Unit - III

Steady state switching characteristics of Devices

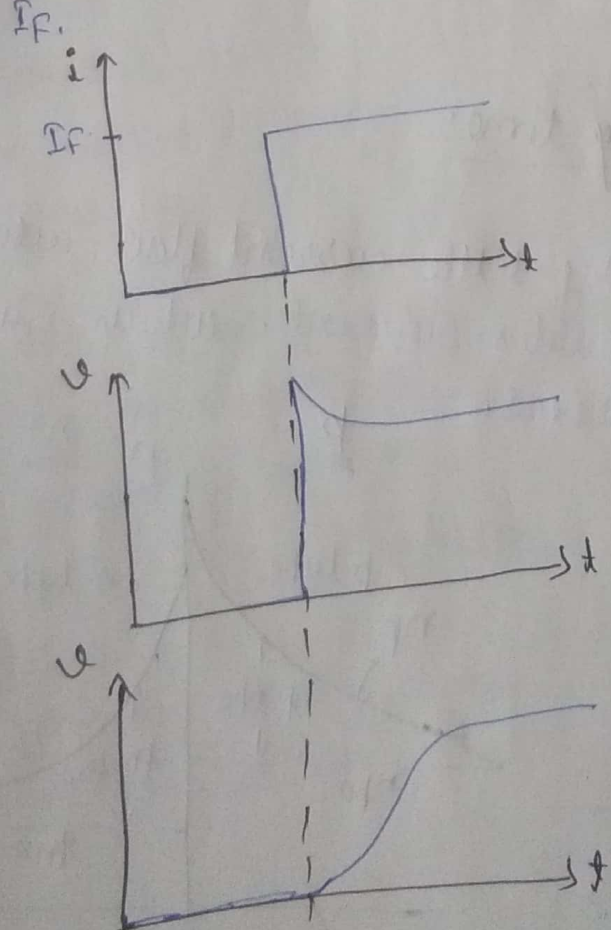
* Diode switching times:

If device is OFF/OPEN, then it is non-conducting. if device is ON/close, then it is conducting.

→ **Diode forward recovery time:**

when diode is driven from reverse biased condⁿ to forward bias condⁿ or opposite of this, then an interval of time elapses before diode recovers to its steady-state. The forward recovery transient depends on magnitude of current that drive the diode.

The diode current is compared with step current



→ Step current as I/P

→ when current is large, overshoot occur since in starting diode behave as resistor.

when i>>

→ when current is small.

when i<<

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The magnitude of overshoot increases as the magnitude of I/P current increases. At large current amplitude, the diode behaves as combination of a resistor and an inductor.

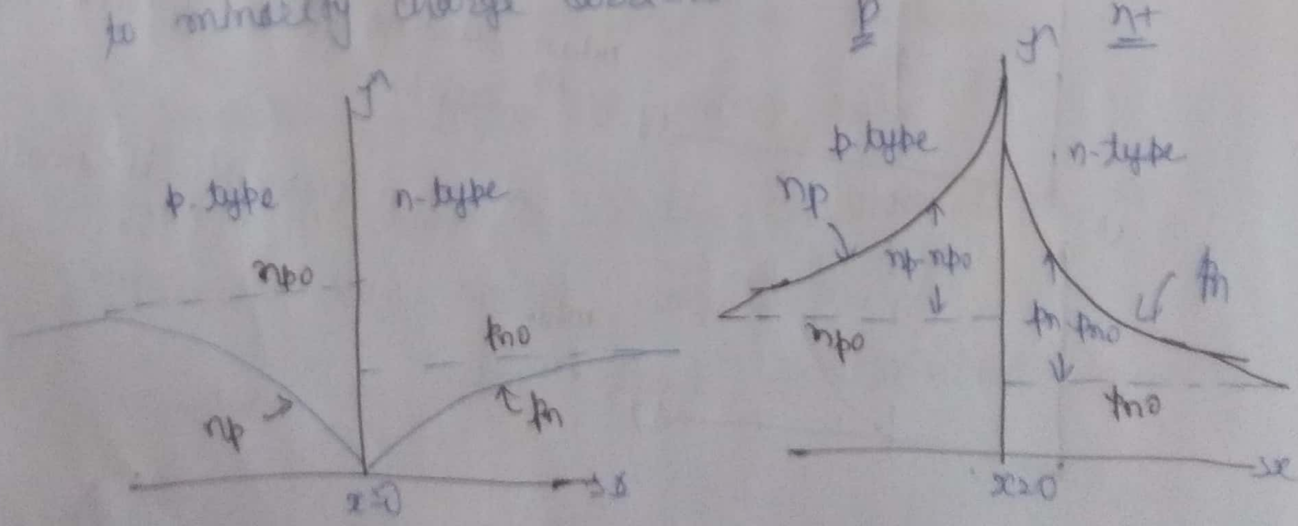
At low currents the diode is represented by parallel resistor-capacitor combination.

At intermediate currents, the diode behaves as a resistor, inductor and capacitor circuit and oscillations may be produced.

For a specified rise time, the forward recovery time t_{fr} is difference b/w the time when diode voltage reaches and remains within 10% of its final value.

→ <u>Diode reverse recovery time:</u>

In reverse bias very little current flow, which is known as reverse saturation current. which is due to minority charge carriers.



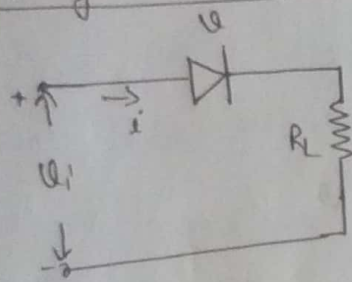
<u>Reverse bias</u>

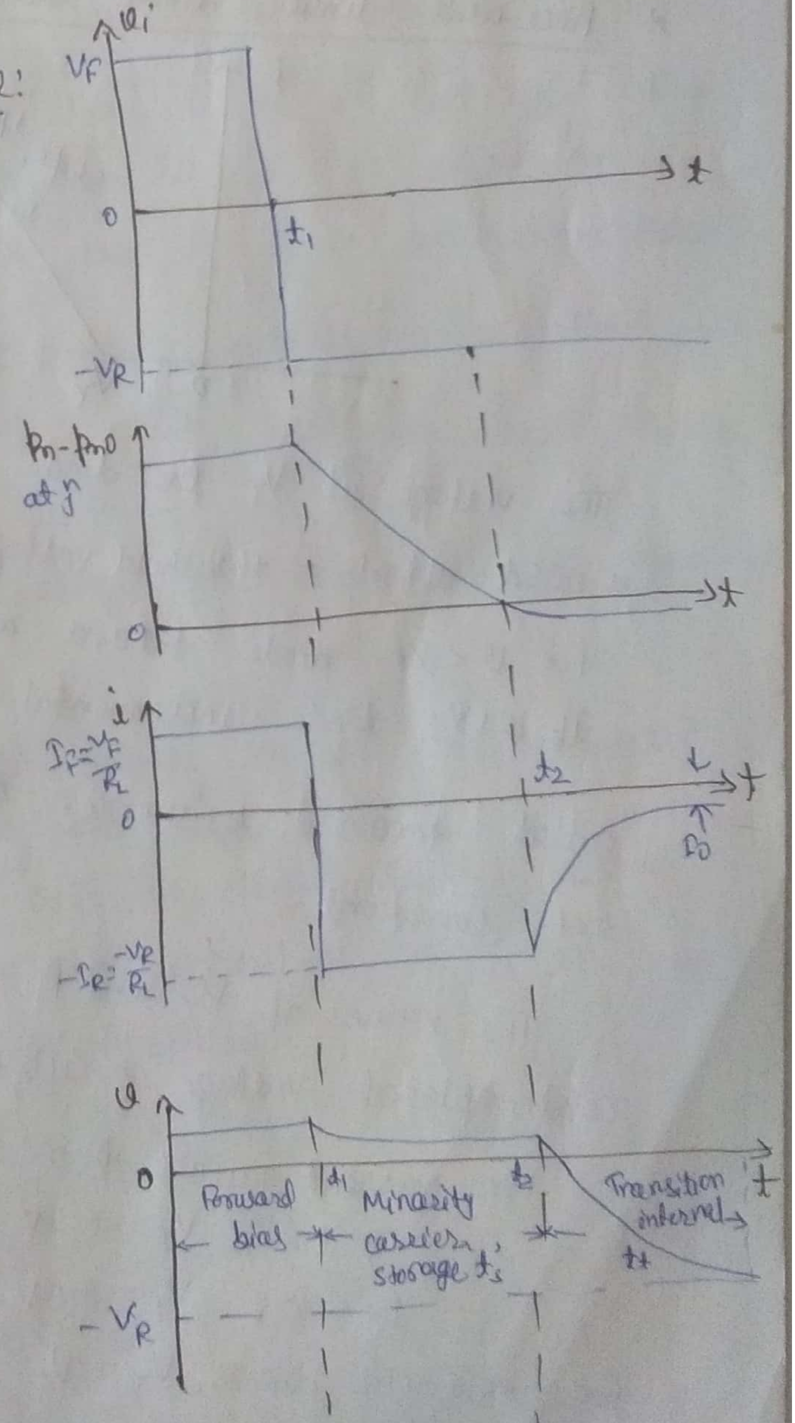
<u>Forward bias</u>

p_{no} & n_{po} is thermal equilibrium value. The away from j^n, the density of minority charge carriers remain unaltered.

If diode is carrying current in forward dir^n and external voltage is suddenly reversed then diode current will not fall immediately to steady state reverse value.

Storage & transition time:





→ Up to $t = t_1$, $v_i = V_F$

The current 'i' is given as,

$i \approx \frac{V_F}{R_L} = I_F$

→ At $t = t_1$, I/P voltage reverse abruptly to value $v_i = -V_R$.

So, current is given as,

$i \approx -\frac{V_R}{R_L} = -I_R$, until $t = t_2$.

→ The injected minority charge carriers drop to zero.

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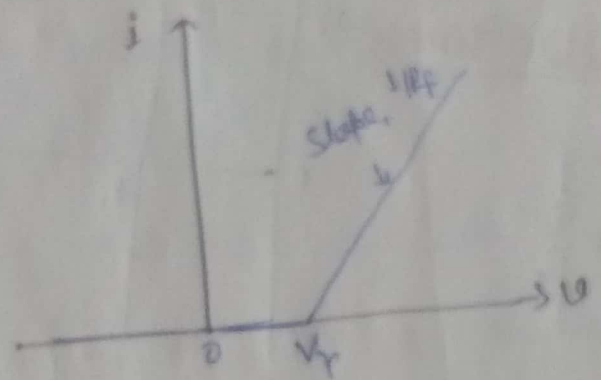
→ When these minority carriers have been swept back across the J, the diode voltage begins to reverse and magnitude of diode current decreases.

→ The time interval from t_1 to t_2, when minority charge becomes zero is called storage time t_s.

→ The time which elapses b/w t_2 and time when diode has nominally recovered is called transition time t_t.

* Piece-wise linear diode characteristics.



The voltage at V_γ the diode behaves as close-circuit, which is called offset or threshold voltage.

For $v < V_\gamma$, diode behaves as open ckt.

If $v > V_\gamma$, diode incremental resistance is $r = \frac{dv}{di}$. It is called forward resistance. The static resistance $R = V/I$ is not constant.

The value of V_γ and R_f depend upon type of diode and contemplated voltage & current swings.

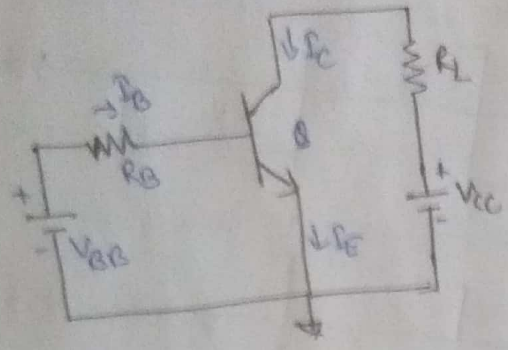
For current swing from cut-off to 10 mA.

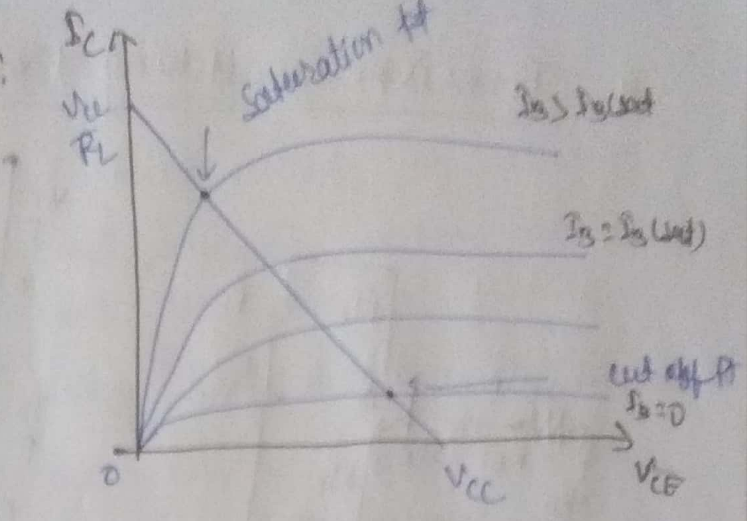
For Ge, $V_\gamma = 0.2V$ & $R_f = 20\Omega$

For Si, $V_\gamma = 0.6V$ & $R_f = 15\Omega$.

For avalanche diodes, $V_\gamma = V_Z$ and R_f is dynamic resistance

* Transistor as switch:





- The transistor has three regions of operation. when both j^{ns} are reverse bias then it is in cut-off. when I/p j^n is FB & O/p j^n is RB then it is in active mode. when both j^{ns} are in FB then it is in saturation mode.

→ when transistor switch from cut-off to saturation and from saturation to cut-off with negligible active region, then it is operated as switch.

→ During saturation j^n voltages are very small but operating currents are large.

→ During cut off, except leakage current all currents are zero but j^n voltages are large.

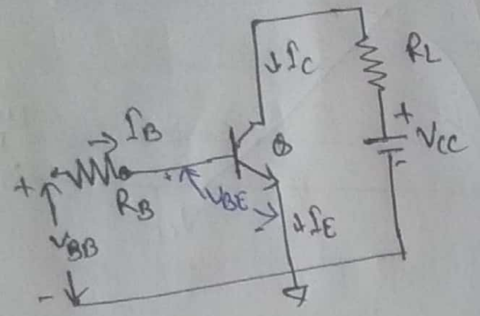
→ when Q is saturated, it acts as closed switch from collector to emitter & when Q is cut-off, it is like an open switch from collector to emitter.

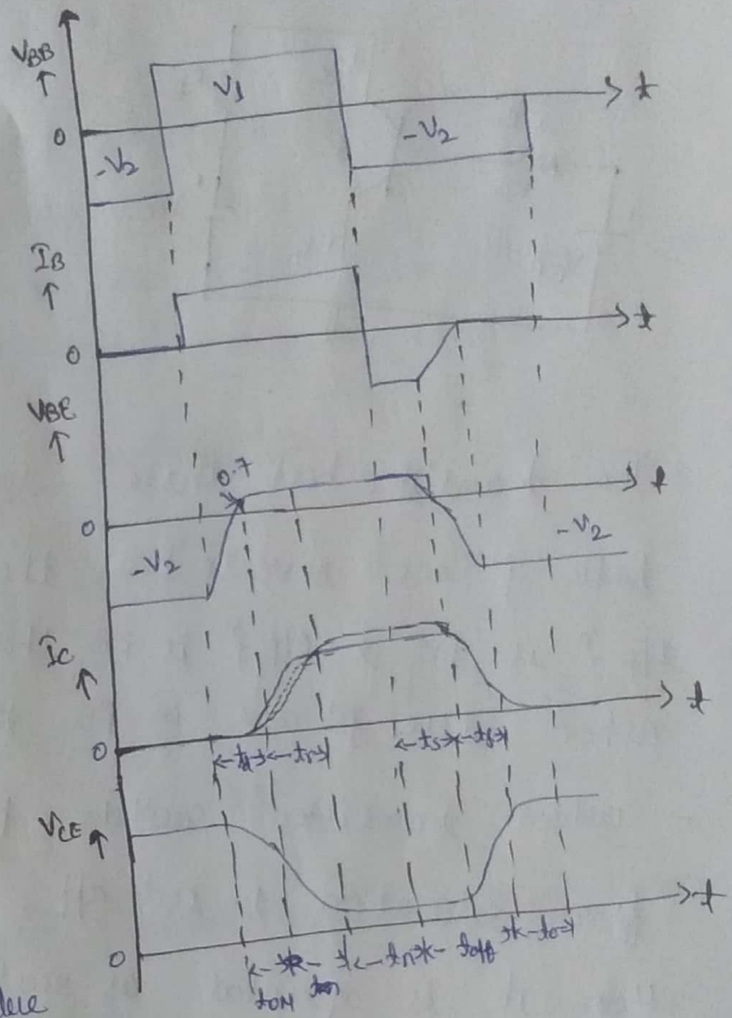
$$I_C = \frac{V_{CC} - V_{CE}}{R_L} \quad \& \quad I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$V_{CE(cut\text{-}off)} = V_{CC}$ & $I_{C(sat)} = V_{CC}/R_L$

$0 < I_B < I_{B(sat)}$ → transistor operate in active region & behave as amplifier.

* Transistor switching times :





→ Transistor acts as switch, when it is either in saturation or cut-off.

→ The collector current doesn't respond immediately to I/P signal. So, the time required to rise to 10% of its max^m value is called as delay time. 't_d'

→ Rise time 't_r' is time duration to rise from 10% to 90% of its final value.

→ Total turn on time is given as, $t_{ON} = t_d + t_r$.

when I/P signal returns to its initial stage, again collector current doesn't change immediately. So, the interval when I_C drops to 90% of final value is called storage time t_s.

→ when I_C falls 90% to 10% of final value is called as fall time.

So, turn off time is equal to $t_s + t_f$.

* Breakdown Voltages of a transistor:

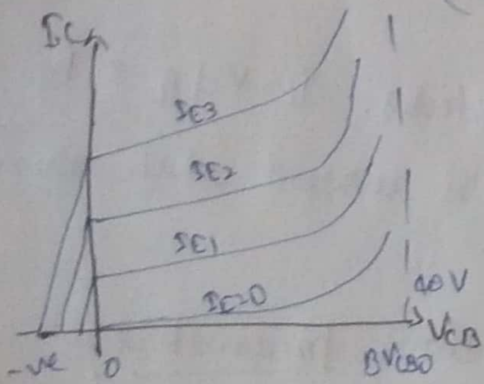
During switching, the voltage change occurs at collector terminal is approx V_{cc}. The max^m allowable voltage depends upon transistor characteristics and base circuitry.

The max^m reverse bias voltage before breakdown is represented by BV_{CBO}. The breakdown occur due to avalanche multiplication of the current I_{CO}, which crosses collector j^n. So, current becomes MI_{CO}.

At high voltage, higher than BV_{CBO}, the multiplication factor M becomes infinite and breakdown attained. The current rises abruptly with small changes in applied voltage.

The multiplication factor is given as,

$$M = \frac{1}{1-\left(\frac{V_{CB}}{BV_{CBO}}\right)^n}$$, where n lies b/w 2 to 10.



The current I_E is given as,

$\alpha = \frac{I_C}{I_E} \Rightarrow I_C = \alpha I_E$

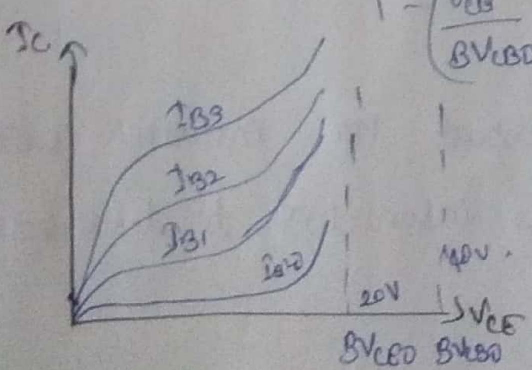
after avalanche multiplication,

$I_C = M\alpha I_E$, So, $\alpha^* = M\alpha$.

In CE

$h_{fe} = \alpha/(1-\alpha) \Rightarrow h_{fe}^* = \frac{\alpha^*}{1-\alpha^*} = \frac{M\alpha}{1-M\alpha}$.

For any base current, it will give large collector current for $M\alpha = 1$. So, $M = \frac{1}{1-\left(\frac{V_{CB}}{BV_{CBO}}\right)^n} = \frac{1}{\alpha}$.



* Transistor (Switch) in saturation:

When transistor switch from saturation to cut-off, the speed of response is important. It depends up on capacitor charging, which appear shunt across the o/p terminals of the transistor. Capacitor is going to charge through R_L. so, R_L is kept small. In saturation current is V_{CC}/R_L. Since R_L is already small, so, V_{CC} kept small to maintain limitations.

The voltage swing is $V_{CC} - V_{CE(sat)}$. The ratio of $V_{CE(sat)}/I_C$ is called as common emitter saturation resistance, $R_{CE(sat)}$. The $V_{CE(sat)}$ depends upon operating voltage as well as type of semiconductor material.

Alloy J has lowest value, Ge transistor has $V_{CE(sat)}$ lesser than Si transistor.

h_{fe} is specified by manufacturer. $I_C = V_{CC}/R_L$ & h_{fe} is known then $I_B = I_C/h_{fe}$. it is current which saturate the transistor.

* Temperature variation of transistor parameters:

At constant base & collector currents, V_{BE} has sensitivity in the range of -1.5 to -2 mV/°C. In saturation the voltage change at one Jn due to change in tempt. is cancelled by the change in other Jn.

At small & moderate current h_{fe} increases with tempt. At high currents, h_{fe} is insensitive to temperature.

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