Basic Electronic Circuits (IEC-103)

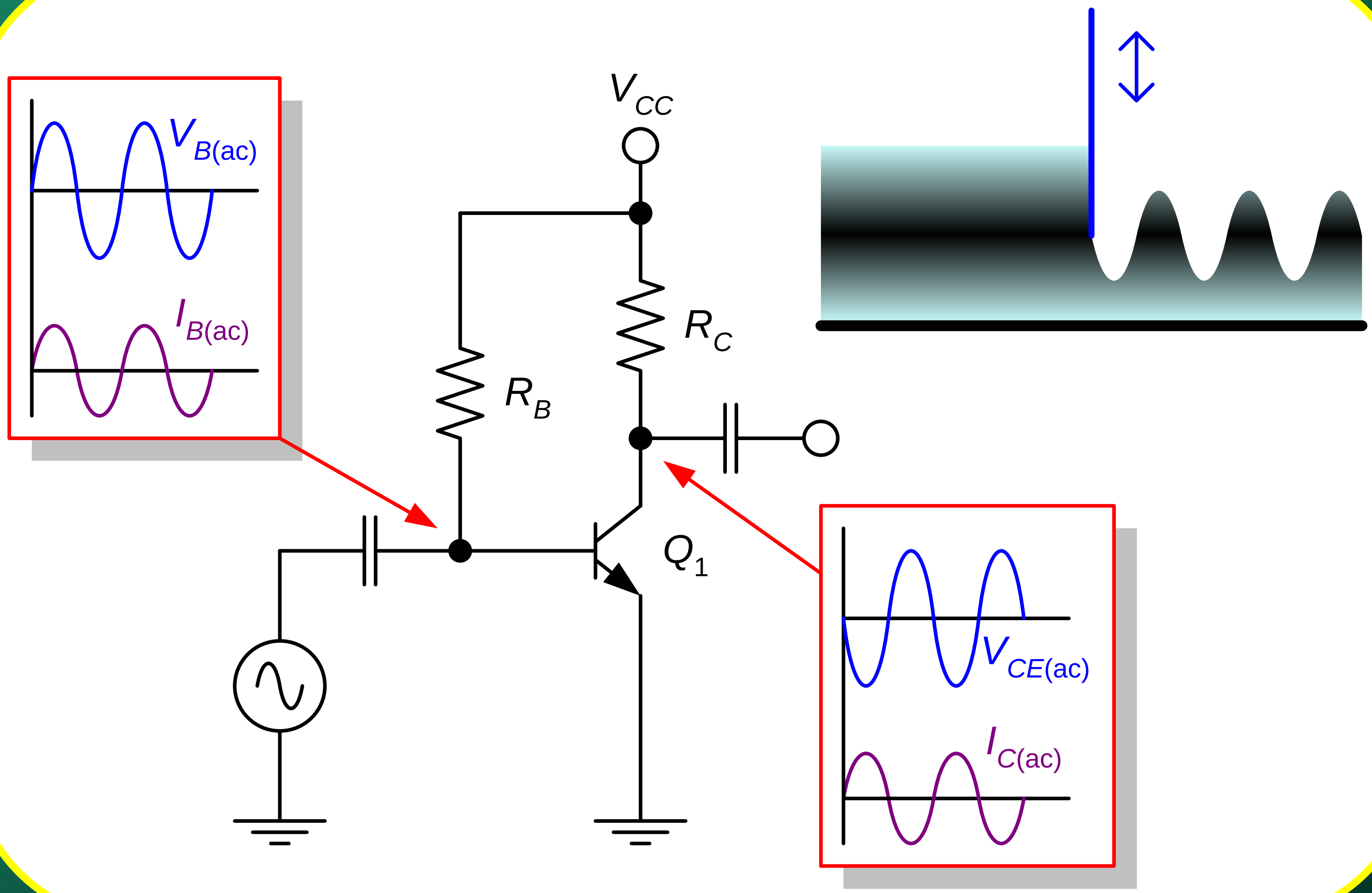
Lecture-16

Transistor Biasing Circuits

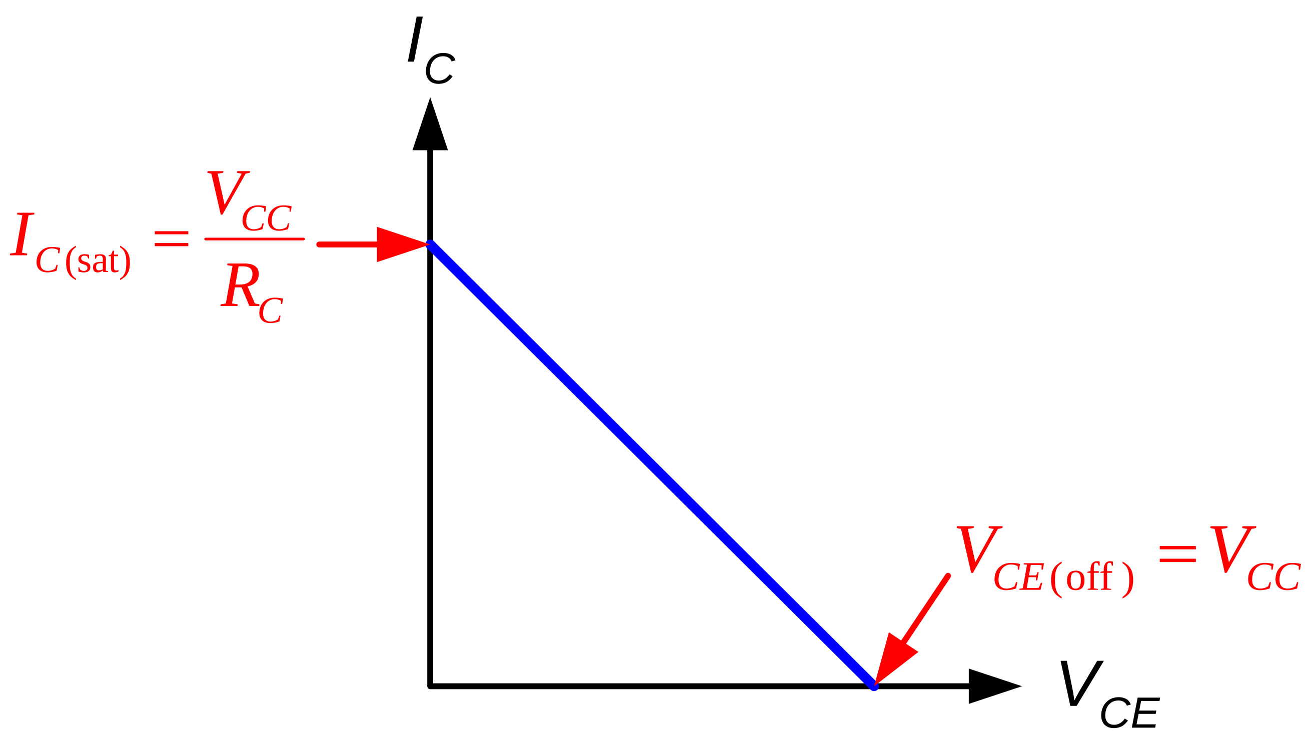
BJT ‘Q’ Point (Bias Point)

- Q point means Quiescent or Operating point.
- Very important for amplifiers because wrong ‘Q’ point selection increases amplifier distortion.
- Need to have a stable ‘Q’ point, meaning the operating point should not be sensitive to variation to temperature or BJT β (h_{FE}), which can vary widely.

Typical Amplifier Operation



A Generic DC Load Line



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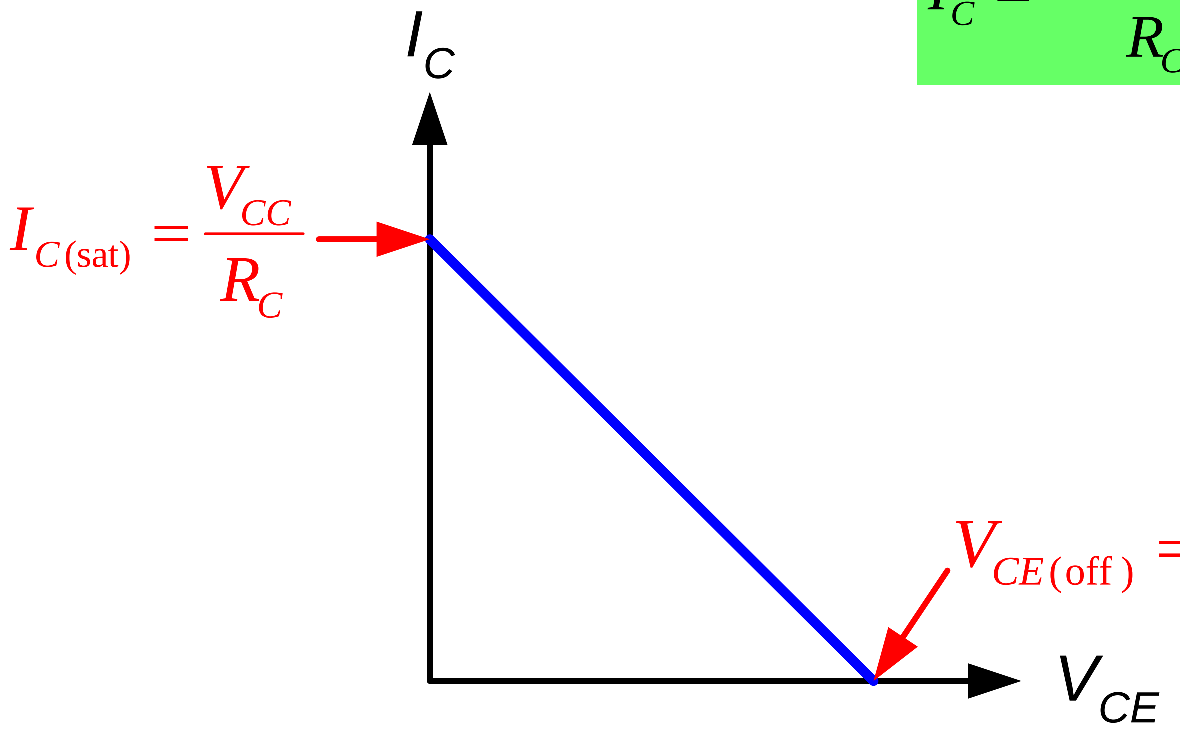
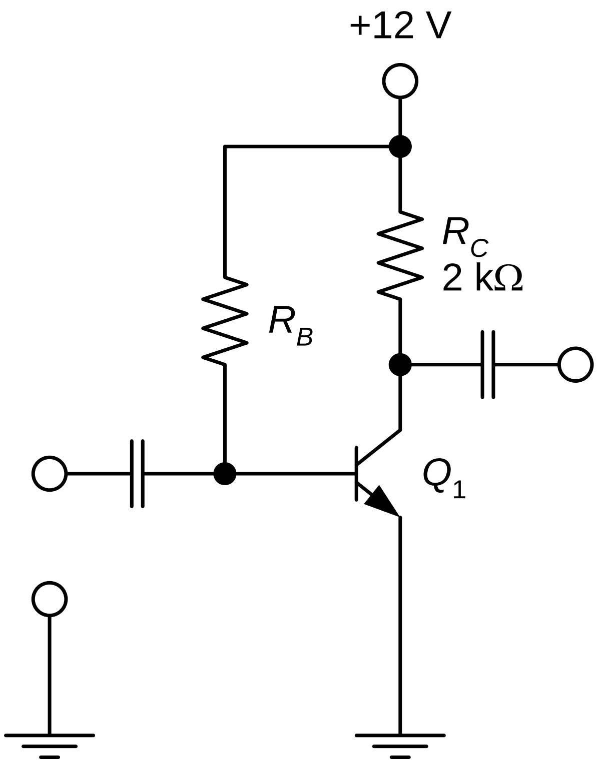
$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$



Example

Plot the dc load line for the circuit shown below.



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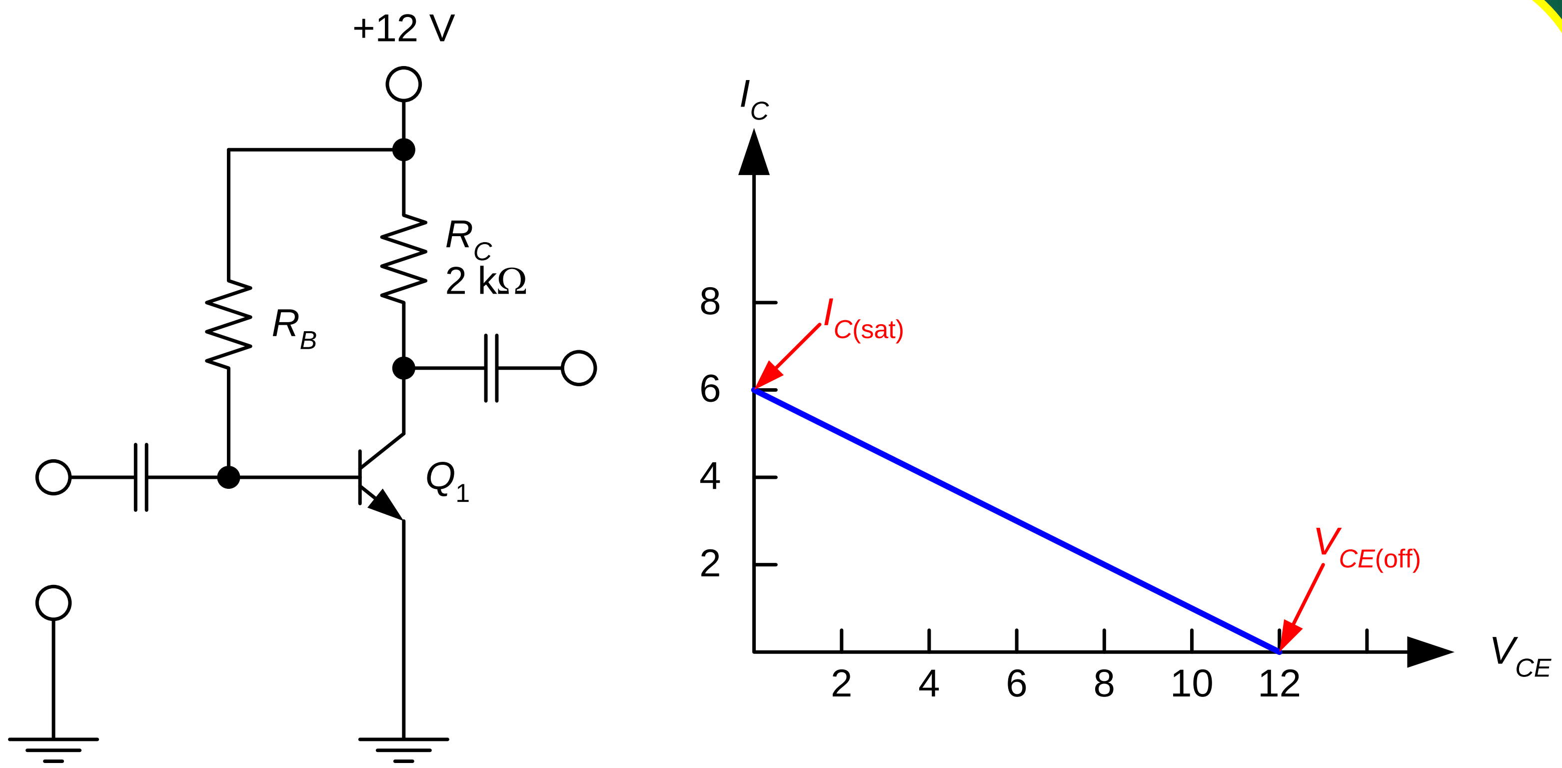
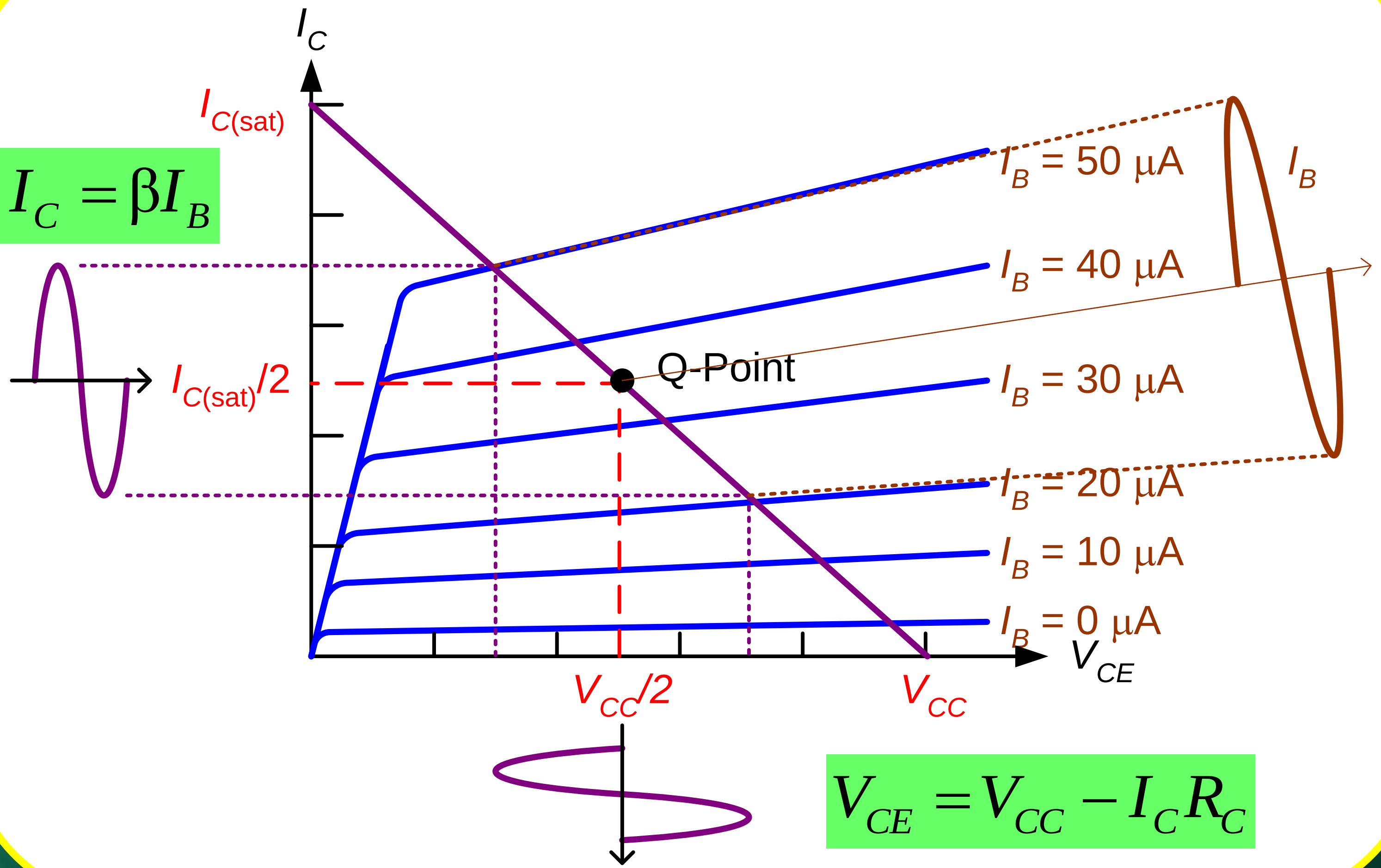


Optimum Q-point

$$I_C = \beta I_B$$

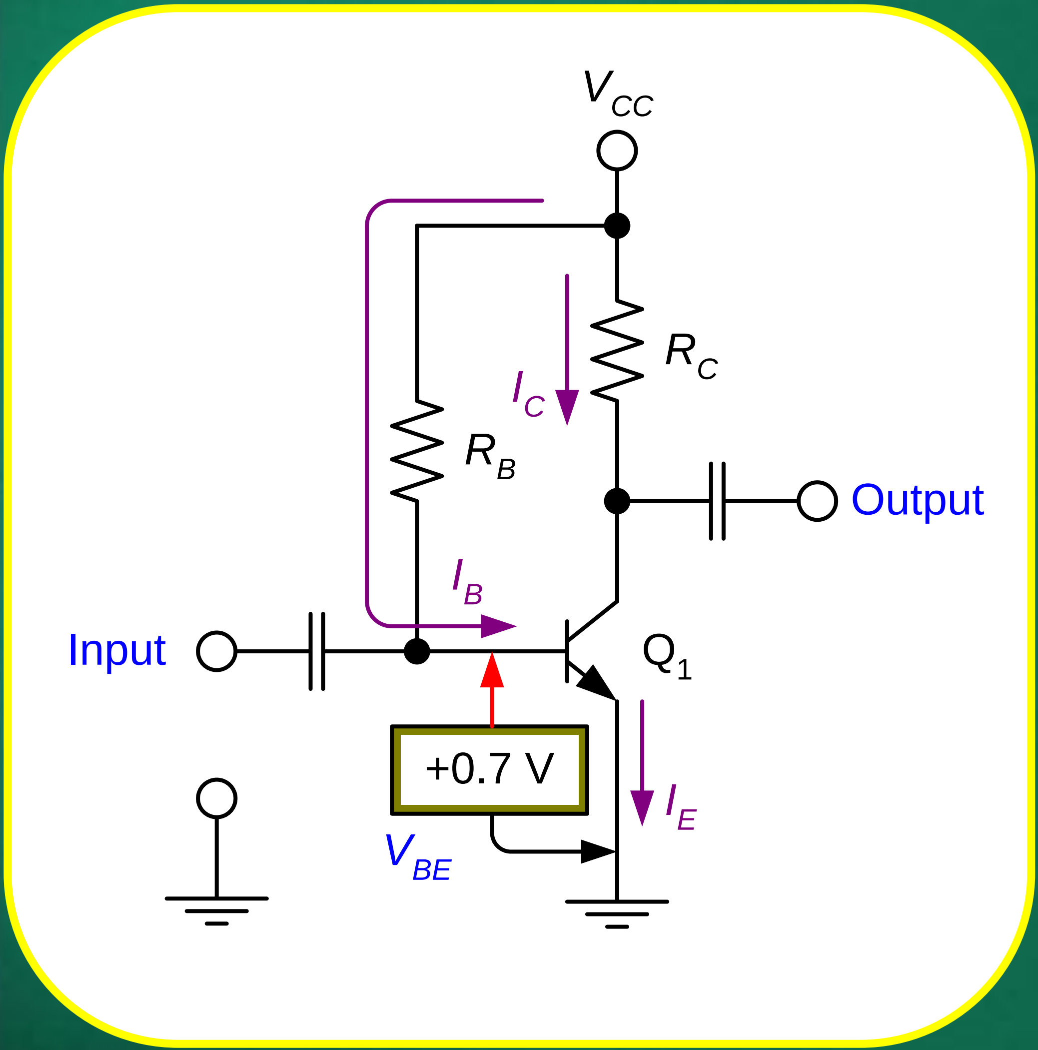


$$V_{CE} = V_{CC} - I_C R_C$$

Bias Circuits

- Different types bias circuits
  - Base Bias
  - Voltage Divider Bias
  - Emitter Bias
  - Collector Feedback Bias
  - Emitter Feedback Bias

Base Bias (Fixed Bias)



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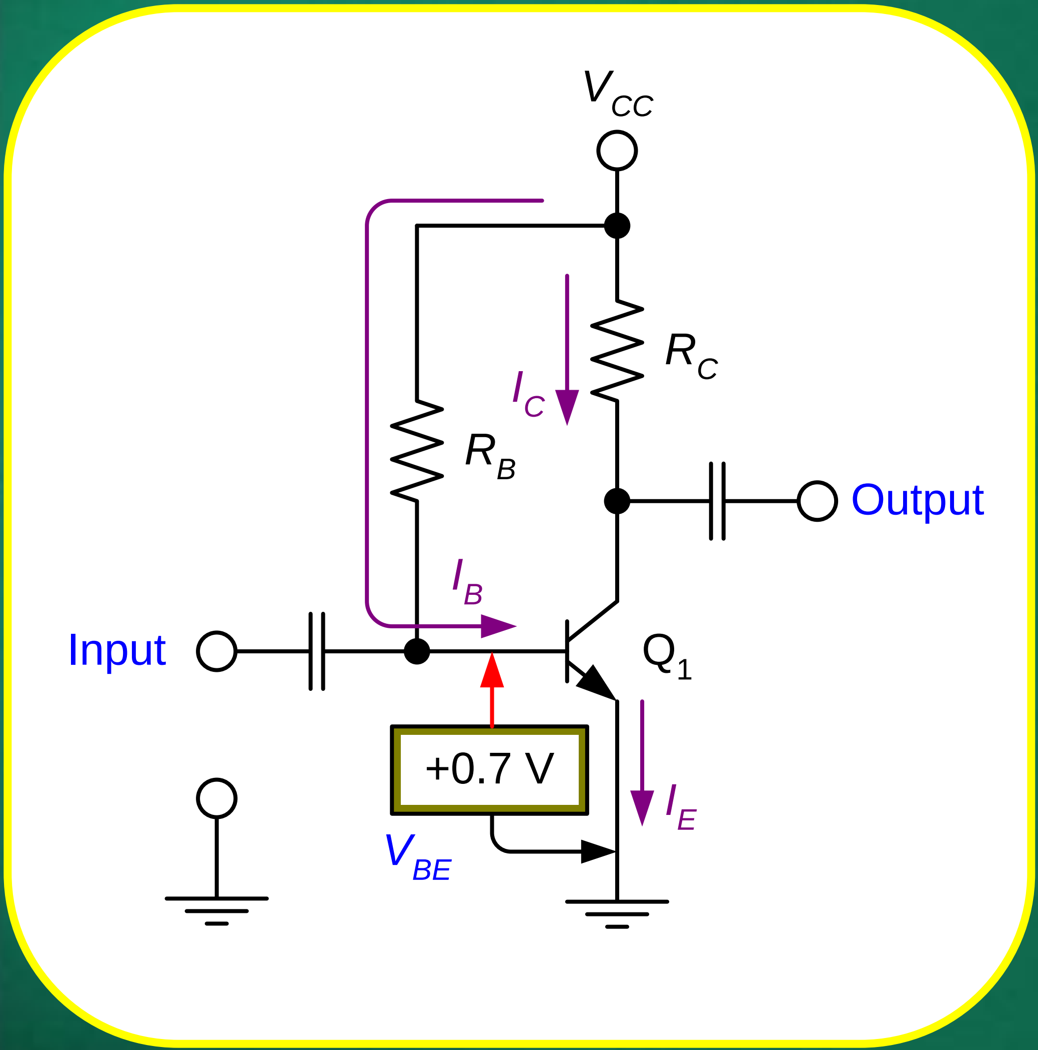

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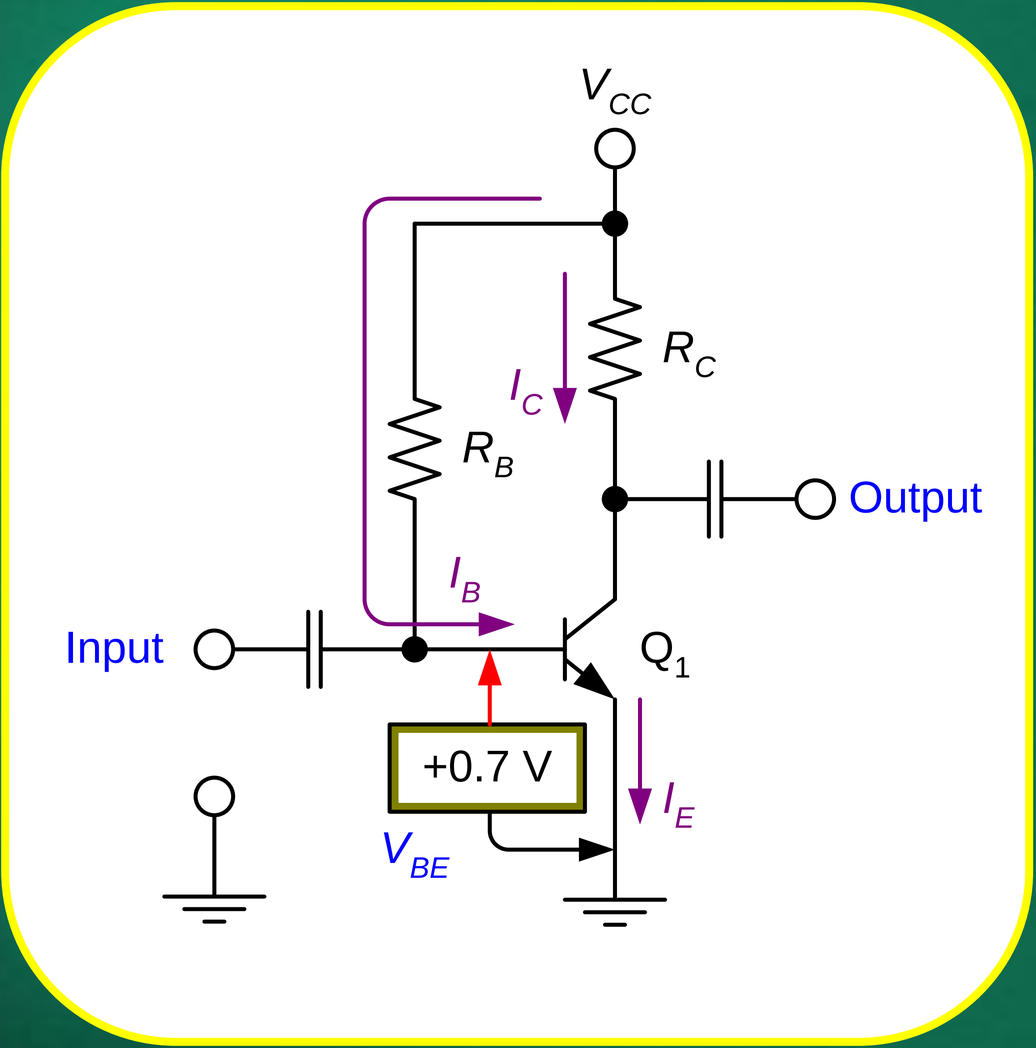

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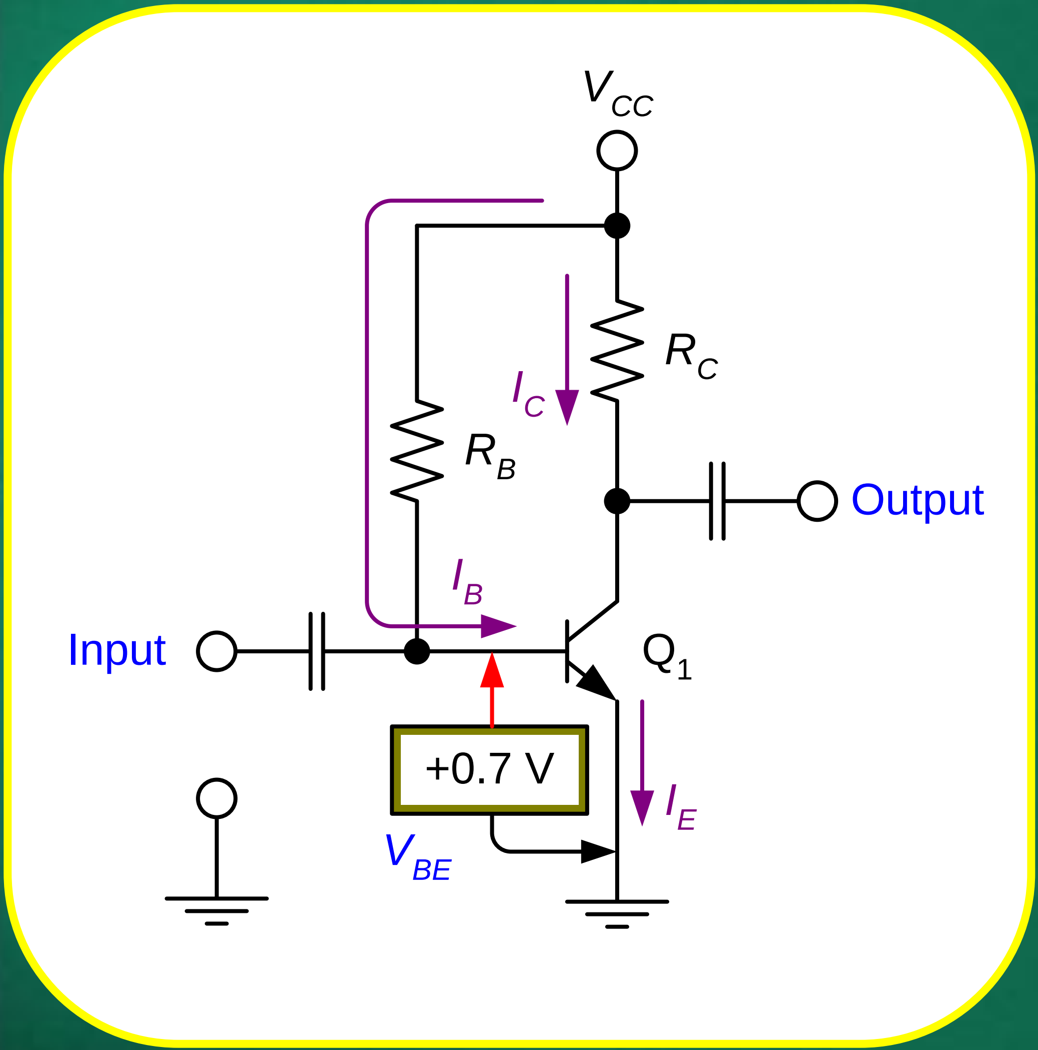

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Example

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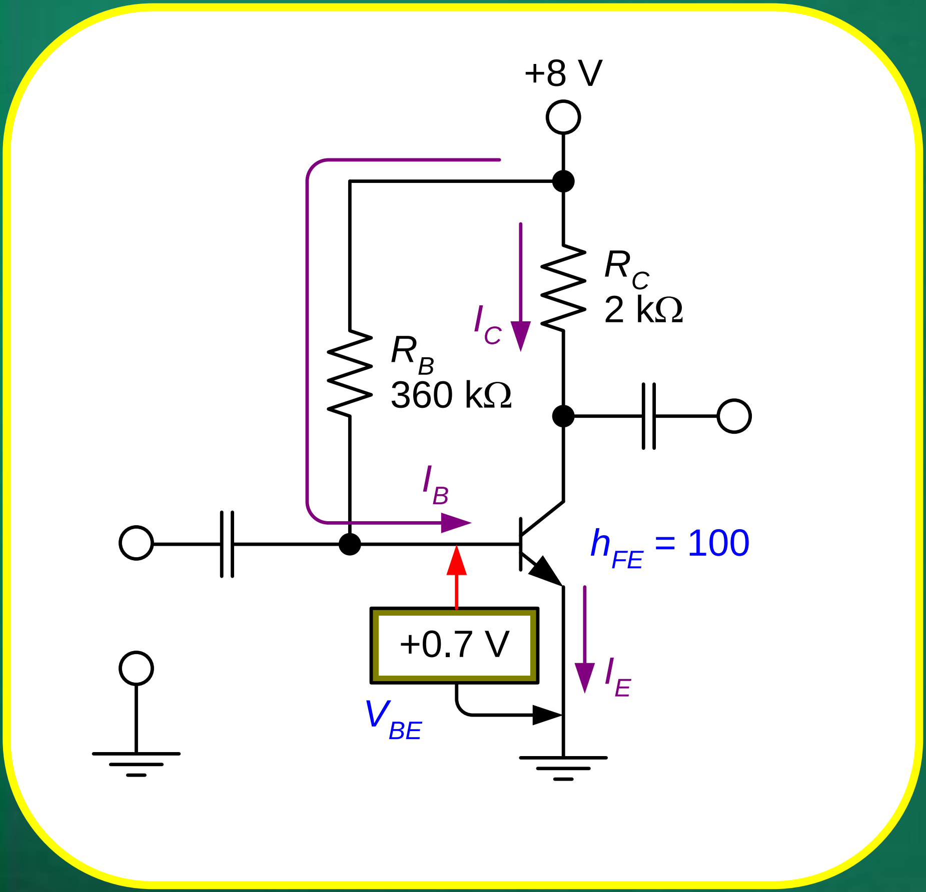

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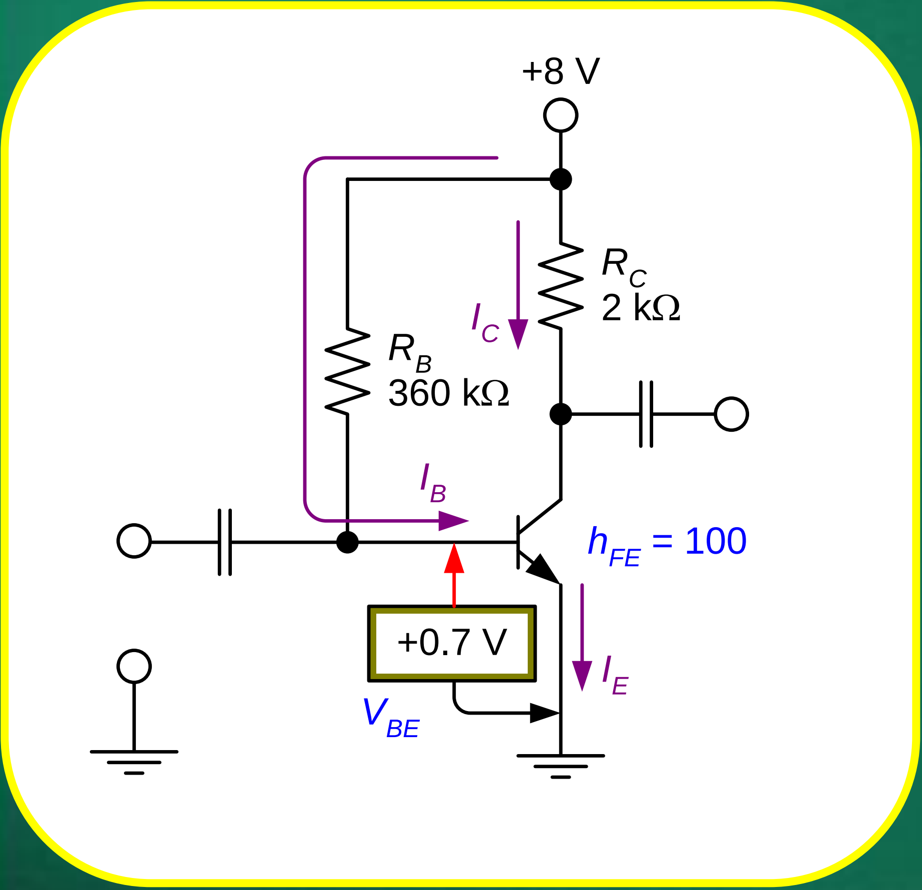

$$I_B = \frac{V_{CC} - 0.7\text{V}}{R_B} = \frac{8\text{V} - 0.7\text{V}}{360\text{k}\Omega}$$

$$= 20.28\mu\text{A}$$

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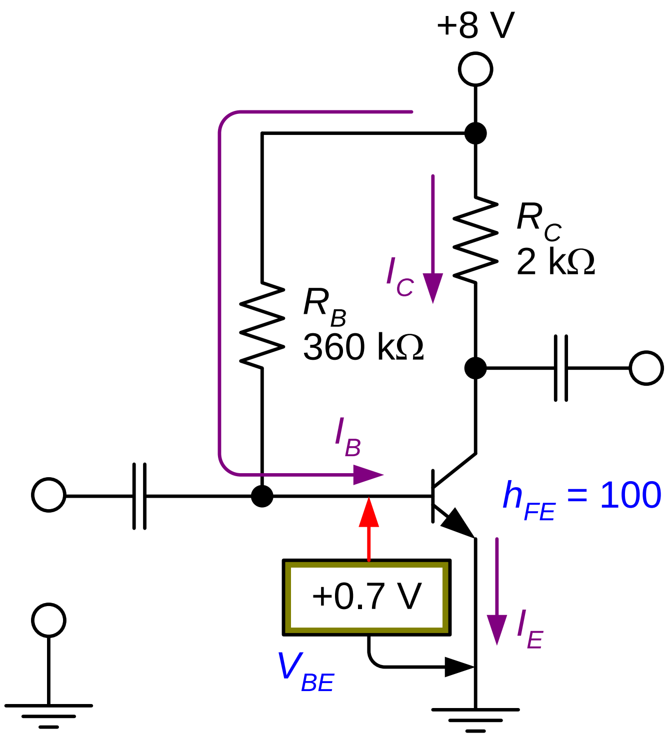

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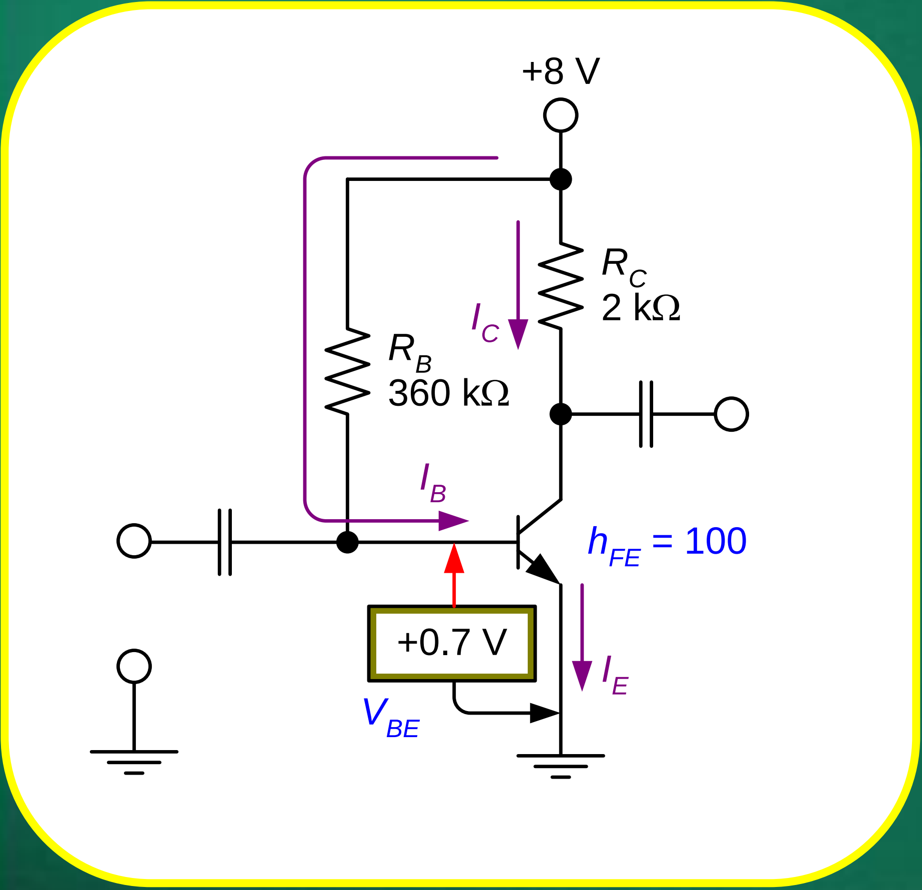

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$$V_{CE} = V_{CC} - I_C R_C$$
$$= 8\text{V} - (2.028\text{mA})(2\text{k}\Omega)$$
$$= 3.94\text{V}$$

Example

Construct the dc load line for the circuit shown in previous example and plot the Q-point from the values obtained. Determine whether the circuit is midpoint biased.

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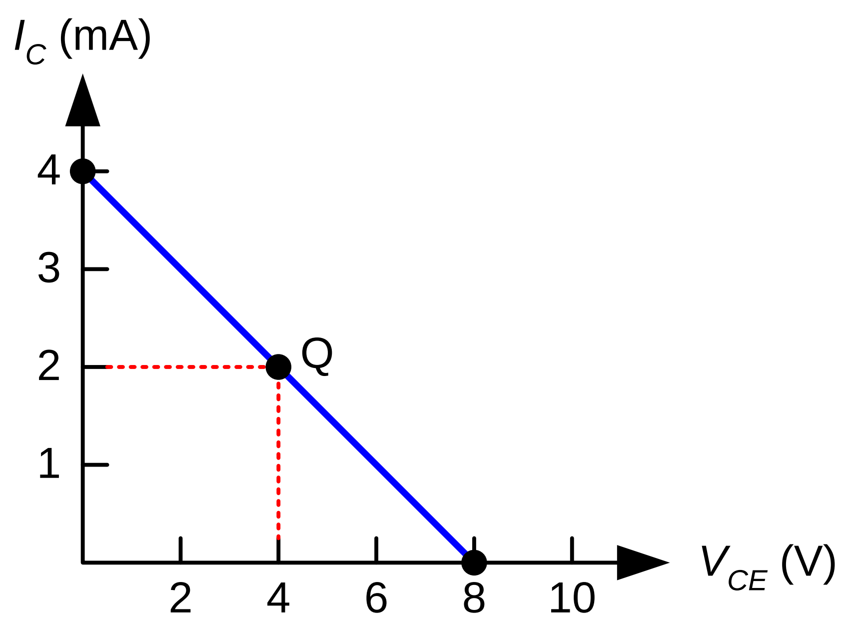

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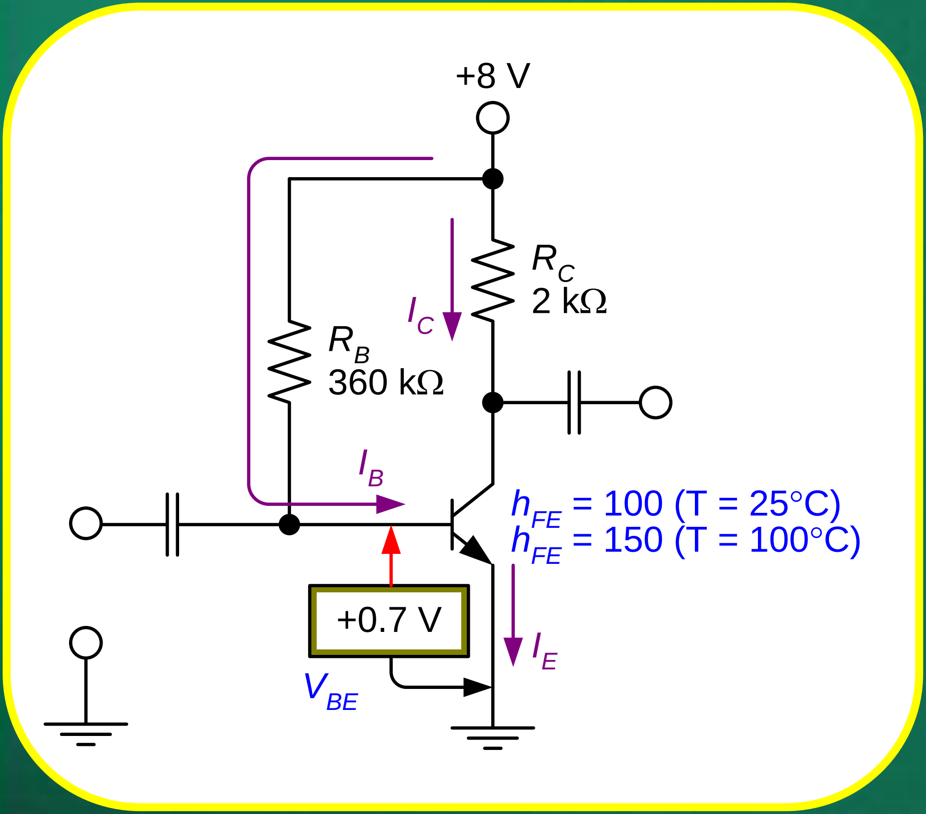
Example (Q-point Shift)

The transistor in the circuit has values of h_{FE}=100 when T=25 °C and h_{FE}=150 when T=100 °C. Determine the Q-point values of I_C and V_{CE} at both of these temperatures.



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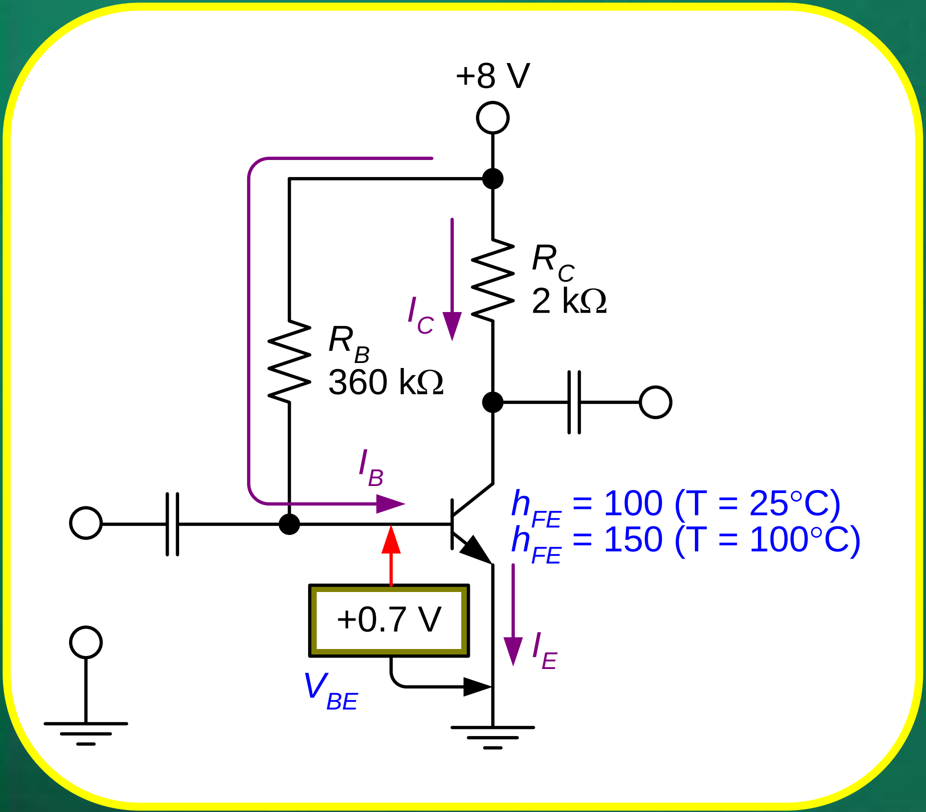
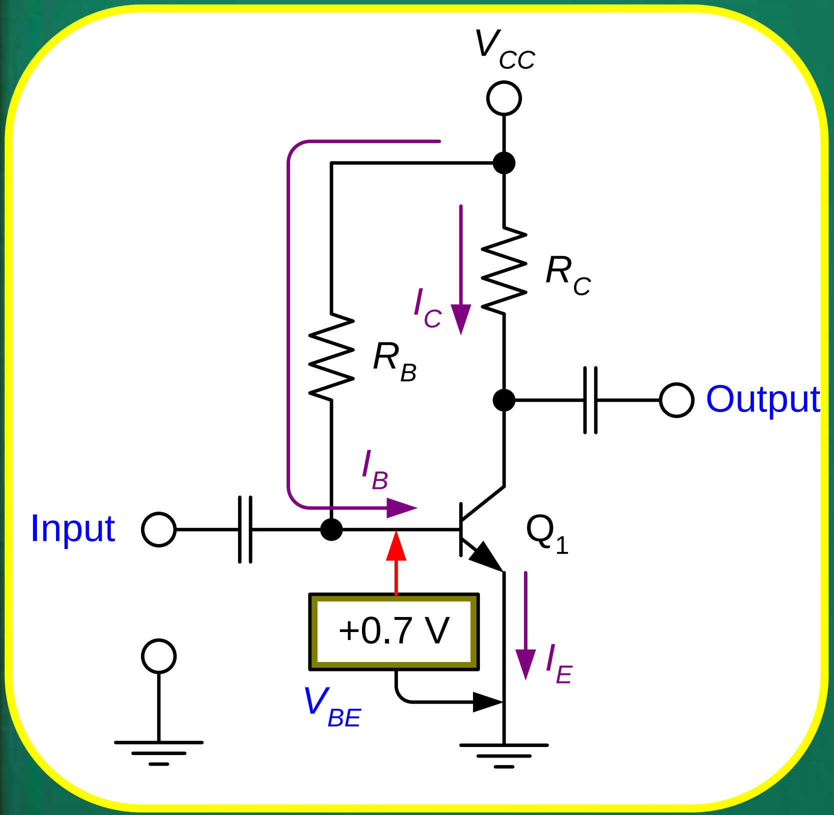


Temp(°C)	I_B (μA)	I_C (mA)	V_{CE} (V)
25	20.28	2.028	3.94
100	20.28	3.04	1.92

Base Bias Characteristics



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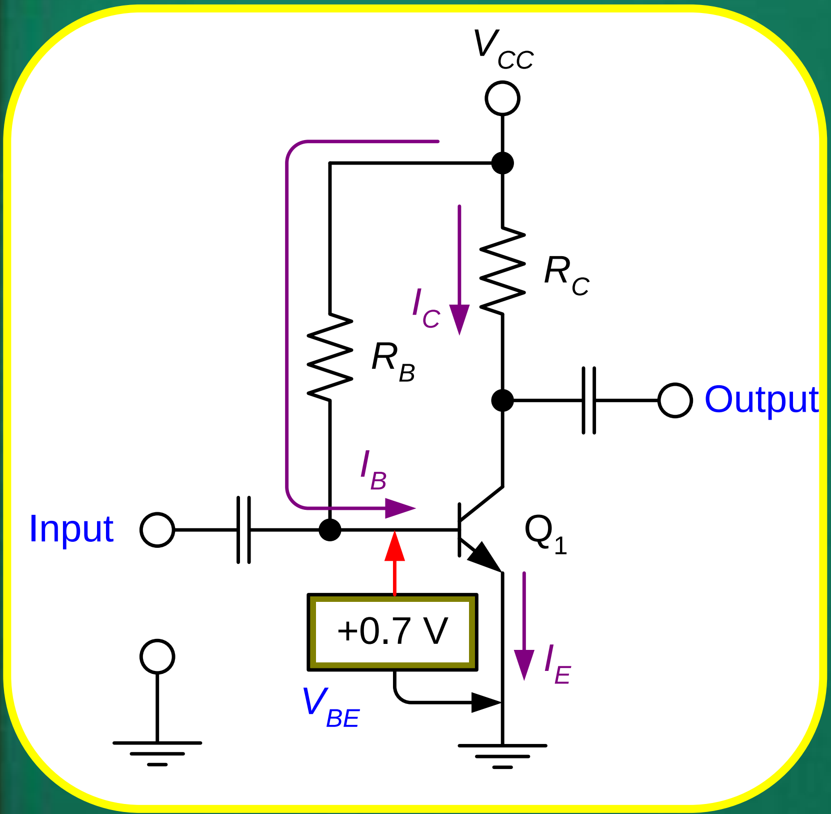

Circuit recognition: A single resistor (R_B) between the base terminal and V_{CC}. No emitter resistor.

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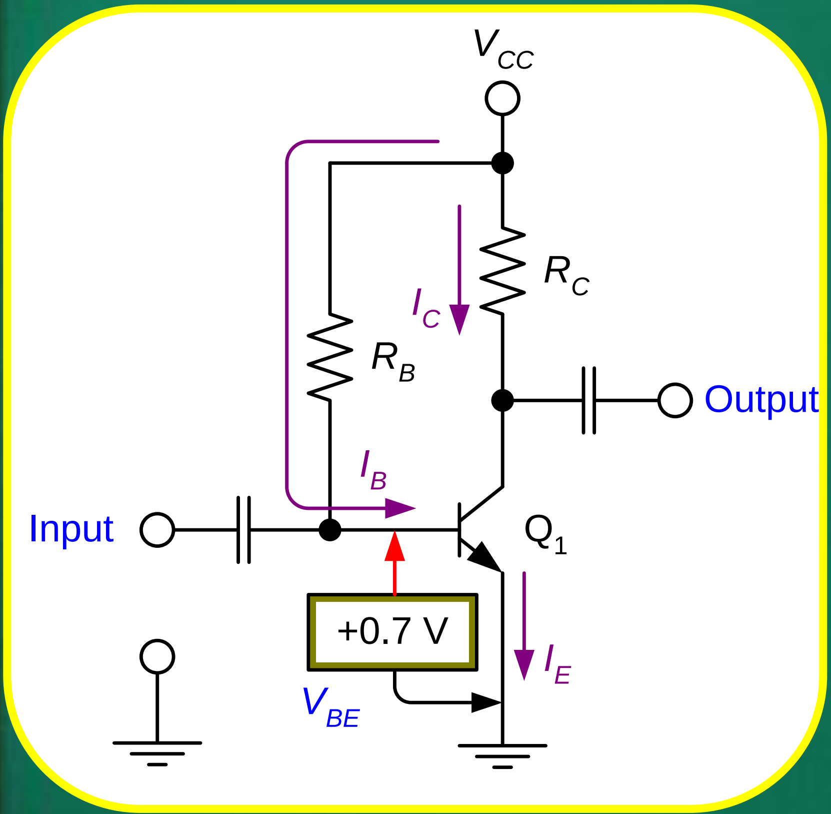

Circuit recognition: A single resistor (R_B) between the base terminal and V_{CC}. No emitter resistor.

Advantage: Circuit simplicity.

Disadvantage: Q-point shift with temp.

Applications: Switching circuits only.

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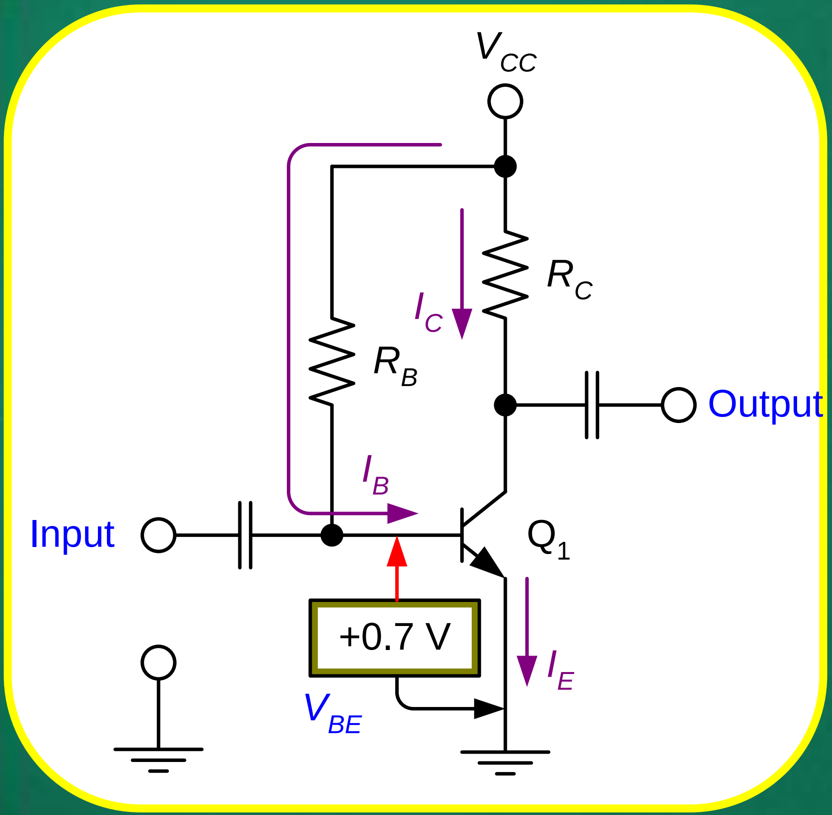
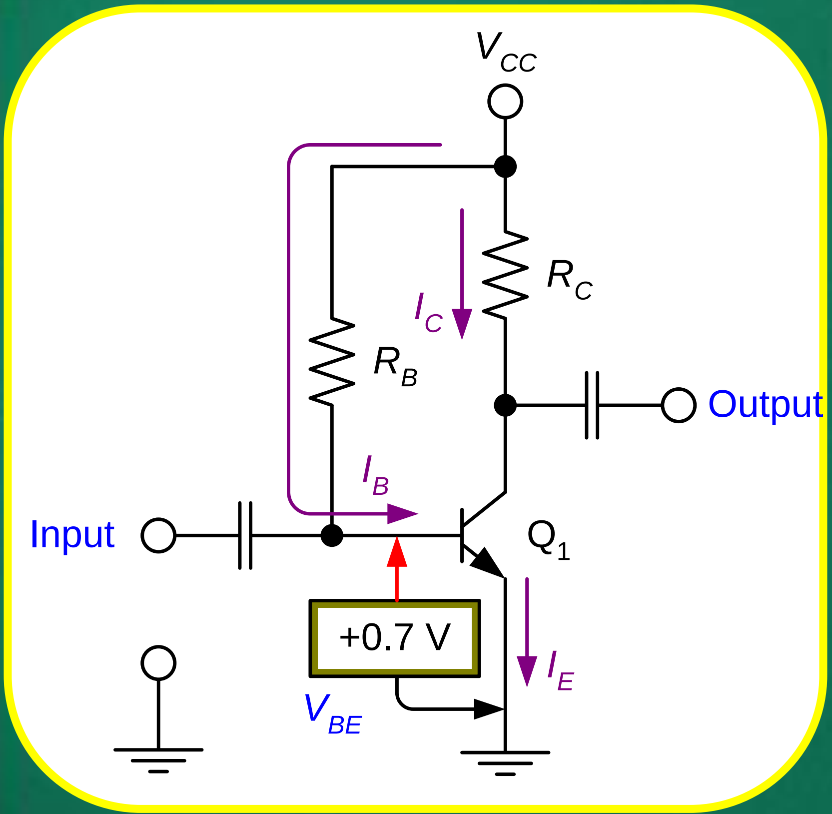


Load line equations:

Base Bias Characteristics



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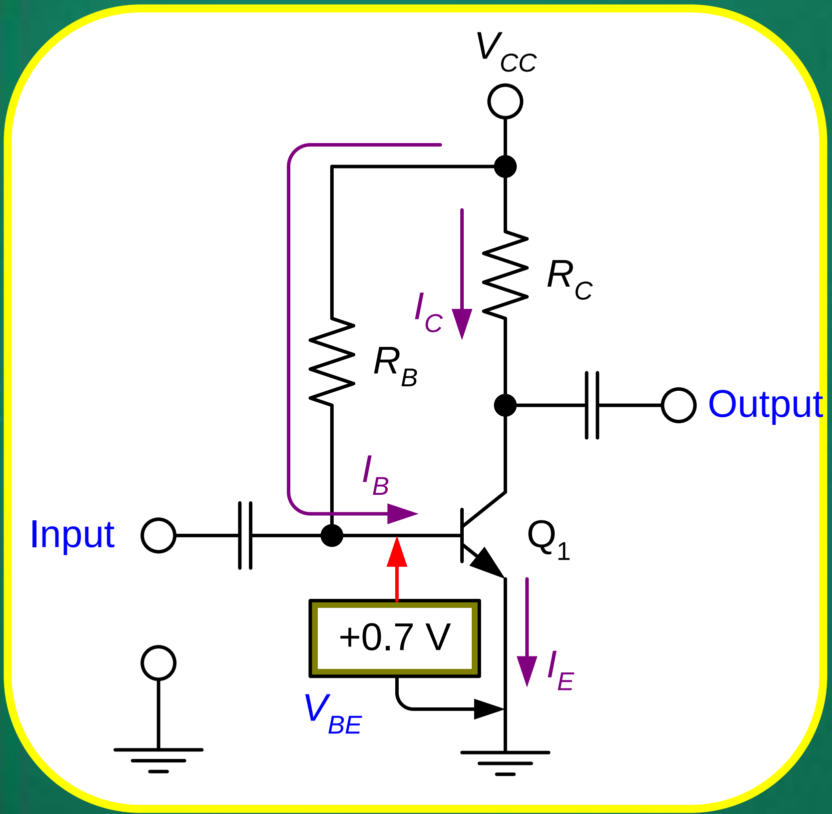

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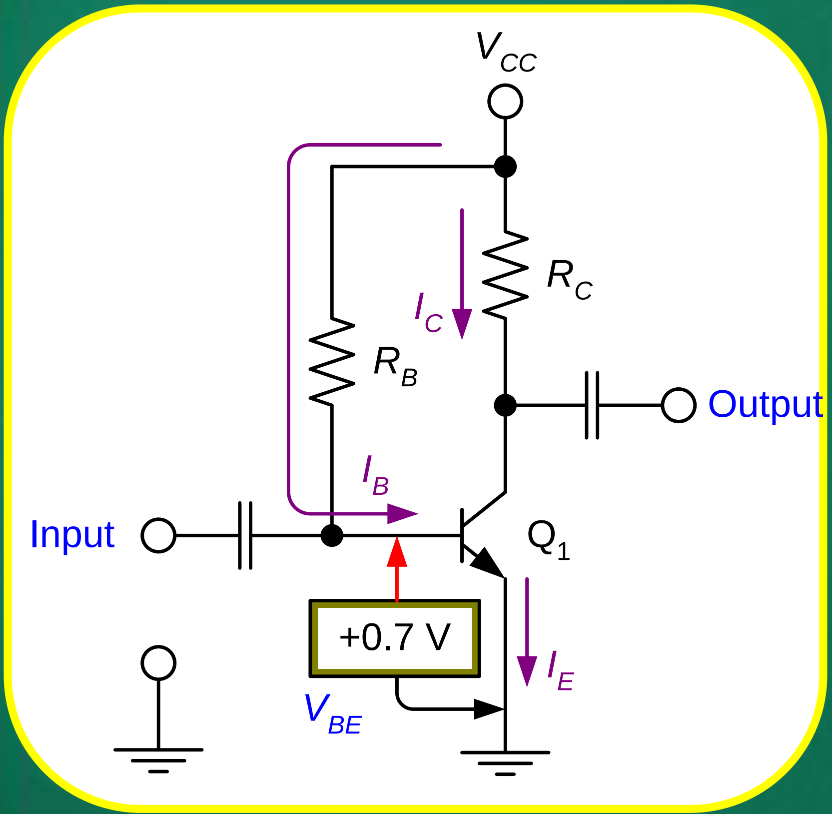

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$$I_C = h_{FE} I_B$$

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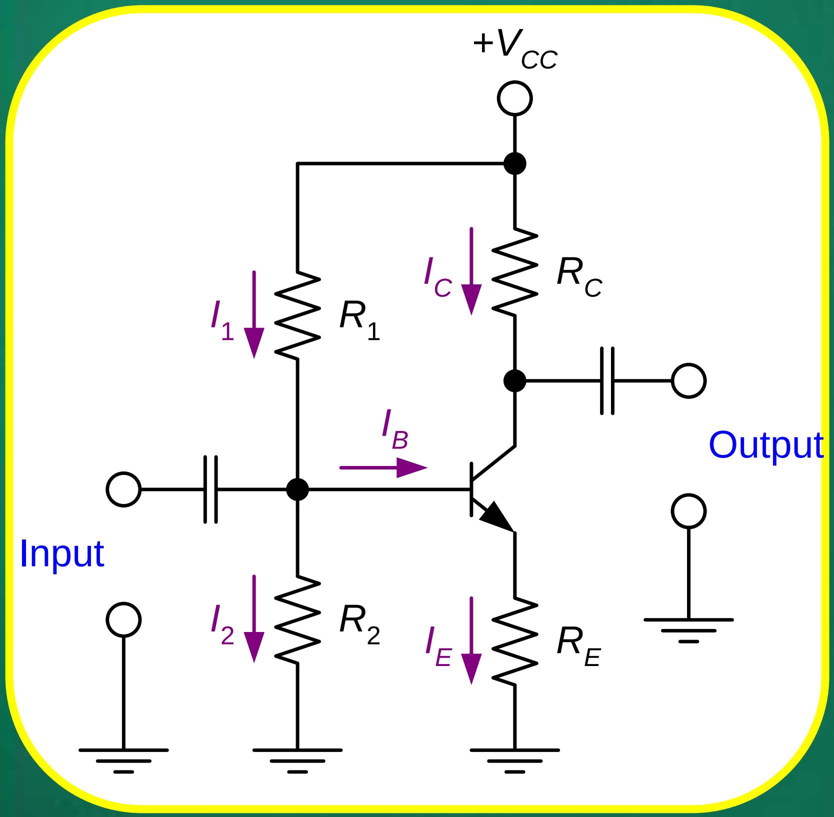
Voltage Divider Bias



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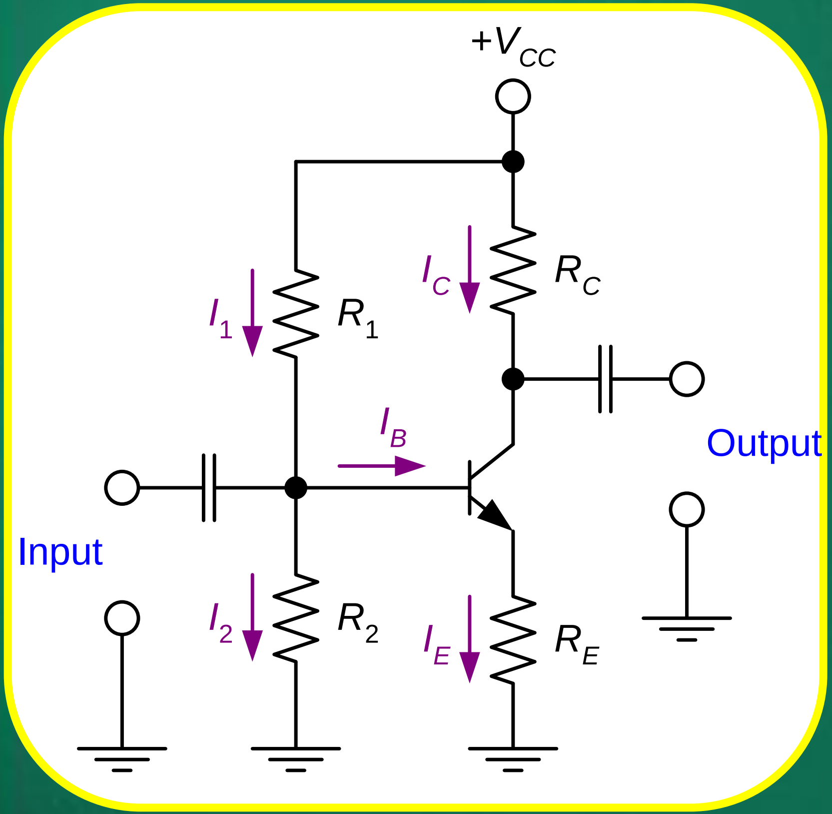

Assume that $I_2 > 10I_B$.

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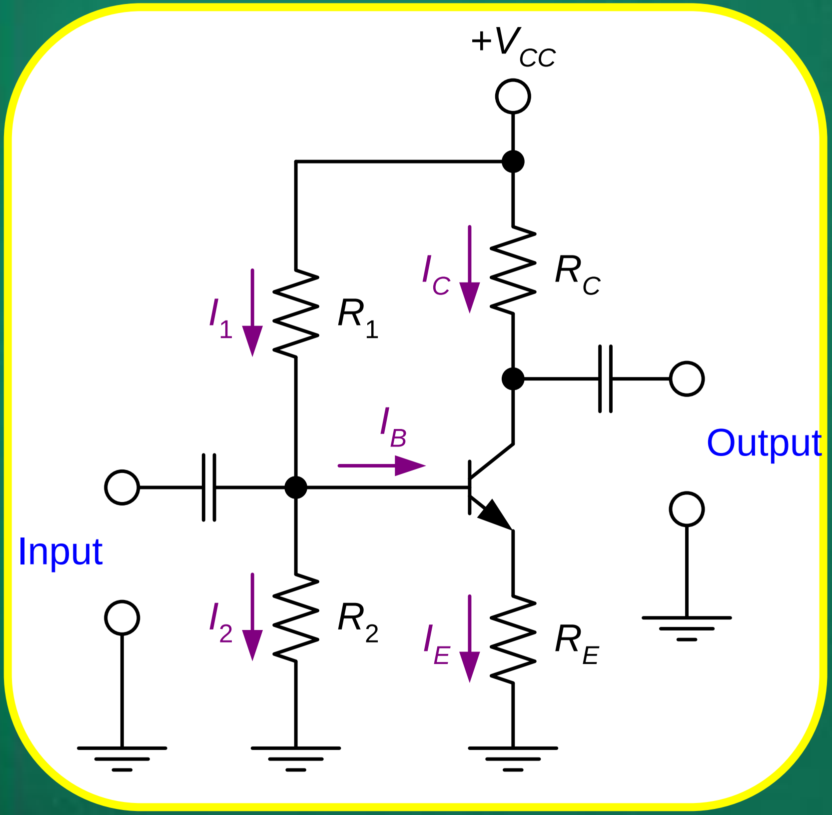

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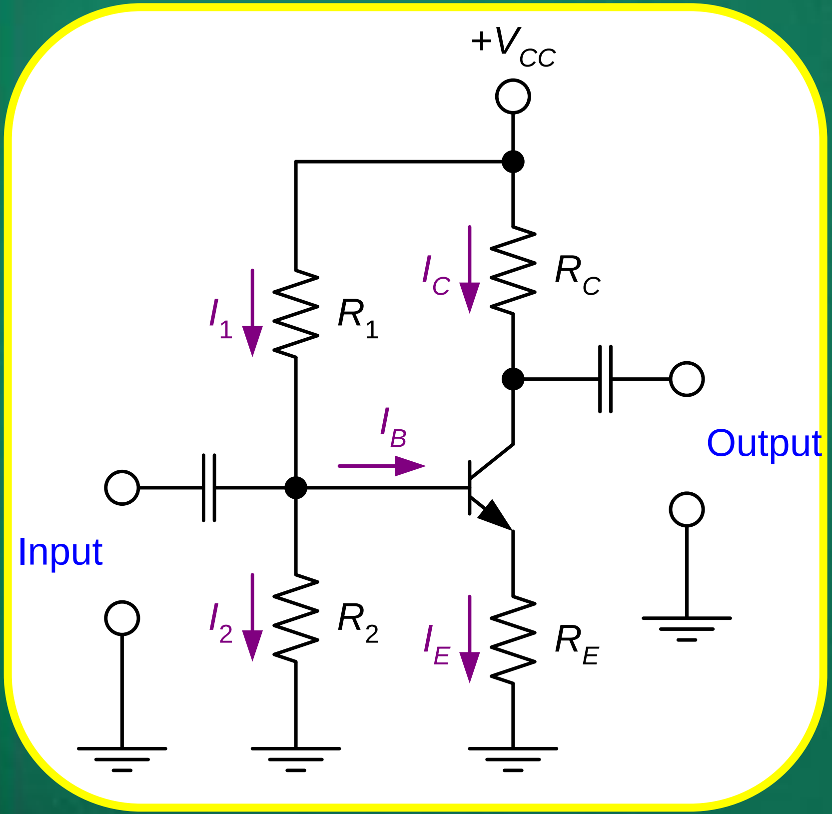

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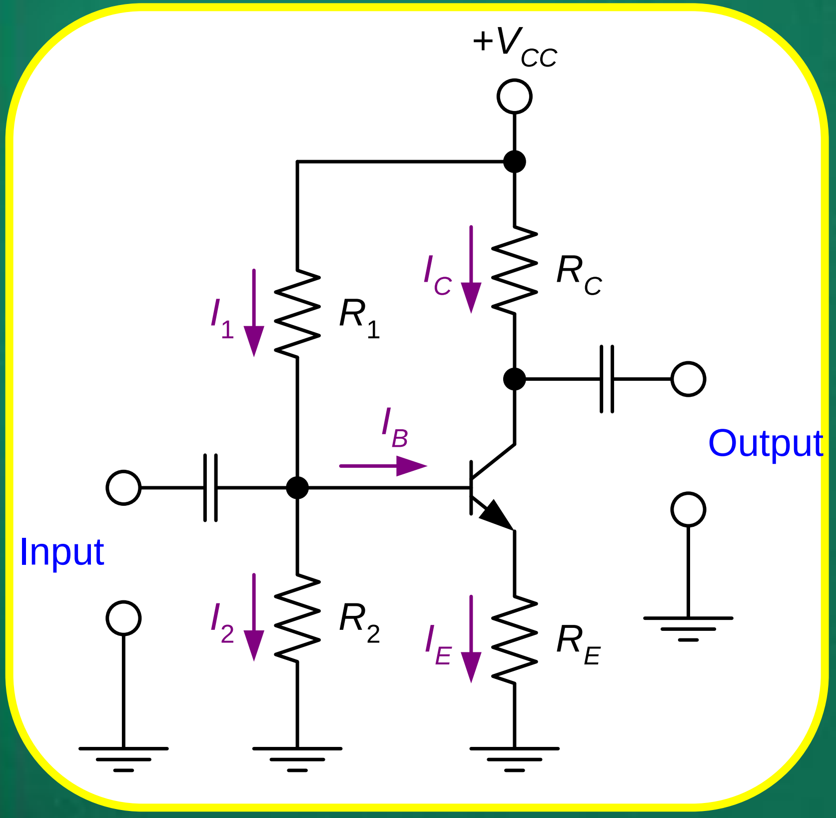

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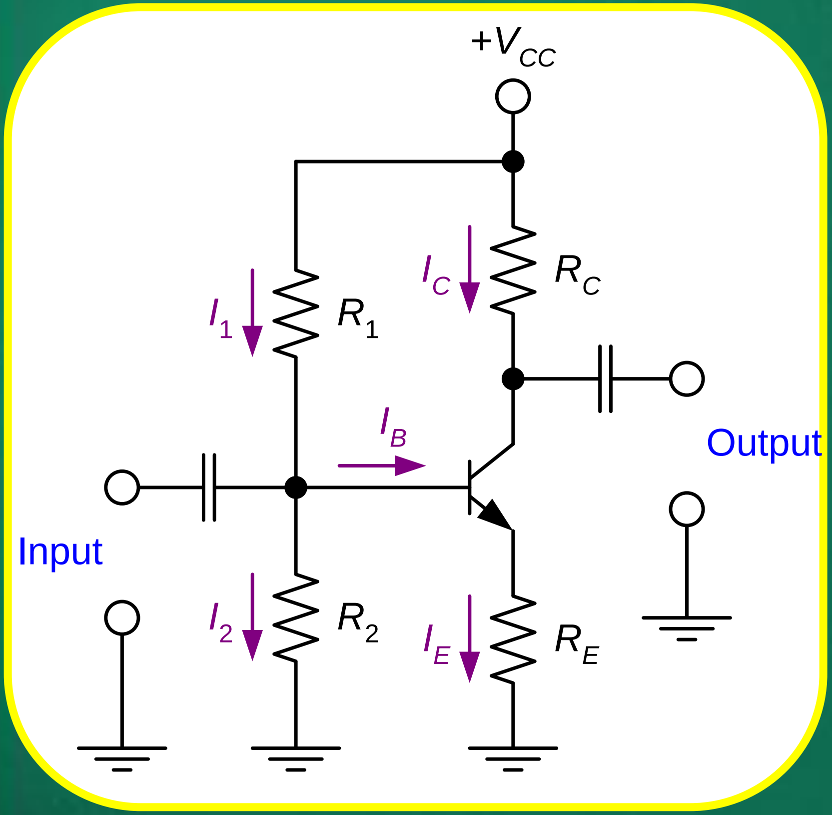

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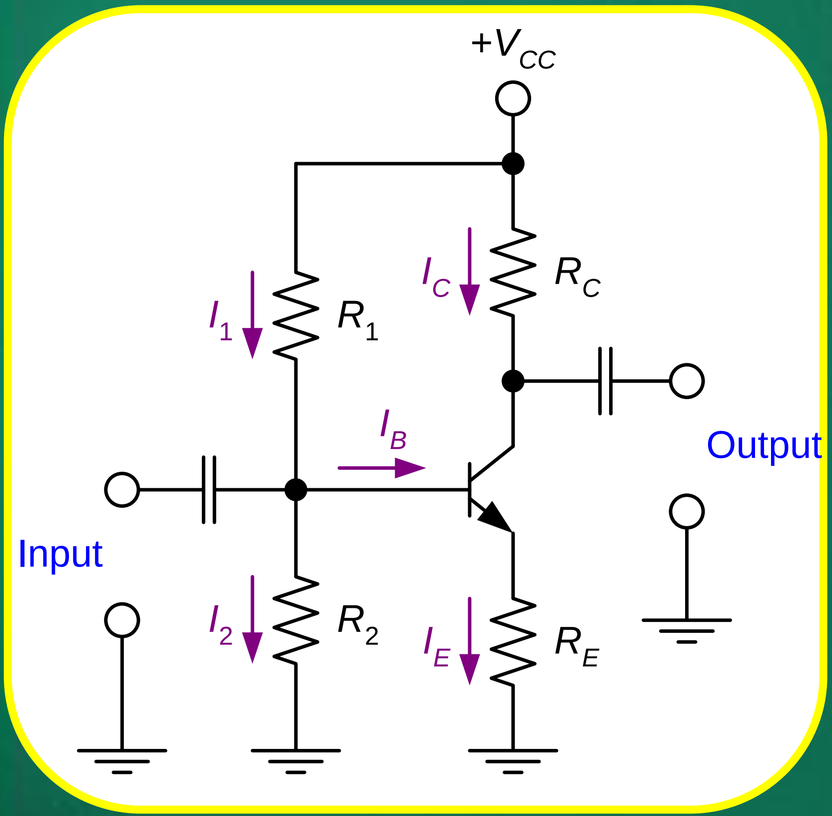

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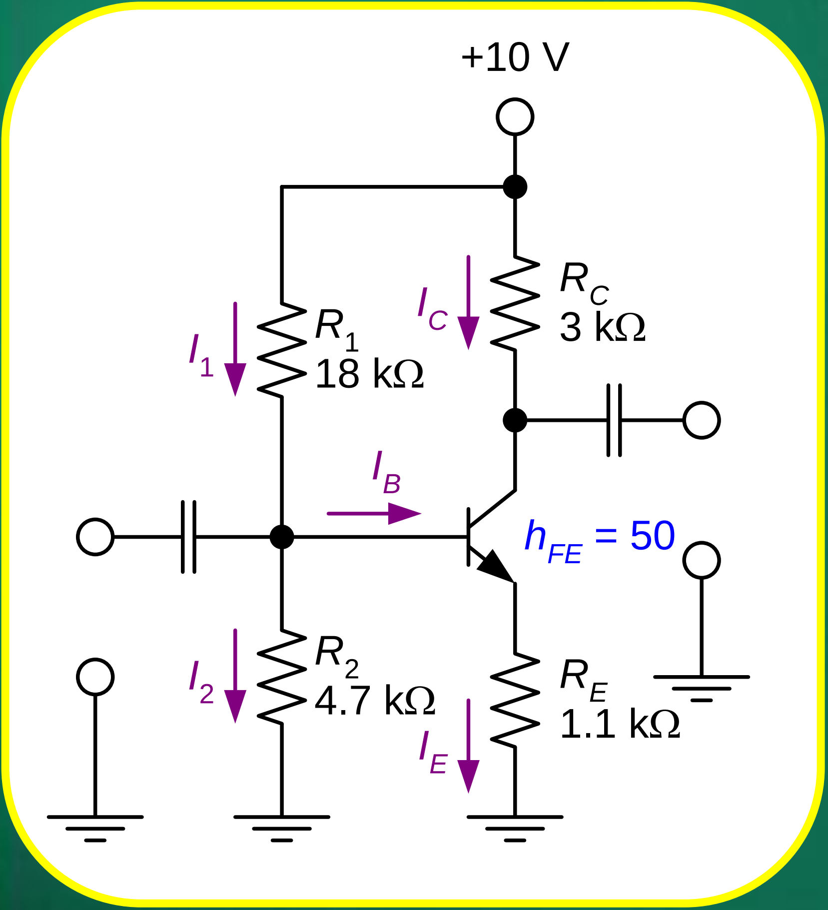
$$V_{CEQ} = V_{CC} - I_{CQ}\left(R_C + R_E\right)$$

Example

Determine the values of I_{CQ} and V_{CEQ} for the circuit shown below.



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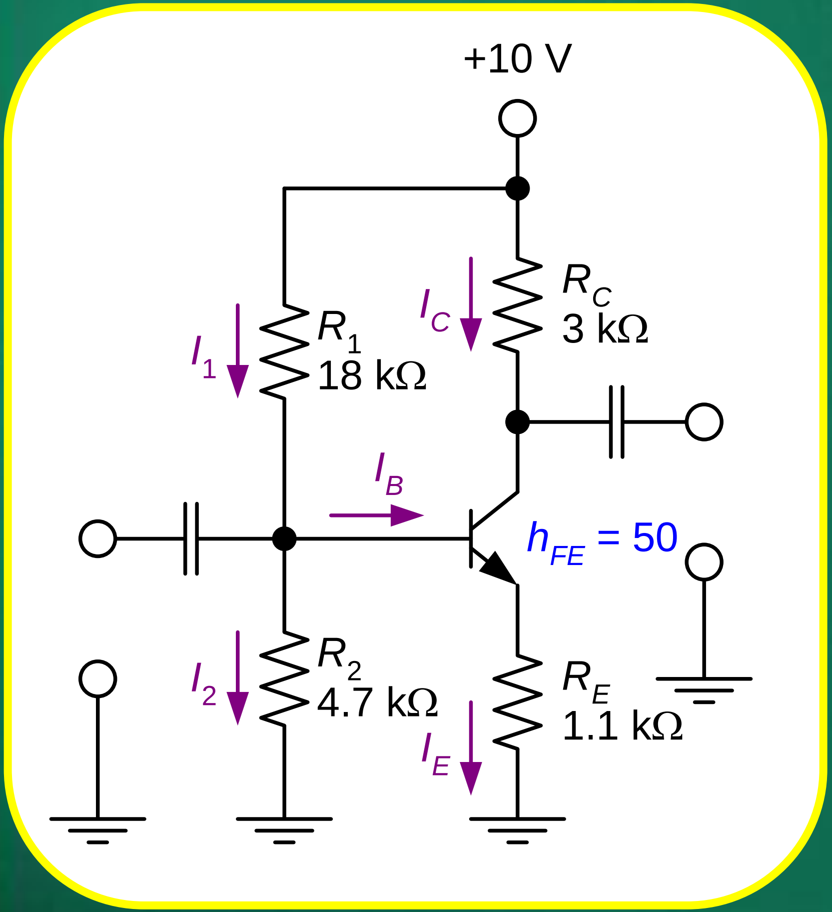

$$V_B = V_{CC}\frac{R_2}{R_1 + R_2}$$

$$= (10\text{V})\frac{4.7\text{k}\Omega}{22.7\text{k}\Omega} = 2.07\text{V}$$

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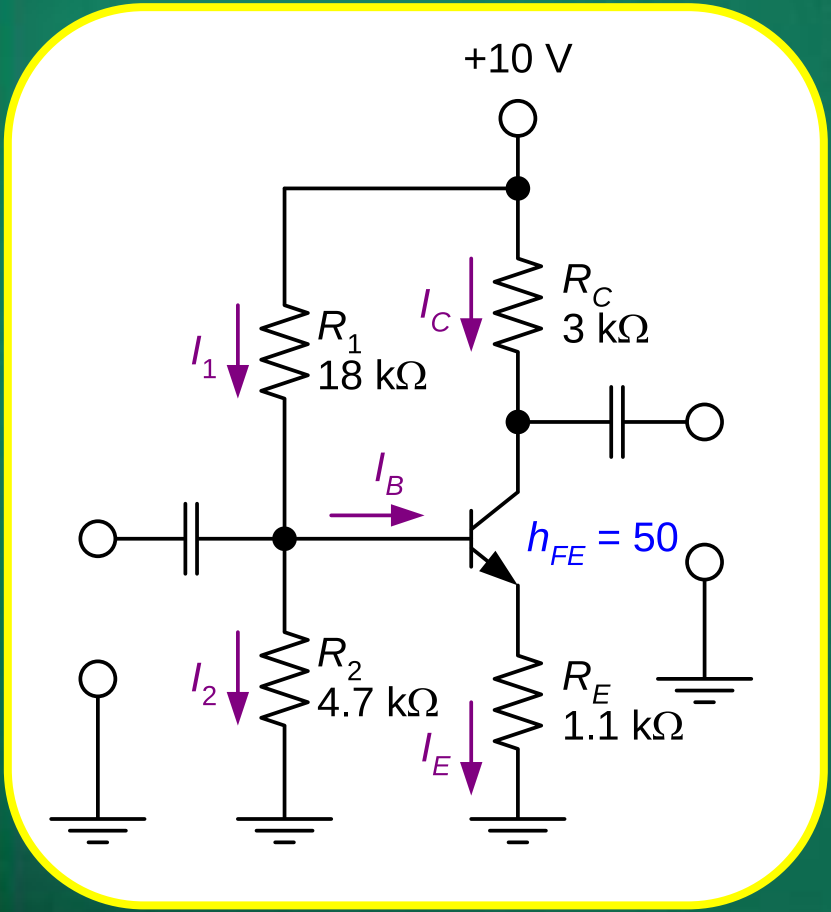

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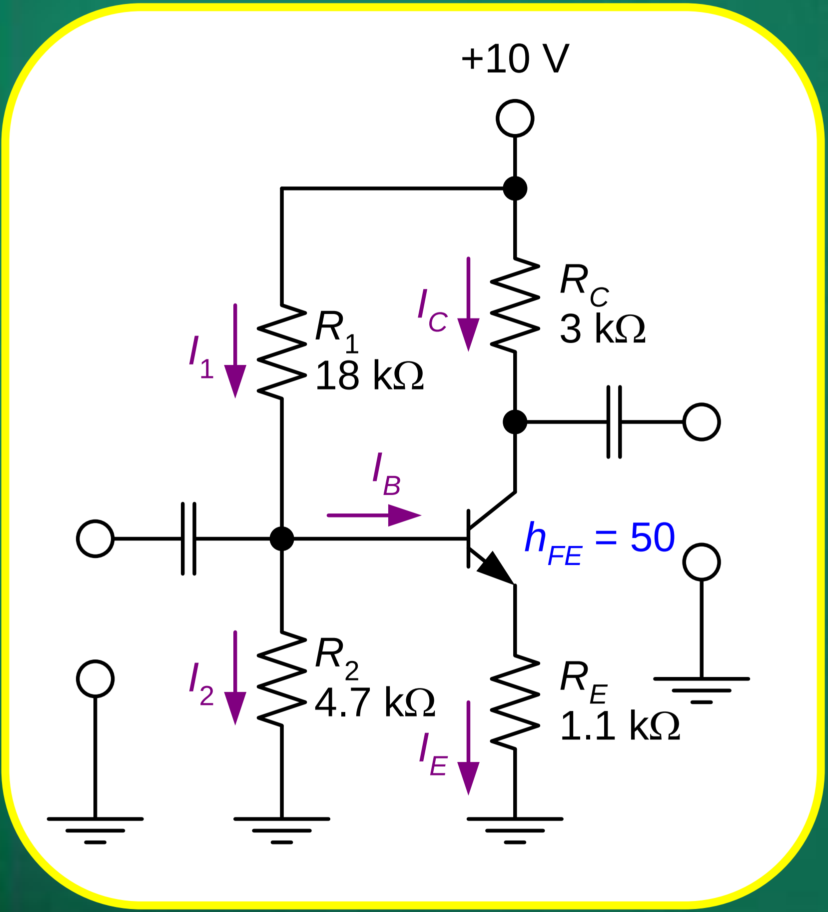

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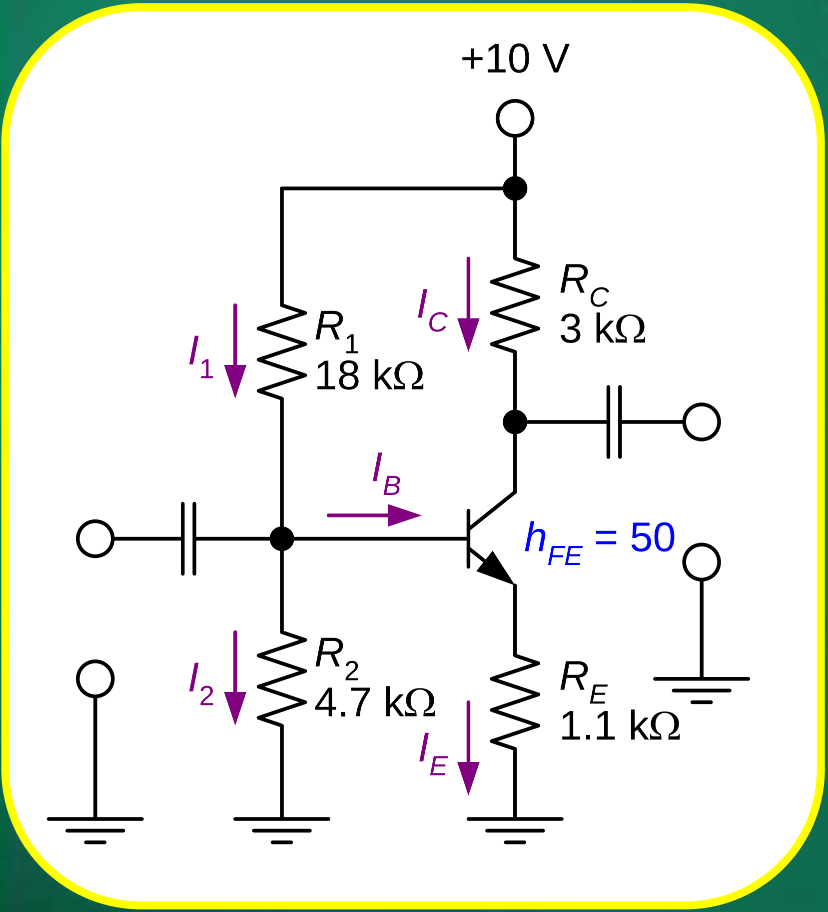

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Because $I_{CQ} \cong I_E$ (or $h_{FE} >> 1$),

$$I_{CQ} \cong \frac{V_E}{R_E} = \frac{1.37\text{V}}{1.1\text{k}\Omega} = 1.25\text{mA}$$

Example

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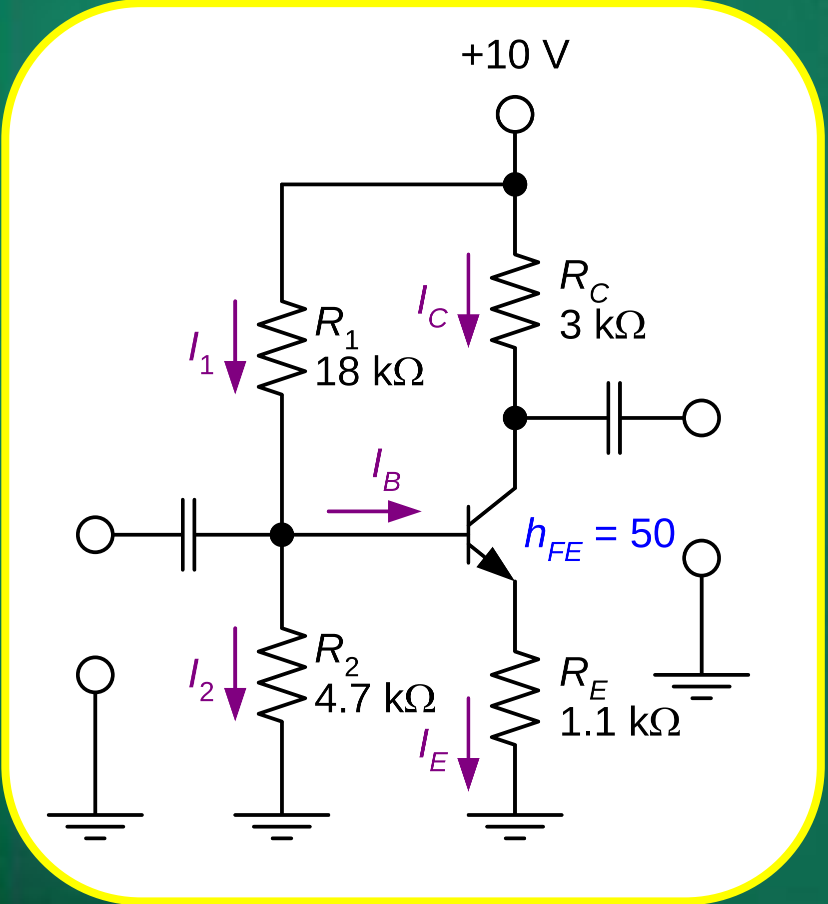

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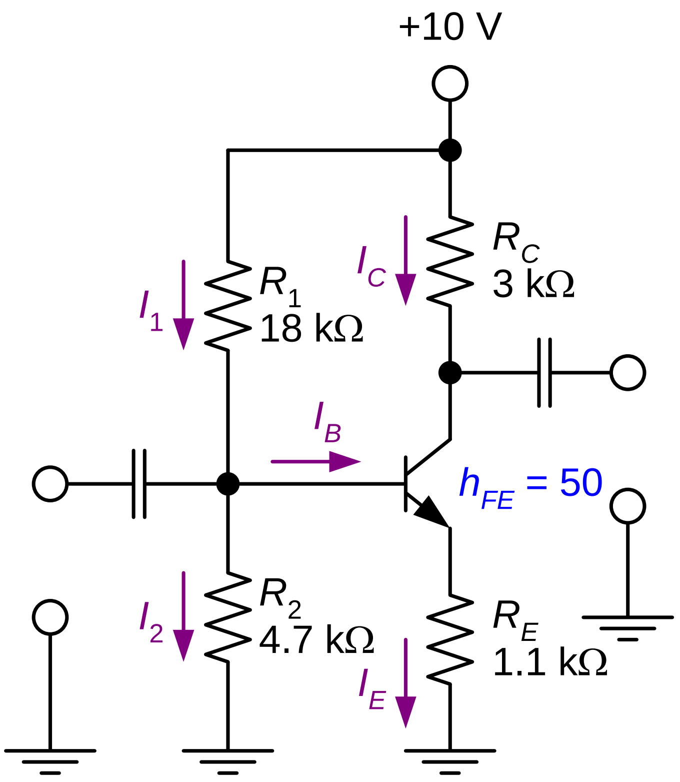
$$V_{CEQ} = V_{CC} - I_{CQ}(R_C + R_E)$$

$$= 10\text{V} - (1.25\text{mA})(4.1\text{k}\Omega) = 4.87\text{V}$$

Example

Verify that $I_2 > 10\ I_B$.



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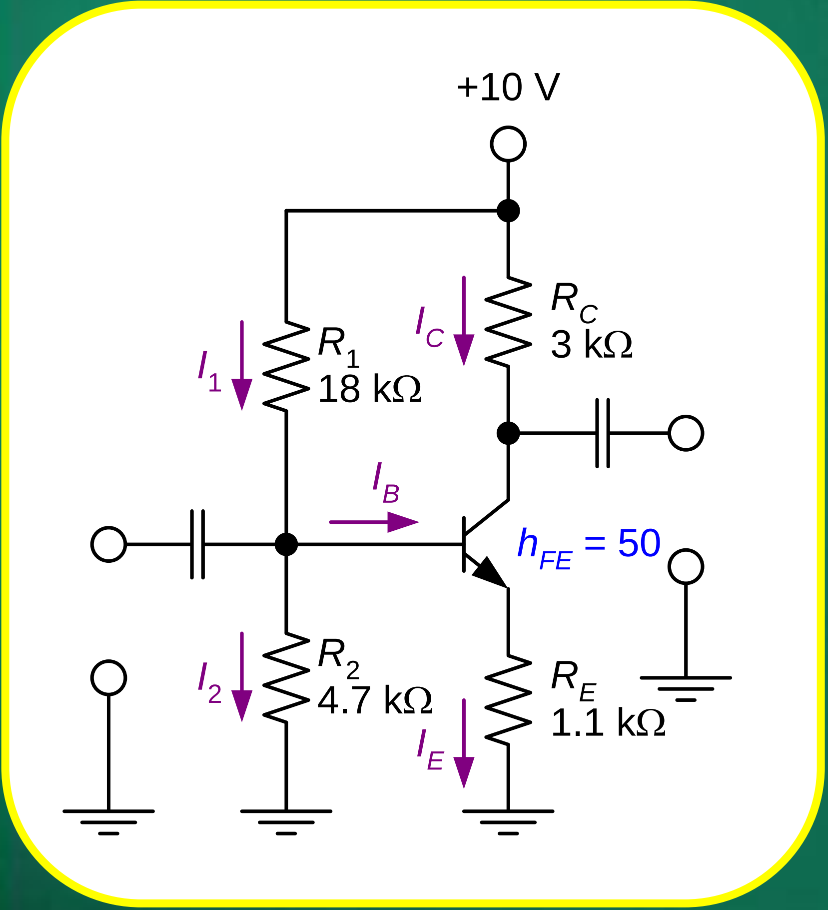

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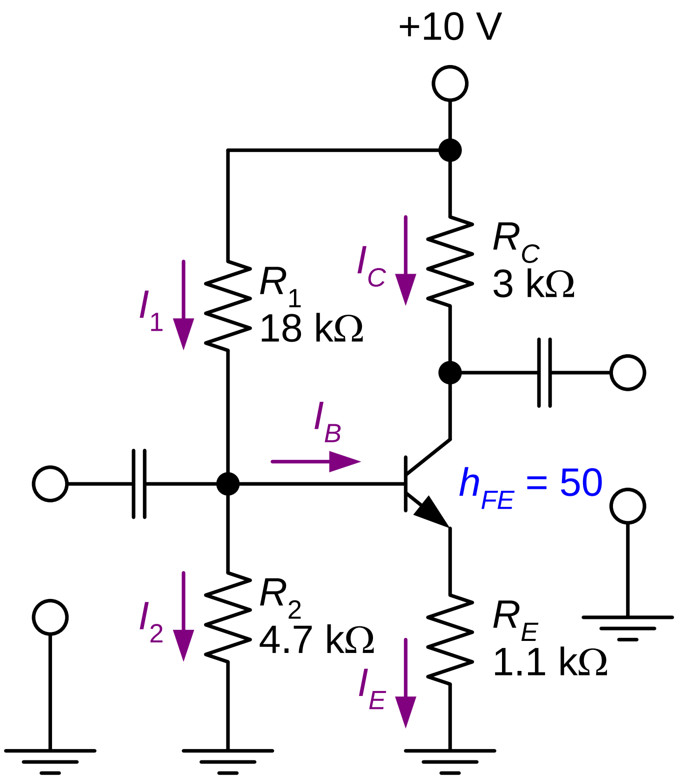

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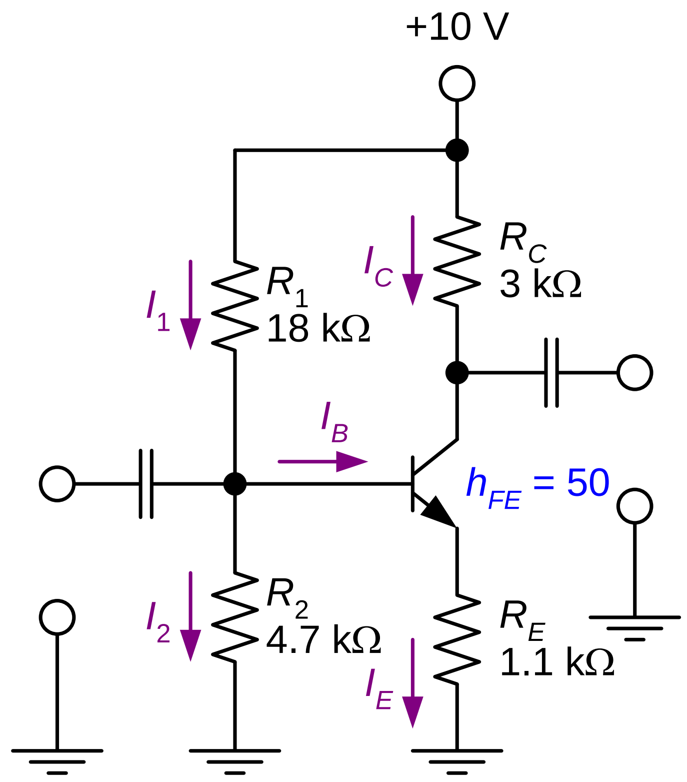

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$$\therefore I_2 > 10 I_B$$

Which value of h_{FE} to use?

Transistor specification sheet may list any combination of the following h_{FE}: max. h_{FE}, min. h_{FE}, or typ. h_{FE}. Use typical value if there is one. Otherwise, use

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$$h_{FE(\text{ave})} = \sqrt{h_{FE(\text{min})} \times h_{FE(\text{max})}}$$

Example

A voltage-divider bias circuit has the following values: R_1=1.5 kΩ, R_2=680 Ω, R_C=260 Ω, R_E=240 Ω and V_{CC}=10 V. Assuming the transistor has $h_{FE}(max)$=300 and $h_{FE}(min)$= 100, determine the value of I_B for the circuit.

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$$I_B = \frac{I_E}{h_{FE(\text{ave})}+1} = \frac{10\text{mA}}{174} = 57.5\mu\text{A}$$

Stability of Voltage Divider Bias Circuit

The Q-point of voltage divider bias circuit is less dependent on h_{FE} than that of the base bias (fixed bias).

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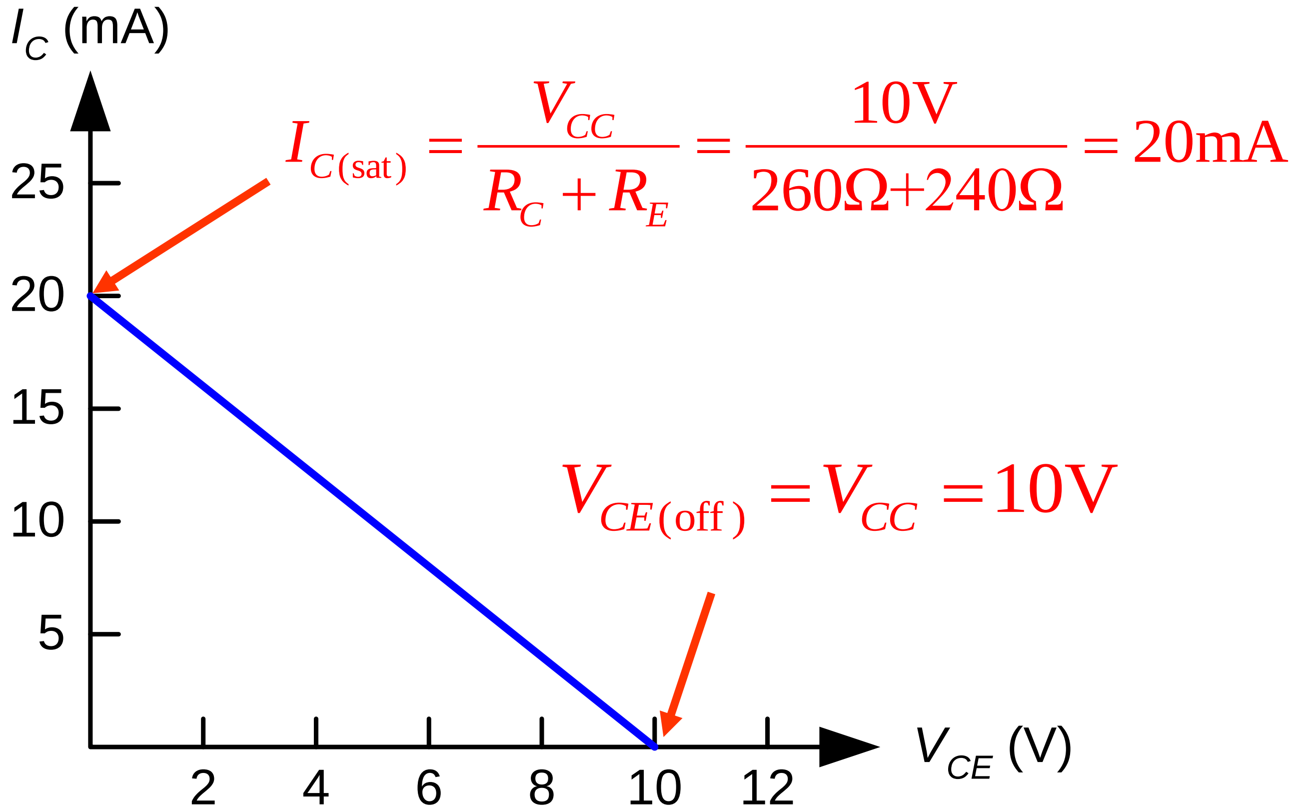
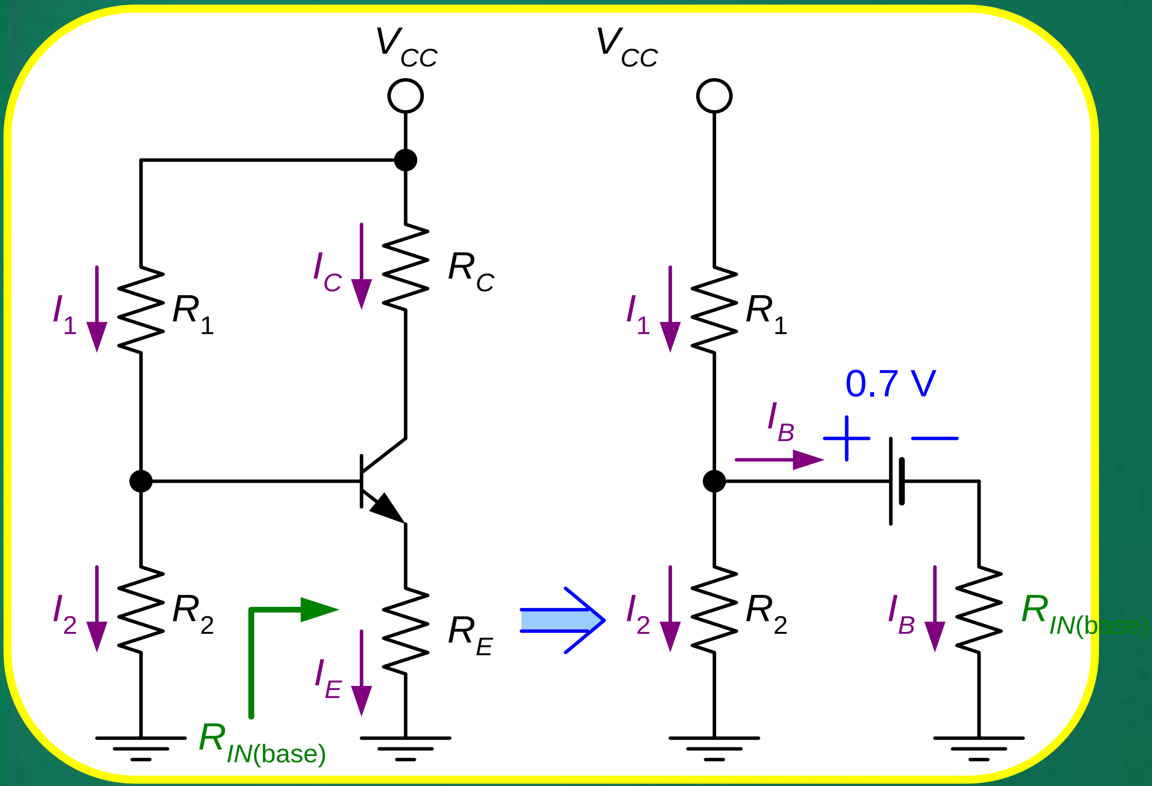
$$\text{At } h_{FE} = 300,\ I_B = \frac{I_E}{h_{FE}+1} = \frac{10\text{mA}}{301} \cong 33\mu\text{A and } I_{CQ} = I_E - I_B \cong 9.97\text{mA}$$

Load Line for Voltage Divider Bias

Circuit values are from previous example



Base Input Resistance



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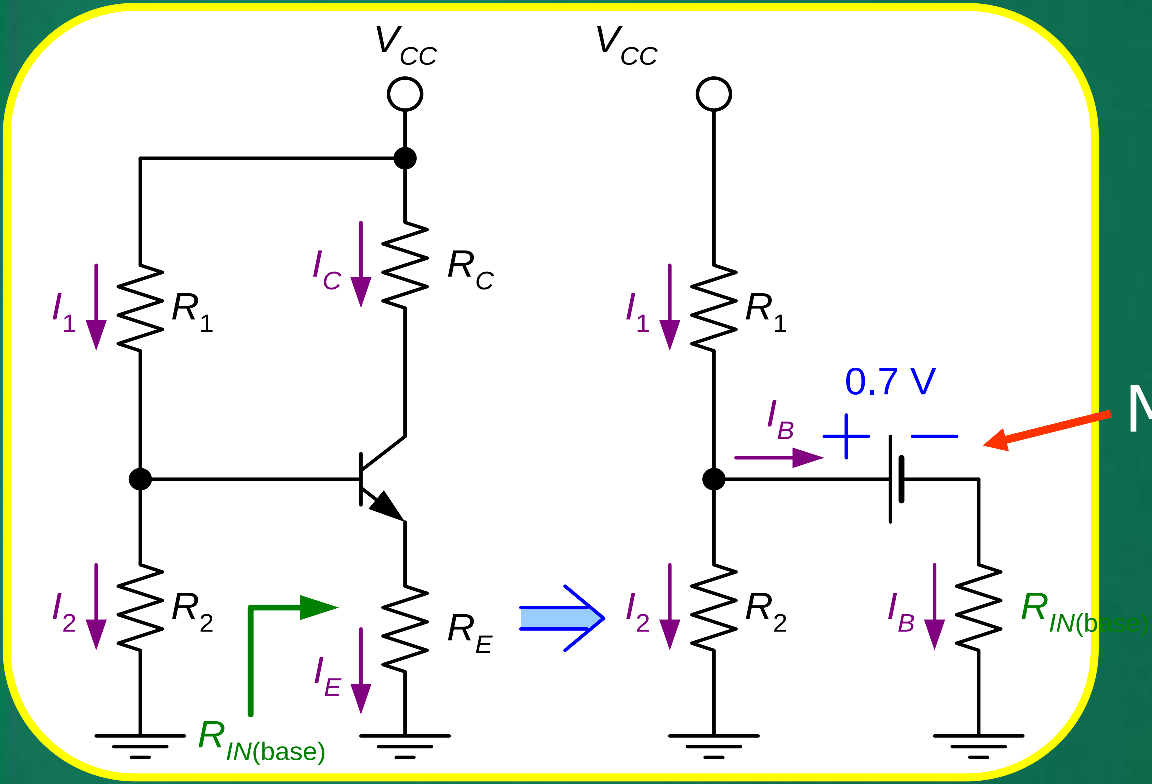
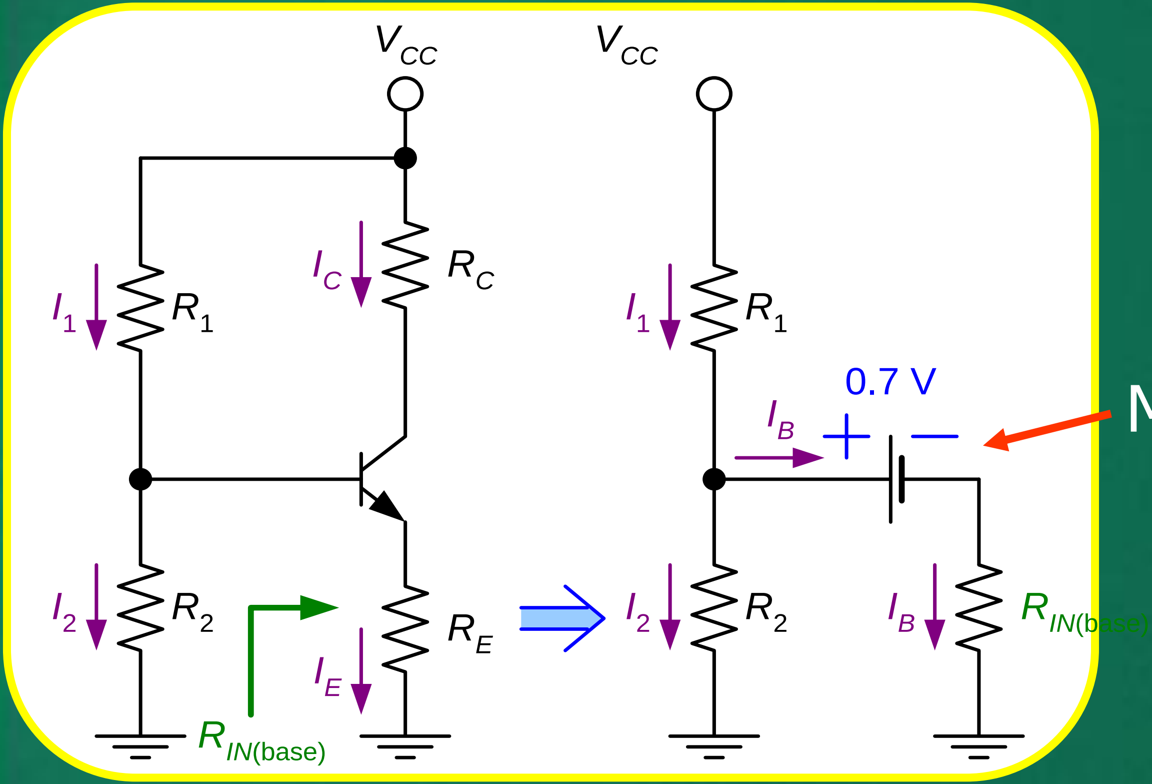


May be ignored.

Base Input Resistance



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$$V_E = I_E R_E = I_B (h_{FE} + 1) R_E$$

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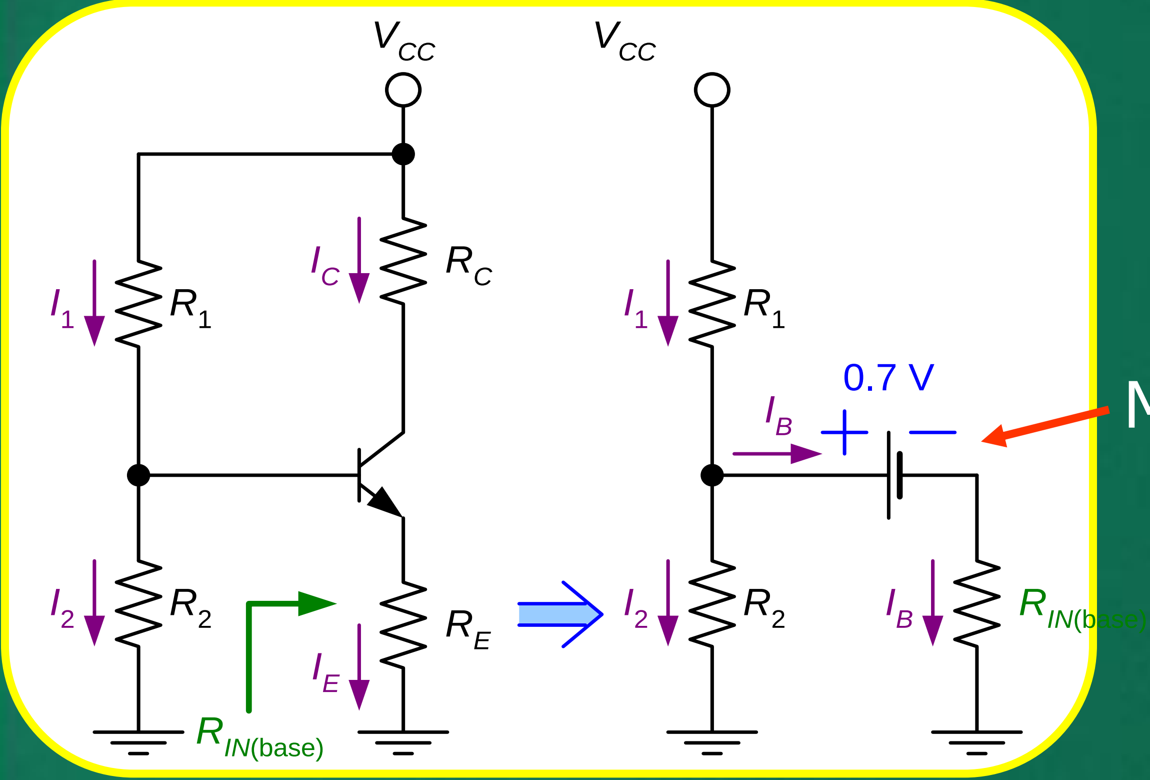

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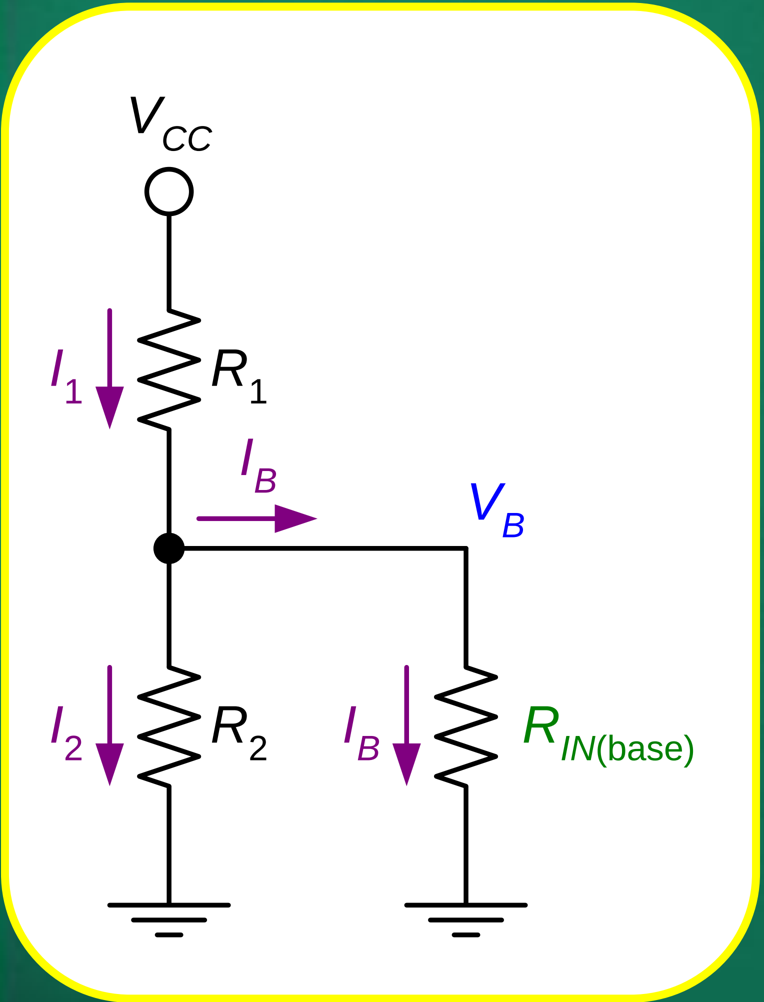
$$V_E = I_E R_E = I_B (h_{FE} + 1) R_E$$

$$R_{IN\,(\text{base})} = \frac{V_E}{I_B} = (h_{FE} + 1) R_E$$
$$\cong h_{FE} R_E$$

Base Input Resistance



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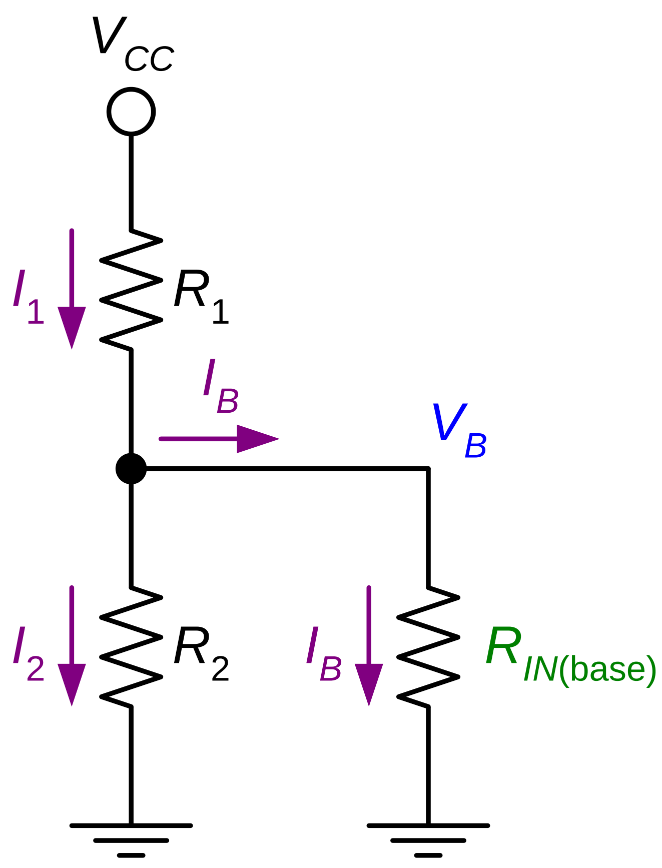
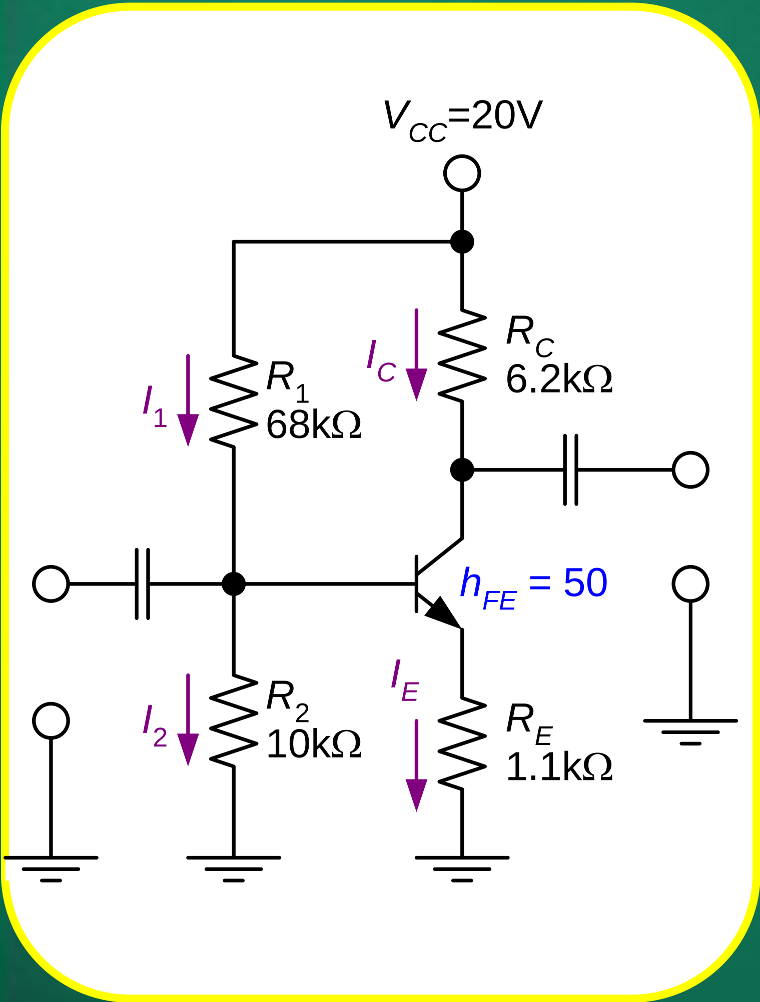


$$V_B = \frac{R_2 // R_{IN\,(\mathrm{base})}}{R_1 + R_2 // R_{IN\,(\mathrm{base})}} V_{CC}$$

$$= \frac{R_2 // \left(h_{FE} R_E\right)}{R_1 + R_2 // \left(h_{FE} R_E\right)} V_{CC}$$

$$= \frac{R_{EQ}}{R_1 + R_{EQ}} V_{CC} \quad \Bigg| \quad R_{EQ} = R_2 // \left(h_{FE} R_E\right)$$

Base Input Resistance



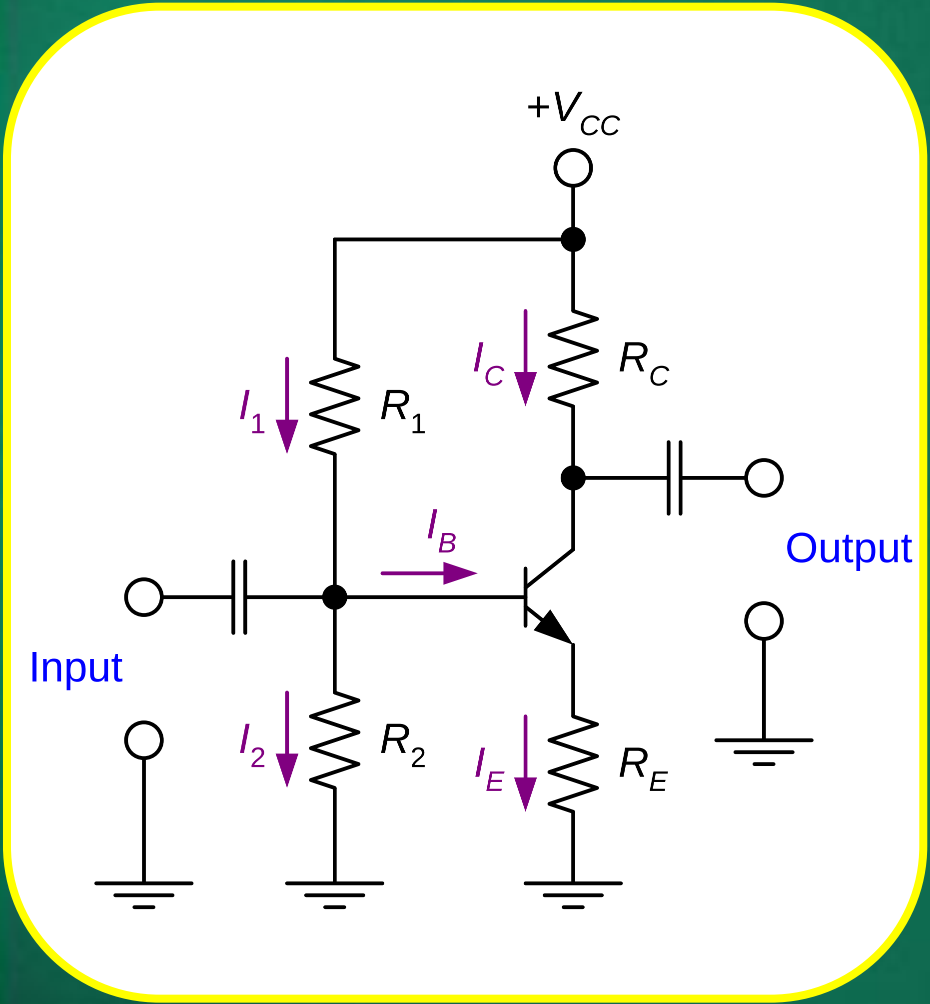
$$R_{EQ} = R_2 // \left(h_{FE} R_E\right)$$
$$= 10\text{k}\Omega // \left(50 \times 1.1\text{k}\Omega\right) = 8.46\text{k}\Omega$$

$$V_B \cong V_{CC} \frac{R_{EQ}}{R_1 + R_{EQ}}$$
$$= \left(20\text{V}\right) \frac{8.46\text{k}\Omega}{68\text{k}\Omega + 8.46\text{k}\Omega} = 2.21\text{V}$$

$$I_{CQ} \cong I_E = \frac{V_E}{R_E} = \frac{V_B - 0.7\text{V}}{R_E}$$
$$= \frac{2.21\text{V} - 0.7\text{V}}{1.1\text{k}\Omega} = 1.37\text{mA}$$

$$V_{CEQ} = V_{CC} - I_{CQ}\left(R_C + R_E\right)$$
$$= 20\text{V} - \left(1.37\text{mA}\right)\left(7.3\text{k}\Omega\right) = 9.99\text{V}$$

Voltage Divider Bias Characteristics



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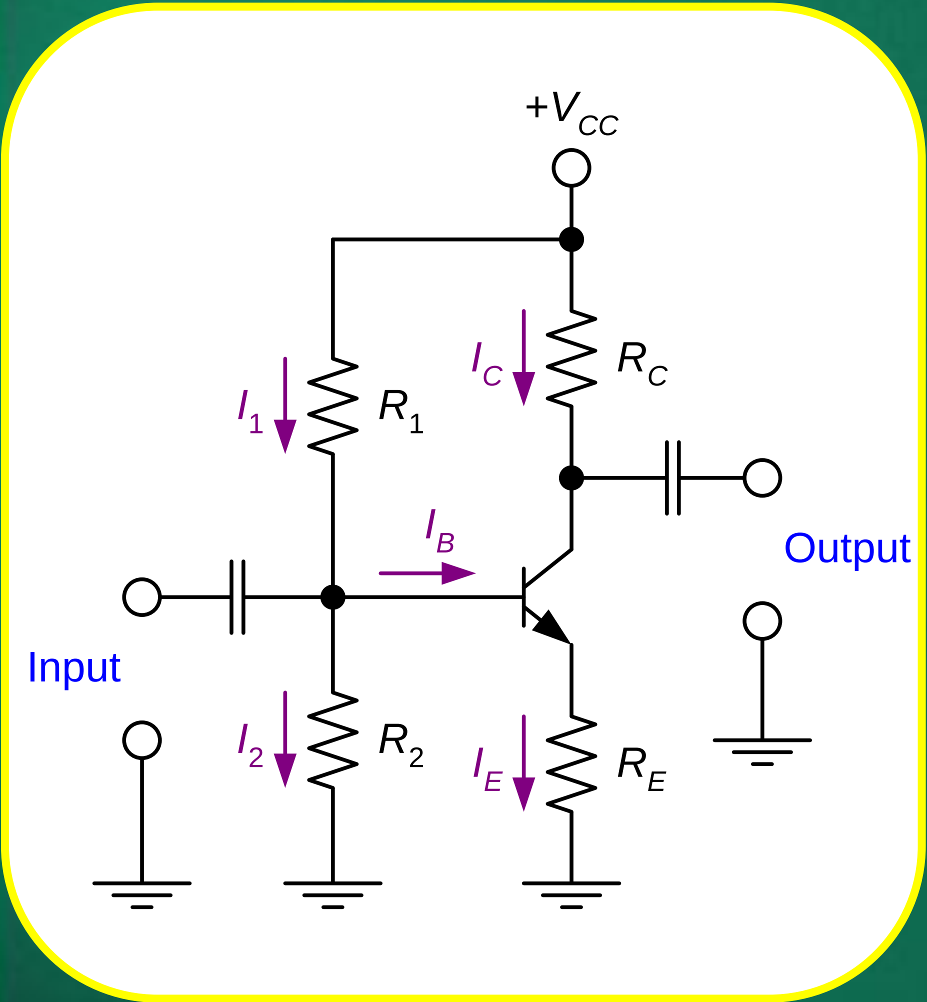

Circuit recognition: The voltage divider in the base circuit.

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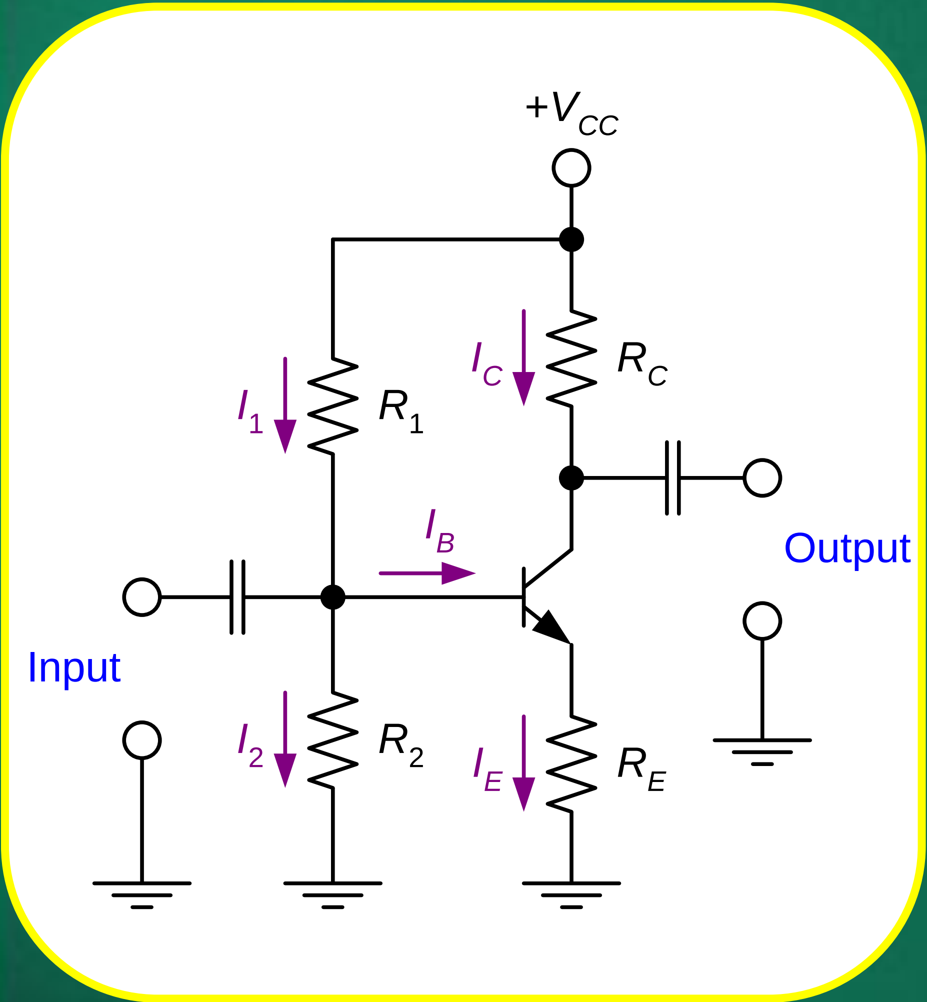


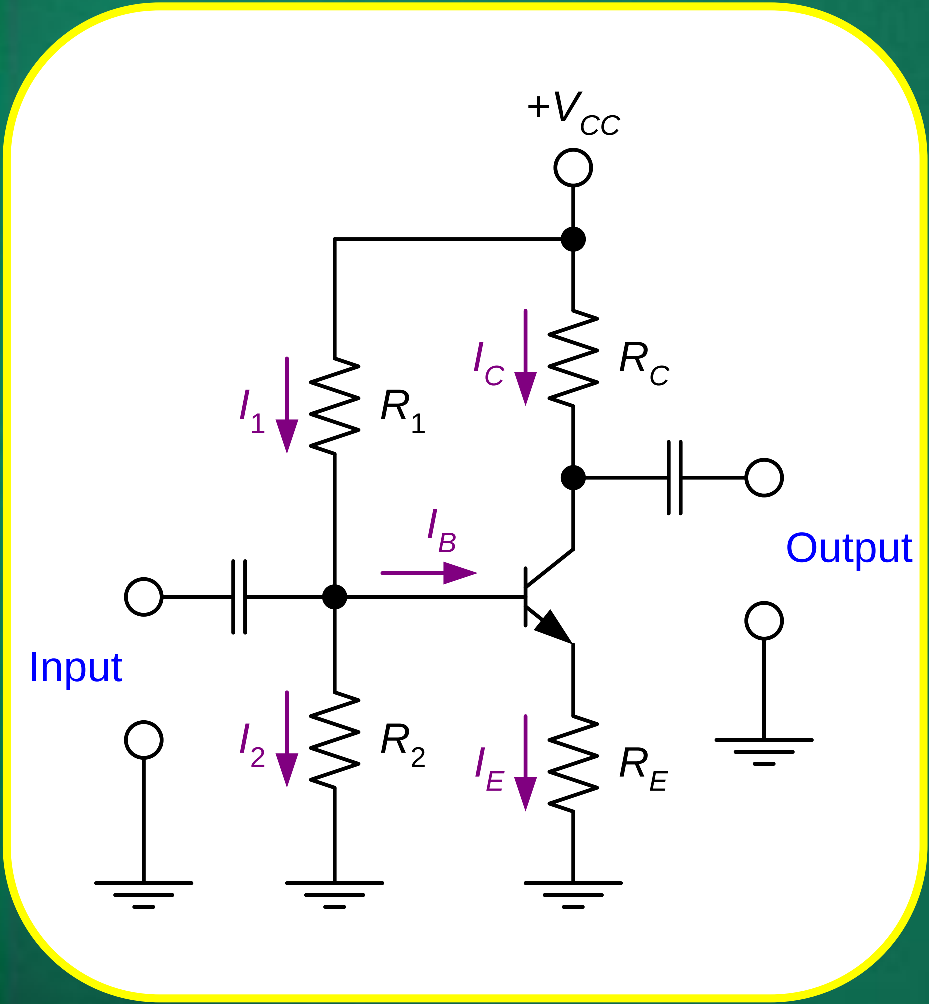
Circuit recognition: The voltage divider in the base circuit.

Advantages: The circuit Q-point values are stable against changes in h_{FE}.

Disadvantages: Requires more components than most other biasing circuits.

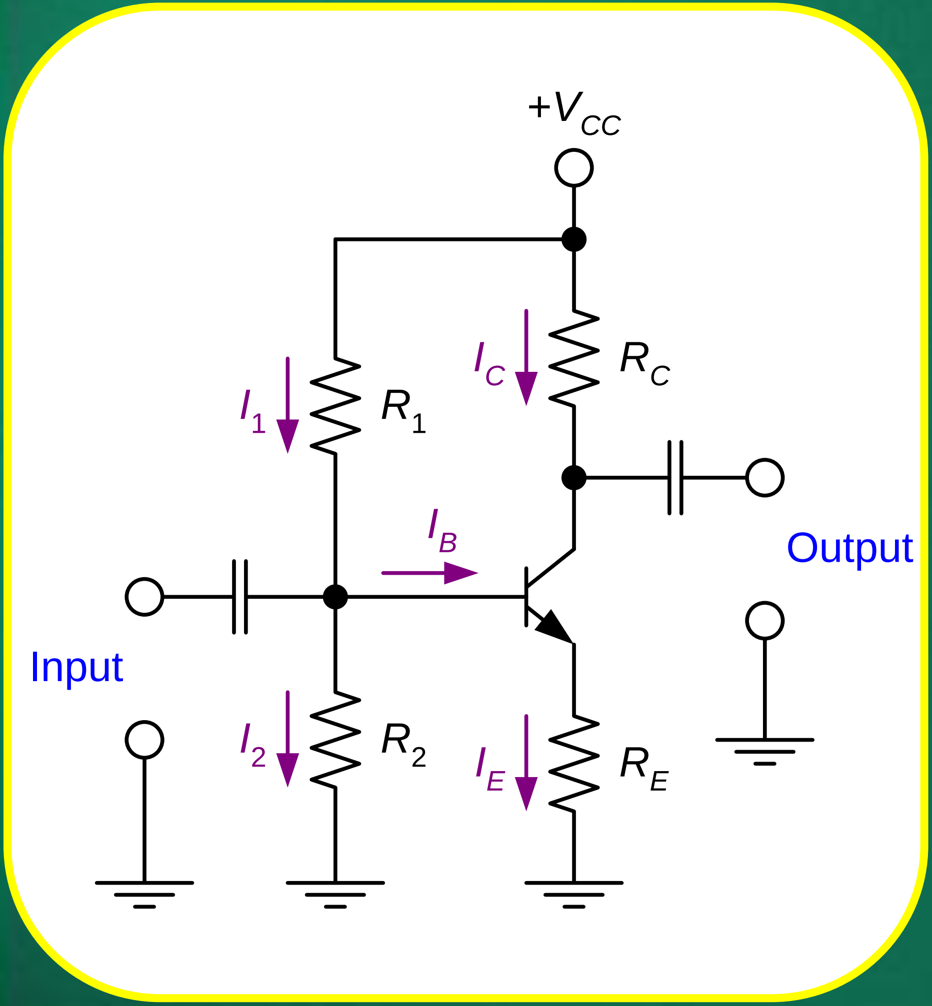
Applications: Used primarily to bias linear amplifier.

Voltage Divider Bias Characteristics



Load line equations:

Voltage Divider Bias Characteristics



Load line equations:

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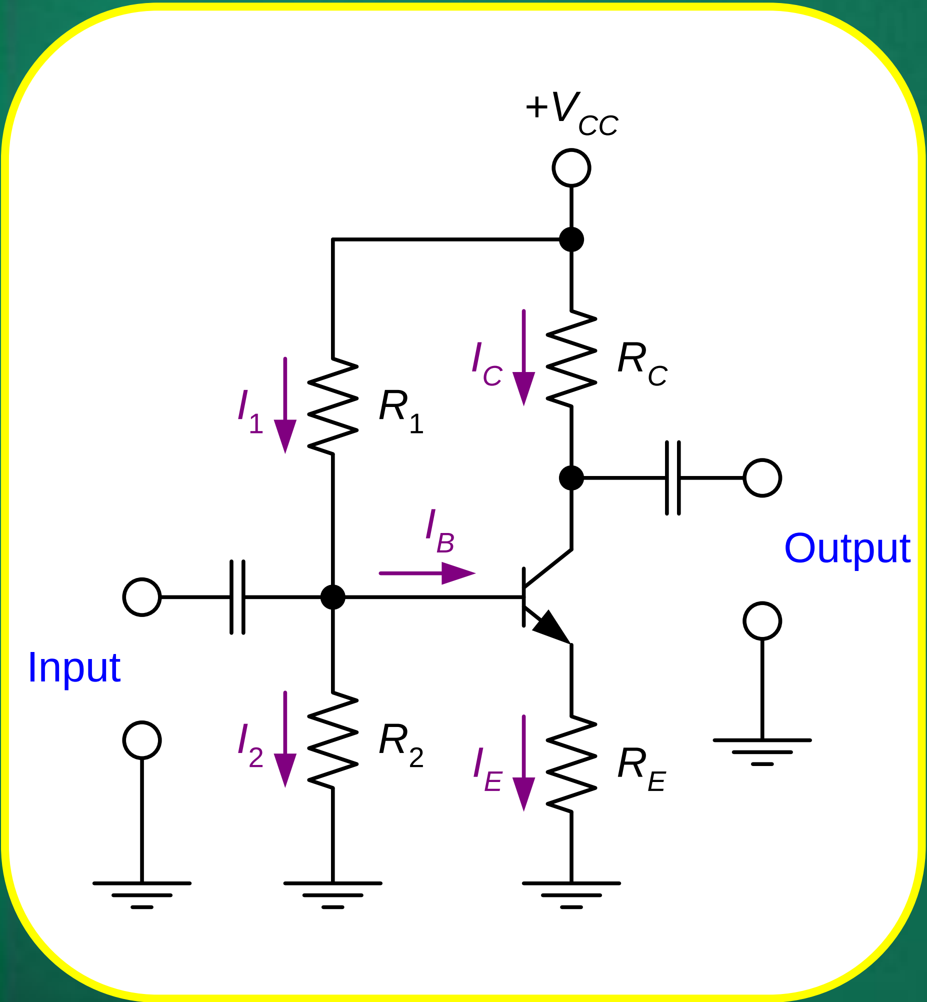
Voltage Divider Bias Characteristics



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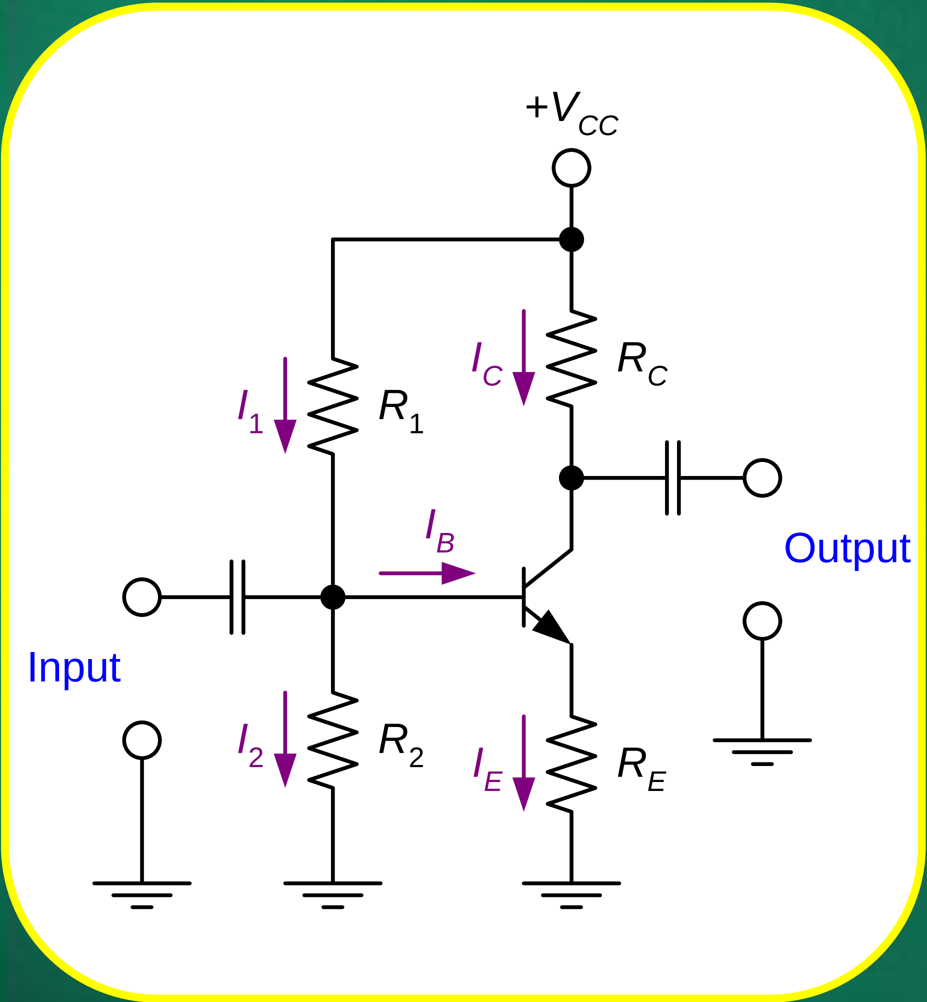

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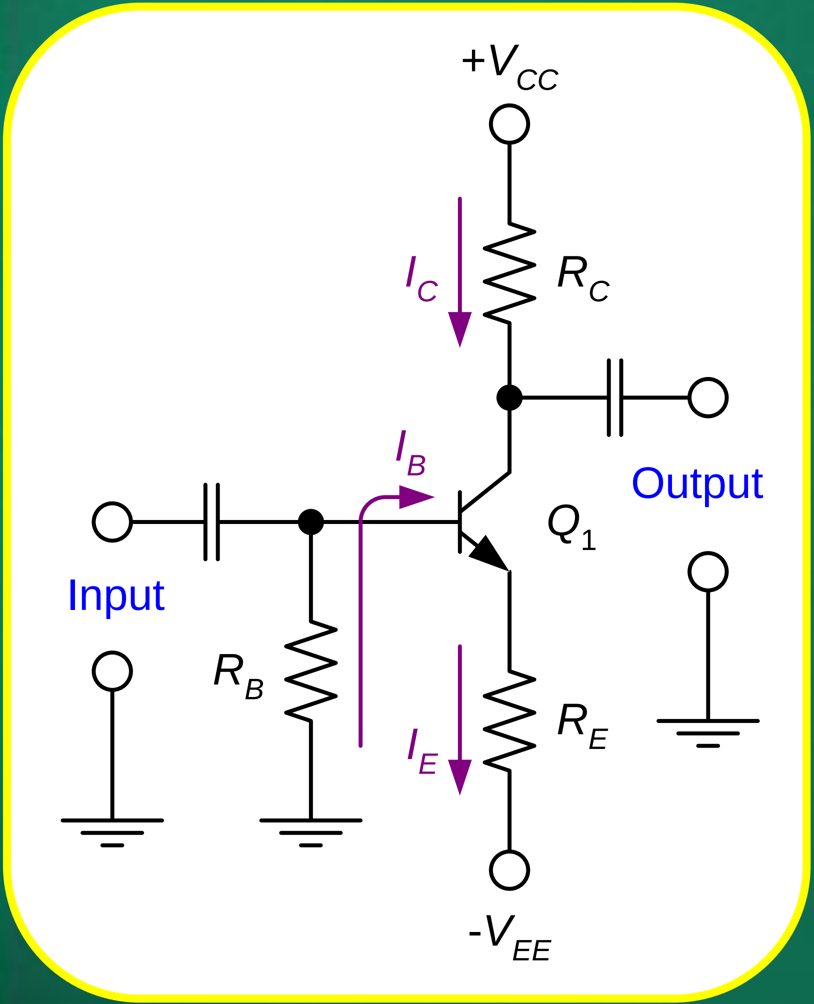
Other Transistor Biasing Circuits

- Emitter Bias Circuits
- Feedback Bias Circuits
  - Collector Feedback Bias
  - Emitter Feedback Bias

Emitter Bias



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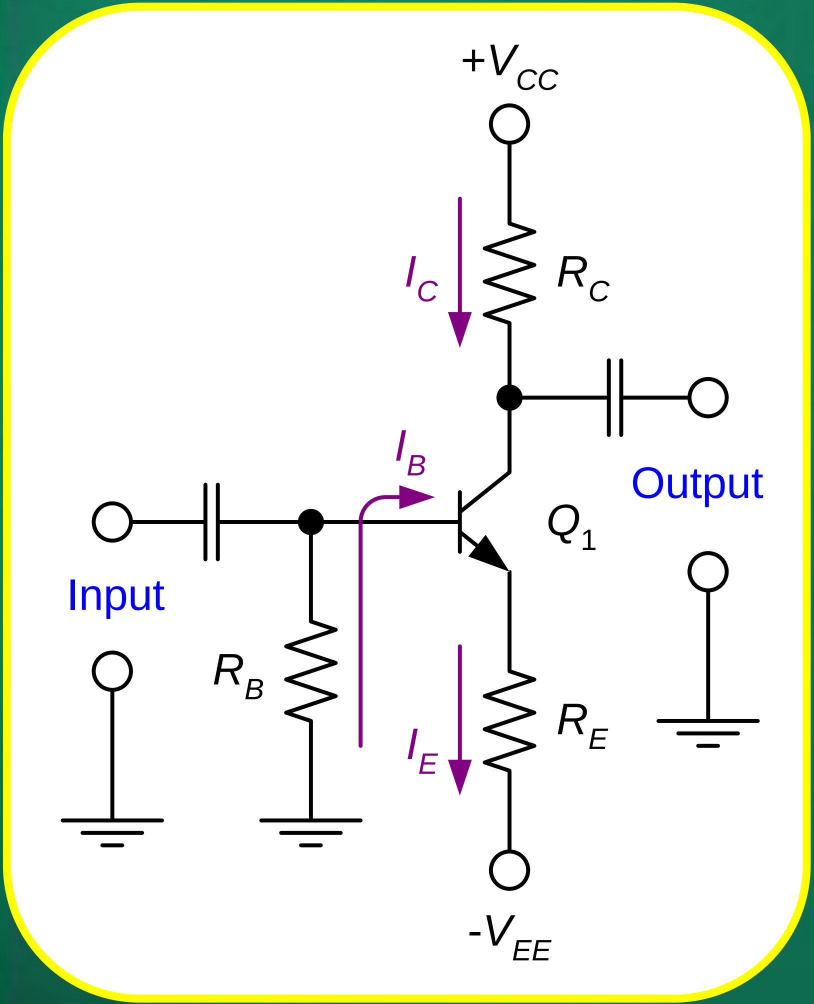
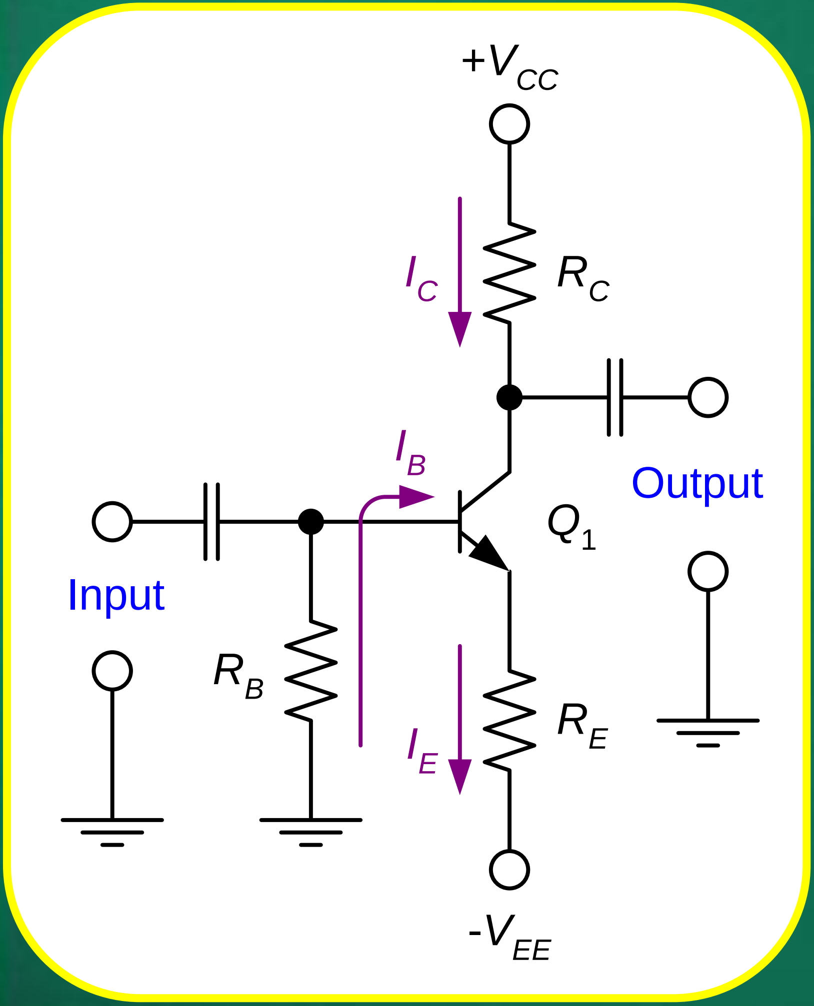


Assume that the transistor operation is in active region.

Emitter Bias



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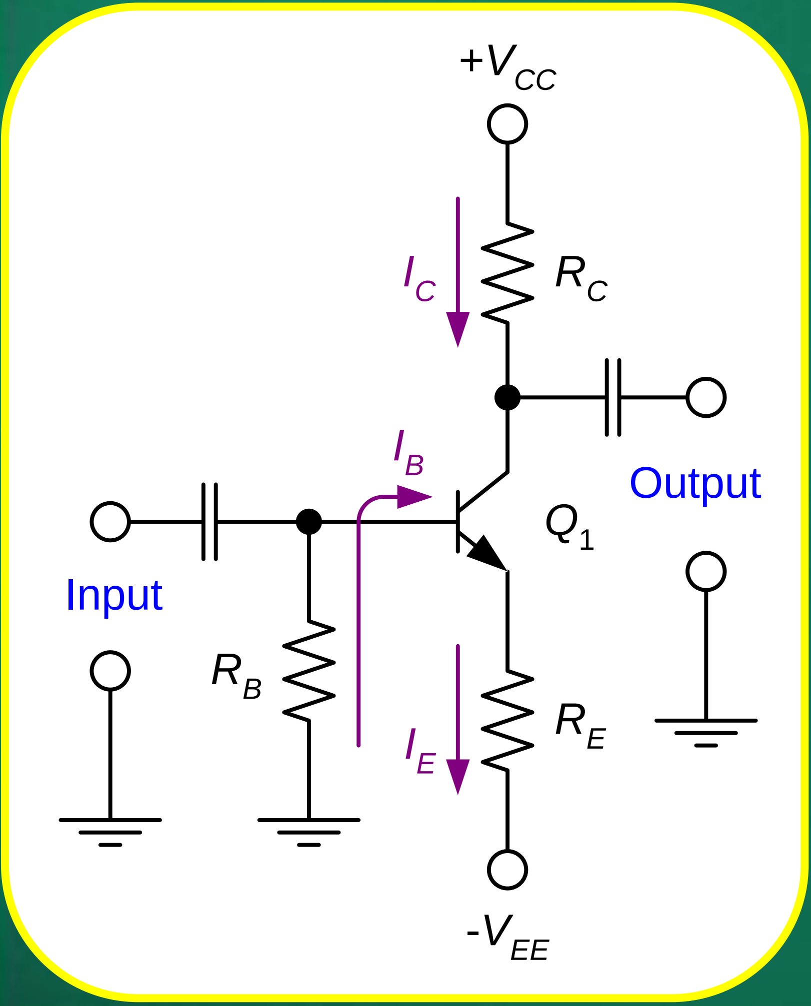

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$$I_B = \frac{V_{EE} - 0.7\text{V}}{R_B + (h_{FE} + 1) R_E}$$

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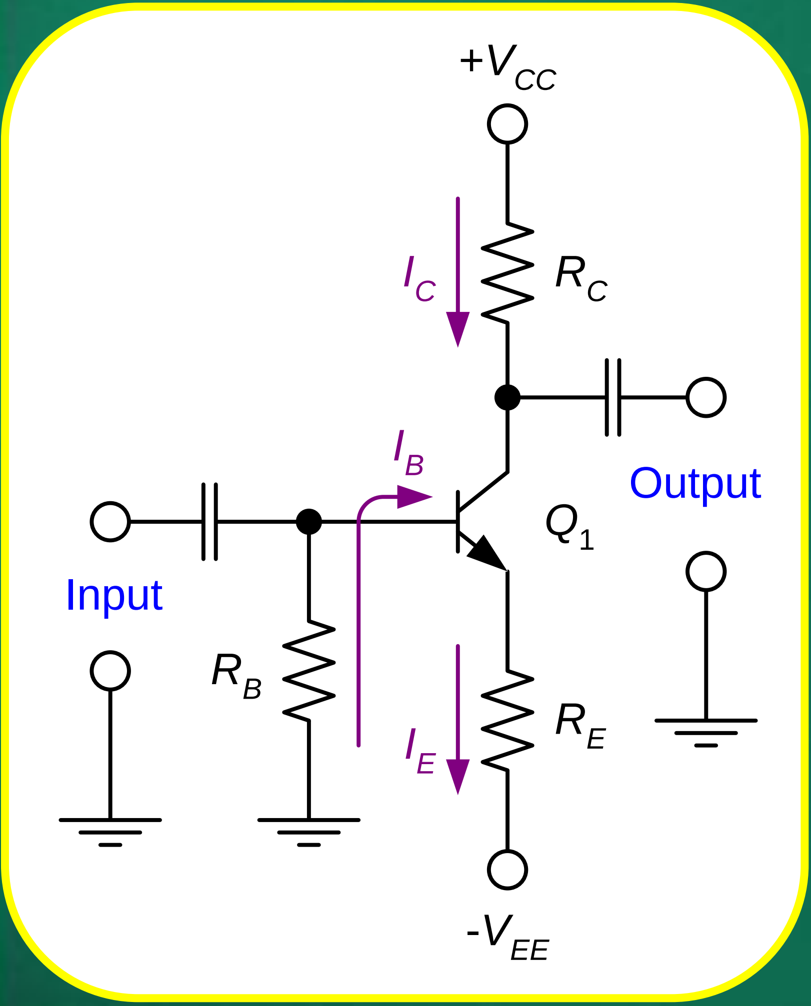

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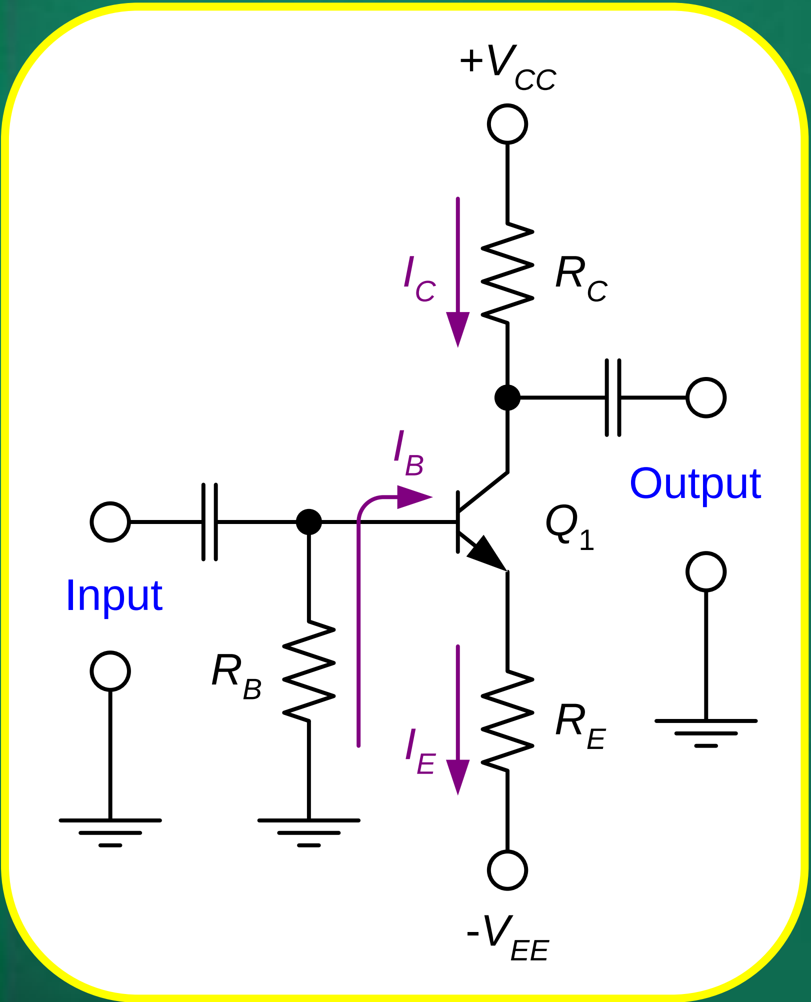

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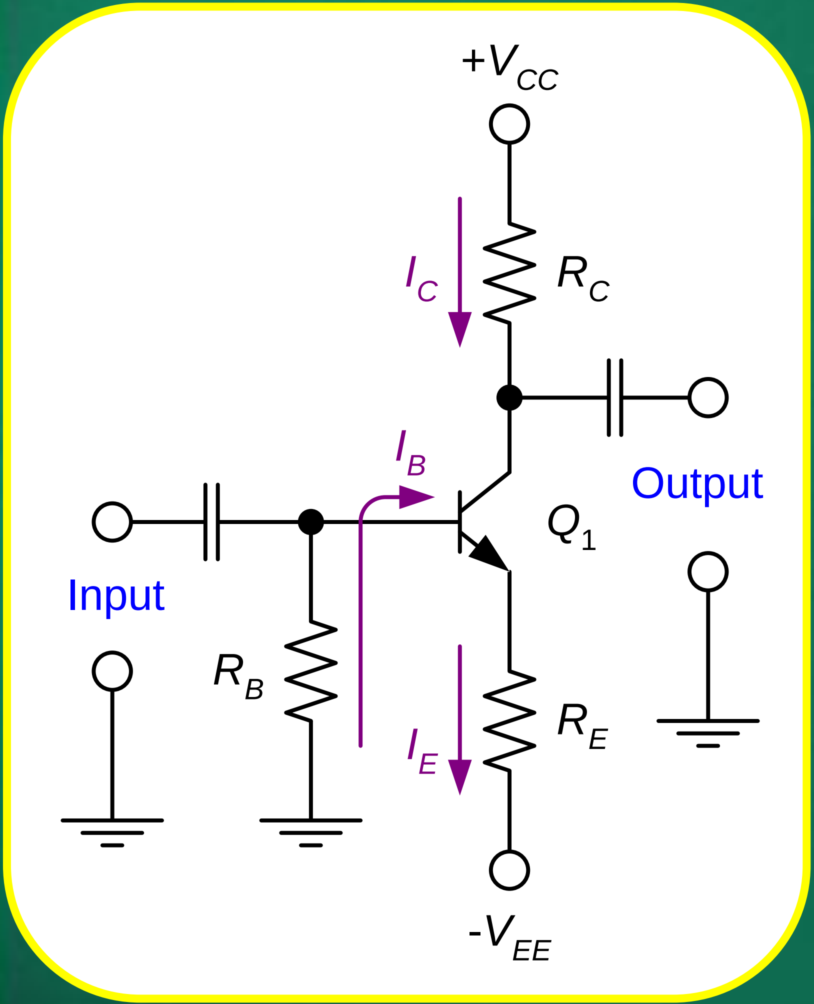

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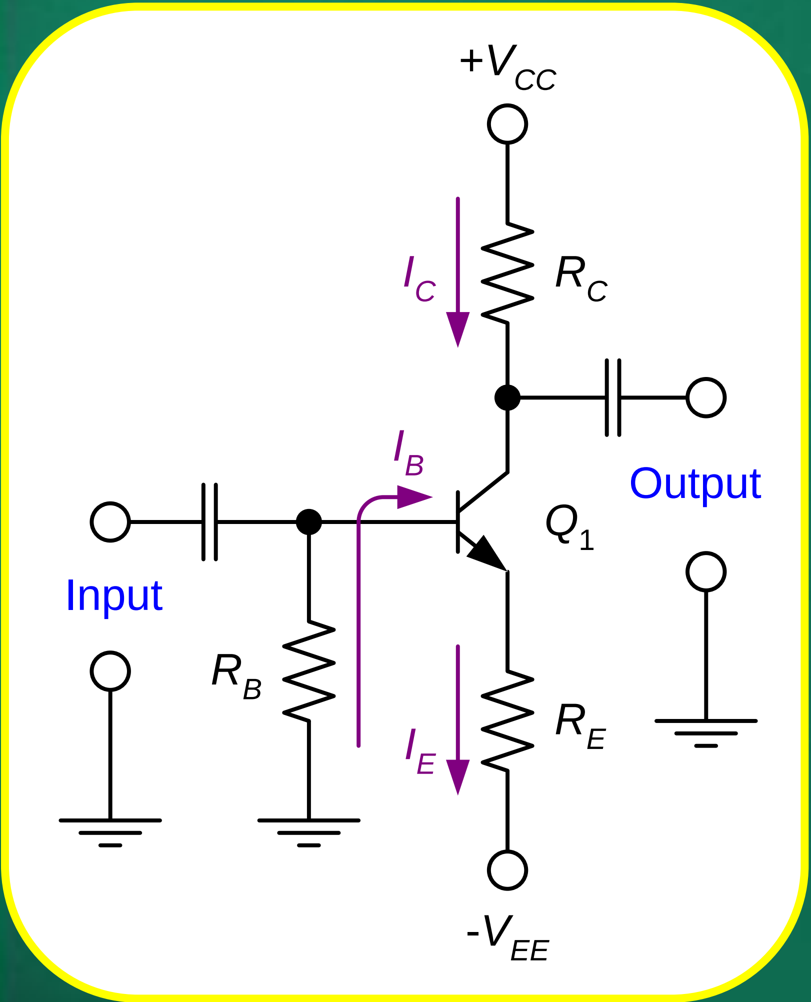

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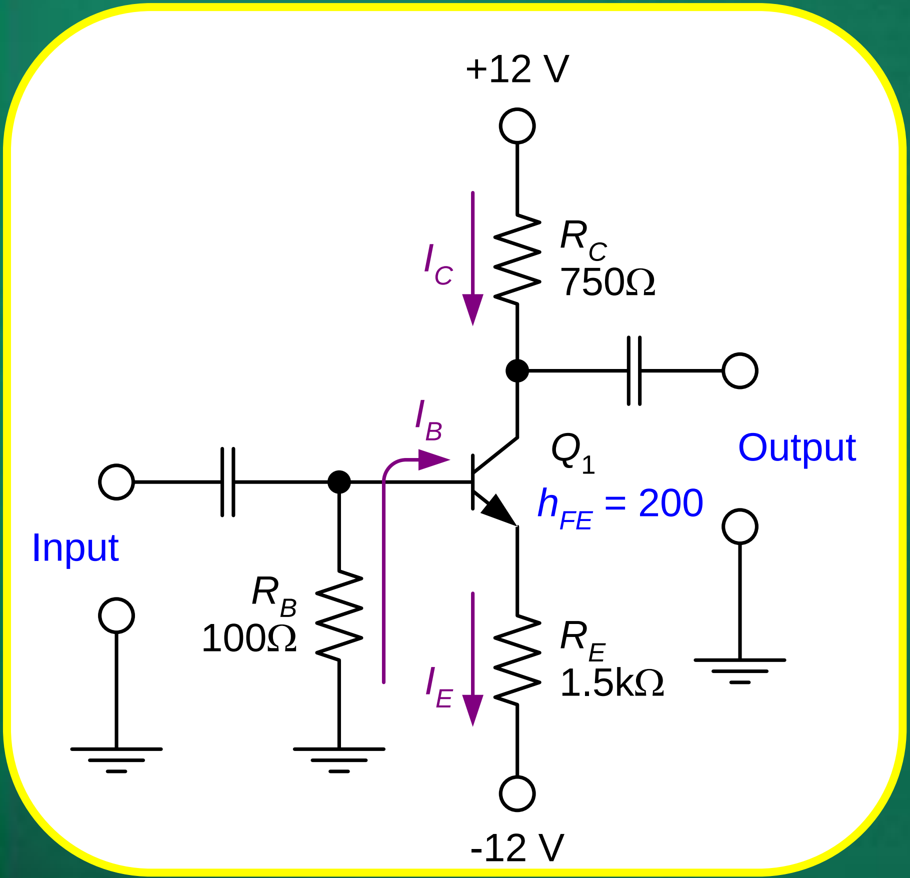
Emitter Bias

Determine the values of I_{CQ} and V_{CEQ} for the amplifier circuit.



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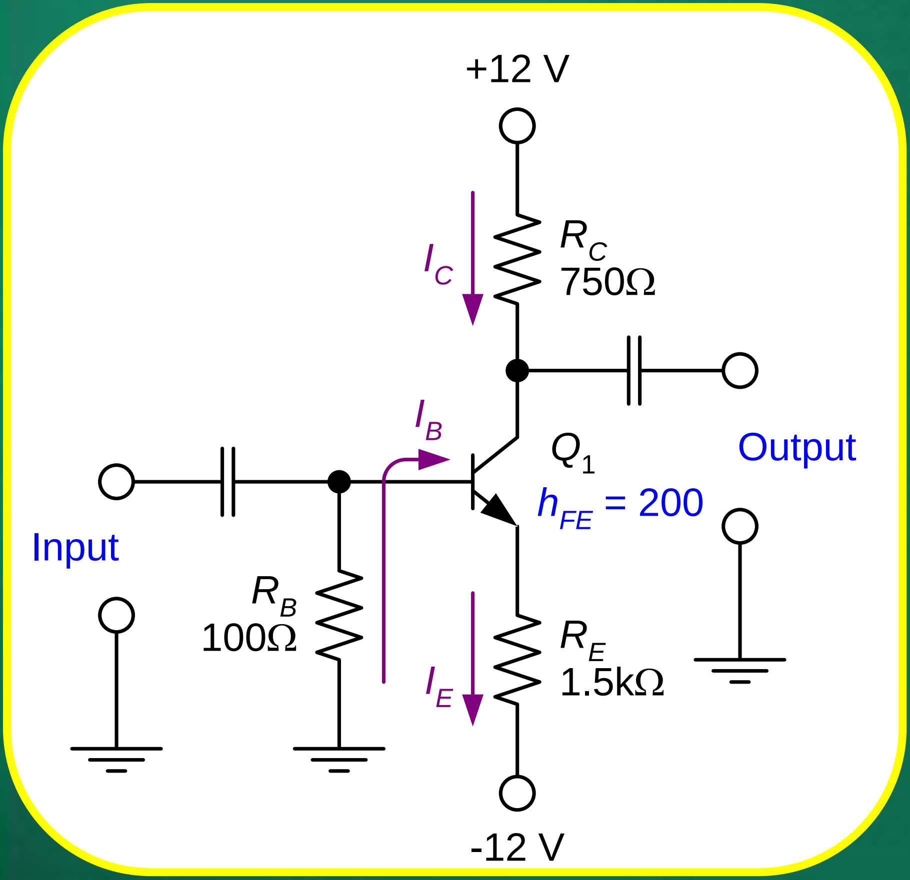
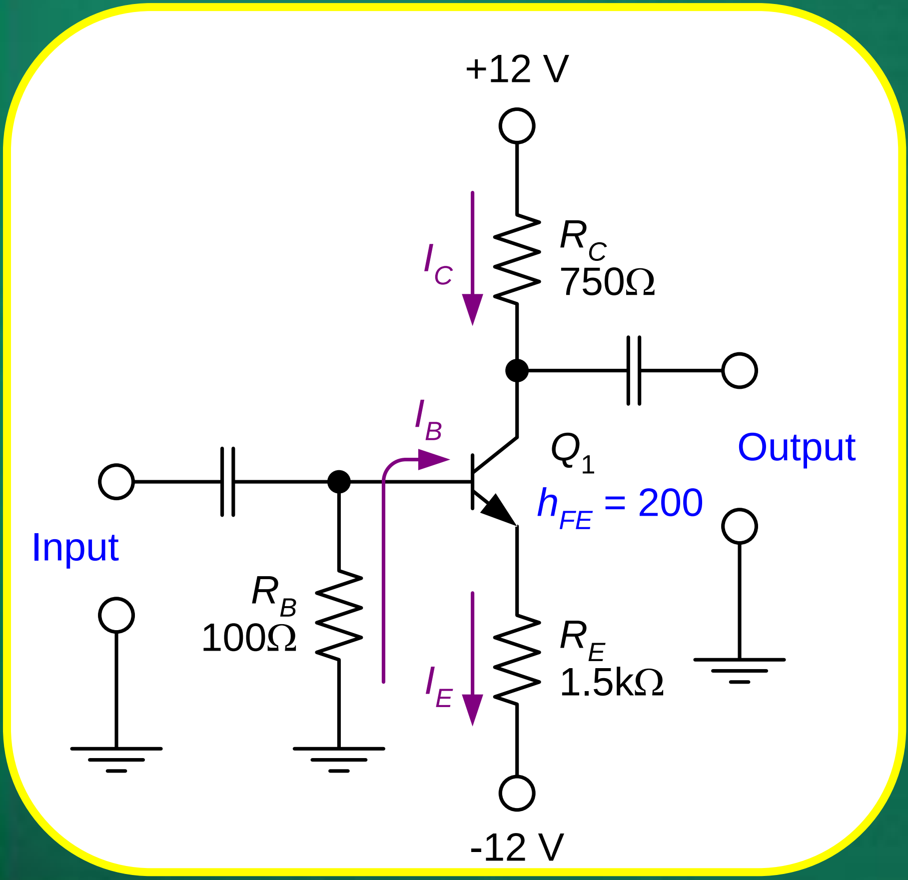


$$I_B = \frac{12\text{V} - 0.7\text{V}}{R_B + (h_{FE} + 1)R_E}$$

$$= \frac{11.3\text{V}}{100\Omega + 201 \times 1.5\text{k}\Omega} = 37.47\mu\text{A}$$

Emitter Bias

Determine the values of I_{CQ} and V_{CEQ} for the amplifier circuit.



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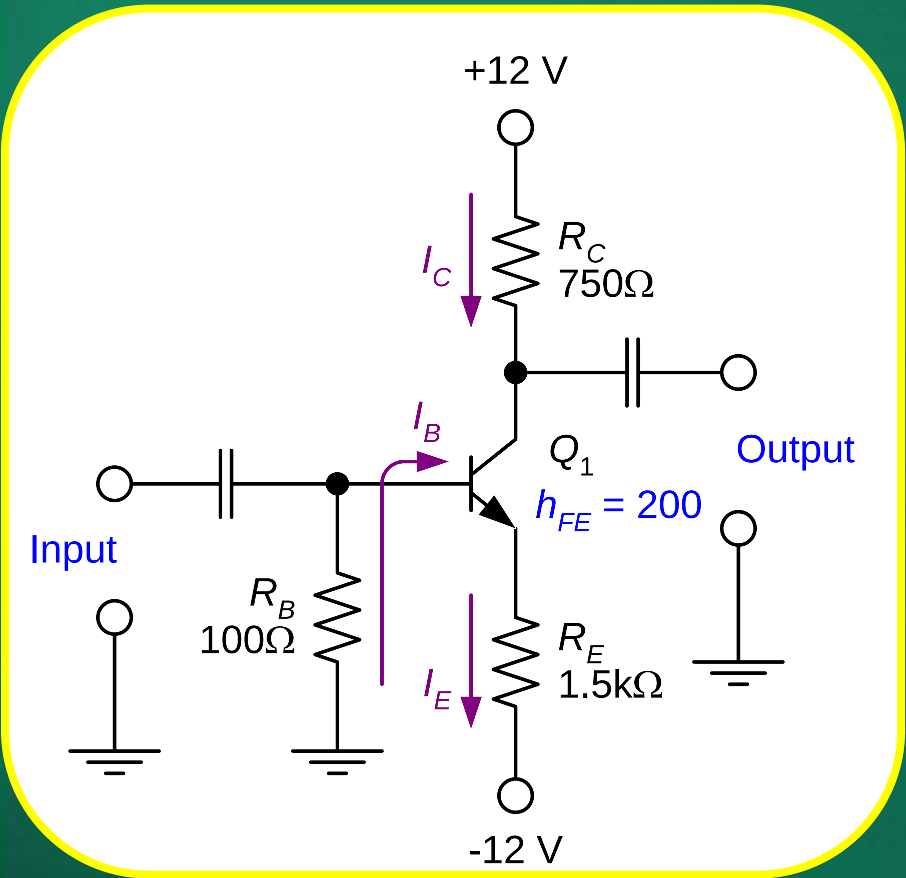
$$I_{CQ} = h_{FE} I_B = 200 \times 37.47\mu\text{A} = 7.49\text{mA}$$

Emitter Bias

Determine the values of I_{CQ} and V_{CEQ} for the amplifier circuit.



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$$I_{CQ} = h_{FE} I_B = 200 \times 37.47\mu\text{A}$$

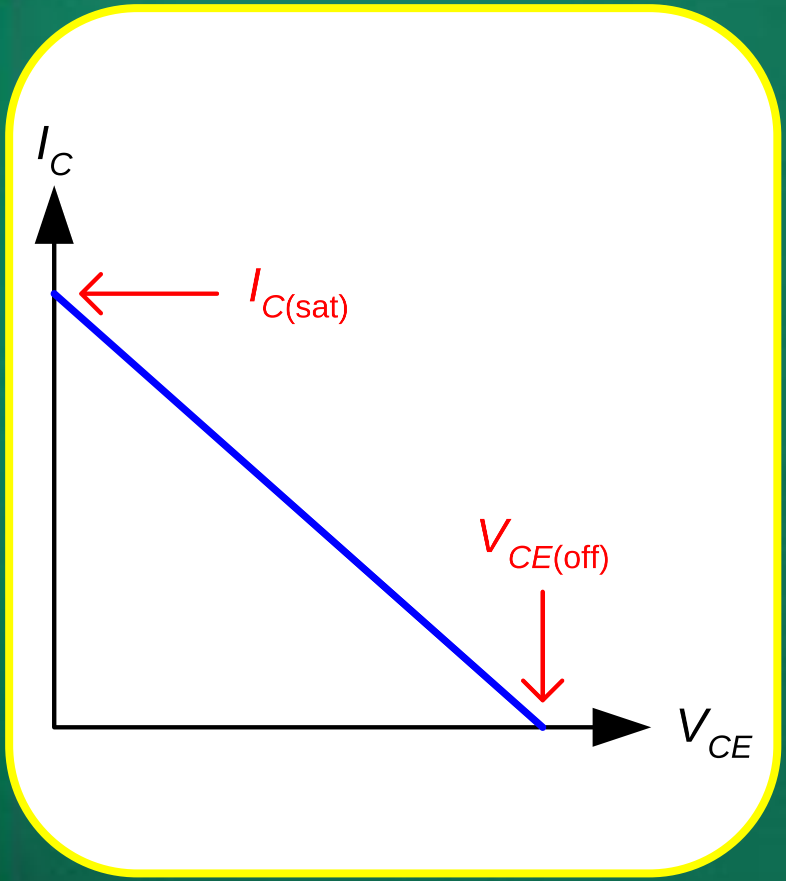
$$= 7.49\text{mA}$$

$$V_{CEQ} \cong V_{CC} - I_C\left(R_C + R_E\right) - (-V_{EE})$$

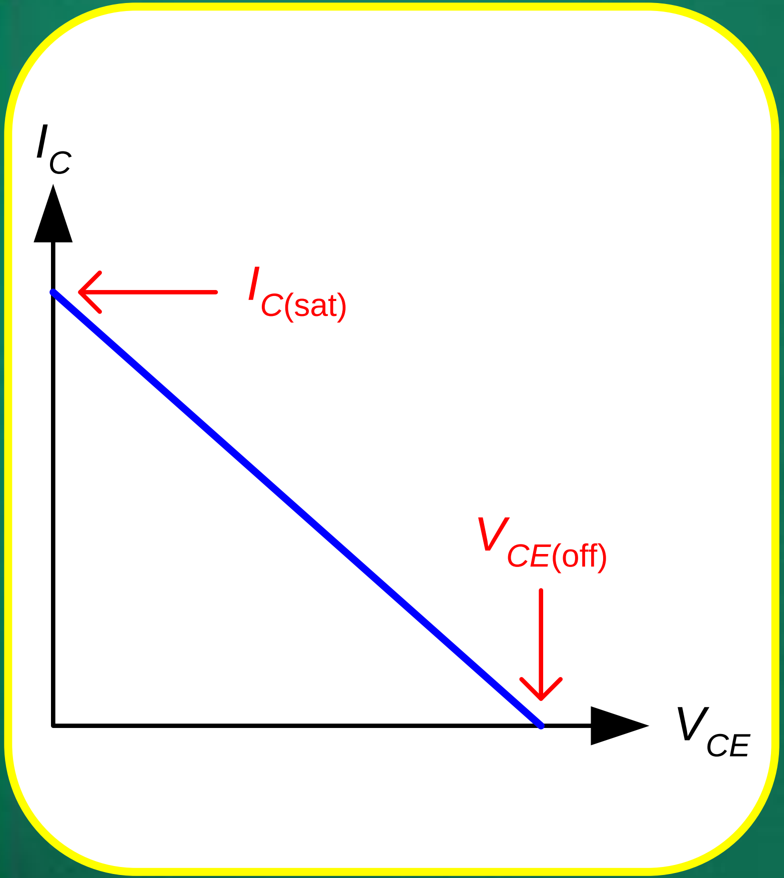
$$= 24\text{V} - 7.49\text{mA}\left(750\Omega + 1.5\text{k}\Omega\right)$$

$$= 7.14\text{V}$$

Load Line for Emitter Bias Circuit

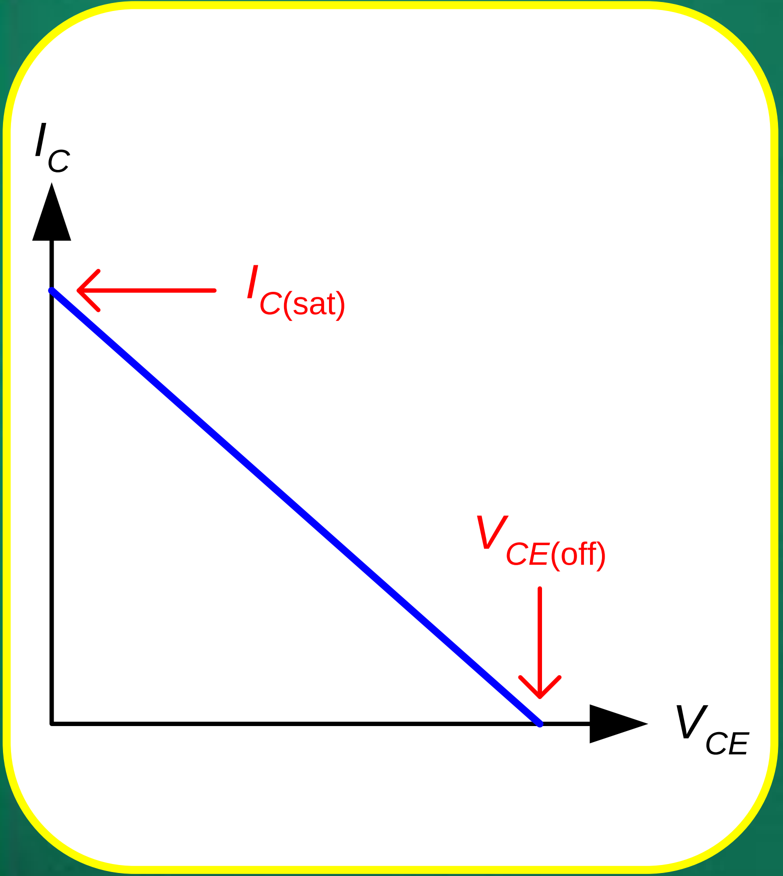


Load Line for Emitter Bias Circuit



$$I_{C(sat)} = \frac{V_{CC} - (-V_{EE})}{R_C + R_E} = \frac{V_{CC} + V_{EE}}{R_C + R_E}$$

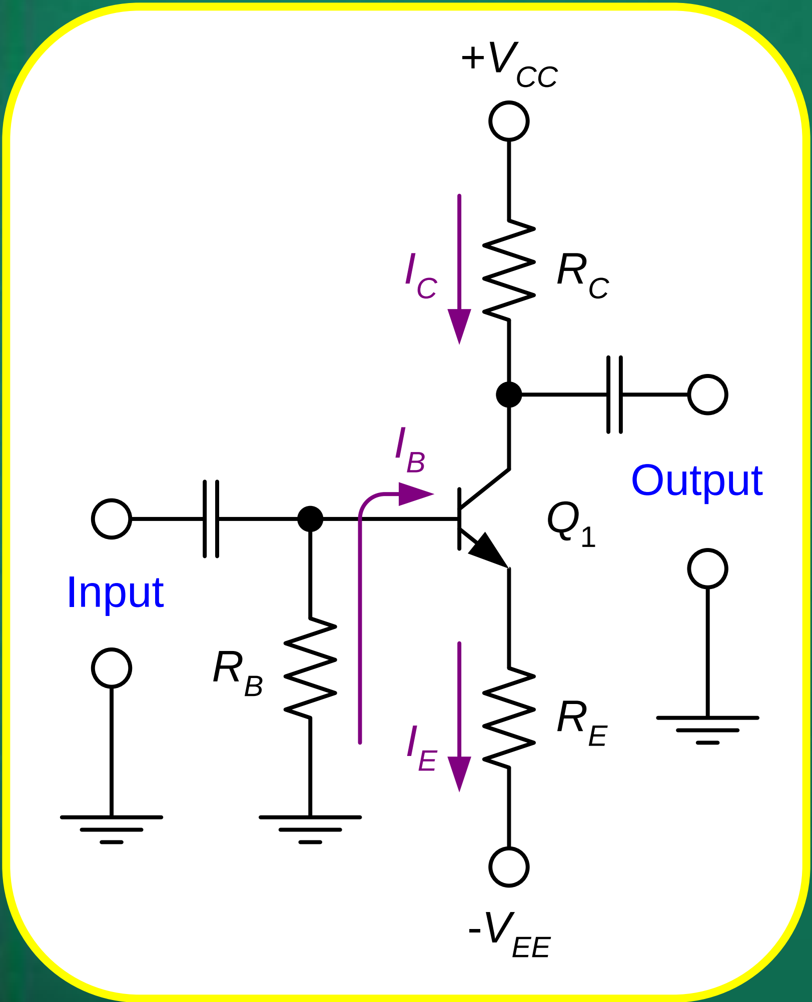
Load Line for Emitter Bias Circuit



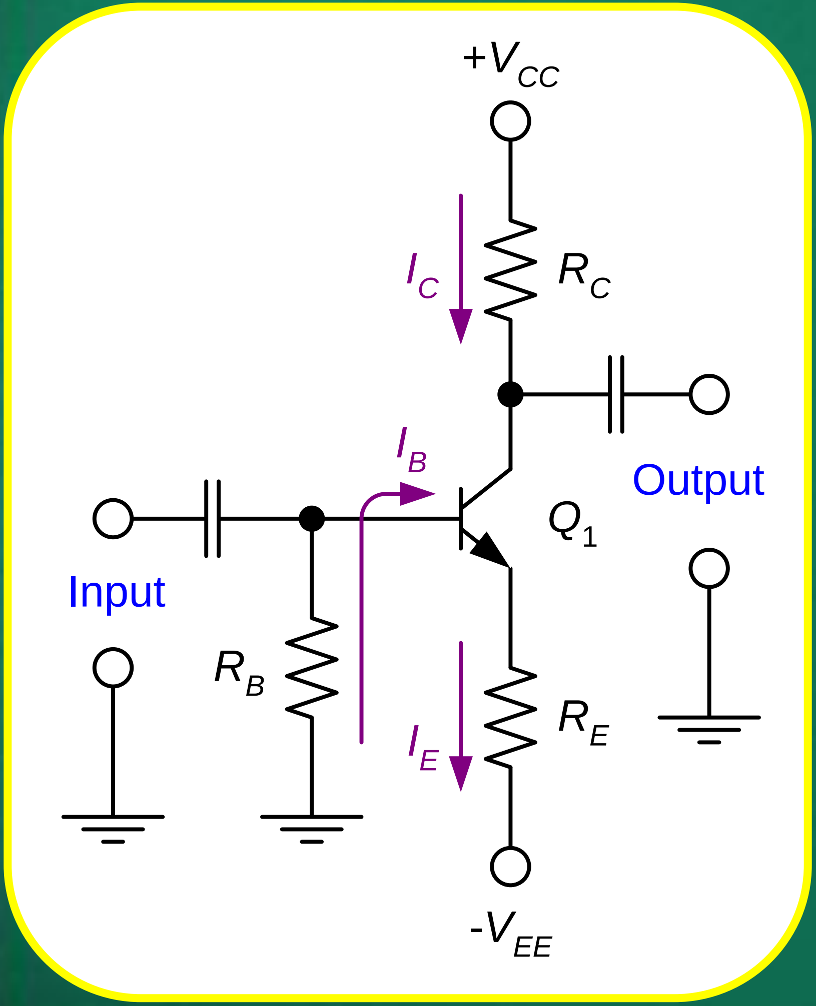
$$I_{C(sat)} = \frac{V_{CC} - (-V_{EE})}{R_C + R_E} = \frac{V_{CC} + V_{EE}}{R_C + R_E}$$

$$V_{CE(off)} = V_{CC} - \left(-V_{EE}\right) = V_{CC} + V_{EE}$$

Emitter Bias Characteristics

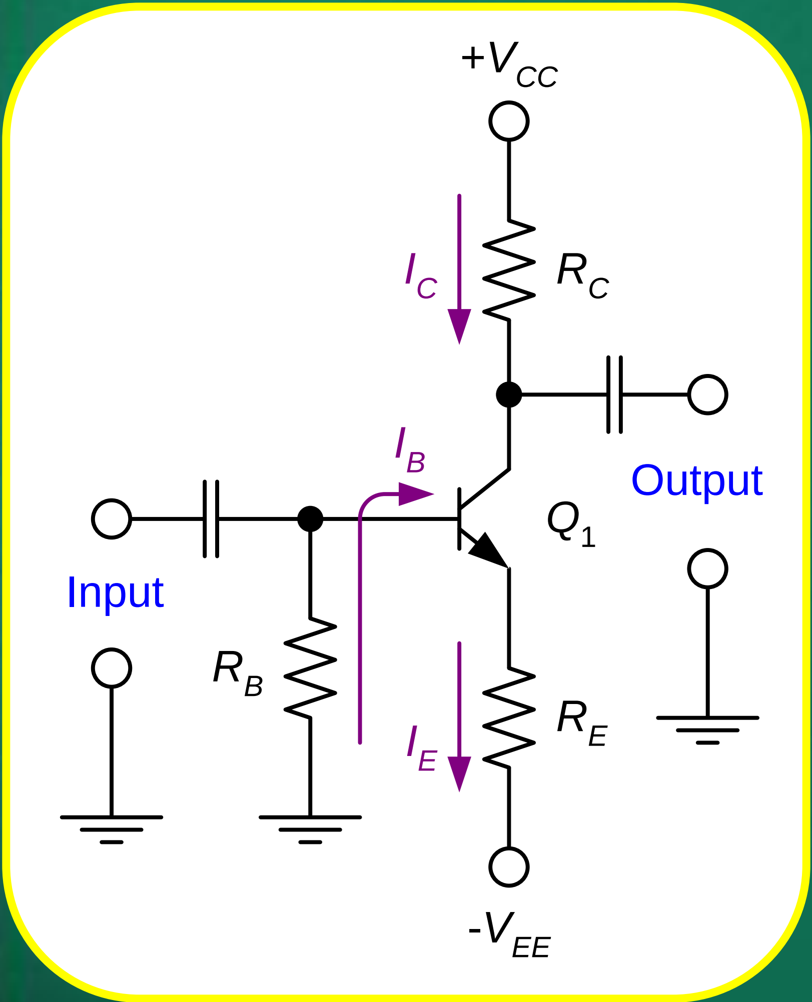


Emitter Bias Characteristics



Circuit recognition: A split (dual-polairty) power supply and the base resistor is connected to ground.

Emitter Bias Characteristics



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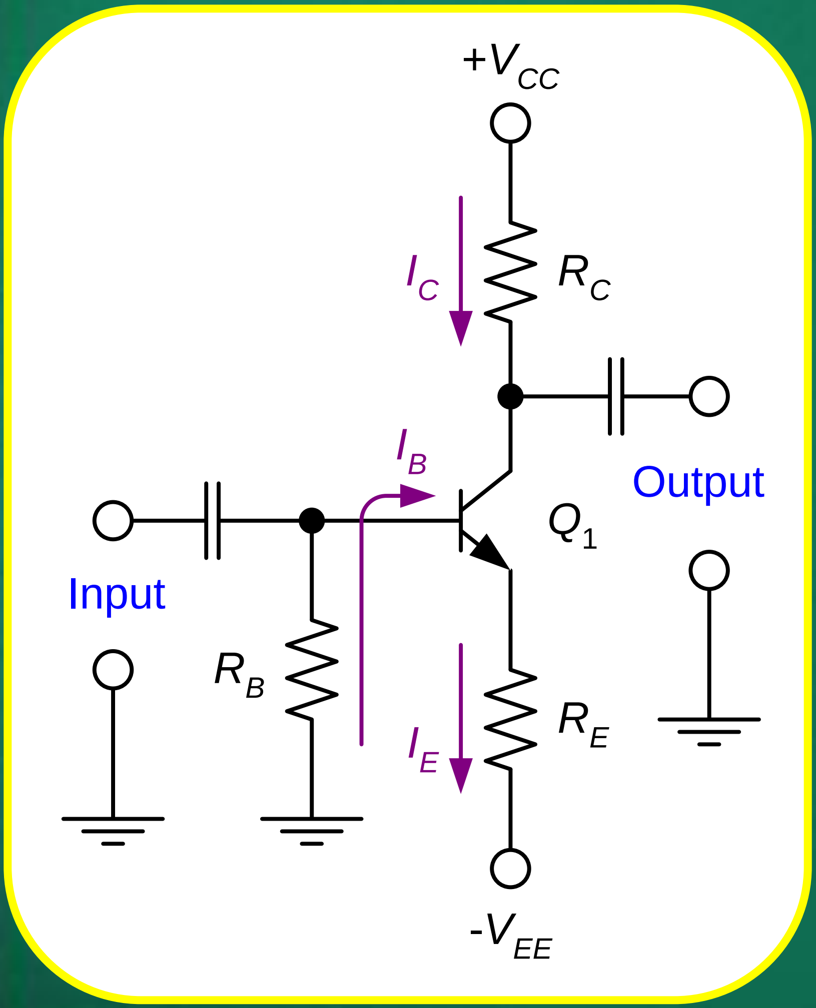
Advantage: The circuit Q-point values are stable against changes in h_{FE}.

Disadvantage: Requires the use of dual-polarity power supply.

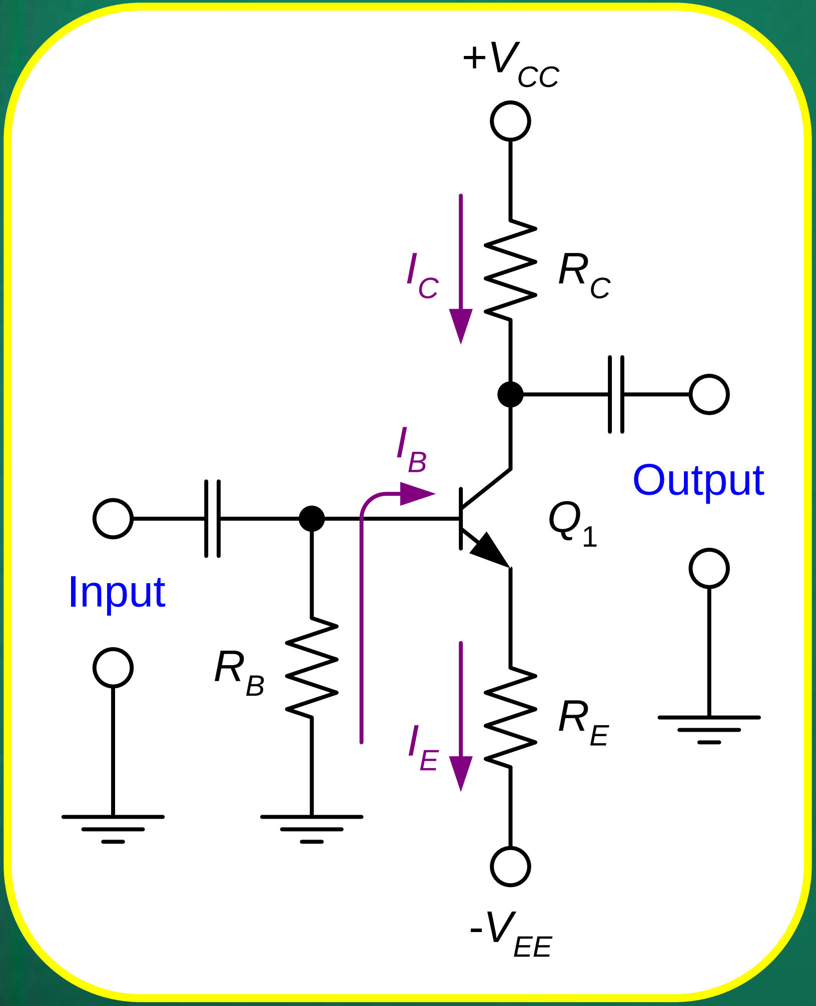
Applications: Used primarily to bias linear amplifiers.

Emitter Bias Characteristics



Load line equations:

Emitter Bias Characteristics



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$$I_{C(\text{sat})} = \frac{V_{CC} + V_{EE}}{R_C + R_E}$$

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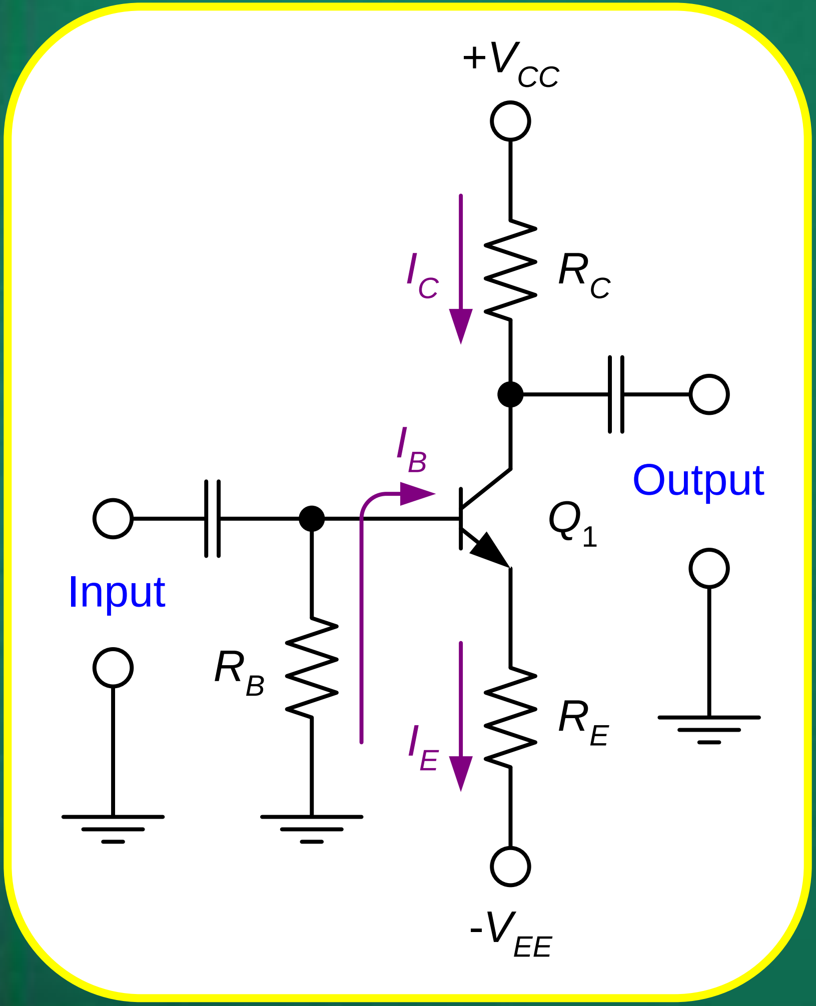
Emitter Bias Characteristics



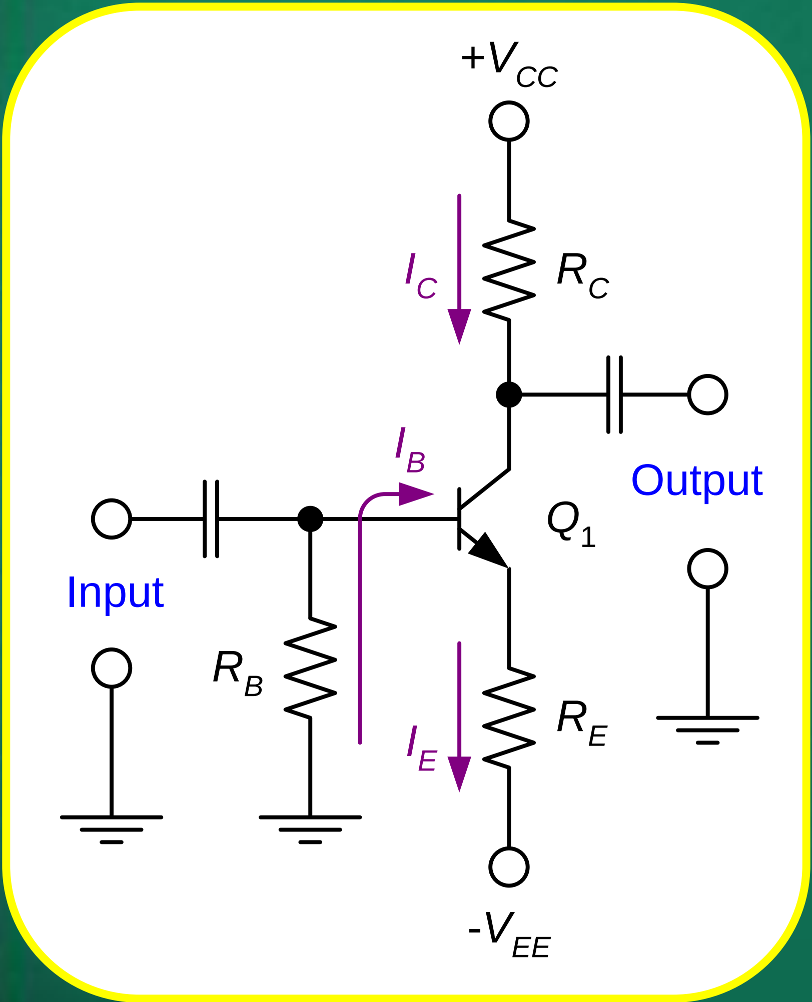
Load line equations:

$$I_{C(\text{sat})} = \frac{V_{CC} + V_{EE}}{R_C + R_E}$$

$$V_{CE(\text{off})} = V_{CC} + V_{EE}$$

Q-point equations:

Emitter Bias Characteristics



Load line equations:

$$I_{C(\mathrm{sat})} = \frac{V_{CC} + V_{EE}}{R_C + R_E}$$

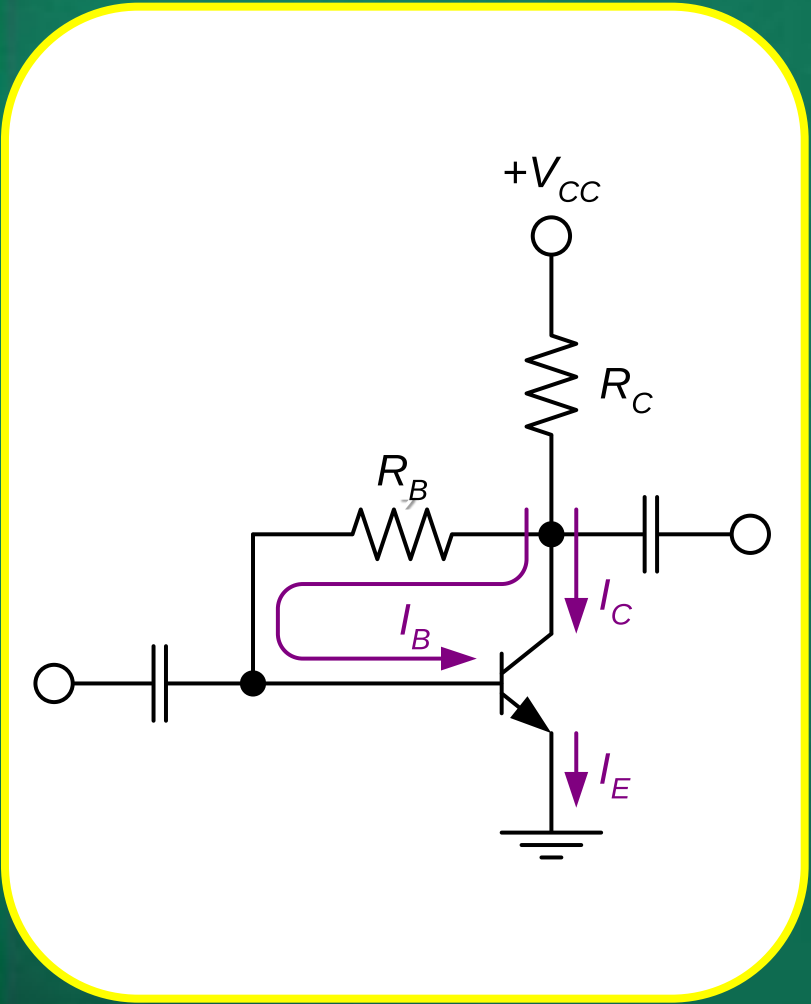
$$V_{CE(\mathrm{off})} = V_{CC} + V_{EE}$$

Q-point equations:

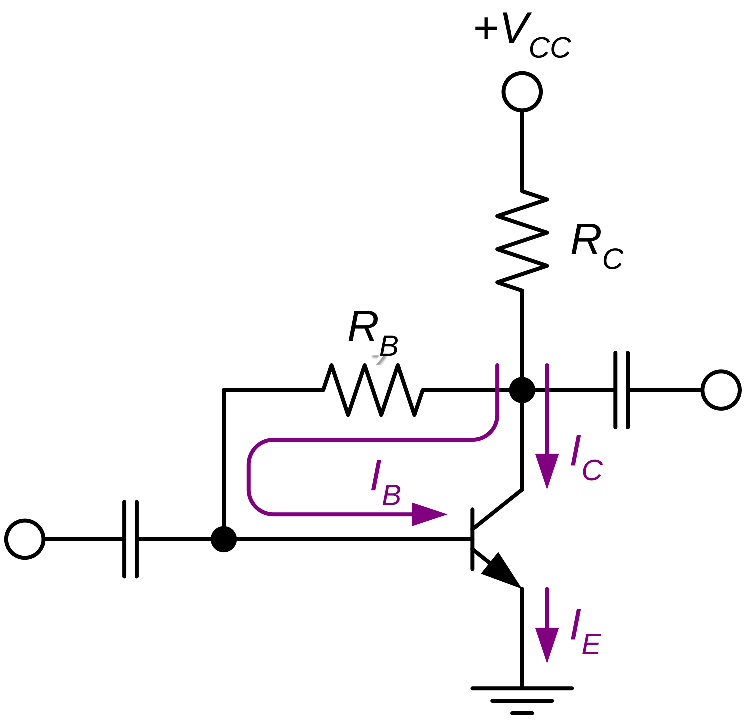
$$I_{CQ} = \left(h_{FE}\right) \frac{-V_{BE} + V_{EE}}{R_B + \left(h_{FE} + 1\right) R_E}$$

$$V_{CEQ} \cong V_{CC} - I_{CQ}\left(R_C + R_E\right) + V_{EE}$$

Collector Feedback Bias

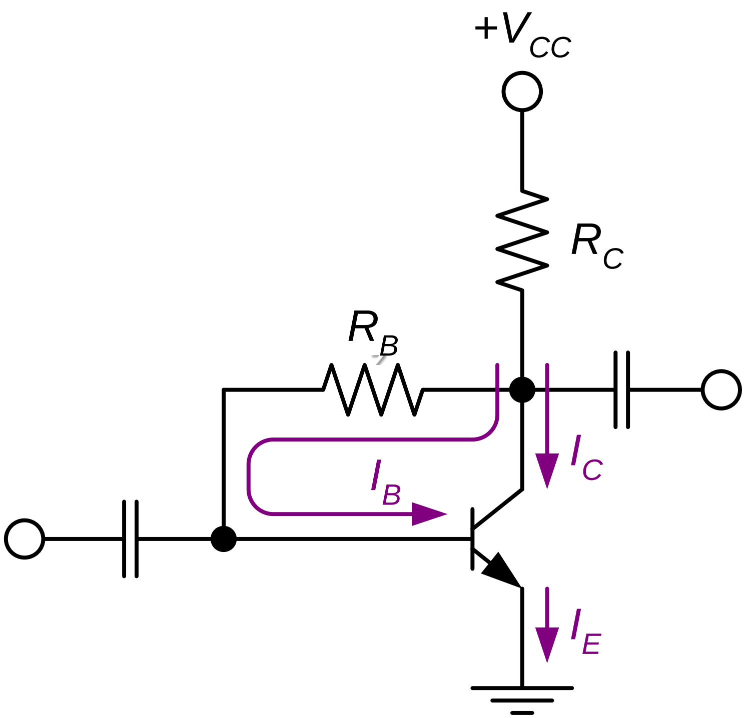


Collector Feedback Bias



$$V_{CC} = (I_C + I_B) R_C + I_B R_B + V_{BE}$$

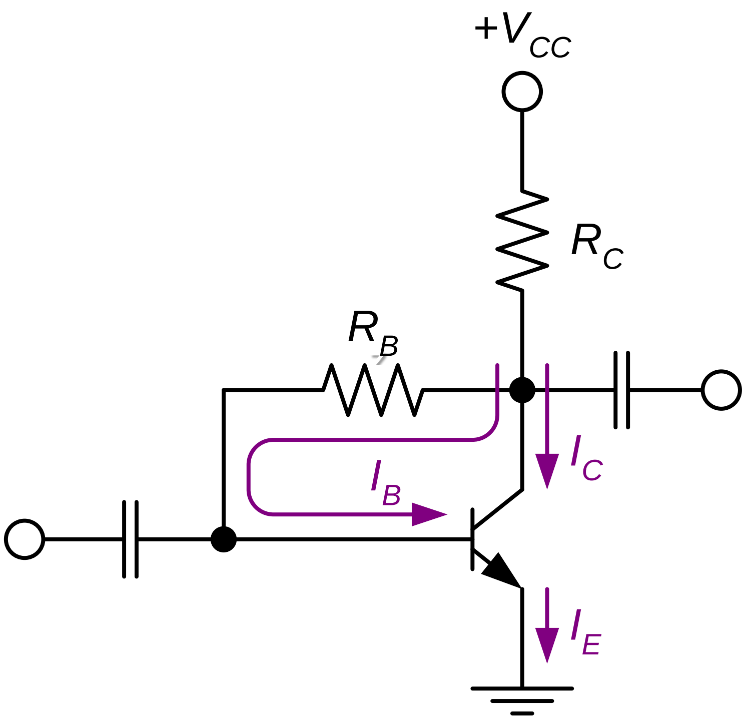
Collector Feedback Bias



$$V_{CC} = (I_C + I_B) R_C + I_B R_B + V_{BE}$$

$$I_B = \frac{V_{CC} - V_{BE}}{(h_{FE} + 1) R_C + R_B}$$

Collector Feedback Bias

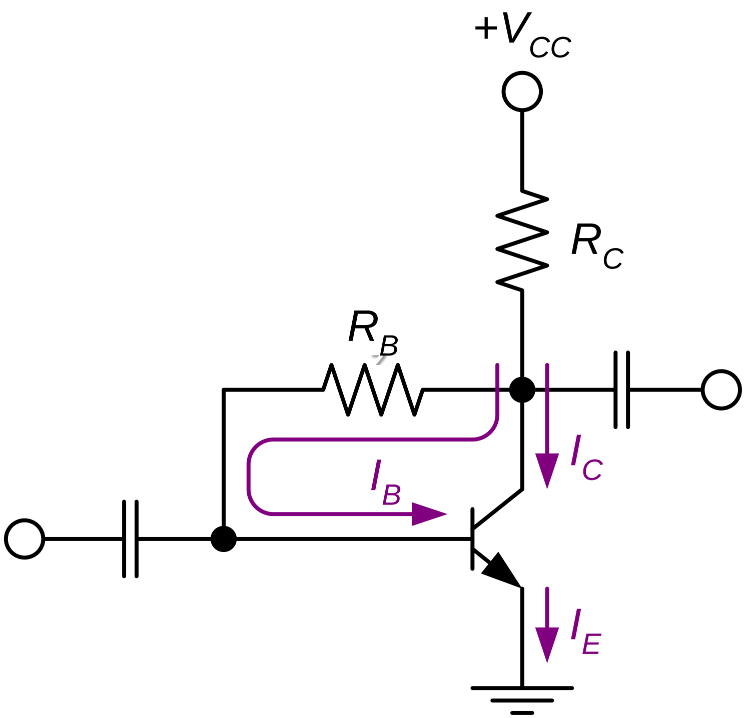


$$V_{CC} = (I_C + I_B) R_C + I_B R_B + V_{BE}$$

$$I_B = \frac{V_{CC} - V_{BE}}{(h_{FE} + 1) R_C + R_B}$$

$$I_{CQ} = h_{FE} I_B$$

Collector Feedback Bias



$$V_{CC} = \left(I_C + I_B\right) R_C + I_B R_B + V_{BE}$$

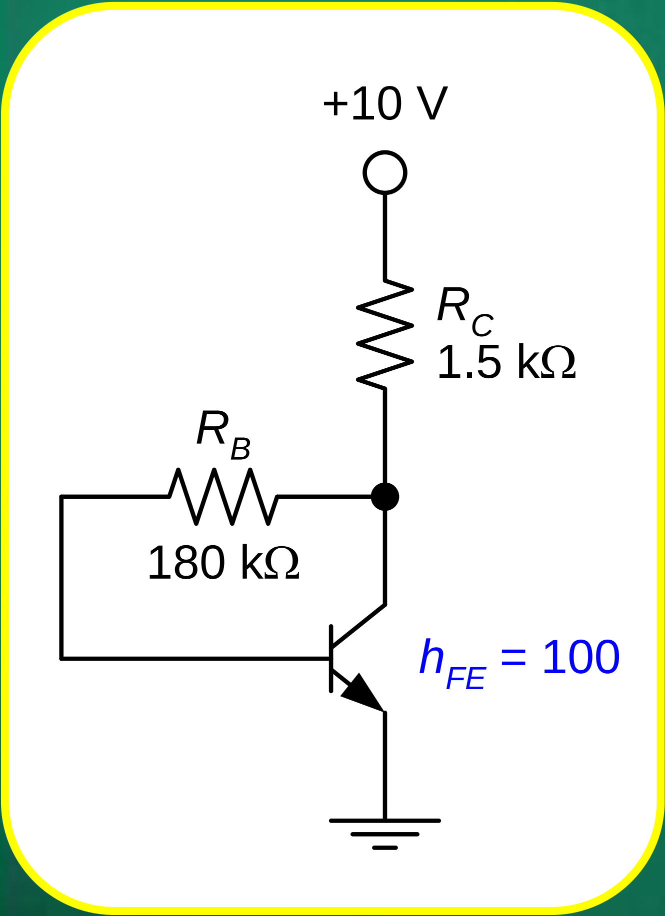
$$I_B = \frac{V_{CC} - V_{BE}}{(h_{FE} + 1) R_C + R_B}$$

$$I_{CQ} = h_{FE} I_B$$

$$V_{CEQ} = V_{CC} - \left(h_{FE} + 1\right) I_B R_C$$
$$\cong V_{CC} - I_{CQ} R_C$$

Example

Determine the values of I_{CQ} and V_{CEQ} for the amplifier shown



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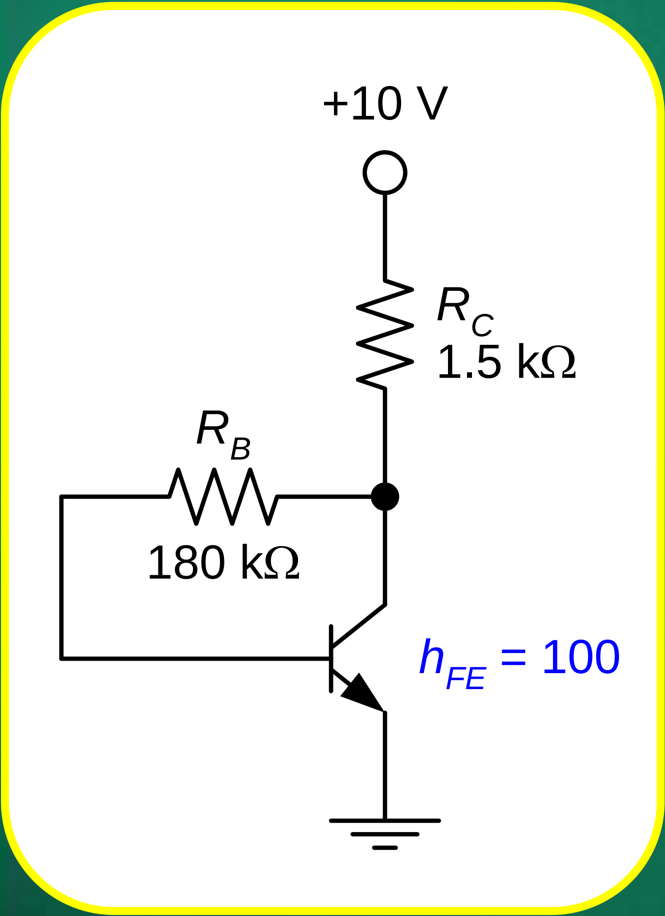
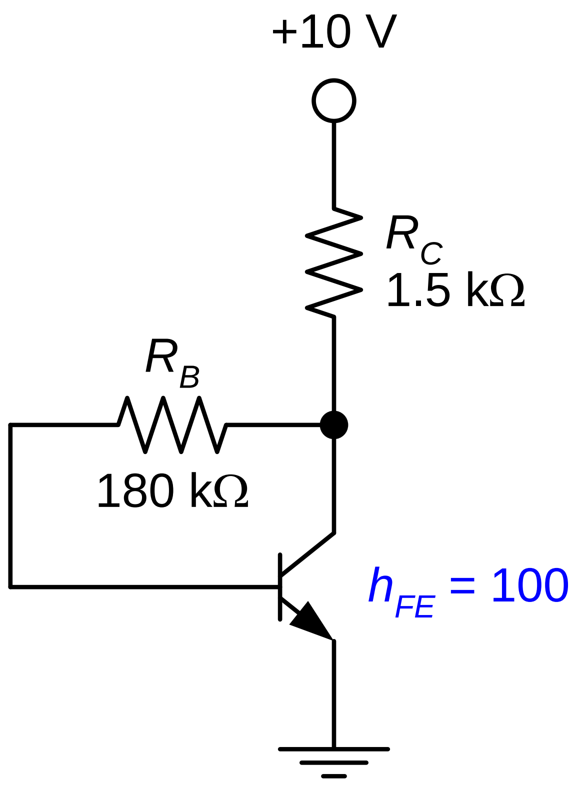


$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \left(h_{FE} + 1\right) R_C}$$

$$= \frac{10\text{V} - 0.7\text{V}}{180\text{k}\Omega + 101 \times 1.5\text{k}\Omega} = 28.05\mu\text{A}$$

Example

Determine the values of I_{CQ} and V_{CEQ} for the amplifier shown



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1) R_C}$$

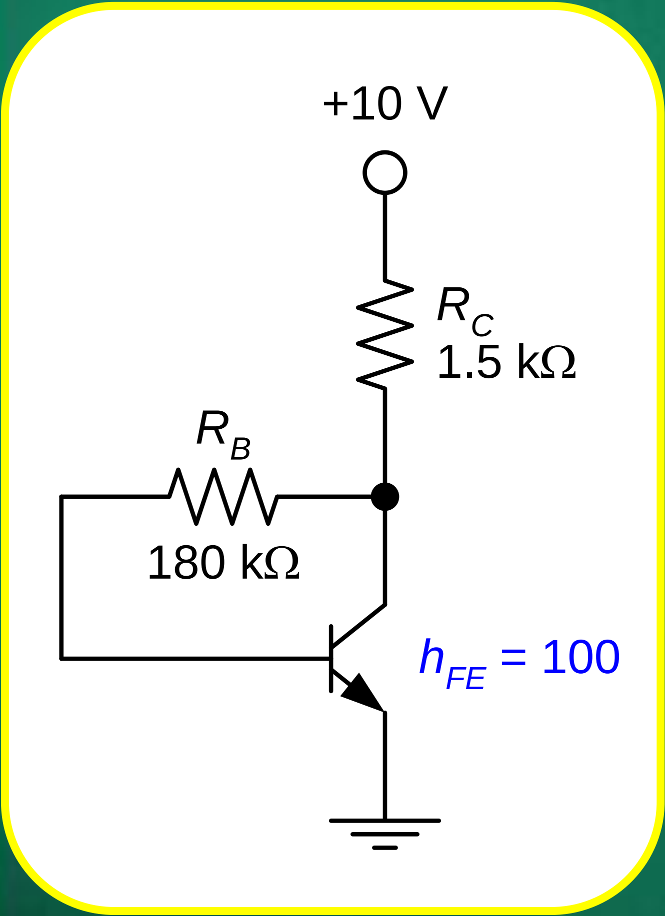
$$= \frac{10\text{V} - 0.7\text{V}}{180\text{k}\Omega + 101 \times 1.5\text{k}\Omega} = 28.05\mu\text{A}$$

$$I_{CQ} = h_{FE} I_B = 100 \times 28.05\mu\text{A}$$

$$= 2.805\text{mA}$$

Example

Determine the values of I_{CQ} and V_{CEQ} for the amplifier shown



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1) R_C}$$

$$= \frac{10\text{V} - 0.7\text{V}}{180\text{k}\Omega + 101 \times 1.5\text{k}\Omega} = 28.05\mu\text{A}$$

$$I_{CQ} = h_{FE} I_B = 100 \times 28.05\mu\text{A}$$

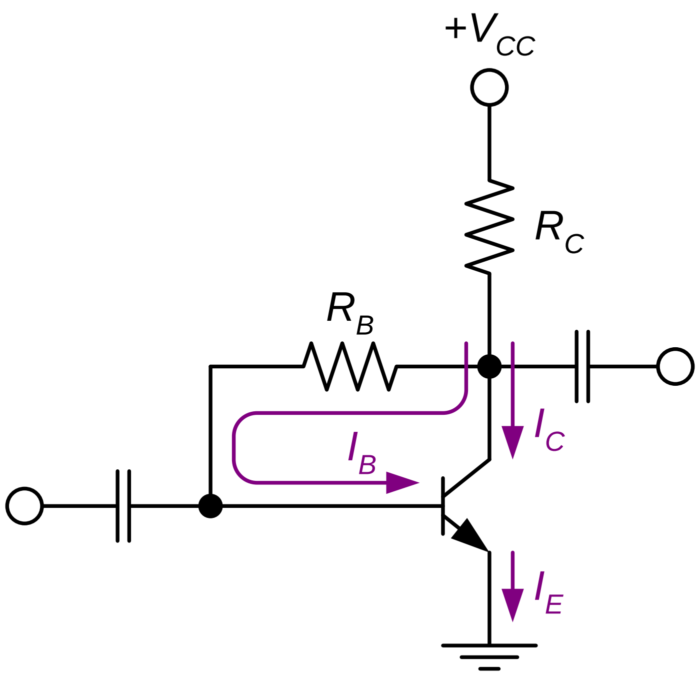
$$= 2.805\text{mA}$$

$$V_{CEQ} = V_{CC} - (h_{FE} + 1) I_B R_C$$

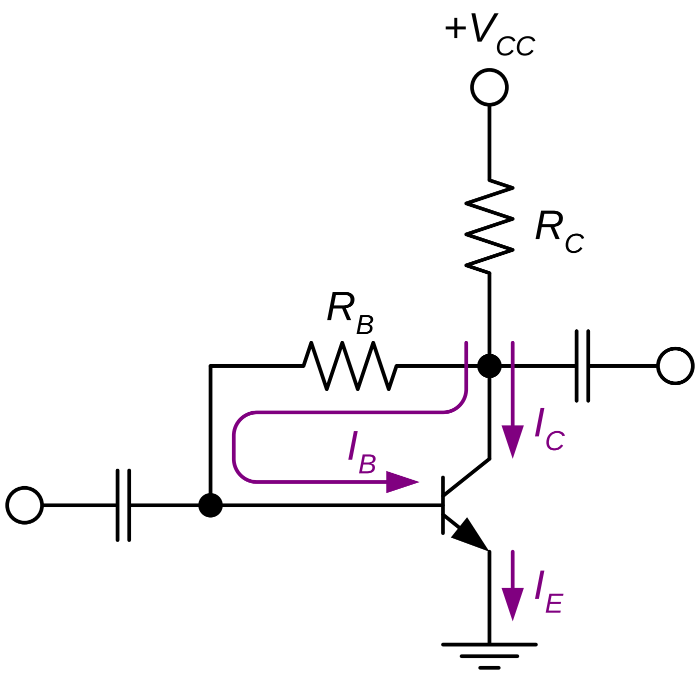
$$= 10\text{V} - 101 \times 28.05\mu\text{A} \times 1.5\text{k}\Omega$$

$$= 5.75\text{V}$$

Circuit Stability



Circuit Stability



h_{FE} increases

↓

I_C increases (if I_B is the same)

↓

V_{CE} decreases

↓

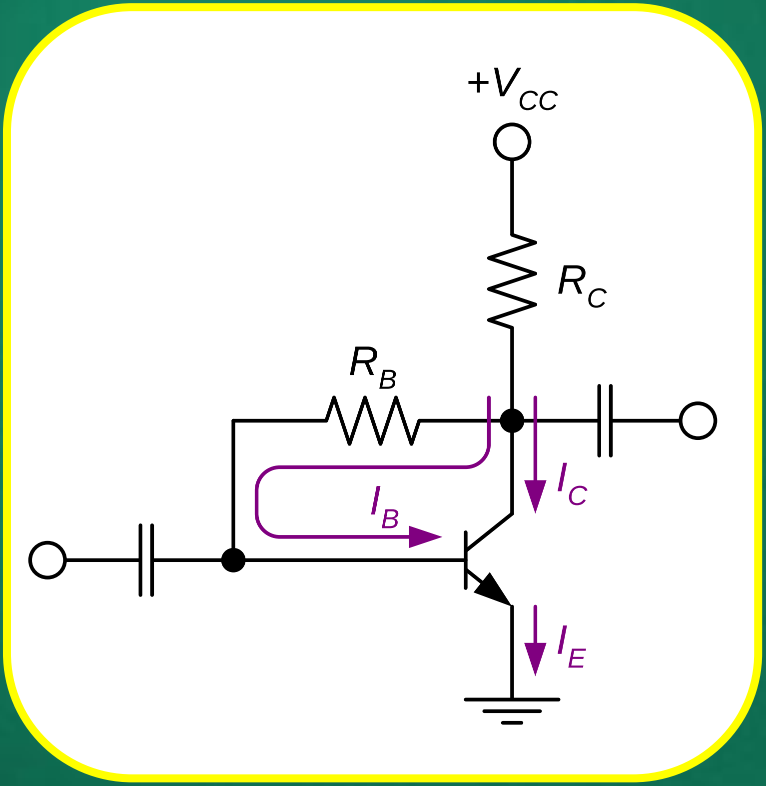
I_B decreases

↓

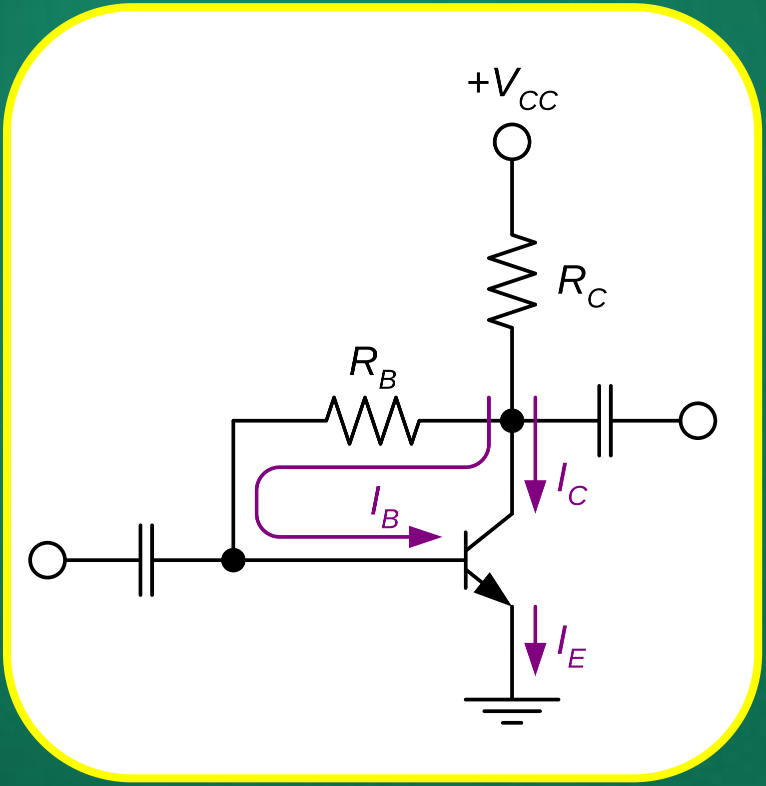
I_C does not increase that much.

Good Stability. Less dependent on h_{FE} and temperature.

Collector Feedback Characteristics

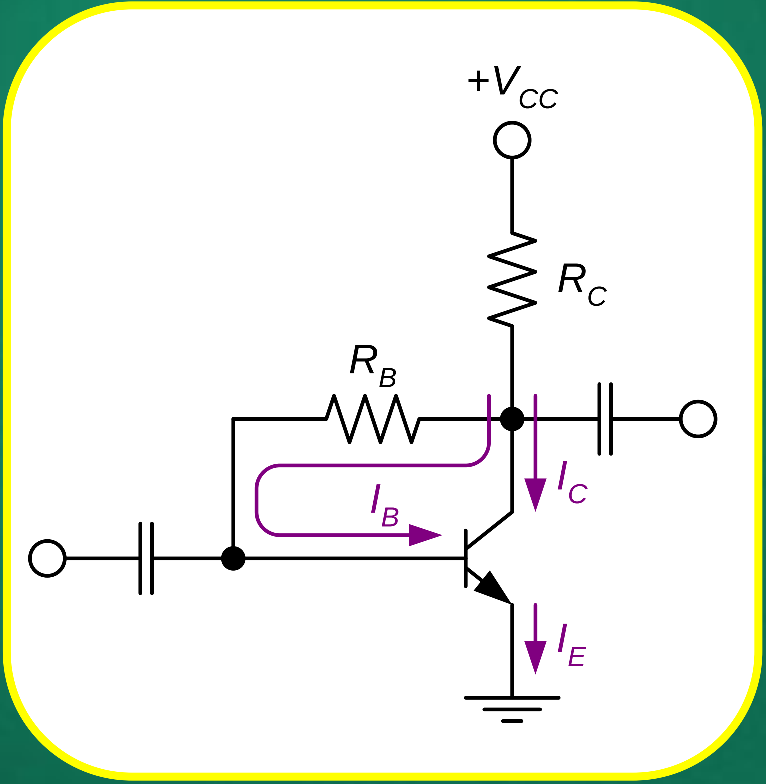


Collector Feedback Characteristics



Circuit recognition: The base resistor is connected between the base and the collector terminals of the transistor.

Collector Feedback Characteristics



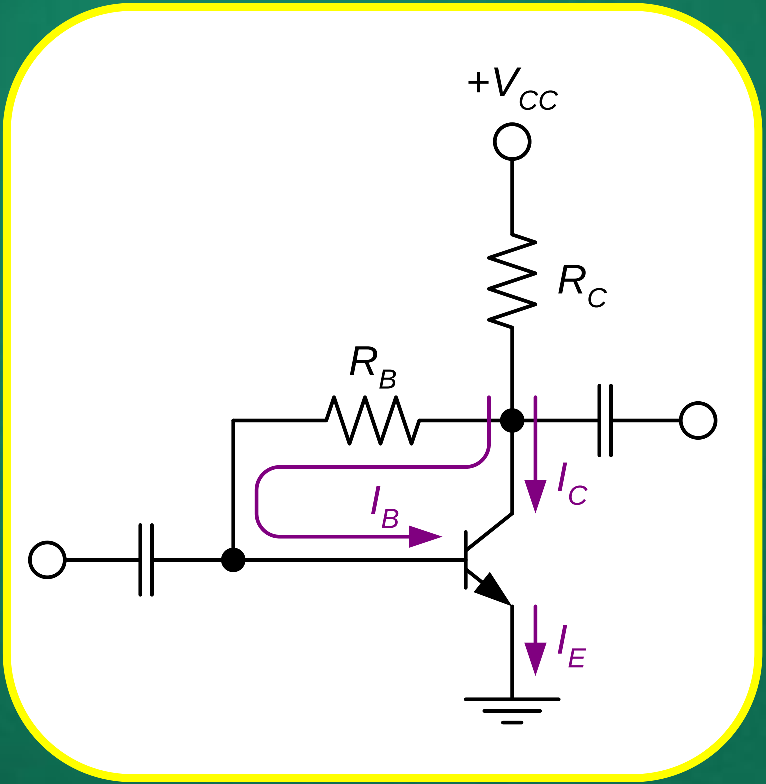
Circuit recognition: The base resistor is connected between the base and the collector terminals of the transistor.

Advantage: A simple circuit with relatively stable Q-point.

Disadvantage: Relatively poor ac characteristics.

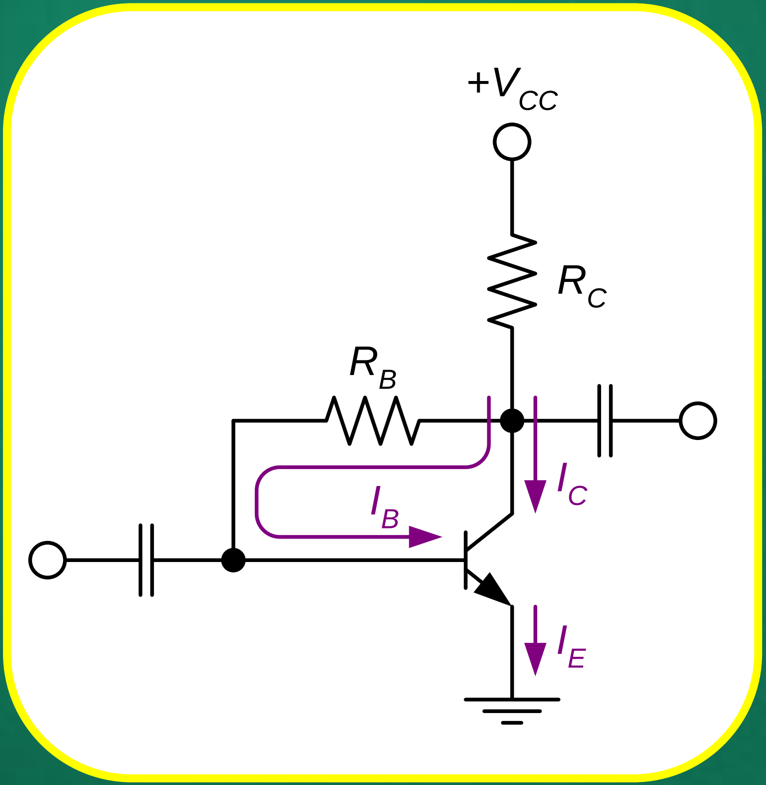
Applications: Used primarily to bias linear amplifiers.

Collector Feedback Characteristics



Q-point relationships:

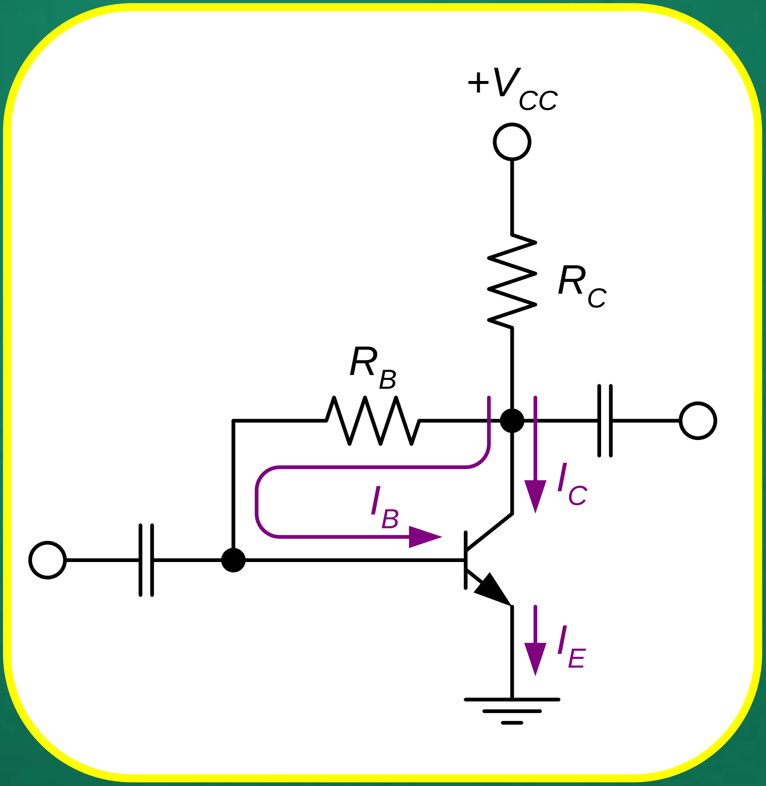
Collector Feedback Characteristics



Q-point relationships:

$$I_B = \frac{V_{CC} - V_{BE}}{(h_{FE} + 1)R_C + R_B}$$

Collector Feedback Characteristics



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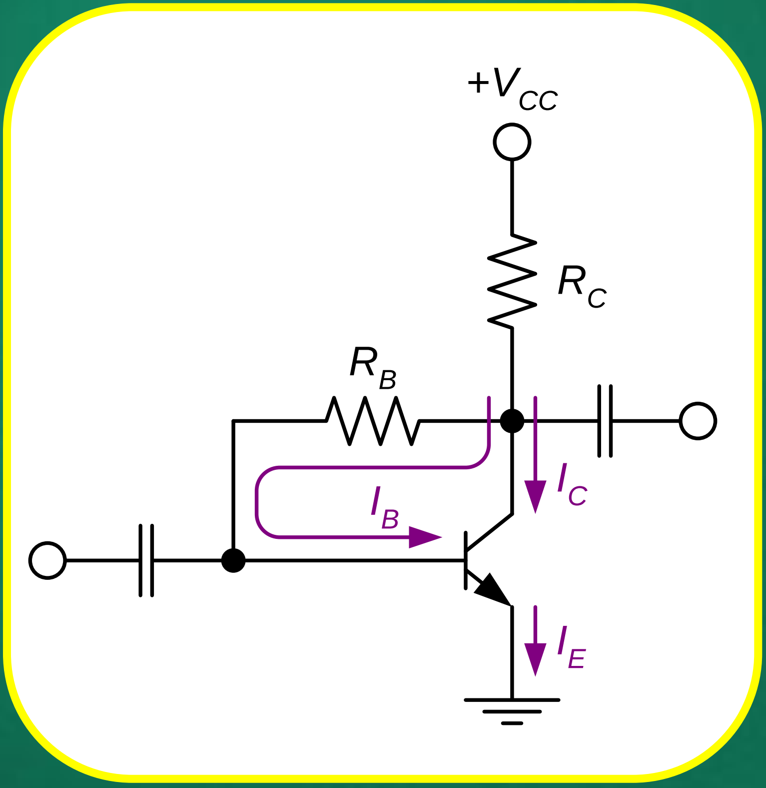
$$I_B = \frac{V_{CC} - V_{BE}}{(h_{FE}+1)R_C + R_B}$$

$$I_{CQ} = h_{FE} I_B$$

Collector Feedback Characteristics



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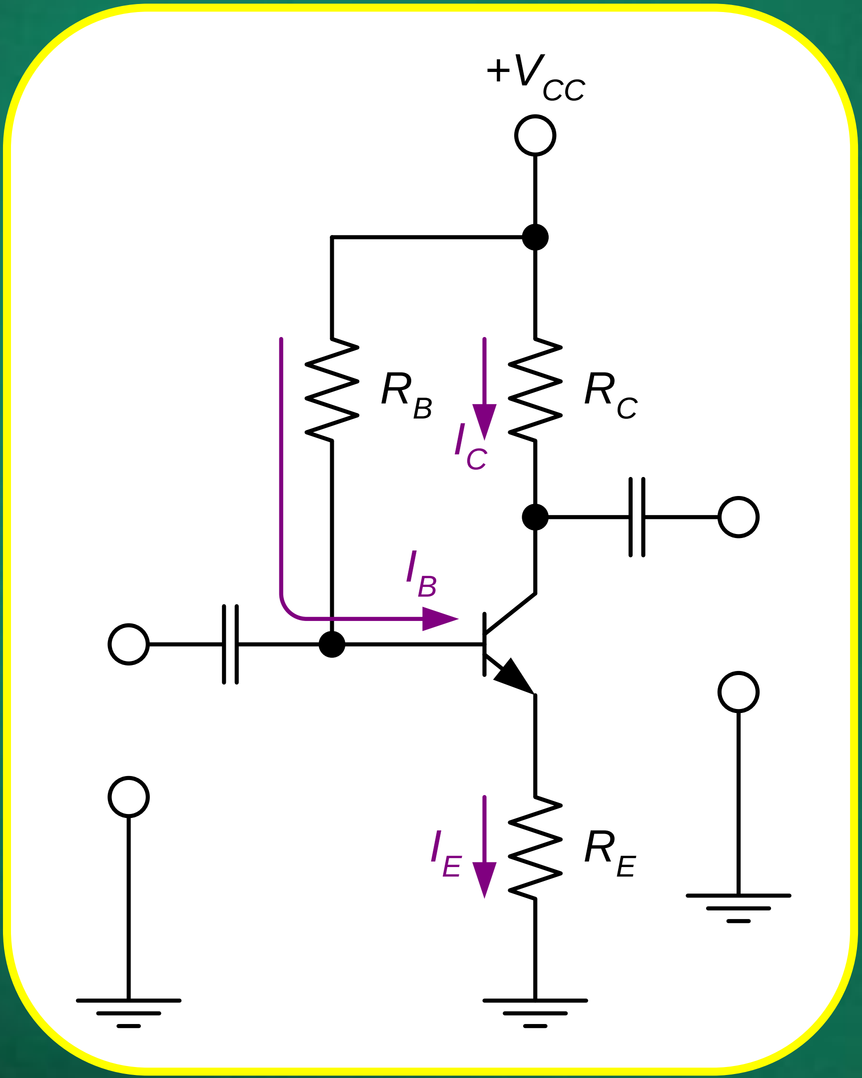
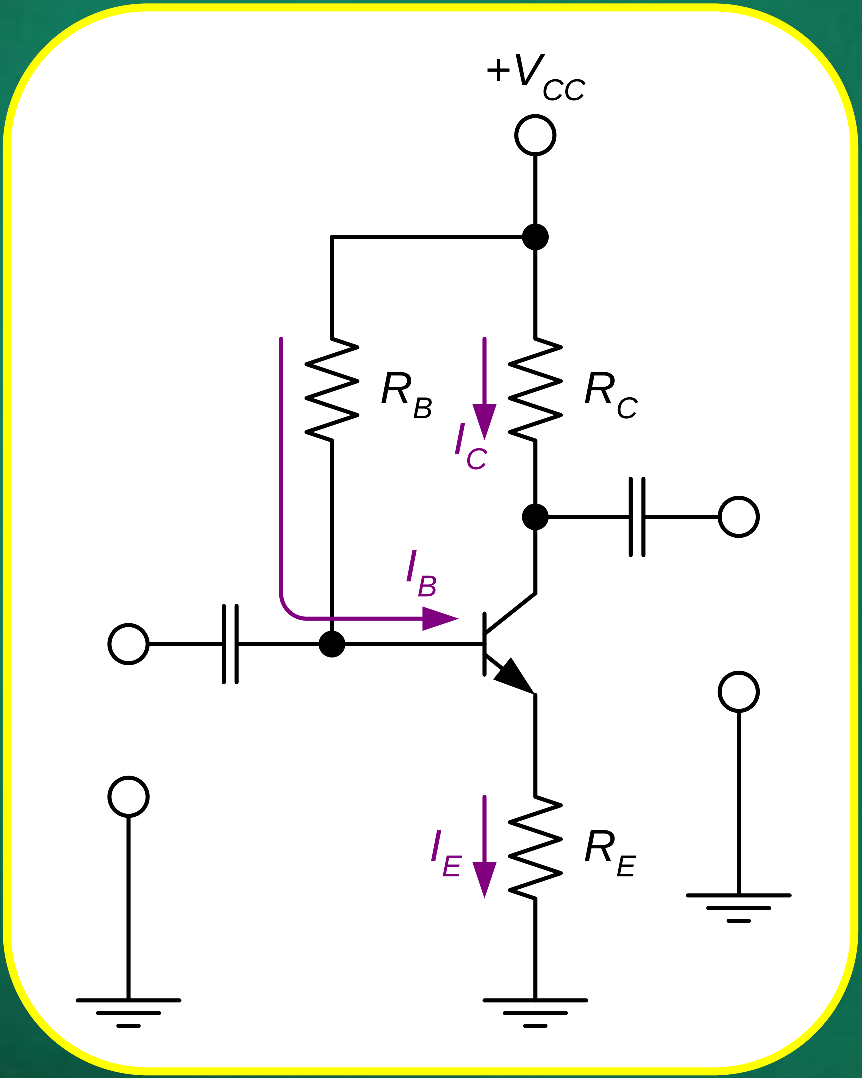
$$I_{CQ} = h_{FE} I_B$$

$$V_{CEQ} \cong V_{CC} - I_{CQ} R_C$$

Emitter Feedback Bias

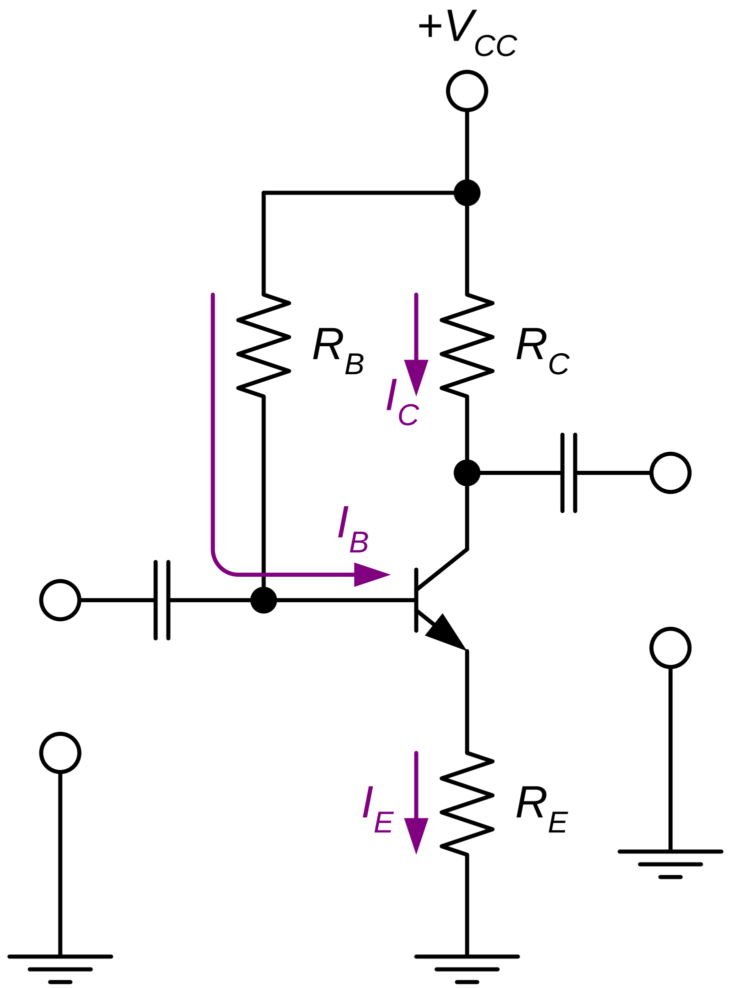


Emitter Feedback Bias



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1) R_E}$$

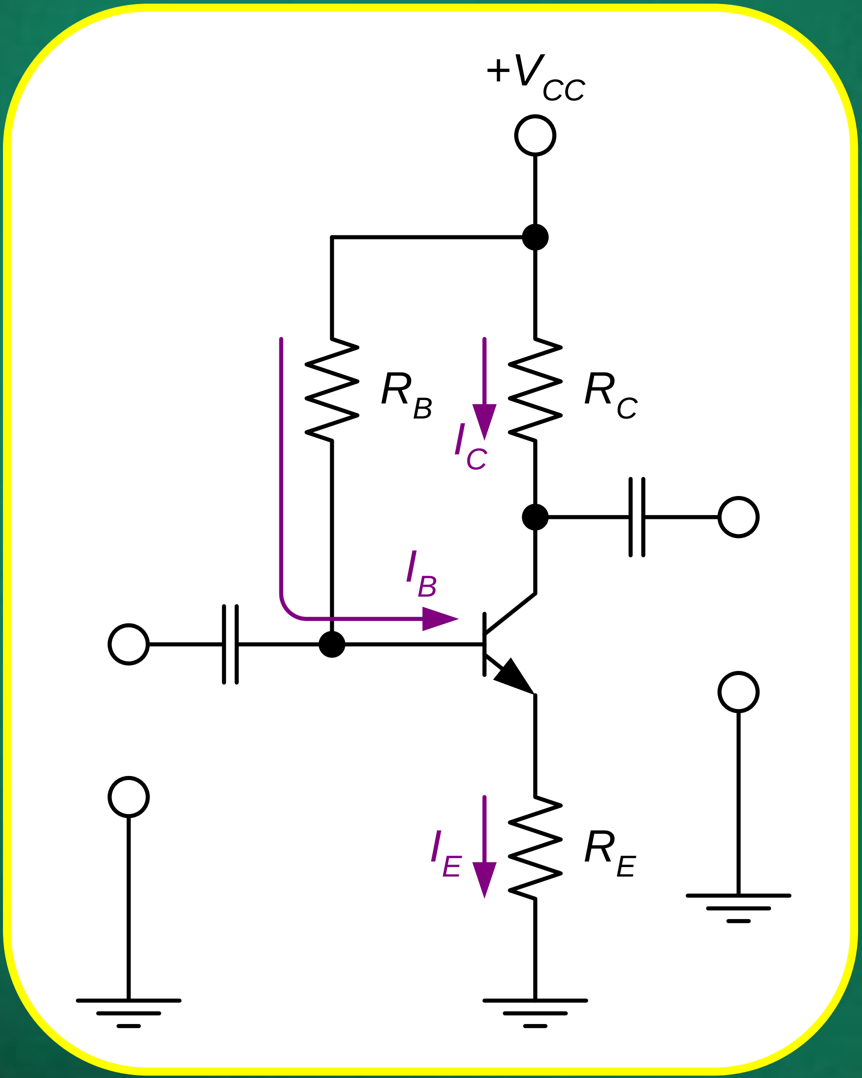
Emitter Feedback Bias



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \left(h_{FE} + 1\right) R_E}$$

$$I_{CQ} = h_{FE} I_B$$

Emitter Feedback Bias



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1) R_E}$$

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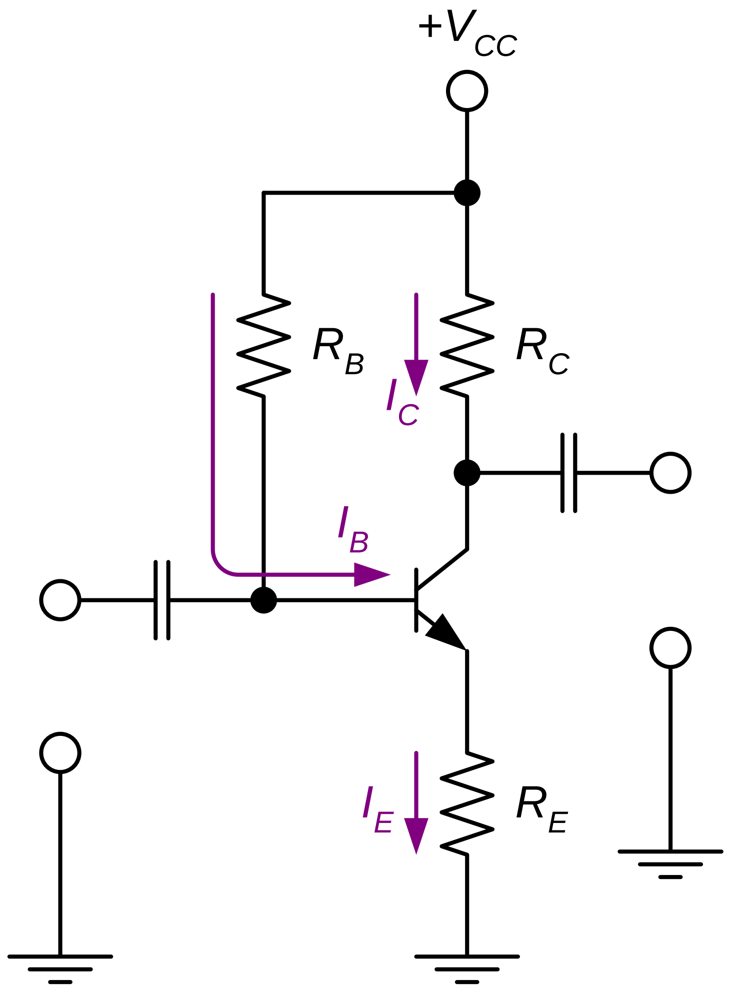
Emitter Feedback Bias



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$$I_{CQ} = h_{FE} I_B$$

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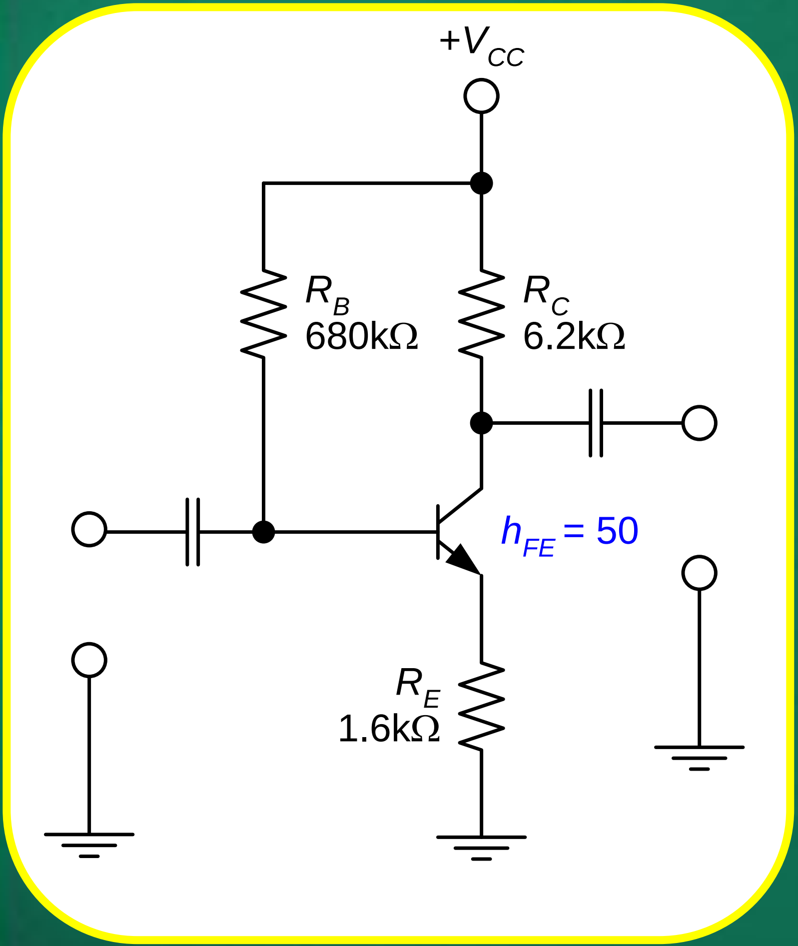
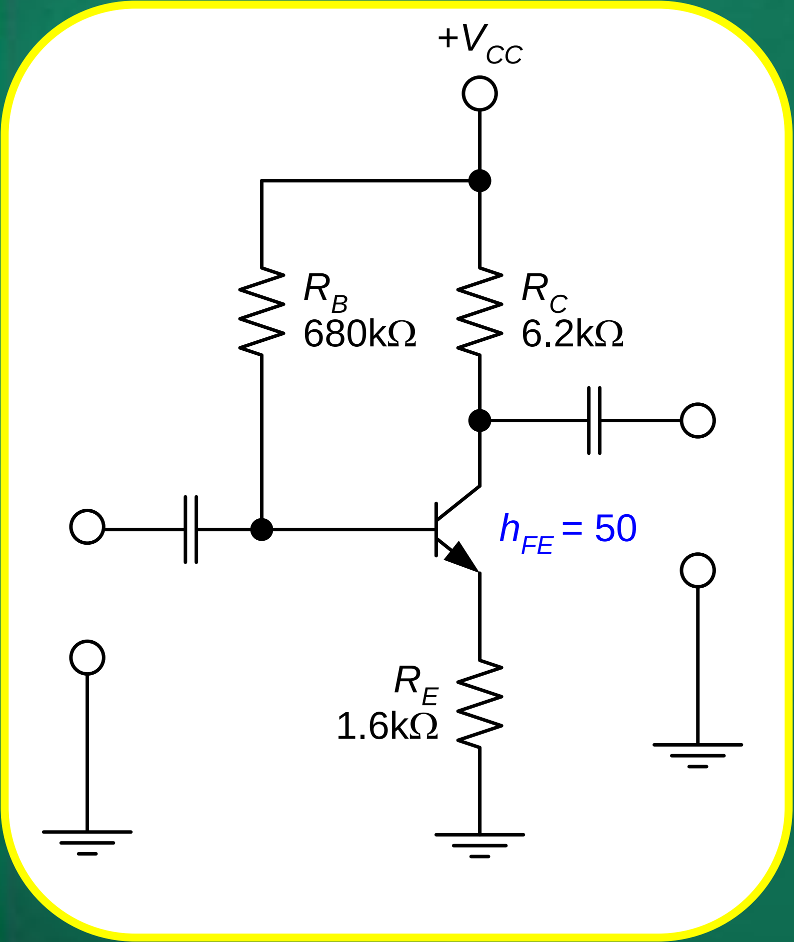
$$\begin{aligned} V_{CEQ} &= V_{CC} - I_C R_C - I_E R_E \\ &\cong V_{CC} - I_{CQ}(R_C + R_E) \end{aligned}$$

Example

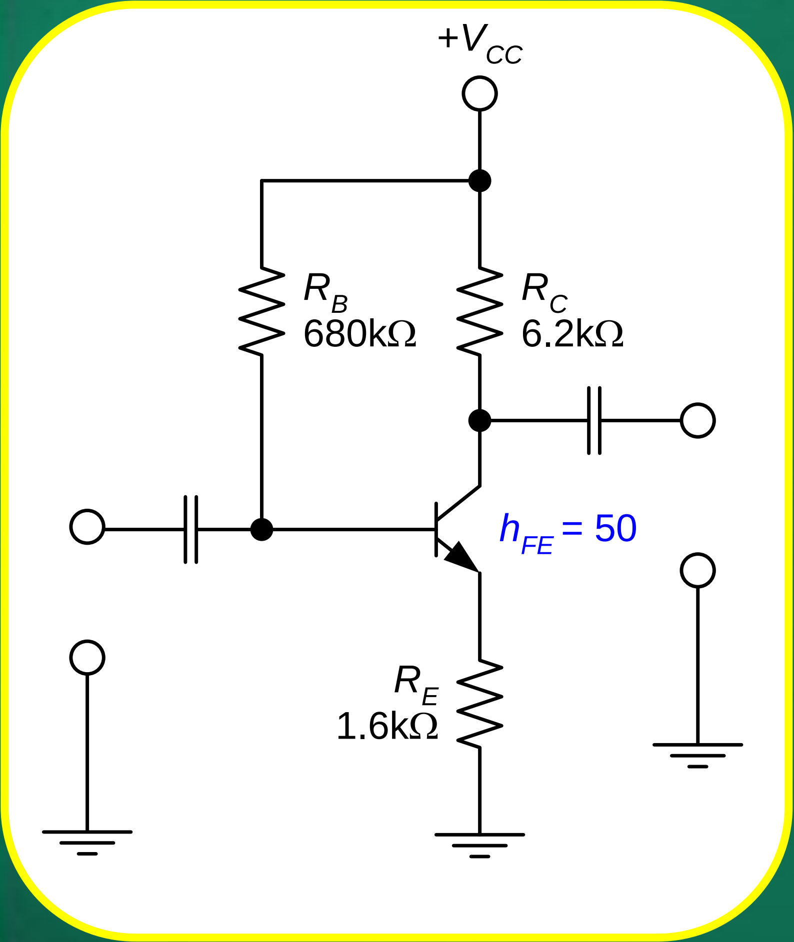


Example



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \left(h_{FE} + 1\right) R_E} = \frac{16\text{V} - 0.7\text{V}}{680\text{k}\Omega + 51 \times 1.6\text{k}\Omega}$$
$$= 20.09\mu\text{A}$$

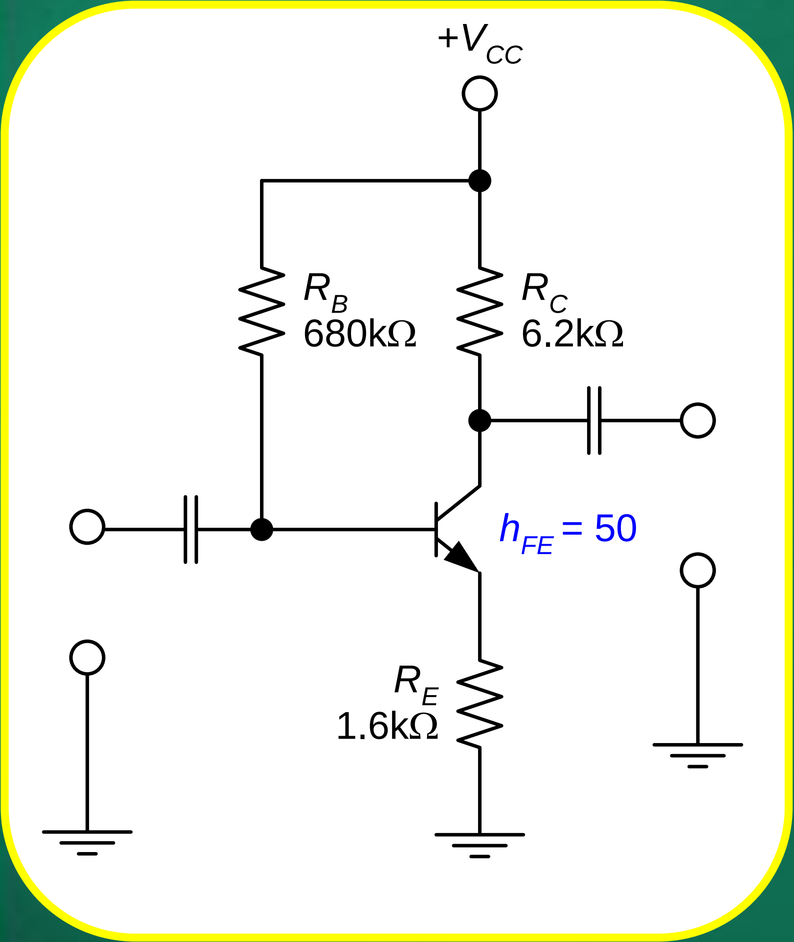
Example



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1) R_E} = \frac{16\text{V} - 0.7\text{V}}{680\text{k}\Omega + 51 \times 1.6\text{k}\Omega}$$
$$= 20.09\mu\text{A}$$

$$I_{CQ} = h_{FE} I_B = 50 \times 20.09\mu\text{A} = 1\text{mA}$$

Example



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1) R_E} = \frac{16\text{V} - 0.7\text{V}}{680\text{k}\Omega + 51 \times 1.6\text{k}\Omega}$$

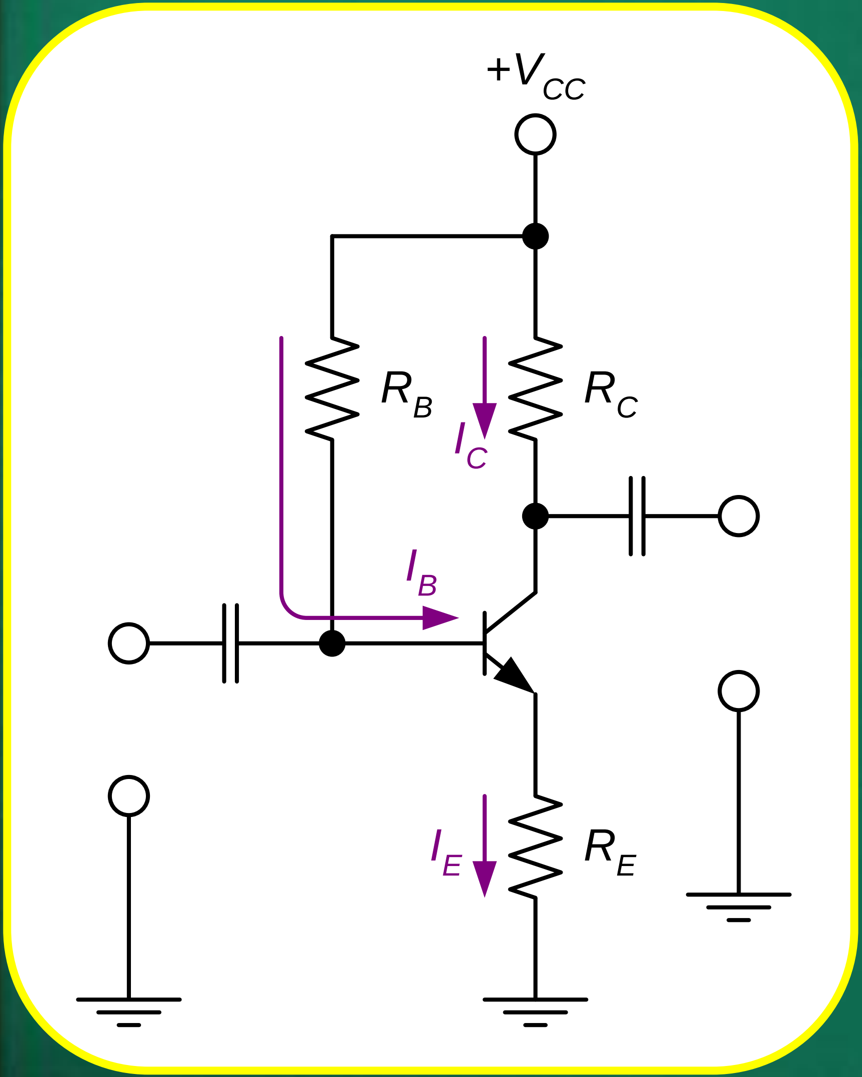
$$= 20.09\mu\text{A}$$

$$I_{CQ} = h_{FE} I_B = 50 \times 20.09\mu\text{A} = 1\text{mA}$$

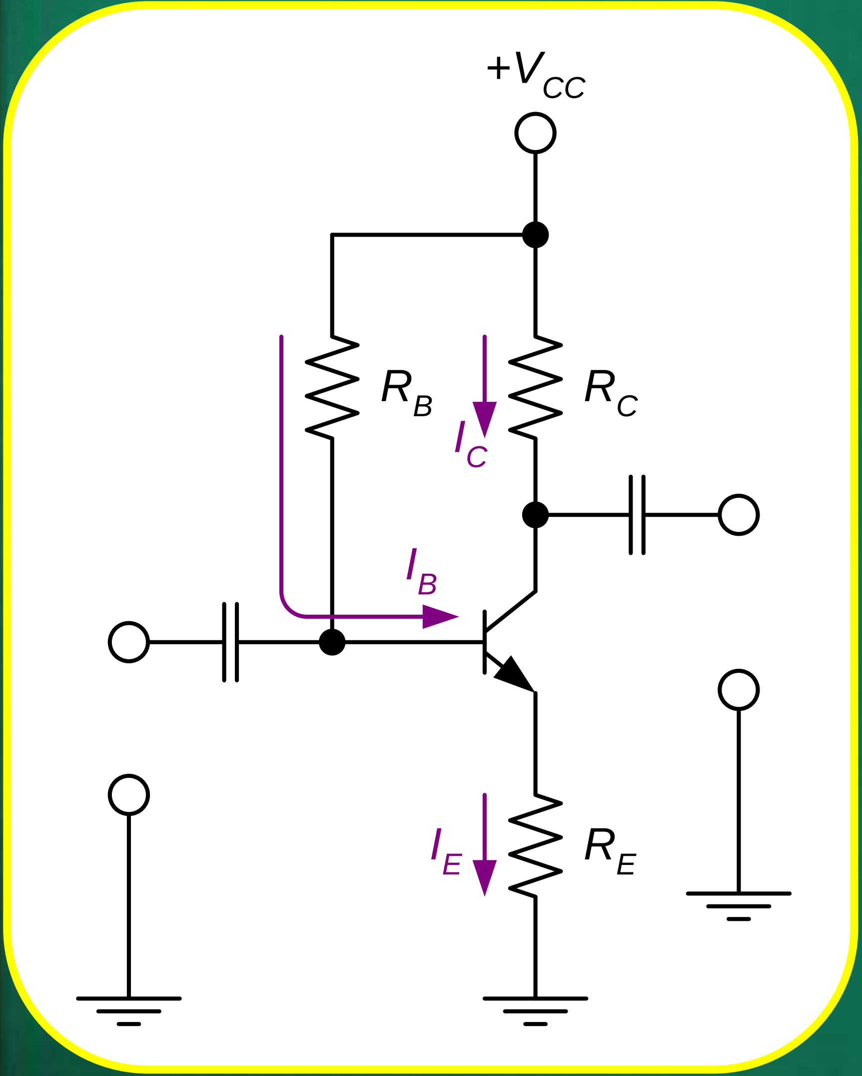
$$V_{CEQ} \cong V_{CC} - I_{CQ}(R_C + R_E)$$

$$= 16\text{V} - (1\text{mA})(7.8\text{k}\Omega) = 8.2\text{V}$$

Circuit Stability



Circuit Stability



h_{FE} increases

↓

I_C increases (if I_B is the same)

↓

V_E increases

↓

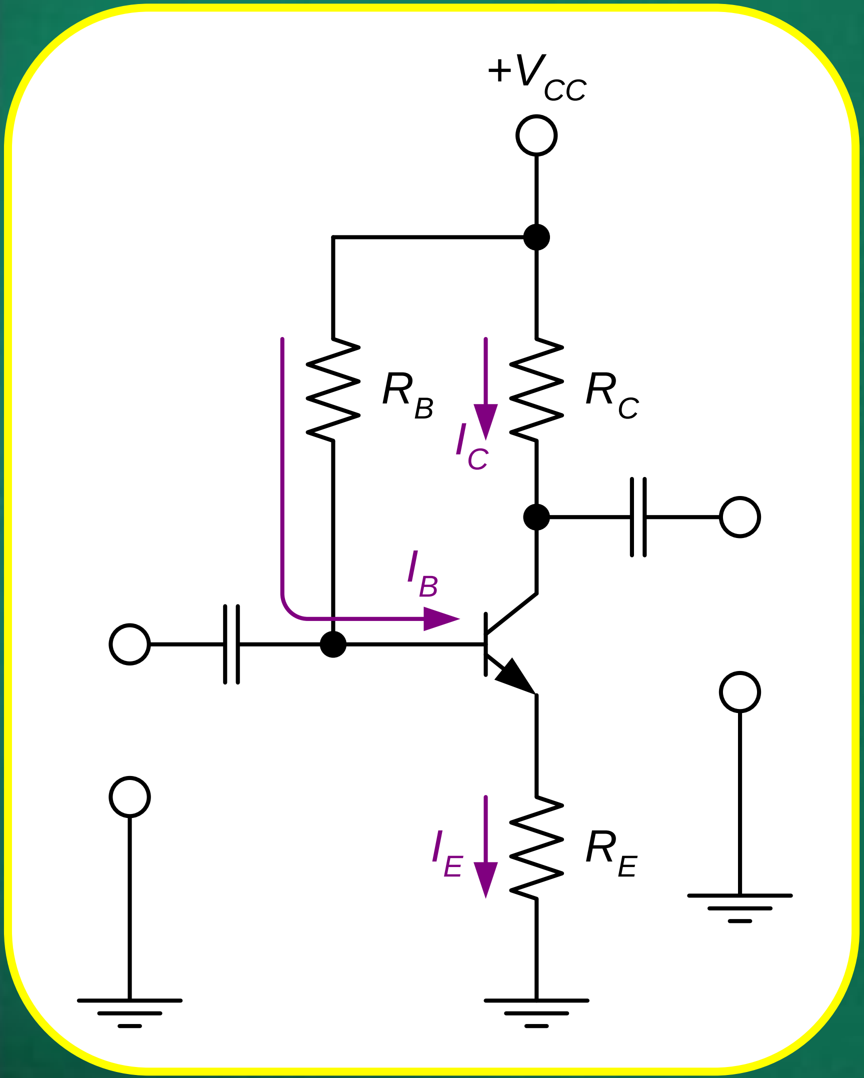
I_B decreases

↓

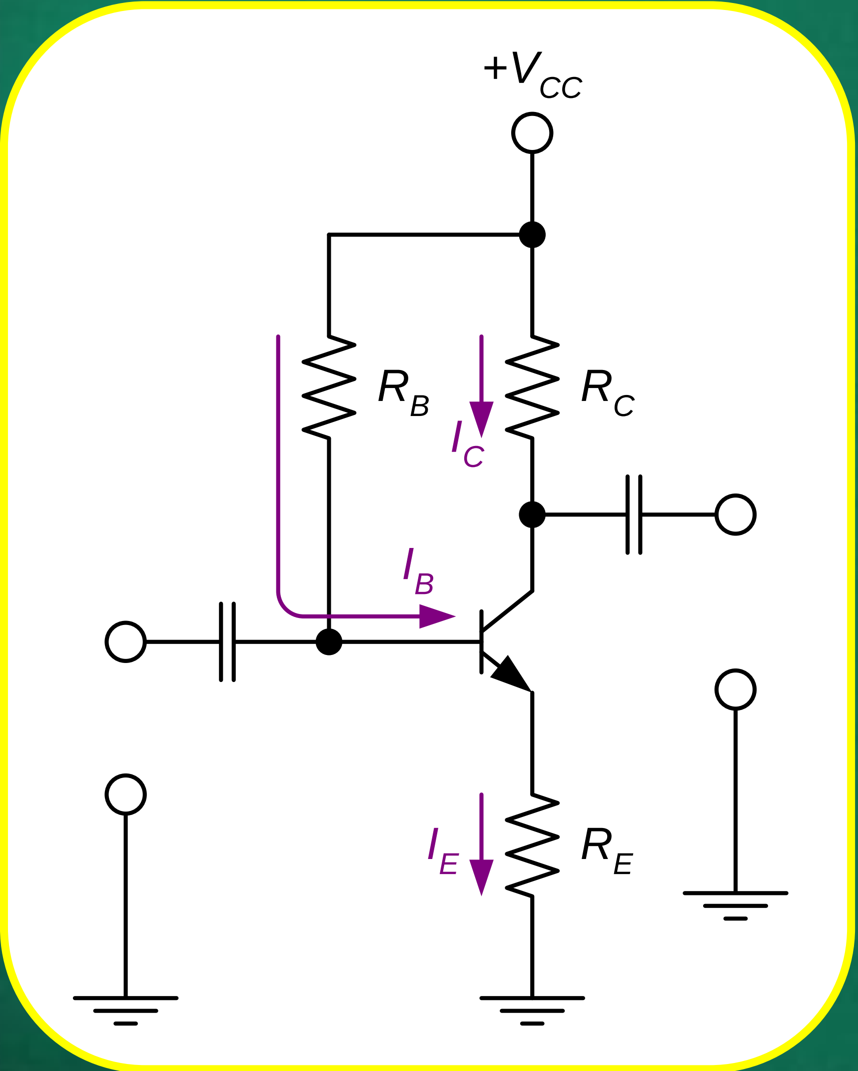
I_C does not increase that much.

I_C is less dependent on h_{FE} and temperature.

Emitter Feedback Characteristics

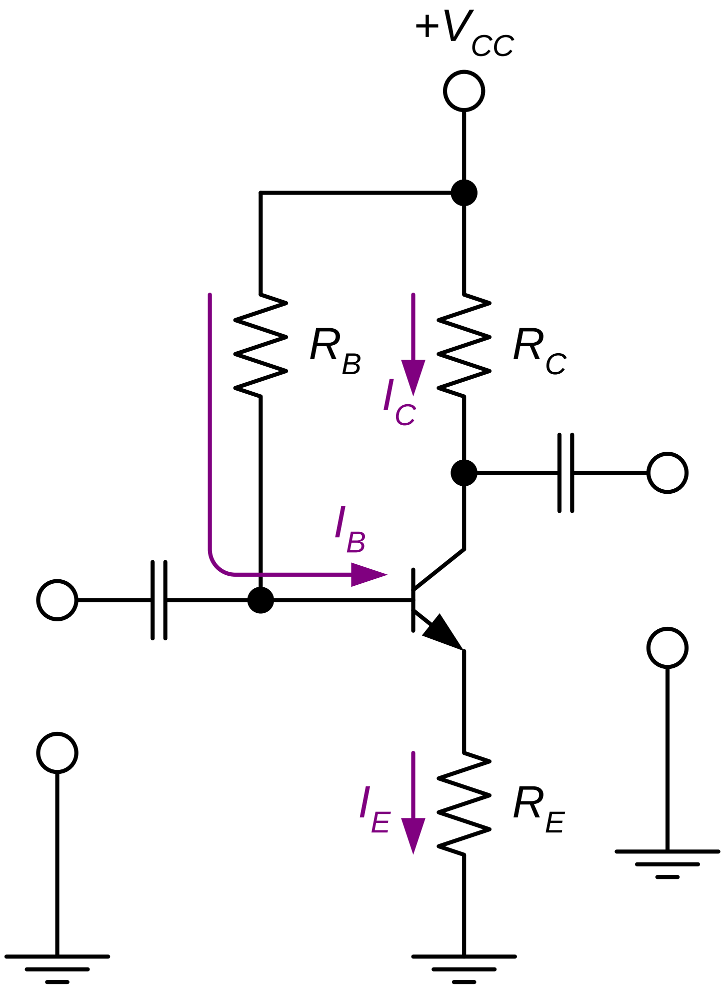


Emitter Feedback Characteristics



Circuit recognition: Similar to voltage divider bias with R_2 missing (or base bias with R_E added).

Emitter Feedback Characteristics



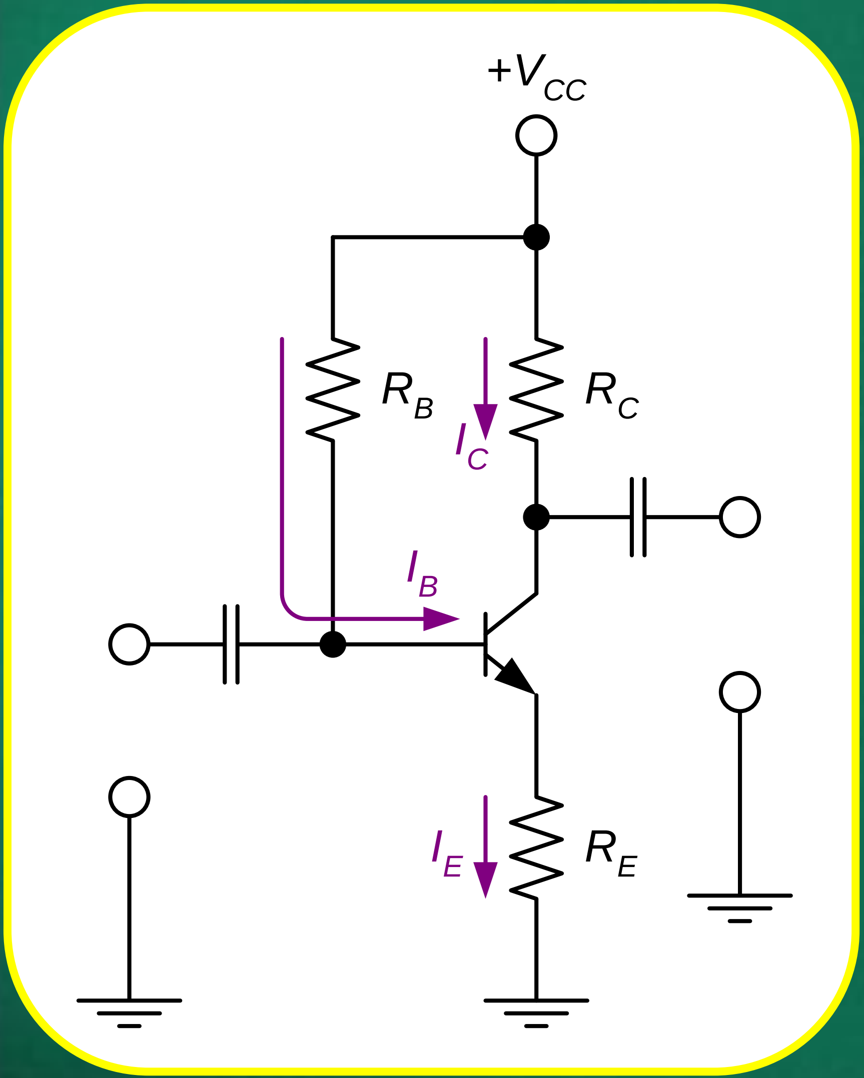
Circuit recognition: Similar to voltage divider bias with R_2 missing (or base bias with R_E added).

Advantage: A simple circuit with relatively stable Q-point.

Disadvantage: Requires more components than collector-feedback bias.

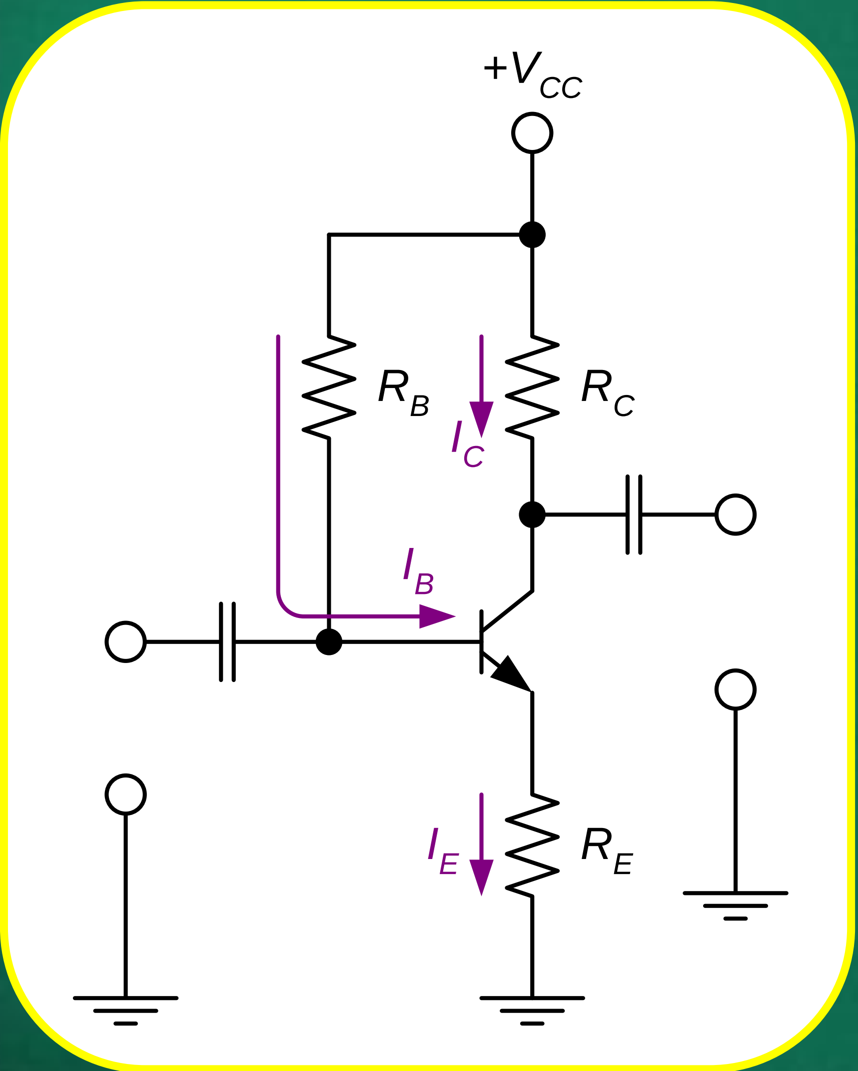
Applications: Used primarily to bias linear amplifiers.

Emitter Feedback Characteristics



Q-point relationships:

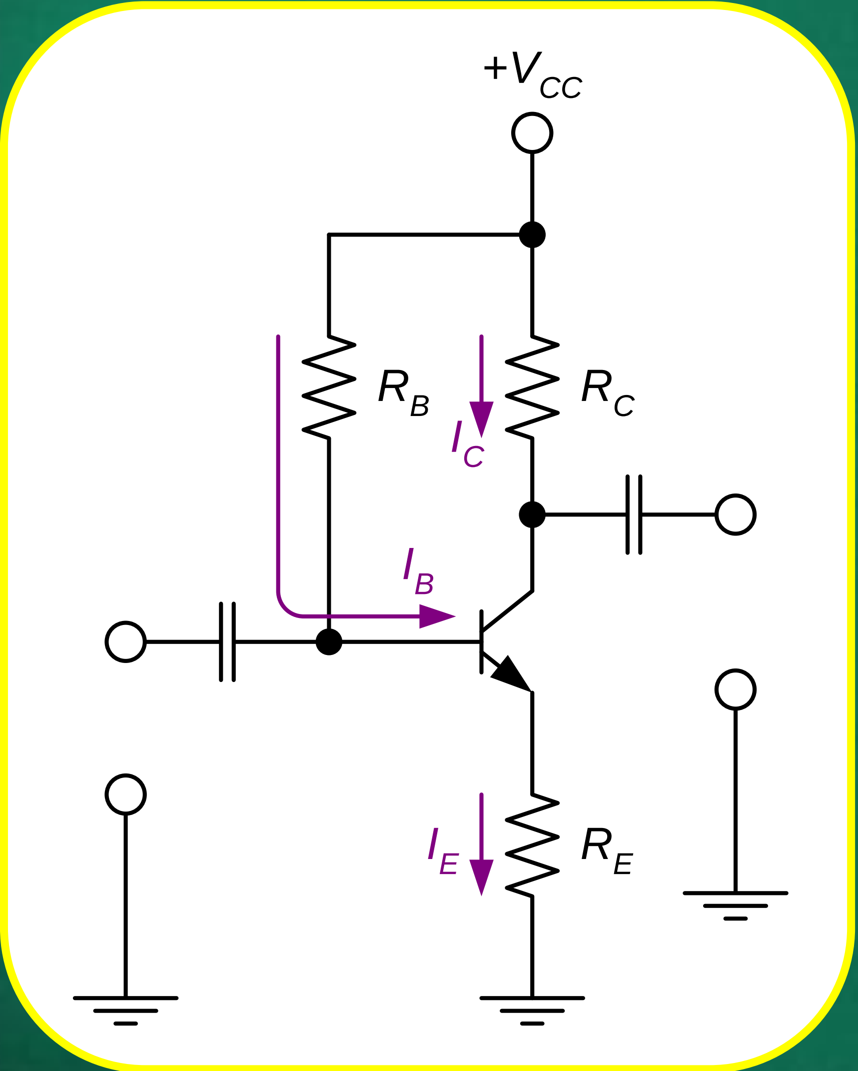
Emitter Feedback Characteristics



Q-point relationships:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (h_{FE} + 1)R_E}$$

Emitter Feedback Characteristics



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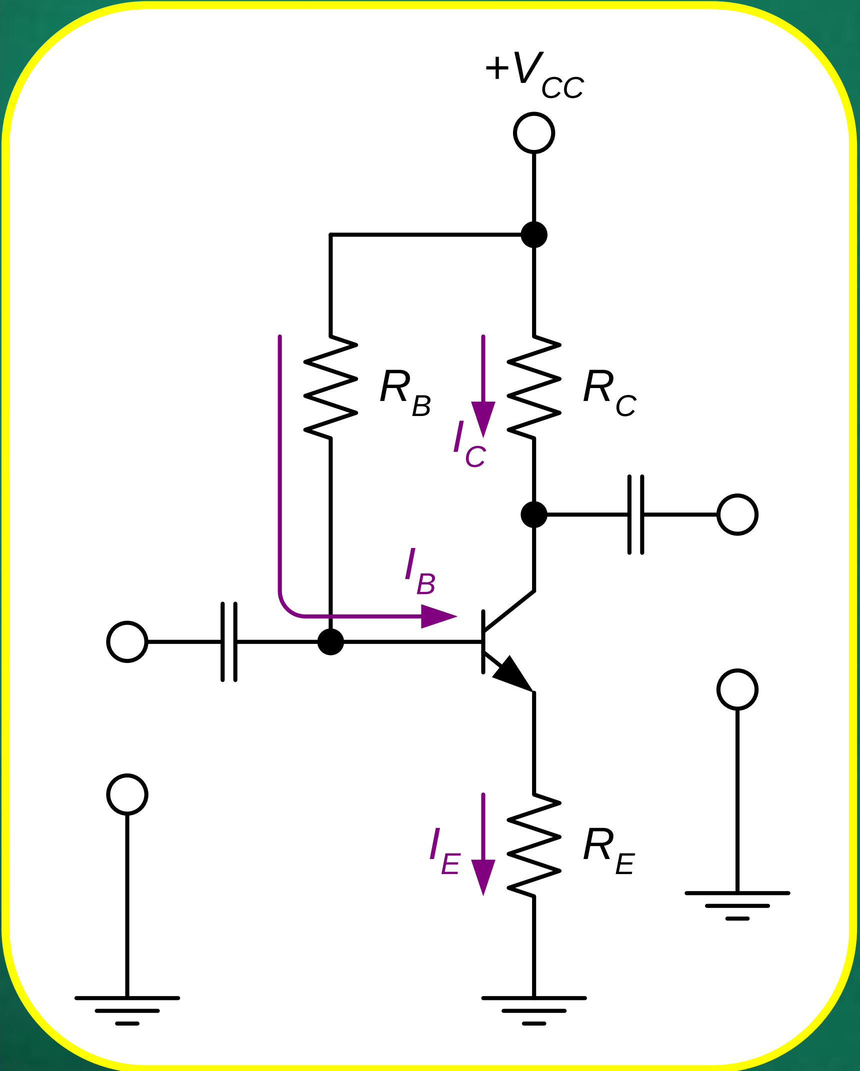
Emitter Feedback Characteristics



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