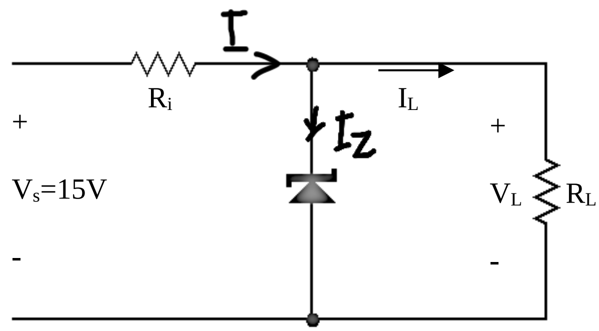
Questions

1. The Zener diode in the following circuit has $V_z = 12V$, minimum current $I_{zmin} = 2mA$, and maximum power $P_{zmax} = 0.6W$. Determine the smallest possible R_i such that the voltage across the load is maintained at 12V. With this value of R_i if the diode is operating in the Zener mode, what is the minimum possible value of R_L? Unless specified otherwise, assume constant voltage drop model for the diode operating in the Zener region.



Solution

$V_Z = V_L = 12V$ (Zener mode).

$I_{Z,min} = 2mA.$

$P_{Z,max} = 0.6W = V_Z \cdot I_{Z,max}$

$\Rightarrow (12V)\, I_{Z,max} = 0.6W$

$\Rightarrow \quad I_{Z,max} = \left(\frac{0.6}{12}\right) A = 50 mA$

$\Rightarrow \quad 2mA \leq I_Z \leq 50 mA$ [Zener mode]

By KCL,

$$I_Z = I - I_L$$
$$= \frac{V_s - V_Z}{R_i} - I_L$$
$$= \frac{(15-12)V}{R_i} - I_L = \frac{3V}{R_i} - I_L.$$

$$2mA \leq I_Z \leq 50mA$$

$$\Rightarrow 2mA \leq \frac{3V}{R_i} - I_L \leq 50mA.$$

$$\Rightarrow \frac{3V}{50mA + I_L} < R_i < \frac{3V}{2mA + I_L}$$

$\therefore$ Minimum R_i (i.e. for $I_L \to 0$; for ~~large~~ $R_L \to \infty$)

$$= \boxed{R_{i,min} = \frac{3V}{50mA} = 60\Omega}$$

With $R_i = 60\Omega$

$$I = \frac{V_s - V_Z}{R_i} = \frac{(15-12)V}{60\Omega} = \frac{3V}{60\Omega}$$
$$= 50mA.$$

$$2mA \leq I_Z \leq 50mA$$

$$\Rightarrow 2mA \leq I - I_L \leq 50mA$$

$$\Rightarrow -48mA \leq -I_L \leq 0 \qquad [\text{Using } I = 50mA]$$

$$\Rightarrow 0 \leq I_L \leq 48mA.$$

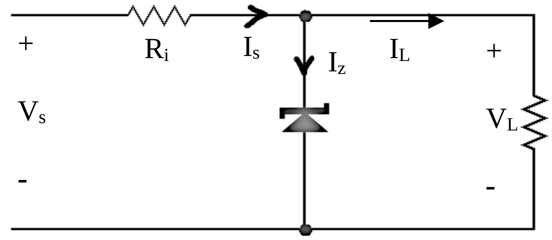
Also, $I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{12V}{R_L}$

$$\Rightarrow 0 \leq \frac{12V}{R_L} \leq 48mA$$

$$\Rightarrow \frac{12V}{48mA} \leq R_L < \infty$$

$$\Rightarrow \boxed{R_{L,min} = \frac{12V}{48mA} = 250\Omega}$$

2. In the following circuit, $V_L = 12V$, $V_s = 20V$, and I_L varies from 0 to 100mA. If the diode is operating in the Zener mode, determine the value of R_i such that P_{zmax} of the diode is as small as possible. Determine P_{zmax} for the calculated value of R_i.



$$I_S = \frac{V_S - V_L}{R_i} = \frac{V_S - V_Z}{R_i} \quad (\because V_Z = V_L)$$

Also, $I_S = I_Z + I_L$

$$\therefore \quad I_Z + I_L = \frac{V_S - V_Z}{R_i}$$

$$\Rightarrow I_L = \frac{V_S - V_Z}{R_i} - I_Z$$

Also,

$$0 \leq \frac{V_S - V_Z}{R_i} - I_Z \leq 0.1$$

$$\Rightarrow -\frac{V_S - V_Z}{R_i} \leq -I_Z \leq 0.1 - \frac{V_S - V_Z}{R_i}$$

$$\Rightarrow \frac{V_S - V_Z}{R_i} \geq I_Z \geq \frac{V_S - V_Z}{R_i} - 0.1$$

$$P_{Z,max} = V_Z . I_{Z,max}$$

Since, $\frac{V_S - V_Z}{R_{imin}} \geq I_{Zmax} \geq \frac{V_S - V_Z}{R_{imin}} - 0.1$

The value of $I_{Z\,max}$ is set by its lower limit being ≥ 0. This restric the minimum $P_{Z,max}$

$\therefore$ min $(I_{Z,max})$ ~~$(I_{Z,min})$~~ $= \frac{20-12}{R_{imin}} - 0.1$

Since $I_{Z,max}$ cannot be negative, minimum value of I_{Zmax} is 0

$$\therefore \frac{20-12}{R_{imin}} - 0.1 = 0$$

(3)

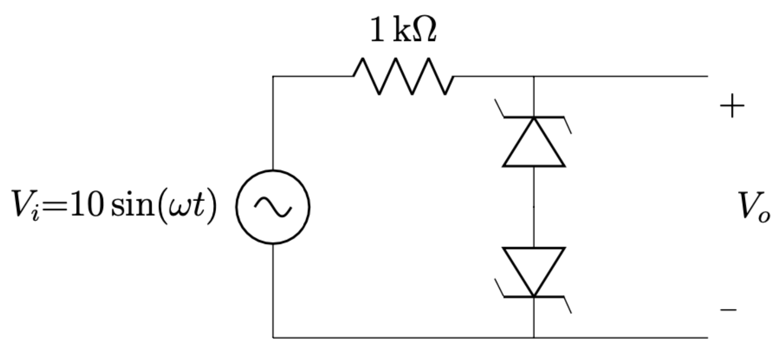
$$\Rightarrow \frac{8}{R_{imin}} = 0.1$$

or $$R_{imin} = \frac{8}{0.1}\,\Omega = 80\,\Omega$$

Because $I_{z,max} \leq 0.1$

$$P_{zmax} = V_Z \cdot 0.1$$
$$= 12 \times 0.1\ W$$
$$\Rightarrow P_{zmax} = 1.2\,W$$

3. The Zener diodes used in the circuit below have the following characteristics: Forward drop = 0.7 V; Zener voltage = - 7 V; Rf (Forward Resistance) = 20 Ω ; Rz (Resistance in Zener region) = 10 Ω. Sketch the output waveform Vo with time.



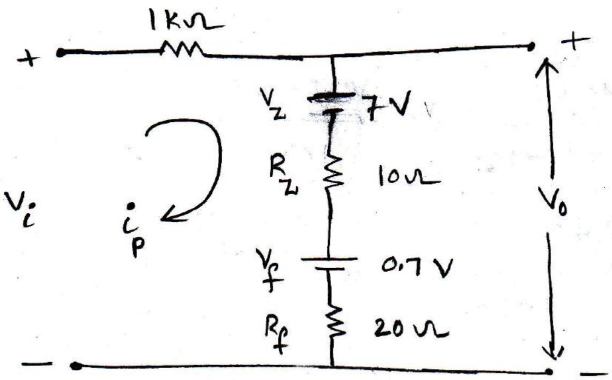
given $V_f = 0.7\,V$; $V_z = -7V$; $R_f = 20\Omega$

and $R_z = 10\Omega$

→ During +ve half cycle,

D_1 acts as a zener and D_2 acts as a normal diode

The circuit reduces to,



when $V_i < (7+0.7 = 7.7V) \Rightarrow V_o = V_i$

when $V_i \geq 7.7V$,

$$i_p = \frac{V_i - 0.7 - 7}{1000+10+20} = \frac{V_i - 7.7}{1030}$$

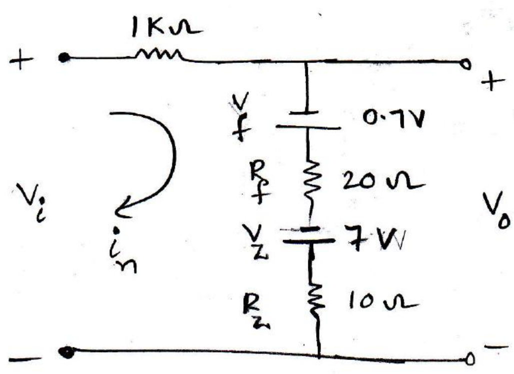
$$\Rightarrow i_{p,max} = \frac{V_{i,max} - 7.7}{1030} = \frac{10-7.7}{1030} = 2.23 \text{ mA}$$

$$\therefore V_{o,max} = V_{i,max} - \left[1K \times i_{p,max}\right] = 10 - 2.23 = 7.77\,V$$

During −ve half cycle,

D_1 acts as a normal diode

and D_2 acts as a zener.



For $-7.7V < V_i < 0$; $V_o = V_i$

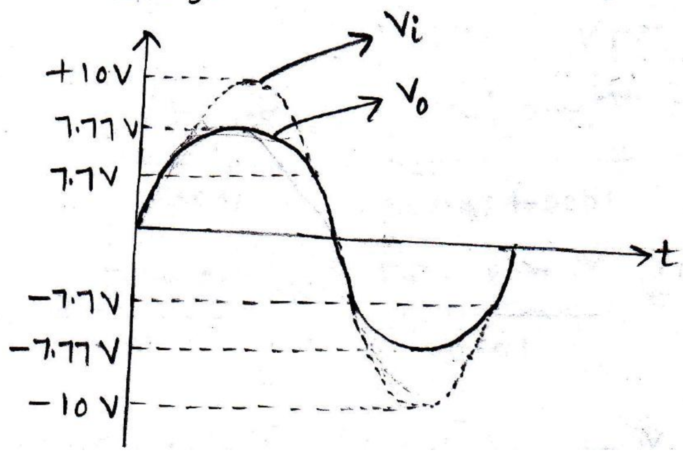
for $V_i < -7.7V$,

$$i_n = \frac{V_i + 7.7}{1000+20+10} = \frac{V_i + 7.7}{1030}$$

$$\Rightarrow i_{n,min} = \frac{V_{i,min} + 7.7}{1030} = \frac{-10 + 7.7}{1030} = -2.23\,mA.$$

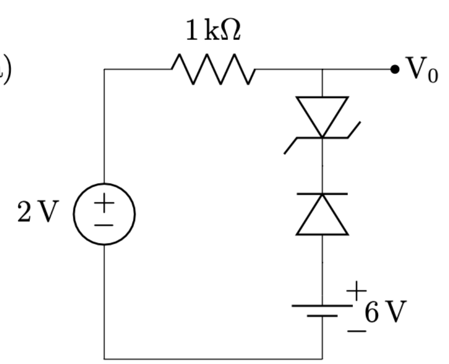
$$V_{o,min} = -10 - i_n \cdot 1K\Omega = -10 + [2.23 \times 10^{-3} \times 1 \times 10^{3}]$$

$$= (-10 + 2.23)V = -7.77V$$

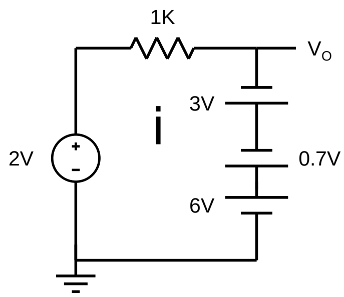


4. Determine the output voltage with reference to ground for the circuits shown below assuming that cut-in voltage of both diode and Zener diode is 0.7V and that Zener voltage is 3V.

(a)



Diode D2 is forward biased. Assume Zener is like a 3V battery. The circuit can be written as



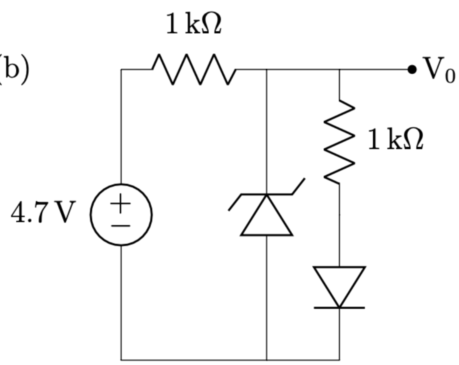
Let us calculate the current to check our assumption

$$-6+0.7+3+i\times10^3+2=0 \Rightarrow i=0.3mA$$

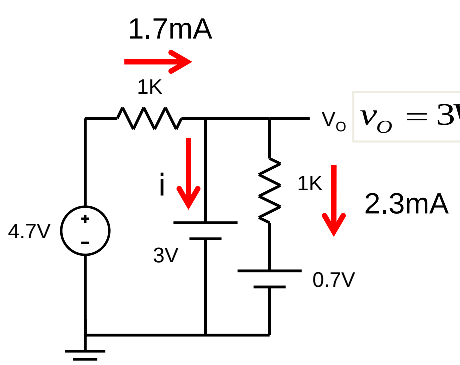
$$-6+0.7+3+v_O=0 \Rightarrow v_O=2.3V$$

Hence, the assumption is correct.

(b)



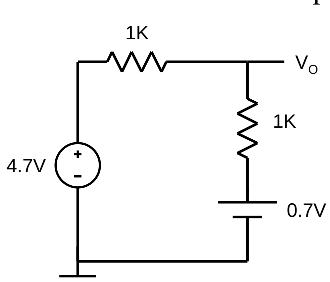
Diode D2 is forward biased. Assume zener is like a 3V battery



$$v_O=3V$$

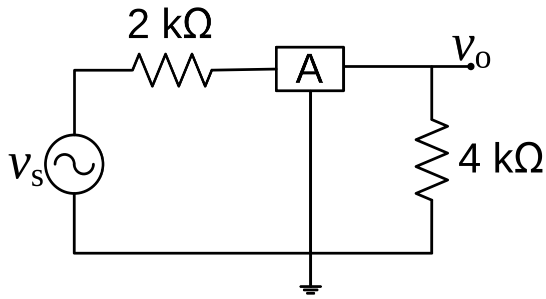
Let us calculate the Zener current to check our assumption

I = -0.6mA so assumption is incorrect and zener is like an open circuit

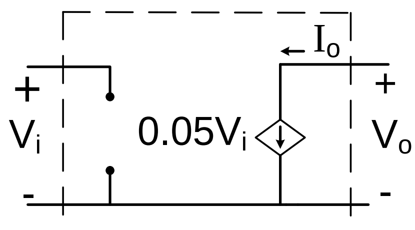


Hence, $v_O=2.7V$

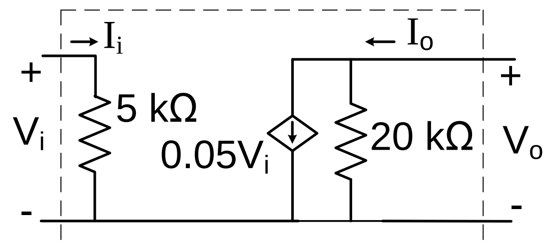
5. Determine the ac voltage gain of the amplifier ‘A’ as shown in (a) using the two transistor models shown in (b) and (c) as dotted region. Assume that the device ‘A’ is biased properly.



(a)



(b)

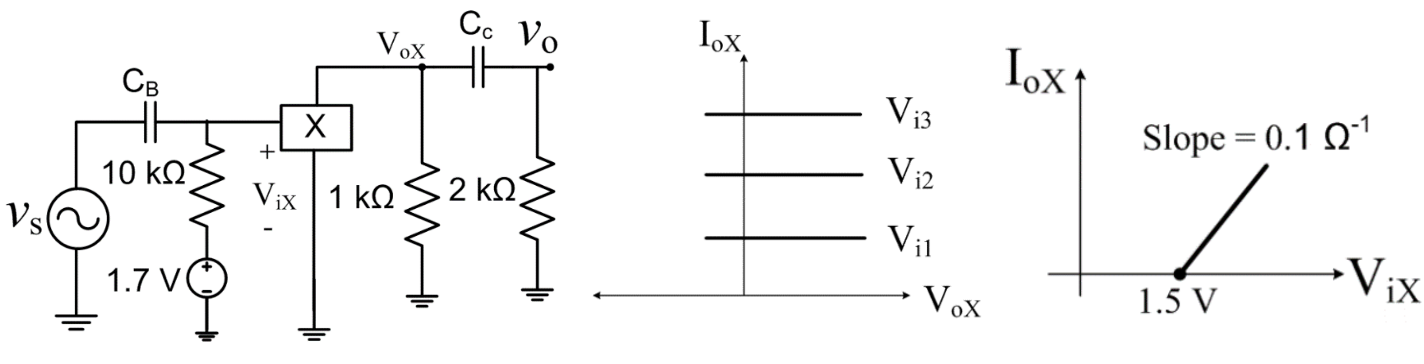


(c)

Solutions:

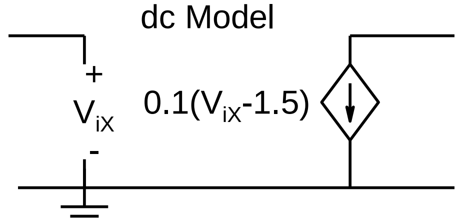
Under model (b)	Under model (c)
$V_i = V_s$ $V_0 = -0.05 V_i \times 4 \times 10^3$ V $\Rightarrow V_0 = -0.05 \times 4 \times 10^3 \times V_s$ V $\Rightarrow \frac{V_0}{V_s} = -\frac{5}{100} \times 4 \times 1000$ $\Rightarrow \frac{V_0}{V_s} = -200$	$V_i = \frac{V_s \times 5}{5+2} = \frac{5V_s}{7}$ $V_0 = -0.05 V_i \left(20k\Omega \parallel 4k\Omega\right)$ $\Rightarrow V_0 = \frac{-0.05 \times 20 \times 4 \times 1000}{24} v_i$ $\Rightarrow V_0 = -\frac{0.05 \times 20 \times 4 \times 1000}{24} \times \frac{5}{7} v_s$ $\Rightarrow \frac{V_0}{s} = -\frac{5 \times 20 \times 4 \times 1000 \times 5}{100 \times 24 \times 7}$ $\Rightarrow \frac{V_0}{V_s} = -119.05$

6. Carry out DC and AC analysis of the amplifier circuit, with amplifier ‘**X**’, whose device characteristics are shown below. Also, sketch V_{iX}, V_{oX} and v_0 for $v_S = 0.2\sin(\omega t)$.

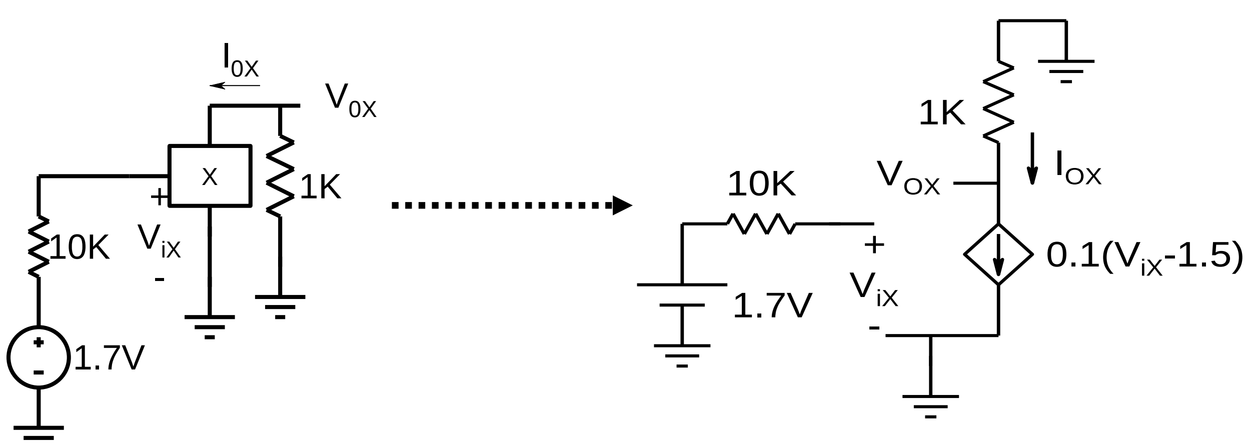


When there is both dc and ac source in the circuit, voltages and currents in general will have a dc component and an ac component. As a result two analysis, one dc and another ac have to be carried out.
Note the convention in naming voltage (or current) at node X
dc Voltage : V_X; ac voltage : v_x; Net Voltage: $V_x = V_X + v_x$
The device can be written as

dc Model

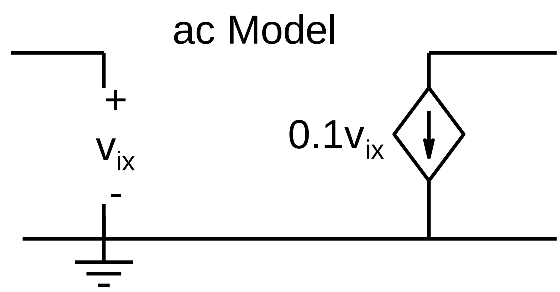


DC analysis:
draw the dc circuit obtained by open circuiting the capacitor

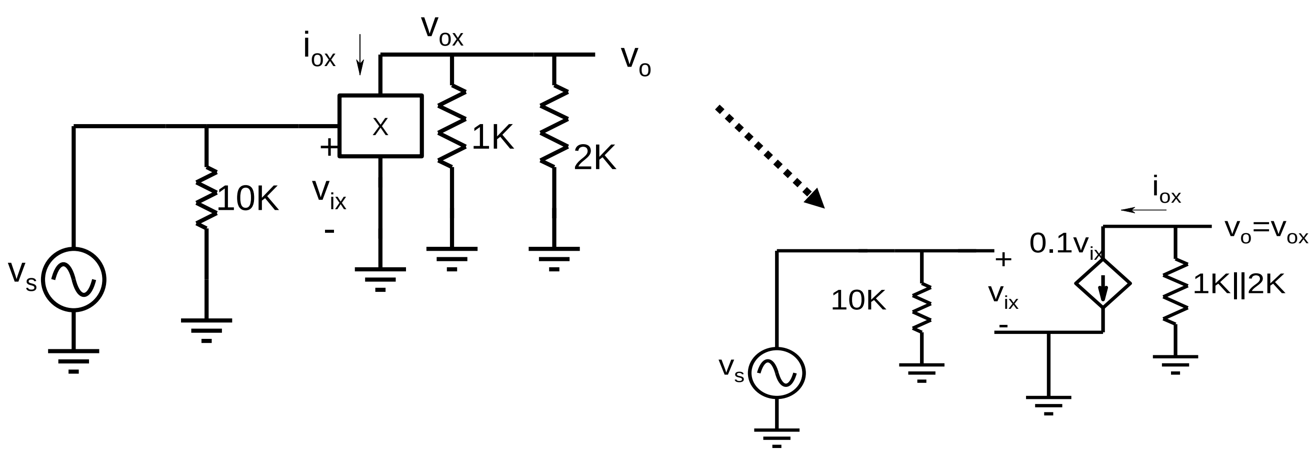


$$I_{OX} = 0.1 \times (1.7 - 1.5) = 20mA$$
$$V_{IX} = 1.7V$$
$$V_{OX} = -20mA \times 1K = -20V$$

Ac Analysis:
Small signal model can be written as



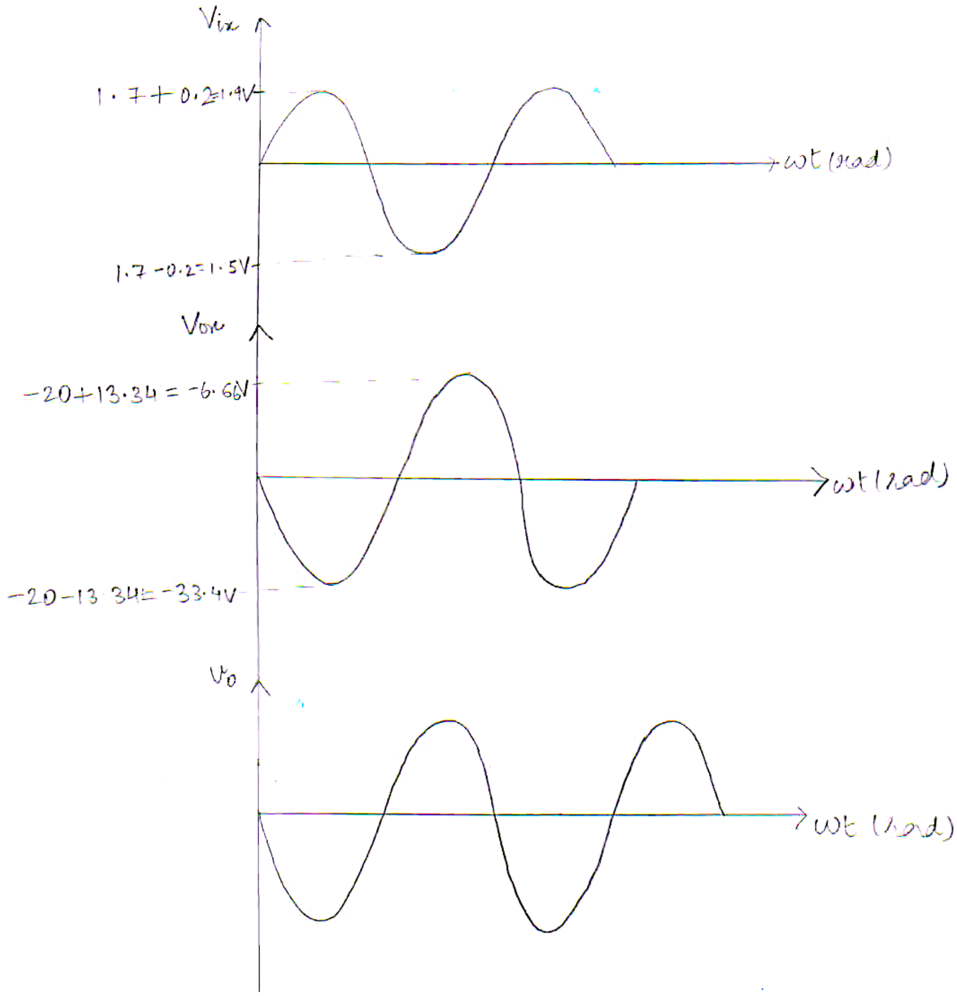
Draw the ac circuit by shorting the dc sources and capacitors



$$i_{ox} = 0.1v_{ix} = 20mASin(\omega t)$$
$$v_{ox} = v_o = -i_{ox}1K \| 2K = -13.34V\ Sin(\omega t)$$

Combining the AC and DC analysis

$$V_{ix} = V_{IX} + v_{ix} = 1.7 + 0.2Sin(\omega t)$$
$$I_{ox} = I_{OX} + i_{ox} = 20mA + 20mASin(\omega t)$$
$$V_{ox} = V_{OX} + v_{ox} = -20 - 13.34Sin(\omega t)$$
$$v_o = -13.34V\ Sin(\omega t)$$



Vin
1.7+0.2=1.9V
ωt (rad)
1.7-0.2=1.5V
Von
-20+13.34 = -6.6V
ωt (rad)
-20-13.34= -33.4V
V0
ωt (rad)