The University of Sheffield
Department of Electronic and Electrical Engineering

EEE123 Problem Sheet

Transistors as Switches

Q1 Why is it important to ensure that a transistor switch is driven on and off properly?

Q2 In the circuit of figure 2, V_{BE} is altered in such a way as to cause I_C to increase linearly over a time t_s.

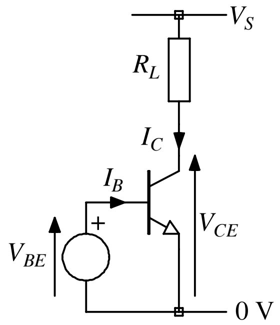

Figure 2

(i) Sketch I_C and V_{CE} as functions of time over the range of t_s. (*Note that all the action in terms of change of I_C will occur over a few tens of mV when V_{BE} is around 0.7 V*)

(ii) What is the largest value that I_C can reach? (Assume here that the transistor has a $V_{CE\,SAT}$ that is much less than the supply voltage, V_S.)

(iii) Show that over the interval t_s the instantaneous product $V_{CE}I_C$ is related to I_C by

$$V_{CE}I_C = V_S I_C - I_C^2 R_L$$

and show that the maximum value of this instantaneous $V_{CE}I_C$ product occurs when $V_{CE} = V_S/2$. You can assume here that I_B makes a negligible contribution to total power dissipation in the transistor.

Q3 The transistor in the circuit of figure 3 has a large signal static current gain, h_{FE}, of between 70 and 250 and is capable of dissipating up to 1 W. When V_i is 10V, the switch must be "on" and when V_i is 0V the switch must be "off". Find,

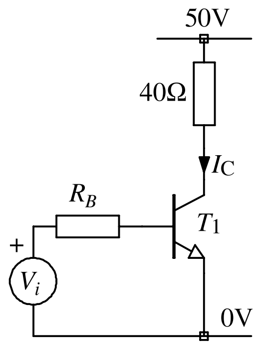

Figure 3

(i) The "on" state I_C through the switch. (1.25A)

(ii) The worst case (largest) I_B in the "on" state. (17.86mA)

(iii) The value of R_B that will ensure proper switching for all possible values of h_{FE}. You can assume here that the "on" state V_{BE} is 0.7V. (521Ω)

(iv) The power loss in the on state if $V_{CE\,SAT}$ = 250mV. (313mW)

(v) When building your circuit you mistakenly picked out a 5.21 kΩ resistor for R_B and the transistor you picked out of the drawer had an h_{FE} at the top end of the range - ie, 250. Calculate the resulting I_C, V_{CE} and power dissipation in the transistor. (448 mA, 32.1 V, 14.4 W)

(vi) What outcome would you expect from the first on-state test of your circuit?

Q4 The MOSFET of figure 4 has an on-state resistance, $r_{DS\,ON}$, of 10 Ω. It is used to activate a relay with inductive and resistive components as shown.

(i) What is the on-state current, I_D, of the MOSFET? (180 mA)

(ii) What is the on-state power loss in the MOSFET? (324 mW)

(iii) What is the on-state stored energy in the inductive part of the relay impedance? (1.62 mJ)

(iv) Show how a diode can be added to the circuit to control the effects caused by inductive stored energy.

(v) The relay switches when the current through it reaches 100 mA. Calculate the time delay between the arrival of an "on-state" drive voltage at V_{GS} and the corresponding relay switching process. (812 μs)

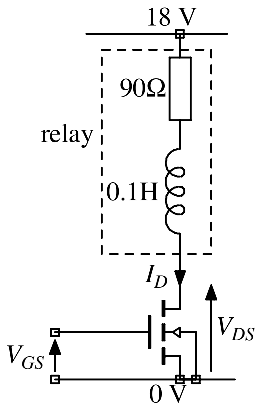

Figure 4

In the last part of this question you might need to revise the work on the transient behaviour of series *L-R* circuits that was done in semester 1 of this module.

Q5 The bipolar transistor circuit of figure 5 is used to switch on a 55 W headlamp of a vehicle with a 12 V electrical system. V_i is generated by the vehicle electrical management computer and is 0 V when an off-state is required and 5 V when the lamp is required to be on. T_1 is a special kind of BJT (actually a combination of more than one transistor) that has a minimum h_{FE} of 2000, an on-state V_{BE} of 1.3 V and a $V_{CE\,SAT}$ of 0.6V. The cold resistance of the lamp is 0.2 Ω.

(i) What is the hot resistance of the lamp? (2.62 Ω)

(ii) What is the value of I_C immediately after switch on? (60 A)

(iii) What is the maximum value of R_B that can be used if the switch is to properly on for the whole on-drive cycle? (123 Ω)

(iv) What is the power loss in T_1 when the lamp is at its normal operating temperature? (2.75 W)

(v) If T_1 were to be replaced by a MOSFET, what $r_{DS\,ON}$ value would give the same power loss as the BJT of parts **(i)** to **(iv)** during normal lamp running? (0.13 Ω)

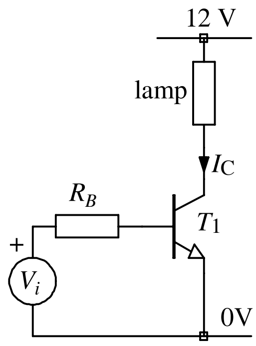

Figure 5

The large transient current demands of loads like lamps are called "inrush" currents. The same behaviour happens when motors are required to accelerate a large inertia on switch on and often happens when transformers are suddenly switched on. Electronic switching circuits must be able to handle the expected inrush currents associated with their loads.

Q6 The switching circuit of figure 6 consists of an ideal switch driving a load of 40Ω in series with an inductance of 100mH as shown.

(i) What is the energy stored in the inductive part of the load if S has been on for a long time? (78mJ)

(ii) What is the purpose of D and R?

(iii) What is the value of I_D immediately after S opens? (1.25A)

(iv) What is the decay time constant of I_D if $R = 0\Omega$? (2.5ms)

(v) What is the maximum R that can be used if S has a maximum voltage rating of 200V? (120Ω) (for experts)

(vi) If $R = 100\Omega$ and the switch switches fifty times per second, what is the power dissipation in R? (2.8W) (for real experts)

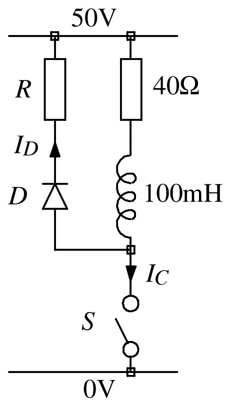

Figure 6

Assume that D is ideal and that there is no capacitance associated with the circuit.

Q7 In the circuit of figure 4, the motor rotates in a clockwise direction when the current through it is in the direction shown.

(i) Which two switches must be on to cause clockwise rotation?

(ii) Which two switches must be on to cause anticlockwise rotation.

(iii) Sketch out the circuit to show where idling diodes could be placed to prevent excessive switch voltages due to motor winding inductance. Indicate which diodes would conduct if the motor had just been switched off from a clockwise rotation state.

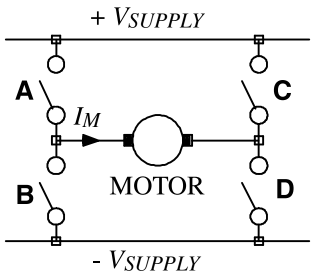

Figure 7

You may find some of the following relationships and definitions useful:

$V = L\dfrac{dI}{dt}$ $\quad I = C\dfrac{dV}{dt}$ $\quad h_{FE} = \dfrac{I_C}{I_B}$ $\quad \beta = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{i_c}{i_b}$ $\quad \tau = RC$

$E = \dfrac{C\,V^2}{2}$ $\quad E = \dfrac{L\,I^2}{2}$ $\quad V(t) = (V_{START} - V_{FINISH})\exp\left(\dfrac{-t}{\tau}\right) + V_{FINISH}$

$V_{AVE} = \dfrac{V_P}{\pi}$ for a half wave rectified sinusoid $\quad V_{rms} = \dfrac{V_P}{\sqrt{2}}$ for a sinusoid

$v_o = A_v\,(v^+ - v^-)$ $\quad \dfrac{kT}{e} = 0.026\text{V}$ $\quad \omega = 2\pi f$

unit multipliers: p = x10^{-12}, n = x10^{-9}, μ = x10^{-6}, m = x10^{-3}, k = x10^{3}, M = x10^{6} G = x10^{9}

All the symbols have their usual meanings