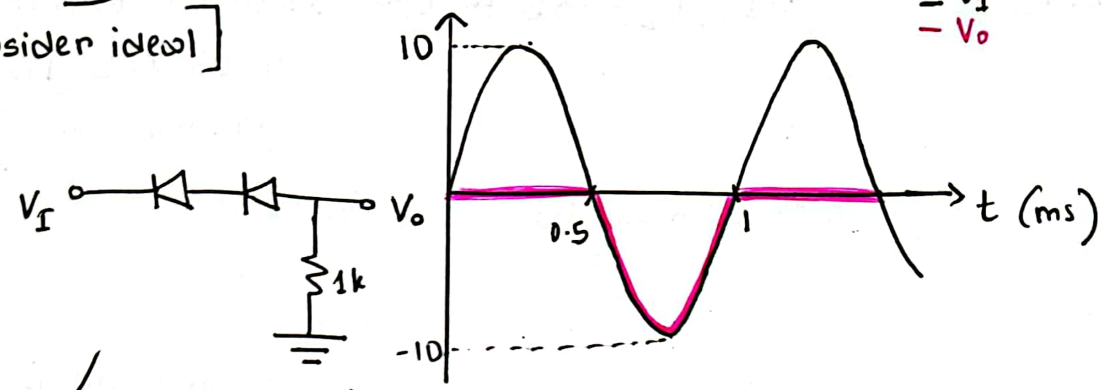
3. Problem Solving on Rectifiers :

Q.1 V_I = 10V peak sine wave of 1 Hz. Sketch the output waveform for the following:

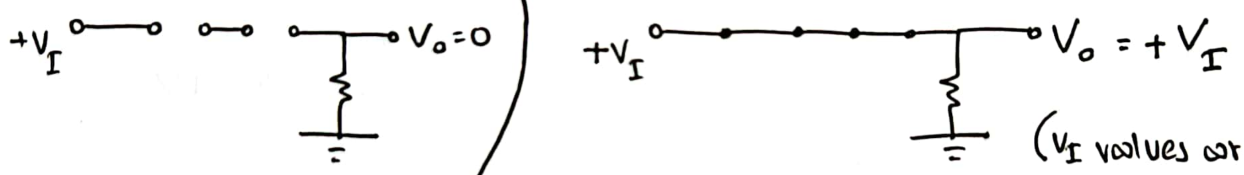
[consider ideal]

(a)



+ve cycle

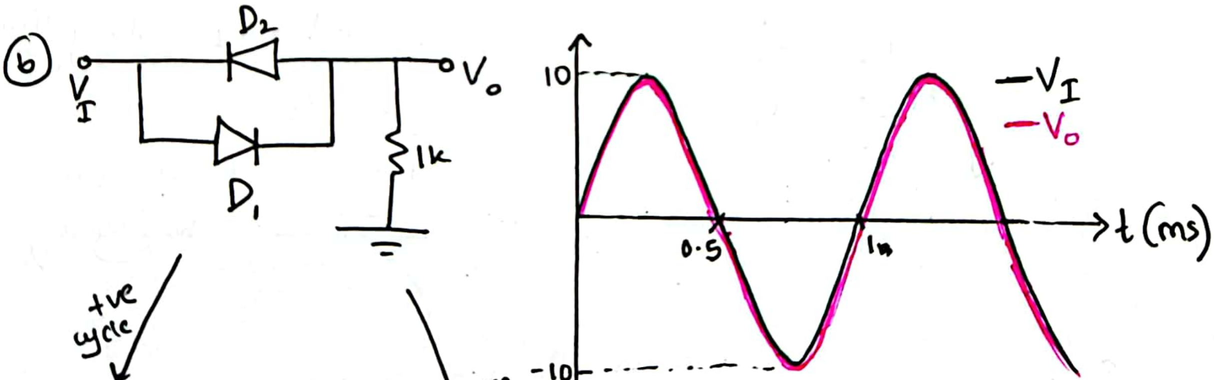
-ve cycle



(V_I values are negative)

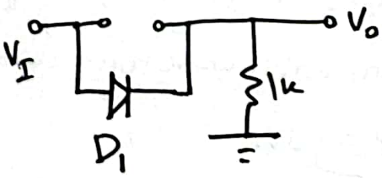
* during +ve half cycle, the diodes are reverse biased, so $I_D = 0$, $V_o = 0$
* during -ve half cycle, " " " forward " , so V_o follows V_I.

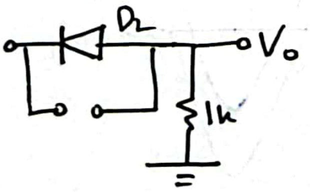
(b)



+ve cycle

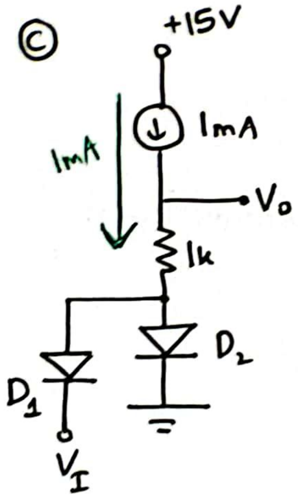
-ve cycle





* output follows input during all cycles, as either diode is forward biased at any time.

(c)

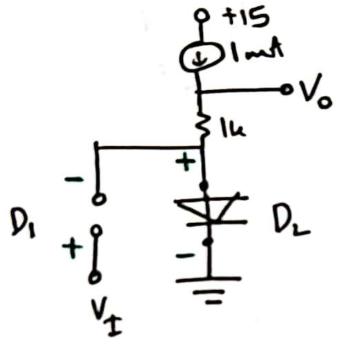


* 1 mA will always flow as shown. It can flow through either D_1, D_2 or both (or even none).

* We can eliminate certain cases such as —

  (i) D_1, D_2 ⟶ both OFF ⟶ impossible as it would violate KCL (1 mA has to go somewhere!)

* consider +ve half cycle for V_I :

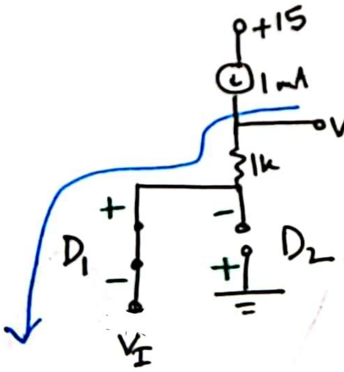


D_1 is OFF

D_2 is ON, as n-side is connected to GND, and pside has a current entering it.

$\therefore V_o = 1mA \times 1k = 1V$

* consider -ve half cycle for V_I :

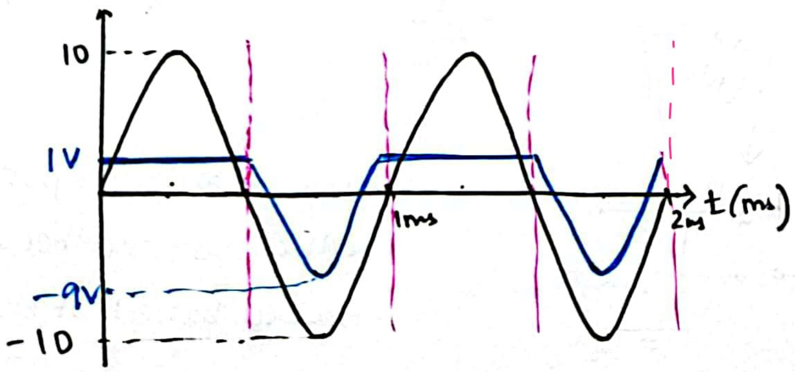


similar to +ve half cycle, D_1 is ON, D_2 is OFF.

$V_o = 1k \times 1mA + V_I$ (along line)

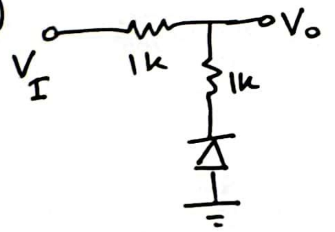
$= 1V + V_I$

$\underline{\underline{= 1 + V_I}}$ (where V_I is -ve half cycle)

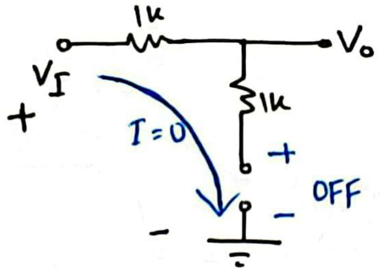


* in -ve half cycle, the entire waveform shifts up by 1V.

(d)



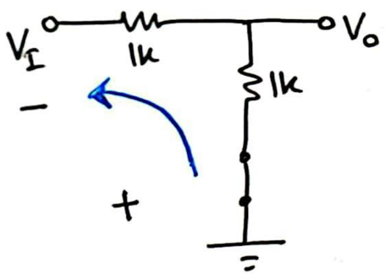
+ve cycle →



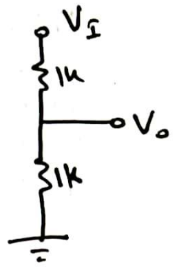
↓ −ve cycle

Voltage across both resistors = 0, as the voltage polarity of input biases the diode into OFF state.

$\boxed{\therefore V_O = V_I}$ (V_I is +ve)



V_I is negative, this biases the diode <u>ON</u>. →

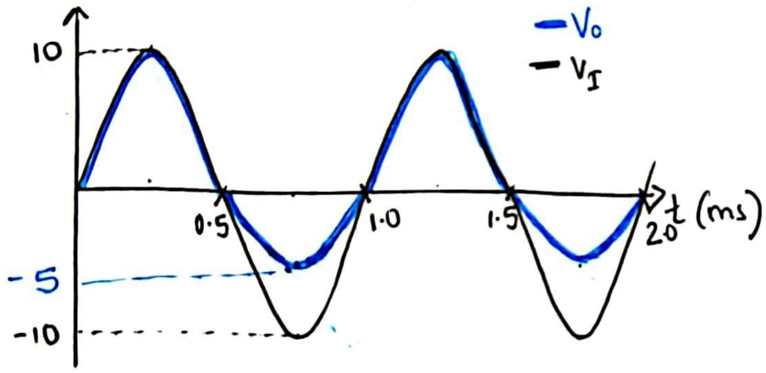


<u>VDR</u>

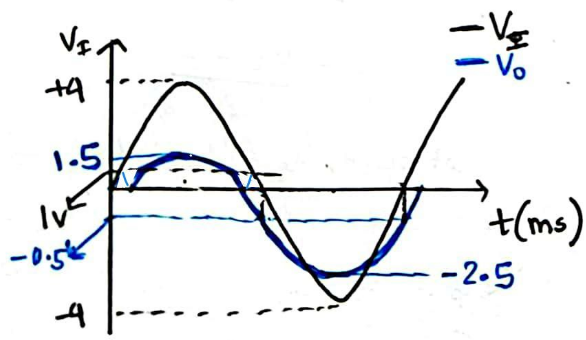
$$\therefore V_o = \frac{1}{1+1} \times V_I$$

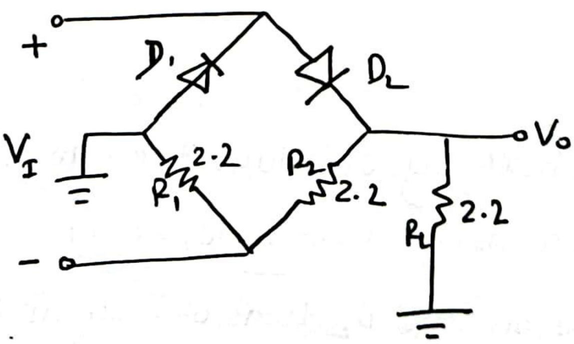
$$\boxed{= \frac{1}{2} V_I}$$

(V_I is −ve)



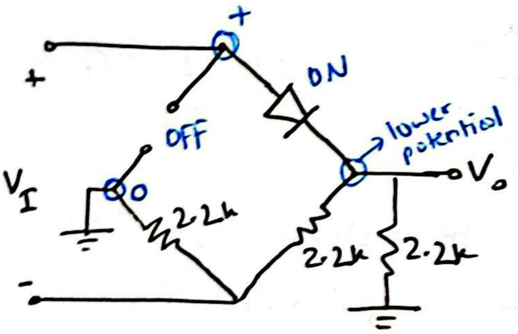
Q.2 Sketch the waveform resulting at V_o. Assume $V_{D_0} = 1V$.

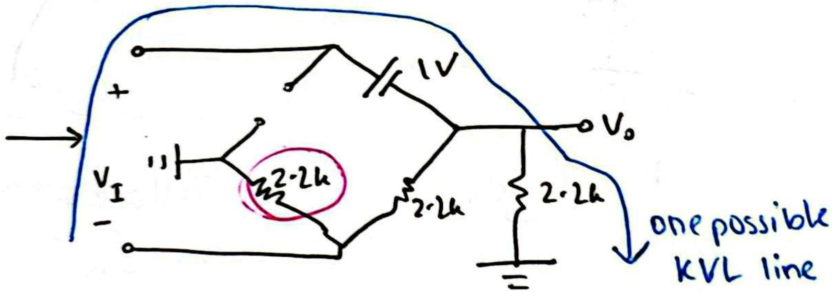




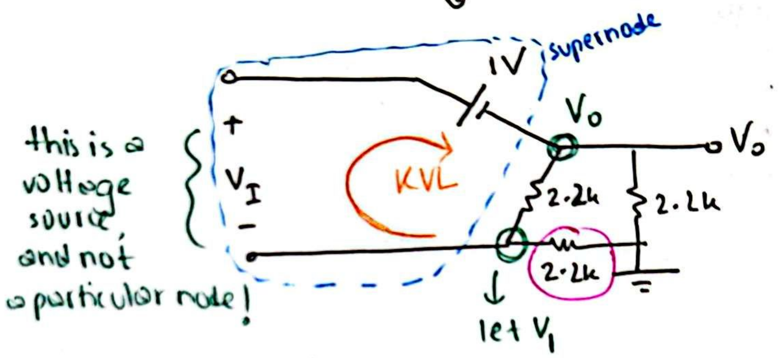
(working in next page)

+ve cycle





OR,



KVL

$$\text{(i)} - \quad -V_1 + 1 = V_I - V_o \qquad (\text{starting} - \text{ending} = \Sigma V)$$

supernode

$$\frac{V_o}{2.2} + \frac{V_o - V_1}{2.2} + \frac{V_1 - V_o}{2.2} + \frac{V_1}{2.2} = 0$$

$$\Rightarrow V_o + V_1 = 0 - \text{(ii)}$$

$$\text{(i)} + \text{(ii)} \Rightarrow V_o + 1 = V_I - V_o$$

$$V_o = \frac{V_I - 1}{2}$$

[at peak, $V_I = 4$, $\therefore V_o = \frac{4-1}{2} = 1.5$]

* at $V_I = 1$, $V_o = 0$, at $V_I = 0$, $V_o = -\frac{1}{2}$

[for $V_I \leq 1$, $V_o = 0$
for $V_I \geq 1$, $V_o = \frac{V_I - 1}{2}$]

at negative peak, $V_I = -4$, $V_o = \frac{-4-1}{2} = -2.5$

* -ve half cycle follows the same pattern as +ve half cycle, as D_1 turns on and D_2 turns off. Circuit appears to be symmetric, so analysis is not repeated.

* in other words, output is half of input shifted down by 0.5. ⟶ Realizing this will enable you to skip this analysis.

Problem 5

The input voltage to a half-wave rectifier is $75\sin(120\pi t)$ V. Assume diode cut-in voltage of $V_{D_0} = 0$ V. Ripple voltage is to be no more than 4 V. If the filter capacitor is 50 µF, determine the minimum load resistance that can be connected to the output.

solⁿ:

$V_p = V_m - V_{D_0} = 75 - 0 = 75$ V

$\omega = 120\pi$
$\Rightarrow 2\pi f = 120\pi$
$f = 60$ Hz
input f = output f

Let $V_r = 4$ V.

$$V_r = \frac{V_p}{fRC}$$

$$R = \frac{V_p}{V_r \times fC} = \frac{75}{4 \times 60 \times 50\,\mu F}$$

$= 6250\ \Omega = 6.25$k

[check what happens if you use lower V_r.]

Problem 6

The output voltage of a FW rectifier has been filtered with two 2.5 µF capacitor in parallel. The peak, average, and frequency of output voltage are 4.3 V, 4 V and 300 Hz respectively. Determine the load resistance.

solⁿ:

$C_{eq} = 2.5 + 2.5 = 5\,\mu F$

$V_p = 4.3$ V

$V_{dc} = 4$ V

$f(\text{input}) = 300/2 = 150$ Hz

$$V_{dc} = V_p - \frac{V_r}{2}$$

$V_r = 2 \times (4.3 - 4)$
$= 0.6$ V

$$V_r = \frac{V_p}{2fRC}$$

$$R = \frac{V_p}{V_r \times 2fC}$$

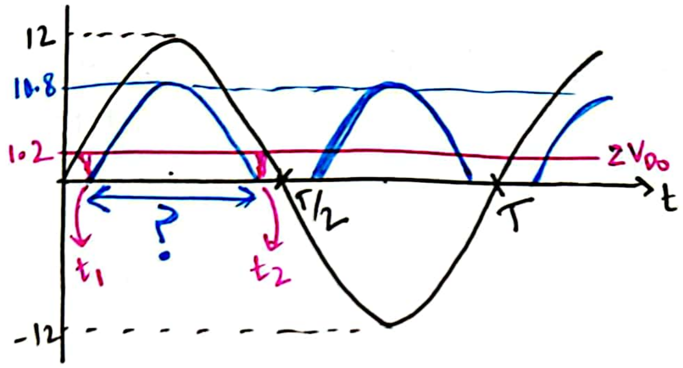
$$= \frac{\cancel{0.6}\ 4.3}{0.6 \times 2 \times 150 \times 5\,\mu F}$$

$= 4.78$ kΩ

Problem 8

A 24V p-p sine wave ac voltage is to be rectified with a FW bridge rect. ckt without filter capacitor. Determine the fraction of time each diode is conducting when on, and the average output voltage. Assume all diodes are identical with $V_{D_0} = 0.6V$.

solⁿ:



$V_o = V_s - 2V_{D_0}$

$= V_m - 1.2$

$= 12 - 1.2 = 10.8V$

t_1,

$t_2 = T/2 - t_1$

$t_1 = \frac{1}{\omega} \sin^{-1}\left(\frac{2V_{D_0}}{V_m}\right)$

$2\pi f$

??

* instead of finding the instances in time, it is perfectly valid to find the angles instead.

↳ in case no f is provided!

at t_1, $1.2 = 12\sin(\omega t_1)$

$\Rightarrow \omega t_1 = \sin^{-1}\left(\frac{1.2}{12}\right)$

$= 5.74°$ (dividing this with $2\pi f$ would give us time in s)

we know, $T/2 \longrightarrow 180°$ or π $\longrightarrow$ $t_2 = T/2 - t_1$

$T \longrightarrow 360°$ or 2π. $= 180° - 5.74° = 174.26°$

∴ the diodes conduct from 5.74° to 174.26°.

∴ fraction of time for which diode conducts: $\frac{174.26° - 5.74°}{180°} \times 100\%$

$= 95.7\%$

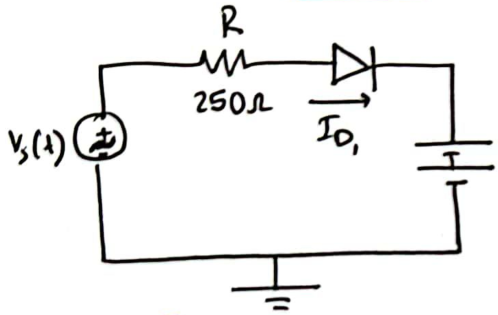
∴ $V_{dc} = \frac{2V_m}{\pi} - 2V_{D_0} = 6.44V$

Problem 1D

A battery V_B is charged through a HW rectifier ckt as shown. The voltage of the battery at the time of charging is 4.5V. The resistance R is 250Ω. $V_s(t)$ is a $24V_{p\text{-}p}$ sine wave. $V_{D_0} = 0.6V$.

i. What is the required value of $V_s(t)$ for diode to conduct?

ii. Determine peak diode current, maximum reverse-bias diode voltage, and the fraction of the cycle over which diode is conducting.



soln: (i) $V_s(t) = ?$ for diode to be ON.

* Diode is ON if $I_{D_1} > 0$

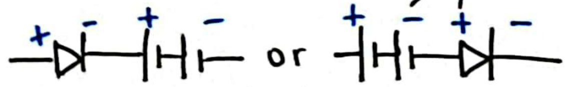
$$\Rightarrow \frac{V_s - V_{D_0} - V_B}{R} > 0$$

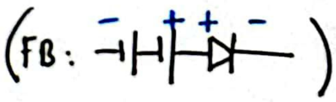
$$\Rightarrow V_s > V_{D_0} + V_B$$

$$\Rightarrow V_s > 0.6 + 4.5$$

$$\Rightarrow V_s > 5.1V$$

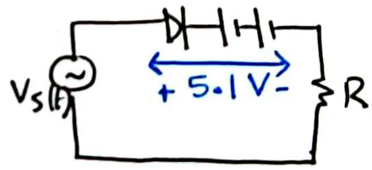
You can think that the battery opposes the forward biasing of the diode ...



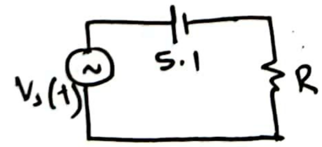


(ii) Rearrange the ckt to a more familiar face:

they are in series, so it is completely fine.



↓



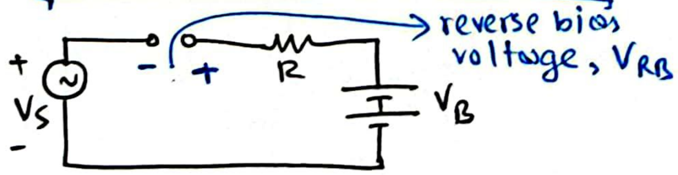
$I_o = V_s - V_{D_0}'$

$V_p = V_m - V_{D_0}'$

$= 12 - 5.1$

$= 6.9V$

$$\boxed{I_{peak} = V_P/R = 27.6\,mA}$$



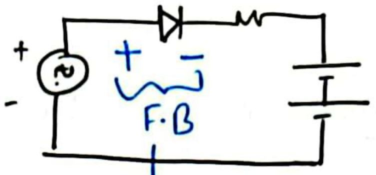
KVL, $-V_s - V_{RB} + 4.5 = 0$

$V_{RB} = -V_s + 4.5$

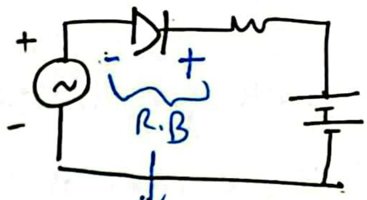
$V_{RB(max)} = -V_{s(min)} + 4.5$

$V_{RB(max)} = -(-12) + 4.5$

$= 16.5\text{ V}$



diode shorts/ON



diode opens/OFF (no current, no voltage drop across resistor)

* similar to problem 8,

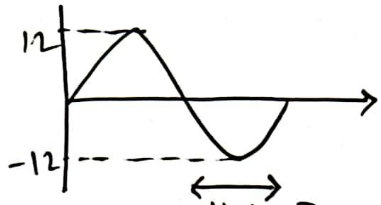
at t_1, $5.1 = 12\sin(\omega t_1)$

$\omega t_1 = \sin^{-1}\left(5.1/12\right)$

$= 25.15°$

$\omega t_2 = 180 - 25.15°$

$= 154.85°$



in this range, the highest magnitude voltage is 12V. Add this to 4.5V to find what the drop across diode is.

$\therefore$ fraction of conduction time $= \dfrac{154.85° - 25.15°}{\cancel{180°}\ 360°} \times 100\%$

$= 36\%$

HW rectifier.

<u>note</u>: $V_{dc} \neq \dfrac{V_m}{\pi} - \dfrac{V_{D0}}{2}$, as $\boxed{V_{D0} << V_m}$ is <u>NOT TRUE</u>

V_{D0}: 5.1, V_m: 12

$\therefore V_{dc} = \dfrac{1}{T}\int_0^T v(t)\,dt$

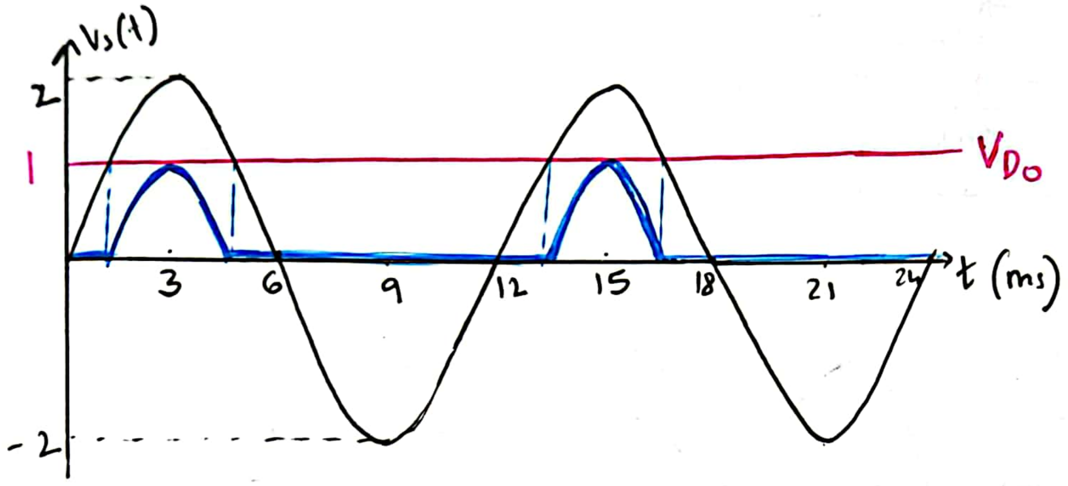
$= \dfrac{1}{2\pi}\int_{25.15}^{154.85} (12\sin\omega t)\,d\omega - \dfrac{1}{2\pi}\int_{25.15}^{154.85} 5.1\,d\omega$.

$= \underline{\underline{\qquad}}$

$\dfrac{1}{2\pi}\int_{25.15}^{154.85} (12\sin \omega t - 5.1)\,d\omega$

Problem 11

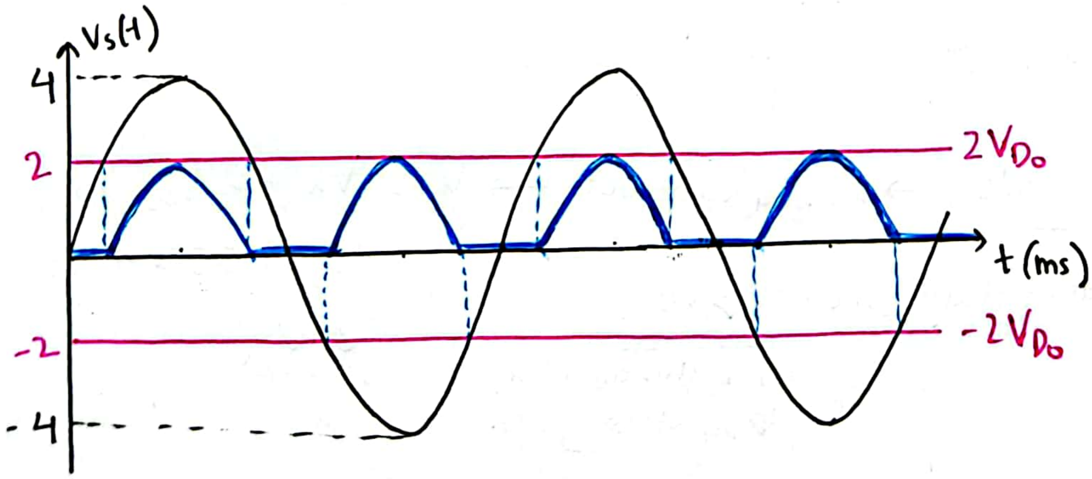
Draw the output waveform for the following input to a HW rectifier without filter capacitor. Assume $V_{D_0} = 1.0\,V$.



$$V_p = V_m - V_{D_0}$$
$$= 2 - 1$$
$$= 1\,V$$

Problem 12

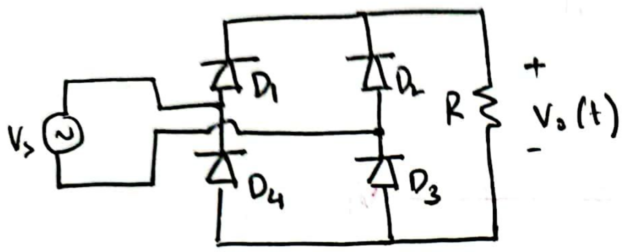
Same as 11, but for FW rectifier.

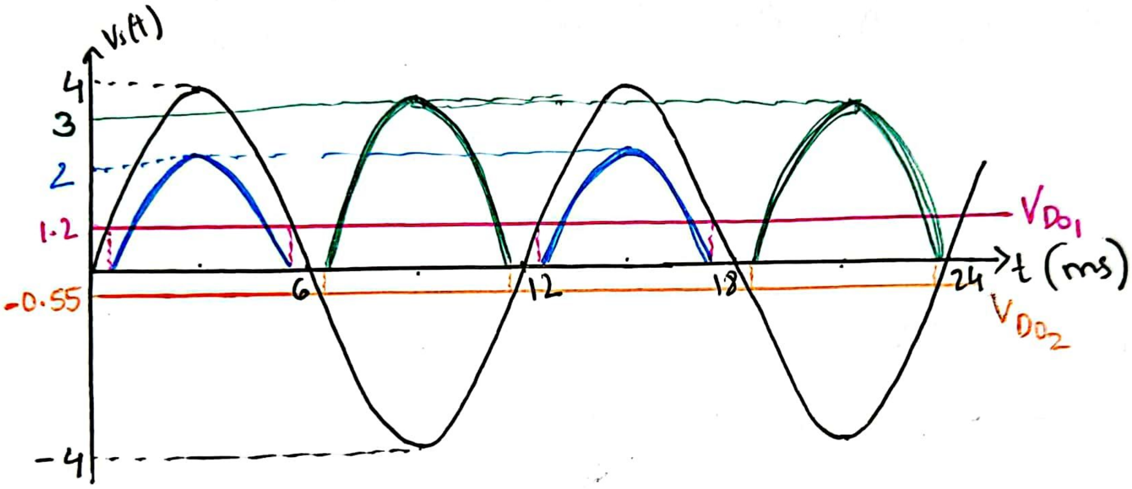


$$V_p = V_m - 2V_{D_0}$$
$$= 4 - 2 \times 1$$
$$= 2\,V$$

Problem 13

Draw output given that $V_{D0_1} = 1.2V$, $V_{D0_2} = 0.55$, $V_{D0_3} = 0.8V$ and $V_{D0_4} = 0.45V$





+ve half cycle $\longrightarrow$ D_1, D_3 conducts $\longrightarrow$ $V_p = V_m - V_{D0_1} - V_{D0_3}$

$= 4 - 1.2 - 0.8$

$= 2\ V$

* conduction starts only when $V_s > V_{D0_1}$ (as for this, ~~V_{D0_3}~~ D_3 already ON)

-ve half cycle $\longrightarrow$ D_2, D_4 conducts $\longrightarrow$ $V_p = V_m - V_{D0_2} - V_{D0_4}$

$= 4 - 0.55 - 0.45$

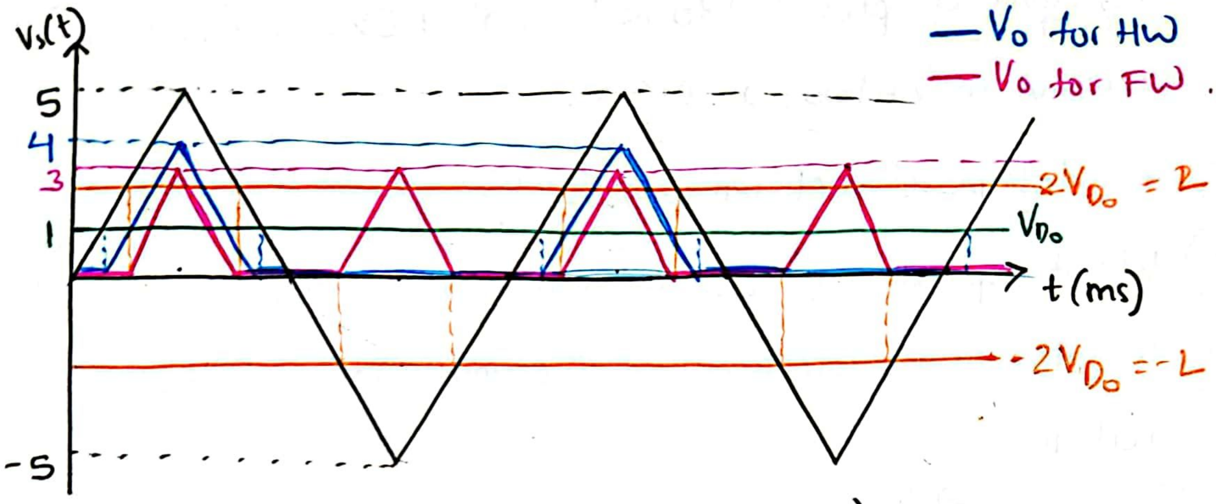
$= 3\ V$

* conduction starts when $V_s > V_{D0_2}$

for this condition, D_4 already ON.

Problem 14 Draw o/p waveform –

(i) For HW (ii) For FW (Assume $V_{D_0} = 1\,V$)

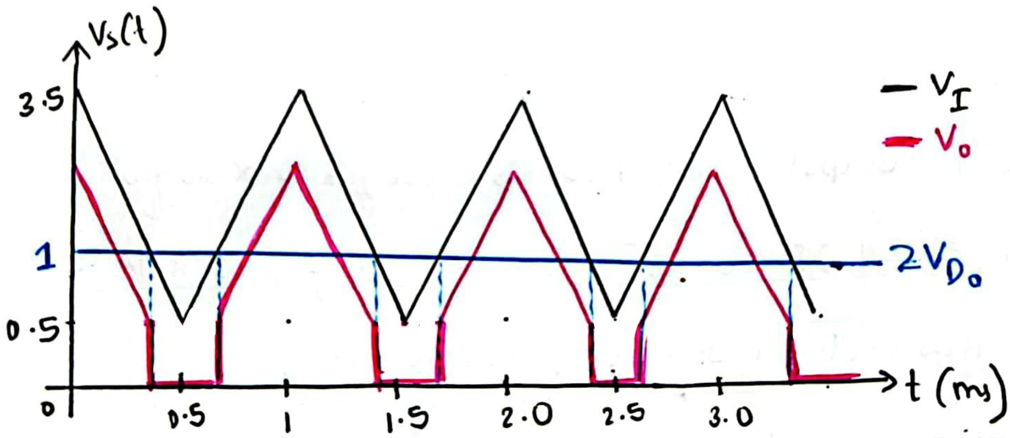


try drawing on separate diagrams!

(i) $V_p = V_m - V_{D_0} = 5 - 1 = 4\ V$

(ii) $V_p = V_m - 2V_{D_0} = 5 - 2\times1 = 3\ V$

Problem 15 Draw o/p waveform for FW rectifier (no filter). Assume $V_{D_0} = 0.5\,V$



$V_p = V_m - V_{D_0} = 3.5 - 0.5 = 3V$

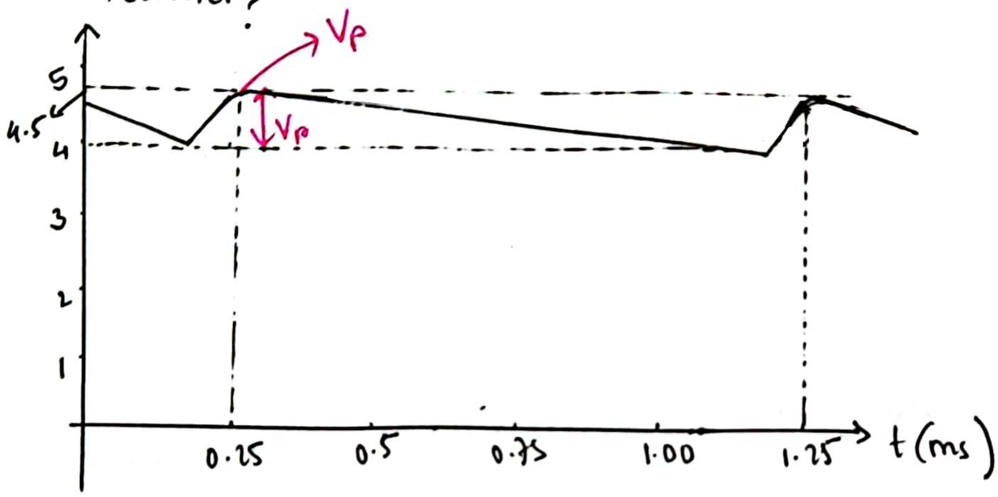
Problem 16

- The following is the rectified output of an ac sinusoidal voltage at 1 kHz frequency, provided to a load of 4.5kΩ. Assume the diodes have a cut-in voltage of 0.5 V.

i) What type of rectifier was used?

ii) What capacitance was used in the rectifier's design?

iii) What was the amplitude of the sinusoidal ac voltage applied to the rectifier?



i) Just visuals are not enough to understand => find out frequency

HW => input f = output f ; FW => input f = 2 × output f.

From graph, $T = 1.25 - 0.25 = 1\,ms$ $\therefore f = 1\,kHz$

This is a HW rectifier as $\boxed{\text{input } f = \text{output } f.}$

ii) $$C = \frac{V_P}{V_r \times f \times R} = \frac{4.5}{(4.5-4)\times 1000 \times 4500}$$

$$= 2\,\mu F$$

iii) $V_p = V_m - 2V_{D_0}$

$\Rightarrow 4.5 = V_m - 2 \times 0.5$

$V_m = 5.5\,V$