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THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2012

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
Each part of each question carries equal 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:

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

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

Exam Questions Begin On The Next Page

Question 1

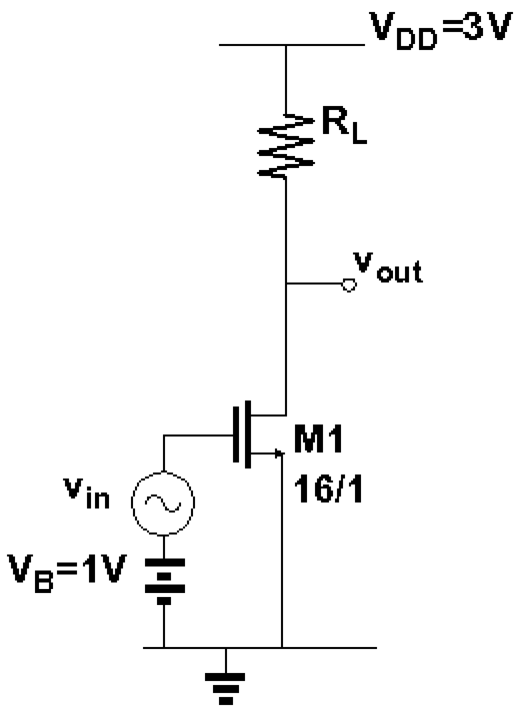

Figure 1a

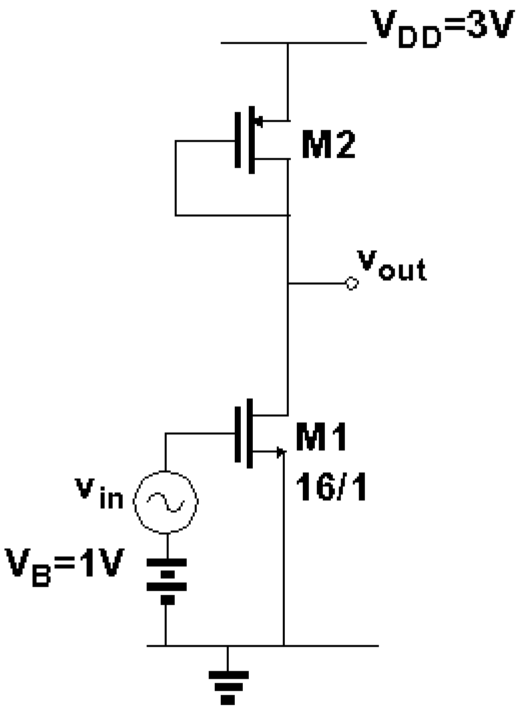

Figure 1b

You may assume $g_{m1} >> g_{ds1}, g_{ds2}$ and $R_L << 1/g_{ds1}$.
Take $V_{tn} = |V_{tp}| = 0.75V$, $K_n' = 200\mu A/V^2$.
Bias voltages and transistor dimensions (in microns) are as shown in the Figures 1a and 1b.

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

(ii) Derive an expression for the small-signal voltage gain (v_{out}/v_{in}) of the circuit in Figure 1a.

(iii) For the circuit in Figure 1a, calculate the value of R_L which gives the maximum small-signal voltage gain, and calculate the value of this voltage gain in dB.

(iv) If R_L in Figure 1a is replaced by a PMOS as shown in Figure 1b, calculate the maximum small-signal voltage gain of the circuit in Figure 1b?

Question 2

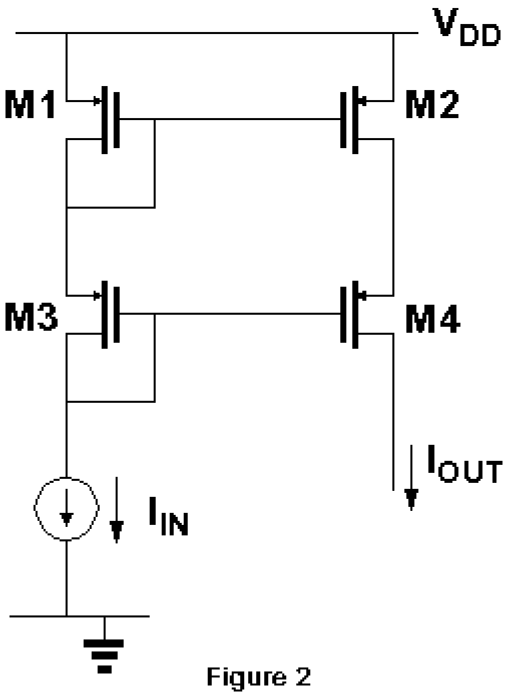

Figure 2

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 current 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?

Question 3

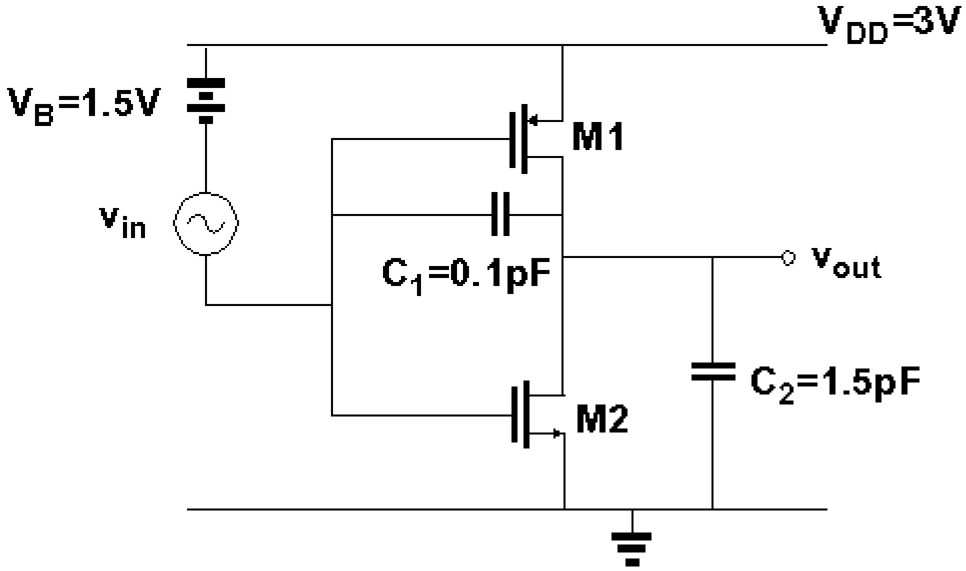

Figure 3

Biasing and component values are as shown in Figure 3.
Take V_{tn}=0.7V, V_{tp}=-0.7V, $\lambda_n=\lambda_p=0.04V^{-1}$.

(i) Draw the small-signal equivalent circuit for the CMOS inverter stage shown in Figure 3.

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

(iii) Calculate the low-frequency gain (v_{out}/v_{in}) in dB, and the break frequencies (i.e. pole and/or zero frequencies).
Assume both transistors are in saturation with a drain current of 200µA.

(iv) Draw a Bode diagram of the gain response.
What is the approximate value of gain at 100Grad/s?

Question 4

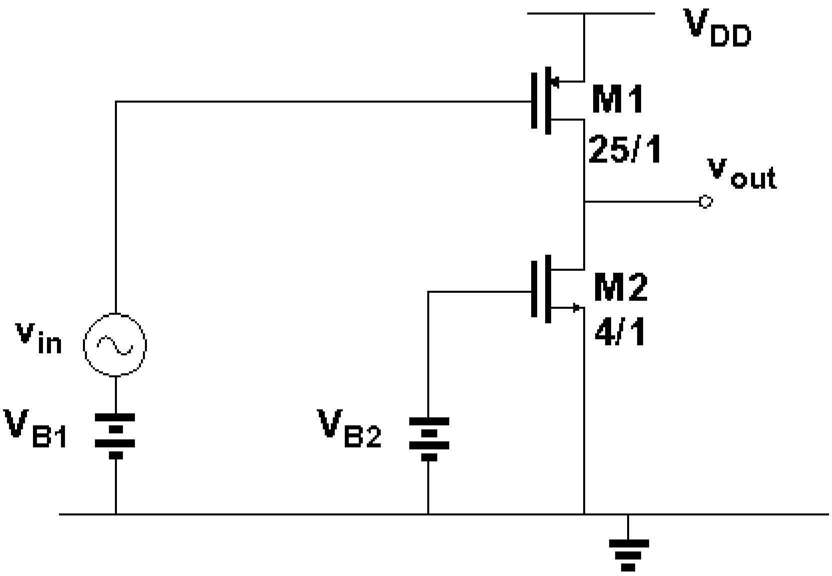

Figure 4

Assume M1 and M2 are operating in saturation.
The dimensions of M1 and M2 (in microns) are as shown in Figure 4.
Take $K_n^{'}$=200μA/V^2, $K_p^{'}$=50μA/V^2, I_{D1}=100μA.
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 small-signal voltage gain (v_{out}/v_{in}) in terms of the small-signal parameters of M1 and M2?

(ii) What is the thermal noise voltage density at the output 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 signal-to-noise ratio at the output over a bandwidth of 1MHz if the input signal is 1mVrms.

(iv) It is desired to increase the signal-to-noise ratio by increasing the current through the transistors only. What current would be required to improve the signal-to-noise ratio at the output by 6dB?