Integrated Circuits Lab
Department of Electrical Engineering
Stanford University

Qualifying exam
January 2006
Prof. K.V. Shenoy

Problem 1

Consider an n-channel MOSFET with: μ_n, C_{ox}, W, L, V_t, V_{GS} and V_{DS}.

(a) What is this transistor's transconductance if operating in triode (linear) mode?

(b) If this transistor is operating in saturation mode rather than in triode (linear) mode, is the |gain| of an amplifier larger or smaller? Please show why.

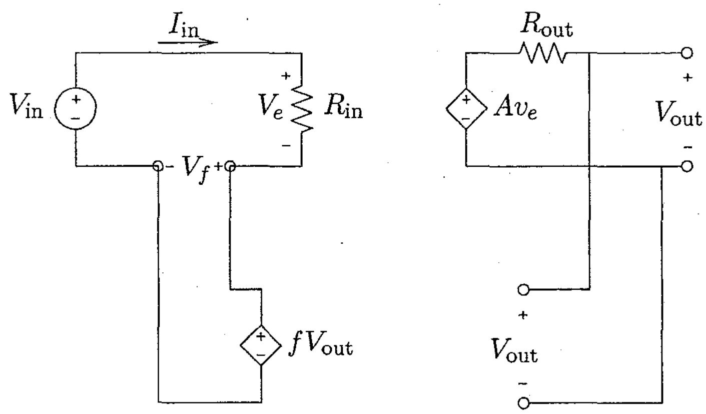
Problem 2

Consider an amplifier with three capacitors C_1, C_2 & C_3. Each capacitor "sees" a resistance, found with the other capacitors removed. These resistances are R_1, R_2 & R_3.

(a) You need to increase the high frequency cutoff of the amplifier and can adjust only one capacitor. Which capacitor should you adjust? Why, and how?

(b) Is this amplifier's dominant pole given by 1/(RC), where R is R_1, R_2 or R_3 and C is C_1, C_2 or C_3?

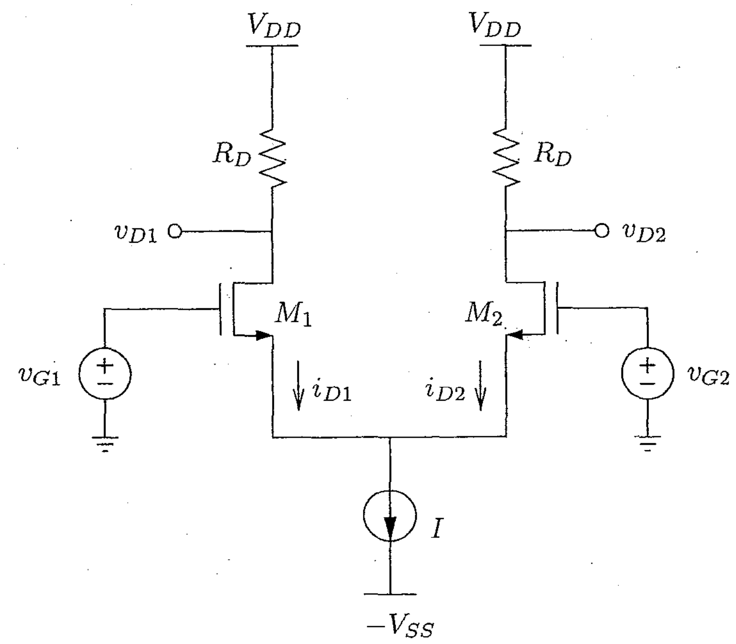
Problem 3



(a) What is the gain ($G = \frac{V_{out}}{V_{in}}$) of this circuit?

(b) The input resistance of this circuit is $R_{in,f\neq 0}$. If f is reduced to zero ($f = 0$), the input resistance is $R_{in,f=0}$. How is $R_{in,f\neq 0}$ related to $R_{in,f=0}$?

Problem 4



- This is a symmetrical differential amplifier, with M_1 and M_2 operating in saturation mode.
- When there is no differential input voltage ($v_{ID} = v_{GS1} - v_{GS2} = 0$) the tail current divides evenly between the two arms ($i_{D1} = i_{D2} = I/2$).
- The gate to source voltages must then also be equal: $V_{GS0} = v_{GS1} = v_{GS2}$.
- And $\frac{I}{2} = K_N(V_{GS0} - V_t)^2$ where $K_N = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}$.

(a) What is the minimum differential input voltage (v_{ID}) that can be applied to cause all current to flow through M_1? Please write expression in terms of $V_{GSO} - V_t$.

(b) What is the common mode rejection ratio? What is it for this circuit (assume differential input and differential output)?

Problem 5

Please describe the major sub-circuits of an op-amp, and the critical design considerations of each.

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Problem 1

You are stranded on a melting glacier with (1) a hand-full of batteries, (2) a hand-full of resistors, (3) an n-channel MOSFET and (4) a length of wire. You need to somehow build an amplifier to try to send for help.

(a) With just these parts, can you build an amplifier? Please "chisel circuit in the ice" & explain its operation.

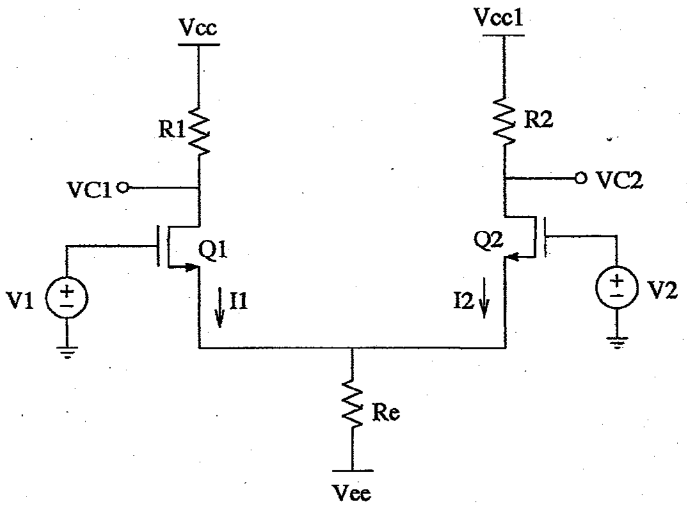
(b) What is your goal with the battery(batteries)?

(c) What is your goal with the resistor(s)?

(d) You now find another MOSFET in your coat pocket, and its a p-FET. Should you modify your circuit? Why?

(e) You suspect that your amplifier's high-frequency cuttoff is too low to be useful. What should you look for (and change if you could) in the circuit and MOSFETs?

Problem 2

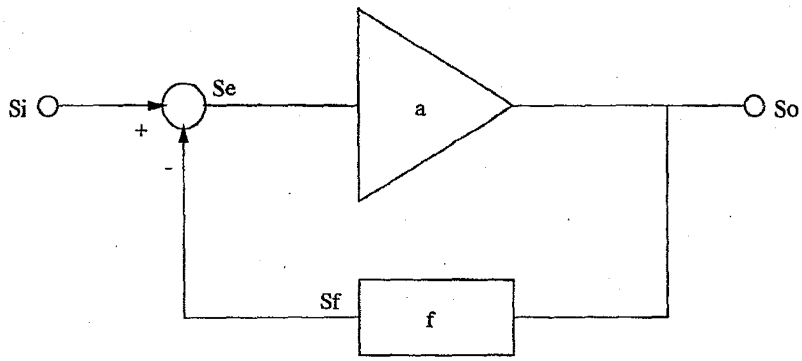


Consider this symmetric differential amplifier. Please explain how the following change when a common-mode voltage is ramped up ($V_{ee} \rightarrow V_{cc}$) at the inputs:

(a) The FETs' mode of operation

(b) The FETs' source voltage

Problem 3



Consider this idealized feedback configuration.

(a) Please derive an expression for the closed-loop gain (A).

(b) Please derive an expression for the closed-loop 3dB frequency ($\omega_{3dB,CL}$) when the basic amplifier (a) is now modeled as a one pole system:

$$a(s) = \frac{a_o}{1 + \frac{s}{\omega_{3dB}}}$$

where a_o is the open-loop DC gain and ω_{3dB} is the 3dB open-loop frequency.

(c) Does the addition of feedback increase the gain-bandwidth product? Why or why not?

Problem 4

Please describe the major sub-circuits of an op-amp, and the critical design considerations of each.

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1. Does the transconductance of a MOSFET depend linearly on I_{DS}? Why (please derive)?

2. To carry the same amount of current under the same bias conditions, should a PMOS transistor be made wider, narrower, or the same as a nearby NMOS? Why (in physical terms)?

3. Please sketch an NMOS differential amplifier with tail current of 1 mA (i.e., a current source of 1 mA between source node and ground). What happens to V_{SOURCE} when the common-mode input voltage is increased? Why?

4. Before the days of digital computers, or even calculators, if you wanted to electronically calculate the natural logarithm (ln) of a number how could you do it? Please sketch and/or write equations to explain.

5. If you wanted to amplify the signal from a photodiode (which acts like a weak current source) with a common source amplifier, should you connect a resistor so as to form a series-x or a shunt-x feedback amplifier? Or is feedback not needed? Please explain.

6. Please describe the major sub-circuits of an op-amp, and the critical design considerations of each.