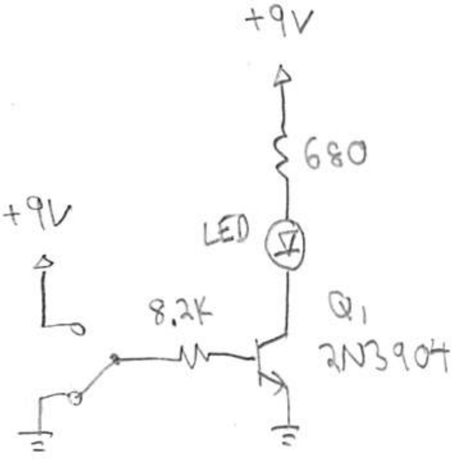
ECE 363
HW 4 Solutions

Total = 100 pts

(1)

(a) Switch connected to ground:

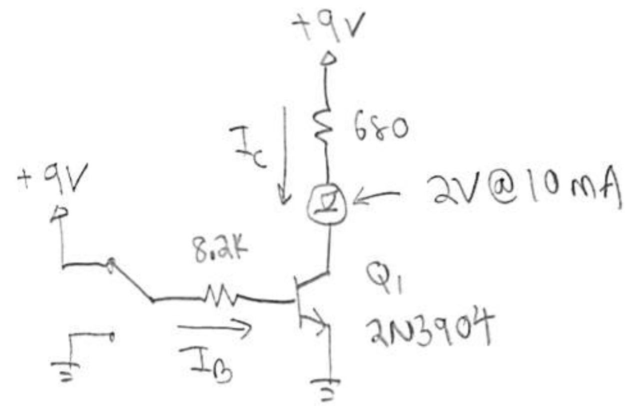


$\Rightarrow$ $\boxed{I_B = 0}$

$\Rightarrow$ Q_1 is OFF

$$\boxed{I_{LED} = I_C = 0}$$

(b) Switch connected to +9V:



From data sheet plots: ← For typical values

$$\left.\begin{aligned} V_{CE(sat)} &= .05V \\ V_{BE(sat)} &= 0.75V \end{aligned}\right\} \text{At } I_C = 10\,mA$$

$$9 - I_B(8.2K) - V_{BE(sat)} = 0 \rightarrow I_B = \frac{9 - 0.75V}{8.2K} = 1.01\,mA \sim \boxed{1.0\,mA}$$

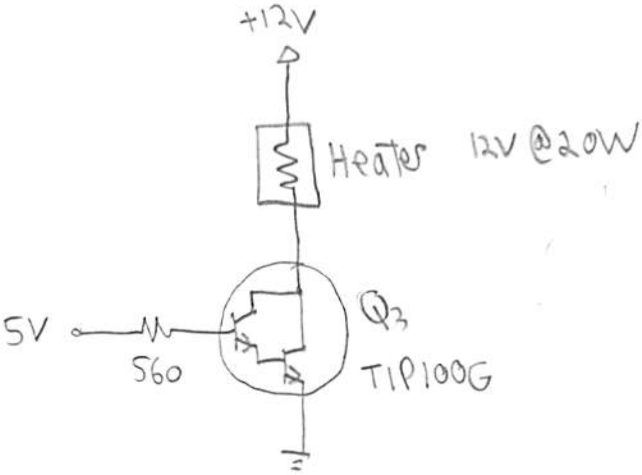
$$9 - I_C(680) - V_F - V_{CE(sat)} = 0 \rightarrow I_C = \frac{9 - 2 - 0.05V}{680\Omega} = \boxed{10.2\,mA}$$

(c) $$\frac{I_C}{I_B} = \frac{10.2\,mA}{1.0\,mA} = \boxed{10.2}$$ YES

☆ NOTE: $\frac{I_C}{I_B} > 10$ is OK

$\frac{I_C}{I_B} \sim 20$ is usually fine for small-signal transistors.

(2)



(a) Heater rating: 12V @ 20W

Rated current $= \frac{20W}{12V} = 1.67A$

Resistance $= \frac{(12V)^2}{20W} = 7.2\Omega$

From TIP100 data sheet plots: ← For typical values

$V_{BE(sat)} = 1.6V$
$V_{CE(sat)} = 0.9V$
] At $I_c \sim 1.67A$

$I_B = \frac{5 - 1.6V}{560\Omega} = .0061A = \boxed{6.1mA}$ ✓ YES, OK with micro controller.

(b) Estimate P:

$P = I_B V_{BE} + I_c V_{CE} = \left(\frac{1.67A}{250}\right)(1.6V) + (1.67A)(0.9V)$

↑ OK To use rated load current since actual current will be less due To $V_{CE(sat)}$

↑ Darlington!

$= 1.51W \xrightarrow{\times 2} 3.03W$ rating

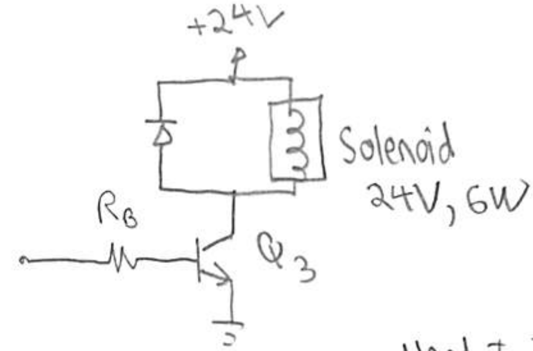
TIP100: Max P = 2W (no HS) X
80W (w/HS) ✓
⇒ Need heat sink!

(c) $T_J = 25°C + (1.51W)(\Theta_{JC} + \Theta_{CS} + \Theta_{SA}) = \boxed{70.4\,°C} < 85°C$

↑ 1.56°C/W ↑ 0.5°C/W ↑ 28°C/W

:) YES, this heat sink is fine.

(3)



(a) In steady state, solenoid is a resistor: $6W = \frac{(24V)^2}{R_L}$

$\rightarrow R_L = 96\Omega$

$I_L = \frac{6W}{24V} = 0.25A \xrightarrow{\times 2} 0.5A$ rating

	Max I_C	V_{CE}	P (no HS)
BC546	100mA ✗		
2N2222A	800mA ✓	50V ✓	500mW

V_{CE}: $> 24 \times 2 = 48V$

↑ (2N2222A)

Need to be $> 2 \times 24 = 48V$

Diode	I_{FSM}	V_{RRM}
1N4148:	1A (1s) ✓ 2A (1µs)	75V ✓
1N4001:	30A (8.3ms)	50V

This works! → 1N4148

Typ $V_{BE(sat)} = 0.88V$

$V_{CE(sat)} = 0.17V$

$P \cong \frac{.25A}{10}(.88V) + .25A(.17V) = .0645W \xrightarrow{\times 2} 129mW$

$< 500mW$ rating

Choose **2N2222A** w/o heat sink

(b) $V_{CE(sat)}$: Typ = 0.13V 0.17V

Max = 0.3V ?

@ 150mA @ 250mA

Max $V_{CE(sat)} = \frac{0.3}{.13} \times .17 = 0.4V$

$V_{BE(sat)}$: Typ = 0.85 0.9V

Max = 1.2V ?

@ 150mA @ 250mA

Max $V_{BE(on)} = \frac{1.2}{0.85} \times 0.9 = 1.27V$

(a) Min $V_L = 24 - 0.4 =$ **23.6V**

Min $I_L = \frac{23.6V}{96\Omega} =$ **.246A**

(c) Typical $V_{BE(sat)} = 0.9V$, $V_{CE(sat)} = 0.17V$ } @ 250mA

$$I_C = \frac{24 - .17V}{96\Omega} = .248A$$

$$I_B = \frac{5 - .9V}{R_B} \sim \frac{.248A}{10} \Rightarrow R_B \sim 165.3\Omega$$

180Ω would also work ↙

Choose $\boxed{R_B = 160\Omega}$

(d)

$$\text{Actual } I_B = \frac{5 - .9}{160\Omega} = 25.6mA \Rightarrow \frac{I_C}{I_B} = \frac{248mA}{25.6mA} = \boxed{9.69}$$

$$\text{worst case } Q_3: \quad I_B = \frac{5 - 1.27}{160} = 23.3mA \Rightarrow \frac{I_C}{I_B} = \frac{246mA}{23.3mA} = \boxed{10.6}$$

↑ still plenty saturated!

(e) Typical $I_B = 25.6mA < 40mA$ OK!

Worst case I_B is max value → min $V_{BE} = 0.6$ @ 150mA

$$\min V_{BE} = \frac{0.6}{0.85} \times 0.9 = 0.635V$$

$$I_B = \frac{5 - 0.635}{160\Omega} = 27.3mA < 40mA \text{ OK!}$$

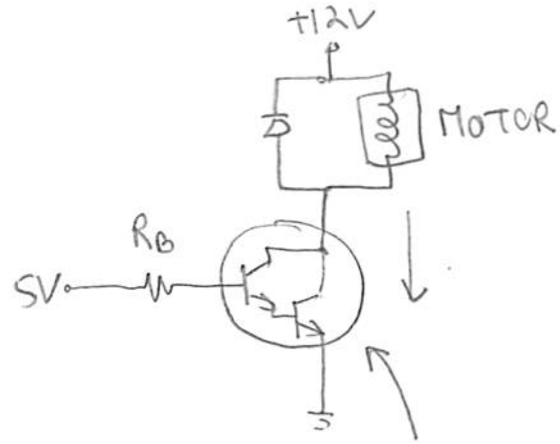
NOTE: Better to be below 50% of current limit.

(Darlington would be better Q_3).

(4)

(a) Stall current = 1.7A

↳ max I_L = 0.85A → ×2 → Need 1.7A rating



	Max I_c	V_{CE}	P (no HS)	P (w/HS)
MPSA29	800mA X			
TIP110	2A ✓	60V	2W	50W

@ .85A Typ $V_{BE(sat)} = 1.5V$, $V_{CE(sat)} = .83V$

60V ↑ Need > 2×12 = 24V ✓

Estimate $P \approx \frac{.85A}{250}(1.5V) + (.85A)(.83V) = 0.71W \xrightarrow{\times 2} 1.42W$ < 2W (typical conditions)

Choose **TIP110**

Need > 1.7A rating
↓
Diode:

	I_{FSM}	V_{RRM}
1N4148	1A (1s) X	
1N4002	30A (8.3ms) ✓	100V ✓

Choose **1N4002**

(b) Max $V_{CE(sat)}$ = 2.5V , ?

Typ $V_{CE(sat)}$ = 1V (2A) , 0.83V (.85A)

Max $V_{CE(sat)} = \frac{2.5}{1} \cdot .83 = 2.08V$

$V_{Motor} = 12 - 2.08 = $ **9.92V**

(c)

$$I_B = \frac{5 - 1.5V}{R_B} \sim \frac{.85A}{250} \Rightarrow R_B = 1029\,\Omega$$

Choose $\boxed{R_B = 1k}$ ← 1.1K would also work.

(d) Max P is when V_{CE} is max.

Max $V_{CE(sat)} = 2.08V$ (from (b))

Max $V_{BE(sat)} = 2.8V$, ?

Typ $V_{BE(sat)} = 1.7V$, $1.5V$

(1.7V at 2A, 1.5V at .85A)

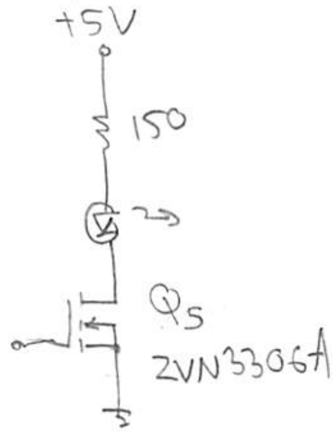
$$\text{Max } V_{BE(sat)} = \frac{2.8}{1.7} \times 1.5 = \underline{\underline{2.47V}}$$

$$P \cong \frac{.85A}{250}(2.47) + .85A(2.08V) = \underline{\underline{1.78W}}$$

$$T_J = 25°C + (1.78W)(2.5°C/W + .5°C/W + 25°C/W)$$
$$= \boxed{74.8°C} < 85°C$$

YES :)

(5)

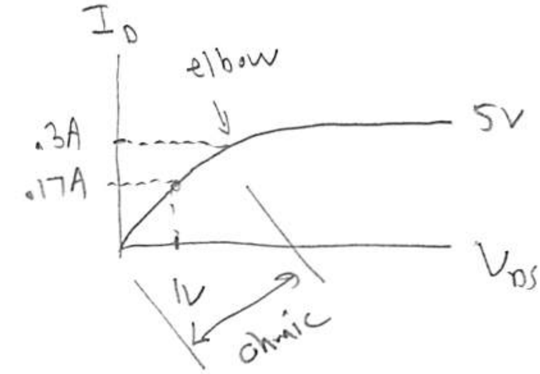


(a) ZVN3306A data sheet:

$$\text{Max } V_{GS,TH} = \boxed{2.4V}$$

(b) When $V_{GS} = 5V$,

$$R_{DS,ON} = \frac{1}{\text{slope}} \sim \frac{1}{\frac{.17A}{1V}} = \boxed{5.9\Omega}$$



Clearly, $I_{LED} = 20mA << 0.3A$

→ ohmic region ✓

$$5 - I_D \times 150 - V_F - I_D R_{DS,ON} = 0$$

$$I_D = \frac{5 - 2.2V}{150 + 5.9\Omega} = \boxed{.018A}$$

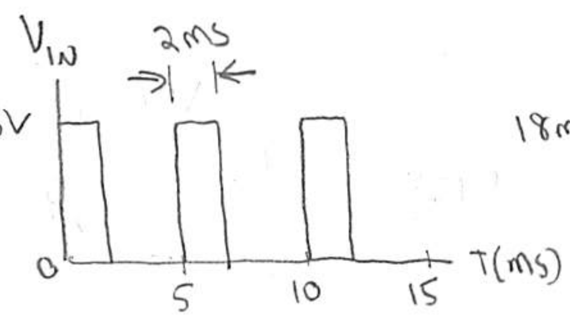
(c)

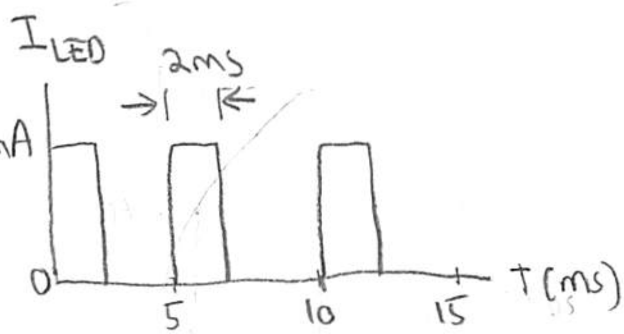
200Hz

→ 1 cycle = 5ms

40% duty cycle

→ ON = 2ms





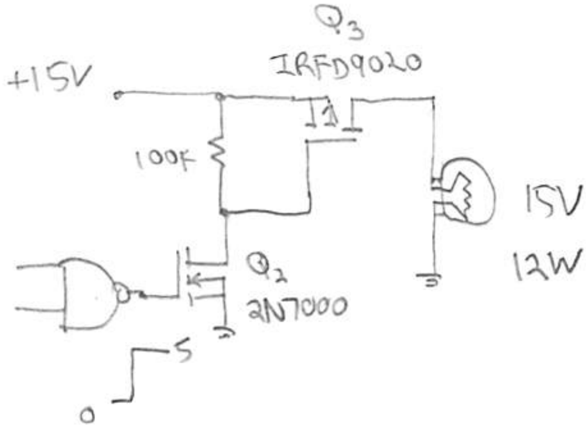
(d) Q_5: Instantaneous $P = (.018A)^2(5.9\Omega) = 1.9mW$

$$\text{Avg } P = 0.4 \times 1.9mW = \boxed{0.76mW}$$

LED: Instantaneous $P = (.018A)(2.2V) = 39.6mW$

$$\langle P \rangle = 0.4 \times 39.6mW = \boxed{15.8mW}$$

(6)



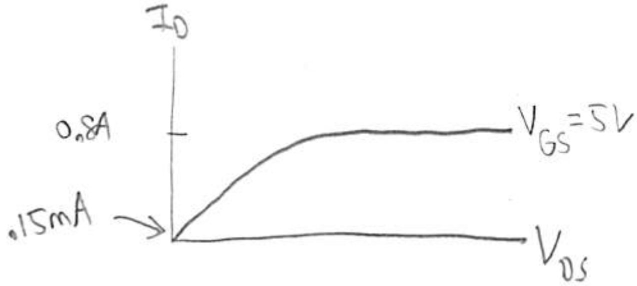
(a) 2N7000 data sheet

Max $V_{GS,TH} = 3V$

(b) NAND output $= 0V << 3V \leftarrow Q_2$ OFF ✓

$= 5V >> 3V \leftarrow Q_2$ ON ✓

(c) $I_D = \dfrac{15 - 0V}{100K + R_{DS,ON}} \approx \dfrac{15V}{100K} = 0.15\,mA \leftarrow$ Tiny!



Definitely in ohmic region! ✓ ⇒ Q_2 is operating near the origin ⇒

(d) IRFD 9020:

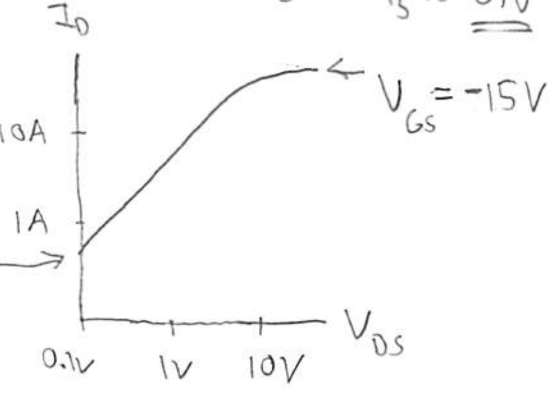
Max $V_{GS,TH} = -4V$

(e) Q_2 is OFF → Q_3 has $V_{GS} \approx 15 - 15 = \underline{0V}$ ← Much more positive than −4V, so Q_3 is OFF

Q_2 is ON → Q_3 has $V_{GS} \cong 0 - 15 = \underline{-15V}$ ← Much more negative than −4V, so Q_3 is ON

(f) Light bulb current rating $= \dfrac{12W}{15V} = 0.8A$

Ohmic ✓ [Clearly in linear region



(9) when Q_3 is ON: $R_{DS,ON} \approx \frac{1}{.8A/.1V} = \frac{1}{8} = \boxed{.125\Omega}$

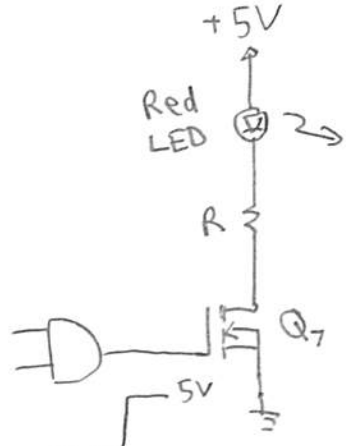
$$R_{Bulb} = \frac{(15V)^2}{12W} = \underline{\underline{18.75\Omega}}$$

$$I_D = \frac{15 - 0V}{.125 + 18.75\Omega} = \boxed{0.795A}$$

Light bulb power = $I_D^2 R_{Bulb}$

$$= (0.795A)^2 (18.75\Omega) = \boxed{11.85W}$$

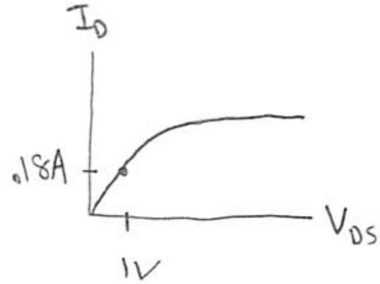
(7)



(a) Compare MOSFETs:

	ZVN3306A	ZVN2106A	IRFD9020
Max cont I_c	270 mA ✓	450 mA ✓	−1.6A
Max V_{DS}	60V ✓	60V ✓	−60V
Max V_{GS}	±20V ✓	±20V ✓	±20V ✓
Max $V_{GS,TH}$	2.4V ✓	2.4V ✓	−4V
Typical $R_{DS,ON}$	$\frac{1V}{.18A} = 5.6\Omega$		0.28Ω

IRFD9020: p-channel! ✗

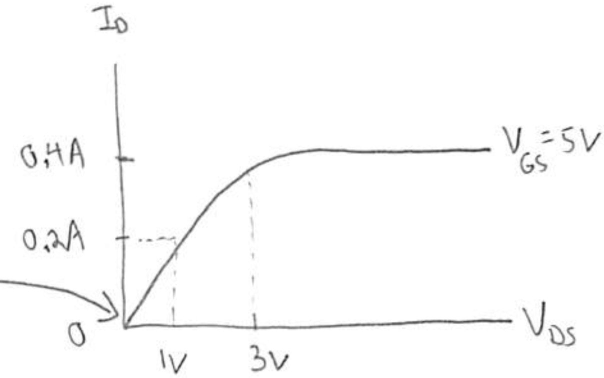


$P = (.010A)^2(5.6\Omega) = .00056W \xrightarrow{\times 2} 1.1mW$

MUCH less than 625 mW rating for ZVN3306

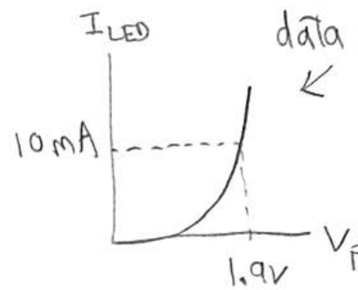
$\Rightarrow$ **ZVN3306A works!**

Ohmic region? Check $I_D - V_{DS}$ curve $\Rightarrow$ Definitely in linear region! [10mA is way down here]



(b) Typical conditions: $Q_7 \Rightarrow R_{DS,ON} \approx \frac{1}{\frac{0.18A}{1V}} = 5.6\Omega$

LED $\rightarrow V_F = 1.9V$



So, $5 - V_F - I_D R - I_D R_{DS,ON} = 0$

$$= \frac{5 - 1.9V - .010 \times 5.6\Omega}{.010A} = 304.4\Omega$$

Choose **$R = 300\Omega$**

(c) From data sheets: LED → $V_F = 2.5V$ (max)

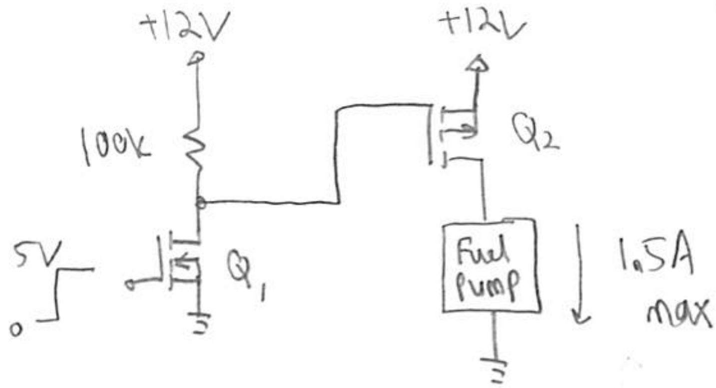
$Q_7 \rightarrow R_{DS,ON} = 5\Omega$ (max at $V_{GS} = 10V$)

Not the most appropriate value to use, especially since typical value is 5.6Ω @ $V_{GS} = 5V$. But we'll use it anyway.

$$\text{Min } I_{LED} = \frac{5 - 2.5V}{300 + 5}$$

$$= \boxed{8.2\,mA}$$

(8) (a) Sketch of circuit:



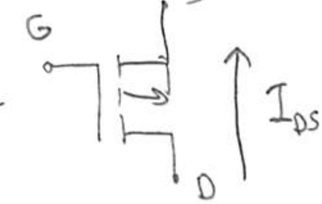
Q_2 needs >3A rating

Power MOSFET!

→ Need logic level shifter

(b) Q_2:

	Max I_{DS}	Max V_{GS}	Max V_{DS}	P
ZVP3310	−.14A ✗			
ZVP2106	−.28A ✗			
IRF9520	−6.8A ✓	±20V	−100V ✓	60W ← (w/ HS)



For $T_C = 25°C$

V_{GS}: ↑ > 2×5 = 10V

V_{DS}: ↑ > 2×12 = 24V

Worst case P (max): $P = (1.5A)^2 \times 0.6\Omega = 1.35W \xrightarrow{\times 2} 2.7W < 60W$

(0.6Ω = max $R_{DS,on}$)

Choose **IRF9520** w/HS ← Choose later

(c) Q_1: $I_D \sim \frac{12V}{100k} = .12mA$ (tiny)

2N7000:

Max I_C	V_{GS}	V_{DS}
200mA	±20V	60V
↑	↑	↑
> .24mA	> 2×5 = 10V	2×12 = 24V
✓	✓	✓

↑ Start with smallest MOSFET

This works!

(d) without HS: $T_J = 25 + 1.35 \times 62 = \boxed{108.7°C} > 85°C$!

Need HS ⇒ $T_J = 25 + 1.35(2.5 + .5 + \Theta_{SA}) < 85°C$

→ $\boxed{\Theta_{SA} < 41.4 °C/W}$