Electronic Circuits

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1

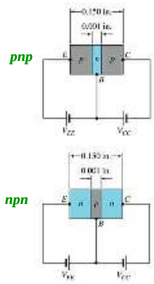
Transistor Construction

There are two types of transistors:

- *pnp*
- *npn*

The terminals are labeled:

- **E - Emitter**
- **B - Base**
- **C - Collector**

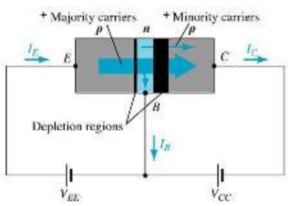


2

Transistor Operation

With the external sources, V_{EE} and V_{CC}, connected as shown:

- **The emitter-base junction is forward biased**
- **The base-collector junction is reverse biased**



3

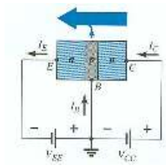
Currents in a Transistor

Emitter current is the sum of the collector and base currents:

$$I_E = I_C + I_B$$

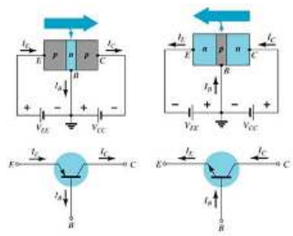
The collector current is comprised of two currents:

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$



4

Common-Base Configuration



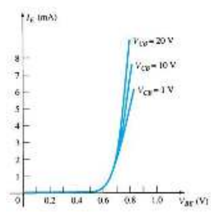
The base is common to both input (emitter–base) and output (collector–base) of the transistor.

5

Common-Base Amplifier

Input Characteristics

This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.

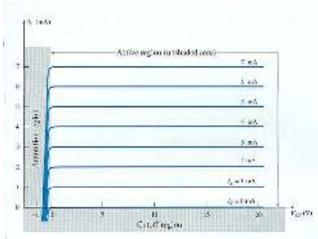


6

Common-Base Amplifier

Output Characteristics

This graph demonstrates the output current (I_C) to an output voltage (V_{CB}) for various levels of input current (I_E).



Operating Regions

- **Active** – Operating range of the amplifier.
- **Cutoff** – The amplifier is basically off. There is voltage, but little current.
- **Saturation** – The amplifier is full on. There is current, but little voltage.

Approximations

Emitter and collector currents:

$$I_C \cong I_E$$

Base-emitter voltage:

$$V_{BE} = 0.7\text{ V (for Silicon)}$$

Alpha (α)

Alpha (α) is the ratio of I_C to I_E :

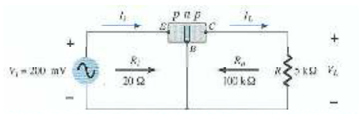
$$\alpha_{dc} = \frac{I_C}{I_E}$$

Ideally: $\alpha = 1$
In reality: α is between 0.9 and 0.998

Alpha (α) in the AC mode:

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$$

Transistor Amplification



Currents and Voltages:

$$I_E = I_i = \frac{V_i}{R_i} = \frac{200\text{mV}}{20\Omega} = 10\text{mA}$$

$$I_C \cong I_E$$

$$I_L \cong I_i = 10\text{ mA}$$

$$V_L = I_L R = (10\text{ ma})(5\text{ k}\Omega) = 50\text{ V}$$

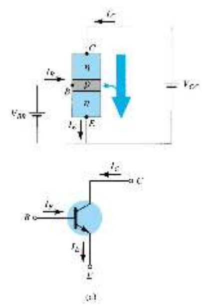
Voltage Gain:

$$A_v = \frac{V_L}{V_i} = \frac{50\text{V}}{200\text{mV}} = 250$$

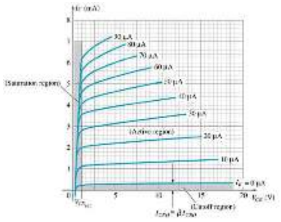
Common–Emitter Configuration

The emitter is common to both input (base-emitter) and output (collector-emitter).

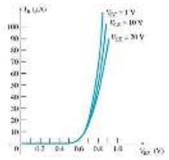
The input is on the base and the output is on the collector.



Common-Emitter Characteristics



Collector Characteristics



Base Characteristics

13

Common-Emitter Amplifier Currents

Ideal Currents

$I_E = I_C + I_B$ $\qquad$ $I_C = \alpha I_E$

Actual Currents

$I_C = \alpha I_E + I_{CBO}$ $\qquad$ where I_{CBO} = minority collector current

I_{CBO} is usually so small that it can be ignored, except in high power transistors and in high temperature environments.

When $I_B = 0\ \mu A$ the transistor is in cutoff, but there is some minority current flowing called I_{CEO}.

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha}\bigg|_{I_B = 0\,\mu A}$$

14

Beta (β)

β represents the amplification factor of a transistor. (β is sometimes referred to as h_{fe}, a term used in transistor modeling calculations)

In DC mode:

$$\beta_{dc} = \frac{I_C}{I_B}$$

In AC mode:

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\bigg|_{V_{CE} = \text{constant}}$$

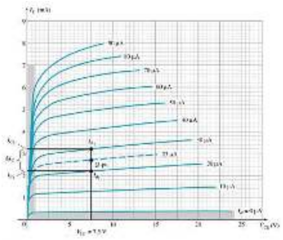
15

Beta (β)

Determining β from a Graph

$$\beta_{AC} = \frac{(3.2\,mA - 2.2\,mA)}{(30\,\mu A - 20\,\mu A)}$$
$$= \frac{1\,mA}{10\,\mu A}\bigg|_{V_{CE} = 7.5}$$
$$= 100$$

$$\beta_{DC} = \frac{2.7\ mA}{25\ \mu A}\bigg|_{V_{CE} = 7.5}$$
$$= 108$$



16

Beta (β)

Relationship between amplification factors β and α

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

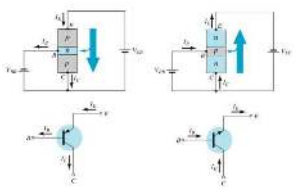
Relationship Between Currents

$$I_C = \beta I_B \qquad I_E = (\beta + 1) I_B$$

17

Common–Collector Configuration

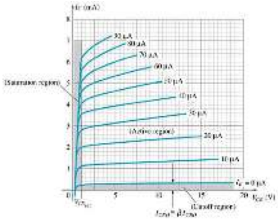
The input is on the base and the output is on the emitter.



18

Common–Collector Configuration

The characteristics are similar to those of the common-emitter configuration, except the vertical axis is I_E.



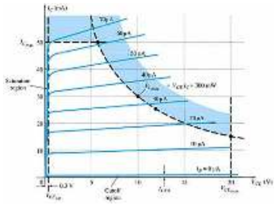
19

Operating Limits for Each Configuration

V_{CE} is at maximum and I_C is at minimum ($I_{Cmax} = I_{CEO}$) in the cutoff region.

I_C is at maximum and V_{CE} is at minimum ($V_{CE\,max} = V_{CEsat} = V_{CEO}$) in the saturation region.

The transistor operates in the active region between saturation and cutoff.



20

Power Dissipation

Common-base:

$$P_{Cmax} = V_{CB} I_C$$

Common-emitter:

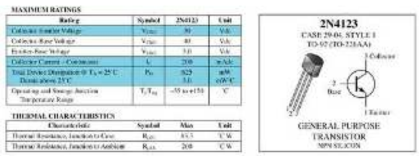
$$P_{Cmax} = V_{CE} I_C$$

Common-collector:

$$P_{Cmax} = V_{CE} I_E$$

21

Transistor Specification Sheet



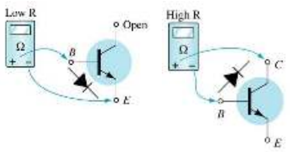
22

Transistor Specification Sheet

23

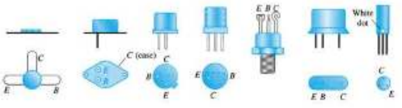
Transistor Testing

- Curve Tracer
  Provides a graph of the characteristic curves.
- DMM
  Some DMMs measure β_{DC} or h_{FE}.
- Ohmmeter



24

Transistor Terminal Identification



25