EE5390: Analog Integrated Circuit Design; Assignment 2

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1. The loop gain $L(s)$ of a system with N extra poles is given by

$$L(s) = \frac{\omega_{u,loop}}{s} \frac{1}{\sum_{m=0}^{N} a_m s^m}$$

$a_0 = 1$. What does the loop gain step response (inverse laplace transform of $L(s)/s$) look like after an initial transient period? Give your answer in terms of the poles of the additional factor (Hint: Split $L(s)$ into a sum of two parts, one of which is $\omega_{u,loop}/s$)

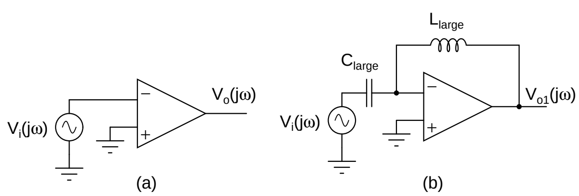

Figure 1: Measuring an opamp's frequency response

2. Simulate the open loop frequency response of the opamp OPA656. If you try to measure it as given in Fig. 1(a), the opamp may not be biased correctly. As you know, the opamp is biased correctly only when there is dc negative feedback around the opamp. A trick to maintain dc negative feedback, but break the feedback loop for higher frequencies is shown in Fig. 1(b). For frequencies where the voltage drop across the capacitor and the current through the inductor are negligible, the input voltage appears directly across the opamp and there is no feedback. Since this is a simulator, use comfortably large values like $C_{large} = 1\,\mathrm{F}$ and $L_{large} = 1\,\mathrm{kH}$.

   What are the dc gain, unity gain frequency, and nondominant pole(s)? Estimate these from magnitude/phase plots.

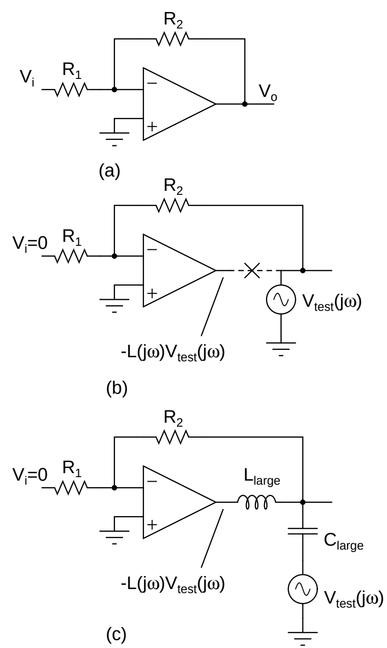

Figure 2: Inverting amplifier

3. Simulate the frequency response and the loop gain of an inverting amplifier (Fig. 2(a)) of gain 100. Loop gain $L(j\omega)$ can be determined by breaking the loop as shown in Fig. 2(b). DC negative feedback has to be maintained and the same trick as in the previous problem can be used (Fig. 2(c)). Do these simulations for $R_1 = 100\,\Omega$ and $R_1 = 10k\,\Omega$. Do the closed loop bandwidths match the unity loop gain frequencies? Are the latter in turn consistent with the opamp's unity gain frequency evaluated in the previous experiment? Explain the results clearly.

4. A two stage amplifier with transfer function $A_0/(1+s/p_1)(1+s/p_2)$ is used in negative feedback to realize an amplifier with a closed loop dc gain k. Instead of the step response, the criterion here is the band-

width. Find the conditions to maximize the bandwidth without the closed loop gain increasing above k for any frequency (This condition is known as maximal flatness, and the mathematical condition is to have $d^n/d\omega^n|H(j\omega)|^2 = 0, n = 1, 2, \ldots$ for as large an n as possible). To avoid mess, assume a general form of the second order transfer function, evaluate the damping factor for maximal flatness, and substitute the values from the transfer function of the amplifier. Determine the magnitude response and step response of this system with a critically damped one with the same closed loop dc gain k.

Appreciating approximations: Approximations are key to understanding anything complicated. Exact expressions, even when possible, may be too complicated to give any insight to the problem. Approximating is not the same as being sloppy. On the contrary, a greater understanding of the problem is required to judiciously use approximations than plug in the whole formula (e.g. see the quadratic eq. example below).
Evaluate the conditions for 1% and 10% accuracy in the approximations below.

1. You are required to calculate $\sqrt{1+x}$ and you approximate it by $1 + x/2$.

2. You are required to solve the quadratic equation ax^2+bx+c and you approximate the roots by $-b/a$, $-c/b$. This works for widely separated real roots. How widely do they have to be separated (ratio)?

3. You have a two stage amplifier in feedback loop with loop gain $L(s) = A_{0,loop}/(1 + s/p_1)(1 + s/p_2)$, $p_2 > p_1$, $p_1 = \omega_{u,loop}/A_{0,loop}$ and you approximate it by moving the lower frequency pole to the origin—i.e. use the transfer function $L(s) \approx (\omega_{u,loop}/s)(1+s/p_2)$ instead. You have to calculate (a) natural frequency ω_n, (b) damping factor ζ. Compare the expressions for the two quantities. Calculate $A_{0,loop}$ to get the above errors (Assume $p_2 = 2\omega_{u,loop}$).