EE2019–Analog Systems and Lab: Tutorial 4

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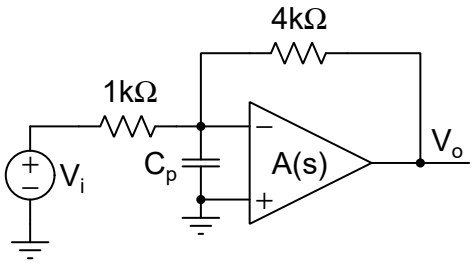

Figure 1: Circuit for problem 1

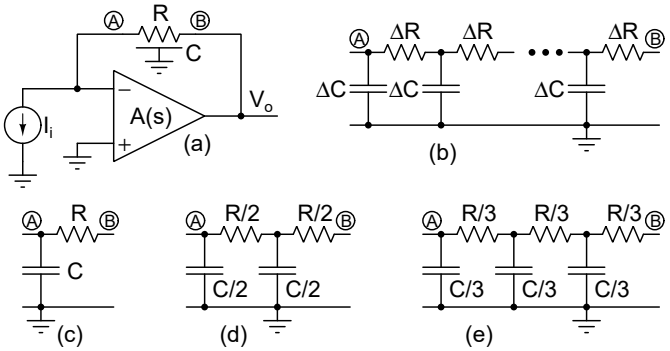

Figure 2: Circuit for problem 2

1. Fig. 1 shows an inverting amplifier. The opamp has a gain $A(s) = A_0/(1 + s/p_1)(1 + s/p_2)$ where $A_0 = 20000$, $p_1 = 1$ krad/s, $p_2 = 10$ Mrad/s. C_p is a parasitic capacitor.

   - What is the phase margin of the system with $C_p = 0$?
   - What is the closed loop bandwidth of the system? (Calculate this from (a) Unity loop gain frequency, (b) Natural frequency of the second order system, and (c) Exact calculation-computing the frequency at which the gain magnitude drops to $1/\sqrt{2}$ times the dc gain.; Compare the estimates so obtained)
   - What is the value of C_p for which the circuit becomes unstable?
   - With C_p being the value calculated in the previous part, can you change the circuit so that the phase margin is 60° without changing the opamp or the closed-loop dc gain V_o/V_i?

2. Fig. 2 shows a transimpedance amplifier. The opamp has a frequency independent gain A_0. The feedback resistor R has a parasitic capacitor C. C is distributed across the length of the resistor and should be modeled as shown in Fig. 2(b) where the infinite number of infinitesimal ΔR and ΔC sum up to R and C respectively. This cannot be analyzed easily, so we model it as shown in Fig. 2(c), (d), or (e). Analyze each case and comment on the effect of A_0 on stability or damping. (In addition to stability, this problem also tells you something about oversimplified models).

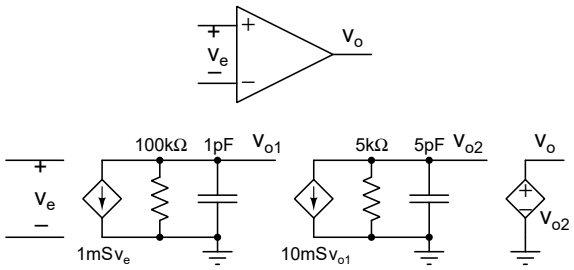

Figure 3: Circuit for problem 3

3. Fig. 3 shows the internal schematic of an opamp. This opamp is used to realize a unity gain, non-inverting amplifier.

   - What is the phase margin?
   - Connect a capacitor across one of the existing capacitors inside the opamp so that the phase margin is 60°.

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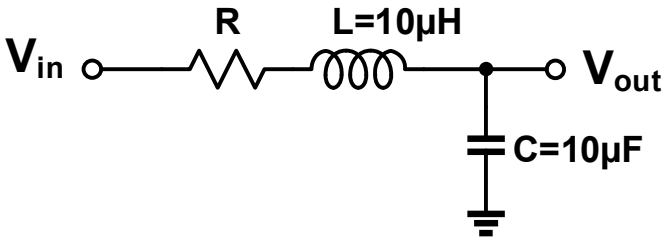
4. Repeat problem-3 if the opamp is used to realize an inverting amplifier of gain -4.

5. In the RLC circuit below



Derive the transfer function $H(s)=V_{out}(s)/V_{in}(s)$ and prove that the circuit is equivalent to a standard 2nd order system with transfer function:

$$H(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

a) Find the expressions for damping factor (ζ), quality factor (Q), natural frequency (w_n) and poles p_1, p_2 (roots of s) and their respective frequencies, w_{p1} and w_{p2} in terms of R, L and C.
b) Considering L=10μH and C=10μF, fill the values in following table for the corresponding values of R

R (Ω)	ζ	Q=1/2 ζ	w_{p1} (rad/s)	w_{p2} (rad/s)
0.02				
0.1				
0.4				
1				
1.4				
2				
5				
10				
20				
100				

c) Enter the circuit in LTSpice and perform following simulations for all the values of R given in the table:
   i. AC magnitude response for $V_{out}(s)/V_{in}(s)$
   ii. Describe the behavior of AC and transient response w.r.t. damping factor, ζ (how the system behaves at lower and higher values of ζ)
   iii. Plot the step response of the closed loop circuit by applying a unit step (0 to 1V with initial delay of 10us and Trise = 1ns) for the time span of 10ms. Comment on the effect of increasing and decreasing phase margin as well as ζ. Find the phase margin and corresponding value of ζ for the fastest settling (when output settles within 95% of the final value).

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6. For the non-inverting amplifier shown in Figure-A and considering the op-amp model shown in Figure-B where *A(s)=Vo(s)/Vi(s)*

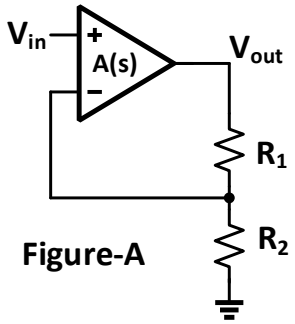

Figure-A

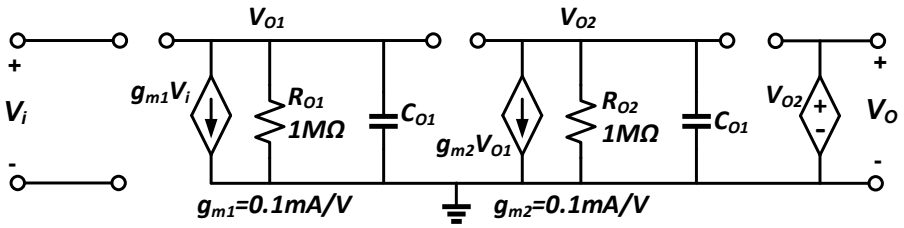

Figure-B

a) Find the loop gain transfer function, LG(s), DC gain A_o, poles p_{1_lg}, p_{2_lg} (roots of s) and their respective frequencies, w_{p1_lg} and w_{p2_lg} in terms of g_{m1}, R_{o1}, C_{o1}, g_{m2}, R_{o2} and C_{o2}.
b) Find the closed loop transfer function, $H(s)=V_{out}(s)/V_{in}(s)$, poles p_{1_cl}, p_{2_cl} (roots of s) and their respective frequencies, w_{p1_cl} and w_{p2_cl} in terms of g_{m1}, R_{o1}, C_{o1}, g_{m2}, R_{o2} and C_{o2}.
c) Prove that, the circuit in Figure-A behaves same as the RLC circuit of problem-5 for feedback factor, β=1 (i.e. R_1=0 or R_2=∞) and find the expressions for damping factor (ζ), quality factor (Q), natural frequency (w_n) in terms of loop gain pole frequencies, w_{p1_lg} and w_{p2_lg} and DC gain, A_o.
d) Considering g_{m1}=g_{m2}=0.1mA/V and R_{o1}=R_{o2}=1MΩ, fill the values in following table for the corresponding values of C_{o1} and C_{o2}

C_{o1} (F)	C_{o2} (F)	Loop Gain				Closed Loop			
		w_{p1_lg} (rad/s)	w_{p2_lg} (rad/s)	w_{ugf} (rad/s)	PM (deg.)	ζ	Q=1/2 ζ	w_{p1_cl} (rad/s)	w_{p2_cl} (rad/s)
1e-9	1e-9								
10e-9	1e-10								
4e-8	2.5e-11								
1e-7	1e-11								
1.41e-7	7.07e-12								
2e-7	5e-12								
5e-7	2e-12								
1e-6	1e-12								
2e-6	5e-13								
1e-5	1e-13								

e) Verify that the increasing spacing between loop gain poles, w_{p1_lg} and w_{p2_lg} has similar effect on damping factor as increasing R has in the RLC circuit of exercise-1.

f) Show the poles of both loop gain poles p_{1_lg}, p_{2_lg} and corresponding closed loop poles, p_{1_cl}, p_{2_cl} for different values of ζ calculated in the above table.

g) Plot phase margin (PM) vs. ζ and find the range of ζ for which phase margin can be calculated as 90-110 times of ζ.

h) Enter the circuit in LTSpice and perform following simulations for all the values of w_{p1_lg}, w_{p2_lg}:

   i. Plot the bode magnitude phase and phase response of the loop gain transfer function for all values of w_{p1_lg}, w_{p2_lg} and corresponding AC magnitude and phase response of the closed loop transfer function. Comment on effect of increasing and decreasing phase margin on the closed loop AC magnitude and phase response.

   ii. Plot the step response of the closed loop circuit by applying a unit step (0 to 1V with initial delay of 10us and Trise = 1ns) for the time span of 10ms. Comment on the effect of increasing and decreasing phase margin as well as ζ. Find the phase margin and corresponding value of ζ for the fastest settling (when output settles within 95% of the final value).

i) Change the value of feedback factor, β=1/10 (i.e. $R_1=10R_2$) and comment about the effect on phase margin, damping factor and unity gain frequency (w_{ugf})