Exercise Test TSEI05, Analog and Discrete-time Integrated Circuits

Date:	February, 2008
Time:	
Place:	
Max.no. of points:	25
Grades:	10p for 3, 15p for 4, and 20p for 5.
Allowed material:	All types of calcuclators except laptops. All types of official tables and handbooks. Textbooks: Johns & Martin: Analog Integrated Circuit Design. Razavi: Design of Analog CMOS Integrated Circuits. Sedra&Smith: Microelectronic Circuits. Dictionaries.
Examiner:	Sune Söderkvist
Responsible teacher:	Sune Söderkvist. Tel.: 281355.
Corrrect (?) solutions:	Solutions and results will be displayed in House B, entrance 25-27, ground floor.

Solutions will be found on the home page in March 27.

Students instructions

- The CMOS transistor operation regions, small-signal parameters, and noise characteristics are found on the last page of this exam.
- Generally, do not just answer yes or no to a short question. You always have to answer with figures, formulas etc., otherwise no or fewer points will be given.
- You may write down your answers in Swedish or English.

Good Luck!

Exercise 1.

The circuit in **Figure 1** is used to establish an appropriate bias voltage V_{bias} to an operational amplifier. The transistors have following parameter values:

	N-channal	P-channal
V_{t0} [V]	0.47	0.62
$\mu_0 C_{ox}$ [muA/V^2]	180	58.5
λ [V^{-1}]	0.03	0.05
γ [V$^{1/2}$]	0.62	0.41
ϕ_F [V]	0.43	0.41

a) Show that all transistors are saturated in this circuit. (1.5p)

b) Determine $\left.\frac{W}{L}\right|_i$, $i = 1, 2, 3$, for transistors Mi , $i = 1, 2, 3$, if $V_{DD} = 3.3$ V, $V_{bias} = 0.6$ V and $I_D = 5\ \mu$ A.

If the potential V_x is just above 2.05 V it shows that $\left.\frac{W}{L}\right|_2 = \left.\frac{W}{L}\right|_1$. Choose $V_x = 2.05$ V here.

Do not neglect the bulk effekt neither the channel-length modulation. (3.5p)

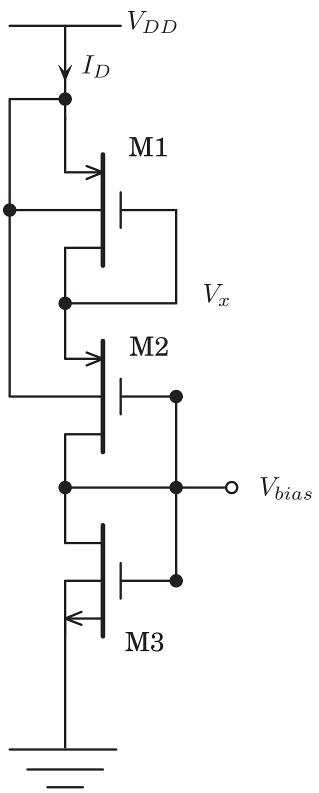

Figure 1: A bias circuit.

Exercise 2.

Sketch a small-signal equivalent circuit and determine the input resistans r_{in} and the output resistans r_{out} for the wide-swing current mirror in **Figure 2**. All transistors are biased to operate in the saturation region. Assume that the transistors small-signal parameters are g_{m1}, g_{ds1}, g_{m2}, g_{ds2}, g_{m3}, g_{ds3} and g_{m4}, g_{ds4} respectively. (5p)

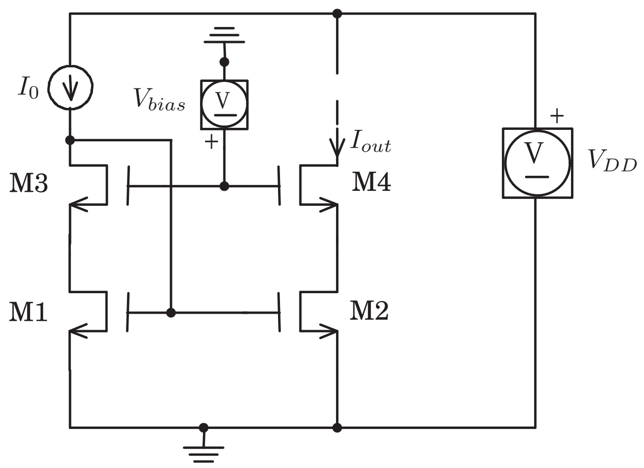

Figure 2: A wide swing current mirror.

Exercise 3.

a) Sketch a figure that shows the construction of a **flash AD-converter** that converts a analog signal V_{in} to a binary signal $B_{out} = [b_1, b_2, b_3]$. Also, shortly describe how this converter works. (3p)

b) Sketch the transfer function for an ideal 3-bit **DA-converter** and determine the output voltage if the reference voltage is 2 V and the binary input is $B_{in} = [1, 0, 1]$.

   Also, determine the minimum output change V_{LSB} in this case. (2p)

Exercise 4.

Figur 3 shows a simplified small-signal model of an OTA, including a compensation capacitor C_c. Derive an expression for the transfer function $H(s) = V_{out}/V_{in}$. (5p)

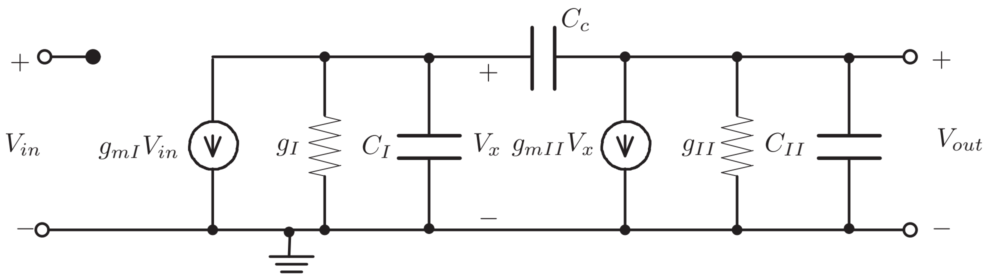

Figure 3: A small-signal model of a two-stage OTA.

Exercise 5.

Consider the two cascaded common-source stages in **Figure 4**, where only the thermal noise generated in the transistors is of interest. The current sources are ideal and hence noiseless. Let the output load capacitance be given by C_L and parasitic capacitanses are only given by gate-source capacitances, C_{gs}. Further $I_{bias1} = I_{bias2} = I_{bias}$. The transistors are identical with the small signal parameters $g_{m1} = g_{m2} = g_m$ and $g_{ds1} = g_{ds2} = g_{ds}$. Both transistors operate in the saturation region.

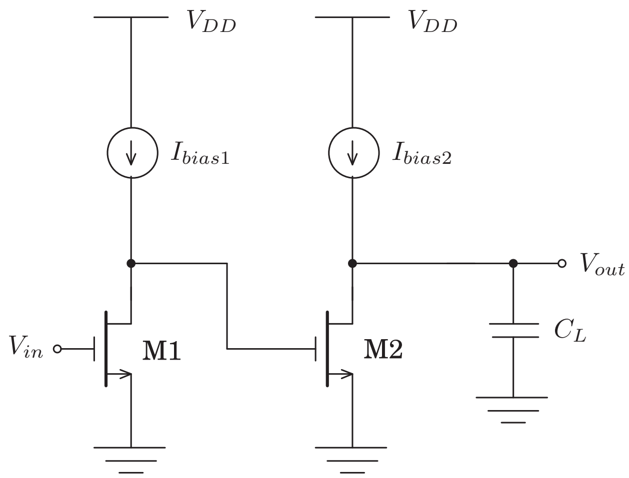

Figure 4: A noisy multi-stage amplifier.

Determine an expression for the spectral density R_{out} of the output thermal noise assuming that the noise from the transistors are uncorrelated. (5p)

Transistor formulas and noise

1 CMOS transistors

Current and threshold voltage formulas and operating regions for an NMOS transistor

Cut-off: $V_{GS} < V_t$ $\quad I_D \approx 0$

Linear: $V_{GS} - V_t > V_{DS} > 0$ $\quad I_D = \alpha(2(V_{GS} - V_t) - V_{DS})V_{DS}$

Saturation: $0 < V_{GS} - V_t < V_{DS}$ $\quad I_D = \alpha(V_{GS} - V_t)^2(1 + \lambda(V_{DS} - V_{eff}))$

$V_{eff} = V_{DSmin} = V_{GSmin} - V_t$

All regions: $V_t = V_{t,0} + \gamma(\sqrt{2\phi_F - V_{BS}} - \sqrt{2\phi_F})$

Small-signal parameters

Linear: $g_m \approx 2\alpha V_{DS}$ $\quad g_{ds} \approx 2\alpha(V_{GS} - V_t - V_{DS})$

Saturation: $g_m \approx 2\sqrt{\alpha I_D}$ $\quad g_{ds} \approx \lambda I_D$

Constants: $\alpha = \frac{1}{2}\mu_{0n}C_{ox}\frac{W}{L}$ $\qquad \lambda = \sqrt{\frac{K_s\epsilon_0}{2qN_A\phi_0}} \cdot \frac{1}{L}$ $\qquad \gamma = \frac{\sqrt{2qN_AK_s\epsilon_0}}{C_{ox}}$

2 Circuit noise

Thermal noise in CMOS transistors
The thermal noise spectral density at the gate of a CMOS transistor is

$$V^2(f) = \frac{8kT}{3} \cdot \frac{1}{g_m}$$

Thermal noise in resistors
The thermal noise spectral density of a resistor is modeled as a parallel noise current source

$$I^2(f) = \frac{4kT}{R}$$

Flicker noise in CMOS transistors
The flicker noise spectral density at the gate of a CMOS transistor is

$$V^2(f) = \frac{K}{WLC_{ox}f}$$