In The Name Of God
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Quchan University
Of
Advanced Technology

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Course: Power Electronic
Name:....................

Question1: For a power diode, the reverse recovery time is 3.9 μs and the rate of diode-current decay is 50 $\frac{A}{\mu s}$. For a softness factor of 0.3, calculate the peak inverse current and the storage charge.

$$\begin{cases} t_{rr} = t_a + t_b = 3.9\mu s \\ \\ S.F. = \frac{t_b}{t_a} = 0.3 \end{cases} \Rightarrow t_a = 3\mu s$$

$$I_{RR} = t_a \frac{di}{dt} = 3 \times 50 = 150\ A$$

$$Q_{RR} = \frac{1}{2} I_{RR} t_{RR} = \frac{1}{2} \times 150 \times 3.9 = 292.5$$

Question2: The waveforms of the transistor switch are shown in the figure 1. The parameteres are $V_{CC} = 250\,V$, $V_{BE(sat)} = 3\,V, I_B = 8\,A, V_{CE(sat)} = 2\,V, I_{CS} = 100\,A, t_d = 0.5\,\mu s, t_r = 1\,\mu s, t_s = 5\,\mu s, t_f = 3\,\mu s$ and $f_s = 10\,kHz$. The duty cycle is $k = 50\%$. The collector to emitter leakage current is $I_{CEO} = 3\,mA$. Determine the power loss due to collector current (a) during turn-on $t_{on} = t_d + t_r$, (b) during conduction period t_n (c) during turn off $t_{off} = t_s + t_f$, (d) during off time t_o, (e) total average power losses P_T.

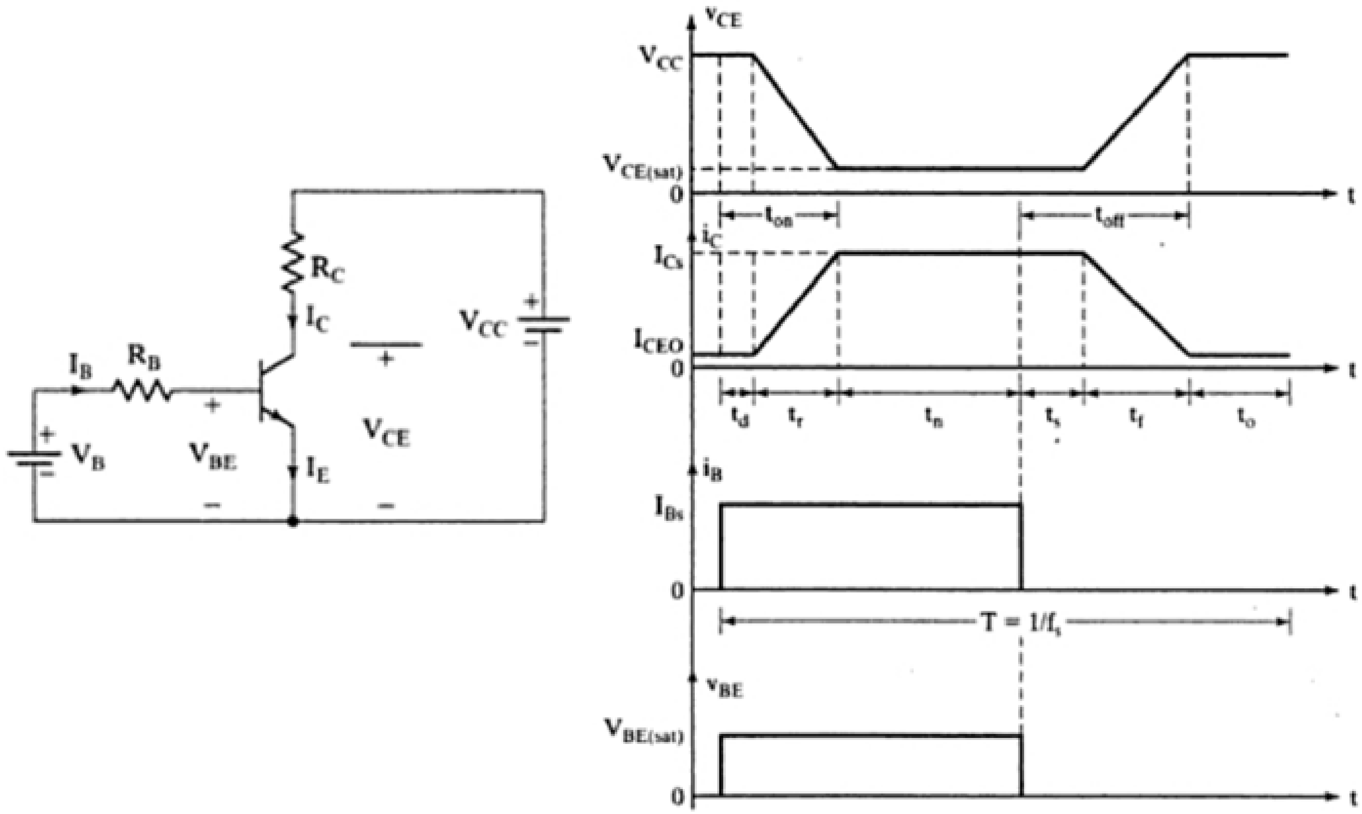

Figure 1: Question 2

$$T = \frac{1}{f_s} = 100\,\mu s.k = 0.5, kT = t_d + t_r + t_n = 50\,\mu s \Rightarrow t_n = 50 - 0.5 - 1 = 48.5\mu s.$$

$$(1-k)T = t_s + t_f + t_o = 50\,\mu s \Rightarrow t_o = 50 - 5 - 3 = 42\mu s.$$

(a) During delay time, $0 \le t \le t_d$:

$$i_c(t) = I_{CEO}, v_{CE} = V_{CC}, P_c(t) = i_c v_{CE} = I_{CEO}V_{CC} = 3 \times 10^{-3} \times 250 = 0.75\,W$$

$$P_d = \frac{1}{T}\int_0^{t_d} P_c(t)dt = I_{CEO}V_{CC}t_d f_s = 3\times10^{-3}\times250\times0.5\times10^{-6}\times10\times10^3 = 3.75\,mW$$

During rise time, $0 \le t \le t_r$: $i_c(t) = \frac{I_{CS}}{t_r}t$, $v_{CE} = V_{CC} + (V_{CE(sat)} - V_{CC})\frac{t}{t_r}$

$$P_c(t) = i_c v_{CE} = I_{CS}\frac{t}{t_r}\big[V_{CC} + (V_{CE(sat)} - V_{CC})\frac{t}{t_r}\big]$$

$$P_r = \frac{1}{T}\int_0^{t_r} P_c(t)dt = t_r I_{CS}\big[\frac{V_{CC}}{2} + \frac{V_{CE(sat)-V_{CC}}}{3}\big] f_s = 1\times10^{-6}\times100\times42.33\times10\times10^3$$
$$= 42.33\,W$$

$$P_{on} = P_d + P_r = 42.33 + 3.75 \times 10^{-3} = 42.33\,W$$

(b) The conduction period, $0 \le t \le t_n$: $i_c(t) = I_{CS}, v_{CE}(t) = V_{CE(sat)}$

$$P_c(t) = i_c v_{CE} = I_{CS}V_{CE(sat)} = 2 \times 100 = 200\,W$$

$$P_n = \frac{1}{T}\int_0^{t_n} P_c(t)dt = I_{CS}V_{CE(sat)}t_n f_s = 2 \times 100 \times 48.5 \times 10^{-6} \times 10 \times 10^3 = 97\,W$$

(c) The storage period, $0 \le t \le t_s$: $i_c(t) = I_{CS}, v_{CE}(t) = V_{CE(sat)}$

$$P_c(t) = i_c v_{CE} = I_{CS}V_{CE(sat)} = 2 \times 100 = 200\,W$$

$$P_s = \frac{1}{T}\int_0^{t_s} P_c(t)dt = I_{CS}V_{CE(sat)}t_s f_s = 2 \times 100 \times 5 \times 10^{-6} \times 10 \times 10^3 = 10\,W$$

The fall times, $0 \le t \le t_f$: $i_c(t) = I_{CS}\big(1 - \frac{t}{t_f}\big), v_{CE}(t) = \frac{V_{CC}}{t_f}t$

$$P_c(t) = i_c v_{CE} = V_{CC}I_{CS}\big[(1 - \frac{t}{t_f})\frac{t}{t_f}\big]$$

$$P_f = \frac{1}{T}\int_0^{t_f} P_c(t)dt = \frac{V_{CC}I_{CS}t_f f_s}{6} = \frac{250 \times 100 \times 3 \times 10^{-6} \times 10 \times 10^3}{6} = 125\,W$$

$$P_{off} = P_s + P_f = 10 + 125 = 135\,W$$

(d) Off-period, $0 \le t \le t_o$: $i_c(t) = I_{CEO}, v_{CE}(t) = V_{CC}$

$$P_c(t) = i_c v_{CE} = I_{CEO} V_{CC} = 3 \times 10^{-3} \times 250 = 0.75\,W$$

$$P_o = \frac{1}{T}\int_0^{t_o} P_c(t)dt = I_{CEO} V_{CC} t_o f_s = 3\times10^{-3}\times250\times42\times10^{-6}\times10\times10^3 = 0.315\,W$$

(e) The total power loss in th transistor due to collector current is:

$$P_T = P_{on} + P_{off} + P_o = 42.33 + 97 + 135 + 0.315 == 274.65\,W$$

Question 3: The maximum junction tempreture of a transistor is $T_J = 125^o\,C$ and the ambient temperature is $T_A = 25^o\,C$. If the thermal impedances are $R_{JC} = 0.4^o\frac{C}{W}$, $R_{CS} = 0.1^o\frac{C}{W}$, $R_{SA} = 0.5^o\frac{C}{W}$. Calculate (a) the maximum power dissipation and (b) the case temperature.

(a)

$$T_J - T_A = P_T(R_{JC} + R_{CS} + R_{SA}) = P_T R_{JA}, R_{JA} = 0.4 + 0.1 + 0.5 = 1.$$

$$125 - 25 = 1P_T \Rightarrow P_T = 100\,W$$

(b)

$$T_C = T_j - P_T R_{JC} = 125 - 100 \times 0.4 = 85^o C$$

Question4: The beta (β) of the transistor in Figure 2 varies from 10 to 60. The load resistance is $R_C = 5\,\Omega$. The dc supply voltage is $V_{CC} = 100\,V$ and the input voltage to the base circuit is $V_B = 8\,V$. If $V_{CE(sat)} = 2.5\,V$ and $V_{BE(sat)} = 1.75\,V$. Find (a) the value of R_B that will result in saturation with an overdrive factor of 20, (b) the forced β, and (c) the power loss in the transistor P_T.

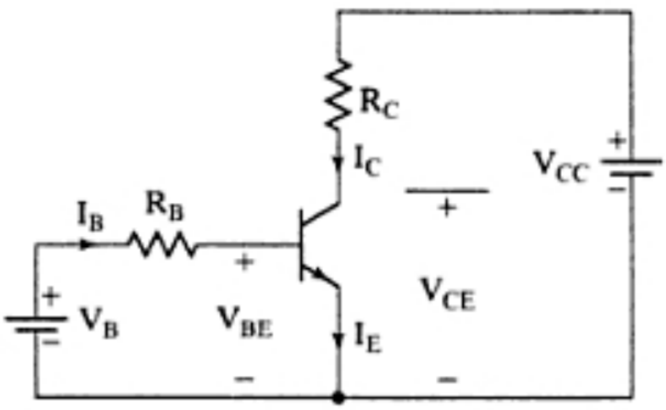

Figure 2: Question 4

$$I_{CS} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{100 - 2.5}{5} = 19.5\,A$$

$$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{19.5}{10} = 1.95\,A, \;\Rightarrow I_B = I_{BS} \times (overdrive factor) = 20 \times 1.95 = 39\,A$$

(a)

$$R_B = \frac{V_B - V_{BE(sat)}}{I_B} = \frac{8 - 1.75}{39} = 0.1602\,\Omega$$

(b)

$$\beta_f = \frac{I_{CS}}{I_B} = \frac{19.5}{33} = 0.59$$

(c)

$$P_T = V_{BE(sat)} \times I_B + V_{CE(sat)} \times I_{CS} = 1.75 \times 39 + 2.5 \times 19.5 = 117\,W$$

Quesion5: A power transistor has its switching waveforms as shown in Figure 3. If the average power loss in the transistor is limited to 300 W. Find the switching frequency at which this transistor can be operated.

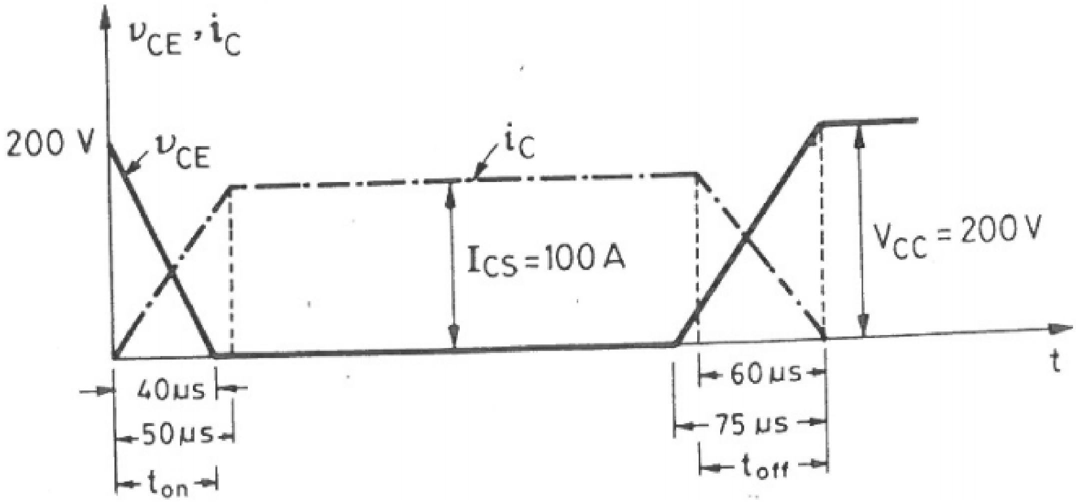

Figure 3: Question 5

Energy loss during turn on

$$= \int_0^{t_{on}} i_C v_{CE} dt = \int_0^{t_{on}} \left(\frac{I_{CS}}{50} \times 10^6 t\right)\left(V_{CC} - \frac{V_{CC}}{40} \times 10^6 t\right) dt = \int_0^{t_{on}} (2 \times 10^6 t)(200 - 5 \times 10^6 t) dt$$

$$= 0.1067\, W - sec$$

Energy loss during turn off

$$= \int_0^{t_{off}} \left(100 - \frac{100}{60} \times 10^6 t\right)\left(\frac{200}{75} \times 10^6 t\right) dt = 0.1603\, W - sec$$

Total energy loss in one cycle

$$0.1067 + 0.1603 = 0.267\, W - sec$$

Average power loss in transistor=switching frequency $\times$ energy loss in one cycle
Allowable switching frequency :

$$f = \frac{300}{0.267} = 1123.6\, Hz$$