ECE60L (Spring 2001), Quiz Solution

Notes: 1. Write your answers on these three sheets.
2. For each problem, 20% of points are allocated for the correct final answer.
3. Use the following information in solving or designing circuits: OpAmps are powered by ±15 V power supplies (power supplies not shown), have a unity-gain bandwidth of $10^6$ Hz, a short-circuit current limit (maximum output current limit) of 250 mA, and a slew rate of 1 V/μs. In circuit design, use commercial resistor values (1, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2, 2.2, 2.4, 2.7, 3, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1) and commercial capacitor values (1, 1.5, 1.8, 2, or 2.2, 3.3, 4.7, and 6.8) values. You can also use 1 μH inductors.

Problem 1. Consider the amplifier circuit below with $v_i = 0.5 \cos(\omega t)$. a) what is the amplifier gain in dB? b) For what range of frequencies, does this amplifier behave as a linear amplifier? (write down all possible limits and choose the most restrictive one.) (15pt)

![Amplifier Circuit Diagram]

**part a:** This is an inverting amplifier:

$$A = \frac{V_o}{V_i} = \frac{5k}{1k} = 5$$

$$A_{dB} = 20 \log_{10} A = 20 \log_{10}(5) = 14 \text{ dB}$$

Two limits impact the bandwidth of this amplifier:

**Bandwidth of OpAmp itself:**

$$A_0 f_0 = f_u = Af \quad \Rightarrow \quad f = \frac{f_u}{A} = \frac{10^6}{5} = 2 \times 10^5 = 200 \text{ kHz}$$

**Slew Rate:**

$$AV \omega \leq S_0 \quad \Rightarrow \quad 5 \times 0.5 \times \omega \leq 1 \text{ V/μs} = 10^6 \text{ V/s}$$

$$\omega \leq \frac{10^6}{2.5} = 4 \times 10^5 \text{ rad/s}$$

$$f = \frac{\omega}{2\pi} = 64 \text{ kHz}$$

The slew rate is the most restrictive, so this OpAmp circuit behaves linearly in the frequency range $0 \leq f \leq 64 \text{ kHz}$. 
Problem 2. The tuner for an FM radio requires a band-pass filter with a central frequency of 100 MHz (frequency of a FM station) and a bandwidth of 2 MHz. a) Design such a filter. b) What are its cut-off frequencies? (15pt)

Because this is not a wide-band filter, the simplest filter will be an RLC filter as is shown. For this filter:

\[ \omega_0 = \frac{1}{\sqrt{LC}} = 2\pi 100 \times 10^6 \]

\[ Q = \frac{\omega_0}{B} = \sqrt{\frac{L}{R^2C}} = \frac{2\pi 100 \times 10^6}{2\pi \times 2 \times 10^6} = 50 \]

Using a \( L = 1 \mu H \) inductor:

\[ \frac{1}{LC} = 4\pi^2 10^{16} \quad \rightarrow \quad \frac{1}{C} = 4\pi^2 10^{16} \times 10^{-6} \quad \rightarrow \quad C = 2.5 \times 10^{-12} \text{ F} \]

Choose: \( C = 2.2 \text{ pF} \)

\[ \frac{L}{R^2C} = 2,500 \quad \rightarrow \quad R^2 = \frac{L}{2,500C} = \frac{0^{-6}}{2,500 \times 2.2 \times 10^{-12}} = 182 \quad \rightarrow \quad R = 13.5 \Omega \]

Choose: \( R = 13 \Omega \) \( (L = 1 \mu H \text{ and } C = 2.2 \text{ pF}) \).

To find the cut-off frequencies, we not:

\[ B = f_u - f_l = 2 \text{ MHz} \]

\[ f_0 = \sqrt{f_u f_l} = 100 \text{ MHz} \]

Solution of the above two equations in two unknowns will give \( f_l \approx 99 \text{ MHz} \) and \( f_u \approx 101 \text{ MHz} \).
Problem 3. Find $V_o$ if $R_1 = R_2 = R$ and $R_3 = R_4 = 2R$. (15 pts)

We have negative feedback: $V_n \approx V_p = V_i$. Using node-voltage method:

Node $V_n$: \[ \frac{V_n - 0}{R_1} + \frac{V_n - V_1}{R_2} = 0 \]

Node $V_1$: \[ \frac{V_1 - V_n}{R_2} + \frac{V_1 - 0}{R_3} + \frac{V_1 - V_o}{R_4} = 0 \]

Letting $V_n = V_i$ and using $R_1 = R_2 = R$ and $R_3 = R_4 = 2R$, the above two equations become:

\[ \frac{V_i - 0}{R} + \frac{V_i - V_1}{R} = 0 \quad \Rightarrow \quad V_1 = 2V_i \]

\[ \frac{V_1 - V_i}{R} + \frac{V_1 - 0}{2R} + \frac{V_1 - V_o}{2R} = 0 \quad \Rightarrow \quad 2V_1 - 2V_1 + V_1 + V_1 - V_o = 0 \]

\[ V_o = 4V_1 - 2V_i = 4(2V_i) - 2V_i = 6V_i \]