1. (5 points) For the following circuit the diode is described by \( I = I_S (\exp(V/V_T) - 1) \)
where \( V_T = 0.026 \text{V} \), \( I_S = 10^{-10} \text{A} \), \( V_{\text{bias}} = 5 \text{V} \) and \( V_{\text{in}}(t) = 0.001 \sin(0.001 \cdot 2\pi \cdot t) \).

   ![Circuit Diagram]

   a) Find \( R \) for a diode bias current of \( I = 3 \text{mA} \) as well as the Q point diode resistance, \( R_d \).
   b) Find \( V_{\text{out}}(t) \) for the given \( V_{\text{in}} \) when \( C = 0 \).

2. (5 points)
   For the following (which approximates a small signal equivalent circuit looking into the base-emitter of a BJT)
   a) Find the Thevenin’s equivalent impedance, \( Z(s) \), seen looking into the b-e port.
   b) Give the zeros and poles of \( Z(s) \).

   ![BJT Circuit Diagram]

3. (5 points)
   For the following circuit M2 has twice the width of M1 but the two transistors are otherwise identical. Assume no channel length modulation (that is, \( \lambda = 0 \)) and a positive threshold voltage, \( V_{\text{th}} > 0 \).
   If \( V_{\text{DD}} \) is much greater than twice the threshold voltage of M1 give the value of \( V_{\text{out}} \).

   ![CMOS Circuit Diagram]
4. (5 points)
Shown are two types of current mirrors.
Sketch (on the same graph) Iout1 & Iout2 for the same input current over the output voltage range $0 \leq V_{out} < V_{max}$, where $V_{max}$ is the maximum op-amp bias voltage.
From the given data, $V_o = 0$, and

$$V = V_o = V_{in} - V_{out} = 5 - RI$$

1) $I = I_s \left( e^{\frac{V_{in}}{V_T}} - 1 \right) \Rightarrow I = I_s \left( e^{\frac{V_{in}}{V_T}} - 1 \right) + I_s = e^{\frac{V_{in}}{V_T}} \frac{V_{in} - IR}{V_T}$

$$V_{in} - R = V_T \ln \left( \frac{I_s}{I_s + 1} \right)$$

$$R = \frac{V_{in} - V_T \ln \left( \frac{I_s}{I_s + 1} \right)}{I}$$

$$= \left[ 5 - 2.6 \times 10^{-2} \times \left( \frac{3 \times 10^{-5}}{10^{-10} + 1} \right) \right] / 3 \times 10^{-3} \approx \left[ 5 - 2.6 \times 10^{-2} \times \ln 3 \times 10^{-7} \right] / 3 \times 10^{-3}$$

$$= \left[ 5 - 2.6 \times 10^{-2} \times (17.2167) \right] / 3 \times 10^{-3} = \left[ 5 - 0.4476 \right] / 3 \times 10^{-3} = \frac{4.552 \times 10^3}{3} = 1.517 \text{ KOhm}$$

For a point inside resistance, $R_d$

$$\frac{dI}{dV} = \frac{V_T}{R_d} = \frac{I_s}{V_T} \times \frac{V_T}{V_T} \approx \frac{I}{V_T} \Rightarrow V_d = \frac{V_T}{I}$$

$$R_d = \frac{V_T}{I} = \frac{2.6 \times 10^{-2}}{3 \times 10^{-3}} = 0.8667 \times 10^3 = 8.667 K\Omega$$

2) When $C = 0$, the signal current is from the $\frac{R_d}{R} \cdot \frac{V_{in}}{R}$

$$I = \frac{V_{in}}{R_d + R} \Rightarrow V_o = \frac{R}{R_d + R} \cdot V_{in}$$

$$= \frac{1.517 \times 10^3}{1.517 \times 10^3 + 8.667} \times V_{in}$$

$$\approx \frac{1.517}{1.526} V_{in} \approx 0.994 V_{in}$$

This is added to the bias, $V_{out} = RI = V_{{out}} = RI + 0.994 V_{in}$

$$= 1.551 + 2.000994 \cdot \sin (0.001 \times 18t)$$
3. Derive and solve for current $I$ and voltage $V$ and find $I$. By KCL

a) $I = \left( RC + \frac{1}{C} \right) V \quad \text{and} \quad V = \left( RC + G + \frac{2m}{C} \right) V, \quad G = \frac{1}{RC}$

$\Rightarrow \quad I = \frac{V}{RC + G + \frac{2m}{C}} = \frac{1}{RC + G + \frac{2m}{C}}$

$b) \quad \text{zero: } x + a = 0$

plote: $x = - \left( \frac{G + \frac{2m}{C}}{RC} \right)$
\[ V_{DS} = V_{DS}' > V_{TH} - V_{PD} \text{ with } M_1 \text{ and } M_2 \text{ in saturation and always by KCL} \]
\[ V_D = V_D' = V_S' \]
\[ V_D' = \beta \left( V_{DD} - V_{OUT} - V_{PD} \right)^2 = V_D' = \beta \left( V_{OUT} - V_{PD} \right)^2 \]
\[ \sqrt{2} \left( V_{DD} - V_{OUT} - V_{PD} \right) = \pm \left( V_{OUT} - V_{PD} \right) \]

As \( M_1 \) and \( M_2 \) are on their minima the + sign, giving

\[ (1 + \sqrt{2}) V_{OUT} = \sqrt{2} V_{DD} + (1 - \sqrt{2}) V_{PD} \]

\[ \Rightarrow \]
\[ V_{OUT} = \frac{\sqrt{2}}{1 + \sqrt{2}} V_{DD} - \left( \frac{\sqrt{2} - 1}{\sqrt{2} + 1} \right) V_{PD} \]
In each circuit $V_{DS}$ is the same for each transistor.

For the right set $V_{DS}$ is the same for the two transistors giving $I_{out2} = I_{in}$ (when $V_{out} > 0$).

For the left set the two $V_{DS}$ will differ for all but one $V_{out}$. 