ELECTRONIC SYSTEM

AMPLIFIER

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PREFACE

This books aims for students of mechatronic engineering with the explanation of the basic concepts of semiconductor devices to diode, transistor, Common emitter, biased voltage divider, collector amplifier, and Common base.

The entire book is written in a simple way to enable them to students understand the concepts quickly and the subject in easy way. This book shall provide knowledge on the theory, concept and application of formula and to acquire the problem solving skills related to the respective processes.

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AMPLIFIER

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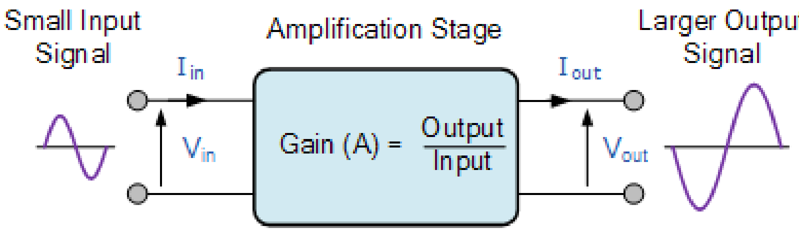
INTRODUCTION

- **WHAT IS AMPLIFIER?**
  - An electronic device that increases the power of a signal.
  - Amplifiers is a circuit that contains the amplifying device, such as a **Transistor**, Field Effect Transistor or Op-amp, with the output signal being much greater than that of the input signal.

- **AMPLIFIER GAIN**
  - Amplifier gain is simply the ratio of the output divided-by the input.



  - There are three different kinds of amplifier gain which can be measured;
    - Voltage Gain (A_v),
    - Current Gain (A_i)
    - Power Gain (A_p)

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INTRODUCTION

- **VOLTAGE GAIN**
  - $$\textit{Voltage Gain}\ (A_V) = \frac{\textit{Output Voltage}}{\textit{Input Voltage}} = \frac{V_{out}}{V_{in}}$$
- **CURRENT GAIN**
  - $$\textit{Current Gain}\ (A_i) = \frac{\textit{Output Current}}{\textit{Input Current}} = \frac{I_{out}}{I_{in}}$$
- **POWER GAIN**
  - $$\textit{Power Gain}\ (A_p) = \frac{\textit{Output Power}}{\textit{Input Power}} = \frac{P_{out}}{P_{in}}$$
- Common Amplifier devices;
  - Hi-fi or home theater unit
  - In car entertainment - (radio ➔AMPLIFIER ➔ sub woofer/speaker)

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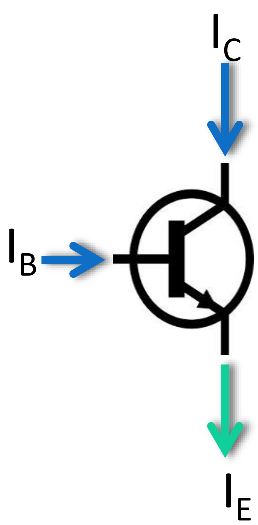
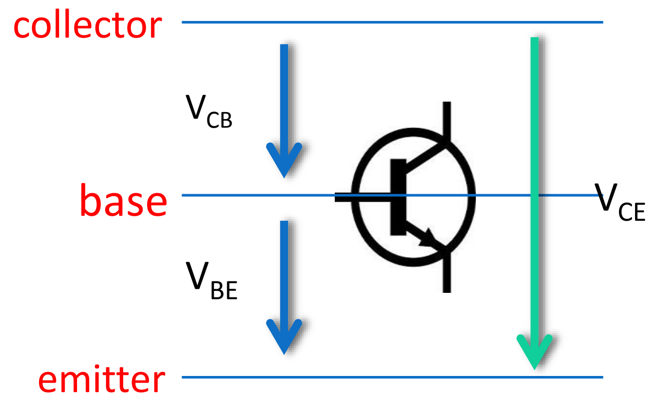
INTRODUCTION

- TRANSISTOR BASIC FORMULA (**K**irchoff **C**urrent **L**aw and **K**irchoff **V**oltage **L**aw)





$I_E = I_B + I_C$

$V_{CE} = V_{CB} + V_{BE}$

$$V_{BE} = 0.7V\ (silicon)$$

$$V_{BE} = 0.3V\ (germanium)$$

$$V_{BE} = 0V\ (if\ not\ stated\ in\ question)$$

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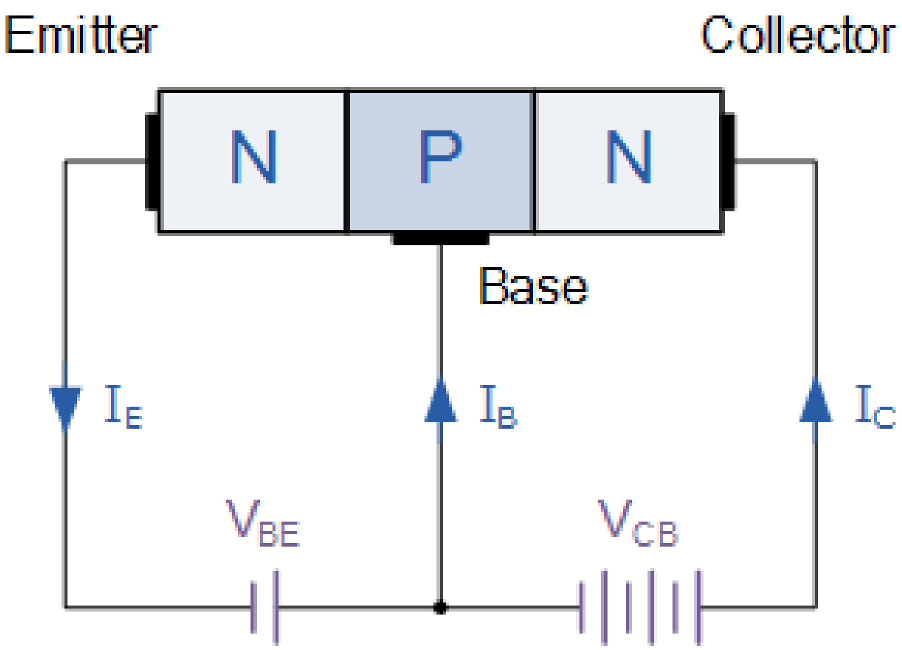
INTRODUCTION

- CONDITIONS FOR TRANSISTOR TO OPERATE



- Pin EB (Emitter Base) – **Forward Biased**

(+ve battery connect to P material while –ve battery connect to N material)

- Pin CB (Collector Base) – **Reverse Biased**

(-ve battery connect to P material while +ve battery connect to N material)

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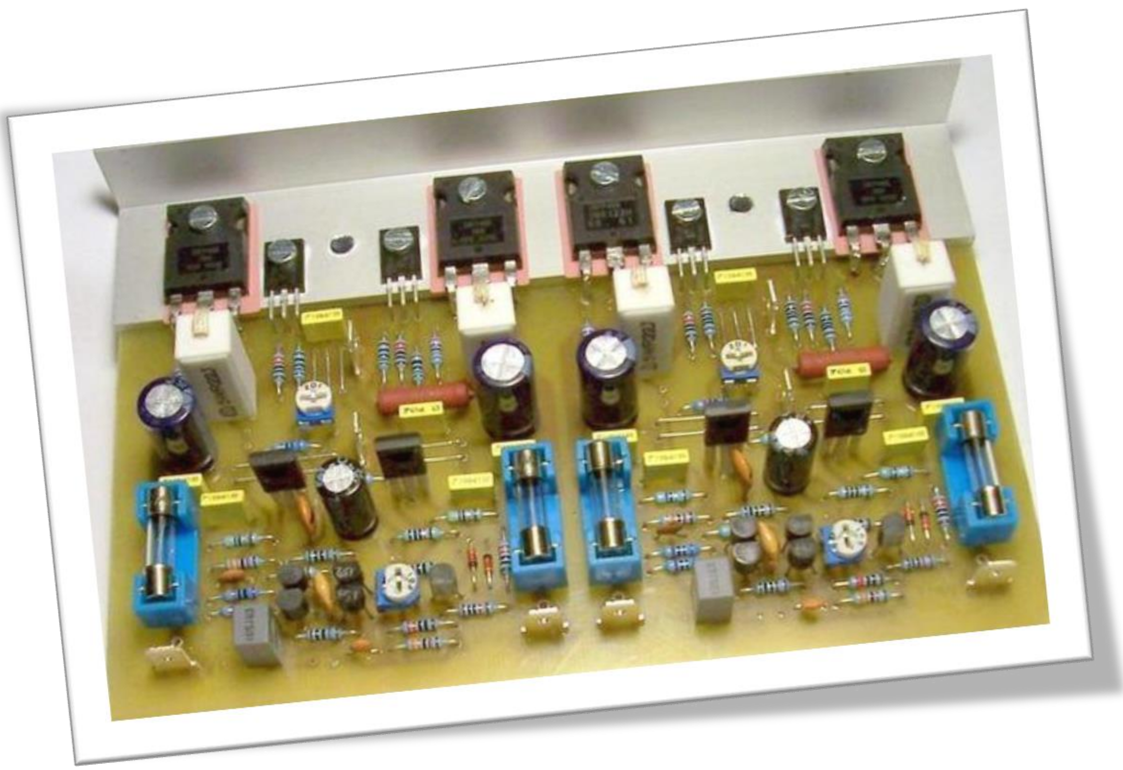
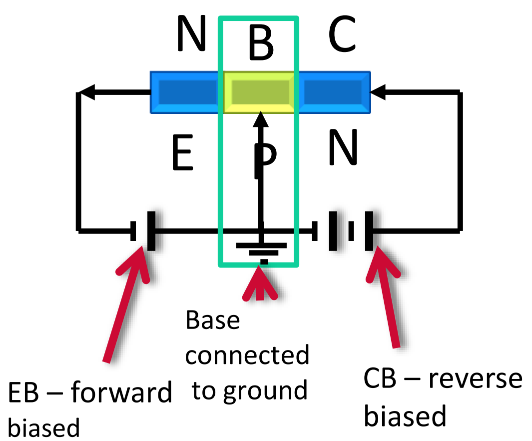
TRANSISTOR AS AMPLIFIER

- There are THREE configuration for transistor to operate as amplifier;
  - Common Base
  - Common Collector
  - Common Emitter

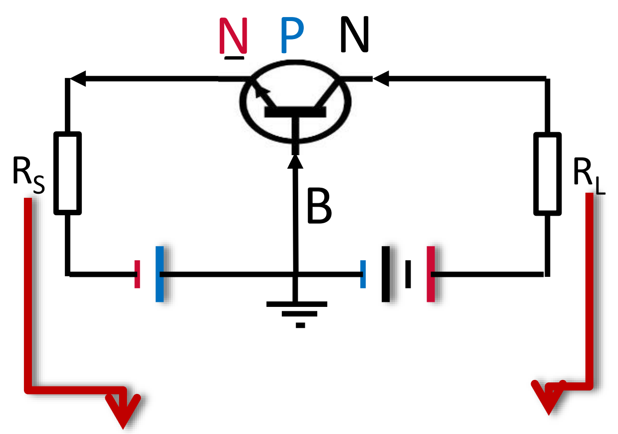


COMMON BASE AMPLIFIER

- BATTERY CONNECTION



- COMMON BASE AMPLIFIER CIRCUIT



R_S ➔ Series Resistance
➔ Input resistance

➔ can be presented as R_E or R_B depend on which terminal connected to input signal

R_L ➔ Load Resistance
➔ Output resistance

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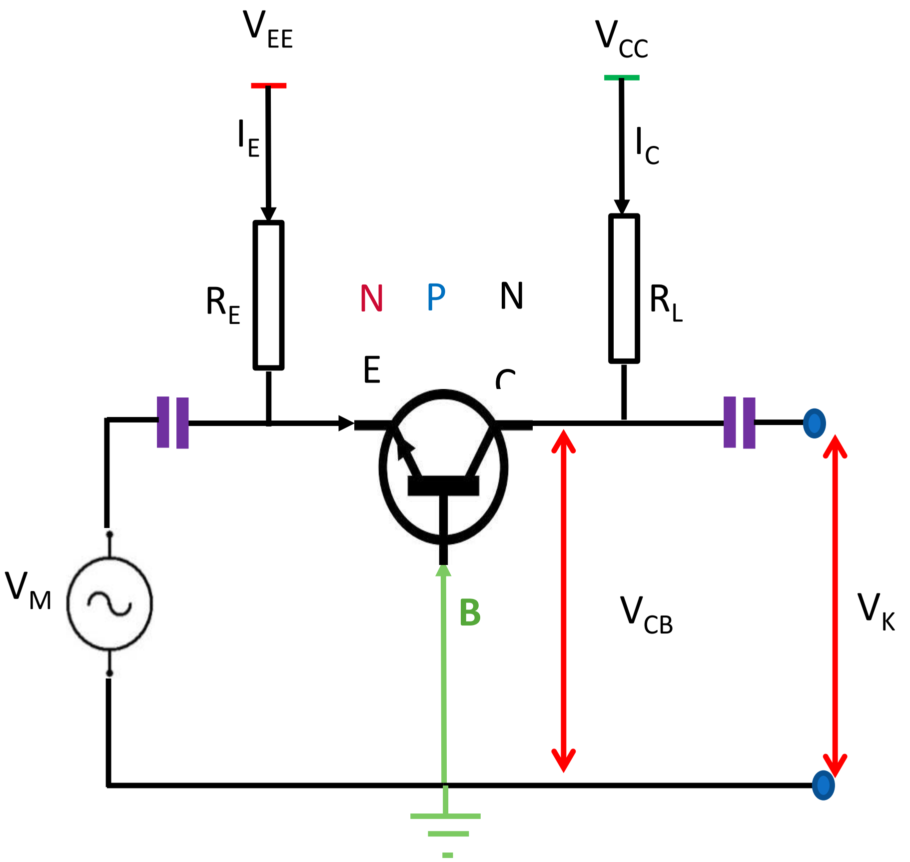
COMMON BASE AMPLIFIER

- COMMON BASE AMPLIFIER CIRCUIT WITH INPUT SIGNAL



$R_L = R_C$

I_B *is so small*

thus $I_E = I_C$

$V_K = V_{CB}$

INPUT
$V_{EE} = \boldsymbol{V_{RE}} + V_{BE}$
$V_{EE} = \boldsymbol{I_E R_E} + V_{BE}$
$I_E = \dfrac{V_{EE} - V_{BE}}{R_E}$

OUTPUT
$V_{CC} = \boldsymbol{V_{RL}} + V_K$
$V_{CC} = \boldsymbol{I_C R_L} + V_K$
$V_K = V_{CC} - I_C R_L$
$I_E = I_C$

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COMMON BASE AMPLIFIER

- **Alpha** (α) is a current gain factor for common base amplifier.
- It can be divided into two condition;

i. $$\alpha_{DC} = \frac{I_C}{I_E}$$

- current gain when collector current, emitter current and V_K at a fixed value.

ii. $$\alpha_{AC} = \frac{\Delta I_C}{\Delta I_E}$$

- current gain when there is a changed of values for collector current and emitter current while V_K at a fixed value.

** V_K = output voltage

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COMMON BASE AMPLIFIER GAIN CALCULATION (E.G. 1)

- Calculate the value of $\boldsymbol{\alpha_{DC}}$ and $\boldsymbol{\alpha_{AC}}$ if given the initial value of collector current (I_C) is 0.98mA, while the emitter current (I_E) is 1mA. Then the value of both current rise to 1mA (for I_C) and 1.05mA (for I_E)

- **SOLUTION**

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

$$\alpha_{DC} = \frac{0.95\ mA}{1\ mA}$$

$$\alpha_{DC} = \mathbf{0.98}$$

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

$$\alpha_{AC} = \frac{1mA\ -\ 0.95\ mA}{1.05mA\ -\ 1\ mA}$$

$$\alpha_{AC} = \mathbf{0.4}$$

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COMMON BASE AMPLIFIER

Common Base Amplifier Characteristic

Input resistance (R_{in})	Low
Output resistance (R_{out})	High
Current gain (A_i)	No
Voltage gain (A_v)	High
Power gain (A_p)	High
Phase shift	No

- $A_i = \frac{I_C}{I_E} I_C \leq I_E$

  $A_i \leq 1$, *thus there is* ***no current gain***

- $A_v = \frac{V_{CB}}{V_{EB}} V_{CE} = V_{CB} + V_{BE}$

  $V_{BE} = V_{CE} - V_{CB}$

  $V_{EB} = V_{CB} - V_{CE}$

  So $A_v = \frac{V_{CB}}{V_{CB} - V_{CE}} \frac{big\ value}{small\ value}$

- Thus **Voltage gain (A_v) is high.**

- A_p refer to A_v**,** thus**Ap is also high**

- EB is forward biased by V_{BB}, thus **input resistance value is small**

- CB is reverse biased by V_{CC}**,** thus **output resistance value is high.**

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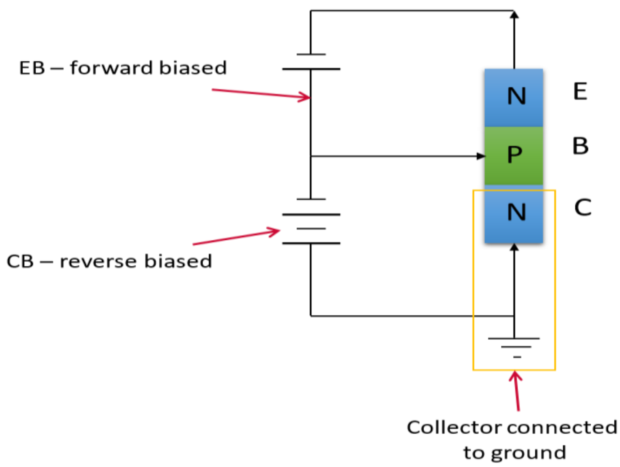
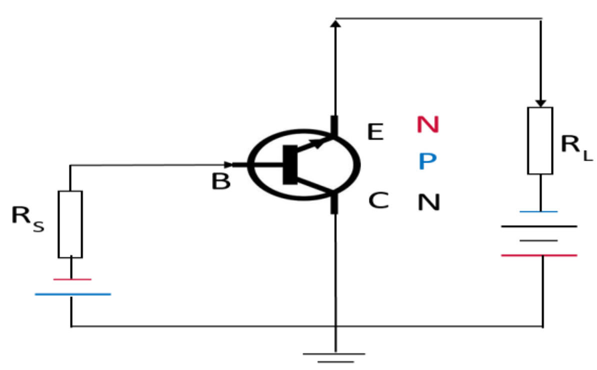
COMMON COLLECTOR AMPLIFIER

- BATTERY CONNECTION



- COMMON COLLECTOR AMPLIFIER CIRCUIT



R_S ➔ Series Resistance
➔ Input resistance
➔ can be presented as R_B

R_L ➔ Load Resistance
➔ Output resistance

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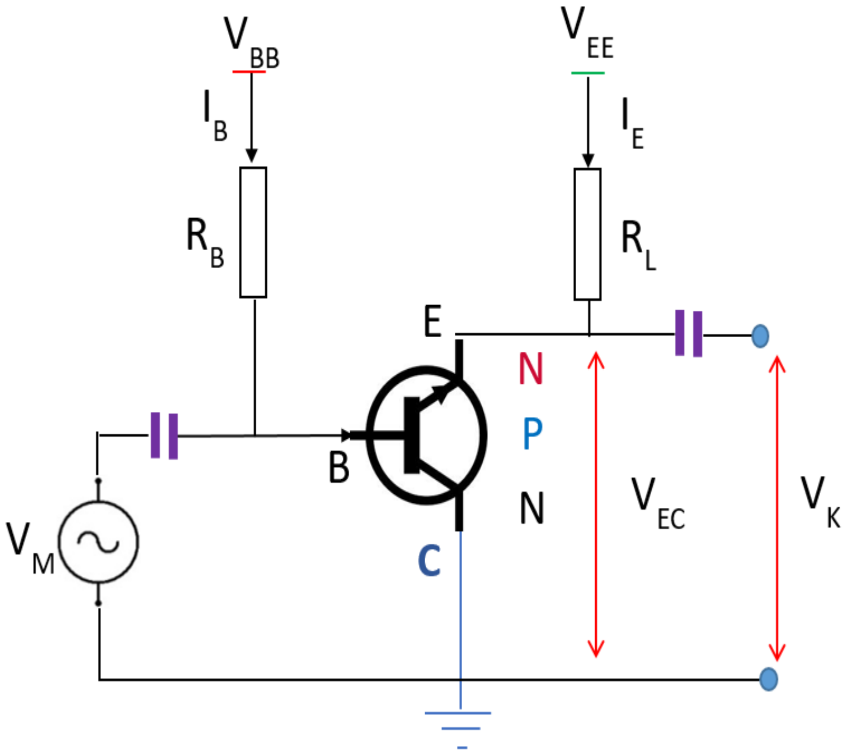
COMMON COLLECTOR AMPLIFIER

- COMMON COLLECTOR AMPLIFIER CIRCUIT WITH INPUT SIGNAL



$R_L = R_E$

$V_K = V_{EC}$

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COMMON COLLECTOR AMPLIFIER

Common Collector Amplifier Characteristic

Input resistance (R_{in})	High
Output resistance (R_{out})	Low
Current gain (A_i)	High
Voltage gain (A_v)	Low
Power gain (A_p)	Low
Phase shift	No

- $A_i = \frac{I_E}{I_B} \frac{big\ value}{small\ value}$ thus $\boldsymbol{A_i}$ **is high**

- $A_v = \frac{V_{EC}}{V_{BC}} V_{EC} = V_{BC} + V_{EB}$

V_{EB} value is small

- $V_{BC} \leq V_{EC}$

So $A_v = \frac{V_{EC}}{V_{BC}} \frac{bigger\ value}{big\ value}$

- Thus **Voltage gain (A_v) is LOW.**

- A_p refer to A_v, thus $\boldsymbol{Ap}$ **is also LOW**

- EB is forward biased by ($V_{EE} - V_{BB}$), thus **input resistance value is HIGH**

- CB is reverse biased by V_{BB}, thus **output resistance value is LOW.**

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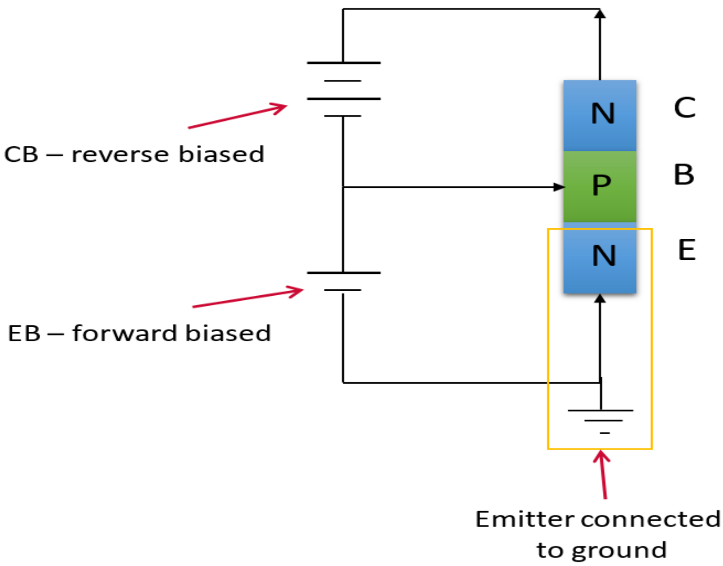
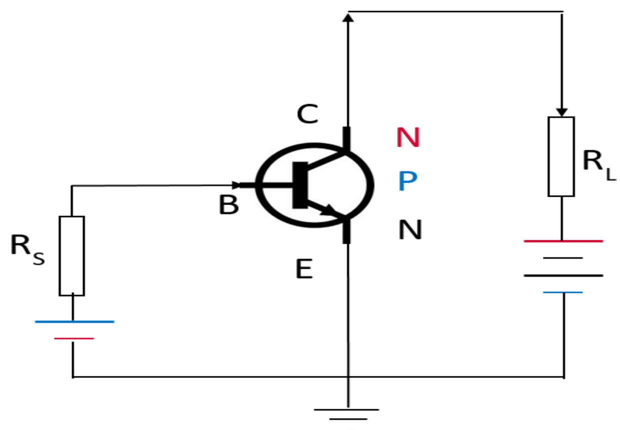
COMMON EMITTER AMPLIFIER

- BATTERY CONNECTION



- COMMON EMITTER AMPLIFIER CIRCUIT

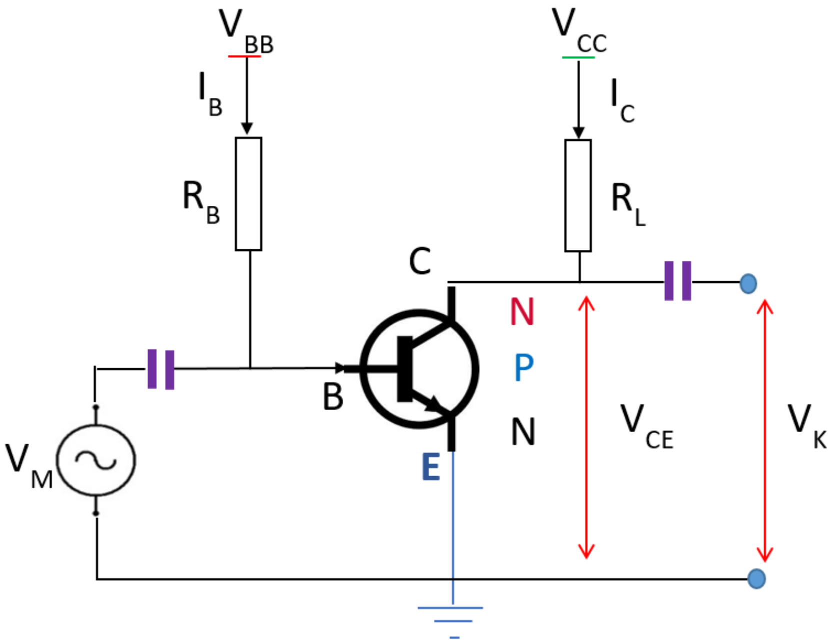


R_S ➔ Series Resistance
➔ Input resistance
➔ can be presented as R_B

R_L ➔ Load Resistance
➔ Output resistance

COMMON EMITTER AMPLIFIER

- COMMON EMITTER AMPLIFIER CIRCUIT WITH INPUT SIGNAL



$R_L = R_C$

$V_K = V_{CE}$

INPUT
$V_{BB} = \boldsymbol{V_{RB}} + V_{BE}$
$V_{BB} = \boldsymbol{I_B R_B} + V_{BE}$
$I_B = \dfrac{V_{BB} - V_{BE}}{R_B}$

OUTPUT
$I_C = \beta . I_B$
$V_{CC} = \boldsymbol{V_{RL}} + V_K$
$V_{CC} = \boldsymbol{I_C R_L} + V_K$
$V_K = V_{CC} + I_C R_L$

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COMMON EMITTER AMPLIFIER

- **Beta** $(\boldsymbol{\beta})$ is a current gain factor for common emitter amplifier.
- It can be divided into two condition;

i. $$\boldsymbol{\beta_{DC} = \frac{I_C}{I_B}}$$

- current gain when collector current, base current and V_K at a fixed value.

ii. $$\boldsymbol{\beta_{AC} = \frac{\Delta I_C}{\Delta I_B}}$$

- current gain when there is a changed of values for collector current and base current while V_K at a fixed value.

V_K also can be represented or written as V_C

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COMMON EMITTER AMPLIFIER

Common Emitter Amplifier Characteristic

Input resistance (R_{in})	Low
Output resistance (R_{out})	High
Current gain (A_i)	High
Voltage gain (A_v)	High
Power gain (A_p)	High
Phase shift	180^0

- $A_i = \frac{I_C}{I_B} \frac{big\ value}{small\ value}$ thus $\boldsymbol{A_i}$ **is HIGH**
- $A_v = \frac{V_{CE}}{V_{BE}} V_{CE} = V_{CB} + V_{BE}$

V_{EB} value is small

So $A_v = \frac{V_{CE}}{V_{CB}} \frac{big\ value}{small\ value}$

- Thus **Voltage gain (A_v) is HIGH.**
- A_p refer to A_v**,** thus $\boldsymbol{Ap}$ **is also HIGH**
- EB is forward biased by (V_{BB}), thus **input resistance value is LOW**
- CB is reverse biased by V_{CC}**,** thus **output resistance value is HIGH.**

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AMPLIFIER SUMMARY

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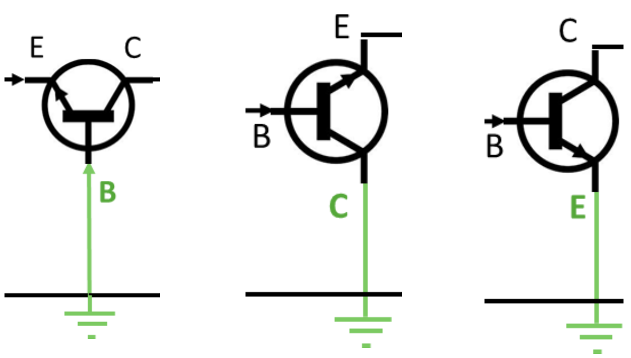
Differentiation between amplifier characteristic

Amplifier / Characteristic	Common Base	Common Collector	Common Emitter
Input resistance (R_{in})	Low	High	Low
Output resistance (R_{out})	High	Low	High
Current gain (A_i)	No	High	High
Voltage gain (A_v)	High	Low	High
Power gain (A_p)	High	Low	High
Phase shift	No	No	180^0

- **Tips to identify types of amplifier**
  - LOOK AT WHICH TRANSISTOR PIN IS GROUNDED



Tips to SOLVE basic amplifier calculation

STEP 1 : Derive Input formula

$V_{EE} = V_{RE} + V_{BE}$ (Common Base)

$V_{BB} = V_{RB} + V_{BE}$ (Common Emitter)

STEP 2 : Determine V_{BE}

silicon = **0.7V** , germanium = **0.3V** @ not mention/none = **0V**

STEP 3 : Determine Input Current

I_C (Common Base) @

I_B (Common Emitter)

STEP 4 : Determine Output Current

$I_E = I_C$ (Common Base) @

$I_C = \beta . I_B$ (Common Emitter)

STEP 5 : Derive Output Formula

$V_{CC} = V_{RL} + V_{CB}$ (Common Base)

$V_{CC} = V_{RL} + V_{CE}$ (Common Emitter)

STEP 6 : Determine Output Voltage

$V_K = V_{CB}$ (Common Base)

$V_K = V_{CE}$ (Common Emitter)

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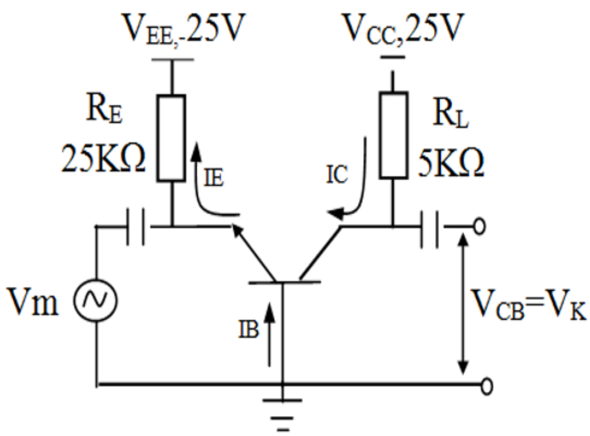
COMMON BASE AMPLIFIER CALCULATION (E.G. 1)



- Determine the output voltage for common base amplifier above

SOLUTION

Given;

R_E = 25 KΩ, R_L = 5 KΩ ,

V_{EE} = 25V, V_{CC} = 25V, V_{BE} = 0V

$$V_{EE} = V_{RE} + V_{BE}$$
$$V_{EE} = I_E R_E + V_{BE}$$

$$I_E = \frac{V_{EE}}{R_E} = \frac{25V}{25K\ \Omega} = \underline{1mA}$$

$$I_C = I_E = \underline{1mA}$$

$$V_C = V_{CC} - I_C . R_C$$
$$= 25V - (1mA)(5K)$$
$$= \underline{\underline{20V}}$$

$$Vc = Vk = \underline{\underline{20V}} .$$

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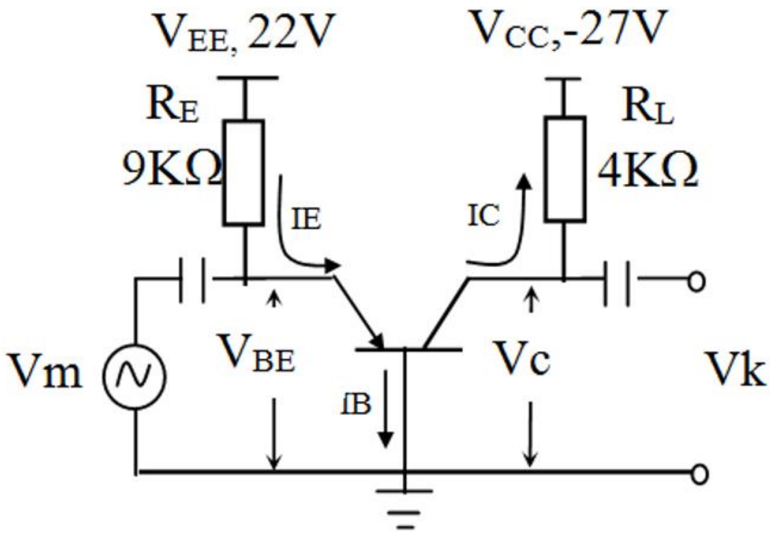
COMMON BASE AMPLIFIER CALCULATION (E.G. 2)



- If silicon types of transistor are used. Determine the output voltage for common base amplifier above

COMMON BASE AMPLIFIER CALCULATION (E.G. 2)

SOLUTION

Given;

$R_E = 9\ K\Omega$, $R_L = 4\ K\Omega$,

$V_{EE} = 22V$, $V_{CC} = -27V$, $V_{BE} = 0.7V$

Input section

$$V_{EE} = V_{RE} + V_{BE}$$

$$V_{EE} = I_E.R_E + V_{BE}$$

$$22V = I_E(9K\Omega) + 0.7V$$

$$I_E = \frac{22V - 0.7V}{9K\Omega} = \underline{2.37mA}$$

Output section

$$I_C = I_E$$

$$I_C = 2.37mA$$

$$V_{RL} = I_C.R_L = (2.37mA)(4K\Omega) = \underline{9.47V}.$$

$$V_C = V_{CC} - V_{RL} = 27V - 9.47V = \underline{\underline{17.5V}}$$

$V_{CC} = -27V$ ➔ In calculation, we only use the magnitude not the direction of the voltage.

➔ Thus, in calculation we only used 27V as voltage value

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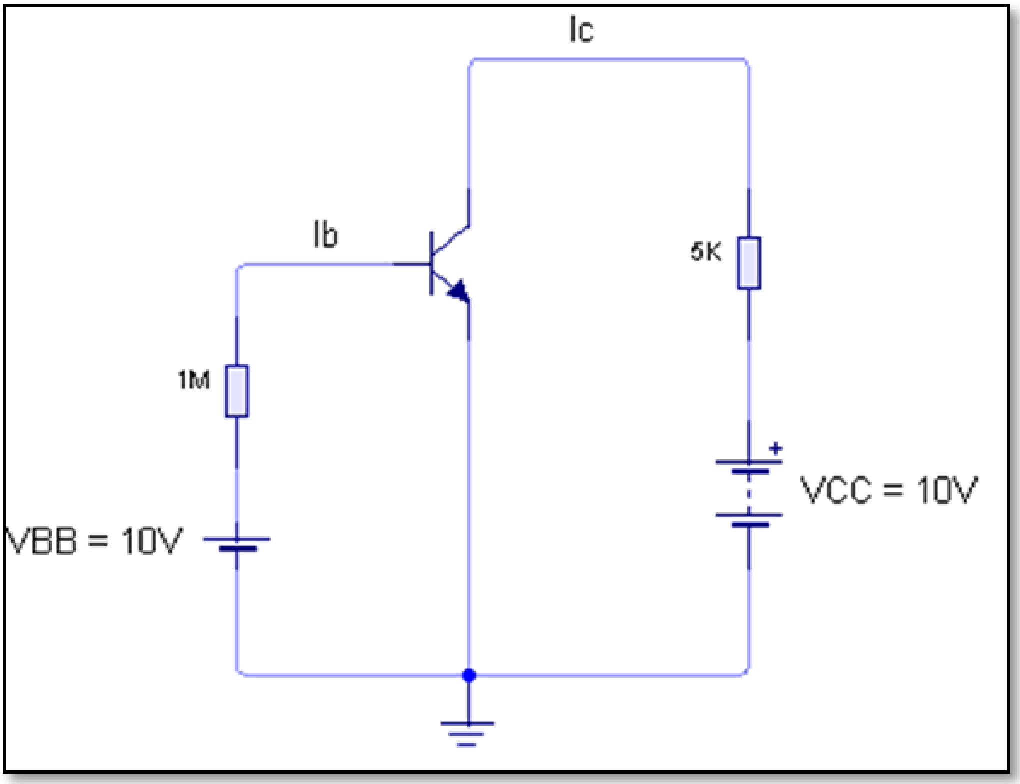
COMMON EMITTER AMPLIFIER CALCULATION (E.G. 3)



Based on figure above;

i. If β transistor is 100 and it is a silicon type transistor, calculate the value for I_C and V_C.

ii. If β transistor is 50, disregard the value of V_{BE}, calculate the value for I_C and V_C.

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COMMON EMITTER AMPLIFIER CALCULATION (E.G. 3)

- **SOLUTION (i)**

Given;

- $R_B = 1M\Omega$
- $R_L = 5\ K\Omega$
- $V_{CC} = 10V$
- $V_{BB} = 10V$
- $V_{BE} = 0.7V$
- $\beta = 100$

$$V_{BB} = V_B + V_{BE}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$I_B = \frac{10V - 0.7V}{1M} = \mathbf{9.3\mu A}$$

$$I_C = \beta . I_B$$
$$I_C = 100\ x\ 9.3\mu$$
$$\boldsymbol{I_C = 0.93\ mA}$$

$$V_{CC} = V_{RL} + V_C$$
$$V_C = V_{CC} - V_{RL}$$
$$V_C = 10\ V - (0.93mA\ x\ 5k\Omega)$$
$$\boldsymbol{V_C = 5.35V}$$

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COMMON EMITTER AMPLIFIER CALCULATION (E.G. 3)

- **SOLUTION (ii)**

Given;

- $R_B = 1M\Omega$
- $R_L = 5\ K$
- $V_{CC} = 10V$
- $V_{BB} = 10V$
- $\beta = 50$

$V_{BB} = V_B + V_{BE}$ **$V_{BE} = 0V$**

$$I_B = \frac{V_{BB}}{R_B}$$

$$I_B = \frac{10V}{1M} = \mathbf{10\mu A}$$

$$I_C = \beta . I_B$$
$$I_C = 50\ x\ 10\mu$$
$$\boldsymbol{I_C = 0.5mA}$$

$$V_{CC} = V_{RL} + V_C$$
$$V_C = V_{CC} - V_{RL}$$
$$V_C = 10\ V - (0.5mA\ x\ 5k\Omega)$$
$$\boldsymbol{V_C = 7.5V}$$

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COMMON EMITTER AMPLIFIER

DC LOAD LINE

- Q POINT
- SATURATION POINT
- CUT OFF POINT

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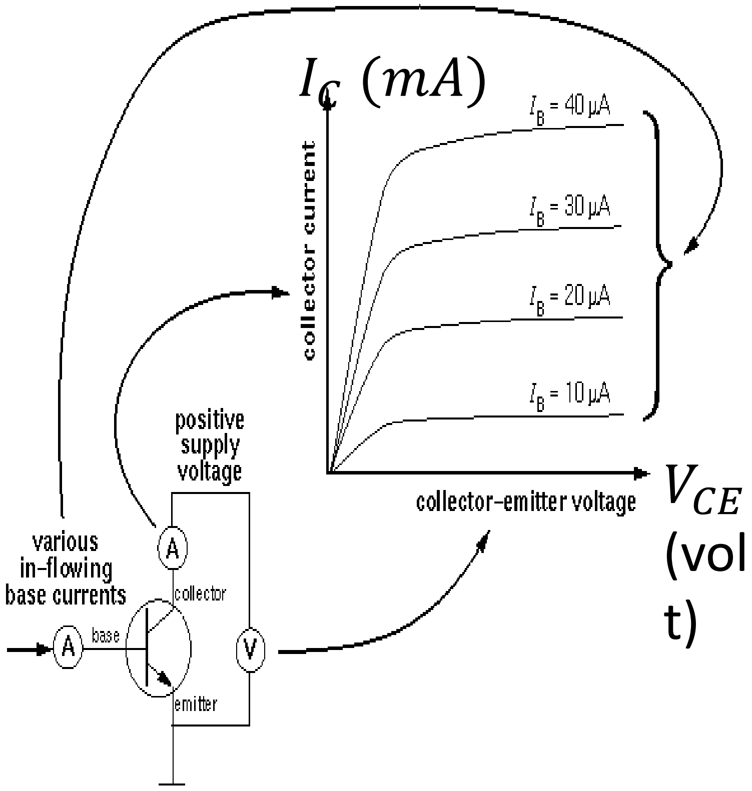
COMMON EMITTER AMPLIFIER CHARACTERISTIC CURVES



The I_C - V_C characteristic curve is the graph of a collector current versus collector voltage that describe the output of common emitter amplifier during any changes of voltage and current

$\boldsymbol{I_B}$ *value proportional to forward biased voltage value* $\boldsymbol{V_{BB}}$

$\boldsymbol{I_C}$ *value proportional to* $\boldsymbol{I_B}$

$\boldsymbol{I_C}$ *value is bigger (usually in mA) than to* $\boldsymbol{I_B}$ *(usually in µA)*

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COMMON EMITTER AMPLIFIER

- **LOAD LINE**
  - Line connecting saturation point, Q point and cut off point.

- **Q POINT (Quiescent Point)** (V_{CEQ} and I_{CQ})
  - Operational point is the point of intersection between V_{CEQ} and I_{CQ} .
  - V_{CEQ}= voltage at operational point. (V_{CE}= V_{CEQ})
  - I_{CQ} = current at operational point. (I_C= I_{CQ})

- **SATURATION POINT** ($I_{C\ saturate}$)
  - Point where the value of I_C is maximum, it's happened when there was no output voltage (**V_C@ V_K = 0V**).

- **CUT OFF POINT** ($V_{C\ cut\ off}$)
  - Point where the value of V_C is maximum, it's happened when there was no output current **(I_C = 0A)**

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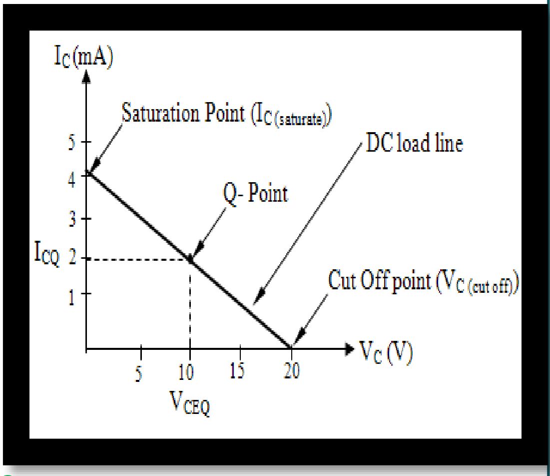
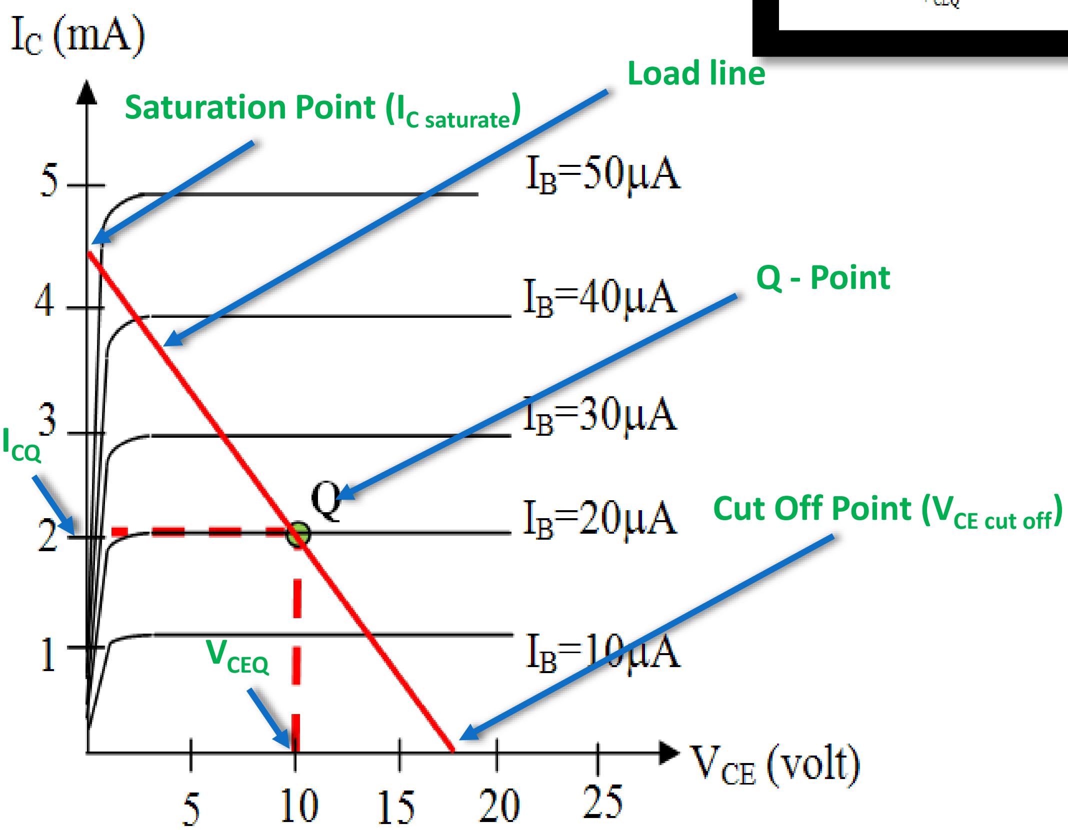
LOAD LINE, Q POINT, SATURATION POINT AND CUT OFF POINT

- **DC LOAD LINE**





Load line gradient depends on R_L and V_{CC} value

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LOAD LINE CALCULATION (E.G 1)

- Refer to figure below, draw the dc load line and Q point. (assume $\beta = 100$)

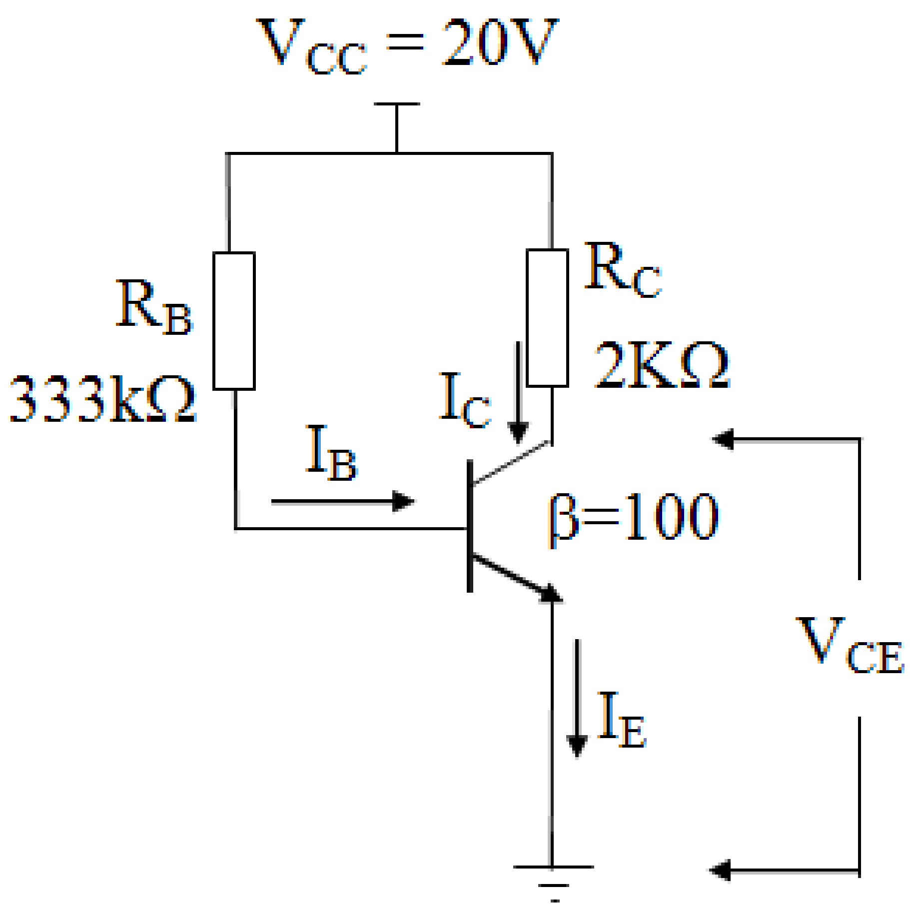

Figure : Common Emitter Amplifier Circuit

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LOAD LINE CALCULATION (E.G 1)

- **SOLUTION**

$$\mapsto I_B = \frac{V_{BB}}{R_B} = \frac{20V}{333k\Omega} = \underline{60\mu A}$$

$$\mapsto I_C = \beta . I_B = (100)(60\mu A) = \underline{6mA}$$

$$\mapsto V_C = V_{CC} - I_C . R_L = 20V - (6mA)(2k\Omega) = 20V - 12V = \underline{8V}$$

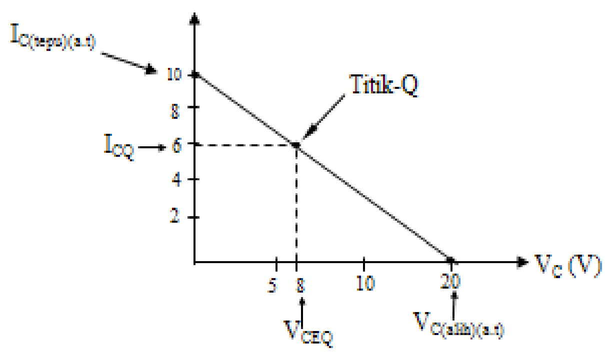
$$\Rightarrow V_{CQ} = V_C = \underline{\underline{8V}}$$

$$\Rightarrow I_{CQ} = I_C = \underline{\underline{6mA}}$$

$$\mapsto I_{C(saturate)(dc)} = \frac{V_{CC}}{R_L} = \underline{\underline{10mA}}$$

$$\mapsto I_C = 0$$

$$\mapsto V_{C(cut\,off)(dc)} = V_{CC} = \underline{\underline{20V}}$$



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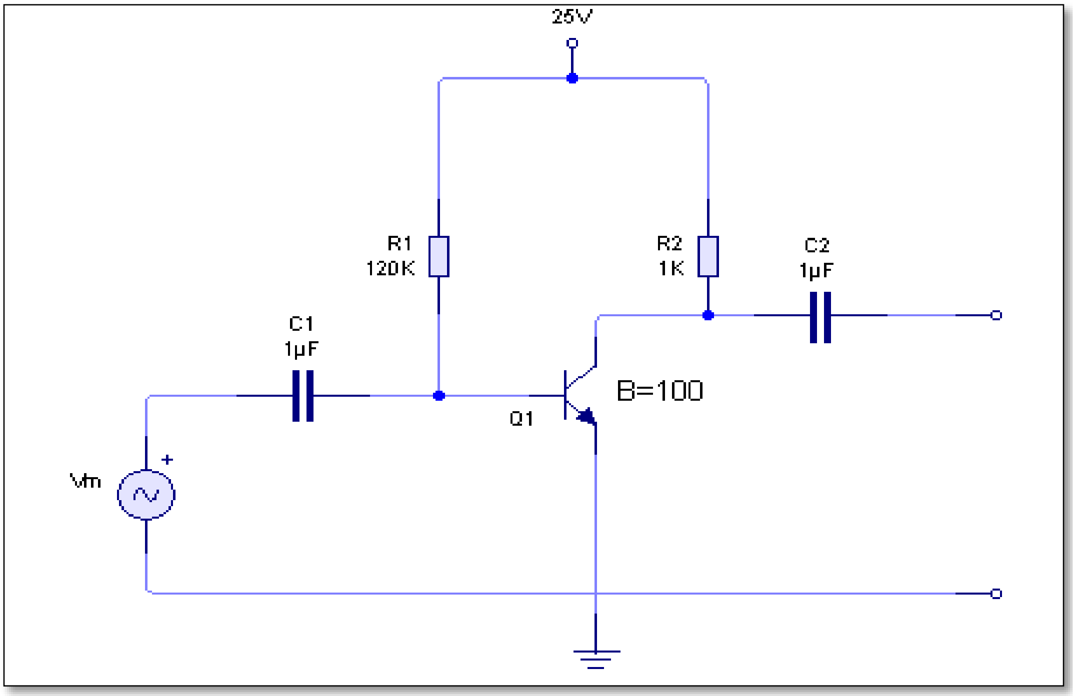
LOAD LINE CALCULATION (E.G 2)

- Based on figure below, calculate;
    i. Ic
    ii. Vc
    iii. AC saturation Ic
    iv. AC cut off voltage

Assume the transistor is ideal



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LOAD LINE CALCULATION (E.G 2)

- **SOLUTION**

Given;

- R_B = 120 KΩ
- R_L = 1 KΩ
- V_{CC} = 25V
- V_{BB} = 25V
- β = 100

V_{BB} = V_B + V_{BE} V_{BE} = 0V

= I_B x R_B

$$I_B = \frac{V_{BB}}{R_B}$$

$$I_B = \frac{25V}{120K} = \mathbf{208.33\mu A}$$

$$I_C = \beta . I_B$$
$$= 100 \; x \; 208.33\mu$$
$$= \mathbf{20.83 \; mA}$$

$$V_{CC} = V_{RL} + V_C$$
$$V_C = V_{CC} - V_{RL}$$
$$V_C = 25\;V - (20.83mA \; x \; 1k\Omega)$$
$$\mathbf{V_C = 4.167V}$$

$$I_{C(saturation)} \;==>\; V_C = 0$$

$$V_{C(cut\;off)} \;==>\; I_C = 0$$

$$I_{C(saturation)} = \frac{V_{CC}}{R_L}$$

$$I_{C(saturation)} = \frac{25V}{1K}$$

$$\mathbf{I_{C(saturation)} = 25mA}$$

$$V_{C\;(cut\;off)} = V_{CC}$$

$$\mathbf{V_{C\;(cut\;off)} = 25V}$$

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COMMON EMITTER AMPLIFIER ENHANCEMENT TECHNIQUE

- BIASING TECHNIQUES OF COMMON EMITTER TRANSISTOR
- BIASED VOLTAGE DIVIDER

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BIASING TECHNIQUES OF COMMON EMITTER TRANSISTOR CONFIGURATION

- β is a gain produced by common emitter amplifier has a downside due to its relation with leakage current when the circuit temperature rises.

- To eliminate β weakness, stable biasing technique were introduced, which is;
  - **base biased with emitter feedback**
  - **biased voltage divider technique**

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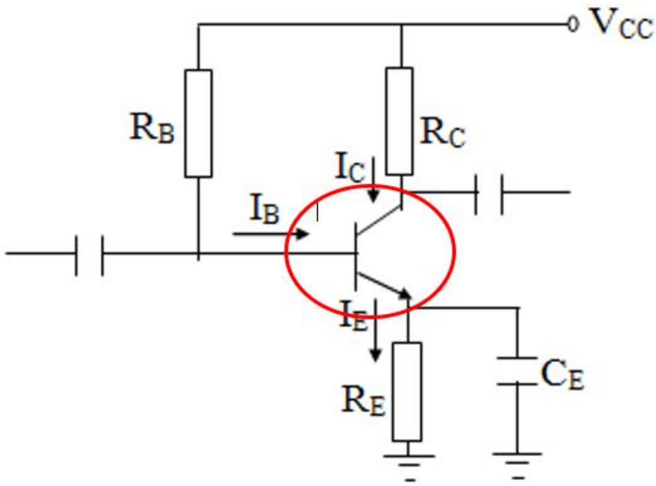
BASE BIASED WITH EMITTER FEEDBACK

- Addition of R_E and C_E before I_E current grounded.



$$I_E \uparrow V_{RE} \uparrow V_{RB} \downarrow$$

- R_E act as stabilizer for operational current (output current I_C).
- R_E will decrease the gain value due to increasing of voltage drop across the R_E resistance.
- C_E act as a shunt capacitor to RE and reduce input resistance.

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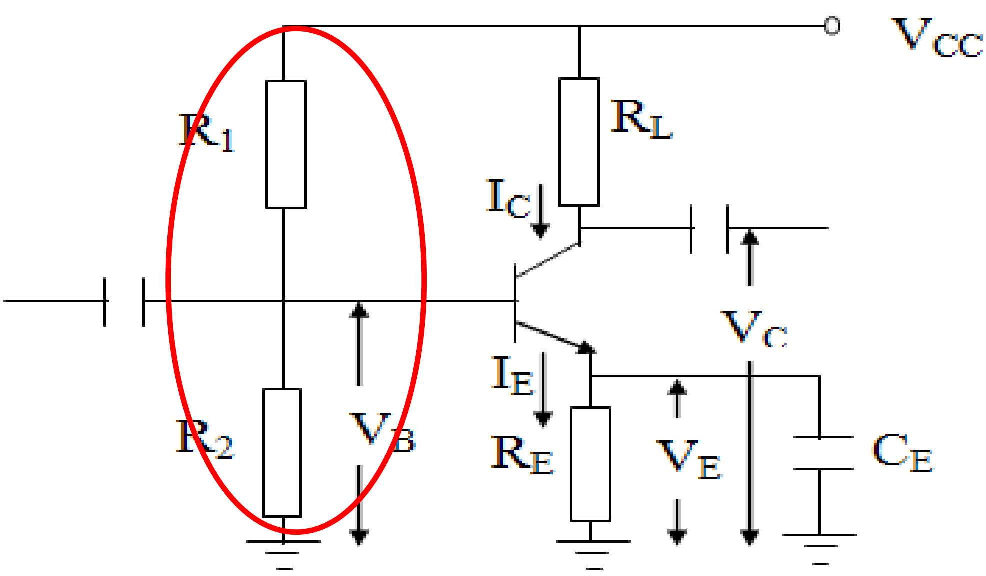
BIASED VOLTAGE DIVIDER TECHNIQUE

- Addition of R_2 to make a voltage divider circuit in input side of amplifier.



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FINAL EXAM QUESTIONS (1)

JUNE 2014

1. Explain the operation of ideal diode. **(3M)**
2. Explain TWO main conditions in biasing a transistor. **(6M)**
3. Explain the following terms based on the characteristic curves of SCR. **(12M)**
   i. Forward Blocking Current
   ii. Reverse Blocking Current
   iii. Holding Current
   iv. Break over Voltage
4. Differentiate between SCR and TRIAC. **(4M)**

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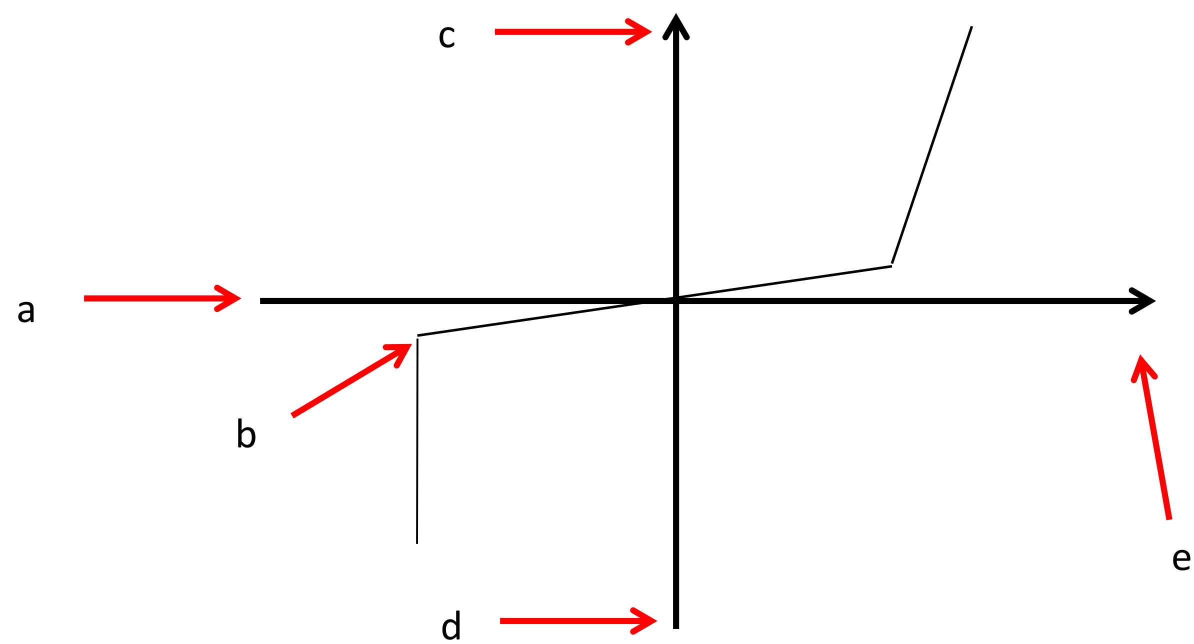
FINAL EXAM QUESTIONS (2)

JUNE 2013

1. Draw and label the schematic symbol of diode. **(1M)**
2. Explain the operation of diode when in forward bias and reverse bias. **(4M)**
3. Draw the schematic of a LED and state 3 characteristic of a LED. **(5M)**
4. Draw and label the structure and schematic symbol of transistor NPN and PNP. **(7M)**
5. Based on figure below; **(8M)**
   i. Label the I-V characteristic curve for zener diode.
   ii. Explain the advantages between zener diode and normal diode.



FINAL EXAM QUESTIONS (3)

POLITEKNIK MALAYSIA MERLIMAU

DEC 2012

1. Draw and label the schematic symbol of component below; **(15M)**
   i. LED
   ii. FET
   iii. TRIAC
   iv. NPN Transistor
   v. PNP Transistor

2. State 3 differences between Field Effect Transistor (FET) and Bipolar Junction Transistor (BJT).
   (6M)

3. Explain the concept of ideal diode during forward bias and reverse bias. **(4M)**

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FINAL EXAM QUESTIONS (4)

JAN 2010

1. Draw and label the symbol and structure of diode. **(2M)**
2. Sketch and label an I-V curve of silicon diode and define the following terms.
    i. Forward current
    ii. Reverse current
    iii. Knee Voltage
    iv. Breakdown voltage
    v. Burn limit

    (12M)
3. State 2 bias conditions for transistor operation. **(2M)**
4. Transistors have 3 terminals. Describe the function of the following terminals;
    i. Emitter
    ii. Base
    iii. Collector

    (6M)
5. List 3 function of SCR.
    (3M)

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FINAL EXAM QUESTIONS (5)

APR 2007

1. Draw schematic symbol of a LED.
   (3M)
2. Sketch and label an I-V curve of silicon diode and define the following terms.
   i. Forward current
   ii. Reverse current
   iii. Breakdown voltage
   iv. Knee voltage
   (10M)
3. State 2 bias conditions for enable a transistor to operate. **(4M)**
4. Draw a structure diagram and schematic symbol for; **(8M)**
   i. transistor **NPN**
   ii. transistor **PNP**

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FINAL EXAM QUESTIONS (6)

JAN 2007

1. Sketch and label an I-V curve of silicon diode and define the following terms.
   i. Forward current
   ii. Reverse current
   iii. Knee Voltage
   iv. Breakdown voltage
   v. Burn limit
   (8M)
2. State 3 advantages of a zener diode compared to a normal diode. **(3M)**
3. Draw the structure diagram and schematic symbol for a SCR. **(4M)**
4. State 3 method can be used to stop a SCR operation. **(6M)**
5. State 2 differences between DIAC and TRIAC. **(4M)**

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