ECE 205 “Electrical and Electronics Circuits”

Spring 2024 – LECTURE 27

MWF – 12:00pm

Prof. Umberto Ravaioli

2062 ECE Building

Lecture 27 – Summary

Learning Objectives

1. Graphical use of *I*-*V* curves
2. Transistor as diode
3. Single Battery Bias of BJT
4. Discussion on BJT amplifier circuits

Quiz 3 next week - Reminder

- **Four problems:**
  - Two on circuit analysis using phasors
  - Two on diode circuits

HINT: read problems very carefully. Do not answer a “different” question.

No Class on 4/1/2024

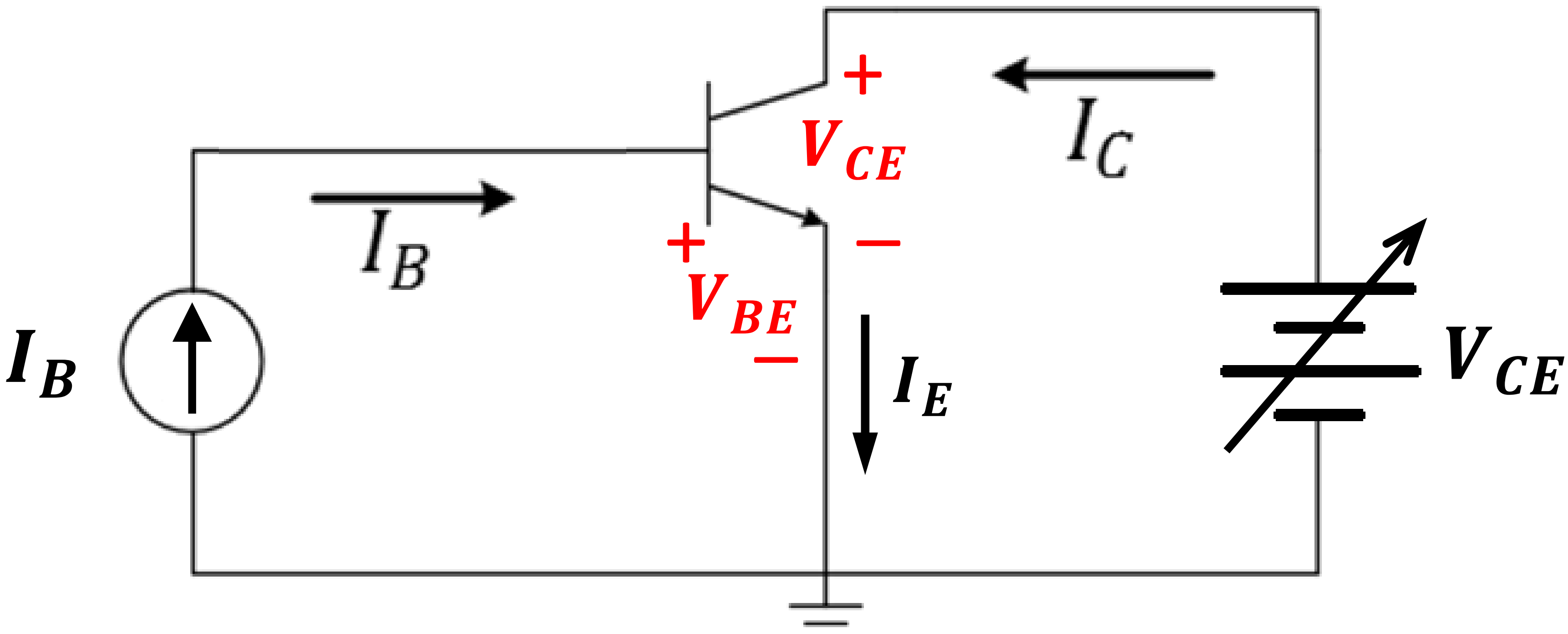
Practice material on BJT (not on Quiz 3)

- **BJT REVIEW PROBLEMS video Part 1**
  - Basic practice problems on *n-p-n* BJTs, including a circuit with resistor on the emitter
- **BJT REVIEW PROBLEMS video Part 2**
  - Discussion on the BJT Darlington pair explaining the behavior of the circuit found in HW 10.6-PL. Also, includes some advanced material for the students who have an interest (not required).
- **BJT REVIEW PROBLEMS video Part 3**
  - Includes solutions for Worksheet 9 and a problem on *p-n-p* transistor.

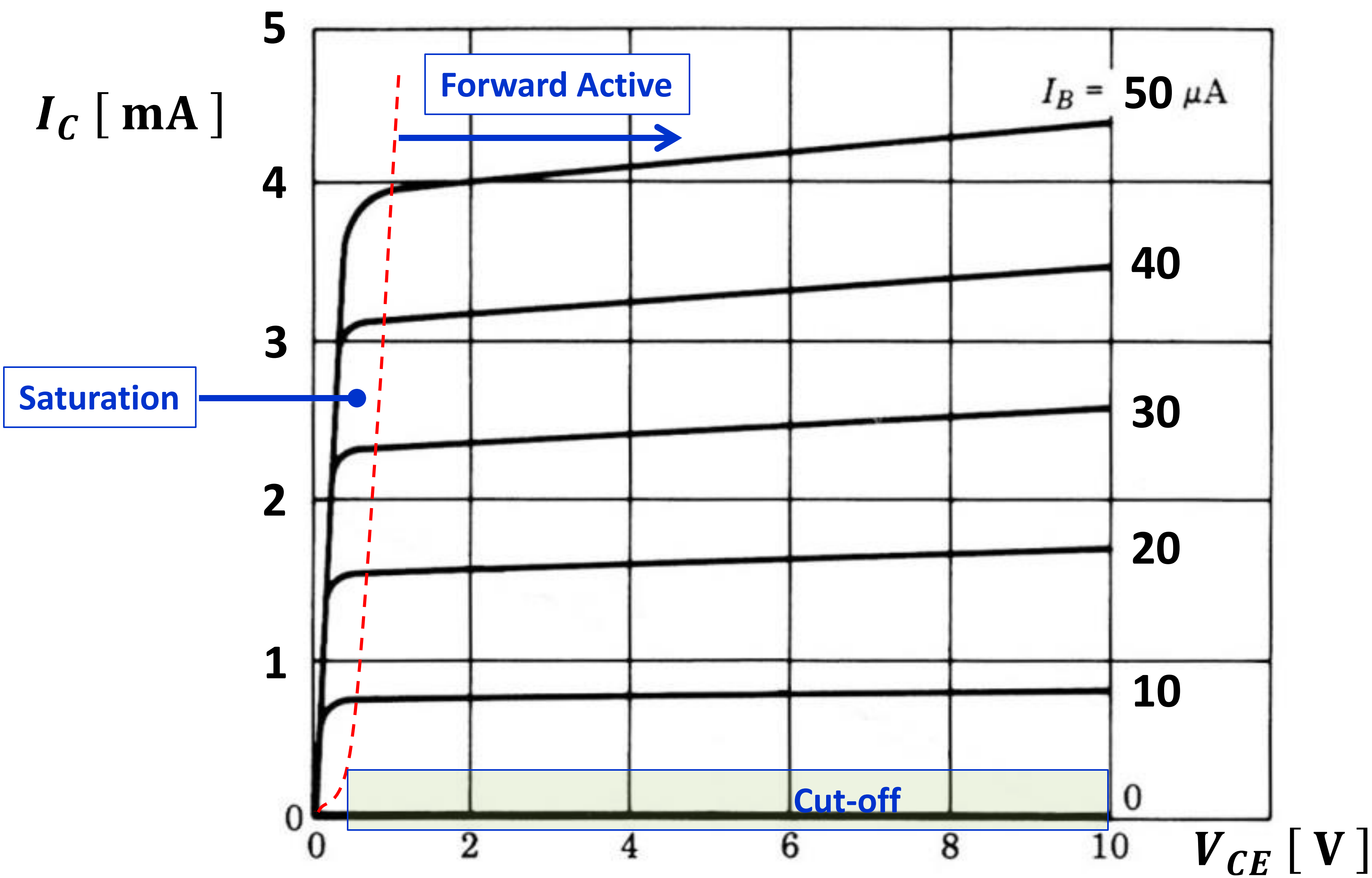
Posted on Canvas in Module Week 11, Lecture 28

BJT I-V curves are measured on actual devices

Measurements are made by ramping the V_{CE} at specific values of base current I_B



BJT I-V curves

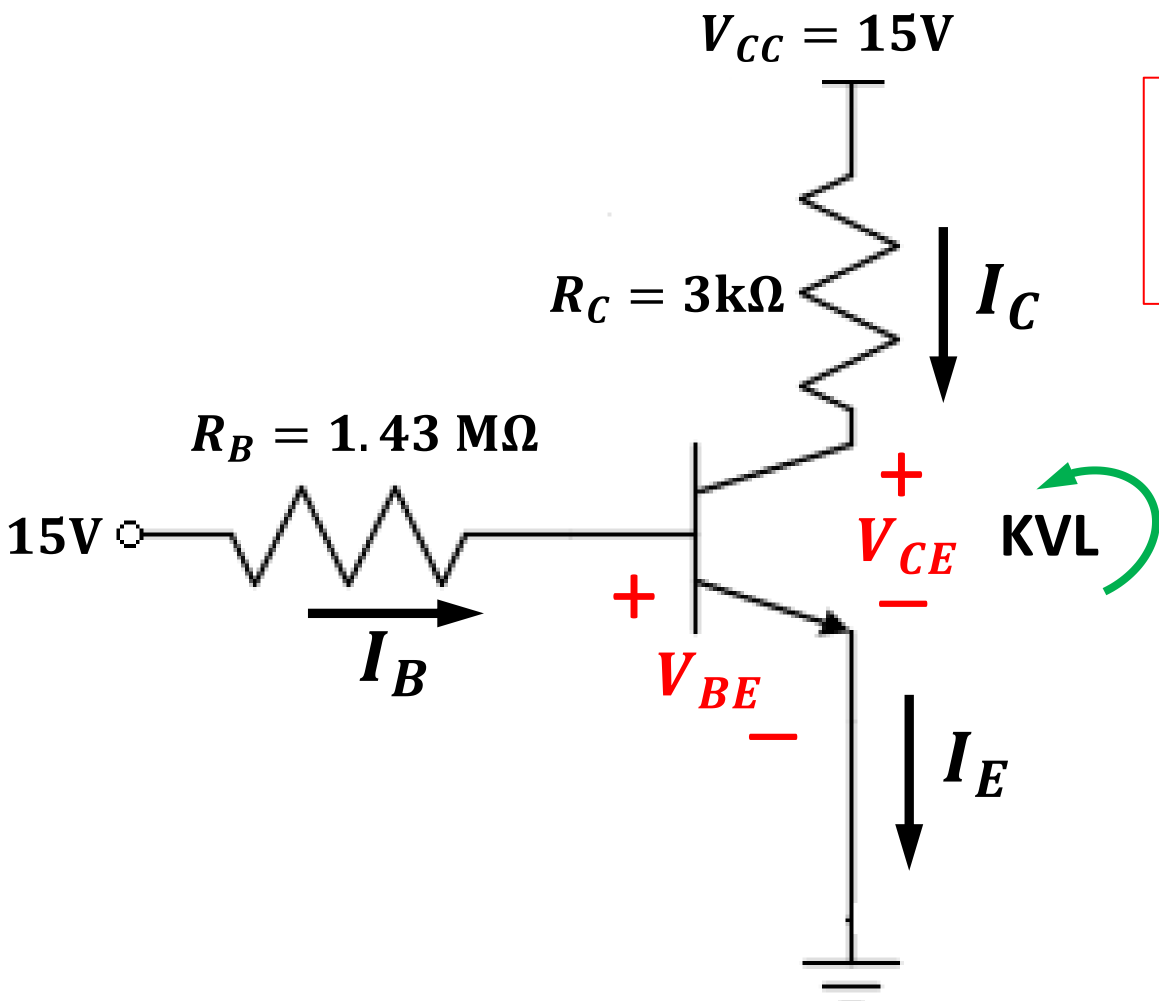


Example of graphical use of BJT I-V curves

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

$\beta = 100$

KVL $V_{CE} = V_{CC} - I_C R_C$



Let's write I_C as a function of V_{CE}

Example of graphical use of BJT I-V curves

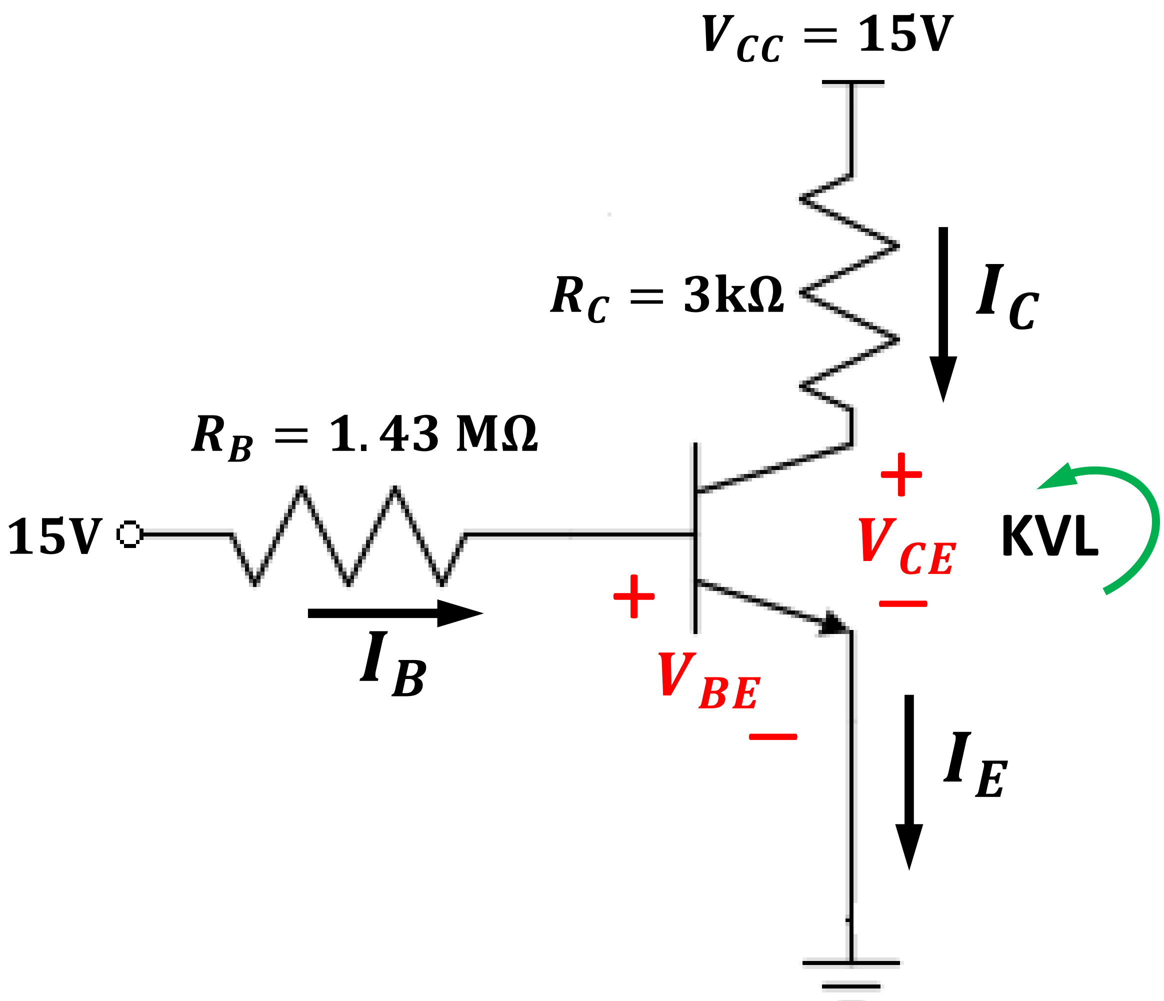
$V_{BE}(\text{on}) = 0.7\text{V}$

$\beta = 100$

KVL $V_{CE} = V_{CC} - I_C R_C$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$

$$I_C = \frac{15 - V_{CE}}{3\text{k}\Omega}$$



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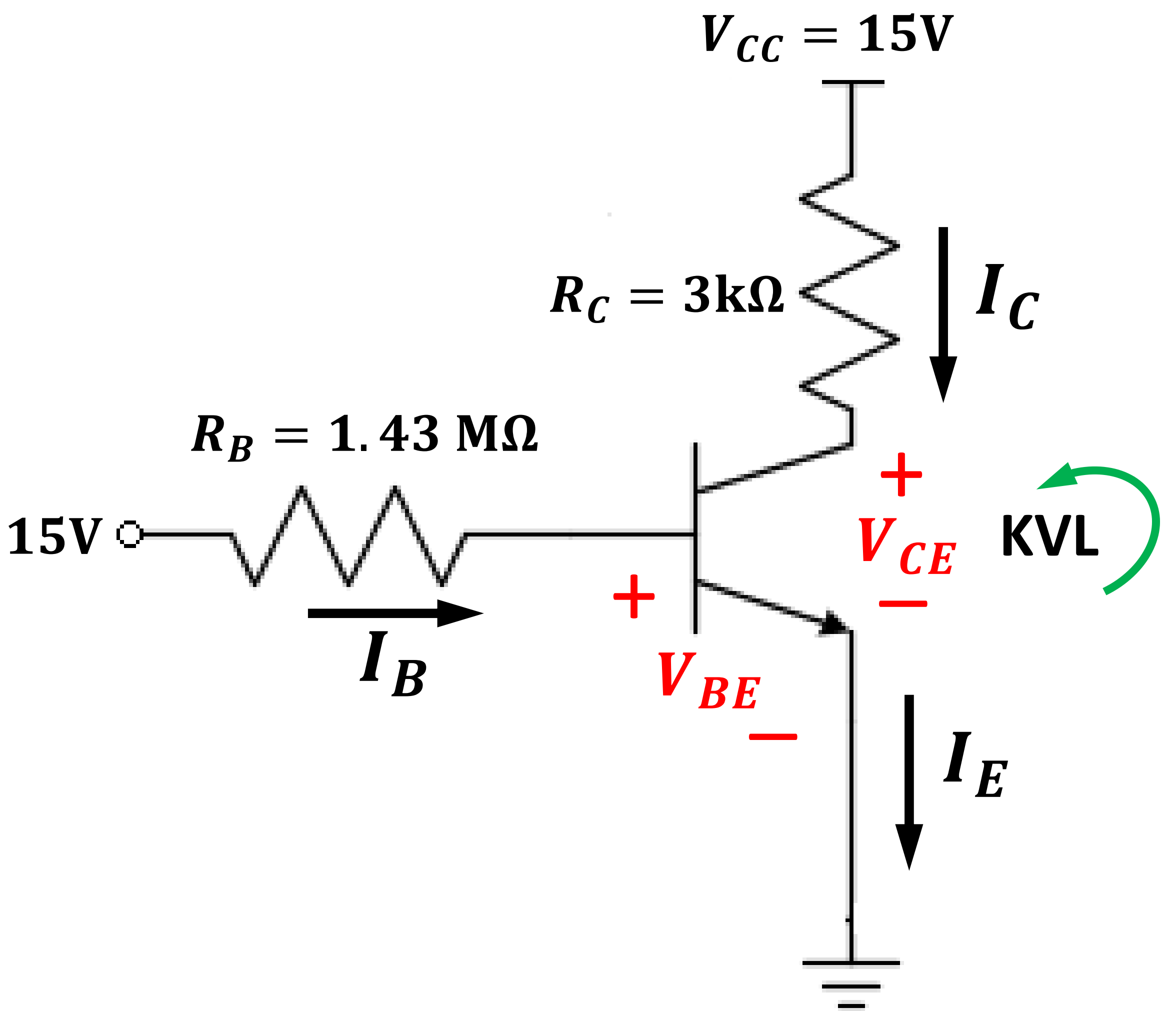

KVL $V_{CE} = V_{CC} - I_C R_C$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$

$$I_C = \frac{15 - V_{CE}}{3\text{k}\Omega}$$

$$I_C = 5\text{mA} - \frac{V_{CE}}{3\text{k}\Omega}$$

Equation of a straight line

V_{CE}	I_C
0V	5mA
15V	0mA

Example of graphical use of BJT I-V curves

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

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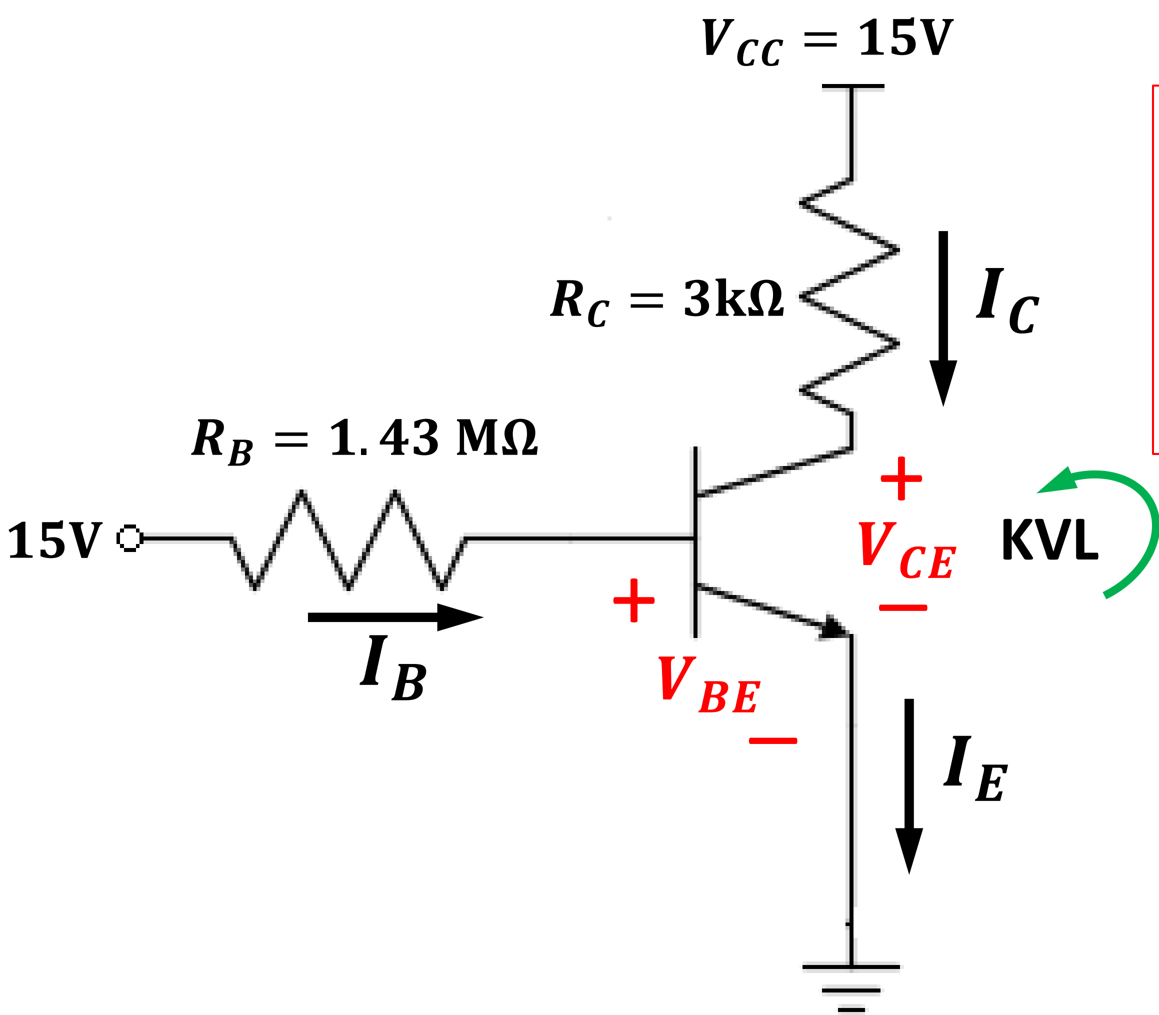
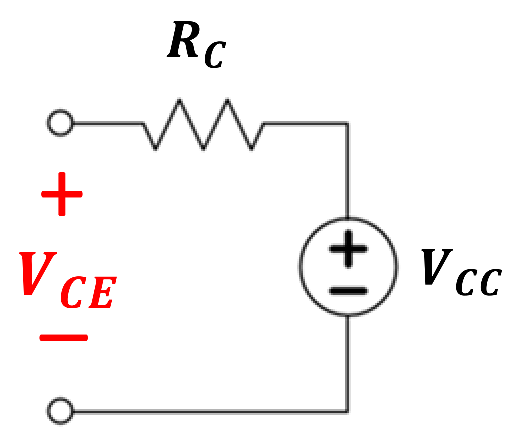
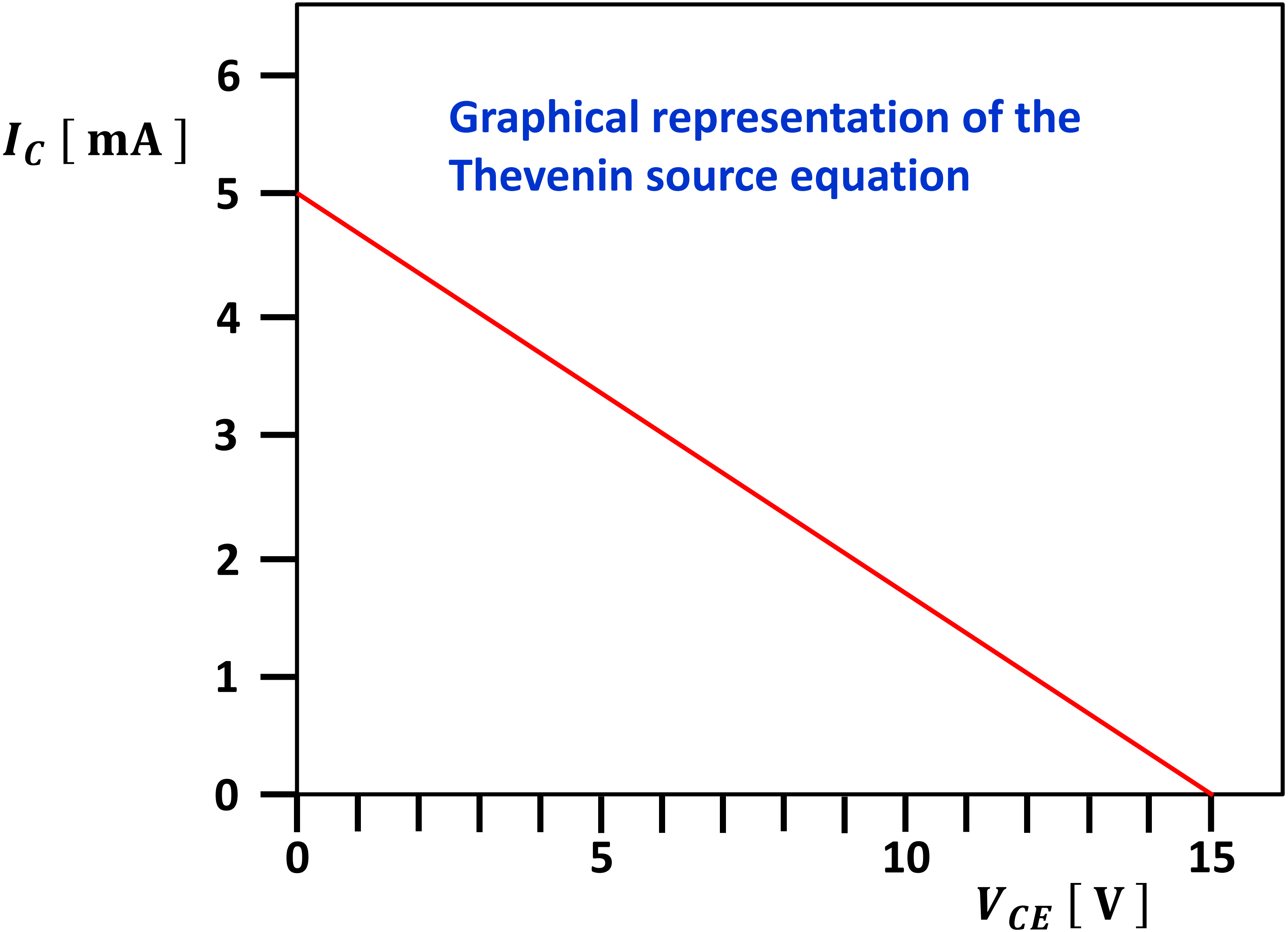
$$I_C = 5\text{mA} - \frac{V_{CE}}{3\text{k}\Omega}$$



This equation just describes the collector biasing network as a Thevenin source. Here, V_{CE} and I_C depend on the behavior of the BJT, which is a non-linear load



Example of graphical use of BJT I-V curves



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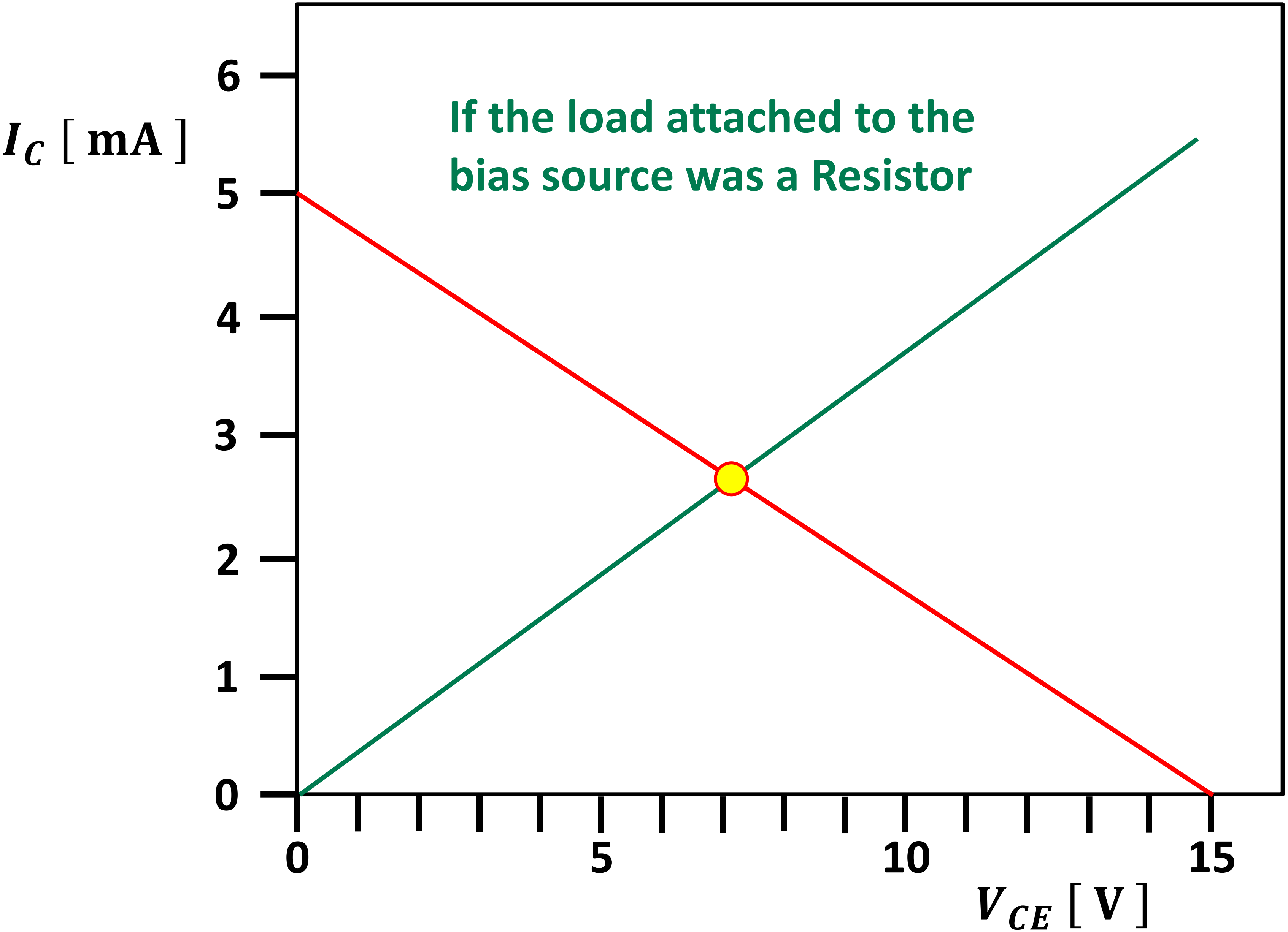

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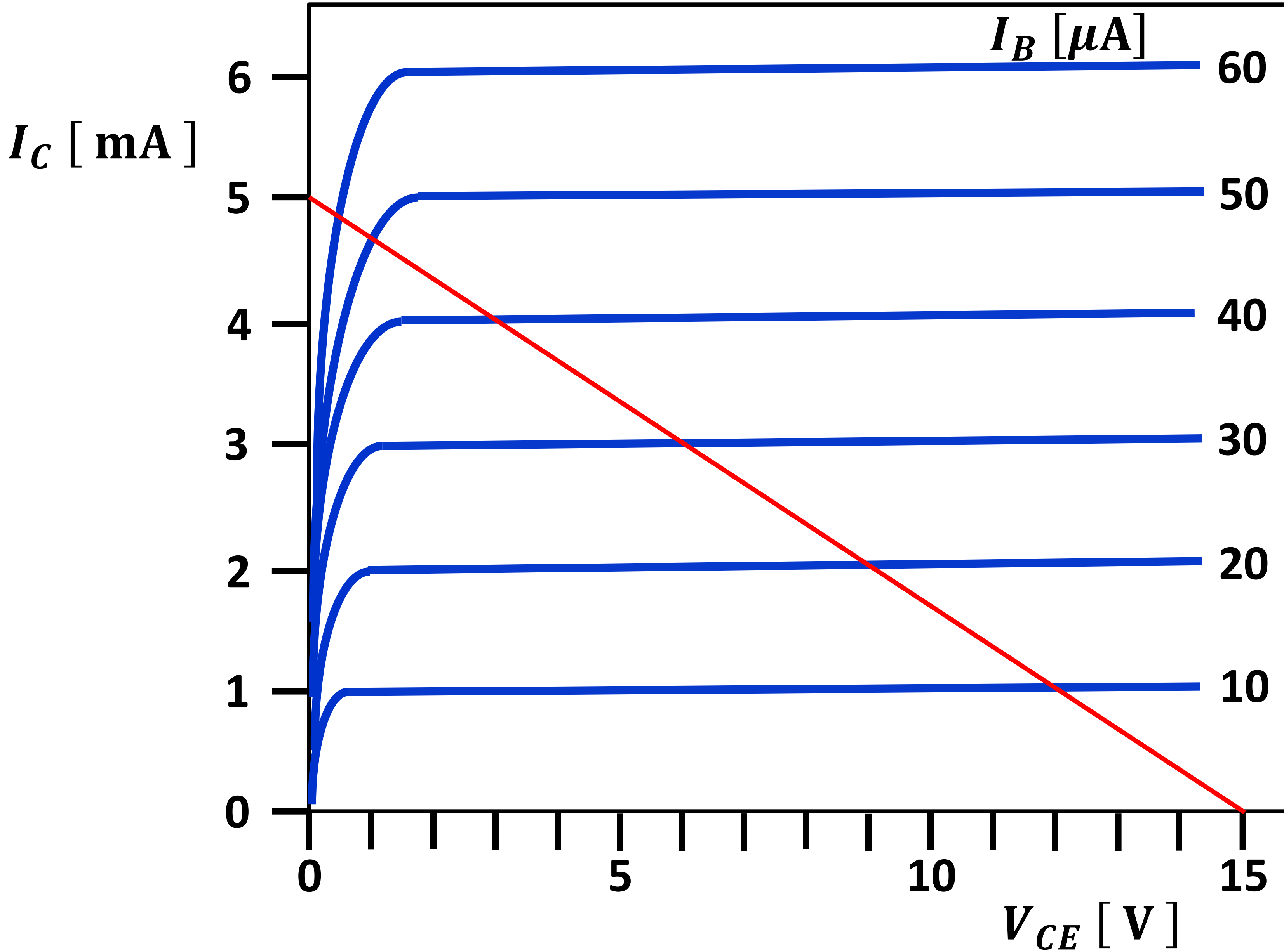
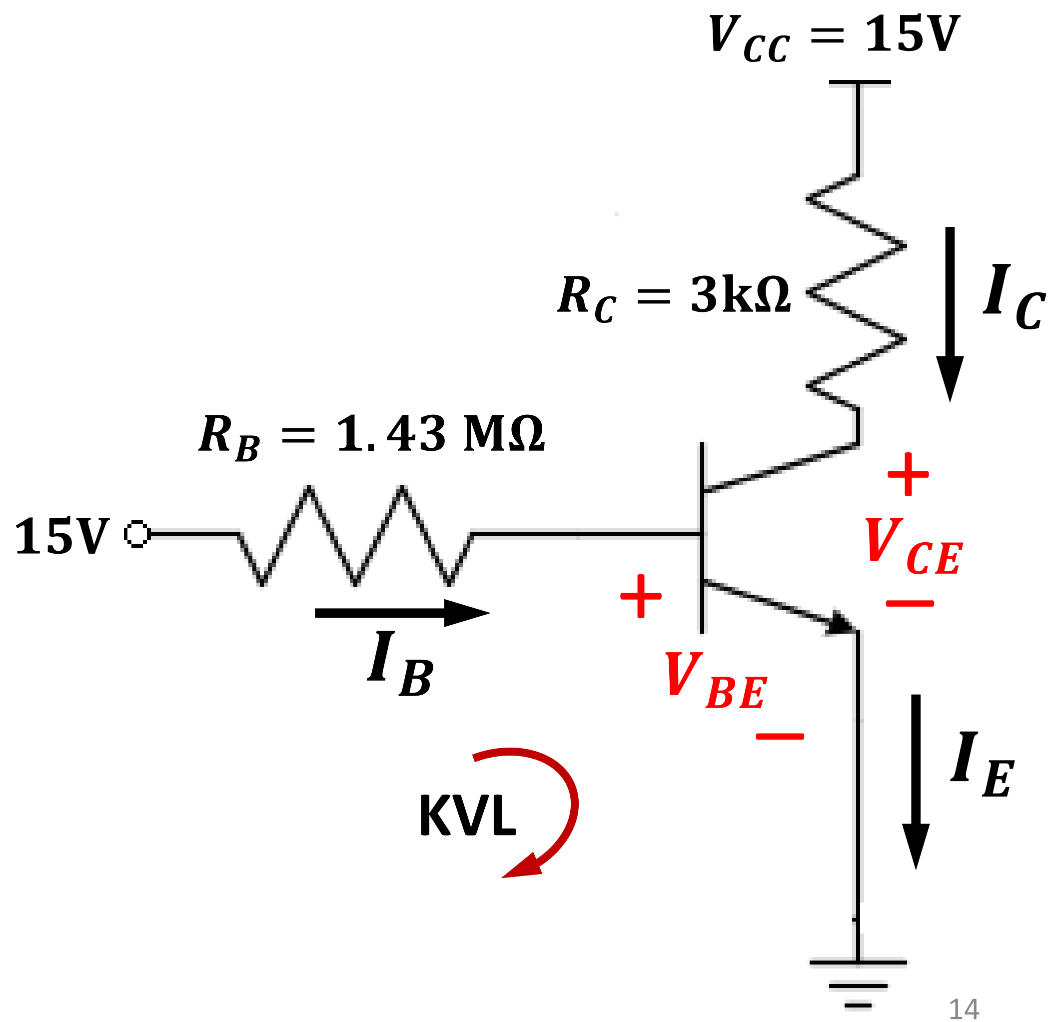


Example of graphical use of BJT I-V curves

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

$$\beta = 100$$

Let's examine the Base circuit:



Example of graphical use of BJT I-V curves

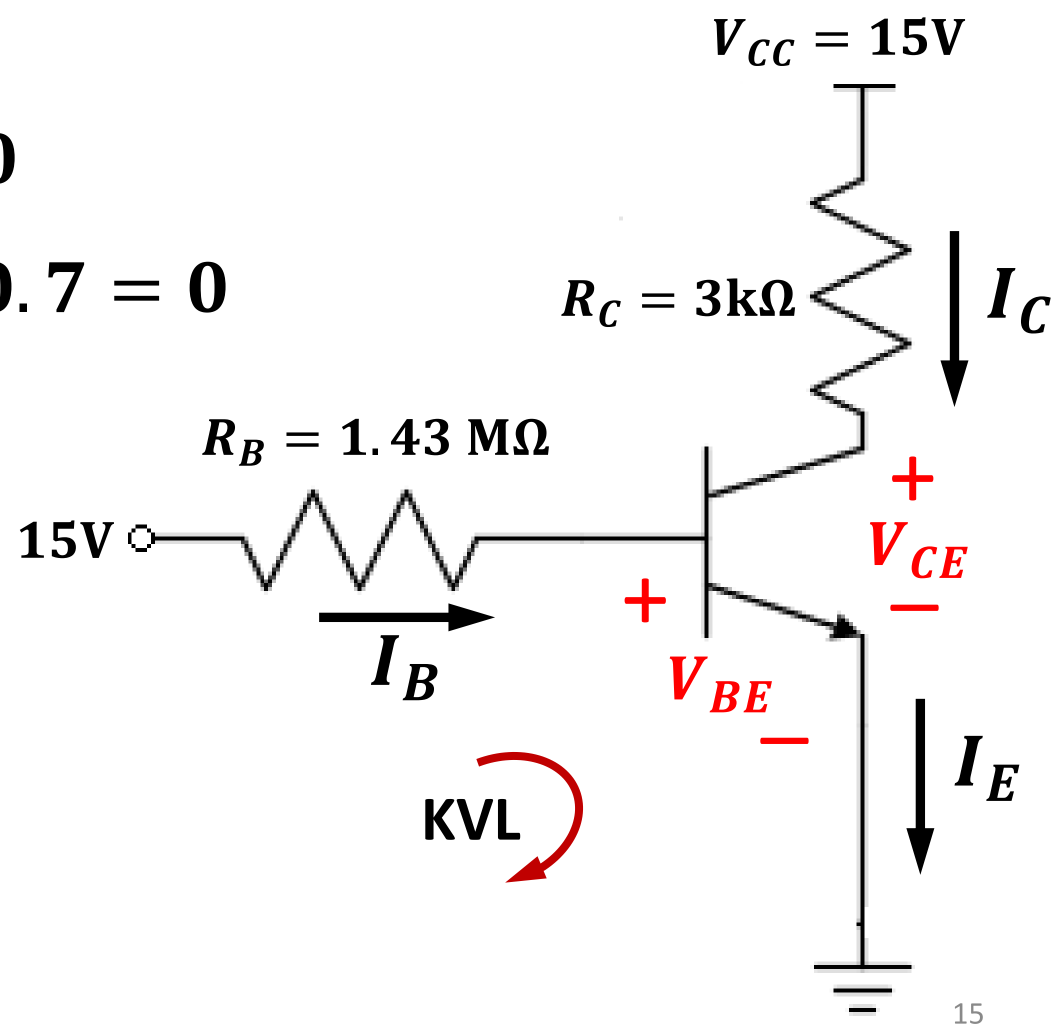
$V_{BE}(\text{on}) = 0.7\text{V}$

$\beta = 100$

Let's examine the Base circuit:

$$-15 + I_B R_B + V_{BE} = 0$$

$$-15 + 1.43\text{M} \times I_B + 0.7 = 0$$



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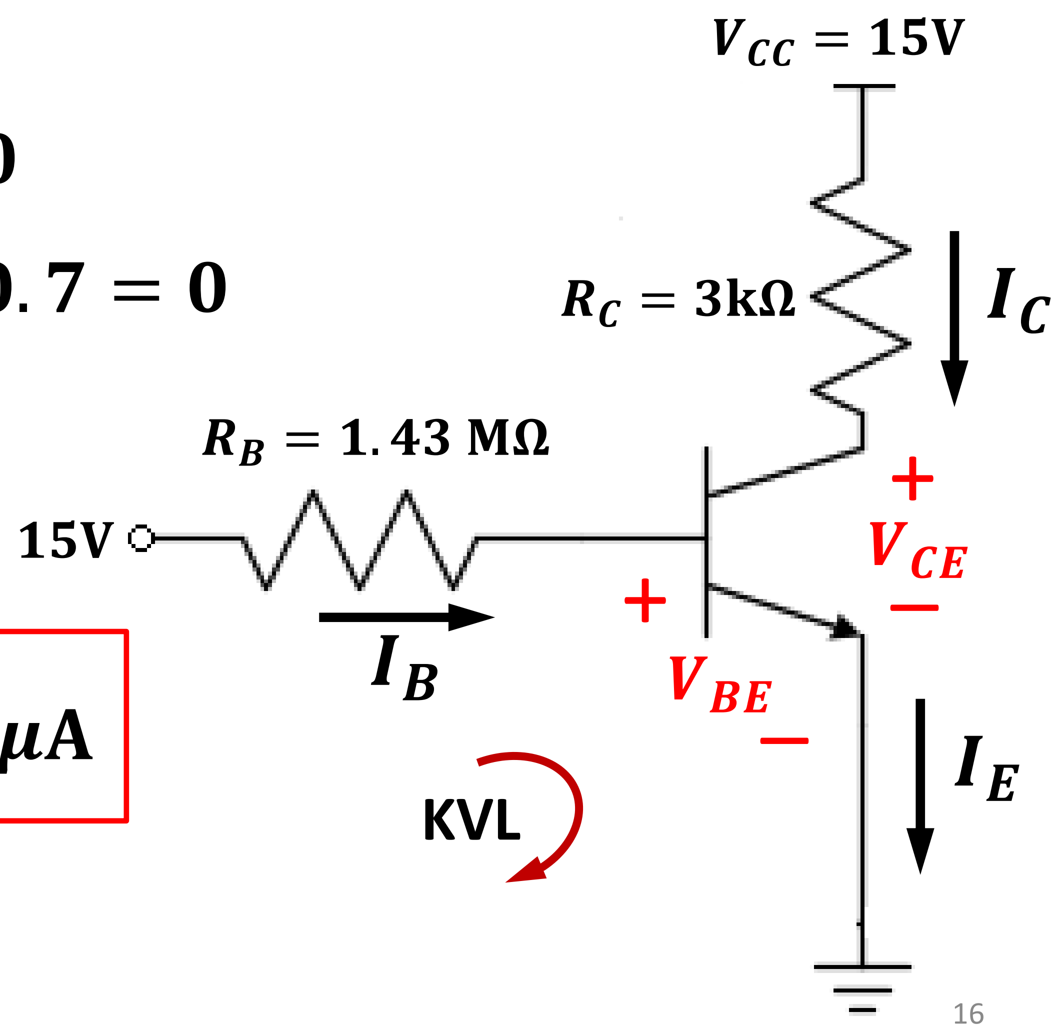
$$I_B = \frac{14.3}{1.43 \times 10^6} = 10\mu\text{A}$$



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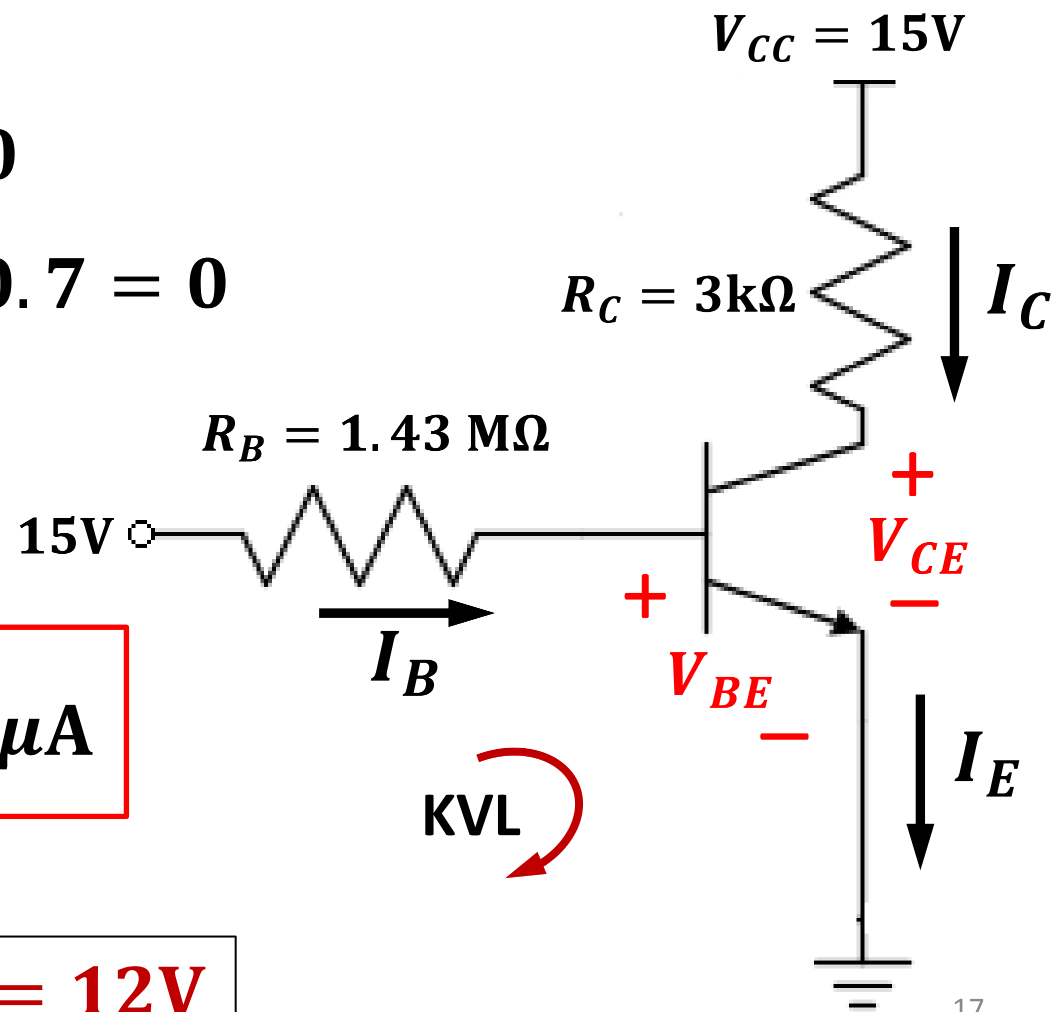
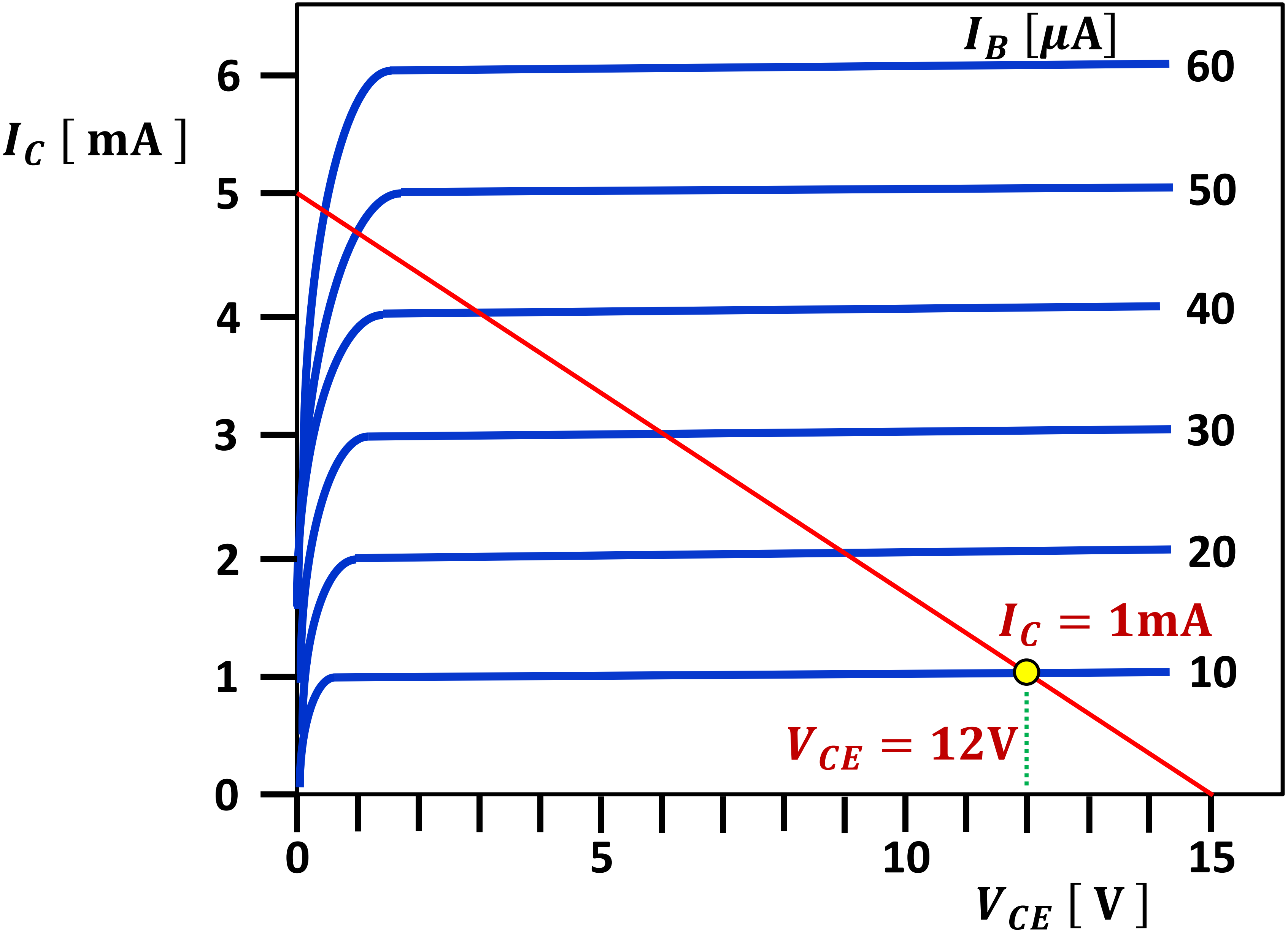


From the curves

$I_C = 1\text{mA}$ $V_{CE} = 12\text{V}$

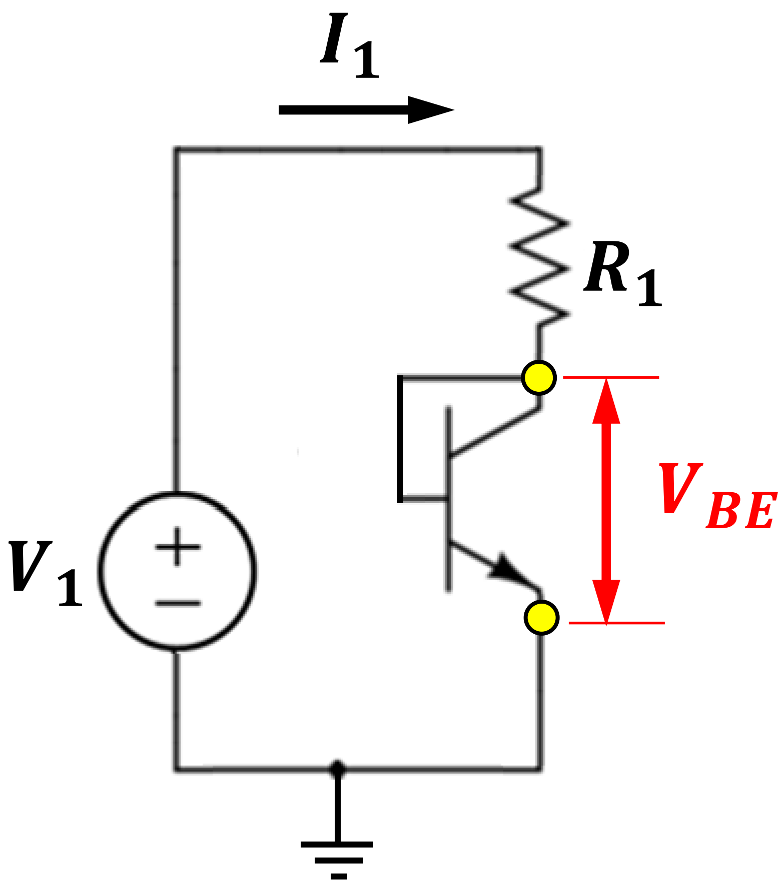
Example of graphical use of BJT I-V curves



BJT wired as a diode

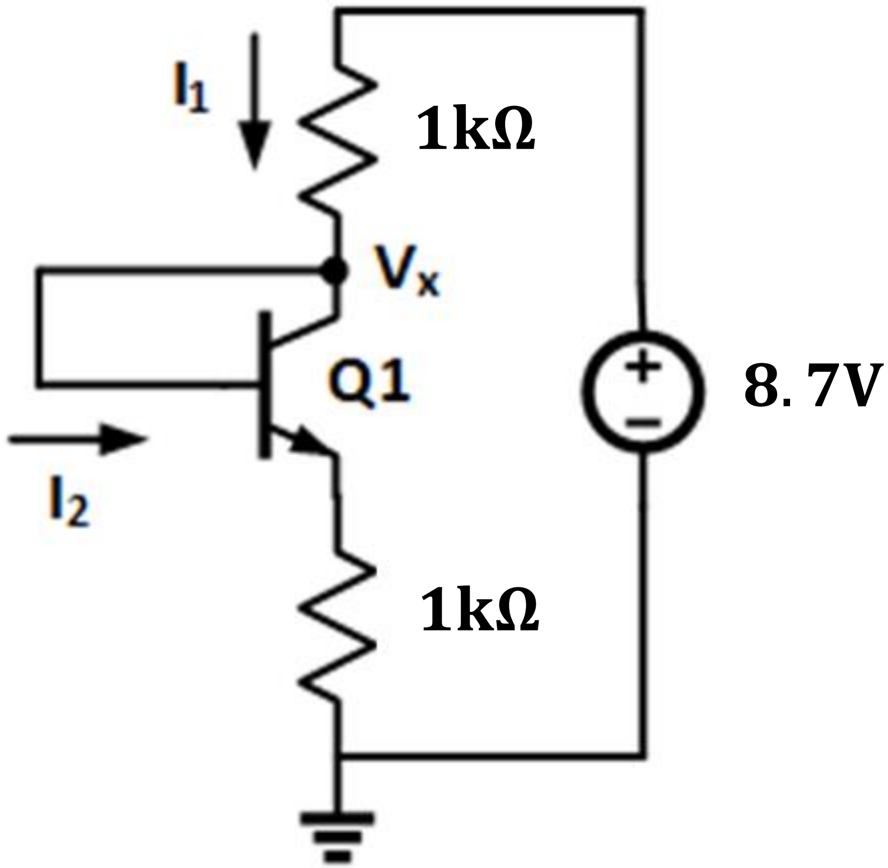
$$-V_1 + R_1 I_1 + V_{BE} = 0$$

$$I_1 = \frac{V_1 - V_{BE}}{R_1}$$



As long as $V_1 > V_{BE}(\text{on})$, the BJT is in Forward-Active mode.

BJT's wired as in the diagram, are often adopted in integrated circuits, to obtain ultra-low leakage diodes and for design of circuits which are temperature compensating.



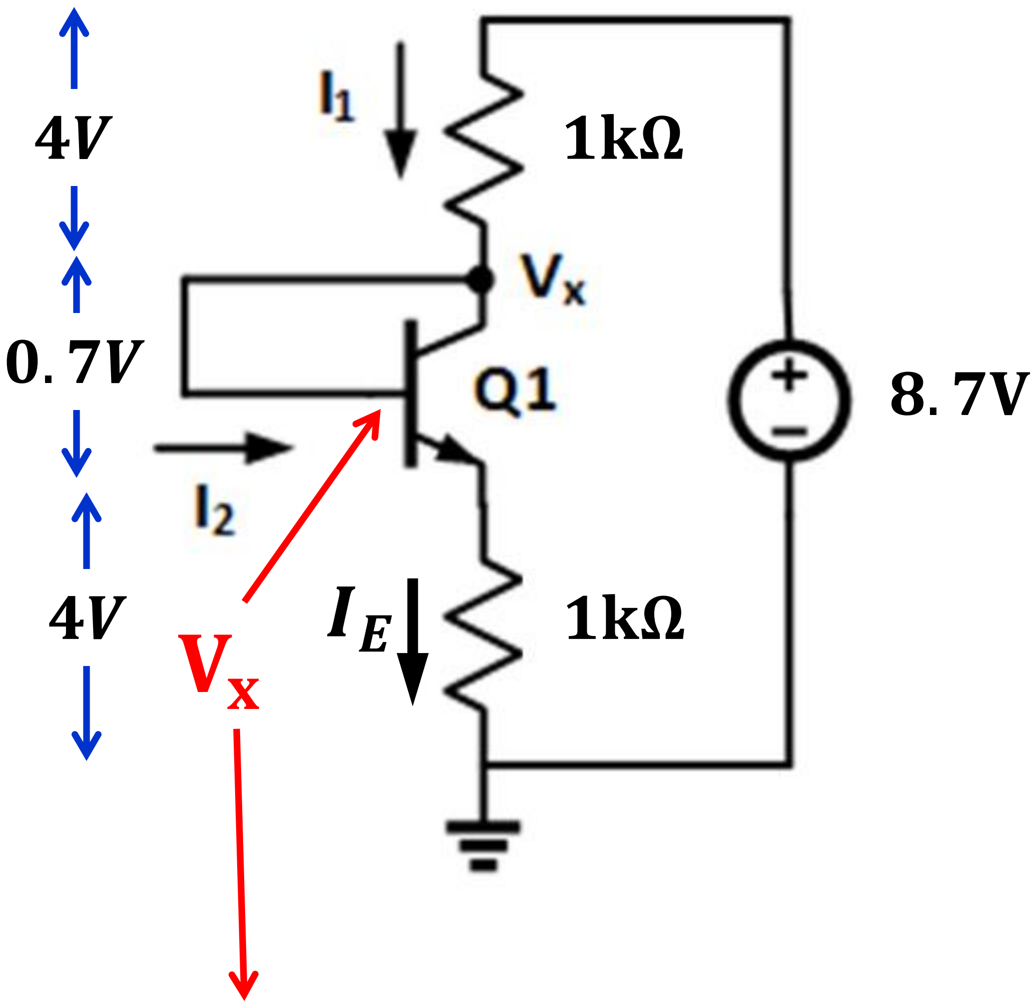
$$\beta = 100$$
$$V_{BE}(on) = 0.7\text{V}$$
$$V_{CE}(sat) = 0.2\text{V}$$

$\beta = 100$

$V_{BE}(on) = 0.7V$

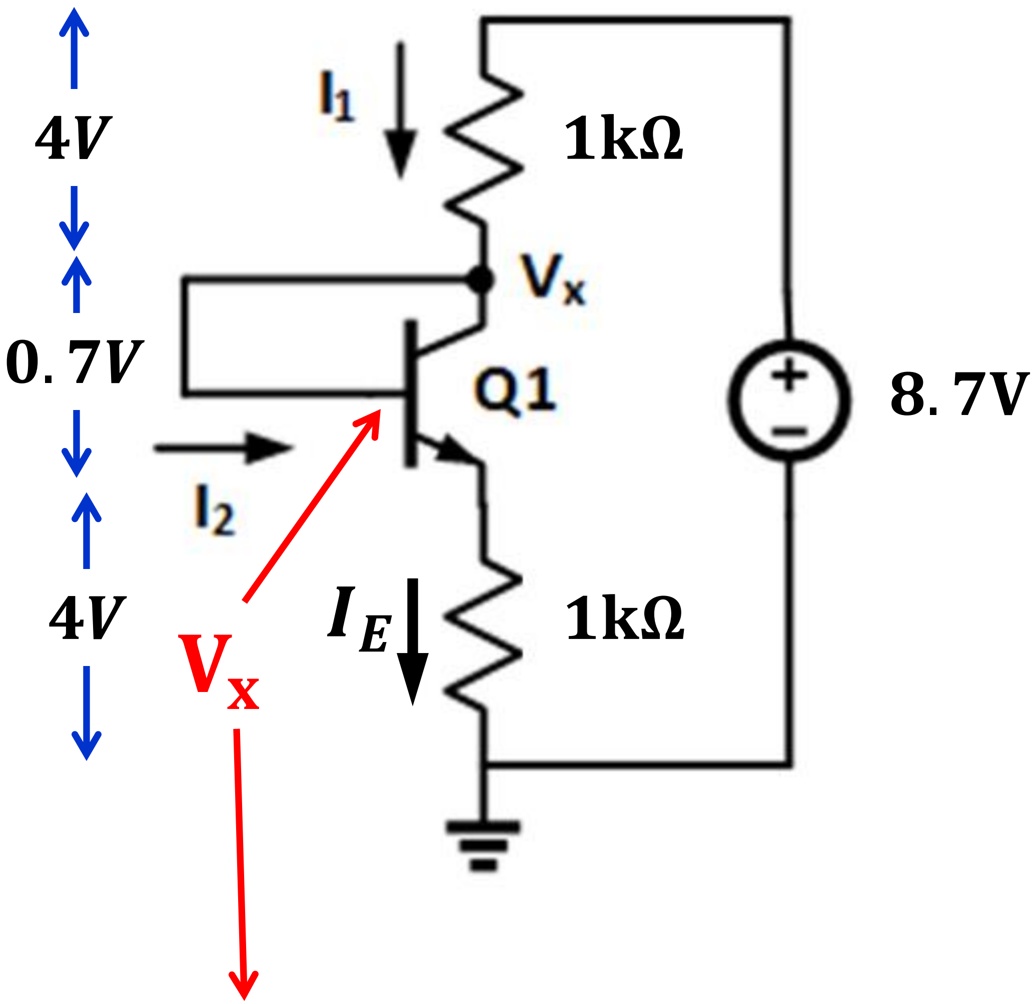
$V_{CE}(sat) = 0.2V$

Assume: BJT ON



$$V_{BE} = V_{CE} = 0.7V$$

$$V_x = V_{CE} + 4V = 4.7V$$



$\beta = 100$

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

$V_{CE}(sat) = 0.2\text{V}$

Assume: BJT ON

$$I_1 = I_C + I_2 = I_C + I_B$$

$$I_1 = I_E$$

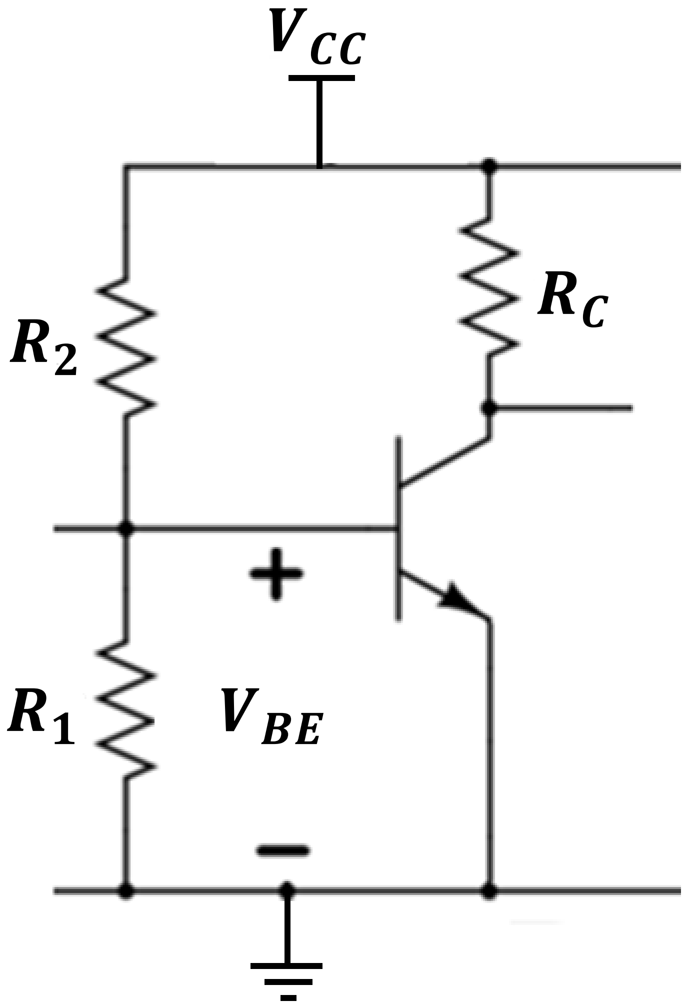
$$I_1 = 1k\Omega \times 4\text{V} = 4\text{mA}$$

$$I_E = 1k\Omega \times 4\text{V} = 4\text{mA}$$

$$V_{BE} = V_{CE} = 0.7V$$

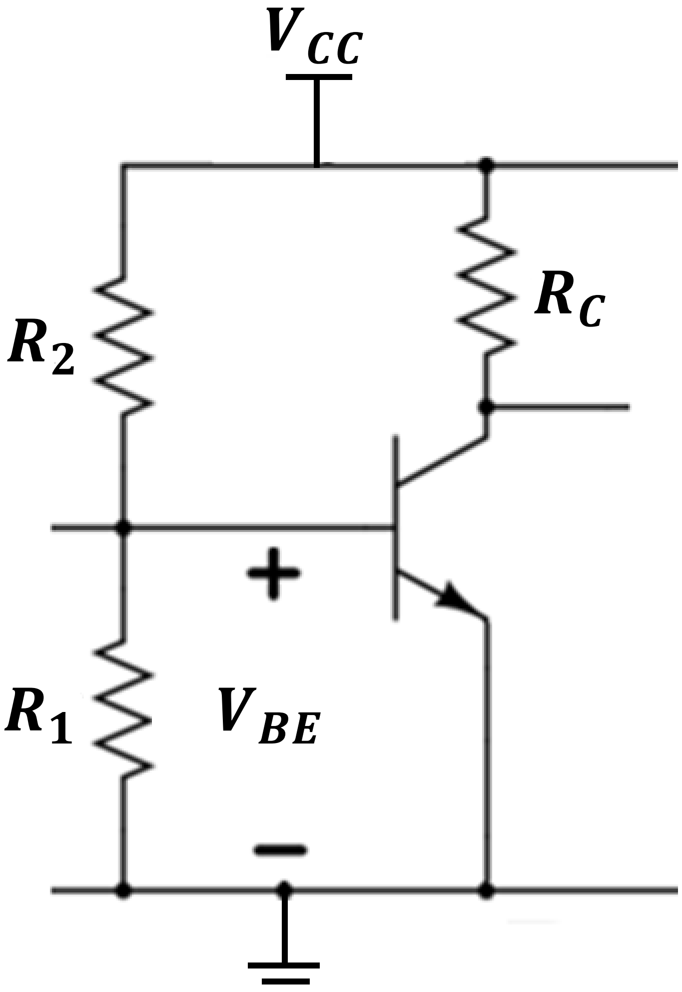
$$\text{V}_\text{x} = V_{CE} + 4V = 4.7V$$

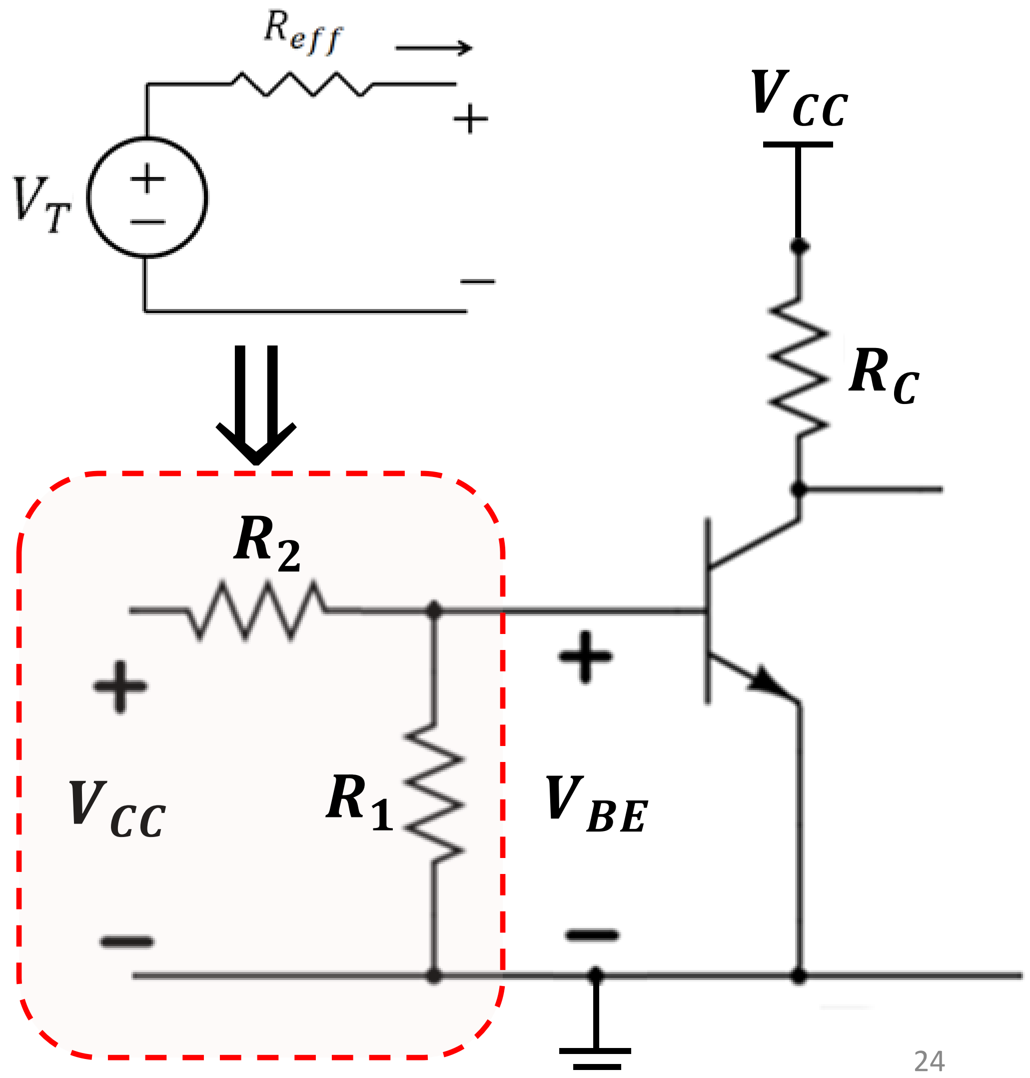
BJT Single battery bias



$$R_{eff} = R_1 // R_2$$

$$V_T = V_{CC} \frac{R_1}{R_1 + R_2}$$





$$R_{eff} = R_1 // R_2$$

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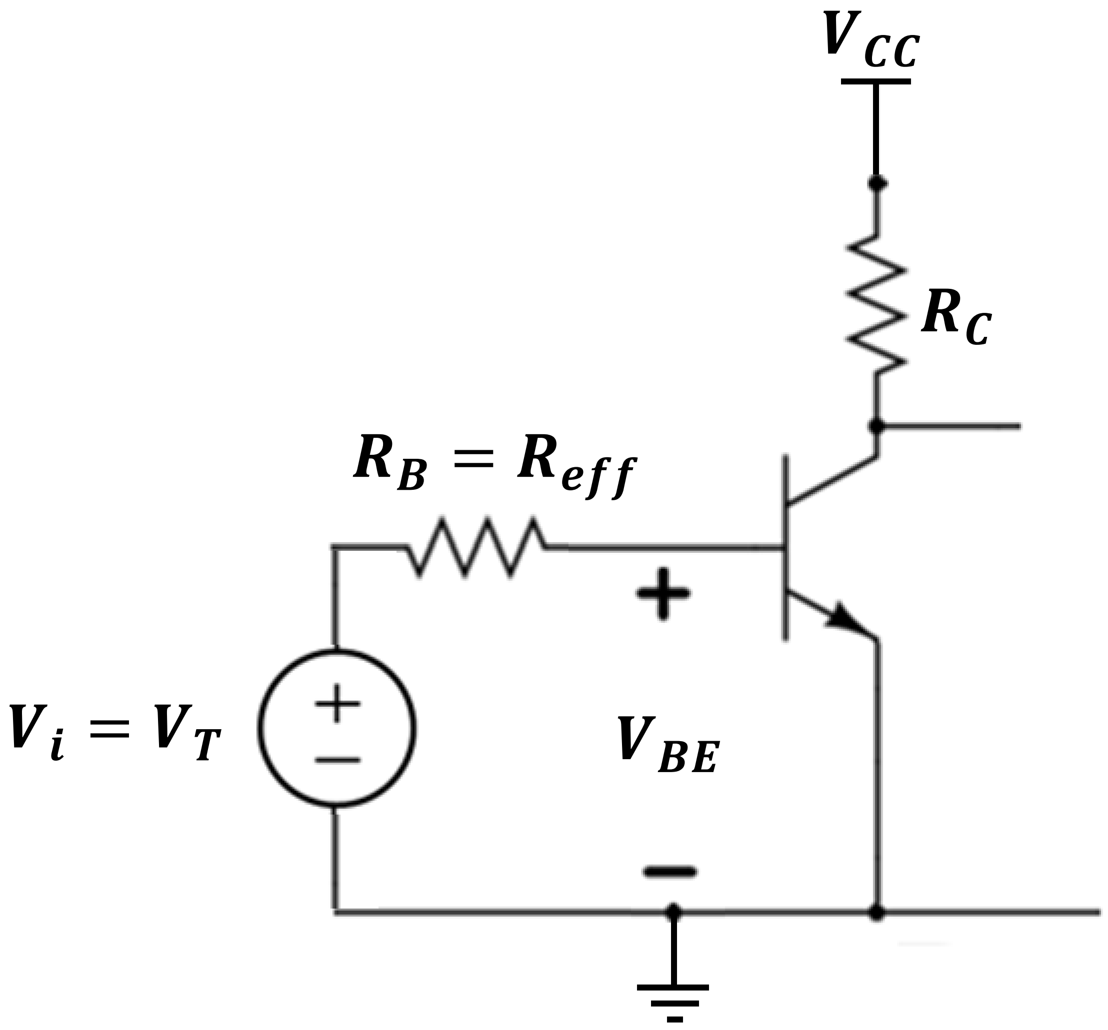
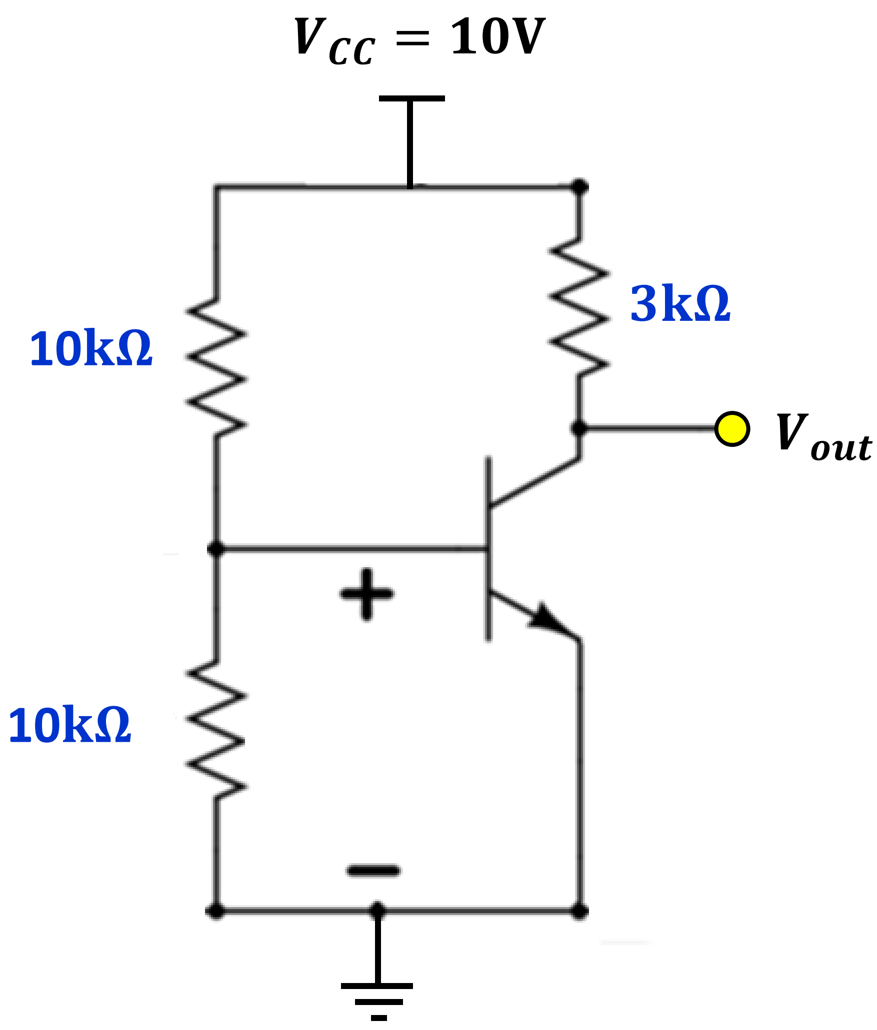


BJT Single Battery Bias Example

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

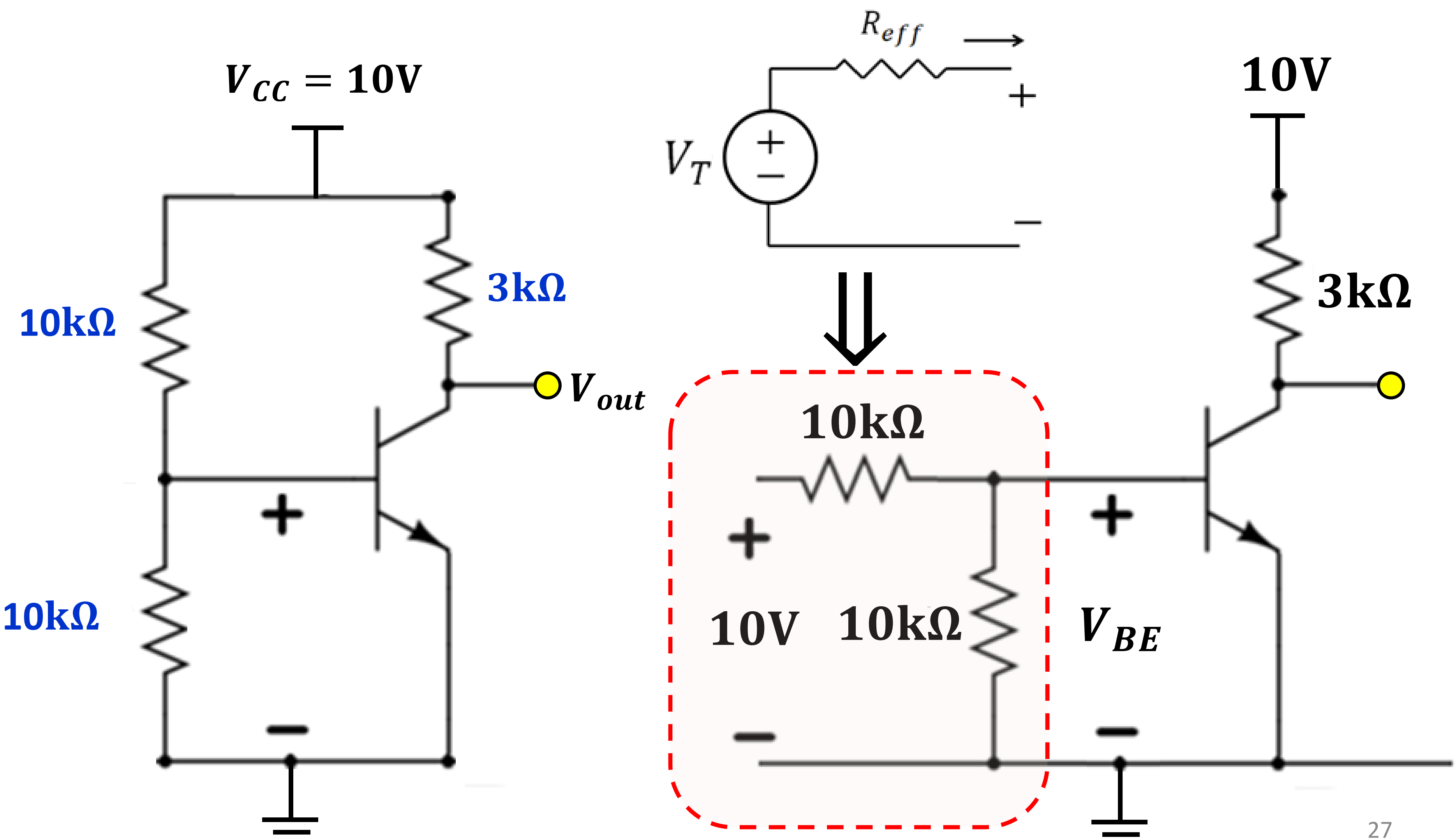
$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 5$



$$R_{eff} = R_1 // R_2 = 5\text{k}\Omega$$

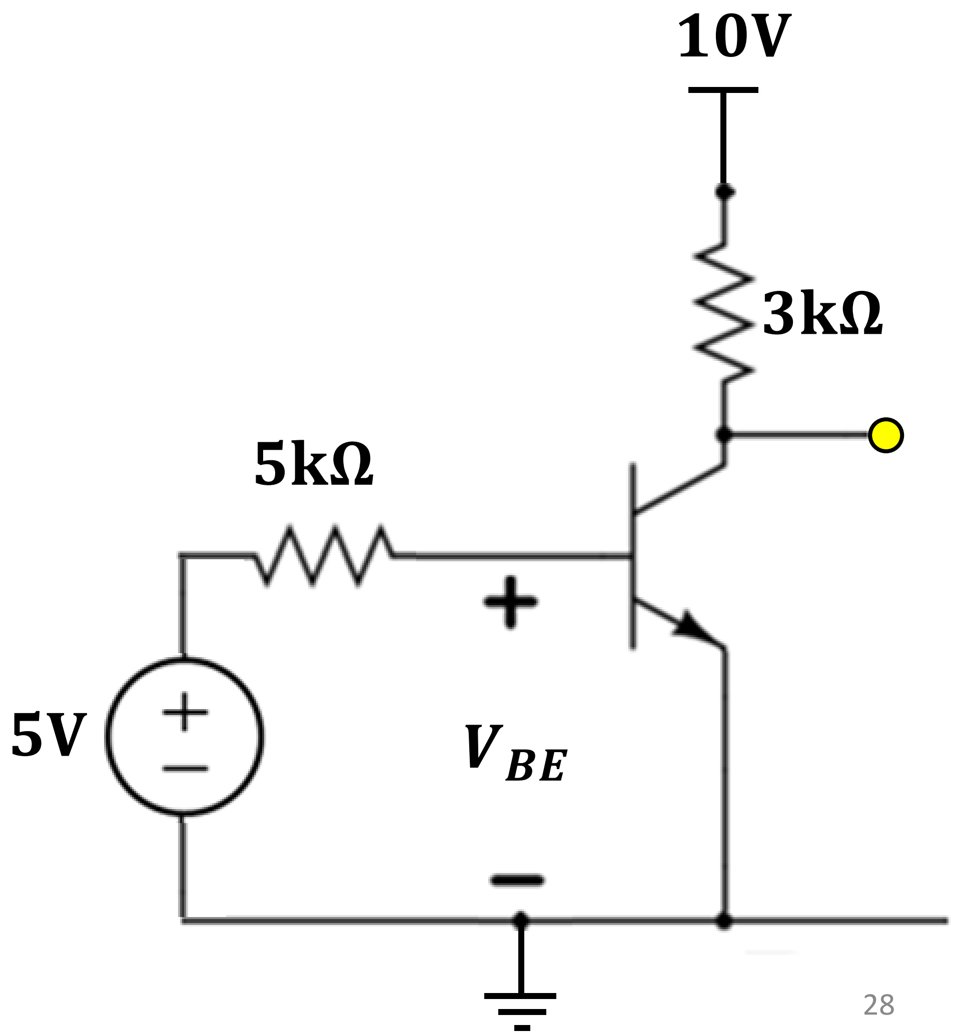
$$V_T = 10 \frac{10k\Omega}{10k\Omega + 10k\Omega} = 5\text{V}$$



Assume Forward-Active Mode $\beta = 5$

$$V_i = R_B I_B + V_{BE} \Rightarrow 5 = 5\text{k}\, I_B + 0.7 \Rightarrow I_B = \frac{4.3}{5\text{k}}$$

$$I_B = 0.86\ \text{mA}$$



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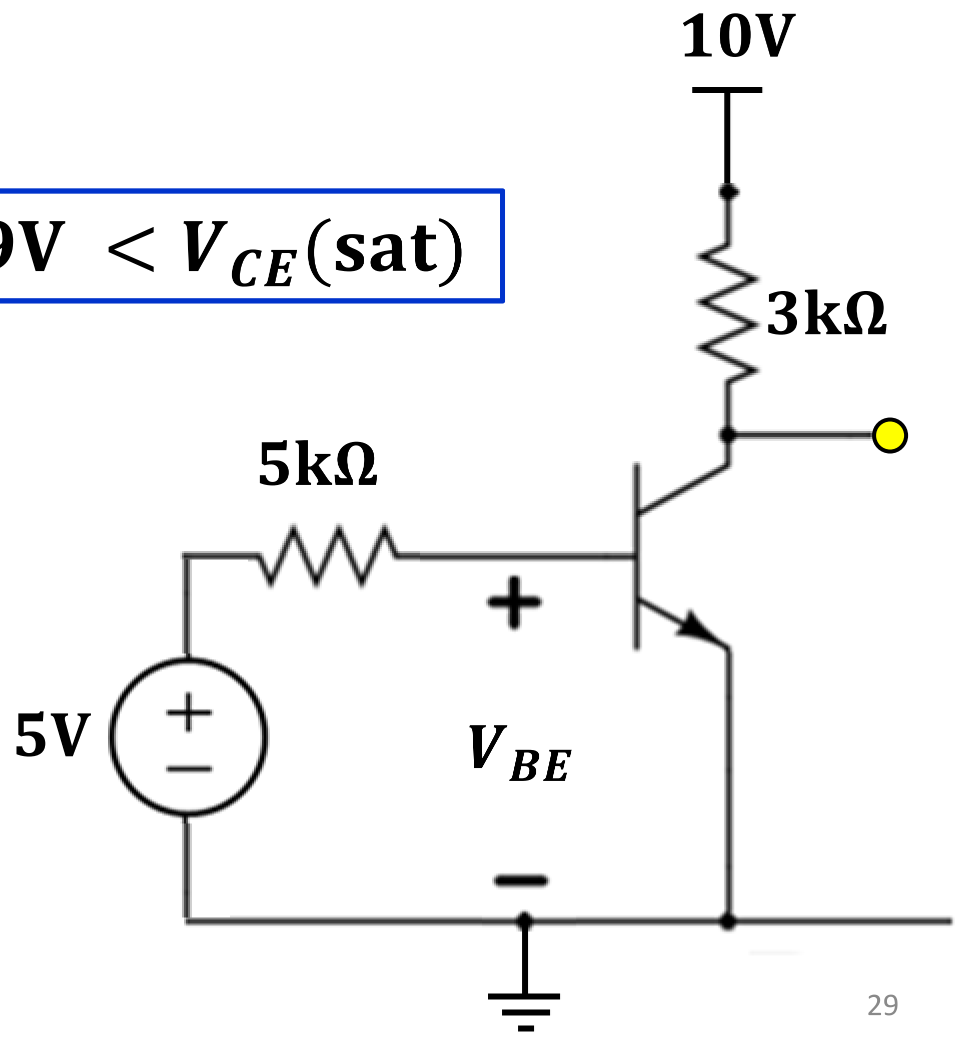
$$I_B = 0.86\ \text{mA}$$

$$I_C = \beta\, I_B = 4.3\text{mA}$$

$$V_{CE} = V_{CC} - 3\text{k}\, I_C = -2.9\text{V} < V_{CE}(\text{sat})$$



Assume Forward-Active Mode $\beta = 5$

$V_i = R_B I_B + V_{BE}$ ⇨ $5 = 5\text{k}\, I_B + 0.7$ ⇨ $I_B = \dfrac{4.3}{5\text{k}}$

$I_B = 0.86\ \text{mA}$

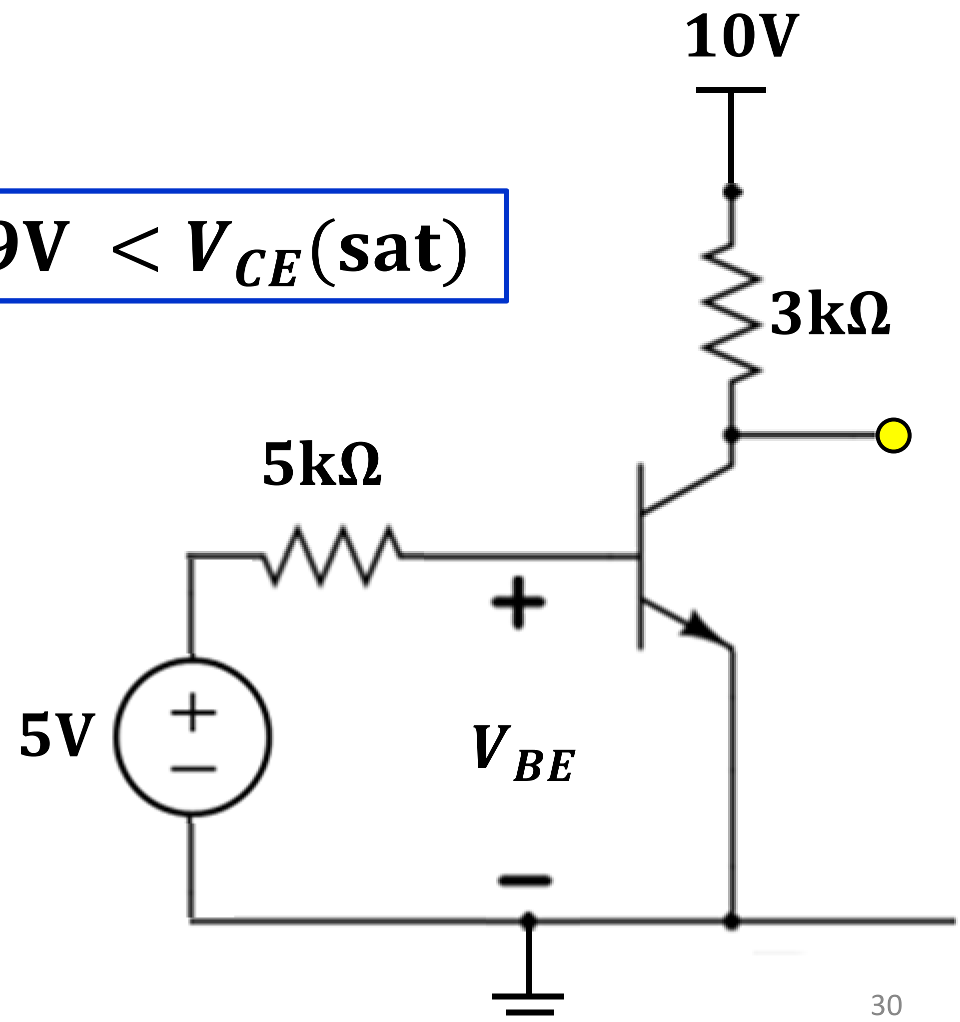
$I_C = \beta\, I_B = 4.3\text{mA}$

$V_{CE} = V_{CC} - 3\text{k}\, I_C = -2.9\text{V} < V_{CE}(\text{sat})$

BJT is in saturation:

$$I_C(\text{sat}) = \frac{10 - 0.2}{3\text{k}} = 3.2\overline{6}\text{mA}$$

$V_{CE} = V_{CE}(\text{sat}) = 0.2\text{V}$



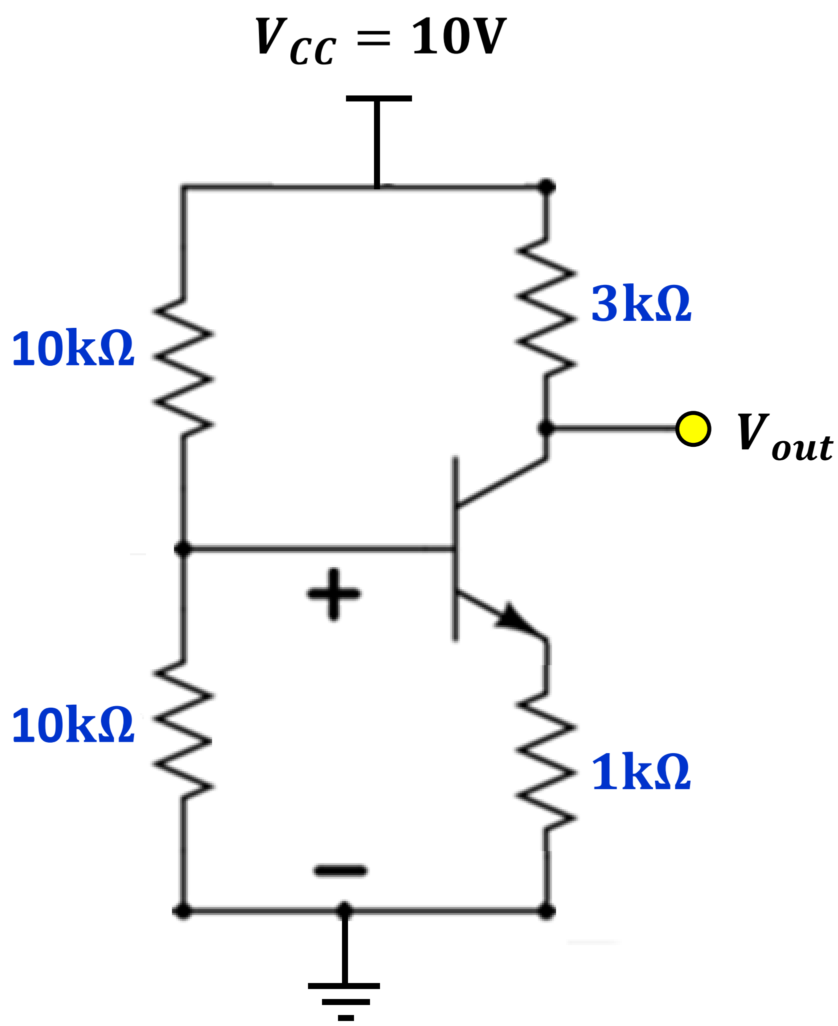
BJT Single Battery Bias – Resistor on Emitter

$$V_{BE}(\mathrm{on}) = 0.7\mathrm{V}$$

$$V_{CE}(\mathrm{sat}) = 0.2\mathrm{V}$$

$$\beta = 5$$

Add Emitter Resistor

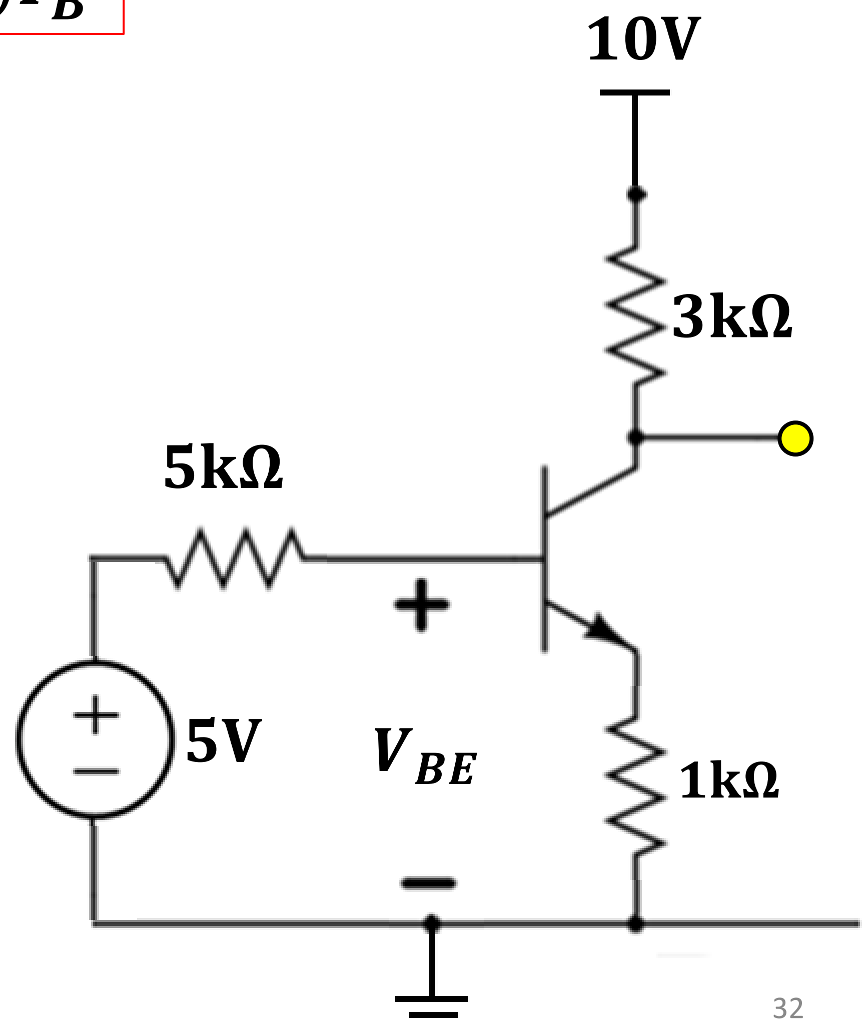


Assume Forward-Active Mode $\beta = 5$

$$V_i = R_B I_B + V_{BE} + R_E I_E$$

$$5 = 5\text{k}\, I_B + 0.7 + 1\text{k}\,(\beta + 1) I_B$$

$$I_B = 0.391\ \text{mA}$$



Assumption is valid

Assume Forward-Active Mode $\beta = 5$

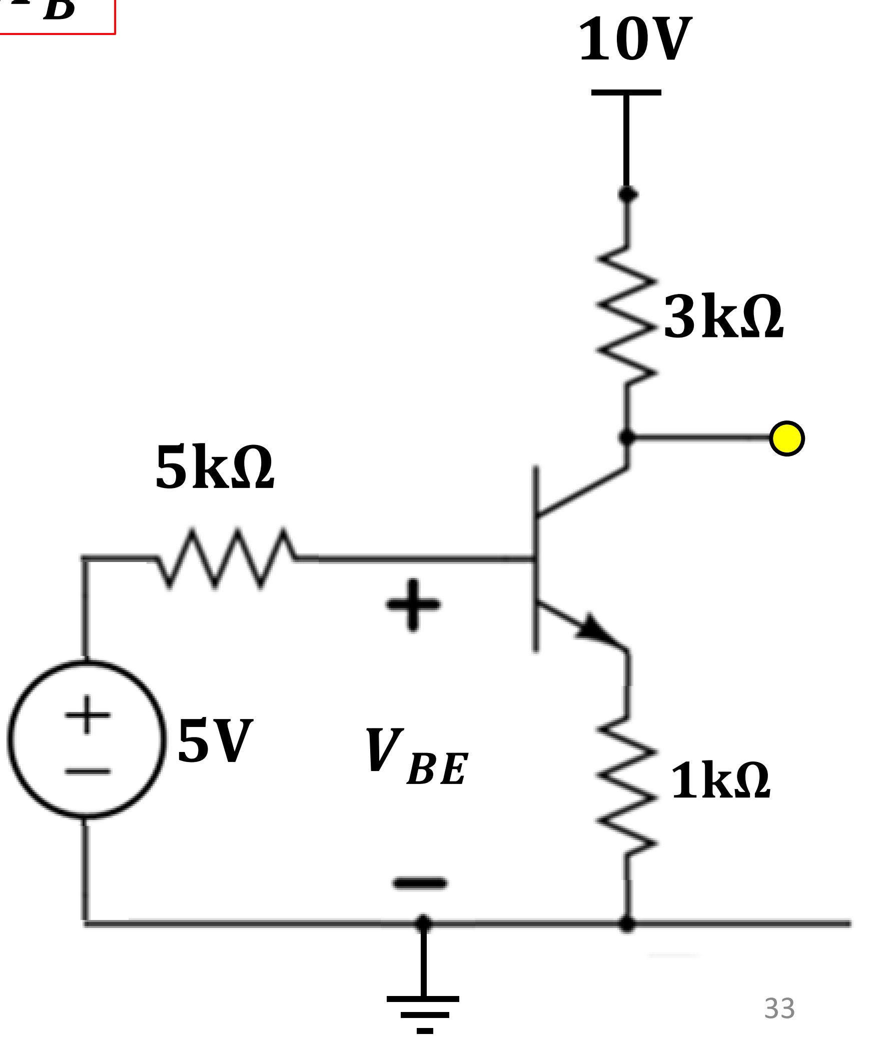
$$V_i = R_B I_B + V_{BE} + R_E I_E$$

$$5 = 5\text{k}\, I_B + 0.7 + 1\text{k}\,(\beta + 1) I_B$$

$$I_B = 0.391\ \text{mA}$$

$$I_C = \beta\, I_B = 1.955\text{mA}$$

$$I_E = (\beta + 1)\, I_B = 2.346\text{mA}$$



Assume Forward-Active Mode $\beta = 5$

$$V_i = R_B I_B + V_{BE} + R_E I_E$$

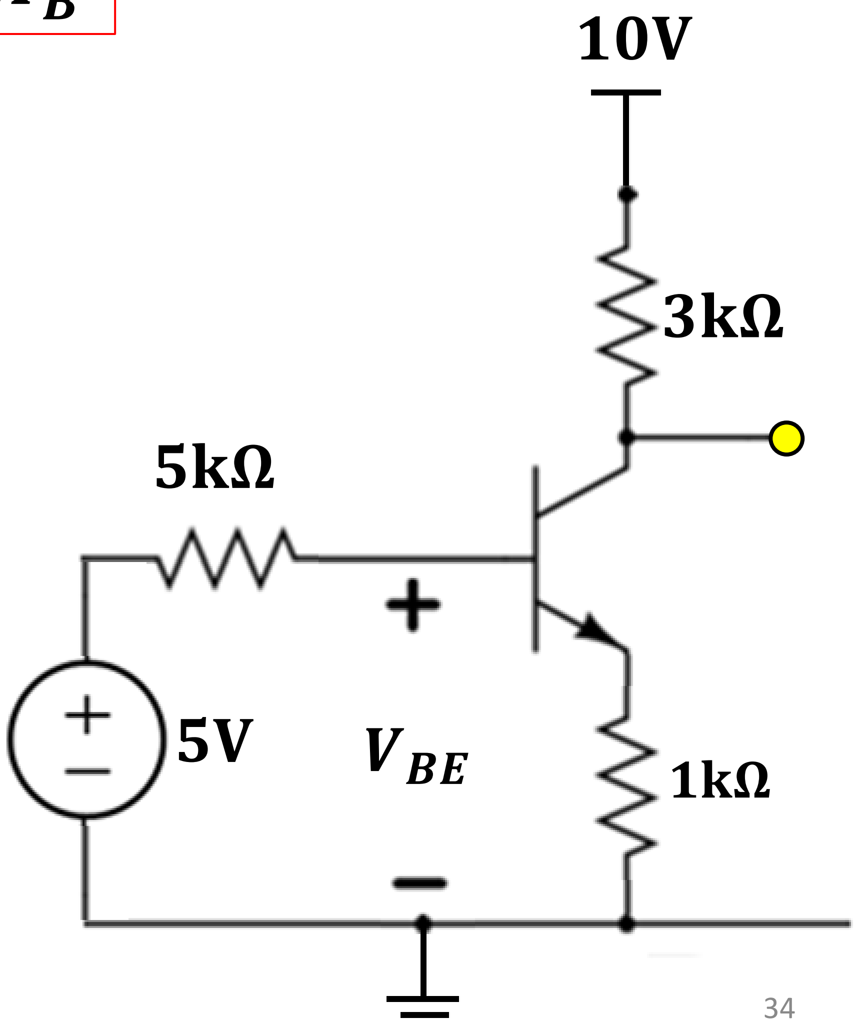
$$5 = 5\text{k}\, I_B + 0.7 + 1\text{k}\,(\beta + 1) I_B$$

$$I_B = 0.391\ \text{mA}$$

$$I_C = \beta\, I_B = 1.955\text{mA}$$

$$I_E = (\beta + 1)\, I_B = 2.346\text{mA}$$

$$V_{CE} = 10 - 3\text{k}\, I_C - 1k\, I_E$$
$$= 1.789\text{V} > V_{CE}(\text{sat})$$



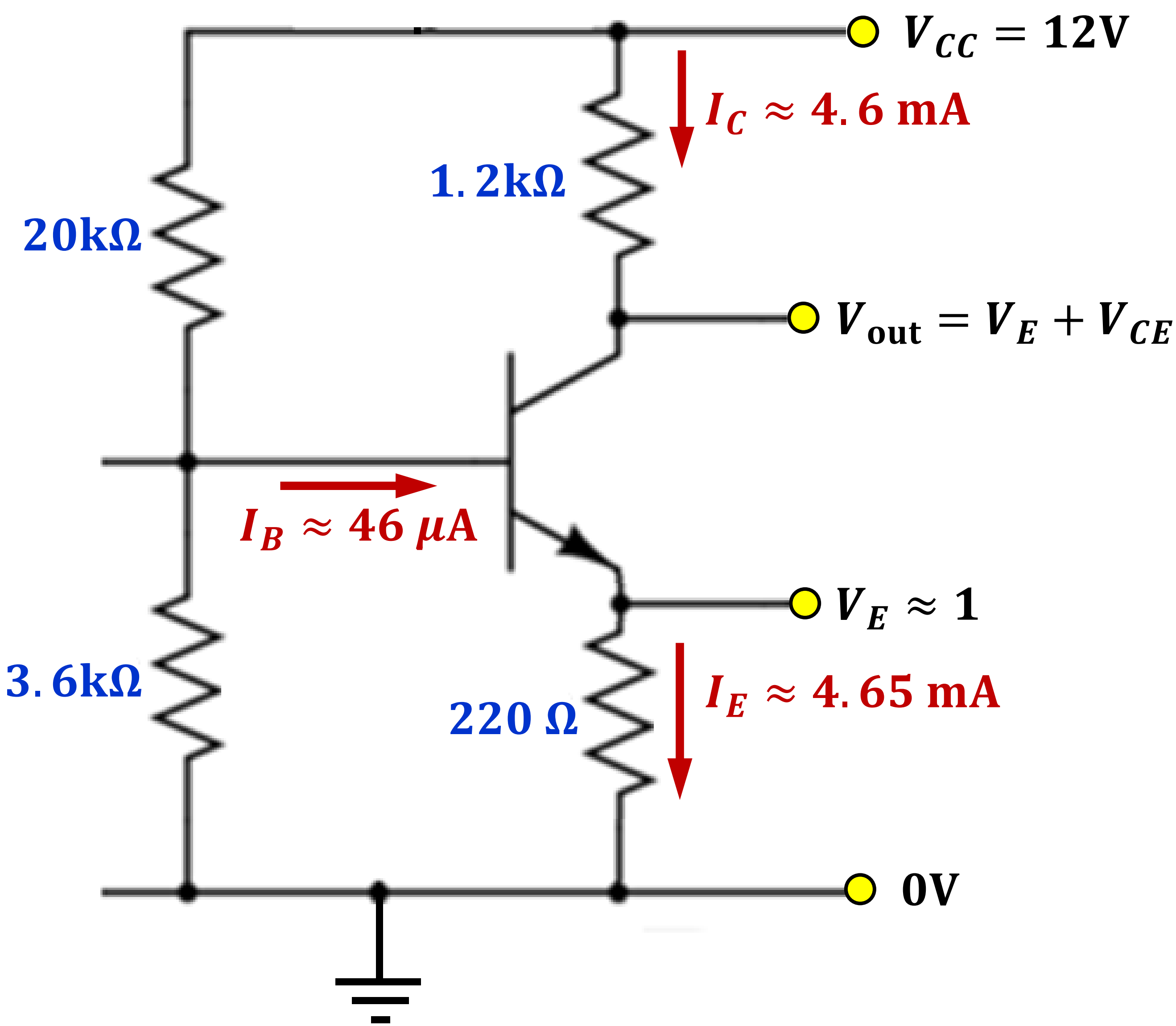
Assumption is valid

BJT

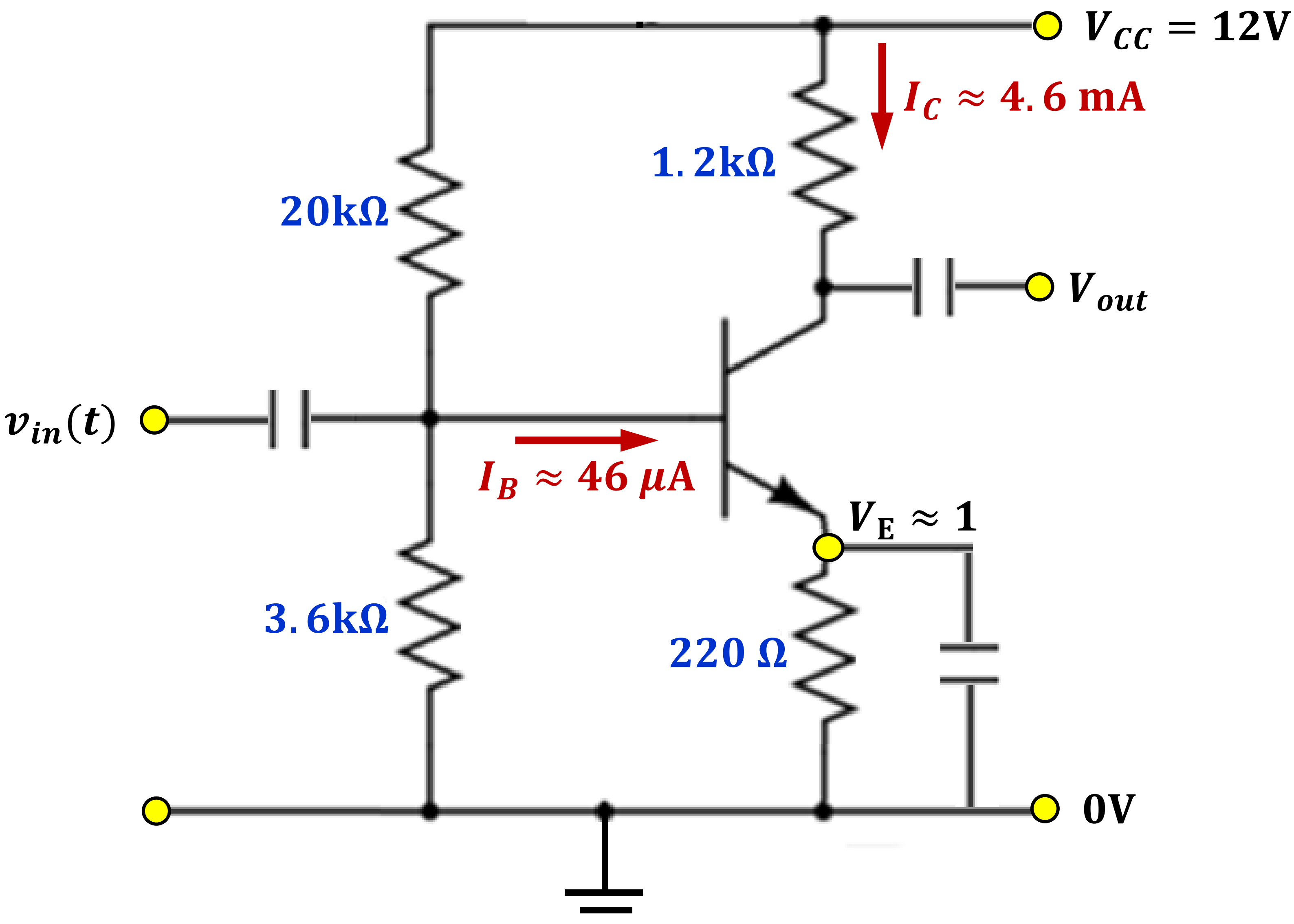
- How does a common emitter amplifier work?

PRACTICAL DESIGN – Single battery bias

Emitter resistor added to improve stabilization if a decrease of supply voltage occurs



PRACTICAL DESIGN – Coupling capacitors for A.C. signal



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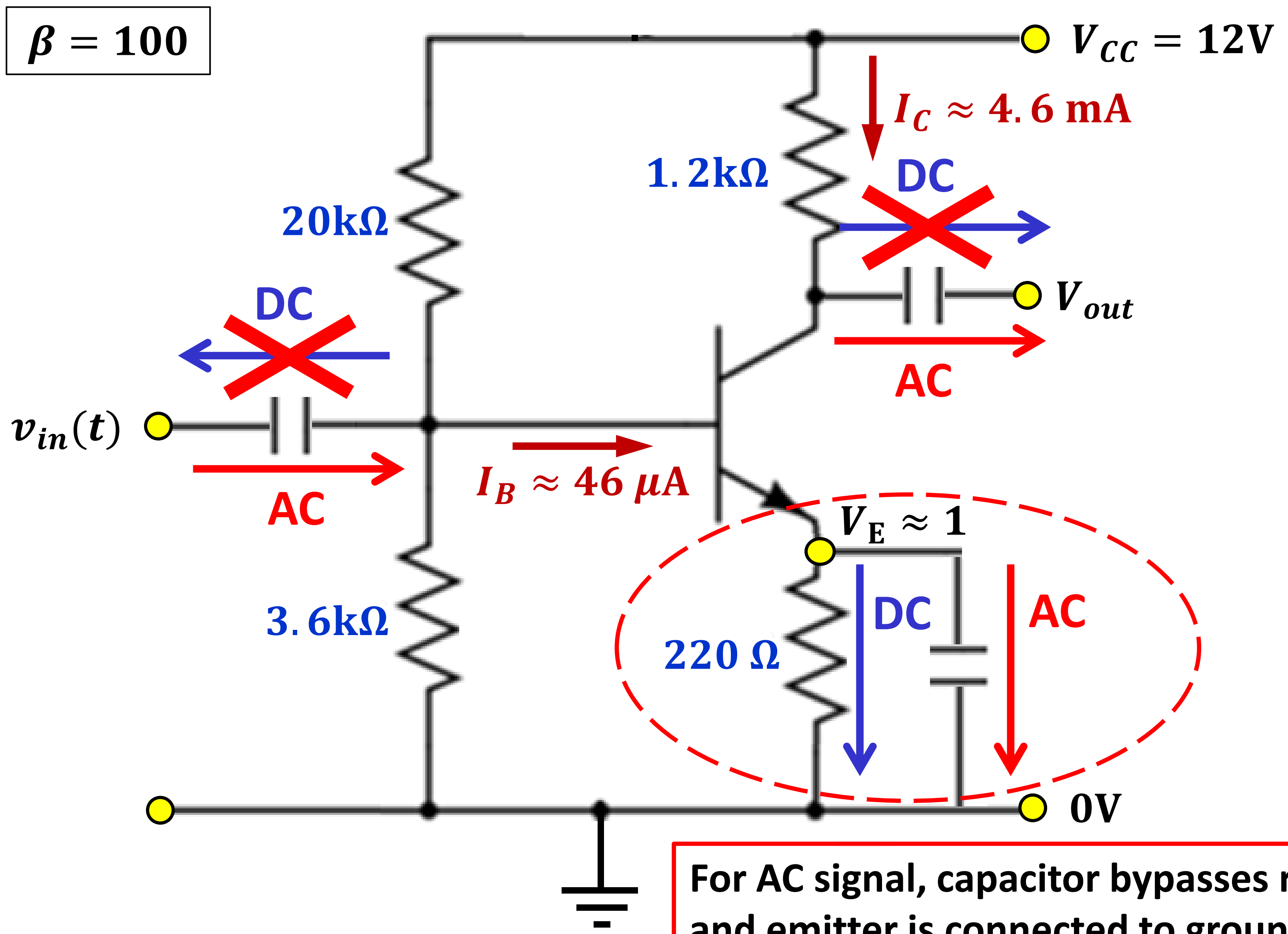
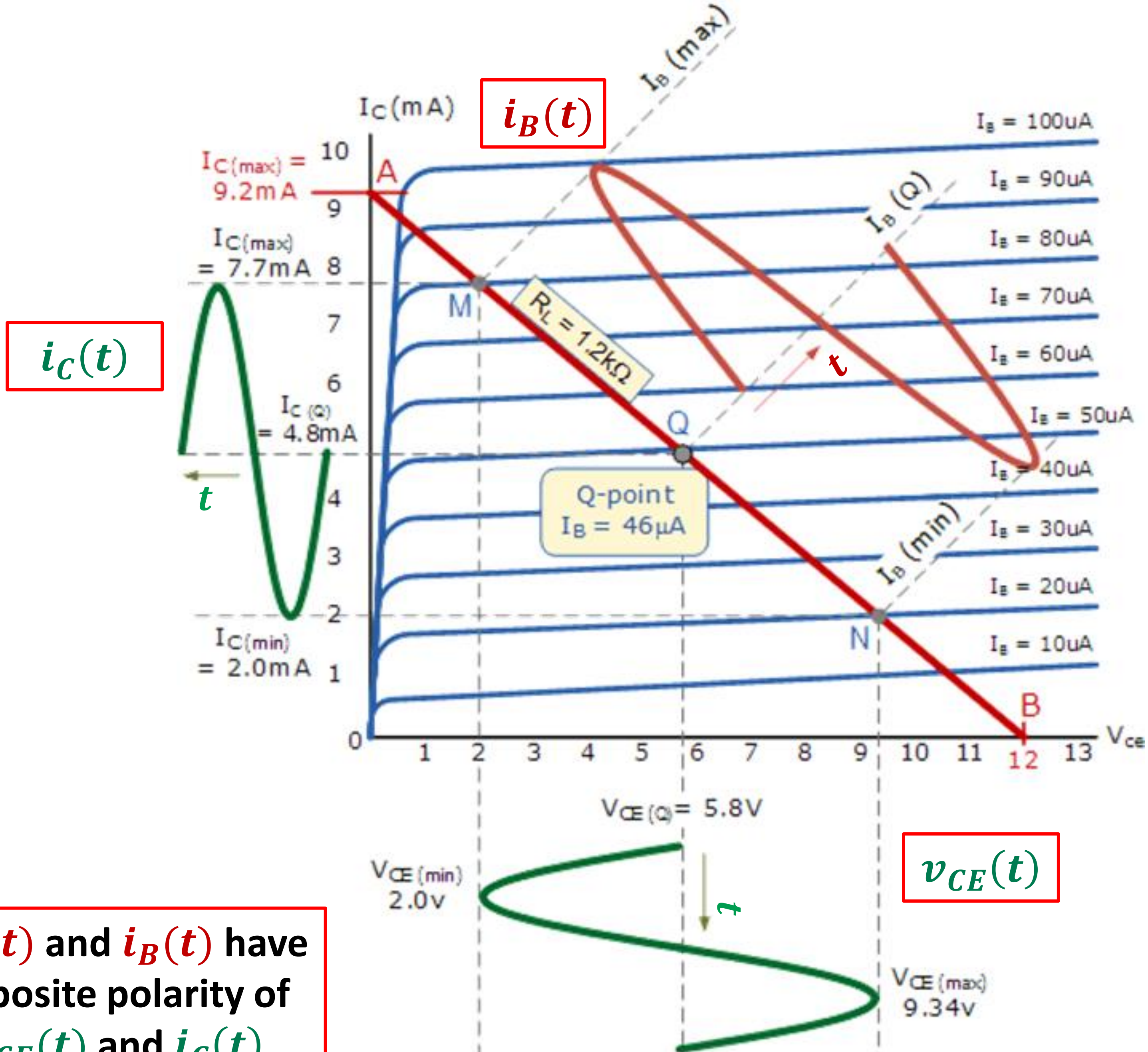


For AC signal, capacitor bypasses resistor and emitter is connected to ground



$v_{in}(t)$ **and** $i_B(t)$ **have opposite polarity of** $v_{CE}(t)$ **and** $i_C(t)$

Transistor stages can be cascaded to obtain more amplification