Problems for Chapter 10 of 'Ultra Low Power Bioelectronics'

Problem 10.1

The gate-to-drain capacitance, C_{gd}, of a transistor causes high-frequency coupling from gate to drain that is of opposite sign from g_m-based low-frequency coupling, thus creating a right-half-plane (RHP) zero. In this problem, we will apply return-ratio analysis to obtain the transfer function of a circuit involving C_{gd}. Figure P10.1 shows a common-source amplifier that is driven by a voltage source with source-impedance R_{in}. You can assume that the output impedance of the transistor, r_0, is much larger than R_{out} and thus can be ignored. Ignore all other capacitances in the transistor as well.

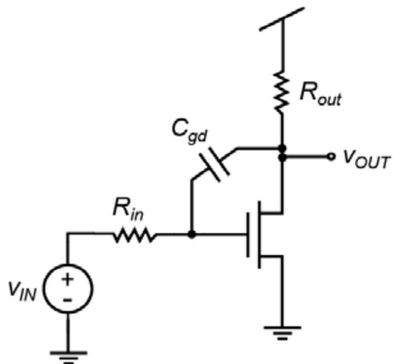

Figure P10.1: A common-source amplifier with C_{gd}.

a) By replacing the transistor's g_m generator with a fake-label current source, compute TF_0, TF_∞, and $R_{inputnulled}$.
b) Compute the transfer function, $V_{out}(s)/V_{in}(s)$, of the circuit.
c) Compute the pole and zero locations of the latter transfer function.

Problem 10.2

In this chapter, we have seen how to compute the transfer function of a feedback network with a passive element using return-ratio analysis. We can think of the passive element as either being in parallel with or in series with a big circuit. For instance, in a Bridged-T network in Figure 10.10, we can think about the capacitor as being in parallel with the whole network, and introduce a fake-label current source to perform return-ratio analysis. We can also think about the capacitor as being in series with the whole network and introduce a fake-label voltage source to perform return-ratio analysis. To show that the two methods are equivalent, introduce a fake-label voltage source in place of the capacitor in Figure 10.10.

a) Calculate TF_0, TF_∞, and $R_{inputnulled}$.
b) Find the transfer function $V_{out}(s)/V_{in}(s)$ and verify that it is the same as that of Equation (10.33).
c) Transform Equation (10.68) into (10.69) to show that this particular example can be generalized to an arbitrary circuit.

Problem 10.3

We have seen how to apply return-ratio analysis to derive the transfer function of an inverting amplifier while taking loading effects into account. The figure below shows a schematic of a band-pass amplifier. The transconductance amplifier in the circuit is non-ideal; it has a finite output impedance of R_{out}.

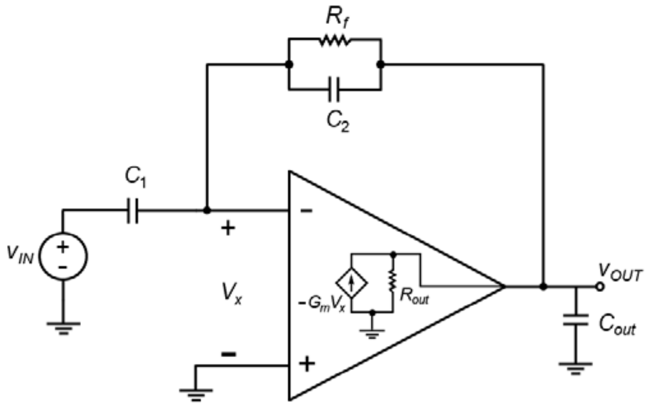

Figure P10.3: A bandpass amplifier.

a) Derive an expression for the transfer function $V_{out}(s)/V_{in}(s)$ taking all loading effects into account.
b) Assume that $R_{out} >> 1/(sC_{out})$, $R_f >> 1/(sC_2)$ in the frequency band of interest, and that C_1, $C_{out} >> C_2$. Use these assumptions to simplify the transfer function in part a).
c) With the assumptions of part b), estimate the corner frequency of this amplifier and estimate the location of a right-half-plane zero if any.

Problem 10.4

We have discussed in this chapter how the concepts of return-ratio analysis can explain why the noise of a cascode transistor barely affects the noise of a common-source amplifier. In this problem, we will verify this fact. Figure P10.4 shows a common-source cascoded amplifier. Assume that all the transistors in the circuit are in saturation. Let $g_{s2} = g_{m2} + g_{mb2}$ be the source conductance of the transistor M_2. Let r_{o1}, r_{o2} be the small-signal output impedances of transistor M_1 and M_2 respectively. You may ignore all other small-signal parameters.

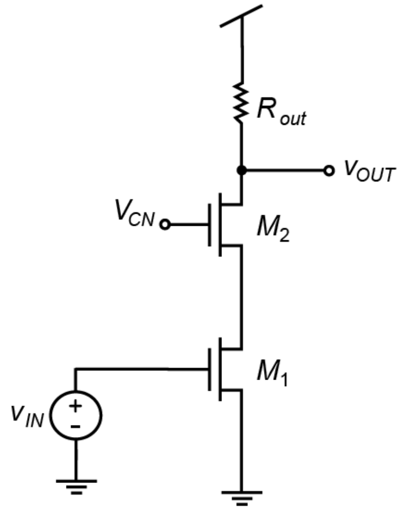

Figure P10.4: A cascoded common-source amplifier

a) Using return-ratio analysis with respect to the g_s generator of M_2, compute the transfer function $TF(s) = V_{out}(s)/V_{in}(s)$.
b) Assuming that $R_{out} << r_{o1}, r_{o2}$, simplify your answer in part b).
c) With the assumptions of part b), calculate the fractional change of the transfer function, $TF(s)$, as a function of the fractional change in the source conductance of M_2.
d) Explain intuitively why the circuit is robust to variations in the g_s of M_2.

Problem 10.5

Derive Equation (10.40) using both forms of Blackman's impedance formula (Equations (10.34) and (10.35)) by:

a) driving with a voltage source
b) driving with a current source

at the source of the transistor in Figure 10.13 (a).

Problem 10.6

Compute the input impedance Z_{in} of the resistive-bridge circuit in Figure 10.9 using Blackman's impedance formula. Verify that your answer is the same as that of Equation (10.31).

Problem 10.7

Compute the input impedance Z_{in} of a common-source amplifier with source degeneration in Figure P10.7 using Blackman's impedance formula. You can assume that the output resistance of the transistor is very large and can be ignored.

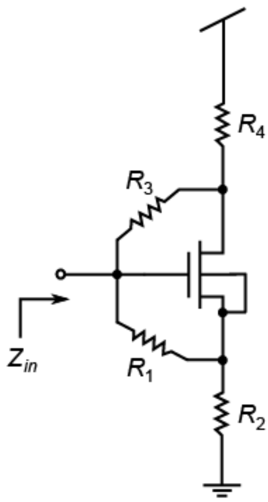

Figure P10.7: A common-source amplifier with source degeneration.

Problem 10.8

Figure P10.8 illustrates a modified super-buffer circuit. In this problem, you will find the transfer function from V_{in} to V_{out} by using return-ratio analysis iteratively. You can assume that the transistors in this problem have very large output impedance, and, therefore, that their output impedance can be ignored.

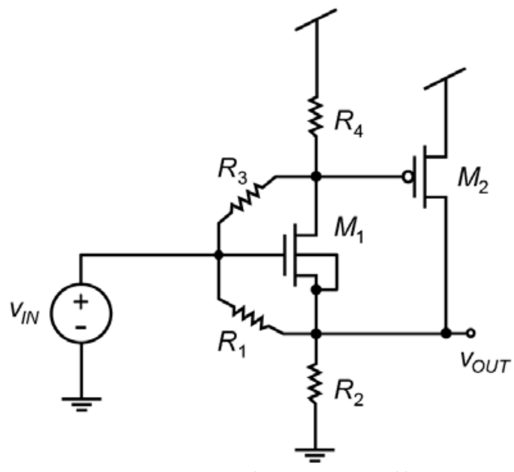

Figure P10.8: A modified super-buffer circuit

a) By disconnecting M_2 from the circuit and using return-ratio analysis for the g_{m1} generator of M_1, compute the transfer function from $V_{in}(s)$ to $V_{out}(s)$. Denote this transfer function as $TF_{gm2=0}$.
b) Now connect M_2 to the circuit. Calculate the transfer function from $V_{in}(s)$ to $V_{out}(s)$ when $g_{m2} = \infty$. Denote this transfer function as $TF_{gm2=\infty}$.

c) Find $R_{inputnulled}$ for the g_{m2} generator by nulling V_{in}. Combine the answers from parts a), b), and c) to compute the transfer function of the super-buffer circuit.

Problem 10.9

Figure P10.9 shows a Wilson current-mirror schematic. This circuit exploits negative feedback to significantly increase its output impedance.

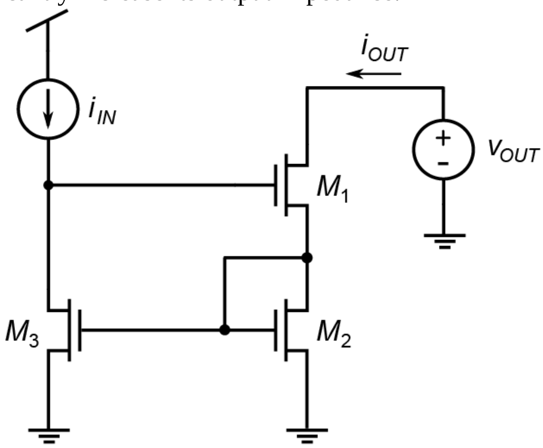

Figure P10.9: A Wilson current mirror.

a) By applying return-ratio analysis around an appropriate small-signal circuit element, calculate the exact dc transfer function from $I_{in}(s)$ to $I_{out}(s)$. Do not neglect the Early effect and the body effect (g_{mbM1}). However, you can make appropriate assumptions based on the fact that $g_m r_o >> 1$ for all transistors.

b) Using Blackman's impedance formula, calculate the output impedance at the drain of M_1.

Problem 10.10

One way to build a negative-resistance element is shown in Figure P10.10. The impedance looking into the source of M_1 will have a negative real part over a range of frequencies. By assuming that the output impedance r_{o1} of M_1 is infinite, derive an expression for $Z_{in}(j\omega)$. What is the frequency range over which $Z_{in}(j\omega)$ has a negative real part?

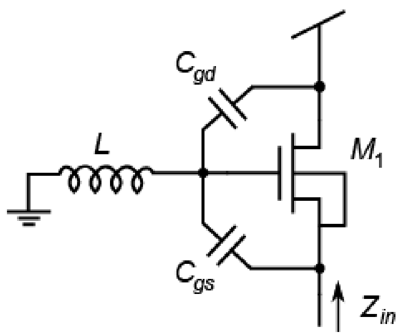

Figure P10.10: A negative-resistance circuit.