Analog Integrated Circuit Design

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Assignment 3

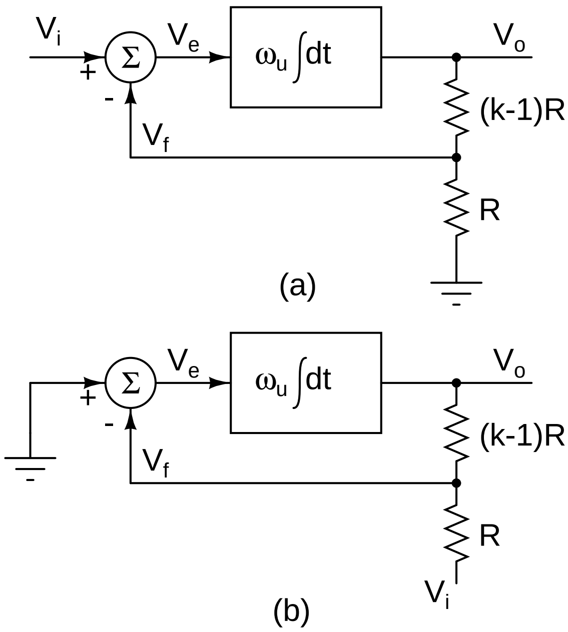

Figure 1: Problem 1

1. Fig. 1(a) shows the amplifier studied in class. Fig. 1(b) shows the same system with the input applied at a different place. Calculate the dc gain, the -3dB bandwidth, and the gain bandwidth product of the system and compare them to the corresponding quantities in Fig. 1(b). Also compare the loop gains. Remark on conventional wisdom such as “constant gain bandwidth product”, “closed loop bandwidth = unity gain frequency/closed loop dc gain”. What is the reason for the discrepancy?

   Draw an equivalent block diagram of Fig. 1(b) such that the classical form of feedback (sensed error integrated to drive the output) is clearly obvious (Hint: compute the error voltage V_e).

2. Assume that an opamp behaves like an ideal integrator with an extra pole p_2, i.e. its transfer function is given by

   $$A(s) = \frac{\omega_u}{s}\frac{1}{1+\frac{s}{p_2}}$$

   If this opamp is placed in unity feedback, determine the natural frequency and the damping or quality factor. Determine the location of the zero p_2 for critical damping. Sketch the loop gain magnitude and phase plots of such a system. Sketch the unit step response of the loop gain function.

3. Assume that an opamp has two poles at the origin and a zero at z_1, i.e. its transfer function is given by

   $$A(s) = \frac{\omega_u z_1}{s^2}\left(1+\frac{s}{z_1}\right)$$

   If this opamp is placed in unity feedback, determine the natural frequency and the damping or quality factor. Determine the location of the zero z_1 for critical damping. Sketch the loop gain magnitude and phase plots of such a system and compare it to the other “good” cases that you are already familiar with.

4. 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 $\omega_{u,loop}/s$)

5. Fig. 2 shows a negative feedback system with an integrator and an ideal delay of T_d in the feedback path.

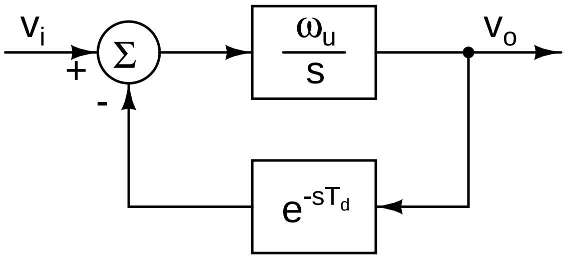

Figure 2: Problem 5

(a) Setup the differential equation for the system above.

(b) V_i is 1 V for a long time and changes to 0 V at $t = 0$. What is the equation for $t > 0$?

(c) Assume that the solution is of the form $V_p \exp(\sigma t)$ with real σ. Obtain the equation from which you will determine σ (You are not required to solve it).

(d) Express the above equation as $f(\sigma) = 0$. Sketch $f(\sigma)$. Determine the extremum of $f(\sigma)$ in terms of T_d. For what value of T_d does the extremum become equal to zero?

(e) Assume that the solution is of the form $V_p \exp((\sigma + j\omega)t)$ with real σ and ω. Obtain the equations from which you will determine σ and ω (You are not required to solve them).

(f) Reduce the above to a single equation in ω.

6. (a) Assume that the solution to the system in Fig. 2 is of the $V_p \cos(\omega t + \phi)$, i.e. a constant amplitude sinusoid. Determine the relationship between T_d and the unity gain frequency ω_u such that this solution exists.

   (b) What is the smallest value of T_d for which it can happen? What is the value of ω in that case?

7. Fig. 3(a) shows a nonlinearity f enclosed in a negative feedback loop with a feedback fraction β. VFig. 3(b) shows a nonlinearity f preceded by an attenuation factor.

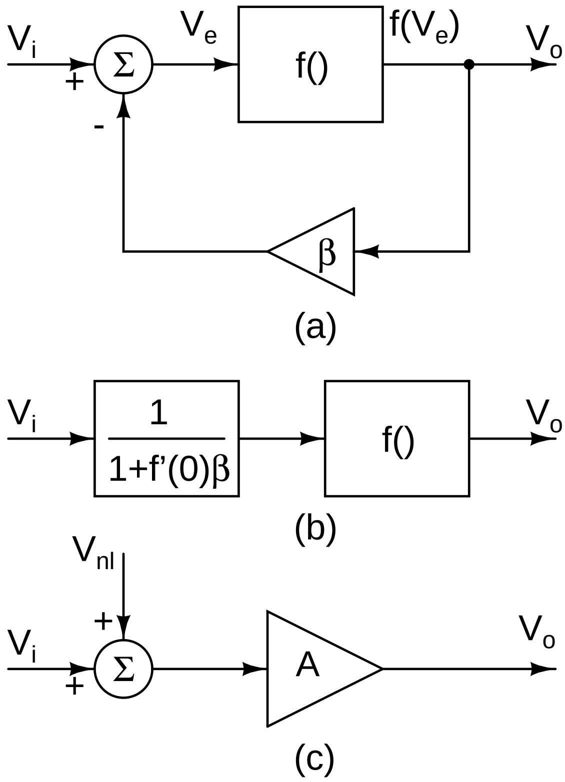

Figure 3: Problem 7

   (a) In Fig. 3(a) and (b), denote the transfer characteristic of the overall system by g, i.e. $V_o = g(V_i)$ and calculate the first three terms (operating point, linear, and second order terms) of the Taylor series of g about the operating point of the circuit in terms of f and its derivatives. Assume that $f(0) = 0$.

   (b) Fig. 3(c) shows the linear small signal equivalent circuit from V_i to V_o with an additional input V_{nl}. This is used to model the nonlinear systems in Fig. 3(a) and (b). Determine the small signal gain A and the input referred nonlinearity V_{nl} (in terms of V_i) such that Fig. 3(c) produces the same output as Fig. 3(a) and (b).