SHOCKLEY DIODE EQUATION

- The V-I relationship for a semiconductor diode is described by Shockley diode equation :

$$I = I_S\left(e^{\frac{qV}{\eta KT}} - 1\right) = I_S\left(e^{\frac{V}{\eta V_T}} - 1\right)$$

or $$V = \eta V_T ln\left(\frac{I}{I_S} + 1\right)$$

- The physical constants fundamental to the diode V-I relationships are :

q = electronic charge = 1.6×10^{-19} Coulomb.
K = Boltzmann's constant = 1.38×10^{-23} Joule/^{o}K
$\mathbf{V_T}$ = Voltage equivalent temperature of the diode.
= KT/q $\approx$ T/11600 $\approx$ 26 mV @ room temperature (300^{o}K)

- In strong forward bias $V >> V_T$, the diode current expression becomes

$$I = I_S\, e^{\frac{V}{\eta V_T}}$$

- In strong reverse bias $V << -V_T$, the diode current expression becomes

$$I = -I_S$$

DYNAMIC RESISTANCE r_d

- When the diode is in the strongly forward biased region the current experiences exponential growth and the diode appears to have non zero dynamic resistance.

- The diode dynamic resistance is given by :

$$r_d = \frac{\partial V}{\partial I} = \frac{\eta V_T}{I_S} e^{-\frac{V}{\eta V_T}} = \frac{\eta V_T}{I_S + I} \approx \frac{\eta V_T}{I}$$

- In strong forward bias $V >> V_T$ or $I >> I_S$

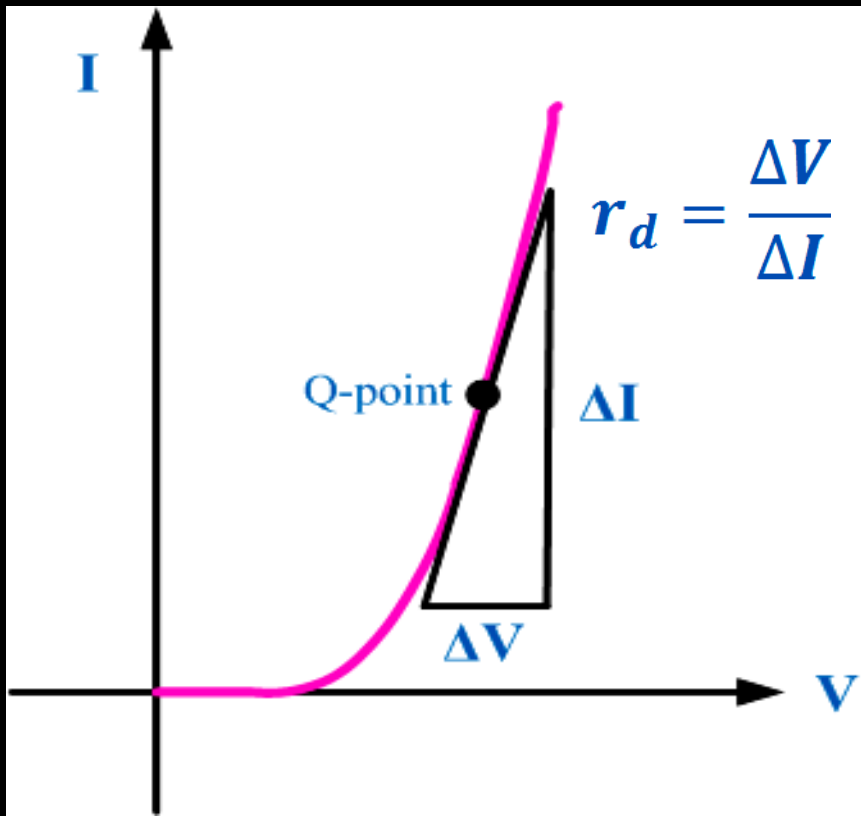
$$r_d \approx 0$$

- In strong reverse bias $V << -V_T$ or $I = -I_S$

$$r_d \approx \alpha$$

- Putting $\eta = 1$ and $V_T = 26$ mV

$$r_d \approx \frac{26\ mV}{I_D}$$



Threshold or Cut-in Voltage V_γ

- The boundary between the conducting and the nonconducting region of **ideal diode is at the origin** of the V-I transfer characteristics.

- For **real diode** (pn-junction diode) the transition between the two regions lies at a positive diode voltage called the **threshold voltage or the cut-in voltage $V\gamma$.**

- **The cut-in voltage $V\gamma$ of the pn-junction diode is such that below which the current is very small (say less than one percent of maximum rated value).**

- Beyond $V\gamma$ the current rises rapidly. Thus **$V\gamma$ determines the boundary between the conducting and nonconducting regions of diode.**

- The value of the threshold voltage **$V\gamma$** can be derived by finding **the intersection of the tangent line at Q point to the voltage axis of the diode.**

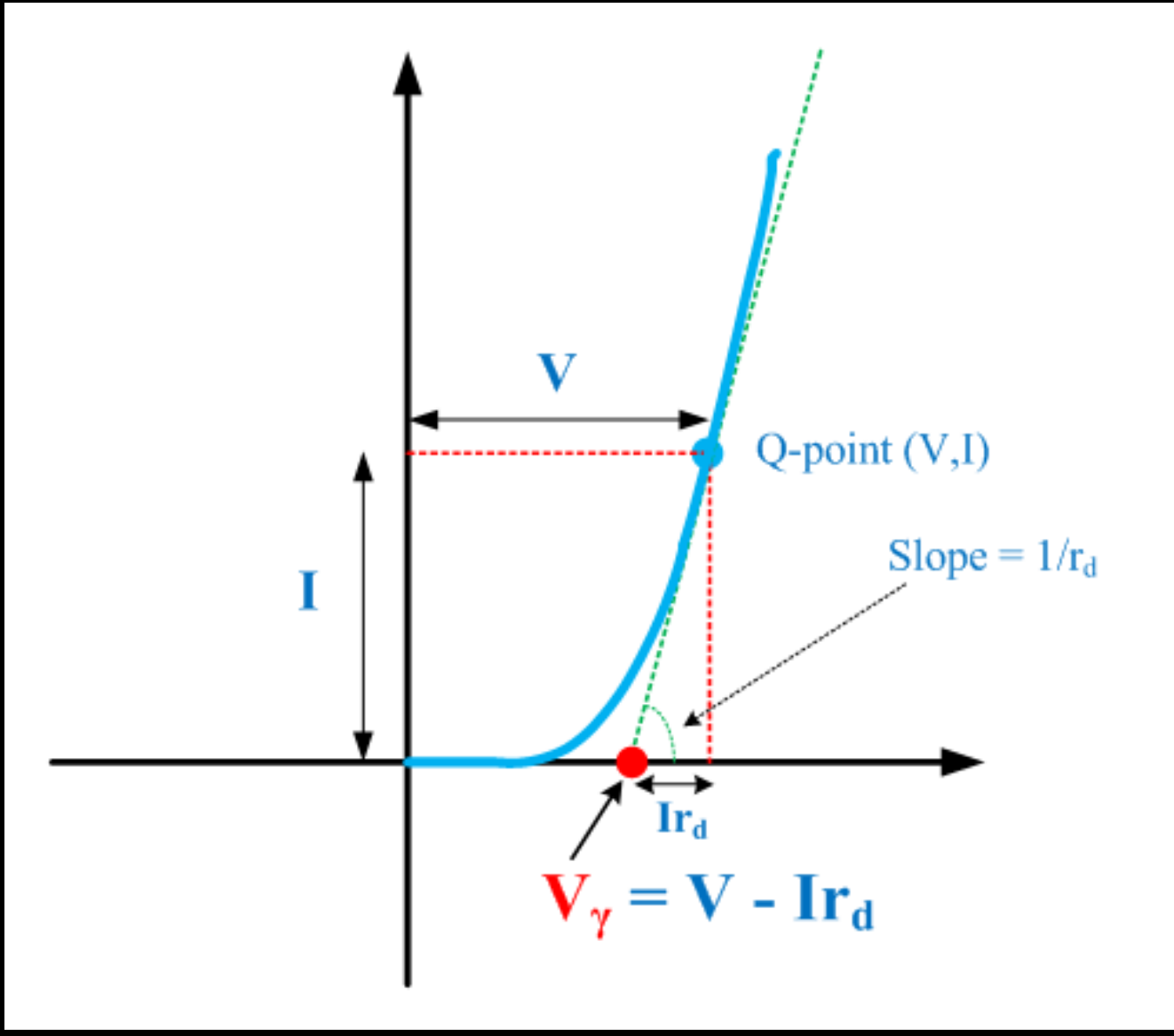
$$V_\gamma = V - Ir_d = V - \eta V_T\left(1 - e^{-\frac{V}{\eta V_T}}\right)$$

$V_\gamma(Si) = 0.6V \; to \; 0.9V$

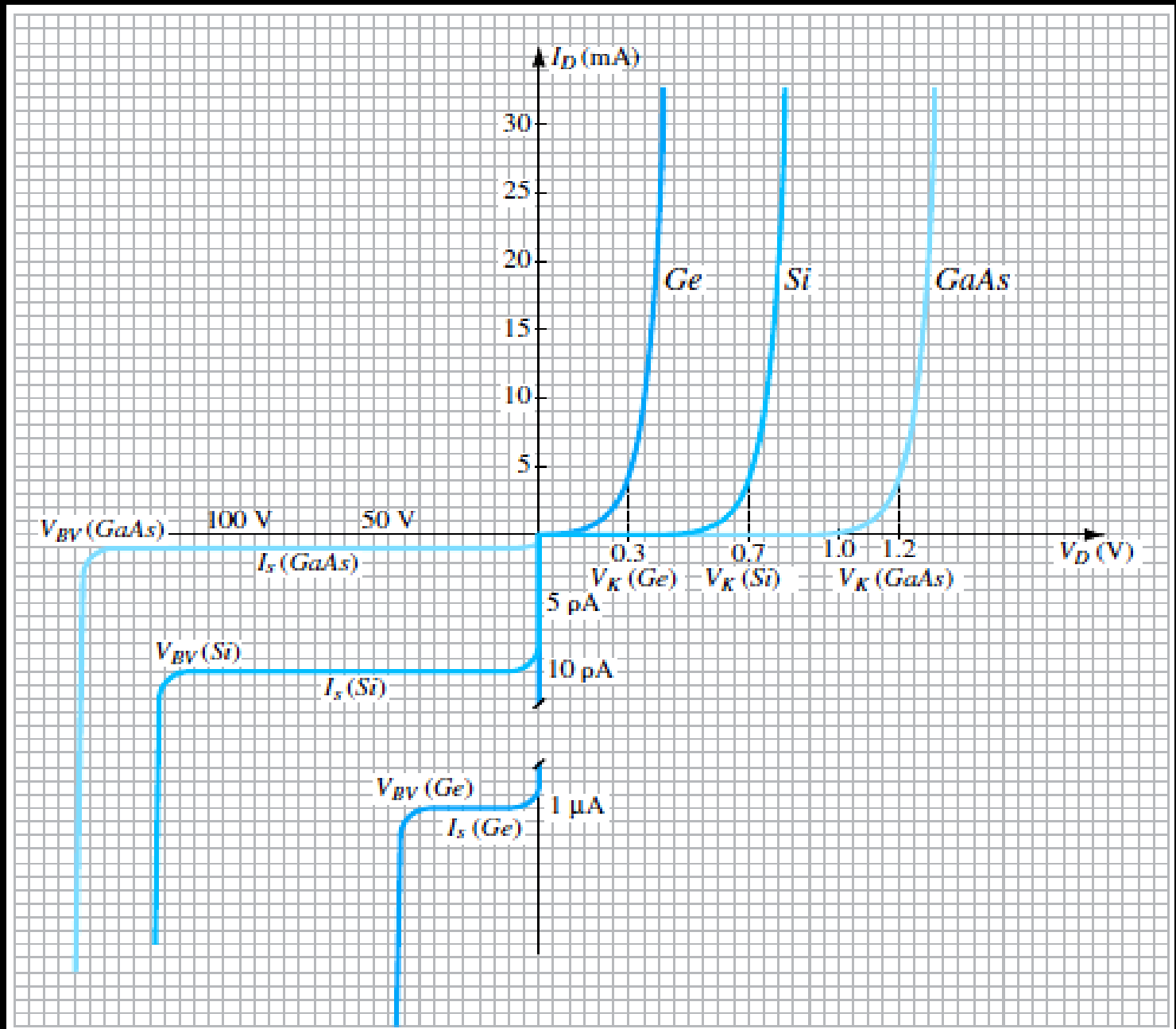
$V_\gamma(Si)_{typical} = 0.7V$

$V_\gamma(Ge) = 0.3V$

$V_\gamma(GaAs) = 1.2V$



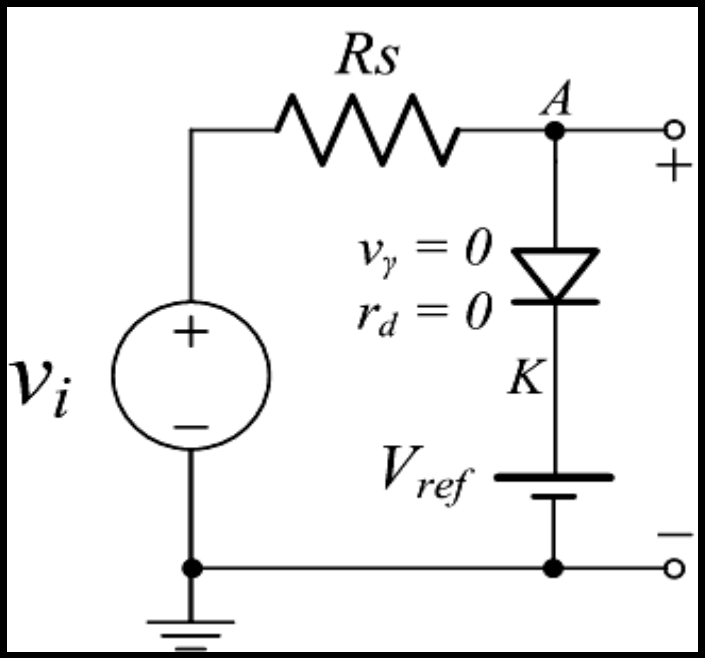
Comparison of Si, Ge & GaAs diode Vγ

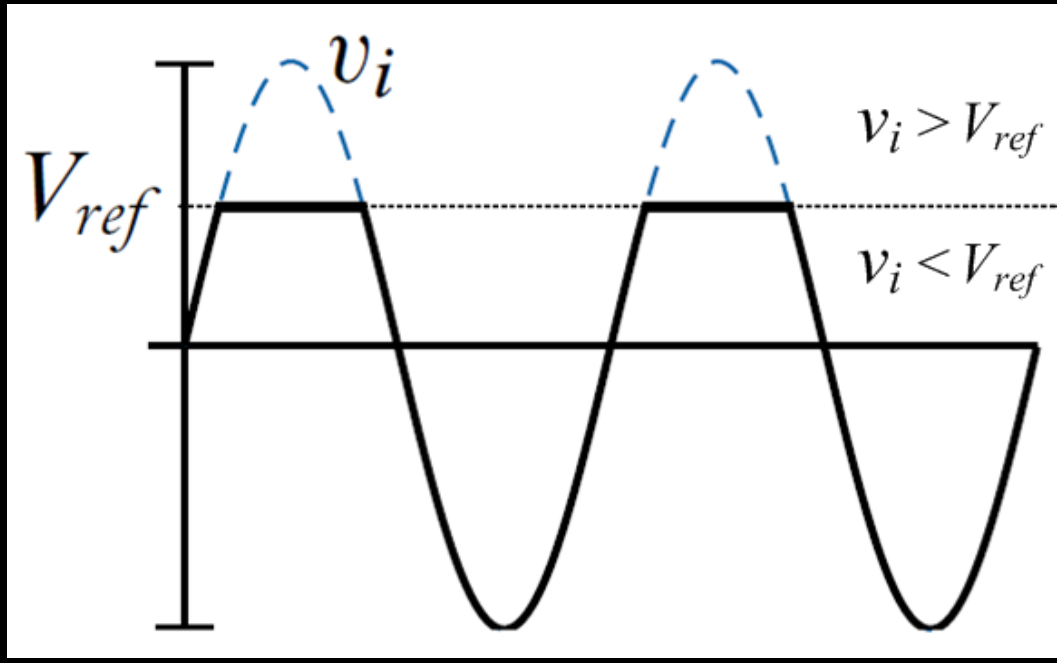


CLIPPER CIRCUITS

- Clippers are networks that employ **diodes to "clip" away a portion of an input signal without distorting the remaining part of the applied waveform.**
- **In particular, when used with a DC bias voltage in series with the diode, the output signal can be limited to the reference voltage level of the DC voltage source.**

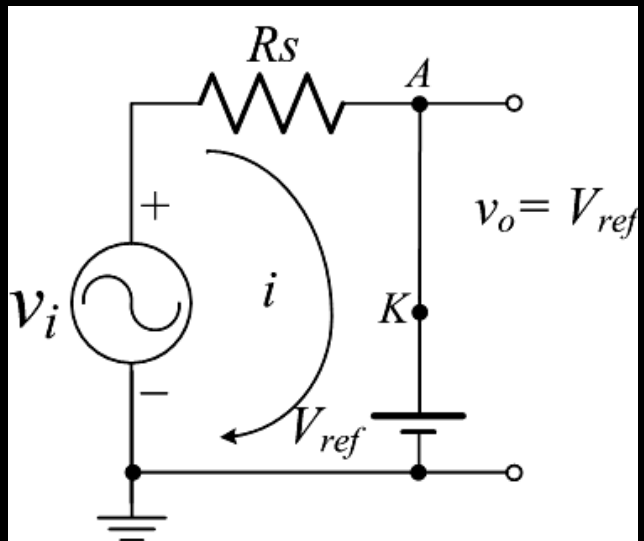
Biased Clipper with Ideal Diode

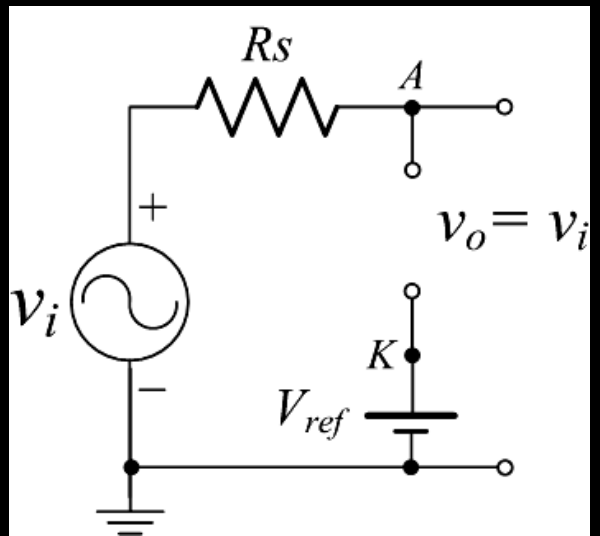




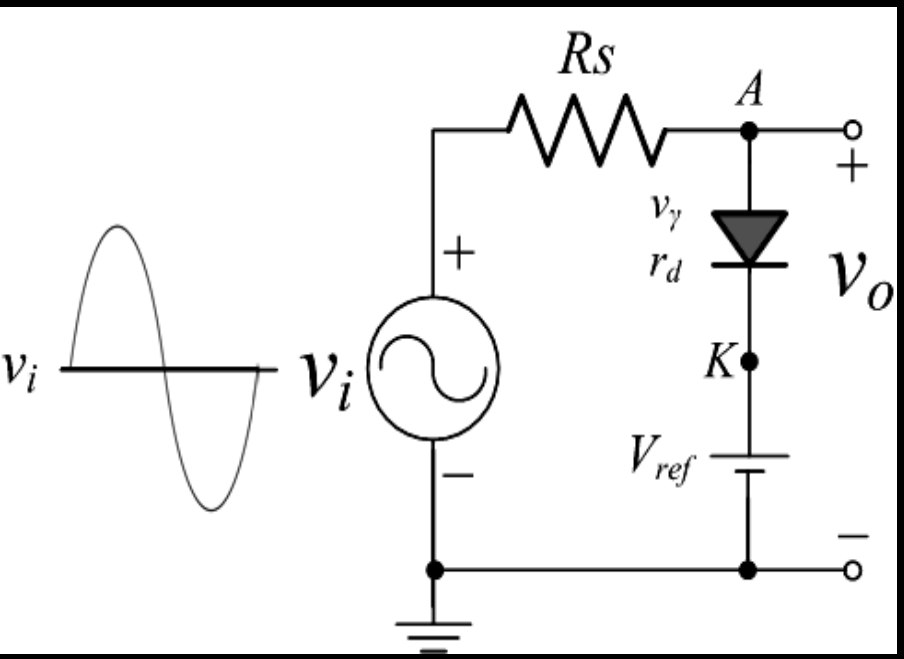
Eqv. Ckt. : diode is forward bias for $v_i \geq V_{ref}$.

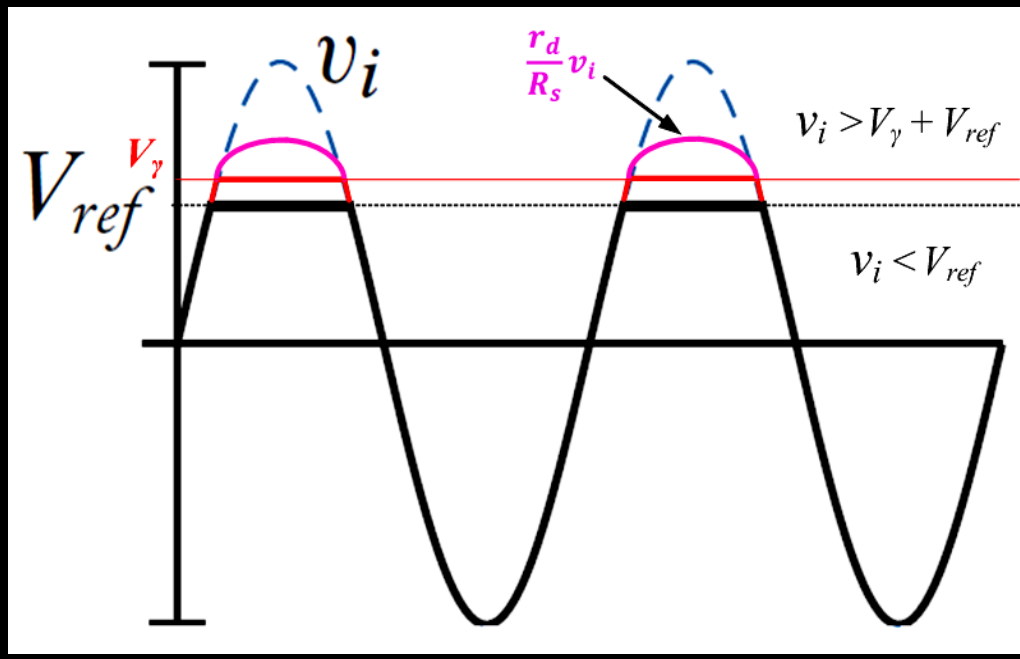
Eqv. Ckt. : diode is reverse bias for $v_i \leq V_{ref}$.



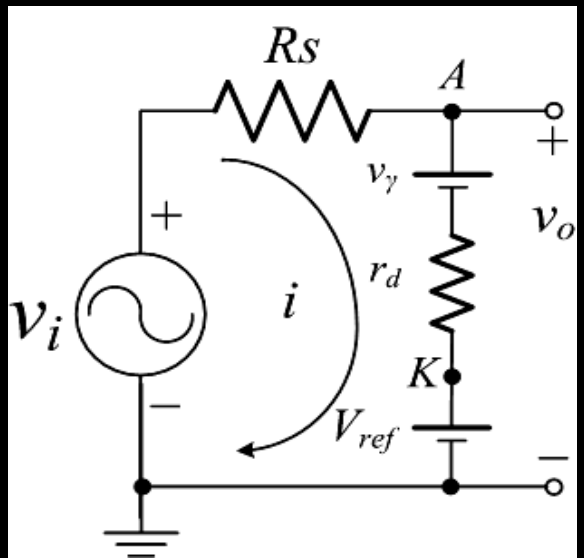


Biased Clipper with Real Diode





Eqv. Ckt. : +ve half cycle of input, diode is forward bias. $v_i > v_\gamma + V_{ref}$

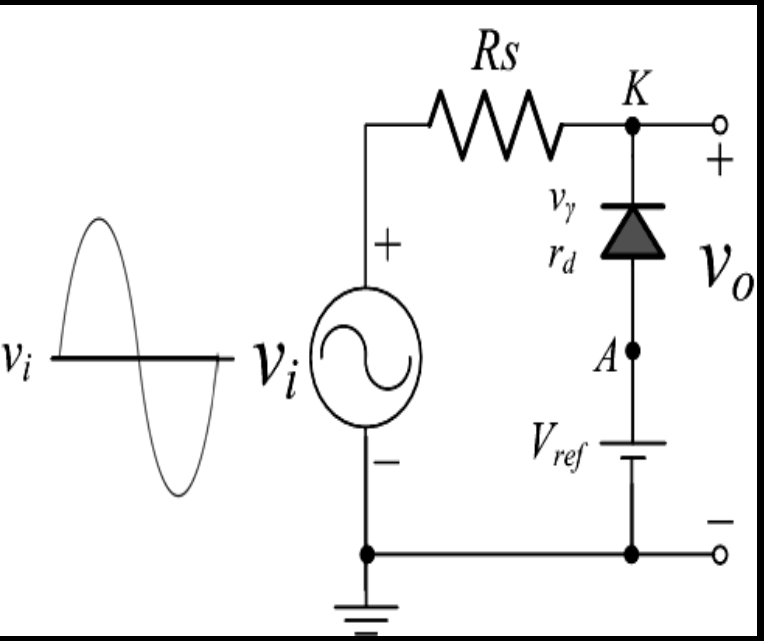


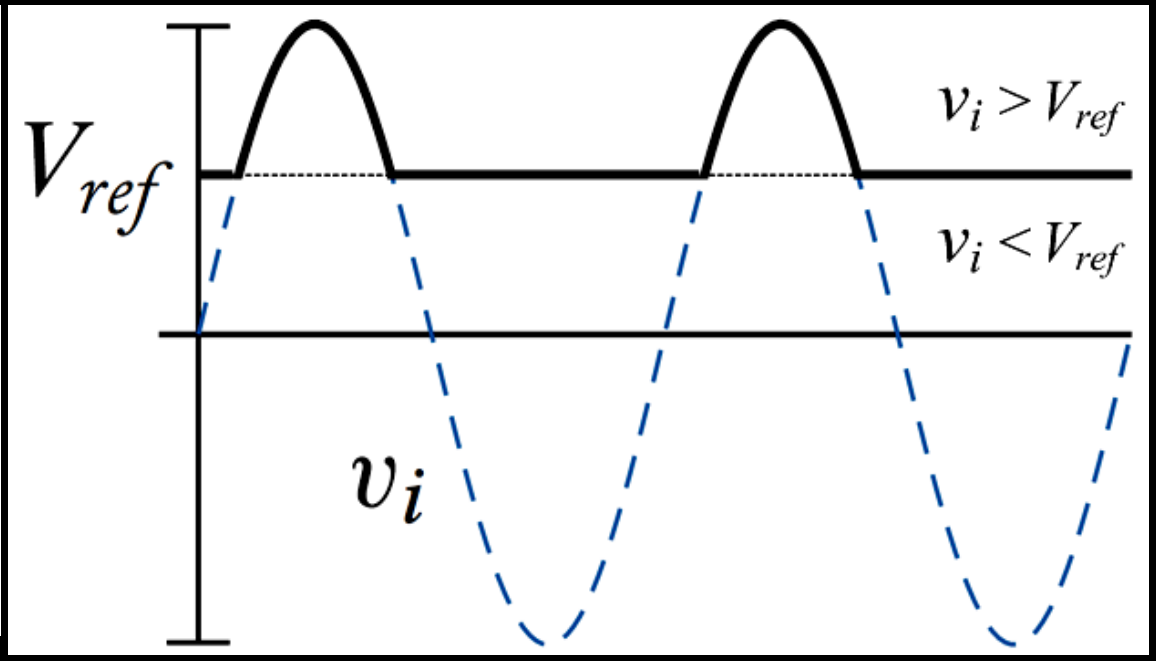
$$v_0 = \frac{r_d}{R_s + r_d} v_i + \frac{R_s}{R_s + r_d} (v_\gamma + V_{ref})$$

$$\text{usually } r_d \ll R_s$$

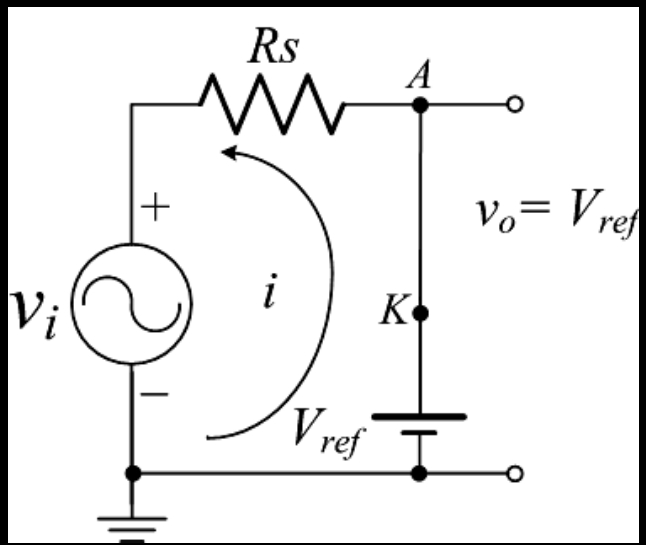
$$v_0 \approx \frac{r_d}{R_s} v_i + (v_\gamma + V_{ref})$$

Biased Clipper

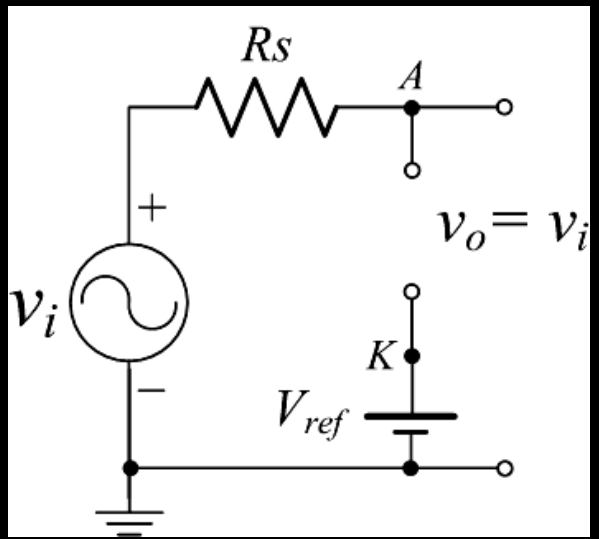




Eqv. Ckt. : diode is forward bias for $v_i \le V_{ref}$.



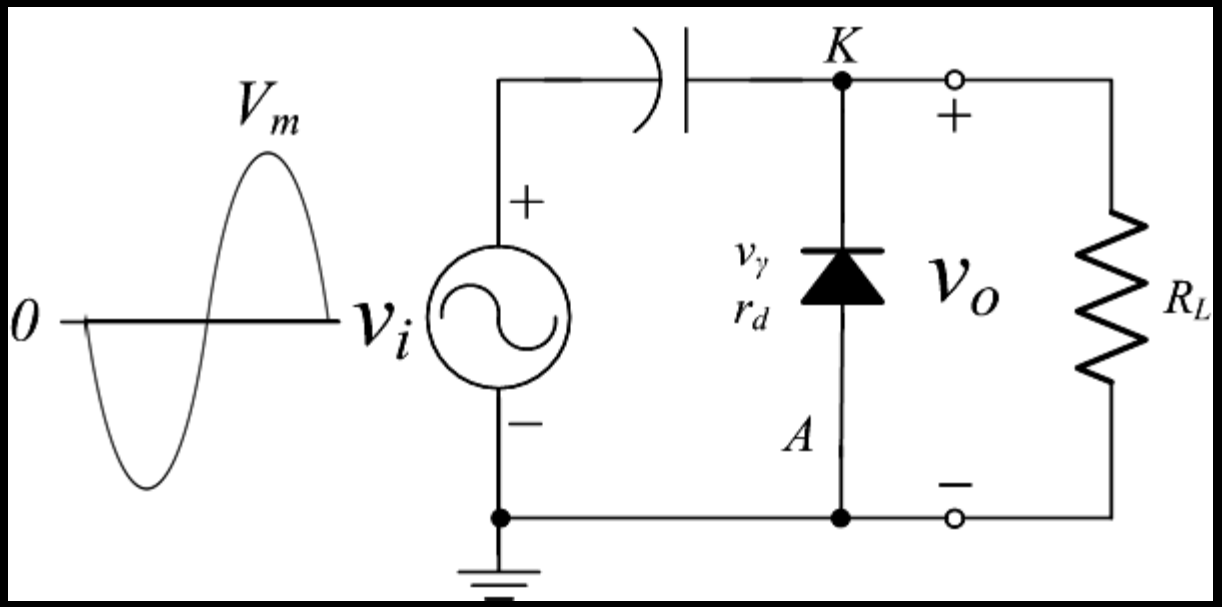
Eqv. Ckt. : diode is reverse bias for $v_i \ge V_{ref}$.

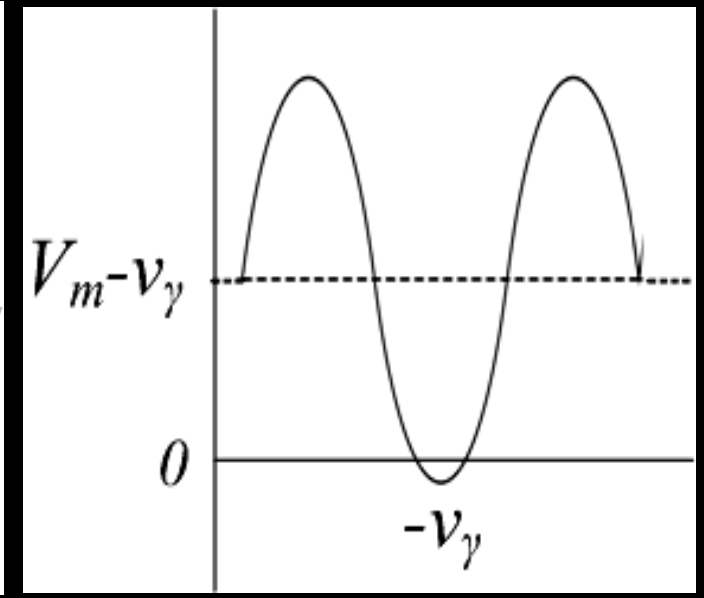


DIODE CLAMPERS

A Clamper circuit adds a DC level to an AC voltage. A Diode Clamper inserts a DC level to the input signal waveform.

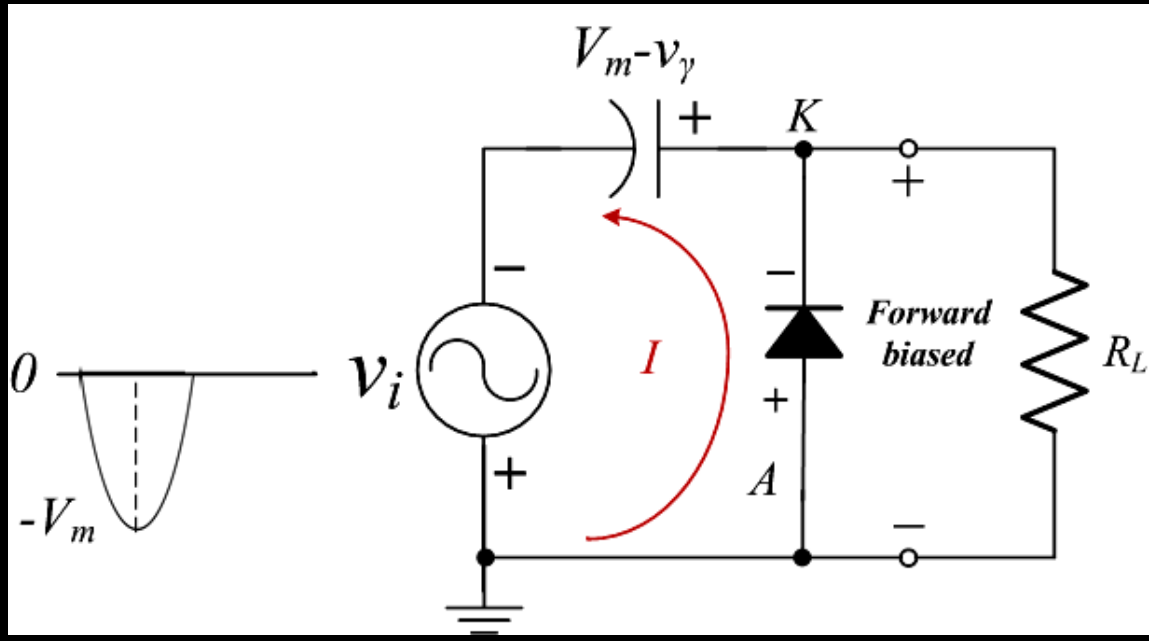
POSITIVE DIODE CLAMPER



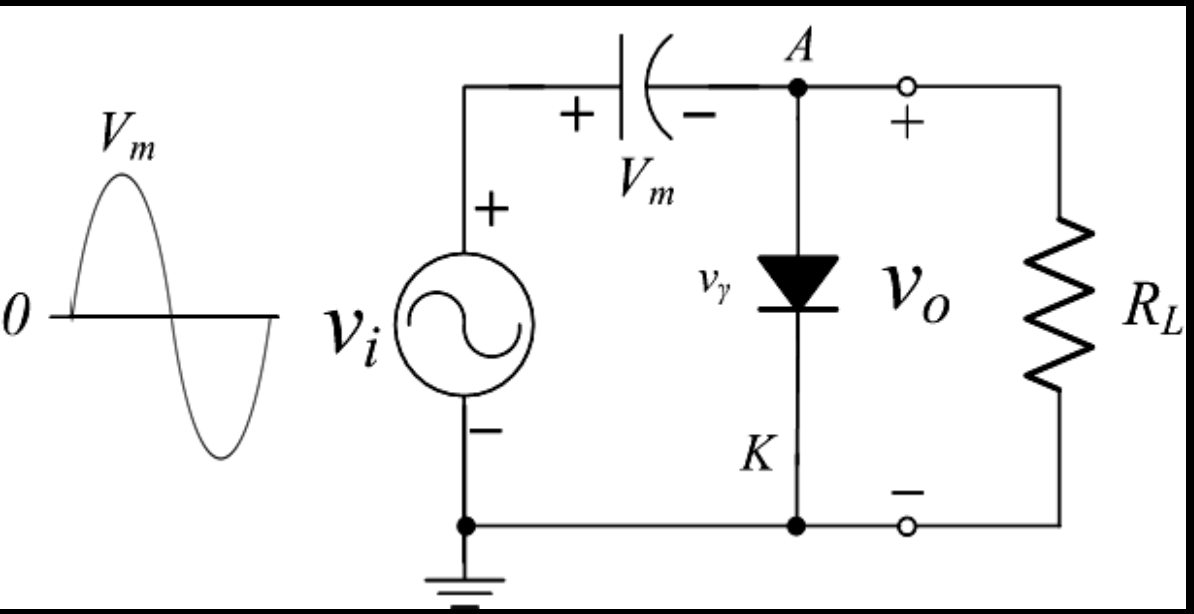


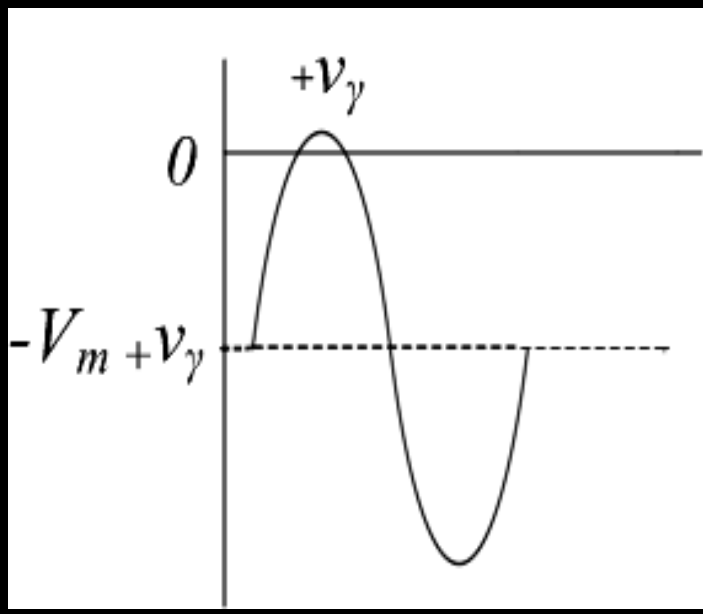
Capacitor charging process for the -ve half cycle of the input signal when Diode is ON.

When the signal crosses -Vm of the -ve half cycle, Diode is OFF.



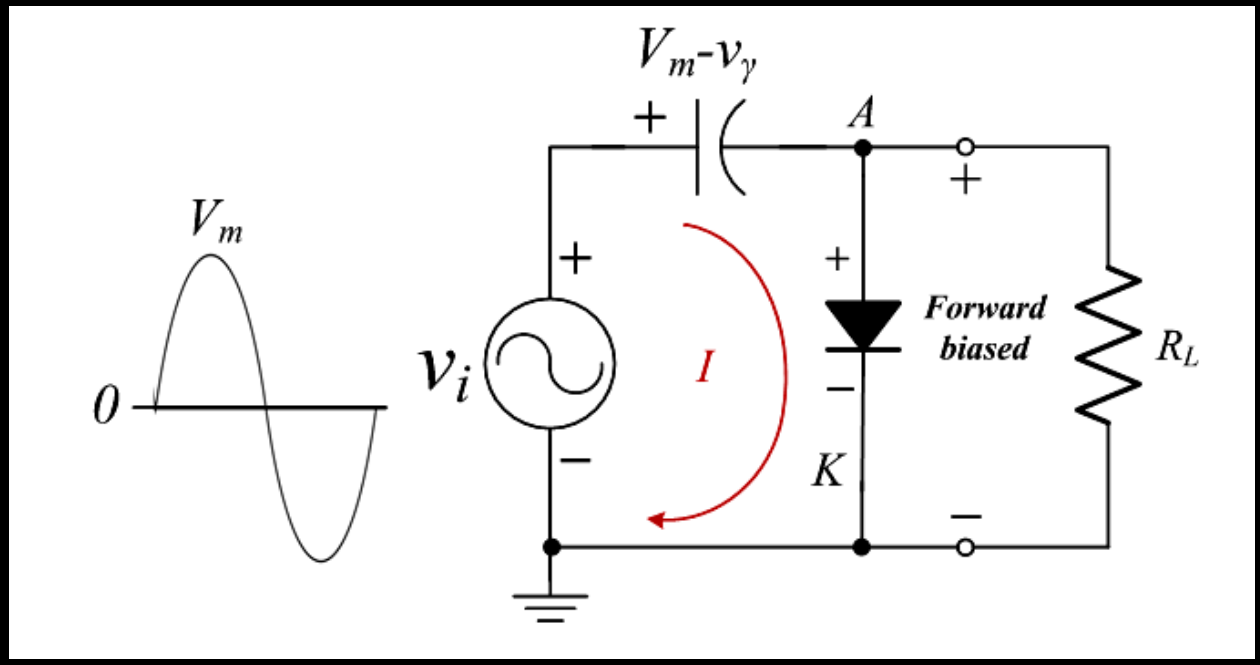
NEGATIVE DIODE CLAMPER





Capacitor charging process for the +ve half cycle of the input signal when Diode is ON.

When the signal crosses Vm of the +ve half cycle, Diode is OFF.

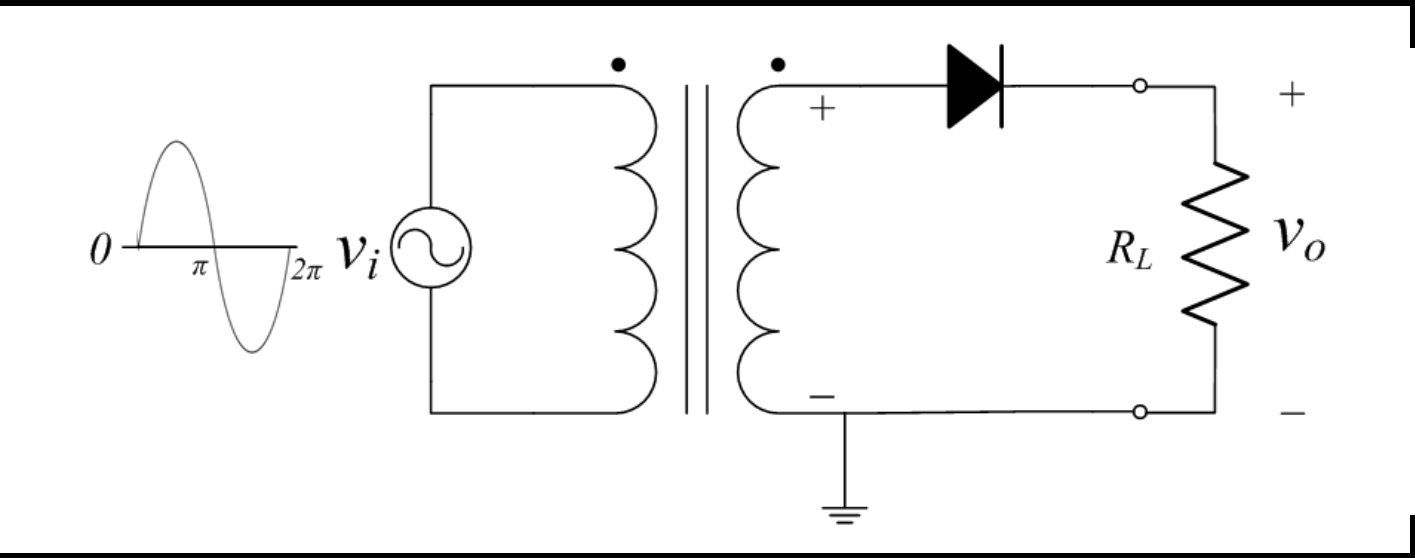


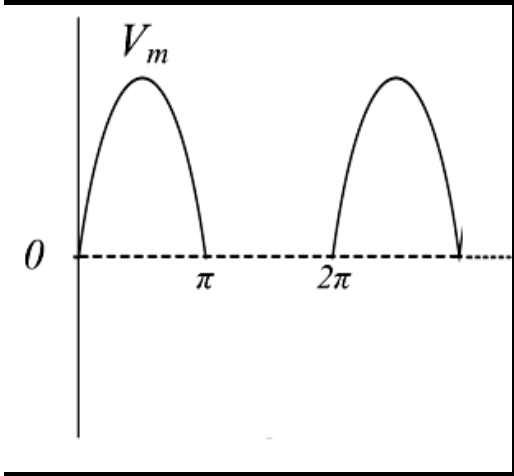
DIODE RECTIFIER

A Rectifier that converts an AC voltage to unidirectional voltage is used as DC power supply

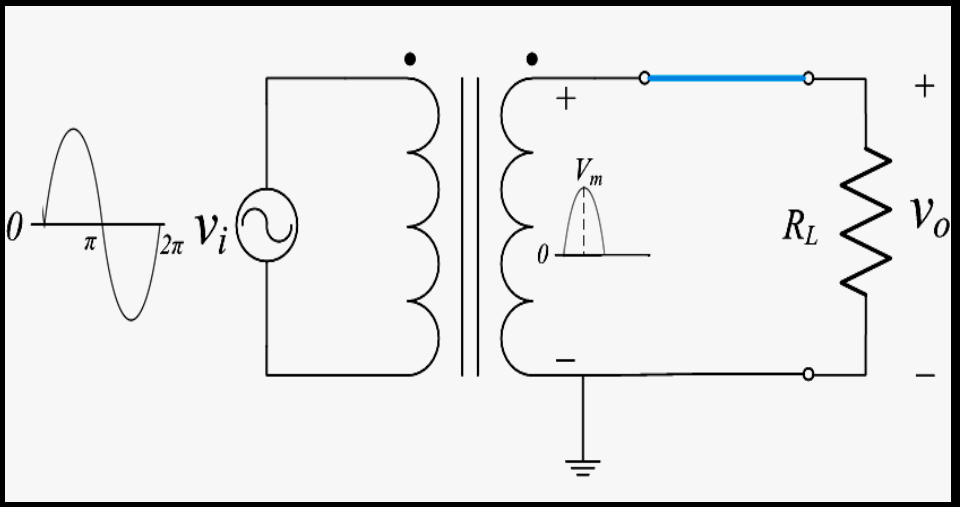
Half Wave Rectifier

It only allows current from the positive half cycle of the input to flow through the load resistor

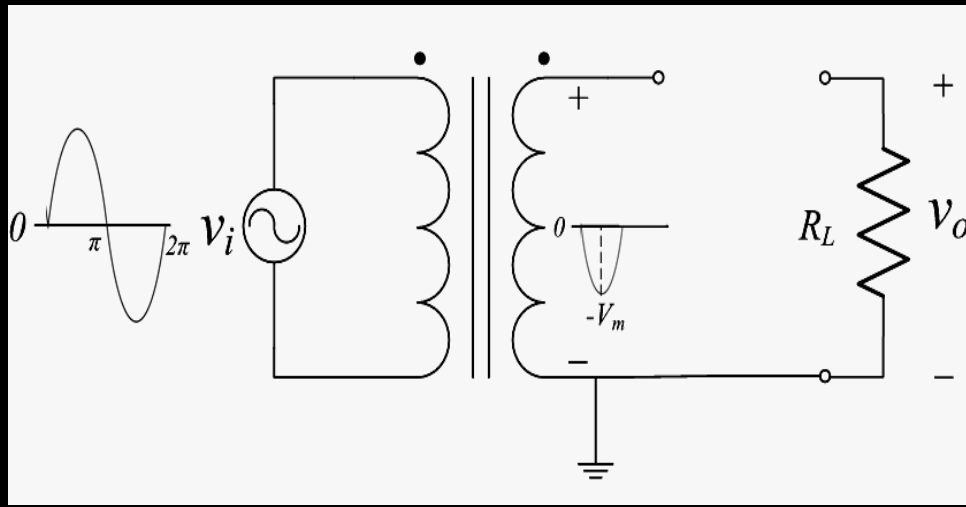




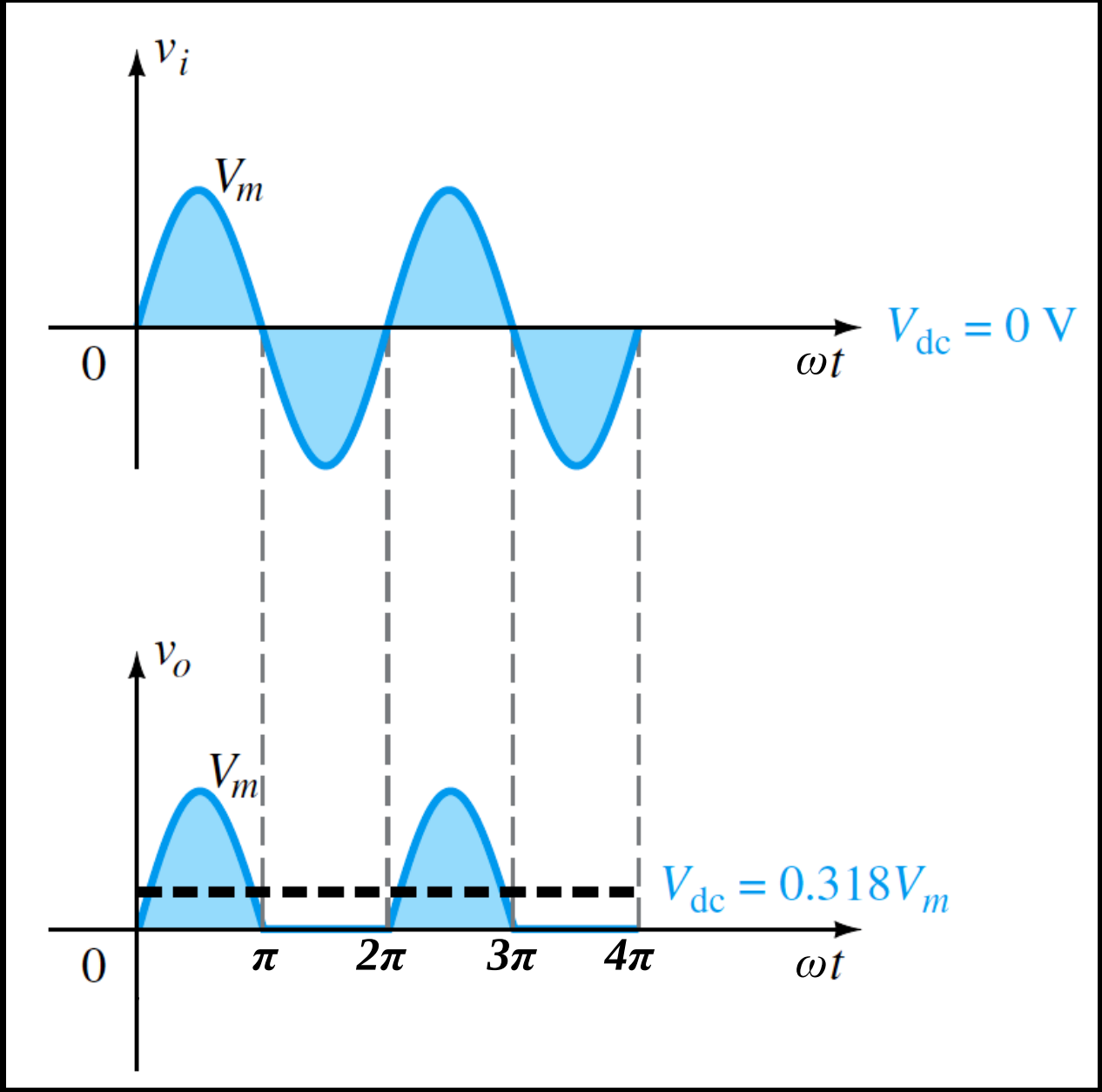
For +ve half cycle Diode is ON



For -ve half cycle Diode is OFF



$$v_i(\omega t) = V_m \sin \omega t$$



$$v_0(\omega t) = \begin{cases} V_m \sin \omega t, & for \quad 0 \leq \omega t \leq \pi \\ 0, & for \quad \pi \leq \omega t \leq 2\pi \end{cases}$$

$$v_0(\omega t) = \begin{cases} V_m \sin \omega t, & for \quad 0 \le \omega t \le \pi \\ 0 & , \quad for \quad \pi \le \omega t \le 2\pi \end{cases}$$

DC Value :

$$V_{0(av)} = \frac{1}{2\pi} \int_0^{2\pi} v_0(\theta)\, d\theta = \frac{V_m}{\pi} = 0.318 V_m$$

RMS Values :

$$V_{0(rms)} = \left[\frac{1}{2\pi}\int_0^{\pi} v_0^2 \, d(\omega t)\right]^{\frac{1}{2}} = \left[\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{\frac{1}{2}}$$

$$= \frac{V_m}{2}$$

$$I_{0(rms)} = \frac{V_{0(rms)}}{R_L} = \frac{V_m}{2R_L}$$

Ripple Voltage :

$$v_r(t) = v_0(t) - V_{0(av)}$$

$$v_r^2(t) = v_0^2(t) - 2v_0(t)V_{0(av)} + V_{0(av)}^2$$

$$\overline{v_r^2(t)} = \overline{v_0^2(t)} - 2\overline{v_0(t)V_{0(av)}} + \overline{V_{0(av)}^2}$$

$$\overline{v_r^2(t)} = \overline{v_0^2(t)} - 2V_{0(av)}^2 + V_{0(av)}^2$$

$$V_{r(rms)}^2 = V_{0(rms)}^2 - V_{0(av)}^2$$

$$V_{r(rms)}^2 = V_{0(rms)}^2 - V_{0(av)}^2$$

RMS Value of Ripple Voltage :

$$V_{r(rms)} = \sqrt{V_{0(rms)}^2 - V_{0(av)}^2}$$

Ripple Factor Γ :

$$RF = \Gamma = \frac{V_{r(rms)}}{V_{0(av)}} = \sqrt{\left(\frac{V_{r(rms)}}{V_{0(av)}}\right)^2 - 1}$$

$$\Gamma = \sqrt{\left(\frac{V_m/2}{V_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21 \text{ or } 121\%$$

Efficiency η :

$$\eta = \frac{P_{ac}}{P_{dc}} = \frac{\frac{V_{dc}^2}{R_L}}{\frac{V_{rms}^2}{R_L}} = \frac{\left(\frac{V_m}{\pi}\right)^2}{\left(\frac{V_m}{2}\right)^2} = 0.406 \; or \; 40.6\%$$

Form Factor :

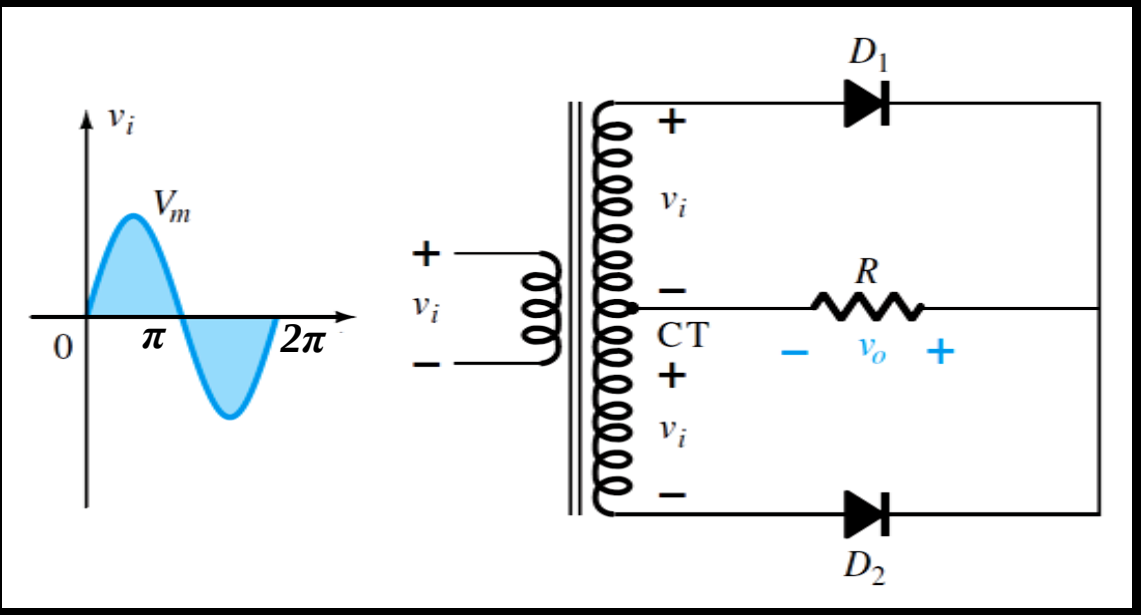
$$Form\ Factor = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{2}}{\frac{V_m}{\pi}} = \frac{\pi}{2} = 1.57$$

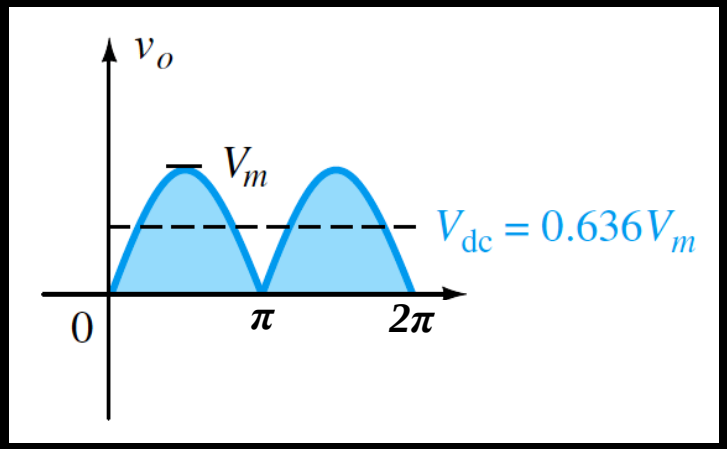
Peak Inverse Voltage PIV :

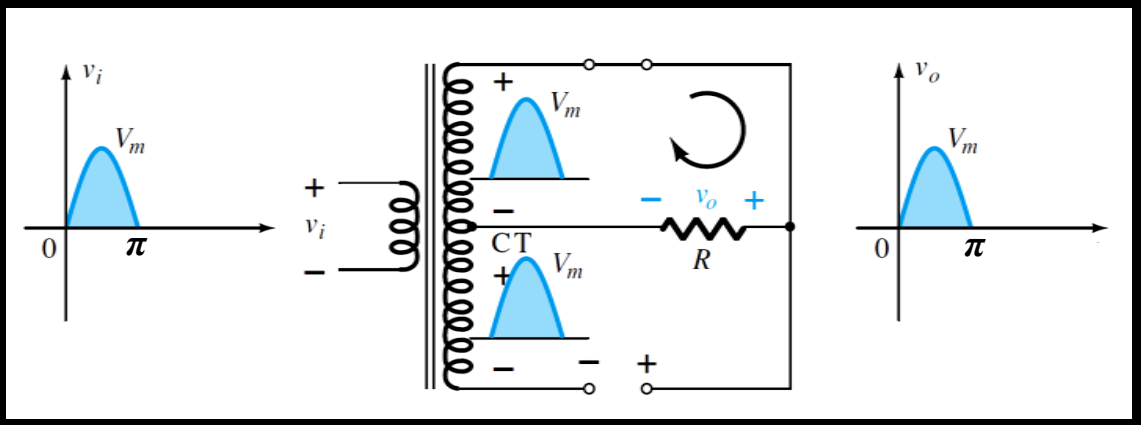
The maximum reverse voltage that a diode can withstand without destroying the junction. For half-wave rectifier, PIV is Vm.

Full Wave Rectifier

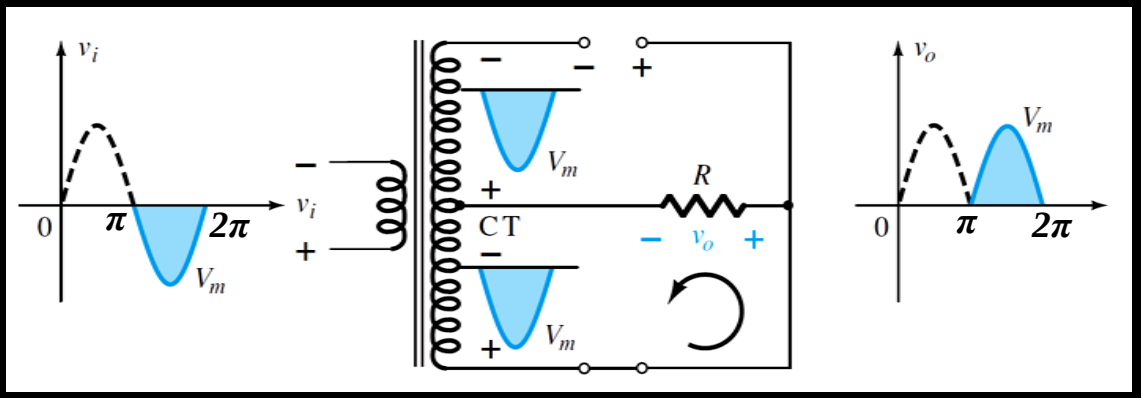
Center-Tapped Transformer





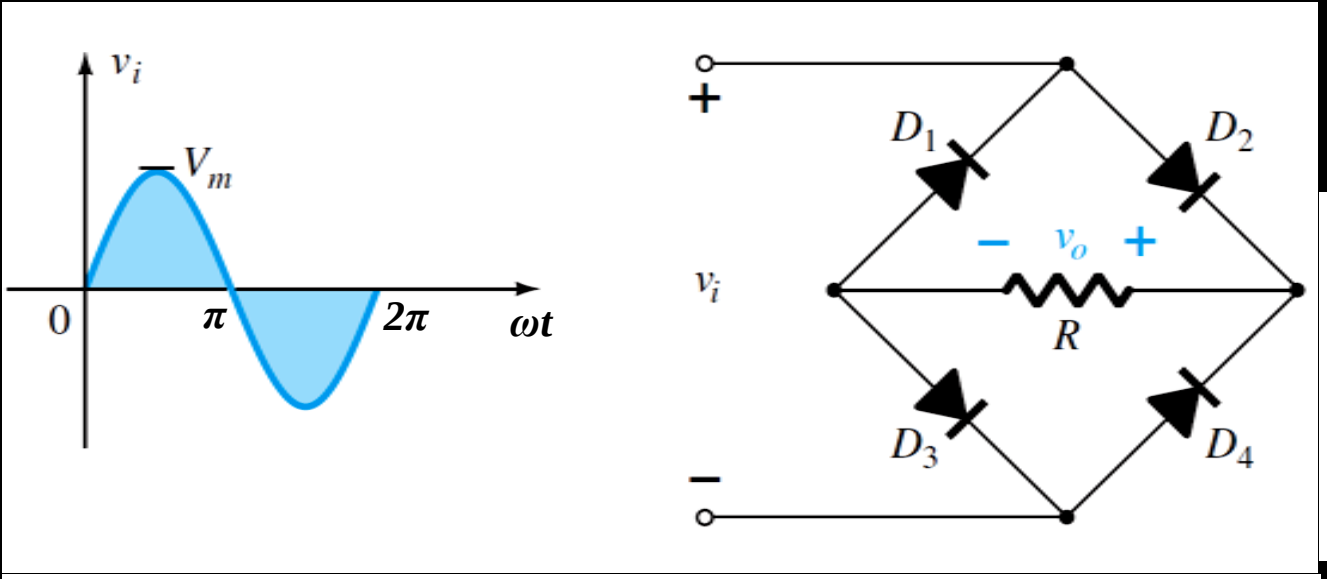


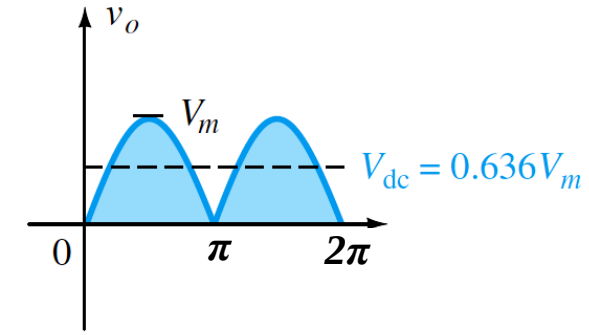
For +ve half cycle
D_1 ON & D_2 OFF



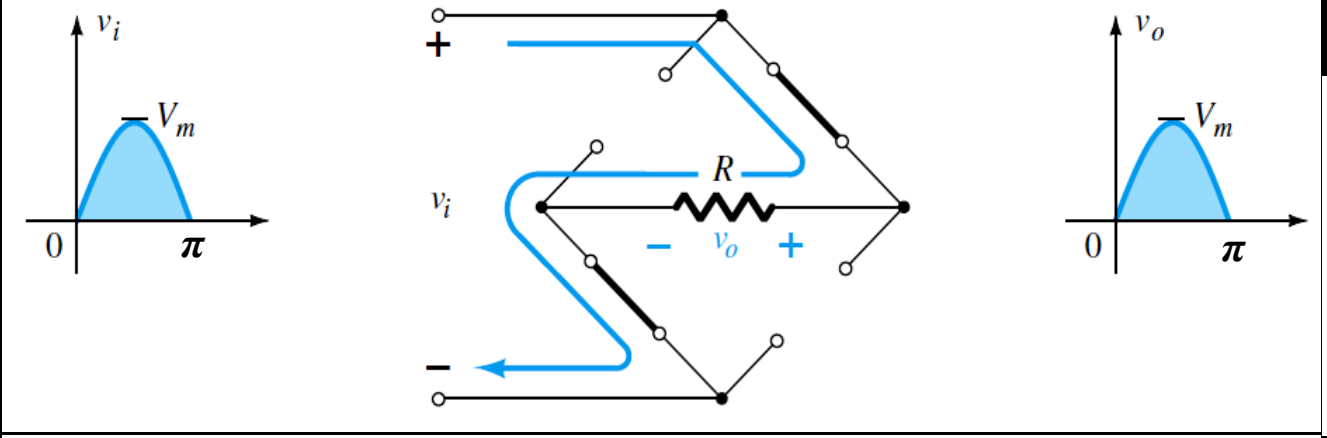
For -ve half cycle
D_2 ON & D_1 OFF

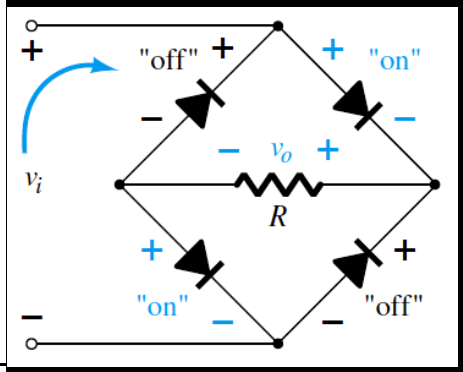
Full Wave Rectifier
Bridge Network



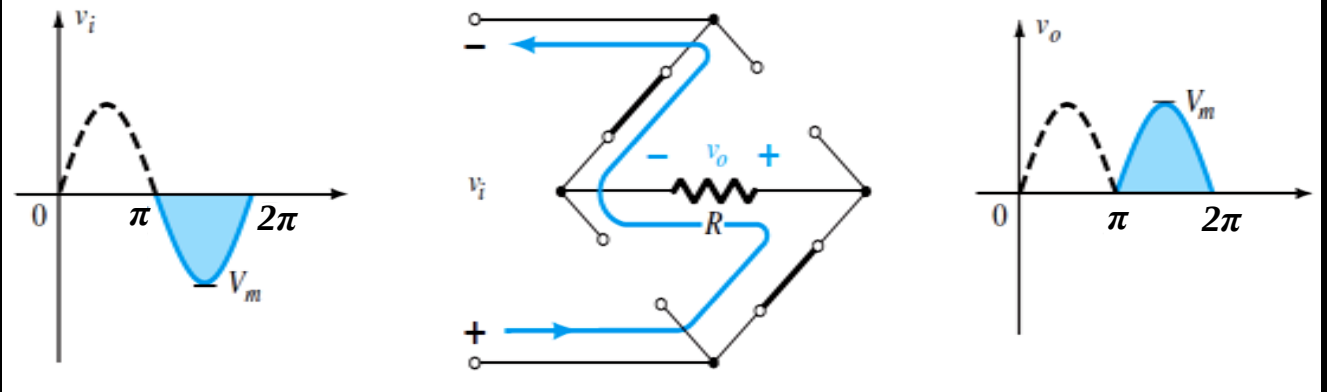


D_2 & D_3 ON

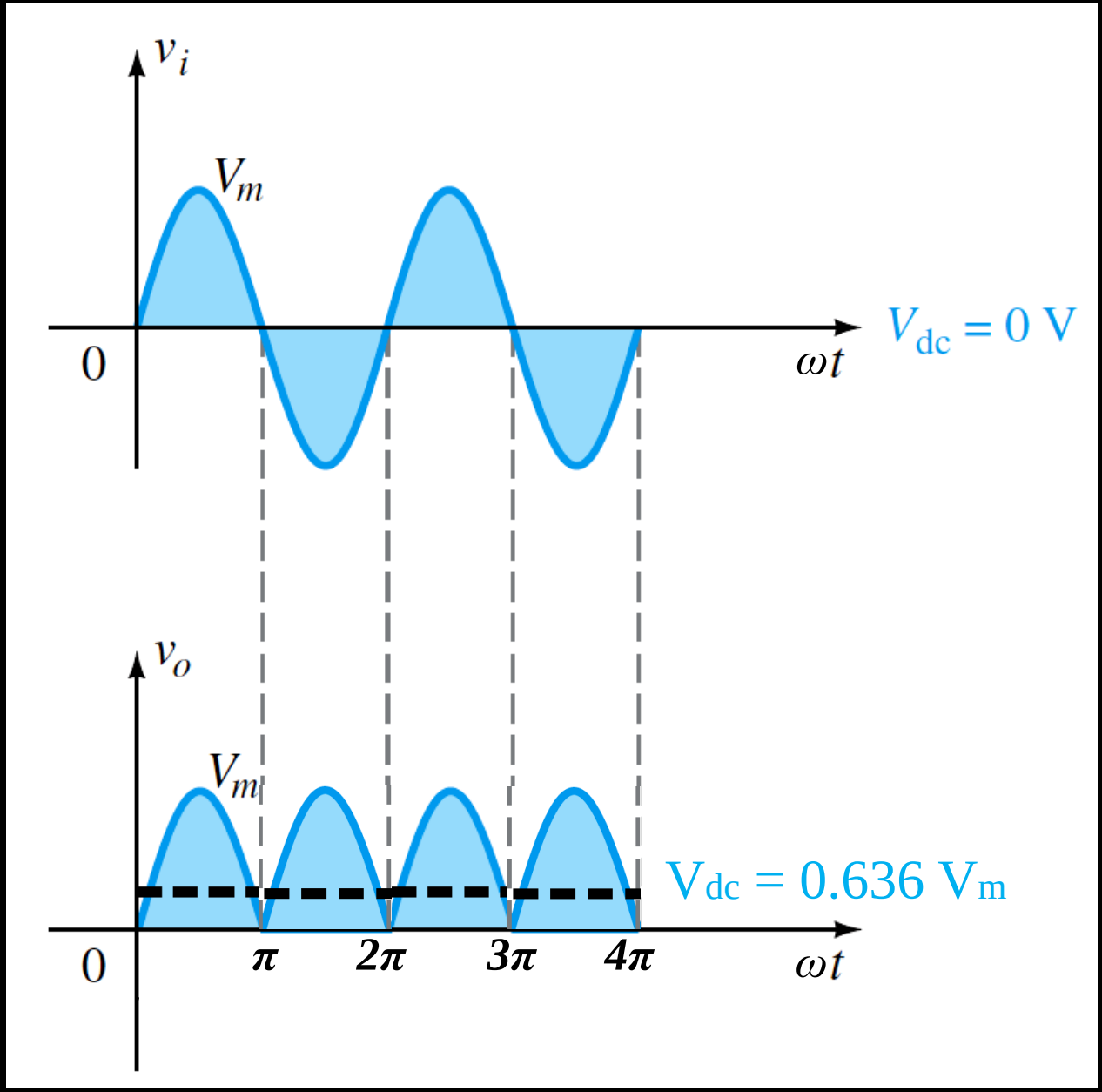




D_1 & D_4 ON



$$v_i(\omega t) = V_m \sin \omega t$$
$$= V_m \sin \theta$$



$$v_0(\omega t) = \begin{cases} V_m \sin \omega t, & for \quad 0 \le \omega t \le \pi \\ -V_m \sin \omega t, & for \quad \pi \le \omega t \le 2\pi \end{cases}$$

$$v_0(\omega t) = \begin{cases} V_m \sin\theta\,, & for \quad 0 \le \omega t \le \pi \\ -V_m \sin\theta\,, & for \quad \pi \le \omega t \le 2\pi \end{cases}$$

DC Value :

$$V_{0(av)} = \frac{1}{2\pi}\int_0^{2\pi} v_0(\theta)\, d\theta = \frac{2V_m}{\pi} = 0.636V_m$$

RMS Values :

$$V_{0(rms)} = \left[\frac{2}{2\pi}\int_0^{\pi} v_0^2\, d(\omega t)\right]^{\frac{1}{2}} = \left[\frac{2}{2\pi}\int_0^{\pi} V_m^2 \sin^2 \omega t\, d(\omega t)\right]^{\frac{1}{2}}$$

$$= \frac{V_m}{\sqrt{2}} = 0.707 V_m$$

$$I_{0(rms)} = \frac{V_{0(rms)}}{R_L} = \frac{V_m}{\sqrt{2} R_L}$$

Ripple Voltage :

$$v_r(t) = v_0(t) - V_{0(av)}$$

$$V_{r(rms)}^2 = V_{0(rms)}^2 - V_{0(av)}^2$$

$$V_{r(rms)} = \sqrt{V_{0(rms)}^2 - V_{0(av)}^2}$$

$$V_{r(rms)}^2 = V_{0(rms)}^2 - V_{0(av)}^2$$

RMS Value of Ripple Voltage :

$$V_{r(rms)} = \sqrt{V_{0(rms)}^2 - V_{0(av)}^2}$$

Ripple Factor Γ :

$$RF = \Gamma = \frac{V_{r(rms)}}{V_{0(av)}} = \sqrt{\left(\frac{V_{0(rms)}}{V_{0(av)}}\right)^2 - 1}$$

$$\Gamma = \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.483 \text{ or } 48.3\%$$

Efficiency η :

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{V_{dc}^2}{R_L}}{\frac{V_{rms}^2}{R_L}} = \frac{\left(\frac{2V_m}{\pi}\right)^2}{\left(\frac{V_m}{\sqrt{2}}\right)^2} = 0.812 \; or \; 81.2\%$$

Form Factor :

$$Form\ Factor = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$$

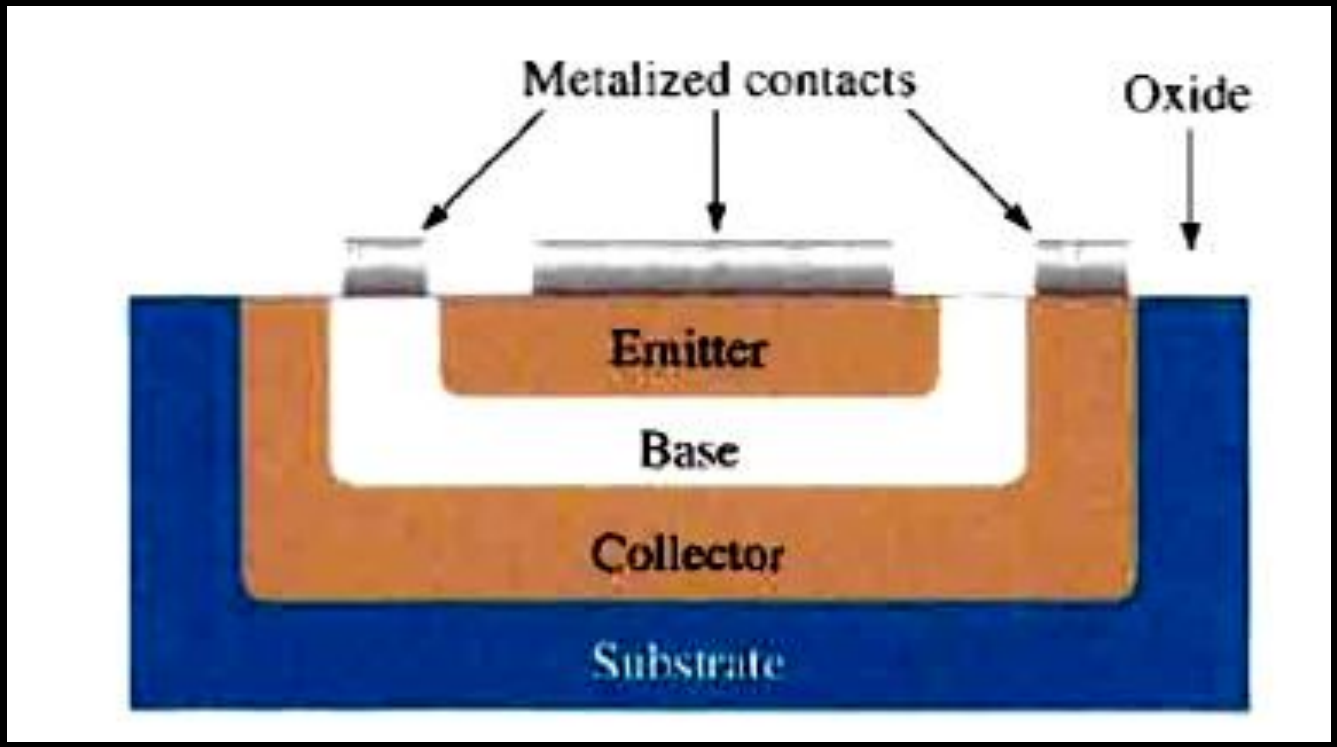
Peak Inverse Voltage PIV :

The maximum reverse voltage that a diode can withstand without destroying the junction. For half-wave rectifier, PIV is Vm.

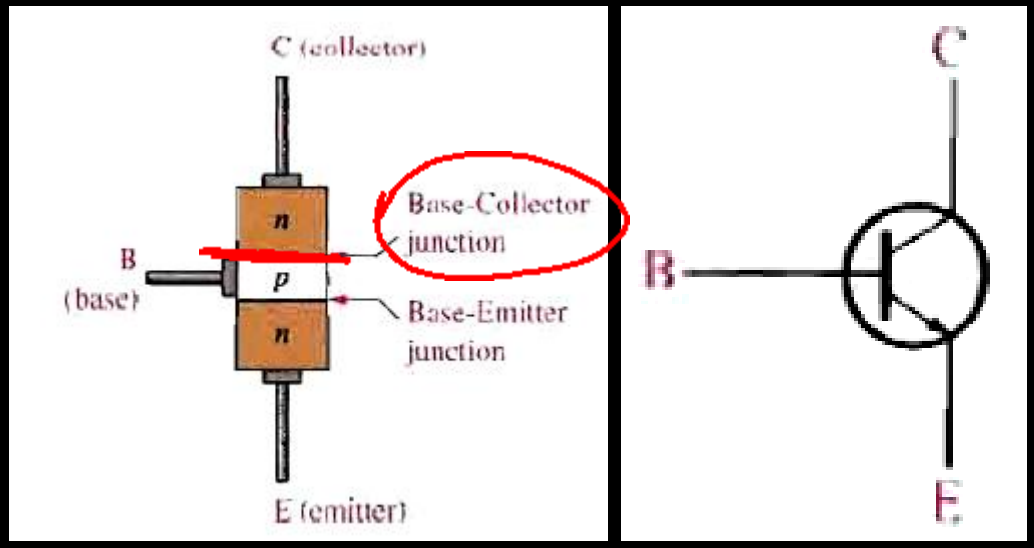
For Full-Wave Center-Tapped Transformer rectifier, PIV is 2Vm.

For Full-Wave Bridge Network rectifier, PIV is Vm.

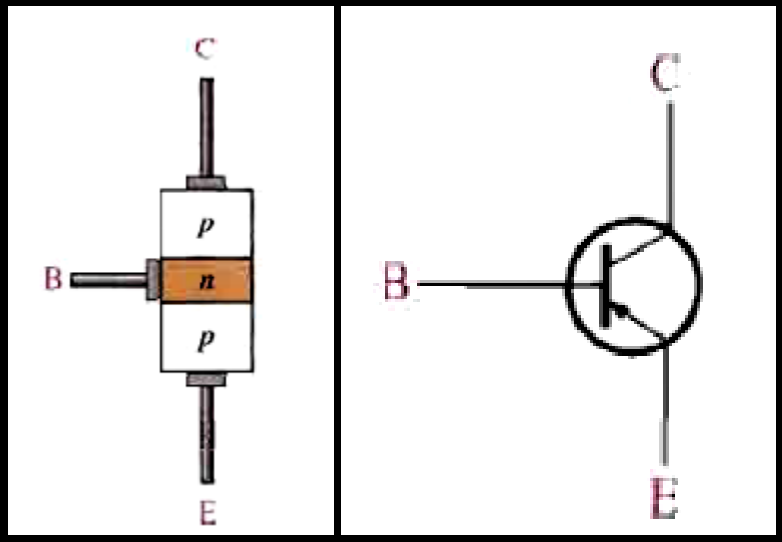
BIPOLAR JUNCTION TRANSISTOR (BJT)



npn-Transistor

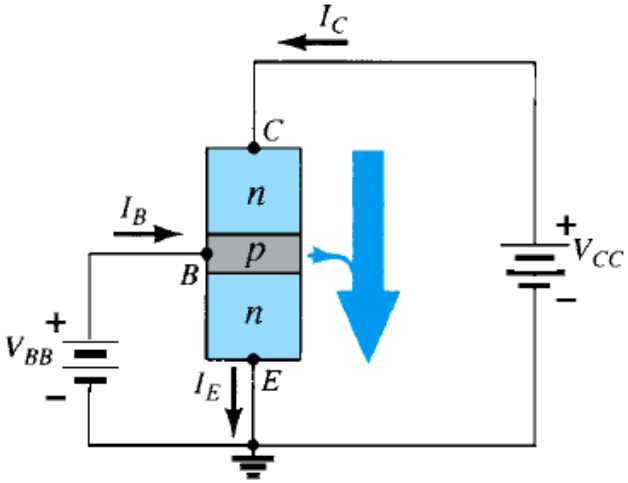


pnp-Transistor

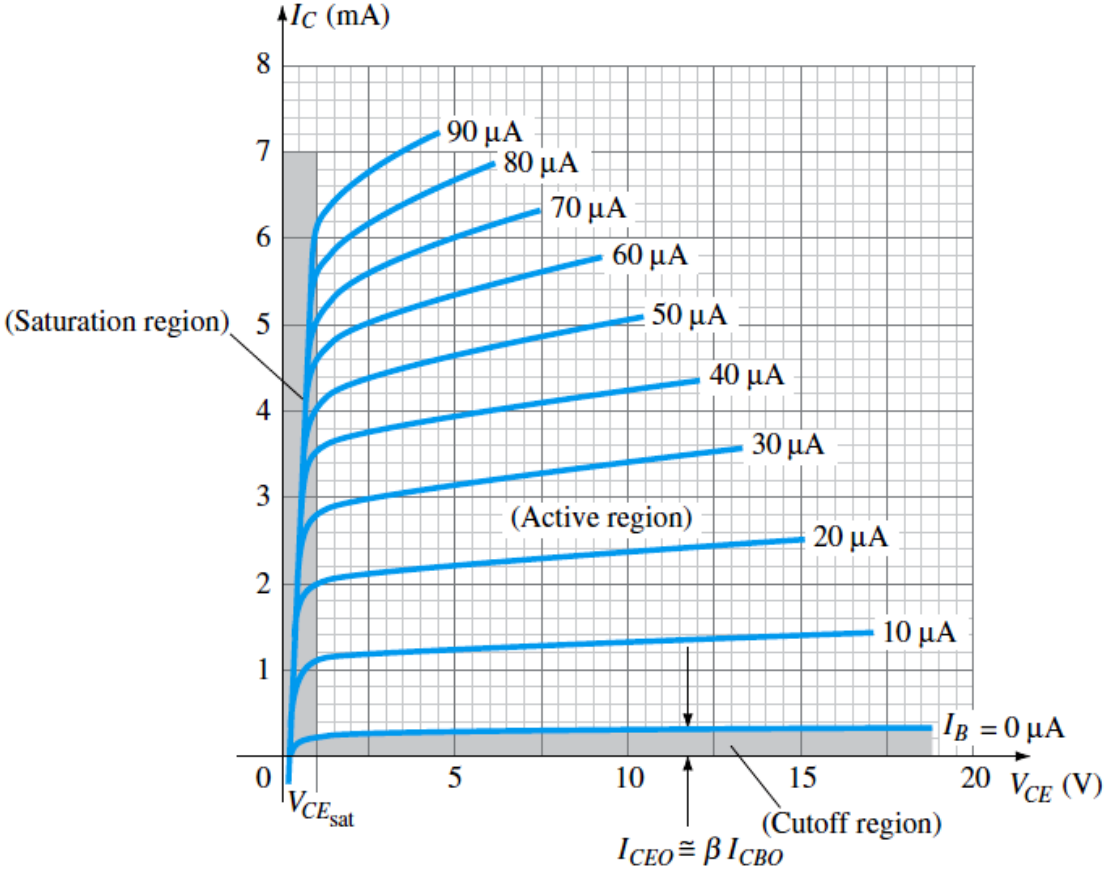


COMMON EMITTER CONFIGURATION

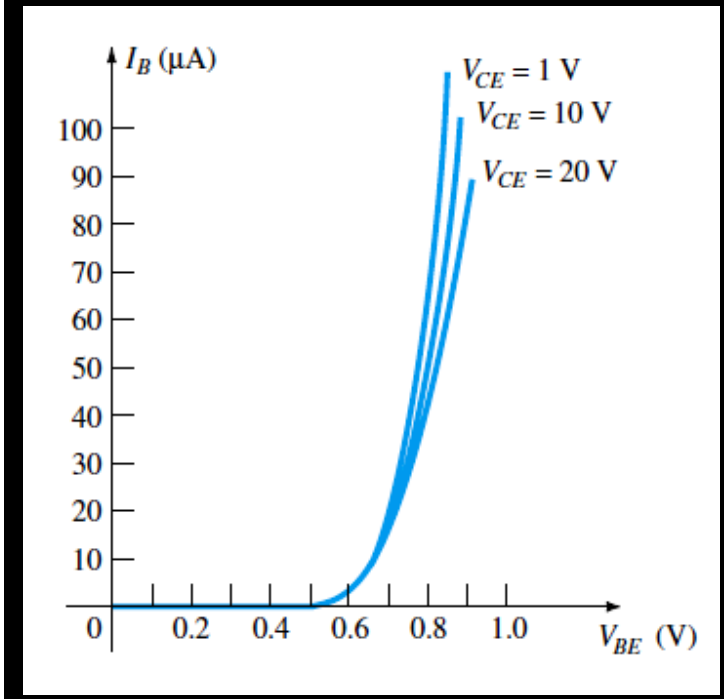
The emitter is common to both the input and output terminals (in this case common to both the base and collector terminals).

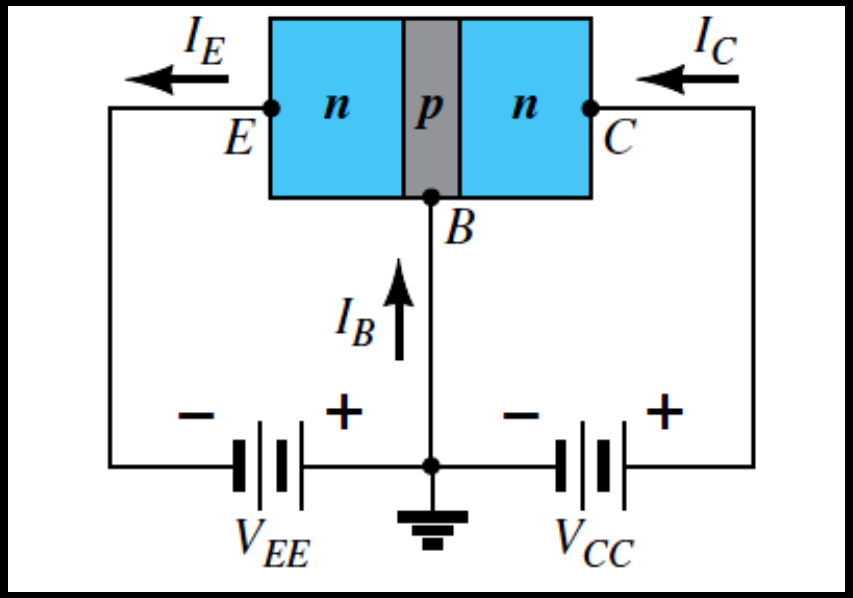


Collector Characteristics



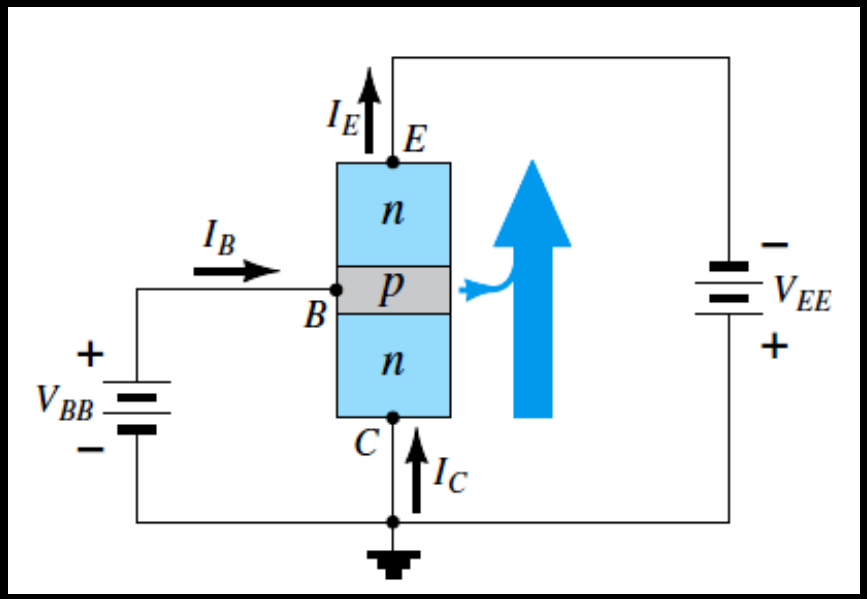
Base Characteristics





COMMON BASE CONFIGURATION

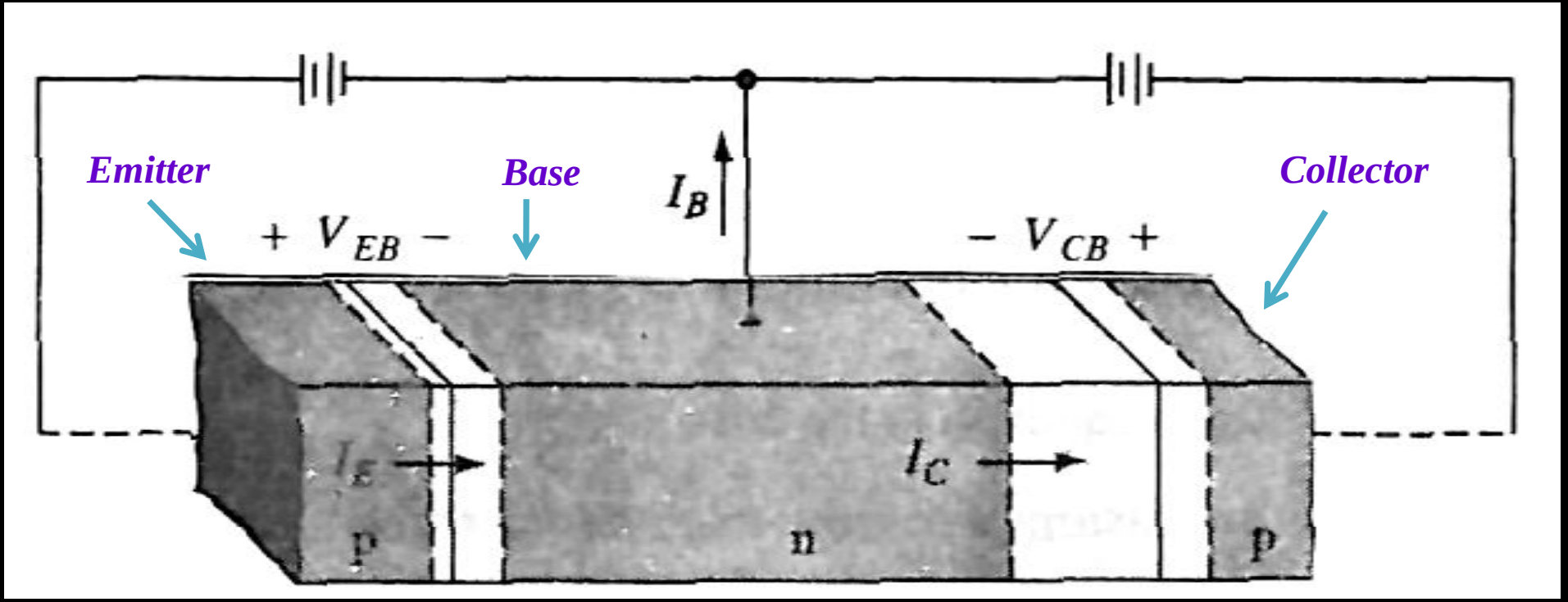
The base is common to both the input and output terminals (in this case common to both the emitter and collector terminals).



COMMON COLLECTOR CONFIGURATION

The collector is common to both the input and output terminals (in this case common to both the base and emitter terminals).

BJT - REGION OF OPERATION

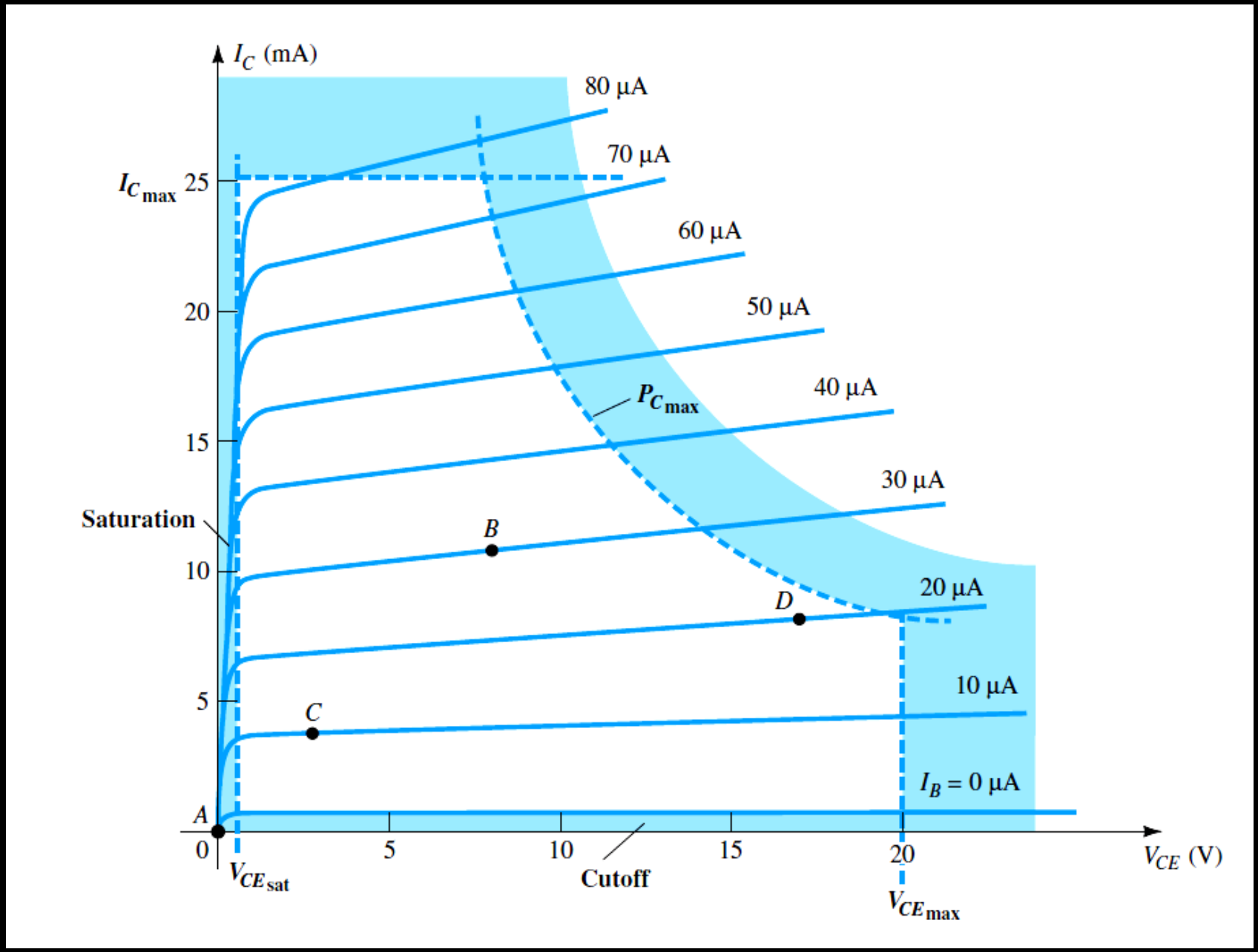


Active Region : EB junction forward bias & BC junction are reverse bias

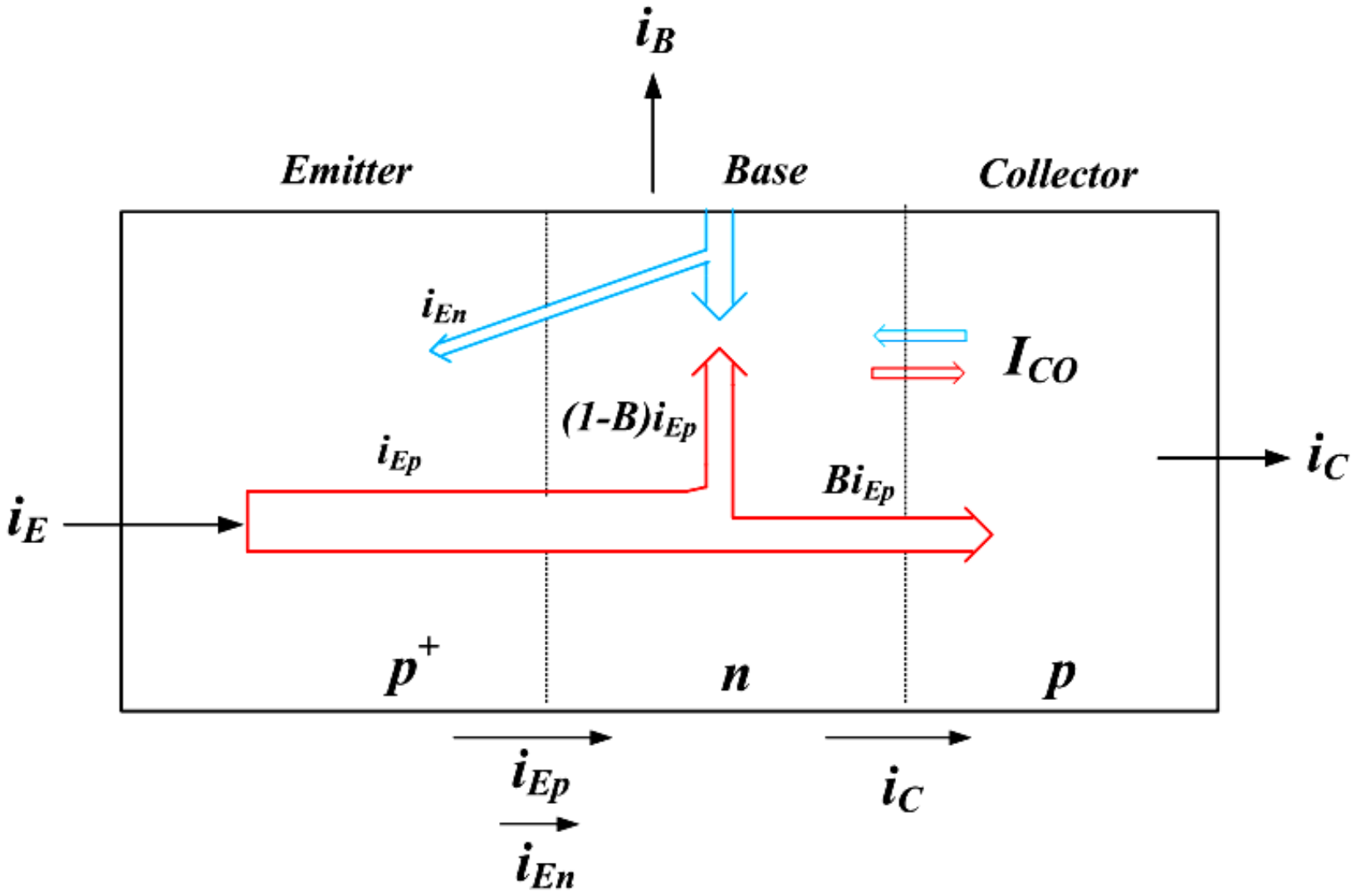
Cut-off Region : EB & BC junction are reverse bias

Saturation Region : EB & BC junction are forward bias

OPERATING REGIONS OF JUNCTION TRANSISTOR



FUNDAMENTALS OF BJT OPERATION



AMPLIFICATION WITH BJT

Emitter Current : $i_E = i_{En} + i_{Ep}$

Collector Current : $i_C = B i_{Ep}$

Base Transport Factor : B

Emitter Injection Efficiency : $\gamma = \dfrac{i_{Ep}}{i_{En} + i_{Ep}}$

For Efficient Transistor

$\gamma \approx 1 \quad B \approx 1$

The Ratio :

$$\frac{i_C}{i_E} = \frac{B i_{Ep}}{i_{En} + i_{Ep}} = B\gamma = \alpha$$

Current transfer ratio, which represents the emitter-to-collector current amplification. $\alpha < 1$

Base Current : $i_B = i_{En} + (1 - B) i_{Ep}$

The Ratio :

$$\frac{i_C}{i_B} = \frac{B i_{Ep}}{i_{En} + (1 - B) i_{Ep}}$$

$$\frac{i_C}{i_B} = \frac{B \dfrac{i_{Ep}}{(i_{En} + i_{Ep})}}{1 - B \dfrac{i_{Ep}}{(i_{En} + i_{Ep})}}$$

Hence

$$\frac{i_C}{i_B} = \frac{B\gamma}{1 - B\gamma} = \frac{\alpha}{1 - \alpha} = \beta$$

Base-to-Collector current amplification factor. Since a is near unity, it is clear that β can be large for a good transistor, and the collector current is large compared with the base current

$$\beta = \frac{\alpha}{1-\alpha} \qquad \textit{Hence} \qquad \alpha = \frac{\beta}{\beta+1}$$

From

$$i_E = i_C + i_B \qquad \textit{and} \qquad i_C = \beta i_B$$

$$i_E = \beta i_B + i_B \qquad \textit{Hence} \qquad i_E = (\beta+1) i_B$$

Considering Collector Reverse Saturation Current

$$i_C = \alpha i_E + I_{CO} \qquad \textit{or} \qquad i_E = \frac{i_C - I_{CO}}{\alpha}$$

$$i_E = i_C + i_B$$

$$i_C = \frac{i_C - I_{CO}}{\alpha} - i_B$$

$$\alpha i_C = i_C - I_{CO} - \alpha i_B$$

Hence

$$i_C = \frac{\alpha}{1-\alpha} i_B + \frac{1}{1-\alpha} I_{CO} \qquad i_C = \beta i_B + (\beta+1) I_{CO}$$