Problem Set 4 Solutions

6.101 Analog Electronics Lab

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Problem 1 First calculate the Thevenin equivalent of the input circuit to the opamp:

\[ V_{Th} = 11V \cdot \frac{4k\Omega}{4k\Omega + 2k\Omega} = 7.3V \]

\[ R_{Th} = 6k\Omega + (2k\Omega||4k\Omega) = 7.3k\Omega \]

The op-amp gain is then:

\[ A_v = \frac{-12k\Omega}{7.3k\Omega} \]

Therefore,

\[ V_O = V_{Th} A_v = 7.3V \left( -\frac{12k\Omega}{7.3k\Omega} \right) = -12V \]

Problem 2 Let \( V_{out1} \) be the output of the first opamp. By matching the magnitude of the current, we have:

\[ \frac{V_i}{R_1} = -\frac{V_{out1}}{R_2} \Rightarrow \frac{V_{out1}}{V_i} = -\frac{R_2}{R_1(sR_2C + 1)} \]

The transfer function of the second opamp is simply:

\[ \frac{V_o}{V_{out1}} = -2 \]

Then:

\[ \frac{V_o}{V_i} = \frac{2R_2}{R_1(sR_2C + 1)} \]

Problem 3 Let \( V_A \) be the voltage at the output of the lower-left opamp and \( V_B \) be the output of the upper opamp. We have the following relationships:

\[ V_o = -\frac{1}{\frac{1}{10k\Omega} + \frac{1}{s(0.1\mu F)}} V_A = -\frac{1000F^{-1}\Omega^{-1}}{s} V_A \]
\[
V_B = -\frac{10k\Omega}{10k\Omega} V_o = -V_o
\]
\[
\frac{V_i}{1k\Omega} + \frac{V_B}{2k\Omega} = -\frac{V_A}{5k\Omega|_{s(0.1\mu F)}} = -\frac{s(0.1\mu F)(5k\Omega)}{5k\Omega} V_A
\]

Solving these equations yields:
\[
\frac{V_o}{V_i} = \frac{1}{\frac{1}{2} + \frac{s}{5000} + \frac{s^2}{100}}
\]

Problem 4 Define the node of the T network as \(v_x\). Define the currents as shown in the figure.

\[
V_{\text{minus}} = V_i
\]
\[
i_1 = \frac{v_i}{R} = i_2
\]
\[
v_x = i_2 R + v_i = \frac{v_i}{R} R + v_i = 2v_i
\]
\[
i_3 = \frac{v_x}{R} = \frac{2v_i}{R}
\]
\[
i_4 = i_2 + i_3 = \frac{v_i}{R} + \frac{2v_i}{R} = \frac{3v_i}{R}
\]
\[
v_o = i_4 R + v_x = \frac{3v_i}{R} R + 2v_i
\]
\[
\frac{v_o}{v_i} = 5
\]

Problem 5 Assuming the zener diode is in breakdown:

\[
V_O = -\frac{R_2}{R_1} V_z = -6.8V
\]
\[
i_2 = \frac{0 - v_o}{R_2} = 6.8mA
\]
\[
i_z = \frac{10 - V_z}{R_s} - i_2 = -6.2mA
\]

The Zener is not in breakdown because \(i_z\) is negative. The zener must be off:
\[
i_2 = \frac{10 - 0}{R_s + R_1} = 1.52mA
\]
\[
v_o = -i_2 R_2 = -1.52V
\]
\[
i_z = 0
\]
Figure 1: Problem 4