Session- 2018-19

# Transistors

- Bipolar Junction Transistors
- Field Effect Transistors



## Bipolar Junction Transistor Construction

**There are two types of transistors:**

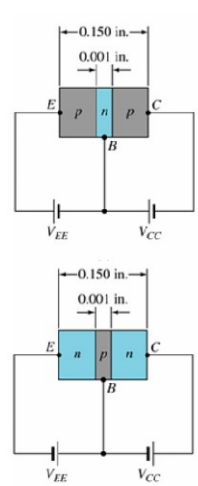
- ***pnp***
- ***npn***

**The terminals are labeled:**

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

***pnp***

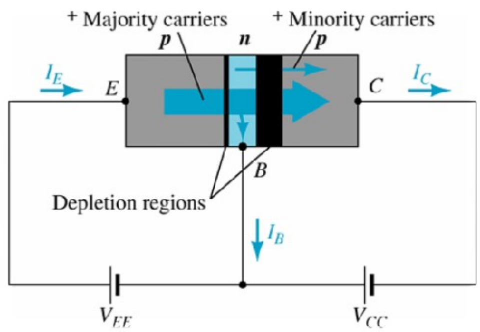
***npn***



# 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





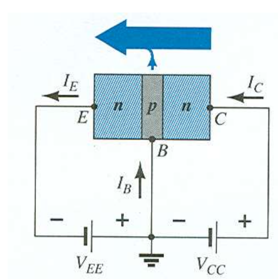

# Currents in a Transistor

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

$$I_E = I_C + I_B$$

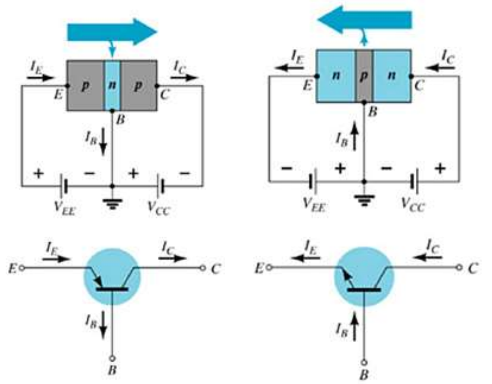
**The collector current is comprised of two currents:**

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



# Configuration

**Common-Base Configuration**



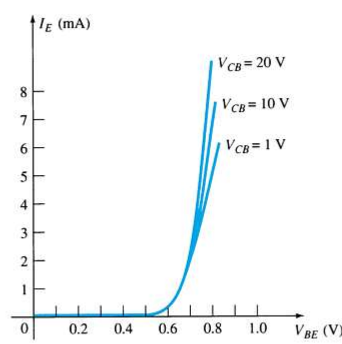

**The base is common to both input (emitter–base) and output (collector–base) of the transistor.**



# Common-Base Amplifier

**Input Characteristics**

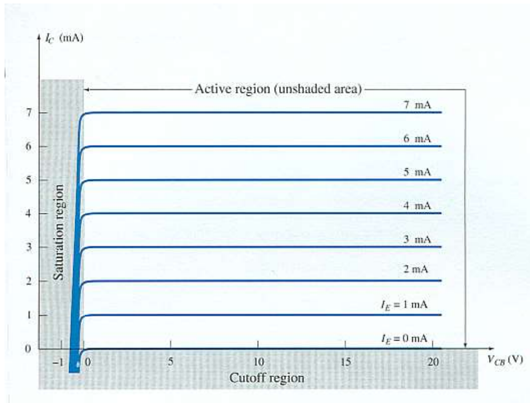
**This curve shows the relationship between of input current ($I_E$) to input voltage ($V_{BE}$) for three output voltage ($V_{CB}$) levels.**



# 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:**

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



# Alpha (α)

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

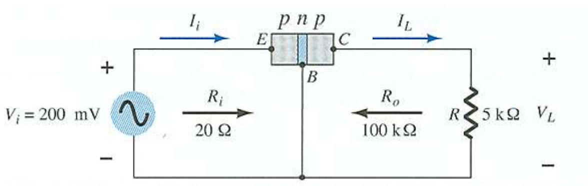
$$\alpha_{dc} = \frac{I_C}{I_E}$$

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

**Alpha ($\alpha$) in the AC mode:**

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

# Transistor Amplification




**Currents and Voltages:**

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

$$I_C \cong I_E$$

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

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

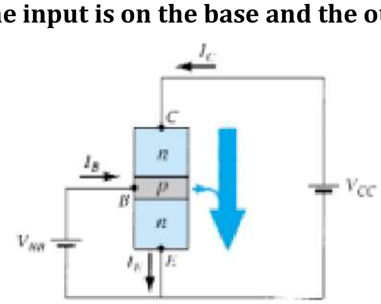
**Voltage Gain:**

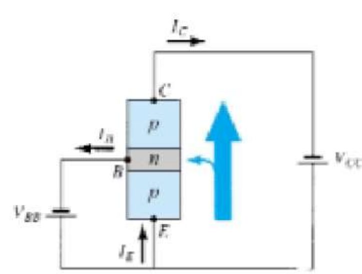
$$A_v = \frac{V_L}{V_i} = \frac{50\text{V}}{200\text{mV}} = 250$$

03-10-2018

# 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.**

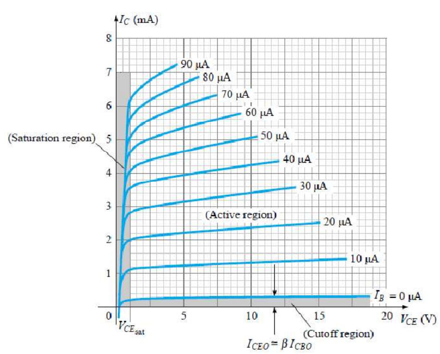


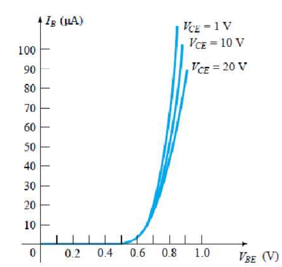

03-10-2018




# 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**

$I_C = \alpha I_E + I_{CBO}$ **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 $I_{CEO}$.**

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



$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = I_C + I_B$$

$$I_E = \alpha (I_C + I_B) + I_{CBO}$$

$$(1-\alpha) I_C = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

$$I_C = \beta I_B + I_{CEO}$$

when $I_B = 0$

$$I_C = I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

# 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:

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

In AC mode:

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

03-10-2018

# Beta (β)

**Determining β from a Graph**

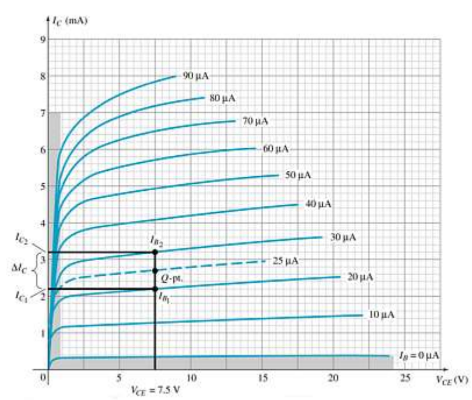
$$\beta_{AC} = \frac{(3.2\,\text{mA} - 2.2\,\text{mA})}{(30\,\mu\text{A} - 20\,\mu\text{A})}$$

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

$$= 100$$

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

$$= 108$$




03-10-2018

# Beta (β)

**Relationship between amplification factors β and α**

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

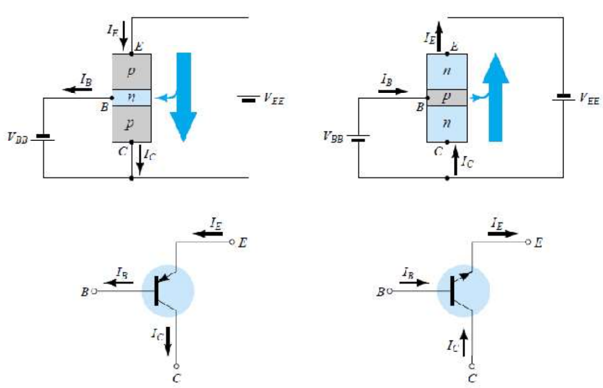
**Relationship Between Currents**

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



# Common–Collector Configuration

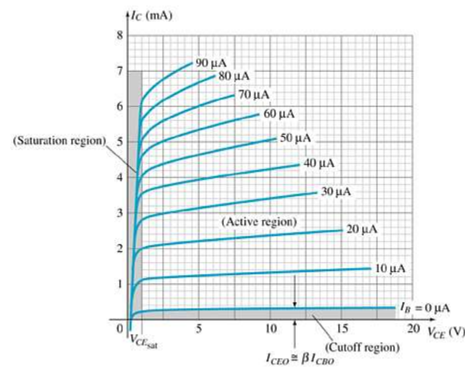
**The input is on the base and the output is on the emitter.**




(a) (b)

# Common–Collector Configuration

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






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

# Power Dissipation

**Common-base:**

$$P_{C\max} = V_{CB} I_C$$

**Common-emitter:**

$$P_{C\max} = V_{CE} I_C$$

**Common-collector:**

$$P_{C\max} = V_{CE} I_E$$



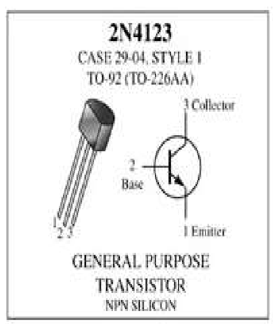
# Transistor Specification Sheet

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 @ $T_A = 25°C$<br>Derate above 25°C | $P_D$ | 625<br>5.0 | mW<br>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 | $R_{θJC}$ | 83.3 | °C/W |
| Thermal Resistance, Junction to Ambient | $R_{θJA}$ | 200 | °C/W |



# Transistor Specification Sheet

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

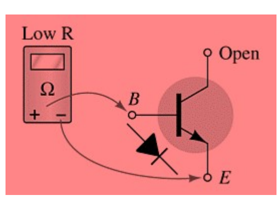
| Characteristic | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | |
| Collector-Emitter Breakdown Voltage (1) ($I_C = 1.0$ mAdc, $I_E = 0$) | $V_{(BR)CEO}$ | 30 | | Vdc |
| Collector-Base Breakdown Voltage ($I_C = 10$ μAdc, $I_E = 0$) | $V_{(BR)CBO}$ | 40 | | Vdc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

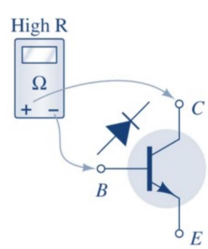
(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%



# Transistor Testing

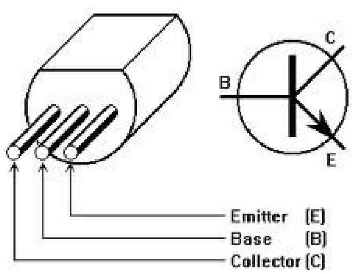
- **Curve Tracer**
  **Provides a graph of the characteristic curves.**
- **DMM**
  **Some DMMs measure $\beta_{DC}$ or $h_{FE}$.**
- **Ohmmeter**

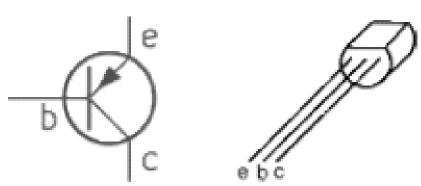


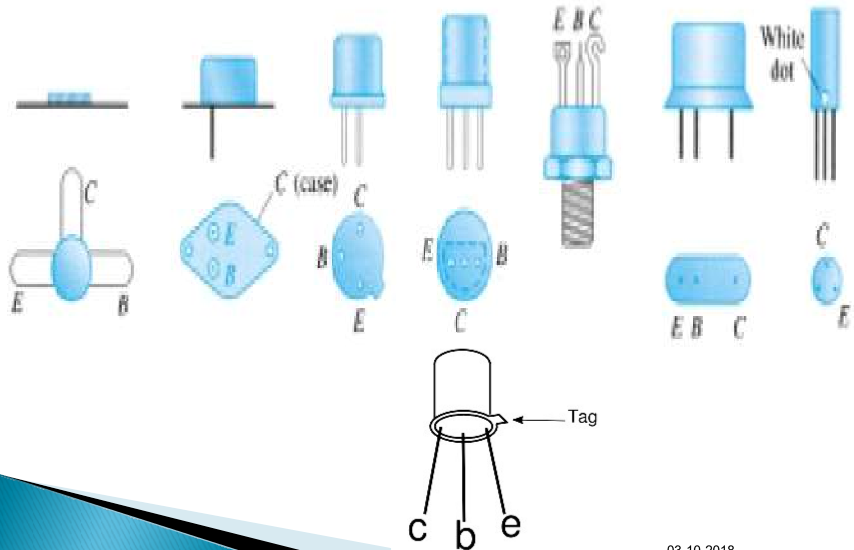

HOLD
BACKLIGHT
OFF
10ADC
COM
VΩmA
CAT II 600V
10A MAX
UNFUSED
MAX 600V
200mA/250V
MAS830L



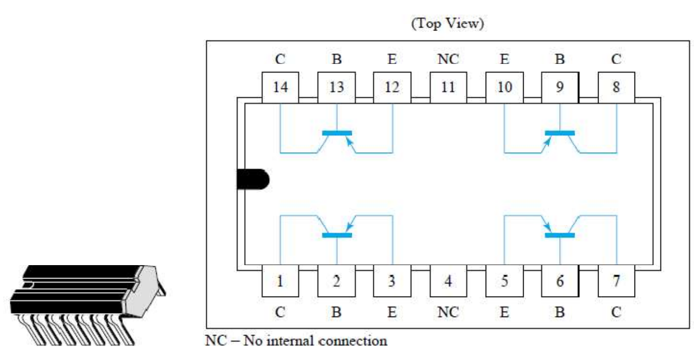

C
B
E
Emitter (E)
Base (B)
Collector (C)


e
b
c
e b c

# Transistor Terminal Identification

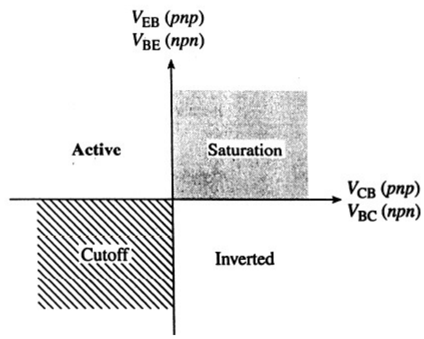



03-10-2018




(a) (b)

03-10-2018




| Biasing Mode | Biasing Polarity E–B Junction | Biasing Polarity C–B Junction |
|---|---|---|
| Saturation | Forward | Forward |
| **Active** | **Forward** | **Reverse** |
| Inverted | Reverse | Forward |
| Cutoff | Reverse | Reverse |

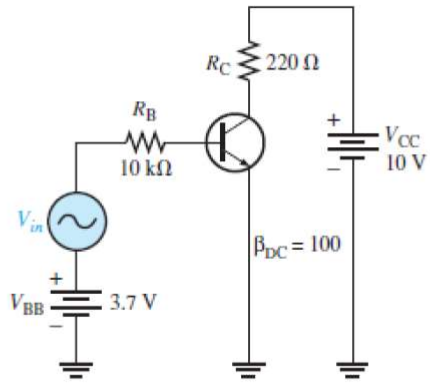


## Summary

| 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(around100ohm) |
| Output Impedance | Medium(around 50kohm) | Low(around 25ohm) | High(around 500kohm) |
| Phase | 180 degree | 0 degree | 0 degree |

**Numerical**

(assume base current to varry 100microamp. around Q.point

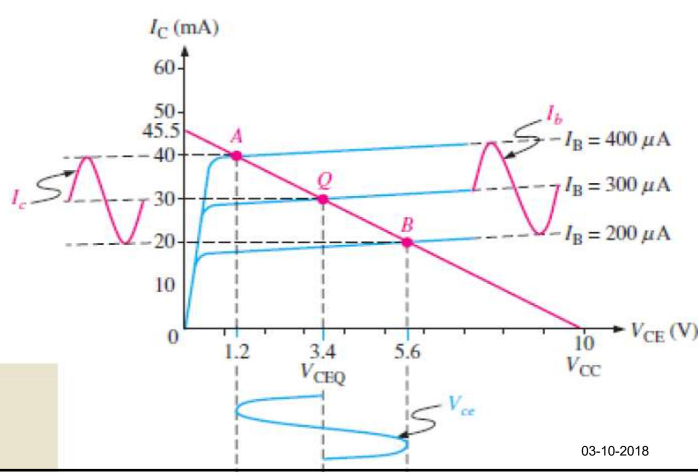



03-10-2018

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

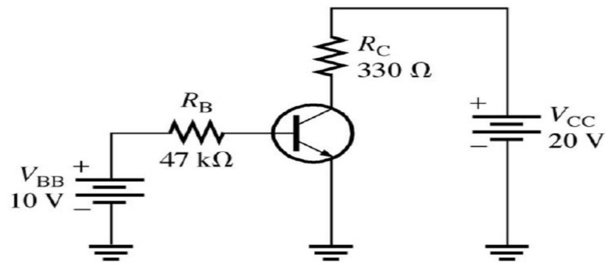
$$I_{CQ} = \beta_{DC} I_{BQ} = (100)(300\ \mu\text{A}) = 30\text{ mA}$$

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




03-10-2018

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






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

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

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

$$= 6.93V = V_{CEQ}$$

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

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

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

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

03-10-2018

$\therefore$ Q-point is in closer to saturation than the cutoff

$\therefore$ $21mA$ is the maximum peak variation ($I_{C(max)}$) of the collector curent

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