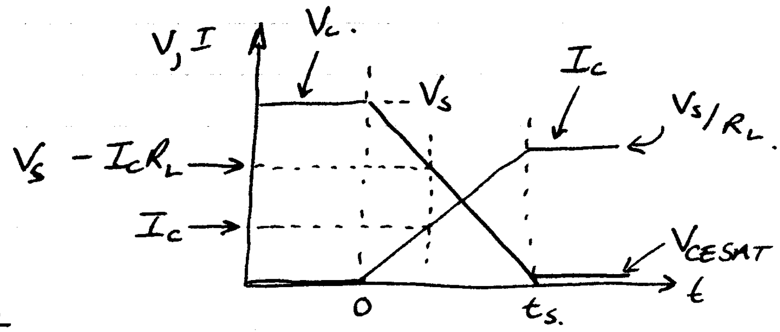
Q1 Since in a well designed switching circuit the transistor is subject either to high votage and low current (ie, the off-state) or to low voltage and high current (ie, the on-state) its VI product is always small compared with load power which is off-state switch voltage (V_S) multiplied by on state switch current (V_S/R_L). If the switch is not driven on + off properly, a fraction of the load power is dissipated in the switch and the switch power dissipation capability is quickly exceeded leading to (often violent) failure.

Q2

(i) →



I_c is function of time.

(ii)
$I_{c\,max} = V_S/R_L$

(iii)
$$P_{DISS} = V_{CE} \times I_c$$
$$= (V_{cc} - I_c R_L) I_c$$
$$= V_{cc} I_c - I_c^2 R_L.$$

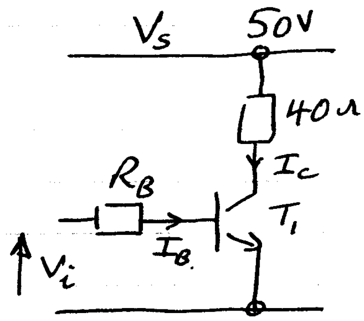
to find the V_c at which P_{DISS} is a max, find the I_c at which P_{DISS} is a maximum

$$\therefore \frac{dP_{DISS}}{dI_c} = V_{cc} - 2 I_c R_L = 0 \text{ for a max.}$$

(one can deduce by inspection that this is a maximum or one can differentiate a second time to find the sign of the curvature.)

$\therefore P_{DISS}$ is a maximum when $I_C = V_S/2R_L$

ie, when $V_{CE} = V_S - \underbrace{\frac{V_S}{2R_L} R_L}_{\equiv I_C R_L} = \underline{\underline{\frac{V_S}{2}}}$.



Q3 (i) $I_{CON} = \frac{50V}{40\Omega} = \underline{\underline{1.25A}}$.

(ii) Largest I_B occurs for smallest h_{FE}

$\therefore I_{BMAX} = \frac{I_{CON}}{h_{FEMIN}}$

$= \frac{1.25A}{70} = \underline{\underline{17.86\ mA}}$.

(iii) $R_B = \frac{V_{i(ON)} - 0.7}{I_{BMAX}} = \frac{10 - 0.7}{17.86\ mA} = \underline{\underline{521\ \Omega}}$.

(iv) In the "on" state $I_{CON} \approx 1.25A$

$\therefore P_{DISS\ IN\ T_1} = I_{CON} \times V_{CESAT}$

$= 1.25 \times 0.25 = \underline{\underline{0.313\ W}}$

(v) If $R_B = 5.21\ k\Omega$, $I_B = \frac{10 - 0.7}{5.21\ k\Omega} = 1.79\ mA$

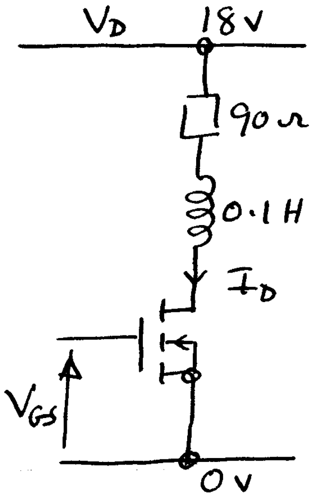
This I_B is then multiplied by the top end h_{FE} of 250 to give

$I_C = 250 \times 1.79\ mA = \underline{\underline{448\ mA}}$

$$V_{CE} = V_S - I_C R_L = 50 - 0.448 \times 40 = \underline{\underline{32.1\,V}}$$

$$\therefore P_{DISS} = 0.448 \times 32.1 = \underline{\underline{14.4\,W}}$$

(vi) BANG. (or PHUT)



Q4 (i) $I_{DON} = \dfrac{V_D}{R_L + r_{DSON}}$

$$= \frac{18}{90+10} = \underline{\underline{180\,mA}}$$

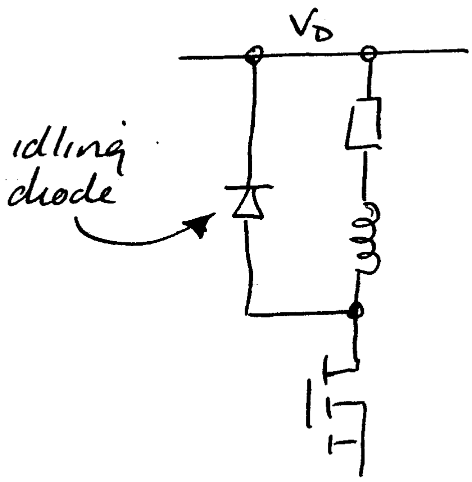
[note that here $r_{DS\,ON}$ is one ninth of R_L so neglecting it is probably unwise.]

(ii) $P_{DISS(ON)} = I_{DON}^2 \, r_{DSON}$

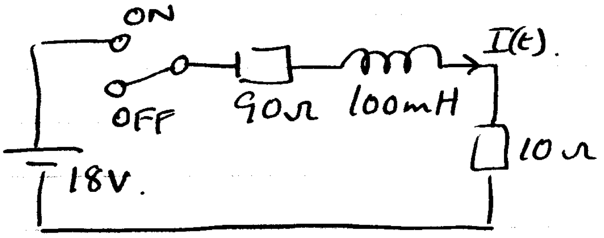
$$= 0.18^2 \cdot 10 = \underline{\underline{324\,mW}}$$

(iii) $E_L = \frac{1}{2} L I^2 = \frac{1}{2} \cdot 10^{-1} \times 0.18^2 = \underline{\underline{1.62\,mJ}}$.

(iv)



(v) When the MOSFET switches on, 18 V is switched across a series circuit consisting of 90Ω, 0.1H and 10Ω. Equivalent behaviour is ...



When switch goes from "off" to "on" $I(t)$ varies as a simple exponential

$$I(t) = I_{CON}\left(1 - e^{-t/\tau}\right)$$

where $I_{CON} = 0.18A$ + $\tau = L/(R_L + r_{DSON})$ $\underline{\underline{= 1ms}}$.

We need to work out how long it takes this current to rise from its initial value of zero to the relay activation current of 100mA.. ... so ... we need to solve

$$100mA = 180mA\left(1 - e^{-t/1ms}\right).$$

or $$e^{-t/1ms} = 1 - \frac{100mA}{180mA} = 0.444.$$

or $$-t/1ms = \ln(0.444) = -0.812$$

or $$t = 1ms \times 0.812 = \underline{\underline{812\mu s.}}$$

Q5 (i) The hot resistance of the lamp can be found from knowledge of the lamp power output with a supply voltage of 12V ...

$$55W = \frac{(12V)^2}{R_{HOT}} \text{ or } R_{HOT} = \frac{144}{55} = \underline{\underline{2.62\,\Omega}}$$

(ii) Immediately after switch on it is the cold resistance of the lamp that determines the initial current ...

$$I_{C\,INITIAL} = \frac{12}{0.2\,\Omega} = \underline{\underline{60\,A}}.$$

(iii) The switch drive must be able to support the 60A initial current so

$$R_{B\,max} = \frac{5V - 1.3V}{I_{B(ON)}} = \frac{5V - 1.3V}{\left(\frac{60A}{2000}\right)}$$

$$= \underline{\underline{123\,\Omega}}.$$

(iv) When the lamp is in its normal running condition

$$P_{LAMP} = 55W = 12V \times I_{LAMP}.$$

$$\text{or } I_{LAMP} = 4.58\,A.$$

$$P_{DISS\ IN\ T_1} = I_{LAMP} \cdot V_{CESAT} = 4.58A \times 0.6V$$

$$= \underline{\underline{2.75\,W}}.$$

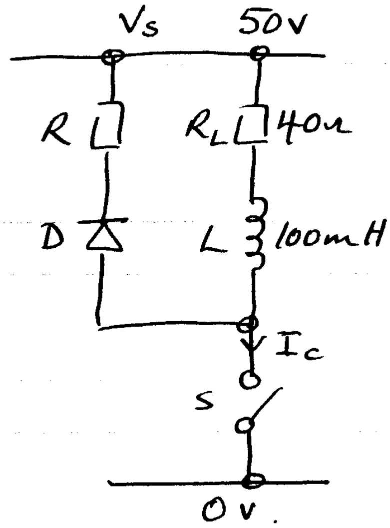
(v) If T_1 replaced by a MOSFET, the switch internal power dissipation becomes

$$I_{LAMP}^2\, r_{DS\,ON}$$

so we need to find out the $r_{DS\,ON}$ that will give a P_{DISS} of 2.75 W ...

$$2.75 = (4.58)^2\, r_{DS\,ON}$$

$$\text{or } r_{DS\,ON} = \underline{\underline{0.13\,\Omega}}.$$



Q6 (i) $E_L = \frac{1}{2} L I_L^2$

$= \frac{1}{2} 0.1 \left(\frac{50}{40}\right)^2$

$= \underline{78 \text{ mJ}}$

(ii) D + R provide a path for the inductor current when the path via the switch S is broken.
D prevents current flow through this idling path when the switch is on and R helps to dissipate the energy stored in L thereby speeding up the decay of inductor current on switch off.

(iii) The value of I_D immediately after the switch opens is the same as the value of I_L immediately before the switch opens (because I_L must be continuous over the instant of switching)

$\therefore I_D @ t=0^+ = I_L @ t=0^- = \frac{50}{40} = \underline{1.25A}$

(iv) If $R = 0\,\Omega$, $\tau = L/R_L = \frac{0.1}{40} = \underline{2.5 \text{ mS}}$

(v) If S can tolerate 200V, $I_D @ t=0^+$ can generate 150V across R

$\therefore R = V/I = 150/1.25 = \underline{120\,\Omega}$

(vi) The energy dissipated in a resistor is
$$E = \int I^2 R \, dt$$
where the limits of the integral represent the time interval of interest.

Thus for a given I, E_{DISS} is proportional to R.

In the circuit of interest, the total energy dissipated at each switch off event is simply the energy stored in L at the instant of switch off. This energy will be shared between R + R_L in proportion to the values of R + R_L.....

Energy stored in L = 78 mJ (from pt (i)).
Proportion of this dissipated in R is
$$\frac{78\,\text{mJ} \times R}{R + R_L} = \frac{78\,\text{mJ} \times 100}{140}$$
$$= 55{\cdot}7\,\text{mJ}.$$

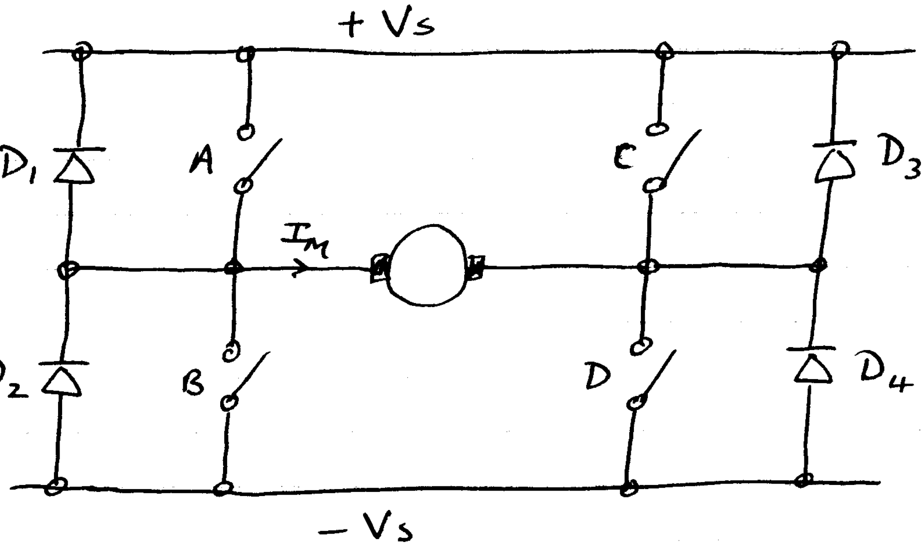
This energy is dissipated at a rate of 50 events per second, so energy dissipated per second, which equals power, is

$$P_{DISS} = E_{DISS/sec} = 55{\cdot}7\,\text{mJ} \times 50\,\text{Hz}$$
$$\underline{\underline{= 2{\cdot}8\,\text{W}}}$$

Q7 (i) A + D must be on to give a current in the direction shown

(ii) B + C must be on to give anti-clockwise rotation

(iii)



If motor had just been switched off from a clockwise rotation state, idling diodes D_2 and D_3 would provide a path to allow inductor current to be continuous over the switching instant.

[Note that in this case the inductive stored energy is returned to the supply. In questions 4 + 6 the inductive stored energy is dissipated as heat.]