Exam UE4002 Summer 2009

Each part of each question carries equal marks.
The body effect may be ignored in each question.
The following equation is given for the drain current of an NMOS in saturation:

$$I_D = \frac{K_n'}{2}\frac{W}{L}(V_{GS} - V_{tn})^2(1 + \lambda_n V_{DS})$$

For dc biasing calculations take $\lambda_n = \lambda_p = 0$.
In each question, capacitances other than those mentioned may be ignored.

Question 1

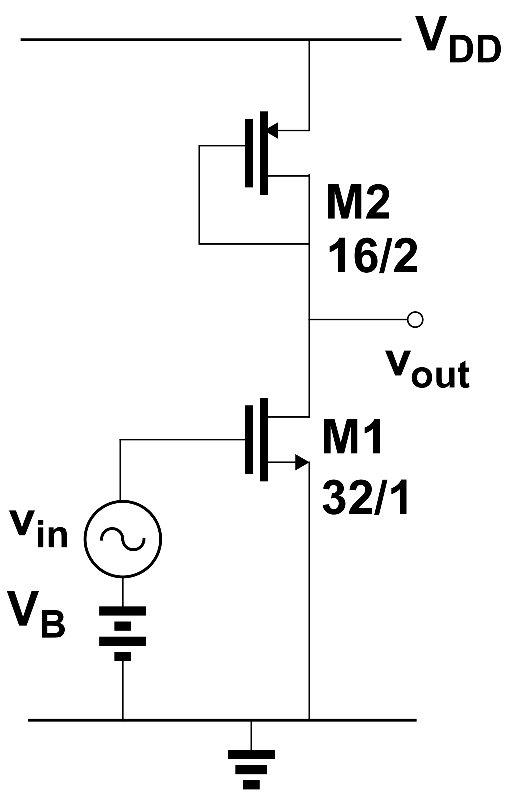

Figure 1a

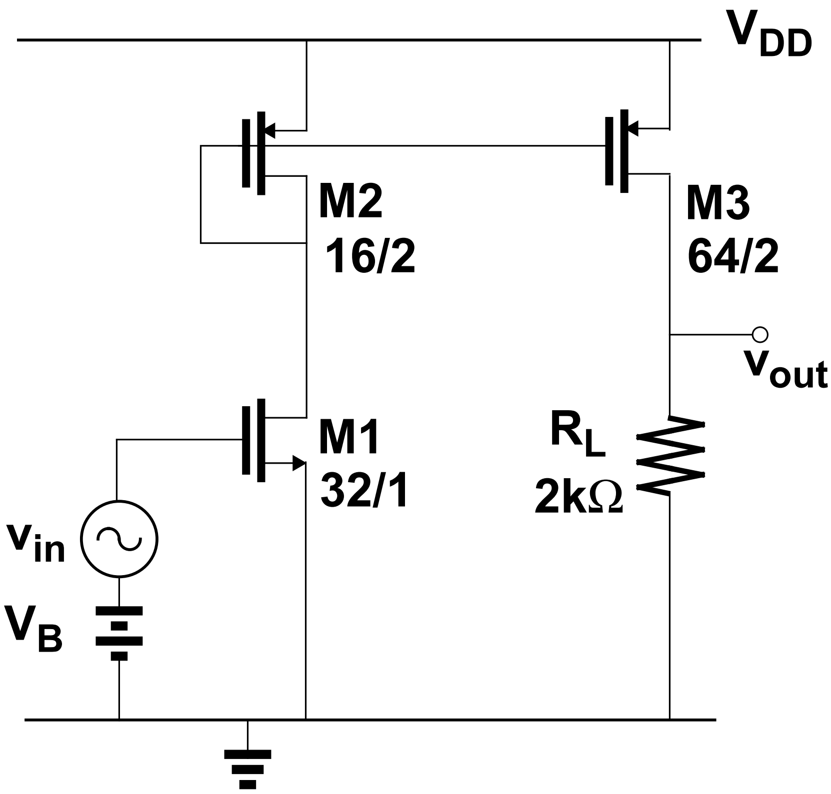

Figure 1b

For the questions below you may assume $g_{m1}, g_{m2} >> g_{ds1}, g_{ds2}$ and that all devices are biased in saturation.

(i) Figure 1a shows a gain stage with a diode-connected load.
Draw the small-signal model for this circuit.

(ii) Derive an expression for the small signal voltage gain (v_{out}/v_{in}).

(iii) Calculate the drain current of M1 and the small-signal voltage gain (v_{out}/v_{in}) in dB if
V_B=1V, $V_{tn}=|V_{tp}|$=0.75V, K_n'=200µA/V^2 , K_p'=50µA/V.
Transistor dimensions in microns are as shown in Figure 1a.

(iv) Calculate the small-signal voltage gain (v_{out}/v_{in}) of the circuit shown in Figure 1b.
Assume $g_{ds3} << 1/R_L$.

Question 2

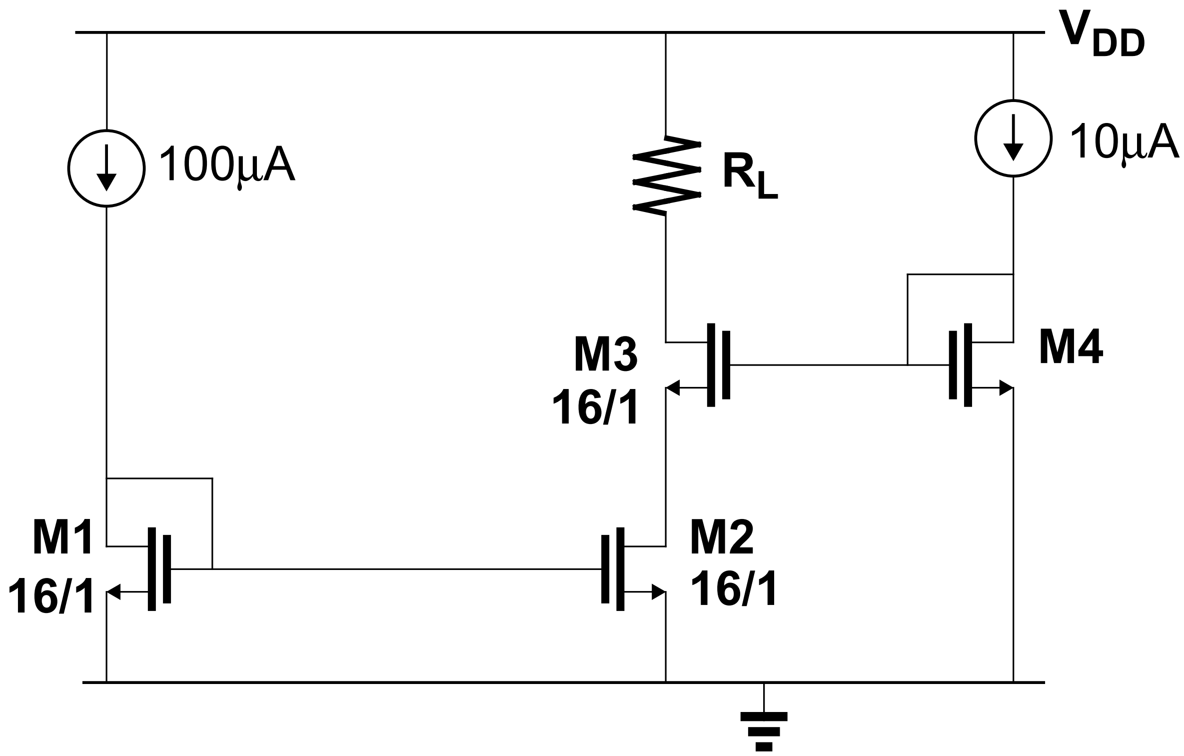

Figure 2

Figure 2 shows an nmos current mirror (M1, M2) with cascoded output. The bias voltage for the cascode is generated by the diode-connected nmos M4 which is biased by a current source as shown.

For this question $K_n' = 200\mu A/V^2$, $V_{tn} = 750mV$, $V_{DD} = 5V$.

The device sizes of M1, M2 and M3 in microns are as indicated in Figure 2.

All devices are biased in saturation.

(i) What is the minimum voltage at the drain of M2 such that M2 is just biased in saturation?
If M4 has L=10, what is the required value of W for M4 such that M2 is just biased in saturation, assuming M3 is in saturation?

(ii) What is then the maximum value of R_L such that M3 is also biased in saturation?

(iii) With M2 just biased in saturation, estimate the percentage inaccuracy of the current mirror due to the finite output conductance of M1 and M2.
For this calculation take $\lambda_n = 0.04V^{-1}$.

(iv) Estimate the 3 sigma percentage inaccuracy of the current mirror due to transistor V_{tn} mismatch.
Note: Assume the mismatch is normally distributed and that the 1 sigma V_{tn} mismatch of a transistor pair (in mV) is given by

$$\sigma_{Vtn} = \frac{A_{Vtn}}{\sqrt{WL}}$$

Take $A_{Vtn} = 10mV\mu m$.

Question 3

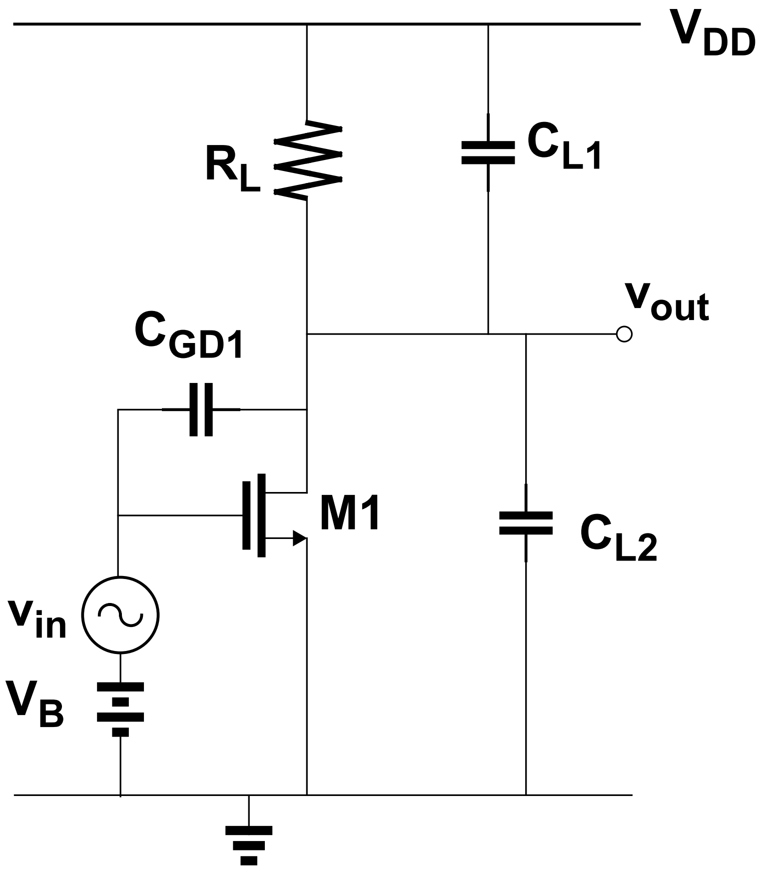

Figure 3

For the questions below you may assume $g_{ds1} << 1/R_L$ and that M1 is biased in saturation.

(i) Figure 3 shows a gain stage with an RC load. Draw the small-signal model for this circuit.

(ii) Ignoring all capacitances except C_{GD1}, C_{L1} and C_{L2}, derive an expression for the high-frequency transfer function from v_{in} to v_{out}.

(iii) Calculate the low-frequency gain (v_{out}/v_{in}) and the break frequencies (i.e. pole and/or zero frequencies) if V_B=1V, V_{tn}=0.75V, I_{D1}=250µA, C_{GD1}=0.2pF, C_{L1}=4pF, C_{L2}=5.8pF, R_L=10kΩ.

(iv) Draw a Bode diagram of the gain response. Indicate the values of gain at d.c. and at frequencies well above the pole and/or zero frequencies.

Question 4

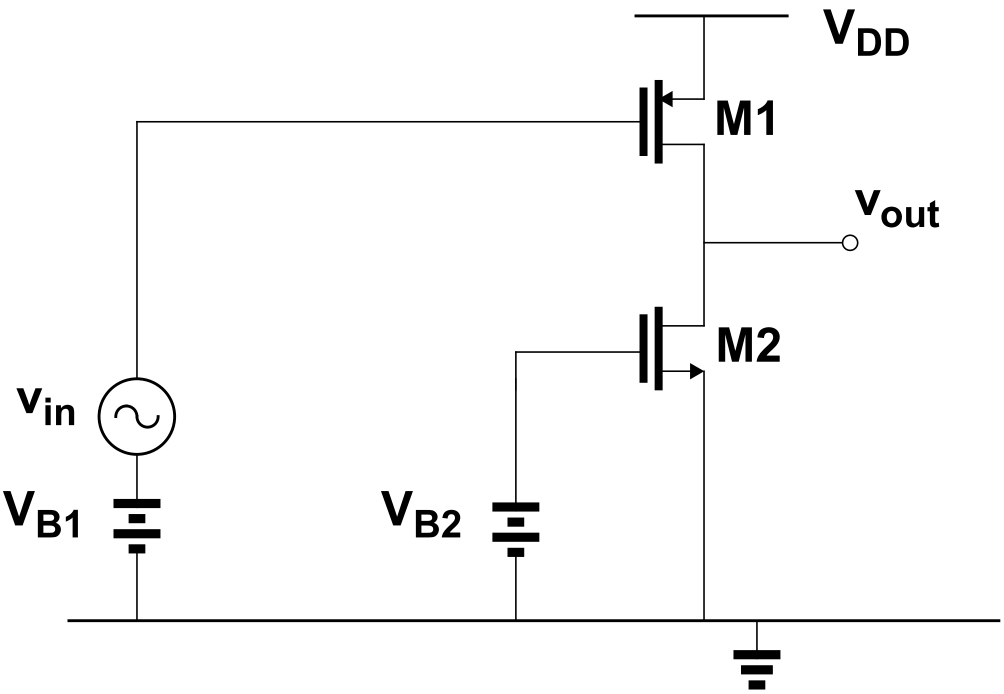

Figure 4

Assume M1 and M2 are operating in saturation. Only thermal noise sources need be considered.

For calculations take Boltzmann's constant $k=1.38X10^{-23}J/^oK$, temperature $T=300^oK$.

(i) Draw the small-signal model for the circuit shown in Figure 4.
What is the low-frequency small-signal voltage gain (v_{out}/v_{in}) in terms of the small-signal parameters of M1 and M2?

(ii) What is the input-referred thermal noise voltage density of the circuit shown in Figure 4?
The answer should be in terms of the small-signal parameters of M1 and M2, Boltzmann's constant k and temperature T.

(iii) Calculate the input-referred thermal noise voltage density of the circuit if
$V_{B1}=2.0V$, $V_{B2}=1.75V$, $V_{DD}=3V$, $V_{tn} = 0.75V$, $V_{tp} = -0.75V$, $\lambda_n=\lambda_p=0.04V^{-1}$.
The drain current of M2 is $200\mu A$.
What is the thermal noise voltage density at the output of the circuit?

(iv) If the input signal v_{in} is a $1mV_{rms}$ sine wave with negligible noise, calculate the maximum bandwidth for which the signal-to-noise ratio at the output is 60dB.