Electronics and
Computer Science

ELEC2208 Power Electronics and Drives

Tutorial 2 - Transistor, Heating & Cooling

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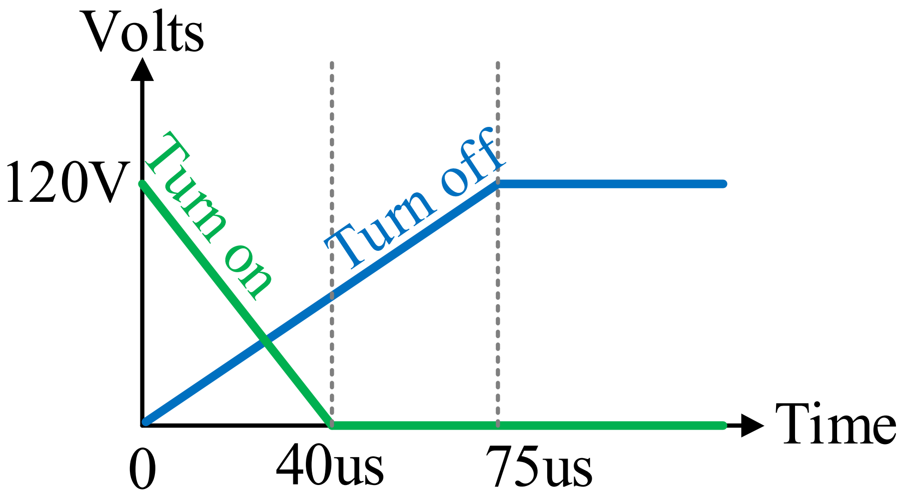
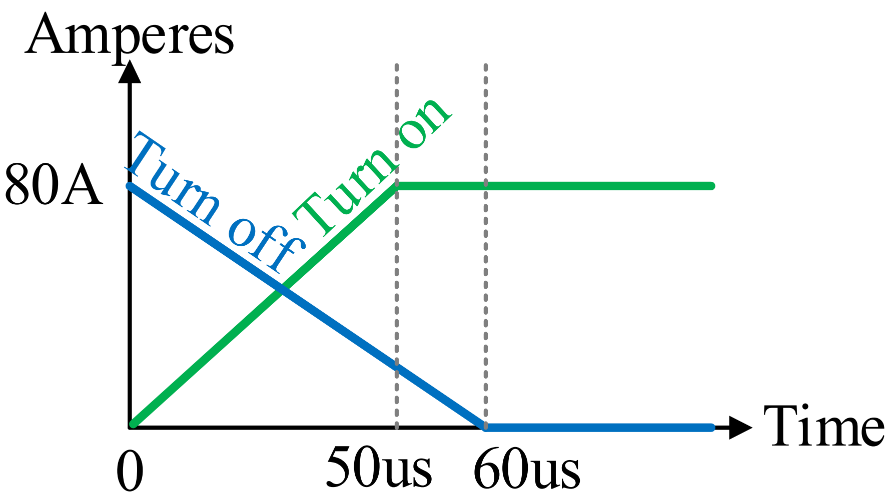
Question 1

A transistor has the switching characteristic shown below. If the mean power loss in the transistor is limited to 200 W, what is the maximum switching rate that can be achieved?



Transistor Voltage



Transistor Current

Mean power loss in transistor

When power loss occurs in a transistor?

(1) OFF state

Voltage: finite, Current ~ 0

$P_{off} \sim 0$

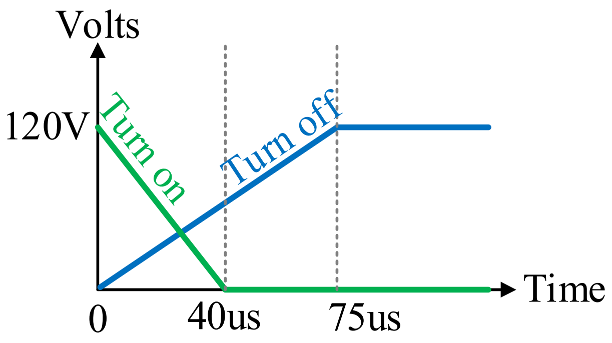
(2) ON state

Current: finite, Voltage ~ 0

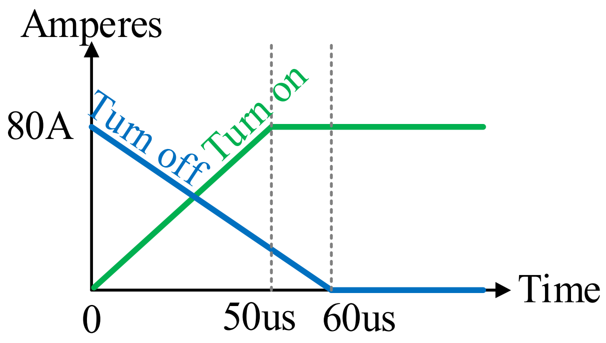
($R \sim m\Omega$) $P_{on} \sim 0$

(3) Switching state

Major power loss!



Transistor Voltage



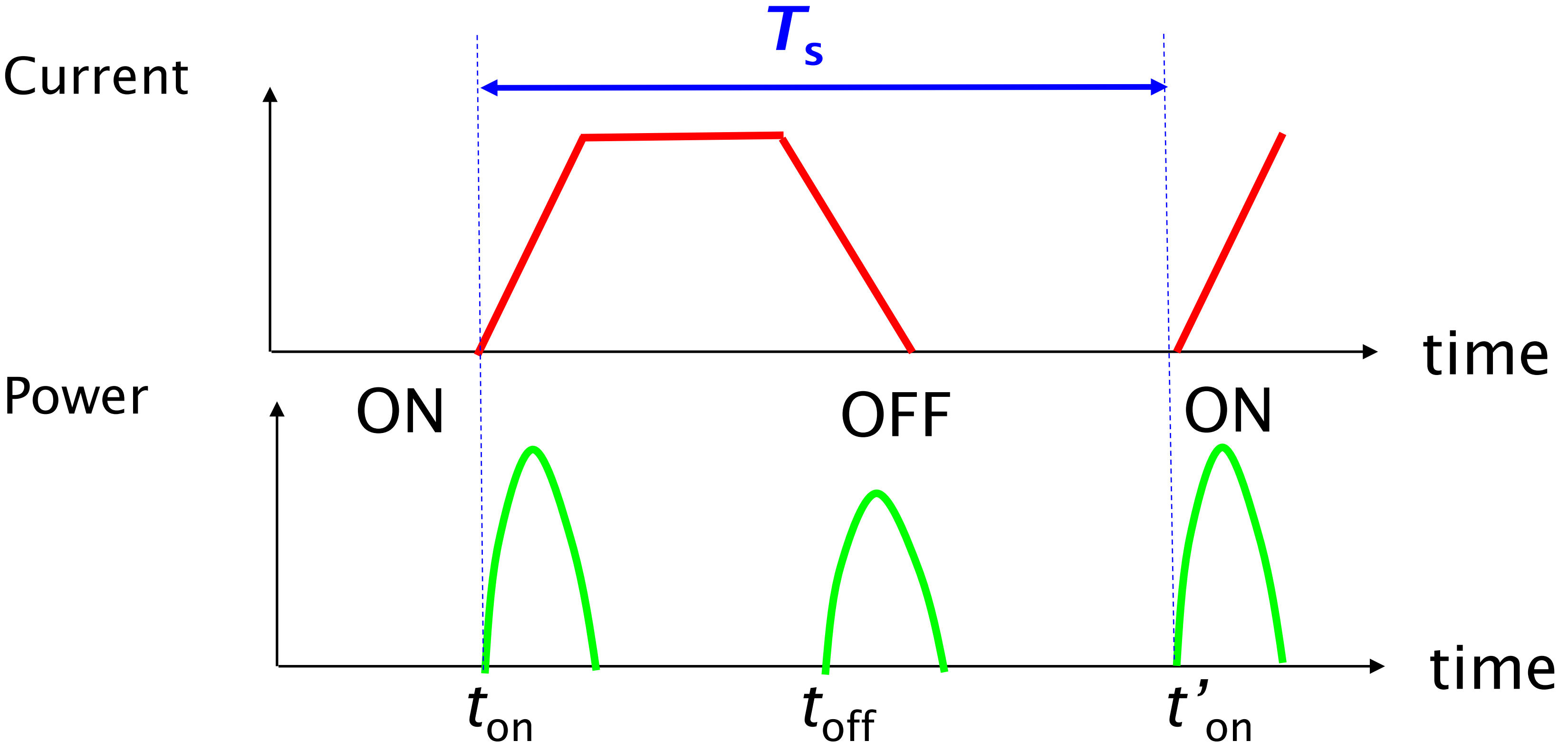
Transistor Current

Mean power loss in transistor

"Mean" → To take an average over a period

Switching rate = Switching frequency f_s

Switching period $T_s = 1/f_s$



P_{on} calculation

$$P_{mean} = \frac{1}{T_s}\int_0^{T_s}\{P_{on}(t) + P_{off}(t)\}dt$$

Calculation of P_{on}

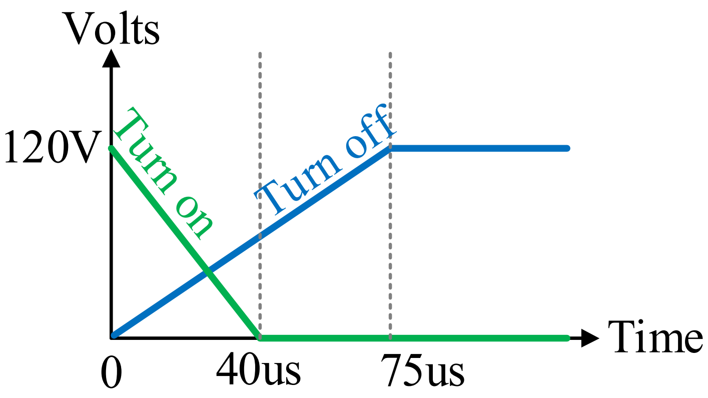
$$P_{on}(t) = v_{on}(t)i_{on}(t)$$

$$v_{on}(t) = -(3\text{x}10^6)t+120 \quad (t\text{-}t_{on} < 40\ \mu\text{s})$$

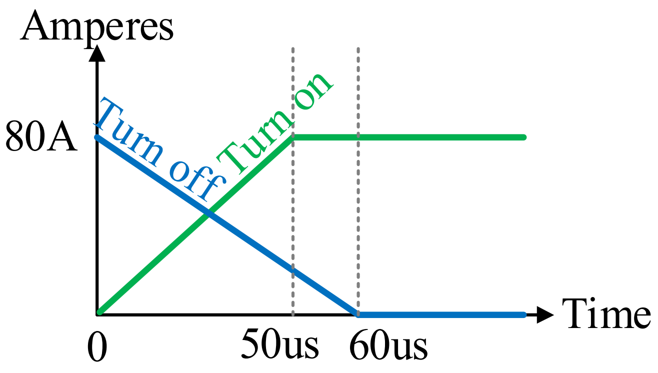
$$i_{on}(t) = (1.6\text{x}10^6)t \quad (t\text{-}t_{on} < 50\ \mu\text{s})$$

$$P_{on} = -(4.8 \times 10^{12})t^2 + (1.92 \times 10^8)t$$

$$(t\text{-}t_{on} < 40\ \mu\text{s})$$



Transistor Voltage



Transistor Current

P_{off} calculation

Calculation of P_{off}

$$P_{off}(t) = v_{off}(t)\, i_{off}(t)$$

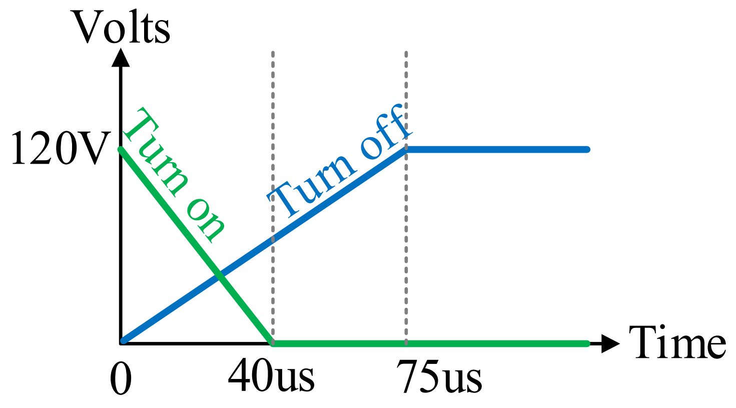
$$v_{off}(t) = (1.6\text{x}10^6)t \quad (t\text{-}t_{off} < 75\ \mu\text{s})$$

$$i_{off}(t) = -(1.3333\text{x}10^6)t+80$$

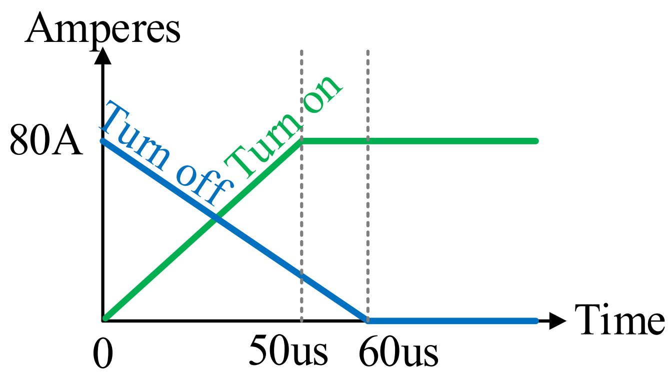
$$(t\text{-}t_{off} < 60\ \mu\text{s})$$

$$P_{off} = -(2.1333 \text{ x } 10^{12})t^2 +(1.28 \text{ x } 10^8)t$$

$$(t\text{-}t_{off} < 60\ \mu\text{s})$$



Transistor Voltage



Transistor Current

Mean power loss in transistor

$$P_{mean} = \frac{1}{T_s}\int_0^{T_s}\{P_{on}(t) + P_{off}(t)\}dt$$

$$= \frac{1}{T_s}\int_0^{40\times10^{-6}}\{-(4.8\times10^{12})t^2 + (1.92\times10^8)t\}dt$$

$$+ \frac{1}{T_s}\int_0^{60\times10^{-6}}\{-(2.1333\times10^{12})t^2 + (1.28\times10^8)t\}dt$$

$$= \frac{1}{T_s}\left[-1.6\times10^{12}t^3 + 0.96\times10^8t^2\right]_0^{40\times10^{-6}}$$

$$+ \frac{1}{T_s}\left[-0.7111\times10^{12}t^3 + 0.64\times10^8t^2\right]_0^{60\times10^{-6}}$$

Mean power loss in transistor

$$P_{mean} = \frac{1}{T_s}\int_0^{T_s}\{P_{on}(t) + P_{off}(t)\}dt$$

$$= \frac{1}{T_s}\{(-0.1024 + 0.1536) + (-0.1536 + 0.2304)\}$$

$$= \frac{0.128}{T_s} \quad \leq 200 \quad \text{(W)}$$

$$f_s = \frac{1}{T_s} \leq 200 \div 0.128 = 1562.5$$

$f_{s(max)}$ = 1562.5 Hz = 1.5625 kHz **($T_{s(min)}$ = 640 μs)**

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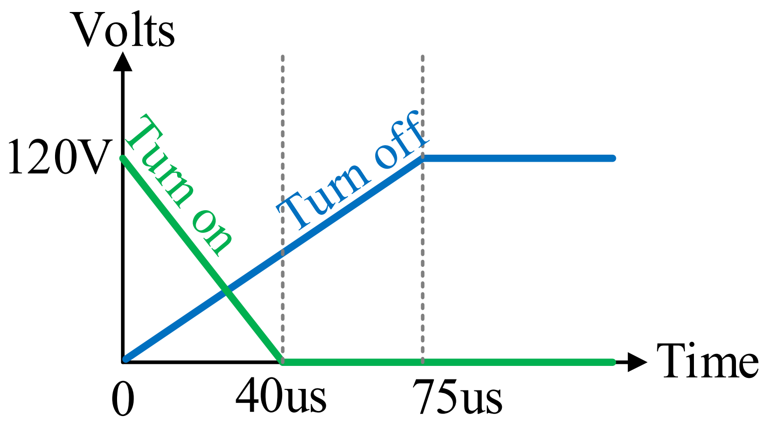
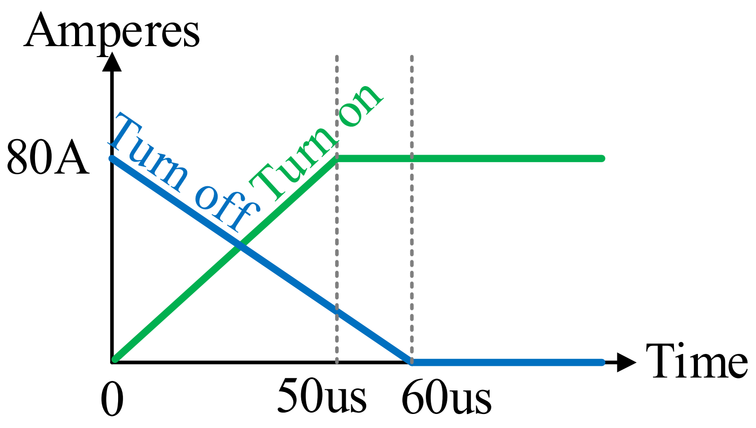
Question 2

For the transistor above (in Question 1), plot curves showing the instantaneous power during turn on and turn off. Find the maximum instantaneous power level developed.



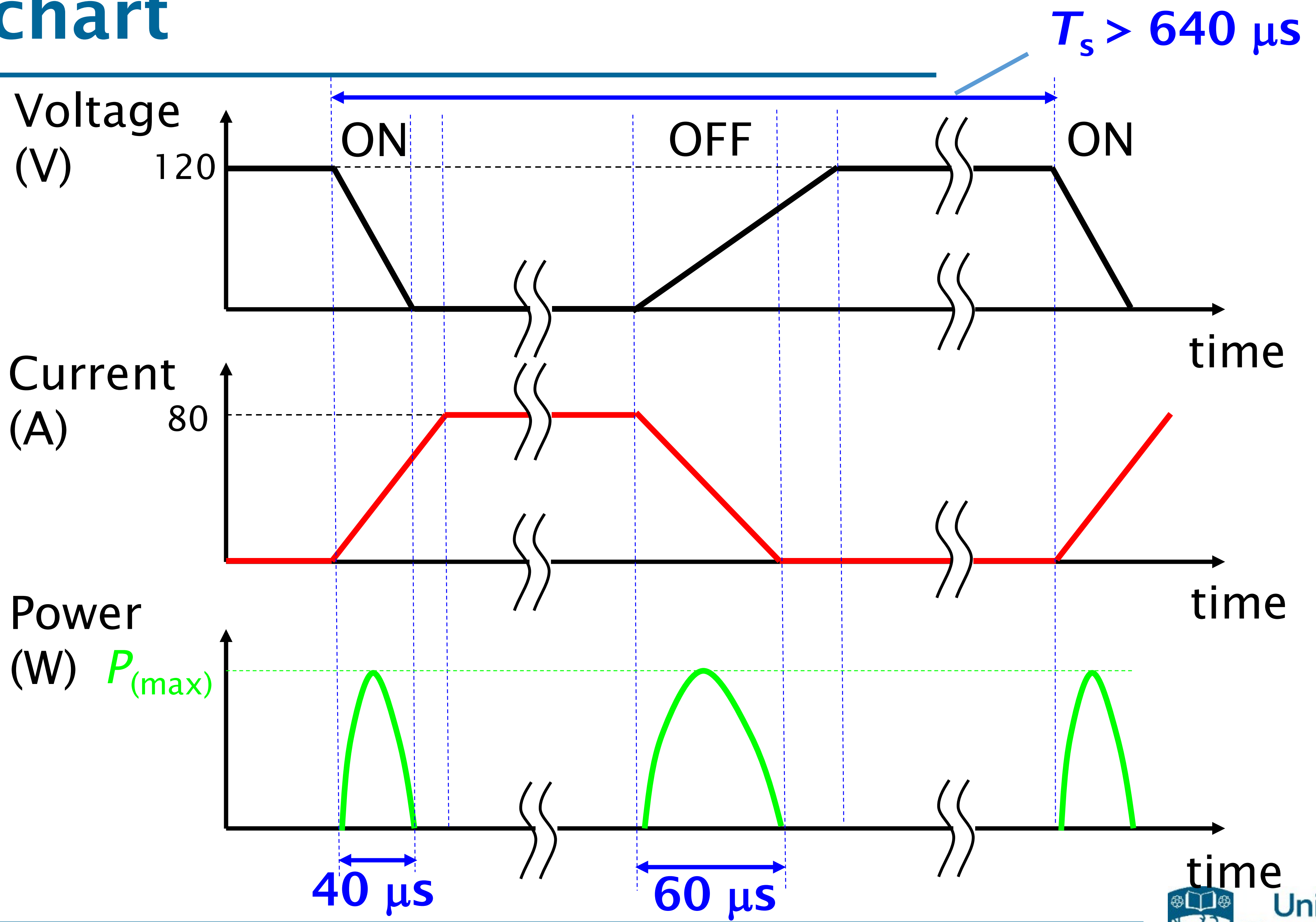
Transistor
Voltage



Transistor
Current

→ **Let us draw a time chart.**

Time chart


T_s > 640 μs
Voltage
(V)
120
ON
OFF
ON
time
Current
(A)
80
time
Power
(W)
$P_{(max)}$
time
40 μs
60 μs

$P_{on(max)}$ Calculation

P_{on} = -(4.8 x 10^{12})t^2 +(1.92 x 10^8)t

$$\frac{dP_{on}}{dt} = (-9.6 \times 10^{12})t + 1.92 \times 10^{8} = 0$$

$$t = \frac{1.92 \times 10^{8}}{9.6 \times 10^{12}} = 2.0 \times 10^{-5} \quad = 20\ \mu\text{s}$$

$P_{on(max)}$ = -(4.8 x 10^{12}) x (20 x 10^{-6})^2 + (1.92 x 10^8) x (20 x 10^{-6})

= 1920 W

$P_{off(max)}$ Calculation

$$P_{off} = -(2.1333 \times 10^{12})t^2 + (1.28 \times 10^8)t$$

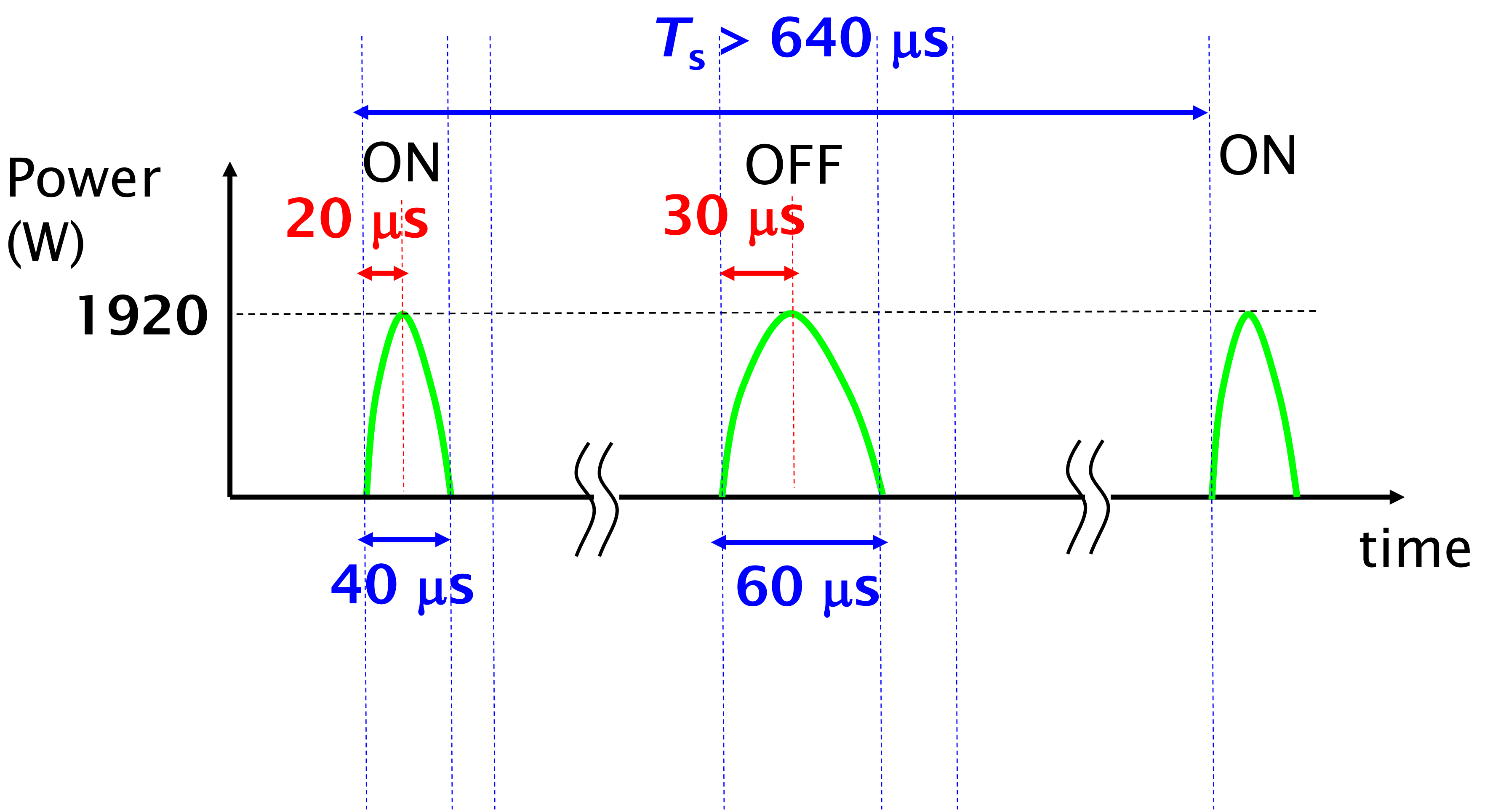
$$\frac{dP_{off}}{dt} = (-4.2666 \times 10^{12})t + 1.28 \times 10^8 = 0$$

$$t = \frac{1.28 \times 10^8}{4.2666 \times 10^{12}} = 3.0 \times 10^{-5} \quad = 30\ \mu\text{s}$$

$$P_{off(max)} = -(2.1333 \times 10^{12}) \times (30 \times 10^{-6})^2 + (1.28 \times 10^8) \times (30 \times 10^{-6})$$

= 1920 W

Instantaneous power curve



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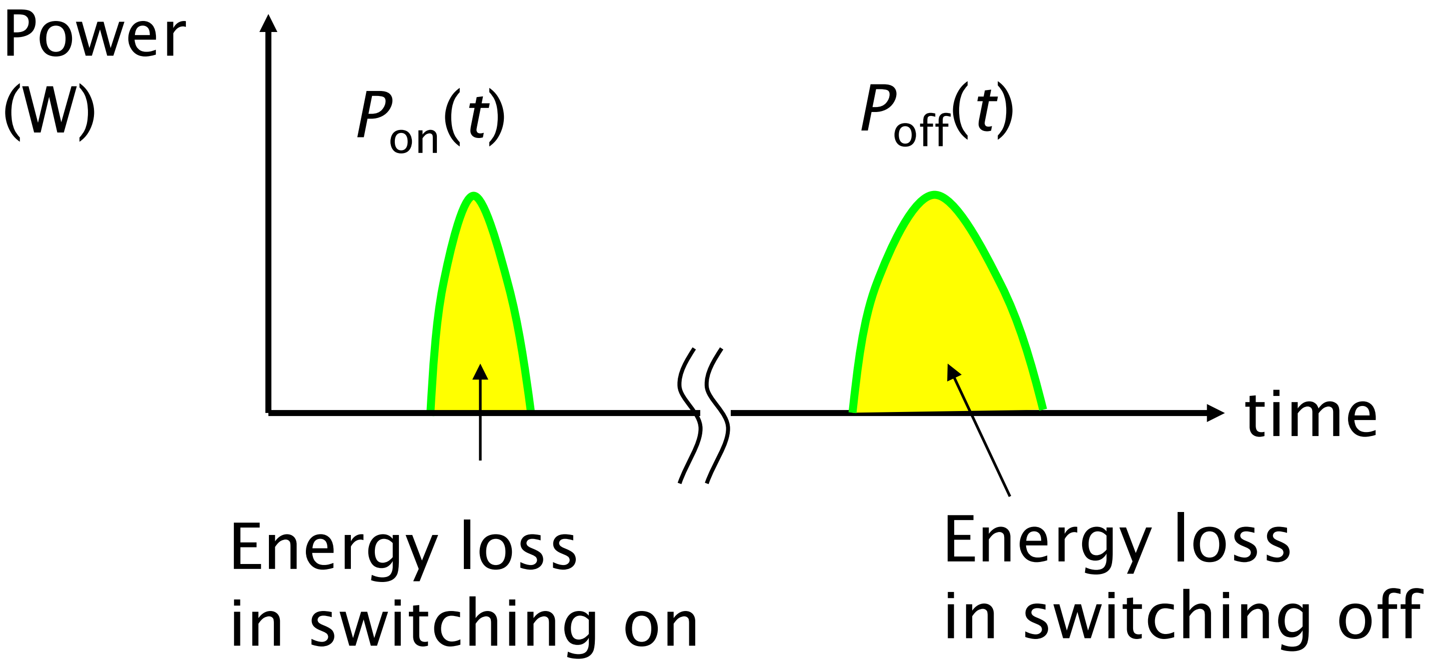
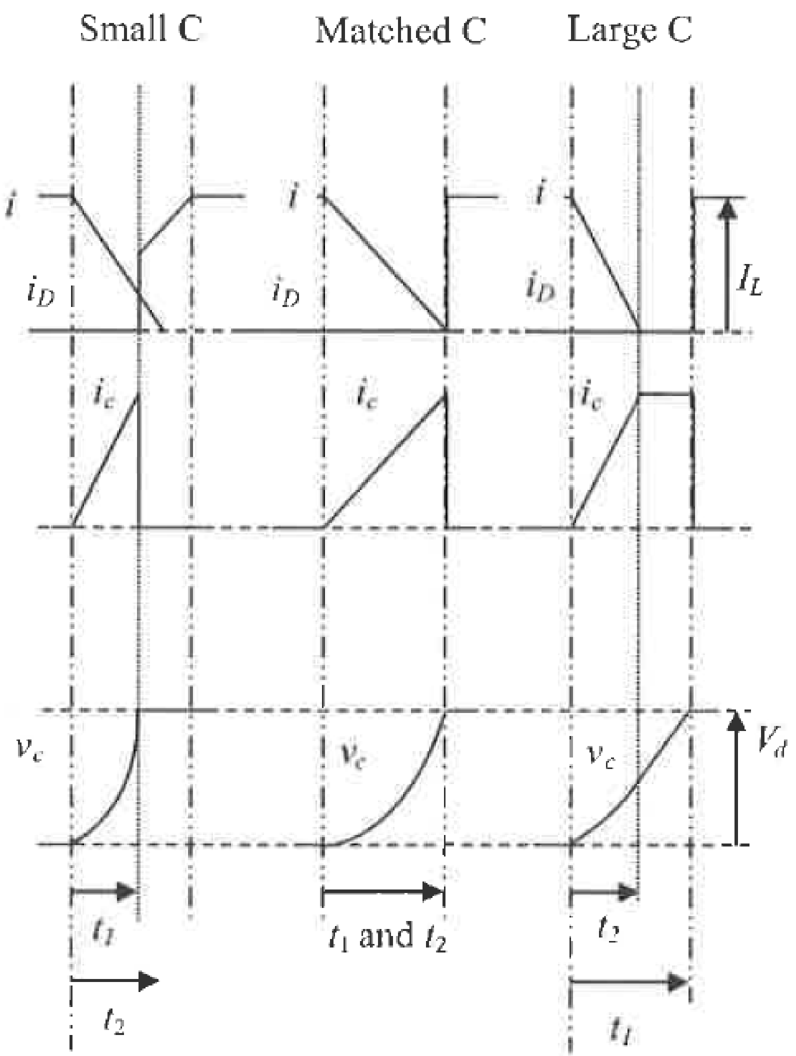
Energy loss in switching

$$P_{mean} = \underbrace{\frac{1}{T_s}\int_0^{T_s}\{P_{on}(t) + P_{off}(t)\}dt}_{\text{Energy (J)}}$$



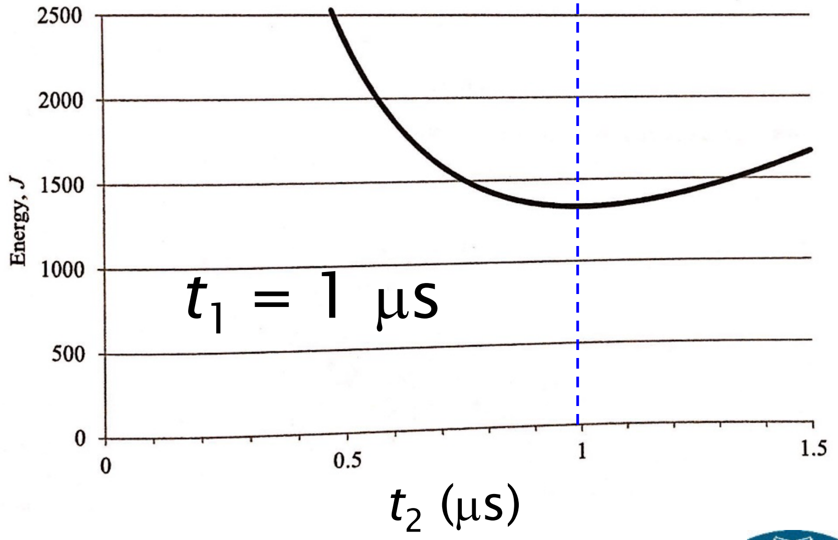
Energy loss in switching



Energy loss in switching off of the transistor snubber.

$$E = V_d I_L \left[\frac{t_2}{2} - \frac{2t_1}{3} + \frac{t_1^2}{2t_2} \right]$$

$\longrightarrow$ Minimum at $t_2 = t_1$



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Question 3

A thyristor is operating with a steady-state power loss of 32 W. If the thermal resistance from the junction to the heat transfer system is 0.81 $^{o}C/W$, what will be the thyristor base temperature if the junction temperature is not exceed 130 ^{o}C at an ambient temperature of 42 ^{o}C ?

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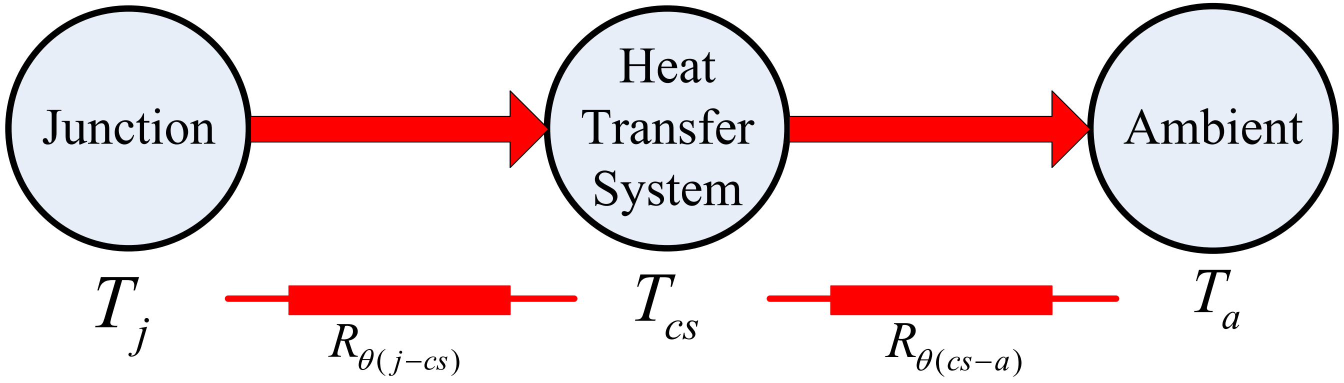
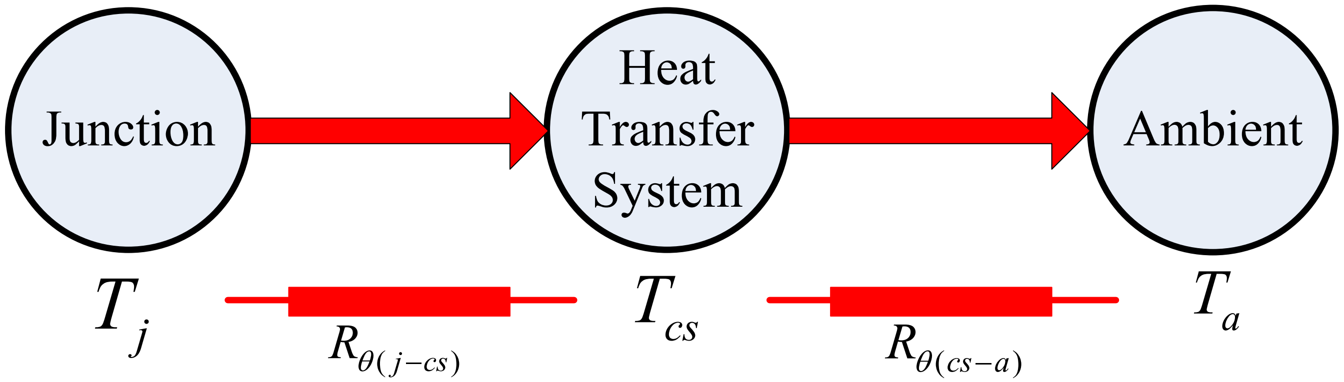
***P* = 32 W**



<130 ^{o}C   0.81 ^{o}C/W   42 ^{o}C

Answer 3



***P* = 32 W**

<130 ºC 0.81 ºC/W 42 ºC

$$\Delta T = T_j - T_{cs} = PR_{\theta(j\text{-}cs)}$$

$$T_j = PR_{\theta(j\text{-}cs)} + T_{CS} = 32 \times 0.81 + T_{CS} = 25.92 + T_{cs} < 130$$

$$T_{CS} < 130 - 25.92 = 104.08$$

$T_{CS} < 104.08$ ºC

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Question 4

A thyristor has a thermal resistance of 0.82 $^{o}C/W$ between its junction and the heat transfer system and 1.96 $^{o}C/W$ between the heat transfer system and the ambient temperature. What will be the maximum allowable power loss in the thyristor if the junction temperature is to be kept below 132 ^{o}C for an ambient temperature of 28 ^{o}C.

Question 4

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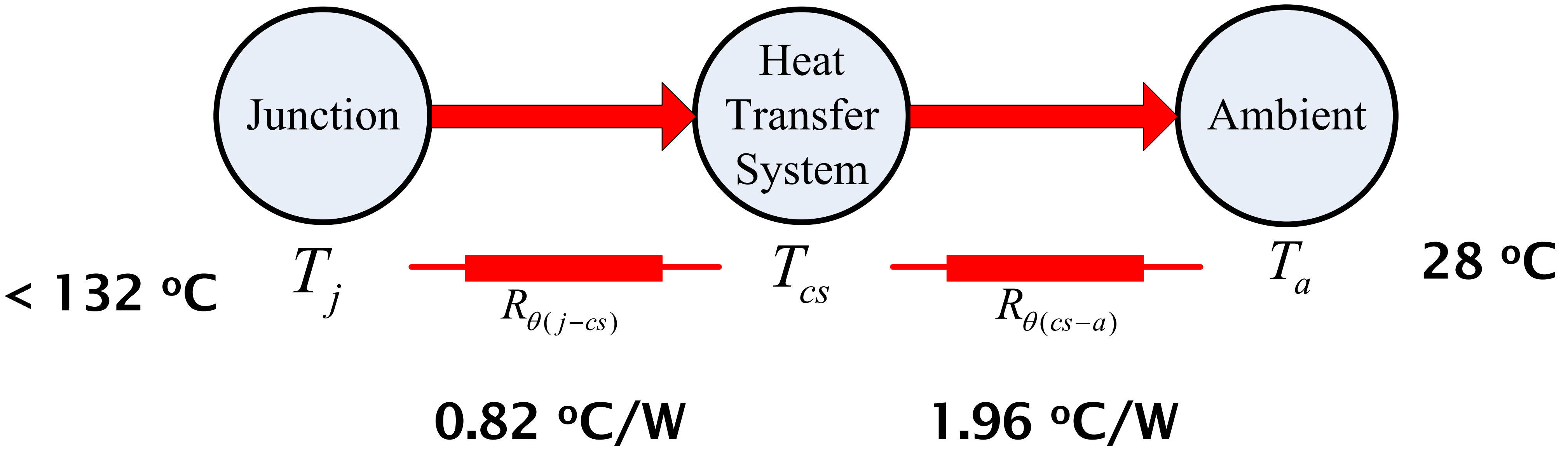
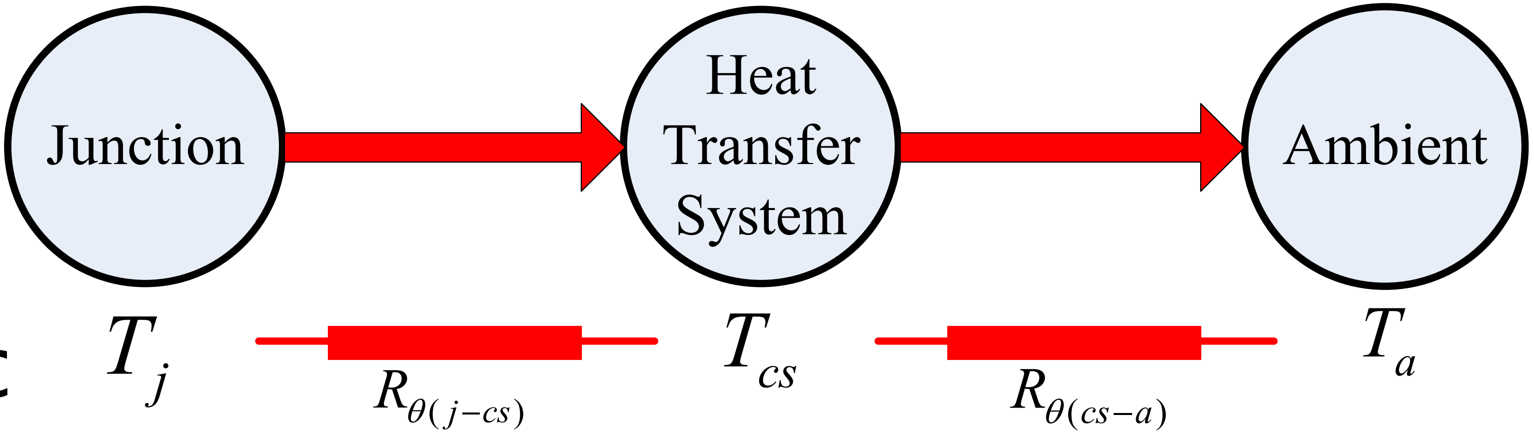


Answer 4



< 132 °C

28 °C

0.82 °C/W **1.96 °C/W**

$$R_{\theta(\text{total})} = R_{\theta(\text{j-cs})} + R_{\theta(\text{cs-a})} = 0.82 + 1.96 = 2.78$$

$$\Delta T = T_\text{j} - T_\text{a} = PR_{\theta(\text{total})}$$

$$T_\text{j} = PR_{\theta(\text{total})} + T_\text{a} = P \times 2.78 + 28 < 132$$

$P < 37.410$ **W**

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