

ESC201A Assignment 6

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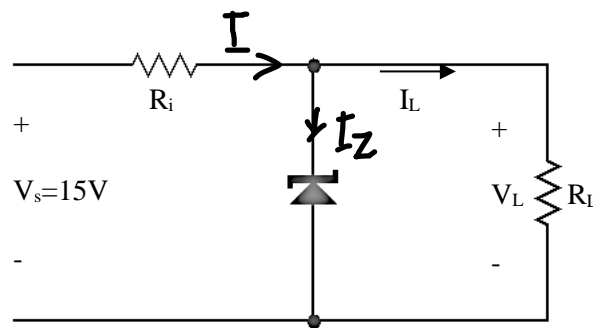
2023-2024 Semester I

Topics

Zener Diodes, Amplifiers model

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

$$V_Z = V_L = 12V \text{ (Zener mode).}$$

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

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

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

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

$$\Rightarrow 2mA \leq I_Z \leq 50mA \text{ [Zener mode]}$$

By KCL,

$$\begin{aligned} I_2 &= I - I_L \\ &= \frac{V_s - V_Z}{R_i} - I_L \\ &= \frac{(15-12)V}{R_i} - I_L = \frac{3V}{R_i} - I_L. \end{aligned}$$

$$2\text{mA} \leq I_2 \leq 50\text{mA}$$

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

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

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

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

With $R_i = 60\Omega$

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

$$2\text{mA} \leq I_2 \leq 50\text{mA}$$

$$\Rightarrow 2\text{mA} \leq I - I_L \leq 50\text{mA}$$

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

$$\Rightarrow 0 \leq I_L \leq 48\text{mA}.$$

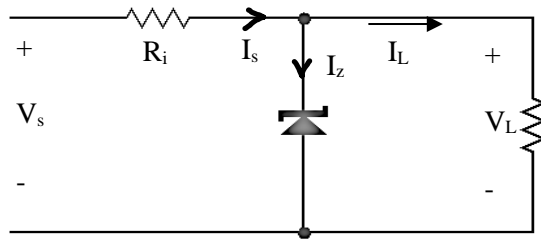
$$\textcircled{a} \text{ Also, } I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{12V}{R_L}$$

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

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

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

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, $I_s = I_z + I_L$

$$\therefore I_z + I_L = \frac{V_s - V_z}{R_i}$$

$$\Rightarrow I_L = \frac{V_s - V_z}{R_i} - I_z$$

also, $0 \leq \frac{V_s - V_z}{R_i} - I_z \leq 0.1$

$$\Rightarrow -\frac{V_s - V_z}{R_i} \leq -I_z \leq 0.1 - \frac{V_s - V_z}{R_i}$$

$$\Rightarrow \frac{V_s - V_z}{R_i} \geq I_z \geq \frac{V_s - V_z}{R_i} - 0.1$$

$$P_{z,max} = V_z \cdot I_{z,max}$$

Since, $\frac{V_s - V_z}{R_{i,min}} \geq I_{z,max} \geq \frac{V_s - V_z}{R_{i,min}} - 0.1$

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

$$\therefore \min(I_{z,max}) = \frac{20 - 12}{R_{i,min}} - 0.1$$

Since $I_{z,max}$ cannot be negative, minimum value of $I_{z,max}$ is 0.

$$\therefore \frac{20 - 12}{R_{i,min}} - 0.1 = 0$$

⑦

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

$$\text{or } R_{\min} = \frac{8}{0.1} \Omega = 80 \Omega$$

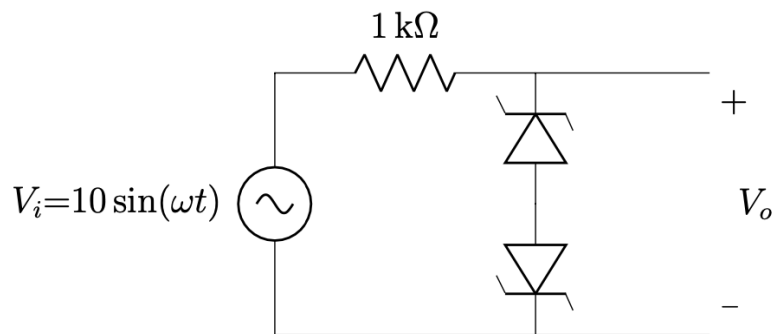
Because $I_{Z, \max} \leq 0.1$

$$P_{Z, \max} = V_Z \cdot 0.1$$

$$= 12 \times 0.1 \text{ W}$$

$$\Rightarrow P_{Z, \max} = 1.2 \text{ W}$$

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



given

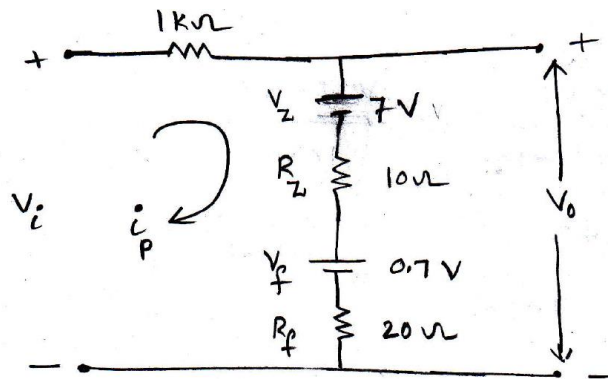
$$V_f = 0.7 \text{ V} ; V_Z = -7 \text{ V} ; R_f = 20 \Omega$$

$$\text{and } R_z = 10 \Omega$$

→ During +ve half cycle,

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

The circuit reduces to,



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

when $V_i \geq 7.7\text{V}$,

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

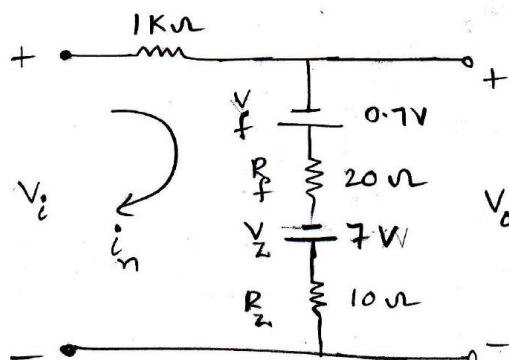
$$\Rightarrow i_{P, \max} = \frac{V_{i, \max} - 7.7}{1030} = \frac{10 - 7.7}{1030} = 2.23\text{ mA}$$

$$\therefore V_{o, \max} = V_{i, \max} - [1\text{k}\Omega \times i_{P, \max}] = 10 - 2.23 = 7.77\text{V}$$

During -ve half cycle,

D_1 acts as a normal diode

and D_2 acts as a Zener.



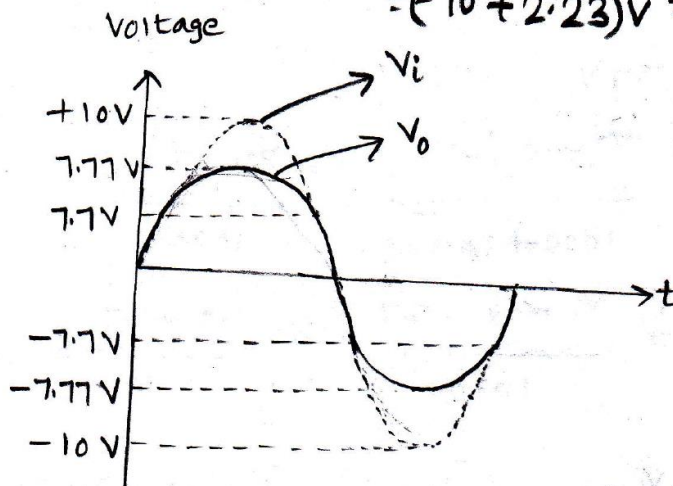
For $-7.7V < V_i < 0$; $V_o = V_i$
 for $V_i < -7.7V$,

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

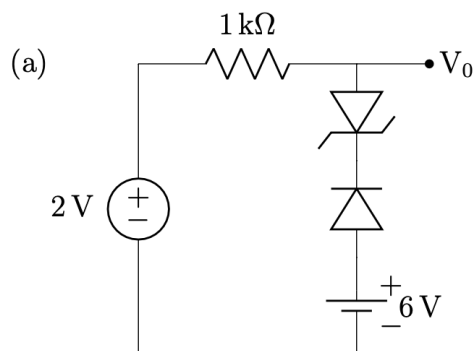
$$\Rightarrow i_{n, \min} = \frac{V_{i, \min} + 7.7}{1030} = \frac{-10 + 7.7}{1030} = -2.23 \text{ mA}$$

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

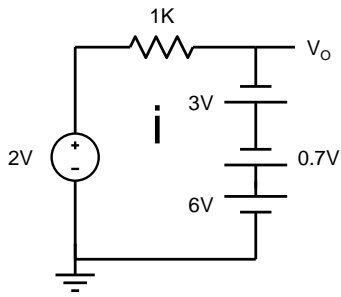
$$= (-10 + 2.23)V = -7.77V$$



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.



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

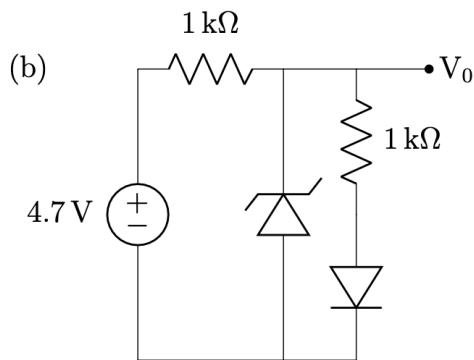


Let us calculate the current to check our assumption

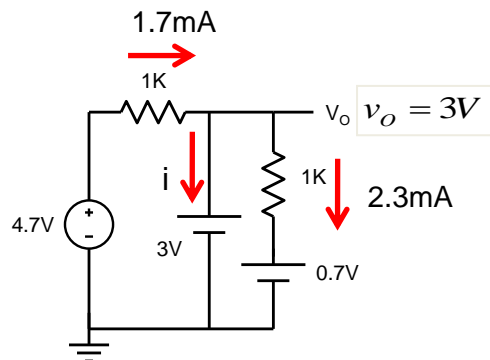
$$-6 + 0.7 + 3 + i \times 10^3 + 2 = 0 \Rightarrow i = 0.3 \text{ mA}$$

$$-6 + 0.7 + 3 + v_o = 0 \Rightarrow v_o = 2.3 \text{ V}$$

Hence, the assumption is correct.

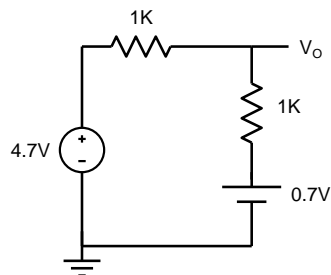


Diode D2 is forward biased. Assume zener is like a 3V battery



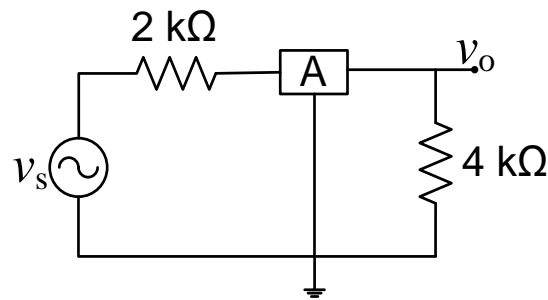
Let us calculate the Zener current to check our assumption

$I = -0.6 \text{ mA}$ so assumption is incorrect and zener is like an open circuit

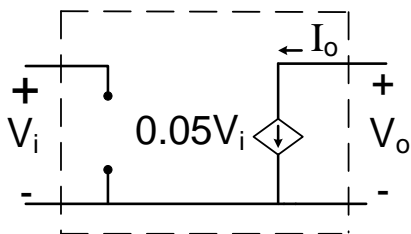


Hence, $v_o = 2.7 \text{ V}$

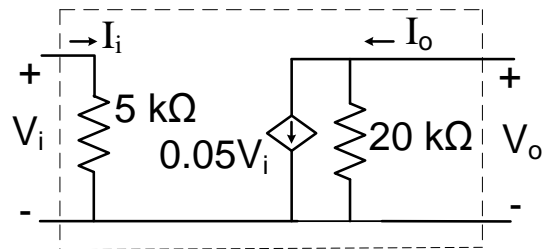
5. Determine the ac voltage gain of the amplifier 'A' as shown in (a) using the two transistor models shown in (b) and (c) as dotted region. Assume that the device 'A' is biased properly.



(a)



(b)



(c)

Solutions:

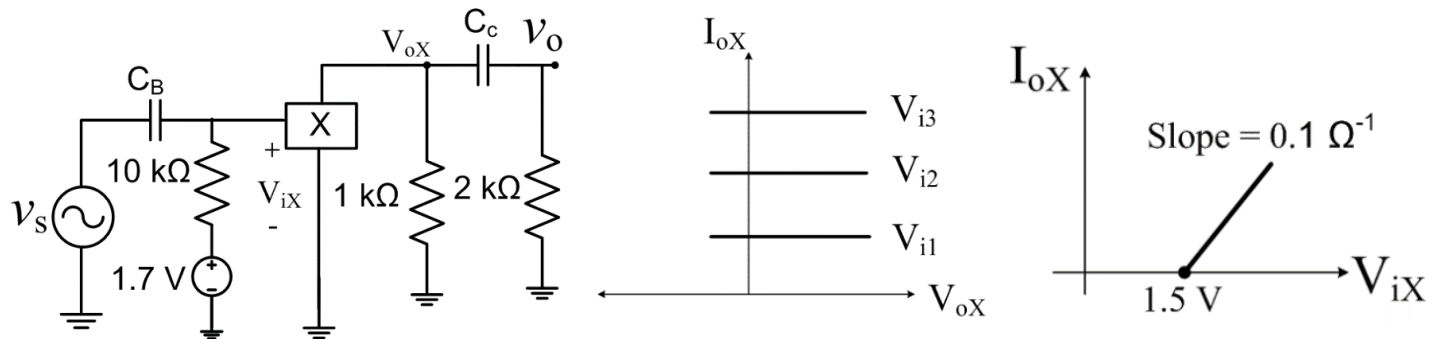
Under model (b)

$$\begin{aligned}
 V_i &= V_s \\
 V_o &= -0.05 V_i \times 4 \times 10^3 \text{ V} \\
 \Rightarrow V_o &= -0.05 \times 4 \times 10^3 \times V_s \text{ V} \\
 \Rightarrow \frac{V_o}{V_s} &= -\frac{5}{100} \times 4 \times 1000 \\
 \Rightarrow \frac{V_o}{V_s} &= -200
 \end{aligned}$$

Under model (c)

$$\begin{aligned}
 V_i &= \frac{V_s \times 5}{5+2} = \frac{5V_s}{7} \\
 V_o &= -0.05 V_i (20 \text{ k}\Omega \parallel 4 \text{ k}\Omega) \\
 \Rightarrow V_o &= -\frac{0.05 \times 20 \times 4 \times 1000}{24} V_i \\
 \Rightarrow V_o &= -\frac{0.05 \times 20 \times 4 \times 1000}{24} \times \frac{5}{7} V_s \\
 \Rightarrow \frac{V_o}{V_s} &= -\frac{5 \times 20 \times 4 \times 1000 \times 5}{100 \times 24 \times 7} \\
 \Rightarrow \frac{V_o}{V_s} &= -119.05
 \end{aligned}$$

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_o for $v_s = 0.2 \sin(\omega t)$.

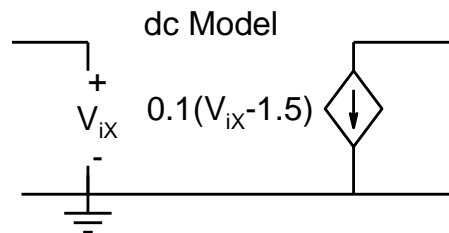


When there is both dc and ac source in the circuit, voltages and currents in general will have a dc component and an ac component. As a result two analysis, one dc and another ac have to be carried out.

Note the convention in naming voltage (or current) at node X

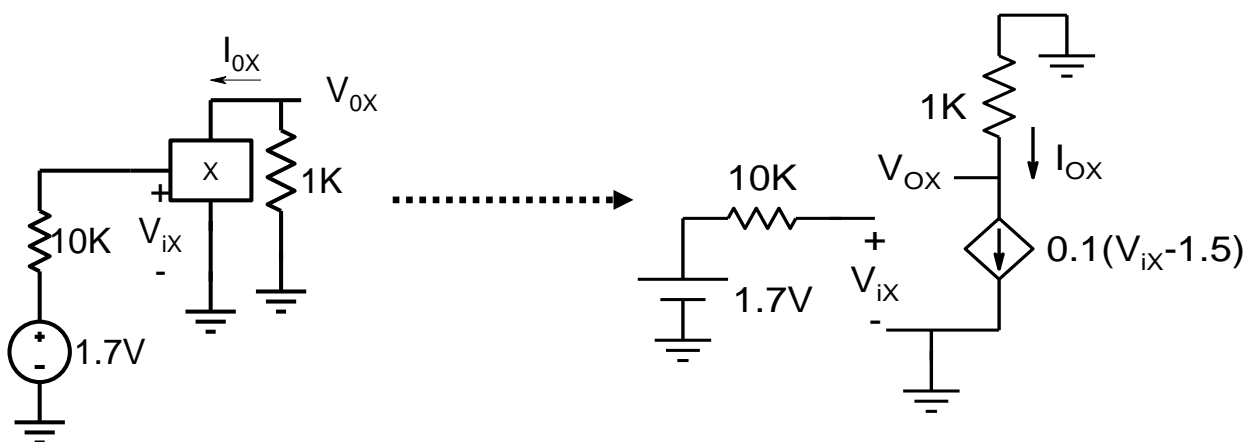
dc Voltage : V_X ; ac voltage : v_x ; Net Voltage: $V_x = V_X + v_x$

The device can be written as



DC analysis:

draw the dc circuit obtained by open circuiting the capacitor



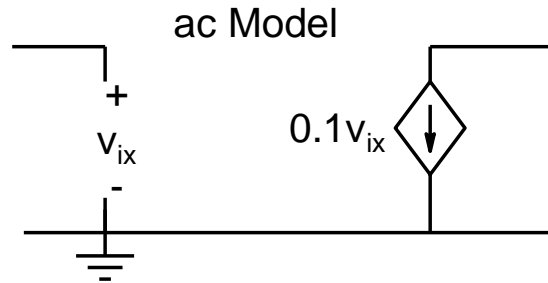
$$I_{ox} = 0.1 \times (1.7 - 1.5) = 20\text{mA}$$

$$V_{IX} = 1.7\text{V}$$

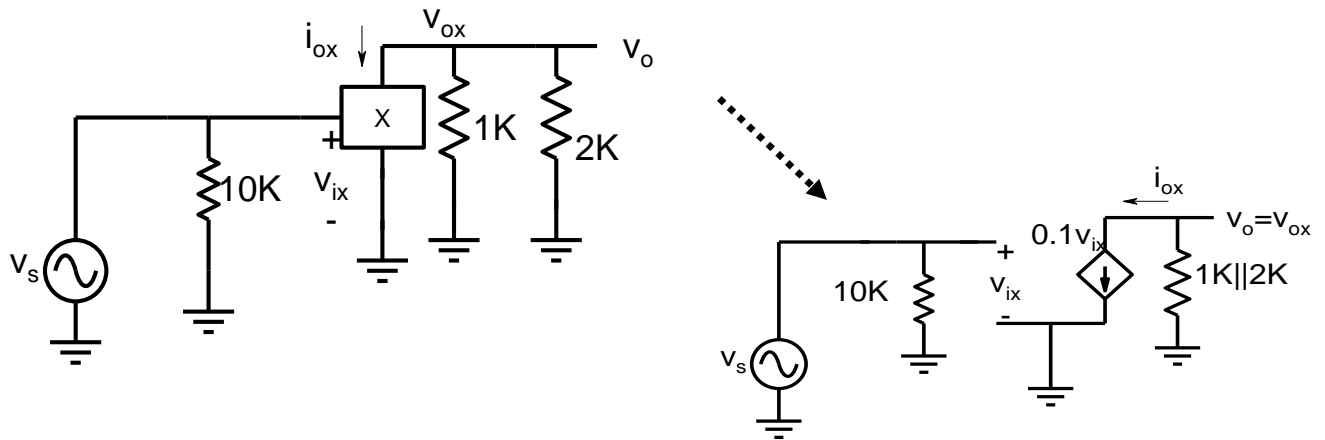
$$V_{ox} = -20\text{mA} \times 1\text{K} = -20\text{V}$$

Ac Analysis:

Small signal model can be written as



Draw the ac circuit by shorting the dc sources and capacitors



$$i_{ox} = 0.1v_{ix} = 20\text{mA}\sin(\omega t)$$

$$v_{ox} = v_o = -i_{ox} 1\text{K} \parallel 2\text{K} = -13.34\text{V} \sin(\omega t)$$

Combining the AC and DC analysis

$$V_{ix} = V_{IX} + v_{ix} = 1.7 + 0.2\sin(\omega t)$$

$$I_{ox} = I_{OX} + i_{ox} = 20\text{mA} + 20\text{mA}\sin(\omega t)$$

$$V_{ox} = V_{OX} + v_{ox} = -20 - 13.34\sin(\omega t)$$

$$v_o = -13.34\text{V} \sin(\omega t)$$

