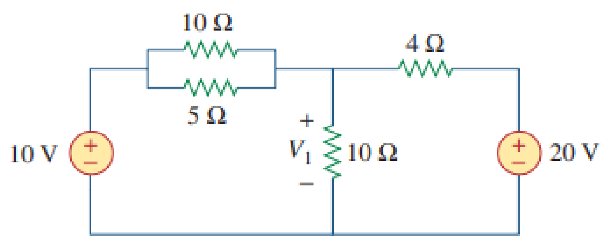
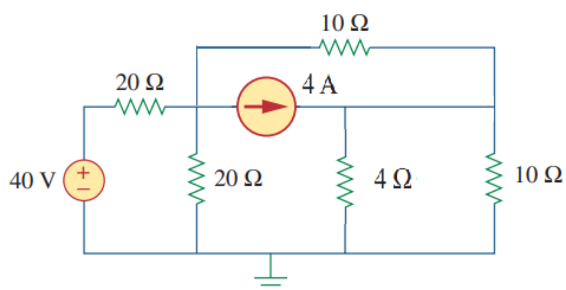
CSE250 [Review]

1. Draw the alternate representations of the following circuits *[Note that the number of floating sources should be minimized]***.**

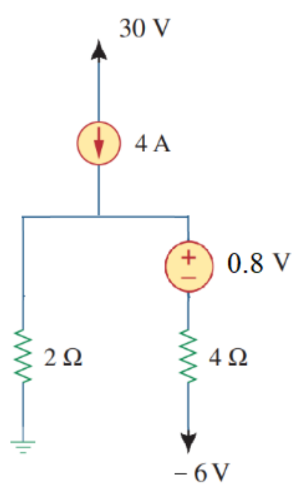
a)



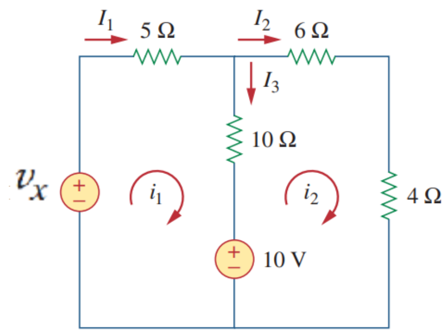
b)



2. Find the loop representation of the following circuit:



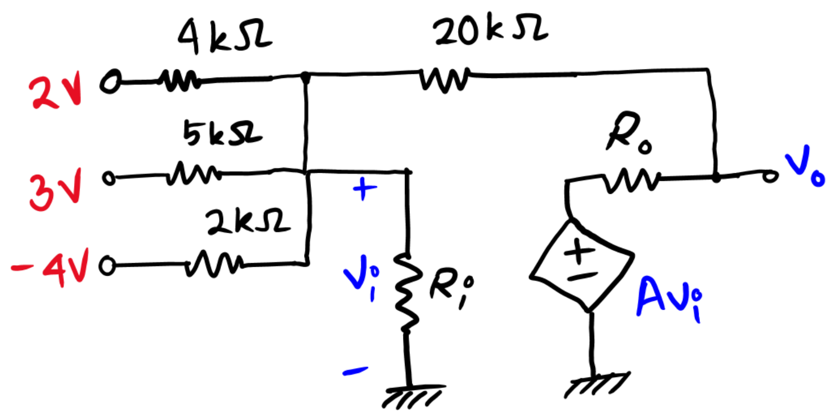
3. Here, v_x = (10+last digit of your ID) V



(i) Draw the alternate circuit representation of the circuit shown in the Figure above *[Note that the number of floating sources should be minimized]***.**

(ii) Apply KCL and KVL on the circuit drawn in (i) and **calculate I_1, I_2, and I_3.**

4.



In the above circuit $A = 100$, $R_i = 100\ k\Omega$ and $R_o = 1\ k\Omega$. Answer the following questions

a. Write the node equations for the nodes indicated by vi and vo.
b. Solve the node equations to find the values of vi and vo.
c. Can circuit theorems based on linearity principle (such as superposition principle) be applied to the above circuit? Explain in short why or why not.

Solution:

a) At node v_i:

$$\frac{2-v_i}{4}+\frac{3-v_i}{5}+\frac{-4-v_i}{2}=\frac{v_i-v_o}{20}+\frac{v_i}{100} \quad \text{.......(i)}$$

At node v_o:

$$\frac{v_i-v_o}{20}+\frac{Av_i-v_o}{1}=0 \quad \text{--------(ii)}$$

b) Simplifying:

(i) becomes:

$$v_i\left(\frac{1}{4}+\frac{1}{5}+\frac{1}{2}+\frac{1}{20}+\frac{1}{100}\right)-v_o\left(\frac{1}{20}\right)=\frac{2}{4}+\frac{3}{5}-\frac{4}{2}$$

$$\therefore\ 1.01v_i-0.05v_o=-0.9 \quad \text{------(iii)}$$

(ii) becomes:

$$v_i\left(-\frac{1}{20}-\frac{100}{1}\right)+v_o\left(1+\frac{1}{20}\right)=0$$

$$-100.05v_i+1.05v_o=0 \quad \text{------.(iv)}$$

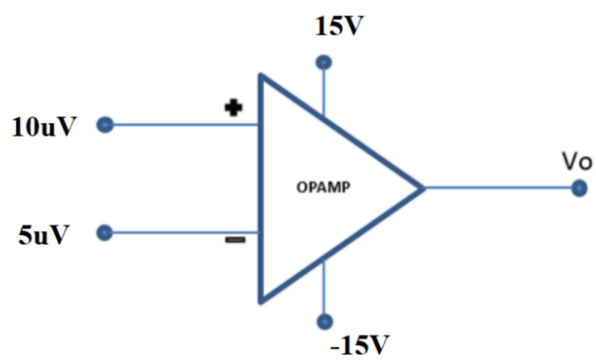
Solving (iii) & (iv) we get:

$$\boxed{\begin{aligned}v_i&=0.24\text{ V}\\ v_o&=22.842\text{ V}\end{aligned}}$$

c) Yes! Because all the circuit elements are linear. (Even the voltage dependent voltage source, because the voltage dependence (Av_i) is Linear.)

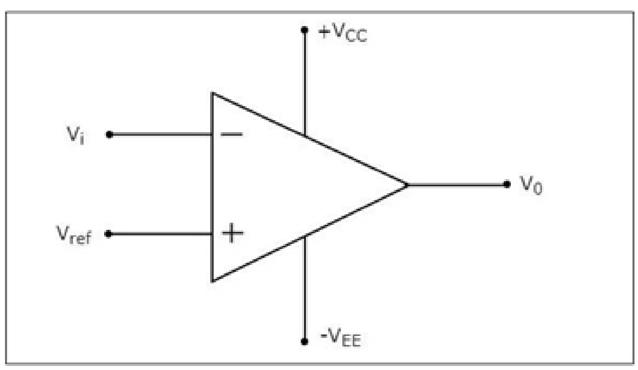
Op-Amp

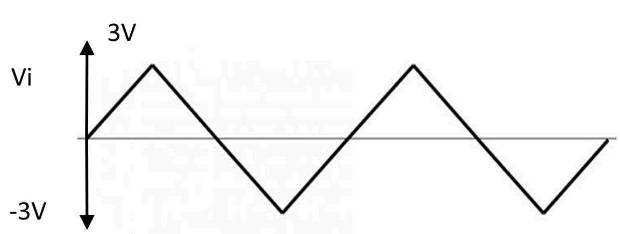
1. Observe the following circuit.



Calculate the value of Vo. Repeat the problem with V+=1 mV and V-=0.2 mV. Consider A=2105.

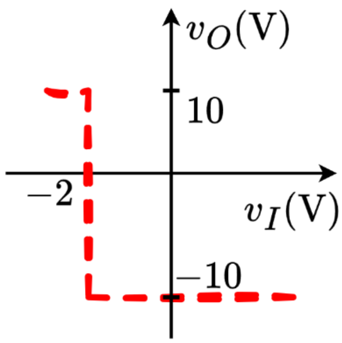
2. Draw output Vo for the following op-amp circuit.

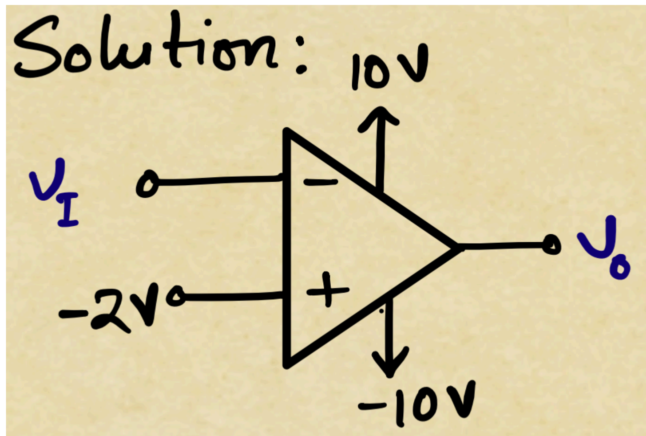




VCC = 15V= -VEE , Vref = 1.5V, Vi is a 6V p-p triangular signal as shown above.

3. Design a circuit using **op-amp** that has the voltage transfer characteristics as shown in the figure below. $v_O(V)$ is the **output voltage** and $v_I(V)$ is the **input voltage**.





4.

A valve is used to release (when valve is OPEN,) or maintain (when valve is CLOSED,) water pressure in a water tank. The valve operates on **ACTIVE LOW** logic. (i.e., the valve is OPENED when given a LOW voltage of 1 V**,** but remains CLOSED when provided a HIGH voltage of 6 V**.**)

A pressure sensor is installed in the water tank that outputs a voltage linearly proportional to pressure, as shown in the table below.

At **0.5 atm** pressure	At **1 atm** pressure	At **1.5 atm** pressure
$v_{0.5\,atm} = 0.5\,V$	$v_{1\,atm} = 3\,V$	$v_{1.5\,atm} = 5.5\,V$

The pressure in the water tank can be measured by the formula $P = h\rho g$, where P**,** (in **Pascals (Pa)** unit) is the water pressure, h is the height of water in the tank (in $metres$), $\rho(= 1000\,kgm^{-3})$ is the density of water and g is the acceleration due to gravity (in ms^{-2}).

[1 atm = 101325 Pa]

i. **Design** a circuit using Op-Amp comparator to automatically turn OPEN the valve if water level exceeds **10 m**.

ii. **Draw** the voltage transfer characteristics (VTC) of the designed Op-Amp.

Solution:

When $h = 10$ m: $P = h\rho g = 98000$ Pa $= 0.967$ atm

From the table we can interpolate and find the exact voltage at this pressure.

For $1 - 0.5 = 0.5$ atm pressure change, the voltage changes by $2.5\ V$

For 1 atm pressure change, the voltage changes by $2.5/0.5\ V = 5\ V$

So, for $0.967 - 0.5 = 0.467$ atm pressure change, the voltage changes by $5 * 0.467\ V$

So, voltage at 0.967 atm pressure is $0.5 + 5 * 0.467\ V = 2.836\ V$

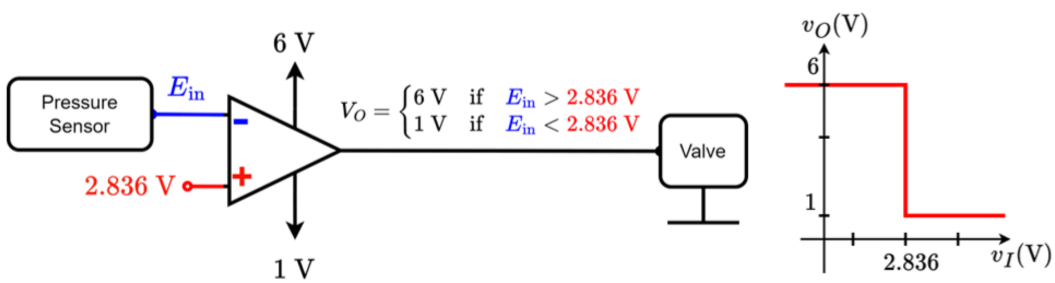
[redacted]

Active low logic:

High water level $->$ High pressure $->$ **High input voltage** $->$ Valve Open $-1\ V = V_L$

Low water level $->$ Low pressure $->$ **Low input voltage** $->$ Valve Closed $-6\ V = V_H$

So the comparator is in inverting configuration. As shown below:



5.

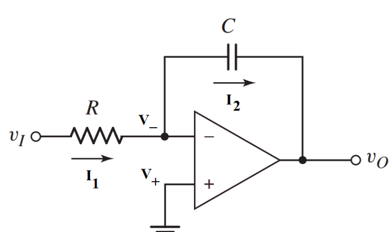


Figure 1 (a)

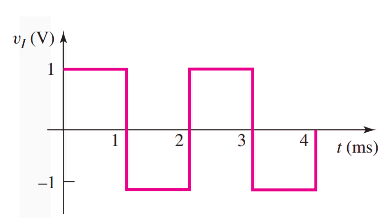


Figure 1 (b)

(a) **Analyze** the circuit drawn in Fig. 1(a) and **determine** the voltage values at the inverting and non-inverting nodes (V_- and V_+). [0.5+0.5]

(b) **Identify** the relation between I_1 and I_2. [1]

(c) **Analyze** the circuit to derive the expression of output voltage V_o. You have to **show** all the steps. [3]

(d) Now consider the input wave v_I given in Fig. 1(b). For circuit parameters R = 10 kΩ and C = 0.1μF, **determine** the output voltage at t = 1 ms. [1]

(e) **Design** a circuit using Op-Amps to implement the following expression: [4]

$f = \frac{1}{4}x + 7y - \frac{d}{dt}z$

Solution

part-(c)

This is an integrator circuit

$\therefore V_0 = \frac{-1}{RC} \int V_i \, dt$

$$V_i = \begin{cases} 1, & 0 \le t < 1 \\ -1, & 1 \le t < 2 \\ 1, & 2 \le t < 3 \\ -1, & 3 \le t < 4 \end{cases}$$

So

$$V_0 = \begin{cases} \frac{-1}{RC}(t) + K_1 \\ \frac{1}{RC}(t) + K_2 \\ \frac{-1}{RC}(t) + K_3 \\ \frac{1}{RC}(t) + K_4 \end{cases}$$

where, K_1, K_2, K_3, K_4 are const.

part-(d)

for $R = 10K\Omega$, $C = 0.1\,\mu F$,

$V_o = \frac{-1}{10 \times 10^3 \times 0.1 \times 10^{-6}} (1 \times 10^{-3}) + K_1$

$\hookrightarrow V_o = -1 + K_1$.

6.

$i_D = I_S(e^{v_D/V_T} - 1)$
$\cong I_S e^{v_D/V_T}$
[Sufficiently forward biased]

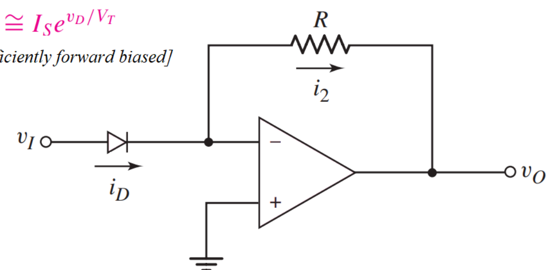


Figure 1

(a) **Analyze** the circuit drawn in Fig. 1 and **determine** the voltage values at the inverting and non-inverting nodes (V_- and V_+). [0.5+0.5]

(b) **Identify** and briefly explain the relation between i_2 and i_D. [1.5]

(c) **Analyze** the circuit to derive the expression of output voltage V_o. You have to **show** all the steps. [3.5]

(d) **Design** a circuit using Op-Amps to implement the following expression: [4]

part-c

$$i_D = I_S(e^{v_D/V_T} - 1)$$
$$\cong I_S e^{v_D/V_T}$$

[Sufficiently forward biased]

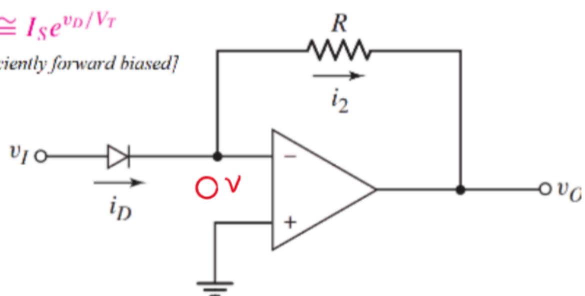


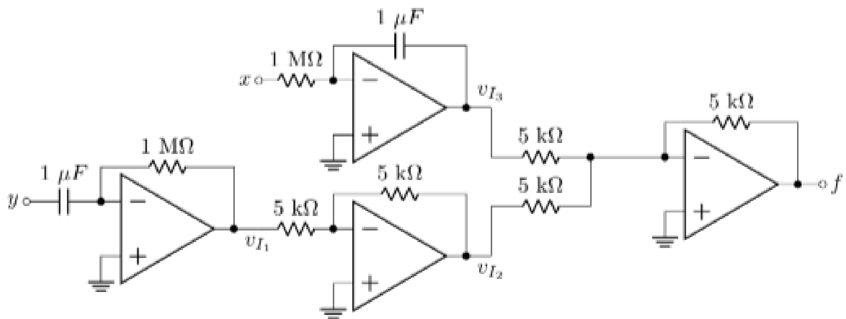
Figure 1

$i_D = i_2$

$\hookrightarrow I_s e^{(V_D/V_T)} = \frac{0 - V_0}{R}$

$\hookrightarrow \boxed{V_0 = -I_s R e^{(V_D/V_T)}}$

7.



(a) **Analyze** the circuit above to find an expression of f in terms of inputs x and y. Also, **determine** the intermediate outputs v_{I_1}, v_{I_2}, and v_{I_3} as denoted in the circuit. [4]

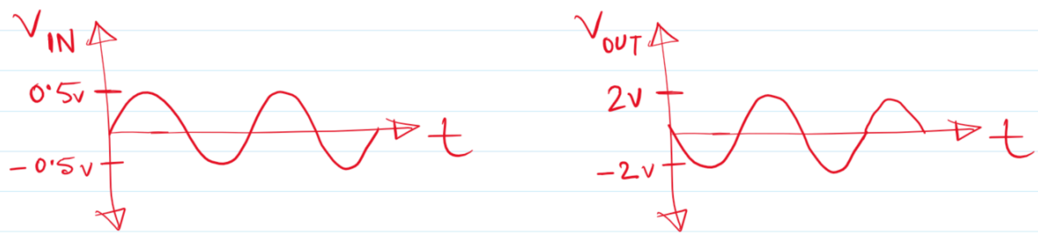
(b) Draw the circuit of an inverting amplifier and **design** it in such a way that the voltage gain, $k = -4$. (*i.e.*, find the values of R_1 and R_2). [3]

(c) **Show** the input and output waveforms of the inverting amplifier of part (b) assuming a sinusoidal input of 0.5 V amplitude. **Calculate** the amplitude of the output. [2]

(d) Consider the inverting amplifier of part (b) again. Assume the input voltage can provide a maximum current of 0.5 μA. **Determine** the design changes required, if any, for the circuit to work. [1]

part-c

c

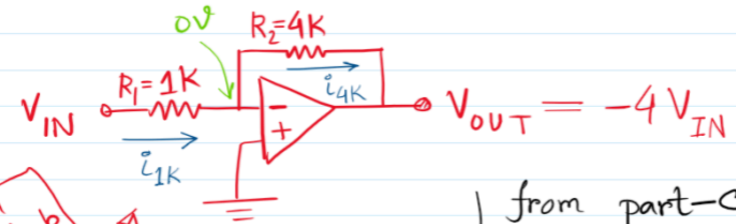


Output Amplitude $\rightarrow$ $|gain| \times$ Input Amplitude

$= |-4| \times 0'5v = 2v$.

part-d

(d)



from part-b

$$i_{1K\,(max)} = 0{\cdot}5\ \mu A$$

$$\hookrightarrow \frac{V_{IN\,(max)} - 0}{R_1} = 0{\cdot}5\,\mu A$$

from part-c, we get,

$$V_{IN\,(max)} = 0{\cdot}5\ v.$$

So, $\frac{0{\cdot}5 - 0}{R_1} = 0{\cdot}5\ \mu A$

$$\hookrightarrow R_1 = \frac{0{\cdot}5}{0{\cdot}5\mu A} = 1\,M\Omega$$

but, $\text{gain} = -4 = \frac{-R_2}{R_1} \rightsquigarrow R_2 = 4R_1 = 4\,M\Omega$.

So, we need to set, $R_1 = 1M\Omega$ instead of $1K\Omega$

$R_2 = 4M\Omega$ instead of $4K\Omega$

**If the input voltage is not mentioned, then the resistance values will be set according to the gain and you will have to assume one of the resistances.

8.

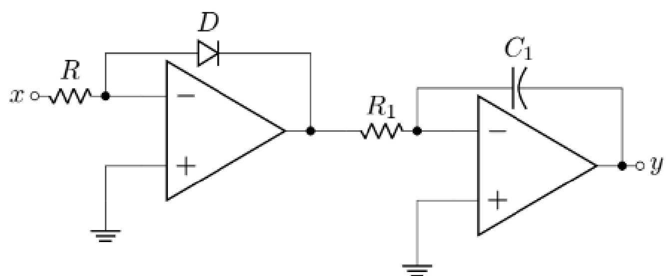
(a) **Design** a circuit using **Op-Amp comparator** to automatically turn ON (or OFF) the street lights. For this, you have a lux sensor installed on top of the street lights (facing above) that outputs a voltage proportional to amount of natural light, as listed below:

$v_{\text{night, 0 lux}} = 1$ V	$v_{\text{dusk, 20 lux}} = 2$ V	$v_{\text{dawn, 80 lux}} = 3$ V

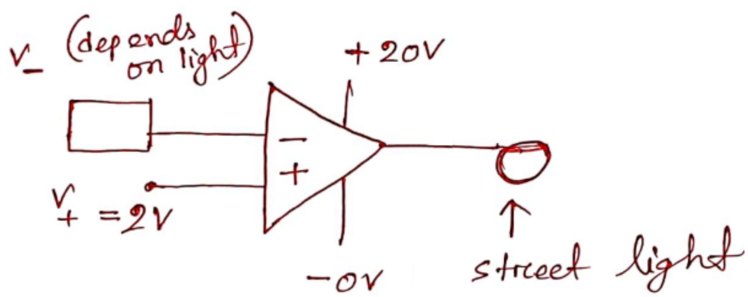
The lights require 20 V and should be ON if the amount of light goes ***below*** 20 lux (at dusk). [3]

(b) **Design** a circuit using Op-Amp to implement the expression: $f = -3\frac{dx}{dt} + 2\exp y + 4z$ [4]

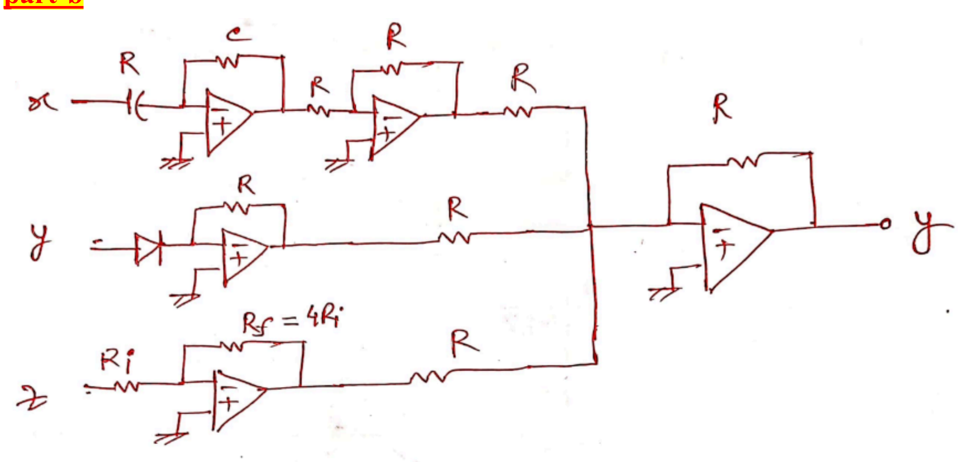
(c) **Analyze** the circuit below to find y as a function of x. For the diode, $I_S R = 1$ and $V_T = 1$. [3]



part-a

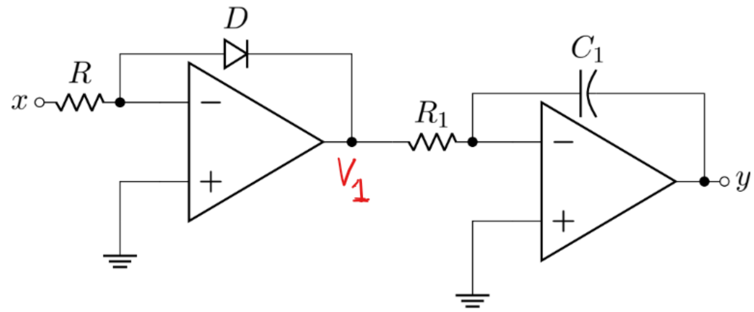


part-b



$RC = 3, \quad V_T = 3$

part-c



$$V_1 = -V_T \ln \frac{x}{I_S R}$$

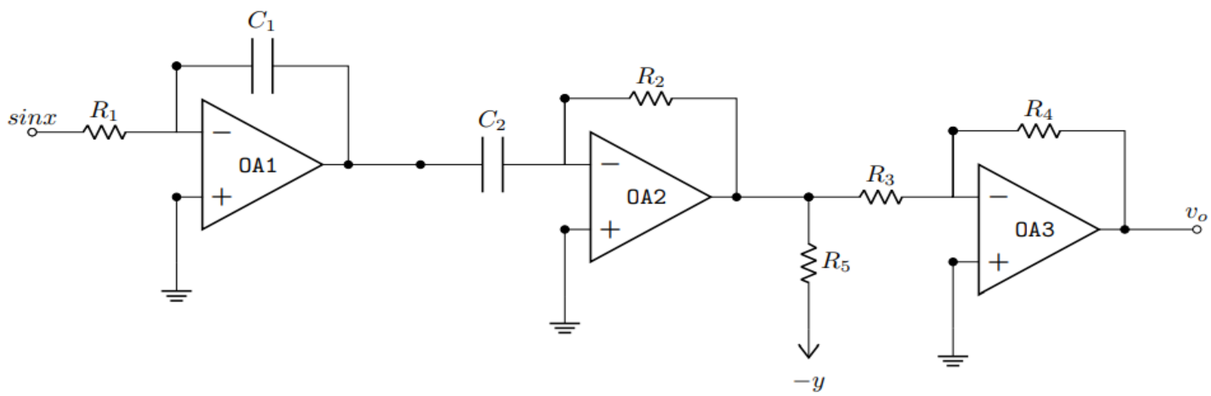
$$y = -\frac{1}{R_1 C_1} \int V_1 \, dt$$

$$= -\frac{1}{R_1 C_1} \int -V_T \ln \frac{x}{I_S R}$$

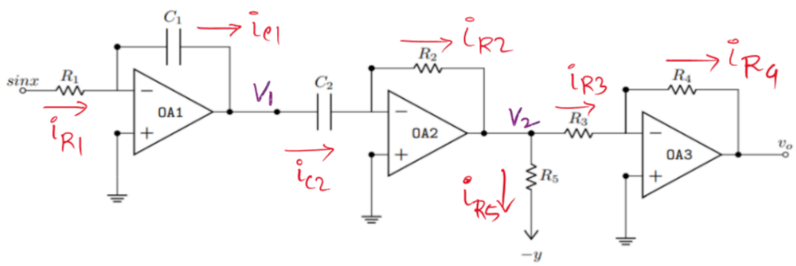
$$= \frac{1}{R_1 C_1} \int \ln x$$

$$\left[V_T = 1, \quad I_S R = 1 \right]$$

9. **Deduce** the expression for output, $\mathbf{V_o}$ from the circuit above



Solution



$$V_1 = \frac{-1}{RC}\int \sin x \, dt$$

$$V_2 = -RC\frac{d}{dt}(V_1)$$

$$= -RC\frac{d}{dt}\left(\frac{-1}{RC}\int \sin x \, dt\right)$$

$$= \sin x$$

Applying KCL,

$$i_{R2} = i_{R5} + i_{R3}$$

$$\hookrightarrow i_{R1} = i_{R5} + i_{R3} \quad \left[\because i_{R1} = i_{c1} = i_{c2} = i_{R2}\right]$$

$$\hookrightarrow \frac{\sin x - 0}{R_1} = \frac{V_2 - (-y)}{R_5} + i_{R4} \quad \left[\because i_{R3} = i_{R4}\right]$$

$$\hookrightarrow \frac{\sin x}{R_1} = \frac{\sin x + y}{R_5} + \frac{0 - V_o}{R_4}$$

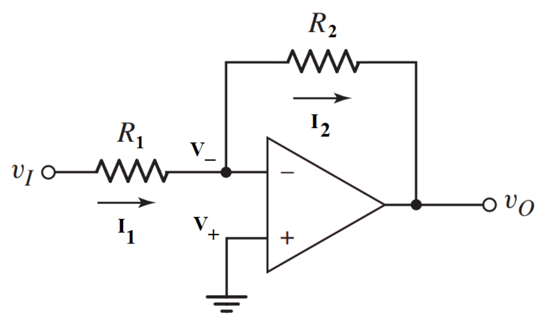
$$\hookrightarrow \frac{\sin x}{R_1} - \frac{\sin x + y}{R_5} = \frac{-V_o}{R_4}$$

$$\hookrightarrow V_o = -\left(\frac{R_4}{R_1}\sin x - \frac{R_4}{5}(\sin x + y)\right)$$

10. Design a circuit using op-amps to implement y=7x by an

(a) Inverting amplifier
(b) Non-inverting amplifier

11.

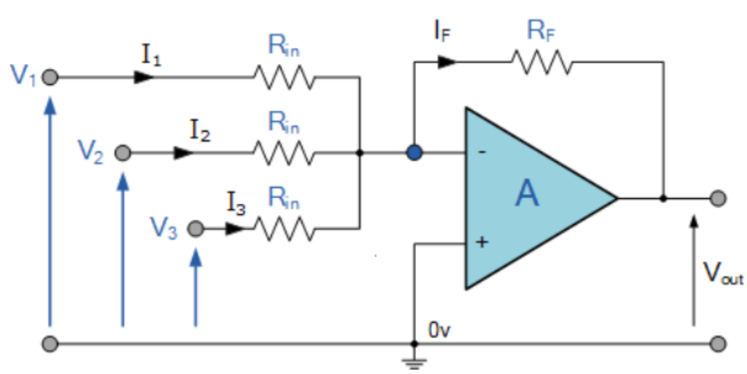


(a) **Design** an inverting amplifier (i.e., find the values of R_1 and R_2 of the circuit shown in the Figure above) in such a way that the voltage gain is **−5**.

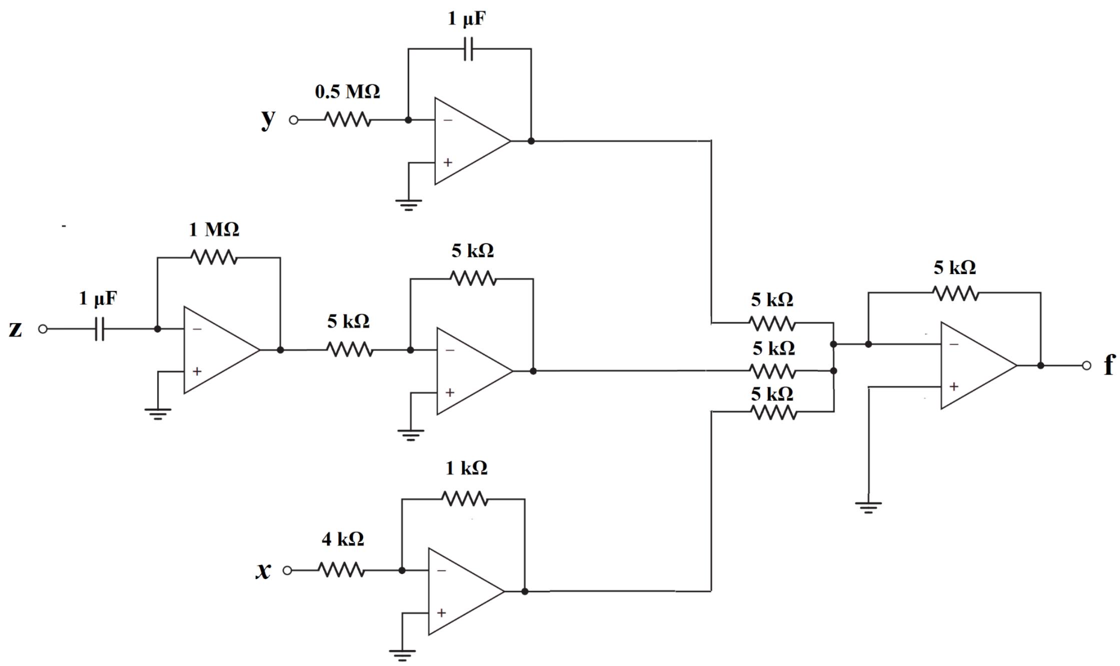
(b) Consider the circuit you drew in (a) again. Assume the input $v_i = 0.1 \sin\omega t$ (V) has a maximum current rating of 5 μA. What design changes, if any, are required for this input, if the voltage gain remains the same? **[Check Problem 8]**

(c) **Draw** the input and output waveforms of the circuit you designed in (c).

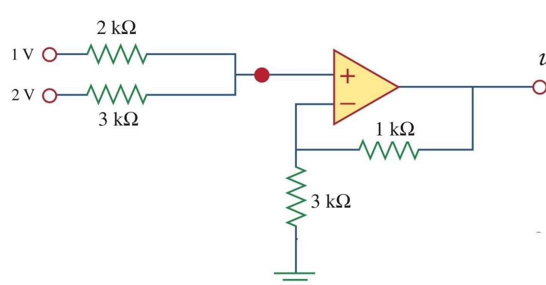
- **Analyze** the following circuit and derive the expression for the output voltage (V_{out}) in terms of the inputs. If V_1=1 V, V_2 = 2V, and V_3 = 1.5 V, and all the resistors have equal values, calculate V_{out}.



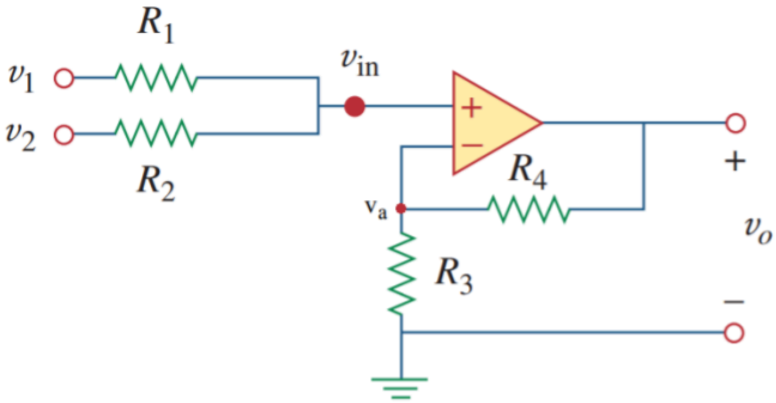
12. **Analyze** the following circuit to find an expression of f in terms of x, y, and z.



13. Consider the Ideal Op-Amp and find the value of Vo.



Solution



$$\frac{v_1 - v_{in}}{R_1} + \frac{v_2 - v_{in}}{R_2} = 0 \qquad (1)$$

but

$$v_a = \frac{R_3}{R_3 + R_4} v_o \qquad (2)$$

Combining (1) and (2),

$$v_1 - v_a + \frac{R_1}{R_2} v_2 - \frac{R_1}{R_2} v_a = 0$$

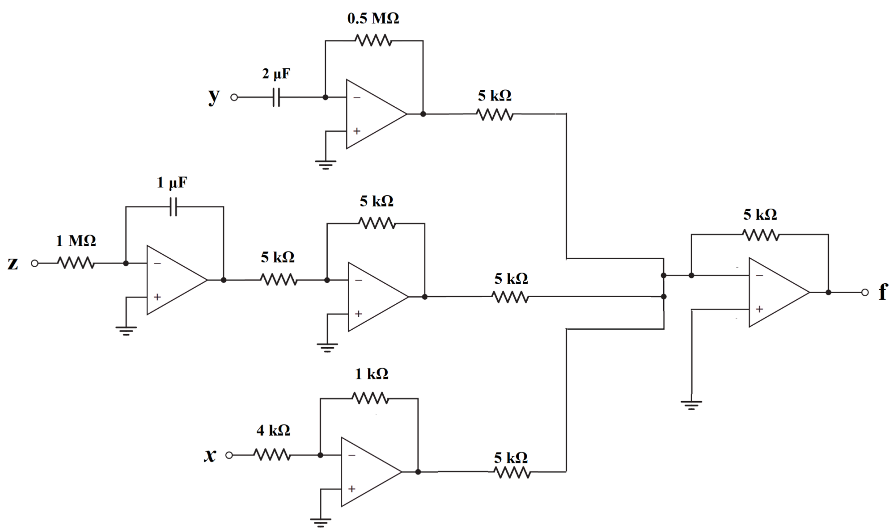
$$v_a\left(1 + \frac{R_1}{R_2}\right) = v_1 + \frac{R_1}{R_2} v_2$$

$$\frac{R_3 v_o}{R_3 + R_4}\left(1 + \frac{R_1}{R_2}\right) = v_1 + \frac{R_1}{R_2} v_2$$

$$v_o = \frac{R_3 + R_4}{R_3\left(1 + \frac{R_1}{R_2}\right)}\left(v_1 + \frac{R_1}{R_2} v_2\right)$$

$$v_O = \frac{R_3 + R_4}{R_3(R_1 + R_2)}(v_1 R_2 + v_2)$$

14.



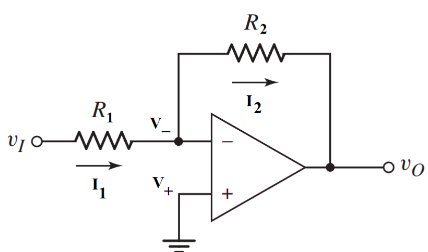


Figure 3(a) **Figure 3(b)**

(a) **Analyze** the circuit in Fig 3(a) to find an expression of f in terms of x, y, and z.
[4]

(b) **Design** an inverting amplifier (i.e., find the values of R_1 and R_2 of the circuit shown in Fig. 3(b)) in such a way that the voltage gain is **−4**.
[3]

(c) **Draw** the input and output waveforms of the circuit you designed in (b).
[2]

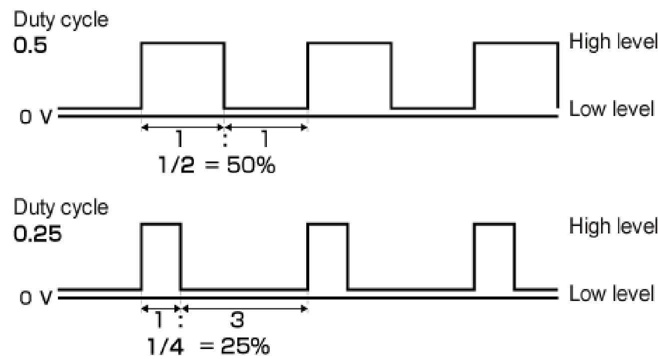
(d) Consider the circuit in Figure 3(b) again. Assume the input $v_i = 0.1 \sin\omega t$ (V) has a maximum current rating of 4 μA. What design changes, if any, is required for this input, if the voltage gain remains the same? **[Check Problem-8]**

15.

Design an op-amp circuit to transform the sinusoidal voltage, $v_I = 5 \cdot sin(\frac{2\pi}{5} \cdot t)$ ($-$ t is in units of ms, and time-period T is 5 ms), to:

[You must evaluate V_{REF}]

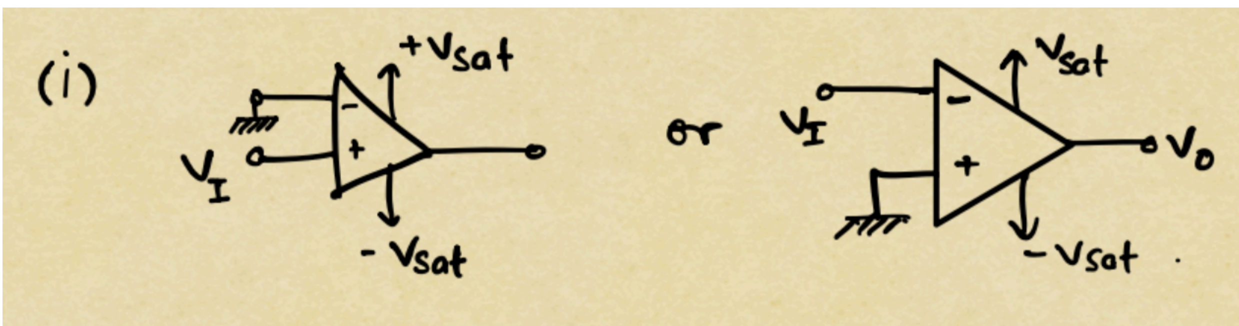
i. A square wave with a duty cycle of **50%**.
ii. A square wave with a duty cycle of **25%**.



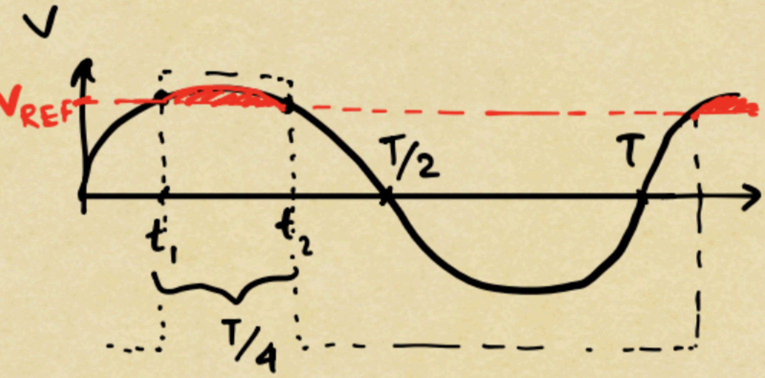
[**Duty Cycle:** Time of positive half cycle ÷ Time period]

For more information on duty cycle, click here!

[**Hint:** If $y = (\theta)$ is a sinusoidal function with period of 2π then $\theta = (\frac{y}{A})$ *and* $\pi - (\frac{y}{A})$. So, for 25% duty cycle find the value of y for which $\Delta\theta = \left(\pi - (\frac{y}{A})\right) - \left(\frac{y}{A}\right) = \frac{Time\ period}{4} = \frac{\pi}{2}$]



(ii)



$$t_1 = \frac{5}{2\pi}\sin^{-1}\left(\frac{V_{REF}}{5}\right)$$

$$t_2 = \frac{T}{2} - t_1 = \frac{5}{2} - \frac{5}{2\pi}\sin^{-1}\left(\frac{V_{REF}}{5}\right)$$

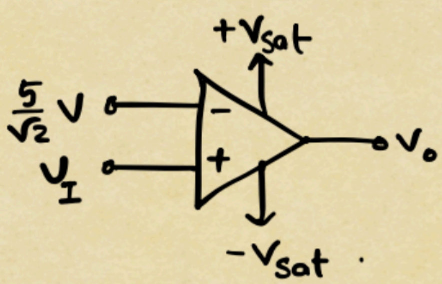
$$\therefore \quad t_2 - t_1 = \frac{T}{4} = \frac{5}{2} - 2\cdot\frac{5}{2\pi}\sin^{-1}\left(\frac{V_{REF}}{5}\right)$$

$$\Rightarrow \frac{5}{4} = \frac{5}{2} - \frac{5\times 2}{2\pi}\sin^{-1}\left(\frac{V_{REF}}{5}\right)$$

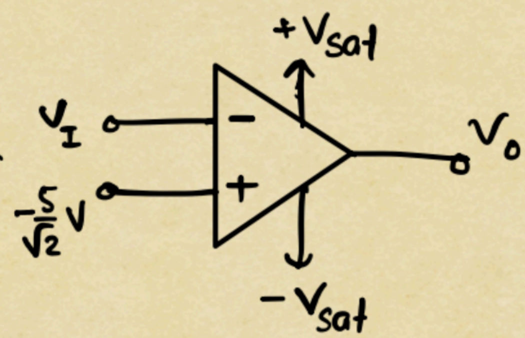
$$\Rightarrow V_{REF} = 5\sin\left(\frac{2\pi}{5}\cdot\frac{5}{8}\right)$$

$$V_{REF} = \frac{5}{\sqrt{2}}\,V$$

$\therefore$

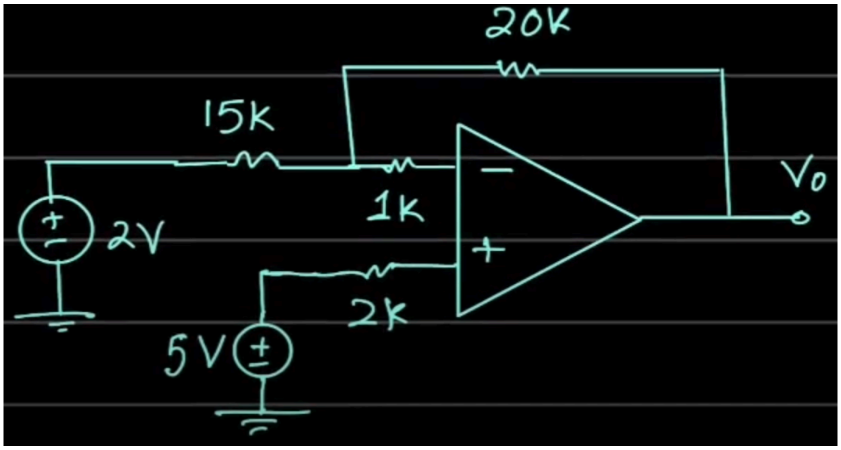


or



16.

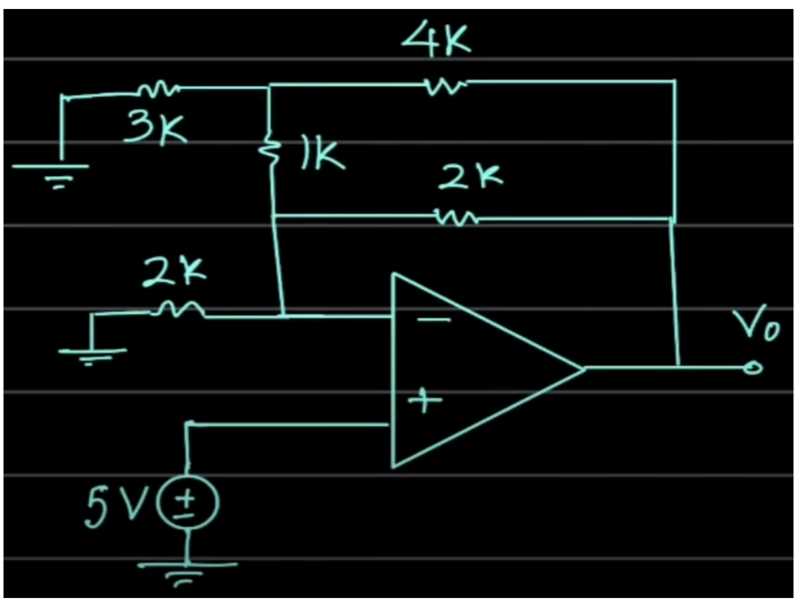
Determine the output voltage, v_0



Solution: (from central playlist)
https://youtu.be/KBWfa-NuYzk?list=PLPf6M92pkd7DRilBZLzKot-39S215ksSw&t=617

17.

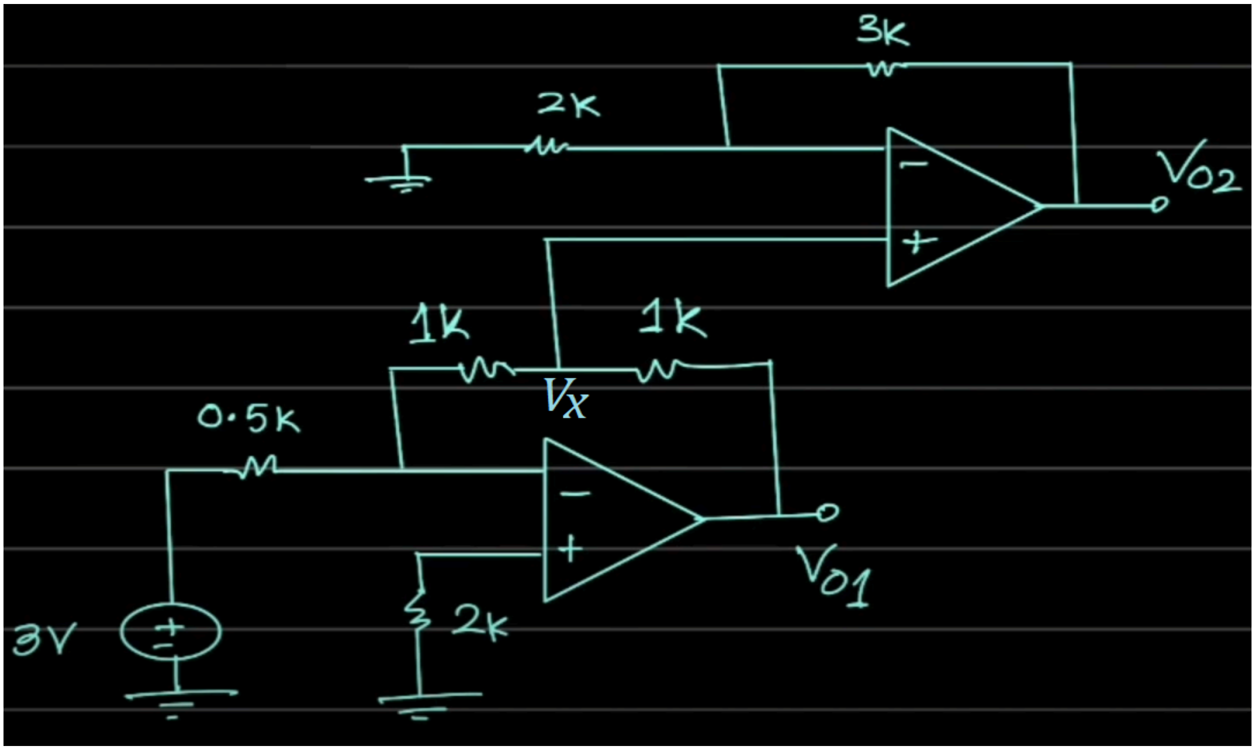
Determine the output voltage, v_0



Solution: (from central playlist)
https://youtu.be/KBWfa-NuYzk?list=PLPf6M92pkd7DRilBZLzKot-39S215ksSw&t=890

18.

Determine the voltages: V_{01} , V_X , V_{02}

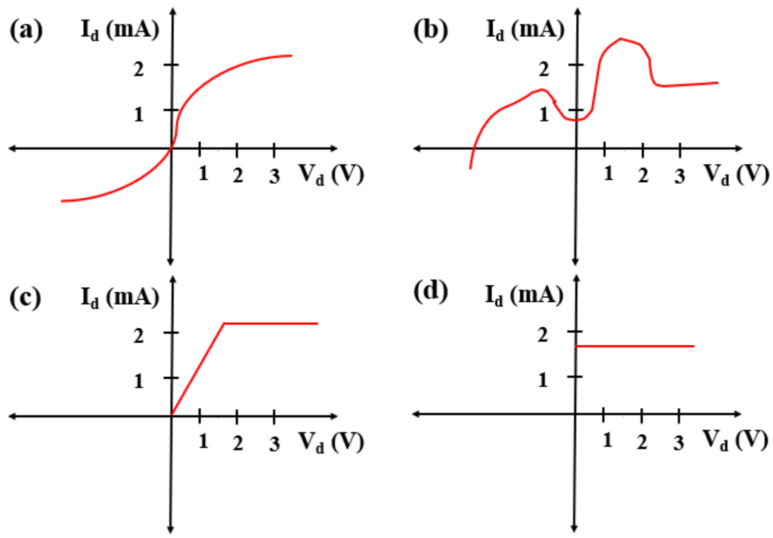


Solution: (from central playlist)
https://youtu.be/KBWfa-NuYzk?list=PLPf6M92pkd7DRilBZLzKot-39S215ksSw&t=1198

Additional Hint for finding V_X : Use Nodal Analysis on the V_X node instead of the current method shown in the video link above.

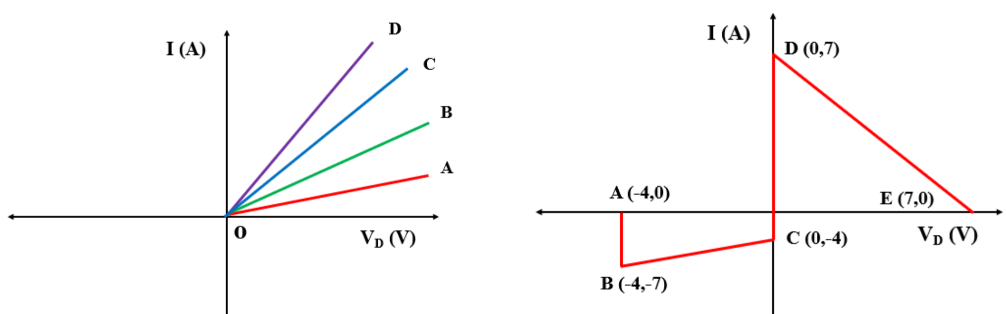
I-V

- Identify which of these I-V curves are Linear and which are Nonlinear:



Ans: Linear: (d)

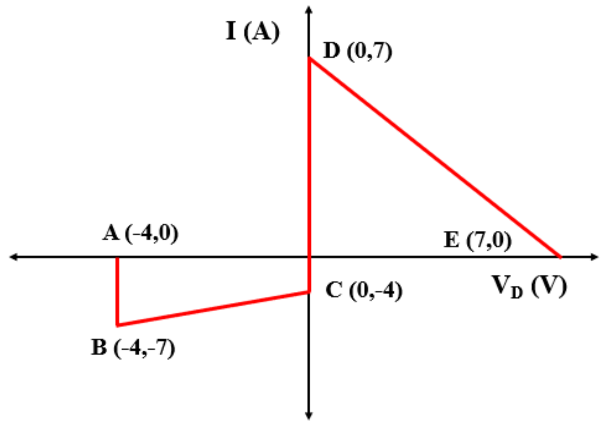
- Write down the slopes of these following regions in ascending order (you do not need to calculate the slopes)



(a) (b)

Ans: (a) |OA|<|OB|<|OC|<|OD|, (b) Slopes of AB and CD are equal(infinity). The DE slope is negative. However, the value of slope is higher than BC here. |BC|<|DE|<|AB|

- Find out the slope of the following curves



Answer: **Slope, |m|=** $\left|\frac{y_2-y_1}{x_2-x_1}\right|$

$|BC| = \left|\frac{y_2-y_1}{x_2-x_1}\right| = \left|\frac{-7+4}{-4+0}\right| = \frac{3}{4}$

$|DE| = \left|\frac{y_2-y_1}{x_2-x_1}\right| = \left|\frac{0-7}{7-0}\right| = 1$ **[Can you identify the issue in this curve?]**

$|AB| = \left|\frac{y_2-y_1}{x_2-x_1}\right| = \left|\frac{-7-0}{-4+4}\right| = \infty$

- Calculate and Show 'C' and 'Io' in the figures

  [Hint: use $-\frac{Vo}{R} = Io$**=c]**

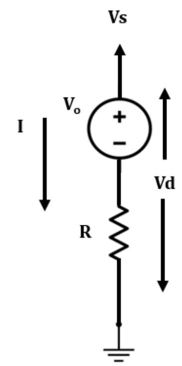
- Draw the alternative circuit diagram, I-V curve and calculate the parameters with the following information:

  i. Vo= 5V, m= 2 $/k\Omega$
  ii. Vo= 3.5 V, m= -2.5$/k\Omega$
  iii. Vo= -5V, m= 5$/k\Omega$

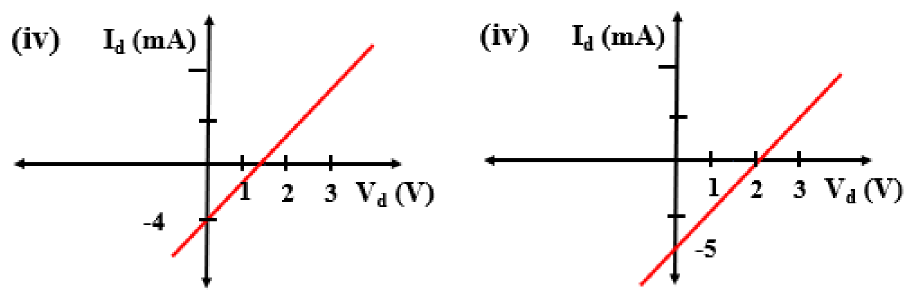
  Solution:

  i. $|R| = |\frac{1}{m}|$ i.e. $\frac{1}{2}\, k\Omega,\ c = -\frac{Vo}{R} = -\frac{5}{0.5} mA = -\ 2.5\, mA$
  ii. $|R| = |\frac{1}{m}|$ i.e. $\frac{1}{2.5}\, k\Omega,\ c = -\frac{3.5}{0.4} mA = -\ 8.75\, mA$
  iii. $|R| = |\frac{1}{m}|$ i.e. $\frac{1}{5}\, k\Omega,\ c = -\frac{-5}{0.2} mA = 25\, mA$

Alternative Diagram:

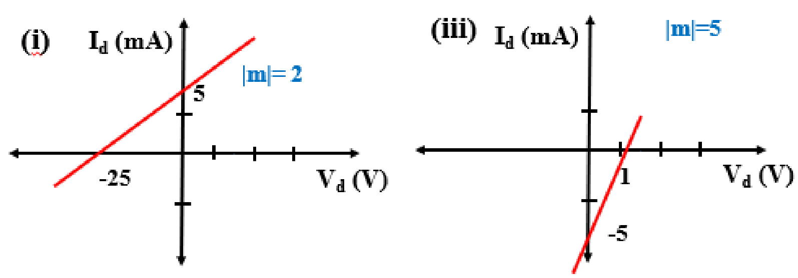


I-V curve:



- Calculate and Show 'C' and 'Vo' in the figures

  [Hint: Use $IoR = -Vo$**]**



- Draw the alternative circuit diagram with the equivalent linear model, I-V curve and calculate the parameters with the following information:

  i. Io= 5 mA, m= $2/k\Omega$
  ii. Io= 3.5 mA, m= -2.5 $/k\Omega$
  iii. Io= -5 mA, m= 5 $/k\Omega$

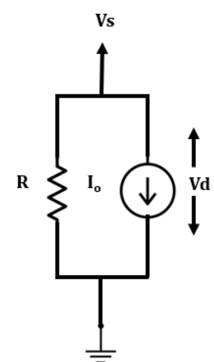
Solution:

i. $|R|= |\frac{1}{m}|$ i.e. $\frac{1}{2}\, k\Omega,\ c = Io$= $5\, mA, Vo =- IoR =- 2.5\, V$

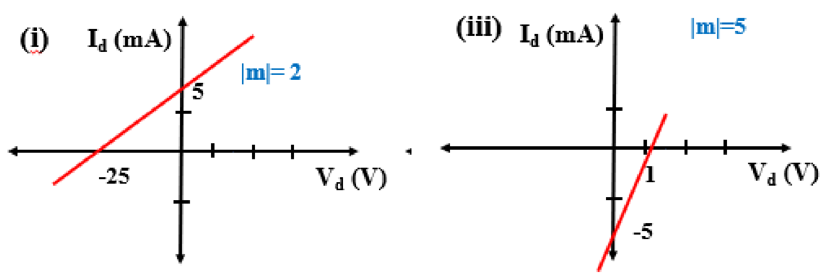
ii. $|R|= |\frac{1}{m}|$ i.e. $\frac{1}{2.5}\, k\Omega,\ \ c = Io = 3.5\, mA,\ \ Vo =- (- IoR) = 1.4\, V$; as m is negative

iii. $|R|= |\frac{1}{m}|$ i.e. $\frac{1}{5}\, k\Omega,\ c = Io =- 5\, mA, Vo =- IoR = 1\, V$

Alternative diagram:

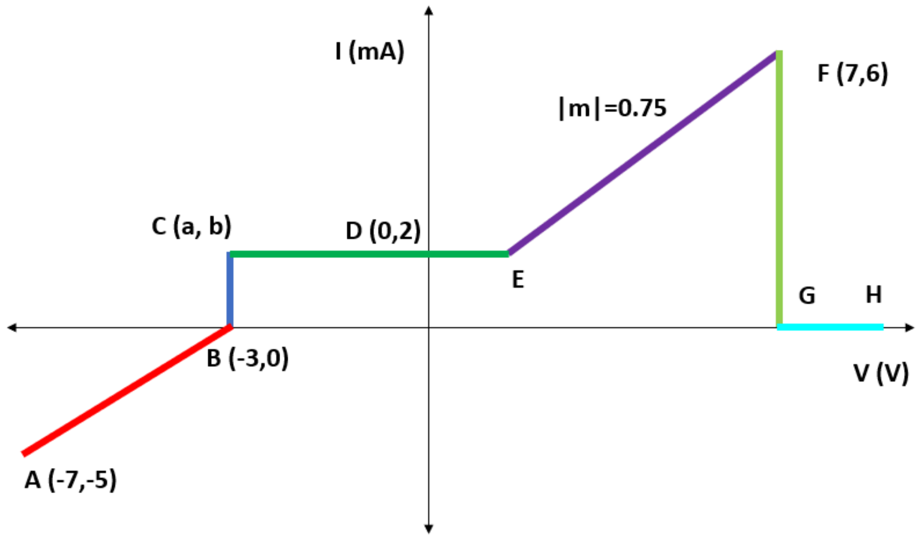


I-V:



- From the I-V curve-

  i. State the device model for each region,



Solution:

i.

AB: Voltage source in series with a resistor/ Current source in parallel with a resistor

BC: Voltage source

CD: Current source

EF: Voltage source in series with a resistor/ Current source in parallel with a resistor

FG: Voltage source

- A Voltage Source, Vo= 10 V in series with a resistor of R= 3 $k\Omega$.

i. Write down the equation representing this curve

ii. Determine the unknown parameters

iii. Label the I-V curve

Solution:

i. y= mx+c

Or, I= m. Vs$-\frac{Vo}{R}$

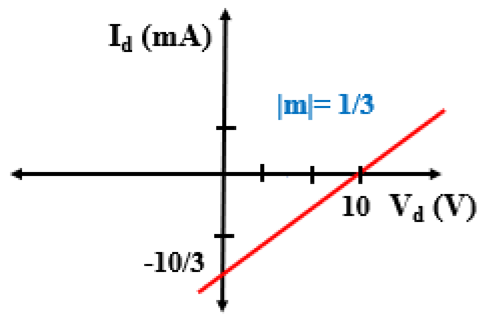
ii. Vo= 10 V, R=3 $k\Omega$

$|\mathbf{m}| = |\frac{1}{R}| = \frac{1}{3}$

Y axis intersection: c= $-\frac{Vo}{R} = -\frac{10V}{3k\Omega} = -\frac{10}{3}$ mA

X axis intersection: Vo= 10 V

iii.



- A Voltage Source, Vo= -10 V in series with a resistor of R= 3 $k\Omega$.

  i. Write down the equation representing this curve
  ii. Determine the unknown parameters
  iii. Label the I-V curve

Solution:

i. y= mx+c

Or, I= m. Vs$-\frac{Vo}{R}$

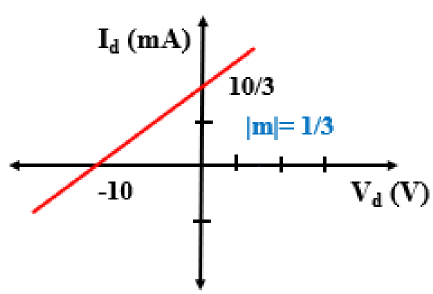
ii. Vo= 10 V, R=3 $k\Omega$

$|\mathbf{m}| = |\frac{1}{R}| = \frac{1}{3}$

Y axis intersection: c= $-\frac{Vo}{R} = -\frac{-10V}{3k\Omega} = \frac{10}{3}$ mA

X axis intersection: Vo= -10 V

Iii.



- A Current Source, Io= 5 mA in parallel with a resistor of R= 5 $k\Omega$.

  i. Write down the equation representing this curve
  ii. Determine the unknown parameters
  iii. Label the I-V curve

Solution:

i. y= mx+c

Or, $Is = \frac{Vs}{R} + Io$

ii. Vo= 10 V, R=5 $k\Omega$

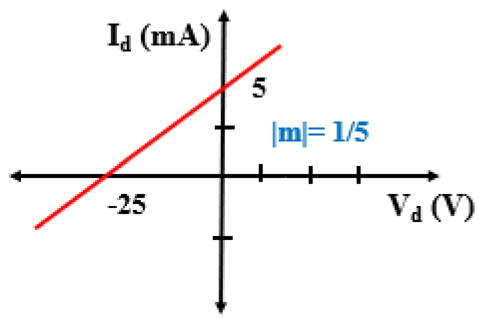
$|\mathbf{m}| = |\frac{1}{R}| = \frac{1}{5}$

Y axis intersection : c= Io= 5 mA

X axis intersection: $IoR = -Vo$

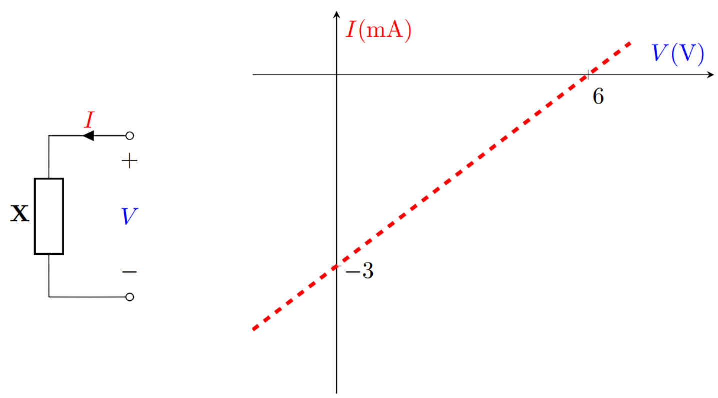
Or, Vo= -5*5 V= -25V

iii.



- You are provided with the following circuit elements:
  - Two 1 kΩ resistors
  - A 4 V voltage source
  - A 2 V voltage source

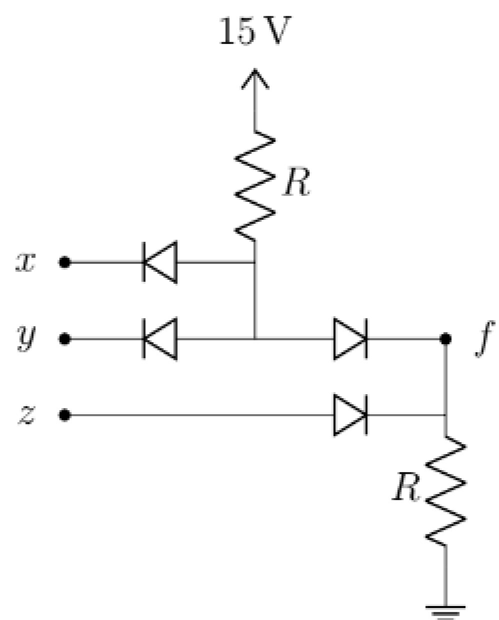
  Can you implement a circuit element X that has an IV characteristics, as seen in the right figure below, but by **ONLY USING THE ELEMENTS MENTIONED ABOVE**? The voltage polarity and current direction should be as shown in the left figure.



Diode Logic Gates

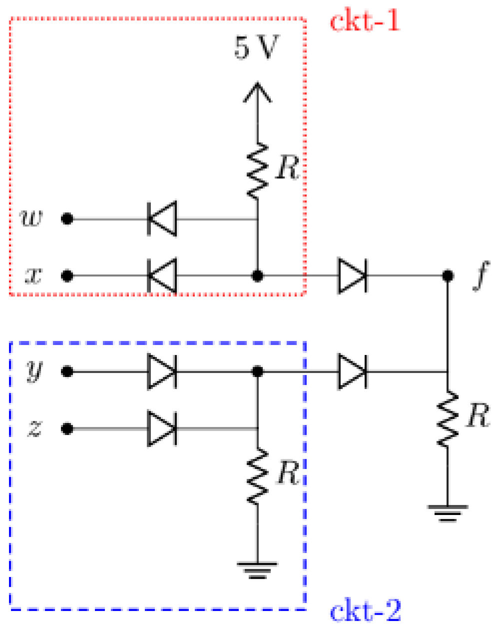
- Assuming x, y, z are boolean variables, analyze the circuits below to find an expression of *"f"* in terms of x, y, and z.

i.



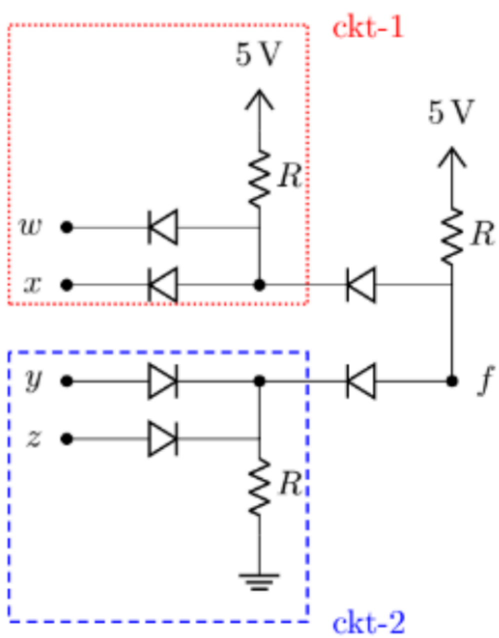
Soln: f= (x.y)+z

ii.



Soln: f=(w.x)+(y+z)

iii.



Soln: f=(w.x).(y+z)

- Implement the following expressions using ideal diodes:

  i. xy+ yz

  ii. XOR [Hint: Can you implement a NOT gate with a diode?]

  iii. XNOR

  iv. (A+B)XY

- Design a 4 input AND gate using ideal diodes

- Design a 3 input OR gate using ideal diodes
- There will be 5 questions from 5 different topics in your exam and you will have to answer 4 out of these . You will need to fulfill the following conditions-

  i. You **must** answer 3 questions from topic “A”, “B” and “C”

  ii. You can answer one question from **either** “D” or “E”

  Deduce the logic function using boolean variables A,B,C,D and E to implement your algorithm for choosing the questions.

- For this question, assume all the diodes are ideal.

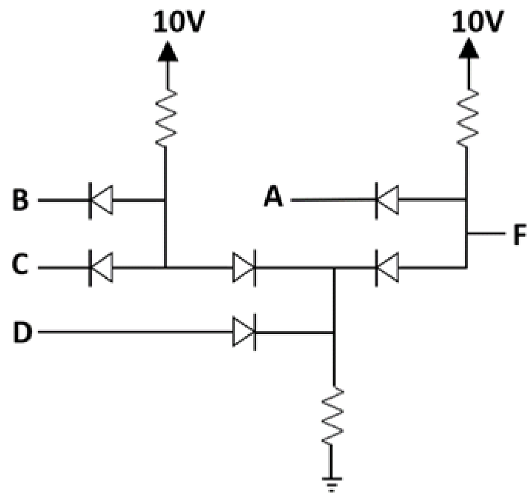


Figure 1

(a) Assuming A, B, C, D are boolean variables, analyze the circuit of Figure 1 to find an expression of F in terms of A, B, C and D.

Solution: F = (B.C + D) . A

(b) Analyze the circuit in Figure 1 to find the output voltage(s) F and complete the table in Figure 2, assuming A, B, C and D are voltage signals

A	B	C	D	F
4V	3V	4V	6V	
5V	3V	4V	2V	
13V	3V	4V	15V	

Figure 2

Hint: AND gate → min( ) operation, OR gate → max( ) operation

(c) Design a circuit using ideal diodes to implement the logic function

f = (x+y)z

- Maisha is designing a game where she needs to determine an algorithm for level upgrades. The quests in level-1 are expressed using Boolean variables A, B, C, D, and E. For upgrading from level-1 to level-2 she will need to fulfill the following conditions-

  i. Quest "A" and "B" must be completed
  ii. At Least one quest has to be completed from "C", "D" and "E"

  (a) **Deduce** the logic function, F, using Boolean variables A, B, C, D, and E to implement Maisha's algorithm. [3]
  (b) **Determine** the values of "F" in the following table using the logic function from (a). [2]

A	B	C	D	E	F
0	0	1	0	1	?
0	1	1	1	0	?
1	0	0	0	0	?
1	1	1	0	0	?

  (c) **Draw** the circuit diagram implementing the logic function from (a). [3]
  (d) **Discuss** whether you can design a NAND gate with Si diodes. [2]
  Solution:

NAND gates require AND gate and NOT gate to implement. We can build AND gates using Si diodes. But we cannot implement NOT gate using Si diodes. So, we cannot implement NAND gate with Si diodes as it is dependent on NOT gate's implementation using Si diode.

- In the **adjacent** figure we have the following parameters:

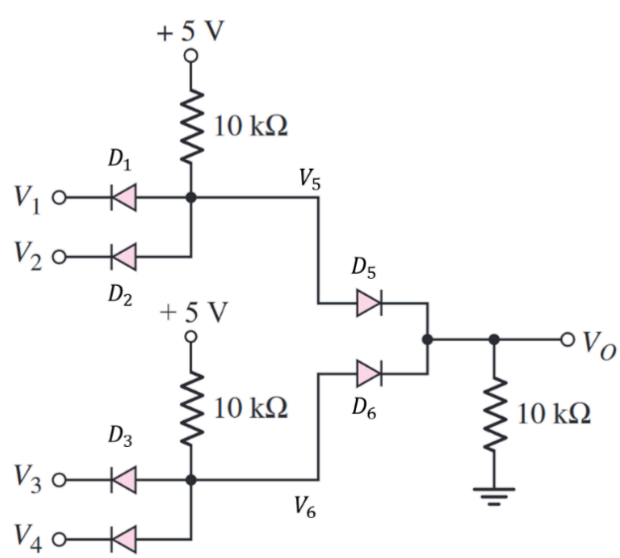
$V_{D1} = 0.3$ V, $V_1 = 2$ **V**

$V_{D2} = 0.5$ V, $V_2 = 1.7$ **V**

$V_{D3} = 0.7$ V, $V_3 = 1.5$ **V**

$V_{D4} = 0.9$ V, $V_4 = 1.1$ **V**

$V_{D5} = V_{D6} = 1.1$ V



i. Find V_5 and V_6. [5]

ii. Find V_O. [5]

iii. **[BONUS – 5 Marks]:** Solve the circuit to get V_O when $V_1 = 7\,V$, $V_2 = 8\,V$ and all other parameters remain the same.

Solution:

$$V_5 = \min(V_1 + V_{D1}, V_2 + V_{D2}) = \min(2.3,\ 2.2) = 2.2\,V$$

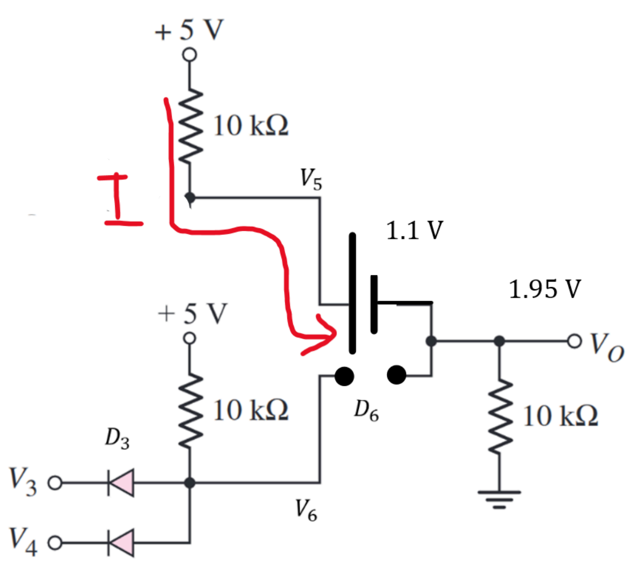
$$V_6 = \min(V_3 + V_{D3}, V_4 + V_{D4}) = \min(2.2,\ 2.0) = 2.0\,V$$

$$V_O = \max(V_5 + V_{D5}, V_6 + V_{D6}) = \max(2.2 - 1.1,\ 2.0 - 1.1) = 2.0 - 1.1\ V = 0.9\,V$$

Bonus:

When $V_1 = 7\,V$ and $V_2 = 8\,V$, D_1 and D_2 are both in reverse bias as both V_1 and V_2 are greater than the $5\,V$ supply voltage. So, between V_5 and V_6 (which is still $2.0\,V$, as obtained from previous answer), the higher voltage will propagate to V_O. But, we still don't know what V_5 is.

So, here is what we will do. We will assume for now that V_5 **<u>is higher than</u>** V_6. As, both diodes will not simultaneously be forward biased, D_5 is assumed to be forward biased. So the circuit becomes:



From the above circuit, $I = (5 - 1.1)/(10 + 10)\ mA = 0.195\ mA$ and $V_5 = 5 - 10I = 3.05\ V$.

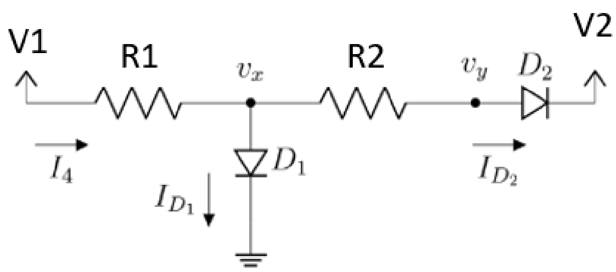
Here, $V_5 = 3.05\ V > V_6 (2\ V)$. So, our assumption that V_5 is higher than V_6 is true. So, the result is:

$$V_O = 3.05 - 1.1\ V = 1.95\ V \textbf{ (Answer)}$$

Diode: Method of assumed states

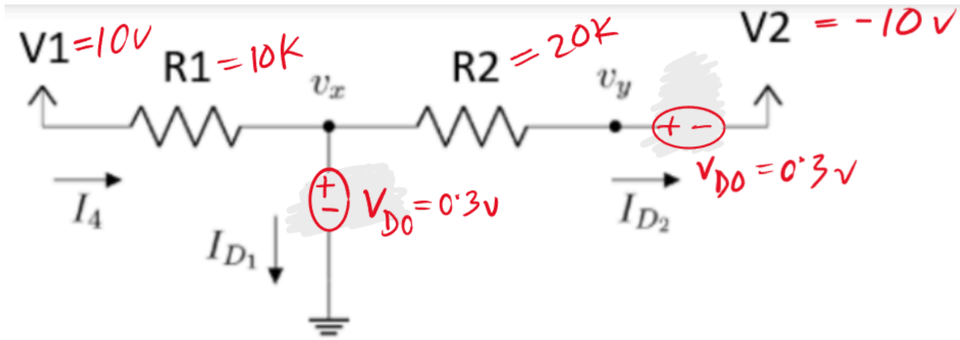
For the following circuits (a) Analyze the following circuit to find the values of I_{D1}, I_{D2}, V_X, and V_Y. Here, use the Method of Assumed State using the CVD model of diode with V_{D0} = 0.3 V. (b) Validate your assumptions about the states of the diodes.

1.



i. V1= 10 V, V2= -10 V, R1= 10 K, R2= 20K
ii. V1= -5 V, V2= 20 V, R1= 10 K, R2= 20K

Solution ==> (i)



Assumption → D_1, D_2 both ON

Calculation

$V_x = 0.3V$

$V_y = (-10+0.3)V = -9.7V$

$I_4 = \frac{10 - V_x}{R_1} = \frac{10-0.3}{10K} = 0.97mA$

$I_{D2} = \frac{V_x - V_y}{R_2} = \frac{0.3-(-9.7)}{20K} = 0.5mA$

Now, $I_4 = I_{D1} + I_{D2}$

$\hookrightarrow I_{D1} = I_4 - I_{D2}$

$\hookrightarrow I_{D1} = (0.97 - 0.5)\,mA$

$\hookrightarrow I_{D1} = 0.47\,mA$

Verification

for $D_1 \longrightarrow i_{D1} > 0$

$\hookrightarrow 0.47\,mA > 0$

True

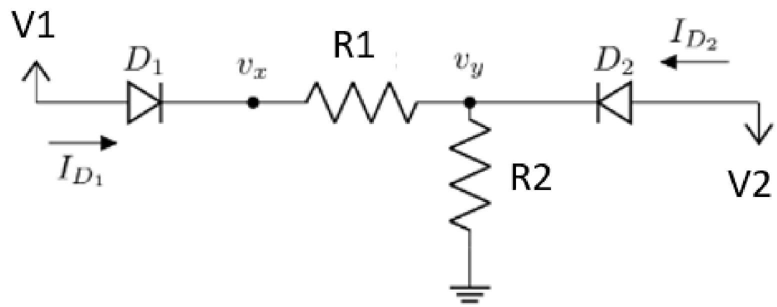
for $D_2 \longrightarrow i_{D2} > 0$

$\hookrightarrow 0.5\,mA > 0$

True

$\therefore$ Assumption correct.

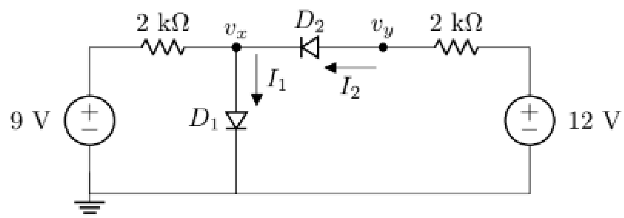
2.



i. V1= 5 V, V2= -3.5 V, R1= 1 K, R2= 10K
ii. V1= 5 V, V2= -3.5 V, R1= 10 K, R2= 10K

3.

Sherlock Holmes found a piece of paper from the pocket of one of Professor Moriarty's victim with the circuit shown below. One side of the paper is missing and the only other available information was that the **D1 diode is on**. Sherlock needs to know the values of v_x, v_y, I_1, and I_2 as it generates the passcode for the victim's locker, which can help him catch Moriarty. Sherlock knows nothing about diodes and asked for your help to solve the case.



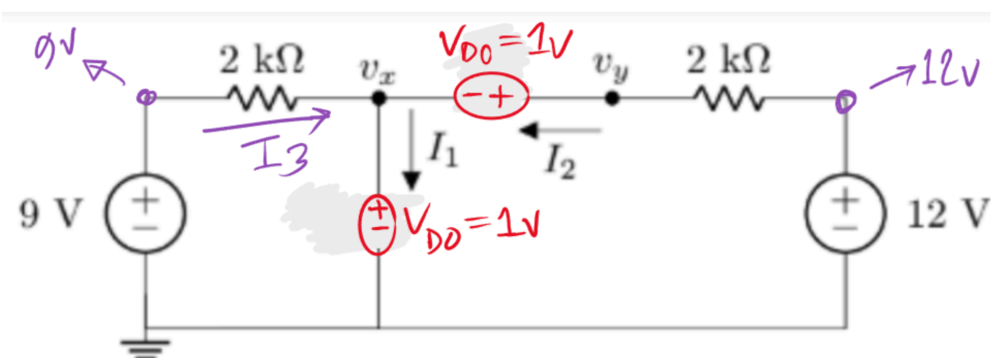
	v_x	I_1	I_2	v_y
Passcode $\Longrightarrow$	?	?	?	?

(a) **Show** the alternative representation of the given circuit. [1.5]

(b) **Analyze** the circuit to **calculate** the values of v_x, v_y, I_1 and I_2, and hence the passcode. You must **validate** your assumption. Use the constant voltage drop model with a forward voltage drop, $V_{D0} = 1$ V. [5+2]

(c) Passive sign convention states that a device is delivering power if $p = v \times I$ for the device is negative, and consuming power if p is positive. **Deduce** whether D_1 is consuming or delivering power. [1.5]

Solution ⇒ part-b



Assumption → D_1, D_2 both ON

Calculation

$V_x = 1v$, $V_y = V_x + 1 = 2v$

$I_3 = \dfrac{9 - V_x}{2K} = \dfrac{9-1}{2K} = 4mA$

$I_2 = \dfrac{12 - V_y}{2K} = \dfrac{12-2}{2K} = 5mA$

$$I_1 = I_3 + I_2 = (4+5)\,mA = 9\,mA$$

Verification

for $D_1 \rightarrow i_{D1} > 0$

$\hookrightarrow I_1 > 0$

$\hookrightarrow 9\,mA > 0 \rightarrow$ True

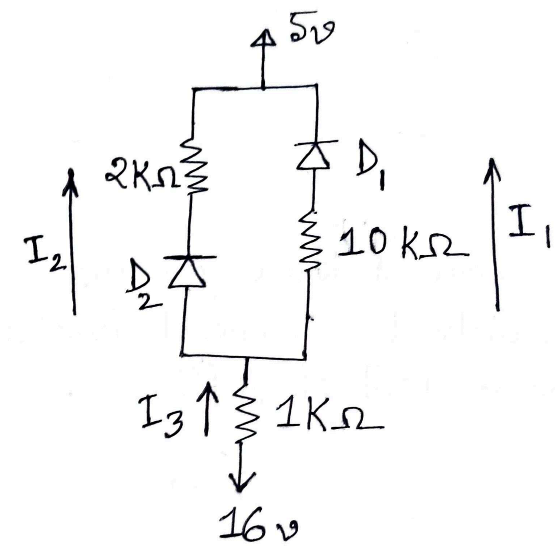
for $D_2 \rightarrow i_{D2} > 0$

$\hookrightarrow I_2 > 0$

$\hookrightarrow 5\,mA > 0 \rightarrow$ True

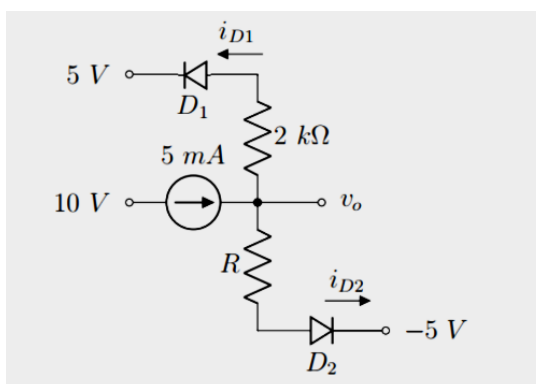
So, Assmption Correct.

4.



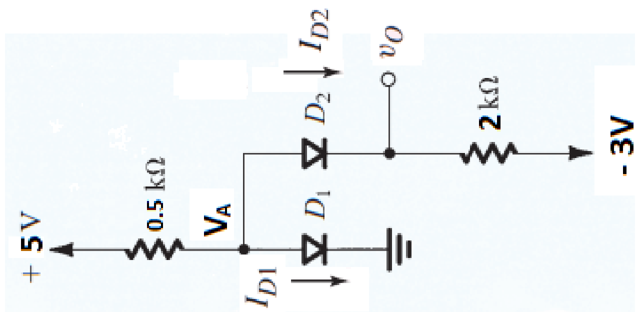
Analyze the circuit given above. **Calculate** the values of $\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$. You must **validate** your assumptions. Use the Constant-Voltage Drop model(CVD Model) with $\mathbf{V_{D0} = 0.8\ V}$.

5.



Find **Vo, $\mathbf{i_{D1}}$ and $\mathbf{i_{D2}}$** for R = 1 kΩ. Assume diode constant voltage drop model with Vdo = 0.7v. In each case, write down the states of the diodes (ON/OFF). You must verify your assumptions.

6.



Analyze the following circuit. **Calculate** the values of V_A, V_0, I_{D1}, and I_{D2}. You must validate your assumptions. Use the Constant-Voltage Drop model with a cut in voltage of 0.6V[V_{D0}=0.6V].

[Hints: You may start with calculating the voltage values first]

- **Please find some other examples here**:
  Week 4 (Method of Assumed State Examples).pdf

Rectifiers

1.

The input of a full-wave rectifier is a cosine voltage with peak V_M = 5 V and frequency 60 Hz, and output load resistance is R = 2 kΩ. Silicon diodes are used in this circuit for which the forward drop is V_{D0} = 0.7 V.

(a) Briefly explain the purpose of a rectifier and describe its operation.
(b) Show the input and output waveforms.
(c) Calculate the DC value of the output voltage.
Now after connecting a capacitor in parallel with the load, the output becomes a ripple voltage **Vout =** V_{DC} **±0.2 V**
(d) Calculate the **peak-to-peak ripple voltage**, and from that, the value of the capacitor.
(e) Calculate the average of the output voltage V_{DC} after connecting the capacitor. Compare this with the DC value determined in 'c' and comment on the difference between these two.

2.

The input of a **Half-wave rectifie**r is a sine voltage with peak VM = 10 V and frequency 55 Hz, and output load resistance is R = 2.5 kΩ. Silicon diodes are used in this circuit for which the forward drop is V_{D0} = 0.4 V.

(a) Calculate the DC value of the output voltage.
Now after connecting a capacitor in parallel with the load, the output becomes a ripple voltage **Vout =** V_{DC} **±0 V.**
(d) Calculate the **peak-to-peak ripple voltage**, and from that, the value of the capacitor.
(e) Calculate the average of the output voltage V_{DC} after connecting the capacitor. Compare this with the DC value determined in 'c' and comment on the difference between these two.
(f) Draw the **Voltage Transfer Characteristic (VTC) curve**

3.

The input of a full-wave rectifier is expressed by, Vs(t)= 7sin(400πt), and output load resistance is R = 5 kΩ. Silicon diodes are used in this circuit for which the forward drop is V_{D0} = 0.3 V.

(a) Calculate the input and output wave frequency.
(b) Show the input and output waveforms.
(c) Calculate the DC value of the output voltage.

Now after connecting a capacitor, C= 100 µF in parallel with the load.

(d) Calculate the peak-to-peak ripple voltage,
(e) Calculate the average of the output voltage V_{DC} after connecting the capacitor. Compare this with the DC value determined in 'c' and comment on the difference between these two.
(f) How can you provide better filtering for the output waves?
(g) What is the frequency of the Ripple voltage?

4.

The input of a **Half-wave rectifier** is a **Square** wave voltage with peak $V_M = 15$ V and frequency 0.5 Hz, and output load resistance is R = 5 kΩ. Silicon diodes are used in this circuit for which the forward drop is $V_{D0} = 0.7$ V.

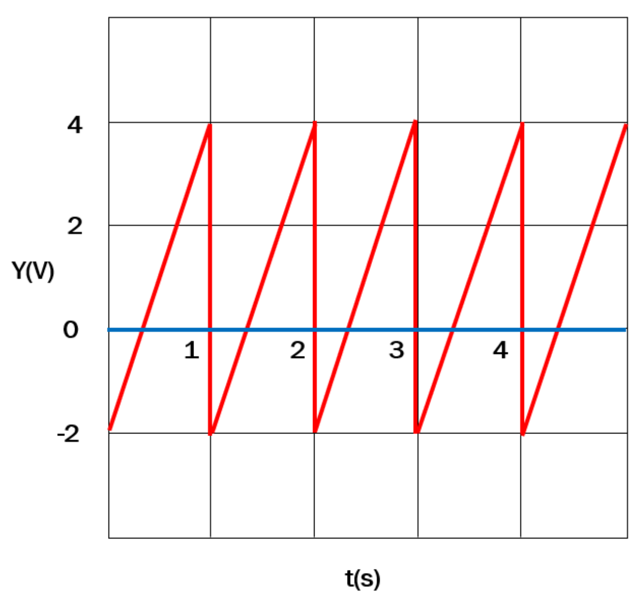
i. Show the input and output waveforms.
ii. Draw the VTC curve

5.

The input of a **full-wave rectifier** is a **Square** wave voltage with peak $V_M = 15$ V and frequency 0.5 Hz, and output load resistance is R = 5 kΩ. Silicon diodes are used in this circuit for which the forward drop is $V_{D0} = 0.7$ V.

i. Show the input and output waveforms.
ii. Draw the VTC curve

6.



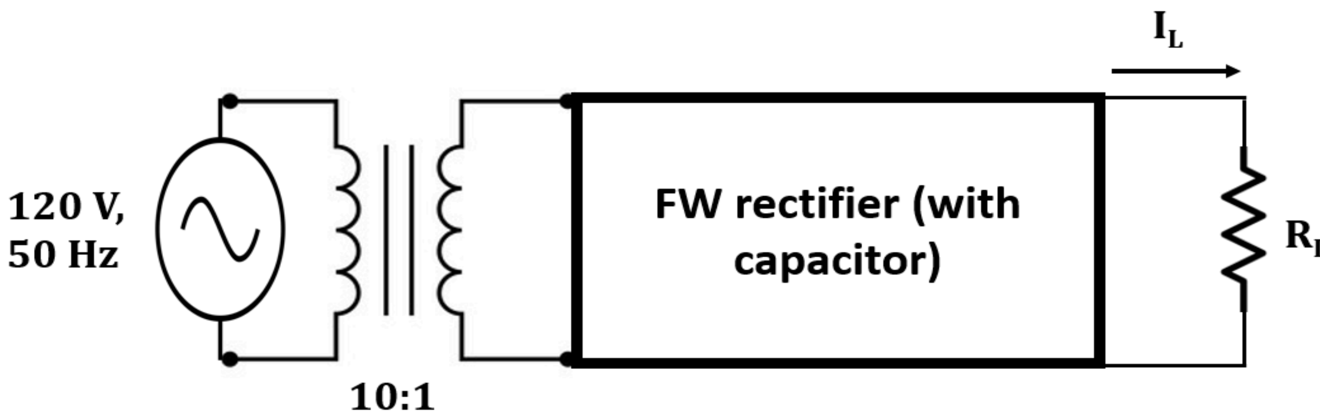
The input of a Half-wave rectifier is exhibited in the Figure above and output load resistance is R = 5 kΩ. Silicon diodes are used in this circuit for which the forward drop is V_{D0} = 0.7 V.

i. Show the input and output waveforms.

ii. Draw the VTC curve

7.

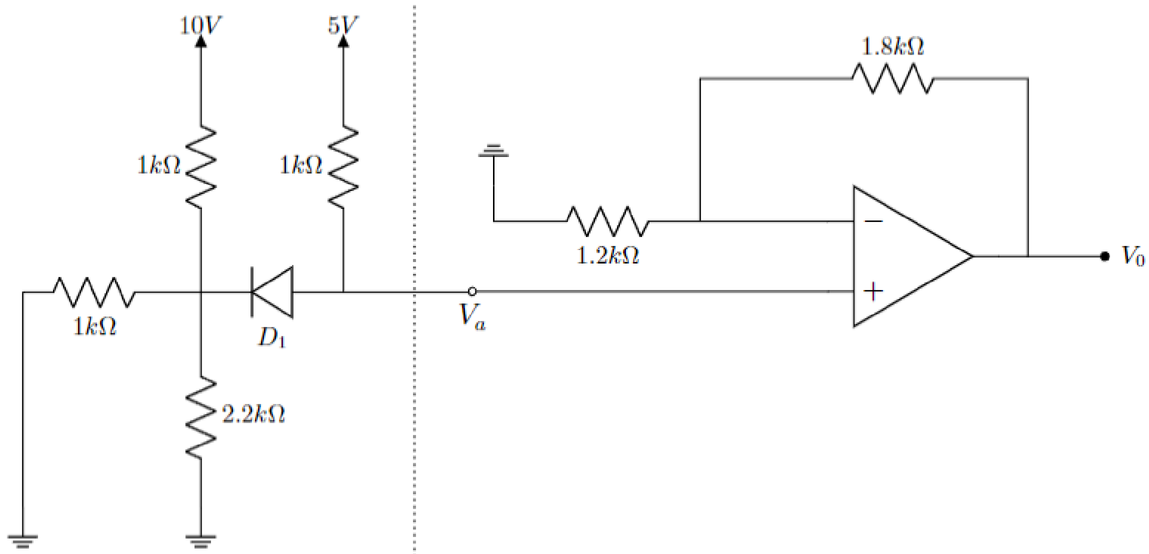
A full-wave rectifier is designed to deliver a maximum current I_L = 120 mA to the load. The rectifier produces an output with a ripple of 5% of the peak output voltage. An input line voltage of 120 V (peak), 50 Hz is available. A 10:1 step-down transformer is used to transform the supply voltage to 12 V (peak).



(a) Draw the Voltage Transfer Characteristics of the full-wave rectifier. [2]
(b) Calculate the peak output voltage. [1]
(c) Determine the value of the Load Resistor to deliver a maximum load current of 120mA. [2]
(d) Deduce the value of the Capacitor and the DC average value. [1]
(e) Assume the transformer is removed and the rectifier is directly connected to the AC power supply line. Discuss the state of the diodes. [Hint: use the Peak Input Value of the rectifier input] [3]

Hybrid Problems

1.



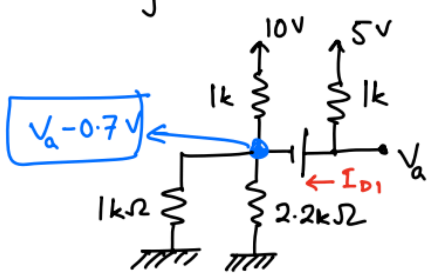
The saturation voltages of the Op-Amp are given as- $V^+_{sat} = +10V$ and $V^-_{sat} = -10V$. The forward voltage drop of the diode, V_D is $0.7V$.

(a) **Determine** the operating mode diode, D_1. Verify your assumption with necessary calculations.

(b) **Calculate** the voltage at - (i) node 'Va', (ii) non-inverting terminal of the Op-Amp, (iii) inverting terminal of the Op-Amp.

(c) Find out the output voltage, Vo of the Op-Amp.

(a) Assuming D_1 to be ON:



Node equation at supernode V_a

$$(V_a - 0.7)\left(1 + 1 + \frac{1}{2.2}\right) + V_a - 10 - 5 = 0$$

$$\boxed{V_a = 4.84\,V}$$

$$\boxed{V_a = 4.84\,V}$$

$\Downarrow$

I_{D1} =

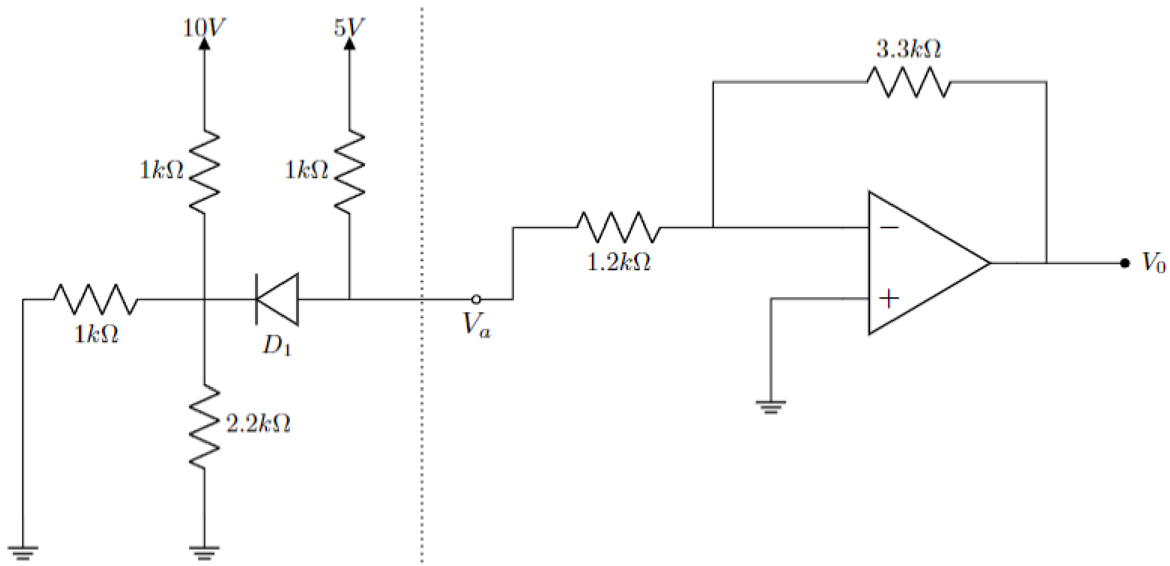
= 0.16 mA > 0

(no current flows into op-amp terminals)

∴ Assumption true.

V0 = (1+1.8/1.2)*Va

2.

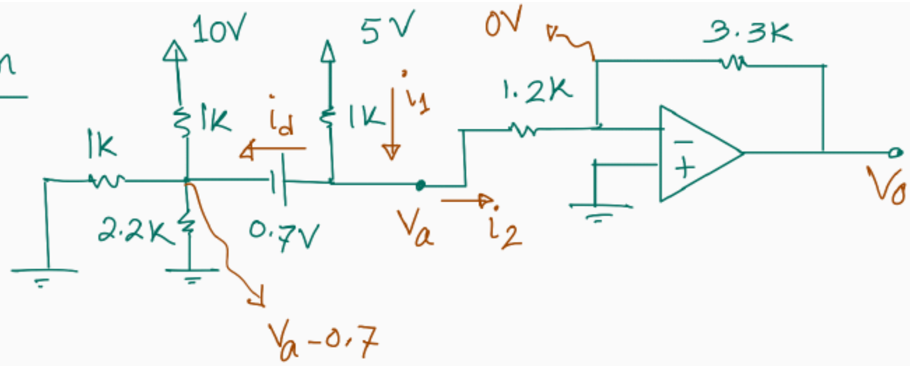


The saturation voltages of the Op-Amp are given as- $V_{sat}^{+} =+ 10V$ and $V_{sat}^{-} =- 10V$. The forward voltage drop of the diode, V_D is $0.7V$.

(a) **Determine** the operating mode diode, D_1. Verify your assumption with necessary calculations.
(b) **Calculate** the voltage at - (i) node 'Va', (ii) non-inverting terminal of the Op-Amp, (iii) inverting terminal of the Op-Amp.
(c) Find out the output voltage, Vo of the Op-Amp.

Soln:

Assume D_1 on



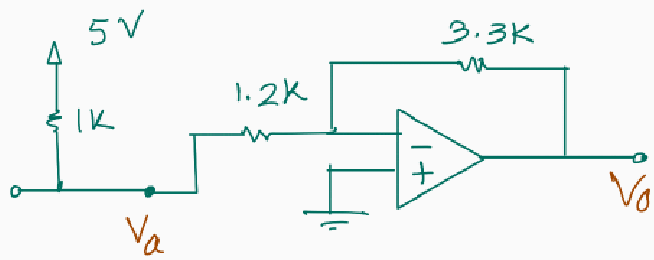
Nodal : $(V_a - 0.7)(1 + 2.2^{-1} + 1) + V_a(1 + 1.2^{-1}) = 10 + 5$

$$\Rightarrow V_a = 3.898\ V$$

$$\therefore i_d = i_1 - i_2 = \frac{5 - V_a}{1} - \frac{V_a - 0}{1.2} = -2.15\ mA < 0\ mA$$

$\boxed{\therefore D_1 \text{ "cannot" be ON}}$

$\therefore$ D1 is OFF → Left side Open → Equivalent ckt :

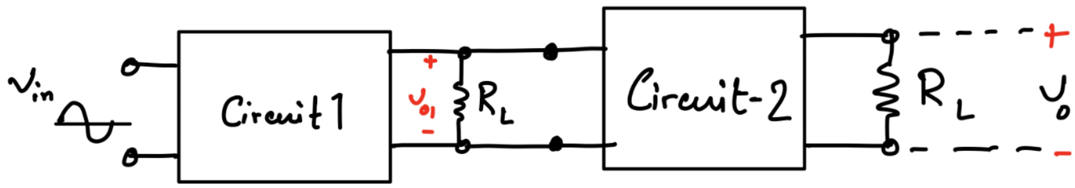


⇒ This is an invterting amplifier with 5V and (1k + 1.2k) at the inverting terminal

$$\therefore V_o = -\frac{3.3}{1 + 1.2} \times 5V = -6.82\ V$$

3.

You are provided with the diagram below as a starting point for designing an AC to DC converter. Input voltage source is an sinusoidal voltage source (V_{in}), with 2V peak to peak voltage (i.e. 1 V amplitude) and the DC voltage is around 10 V (with ripple) at the output terminals (v_o).



So, in order to solve this problem, you are provided with a single diode (with $V_{D0} = 0.7$ V), two resistors (R_1 and R_2, excluding the load resistors R_L) and an UA741 op-amp.

(a) Design **circuit-1** with the single diode and $R_L = 10\ k\Omega$ (R_L is already provided in the diagram as output terminals of **circuit-1**) to get a rectified voltage and determine the DC value of the output voltage (v_{o1}) of the circuit. [1+2]

(b) Determine the ripple voltage of v_{o1}. [Ripple voltage is defined as the difference between the maximum and minimum value of a DC voltage.] [2]

(c) What should be the value of a capacitor used at the output end of **circuit-1** with R_L to reduce the ripple voltage of v_{o1} to $0.1\ V$. How should the capacitor be connected with R_L in the diagram? [4+1]

(d) Design an amplifier using an operational amplifier as **circuit-2** to increase the DC voltage level of the output voltage of the circuit designed in (c) to 10 V. Find the ripple voltage of the amplified voltage signal. [4+1]