UE4002 Summer 2007

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

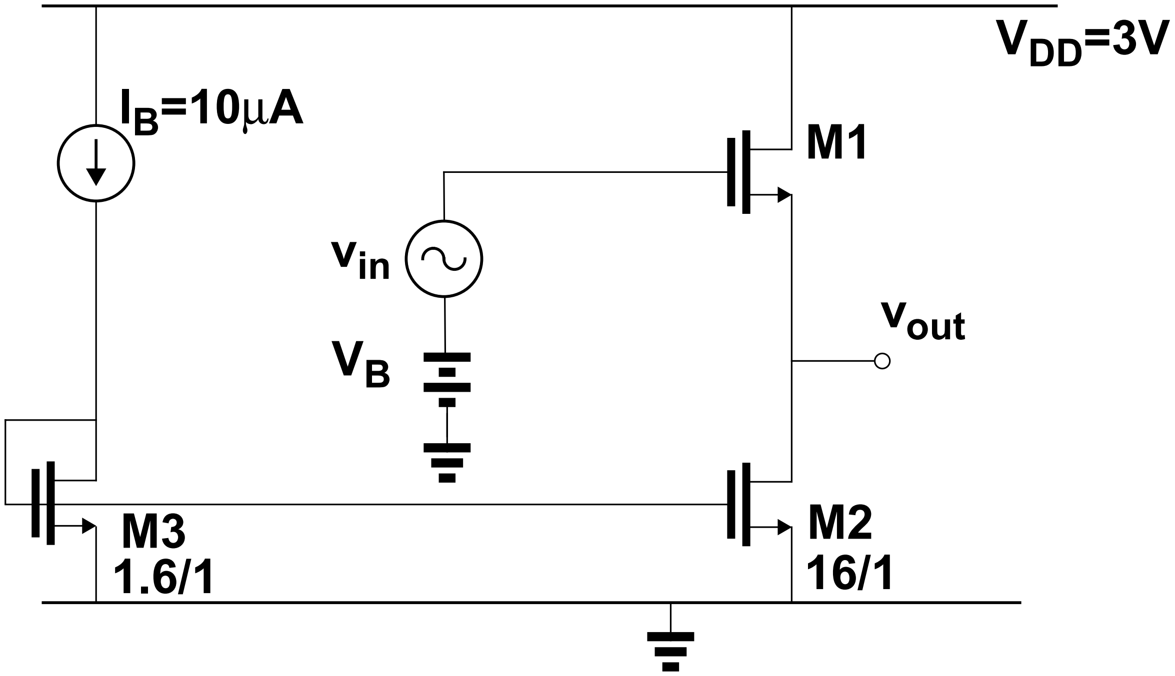

Figure 1

Figure 1 shows an NMOS source follower.

Biasing and transistor dimensions are as shown in Figure 3. Take $K_n' = 200\mu A/V^2$, V_{tn}=750mV.

Assume all transistors are in saturation.

(i) Draw the small-signal equivalent circuit for the source follower stage shown in Figure 1.

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

(iii) The source follower is to be used as a DC level-shifter, where the DC voltage at the source of M1 is 1V lower than at the gate of M1.
What value of W/L is required for M1 to achieve this?

(iv) What are the minimum and maximum values of V_B for which the levelshifter works as required?

Question 2

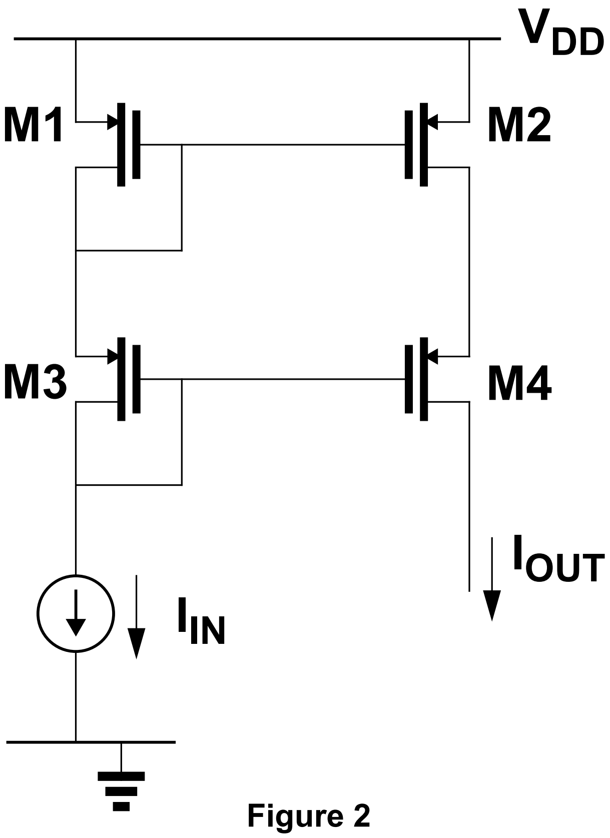

Figure 2

Figure 2 shows a cascoded current mirror.
Assume $I_{IN}=I_{OUT}=100\mu A$, $V_{DD}=3V$, $K_p'=50\mu A/V^2$, $V_{tp}=-750mV$.
All transistors have W/L=64/1.

(i) It is required to measure the small-signal output resistance of the current mirror (i.e. the small-signal resistance looking into the drain of M4). Draw a small-signal model showing how this can be done.

(ii) Derive an expression for the small-signal output resistance.
Reduce this to its simplest form assuming $g_{m1}, g_{m2}, g_{m3}, g_{m4} >> g_{ds1}, g_{ds2}, g_{ds3}, g_{ds4}$.

(iii) What is the maximum voltage at the output node, i.e. the drain of M4, such that all transistors are biased in saturation?

(iv) It is desired to increase the mirroring ratio by increasing the width of M2 only. What is the largest value of output current I_{OUT} such that M2 remains in saturation?

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Question 3

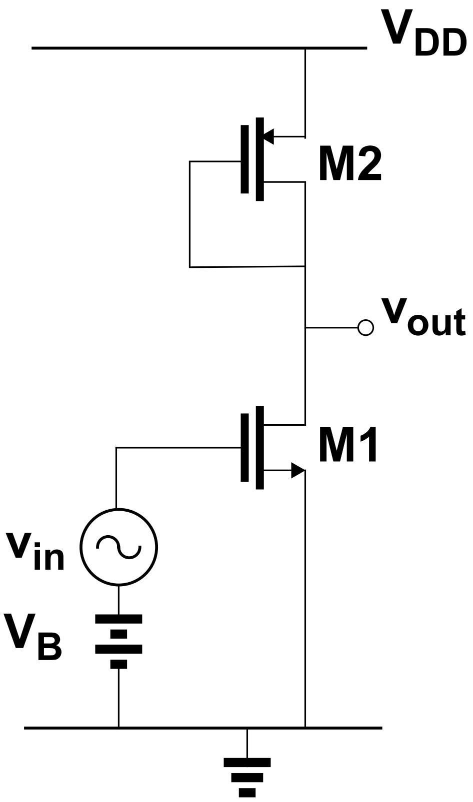

Figure 3a

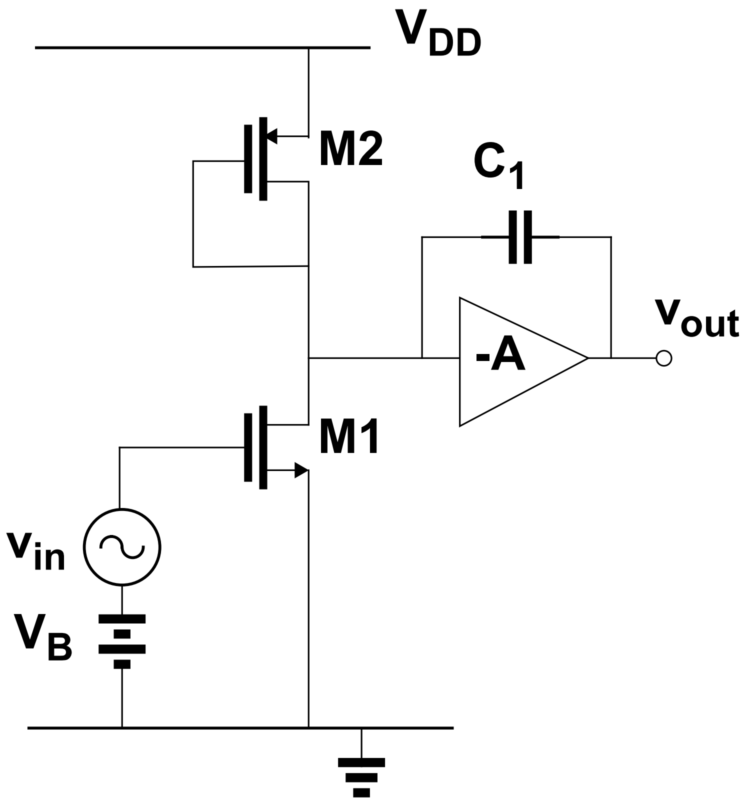

Figure 3b

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 3a shows a gain stage with a diode-connected load.
Draw the small-signal model for this circuit.
Give an expression for the small-signal voltage gain (v_{out}/v_{in}).

(ii) In Figure 3b the amplifier of Figure 3a is cascaded with an ideal amplifier with a small-signal gain of -A.
Give an expression for the small-signal low-frequency voltage gain (v_{out}/v_{in}) of this circuit.
Give also an expression for the frequency of the dominant pole of the circuit shown in Figure 3b.

(iii) Calculate the small-signal low-frequency voltage gain (v_{out}/v_{in}) in dB, and the dominant pole frequency of the circuit shown in Figure 3b if
V_B=1V,$|V_{GS2}|$=1.75V, V_{tn}=$|V_{tp}|$=0.75V, I_{D1}=200µA, A=-50, C_1=100pF

(iv) Assuming the circuit shown in Figure 3b is first-order, give an expression for its unity gain frequency.
What is the effect on the unity gain frequency if V_B is increased to 1.25V, assuming M1 remains in saturation?

Question 4

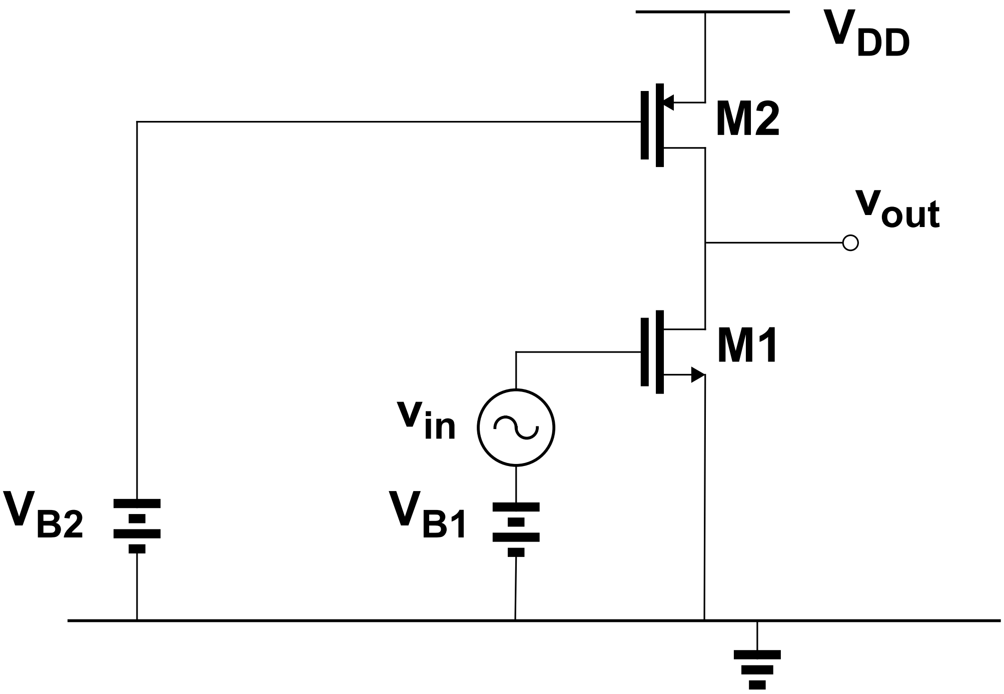

Figure 4

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/^{o}K, temperature T=300^{o}K.

(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 M1?
What is the input-referred thermal noise voltage density of M2?
Answers 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 M1 and the input-referred thermal noise voltage density of M2 if
V_{B1}=1.0V, V_{B2}=1.25V, V_{DD}=3V, V_{tn} = 0.75V, V_{tp} = -0.75V, $\lambda_n=\lambda_p=0.04V^{-1}$.
The drain current of M1 is 100μA.
Which is the dominant noise source?

(iv) Calculate the total noise voltage at the output over a bandwidth of 1MHz.
If the input signal v_{in} is a 1mV_{rms} sine wave, calculate the signal-to-noise ratio in dB at the output over a bandwidth of 1MHz.