Analog Integrated Circuit Design

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Assignment 2

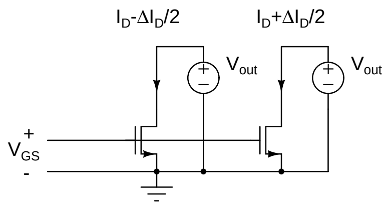

Figure 1: Problem 1

1. Two transistors carrying a current I_D are required to have a current mismatch $\leq \sigma_{I_D}$ and operate in saturation with an output voltage V_{out} (Fig. 1). The smaller the value of V_{out}, the higher the compliance of the current source. Write down the expression for variance of current mismatch normalized to the nominal current, ω_T, and the current noise spectral density S_{Id}. The expressions should be in terms of V_{out} and I_D, transistor dimensions, and the parameters A_{VT}, A_β. Comment on the tradeoffs implied by these expressions.

2. A resistor ladder with N resistors of nominally the same value R_0 is driven from a 1 V source as shown in Fig. 2. If the resistors have an error ($\Delta R/R$) with standard deviation σ_R, determine the standard deviation of the L^{th} tap voltage V_L (not normalized to the nominal value). Which tap voltage has the maximum error (σ)? Compute the maximum error. Write down the expression for the voltage error and separate it into uncorrelated parts so that you can add the respective variances).

   This is a circuit that could be used in digital-to-analog or analog-to-digital converters where you have to ensure that the worst case error is sufficiently smaller than the least significant voltage $1/M$ volts.

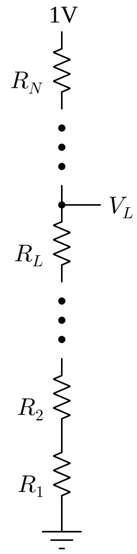

Figure 2: Problem 2

3. Fig. 3 shows the three basic single transistor amplifiers. Bulk terminal is connected to ground in all circuits. Determine the forward transfer function V_o/V_i (with $I_i = 0$) and the reverse transfer function I_o/I_i (with $V_i = 0$). Use the transistor model shown in Fig. 3(d). Do this cleanly as follows, so that you gain intuition and also see similarities and differences between the three circuits.

   Write nodal analysis equations in matrix form with V_o and V_g or V_s as variables with both V_i and I_i as inputs. Use source transformation for V_i. From this, using Cramer's rule, you should be able immediately write down the forward and reverse transfer functions mentioned above.

   Determine the ratio of reverse transfer function to the forward transfer function. Knowing what you do about the relative magnitudes of transistor par-

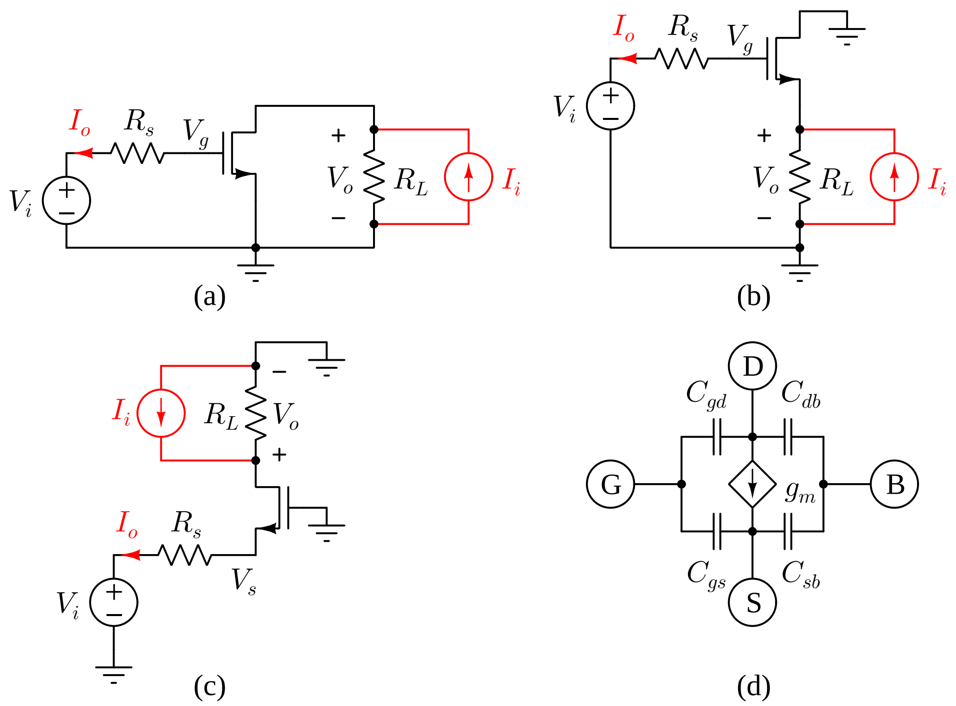

Figure 3: Problem 3

asitics, qualitatively sketch the magnitudes of these ratios. Which circuit provides the best reverse isolation? Which is the worst?

If there are additional parasitic or load capacitors in the circuit, you should be able to absorb them into the expressions obtained above.

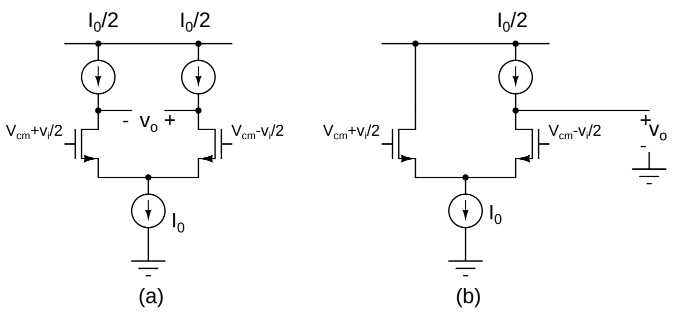

Figure 4: Problem 4

4. Determine the small signal dc gains of the two amplifiers in Fig. 4. Calculate the tail node voltage in each case. The transistors can be modeled using g_m and g_{ds}. Explain the results.

5. The common mode gain of a differential amplifier is measured by applying a small signal common mode input v_{cm} as shown in Fig. 5. Fig. 5(a) has a current mirror load and Fig. 5(b) has a current source load which is independently biased. What is the common mode gain of these two configurations? Express the answer in terms of the small signal parameters of: $M_0\,(g_{m0},\, g_{ds0})$, $M_{1,2}\,(g_{m0},\, g_{ds1} = 0)$, $M_{3,4}\,(g_{m3},\, g_{ds3})$

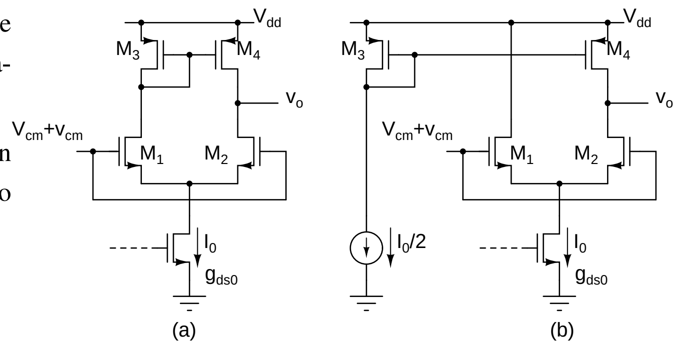

Figure 5: Problem 5

6. Determine the small signal output resistance of the single stage opamp shown in Fig. 6. Model the tran-

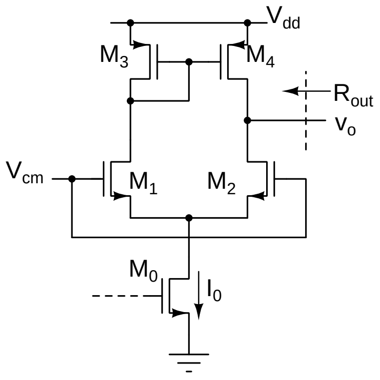

Figure 6: Problem 6

sistors as follows: M_0 (g_{m0}, $g_{ds0} = 0$), $M_{1,2}$ (g_{m0}, g_{ds1}), $M_{3,4}$ (g_{m3}, $g_{ds3} = 0$). Determine the current through each transistor when a small signal test voltage v_{test} is applied to the output terminal.