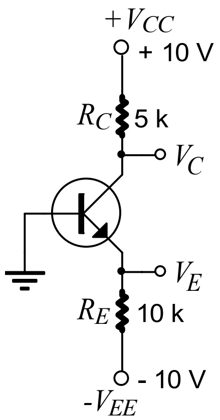
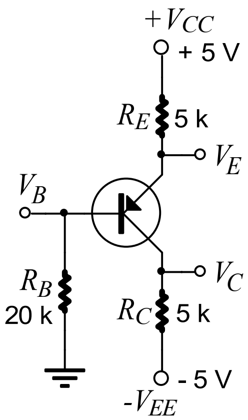
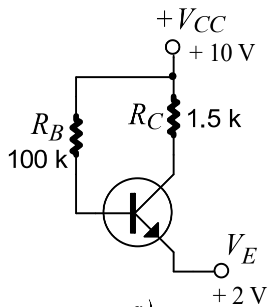
Applications



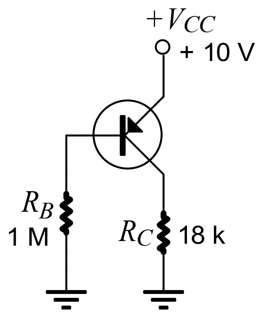
P1)



P2)



a)



b)

P3)

S5 – P1. In the circuit shown in figure (*P1*) the voltage at the emitter was measured: $v_E = -0.7\,\text{V}$. If $\beta = 50$, find I_E, I_B, I_C, V_C and α.

$$I_E = \frac{V_{R_E}}{R_E} = \frac{V_E - (-V_{EE})}{R_E} \qquad I_E = \frac{V_E - (-V_{EE})}{R_E} = \frac{-0.7 + 10}{10k} = 0.93\,\text{mA}.$$

$$I_E = I_C + I_B\,,\;\; I_C = \beta \cdot I_B\,, \qquad I_E = \beta \cdot I_B + I_B = (\beta + 1) \cdot I_B\,, \qquad I_B = \frac{I_E}{\beta + 1} = \frac{0.93}{51} = 18.2\,\mu\text{A}.$$

$$I_C = I_E - I_B = 0.912\,\text{mA}.$$

$$V_C = V_{CC} - R_C I_C = 10 - 0.912m \cdot 5k = 5.44\,\text{V}.$$

$$V_{CE} = V_C - V_E = 5.44 - (-0.7) = 6.14\,\text{V} \qquad (V_{CE} > V_{CEsat}),$$

$$I_C = \alpha \cdot I_E\,, \qquad \alpha = \frac{I_C}{I_E} = \frac{\beta}{\beta + 1} = 0.98\,.$$

S5 – P2. Home-work

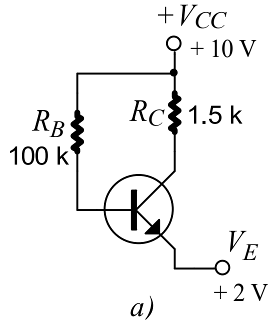
A single measurement indicates the emitter voltage in the circuit of figure (*P2*) to be $1.0\,\text{V}$. Under the assumption that $v_{EB} = V_D = 0.7\,\text{V}$ what are: I_B, I_C, I_E, V_C, β and α. (Isn't it surprising what only one measurement can do?)

$$I_B = \frac{V_B}{R_C} = \frac{V_E - V_{BE}}{R_B} = \frac{1-0.7}{20k} = 0.015\,\text{mA} = 15\,\mu\text{A},\; I_E = \frac{V_{CC}-V_E}{R_E} = \frac{5-1}{5k} = 0.8\,\text{mA}.$$

$$I_C = I_E - I_B = 0.785\,\text{mA},\; V_C = -V_{EE} + R_C I_C = -5 + 5k \cdot 0.785m = -1.075\,\text{V},$$

$$V_{CE} = V_C - V_E = 2.075\,\text{V}\;(>V_{CEsat}),\; \beta = \frac{I_C}{I_B} = \frac{785\mu}{15\mu} = 52.3\,,\; \alpha = \frac{I_C}{I_E} = \frac{785\mu}{800\mu} = 0.98\,.$$

S5 – P3. Identify wheather the transistors in figures (*P3*) operate in the active or saturation mode. What is the base voltage in each case? If active, what is the collector voltage? Consider V_D=0.7 V and the cases with β=50 and β=100.



a)

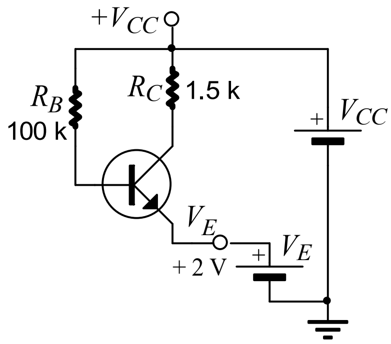
a) $V_B = V_E + V_{BE} = V_E + V_D = 2.7\,\text{V}$,

$$I_B = \frac{V_{CC}-V_B}{R_B} = \frac{12-2.7}{100k} = 93\,\mu\text{A}.$$

$$I_{C\max} = \frac{V_{CC}-V_E}{R_C} = \frac{12-2}{1.5k} = 6.7\,\text{mA},$$

$$I_{Bsat} = \frac{I_{C\max}}{\beta} = \frac{6.7}{50...100} = 134\,\mu\ldots 67\,\mu\text{A},$$

- For β=50, $I_B < I_{Bsat}$ (93 μ<134 μA), the BJT is in the active mode and
  $V_C = V_{CC} - R_C I_C = V_{CC} - R_C \beta \cdot I_B$
  $V_C = 12 - 1.5k \cdot 50 \cdot 93\mu = 5.025\,\text{V}$.
- For β=100, $I_B > I_{Bsat}$ (93 μ>67 μA), the BJT is in the saturation mode.



b) Home-work

$V_B = V_E - V_{EB} = V_{CC} - V_D = 10 - 0.7 = 9.3\,\text{V}$, $I_B = \dfrac{V_B}{R_B} = \dfrac{9.3}{1M} = 9.3\,\mu\text{A}$.

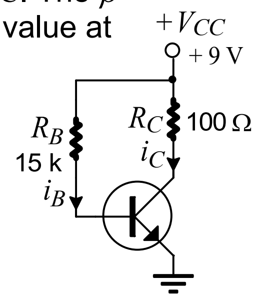
$I_{C\max} = \dfrac{V_{CC}}{R_C} = \dfrac{10}{18k} = 0.56\,\text{mA}$, $I_{Bsat} = \dfrac{I_{C\max}}{\beta} = \dfrac{0.56}{50...100} = 11\mu\ldots 5.6\mu\text{A}$,

- For β=50 , $I_B < I_{Bsat}$ (9.3 μ<11 μA), the BJT is in the active mode and $V_C = R_C I_C = R_C \beta \cdot I_B = 18k \cdot 50 \cdot 9.3\mu = 8.37\,\text{V}$.
- For β=100 , $I_B > I_{Bsat}$ (9.3 μ>5.6 μA), the BJT is in the saturation mode.

S5 – P4. The data sheet for a particular transistor specifies a minimum β of 50 and a maximum β of 130, $v_{BE}=V_D=0.7\,\text{V}$ and $V_{CEsat}=0.3\,\text{V}$.

a) What range of Q point can be expected if an attempt is made to mass-produce the circuit in figure. Is this range acceptable?

b) The base bias circuit is subject to a temperature variation from 0 to 70°C. The β decreases by 20% at 0°C and increases by 35% at 70°C from its nominal value at 25°C. Compute the Q point limits for the specified temperature range.



a) $I_B = \dfrac{V_{CC} - v_{BE}}{R_B} = \dfrac{V_{CC} - V_D}{R_B} = \dfrac{9 - 0.7}{15k} = 0.553\,\text{mA}$.

$I_C = \beta \cdot I_B = (50...130) \cdot 0.553m = 28...72\ \text{mA}$.

$V_{CE} = V_{CC} - R_C I_C = 9 - 0.1k \cdot (28...72)m = 6.2...1.8\,\text{V}$.

This range of Q point is not acceptable because of the big variations of I_C and V_{CE}.

b) $\beta_{\min} = 0.8 \cdot 50 = 40$, $\beta_{\max} = 1.35 \cdot 130 = 175.5$;

$I_{C\min} = \beta_{\min} \cdot I_B = 40 \cdot 0.553m = 22\,\text{mA}$, $V_{CE\max} = V_{CC} - R_C I_{C\max} = 9 - 0.1k \cdot 22m = 6.8\,\text{V}$.

$I_{C\max} = \beta_{\max} \cdot I_B = 175.5 \cdot 0.553m = 97\,\text{mA}$, $V_{CE\min} = V_{CC} - R_C I_{C\max} = 9 - 0.1k \cdot 97m = -0.7\,\text{V}$.

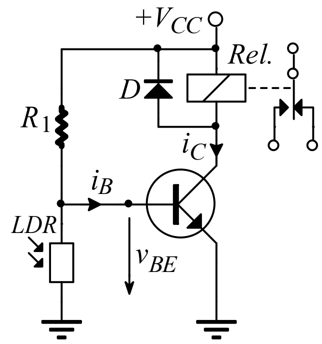
A negative value for V_{CE} is not possible; it means that the transistor is saturated. The maximum I_C and maximum β in active mode are:

$I_{C\max} = \dfrac{V_{CC} - V_{CEsat}}{R_C} = \dfrac{9 - 0.3}{0.1k} = 87\,\text{mA}$, $\beta = \dfrac{I_{C\max}}{I_B} = \dfrac{87m}{0.553m} = 157$. For $\beta > 157$ the circuit will saturate the BJT and the corresponding Q point is: $I_C = 87\,\text{mA}$ and $V_{CE} = V_{CEsat} = 0.3\,\text{V}$.

S5 – P5. Design optical relay with BJT.

a) What R_1 is necessary for the relay to be energized when the light determines a photo-resistance value $R_{LDR} = 5\text{k}\Omega$ (light decreasing resistance or light dependent resistance)?

Consider the circuit in figure with: $V_{CC} = 12\text{V}$, $V_{BE} = V_D = 0{,}7\text{V}$, $\beta = 100$, a relay resistance $R_{Rel} = 1\text{k}\Omega$ and a relay threshold voltage (at which the relay switch) $V_T = 6\text{V}$.



b) For the circuit determined previously, for what photo-resistance value will the relay switch if the transistor $\beta = 200$.

a) The relay switches when the threshold voltage is applied over the relay. The relay current is the collector current of the transistor (the diode is reversed bias - cutoff - when the relay is energized). The transistor currents are:

$$i_C = i_{Rel} - i_A = i_{Rel} = \frac{V_T}{R_{Rel}} = \frac{6}{1\text{k}} = 6\text{mA}.$$

The transistor is in active mode: $V_{CE} > V_{CEsat} = 0.2...0.4\text{V}$; $V_{CE} = V_{CC} - V_{Rel} = 12 - 6 = 6\text{V}$

that gives: $I_C = \beta \cdot I_B$ and $i_B = \frac{i_C}{\beta} = \frac{6\text{m}}{100} = 0{,}06\text{mA}$.

The previous base current should appear for $R_{LDR} = 5\text{k}\Omega$. The currents in photo-resistance and in R_1 can be determined by Ohm's Law and IKL (Current Kirkhhoff Law):

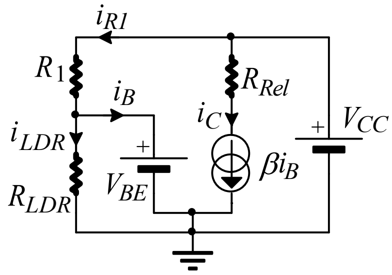
$$i_{LDR} = \frac{V_{BE}}{R_{LDR}} = \frac{0{,}7}{5\text{k}} = 0{,}14\text{mA}, \quad i_{R1} = i_B + i_{LDR} = 0{,}2\text{mA}, \quad R_1 = \frac{V_{CC} - V_{BE}}{i_{R1}} = \frac{11{,}3}{0{,}2\text{m}} \cong 56\text{k}\Omega.$$

b) Home-work

If the BJT current factor increases, the current needed in the transistor base decreases (the collector current remains the same), the current would be the same and the relay would switch for a different value of photo-resistance (hence a different light):

$$i_{LDRb} = i_{R1} - \frac{i_C}{\beta_b} = 0{,}2\text{m} - \frac{6\text{m}}{200} = 0{,}17\text{mA}, \quad R_{LDRb} = \frac{V_{BE}}{i_{LDRb}} = \frac{0{,}7}{0{,}17\text{m}} = 4{,}12\text{k}\Omega .$$

The analysis have been made with the BJT model implicitly assumed. The equivalent circuit (with the transistor model) is represented in the next figure.



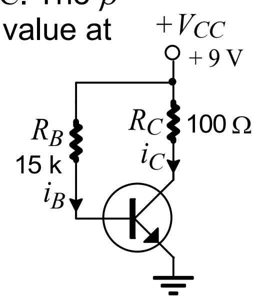
Notes:

1. For the proposed application a photo-resistance change from 5kΩ to about 4kΩ is acceptable; the optical relay will switch at a little bit higher light for a transistor with a higer current factor.
2. The diode is placed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a voltage spike dangerous to the transistor. Such a diode should be used when the relays are switched by electronic components.

S6 – P1. The data sheet for a particular transistor specifies a minimum β of 50 and a maximum β of 130, $v_{BE}=V_D=0.7\text{ V}$ and $V_{CEsat}=0.3\text{ V}$.

a) What range of Q point can be expected if an attempt is made to mass-produce the circuit in figure. Is this range acceptable?

b) The base bias circuit is subject to a temperature variation from 0 to 70°C. The β decreases by 20% at 0°C and increases by 35% at 70°C from its nominal value at 25°C. Compute the Q point limits for the specified temperature range.



a) $I_B = \dfrac{V_{CC} - v_{BE}}{R_B} = \dfrac{V_{CC} - V_D}{R_B} = \dfrac{9 - 0.7}{15k} = 0.553\text{ mA}.$

$I_C = \beta \cdot I_B = (50...130) \cdot 0.553m = 28...72\text{ mA}.$

$V_{CE} = V_{CC} - R_C I_C = 9 - 0.1k \cdot (28...72)m = 6.2...1.8\text{ V}.$

This range of Q point is not acceptable because of the big variations of I_C and V_{CE}.

b) $\beta_{\min} = 0.8 \cdot 50 = 40$, $\beta_{\max} = 1.35 \cdot 130 = 175.5$;

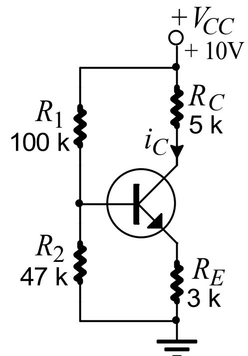
$I_{C\min} = \beta_{\min} \cdot I_B = 40 \cdot 0.553m = 22\text{ mA}$, $V_{CE\max} = V_{CC} - R_C I_{C\max} = 9 - 0.1k \cdot 22m = 6.8\text{ V}.$

$I_{C\max} = \beta_{\max} \cdot I_B = 175.5 \cdot 0.553m = 97\text{ mA}$, $V_{CE\min} = V_{CC} - R_C I_{C\max} = 9 - 0.1k \cdot 97m = -0.7\text{ V}.$

A negative value for V_{CE} is not possible; it means that the transistor is saturated. The maximum I_C and maximum β in active mode are:

$I_{C\max} = \dfrac{V_{CC} - V_{CEsat}}{R_C} = \dfrac{9 - 0.3}{0.1k} = 87\text{ mA}$, $\beta = \dfrac{I_{C\max}}{I_B} = \dfrac{87m}{0.553m} = 157$. For $\beta>157$ the circuit will saturate the BJT and the corresponding Q point is: $I_C=87\text{ mA}$ and $V_{CE}=V_{CEsat}=0.3\text{ V}$.

S6 – P2. Consider the circuit of figure, *a)* initially for infinite β, *b)* then for $\beta=100$. Find the voltages at all nodes and the currents through all branches in the circuit for $v_{BE}=V_D=0.7\text{ V}$.



a) $I_B = \dfrac{I_E}{\beta} = \dfrac{I_E}{\infty} = 0$;

V_{CC}, R_1 and R_2 is a voltage divider, operating with no load ($I_B=0$)

$V_2 = V_B = \dfrac{R_2}{R_1 + R_2} V_{CC} = 3.2\text{ V},\ V_E = V_B - V_{BE} = 2.5\text{ V}.$

$I_E = \dfrac{V_E}{R_E} = \dfrac{2.5}{3k} = 0.83\text{ mA},\ I_C = I_E - I_B = I_E = 0.83\text{ mA},$

$V_C = V_{CC} - R_C I_C = 10 - 5k \cdot 0.83m = 5.83\text{ V}.$

b) Home-work

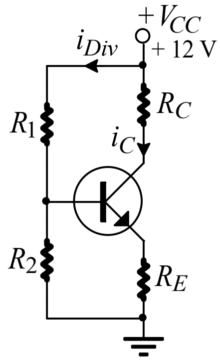
$$V_{BB} = 3.2\,\text{V},\ R_B = R_1 \| R_2 = 32\,\text{k}\Omega,\ I_E = \frac{V_{BB} - V_{BE}}{R_E + R_B/(\beta+1)} = \frac{2.5}{3k + 32k/101} = 0.754\,\text{mA},$$

$$I_B = I_E/(\beta+1) = 7.46\,\mu\text{A},\ I_C = \beta \cdot I_B = 0.746\,\text{mA},$$

$$V_B = V_{BB} - R_B I_B = 3.2 - 32k \cdot 7.46\mu = 2.96\,\text{V},\ V_E = R_E I_E = 3k \cdot 0.754m = 2.26\,\text{V},$$

$$V_C = V_{CC} - R_C I_C = 10 - 5k \cdot 0.746m = 6.27\,\text{V}.$$

S6 – P3. *a)* Design the bias network of the circuit in figure to establish a current $I_C = 1\,\text{mA}$ whith $v_{BE} = V_D = 0.7\,\text{V}$, using a power supply $V_{CC} = 12\,\text{V}$.
b) Calculate the expected range of I_C and V_{CE} if the transistor β is in the range of 100 to 300.
Hints: 1. Allocate one-third of the supply voltage to the votage drop across R_2 and another third to the voltage drop across R_C, leaving one-third for possible signal swing at the collector.
2. Consider the current in the divider at least a tenth of the collector current.



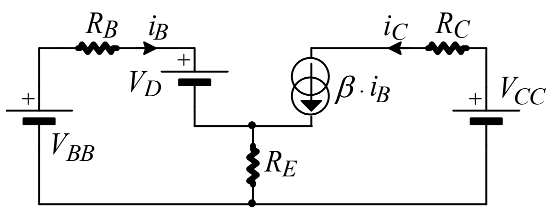
$$a)\ V_B = \frac{V_{CC}}{3} = 4\,\text{V},\quad V_E = V_B - V_{BE} = 3.3\,\text{V},\quad R_E = \frac{V_E}{I_E} \cong \frac{V_E}{I_C} = \frac{3.3}{1m} = 3.3\,\text{k}\Omega,$$

$$\left(I_E = I_C + I_B = I_C + \frac{I_C}{\beta} = I_C\left(1 + \frac{1}{\beta}\right) \cong I_C\right) \qquad R_C = \frac{V_{CC} - V_C}{I_E} = \frac{V_{CC}/3}{I_C} = \frac{4}{1m} = 4\,\text{k}\Omega,$$

$$I_{Div} = \frac{I_C}{10} = 0.1\ \text{mA},\ R_1 + R_2 \cong \frac{V_{CC}}{I_{Div}} = \frac{12}{0.1m} = 120\,\text{k}\Omega,$$

$$V_B (= V_{BB}) \cong \frac{R_2}{R_1 + R_2} V_{CC} \Rightarrow R_2 = \frac{V_B}{V_{CC}}(R_1 + R_2) = \frac{4}{12} 120k = 40\,\text{k}\Omega,\quad R_1 = (R_1 + R_2) - R_2 = 80\,\text{k}\Omega.$$

We could, of course, obtain a value much closer to the desired I_C by designing with exact equations (considering R_B that gives different values for V_B and V_{BB}). However, since our work is based on first order models, it does not make sense to strive for accuracy better than about 10%.



b)

$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC} = 4\,\text{V},\ R_B = R_1 \| R_2 = 27\,\text{k}\Omega,$$

$$I_C = \beta \frac{V_{BB} - V_{BE}}{R_B + R_E \cdot (\beta+1)} = \frac{(100...300) \cdot 3.3}{27k + 3.3k \cdot (101...301)} = 0.917...0.971\,\text{mA},$$

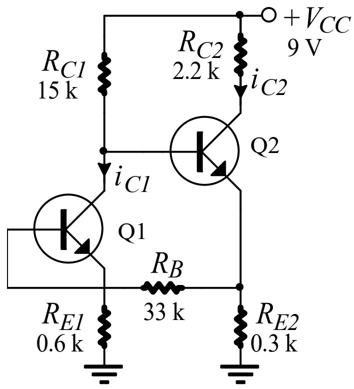
$$V_{CE} \cong V_{CC} - (R_C + R_E) \cdot I_C = 12 - (4k + 3.3k) \cdot (0.917...0.971)m = 5.31...4.91\,\text{V}.$$

The current variation is: $\frac{\Delta I_C}{I_{Cmed}} = \frac{0.054}{0.944} = 5.7\,\%$ for a current gain variation of $\frac{\Delta\beta}{\beta_{med}} = \frac{200}{200} = 100\,\%$; the variation is reduced significantly (approximately 18 times).

S6 – P4. The transistors in figure have β=300, $V_{BE1}=V_{D1}=0.6\,\text{V}$ and $V_{BE2}=V_{D2}=0.7\,\text{V}$. What are I_C and V_{CE} at the Q point for the transistor.

We assume $I_C= I_E$ (the currents differ by about 0.3% for the given β). We neglect also the base curents in respect to the collector currents; after the currents are determined, we verify these assumptions. We need two equations (KVL) to determine the two collector currents:

(a) $V_{CC} = R_{C1}I_{C1} + V_{BE2} + R_{E2}I_{C2}$, *(b)* $R_{E2}I_{C2} = R_B\frac{I_{C1}}{\beta} + V_{BE1} + R_{E1}I_{C1}$.



By replacing the 2nd equation *(b)* in the 1st one *(a)* we get:

$V_{CC} = R_{C1}I_{C1} + V_{BE2} + R_B\frac{I_{C1}}{\beta} + V_{BE1} + R_{E1}I_{C1}$ and

$$I_{C1} = \frac{V_{CC} - V_{BE1} - V_{BE2}}{R_{C1} + R_{E1} + \frac{R_B}{\beta}} = \frac{9 - 0.6 - 0.7}{15k + 0.6k + \frac{33k}{300}} = 0.49\,\text{mA}.$$

$$I_{C2} = \frac{V_{CC} - R_{C1}I_{C1} - V_{BE2}}{R_{E2}} = \frac{9 - 15k\cdot 0.49m - 0.7}{0.3k} = 3.17\,\text{mA}.$$

We check the currents: $I_{B1} << I_{C2}$ and $I_{B2} << I_{C1}$:

$I_{B1} = \frac{I_{C1}}{\beta} = \frac{490\mu}{30} = 1.63\,\mu\text{A}$, $\frac{I_{C2}}{I_{B1}} = \frac{3170\mu}{1.63\mu} = 1945$, so that

$I_{B1} << I_{C2}$ (1940 times lower);

$I_{B2} = \frac{I_{C2}}{\beta} = \frac{3170\mu}{300} = 10.6\,\mu\text{A}$, $\frac{I_{C1}}{I_{B2}} = \frac{490\mu}{10.6\mu} = 46$, so that $I_{B2} << I_{C1}$ (46 times lower).

Finnaly, the C-E voltages are computed:

$$V_{CE2} \cong V_{CC} - (R_{C2} + R_{E2})\cdot I_{C2} = 9 - (2.2k + 0.3k)\cdot 3.17m = 1.075\,\text{V};$$

$$V_{CE1} = V_{BE2} + R_B\frac{I_{C1}}{\beta} + V_{BE1} = 0.7 + 33k\frac{0.49m}{300} + 0.6 = 1.354\,\text{V}.$$