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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

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SUMMER EXAMINATIONS, 2013
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FOURTH YEAR ENGINEERING (ELECTRICAL AND ELECTRONIC)

ANALOG IC DESIGN
UE4002

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Time allowed **1 ½ Hours**
Answer three out of four questions.
70% of the module marks are allocated to this exam.
The exam is marked out of 60 and the result converted to a mark out of 70.
Each question carries a total of 20 marks with each sub-part carrying 5 marks.

The use of an approved calculator is permitted.

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

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

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

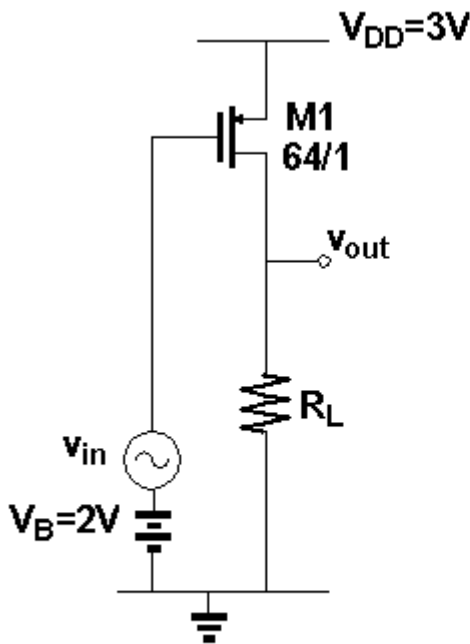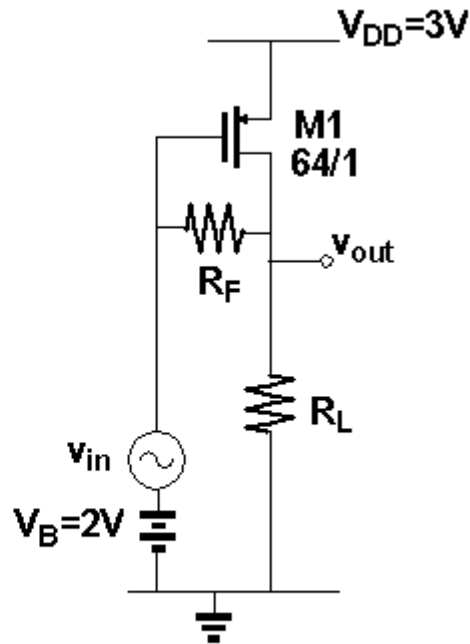**Exam Questions Begin On The Next Page**

Question 1

Figure 1a

Figure 1b

You may assume R_L, R_F << $1/g_{ds1}$. Take $|V_{tp}| = 0.75V$, $K_p'=50\mu A/V^2$, $R_L=15k\Omega$, $R_F=5k\Omega$. Bias voltages and transistor dimensions (in microns) are as shown in the Figures 1a and 1b.

Assume M1 is in saturation.

   (i)   Draw the small-signal equivalent circuit for the circuit shown in Figure 1a and derive an expression for the small-signal voltage gain (v_{out}/v_{in}) of the circuit.

   (ii) For the circuit in Figure 1a, calculate the value of the small-signal voltage gain in dB.

   (iii) Draw the small-signal equivalent circuit for the circuit shown in Figure 1b and derive an expression for the small-signal voltage gain (v_{out}/v_{in}) of the circuit.

   (iv) For the circuit in Figure 1b, calculate the value of the small-signal voltage gain in dB.
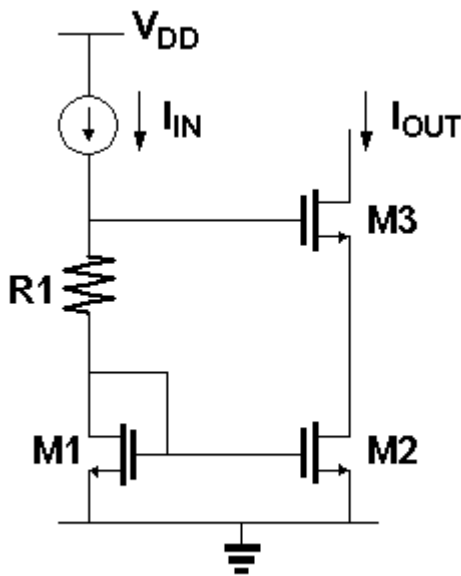
Question 2

Figure 2

Figure 2 shows a cascoded current mirror.
Assume $K_n'=200\mu A/V^2$, $V_{tn}=800mV$.
All transistors have W/L=25μm/2μm.

(i) If $I_{IN}=I_{OUT}=200\mu A$, what is the minimum voltage at the output node, i.e. the drain of M3, such that all transistors are biased in saturation?
What minimum value of R1 is required to ensure M2 is in saturation?

(ii) The current mirror is modified by changing M2 and R1 only.
What W/L of M2 and minimum value of R1 would be required to increase the output current to 800μA and still ensure all transistors are in saturation?

(iii) 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 M3). Draw a small-signal equivalent circuit showing how this can be done.
You may assume that the gates of M2 and M3 are at small-signal ground.

(iv) Derive an expression for the small-signal output resistance, and reduce this to its simplest form assuming
g_{m1}, g_{m2}, g_{m3} >> g_{ds1}, g_{ds2}, g_{ds3}.
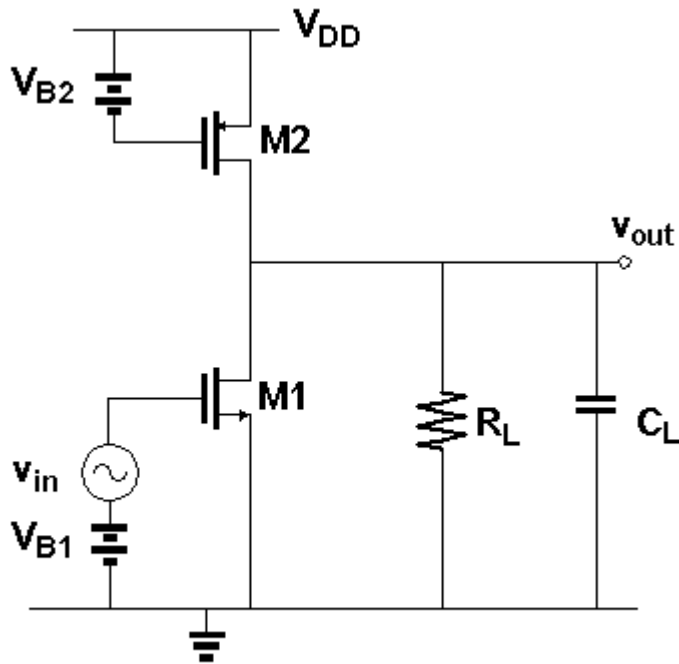
Question 3

Figure 3

For the questions below you may assume $1/R_L \gg g_{ds1}, g_{ds2}$, and that all transistors are biased in saturation.

All transistors have W/L=25μm/1μm.

Take $K_n' = 200\mu A/V^2$, $I_{D1} = 100\mu A$

(i) Draw the small-signal equivalent circuit of the gain stage shown in Figure 3.

(ii) Derive an expression for the high-frequency transfer function from v_{in} to v_{out}.

(iii) What value of R_L is required to give a small-signal dc gain (v_{out}/v_{in}) of 20dB?

(iv) With the value of R_L calculated in (iii), what value of C_L is required to give a small-signal gain of -40dB at 10MHz?

Draw a Bode diagram of the gain response. Indicate the value of d.c. gain and the pole frequency.

Question 4
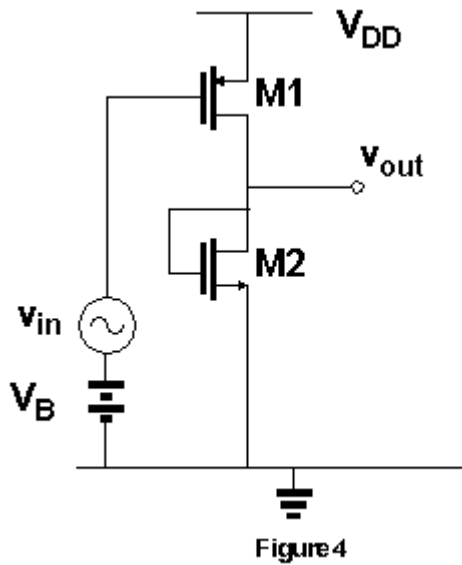
Figure 4

Assume M1 and M2 are operating in saturation.
Only thermal noise sources need be considered.
For calculations take Boltzmann's constant $k=1.38 \times 10^{-23}$ J/°K, temperature T=300°K

For the circuit shown in Figure 4:

(i) Draw the small-signal equivalent circuit.
Give an expression for the low-frequency small-signal voltage gain (v_{out}/v_{in}) of the circuit?
Assume that $g_{m1}, g_{m2} >> g_{ds1}, g_{ds2}$.

(ii) Give an expression for the input-referred thermal noise voltage density 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.
For this calculation take $|V_{GS1}| = 1$V, $V_{GS2} = 2.8$V, $V_{tn} = 0.8$V, $|V_{tp}| = 0.8$V.
The drain current of M1 is 100μA.

(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 in this bandwidth, calculate the signal-to-noise ratio in dB at the output over the bandwidth of 1MHz.