Week 4

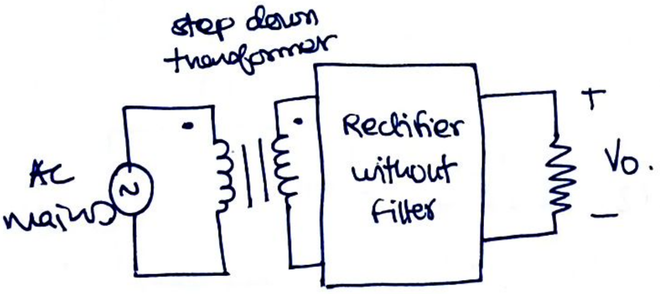
Rectifiers

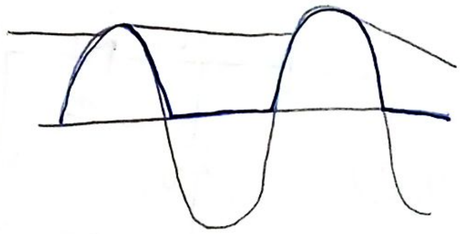
* A rectifier is used to convert an AC voltage to a DC voltage (typically 5 to 20V) eg: a mobile phone chargers.

* Two methods:

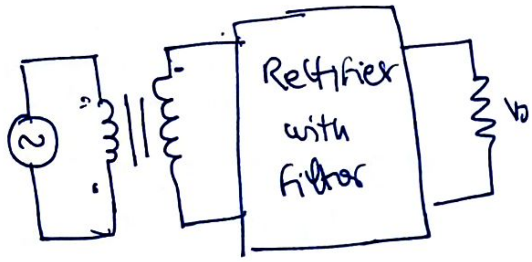
  AC mains → step down transformer → DC voltage

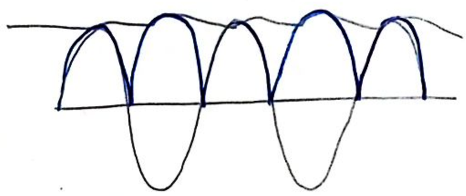
  AC mains → DC voltage → lower DC voltage.





half wave rectifier.

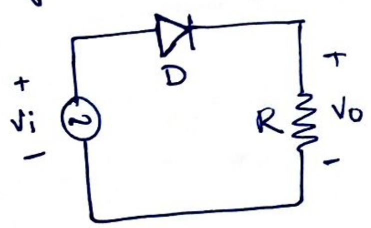


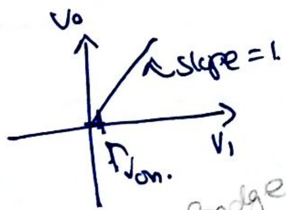


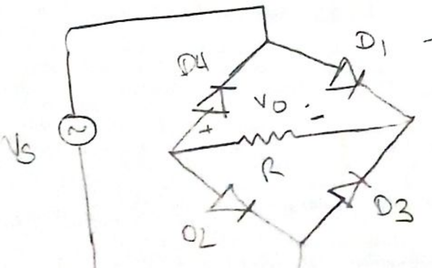
Full wave rectifier.

A voltage regulator would be typically used to remove the ripple riding on the DC output.

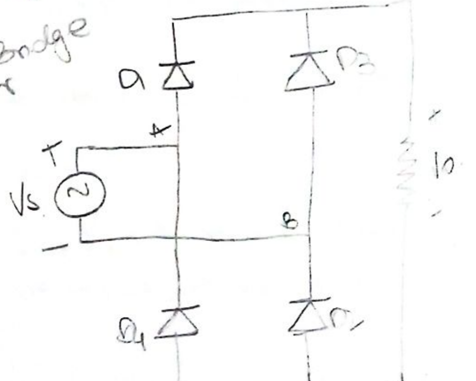
Half wave rectifier without filter.



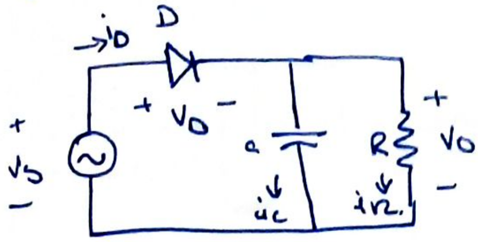


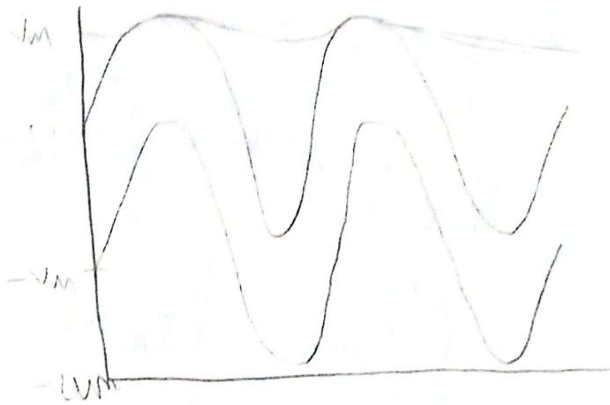


→ Full wave Bridge rectifier



Half wave rectifier with capacitor filter.





Because of load current i_R, there is a drop in the output voltage → "ripple"

The peak diode current is much larger than the average load current.

$V_D(t) = V_S(t) - V_O(t) \approx V_S(t) - V_m.$

The maximum reverse bias ("Peak Inverse Voltage" or PIV) across the diode is $2V_m$.

Ripple voltage $V_R = V_m \times \frac{T}{RC}.$

(a) Filter capacitance.

1. In the discharge phase.

$$V_O(t) = V_m e^{-t/\tau} \approx V_m\left(1 - \frac{t}{\tau}\right)$$

The drop in $V_O(t)$ is given by the second term.

Using $T_2 \approx T$

$$V_R = V_m \frac{T}{\tau} = V_m \frac{T}{RC}$$

~~R~~ 2. Assuming $i_C = i_R = \frac{V_O}{R} \approx \frac{V_m}{R}$ in the discharge phase we get.

$$i_C = \frac{V_m}{R} = C\frac{\Delta V_O}{\Delta t} \approx C\frac{V_R}{T} \Rightarrow V_R = V_m \frac{T}{RC}$$

b) Average diode current

Using charge balance,

$$\int_{T-T_c}^{T} (i_D - i_R)\,dt = \int_{0}^{T-T_c} i_R\,dt$$

$$\int_{T-T_c}^{T} i_D\,dt = \int_{0}^{T} i_R\,dt$$

$$i_D^{av} = \frac{1}{T}\int_{0}^{T} i_D\,dt = \frac{1}{T}\int_{T-T_c}^{T} i_D\,dt.$$

$$= \frac{1}{T}\int_{0}^{T} i_R\,dt \approx \frac{V_m}{R}$$

Peak diode current

$$i_D^{peak} = C\frac{d}{dt}(V_m\cos\omega t)\Big|_{t=T_c} + \frac{V_m}{R}.$$

$$= -\omega C V_m \sin(-\omega T_c) + \frac{16V}{100\Omega}$$

$$= \omega C V_m \sin\omega T_c + 0.16$$

$V_m\cos(-\omega T_c) = V_m - V_R$ giving.

$$\omega T_c = \cos^{-1}\left(1-\frac{V_R}{V_m}\right) = \cos^{-1}\left(1-\frac{2}{16}\right) = 29°$$

analytic expression:

$$V_m\cos(-\omega T_c) = V_m - V_R$$

$$\Rightarrow \cos\omega T_c = 1 - \frac{V_R}{V_m} \equiv 1-x.$$

$$\sin\omega T_c = \sqrt{1-\cos^2\omega T_c} = \sqrt{1-(1-x)^2} \approx \sqrt{2x} = \sqrt{\frac{2V_R}{V_m}}$$

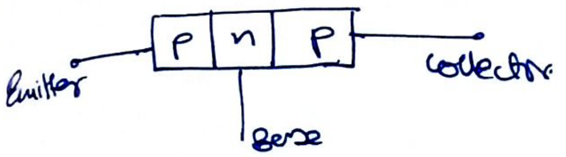
$$i_D^{peak} = i_R + C\frac{d}{dt}(V_m\cos\omega t)\Big|_{t=-T_c)}$$

$$= i_R + \omega C V_m \sin\omega T_c$$

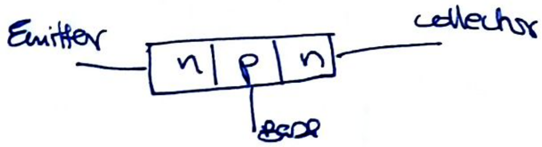
$$= i_R + \omega C V_m\sqrt{\frac{2V_R}{V_m}}.$$

(c) Maximum reverse bias $\approx 2V_m$

Bipolar Junction Transistors.



pnp transistor.



npn transistor.

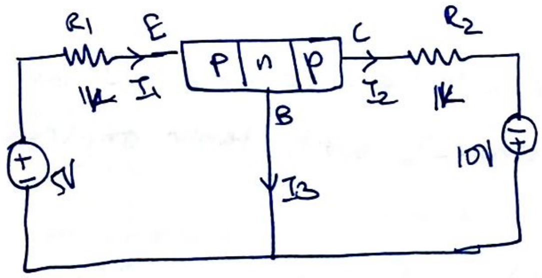
* Bipolar : both electrons & holes contribute to conduction.
* Junction: devices includes two p-n junctions.

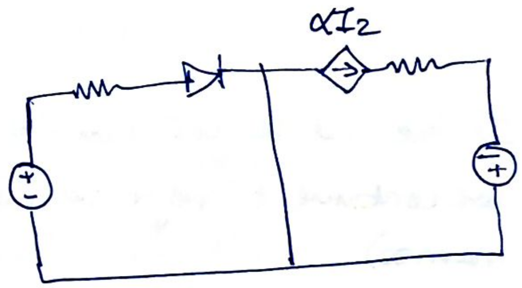
Transistor : transfer resistor.

* A BJT is two diodes connected back to back.

WRONG! Lets see why...

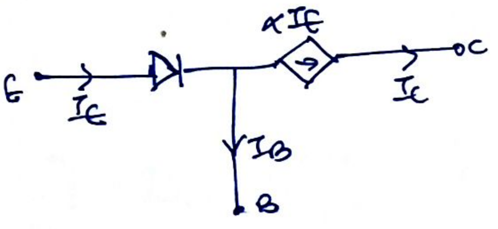
Consider.





When we replace BJT with 2 diodes, we assume that there is no interaction between the two diodes, which may be expected if they are "far apart".
However in a BJT exactly the opposite is true. For higher performance, the base region is made as short as possible and the two diodes cannot be treated as independent devices.

BJT in active mode



$I_C = \alpha I_E$. $\alpha \approx 1$

$I_B = I_E - I_C = I_E(1-\alpha)$

$$\beta = \frac{I_C}{I_B} = \frac{\alpha}{1-\alpha}$$

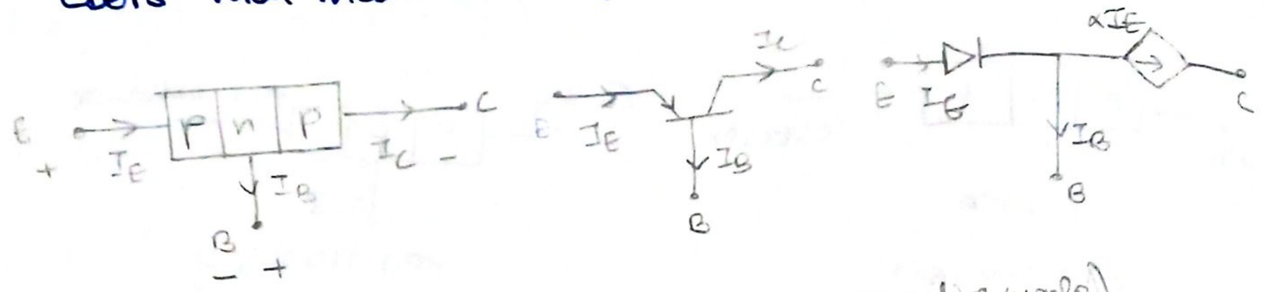
$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$I_C = \alpha I_E = \beta I_B$

$V_{BE} = 0.7\ V$

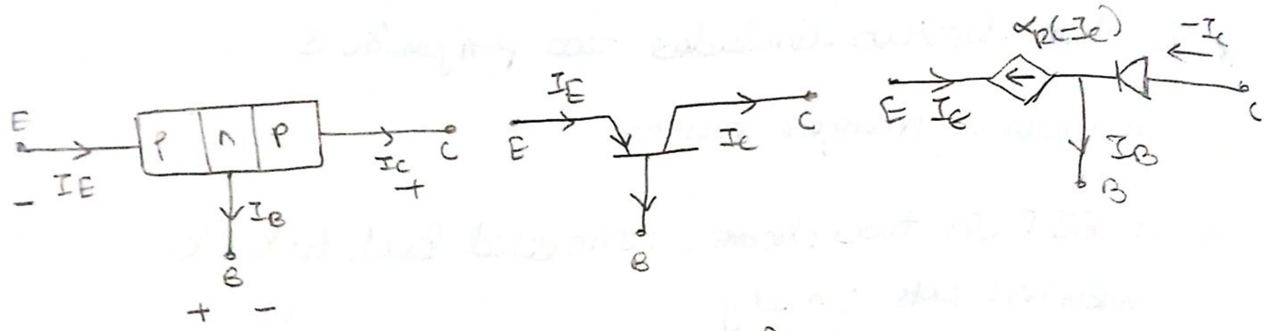
$V_C = V_{CC} - I_C R_C$

Ebers-Moll model for a pnp Transistor.



▲ Active mode ("forward" active mode)

B-E in f.b B-C in r.b



▲ Reverse active mode

B-E in r.b B-C in f.b

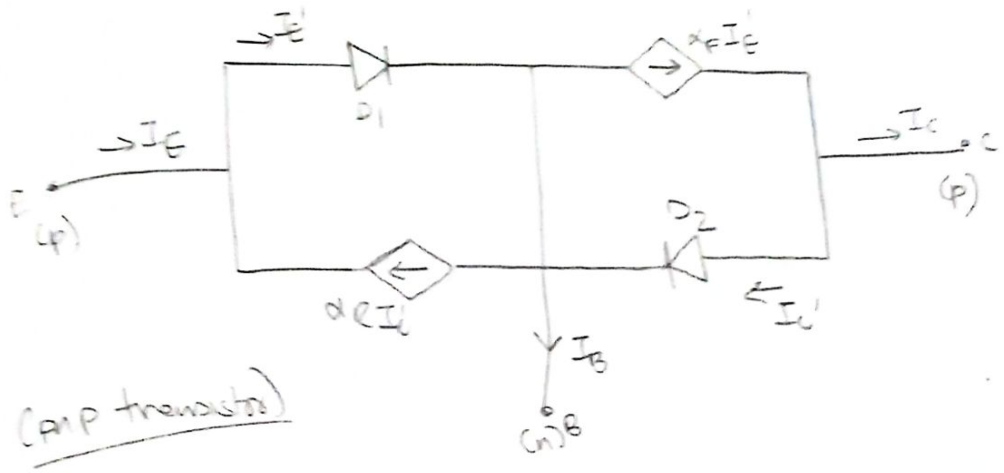
In the reverse active mode, emitter ⇔ collector. (However we continue to refer to the terminals with their original names)

The two α's, α_F (forward α) and α_R (reverse α) are generally quite different.

The corresponding current gains (β_F and β_R) differ significantly since $\beta = \frac{\alpha}{1-\alpha}$

In amplifiers the BJT is biased in the forward active mode (simply called active mode) in order to make use of higher value of β in that mode.

The Ebers Moll model combines the forward & reverse operations of a BJT in a single comprehensive model.

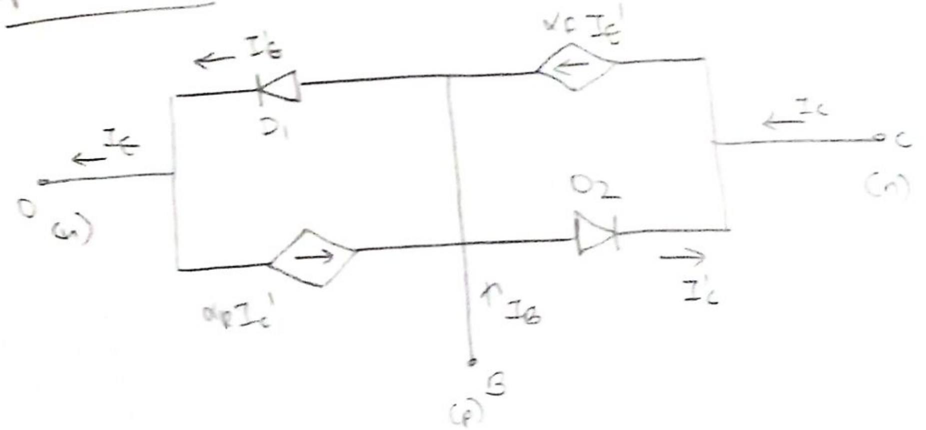


(pnp transistor)

$$I_E' = I_{ES}\left[\exp\left(\frac{V_{EB}}{V_T}\right) - 1\right] \qquad I_C' = I_{CS}\left[\exp\left(\frac{V_{CB}}{V_T}\right) - 1\right]$$

mode	B-E	B-C	
Forward active	Forward	reverse	$I_E' \gg I_C'$
Reverse active	reverse	Forward	$I_C' \gg I_E'$
Saturation	Forward	Forward	I_E' and I_C' are comparable
Cutoff	reverse	reverse	I_E' and I_C' are negligible

(npn transistor)



$$I_E' = I_{ES}\left[\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right] \qquad I_C' = I_{CS}\left[\exp\left(\frac{V_{BC}}{V_T}\right) - 1\right]$$

BJT I-V characteristics

* linear region : B-E under forward bias, B-C under r.b, $I_C = \beta_F I$
* saturation region : BE under f.b, B-C under f.b, $I_C < \beta_F I_B$