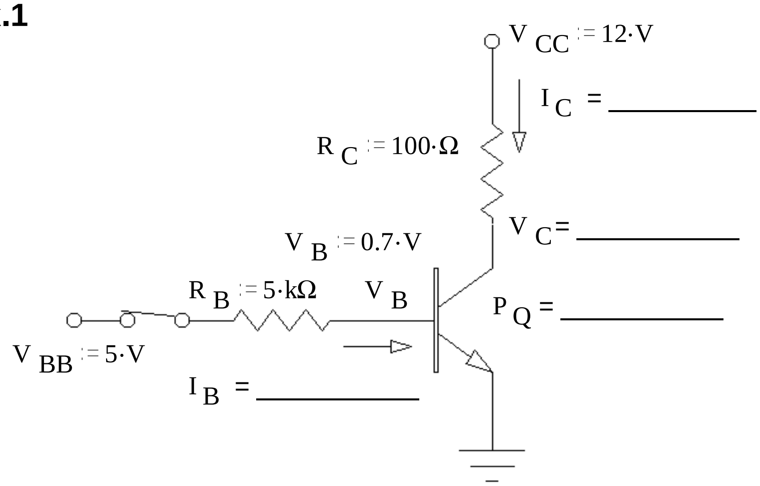
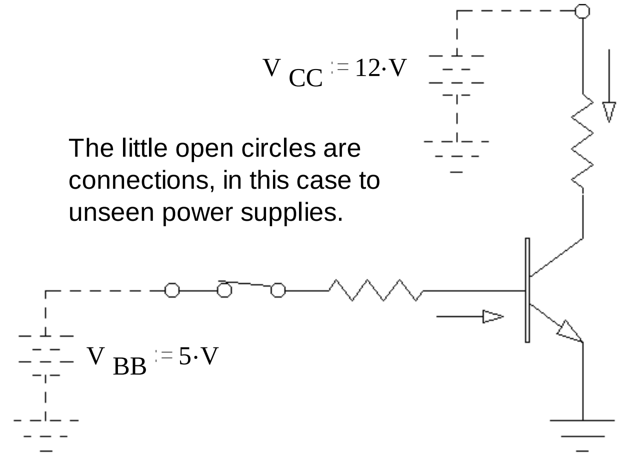
ECE 2210 Transistor Switching Circuit Examples

A.Stolp 11/21/06
rev 12/3/14, 10/13/21

Ex.1





The little open circles are connections, in this case to unseen power supplies.

If: $\beta := 100$ $\quad I_B := \frac{V_{BB} - 0.7 \cdot V}{R_B}$ $\quad I_B = 0.86 \cdot mA$

$I_C := \beta \cdot I_B$ $\quad I_C = 86 \cdot mA$

$V_C := V_{CC} - R_C \cdot I_C$ $\quad V_C = 3.4 \cdot V$

$P_Q := V_C \cdot I_C$ $\quad P_Q = 292.4 \cdot mW$

If: $\beta := 200$ $\quad I_B := \frac{V_{BB} - 0.7 \cdot V}{R_B}$ $\quad I_B = 0.86 \cdot mA$

$I_C := \beta \cdot I_B$ $\quad I_C = 172 \cdot mA$

$V_C := V_{CC} - R_C \cdot I_C$ $\quad V_C = -5.2 \cdot V$

must be in saturation: $\quad V_C := 0.2 \cdot V$

$I_C := \frac{V_{CC} - V_C}{R_C}$ $\quad I_C = 118 \cdot mA$

$P_Q := V_C \cdot I_C$ $\quad P_Q = 23.6 \cdot mW$

Since saturation can depend on β, You usually assume a small β when designing a circuit that should saturate (a switching circuit).

If: $R_C := 50 \cdot \Omega$ $\quad I_C := \beta \cdot I_B$ $\quad I_C = 172 \cdot mA$ $\quad V_C := V_{CC} - R_C \cdot I_C$ $\quad V_C = 3.4 \cdot V$

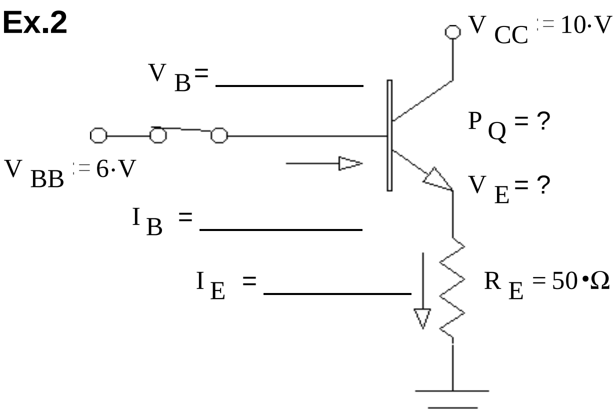
same $\beta := 200$ $\quad P_Q := V_C \cdot I_C$ $\quad P_Q = 584.8 \cdot mW$

Saturation also depends on R_C and V_{CC}.

What is the largest value that R_B could be and still keep the transistor in saturation?

$I_{Csat} := \frac{V_{CC} - 0.2 \cdot V}{R_C}$ $\quad I_{Csat} = 236 \cdot mA$ $\quad I_B := \frac{I_{Csat}}{\beta}$ $\quad I_B = 1.18 \cdot mA$ $\quad R_{Bmax} = \frac{5 \cdot V - 0.7 \cdot V}{I_B} = 3.644 \cdot k\Omega$

Ex.2



$V_B := 6 \cdot V$ $\quad V_E := 5.3 \cdot V$ $\quad R_E := 50 \cdot \Omega$

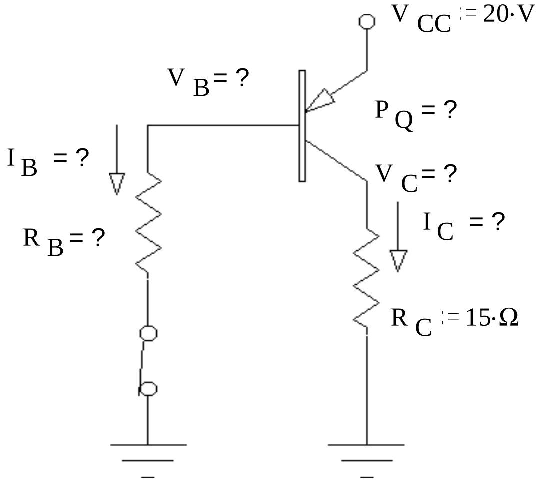
$I_E := \frac{V_E}{R_E}$ $\quad I_E = 106 \cdot mA$ $\quad$ Doesn't depend on β

$I_B := \frac{I_E}{\beta + 1}$ $\quad I_B = 0.5 \cdot mA$ $\quad \simeq \frac{I_E}{\beta} = 0.53 \cdot mA$

If β is big enough.

$P_Q := (V_{CC} - V_E) \cdot I_E$ $\quad P_Q = 0.498 \cdot W$

Ex.3 If the load must be connected to ground, a PNP transistor is often a better choice.



Let's assume a a small β and saturation and find the R_B necessary.

a small β: $\beta := 20$

$V_C := V_{CC} - 0.2 \cdot V$ $\quad V_C = 19.8 \cdot V$

$R_C := 15 \cdot \Omega$

$I_{Csat} := \frac{V_C}{R_C}$ $\quad I_{Csat} = 1.32 \cdot A$

$I_B := \frac{I_{Csat}}{\beta}$ $\quad I_B = 66 \cdot mA$

$V_B := V_{CC} - 0.7 \cdot V$ $\quad V_B = 19.3 \cdot V$

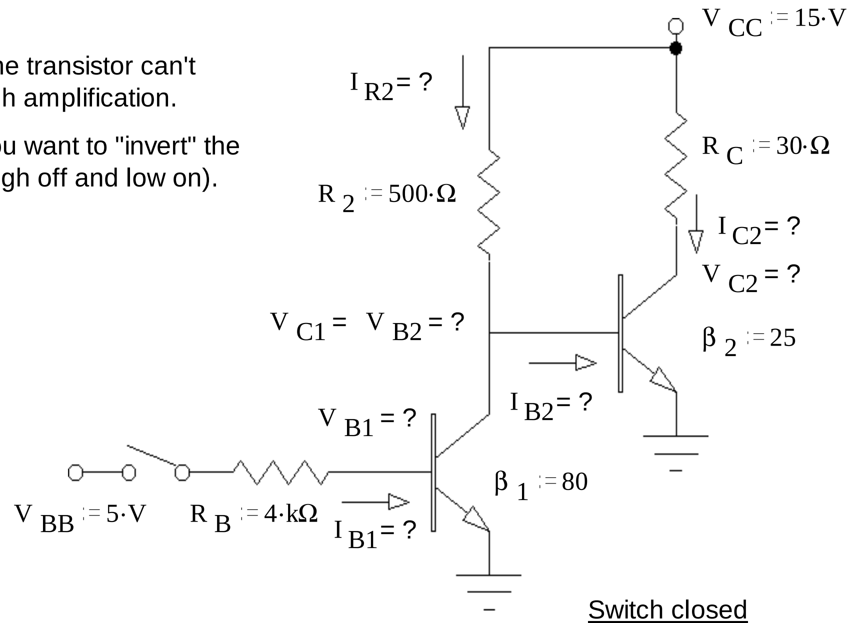
$R_B := \frac{V_B}{I_B}$ $\quad R_B = 292 \cdot \Omega$

$P_Q := 0.2 \cdot V \cdot I_{Csat}$ $\quad P_Q = 264 \cdot mW$

Ex.4

Sometimes one transistor can't provide enough amplification.

Sometimes you want to "invert" the input (make high off and low on).



Switch open

$I_{B1o} := 0$ $\quad V_{B1o} := 0 \cdot V$

$V_{B2o} := 0.7 \cdot V$

$I_{B2o} := \frac{V_{CC} - 0.7 \cdot V}{R_2}$ $\quad I_{B2o} = 28.6 \cdot mA$

$I_{R2o} := I_{B2o}$ $\quad I_{R2o} = 28.6 \cdot mA$

$I_{C2o} := \beta_2 \cdot I_{B2o}$ $\quad I_{C2o} = 715 \cdot mA$

$V_{C2o} := V_{CC} - R_C \cdot I_{C2o}$ $\quad V_{C2o} = -6.45 \cdot V$

Q_2 must be in saturation: $\quad V_{C2o} := 0.2 \cdot V$

$I_{C2o} := \frac{V_{CC} - V_{C2o}}{R_C}$ $\quad I_{C2o} = 493.3 \cdot mA$

Switch closed

$I_{B1c} := \frac{5 \cdot V - 0.7 \cdot V}{R_B}$ $\quad I_{B1c} = 1.08 \cdot mA$

assume Q_1 is in saturation $\quad V_{C1c} := 0.2 \cdot V$

$I_{C1c} := \frac{V_{CC} - V_{C1c}}{R_2}$ $\quad I_{C1c} = 29.6 \cdot mA$

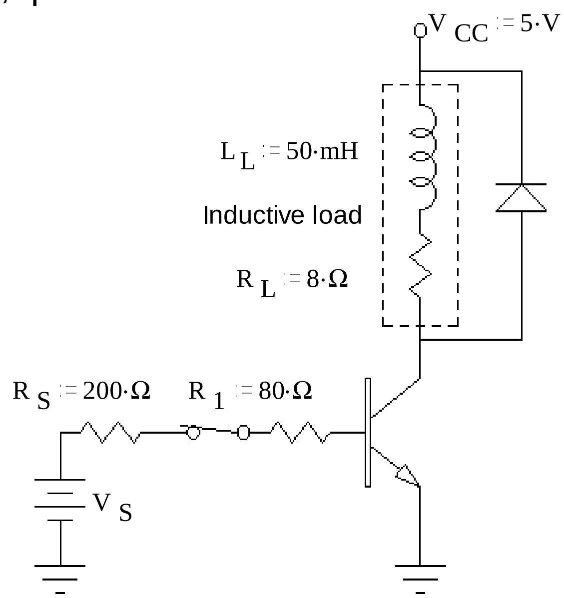
$\beta_1 \cdot I_{B1c} = 86 \cdot mA$ $\quad I_{C1}$ is controlled by R_2

$V_{B2c} := V_{C1c}$ $\quad V_{B2c} = 0.2 \cdot V$

$I_{B2c} := 0$ $\quad I_{C2c} := 0 \quad = \quad I_{RCc}$

When the switch is open, current flows in through the load resistor, R_C, When it is closed, no current flows though the load. This is an example of logical "inversion".

Ex.5 Modified from F07 Final



A transistor is used to control the current flow through an inductive load (in the dotted box, it could be a relay coil or a DC motor).

a) Assume the transistor is in saturation (fully on) and that switch has been closed for a long time. What is the load current?

$I_C = ?$

$I_{Csat} := \dfrac{V_{CC} - 0.2 \cdot V}{R_L}$ $\quad I_{Csat} = 600 \cdot mA$

b) $\beta := 80$ find the minimum value of V_S, so that the transistor will be in saturation.

$I_{Bmin} := \dfrac{I_{Csat}}{\beta}$ $\quad I_{Bmin} = 7.5 \cdot mA$

$V_{Smin} := I_{Bmin} \cdot (R_S + R_1) + 0.7 \cdot V$ $\quad V_{Smin} = 2.8 \cdot V$

Use this V_S for the rest of the problem.

c) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch opens. $I_{Dmax} = I_{Csat} = 600 \cdot mA$ from part a)

d) You got a bad transistor. $\beta := 60$ Find the new I_C, and V_{CE} and P_Q.

$I_C = ?$ $\quad I_C := \beta \cdot I_{Bmin}$ $\quad I_C = 450 \cdot mA$ Now operating in active region

$V_{CE} = ?$ $\quad V_{CE} := V_{CC} - R_L \cdot I_C$ $\quad V_{CE} = 1.4 \cdot V$

$P_Q = ?$ $\quad P_Q := V_{CE} \cdot I_C$ $\quad P_Q = 0.63 \cdot W$

$\beta = 60$ Use this for the rest of the problem.

c) Find the minimum value of R_L so that the transistor will be in saturation.

$I_B := \dfrac{V_{Smin} - 0.7 \cdot V}{R_S + R_1}$ $\quad I_B = 7.5 \cdot mA$

$I_{Cmax} := \beta \cdot I_B$ $\quad I_{Cmax} = 450 \cdot mA$

$R_{Lmin} := \dfrac{V_{CC} - 0.2 \cdot V}{I_{Cmax}}$ $\quad R_{Lmin} = 10.7 \cdot \Omega$

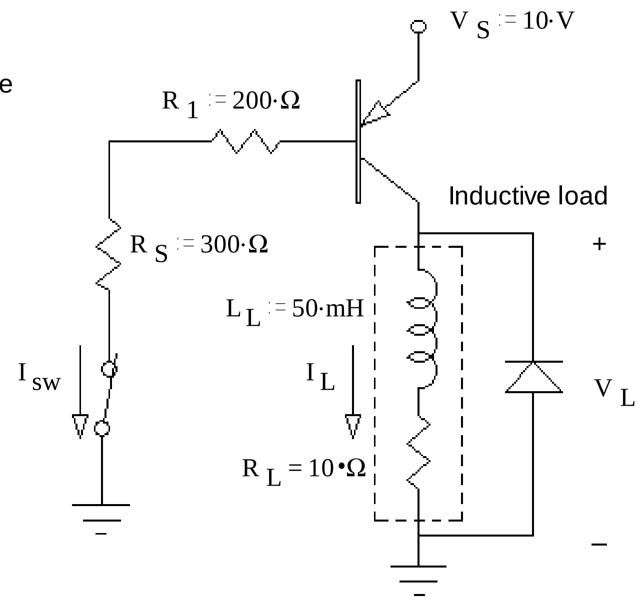
d) R_L, can't be changed, so find the maximum value of R_1 so that the transistor will be in saturation.

$I_{Csat} = 600 \cdot mA$ from part a)

$I_{Bmin} := \dfrac{I_{Csat}}{\beta}$ $\quad I_{Bmin} = 10 \cdot mA$

$R_{1max} = \dfrac{V_{Smin} - 0.7 \cdot V}{I_{Bmin}} - R_S = 10 \cdot \Omega$

Ex.6 From F05 Final with modifications from F06 Final



A transistor is used to control the current flow through an inductive load (in the dotted box, it could be a relay coil or a DC motor).

a) $\beta := 25$ Assume the transistor is in the active region, find I_{sw}, I_L, V_L, V_{EC} and P_Q.

$I_B := \dfrac{V_S - 0.7 \cdot V}{R_S + R_1}$ $\qquad I_B = 18.6 \cdot mA = I_{sw}$

$I_L := \beta \cdot I_B$ $\qquad I_L = 465 \cdot mA$

$R_L := 10 \cdot \Omega$

$V_L := I_L \cdot R_L$ $\qquad V_L = 4.65 \cdot V$

$V_{EC} := V_S - V_L$ $\qquad V_{EC} = 5.35 \cdot V$

$P_Q := V_{EC} \cdot I_L$ $\qquad P_Q = 2.488 \cdot W$

b) Was the transistor actually operating in the active region? yes no (circle one) yes

How do you know? (Specifically show a value which is or is not within a correct range.)

$V_{EC} = 5.35 \cdot V > 0.2 \cdot V$

c) Find the maximum value of R_1, so that the transistor will be in saturation.

If saturated: $V_{EC} := 0.2 \cdot V$

$I_{Csat} := \dfrac{V_S - 0.2 \cdot V}{R_L}$ $\qquad I_{Csat} = 0.98 \cdot A$

$I_{Bmin} := \dfrac{I_{Csat}}{\beta}$ $\qquad I_{Bmin} = 39.2 \cdot mA$

$R_{1max} = \dfrac{V_S - 0.7 \cdot V}{I_{Bmin}} - R_S = -63 \cdot \Omega$ **NOT POSSIBLE**

d) $R_1 = 200 \cdot \Omega$ and can't be changed, find the minimum value of β so that the transistor will be in saturation.

$I_{Csat} = 0.98 \cdot A$ $\qquad \beta_{min} := \dfrac{I_{Csat}}{I_B}$ $\qquad \beta_{min} = 52.7$

e) How much power is dissipated by the transistor if it has the β you found in part d)

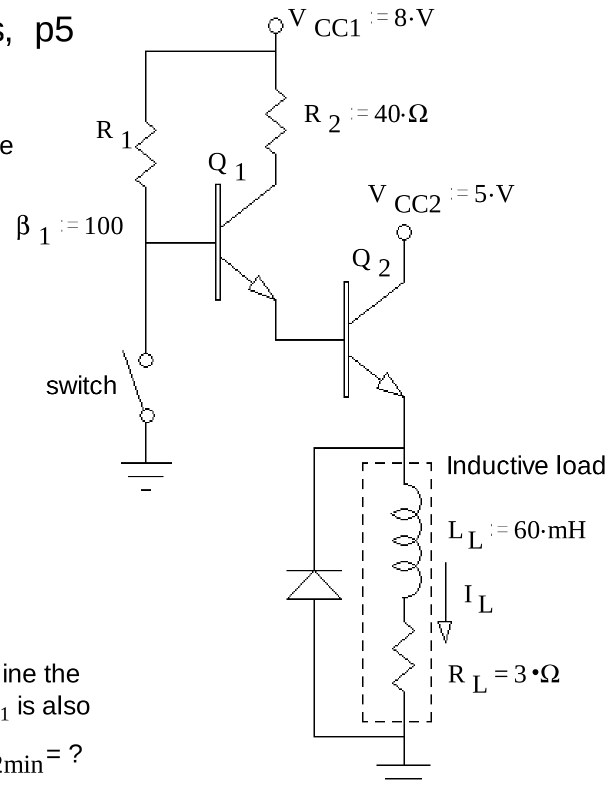
$P_Q := 0.2 \cdot V \cdot I_{Csat}$ $\qquad P_Q = 0.196 \cdot W$

f) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch opens. $\quad I_{Dmax} = I_{Csat} = 0.98 \cdot A$ $\quad$ from part a)

g) The switch is open for a while. What is the load current (I_L) now? 0

Ex.7 From F13 Final



Transistors are used to control the current flow through an inductive load (in the dotted box, it could be a relay coil or a DC motor).

a) In order for current to flow in through the load, the switch should be: i) closed or ii) open (Circle one)

b) Assume the switch has been in the position you circled above for a long time. I_L is 1.3A. Find the power dissipated by transistor Q_2 (neglect base current and V_{BE}).

$I_L := 1.3 \cdot A$ $\quad P_{Q2} = ?$ $\quad R_L := 3 \cdot \Omega$

$V_{CE2} := V_{CC2} - I_L \cdot R_L$ $\quad V_{CE2} = 1.1 \cdot V$

$P_{Q2} := V_{CE2} \cdot I_L$ $\quad P_{Q2} = 1.43 \cdot W$

c) This is an unacceptable power loss, so you would like to determine the minimum β_2 needed so that Q_2 will be in saturation. Assume Q_1 is also in saturation. You may assume $I_E = I_C$ for both traistors. $\quad \beta_{2min} = ?$

$$I_L := \frac{V_{CC2} - 0.2 \cdot V}{R_L} \qquad I_L = 1.6 \cdot A = I_{C2}$$

$V_{E2} := V_{CC2} - 0.2 \cdot V$ $\quad V_{E2} = 4.8 \cdot V$

$V_{B2} := V_{E2} + 0.7 \cdot V$ $\quad V_{B2} = 5.5 \cdot V$

$V_{C1} := V_{B2} + 0.2 \cdot V$ $\quad V_{C1} = 5.7 \cdot V$

$$I_{C1} := \frac{V_{CC1} - V_{C1}}{R_2} \qquad I_{B2} := I_{C1} \qquad I_{B2} = 57.5 \cdot mA \qquad \beta_{2min} = \frac{I_L}{I_{B2}} = 27.826$$

Better answer

$$I_{B2} := I_{C1} \cdot \left(\frac{\beta_1 + 1}{\beta_1}\right) \qquad I_{B2} = 58.075 \cdot mA \qquad \beta_{2min} = \frac{I_L}{I_{B2}} - 1 = 26.551$$

You replace Q_2 with a new transistor that has a β greater than what you just calculated.

d) How much power is dissipated by the new transistor Q_2 (neglect base current and V_{BE})? $\quad P_{Q2} = ?$

$P_{Q2} := 0.2 \cdot V \cdot I_L$ $\quad P_{Q2} = 320 \cdot mW$

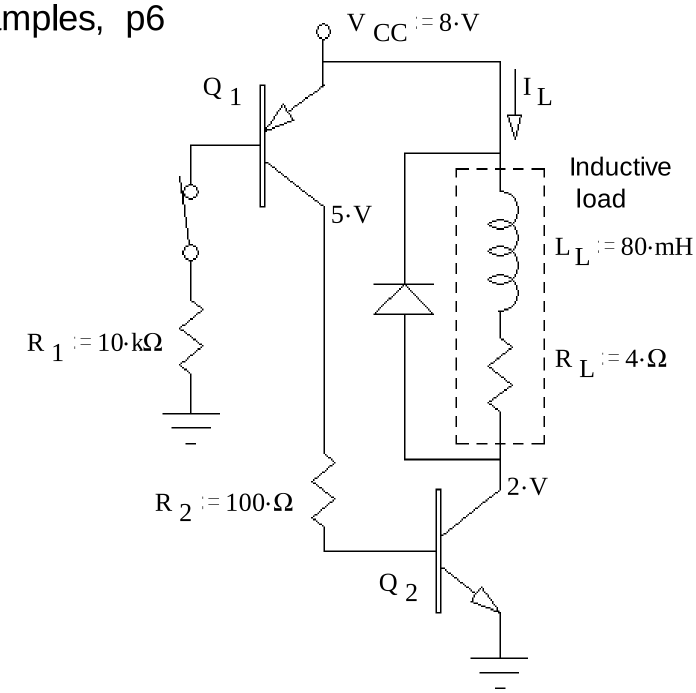
e) What is the maximum value of R_1 needed to saturate Q_1? $\quad \beta_1 = 100$

$$I_{B1min} := \frac{I_{C1}}{\beta_1} \qquad I_{B1min} = 0.575 \cdot mA \qquad V_{B1} := V_{B2} + 0.7 \cdot V \qquad V_{B1} = 6.2 \cdot V$$

$$R_{1max} := \frac{V_{CC1} - V_{B1}}{I_{B1min}} \qquad R_{1max} = 3.13 \cdot k\Omega$$

f) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch closes. $\quad I_{Dmax} = I_L = 1.6 \cdot A$ $\quad$ from part c)



Ex.8 From F12 Final

A couple of transistors are used to control the current flow through an inductive load. The switch has been closed, as shown, for a long time.

a) You measure the voltage at each collector (referenced to ground) as shown on the drawing. Find the power dissipated by transistor Q_2.

$V_{C1} := 5 \cdot V$ $\quad V_{C2} := 2 \cdot V$

$I_L := \frac{V_{CC} - 2 \cdot V}{R_L}$ $\quad I_L = 1.5 \cdot A$

$P_{Q2} := V_{C2} \cdot I_L$ $\quad P_{Q2} = 3 \cdot W$

b) Find the β of transistor Q_2.

$V_{R2} := 5 \cdot V - 0.7 \cdot V$ $\quad V_{R2} = 4.3 \cdot V$

$I_{R2} := \frac{V_{R2}}{R_2}$ $\quad I_{R2} = 43 \cdot mA$

$\beta_2 := \frac{I_L}{I_{R2}}$ $\quad \beta_2 = 34.884$

c) Find the β of transistor Q_1.

$I_{R1} := \frac{V_{CC} - 0.7 \cdot V}{R_1}$ $\quad \beta_1 := \frac{I_{R2}}{I_{R1}}$ $\quad \beta_1 = 58.9$

d) Find the minimum β for transistor Q_1 to be in saturation. $\beta_{1min} = ?$

If Q_1 is saturated: $V_{R2} := V_{CC} - 0.2 \cdot V - 0.7 \cdot V$ $\quad V_{R2} = 7.1 \cdot V$

If Q_1 is saturated: $I_{R2} := \frac{V_{R2}}{R_2}$ $\quad I_{R2} = 71 \cdot mA$ $\quad \beta_{1min} := \frac{I_{R2}}{I_{R1}}$ $\quad \beta_{1min} = 97.3$

You replace Q_1 with a different transistor so that now: $\beta_1 := 200$ Use this from now on.

e) Find the new load current (I_L) assuming transistor Q_2 is in the active region.

Q_1 is saturated: $I_{R2} = 71 \cdot mA$ $\quad I_L := I_{R2} \cdot \beta_2$ $\quad I_L = 2.477 \cdot A$

f) Check the assumption that Q_2 is in the active region and recaculate I_L if necessary.

$I_{R2} \cdot \beta_2 \cdot R_L = 9.907 \cdot V$ $\quad V_{CE2} := V_{CC} - I_{R2} \cdot \beta_2 \cdot R_L$ $\quad V_{CE2} = -1.907 \cdot V$ **Not possible**

Q_2 is saturated: $I_L := \frac{V_{CC} - 0.2 \cdot V}{R_L}$ $\quad I_L = 1.95 \cdot A$

g) Does the diode in this circuit ever conduct a significant current? If yes, when and how much?

When the switch opens. $I_{Dmax} = 1.95 \cdot A$ from part f)