EE 140/240A Prof. Pister
Spring 2016

Homework Assignment #7v1.1

Due by online submission **Wednesday** 3/16/2016 (Thursday 9am)

1. We usually approximate $A_0/(1+A_0 f)$ by $1/f$. How good or bad an estimate is that? Show that the approximate fractional error (gain_error/gain) is $-1/(A_0 f)$. (helpful hint: $1/(1+x) \sim= 1-x$ if $x<<1$)
   [2 pts]
2. In a single pole op-amp with $A_0=1{,}000$, $\omega_p=1M$ rad/s, a feedback factor of f=0.1 is used. Find:
   a. the exact low-frequency closed loop gain $A_0/(1+A_0 f)$ (use a calculator if needed)
   b. the approximate low-frequency closed-loop gain, 1/f
   c. the exact error between $A_0/(1+A_0 f)$ and 1/f (again, use a calculator if needed)
   d. the approximate error, using the result from the previous problem
   [8 pts]
3. For the previous amplifier
   [12 pts total]
   a. Draw a Bode plot (magnitude and phase) of the open loop amplifier (with no feedback)
   [3 pts: 1 each for magnitude, pole frequency, -45 degrees at pole frequency]
   b. On the same plot, draw the Bode plot of the closed-loop amplifier
   [3 pts, as above]
   c. What is the open-loop unity gain frequency? Closed-loop unity gain frequency?
   [2pts]
   d. What is the open-loop pole frequency? Closed-loop pole frequency?
   [2pts]
   e. What is the open-loop gain-bandwidth product? Closed-loop gain-bandwidth product?
   [2pts]
4. For the previous amplifier,
   [10pts, 2 each]
   a. What is the time constant of the step response of the open-loop amplifier?
   b. Draw the time response to a 1mV step change in the input of the open-loop amplifier. Label the axes clearly (and use a scale on both axes that allows you to show the exponential response)
   c. What is the time constant of the step response of the closed-loop amplifier?
   d. Draw the time response to a 1mV step change in the input of the closed-loop amplifier. Again, choose appropriate axes and label them.
   e. Comment on how your answer to part d would look on the axes used for part b.
5. A two-stage CMOS op-amp running at a particular bias point has the following parameters: G_{m1}=0.1mS, R_{o1}=1MΩ, C_1=0.1pF, Cc=0pF, G_{m2}=1mS, R_{o2}=10kΩ, C_2=10pF.
   a. On the following page, plot the magnitude and phase of the overall gain of this uncompensated amplifier.
   [4 pts: magnitude, pole frequency, $1/\omega^2$ roll-off, -90 degrees at pole frequency]
   b. Where in the complex plane are the poles of the uncompensated amplifier?
   c. What is the phase margin if f=1?
   d. Is it unity-gain stable?
   [6pts total for b,c,d]
6. For the same amplifier as above, we now add Cc=1pF. For this problem, you may ignore the RHP zero that this introduces. On the following page,
   [21 total]
   a. Plot the magnitude of the second stage gain vs. frequency
   [2 pts: magnitude, pole frequency]
   b. Plot the magnitude of the input *capacitance* of the second stage vs. frequency
   [4 pts: low frequency capacitance, high frequency capacitance, pole+zero frequencies]

c. Plot the magnitude of the input *impedance* of the second stage vs. frequency. Add a line for the output impedance of the first stage.

[4 pts: 1 for each region]

d. Now plot the magnitude of the gain of the compensated first stage on the top plot

[2pt: getting the low frequency gain right; shape should be the same as 6c]

e. Draw the Bode plot of the overall compensated amplifier on the same plot as part 5a

[3 pts: low freq gain, 1^{st} pole, 2^{nd} pole]

f. Where in the complex plane are the compensated poles of the amplifier?

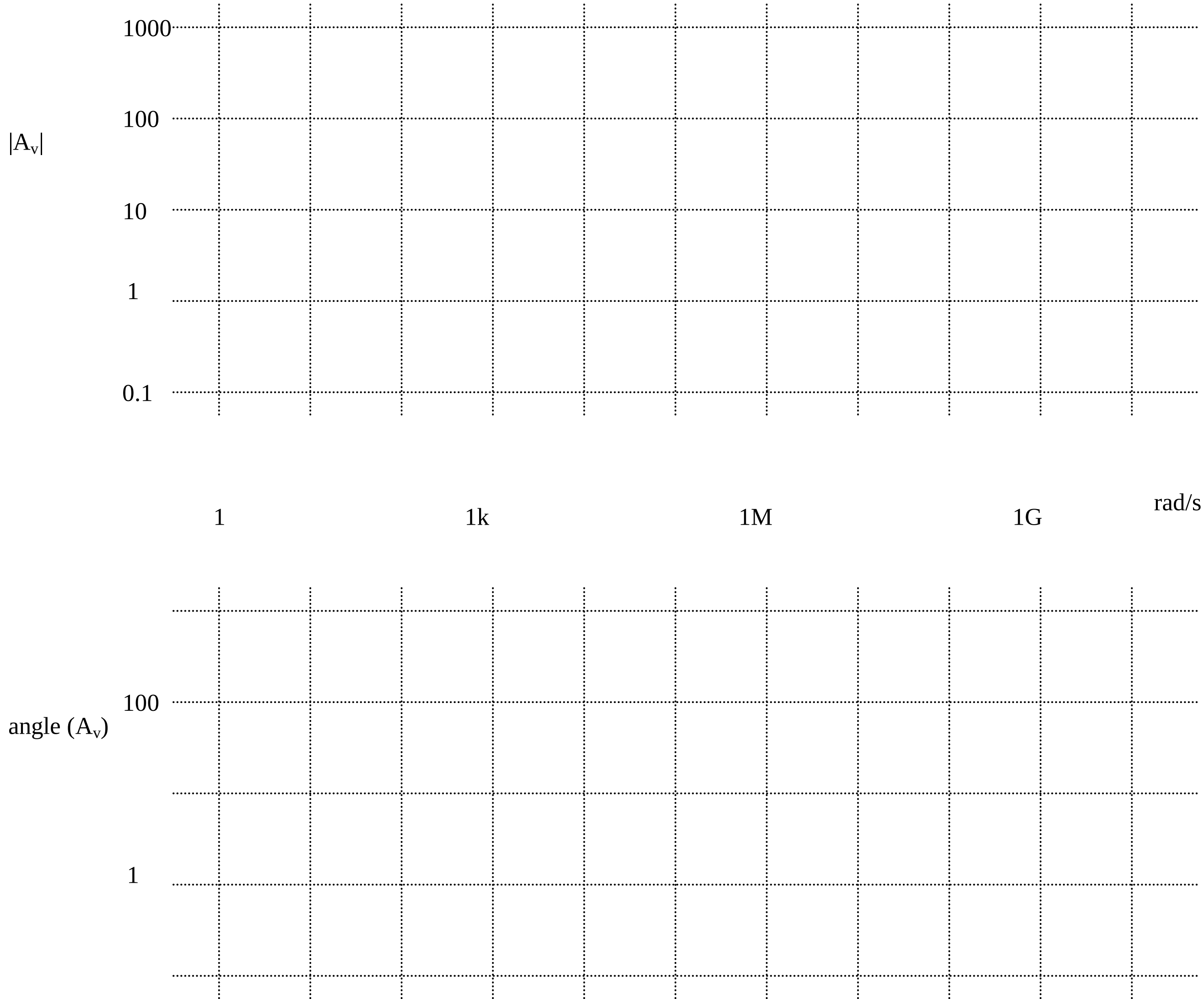
g. What is the phase margin if f=1?

h. Is it unity-gain stable?

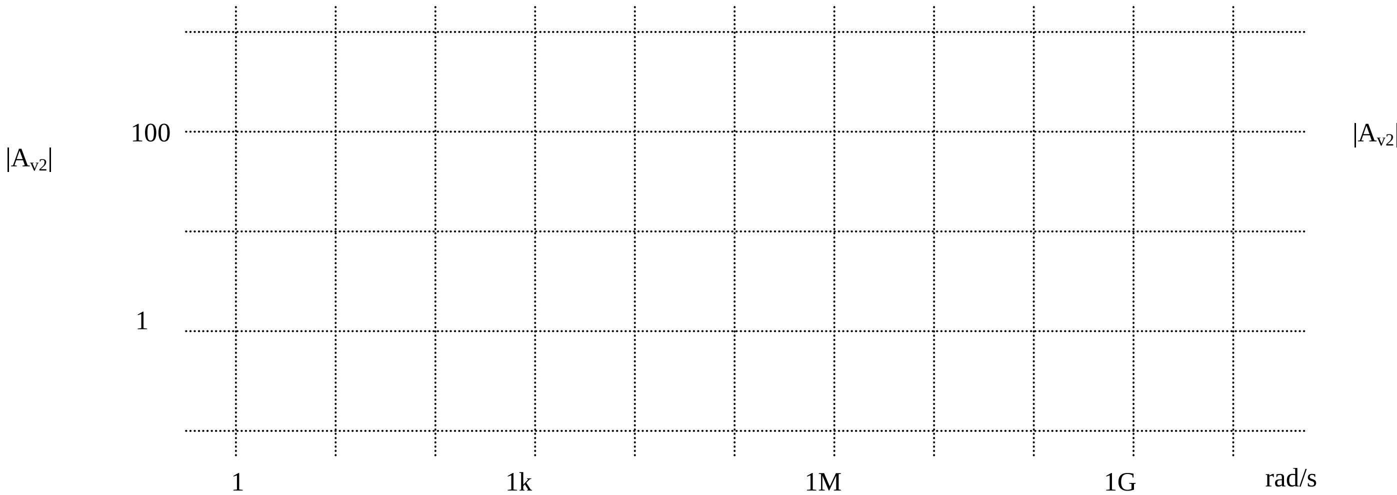
[6pts total for f,g,h]

7. [240A] You use resistive feedback with temperature dependent resistors $R(T)=R_0(1+\alpha\,\Delta T)(1+\varepsilon_{match})$ where $\alpha = 10^{-3}$/K and ε_{match} is a random variable with a Gaussian distribution with a standard deviation of 0.2%. What is the expected gain error due to resistor variation in f? Does it depend on f? What is the difference in temperature between resistors in the feedback network necessary to give that same error? What is the minimum gain necessary to keep the error due to finite gain (problem 1) less than the error due to resistor variation?

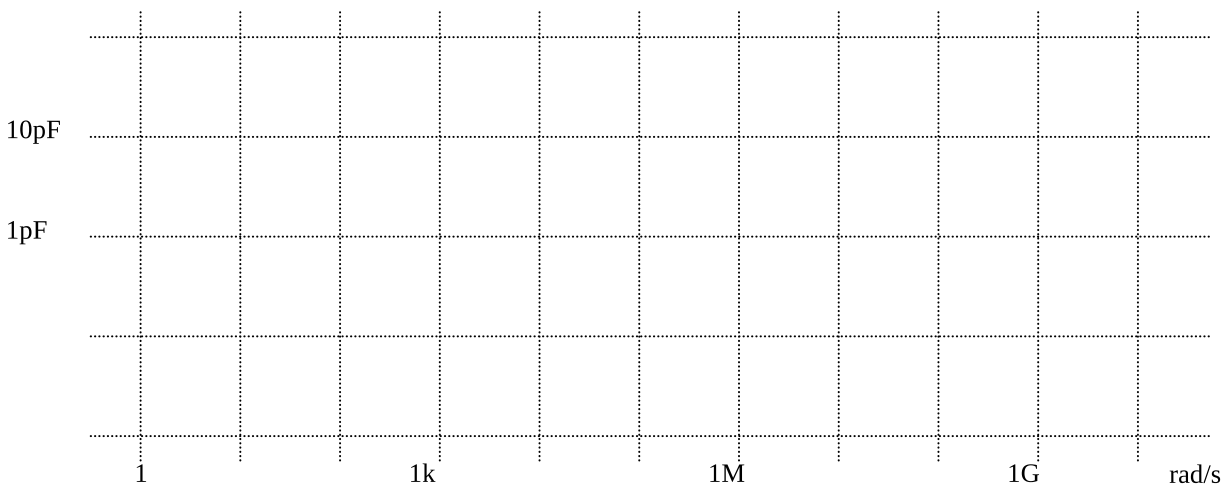
Bode plot for problem 5a) and 6e)



Problem 6, part a) Second stage gain – $|A_{v2,0}|$; part d) $|A_{v1,c}|$



problem 6, part b) magnitude of second stage input (Miller) capacitance



problem 6, part c) second stage input impedance, and R_{o1}