EE204: Analog Circuits

Dept of Electrical Engineering, IITB

Autumn Semester 2023

Assignment 4 **Date: 02-10-2023**

Total Marks: 10

Submission Deadline: 11:59 p.m., 07-10-2023

Mode of submission: Scan your assignment and upload on Moodle as a single pdf file.

Consider ideal op-amps for both questions.

Q1*:* The Circuit shown in Figure 1(a) uses a thermistor to indicate

- If temperature(T) is already below T_{MIN} or above T_{MAX} and
- will generate a falling edge or rising edge when temperature is going below T_{MIN} or going above T_{MAX} .

D_1 and D_2 are LEDs (light emitting diodes). R_{TH} is the resistance of the thermistor of which the thermal characteristic is expressed as $R_{TH}(T) = R_{TH}(T_0)e^{B\left(\frac{1}{T}-\frac{1}{T_0}\right)}$, where T is absolute temperature in Kelvin (K). T_0 = 298 K (25^{0}C), $R_{TH}(T_0)$ = 25kΩ, B = 4000 K.

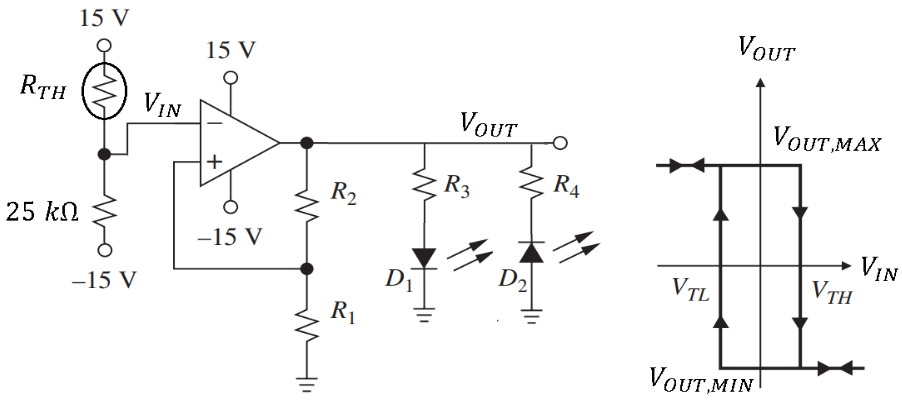
- When the temperature rises above T_{MAX} then V_{IN} exceeds V_{TH} $i.e.$ $V_{IN} > V_{TH}$ D_2 should turn on(emitting light).
- When the temperature falls below T_{MIN} and V_{IN} is lower than V_{TL} $i.e. V_{IN} < V_{TL}$ D_1 should turn on(emitting light).
- Op-Amp output saturates at ± 13V.

Figure 1(b) shows the V_{OUT} vs V_{IN} hysteresis transfer characteristic for the circuit in Figure 1(a).

You will design the schmitt trigger as per following requirements

(1) Choose R1 and R2 for your design according to limits: $1k\Omega \le R1, R2 \le 25k\Omega$.
(2) V_{TH} = 1.x and V_{TL} = -1.x, where x is last digit of your roll number.
(3) LED D_1 has safe forward current between 1 mA and 5 mA and forward drop is 1V.
(4) LED D_2 has safe forward current between 1 mA and 5 mA and forward drop is 2V.

(a) Determine V_{TH} and V_{TL} for your roll number. [0.5 Marks]
(b) Determine R_1 and R_2 for above V_{TH} and V_{TL}. [1.5 Marks]
(c) Determine R_3 and R_4 as per instructions (3) and (4). [1.5 Marks]
(d) Calculate T_{MAX} and T_{MIN}. [1.5 Marks]



(a) *Figure 1* (b)

Solution

1 a) Sample solution for roll number last digit '5'.

$$\boxed{\begin{aligned} V_{TH} &= 1.5\text{ V} \\ V_{TL} &= -1.5\text{ V} \end{aligned}}$$

$V_{TH} = 1.5$ V — 0.25 Marks

$V_{TL} = -1.5$ V — 0.25 Marks

Students will choose based on their roll no.

b) $V_{TH} = \dfrac{13 R_1}{R_1 + R_2}$ V — ① — 0.25 Marks

$V_{TL} = \dfrac{-13 R_1}{R_1 + R_2}$ V — ② — 0.25 Marks

from ①

$$1.5 = \frac{13 R_1}{R_1 + R_2}$$

$$1.5R_1 + 1.5R_2 = 13R_1$$

$$1.5R_2 = 11.5 R_1$$

Students can choose any value

let $R_1 = 1.5\,k\Omega$ — 0.5 Marks

$R_2 = 11.5\,k\Omega$ — 0.5 Marks

c) for D_1 to pass safe current

$1mA \leq \dfrac{13 - 1}{R_3} \leq 5mA$ — 0.5 Marks

$$1mA \leq \frac{12}{R_3} \leq 5mA$$

$\boxed{2.4k\Omega \leq R_3 \leq 12k\Omega}$ — 0.25 Marks

for D_2 to pass safe current

$1mA \leq \dfrac{-2 - (-13)}{R_4} < 5mA$ — 0.5 Marks

$\boxed{2.2k\Omega \leq R_4 < 11\,k\Omega}$ — 0.25 Marks

d) Finding T_{MAX}, As T increases R_{TH} decreases and V_{IN} increases, at $T = T_{MAX}$, $V_{IN} = V_{TH}$

Answer depends on student roll no.

For $V_{TH} = 1.5V$

$$V_{TH} = 15 - \frac{30 \quad R_{TH}}{25K + R_{TH}} \quad \text{— 0.25 Marks}$$

$$1.5 = 15 - \frac{30 R_{TH}}{25K + R_{TH}}$$

$$R_{TH} = 20.45 \ K\Omega$$

$$20.45 \ K\Omega = 25K\Omega \ e^{4000\left(\frac{1}{T} - \frac{1}{298}\right)}$$

$$4000\left(\frac{1}{T} - \frac{1}{298}\right) = \ln \frac{20.45}{25}$$

$$\boxed{T_{MAX} = 302.52 \ K} \quad \text{— 0.5 Marks}$$

Finding T_{MIN}, As T decreases R_{TH} increases and V_{IN} decreases, at $T = T_{MIN}$, $V_{IN} = -V_{TH}$

For $V_{TH} = -1.5V$

$$V_{TH} = 15 - \frac{30 \quad R_{TH}}{25K + R_{TH}}$$

$$-1.5 = 15 - \frac{30 R_{TH}}{25K + R_{TH}} \quad \text{— 0.25 Marks}$$

$$R_{TH} = 30.55 \ K\Omega$$

$$30.55 \ K\Omega = 25K\Omega \ e^{4000\left(\frac{1}{T} - \frac{1}{298}\right)}$$

$$4000\left(\frac{1}{T} - \frac{1}{298}\right) = \ln \frac{25}{30.55}$$

$$\boxed{T_{MIN} = 293.6 \ K} \quad \text{— 0.5 Marks}$$

Q2: For the circuit shown in Figure 2(a), Op-Amps are dual supply Op-Amps and turn on voltages for D_1 and D_2 are equal to 0.7V .

(a) Derive an expression for V_{OUT} when $V_{IN} > 0$. [1 Marks]
(b) Derive an expression for V_{OUT} when $V_{IN} < 0$. [1 Marks]
(c) To achieve relation $V_{OUT} = A|V_{IN}|$, where A represents slope in Figure 2(b), what should be the relation between R1, R2 and R3. [1 Marks]
(d) Consider condition for R_1, R_2, R_3 and R_4 as $1k\Omega \le R_1, R_2, R_3, R_4 \le 10k\Omega$, design the full wave rectifier for A=3. [2 Marks]

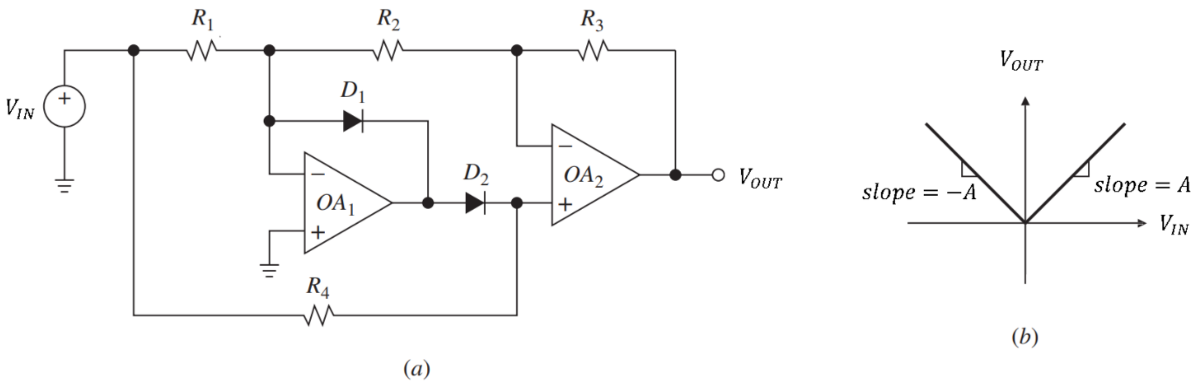
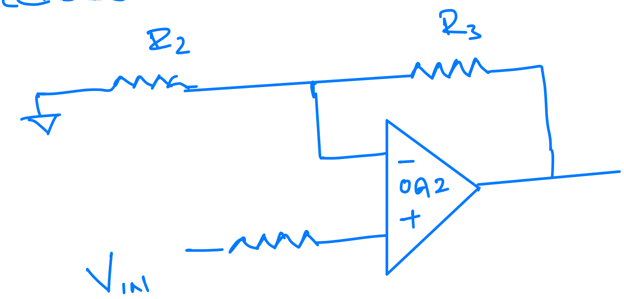


Figure 2

Solution

1 a) For $V_{IN} > 0$

D1 turns ON and OA1 is in negative feedback, D2 is OFF — 0.5 Marks



$$\boxed{V_{OUT} = V_{IN}\left(1 + \frac{R_3}{R_2}\right)}$$

0.5 Marks

b) For $V_{IN} < 0$

D_1 turns OFF and D_2 turns ON

OA1 is in −Ve feedback through — 0.5 Marks

D2 − OA2 − R3 − R2

$$\frac{V_{IN} - 0}{R_1} = \frac{0 - V_{OUT}}{R_2 + R_3}$$

$$\boxed{V_{out} = -\left(\frac{R_2 + R_3}{R_1}\right) V_{in}}$$ — 0.5 Marks

c) for $V_{out} = A|V_{in}|$

$$\left(1 + \frac{R_3}{R_2}\right) = \frac{R_2 + R_3}{R_1}$$ – 0.25 Marks

$$\boxed{R_1 = R_2}$$ – 0.25 Marks

$$1 + \frac{R_3}{R_2} = A$$

$$\boxed{R_3 = (A-1)\, R_2}$$ — 0.5 Marks

d) for $A = 3$

student can choose any value.

let $R_1, R_2 = 3k\Omega$ — 1 Mark

$R_3 = 6k\Omega$ — 0.5 Marks

R_4 has no constraint so R_4 can be anything – 0.25 Marks

let $R_4 = 8k\Omega$ — 0.25 Marks