(i) (6 pts.)

For the above diode circuit the diode is described by the curve on the right, \( I_d \) being 0 for \( V_d < V_b \). Assuming the fixed battery voltage is greater than the diode break voltage, \( V_{dd} > V_b > 0 \).

a) Find the current and voltage of the diode as connected.

b) By adjusting \( R \geq 0 \) give the maximum diode voltage possible.

(ii) (7 pts.)

For the above (switched current) circuit the switch \( S \) closes at \( t=0 \) and opens at \( t=t_1=1 \) (after which it stays open). Assuming identical transistors (with gate capacitors having no leakage), and normalizations to \( R=1 \), \( I_{in}(t)=2+\sin(\pi t/2) \), and \( V_{dd} = 10 \) (sufficiently large to keep M2 in saturation), sketch \( V_{out}(t) \) for \( 0<t \) and give a formula for it.
(iii) (7 pts.)

An operational transconductance amplifier (OTA) is described by \( I_0 = G \cdot V_d \), with constant \( G > 0 \), and has the following symbol (for which the output current returns via ground and there are no currents into the input leads where the difference voltage \( V_d \) is measured).

Use the OTA in the following circuit and

a) Give the transfer function \( V_{out}(s) / V_{in}(s) \) and determine its poles and zeros.

b) Give the impulse response of the circuit.
a) Operation is when $i_d = i_0$ where $i_d = \text{driving current}$.

By Kirchhoff's Voltage Law (KVL):
\[ V_{dd} - V_d = R i_d \]
\[ i_d = \frac{V_{dd} - V_d}{R} \quad \text{for } i_d > 0 \]

By Kirchhoff's Current Law (KCL):
\[ i_d = i_0 - i_o = \frac{V_{dd} - V_d}{R} \quad \text{for } i_d > 0 \]
\[ i_d = \frac{V_{dd} - V_d}{R} \]

\[ (g + \sigma) V_d = g V_b + (g + \sigma) V_{dd} \]
\[ \Rightarrow V_d = \frac{g V_b + (g + \sigma) V_{dd}}{g + \sigma} \]
\[ \Rightarrow |V_d| = \frac{g(V_b - V_o) - g - V_b}{g + \sigma} \]
\[ = g \left( \frac{g V_b + (g + \sigma) V_{dd} - V_b}{g + \sigma} \right) \]
\[ = \frac{g g V_b + g g V_{dd} - g V_b - g V_b}{g + \sigma} \]
\[ = \frac{g V_b (V_{dd} - V_b)}{g + \sigma} \]

b) As $V_o = \frac{R V_b + V_{dd}}{1 + R g}$ and $R g > 0$ [in which case the denominator is > 0]
this maximum is at the greatest voltage available, that is at $V_{oo}$ (which occurs for $R = 0$ giving a vertical load line).
(c2) For 0 ≤ t ≤ t_1, the voltages on the gates of M_1, M_2 are equal, so that \( V_{ds_1} = V_{ds_2} \) (or M_2 = M_1, & both are in saturation).

At \( t = t_1 \), \( V_{gs_1} = V_{gs_2} \) and for \( t > t_1 \), \( V_{gs_2}(t) = V_{gs_2}(t_1) \).

So that \( V_{ds_2}(t) = V_{ds_2}(t_1) = V_{ind}(t_1) \) so that

\[
V_{out}(t) = V_{dd} - R \cdot I_{ds_2}(t) = V_{dd} - R \left\{ \begin{array}{ll}
I_{ind}(t) & 0 \leq t \leq t_1 \\
I_{ind}(t_1) & t_1 \leq t
\end{array} \right.
\]

\[
= \left\{ \begin{array}{ll}
V_{dd} - (2 + \sin(\pi t/2)) & 0 \leq t \leq 1 \\
V_{dd} - (2 + \sin(\pi t/2)) & 1 \leq t
\end{array} \right.
\]

\[
= \left\{ \begin{array}{ll}
8 - \sin(\pi t/2) & 0 \leq t \leq 1 \\
7 & 1 \leq t
\end{array} \right.
\]

Sketch:

\[
\begin{align*}
V_{out}(t) & \\
& = \begin{cases} 
8 - \sin(\pi t/2) & 0 \leq t \leq 1 \\
7 & 1 \leq t
\end{cases}
\end{align*}
\]
a) \[ \frac{\text{d}i_c}{\text{d}t} = V_{\text{in}} - V_{\text{out}} \]

\[ i_c = I_o = \frac{V_{\text{out}}}{R} \quad \Rightarrow \quad CG \frac{\text{d}V_{\text{out}}}{\text{d}t} + V_{\text{out}} = V_{\text{in}} \]

\[ \Rightarrow (\frac{1}{CS} + 1)V_{\text{out}}(t) = V_{\text{in}}(t) \]

\[ \Rightarrow \quad \frac{V_{\text{out}}(t)}{V_{\text{in}}(t)} = \frac{1}{\frac{1}{CS} + 1} = \frac{1}{S + \frac{1}{CS}} \]

Pole @ \( S = -\frac{1}{CS} \)

Zero @ \( S = \infty \)

b) Impulse response, \( V_{\text{in}}(t) = 6(t) \quad \Rightarrow \quad V_{\text{in}}(t) = 1 \)

\[ V_{\text{out}}(t) = \frac{1}{\frac{1}{CS}} \]

\[ \Rightarrow \quad V_{\text{out}}(t) = \frac{1}{\frac{1}{CS}} e^{-\frac{t}{CS}} 1(t) \quad 1(t) = \text{unit step} \]