

Session- 2018-19

Transistors

- Bipolar Junction Transistors
- Field Effect Transistors

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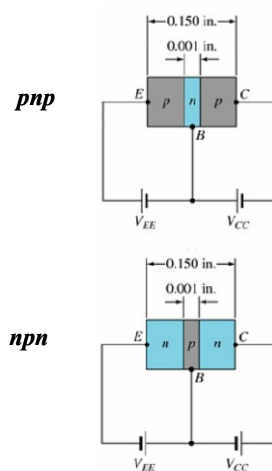
Bipolar Junction Transistor Construction

There are two types of transistors:

- *npn*
- *npn*

The terminals are labeled:

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

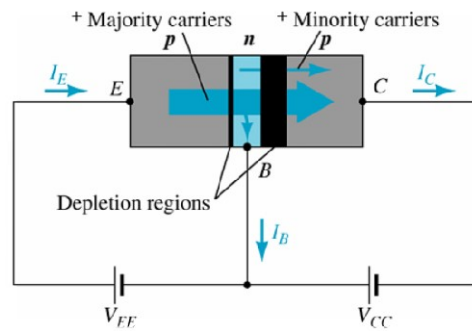


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Transistor Operation

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



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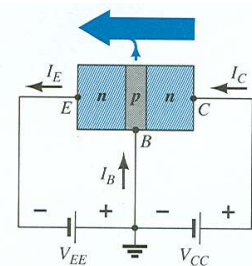
Currents in a Transistor

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:

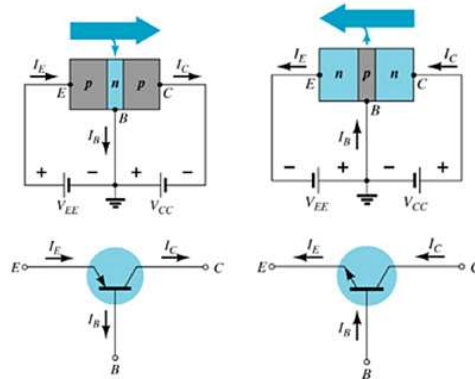
$$I_C = I_{C_{\text{majority}}} + I_{C_{\text{minority}}}$$



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Configuration

Common-Base Configuration



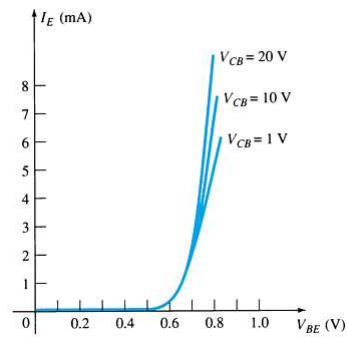
The base is common to both input (emitter–base) and output (collector–base) of the transistor.

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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.

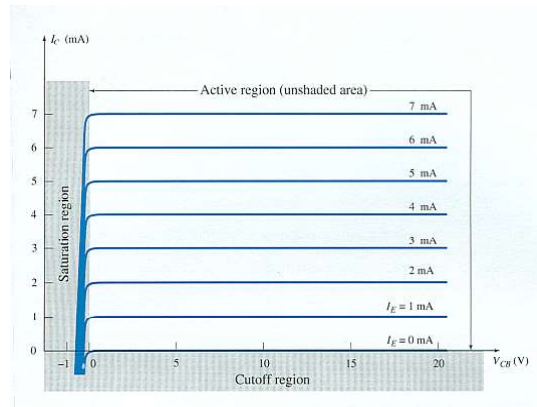


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Common-Base Amplifier

Output Characteristics

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



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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.

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Approximations

Emitter and collector currents:

$$I_C \cong I_E$$

Base-emitter voltage:

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

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Alpha (α)

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

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

Ideally: $\alpha = 1$

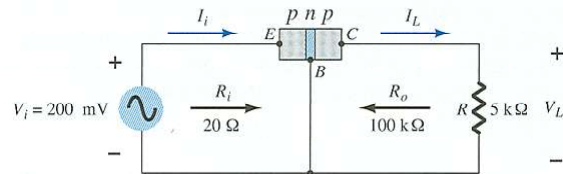
In reality: α is between 0.9 and 0.998

Alpha (α) in the AC mode:

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

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Transistor Amplification



Currents and Voltages:

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

$$I_C \cong I_E$$

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

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

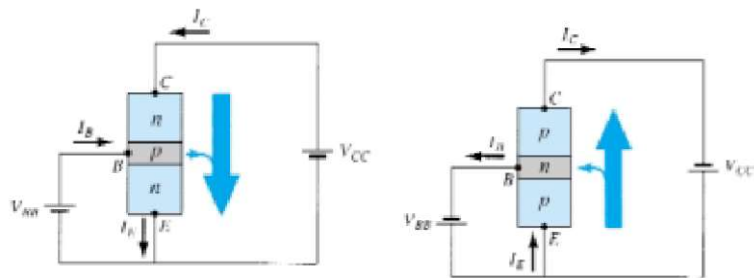
Voltage Gain:

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

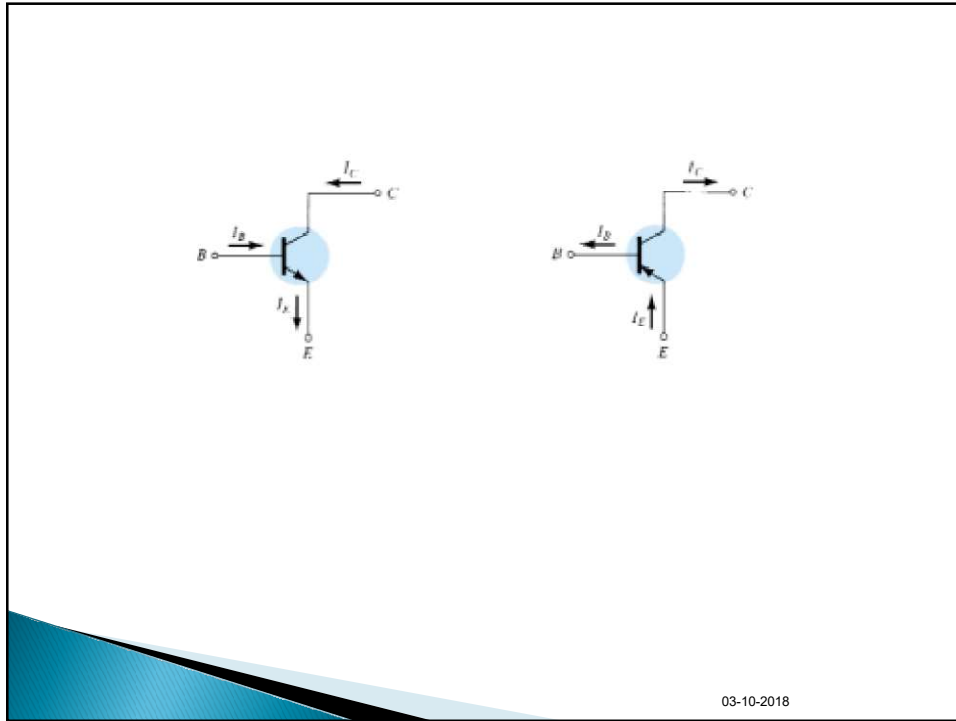
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Common-Emitter Configuration

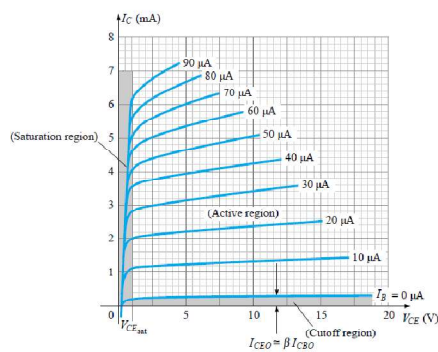
- The emitter is common to both input (base-emitter) and output (collector-emitter).
- The input is on the base and the output is on the collector.



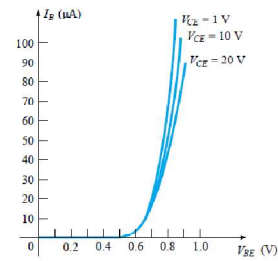
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Common-Emitter Characteristics



Output Characteristics



Input Characteristics

Common-Emitter Amplifier Currents

Ideal Currents

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

Actual Currents

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

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

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

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

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$$\begin{aligned}
 I_C &= \alpha I_E + I_{CBO} \\
 I_E &= I_C + I_B \\
 I_E &= \alpha (I_C + I_B) + I_{CBO} \\
 (1-\alpha)I_C &= \alpha I_B + I_{CBO} \\
 I_C &= \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha} \\
 I_C &= \beta I_B + I_{CEO} \\
 \text{when } I_B &= 0 \\
 I_C &= I_{CEO} = \frac{I_{CBO}}{1-\alpha}
 \end{aligned}$$

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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:

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

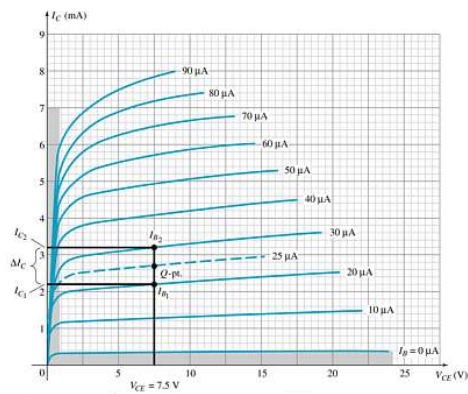
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Beta (β)

Determining β from a Graph

$$\begin{aligned} \beta_{AC} &= \frac{(3.2 \text{ mA} - 2.2 \text{ mA})}{(30 \mu\text{A} - 20 \mu\text{A})} \\ &= \frac{1 \text{ mA}}{10 \mu\text{A}} \Big|_{V_{CE} = 7.5} \\ &= 100 \end{aligned}$$

$$\begin{aligned} \beta_{DC} &= \frac{2.7 \text{ mA}}{25 \mu\text{A}} \Big|_{V_{CE} = 7.5} \\ &= 108 \end{aligned}$$



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Beta (β)

Relationship between amplification factors β and α

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

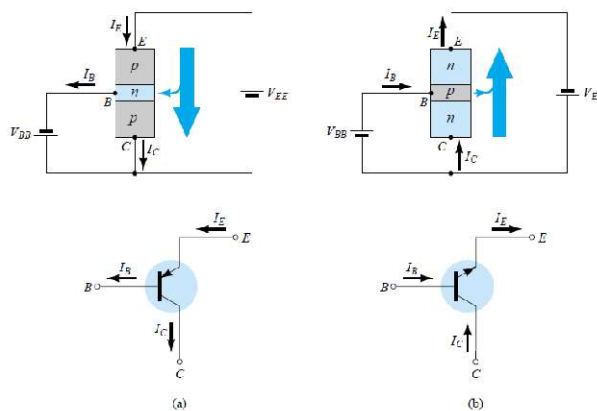
Relationship Between Currents

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

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Common-Collector Configuration

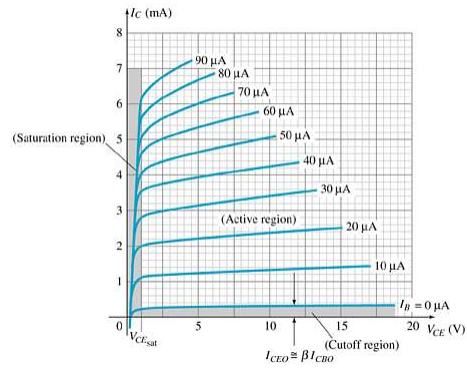
The input is on the base and the output is on the emitter.



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Common-Collector Configuration

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



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Relations

$$I_E = I_C + I_B$$

we have

$$\frac{I_C}{\alpha} = I_C + \frac{I_C}{\beta}$$

and dividing both sides of the equation by I_C will result in

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

or

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

so that

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

or

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

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Power Dissipation

Common-base:

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

Common-emitter:

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

Common-collector:

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

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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_{EB0}	5.0	Vdc
Collector Current - Continuous	I_C	200	mAdc
Total Device Dissipation @ $T_A = 25^\circ\text{C}$ 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



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Transistor Specification Sheet

ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ\text{C}$ unless otherwise noted)

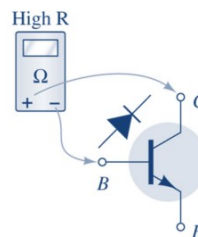
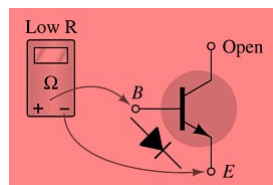
Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector-Emitter Breakdown Voltage (1) ($I_C = 1.0\text{ mAdc}$, $I_B = 0$)	$V_{(BR)CEO}$	30		Vdc
Collector-Base Breakdown Voltage ($I_C = 10\text{ }\mu\text{Adc}$, $I_E = 0$)	$V_{(BR)CBO}$	40		Vdc
Emitter-Base Breakdown Voltage ($I_E = 10\text{ }\mu\text{Adc}$, $I_C = 0$)	$V_{(BR)EBO}$	5.0	-	Vdc
Collector Cutoff Current ($V_{CE} = 20\text{ Vdc}$, $I_B = 0$)	I_{CBO}	-	50	nAdc
Emitter Cutoff Current ($V_{EB} = 3.0\text{ Vdc}$, $I_C = 0$)	I_{EBO}	-	50	nAdc
ON CHARACTERISTICS				
DC Current Gain (1) ($I_C = 2.0\text{ mAdc}$, $V_{CE} = 1.0\text{ Vdc}$) ($I_C = 50\text{ mAdc}$, $V_{CE} = 1.0\text{ Vdc}$)	h_{FE}	50 25	150 -	-
Collector-Emitter Saturation Voltage (1) ($I_C = 50\text{ mAdc}$, $I_B = 5.0\text{ mAdc}$)	$V_{CE(sat)}$	-	0.3	Vdc
Base-Emitter Saturation Voltage (1) ($I_C = 50\text{ mAdc}$, $I_B = 5.0\text{ mAdc}$)	$V_{BE(sat)}$	-	0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS				
Current Gain - Bandwidth Product ($I_C = 10\text{ mAdc}$, $V_{CE} = 20\text{ Vdc}$, $f = 100\text{ MHz}$)	f_T	250		MHz
Output Capacitance ($V_{CE} = 5.0\text{ Vdc}$, $I_C = 0$, $f = 100\text{ MHz}$)	C_{ob}	-	4.0	pF
Input Capacitance ($V_{BE} = 0.5\text{ Vdc}$, $I_C = 0$, $f = 100\text{ kHz}$)	C_{ib}	-	8.0	pF
Collector Base Capacitance ($I_C = 0$, $V_{CB} = 5.0\text{ V}$, $f = 100\text{ kHz}$)	C_{cb}	-	4.0	pF
Small-Signal Current Gain ($I_C = 2.0\text{ mAdc}$, $V_{CE} = 10\text{ Vdc}$, $f = 1.0\text{ kHz}$)	h_{fe}	50	200	-
Current Gain - High Frequency ($I_C = 10\text{ mAdc}$, $V_{CE} = 20\text{ Vdc}$, $f = 100\text{ MHz}$) ($I_C = 2.0\text{ mAdc}$, $V_{CE} = 10\text{ V}$, $f = 1.0\text{ kHz}$)	h_{fe}	2.5 50	- 200	-
Noise Figure ($I_C = 100\text{ }\mu\text{Adc}$, $V_{CE} = 5.0\text{ Vdc}$, $R_G = 1.0\text{ k ohm}$, $f = 1.0\text{ kHz}$)	NF	-	6.0	dB

(1) Pulse Test: Pulse Width = 300 μs . Duty Cycle = 2.0%.

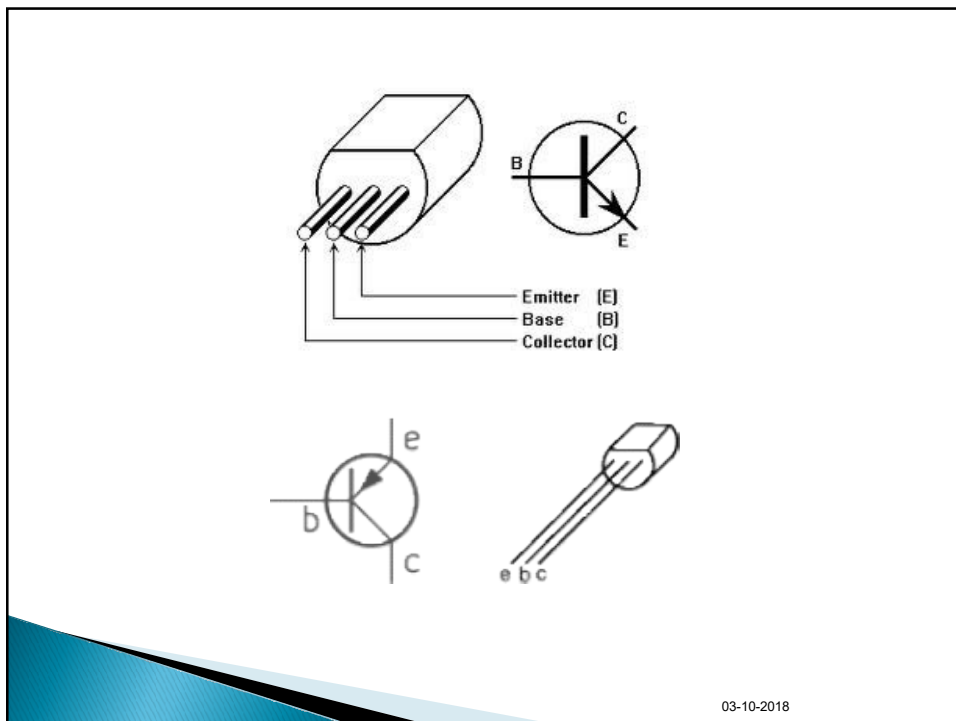
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Transistor Testing

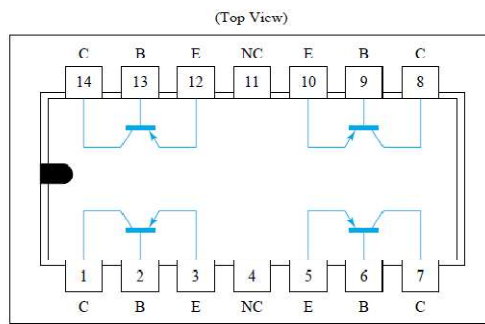
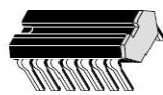
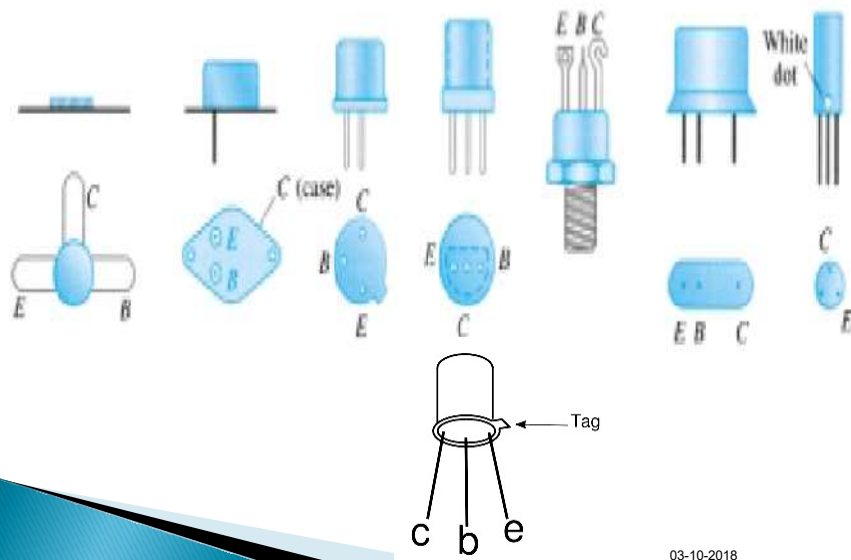
- **Curve Tracer**
Provides a graph of the characteristic curves.
- **DMM**
Some DMMs measure β_{DC} or h_{FE} .
- **Ohmmeter**



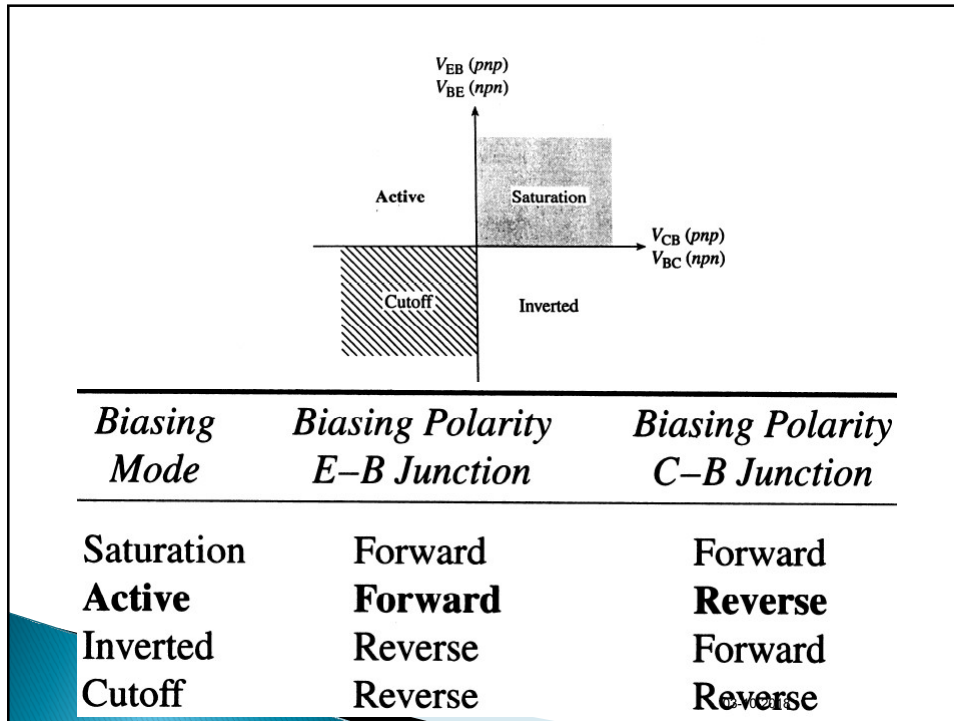
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Transistor Terminal Identification



(b)



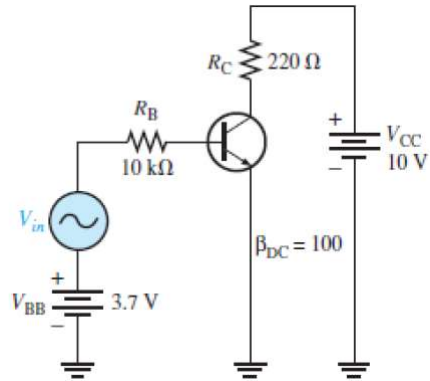
Summary

Parameters	Common Emitter	Common Collector	Common Base
Voltage Gain	Medium(around 500)	Low(less than unity)	High
Current Gain	Medium(around 100)	High(More than CE)	Low(around 0.9 to .998)
Input Impedance	Medium(around 800ohm)	High(around 750kohm)	Low(around 100ohm)
Output Impedance	Medium(around 50kohm)	Low(around 25ohm)	High(around 500kohm)
Phase	180 degree	0 degree	0 degree

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Numerical

(assume base current to vary 100microamp. around Q.point)

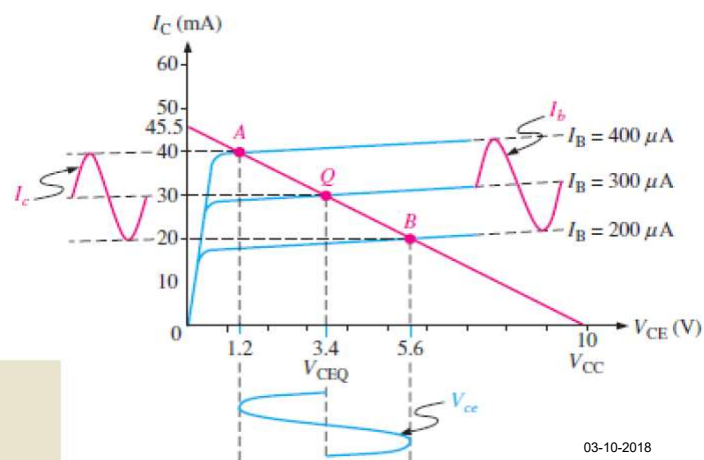


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$$I_{BQ} = \frac{V_{BB} - 0.7 \text{ V}}{R_B} = \frac{3.7 \text{ V} - 0.7 \text{ V}}{10 \text{ k}\Omega} = 300 \mu\text{A}$$

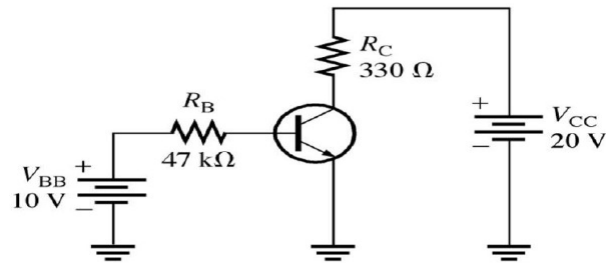
$$I_{CQ} = \beta_{DC} I_{BQ} = (100)(300 \mu\text{A}) = 30 \text{ mA}$$

$$V_{CEQ} = V_{CC} - I_{CQ} R_C = 10 \text{ V} - (30 \text{ mA})(220 \Omega) = 3.4 \text{ V}$$



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2. Determine Q-point and find the maximum peak value of base current, for linear operation $\beta_{dc} = 200$



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$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10V - 0.7V}{47K\Omega} = 198\mu A = I_{BQ}$$

$$I_C = \beta_{DC} I_B = (200)(198\mu A) = 39.6mA = I_{CQ}$$

$$V_{CE} = V_{CC} - I_C R_C = 20V - 13.07 \\ = 6.93V = V_{CEQ}$$

$$* I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{20V}{330\Omega}$$

$$* I_{C(\text{cut off})} = 0$$

$$I_{C(sat)} - I_{CQ} = 60.6 - 39.6 = 21mA$$

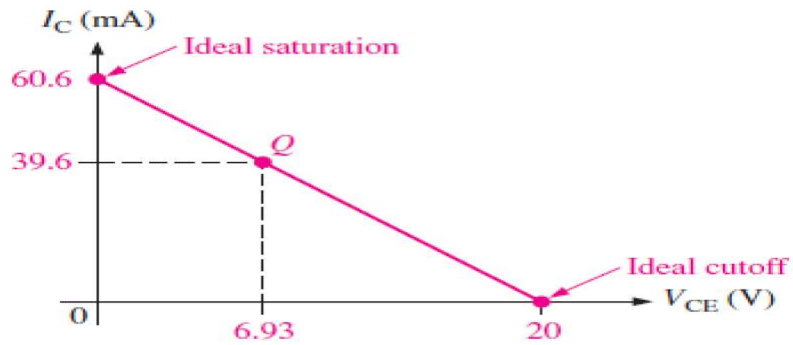
$$I_{CQ} - I_{C(\text{cut off})} = 39.6 - 0 = 39.6mA$$

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∴ Q-point is in closer to saturation than the cutoff

∴ 21mA is the maximum peak variation ($I_{C(max)}$) of the collector current

$$\therefore I_{b(peak)} = \frac{I_{C(peak)}}{\beta_{DC}} = \frac{21mA}{200} = 105\mu A \text{ \#}$$



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