Electronic and Digital Circuits (ELC 225a)

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Outline

1. Bipolar Junction Transistor
   - Introduction
   - Device Structure and Physical Operation
   - Current-Voltage Characteristics
   - DC Operation
   - Small-Signal Operation
   - Applications: Basic BJT Amplifier Circuits

Introduction

Bipolar Junction Transistor

1. One of the main building blocks in electronic systems
2. Three terminal device that can be used for both analog and digital circuits
3. Incorporate two back-to-back PN junctions
4. Can be used as a control device
5. Control is generally due to electric current (flow of charge carriers), i.e. the current flow in one terminal controls the current between the other two terminals

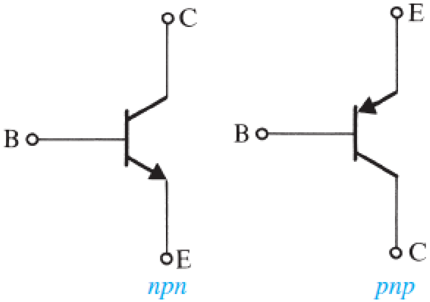
BJT Circuit Symbols

Three Terminals Device

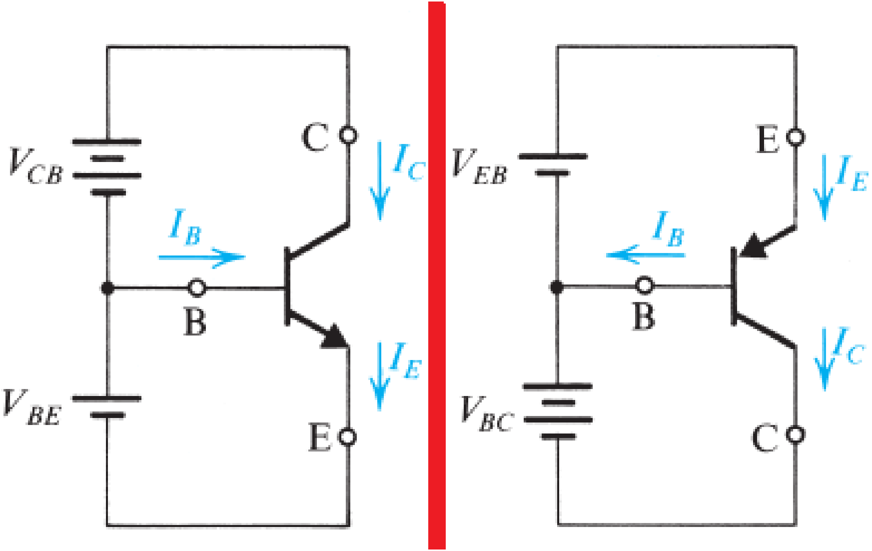
- Base (B) $\Rightarrow$ Control terminal
- Emitter (E)
- Collector (C)

Two Types

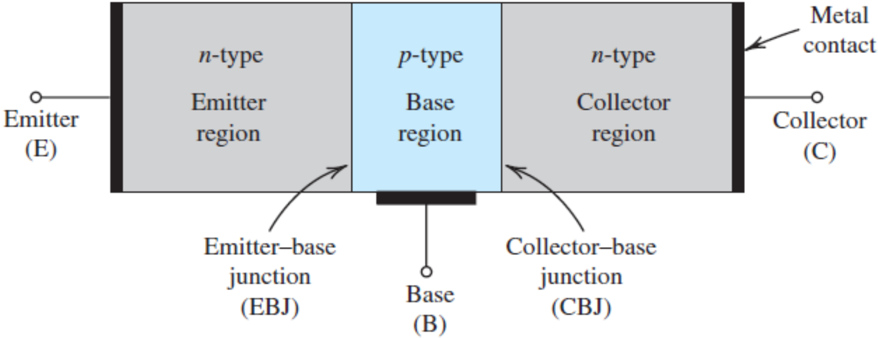
- npn Type
- pnp Type



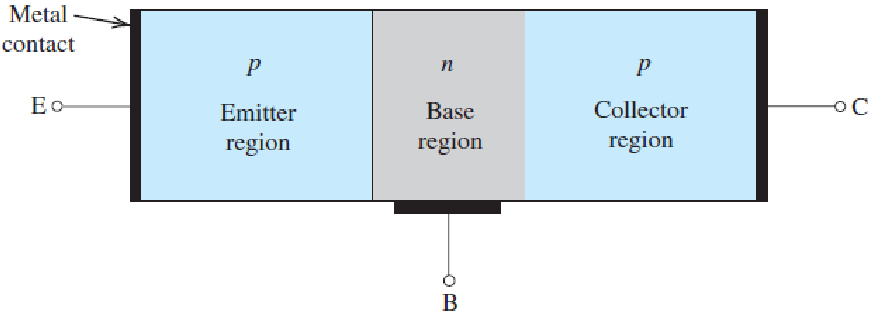
Terminology



Device Structure: npn Type



Device Structure: pnp Type

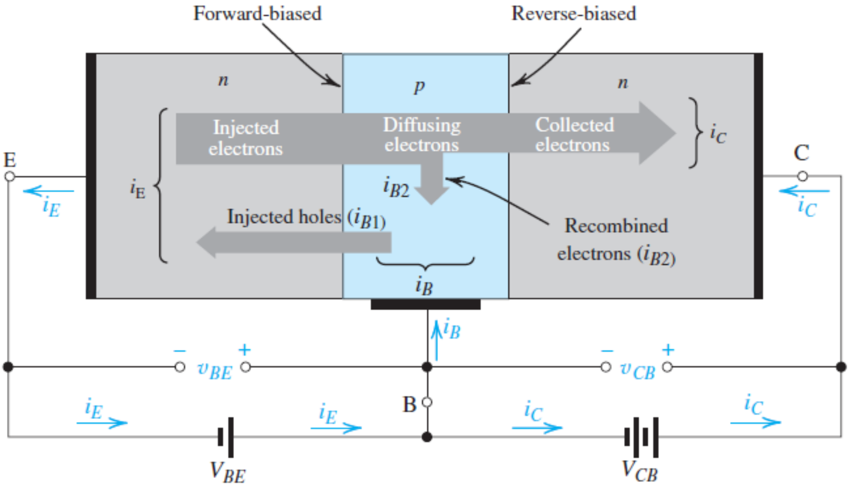


BJT Modes of Operation

BJT Modes of Operation

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

Physical Operation: npn Type BJT



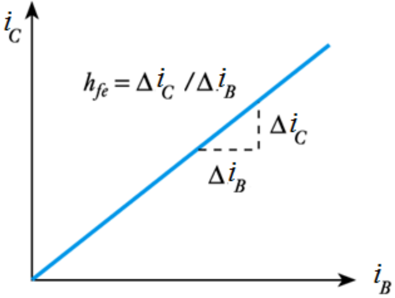
Physical Operation: npn Type BJT

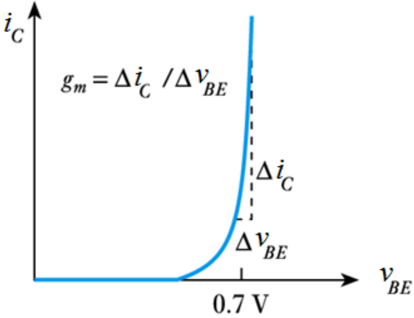
- Collector is normally more positive than the Emitter
- V_{CE} might be a few volts
- The device resembles two back-to-back diodes

With positive V_{BE}

- This forward biases the Base-Emitter junction
- The base region is lightly doped and very thin
- Because it is lightly doped, the current produced is mainly electrons flowing from the emitter to the base
- Because the base region is thin, most of the electrons entering the base get swept across the Base-Collector junction into the collector
- This produces a collector current that is much larger than the base current
- This gives current amplification

Input-Output Relations

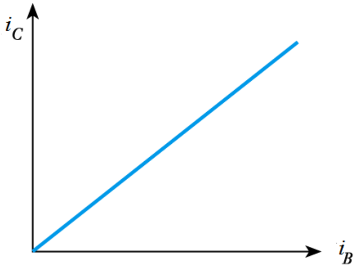




Current-Current ($i_C - i_B$) Characteristics

Collector Current - Base Current Relation

$$i_C = \beta i_B$$



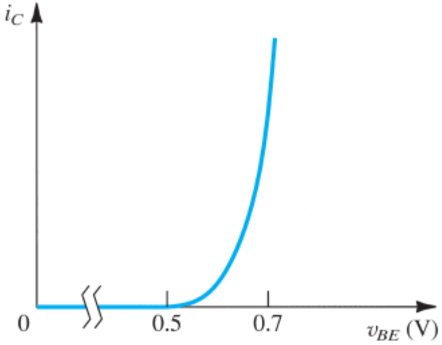
1. Characteristic is approximately linear
2. Magnitude of collector current is generally many times that of the base current
3. The device provides current gain β

Current-Voltage ($i_C - v_{BE}$) Characteristics

Collector Current - Base-Emitter Voltage Relation

$$i_C = I_S \exp\left[\frac{v_{BE}}{V_T}\right]$$

Note: Both I_S and V_T are temperature dependent.



Current–Voltage Relationships in the Active Mode

$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$$

$$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$$

Note: For the *pnp* transistor, replace v_{BE} with v_{EB}.

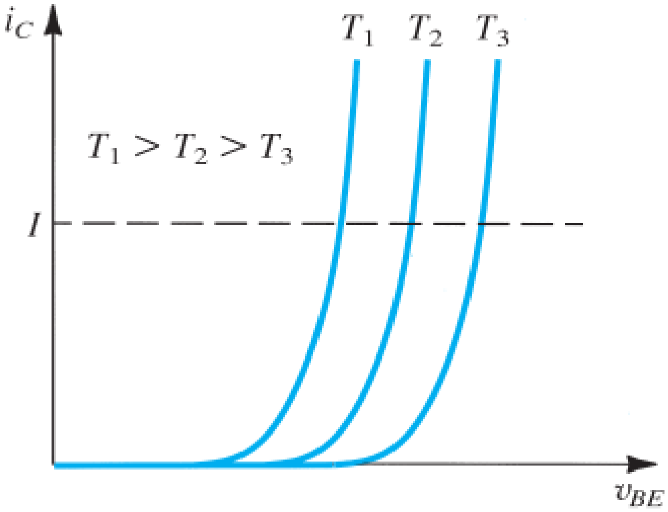
$$i_C = \alpha i_E \qquad i_B = (1-\alpha) i_E = \frac{i_E}{\beta+1}$$

$$i_C = \beta i_B \qquad i_E = (\beta+1) i_B$$

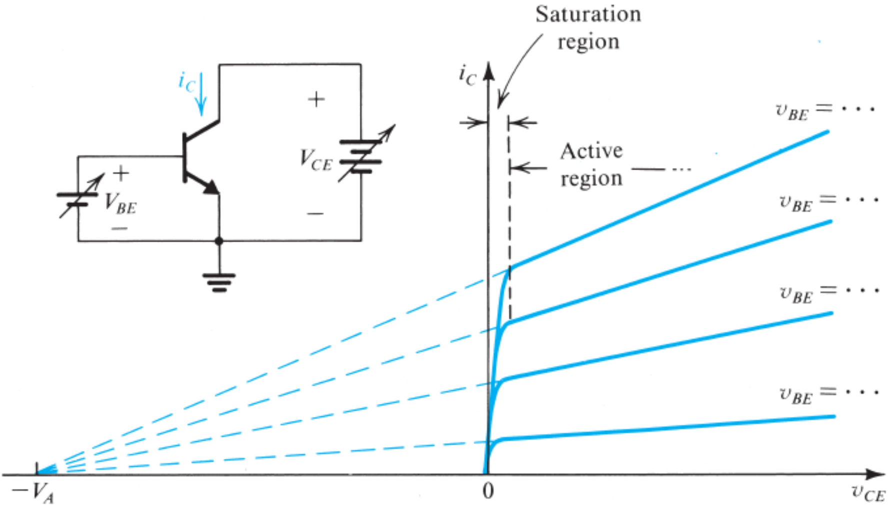
$$\beta = \frac{\alpha}{1-\alpha} \qquad \alpha = \frac{\beta}{\beta+1}$$

$$V_T = \text{thermal voltage} = \frac{kT}{q} \simeq 25 \text{ mV} \quad \text{at room temperature}$$

Current-Voltage Characteristics



Common-Emitter Characteristics - Early Voltage

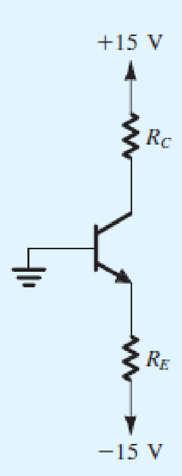


DC Operation: Example 1

$\beta = 100$
$v_{BE} = 0.7$ V at $i_C = 1$ mA

Design the circuit so that a current of $2mA$ flows through the collector and a voltage of $+5V$ appears at the collector.

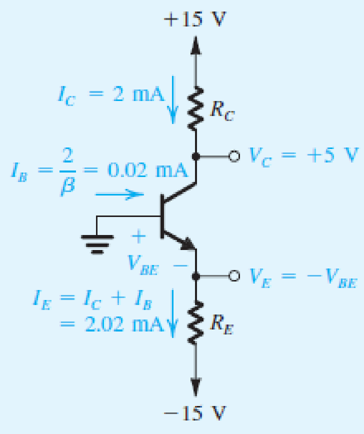
Design the circuit $\Leftarrow$ Find the values of R_C and R_E



Given;
$I_C = 2$ mA
$V_C = 5$ V

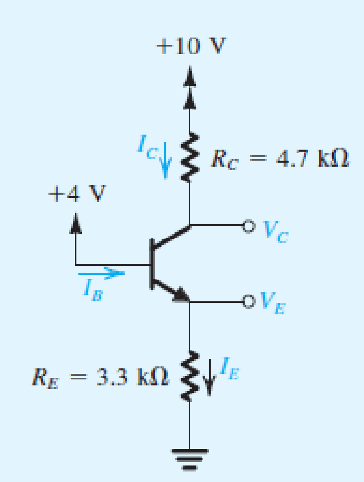
Then;

1. $R_C = \dfrac{+15 - V_C}{I_C}$
2. $I_E = \dfrac{\beta + 1}{\beta} I_C$
3. $V_{BE} = v_{BE} + V_T \ln\left(\dfrac{I_C}{i_C}\right)$
4. $R_E = \dfrac{(0 - V_{BE}) - (-15)}{I_E}$

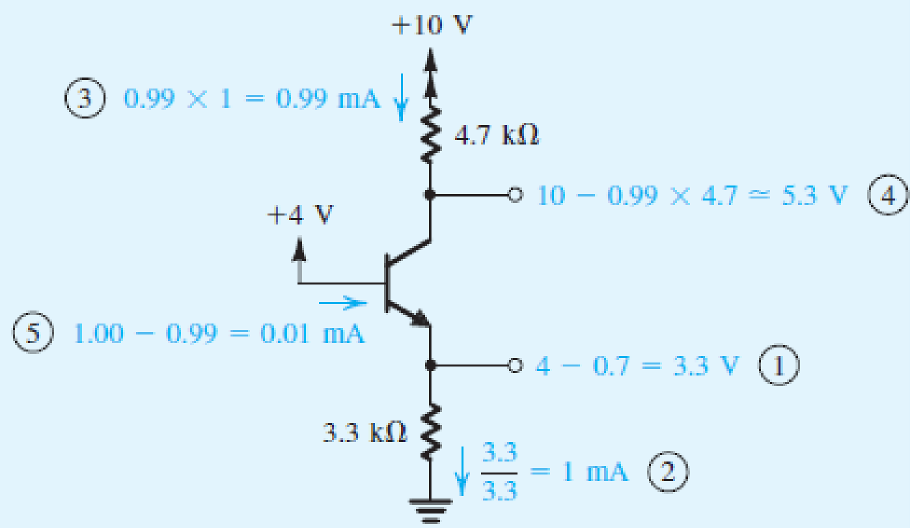


DC Operation: Example 2

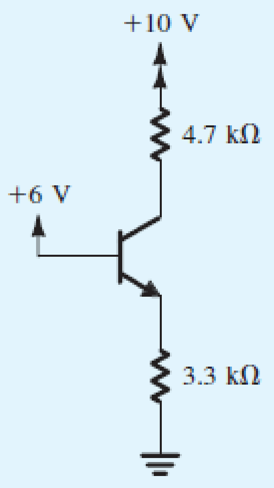
$\beta = 100$
Analyze this circuit to determine all node voltages and branch currents



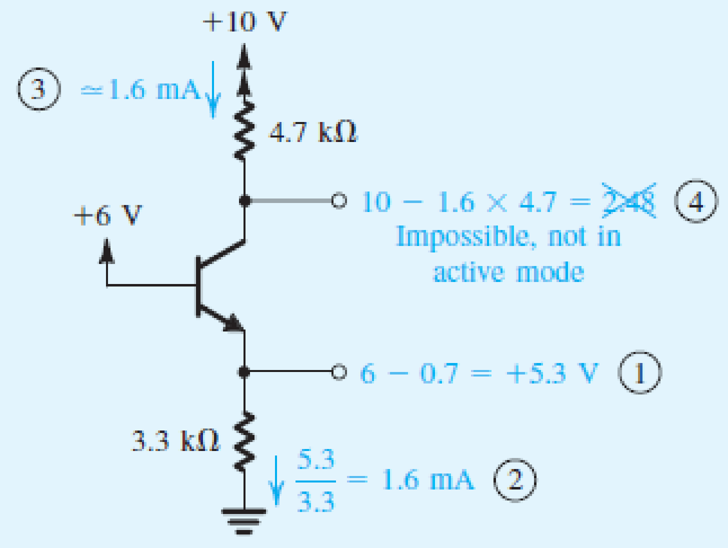
DC Operation: Example 2



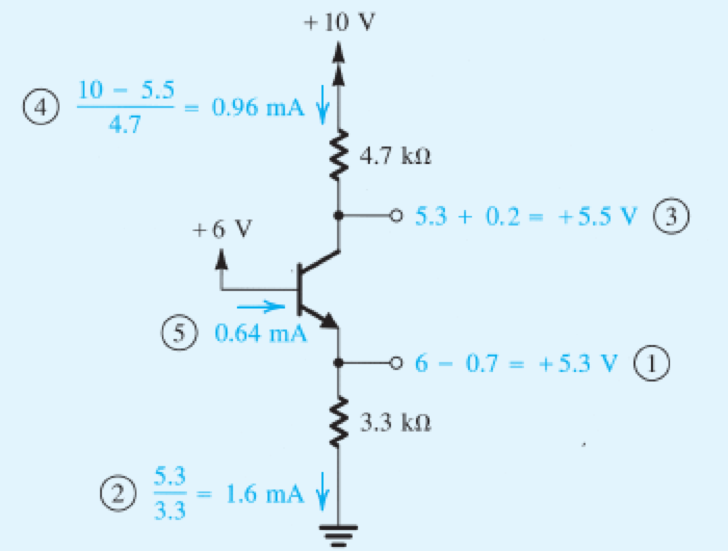
$\beta = 50$
Analyze this circuit to determine all node voltages and branch currents



DC Operation: Example 3

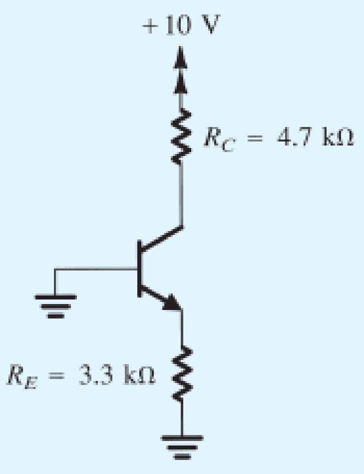


DC Operation: Example 3

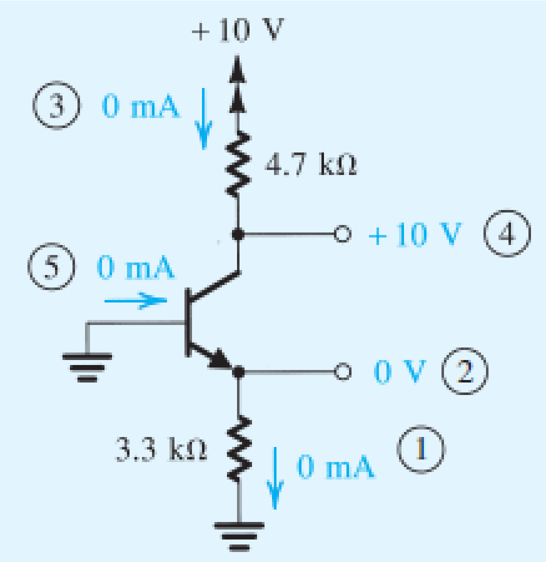


DC Operation: Example 4

$\beta = 100$
Analyze this circuit to determine all node voltages and branch currents

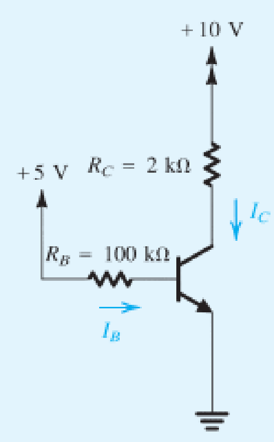


DC Operation: Example 4

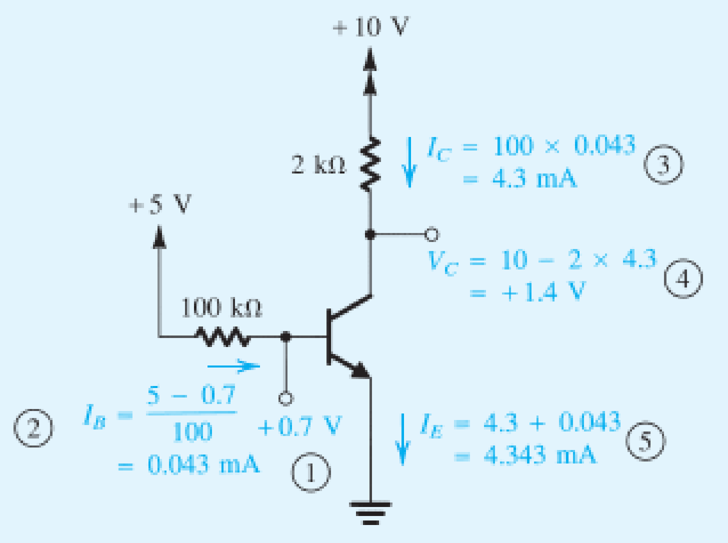


DC Operation: Example 5

$\beta = 50$
Analyze this circuit to determine all node voltages and branch currents



DC Operation: Example 5



References

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Thank You

Questions ?

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