BME 202 Electronics

Lecture 4: Bipolar Junction Transistors

Outline

- Basic construction and operation of BJT transistors
- Proper biasing
- Characteristics of *npn* and *pnp* transistors
- Testing a transistor and identifying terminals

Transistor Construction

There are two types of

Bipolar Junction Transistors:

pnp and *npn*

The terminals are labeled:

E - Emitter

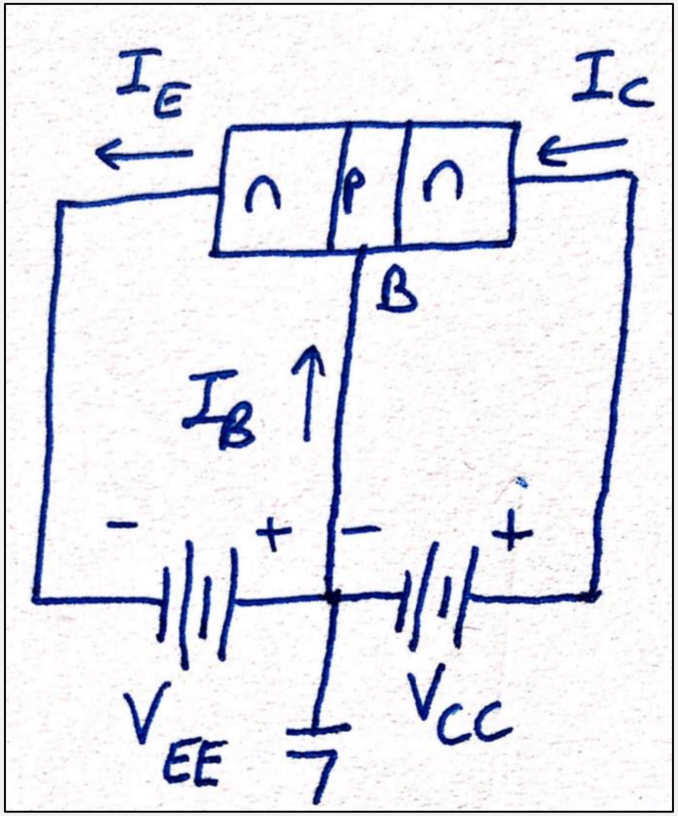
B - Base

C - Collector

Transistor Operation

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

One p-n junction of a transistor is reverse-biased whereas the other is forward biased.



The emitter-base junction is forward biased

The base-collector junction is reverse biased

$$I_E = I_C + I_B$$

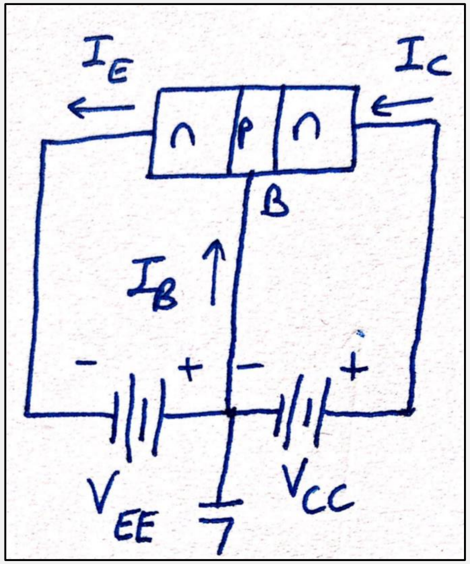
Currents in a Transistor

The emitter current is the sum of the collector and base currents:

$$I_E = I_C + I_B$$

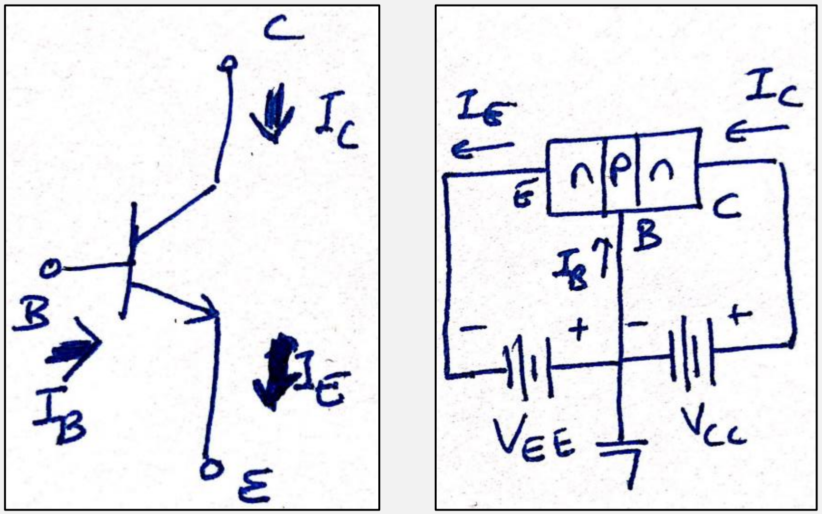
The collector current is comprised of two currents:

$$I_C = I_{C\,(majority)} + I_{CO\,(minority)}$$

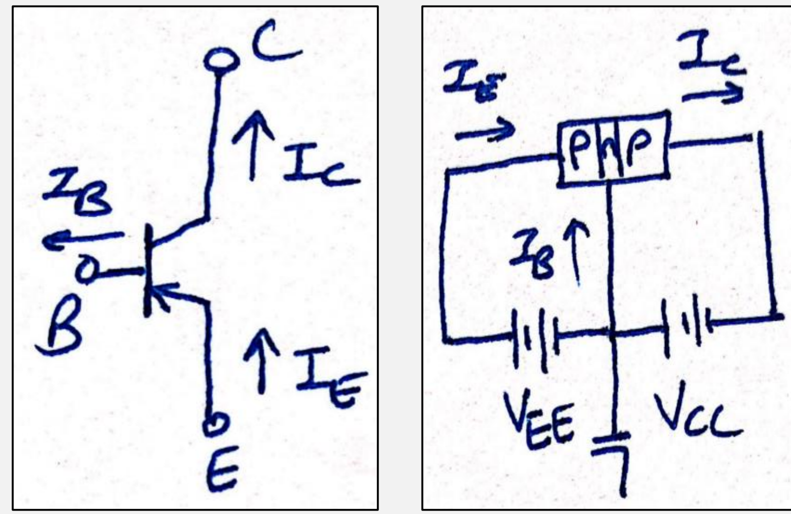


Common-Base Configuration

NPN



PNP



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

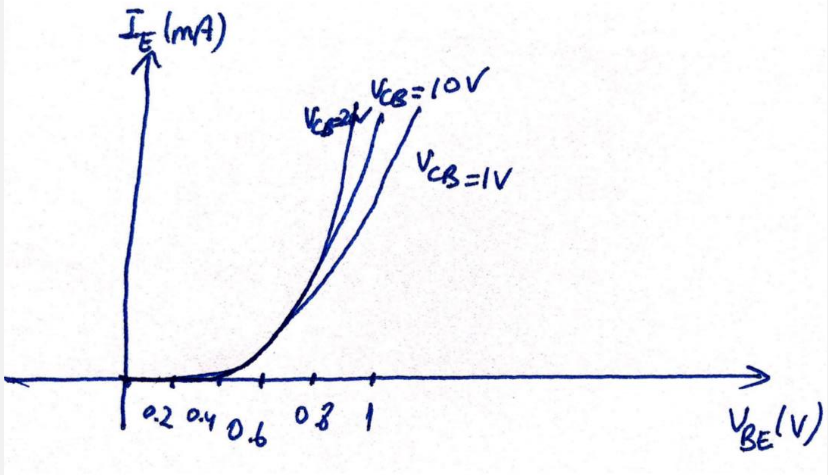
The arrow in the graphic symbol defines the direction of emitter current through the device

Common-Base Amplifier

Two sets of characteristics are required to describe a three terminal device: one for the *driving point or input* parameters and the other for the *output* side.

Input Characteristics

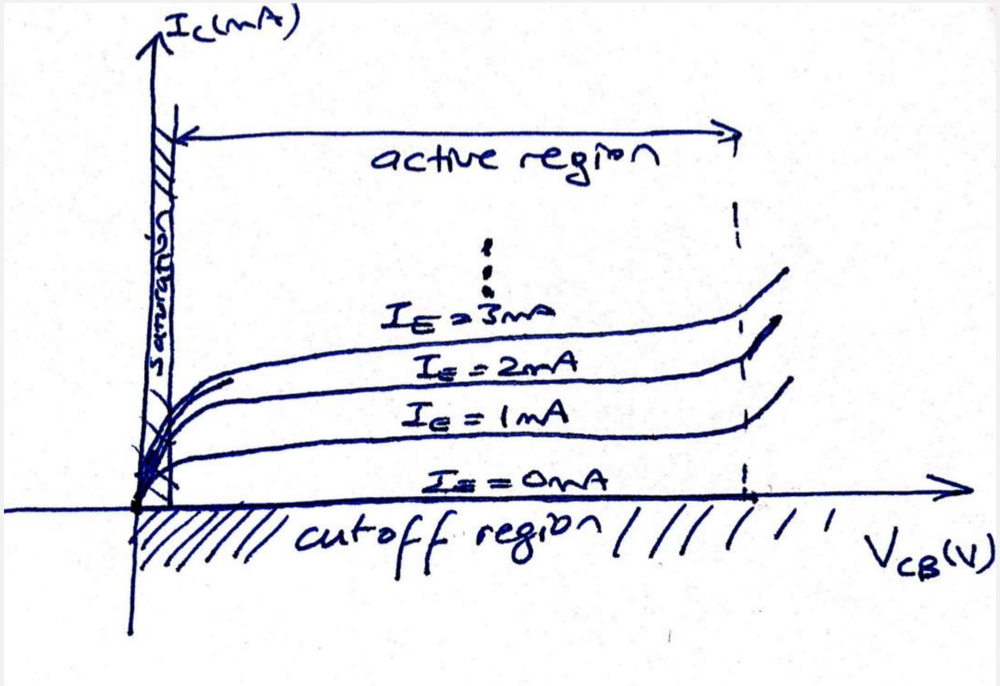
This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.



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).

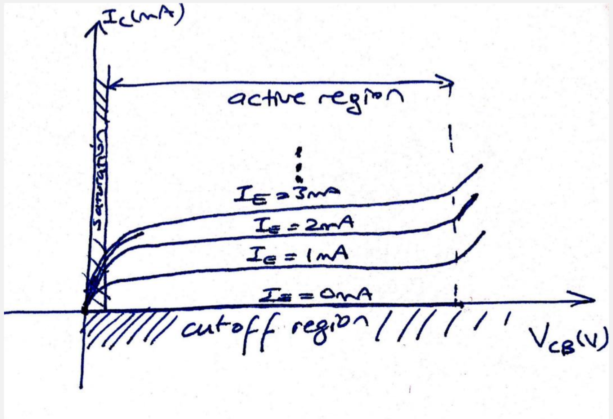


The output or collector set of characteristics has three basic regions of interest: *active, cutoff* and *saturation*.

Operating Regions

Active:

- Operating range of the amplifier.
- Base-emitter junction is forward-biased whereas the collector base junciton is reverse-biased.
- $I_C \cong I_E$



Cutoff:

- The amplifier is basically off. There is voltage, but little current.
- Base-emitter and collector-base junctions are both reverse biased.

Saturation:

- The amplifier is fully on. There is current, but little voltage.
- Base-emitter and collector-base junctions are both forward biased.

Approximations

Emitter and collector currents: a first approximation to the relationship between I_E and I_C

$$I_C \cong I_E$$

Base-emitter voltage: once a transistor is in the on state, the base-to-emitter voltage will be assumed

$$V_{BE} \cong 0.7V$$

(for Silicon)

Alpha (α)

DC mode: levels of I_E and I_C due to majority carriers are related by a quantity called alpha:

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

Ideally: $\alpha = 1$

In reality: α falls somewhere between 0.9 and 0.998

AC mode: for ac situation where the point of operation moves on the characteristic curve, an average ac alpha is defined by:

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

Common-Emitter Configuration

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

The input is applied to the base and the output is taken from the collector.

Common-Emitter Amplifier Currents

Ideal Currents $I_E = I_C + I_B$ $I_C = \alpha I_E$

Actual Currents $I_C = \alpha I_E + I_{CBO}$ 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 μA the transistor is in cutoff, but there is some minority current flowing called I_{CEO}.

$$I_{CEO} = \left.\frac{I_{CBO}}{1-\alpha}\right|_{I_B = 0\ \mu A}$$

Beta (β)

β represents the amplification factor of a transistor.

In DC mode:

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

In AC mode:

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

β_{ac} is sometimes referred to as h_{fe}, a term used in transistor modeling calculations

Beta (β)

Determining β from a graph

$$\beta_{AC} = \frac{(3.2\ mA - 2.2\ mA)}{(30\ \mu A\ -\ 20\ \mu A)}$$

$$= \frac{1\ mA}{10\ \mu A}\bigg|_{V_{CE}=7.5V}$$

$$= 100$$

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

$$= 108$$

Beta (β)

Relationship between amplification factors β and α :

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

Relationship between Currents:

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

Common-Collector Configuration

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

Primarily used for *impedance matching* purposes.

Common-Collector Configuration

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

Operating Limits

V_{CE} is maximum and I_C is minimum in the cutoff region.

$$I_{C(\max)} = I_{CEO}$$

I_C is maximum and V_{CE} is minimum in the saturation region.

$$V_{CE(\max)} = V_{CE(sat)} = V_{CEO}$$

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

Power Dissipation

Common-base:

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

Common-emitter:

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

Common-collector:

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

Transistor Specification Sheet

MAXIMUM RATINGS

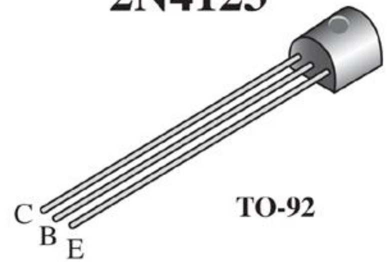
Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	V_{CEO}	30	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ T_A = 25˚C Derate above 25˚C	P_D	625 5.0	mW mW˚C
Operating and Storage Junction Temperature Range	T_j, T_{stg}	–55 to +150	˚C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	˚C W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	˚C W

FAIRCHILD
SEMICONDUCTOR ™

2N4123



General Purpose Transistor NPN Silicon

Transistor Testing

Curve Tracer — Provides a graph of the characteristic curves.

DMM — Some DMMs measure β_{DC} or h_{FE}.

Ohmmeter