

## Electronic Circuits

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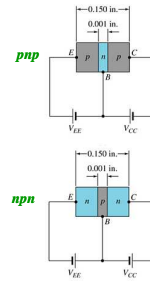
## Transistor Construction

There are two types of transistors:

- *pnp*
- *npn*

The terminals are labeled:

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

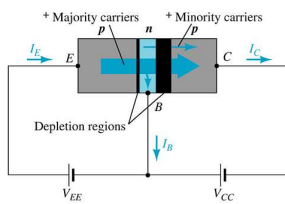


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## Transistor Operation

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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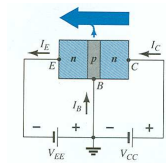
## Currents in a Transistor

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

$$I_E = I_C + I_B$$

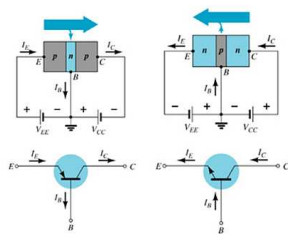
The collector current is comprised of two currents:

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



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## Common-Base Configuration



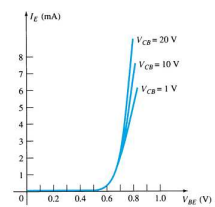
The base is common to both input (emitter-base) and output (collector-base) of the transistor.

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## Common-Base Amplifier

### Input Characteristics

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

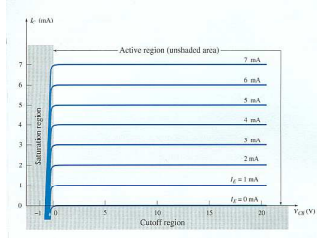


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## Common-Base Amplifier

### 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 ( $\alpha$ )

Alpha ( $\alpha$ ) is the ratio of  $I_C$  to  $I_E$  :

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

Ideally:  $\alpha = 1$

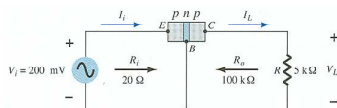
In reality:  $\alpha$  is between 0.9 and 0.998

Alpha ( $\alpha$ ) 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:

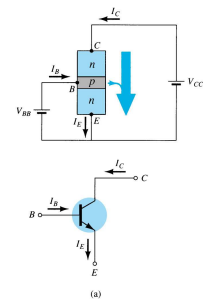
$$A_v = \frac{V_L}{V_i} = \frac{50\text{V}}{200\text{mV}} = 250$$

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## Common-Emitter Configuration

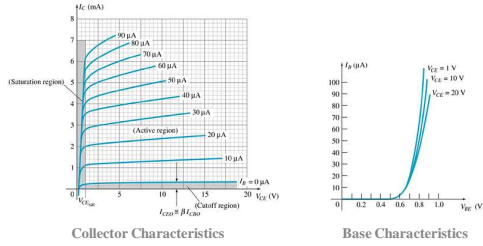
The emitter is common to both input (base-emitter) and output (collector-emitter).

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



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## Common-Emitter Characteristics



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## Common-Emitter Amplifier Currents

### Ideal Currents

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

### 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  $I_{CEO}$ .

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

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## Beta ( $\beta$ )

$\beta$  represents the amplification factor of a transistor. ( $\beta$  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:

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

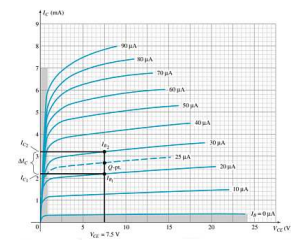
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## Beta ( $\beta$ )

Determining  $\beta$  from a Graph

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

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



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## Beta ( $\beta$ )

Relationship between amplification factors  $\beta$  and  $\alpha$

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

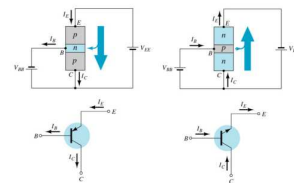
Relationship Between Currents

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

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## Common-Collector Configuration

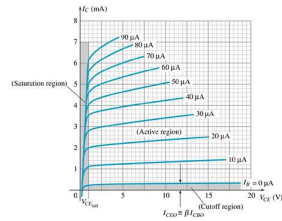
The input is on the base and the output is on the emitter.



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## Common-Collector Configuration

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



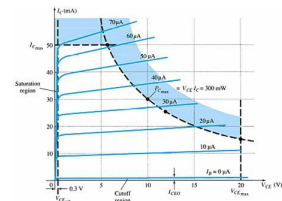
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## Operating Limits for Each Configuration

$V_{CE}$  is at maximum and  $I_C$  is at minimum ( $I_{Cmax} = I_{CE0}$ ) in the cutoff region.

$I_C$  is at maximum and  $V_{CE}$  is at minimum ( $V_{CEmax} = V_{CEsat} = V_{CE0}$ ) in the saturation region.

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



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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 Breakdown Voltage  $V_{CE0}$  30 Vdc

Collector-Base Voltage  $V_{CB0}$  30 Vdc

Emitter-Base Voltage  $V_{EB0}$  5.0 Vdc

Collector Current - Continuous  $I_C$  200 mAdc

Total Device Dissipation at  $T_C = 25^\circ\text{C}$   $P_D$  625 mW

Dissip above  $25^\circ\text{C}$  5.0 mW/°C

Operating and Storage Junction Temperature Range  $T_J, T_{stg}$  -55 to +150 °C

Operating and Storage Junction Temperature Range

Thermal Resistance, Junction to Case  $R_{\theta jc}$  33.3 °C/W

Thermal Resistance, Junction to Ambient  $R_{\theta ja}$  200 °C/W

Thermal Resistance, Junction to Ambient



Thermal Resistance, Junction to Case

Thermal Resistance, Junction to Ambient

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## Transistor Specification Sheet

Characteristics	Symbol	Min	Max	Unit
<b>OFF CHARACTERISTICS</b>				
Collector-Emitter Breakdown Voltage (1)	$V_{CE0}$	30	—	Vdc
Collector-Base Breakdown Voltage (1)	$V_{CB0}$	30	—	Vdc
Emitter-Base Breakdown Voltage (1)	$V_{EB0}$	5.0	—	Vdc
Collector Current - Continuous (1)	$I_C$	—	200	mAdc
Emitter Current - Continuous (1)	$I_E$	—	200	mAdc
Base Current - Continuous (1)	$I_B$	—	50	mAdc
<b>ON CHARACTERISTICS</b>				
DC Current Gain (1)	$\beta_{DC}$	20	150	—
Collector-Emitter Saturation Voltage (1)	$V_{CE(sat)}$	—	0.3	Vdc
Base-Emitter Saturation Voltage (1)	$V_{BE(sat)}$	—	0.65	Vdc
<b>SMALL-SIGNAL CHARACTERISTICS</b>				
Current Gain - Breakdown Point (1)	$\beta_{DC}$	20	—	dBdc
Output Capacitance (1)	$C_{out}$	—	4.0	pF
Input Capacitance (1)	$C_{in}$	—	8.0	pF
Collector-Base Capacitance (1)	$C_{cb}$	—	4.0	pF
Small-Signal Current Gain (1)	$\beta_{AC}$	30	200	—
Current Gain - High Frequency (1)	$\beta_{AC}$	2.0	—	—
Noise Figure (1)	NF	—	6.0	dB

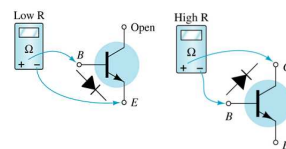
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## Transistor Testing

- Curve Tracer  
Provides a graph of the characteristic curves.

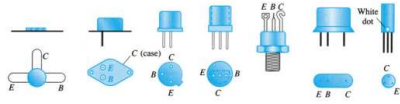
- DMM  
Some DMMs measure  $\beta_{DC}$  or  $h_{FE}$ .

- Ohmmeter



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## Transistor Terminal Identification



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