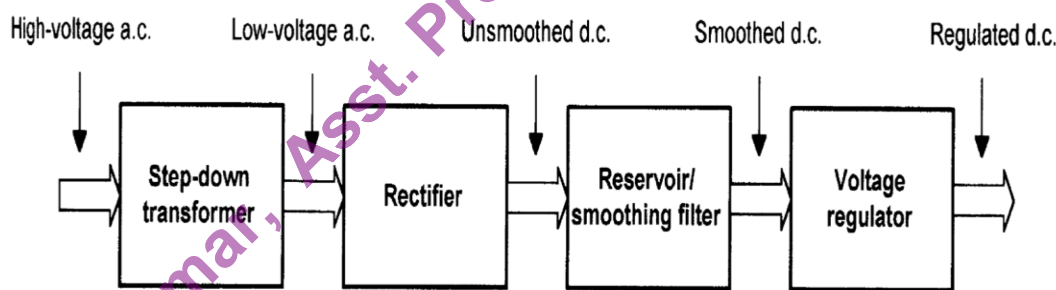
DC Power Supply

- A step-down transformer of appropriate turns ratio is used to convert high voltage from the mains to a low voltage.
- The a.c. output from the transformer secondary is then rectified using conventional silicon rectifier diodes to produce an unsmoothed (sometimes referred to as pulsating d.c.) output.
- The output is smoothed and filtered before being applied to a circuit which will regulate (or stabilize) the output voltage so that it remains relatively constant in spite of variations in both load current and incoming mains voltage.



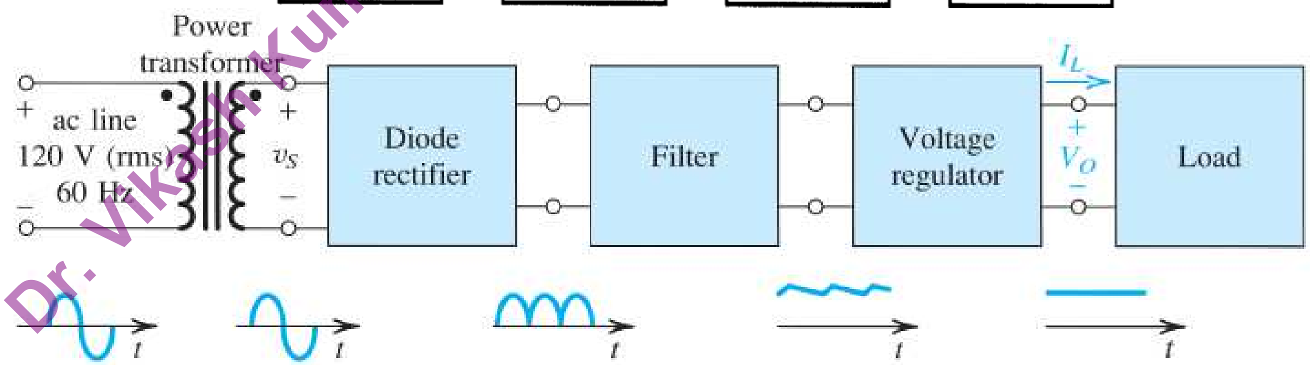
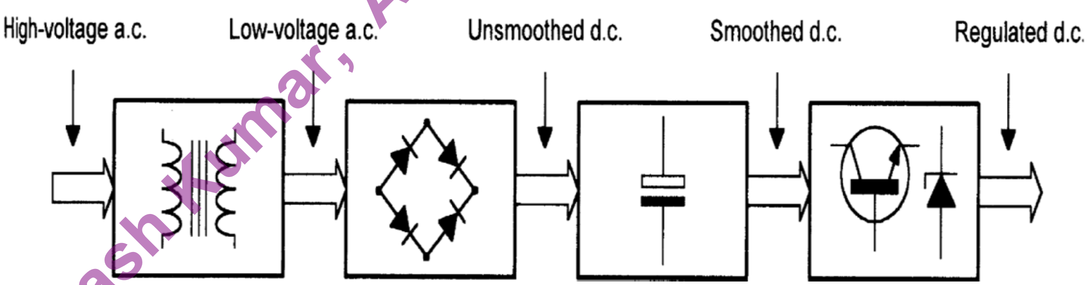


Figure 4.22 Block diagram of a dc power supply.

DC Power Supply

- The iron-cored step-down transformer feeds a rectifier arrangement (often based on a bridge circuit).
- The output of the rectifier is then applied to a high-value reservoir capacitor. The capacitor helps to smooth out the voltage pulses produced by the rectifier.
- A stabilizing circuit (often based on a series transistor regulator and a zener diode voltage reference) provides a constant output voltage.



Rectifiers

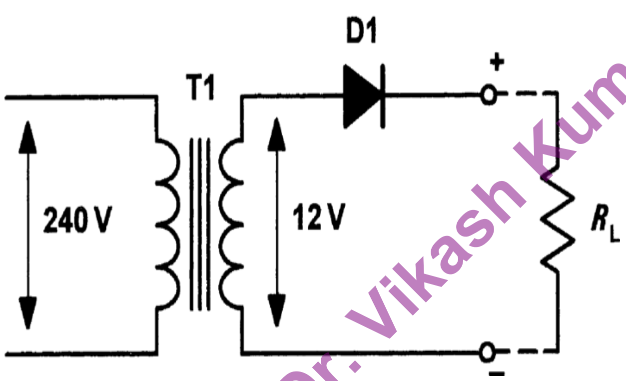
- Semiconductor diodes are commonly used to convert alternating current (AC) to pulsating direct current (DC), in which case they are referred to as rectifiers.
- Types- Half-wave rectifier, Full-wave rectifier.
- Half-wave rectifier uses **single diode** and operates on only either **positive** or **negative half-cycles** of the supply.
- Full-wave rectifier uses two diodes with centre tap transformer and operates in both positive and negative half cycles.
- Bridge rectifier uses four diodes and operates in both positive and negative half cycles.
- For a transformer having V_p = primary voltage, V_s= secondary voltage, N_p = number of turns in the primary & N_s = number of turns in the secondary, the transformer equation can be written as

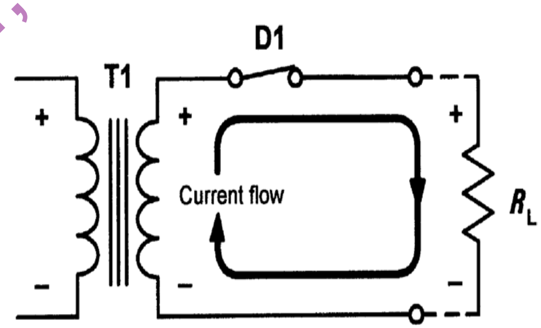
$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \Rightarrow V_s = \frac{N_s}{N_p} \times V_p$$

- Mains voltage (220 to 240 V) is applied to the primary of a step-down transformer (T_1).
- The secondary of T_1 steps down the 240 V RMS to 12 V RMS (the turns ratio of T_1 will thus be 240/12 or 20:1).

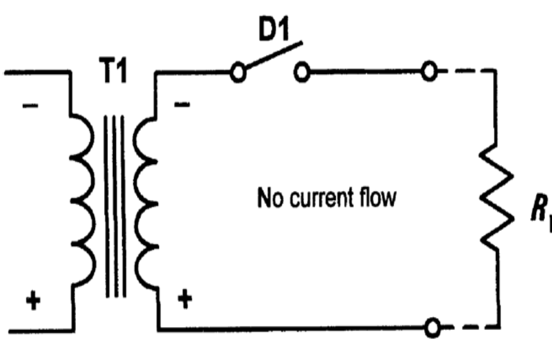
Half-wave Rectifier

- In Half Wave Rectifier, when AC supply is applied at the input, positive half cycle appears across the load, whereas the negative half cycle is suppressed.
- D_1 will be forward biased during each positive half-cycle (relative to common) and will effectively behave like a closed switch.
- D_1 will be reverse biased during each negative half-cycle and will effectively behave like a open switch.
- The switching action of diode results in a pulsating output voltage which is developed across the load resistor (R_L).
- Mains supply and output developed across R_L both have same frequency 50 Hz.





(a)



(b)

Half Wave Rectifier (With Ideal Diode)

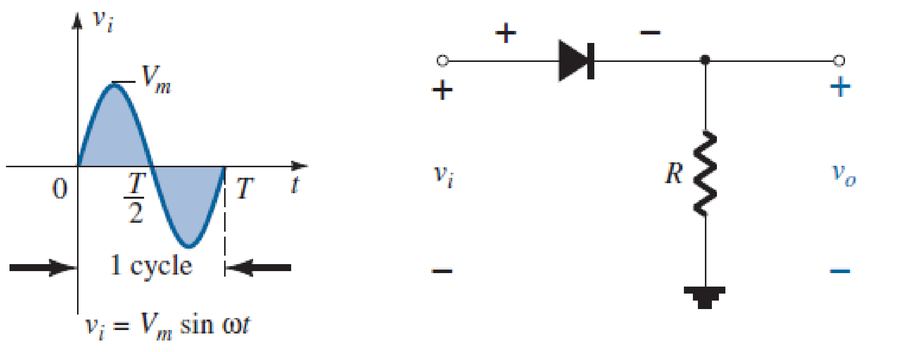


FIG. 44
Half-wave rectifier.

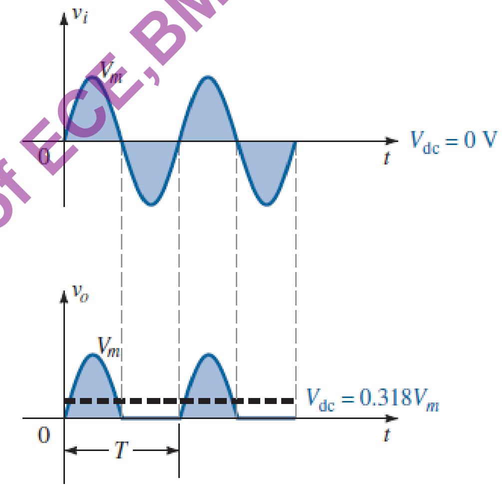


FIG. 47
Half-wave rectified signal.

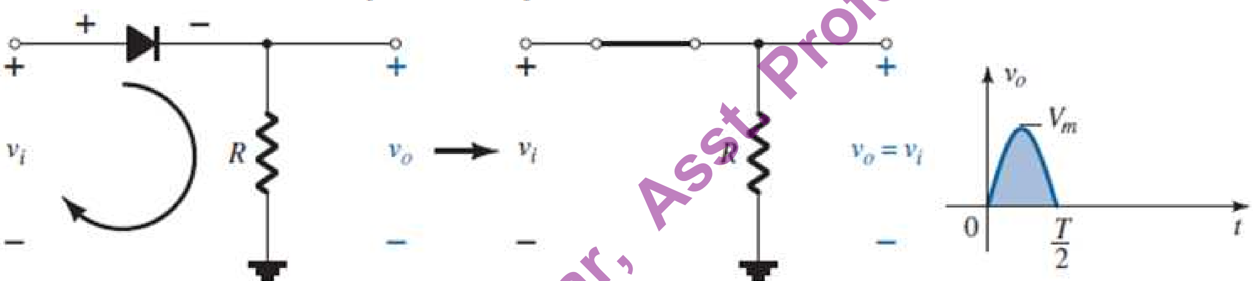


FIG. 45
Conduction region ($0 \rightarrow T/2$).

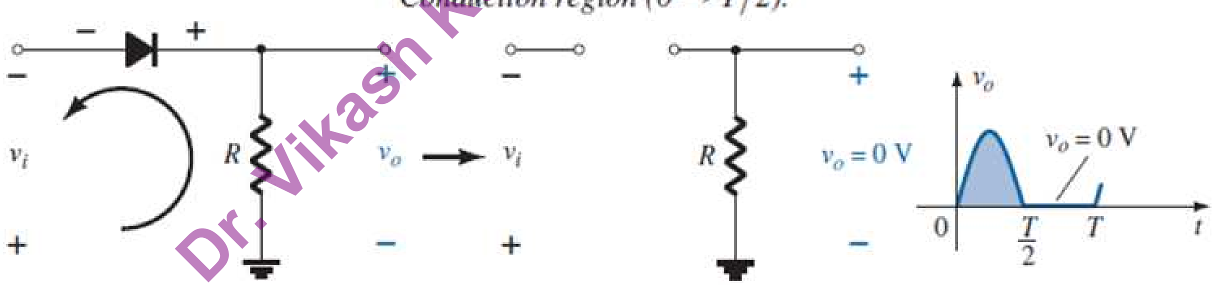


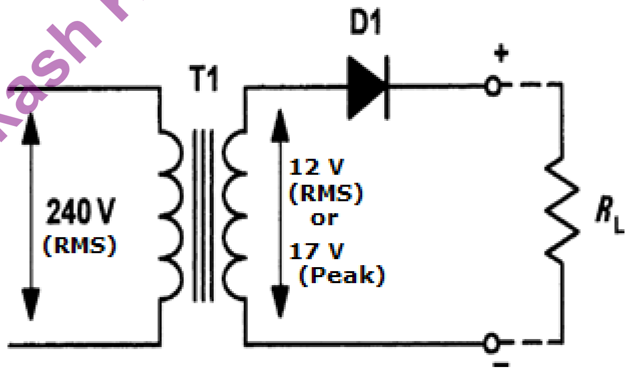
FIG. 46
Nonconduction region ($T/2 \rightarrow T$).

Half-wave Rectifier (Practical Diode)

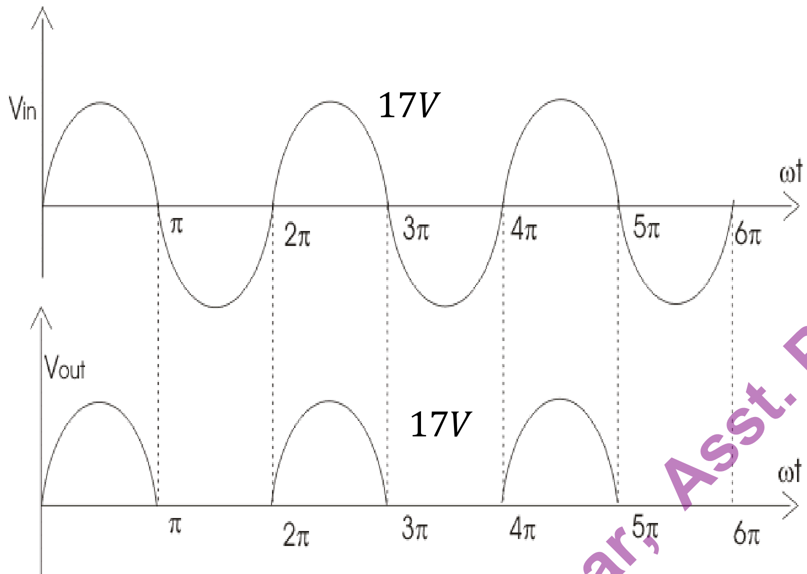
- During the positive half-cycle, the diode will drop the 0.6 V to 0.7 V forward threshold voltage normally associated with silicon diodes.
- Assuming that the secondary of T_1 provides 12 V RMS, the peak voltage output from the transformer's secondary winding will be given by:

$$\left(V_{RMS}\right)_{\text{sine wave}} = \frac{V_{Peak}}{\sqrt{2}} \Rightarrow V_{Peak} = 1.414 \times V_{RMS}$$

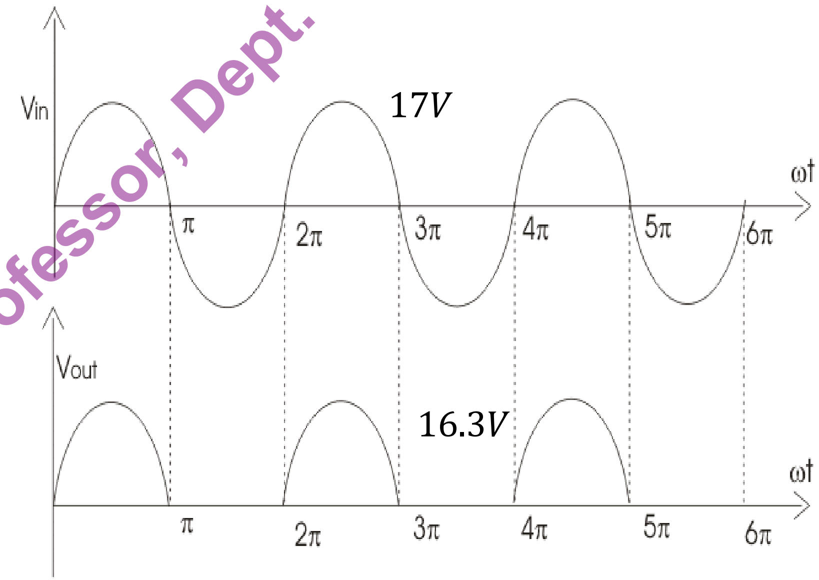
- The peak voltage applied to D_1 will thus be 16.968 V or approximately 17 V.
- For HWR, the negative half-cycles are blocked by D_1 and thus only the positive half-cycle appear across R_L.
- The actual peak voltage across R_L will be the 17 V positive peak being supplied from the secondary on T_1, minus the 0.7 V forward threshold voltage dropped by D_1.
- Positive half-cycle pulses having a peak amplitude of 16.3 V will appear across R_L.



Half-wave Rectifier- Waveforms



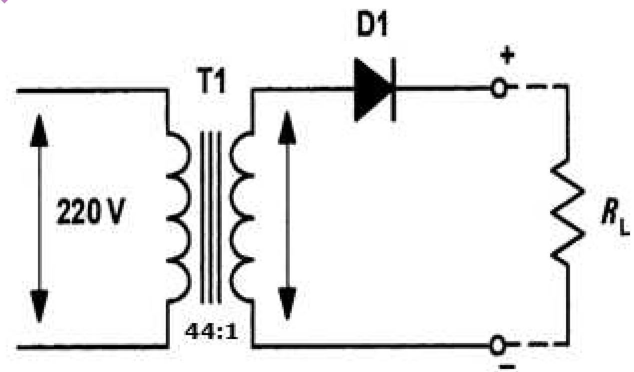
HWR waveform with Ideal Diode



HWR waveform with Practical Silicon Diode

Problem 1

A mains transformer having a turns ratio of 44:1 is connected to a 220 V RMS mains supply. If the secondary output is applied to a half-wave rectifier, determine the peak voltage that will appear across a load.



The RMS secondary voltage is given by

$$V_s = \frac{N_s}{N_p} \times V_p = \frac{1}{44} \times 220 = 5V$$

The peak voltage developed after rectification will be

$$(V_{Peak})_{\text{secondary}} = 1.414 \times (V_{RMS})_{\text{secondary}} = 7.07V$$

Assuming if the diode is ideal, the peak voltage developed across load will be

$$V_{\text{load}} = 7.07V$$

Assuming if the diode is practical silicon diode, the peak voltage developed across load will be

$$V_{\text{load}} = 7.07 - 0.7 = 6.37V$$

Full-wave Rectifiers

- The half-wave rectifier circuit is relatively inefficient as conduction takes place only on alternate half-cycles.
- A better rectifier arrangement would make use of both positive and negative half-cycles.
- A Rectifier circuit that rectifies both the positive and negative half cycles is termed as a **Full wave rectifier** as it rectifies the complete cycle.
- They are not only more efficient but are significantly less demanding in terms of the reservoir and smoothing components.
- A FWR can be constructed of Two types: Bridge rectifier & Bi- phase (or Centre tapped transformer).

Bi-phase (or Centre Tapped Transformer) Rectifier Circuits

- A rectifier circuit whose transformer secondary is tapped to get the desired output voltage, using two diodes alternatively, to rectify the complete cycle is called as a Center-tapped circuit.
- The center tapping provides two separate output voltages which are equal in magnitude but opposite in polarity to each other.

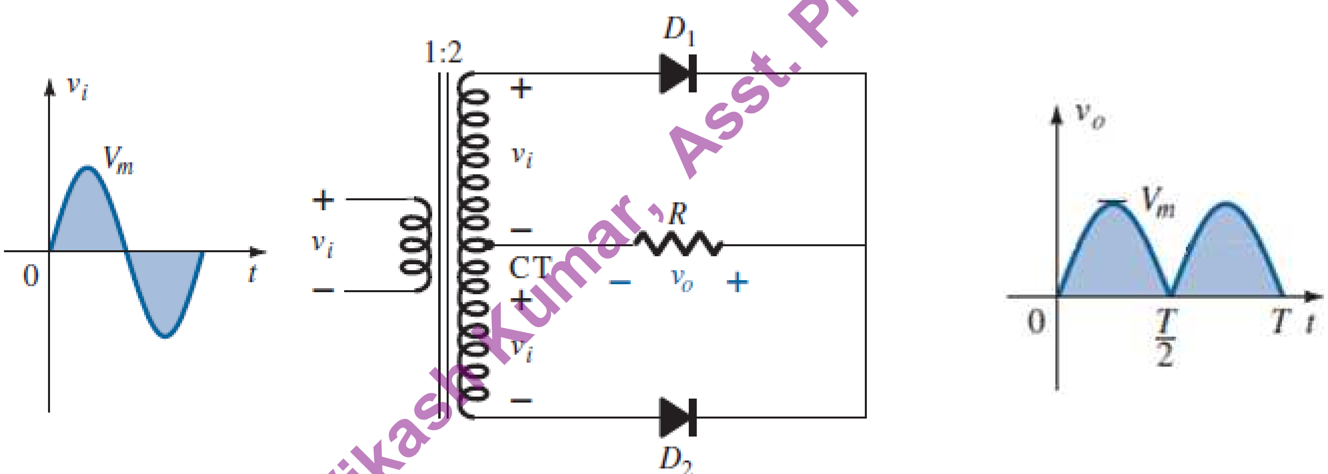


FIG. 60
Center-tapped transformer full-wave rectifier.

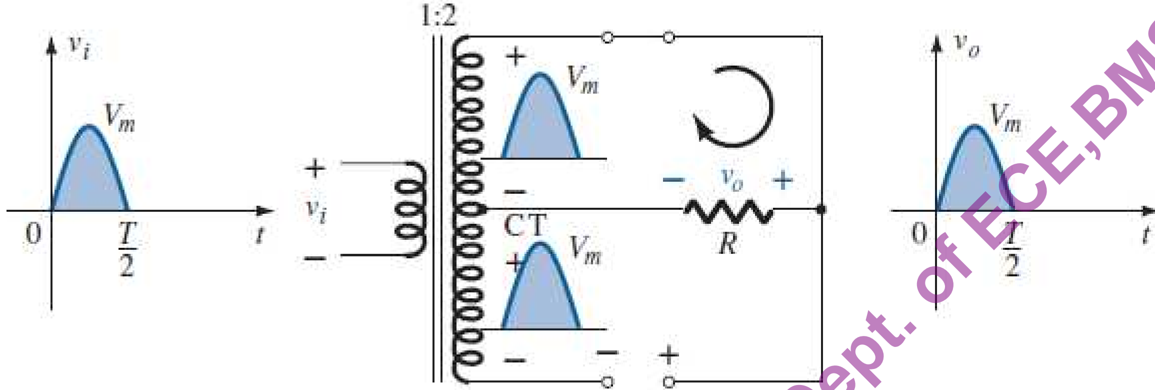


FIG. 61
Network conditions for the positive region of v_i.

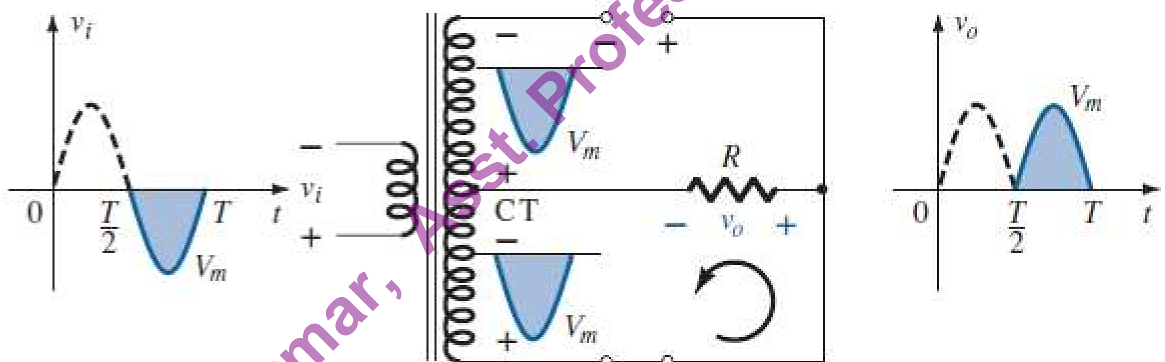
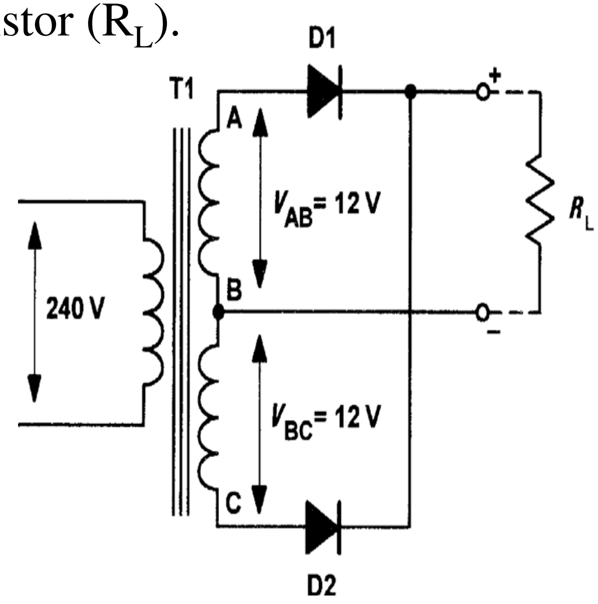


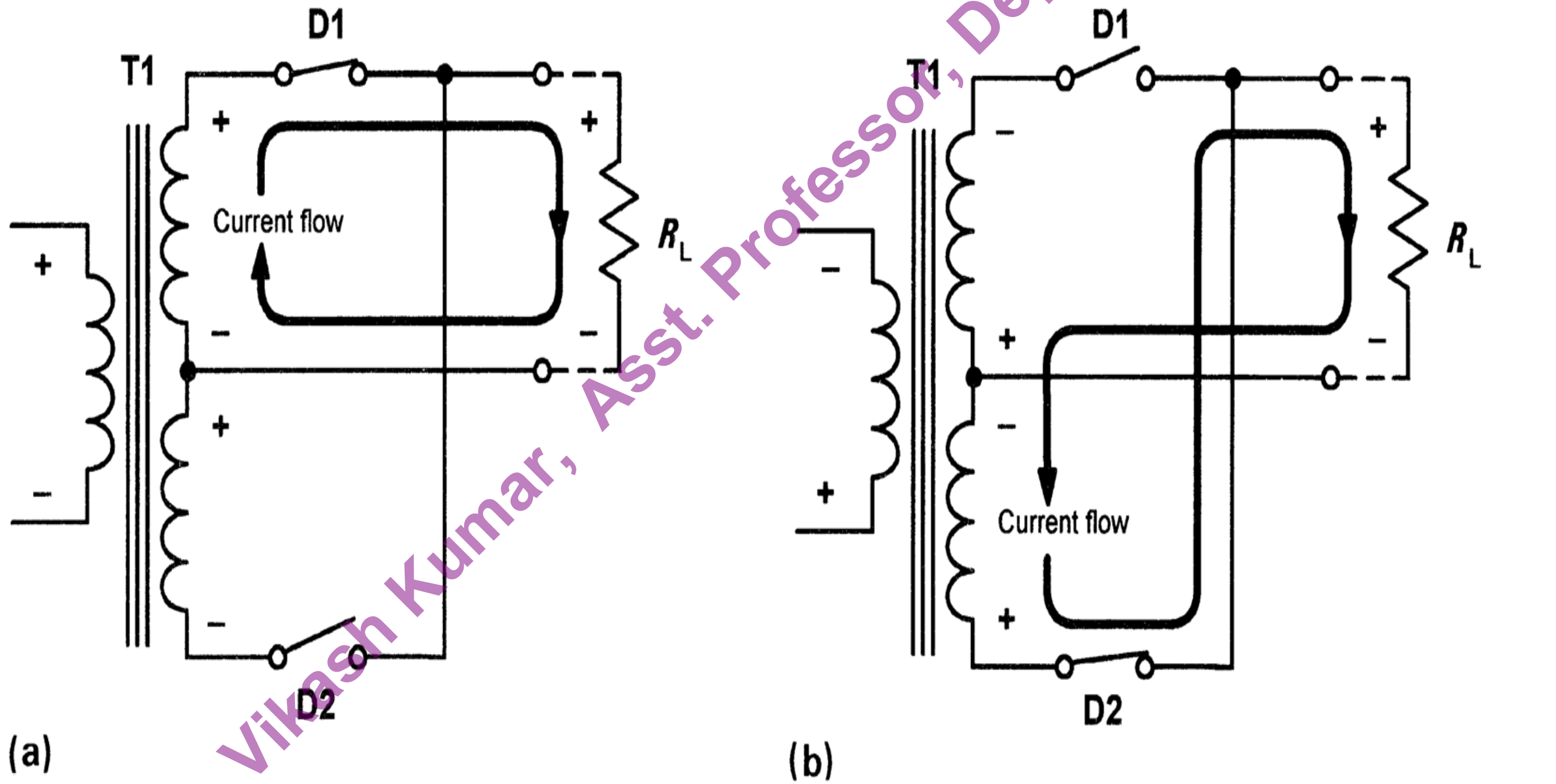
FIG. 62
Network conditions for the negative region of v_i.

Bi-phase Rectifier Circuits - Working

- Mains voltage (240 V) is applied to the primary of the step-down transformer (T_1) which has two identical secondary windings, each providing 12 V RMS (the turns ratio of T1 will thus be 240/12 or 20:1 for each secondary winding).
- On positive half-cycles, point A will be positive with respect to point B. Similarly, point B will be positive with respect to point C. In this condition D_1 will allow conduction while D_2 will not allow conduction.
- On negative half-cycles, point C will be positive with respect to point B. Similarly, point B will be positive with respect to point A. In this condition D_2 will allow conduction while D_1 will not allow conduction.
- As with the half-wave rectifier, the switching action of the two diodes results in a pulsating output voltage being developed across the load resistor (R_L).
- However, unlike the half-wave circuit the pulses of voltage developed across R_L will occur at a frequency of 100 Hz (not 50 Hz).
- This doubling of the ripple frequency allows us to use smaller values of reservoir and smoothing capacitor to obtain the same degree of ripple reduction (Since the reactance of a capacitor is reduced as frequency increases).



Equivalent Circuits during Positive and Negative Half-cycle



Bridge Rectifier

- The bridge rectifier is a full wave rectifier which utilizes four diodes connected in bridge form.
- This arrangement avoids the need to have two separate secondary windings. It uses 4 diodes.
- Four diodes called D_1, D_2, D_3 and D_4 are used for constructing a bridge type network so that two of the diodes conduct for one half cycle and two conduct for the other half cycle of the input supply.

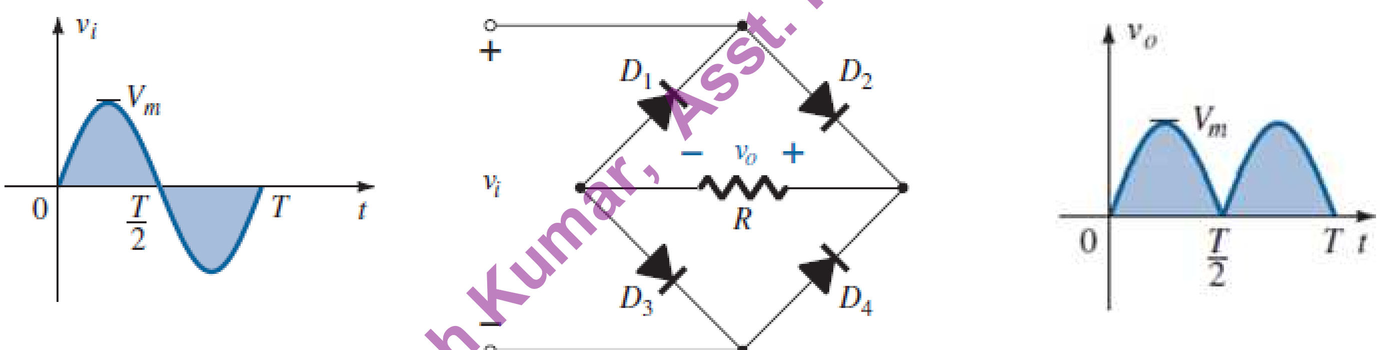


FIG. 53
Full-wave bridge rectifier.

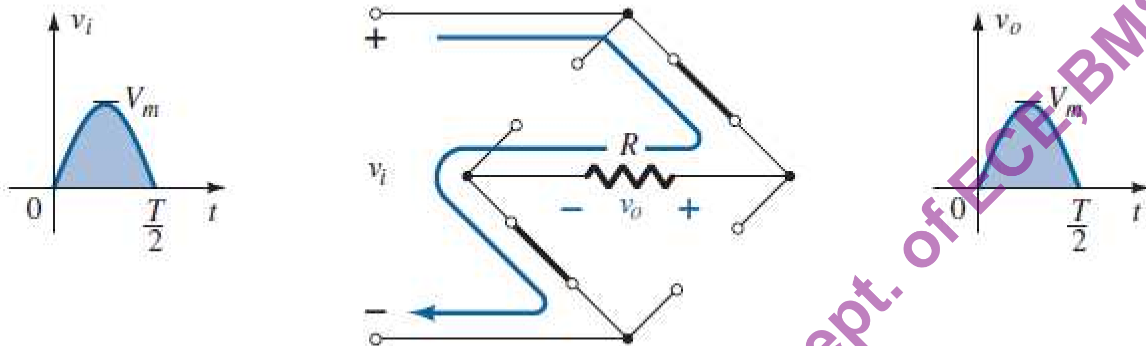


FIG. 55
Conduction path for the positive region of v_i.

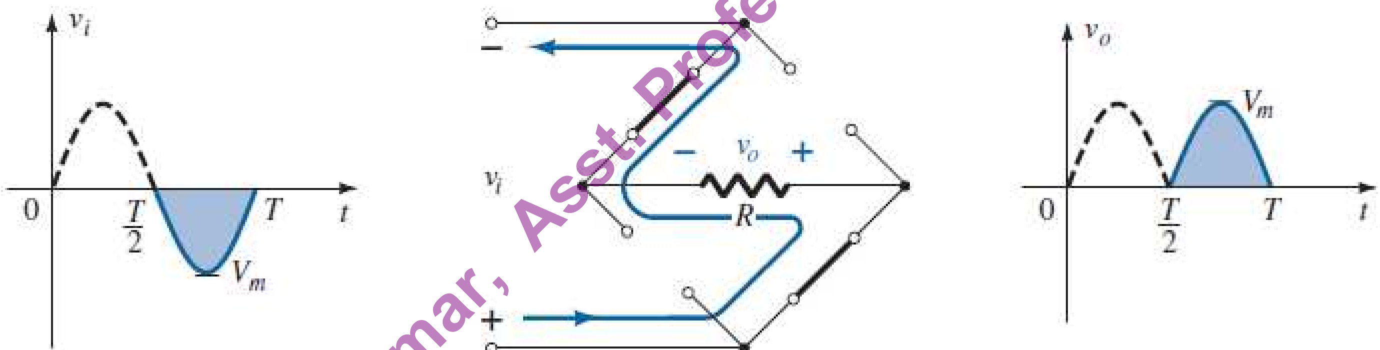
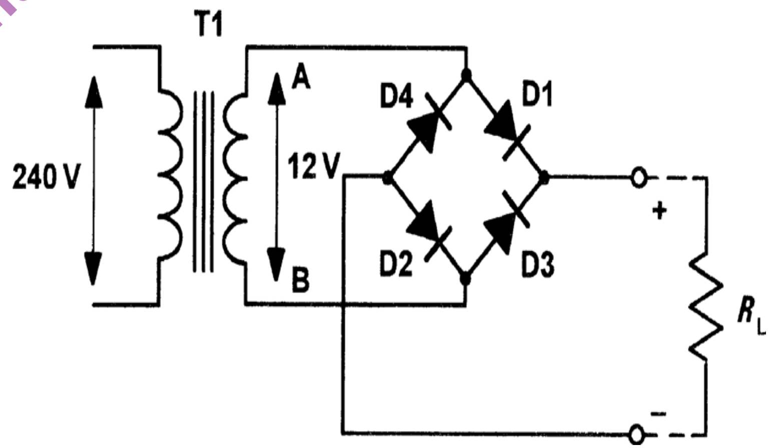


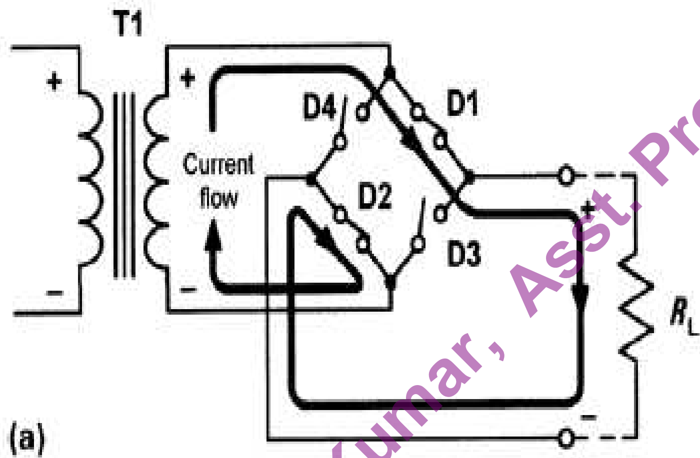
FIG. 56
Conduction path for the negative region of v_i.

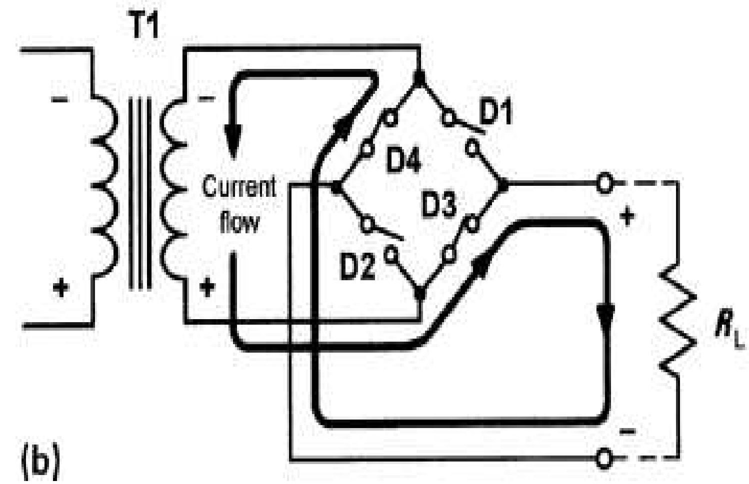
Bridge Rectifier Circuits - Working

- Mains voltage (240 V) is applied to the primary of a step-down transformer (T_1). The secondary winding provides 12 V RMS (approximately 17 V peak) and has a turns ratio of 20:1.
- On positive half-cycles, point A will be positive with respect to point B. In this condition D_1 and D_2 will allow conduction while D_3 and D_4 will not allow conduction.
- On negative half-cycles, point B will be positive with respect to point A. In this condition D_3 and D_4 will allow conduction while D_1 and D_2 will not allow conduction.
- The result is that current is routed through the load in the same direction on successive half-cycles.
- If the diode is practical silicon diode, the peak output voltage is approximately 16.3 V (i.e. 17 V less the 0.7 V forward threshold voltage).



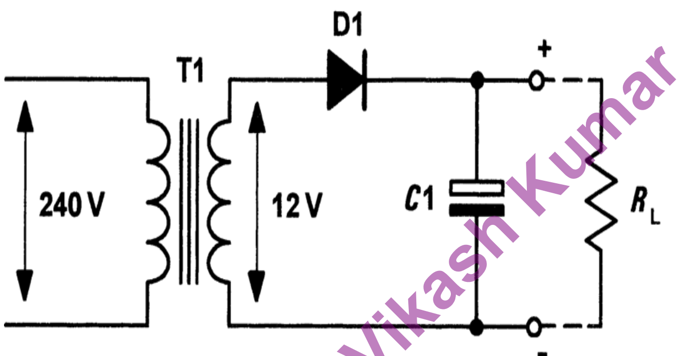
Equivalent Circuits during Positive and Negative Half Cycles



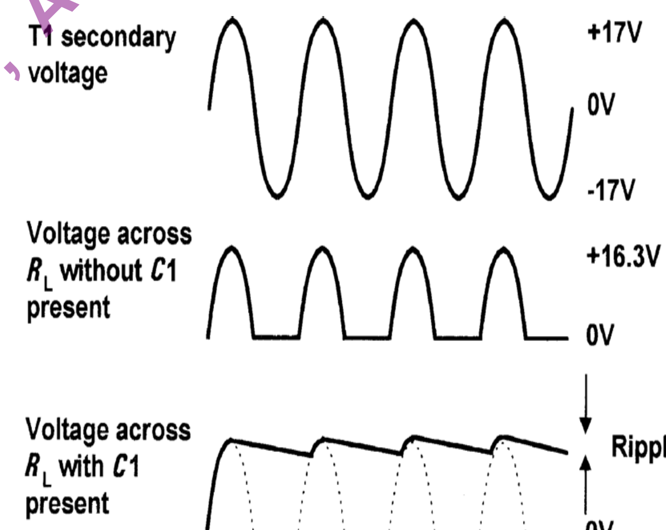


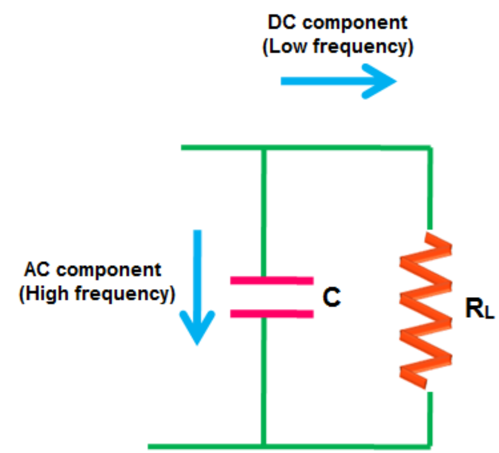
Reservoir and Smoothing Circuits

- Improvement in Half-wave rectifier circuit is possible by adding a capacitor, C_1, to ensure that the output voltage remains at, or near, the peak voltage even when the diode is not conducting.
- When the primary voltage is first applied to T_1, the first positive half-cycle output from the secondary will charge C_1 to the peak value seen across R_L.
- Hence C_1 charges to 16.3 V at the peak of the positive half-cycle. Because C_1 and R_L are in parallel, the voltage across R_L will be the same as that across C_1.
- The time required for C_1 to charge to the maximum (peak) level is determined by the charging circuit time constant (the series resistance multiplied by the capacitance value).



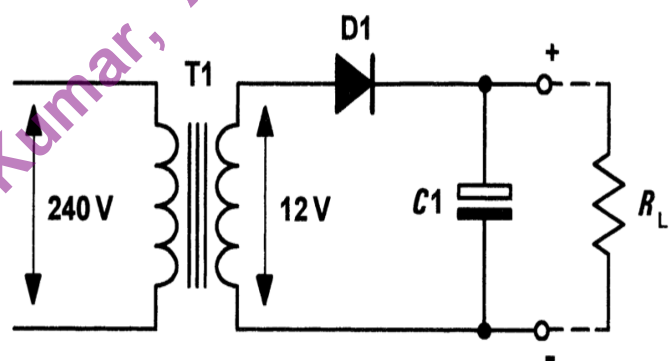
A simple half-wave rectifier circuit with reservoir capacitor





Half-wave Rectifier with Capacitor Filter

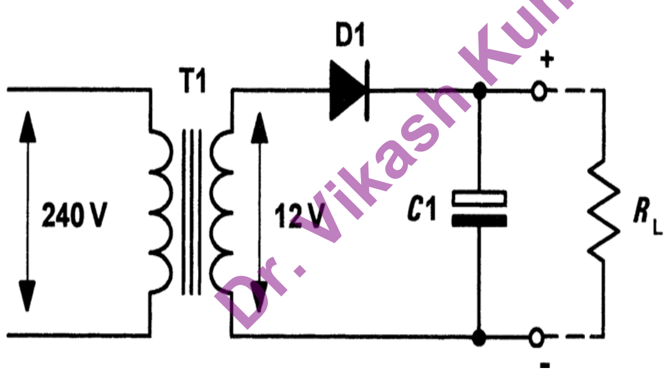
- The series resistance comprises the secondary winding resistance together with the forward resistance of the diode and the (minimal) resistance of the wiring and connections. Hence C_1 charges very rapidly as soon as D_1 starts to conduct.
- The time required for C_1 to discharge is, in contrast, very much greater. The discharge time constant is determined by the capacitance value and the load resistance, R_L.
- During this time, D_1 will be reverse biased and will thus be held in its non-conducting state. As a consequence, the only discharge path for C_1 is through R_L.
- In practice, R_L is very much larger than the resistance of the secondary circuit and hence C_1 takes an appreciable time to discharge.

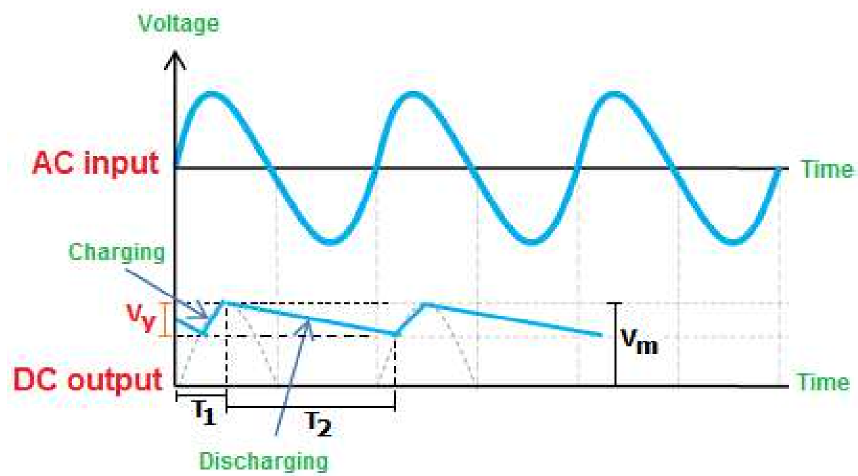


A simple half-wave rectifier circuit
with reservoir capacitor

Half-wave Rectifier with Capacitor Filter

- C_1 is referred to as a reservoir capacitor. It stores charge during the positive half-cycles of secondary voltage and releases it during the negative half-cycles.
- C_1 will discharge by a small amount during the negative half-cycle periods from the transformer secondary.
- Small variation in dc output voltage is ripple.
- Since ripple is undesirable we must take additional precautions to reduce it. One obvious method of reducing the amplitude of the ripple is that of simply increasing the discharge time constant.
- Discharge time constant can be increased by increasing the value of C_1 or by increasing the resistance value of R_L. Usually R_L cant be changed.
- Increasing the value of C_1 is a more practical alternative and very large capacitor values (often in excess of 4,700 µF) are typical.

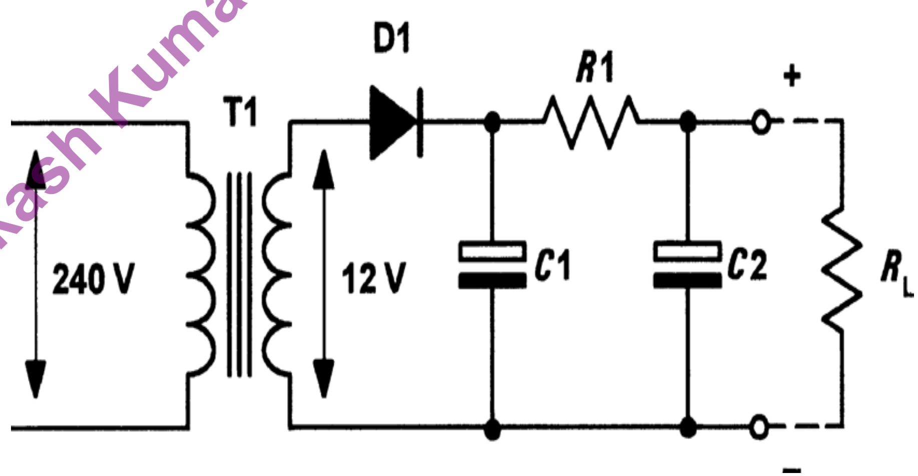




R-C Smoothing Filter (Refinement to the Circuit to Reduce Ripple)

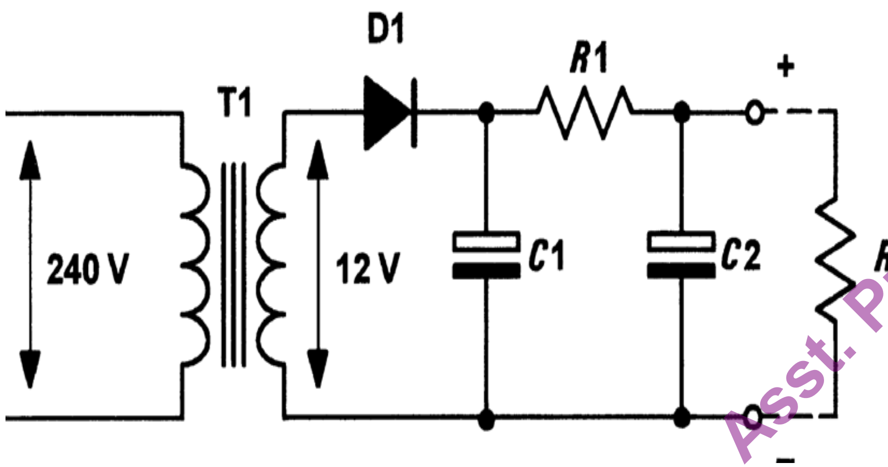
- Figure shows a further refinement of the half wave rectifier circuit using R-C smoothing filter circuit.
- This circuit employs two additional components, R_1 and C_2, which act as an additional filter to remove the ripple.
- The value of C_2 is chosen so that the component exhibits a negligible reactance at the ripple frequency (50 Hz for a half-wave rectifier or 100 Hz for a full-wave rectifier)
- The amount of ripple is reduced by an approximate factor equal to:

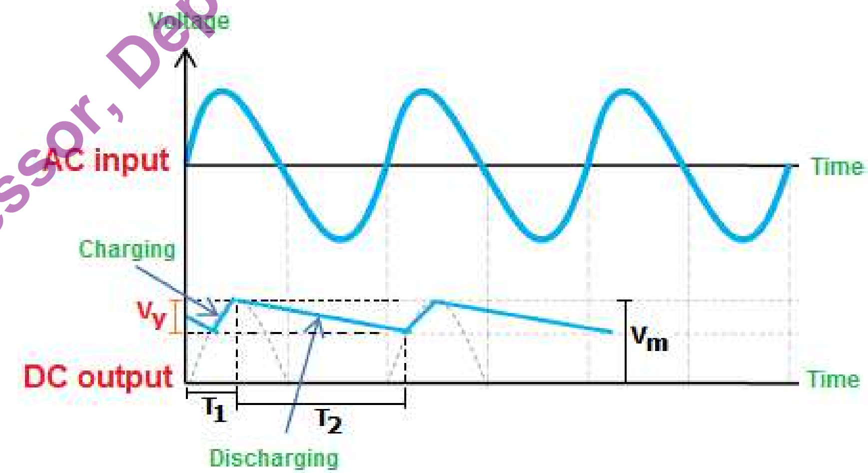
$$\frac{X_{C_2}}{\sqrt{R_1^2 + X_{C_2}^2}} \text{ where } X_{C_2} = \frac{1}{j\omega C_2}$$



Problem 2

The R–C smoothing filter in a 50 Hz mains operated half-wave rectifier circuit consists of $R_1 = 100\ \Omega$ and $C_2 = 1000\ \mu F$. If 1 V of ripple appears at the input of the circuit, determine the amount of ripple appearing at the output.





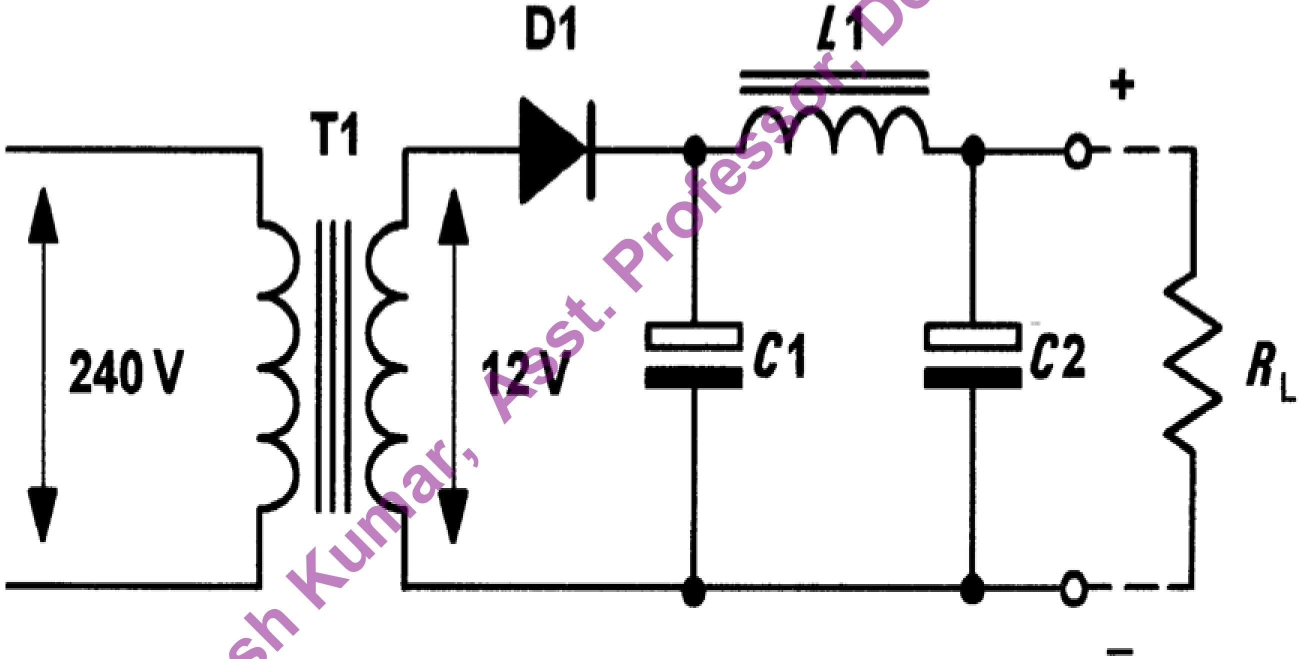
The reactance of filter circuit is

$$\left|X_{C_2}\right| = \left|\frac{1}{j\omega C_2}\right| = \frac{1}{\omega C_2} = \frac{1}{2\pi f C_2} = \frac{1}{2\times 3.14\times 50\times 1000\times 10^{-6}} = 3.18\Omega$$

The amount of ripple at the output of the circuit is

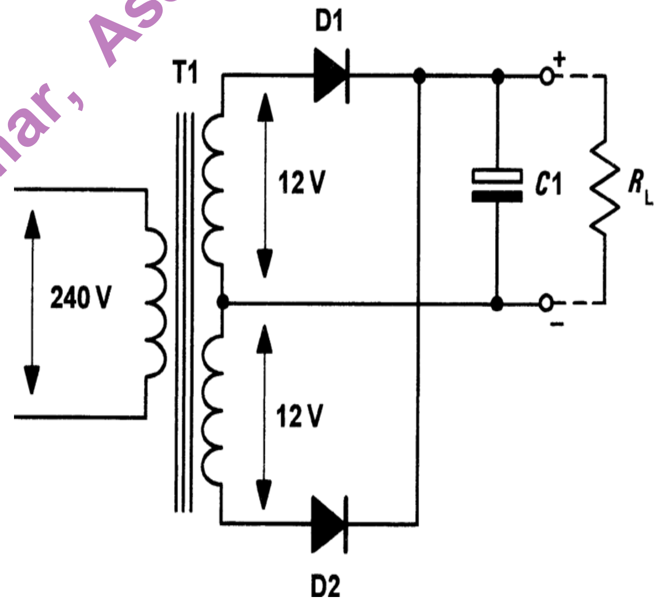
$$V_{ripple} = 1\times\left(\frac{X_{C_2}}{\sqrt{R_1^2 + X_{C_2}^2}}\right) = 1\times\left(\frac{3.18}{\sqrt{(100)^2 + (3.18)^2}}\right) = 0.032 = 32mV$$

Half-wave Rectifier Circuit with L–C Smoothing Filter



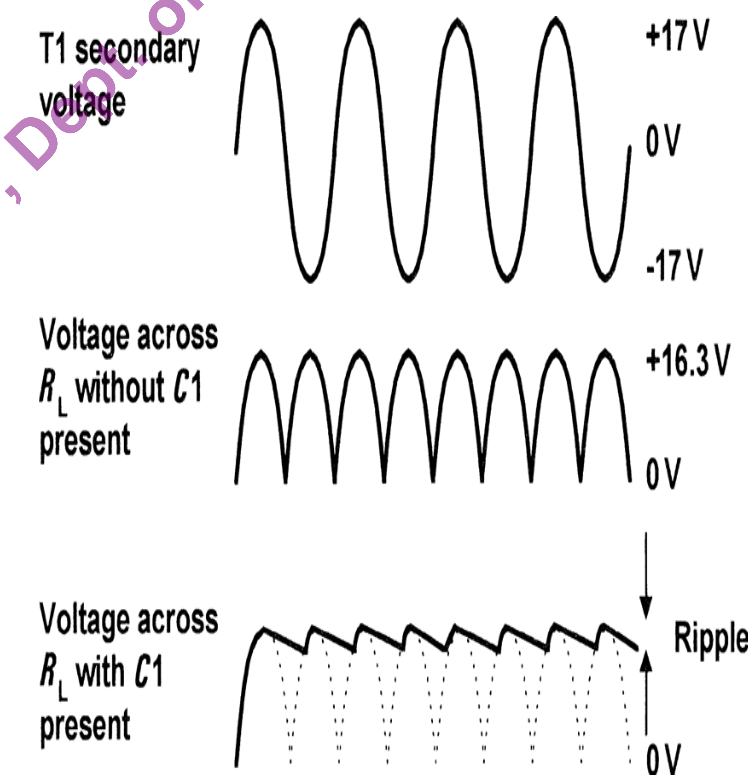
Bi-phase Rectifier Circuits with Capacitor Filter

- The current is routed through the load in the same direction on successive half-cycles.
- Pulsating output voltage being developed across the load resistor (R_L). Frequency of the output is 100 Hz. This doubling of the ripple frequency allows us to use smaller values of reservoir and smoothing capacitor to obtain the same degree of ripple reduction.
- Peak voltage produced by each of the secondary windings will be approximately 17 V and the peak voltage across R_L will be 16.3 V.
- If C_1 is added at the output, it charges to approximately 16.3 V at the peak of the positive half-cycle and holds the voltage at this level when the diodes are in their non-conducting states.

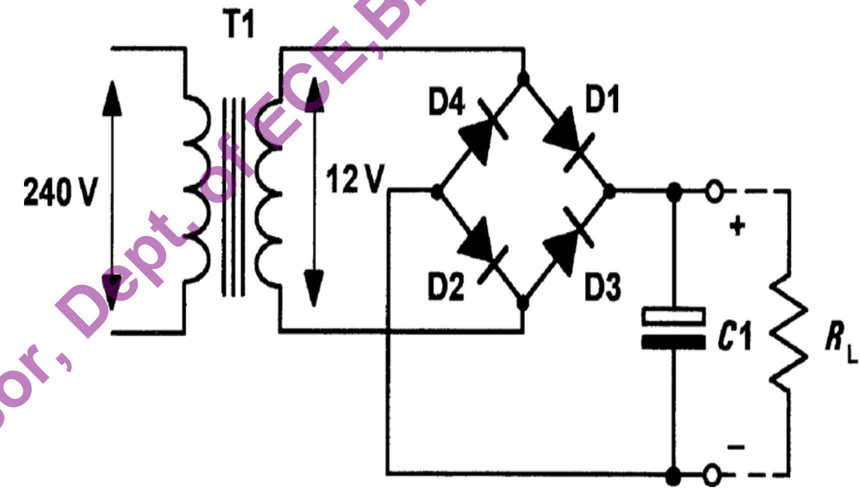


Bi-phase Rectifier Circuits- Waveforms

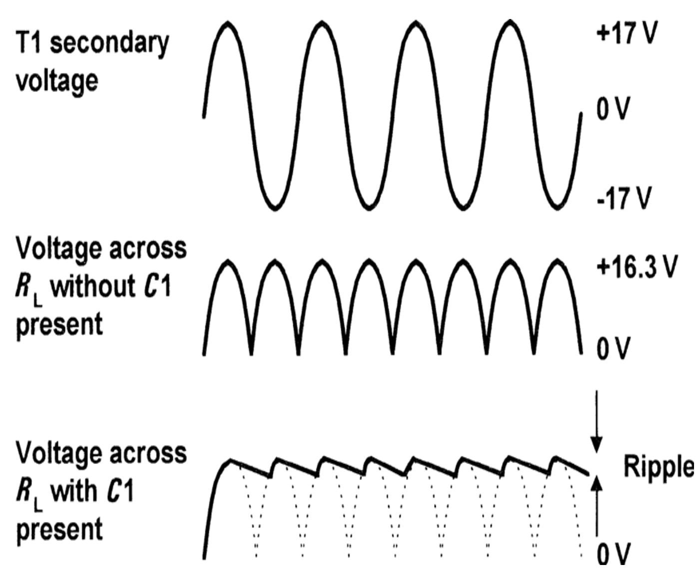
- The time required for C_1 to charge to the maximum (peak) level is determined by series resistance which comprises of secondary winding resistance together with the forward resistance of the diode and the (minimal) resistance of the wiring and connections. Hence C_1 charges very rapidly as soon as either D_1 or D_2 starts to conduct.
- The time required for C_1 to discharge is, in contrast, very much greater.
- The discharge time contrast is determined by the capacitance value and the load resistance, R_L which is large.
- C_1 takes an appreciable time to discharge.
- During this time, D_1 and D_2 will be reverse biased and held in a non-conducting state, thus only discharge path for C_1 is through R_L.
- The ripple frequency (100 Hz) is twice that of the half-wave circuit.



Bridge Rectifier Circuits with Capacitor Filter

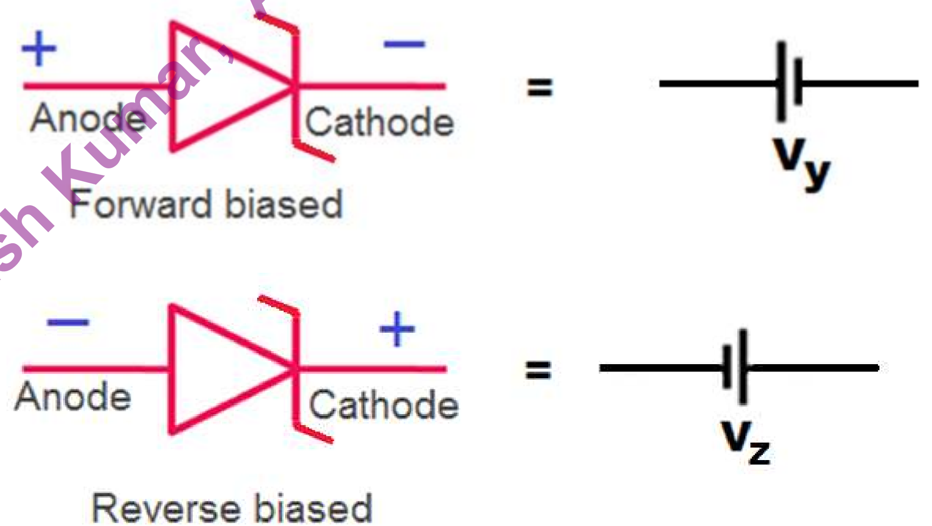


- Reservoir capacitor (C_1) can be added to maintain the output voltage when the diodes are not conducting.
- This component operates in exactly the same way as for the bi-phase circuit and the secondary and rectified output waveforms are shown in Fig.
- C_1 charges to approximately 16.3 V at the peak of the positive half-cycle and holds the voltage at this level when the diodes are in their non-conducting states.
- The ripple frequency is twice that of the incoming AC supply.
- R–C and L–C ripple filters can be added to bi-phase and bridge rectifier circuits in exactly the same way as those shown for the half-wave rectifier arrangement.

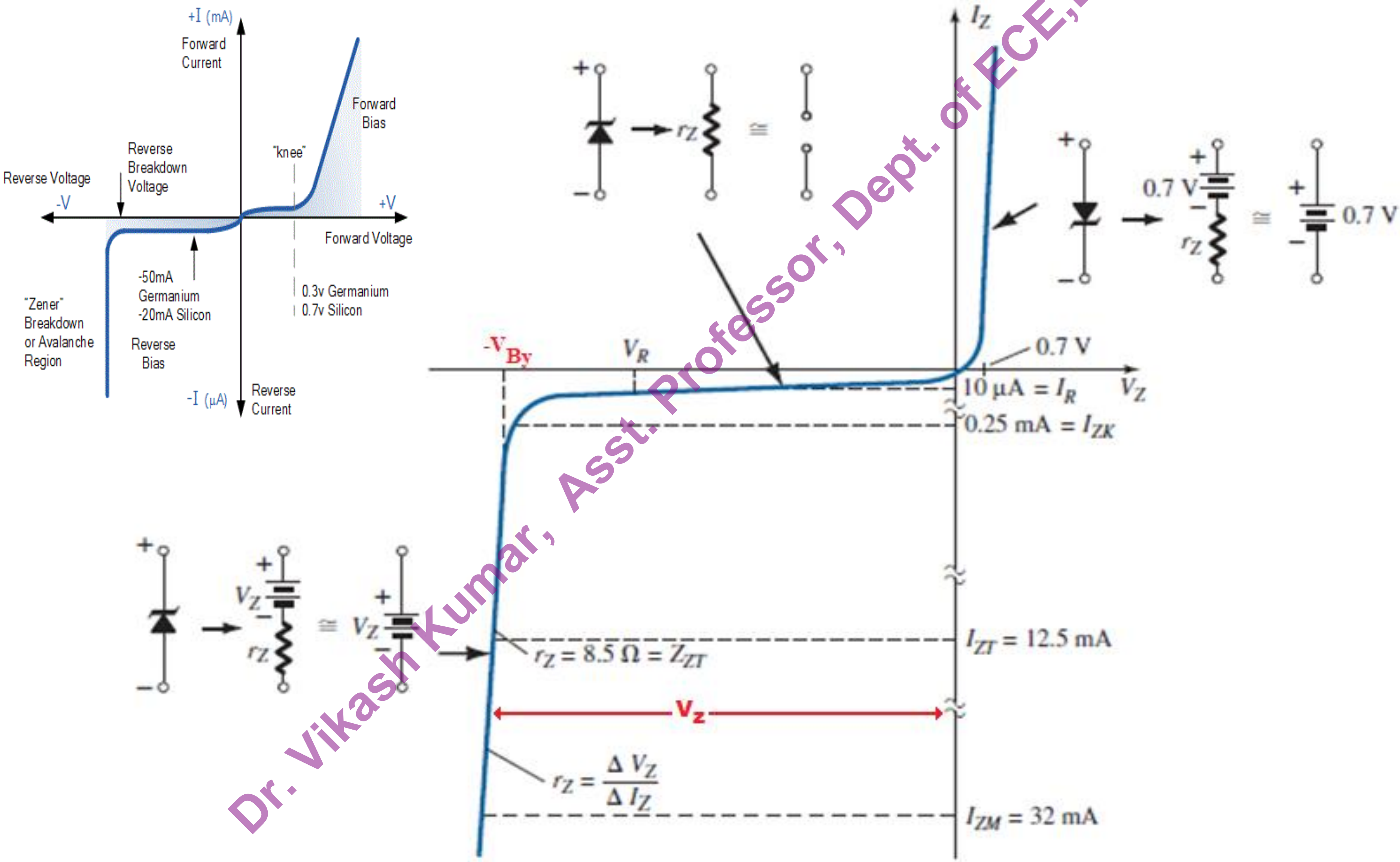


Zener Diode

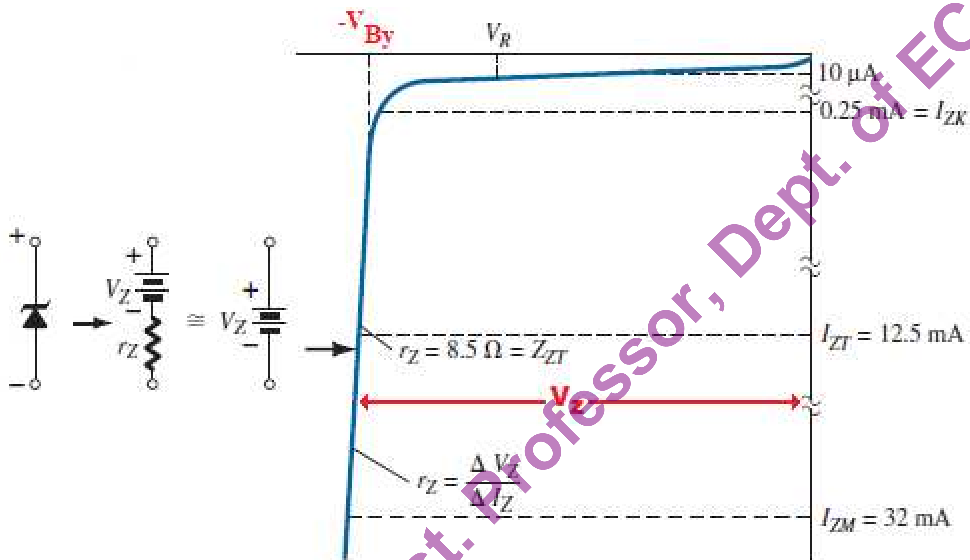
- Zener diode is a type of diode that, unlike a normal diode, allows current to flow not only in forward direction, but also in the reverse direction, when the breakdown voltage is reached.
- Here both PN junctions are moderately doped.
- When Forward biased, it will work as normal diode.
- Zener diode is always operated in Reverse bias.
- Major application is as a "**voltage regulator circuit**". Popularly known as "Constant voltage device".



I-V Characteristics of Zener Diode

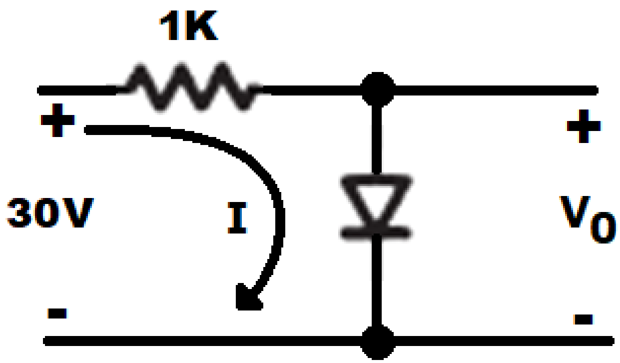


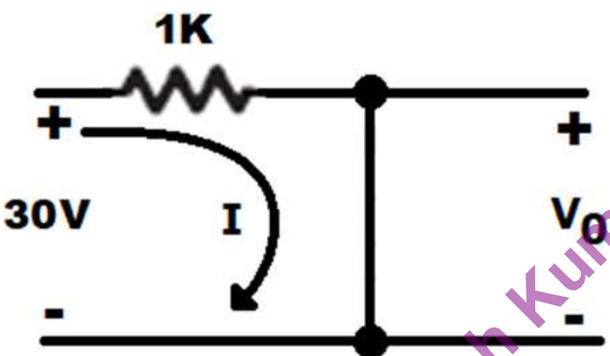
I-V Characteristics of Zener Diode



- When reverse voltage is less than breakdown voltage ($V_{B\gamma}$), the current through the Zener diode is leakage current and it is not conducting.
- When reverse voltage equals breakdown voltage ($V_{B\gamma}$), the current suddenly increased to I_{ZK} and this is due to breakdown phenomena.
- When reverse voltage exceeds $V_{B\gamma}$, more and more current will be passing through the Zener diode but the **voltage drop across Zener diode will be maintained almost a constant** and it is around its breakdown voltage.

Find the current I and output voltage V_0 when (a) diode is ideal (b) diode is non-ideal (practical) ? Assume the diode to be silicon diode.





(a) Diode is ideal

- **Ideal diode FB → Short circuit (SC).**
- Ideal diode RB → Open circuit (OC).

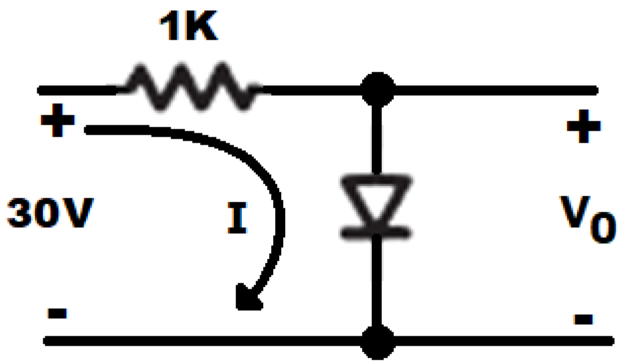
- **Voltage across short circuit path is zero.**

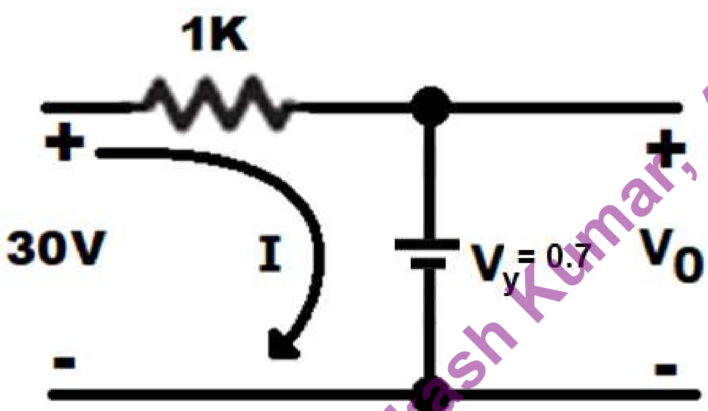
(i) $V_0 = 0$ V

(ii) Apply KVL,

$$30 - I \times 1K = 0 \Rightarrow I = \frac{30}{1K} = 30 \text{ mA}$$

Find the current I and output voltage V_0 when (a) diode is ideal (b) diode is non-ideal (practical) ? Assume the diode to be silicon diode.





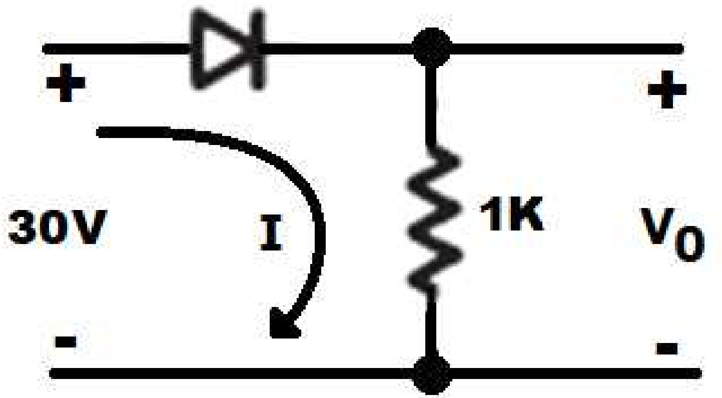
(b) Diode is non-ideal (Practical)

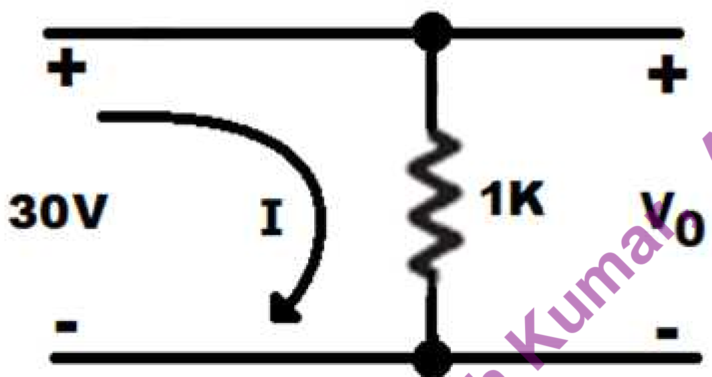
(i) $V_0 = 0.7$ V

(ii) Apply KVL,

$$30 - I \times 1K - 0.7 = 0 \Rightarrow I = \frac{29.3}{1K} = 29.3 \text{ mA}$$

5. **Find the current I and output voltage V_0 when (a) diode is ideal? Assume the diode to be silicon diode.**





(a) Diode is ideal

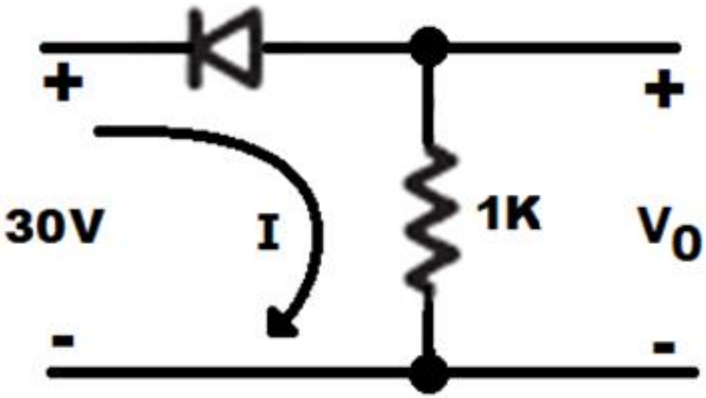
- Ideal diode FB → Short circuit (SC).
- Ideal diode RB → Open circuit (OC).

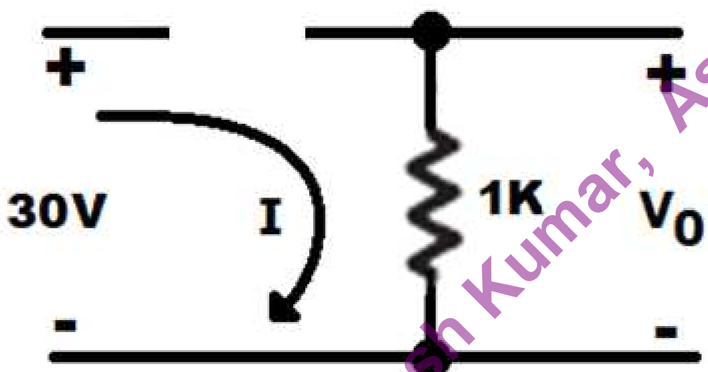
(i) V_0=30 V

(ii) Apply KVL,

$$30 \text{ - I}\times\text{1K=0} \;\Rightarrow I = \frac{30}{1K} = 30 \text{ mA}$$

6. Find the current I and output voltage V_0 when (a) diode is ideal? Assume the diode to be silicon diode.





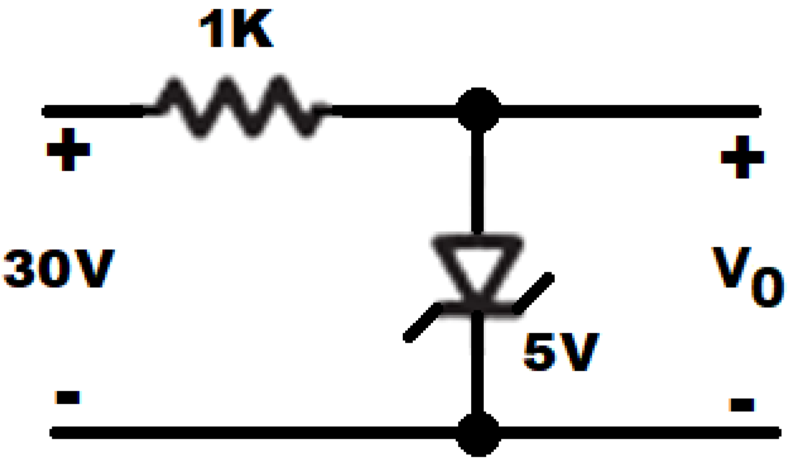
(a) Diode is ideal

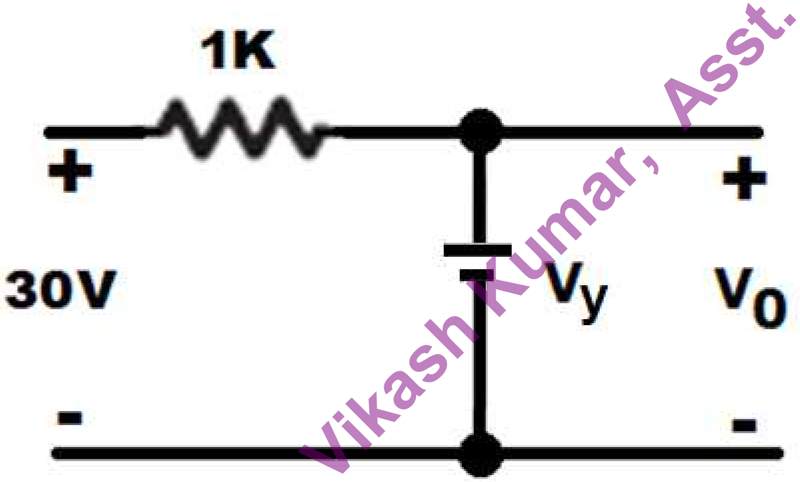
- Ideal diode FB → Short circuit (SC).
- Ideal diode RB → Open circuit (OC).

$(i)\ V_0 = 0\ \mathrm{V}$

$(ii)\ I = 0\ \mathrm{mA}$

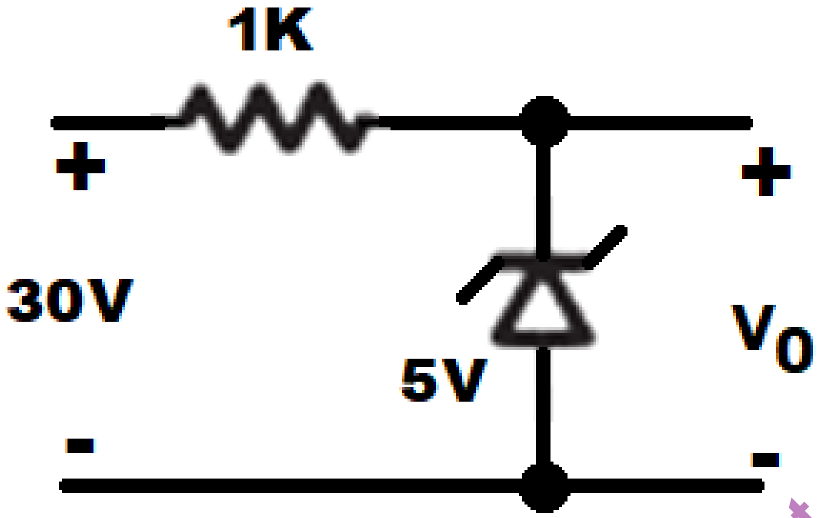
9. Find the output voltage V_0 Assume practical silicon diode and the breakdown voltage of Zener diode to be 5V.

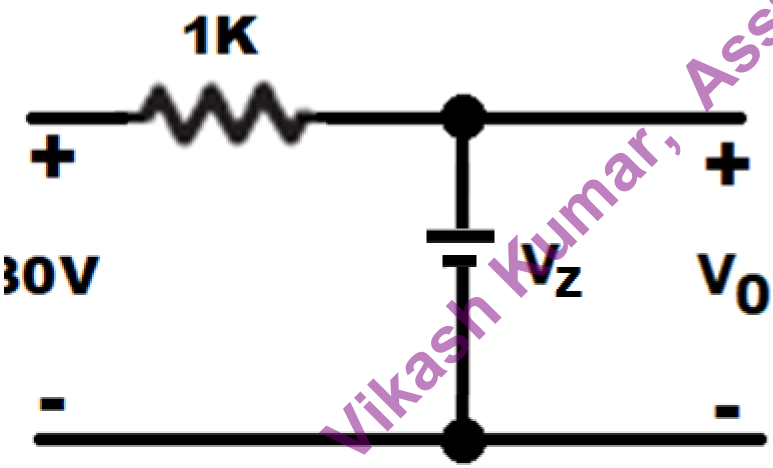




$$V_0 = V_\gamma = 0.7$$

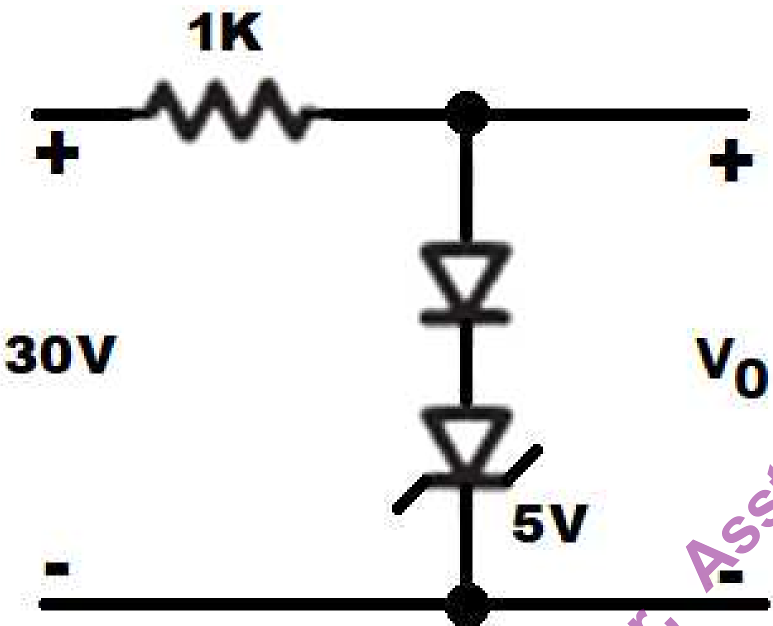
Find the output voltage V_0 Assume practical silicon diode and the breakdown voltage of Zener diode to be 5V.





$$V_0 = V_z = 5V$$

Find the output voltage V_0 Assume practical silicon diode and the breakdown voltage of Zener diode to be 5V.



$(a) -1.4V$

$(b) -5V$

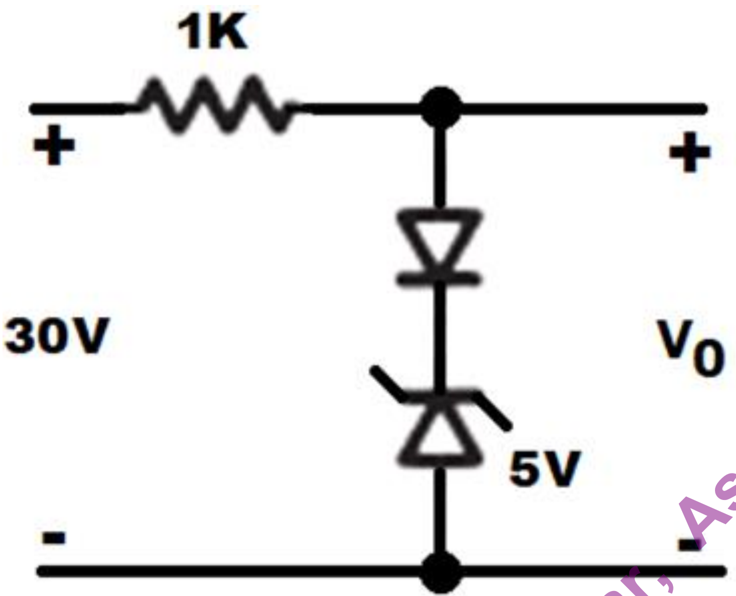
$(c) -4.3V$

$(d) 4.3V$

$(e) 1.4V$

$(f) 5.7V$

Find the output voltage V_0 Assume practical silicon diode and the breakdown voltage of Zener diode to be 5V.



$(a) -1.4V$

$(b) -5V$

$(c) -4.3V$

$(d) 4.3V$

$(e) 1.4V$

$(f) 5.7V$