Lecture Notes for Semiconductor Devices and Circuits : BJT

(Electronics : PHYS4008)

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1. Transistor and type

2. BJT
   2.1 Its Basic structure  Mechanism of transistor
   2.2 Minority carrier concentration in a transistor
   2.3 Region of operation
   2.4 Transistor connection
   2.5 Transistor biasing
   2.6 BJT Load line
1. Transistor & Type

- A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power.
- It is composed of semiconductor material with at least three terminals for connection to an external circuit.

![Diagram of Transistor Types](image)

- **BJT (Bipolar)**: n-p-n, p-n-p
- **FET (Unipolar)**: JFET, MOSFET
2. Bipolar Junction transistor (BJT)

- It is a three terminals current controlled active device. It is called Bipolar as it lies on the two types of charge carriers.

- BJT consist of a Si (or Ge) crystal in which a layer of n type Si (or Ge) is sandwiched between two layer of p type Si (or Ge) called p-n-p Transistor. Alternatively, a Transistor may also consist of a layer of p type Si (or Ge) sandwiched between two layer of n type Si(or Ge) called n-p-n Transistor.
2.1 Mechanism of Transistor

• The forward-biased junction that injects holes into the center N-region is called the emitter junction.

• The reverse-biased junction that collects the injected holes is called the collector junction.

• The p+ region, which serves as the source of injected holes, is called the emitter.

• the p-region into which the holes are swept by the reverse-biased junction is called the collector. The center n-region is called the base.
2.2 Minority carrier concentration in a transistor

- As the Potential barrier at the emitter base junction is lowered due to forward biasing the Minority carrier concentration across it increases.

- As the doping of emitter is much higher the minority carrier injected into the base is much higher and P<sub>n</sub> is much higher than n<sub>p</sub>.

- As the collector base junction is reverse bias the minority concentration across this junction is lowered.
2.3 Region of BJT Operation

ii) **Cut-off region**: Both emitter junction and collector junction are in reversed bias i.e. The transistor is off. There is no conduction between the collector and the emitter. ($I_B = 0$ therefore $I_C = 0$)
ii) **Active region:**
The transistor is on. The collector current is proportional to and controlled by the base current \((I_C = \beta I_B)\) and relatively insensitive to \(V_{CE}\). In this region the transistor can be an amplifier.

As Emitter is heavily doped, a large number of electrons diffuse into the base (only a small fraction combine with holes)

The number of these electrons scales as \(e^{\frac{V_{BE}}{V_T}}\)

- If the base is “thin” these electrons get near the depletion region of BC junction and are swept into the collector if \(V_{CB} \geq 0\) \((V_{BC} \leq 0 : \text{BC junction is reverse biased!})\)
  \[
i_C = I_S e^{\frac{V_{BE}}{V_T}}
\]
- In this picture, \(i_c\) is independent of \(V_{BC}\) (and \(V_{CE}\)) as long as
  \[
  V_{BC} = V_{BE} - V_{CE} = V_{D0} - V_{CE} \leq 0
  \]
  \[
  V_{CE} \geq V_{D0}
  \]
- Base current is also proportional to \(e^{\frac{V_{BE}}{V_T}}\) and therefore, \(i_c : i_B = i_C / \beta\)

F. Najmabadi, ECE65, Winter 2012
iii) Saturation region: The transistor is on. The collector current varies very little with a change in the base current in the saturation region. The $V_{CE}$ is small, a few tenths of a volt. The collector current is strongly dependent on $V_{CE}$ unlike in the active region. It is desirable to operate transistor switches in or near the saturation region when in their on state.

- **BE junction is forward biased** ($v_{BE} = V_{D0}$)

  Similar to the active mode, a large number of electrons diffuse into the base.

  - **Forward-biased**
  - **Reverse-biased**

  For $v_{BC} \geq 0$, **BC junction is forward biased** and a diffusion current will set up, reducing $i_C$.

  1. **Soft saturation**: $v_{CE} \geq 0.3 \text{ V (Si)}^*$
     
     $v_{BC} \leq 0.4 \text{ V (Si)}$, diffusion current is small and $i_C$ is very close to its active-mode level.

  2. **Deep saturation region**: $0.1 < v_{CE} < 0.3 \text{ V (Si)}$ or $v_{CE} \approx 0.2 \text{ V} = V_{sat} \text{ (Si)}$, $i_C$ is smaller than its active-mode level ($i_C < \beta i_B$).
     
     Called saturation as $i_C$ is set by outside circuit & does not respond to changes in $i_B$.

  3. **Near cut-off**: $v_{CE} \leq 0.1 \text{ V (Si)}$
     
     Both $i_C$ & $i_B$ are close to zero.

* Sedra & Smith includes this in the active region, i.e., BJT is in active mode as long as $v_{CB} \geq 0.3 \text{ V.}
2.4 Transistor connection

i) Common Base Connection

Input characteristics

\[
\begin{align*}
I_E (mA) & \\
V_{CE} = 10 V & \\
V_{CE} = 0 V & 
\end{align*}
\]

\[
\begin{align*}
V_{EB} (mV) & \\
0 & \\
10 & \\
20 & \\
30 & \\
40 & \\
50 & 
\end{align*}
\]
Output characteristics

Collector Current Ic (mA)

Collector Base Voltage Vcb (Volt)

Active Region

Cut off region

Ie = 50mA
Ie = 40mA
Ie = 30mA
Ie = 20mA
Ie = 10mA
Ie = 0mA
ii) Common Emitter Connection

Input characteristics

\[ I_B (\mu A) \]

\[ V_{BE} (VOLTS) \]
Output characteristics

- Saturation Mode
- Active Mode
- Cutoff Mode

- $I_C$ vs. $V_{CE}$ for different $I_B$ values:
  - $I_B = 80 \mu A$
  - $I_B = 60 \mu A$
  - $I_B = 40 \mu A$
  - $I_B = 20 \mu A$
  - $I_B = 0 \mu A$
iii) Common collector Connection

![Common collector circuit diagram]

- $V_B$ (input voltage)
- $R_B$ (resistor)
- $I_B$ (base current)
- $I_E$ (emitter current)
- $I_C$ ( collector current)
- $V_{CC}$ (supply voltage)
- $P_{NP}$ (PNP transistor)
- $R_L$ (load resistor)

Graph showing input characteristics:
- $I_B$ vs. $V_{BE}$
- Two curves for $V_{BE} = 3V$ and $V_{BE} = 5V$

Input characteristics
Output characteristics

Collector Current $I_C$ (mA)

Collector Base Voltage $V_{CB}$ (Volt)

Active Region

$I_E = 50mA$

$I_E = 40mA$

$I_E = 30mA$

$I_E = 20mA$

$I_E = 10mA$

$I_E = 0mA$

Cut off region
2.5 Transistor biasing circuit

i) Emitter feedback bias

- An increasing in the collector current produces an increase in the voltage across the emitter resistor, which reduces the base current consequently the collector current.

- The emitter Resistor serves as the Feedback element. If we adding voltage as a collector then we get \( V_{CE} + I_E R_E + I_c R_c - V_{CC} = 0 \).
Since, $I_E \approx I_C$, we get

$$I_C \approx \frac{V_{CC} - V_{CE}}{R_g + R_E}$$

If we adding the voltages around the base loop, we get

$$I_E R_E + V_{BE} + I_B R_B - V_{CC} = 0$$

Since, $I_E \approx I_C$ and $I_B = \frac{I_C}{\beta_{DC}}$, we get

$$I_C = \frac{V_{CC} - V_{BE}}{R_E + \frac{R_B}{\beta_{DC}}}$$
ii) Collector Feedback Bias (self Bias)

- This biasing method which requires two resistors to provide the necessary DC bias for the transistor. The collector to base feedback configuration ensures that the transistor is always biased in the active region regardless of the value of Beta (β).

- The collector current which is less than $V_{CC}/R_c$, Hence the transistor can’t be saturated.
### iii) Voltage Divider Bias

- The circuit known as voltage divider bias because of the voltage divider formed by $R_{B1}$ and $R_{B2}$.
- The voltage across $R_{B2}$ forward biases the emitter diode.

![Circuit Diagram](image)

\[
\begin{align*}
V_C &= V_{CC} - R_C I_C = (V_E + V_{CE}) \\
V_E &= I_E R_E = V_B - V_{BE} \\
V_{CE} &= V_C - V_E = V_{CC} - (I_C R_C + I_E R_E) \\
V_B &= V_{BE} + V_E = V_{RB2} = \left(\frac{R_{B2}}{R_{B1} + R_{B2}}\right) V_{CC} \\
I_{B2} &= \frac{V_B}{R_{B2}} \\
I_{B1} &= I_B + I_{B2} = \frac{V_{CC} - V_B}{R_{B1}} \\
R_B &= \frac{R_{B1} \times R_{B2}}{R_{B1} + R_{B2}} \\
I_B &= \frac{V_B - V_{BE}}{R_B + (1 + \beta) R_E} \\
I_C &= \beta_{(DC)} I_B \\
I_E &= I_C + I_B = \frac{V_E}{R_E}
\end{align*}
\]
iv) Emitter Bias

If $R_B$ is small enough, the base voltage is approximately zero. The voltage across emitter resistor is $V_{EE} - V_{BE}$.

\[ I_E = \frac{V_{EE} - V_{BE}}{R_E} \]
2.6 BJT Transfer Function on the Load line

Saturation: $V_{ih} < v_i$
$i_B$ increases but $i_C$ unchanged

Load Line (CE - KVL)
$v_{ce} = V_{cc} - R_C i_C$

Active: $V_{D0} \leq v_i \leq V_{ih}$
$i_B$ & $i_C$ increase together

Cut - off: $v_i < V_{D0}$
References

1. Solid state electronic devices by Ben G. Streetman and S.K Banerjee
2. Lecture notes: Sec. 3 Sedra & Smith
3. Electronics devices and Circuit Theory By Robert L. Boylestad
5. Working Principle of MOSFET and MOSFET Characteristics
   https://www.electrical4u.com/mosfet-working-principle-of-p-channel-n-channel-mosfet/