# EE5320: Analog Integrated Circuit Design; Assignment 1

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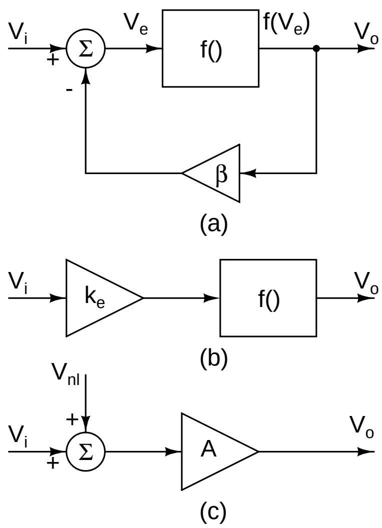


Figure 1: Problem 2

1. Fig. 1(a) shows a nonlinearity $f$ enclosed in a negative feedback loop with a feedback fraction $\beta$.

   If the overall nonlinear transfer characteristic from $V_i$ to $V_o$ is given by $g()$, determine the coefficients of Taylor series of $g(V_i)$ around $V_i = 0$ in terms of the Taylor series coefficients of $f()$. For simplicity, assume $f(0) = 0$. Determine these up to the third order.

   In Fig. 1(a), deterine the small signal linear gain $k_+e = V_e/V_i$. Fig. 1(b) shows $f()$ preceded by a gain $k_e$. In other words, in terms of small signals, the same signal is applied to $f()$ in both Fig. 1(a) and (b). Determine the Taylor series of $g_1()$ which is the nonlinear function relating $V_o$ to $V_i$ in Fig. 1(b). As before, compute it up to the third order and compare the results to those obtained for Fig. 1(a).

   The gain $A$ in Fig. 1(c) is the same as the small signal gain from $V_i$ to $V_o$ in Fig. 1(a). Determine the nonlinear voltage $V_{nl}$,(in terms of $V_i$ and the small signal parameters of Fig. 1(a)) which should be added to the input so that (i) The part proportional to $V_i^2$ is the same as in Fig. 1(a), (ii) The part proportional to $V_i^3$ is the same as in Fig. 1(a).

   Repeat the above computations of $V_{nl}$ to make the nonlinear output components in Fig. 1(c) to be the same as that in Fig. 1(b).

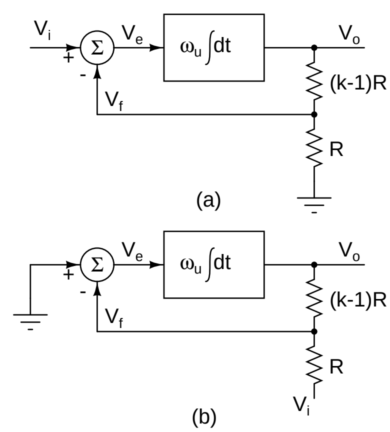


Figure 2: Problem 1

2. Fig. 2(a) shows the amplifier studied in class. Fig. 2(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. 2(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. 2(b) such that the classical form of feedback (sensed error integrated to drive the output) is clearly obvious (Hint: compute the error voltage $V_e$).

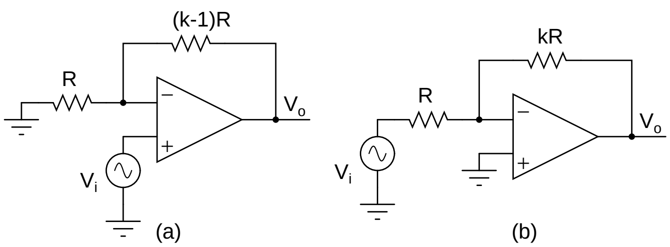


Figure 3: Problem 2

3. Fig. 3(a) and Fig. 3(b) shows amplifiers which realize gains of $k$ and $-k$ respectively with ideal opamps. Compare the following parameters of the two circuits. Model the opamp as an integrator $\omega_u/s$.

   (a) Input impedance

   (b) Bandwidth

   (c) Differential ($V_+(s) - V_-(s)$) and common mode (($V_+(s) + V_-(s))/2$) input voltages of the opamps

   Assuming that the sign of the gain is unimportant in your application, what would make you choose one over the other? Is there any reason to choose Fig. 3(b) at all?

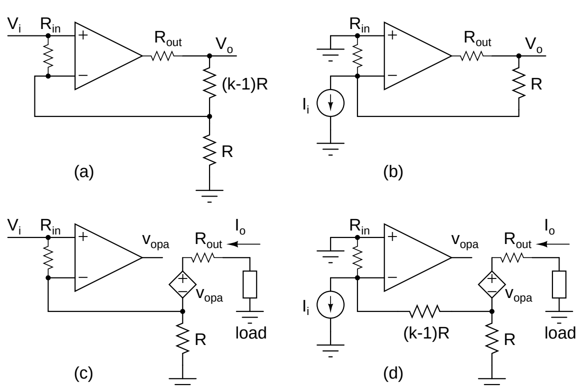


Figure 4: Problem 3: (a) VCVS, (b) CCVS, (c) VCCS, (d) CCCS

4. Fig. 4 shows the four types of controlled sources using an opamp. Model the opamp as an integrator $\omega_u/s$. For each of these, calculate the transfer ratio (output/input), input impedance, and output impedance at (a) dc, and (b) an arbitrary frequency $\omega$. For (b), set $R_{out} = 0$ when calculating the input impedance and $R_{in} = \infty$ while calculating the output impedance. What happens to these three quantities at high frequencies in each case?

5. The loop gain $L(s)$ of a system with $N$ extra poles and $M < N$ extra zeros is given by

$$L(s) = \frac{\omega_{u,loop}}{s} \frac{\sum_{m=0}^{M} b_m s^m}{\sum_{n=0}^{N} a_n s^n}$$

   $b_0 = a_0 = 1$. What does the loop gain step response (inverse laplace transform of $L(s)/s$) look like after the 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 $\omega_{u,loop}/s$; This problem doesn't require a lot of algebra, but requires reasoning and basics of polynomials)

6. Assume that an opamp has two poles at the origin and a zero elsewhere, 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.