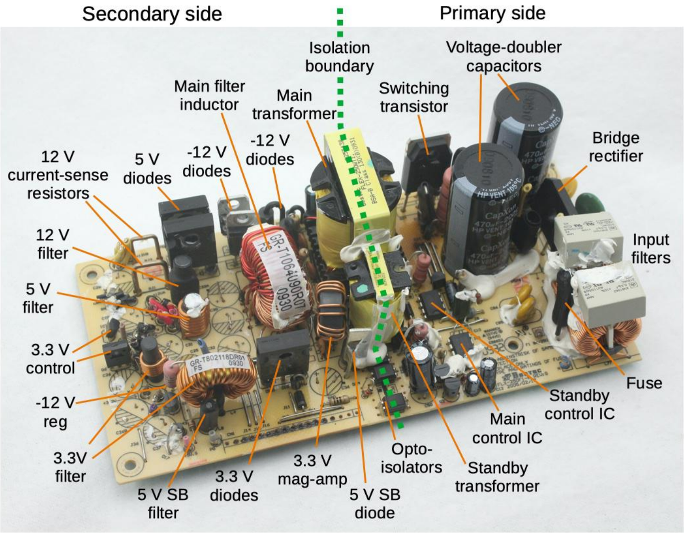


BJT Circuits at DC

Kizito NKURIKIYEYEZU, Ph.D.

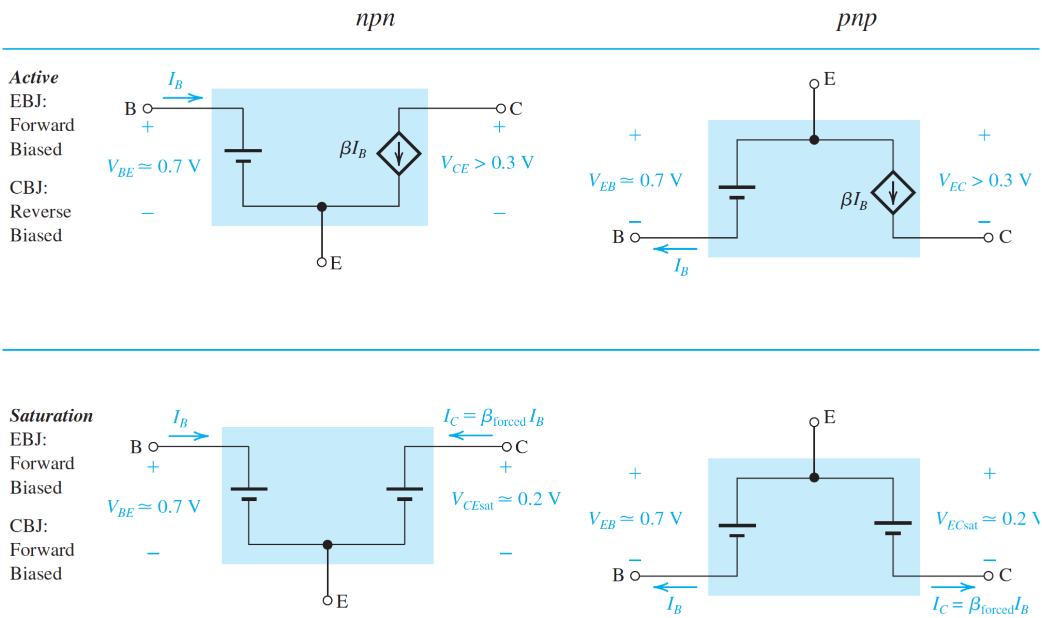


FIG 1. Simplified Models for the Operation of the BJT in DC Circuits

BJT DC analysis steps

Use the following steps when analyzing BJT circuits with DC voltages:

1. Assume that the transistor is operating in active mode.

This analysis is mainly used to identify the operating point.

BJT DC analysis steps

Use the following steps when analyzing BJT circuits with DC voltages:

1. Assume that the transistor is operating in active mode.
2. Determine I_C , I_B, V_{CE} and V_{BE} using the active mode model.

This analysis is mainly used to identify the operating point.

BJT DC analysis steps

Use the following steps when analyzing BJT circuits with DC voltages:

1. Assume that the transistor is operating in active mode.
2. Determine I_C , I_B, V_{CE} and V_{BE} using the active mode model.
3. Check for consistency of results with active-mode operation such as $V_{CE} > V_{CEsat}$.

This analysis is mainly used to identify the operating point.

BJT DC analysis steps

Use the following steps when analyzing BJT circuits with DC voltages:

1. Assume that the transistor is operating in active mode.
2. Determine I_C , I_B, V_{CE} and V_{BE} using the active mode model.
3. Check for consistency of results with active-mode operation such as $V_{CE} > V_{CEsat}$.
4. If it is satisfied, the analysis is over.

This analysis is mainly used to identify the operating point.

BJT DC analysis steps

Use the following steps when analyzing BJT circuits with DC voltages:

1. Assume that the transistor is operating in active mode.
2. Determine I_C , I_B, V_{CE} and V_{BE} using the active mode model.
3. Check for consistency of results with active-mode operation such as $V_{CE} > V_{CEsat}$.
4. If it is satisfied, the analysis is over.
5. If not, assume saturation mode and repeat the analysis like active mode.

This analysis is mainly used to identify the operating point.

Example I

In Fig. 2, if $\beta = 100$ and $V_{BE} = 0.7\,V$, which mode is the transistor operating in?

- Using Kirchhoff's Voltage Law (KVL) on the base-emitter loop (Equation (1))

$$4\,V = V_{BE} + 3.3\,\text{k}\Omega I_E \tag{1}$$

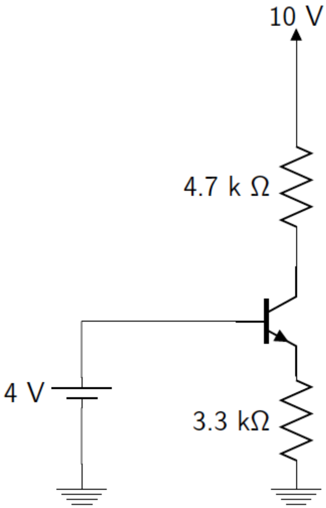


FIG 2. Example I

Example I

In Fig. 2, if $\beta = 100$ and $V_{BE} = 0.7\,V$, which mode is the transistor operating in?

- Using Kirchhoff's Voltage Law (KVL) on the base-emitter loop (Equation (1))

$$4\,V = V_{BE} + 3.3\,\mathrm{k\Omega}\,I_E \qquad (1)$$

- Solving Equation (1) gives $I_E = 1\,mA$

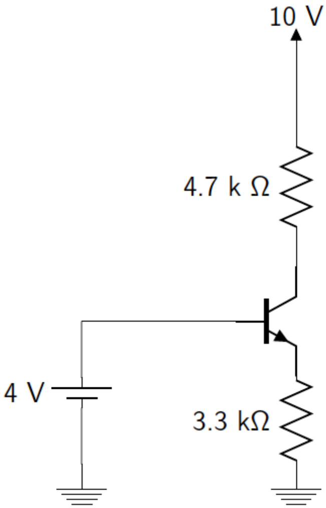


FIG 2. Example I

Example I

In Fig. 2, if $\beta = 100$ and $V_{BE} = 0.7\,V$, which mode is the transistor operating in?

- Using Kirchhoff's Voltage Law (KVL) on the base-emitter loop (Equation (1))

$$4\,V = V_{BE} + 3.3\,\mathrm{k}\Omega\, I_E \tag{1}$$

- Solving Equation (1) gives $I_E = 1\,mA$
- The base current I_B is calculated from its relationship to the emitter current

$$I_B = \frac{I_E}{\beta + 1} = 9.9\,\mu\mathrm{A} \tag{2}$$

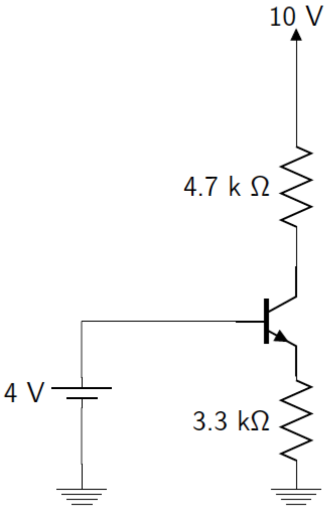


FIG 2. Example I

Example I

In Fig. 2, if $\beta = 100$ and $V_{BE} = 0.7\,V$, which mode is the transistor operating in?

- Using Kirchhoff's Voltage Law (KVL) on the base-emitter loop (Equation (1))

$$4\,V = V_{BE} + 3.3\,\mathrm{k}\Omega\, I_E \tag{1}$$

- Solving Equation (1) gives $I_E = 1\,mA$
- The base current I_B is calculated from its relationship to the emitter current

$$I_B = \frac{I_E}{\beta + 1} = 9.9\,\mu\mathrm{A} \tag{2}$$

- The collector current I_C is thus

$$I_C = \beta I_B = 0.99\,mA \tag{3}$$

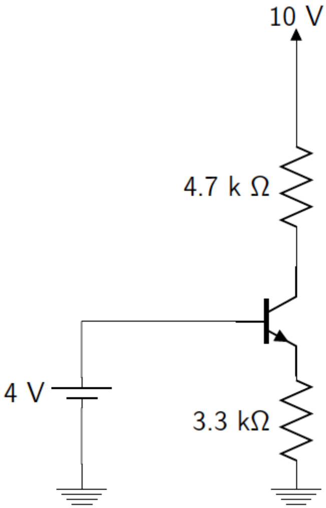


FIG 2. Example I

Example I

- To know the mode of operation of the transistors, we need to know V_{CE}.

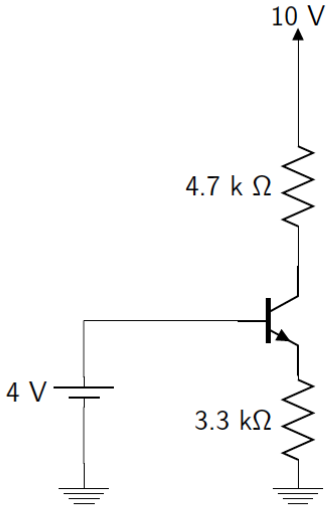


FIG 3. Example I

Example I

- To know the mode of operation of the transistors, we need to know V_{CE}.
- V_{CE} is obtained by applying KVL on the *CE* loop as shown in Equation (4):

$$V_{CE} = 10V - 4.7\,\text{kV}I_C - 3.3\,\text{kV}I_E = 2.047V \quad (4)$$

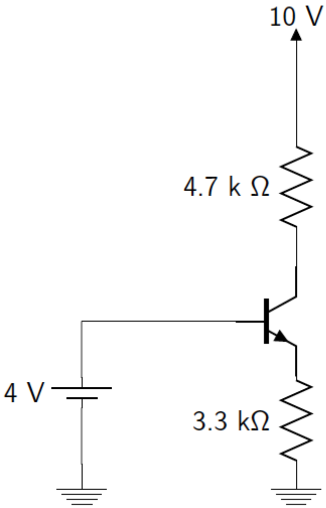


FIG 3. Example I

Example I

- To know the mode of operation of the transistors, we need to know V_{CE}.
- V_{CE} is obtained by applying KVL on the *CE* loop as shown in Equation (4):

$$V_{CE} = 10V - 4.7\,\text{kV}I_C - 3.3\,\text{kV}I_E = 2.047V \quad (4)$$

- Since $V_{CE} > V_{CEsat}$, it is operating in active mode.

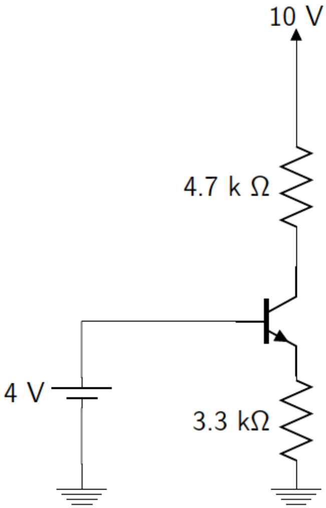
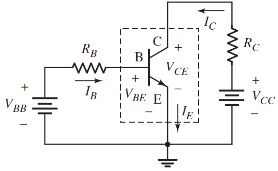


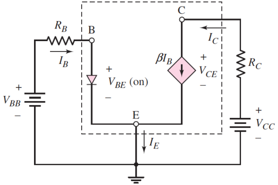
FIG 3. Example I

NPN Common-Emitter circuit

- We will assume that the *BEJ* is forward biased, so the voltage drop across that junction is the cut-in or turn-on voltage V_{BE}(on).



(a) npn transistor common-emitter



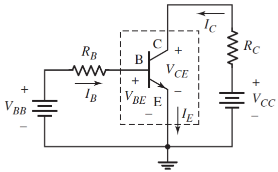
(b) dc equivalent circuit.

FIG 4. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

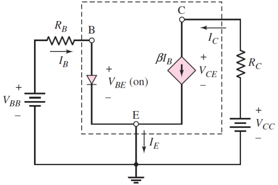
NPN Common-Emitter circuit

- We will assume that the *BEJ* is forward biased, so the voltage drop across that junction is the cut-in or turn-on voltage $V_{BE}(\text{on})$.
- The base current is given in Equation (5)

$$I_B = \frac{V_{BB} - V_{BE}(on)}{R_B} \tag{5}$$



(a) npn transistor common-emitter



(b) dc equivalent circuit.

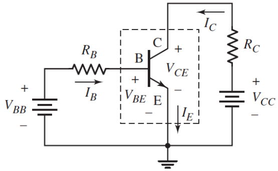
FIG 4. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

NPN Common-Emitter circuit

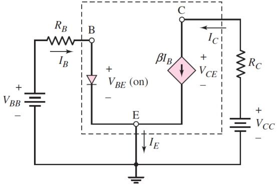
- We will assume that the *BEJ* is forward biased, so the voltage drop across that junction is the cut-in or turn-on voltage $V_{BE}(\text{on})$.
- The base current is given in Equation (5)

$$I_B = \frac{V_{BB} - V_{BE}(on)}{R_B} \qquad (5)$$

- Equation (5) implies that $V_{BB} > V_{BE}(on)$—which means that $I_B > 0$. Otherwise, $V_{BB} < V_{BE}(on)$, the transistor is OFF and $I_B = 0$.



(a) npn transistor common-emitter



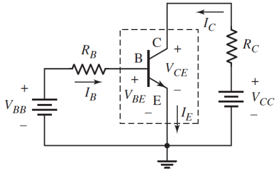
(b) dc equivalent circuit.

FIG 4. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

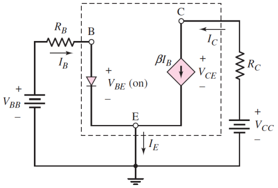
NPN Common-Emitter circuit

- The collector current is given Equation (6)

$$I_C = \beta I_B \qquad (6)$$



(a) npn transistor common-emitter



(b) dc equivalent circuit.

FIG 5. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

NPN Common-Emitter circuit

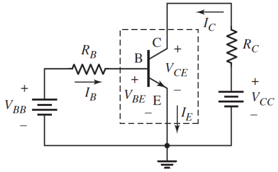
- The collector current is given Equation (6)

$$I_C = \beta I_B \qquad (6)$$

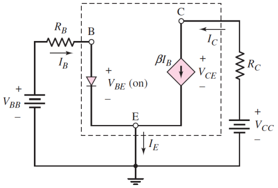
- Kirchhoff's voltage law allows to compute V_{CC} and V_{CE}

$$V_{CC} = I_C R_C + V_{CE} \qquad (7)$$

$$V_{CE} = V_{CC} - I_C R_C \qquad (8)$$



(a) npn transistor common-emitter



(b) dc equivalent circuit.

FIG 5. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

NPN Common-Emitter circuit

- The collector current is given Equation (6)

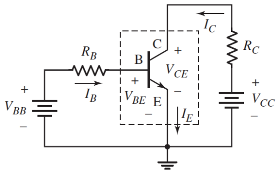
$$I_C = \beta I_B \tag{6}$$

- Kirchhoff's voltage law allows to compute V_{CC} and V_{CE}

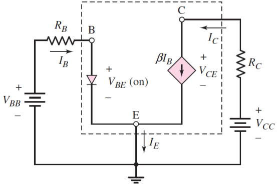
$$V_{CC} = I_C R_C + V_{CE} \tag{7}$$

$$V_{CE} = V_{CC} - I_C R_C \tag{8}$$

- Equation (8) implicitly assumes that $V_{CE} > V_{BE}(on)$—which means that the BCJ is reverse biased and the transistor is the forward active mode



(a) npn transistor common-emitter



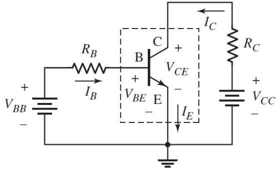
(b) dc equivalent circuit.

FIG 5. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

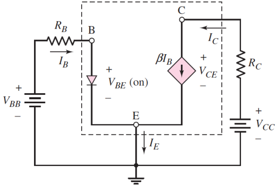
NPN Common-Emitter circuit

- The power dissipated in the transistor is given by Equation (9)

$$P_T = I_B V_{BE}(on) + I_C V_{CE} \quad (9)$$



(a) npn transistor common-emitter



(b) dc equivalent circuit.

FIG 6. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

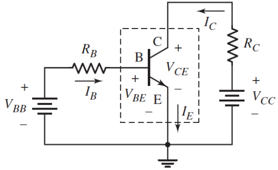
NPN Common-Emitter circuit

- The power dissipated in the transistor is given by Equation (9)

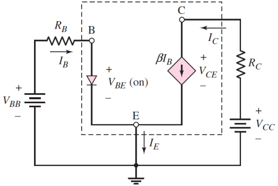
$$P_T = I_B V_{BE}(on) + I_C V_{CE} \quad (9)$$

- However, in most cases $I_C \ggg I_B$ and $V_{CE} > V_{BE}(on)$. Thus, Equation (9) can be simplified as shown in Equation (10)

$$P_T \approxeq I_C V_{CE} \quad (10)$$



(a) npn transistor common-emitter



(b) dc equivalent circuit.

FIG 6. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

NPN Common-Emitter circuit

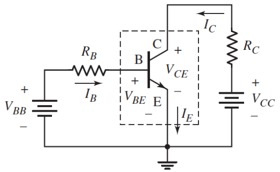
- The power dissipated in the transistor is given by Equation (9)

$$P_T = I_B V_{BE}(on) + I_C V_{CE} \quad (9)$$

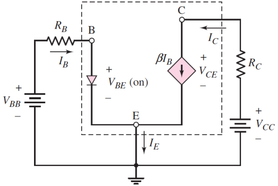
- However, in most cases $I_C \ggg I_B$ and $V_{CE} > V_{BE}(on)$. Thus, Equation (9) can be simplified as shown in Equation (10)

$$P_T \approxeq I_C V_{CE} \quad (10)$$

- The approximation in Equation (10), however, is not valid in the saturation mode.



(a) npn transistor common-emitter



(b) dc equivalent circuit.

FIG 6. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

Example II

Calculate the base, collector, emitter currents, the V_{CE} voltage and the transistor power dissipation for the common-emitter circuit shown in Fig. 7. Assume $\beta = 200$ and $V_{BE}(on) = 0.7\,V$

- The base current is found as

$$
\begin{aligned}
I_B &= \frac{V_{BB} - V_{BE}(on)}{R_B} \\
&= \frac{4\,V - 0.7\,V}{220k} \\
&= 15\,\mu A
\end{aligned}
\tag{11}
$$

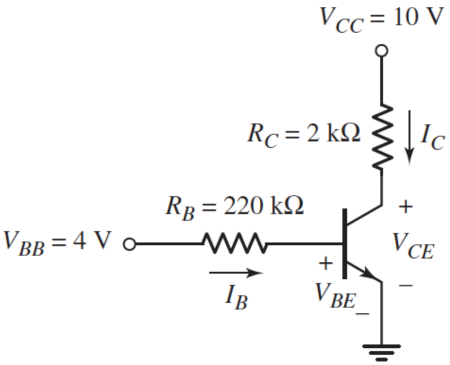


FIG 7. Example 2

Example II

Calculate the base, collector, emitter currents, the V_{CE} voltage and the transistor power dissipation for the common-emitter circuit shown in Fig. 7. Assume $\beta = 200$ and $V_{BE}(on) = 0.7V$

- The base current is found as

$$I_B = \frac{V_{BB} - V_{BE}(on)}{R_B} = \frac{4V - 0.7V}{220k} = 15\,\mu\text{A} \tag{11}$$

- The collector current is

$$I_C = \beta I_B = 200 \times 15\,\mu\text{A} = 3mA \tag{12}$$

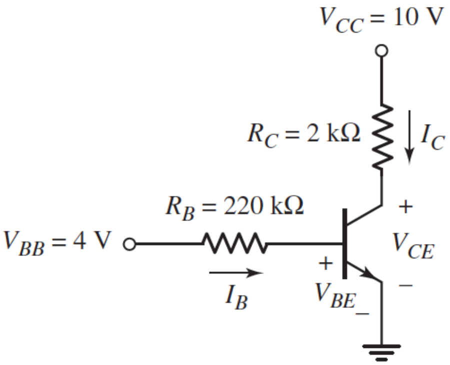


FIG 7. Example 2

- The emitter current is

$$I_E = (1+\beta) I_B = 3.02mA \quad (13)$$

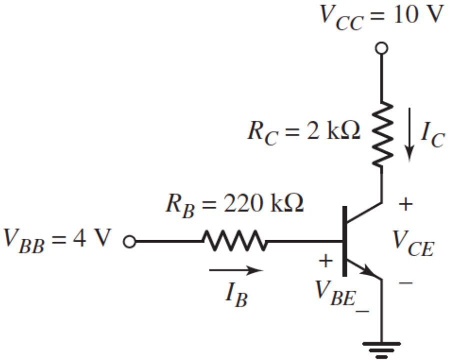


FIG 8. Example 2

- The emitter current is

$$I_E = (1 + \beta) I_B = 3.02 mA \qquad (13)$$

- The collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C = 4V \qquad (14)$$

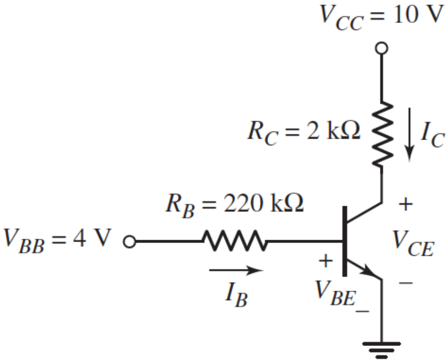


FIG 8. Example 2

- The emitter current is

$$I_E = (1+\beta)I_B = 3.02mA \qquad (13)$$

- The collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C = 4V \qquad (14)$$

- The power dissipated is

$$\begin{aligned} P_T &= I_B V_{BE}(on) + I_C V_{CE} \\ &= 0.015 \times 0.7 + 3 \times 4 \qquad (15) \\ &= 12mW \end{aligned}$$

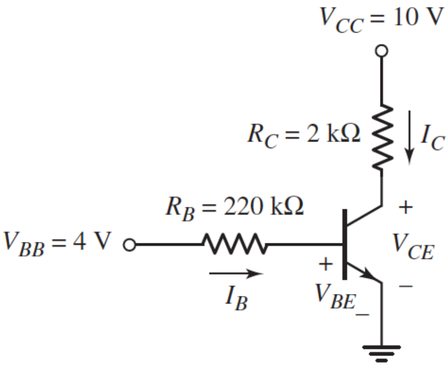


FIG 8. Example 2

- The emitter current is

$$I_E = (1+\beta)I_B = 3.02mA \quad (13)$$

- The collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C = 4V \quad (14)$$

- The power dissipated is

$$\begin{aligned} P_T &= I_B V_{BE}(on) + I_C V_{CE} \\ &= 0.015 \times 0.7 + 3 \times 4 \quad (15) \\ &= 12mW \end{aligned}$$

- Since $V_{BB} > V_{BE}(on)$ and $V_{CE} > V_{BE}(on)$, the transistor is biased in the forward-active mode.

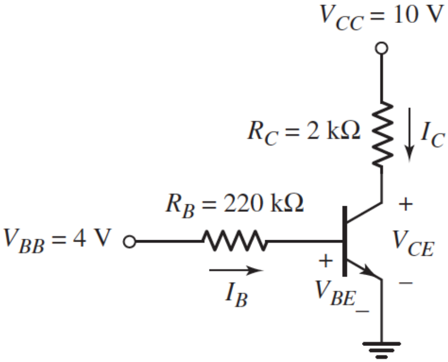
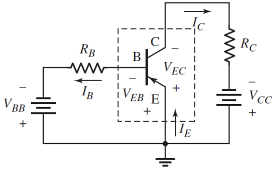


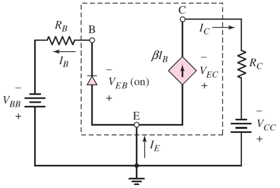
FIG 8. Example 2

PNP Common-Emitter circuit

- In Fig. 9, the emitter is at ground potential, which means that the polarities of the V_{BB} and V_{CC} power supplies must be reversed compared to those in the npn circuit.



(a) pnp transistor common-emitter



(b) dc equivalent circuit.

FIG 9. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

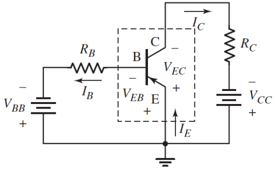
PNP Common-Emitter circuit

- In Fig. 9, the emitter is at ground potential, which means that the polarities of the V_{BB} and V_{CC} power supplies must be reversed compared to those in the npn circuit.
- The analysis proceeds exactly as before, and we can write:

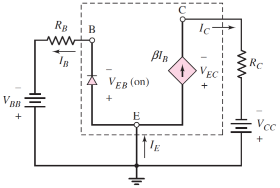
$$I_B = \frac{V_BB - V_{EB}(on)}{R_B} \quad (16)$$

$$I_C = \beta I_B \quad (17)$$

$$V_{EC} = V_{CC} - I_C R_C \quad (18)$$



(a) pnp transistor common-emitter



(b) dc equivalent circuit.

FIG 9. Common emitter—Transistor equivalent circuit is shown within the dotted lines with piecewise linear transistor parameters.

Example 3

Find I_B, I_C, I_E and R_C such that $V_{EC} = \frac{1}{2}V^+$ for the circuit given in Fig. 10. Assume $\beta = 100$ and $V_{EB}(on) = 0.6\,V$

$$I_C = \beta I_B = (100)(5\mu A) \Rightarrow 0.5\,\text{mA}$$

and the emitter current is

$$I_E = (1+\beta)I_B = (101)(5\mu A) \Rightarrow 0.505\,\text{mA}$$

For a C–E voltage of $V_{EC} = \frac{1}{2}V^+ = 2.5$ V, R_C is

$$R_C = \frac{V^+ - V_{EC}}{I_C} = \frac{5 - 2.5}{0.5} = 5\,\text{k}\Omega$$

In this case, $(V^+ - V_{BB}) > V_{EB}(on)$. Also, because VEC > VEB(on), the pnp bipolar transistor is biased in the forward-active mode.

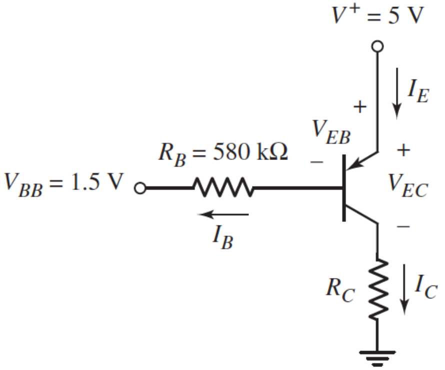


FIG 10. Example 3

The end