QU12

1. a.) lowpass filter
   b.) $\tau = RC = (10^3)(10^{-11}) = 10 \text{ nS}$
   c.)

   ![Graph](image)

   pull up response to unit step $\Rightarrow V_o(t) = 1 - e^{-t/\tau}$
   pull down response to unit step $\Rightarrow V_o(t) = e^{-t/\tau}$

2. $V_{gs} - V_T = V_{osat}$ for saturation $V_{os} \geq V_{osat}$
   for transistor to be on $V_{gs} \geq V_T$

<table>
<thead>
<tr>
<th>$V_{osat}$</th>
<th>$V_{osat}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 V</td>
<td>4 V</td>
</tr>
<tr>
<td>SAT</td>
<td>LIN</td>
</tr>
<tr>
<td>NO $V_{osat}$</td>
<td>$V_{osat}$ = -3 V</td>
</tr>
<tr>
<td>OFF</td>
<td>SAT</td>
</tr>
</tbody>
</table>
Using Superposition

1)

\[ V_{x1} = \frac{-2.46}{2.46} = -1 \text{ V} \]

current flows in loop, so \( V_{x2} = 0 \text{ V} \)

3)

current flows in the loop, so \( V_{x3} = 0 \text{ V} \)

\[ V_{x} = V_{x1} + V_{x2} + V_{x3} = -1 \text{ V} \]
c.) When Vin is positive, Vout is negative, and all the diodes are reverse biased. The gain, \( \frac{\text{Vout}}{\text{Vin}} = -\frac{R_2}{R_4} \).

When input is negative, diodes will turn on at different voltages of Vin. Assume Vdiodc = 0 V, then we can write \( \frac{\text{Vout}}{R_2} = -\frac{\text{Vin}^-}{R_4} \). This is the point in which all the current flowing into \( R_2 \) goes into \( R_4 \). So, current will flow through the diode when Vout is greater than this point. When current flows through the first diode, the gain becomes \( -\frac{R_2 l n R_3}{R_1} \).

h.) The LM393 comparator has an open-drain. When Vin is above Vout, the output floats. When Vin is below Vout, Vout = Vin. (It is an unity gain buffer.)

l.) Consider the 2 boundary cases.

For the first case, redraw the circuit like this:

\[ \text{Vin} \rightarrow \text{op-amp} \rightarrow \text{Vout} \quad \text{and} \quad \frac{\text{Vout}}{\text{Vin}} = 1. \]

For the second case,

\[ \text{Vin} \rightarrow \text{op-amp} \rightarrow \text{Vout} \quad \text{and} \quad \frac{\text{Vout}}{\text{Vin}} = -1 \]
for all other cases,

\[
V_{\text{in}} = \frac{R_4}{R_3 + R_4} \cdot V_{\text{in}} \\
V_{\text{in}} - V' = \frac{V' - V_{\text{out}}}{10K} = D \cdot (V_{\text{in}} - V') = V' - V_{\text{out}} \\
V_{\text{out}} = 2V' - V_{\text{in}} = D \cdot V_{\text{out}} = \frac{2R_4}{R_3 + R_4} \cdot (V_{\text{in}} - V_{\text{in}})
\]

\[
\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{2R_4}{R_3 + R_4} - 1
\]

k.) This circuit has negative feedback even though the feedback is connected to the positive terminal because the gain of the BJT amplifier is negative. So, the inputs are at the same voltage, 1000 times less current is flowing through the 100Ω resistor. The current will flow through the BJT and cause V_{\text{out}} to rise. (V = IR) Say for example that 1A is flowing through the load. Then 1mA is flowing through the BJT, and the resistor on its emitter. V_{\text{out}} will be equal to V = IR = (1mA)(1000) = 1V, and it is given that 1V/A, so we can figure out how much current is flowing through the load by monitoring the voltage at V_{\text{out}}.
OP-Amp 2 is an unity gain buffer so $V_{\text{in}}^{\text{out}} = V_{\text{out}}$.

\[ V_{\text{in}} = \frac{E_{\text{in}}^{+} + V_{\text{out}}}{2} = V_{i} \]

The current through $R_{i}$ = current through $R_{2}$, so voltage drop is the same also. $V_{2} = 2\left(\frac{E_{\text{in}}^{+} + V_{\text{out}}}{2}\right) - E_{\text{in}}^{-}$.

\[ \text{Drop across } R = (E_{\text{in}}^{+} + V_{\text{out}} - E_{\text{in}}^{-}) - V_{\text{out}} = E_{\text{in}}^{+} - E_{\text{in}}^{-} = \Delta E_{\text{in}} \]

\[ I_{\text{out}} = \frac{\Delta E_{\text{in}}}{R} \]