Lecture 3 Bipolar Junction Transistor

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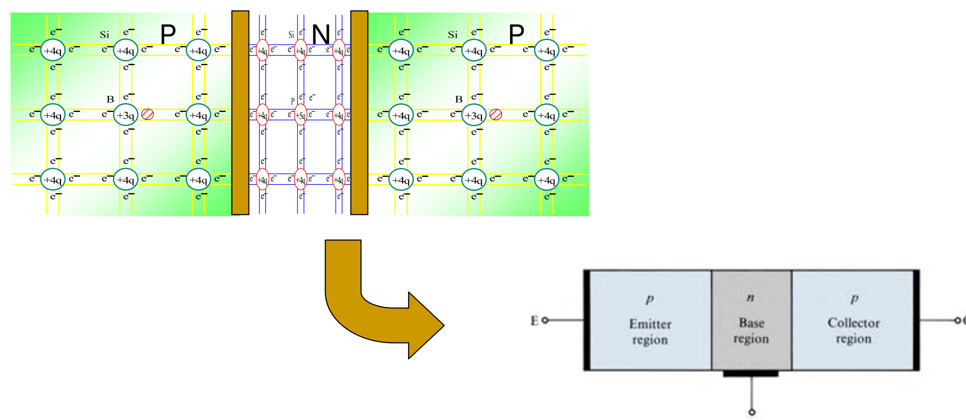
Bipolar Junction Transistor

- Outline
  - 3.1 Introduction
  - 3.2 Bipolar Junction Transistor (BJT)
  - 3.3 DC analysis
  - 3.4 Fixed Biasing
  - 3.5 Fixed Biasing with R_E
  - 3.6 Self Biasing
  - 3.7 Voltage Divider Biasing

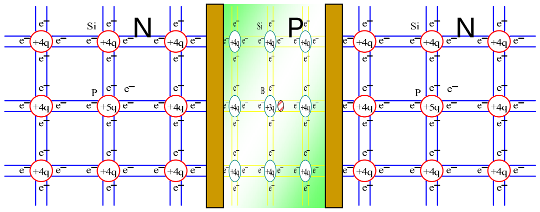
Introduction

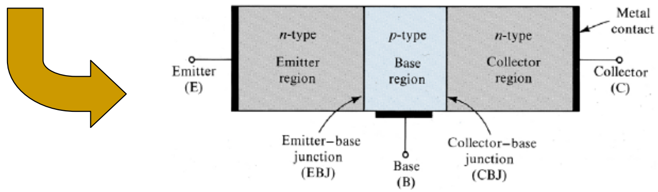
Transistor semiconductor (PNP)

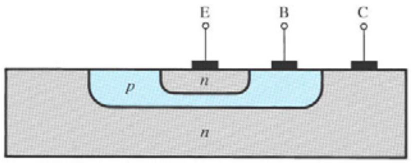


- Three terminal device
  - Three semiconductor regions, above is "pnp"
  - E: Emitter, B: Base, C: Collector
  - Voltage between two terminals to control current
    Use as Amplifier or Switch

Transistor semiconductor (NPN)



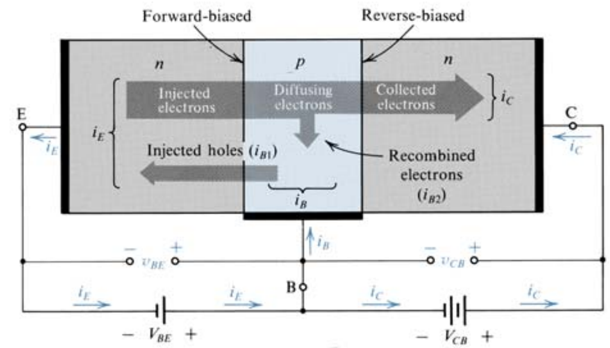




Vertical *npn*

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

NPN Transistor



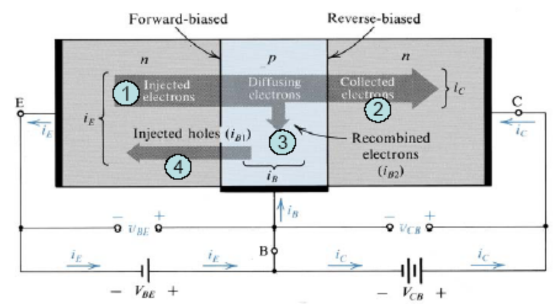
The Beta

- Can relate i_B and i_C by the following equation

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

- $\beta = i_C / i_B$
  - β is constant for a particular transistor
  - On the order of 100-200 in modern devices (but can be higher)
  - called ***common emitter current gain***.
  - is also denoted by β_F.

Emitter Current



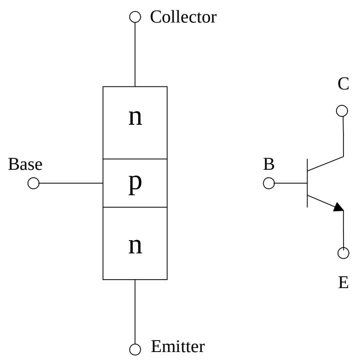
Treat transistor as a super-node, by KCL we obtain

$$i_E = i_B + i_C = \frac{1}{\beta} i_C + i_C = \frac{1+\beta}{\beta} i_C \quad \text{or} \quad i_C = \frac{\beta}{1+\beta} i_E$$

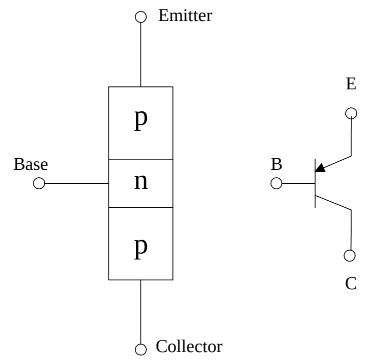
$$\therefore \boxed{i_C = \alpha i_E} \quad \text{where} \quad \boxed{\alpha = \frac{\beta}{1+\beta}} \quad \text{or} \quad \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

α is called ***common base current gain***. $\alpha < 1$ but very close to 1.

Symbol of Transistors



NPN



PNP

Current Controlled Source

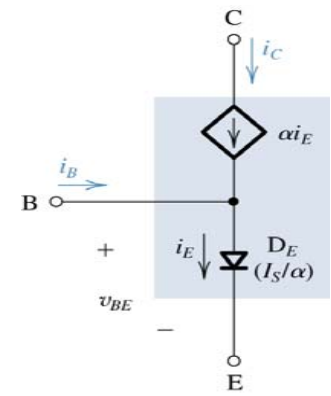
- i_C independent of V_{CE}
  Nonlinear voltage
  Controlled Source
- Change voltage controlled source to current controlled source

Equivalent Circuit

$$i_E = i_C + i_B$$

$$i_B = \frac{i_C}{\beta}$$

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

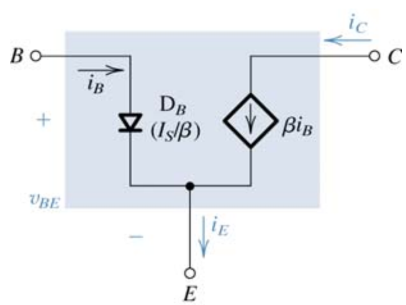


(b)

วงจรเทียบเคียง BJT แบบ T model

Simplify Current Controlled Source Model

- วงจร two port network ของ BJT มีอินพุต ขา B และ เอาต์พุตขา C.
- β คืออัตราขยายกระแส
- Constant n=1 except
  - High currents
- Constant n=2 except
  - Low currents



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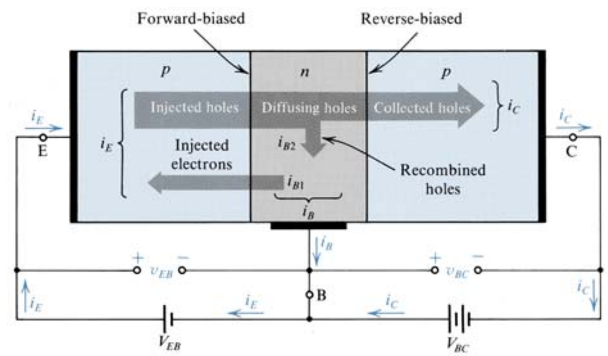
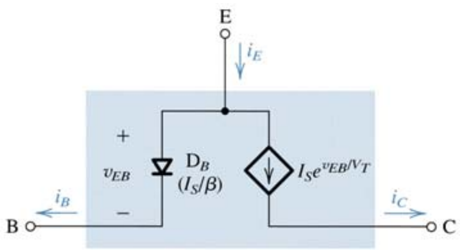
วงจรเทียบเคียง BJT แบบ π model

PNP Transistor

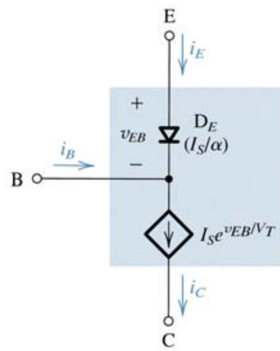


Large-signal models

- แบบจำลองของ BJT ชนิด pnp ที่ทำงานในโหมดแอกทีฟ.
- เราสามารถแทนแรงดัน vBE ด้วยแรงดัน vEB

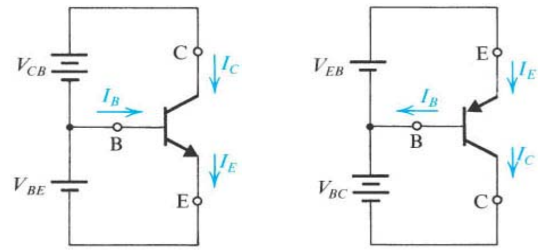


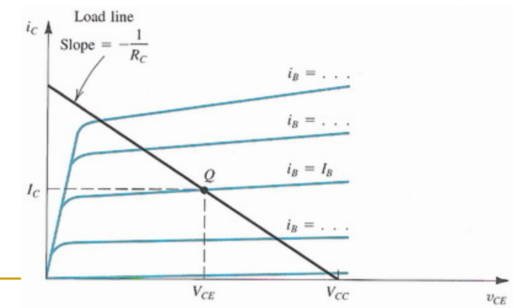
วงจรเทียบเคียง BJT ชนิด PNP แบบ π model



วงจรเทียบเคียง BJT ชนิด PNP แบบ T model

Transistor Characteristic





Summary of the BJT current-voltage relationships in the active mode

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

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

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

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

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

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

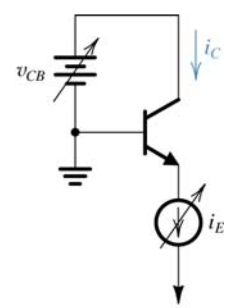
$$V_T = \text{thermal voltage} = \frac{kT}{q} \cong 25 \text{ mV}$$

BJT Characteristics

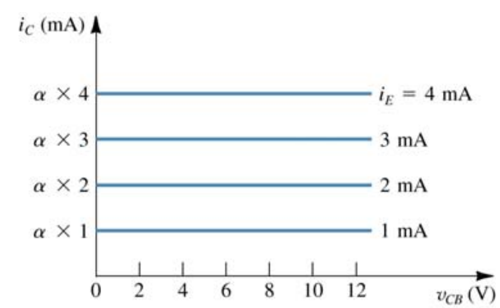
•คุณลักษณะความสัมพันธ์ i_C-v_{CB} ของ BJT ชนิด npn ใน active mode.

•ที่ Collector เป็น current source คงที่ตลอด ซึ่งกระแสถูกควบคุมโดย emitter current i_E

$$i_C = \alpha I_E$$



(a)



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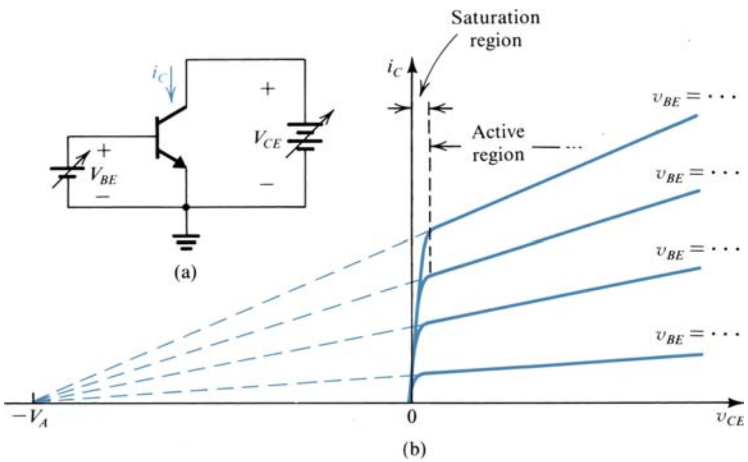
BJT Characteristics

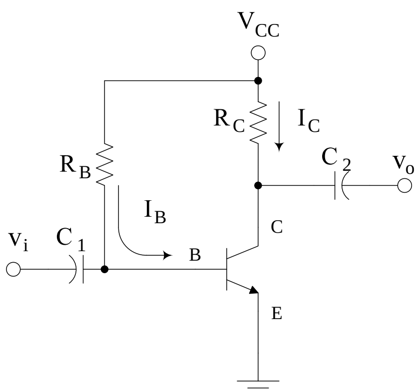
- ทดลองหาคุณลักษณะ i_C-v_{CE} ของ BJT.



DC Analysis

- Fixed Biasing.
- Emitter-Stabilized Bias Circuit
- DC Bias with Voltage Feedback.
- Voltage Divider Biasing.

1. Fixed Biasing



$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad (1)$$

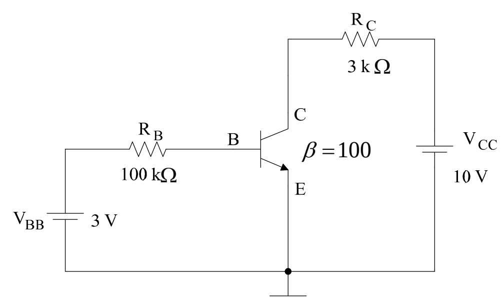
$$I_C = \beta I_B$$

$$V_{CE} + I_C R_C - V_{CC} = 0 \quad (2)$$

$$V_{CC} = I_C R_C + V_{CE} \quad (3)$$

$$V_{CE} = V_{CC} - I_C R_C \quad (4)$$

Ex1 Find I_c and V_{CE} in circuit bias BJT

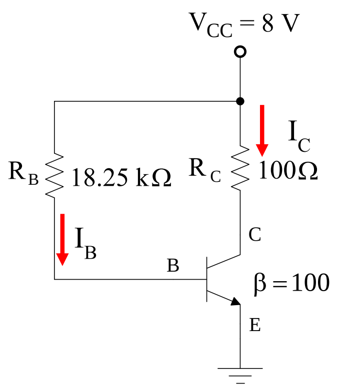


$$I_B = \frac{V_{BB} - V_{BE}}{R_{BB}} = \frac{3V - 0.7V}{100k\Omega} = 0.023mA$$

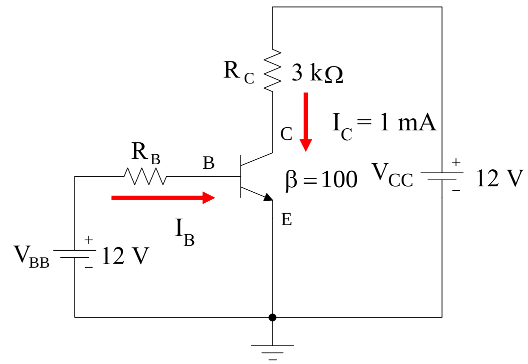
$$I_C \cong \beta I_B = 100 \times 0.023mA = 2.3mA$$

$$V_{CE} = V_{CC} - 2.3mA \times 3k\Omega = 3.1V$$

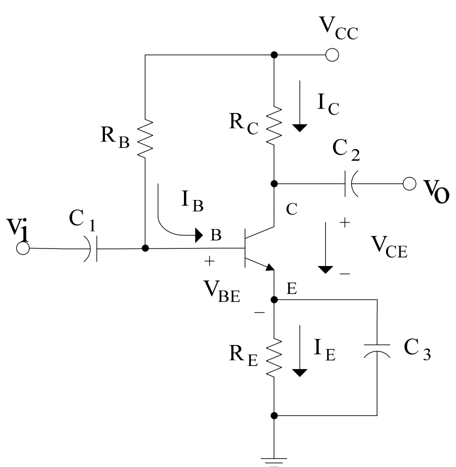
Ex2. Find I_B, I_C and V_{CE} on circuit



Ex3. Find V_{CE}, I_B and R_B on circuit



2. Emitter-Stabilized Bias Circuit



$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0 \quad (1)$$

$$I_E = (\beta + 1) I_B \quad (2)$$

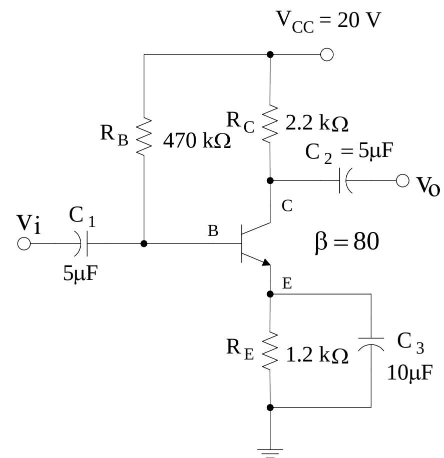
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E} \quad (3)$$

$$I_E R_E + V_{CE} + I_C R_C - V_{CC} = 0 \quad (4)$$

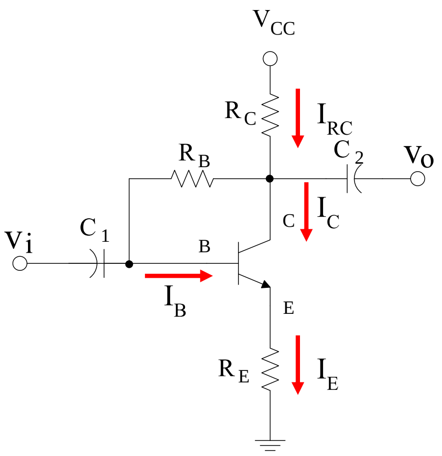
$$V_{CE} - V_{CC} + I_C (R_C + R_E) = 0 \quad (5)$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E) \quad (6)$$

Ex4. Find I_B, I_C and V_{CE} on circuit $\beta = 80$



3. DC Bias with Voltage Feedback



$$V_{CC} - I_{R_C} R_C - I_B R_B - V_{BE} - I_E R_E = 0 \quad (1)$$

$$V_{CC} - \beta I_B R_C - I_B R_B - V_{BE} - \beta I_B R_E = 0 \quad (2)$$

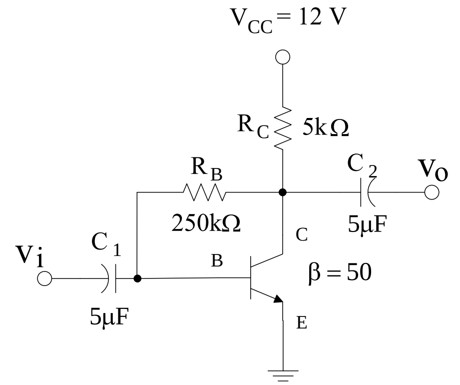
$$V_{CC} - V_{BE} - \beta I_B (R_C + R_E) - I_B R_B = 0 \quad (3)$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} \quad (4)$$

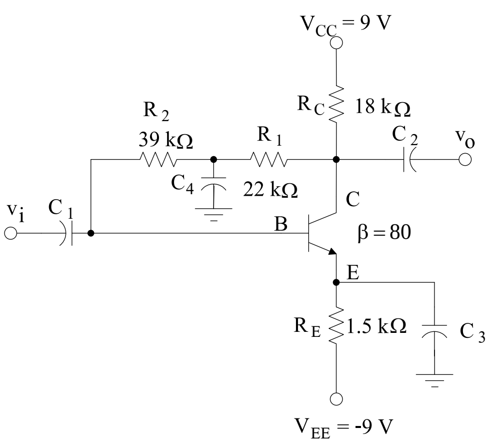
$$I_C = \beta I_B$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E) \quad (5)$$

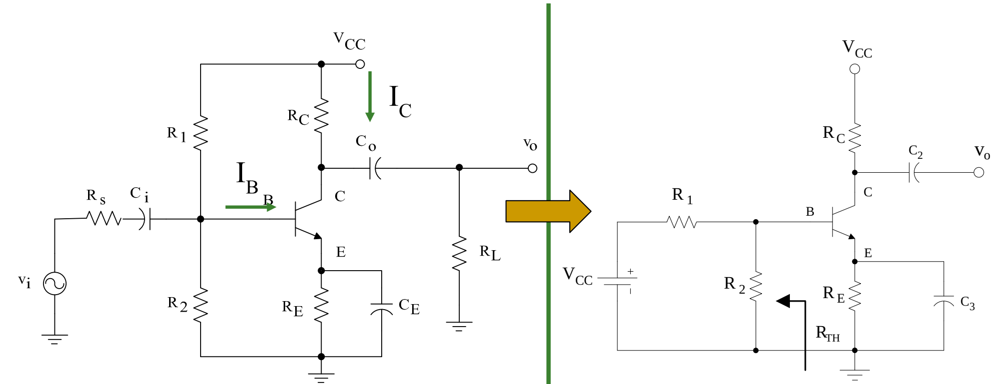
Ex5. Find I_B, I_C and V_{CE} on circuit



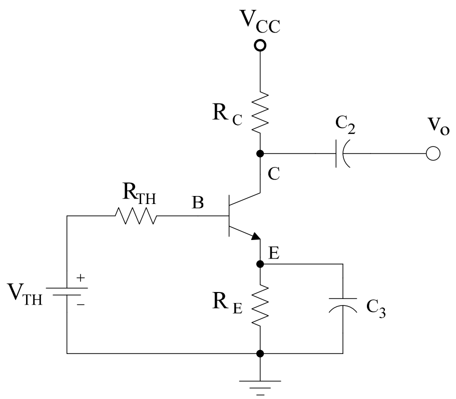
Ex6. Find I_B, I_C and V_{CE} on circuit



4. Voltage Divider Biasing



Voltage Divider Biasing (con)



Thevenin equivalent

$$R_{Th} = R_1 \| R_2 \quad (1)$$

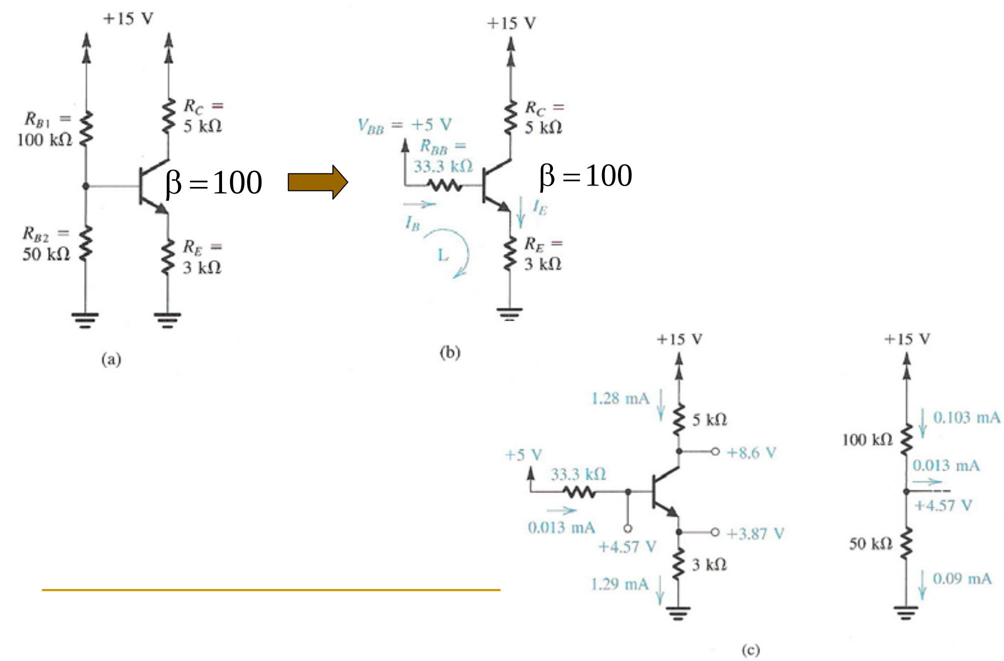
$$V_{Th} = V_R = \frac{R_2 V_{CC}}{R_1 + R_2} \quad (2)$$

$$V_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0 \quad (3)$$

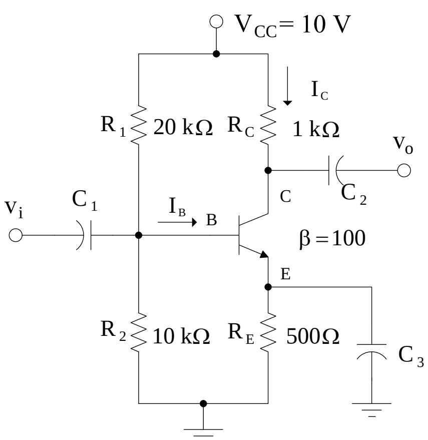
$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (\beta + 1) R_E} \quad (4)$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E) \quad (5)$$

Ex7. Find I_B, I_C and V_{CE} on circuit

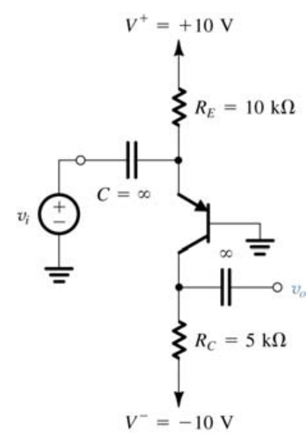


Ex8. Find I_B, I_C and V_{CE} on circuit



PNP Transistor Amplifier

Ex9. Find I_B, I_C and V_{CE} on circuit $\beta = 100$



(a)

DC Analysis

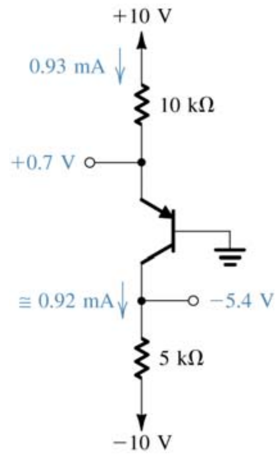
- Find operating pt. Q

$$I_E = \frac{10 - V_E}{R_E} \cong \frac{10 - 0.7}{10} = 0.93mA$$

- Let us β =100 and α =0.99

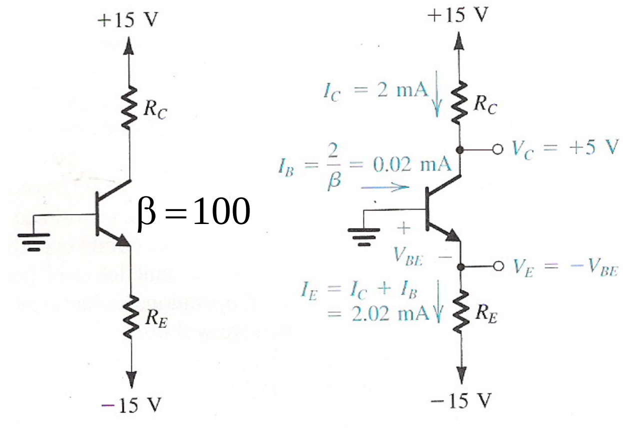
$$I_C = 0.99 I_E = 0.92mA$$
$$V_C = -10 + I_C R_C = -5.4V$$

- The transistor is active



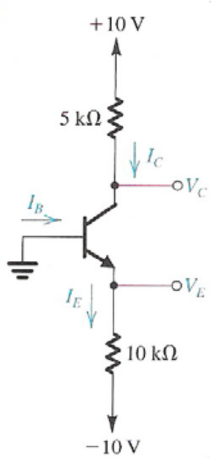
(b)

Ex10. Design amplifier circuit at I_C = 2 mA and V_C = +5 V Find R_C and R_E

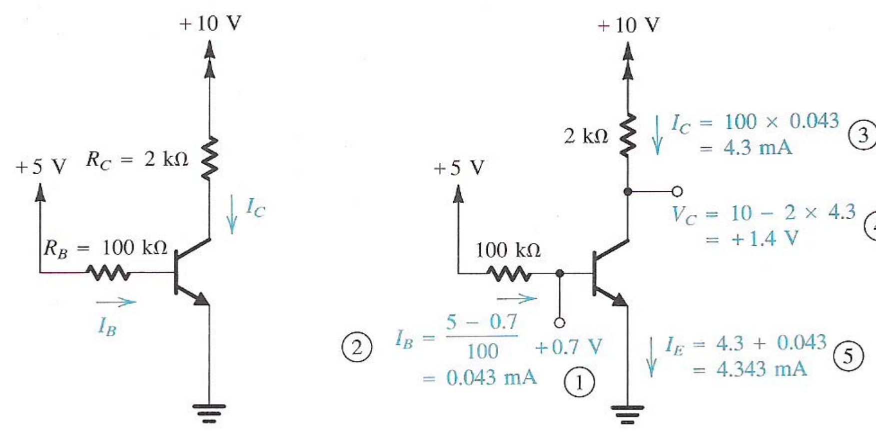


(a) (b)

Ex11. Find I_E, I_B, I_C and V_C circuit at V_E = -0.7, β = 50



Ex12. Find I_E, I_B, I_C and V_C circuit at V_{BE} = 0.7, β = 100



(a) (b)

เอกสารอ้างอิง (References)

1. Adel S. Sedra, Kenneth C. Smith "Microelectronic Circuit"
2. ผศ.สักรียา ชิตวงศ์ "วิศวกรรมอิเล็กทรอนิกส์"

Thank you