Solutions UE4002 Summer 2010

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

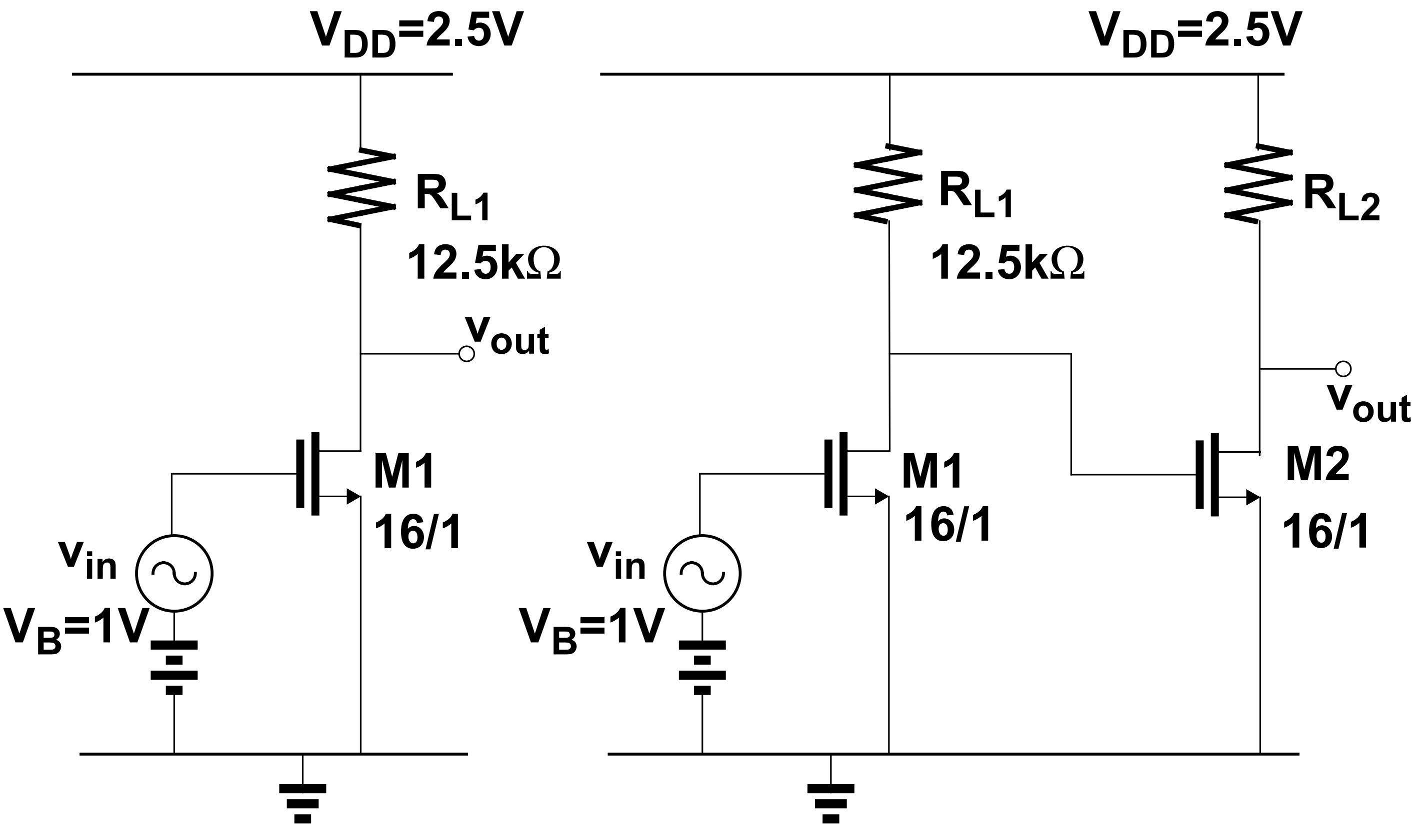

Figure 1a **Figure 1b**

For the questions below you may assume $g_{ds1}, g_{ds2} << 1/R_{L1}, 1/R_{L2}$ and that all devices are biased in saturation.
DC bias voltages, transistor dimensions and resistor values are as shown in the figures.
Take $K_n' = 200\mu A/V^2$, $V_{tn} = 0.75V$.

(i) Figure 1a shows a gain stage with a resistive load.
Draw the small-signal model for this circuit.
Derive an expression for the small signal voltage gain (v_{out}/v_{in}).
(ii) For the circuit in Figure 1a, calculate the drain current of M1 and the small-signal voltage gain (v_{out}/v_{in}) in dB.
(iii) Calculate the drain current of M2 in the circuit shown in Figure 1b.
(iv) Calculate the maximum small-signal voltage gain (v_{out}/v_{in}) of the circuit shown in Figure 1b.

Question 2

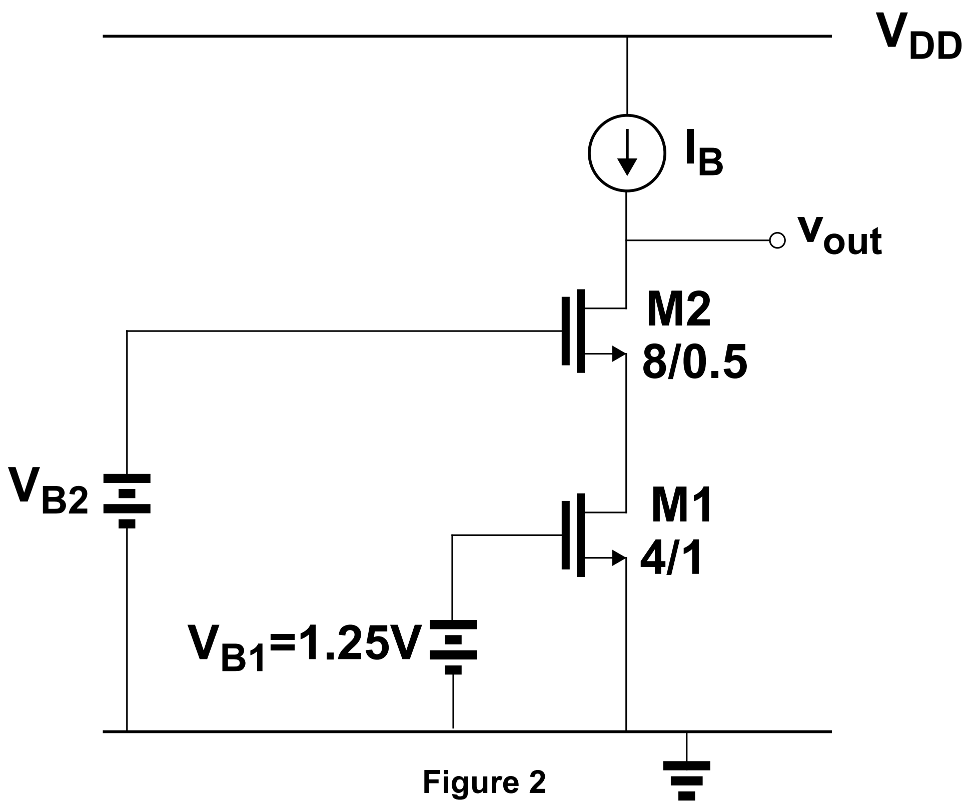

Figure 2

Figure 2 shows a cascode stage with an ideal current source load.
Biasing and transistor dimensions are as shown in Figure 2.
Take $K_n' = 200\mu A/V^2$, $V_{tn} = 0.75V$.
Assume all transistors are biased in saturation.

(i) What is the minimum value of V_{B2} such that M1 is in saturation?
What is then the minimum voltage at the output node (v_{out}) such that M2 is in saturation?

(ii) Draw a small-signal equivalent circuit of the cascode stage, showing how to measure the small-signal output resistance i.e. the resistance looking into the node v_{out}.

(iii) Derive an expression for the small-signal output resistance in terms of the small-signal parameters of M1 and M2.
Simplify the expression assuming $g_{m1}, g_{m2}, >> g_{ds1}, g_{ds2}$.

(iv) Calculate the small-signal output resistance.
Take $\lambda_n = 0.04/L\ V^{-1}$ with L in microns.

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Question 3

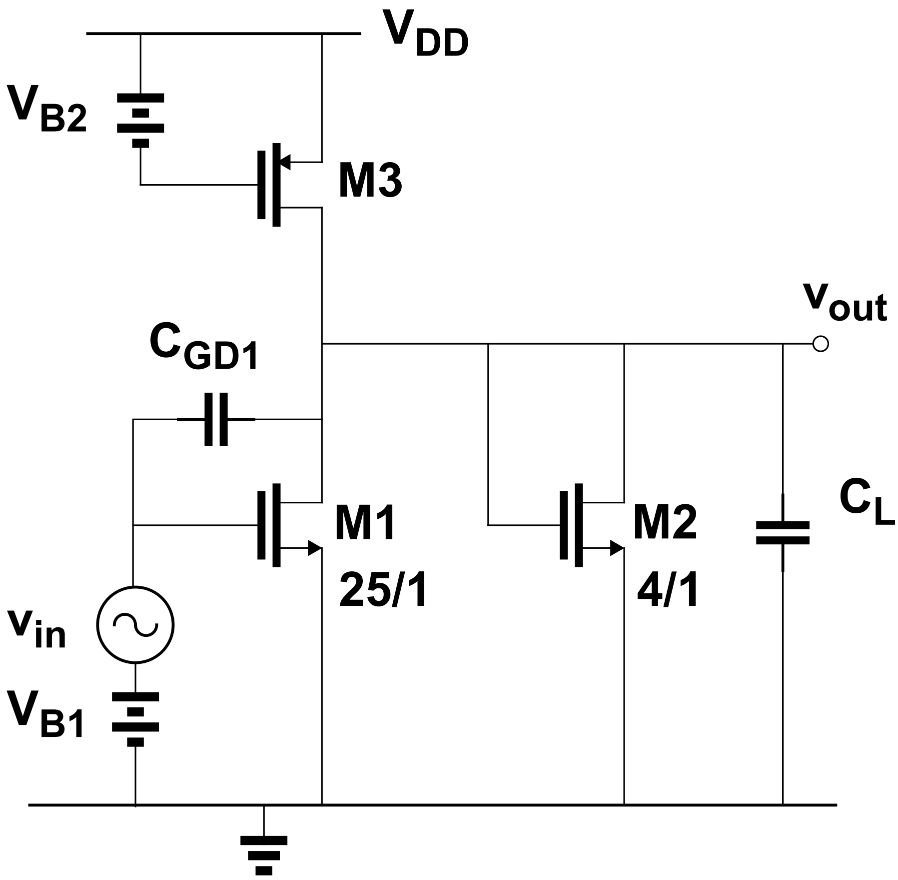

Figure 3

For the questions below you may assume $g_{m1},g_{m2}>>g_{ds1},g_{ds2},g_{ds3}$, and that all transistors are biased in saturation. Transistor dimensions are as shown in Figure 3.

(i) Figure 3 shows a capacitively loaded gain stage. Draw the small-signal model for this circuit.

(ii) Ignoring all capacitances except C_{GD1},and C_L, 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 $K_n'=200\mu A/V^2$, $I_{D1}=100\mu A$, $|I_{D3}|=200\mu A$, $C_{GD1}=0.1pF$, $C_L=7.9pF$.

(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

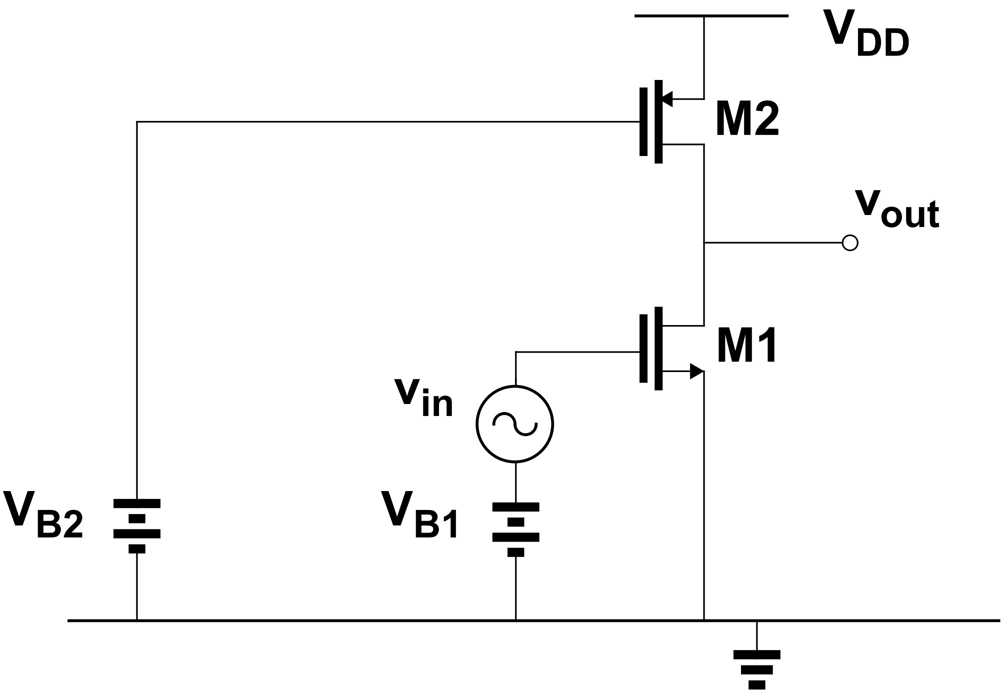

Figure 4

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

For calculations take Boltzmann's constant $k=1.38\text{X}10^{-23}\,\text{J/}^{o}\text{K}$, temperature $T=300^{o}\text{K}$.

(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 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}=1.0V, V_{B2}=1.75V, V_{DD}=3V, V_{tn} = 0.75V, V_{tp} = -0.75V, $\lambda_n=\lambda_p=0.04\text{V}^{-1}$.
The drain current of M2 is 100µA.
Calculate the thermal noise voltage density at the output of the circuit.

(iv) What minimum value of input signal is required for an output signal-to-noise ratio of 60dB over a bandwidth of 1MHz?