Homework Assignment #5
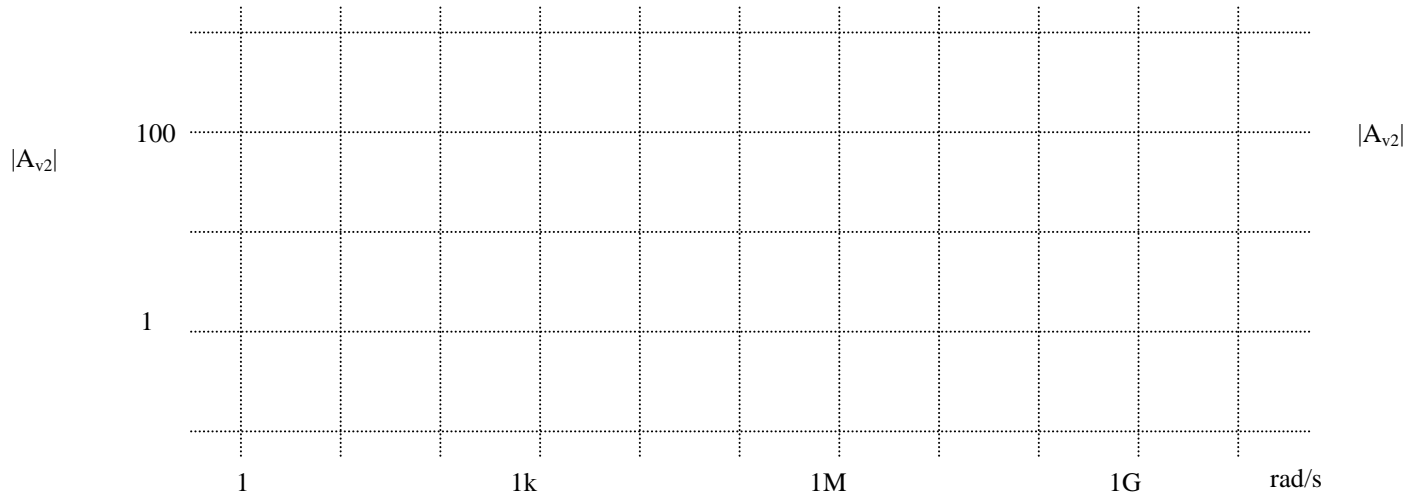Due by online submission **Thursday** 3/2/2017

1. We usually approximate the closed loop gain $A_0/(1+A_0f)$ by $1/f$. How good or bad an estimate is that? Show that the fractional gain error (gain_error/gain) is $-1/(A_0f)$.
2. In a single pole op-amp with $A_0=10,000$, $\omega_p=1M$ rad/s, a feedback factor of $f=0.1$ is used. Find:
   a. the exact low-frequency closed loop gain $A_0/(1+A_0f)$ (use a calculator if needed)
   b. the approximate low-frequency closed-loop gain, $1/f$
   c. the fractional gain error, using the result from the previous problem
   d. what is the fractional gain error at $10\omega_p$? $100\omega_p$?
3. For the previous amplifier
   a. Draw a Bode plot (magnitude and phase) of the open loop amplifier (with no feedback)
   b. On the same plot, draw the Bode plot of the closed-loop amplifier
   c. What is the open-loop unity gain frequency? Closed-loop unity gain frequency?
   d. What is the open-loop pole frequency? Closed-loop pole frequency?
   e. What is the open-loop gain-bandwidth product? Closed-loop gain-bandwidth product?
4. For the previous amplifier,
   a. What is the time constant of the step response of the open-loop amplifier?
   b. Draw the time response to a $1\mu V$ 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 $1\mu V$ 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:
   $G_{m1}=1mS$, $R_{o1}=1M\Omega$, $C_1=1pF$, $C_c=0pF$, $G_{m2}=1mS$, $R_{o2}=100k\Omega$, $C_2=10pF$.
   a. On the following page, plot the magnitude and phase of the overall gain of this uncompensated amplifier.
   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?
6. For the same amplifier as above, we now add $C_c=1pF$. For this problem, you may ignore the RHP zero that this introduces. On the following page,
   a. Plot the magnitude of the second stage gain vs. frequency
   b. Plot the magnitude of the input *capacitance* of the second stage vs. frequency
   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.
   d. Now plot the magnitude of the gain of the compensated first stage on the top plot
   e. Draw the Bode plot of the overall compensated amplifier on the same plot as part 5a
   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?
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?
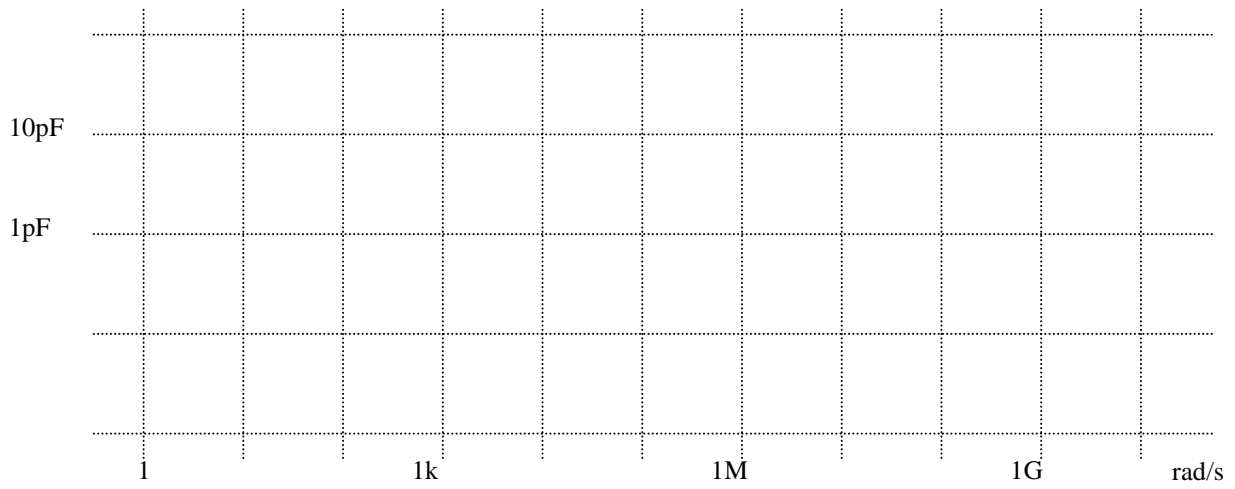
Bode plot for problem 5a) and 6e)

$|A_v|$

1000

100

10

1

0.1

1   1k   1M   1G   rad/s

angle (A_v)

100

1
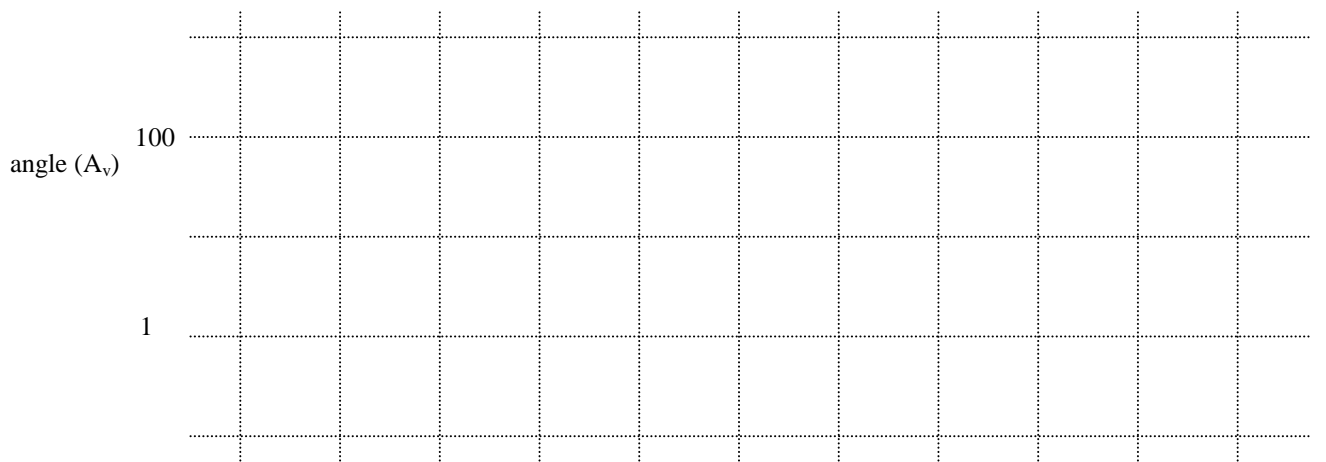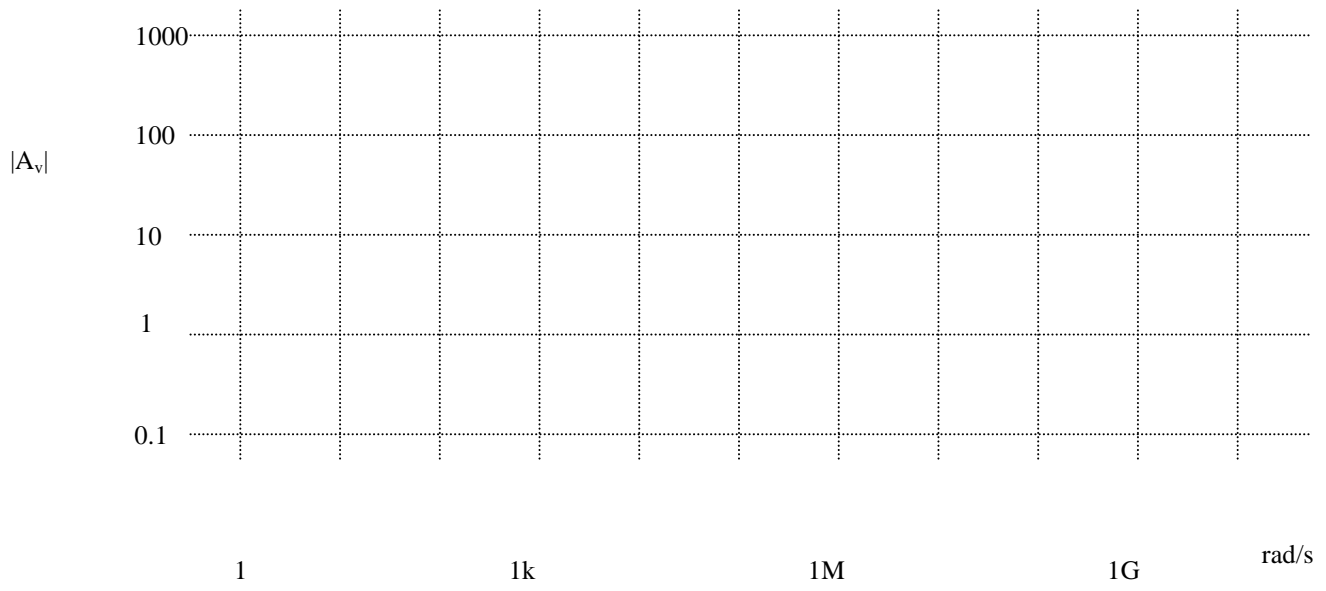
Problem 6, part a) Second stage gain – $|A_{v2,0}|$; part d) $|A_{v1,c}|$

$|A_{v2}|$

100

1

$|A_{v2}|$

1   1k   1M   1G   rad/s

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

10pF

1pF

1   1k   1M   1G   rad/s

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

1M

100k

$|Z_{in2}|$

10k

1k

1   1k   1M   1G   rad/s