Faculty of Engineering

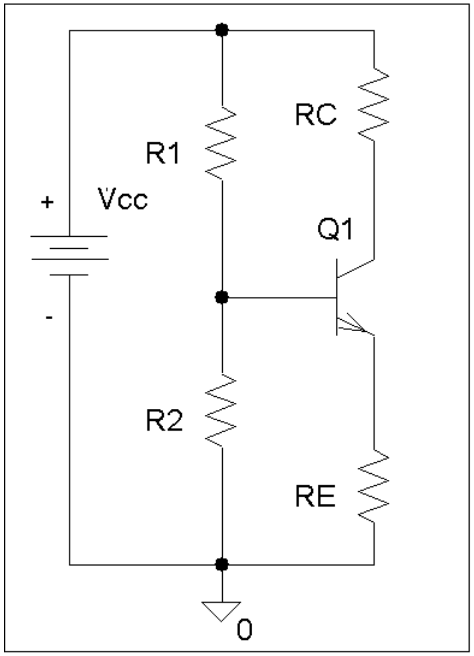
ECE 334: Electronic Circuits

Lecture 3:
BJT DC Circuit Analysis

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 the operating point should not be sensitive to variation to temperature or BJT β, which can vary widely

Example 1: Four Resistor bias Circuit for Stable ‘Q’ Point



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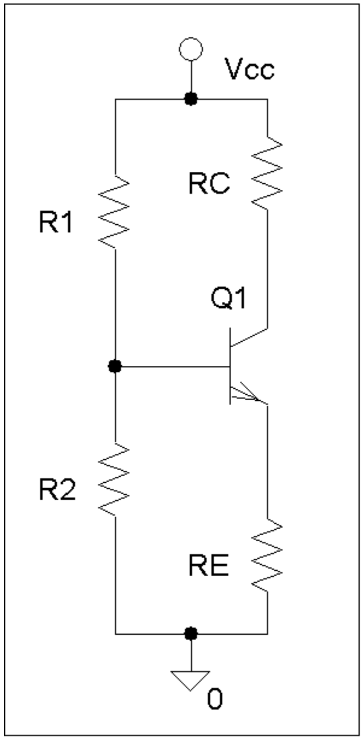
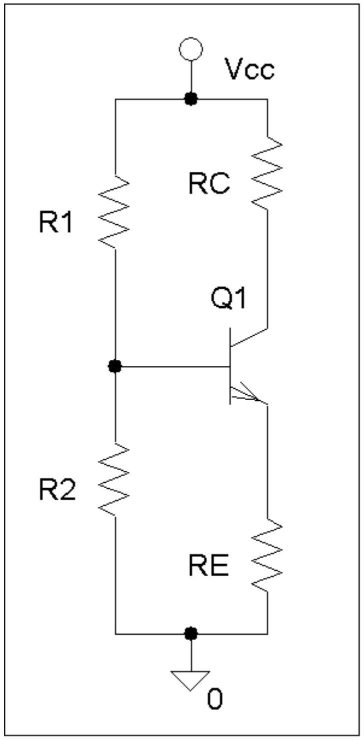


By far best circuit for providing stable bias point

Example 1



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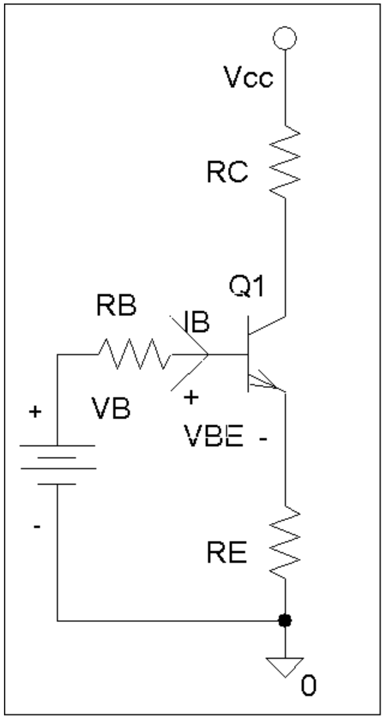


$$V_B = V_{TH} = \frac{Vcc\, R_2}{R_1 + R_2} \qquad R_B = R_{TH} = \frac{R_1\, R_2}{R_1 + R_2}$$

Example 1 (2)

Applying KVL to the base-emitter circuit of the Thevenized Equivalent form

$V_B - I_B R_B - V_{BE} - I_E R_E = 0$ (1)

Since $I_E = I_B + I_C = I_B + \beta I_B = (1+\beta) I_B$ (2)

Replacing I_E by $(1+\beta)I_B$ in (1), we get

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

If we design $(1+\beta)R_E >> R_B$ (say $(1+\beta)R_E >> 100R_B$)

Then $$I_B \approx \frac{V_B - V_{BE}}{(1+\beta)R_E} \qquad (4)$$

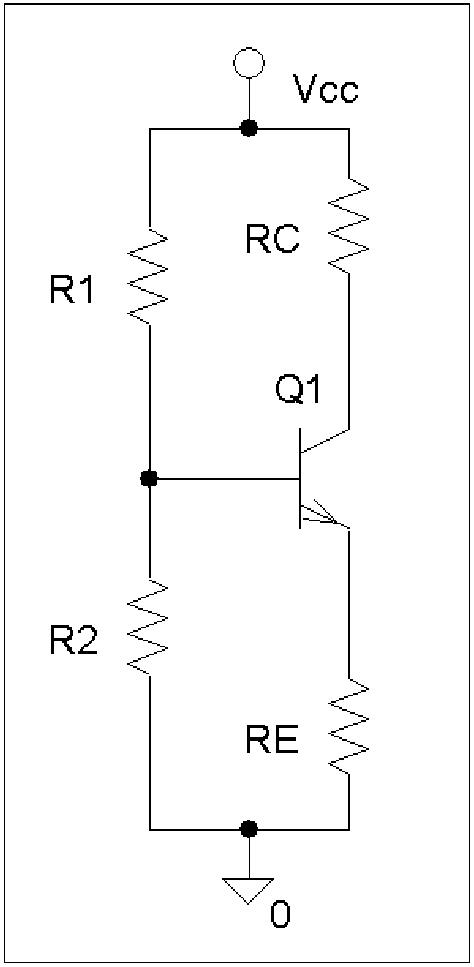
Example 1 (3)

And $$I_C = I_E \approx \frac{V_B - V_{BE}}{R_E} \quad \text{(for large } \beta\text{)} \qquad (5)$$

Hence I_C and I_E become independent of β!

Thus we can setup a Q-point independent of β which tends to vary widely even within transistors of identical part number (For example, β of 2N2222A, a NPN BJT can vary between 75 and 325 for I_C = 1 mA and V_{CE} = 10V)

Example 2



A 2N2222A is connected as shown with $R_1 = 6.8\ k\Omega$, $R_2 = 1\ k\Omega$, $R_C = 3.3\ k\Omega$, $R_E = 1\ k\Omega$ and $V_{CC} = 30V$. Assume $V_{BE} = 0.7V$.

Compute V_{CC} and I_C for β = i)100 and ii) 300

Example 2 (2)

i) $\beta = 100$

$$V_B = V_{TH} = \frac{Vcc\,R_2}{R_1 + R_2} = \frac{30 * 1}{6.8 + 1} = 3.85\text{V}$$

$$R_B = R_{TH} = \frac{R_1\,R_2}{R_1 + R_2} = \frac{6.8 * 1}{6.8 + 1} = 0.872\text{k}\Omega$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta)R_E} = \frac{3.85 - 0.7}{0.872 + 101 * 1} = 30.92\mu\text{A}$$

$I_{CQ} = \beta I_B = 3.09$ mA

$I_{EQ} = (1+\beta)I_B = 3.12$ mA

$V_{CEQ} = V_{CC} - I_C R_C - I_E R_E = 30 - 3.09 * 3.3 - 3.12 * 1 = 16.68\text{V}$

Example 2 (3)

i) β = 300

$$V_B = V_{TH} = \frac{Vcc\,R_2}{R_1 + R_2} = \frac{30*1}{6.8+1} = 3.85\mathrm{V}$$

$$R_B = R_{TH} = \frac{R_1\,R_2}{R_1 + R_2} = \frac{6.8*1}{6.8+1} = 0.872\mathrm{k}\Omega$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta)R_E} = \frac{3.85-0.7}{0.872+301*1} = 10.43\mu\mathrm{A}$$

I_{CQ} = 300I_B = 3.13 mA
I_{EQ} = (1+ β)I_B = 3.14 mA

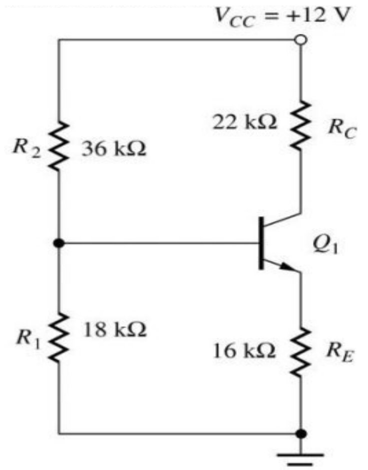
V_{CEQ} = V_{CC}-$I_C R_C$-$I_E R_E$ = 30-3.13*3.3-3.14*1=16.53V

Example 2 (4)

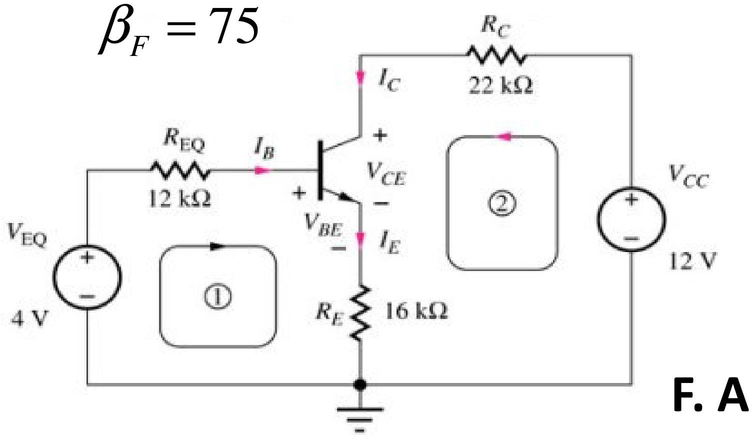
	β = 100	β = 300	% Change
VCEQ	16.68 V	16.53 V	0.9 %
ICQ	3.09 mA	3.13 mA	1.29 %

The above table shows that even with wide variation of β the bias points are very stable.

Example 3



$$\beta_F = 75$$



$$V_{EQ} = V_{CC}\frac{R_1}{R_1+R_2} \qquad R_{EQ} = R_1 \| R_2 = \frac{R_1R_2}{R_1+R_2}$$

$$V_{EQ} = R_{EQ}I_B + V_{BE} + R_EI_E$$

$$4 = 12{,}000\ I_B + 0.7 + 16{,}000\ (\beta_F + 1)I_B$$

$$\therefore I_B = \frac{V_{EQ} - V_{BE}}{R_{EQ} + (\beta_F + 1)R_E} = \frac{4\,\text{V} - 0.7\,\text{V}}{1.23 \times 10^6\ \Omega} = 2.68\ \mu\text{A}$$

$$I_C = \beta_F I_B = 201\ \mu\text{A}$$

$$I_E = (\beta_F + 1)I_B = 204\ \mu\text{A}$$

$$V_{CE} = V_{CC} - R_CI_C - R_EI_E$$

$$V_{CE} = V_{CC} - \left(R_C + \frac{R_F}{\alpha_F}\right)I_C = 4.32\ \text{V}$$

F. A. region correct - Q-point is (201 μA, 4.32 V)

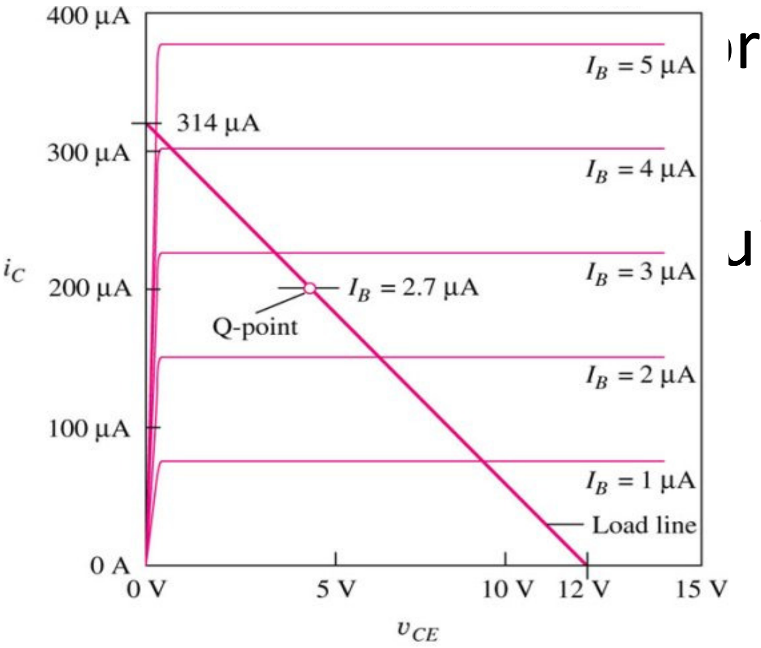
Example 3 (2)

- All calculated currents > 0, $V_{BC} = V_{BE} - V_{CE} = 0.7 - 4.32 = -3.62$ V

$$V_{CE} = V_{CC} - \left(R_C + \frac{R_F}{\alpha_F}\right) I_C = 12 - 38,200\, I_C$$

- Hence, base-collector junction is reverse-biased,

rward-active region operation



uit is:

The two points needed to plot the load line are (0, 12 V) and (314 μA, 0). Resulting load line is plotted on common-emitter output characteristics.

I_B = 2.7 μA, intersection of corresponding characteristic with load line gives Q-point.

Four-Resistor Bias Network for BJT: Design Objectives

- We know that

$$I_E = \frac{V_{EQ} - V_{BE} - R_{EQ} I_B}{R_E} \cong \frac{V_{EQ} - V_{BE}}{R_E} \quad \text{for} \quad R_{EQ} I_B << (V_{EQ} - V_{BE})$$

- This implies that $I_B << I_2$, so that $I_1 = I_2$. So base current doesn't disturb voltage divider action. Thus, Q-point is independent of base current as well as current gain.
- Also, V_{EQ} is designed to be large enough that small variations in the assumed value of V_{BE} won't affect I_E.
- Current in base voltage divider network is limited by choosing $I_2 \leq I_C/5$.

This ensures that power dissipation in bias resistors is < 17 % of total quiescent power consumed by circuit and $I_2 >> I_B$ for $\beta > 50$.

Four-Resistor Bias Network for BJT: Design Guidelines

- Choose Thévenin equivalent base voltage $\frac{V_{CC}}{4} \le V_{EQ} \le \frac{V_{CC}}{2}$
- Select R_1 to set $I_1 = 9I_B$. $R_1 = \frac{V_{EQ}}{9 I_B}$
- Select R_2 to set $I_2 = 10I_B$. $R_2 = \frac{V_{CC} - V_{EQ}}{10 I_B}$
- R_E is determined by V_{EQ} and desired I_C. $R_E \cong \frac{V_{EQ} - V_{BE}}{I_C}$
- R_C is determined by desired V_{CE}. $R_C \cong \frac{V_{CC} - V_{CE}}{I_C} - R_E$

Example 4

- **Problem:** Design 4-resistor bias circuit with given parameters.
- **Given data:** I_C = 750 μA, β_F **=** 100, V_{CC} = 15 V, V_{CE} = 5 V
- **Assumptions:** Forward-active operation region, V_{BE} = 0.7 V
- **Analysis:** Divide **(**V_{CC} **-** V_{CE}**)** equally between R_E and R_C. Thus, V_E = 5 V and V_C = 10 V

$$R_C = \frac{V_{CC} - V_C}{I_C} = 6.67 \text{ k}\Omega$$

$$R_E = \frac{V_E}{I_E} = 6.60 \text{ k}\Omega$$

$$V_B = V_E + V_{BE} = 5.7 \text{ V}$$

$$I_B = \frac{I_C}{\beta_F} = 7.5 \ \mu\text{A}$$

$$I_2 = 10 I_B = 75.0 \ \mu\text{A}$$

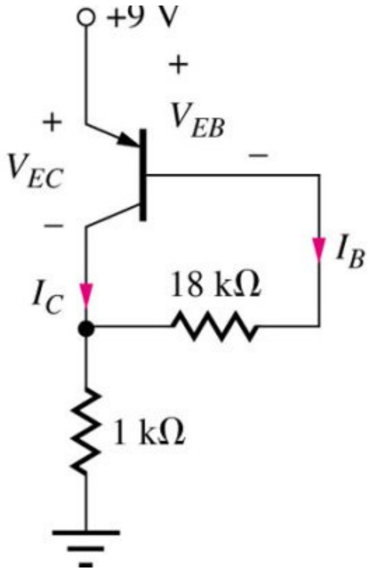
$$I_1 = 9 I_B = 67.5 \ \mu\text{A}$$

$$R_1 = \frac{V_B}{9 I_B} = 84.4 \text{ k}\Omega$$

$$R_2 = \frac{V_{CC} - V_B}{10 I_B} = 124 \text{ k}\Omega$$

Example 5

- **Problem:** Find Q-point for *pnp* transistor in 2-resistor bias circuit with given parameters.
- **Given data:** β_F **=** 50, V_{CC} = 9 V
- **Assumptions:** Forward-active operation region, V_{EB} = 0.7 V
- **Analysis:**



$$9 = V_{EB} + 18{,}000\ I_B + 1000\ (I_C + I_B)$$
$$\therefore 9 = V_{EB} + 18{,}000\ I_B + 1000\ (51) I_B$$

$$\therefore I_B = \frac{9\text{V} - 0.7\text{V}}{69{,}000\ \Omega} = 120\ \ \mu\text{A}$$
$$I_C = 50\, I_B = 6.01\ \text{mA}$$

$$V_{EC} = 9 - 1000\ (I_C + I_B) = 2.88\ \ \text{V}$$
$$V_{BC} = 2.18\ \ \text{V}$$

Forward-active region operation is correct Q-point is : (6.01 mA, 2.88 V)