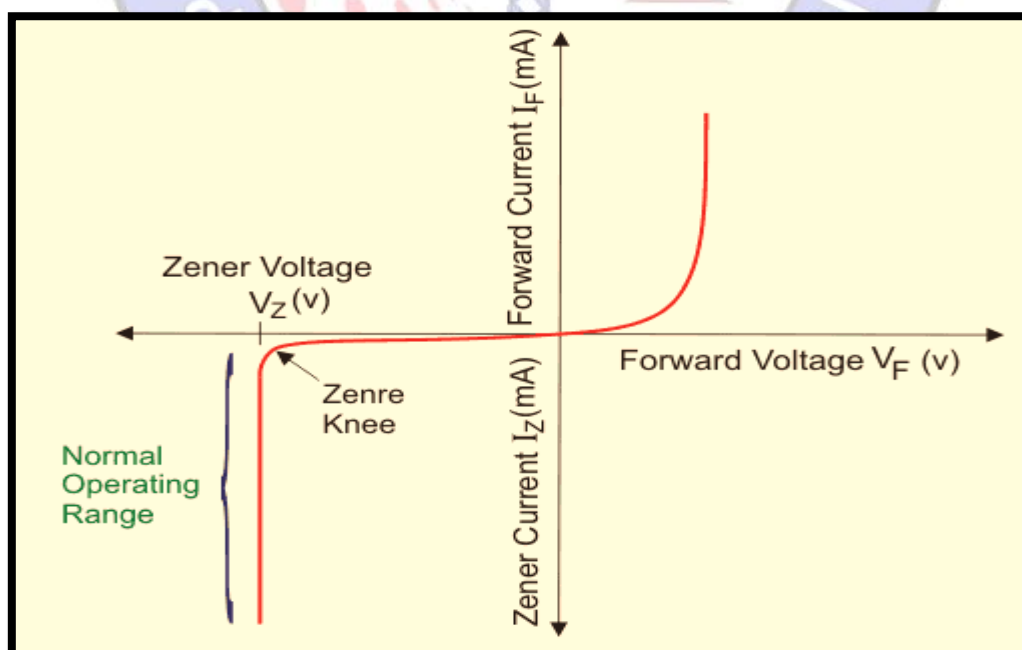
To study and measure the effects of forward and reverse bias on the Zener diode current. To construct a Zener voltage regulator and experimentally determine the range over which the Zener maintains a constant output voltage.

Required Parts and Equipment's

1. A Zener diode
2. Electronic Test Board (M50)
3. Dual-Channel Oscilloscope
4. DC Power Supply
5. Resistor 1k Ω

Theory

Diodes which are designed with adequate power dissipation capabilities to operate the break down region may be employed as voltage reference or constant voltage devices such diode are known as avalanche break down of Zener diodes.



Zener diode characteristics

There are two mechanism which cause reverse break down of diodes, one is called the Zener effect and the other the avalanche effect both these effects are due to the large fields that are set up across the depletion layer when the diode junction is reverse biased, these fields can become large enough to break electrons away from their covalent bonds and provide carries for conduction, this is called the Zener break down.

A Zener Diode is constructed for operation in the reverse breakdown region. The relation between I-V is almost linear in this case $V_Z = V_{Z0} + I_Z r_z$, where r_z is the dynamic resistance of the Zener at the operating point. V_{Z0} is the voltage at which the straight-line approximation of the I-V characteristic intersects the horizontal axis. After reaching a certain voltage, called the breakdown voltage, the current increases widely even for a small change in voltage. However, there is no appreciable change in voltage. So, when we plot the graph, we should get a curve very near to x-axis and almost parallel to it for quite some time. After the Zener potential V_Z there will be a sudden change and the graph will become exponential.

Procedure

1. Connect the circuit shown in Figure (1), the power supply is set to zero volts.

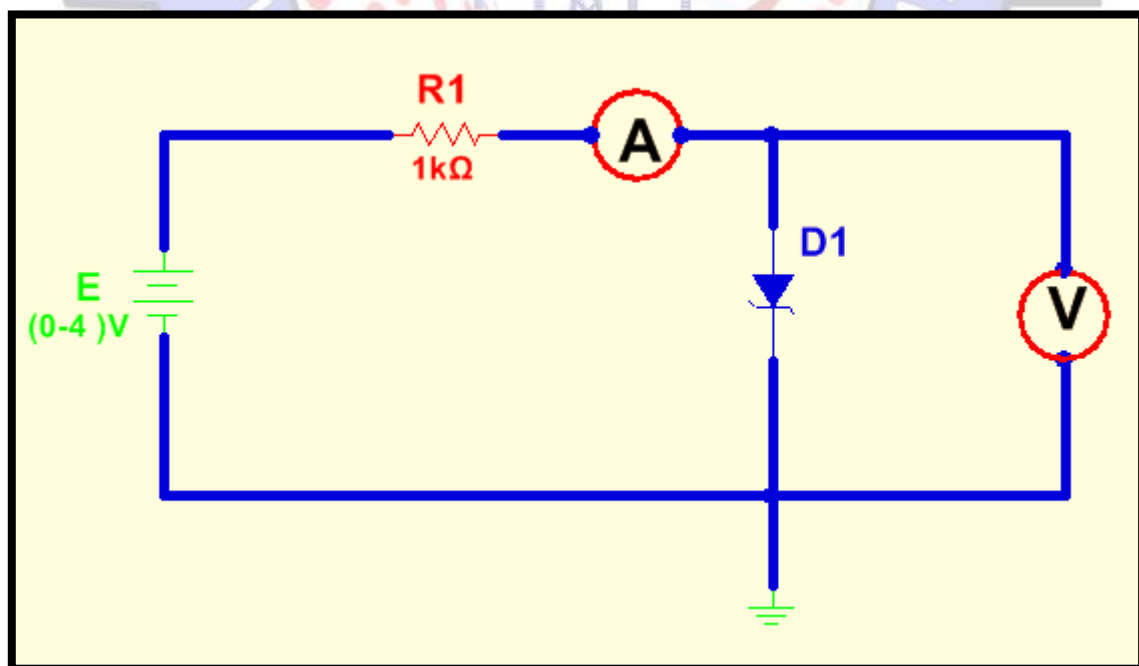


Figure (2)



2. Measure and record in table (1), the forward current in the diode at each level of voltage (V_f).
3. Determine the forward resistance $R_f = V_f / I_f$.
4. Reverse the diode in the circuit of Figure (2).
5. Measure and record in the table (1), the reverse current in the diode at each level of voltage.
6. Calculate $R_Z = V_Z / I_Z$, and record the result in table (1)
7. Connect the circuit of Figure (3), the output of the power supply.
8. Slowly increase the supply voltage until $E=20V$, this voltage must remain constant, change the load resistance and record V_i, I_i, I_Z, R_Z , in table (2).

V_f	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
I_f								
R_f								

Table (1)

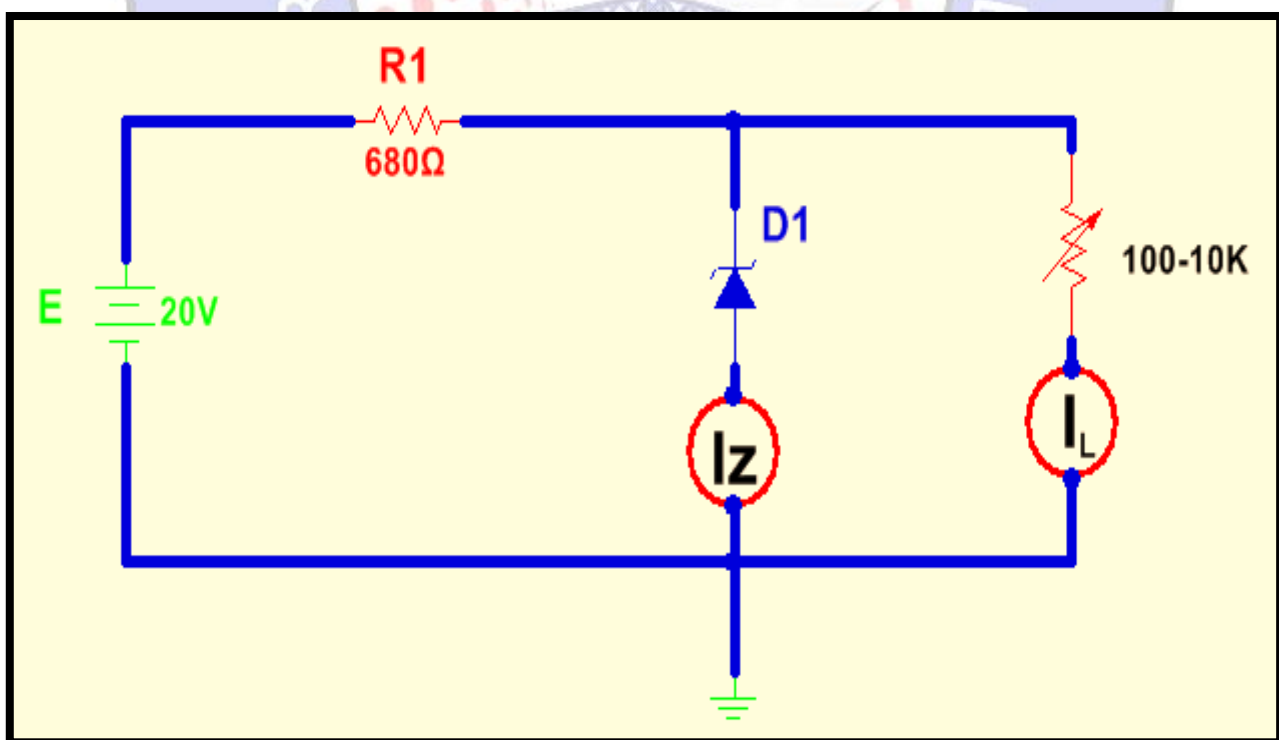


Figure (3)



E (V)	$R_L(\Omega)$	$V_L(V)$	$I_L(mA)$	$I_Z(mA)$
20	200			
	400			
	600			
	800			
	1K			
	1.5K			
	2K			
	4K			
	6K			
	8K			
10K				

Table (2)

Discussion

1. Current for sufficiently long time may change the characteristics.
2. Zener diodes are used in voltage regulation in circuits because even when, a large current flow through, their voltage does not change appreciably



Experiment No.6

Zener Diode Application

Object

The purposes of this experiment are to demonstrate Zener diode as a simple voltage regulator.

Required Parts and Equipment's

1. Variable DC Power Supply.
2. Digital Multimeters.
3. Zener Diode, ZPD (3.6V, 0.5W).
4. Carbon Resistors 330Ω (2W), 1kΩ (2W).
5. Variable Box Resistor
6. Leads and Wires.

Theory

A Zener diode operating in breakdown acts as a voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse current values.

The minimum value of reverse current required to maintain the Zener diode in breakdown for voltage regulation is known as the knee current I_{ZK} as illustrated in Fig.1. When the reverse current is reduced below I_{ZK} , the voltage decreases drastically and regulation is lost.

On the other hand, the maximum current that the diode can withstand is abbreviated as I_{ZM} , and is defined as the Zener current above which the diode may be damaged due to excessive power dissipation. This current can be determined from:

$$I_{ZM} = \frac{P_{ZM}}{V_Z}$$

Where P_{ZM} represents the maximum DC power dissipation of the zener diode, which is usually specified in the datasheet.

So, the practical operating range of the zener diode current should be maintained between I_{ZK} and I_{ZM} for proper voltage regulation.

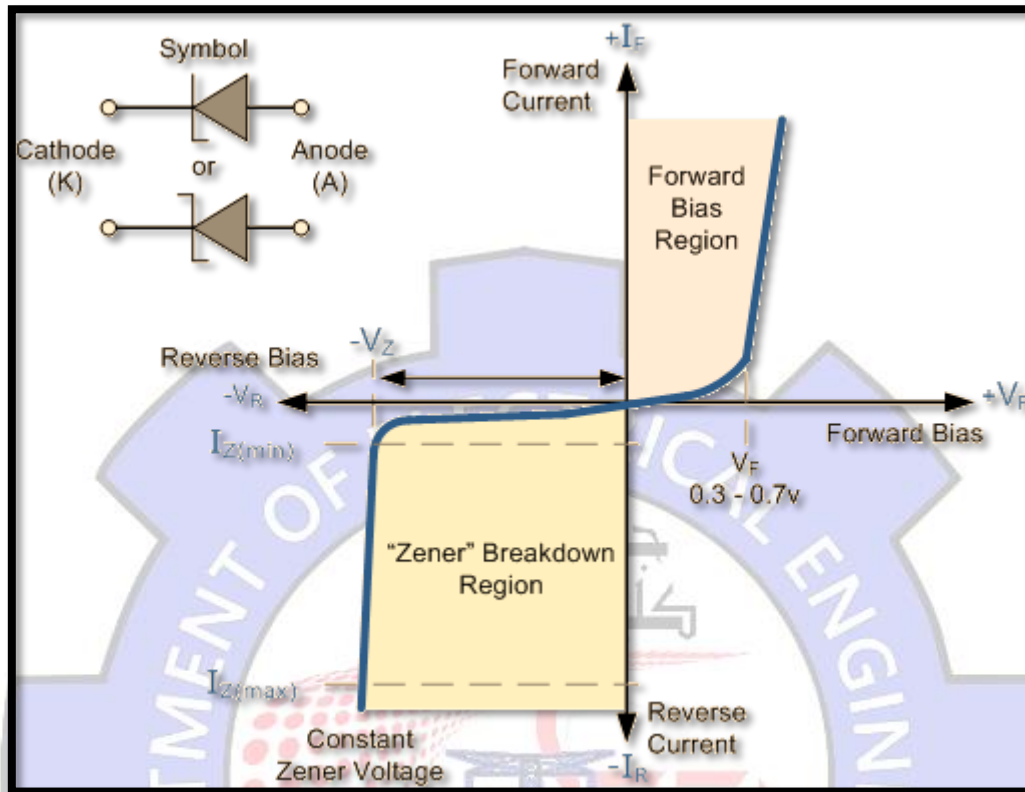


Figure 1: Zener Diode Symbol and IV Characteristic

Fig.2 shows the ideal and practical models of the zener diode in the reverse breakdown region.

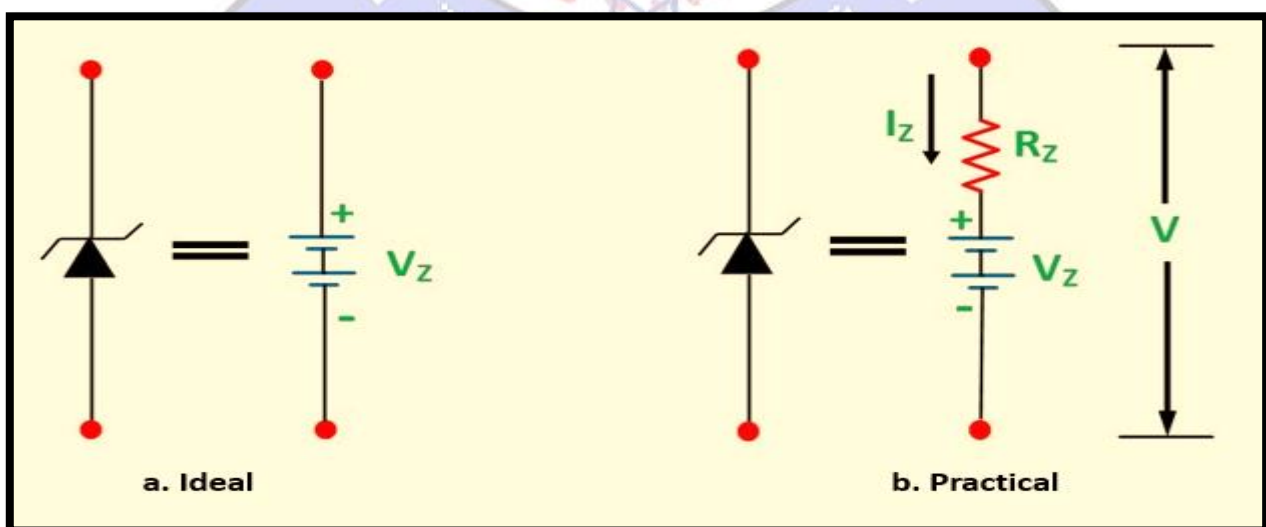


Figure 2: Zener Diode Equivalent Circuit Models

The ideal model of the zener diode shown in Fig.2a has a constant voltage drop equal to the nominal zener voltage. This constant voltage drop is represented by a DC voltage source which indicates that the effect of reverse breakdown is simply a constant voltage across the zener terminals.

Fig.2b represents the practical model of the zener diode, in which the internal zener resistance R_Z is included. Since the actual voltage curve is not ideally vertical, a change in zener current ΔI_Z produces a small change in zener voltage ΔV_Z as illustrated in Fig.3. By Ohm's law, the ratio of ΔV_Z to ΔI_Z is the zener diode internal resistance as expressed in the following equation:

$$R_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

In most cases, we can assume that R_Z is constant over the full linear range of the zener diode current values.

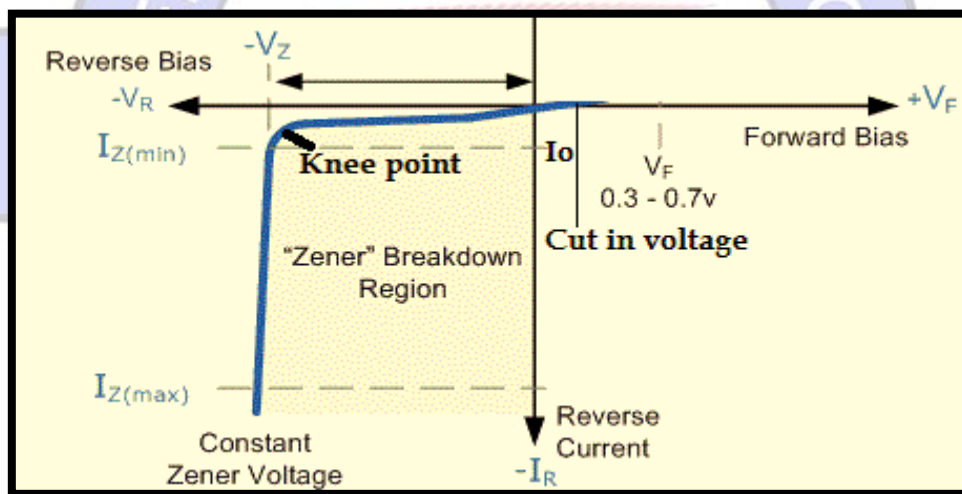


Figure 3: Reverse Characteristic of a Zener Diode Showing the Determination of the Internal Resistance R_Z

▪ The Zener Diode as a Voltage Regulator

The zener diode is often used as a voltage regulator in DC power supplies. Fig.4 presents a simple voltage regulator circuit. In this circuit, the zener diode should

maintain a constant output voltage against variations in input voltage V_{in} , or load resistance R_L . Resistor R_S is used as a series current limiting resistor.

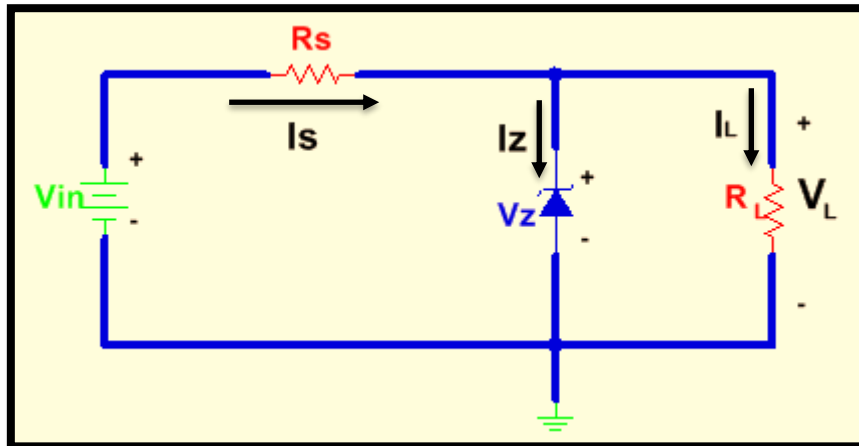


Figure 4: Simple Zener Diode Voltage Regulator

The analysis of the circuit depends on the state of the zener diode if it enters the zener breakdown region or not. To determine the state of the zener diode, we can remove it from the circuit temporarily and calculate the voltage across the open circuit. The load voltage in this case can be obtained from the voltage divider rule:

$$V_L = \frac{R_L \cdot V_{in}}{R_S + R_L}$$

If $V_L \geq V_Z$, then the zener diode is ON, and the appropriate equivalent model can be substituted. On the other hand, if $V_L < V_Z$, the zener diode is OFF, and it is substituted with an open circuit.

When the zener diode operates in its zener breakdown region, it can be substituted simply with a constant voltage source V_Z . In this case:

$$V_L = V_Z$$

The source current I_S can be found from the equation:

$$I_S = \frac{V_{in} - V_Z}{R_S}$$

The load current is calculated as the ratio of load voltage to load resistance:

$$I_L = \frac{V_L}{R_L}$$

The zener current is obtained by applying Kirchhoff's current law:

$$I_Z = I_S - I_L$$

The power dissipated by the zener diode is determined from:

$$P_Z = V_Z \cdot I_Z$$

This value of P_Z must be less than the maximum power rating of the diode P_{ZM} in order to avoid damaging the zener diode.

▪ Zener Voltage Regulator with a Variable Load Resistance

Fig.5 shows a zener voltage regulator with a variable load resistor across the output terminals. The zener diode maintains a nearly constant voltage across R_L as long as the zener current is greater than I_{ZK} and less than I_{ZM} . This is called load regulation.

When the output terminals of the zener regulator are open ($R_L = \infty$), the load current is zero and the entire source current I_S passes through the zener diode. When a load resistor R_L is connected, part of the source current passes through the zener diode, and part through R_L . As

R_L is decreased, the load current I_L increases and I_Z decreases. The source current passing through R_S remains essentially constant.

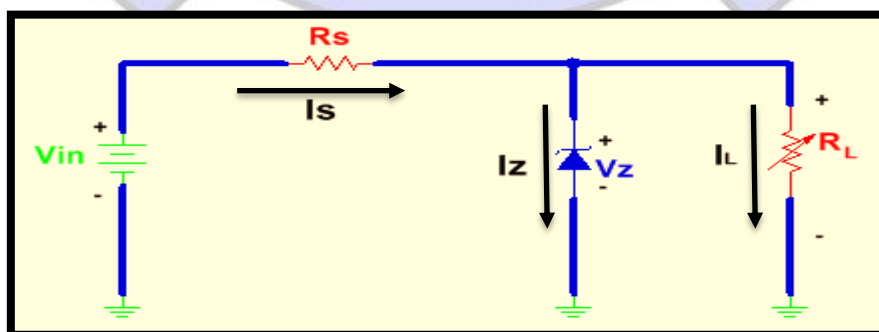


Figure 5: Zener Regulator with Variable Load Resistance and Fixed Input Voltage

To determine the minimum load resistance that will turn on the zener diode, we simply calculate the value of R_L that will result in a load voltage $V_L = V_Z$. Assuming $I_{ZK}=0$, we have from voltage divider rule:

$$V_L = V_Z = \frac{R_L \cdot V_{in}}{R_S + R_L}$$

Solving for R_L yields:

$$R_{L(\min)} = \frac{R_S \cdot V_Z}{V_{in} - V_Z}$$

▪ **Zener Voltage Regulator with a Variable Input Voltage**

Fig.6 illustrates how a zener diode can be used to regulate a varying input DC voltage. This is called input or line regulation.

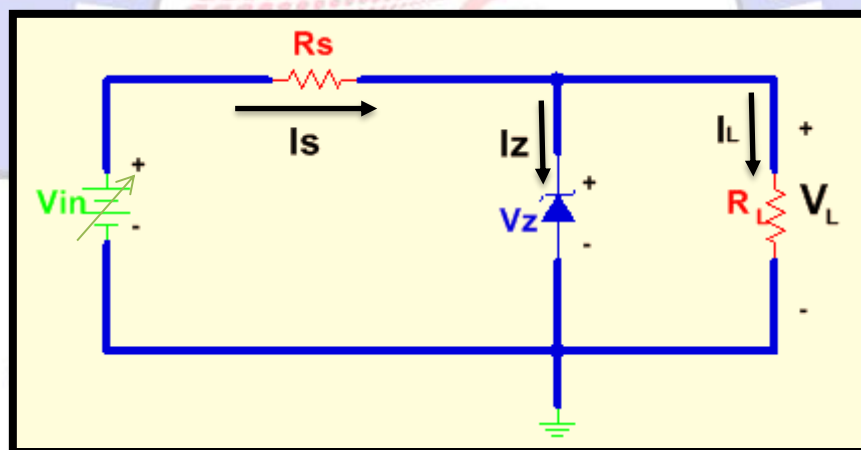


Figure 6: Zener Regulator with Variable Input Voltage and Fixed Load Resistance

For fixed values of R_L , the input voltage must be sufficiently large to turn on the zener diode. Neglecting I_{ZK} , the minimum turn-on voltage is determined by:

$$V_L = V_Z = \frac{R_L \cdot V_{in}}{R_S + R_L}$$

Solving for V_{in} , we have:

$$V_{in(\min)} = \frac{(R_S + R_L) \cdot V_Z}{R_L}$$

The maximum value of V_{in} is limited by the maximum zener current I_{ZM} . We have:

$$I_{S(\max)} = I_{ZM} + I_L$$

I_L is given by:

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$$

Therefore, the maximum input voltage is given by:

$$V_{in(\max)} = I_{S(\max)} \cdot R_S + V_Z$$

Or,

$$V_{in(\max)} = \left(I_{ZM} + \frac{V_Z}{R_L} \right) \cdot R_S + V_Z$$

Procedure

1. Connect the zener diode test circuit shown in Fig.7. Increase the input voltage gradually in several steps from 0 to 15V, and record V_Z and I_Z according to Table 1.

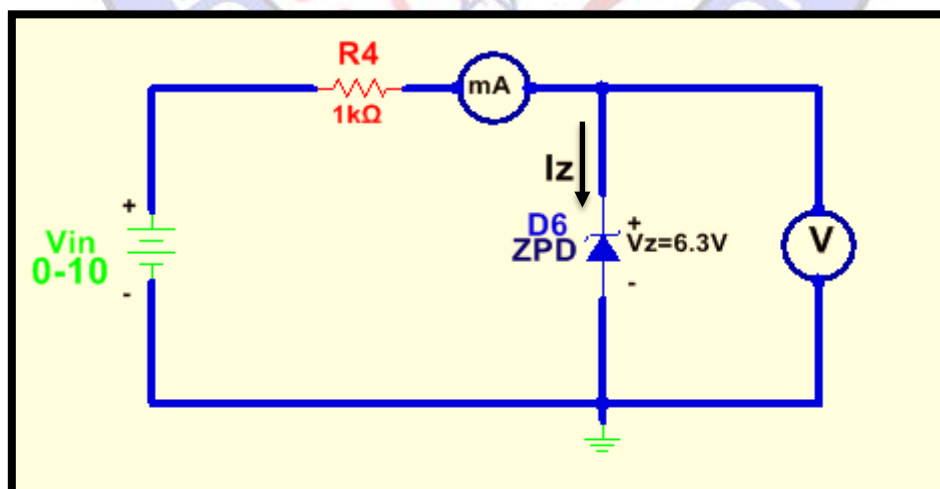


Figure 7: Practical Circuit Used to Obtain the Characteristics of the Zener Diode



$V_{in}(V)$	$V_Z(V)$	$I_Z(mA)$
0		
1		
2		
3		
4		
4.5		
5		
5.5		
6		
7		
8		
10		
12		
14		
15		

Table 1: Recorded Data for the Circuit of Figure 7

2. Connect the voltage regulator circuit shown in Fig.8, and vary the load resistor R_L in several steps as shown in Table 2. Record V_L , I_S , I_Z , and I_L where $I_L = I_S - I_Z$.
3. Connect the voltage regulator circuit shown in Fig.9, and vary the input voltage in several steps from 0 to 15V as shown in Table 3. Record V_L , I_S , I_Z , and I_L where $I_L = I_S - I_Z$.

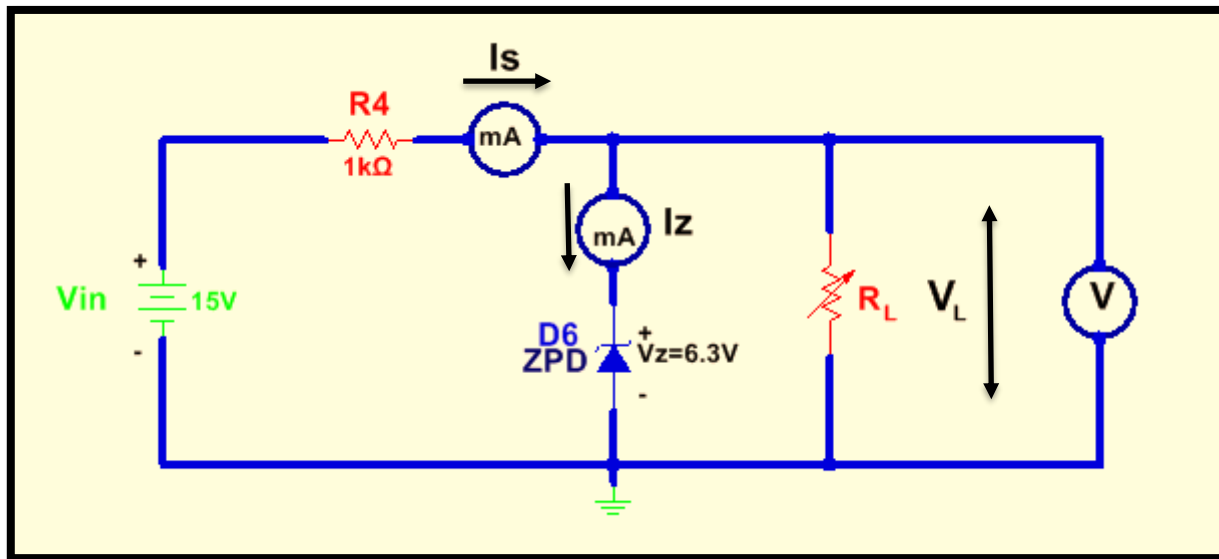


Figure 8: Practical Circuit for Zener Diode Voltage Regulator with Variable Load Resistor

$R_L(\Omega)$	$V_L(V)$	$I_S(mA)$	$I_Z(mA)$	$I_L(mA)$
50				
100				
150				
200				
300				
500				
800				
1.0K				
1.5K				
2.0K				
4.0K				
100K				

Table 2: Recorded Data for the Voltage Regulator Circuit of Figure 8

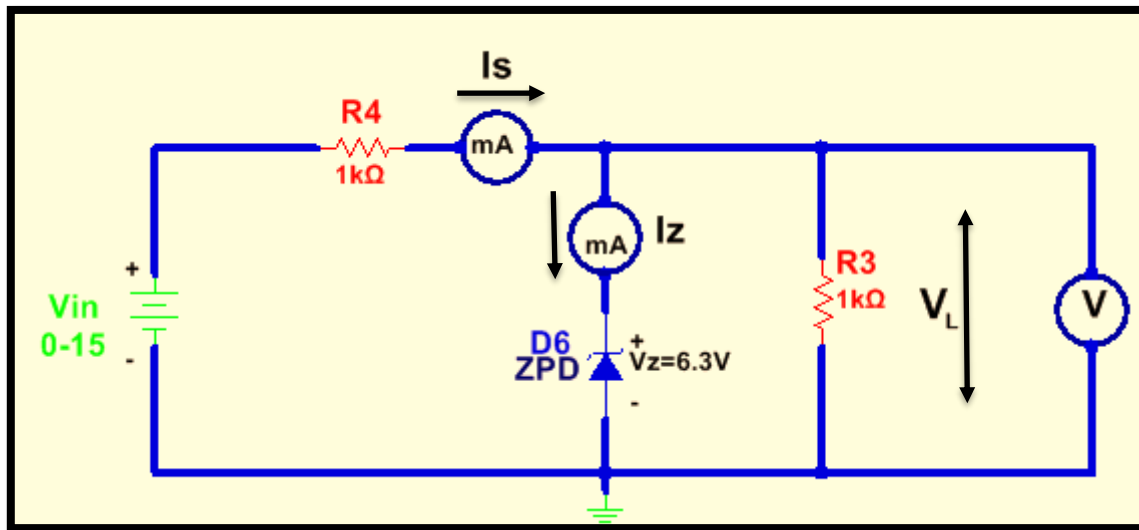


Figure 9: Practical Circuit for Zener Diode Voltage Regulator with Variable Input Voltage

$R_L(\Omega)$	$V_L(V)$	$I_S(mA)$	$I_Z(mA)$	$I_L(mA)$
0				
1				
2				
4				
5				
6				
6.5				
7				
10				
12				
14				
15				

Table 3: Recorded Data for the Voltage Regulator Circuit of Figure 9



Discussion

1. Plot the characteristic curve of the zener diode in the reverse-breakdown region from the results obtained in step 1 of the procedure.
2. Determine the internal resistance R_Z of the zener diode from your data. Do this calculation only on the straight-line breakdown region of the characteristic curve plotted in step 1 above.
3. Determine the power dissipation in the zener diode for the maximum zener current flowing through it from the obtained data of step 1 in the procedure, and compare it with P_{ZM} .
4. For the zener diode voltage regulator circuit of Fig.8, sketch the relation between V_L and I_L (V_L versus I_L). Plot the relation between I_S and R_L . Sketch also the relation between I_Z and I_L . Comment on the resulting curves.
5. Calculate the theoretical minimum value of R_L required for putting the zener diode in the zener breakdown region for the regulator circuit of Fig.8. What value of load resistance results in the maximum zener current? Determine the maximum Zener current $I_{Z(max)}$ in this case and compare it with I_{ZM} .
6. Plot the relation between V_L and V_{in} for the voltage regulator circuit in Fig.9, and comment on the resulting sketch. From this sketch, determine the minimum value of input voltage required to turn-on the zener diode.
7. Calculate the theoretical minimum value of V_{in} required to turn-on the zener diode in the voltage regulator circuit of Fig.9. Determine also the maximum permissible value of V_{in} knowing that the maximum DC power dissipation of the PZD zener diode is 0.5W.
8. Explain the difference between line regulation and load regulation.



Experiment No.7

Light Emitting Diodes

Object

The purpose of this experiment is to determine and plot the characteristics of the light emitting diode in the forward-bias region, and to compare between different colored diodes.

Required Parts and Equipment's

1. Variable DC Power Supply.
2. Digital Multimeters.
3. Electronic Test Board(M50).
4. Light Emitting Diodes (LEDs) with different colors (Red, Yellow, and Green).
5. Resistor (470Ω , 1W).
6. Leads and Wires.

Theory

The Light-Emitting Diode (LED) is a semiconductor PN junction diode that emits visible light or near-infrared radiation when forward biased. LEDs switch off and on rapidly, are very rugged and efficient, have a very long lifetime, don't heat up, and are easy to use. They are used as indicators, displays, and as light transmitters.

Various impurities are added during the doping process to vary the color output. The LED is basically, just a specialized type of PN junction diode, made from a very thin layer of fairly heavily doped semiconductor material. Fig.1 depicts the construction of the light emitting diode.

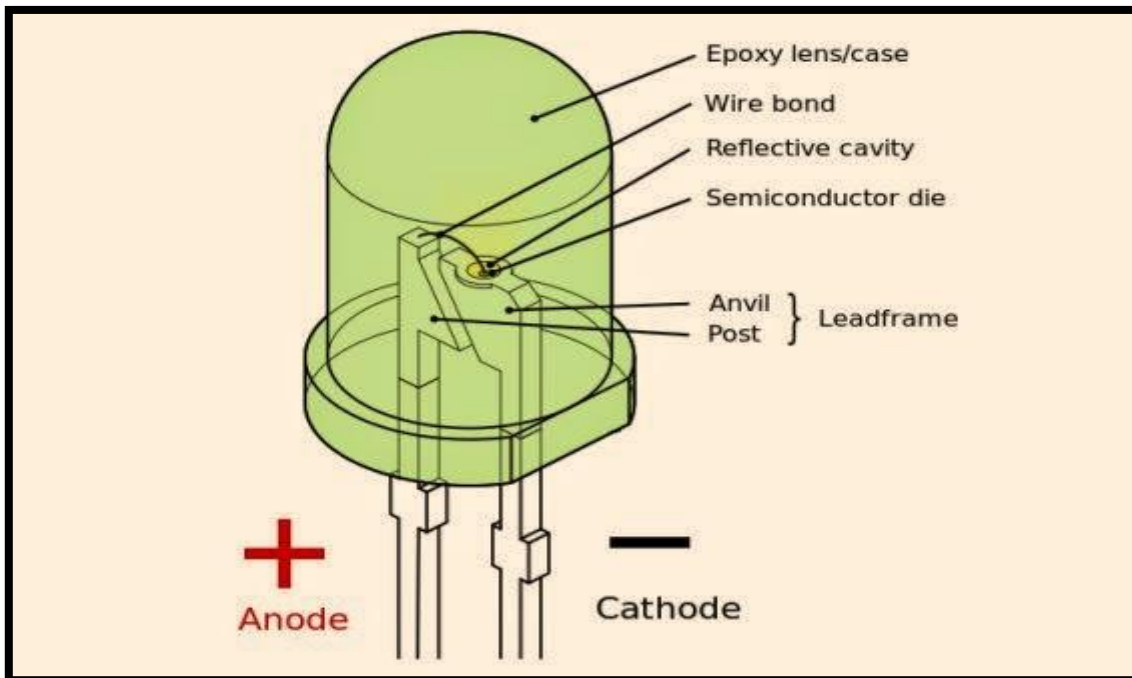


Figure 1: LED Construction

When the diode is forward biased, electrons from the semiconductor's conduction band recombine with holes from the valence band releasing sufficient energy to produce photons which emit a monochromatic (single color) of light. Because of this thin layer a reasonable number of these photons can leave the junction and radiate away producing a colored light output. Then we can say that when operated in a forward biased direction Light Emitting Diodes are semiconductor devices that convert electrical energy into light energy. Fig.2 shows the LED external package and its electronic symbol.

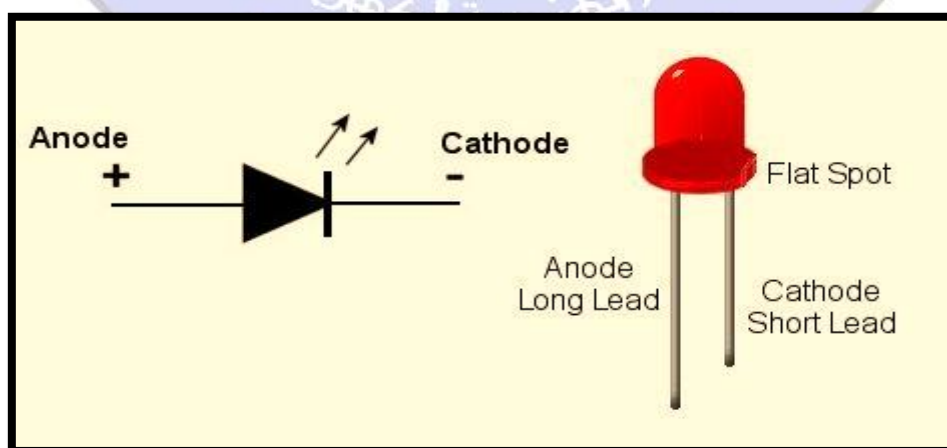


Figure 2: The LED Package and Symbol



As shown from Fig.1, the cathode is the short lead and there may be a slight flat on the body of round LEDs. Light emitting diodes are available in a wide range of colors with the most common being RED, ORANGE, YELLOW and GREEN, and are thus widely used as visual indicators and as moving light displays. Visible LEDs emit relatively narrow bands of green, yellow, orange, or red light. Infrared LEDs emit in one of several bands just beyond red light.

Light Emitting Diodes are made from special semiconductor compounds such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), Gallium Arsenide Phosphide (GaAsP), Silicon Carbide (SiC) or Gallium Indium Nitride (GaInN) all mixed together at different ratios to produce a distinct wavelength of color. Silicon and germanium are not used because they are heat producing materials and are very poor in producing light. Thus, the actual color of a light emitting diode is determined by the wavelength of the light emitted, which in turn is determined by the actual semiconductor compound used in forming the PN junction during the manufacturing process. Therefore, the color of an LED is determined by the semiconductor material, not by the coloring of the 'package' (the plastic body). Table 1 below shows typical technical data for some LEDs with diffused packages.

Type	Color	I_D Max.	V_D Typ.	V_D Max.	Wavelength
Standard	Red	30mA	1.7V	2.1V	660nm
Standard	Bright red	30mA	2.0V	2.5V	625nm
Standard	Yellow	30mA	2.1V	2.5V	590nm
Standard	Green	25mA	2.2V	2.5V	565nm
High intensity	Blue	30mA	4.5V	5.5V	430nm

Table 1: Some Important Characteristics of Typical LEDs

When an LED is forward biased to the threshold of conduction, its current increases rapidly and must be controlled to prevent destruction of the device. The light output is quite linearly proportional to the forward LED current as shown in Fig.3.

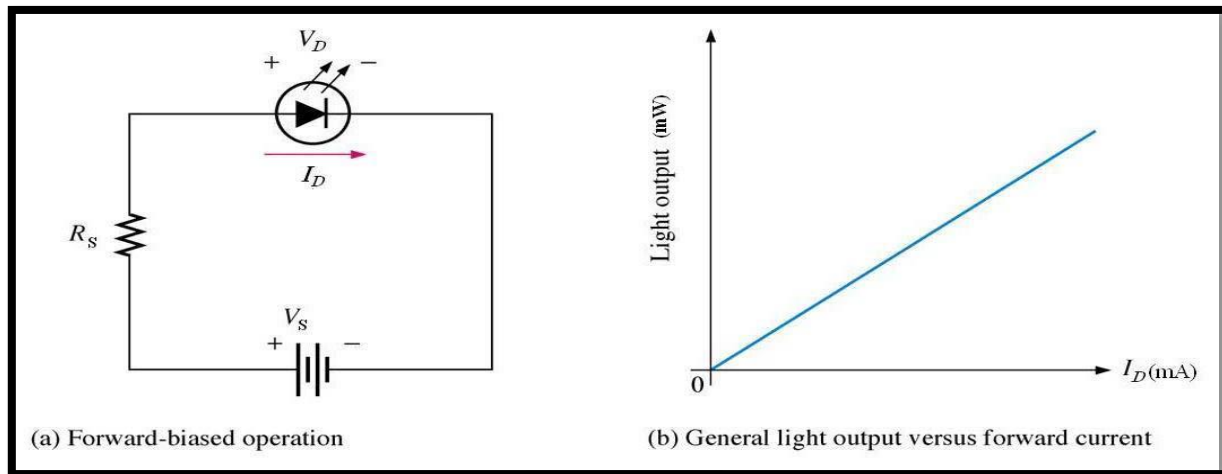


Figure 3: LED Bias Circuit and Power Output Characteristic

A series resistor (R_s) should be used to limit the current through the LED to a safe value. The LED diode voltage drop ranges from about 1.3V to about 3.6V. This resistor is calculated from:

$$R_s = \frac{V_s - V_D}{I_{D(\max)}}$$

Where V_s is the source bias voltage, V_D is the LED voltage drop, and $I_{D(\max)}$ is the maximum current of the LED

Fig.4 shows the IV characteristics in the forward bias region for some typical diodes with different colored packages.

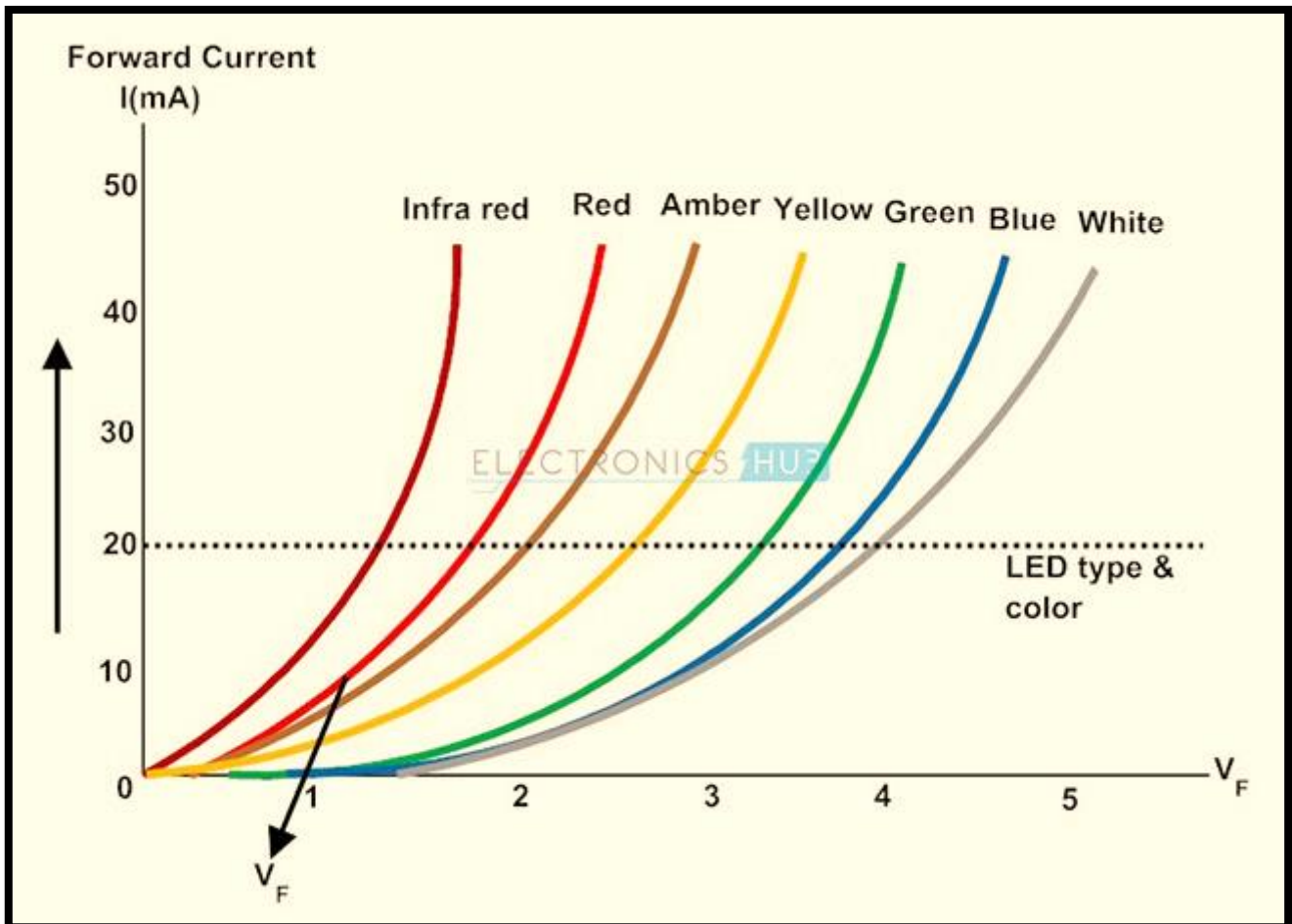


Figure 4: LED I-V Characteristics Curves Showing the Different Colors Available

Procedure

1. Connect the circuit shown in Fig.5, and increase the input DC voltage from 0V to 15V in several steps. Use red LED and record, V_D and, I_D according to Table 2.

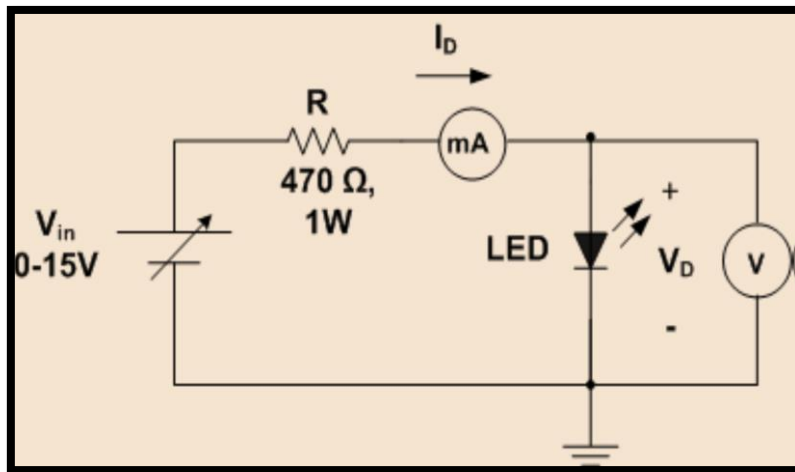


Figure 5: The LED Test Circuit

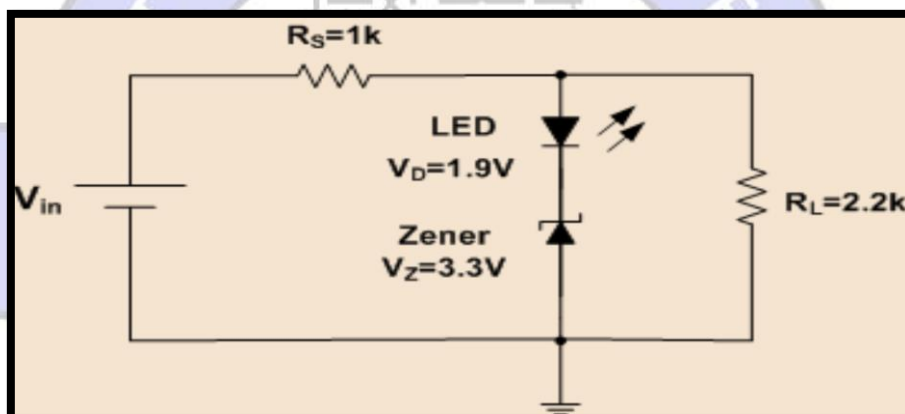
$V_{in}(V)$	$V_D(V)$	$I_D(mA)$
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Table 2: Recorded Data of the LED Test Circuit

2. Repeat step 1 after replacing the red LED with a yellow colored one. If possible
3. Repeat step 1 after replacing the LED with a green colored one. If possible

Discussion

1. Plot the forward characteristics of each LED on the same graph.
2. From the sketched curves, determine the threshold voltage for each LED. Determine also the forward static resistance at 10mA for each diode.
3. Which factor determines the color of the emitted light of the LED?
4. A certain LED has a typical forward voltage of 2.2V, and a maximum current of 30mA. If this diode is to be connected to a voltage source of 15V, determine the suitable value of the current limiting resistor. Find the current flowing in the LED when the input voltage is reduced to 8V. Assume the voltage drop across the diode remains constant.
5. Determine the minimum input voltage required to turn on the Zener diode in the following circuit.



6. What are the features of LEDs over conventional bulbs? Name some applications for LEDs.
7. A yellow colored LED with a forward voltage drop of 2.1V is to be connected to a 5.0V stabilized DC power supply. Calculate the value of the series resistor required to limit the forward current to less than 10mA. Also calculate the current flowing through the diode if a 100Ω series resistor is used instead of the calculated first.
8. How can you connect two LED diodes with different colors in parallel to the same DC power supply? Sketch the circuit diagram and justify the method of wiring.