ESc201 : Introduction to Electronics

Bipolar Junction Transistor

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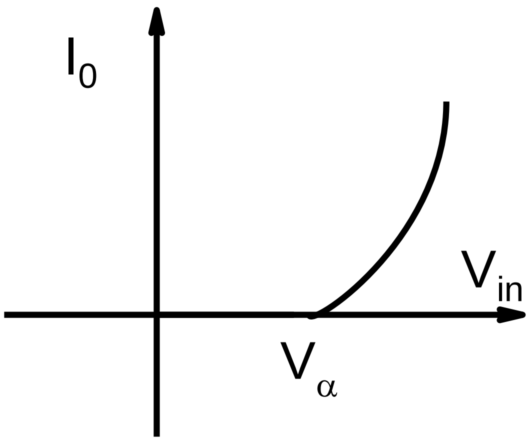
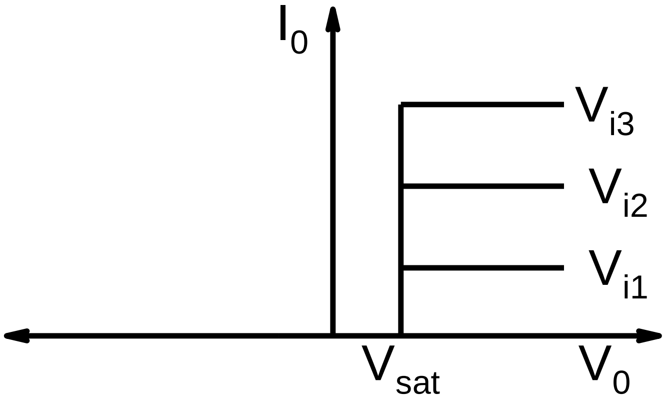
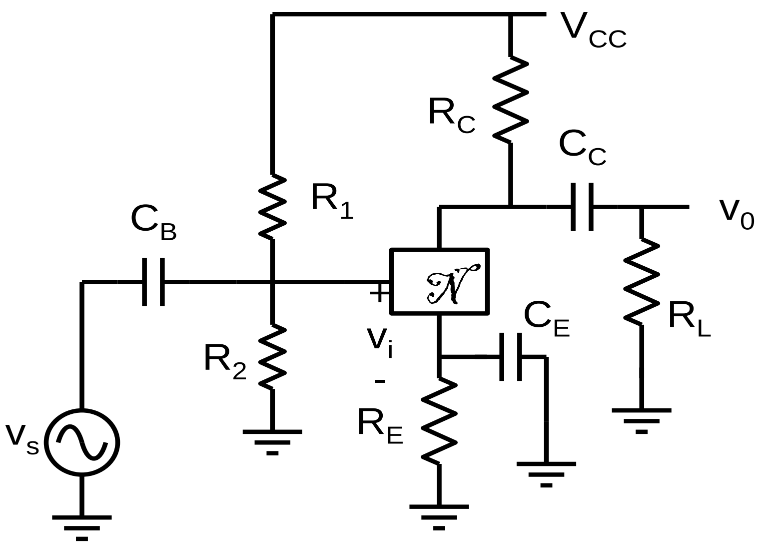
Building amplifiers with non-linear devices

RECAP



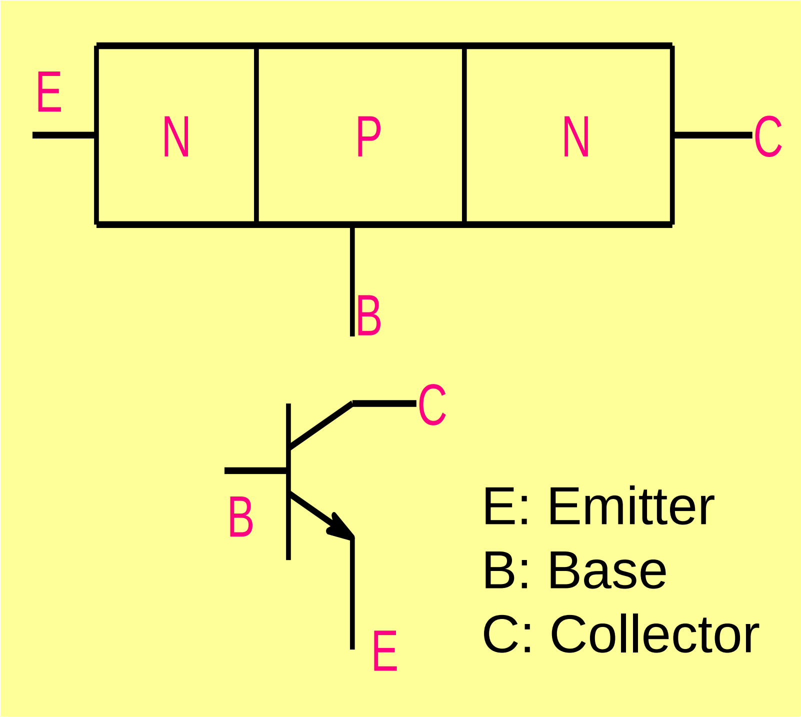




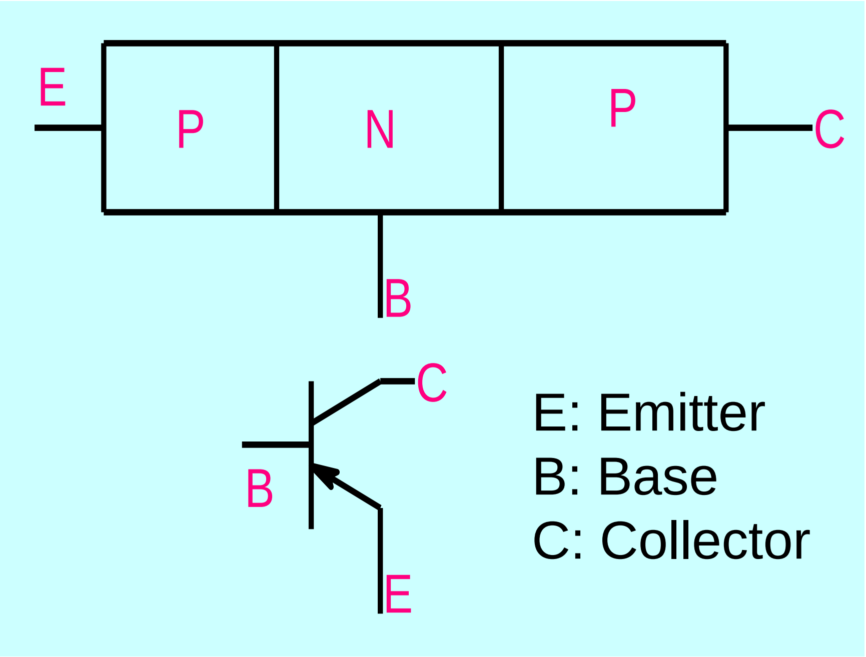
Amplifier will work properly (with small distortion only if we restrict the amplitude of input signal to small values.

How small depends on the nature of non-linearity. The stronger the non-linearity the lesser the signal amplitude.

Bipolar Junction Transistor (BJT)

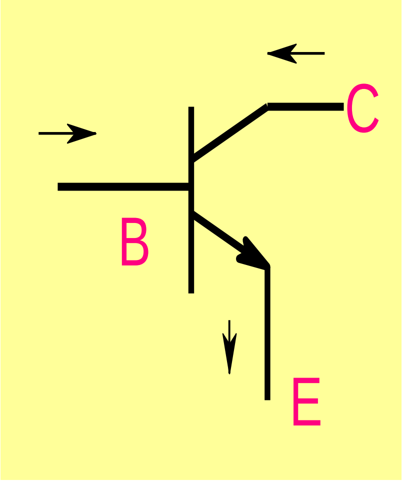


NPN



PNP

DC current-voltage characteristics of NPN transistor



$$I_C + I_B = I_E$$

Two independent currents

Let them be I_B and I_C

There can be three voltages: $$V_{BE}, V_{BC}, V_{CE}$$

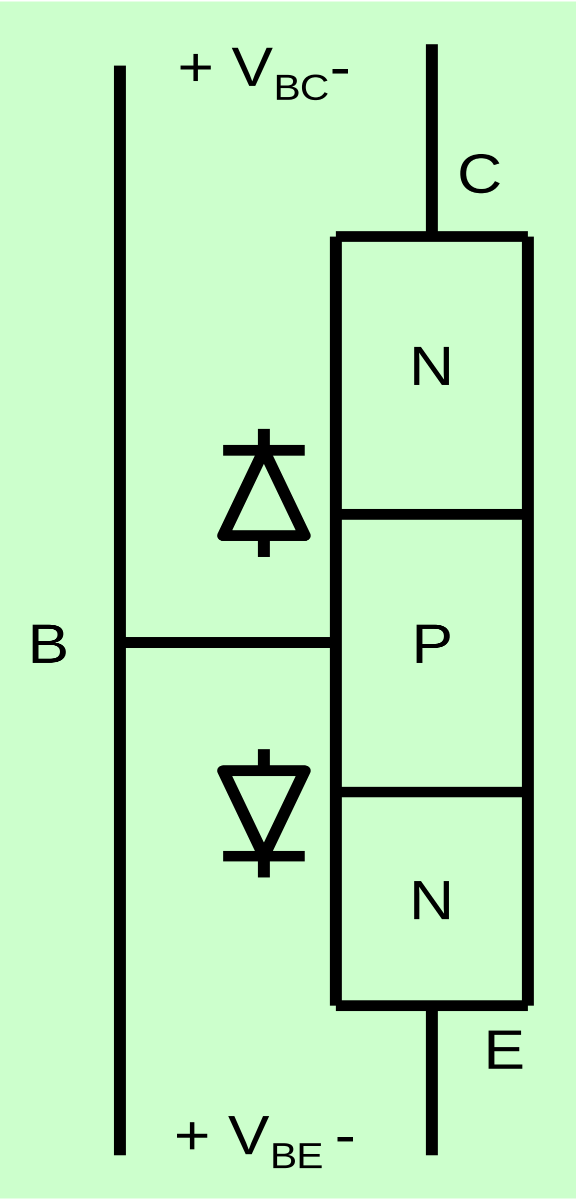
Again, only two are independent. Often V_{BE} and V_{CE} are chosen.

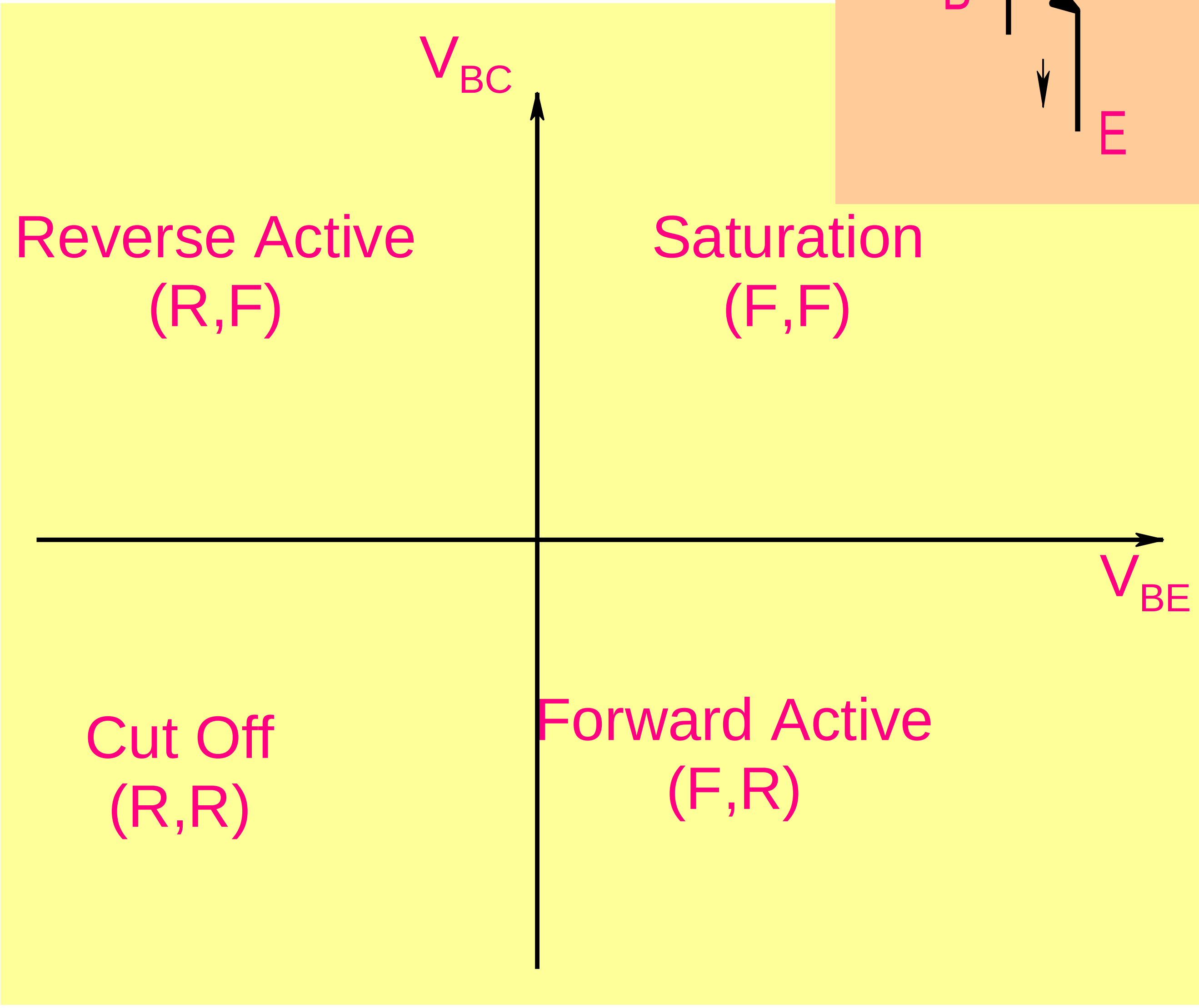
$$V_{BE} = V_B - V_E; V_{BC} = V_B - V_C; V_{CE} = V_C - V_E$$

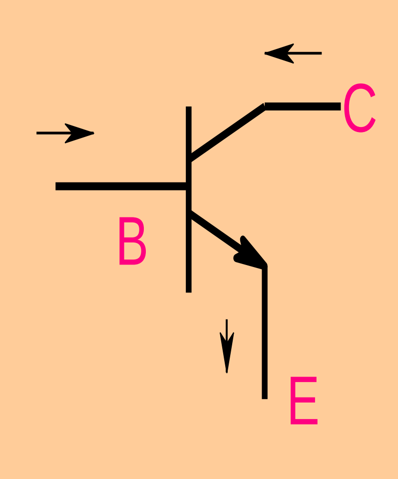
$$V_{BC} = V_{BE} - V_{CE}$$

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

Modes of operation

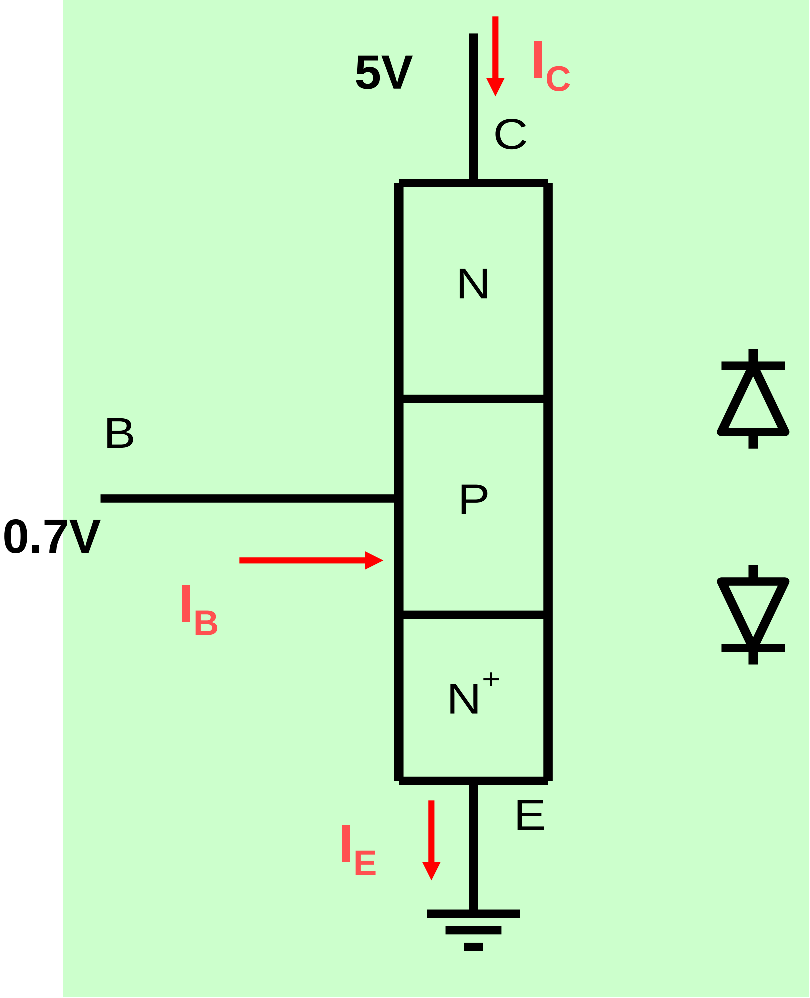






Forward Active Mode

Base Emitter (BE) junction is forward biased and Base Collector (BC) junction is reverse biased

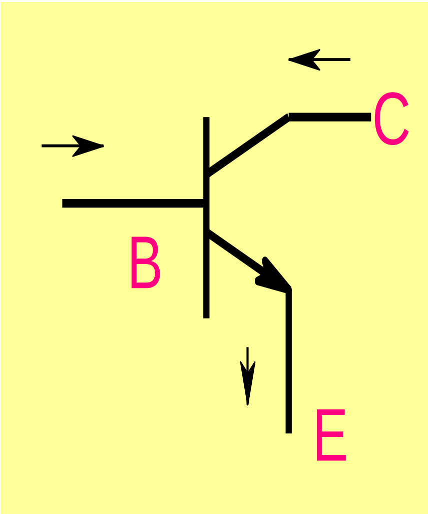


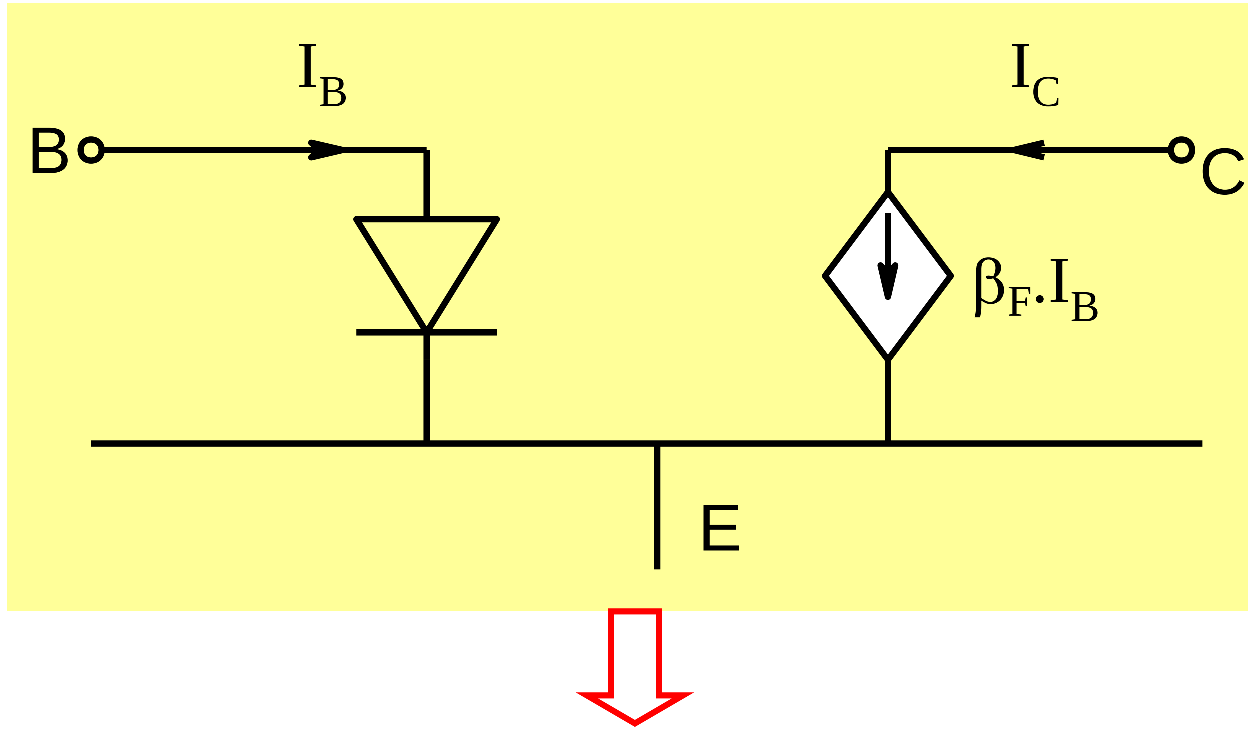
Current Gain

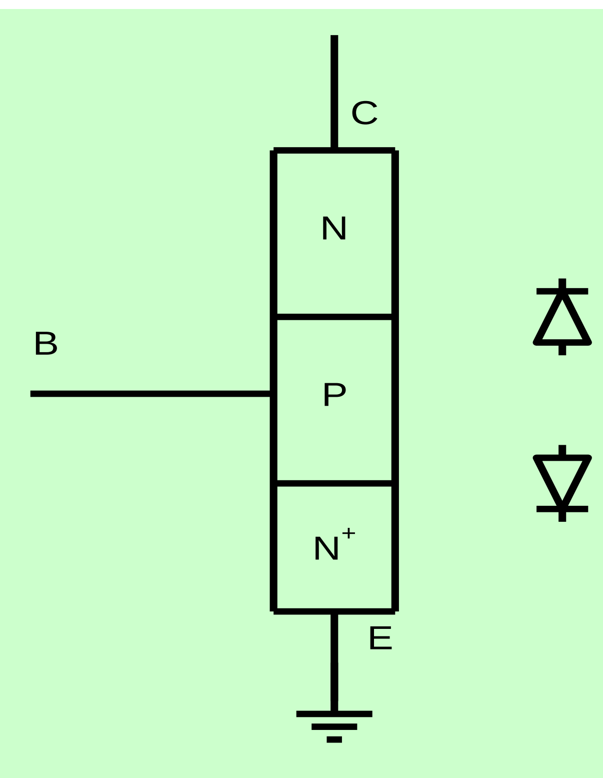
$$\frac{I_C}{I_B} = \beta_F$$

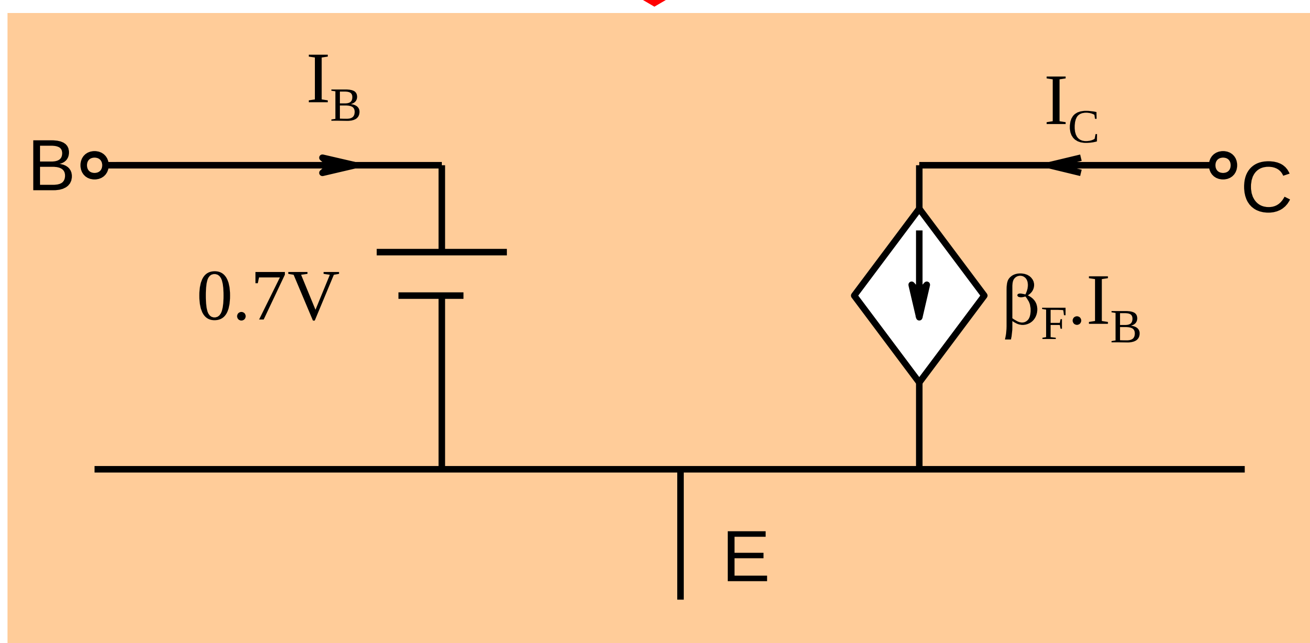
$$V_{BE} \cong 0.7V$$

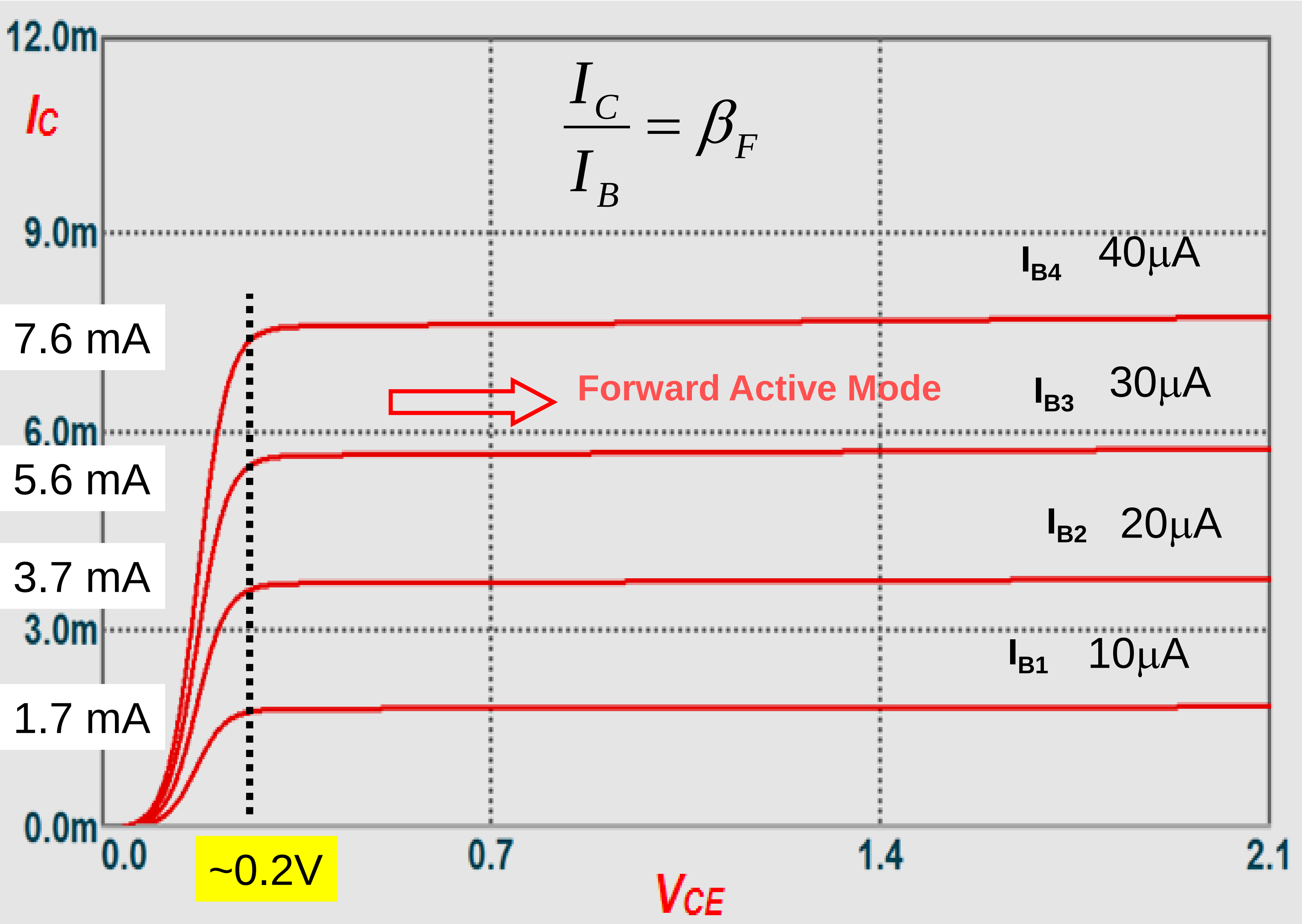
Forward Active Mode



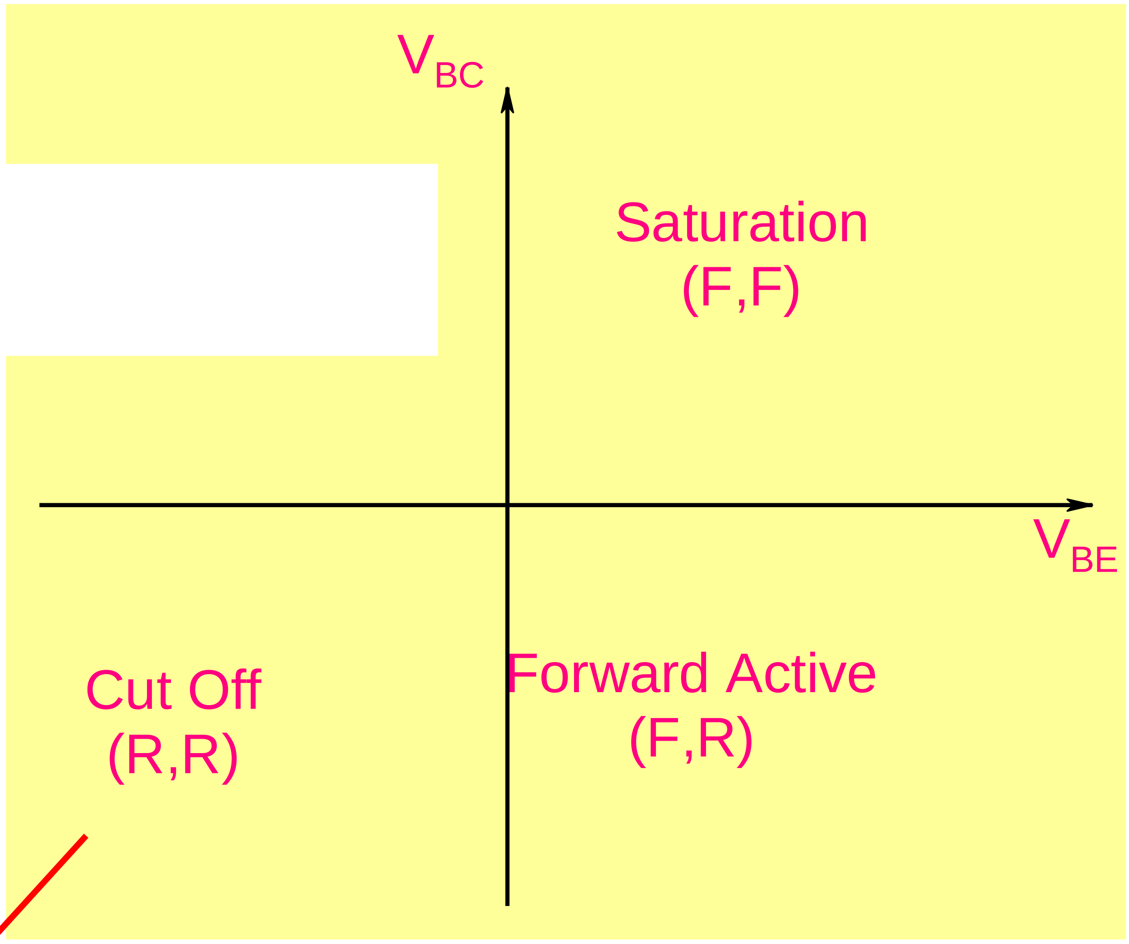








12.0m
I_C
$\frac{I_C}{I_B} = \beta_F$
9.0m
I_{B4} 40µA
7.6 mA
Forward Active Mode
I_{B3} 30µA
6.0m
5.6 mA
I_{B2} 20µA
3.7 mA
3.0m
I_{B1} 10µA
1.7 mA
0.0m
0.0
~0.2V
0.7
1.4
2.1
V_{CE}

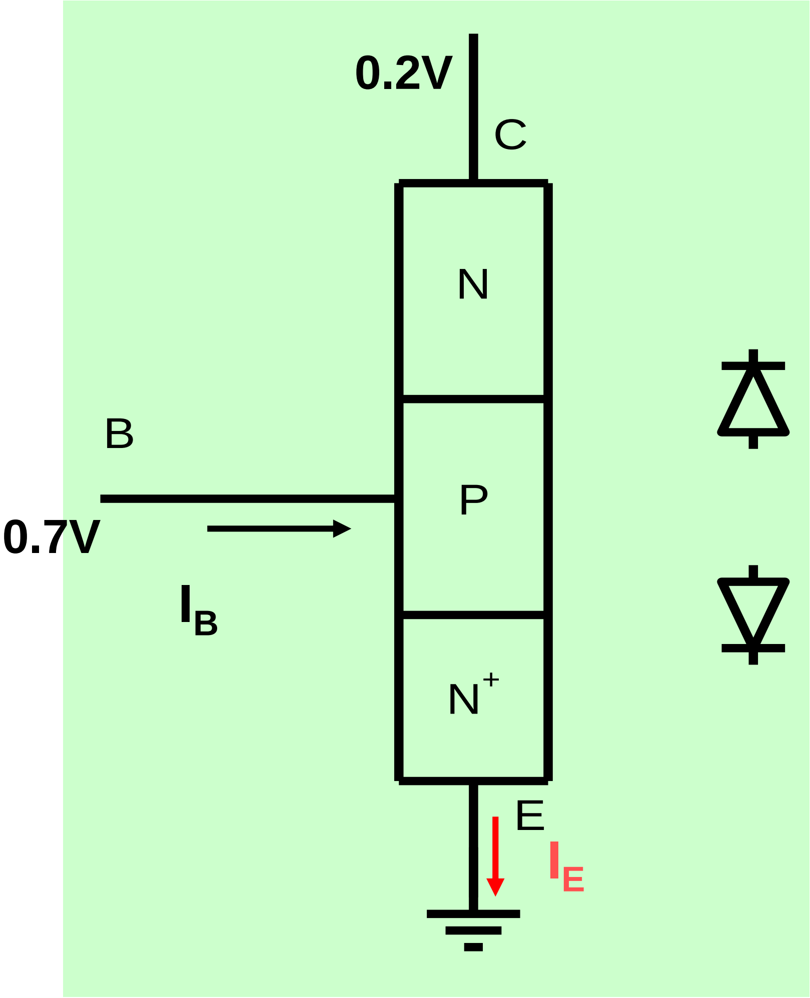


$$I_B \cong 0;\ I_C \cong 0;\ I_E \cong 0$$

Transistor acts like an open circuit

Saturation Mode

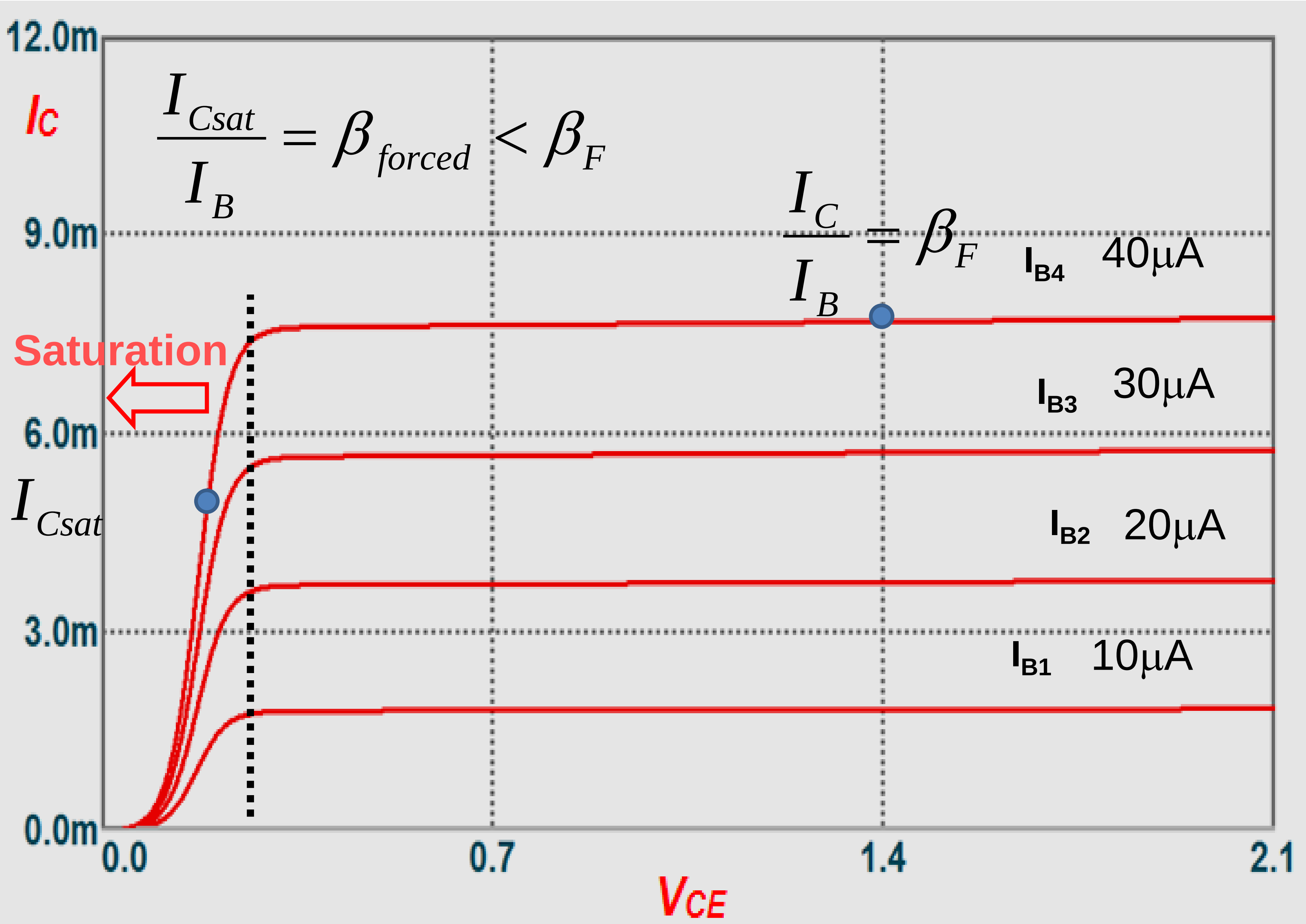
Both BE and BC junctions are forward biased



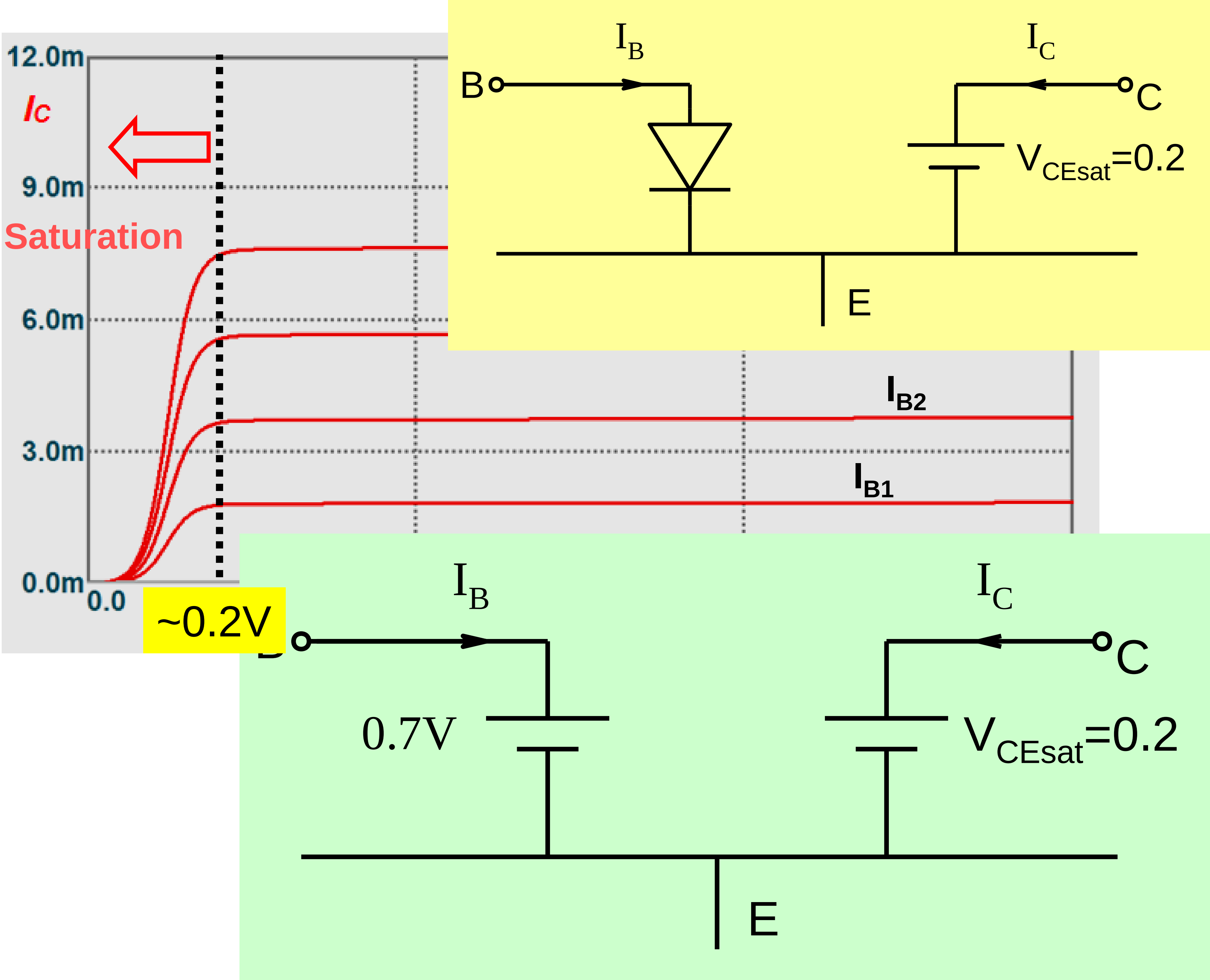
$$V_{BE} \cong 0.7V$$

$$V_{BC} \cong 0.5V$$

$$V_{BE} - V_{BC} \cong 0.2V$$

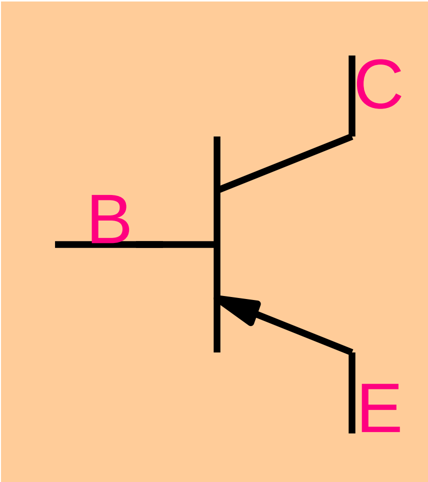


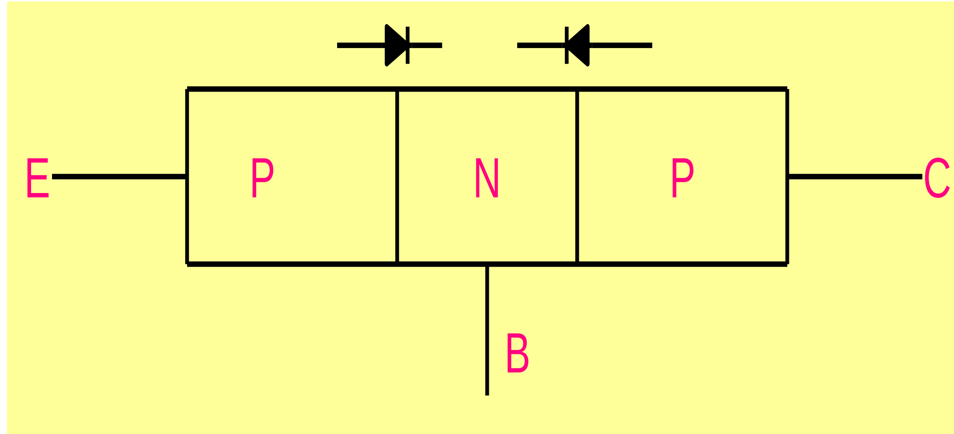
$\frac{I_{Csat}}{I_B} = \beta_{forced} < \beta_F$
$\frac{I_C}{I_B} = \beta_F$
I_C
12.0m
9.0m
6.0m
3.0m
0.0m
Saturation
I_{Csat}
I_{B4} 40μA
I_{B3} 30μA
I_{B2} 20μA
I_{B1} 10μA
0.0
0.7
1.4
2.1
V_{CE}

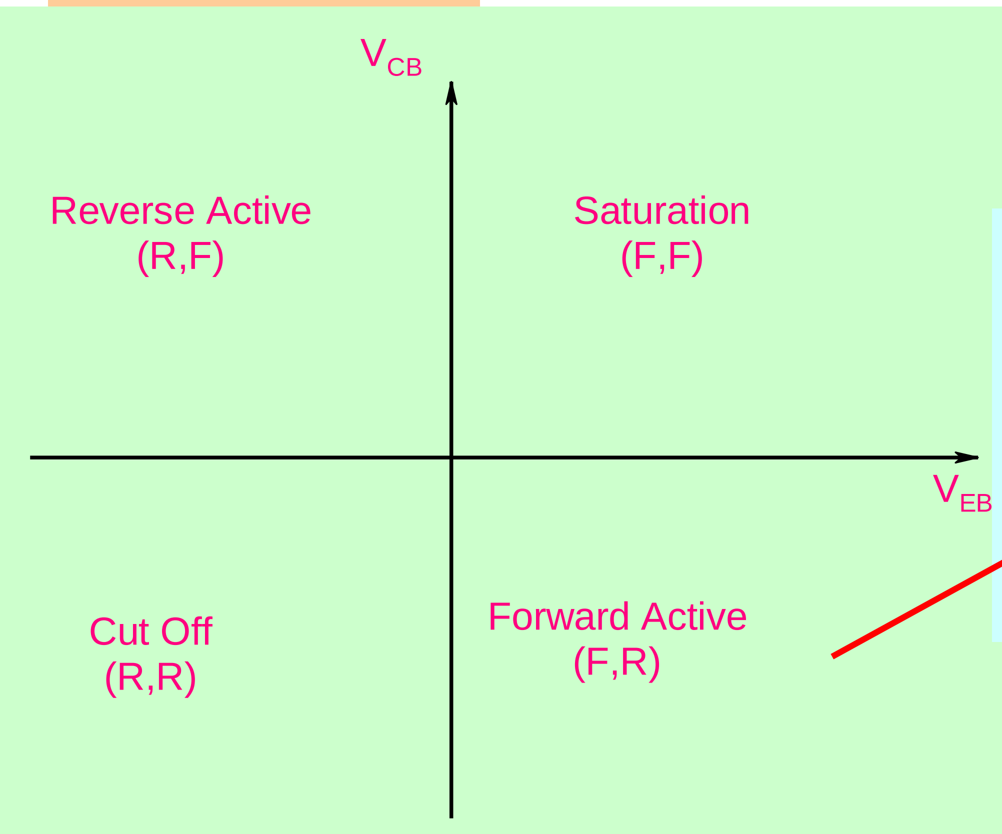


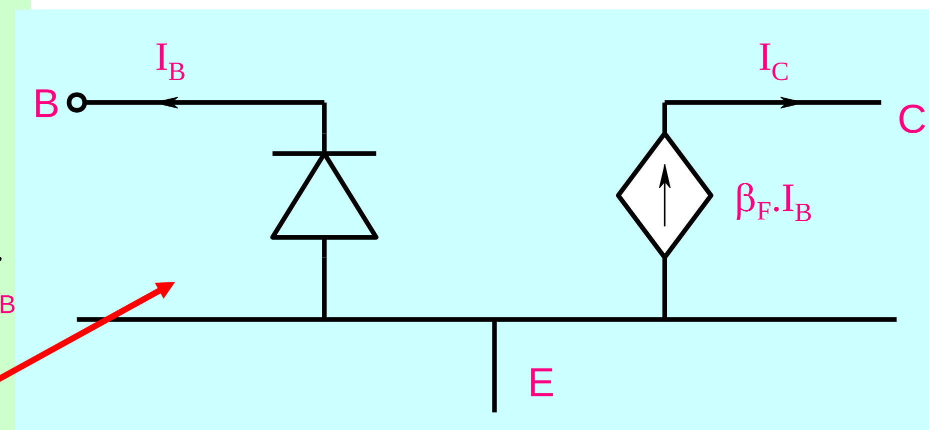
12.0m
9.0m
6.0m
3.0m
0.0m
0.0
I_C
Saturation
I_{B2}
I_{B1}
~0.2V
I_B
I_C
B
C
V_{CEsat}=0.2
E
I_B
I_C
C
0.7V
V_{CEsat}=0.2
E

PNP Transistor









Transistor Circuit Analysis

Useful ideas to remember

Forward Active Mode

Base Emitter (BE) junction is forward biased and Base Collector (BC) junction is reverse biased

Current Gain $$\frac{I_C}{I_B} = \beta_F$$

$$V_{BE} \cong 0.7V$$

Cut off Mode

Both the junctions are reverse biased

$$I_B \cong 0;\ I_C \cong 0;\ I_E \cong 0$$

Transistor acts like an open circuit

Saturation Mode

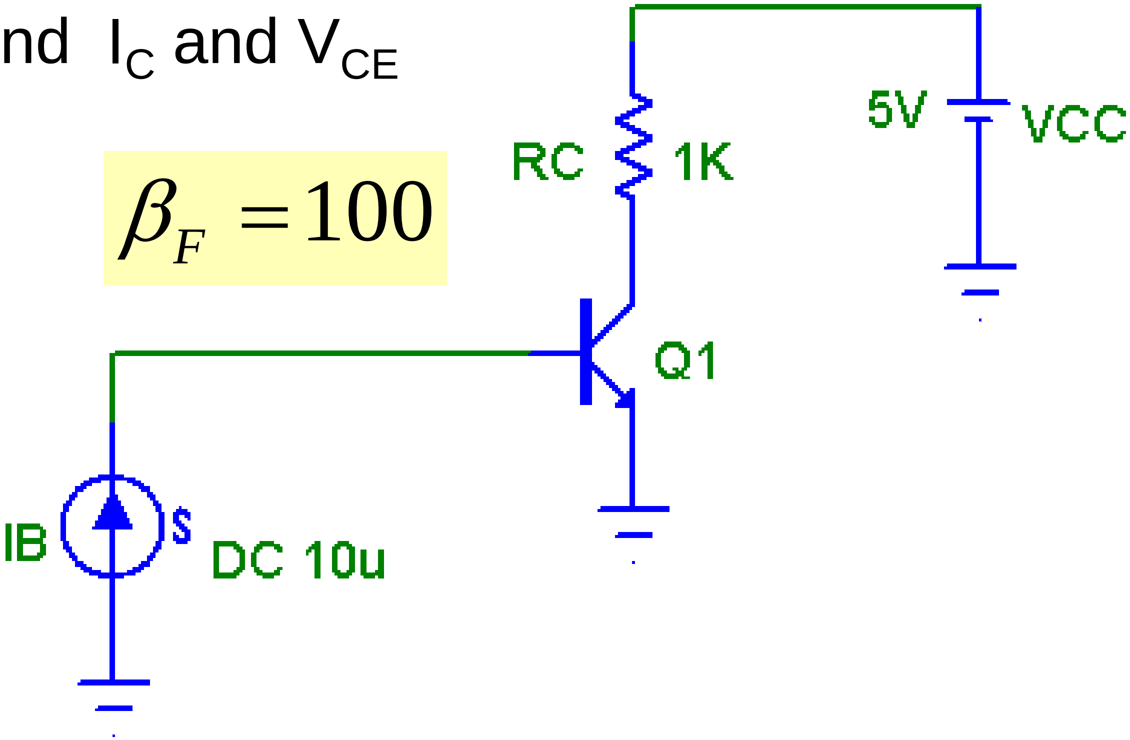
Both the junctions are forward biased

$$V_{BE} \cong 0.7V \qquad V_{BC} \cong 0.5V \qquad V_{BE} - V_{BC} \cong 0.2V$$

Dc Transistor Circuit Analysis Example-1

Find I_C and V_{CE}

$$\beta_F = 100$$



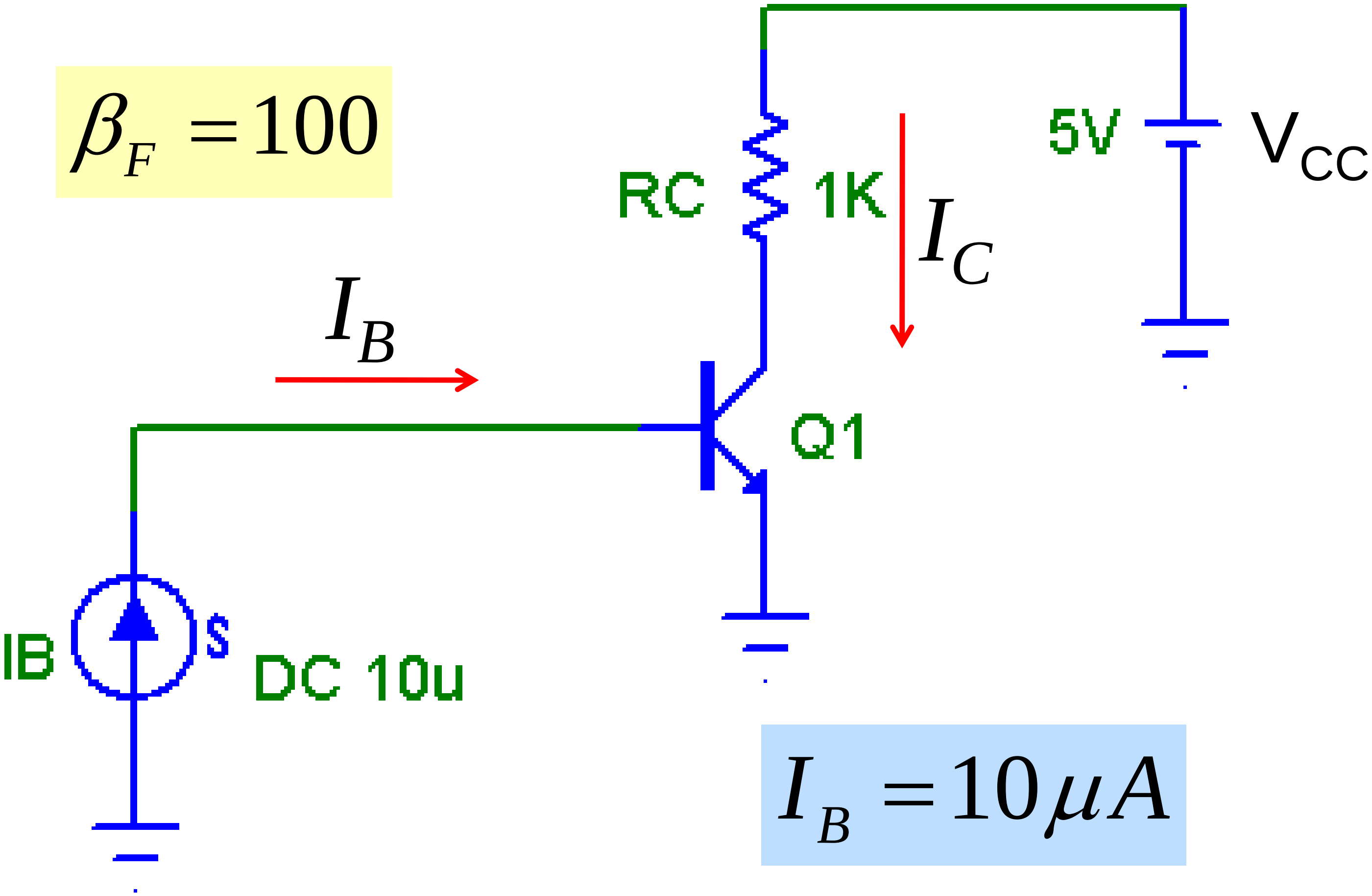
Base current is flowing into the transistor so transistor cannot be in cutoff mode.

Therefore transistor can be either in forward active or saturation mode of operation.

Let us assume that transistor is in forward active mode and carry out analysis.

Need to check if our assumption is correct.

$$\beta_F = 100$$



$$I_B = 10\mu A$$

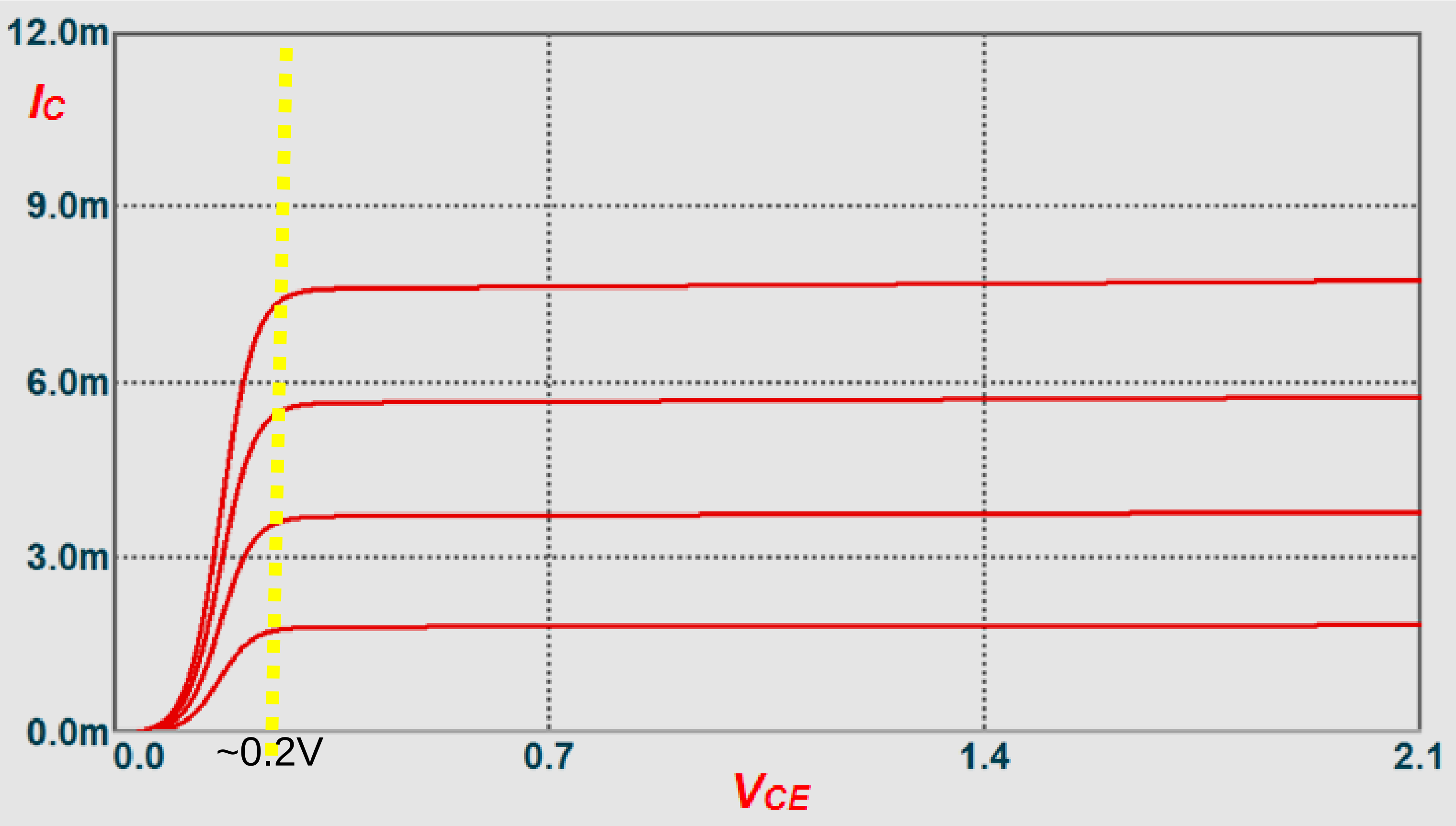
$$I_C = \beta_F I_B = 1mA$$

$$V_{CE} = 5 - I_C \times R_C = 4V$$

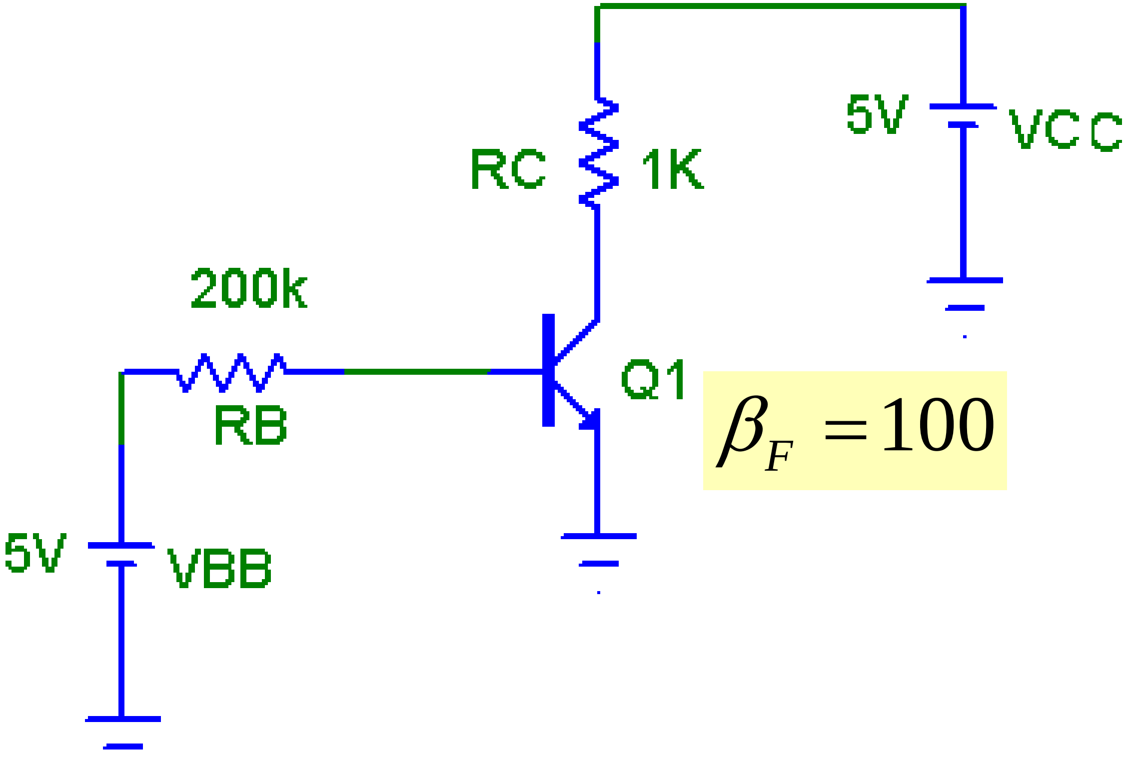
How do we check if transistor is indeed in forward active mode?

We check if $V_{CE} > 0.2V$

Since this is true for our circuit, the analysis is correct and our answers are right

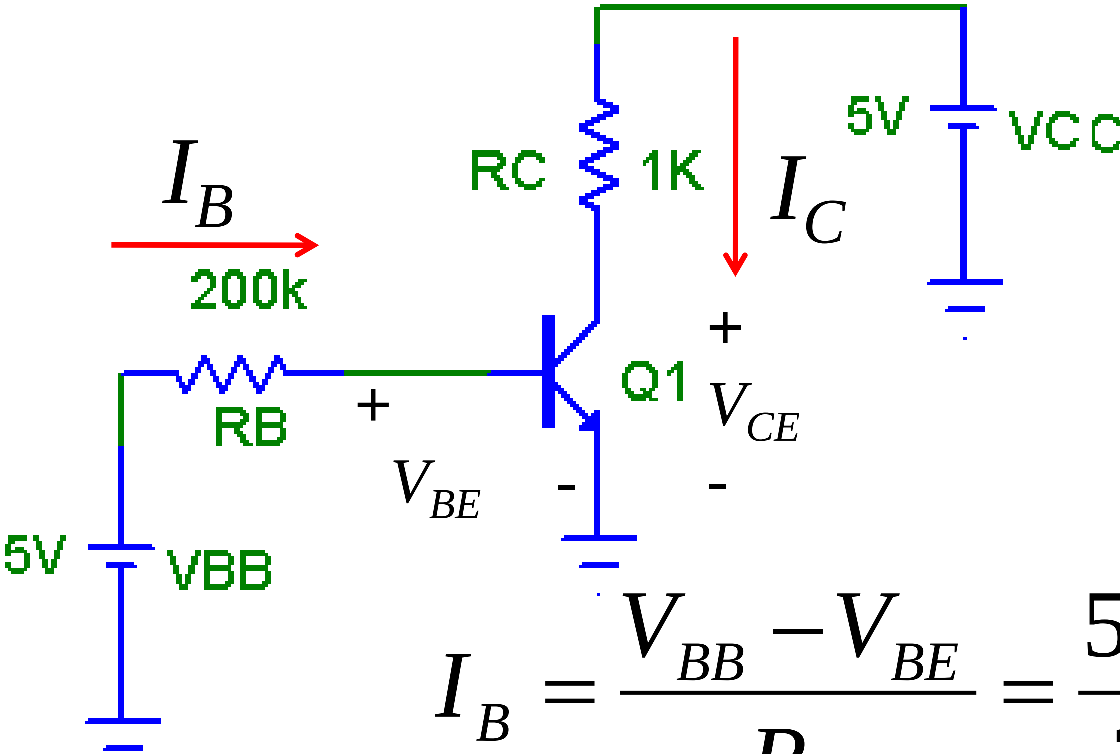


Example-2 Find I_C and V_{CE}



$$\beta_F = 100$$

Let us assume that transistor is in forward active mode and carry out analysis but we must check later on to make sure that our assumption is correct.



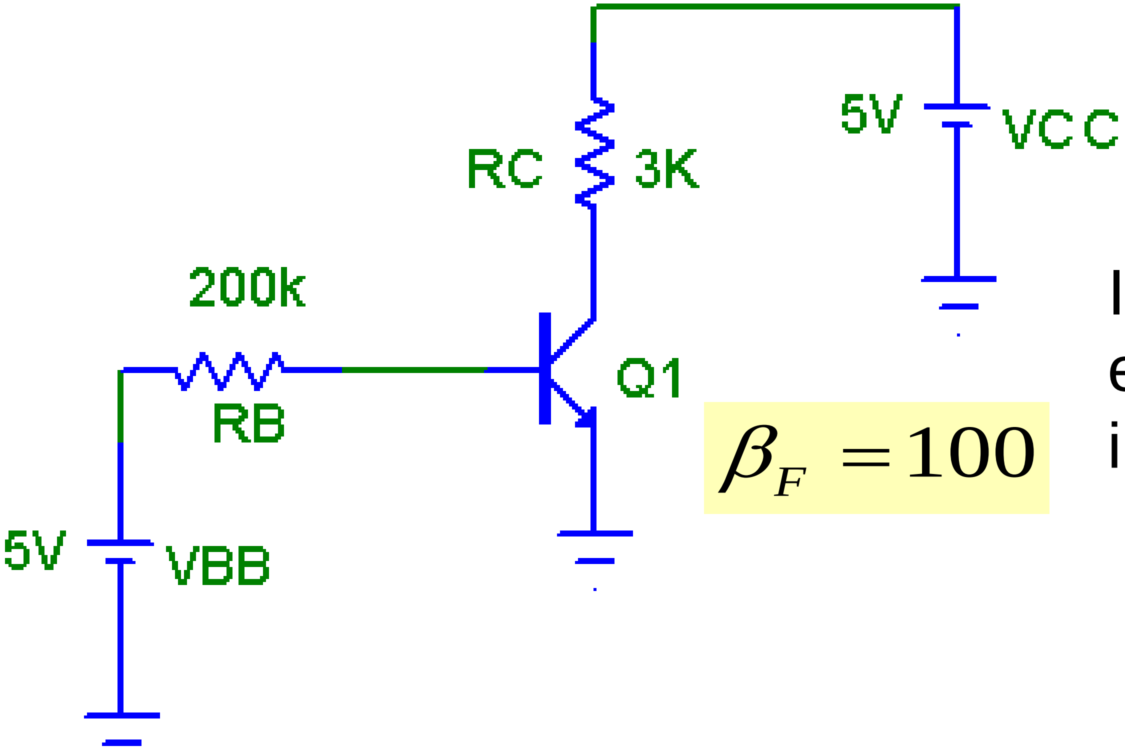
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5-0.7}{200k} = 21.5\mu A$$

$$I_C = \beta_F I_B = 2.15mA$$

$$V_{CE} = 5 - I_C \times R_C = 2.85V$$

Since V_{CE} > 0.2V, our analysis is correct and Tr. is in active mode.

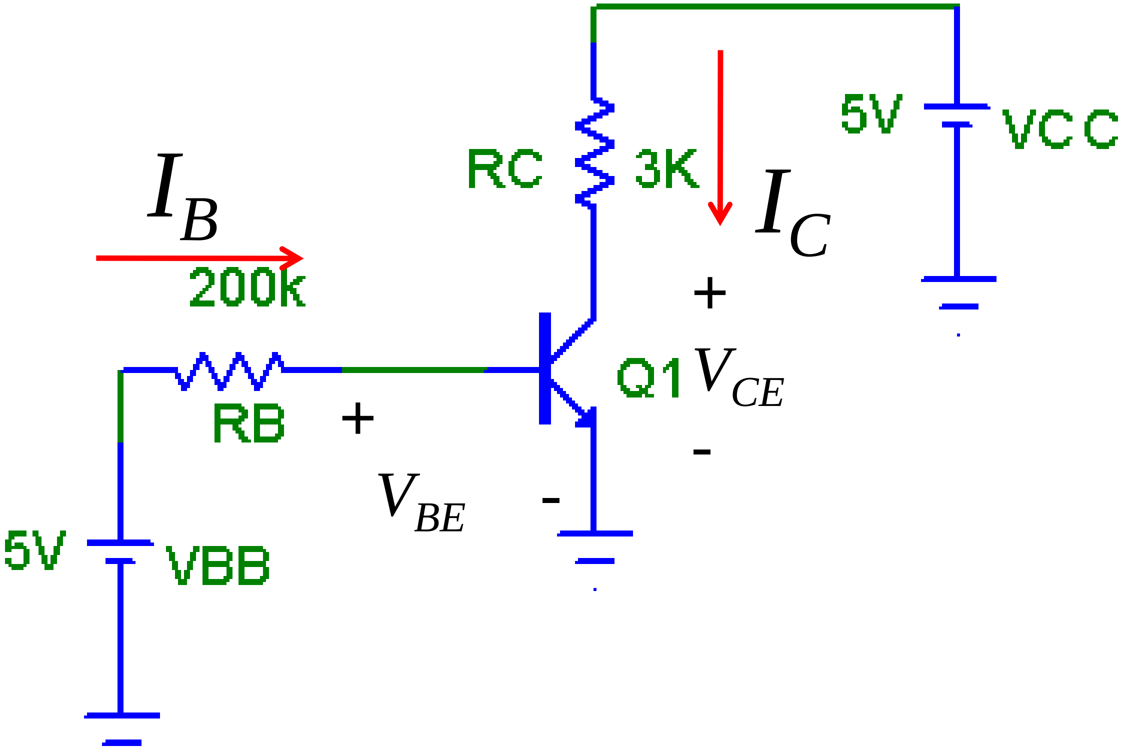
Example-3



$$\beta_F = 100$$

It is same as example-2 except that RC has been increased to 3K.

As before we assume that transistor is in forward active mode and carry out analysis



$$I_B = \frac{V_{BB} - 0.7}{R_B} = 21.5\mu A$$

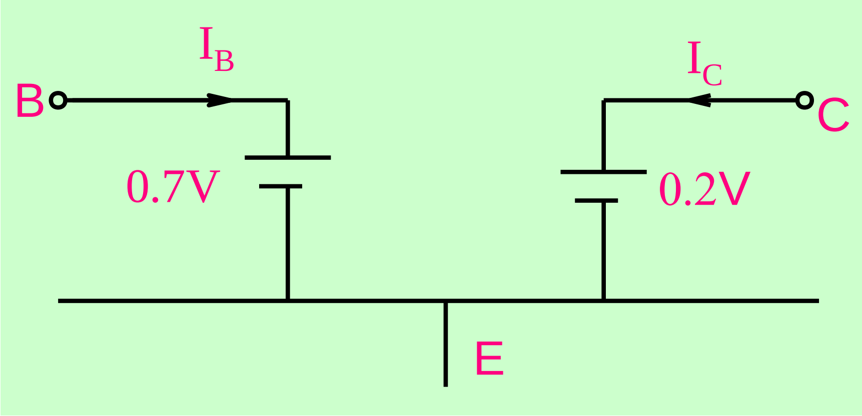
$$I_C = \beta_F I_B = 2.15mA$$

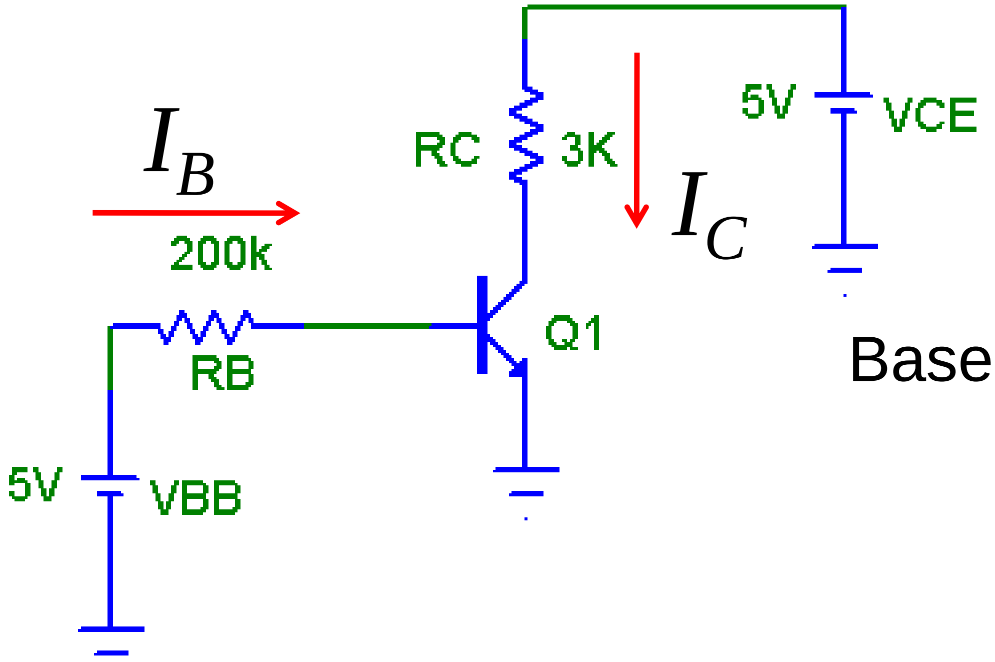
$$V_{CE} = 5 - I_C \times R_C = -1.45V$$

Since $V_{CE} < 0.2V$, our assumption is incorrect and transistor is actually in saturation mode.

In saturation mode: $I_C \neq \beta_F I_B$

The transistor model in saturation is





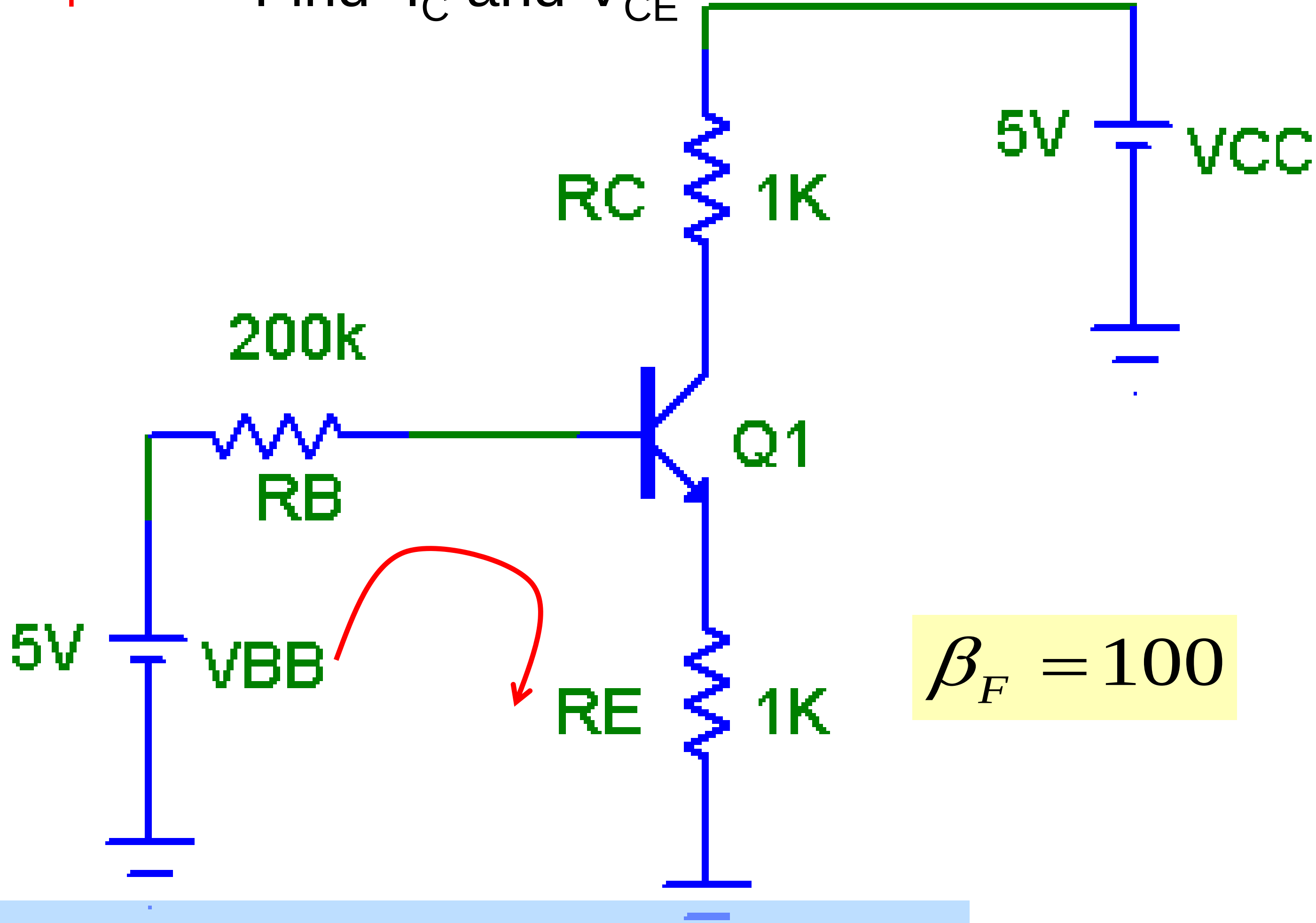
$$I_C = \frac{5-0.2}{3K} = 1.6mA$$

Base current is same as before:

$$I_B = 21.5\mu A$$

$$\beta_{forced} = \frac{I_C}{I_B} = \frac{1.6mA}{21.5\mu A} = 74.4$$

Example-4 Find I_C and V_{CE}



$$\beta_F = 100$$

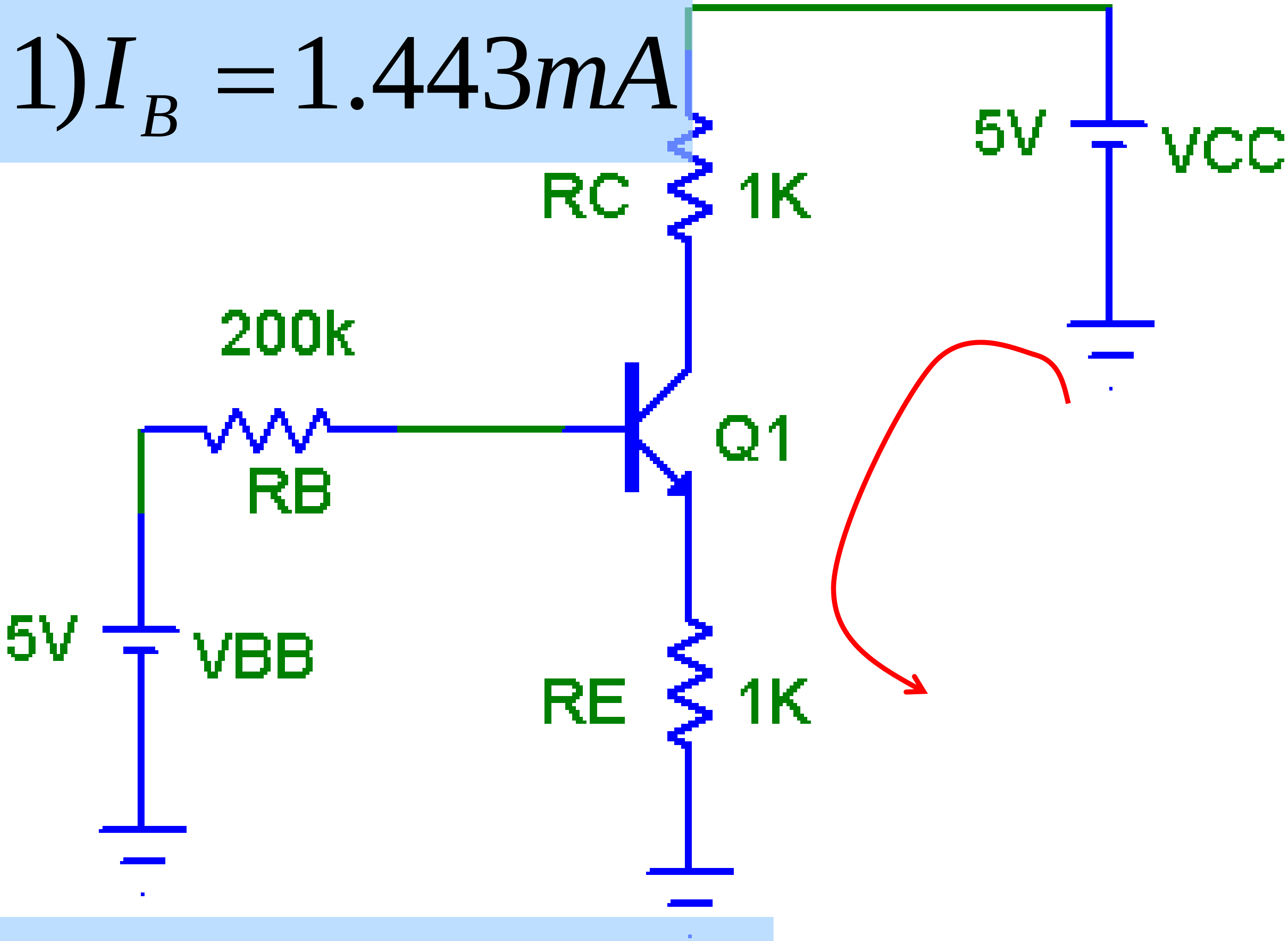
$$-V_{BB} + I_B R_B + 0.7 + I_E R_E = 0$$

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

$$I_B = \frac{V_{BB} - 0.7}{R_B + (1+\beta) R_E} = 14.29\mu A$$

$$I_C = \beta_F I_B = 1.429mA$$

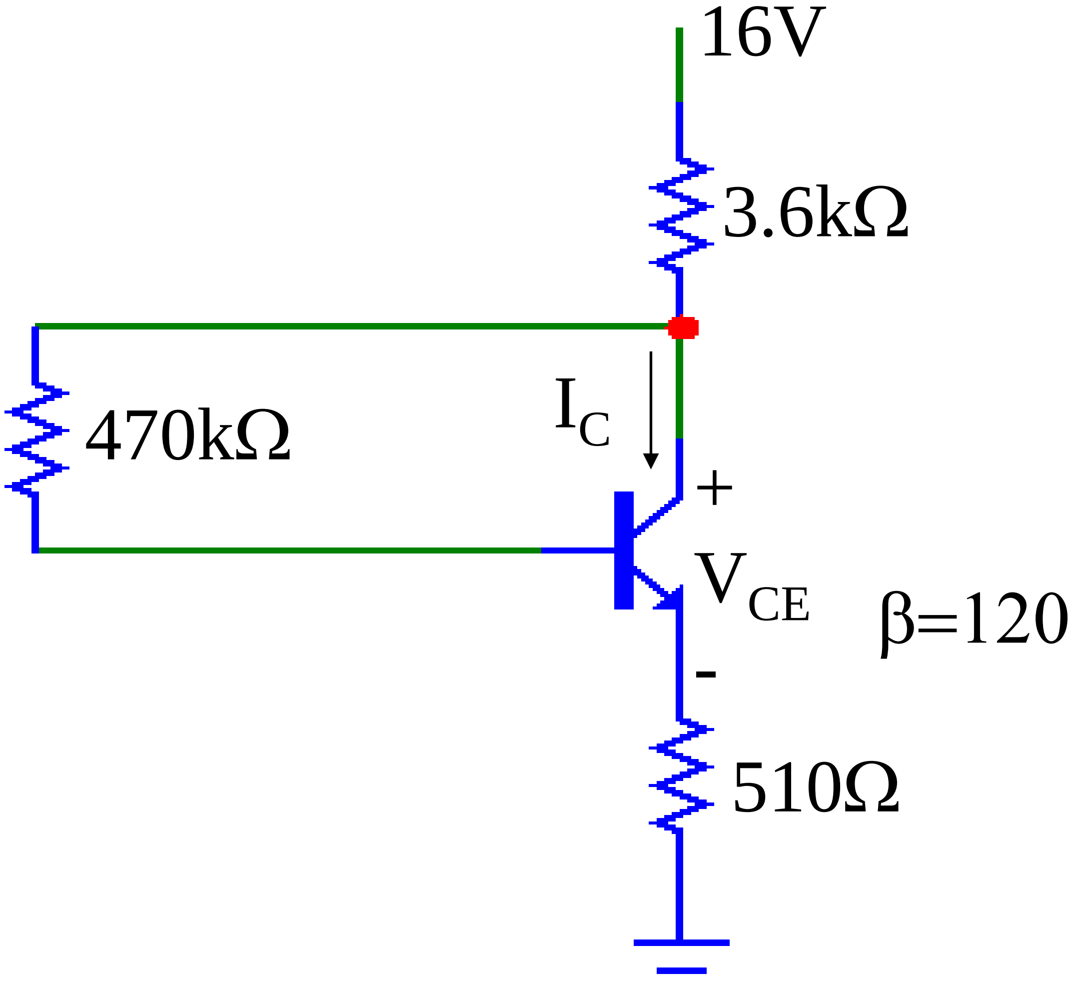
$$I_E = (\beta_F + 1) I_B = 1.443mA$$

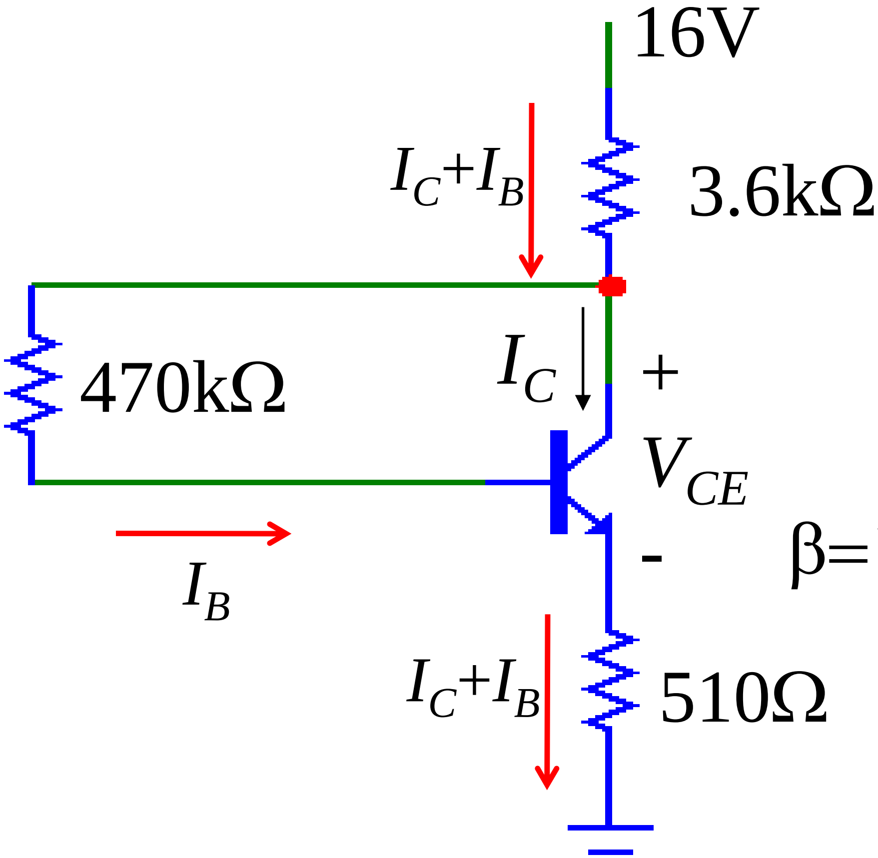


$$-V_{CC} + I_C R_C + V_{CE} + I_E R_E = 0$$

$$V_{CE} = 2.129V$$

Example-5 Find I_C and V_{CE}



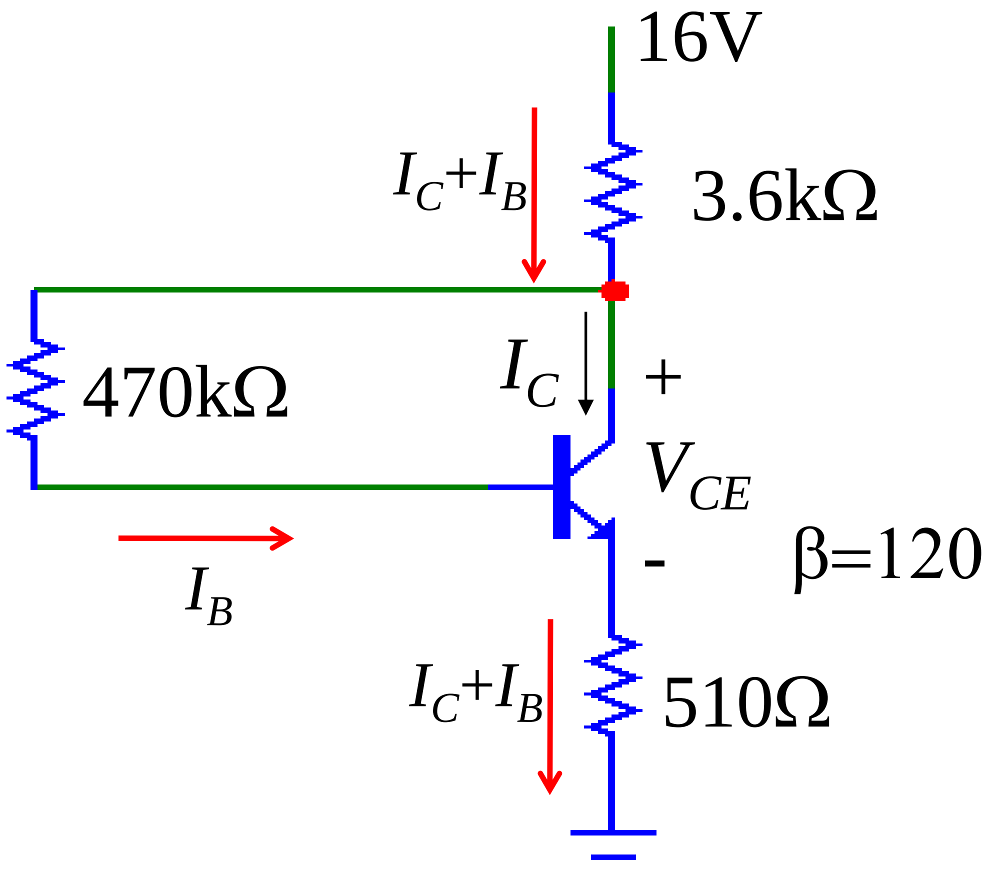


$$I_C + I_B = (\beta + 1)I_B = 121 I_B$$

$$-16 + (121 I_B)3.6k + I_B 470k + 0.7 + (121 I_B)510 = 0$$

$$I_B = \frac{16 - 0.7}{121 \times 3.6k + 470k + 121 \times 510} = 0.0158mA$$

$$I_C = \beta I_B = 120 \times 0.0158mA = 1.9mA$$



$$I_B = 0.0158mA$$

$$I_C = 1.9mA$$

$$I_B 470k + 0.7 - V_{CE} = 0$$

$$V_{CE} = 0.0158 \times 470 + 0.7 = 8.13V$$