UE 4010 Summer 2005 Part A

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

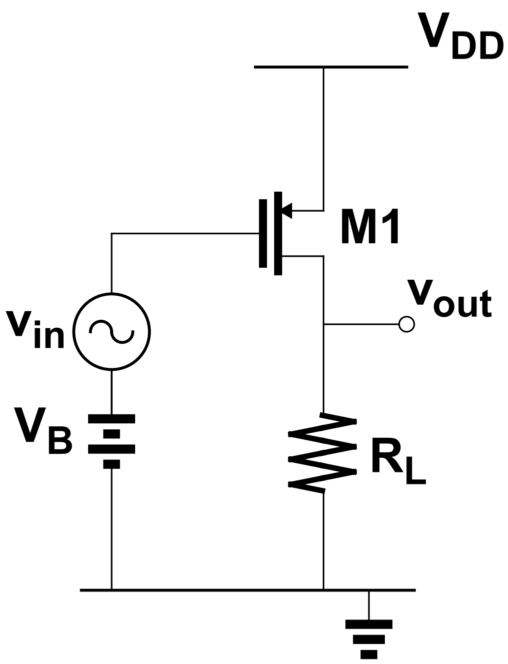


Figure 1a

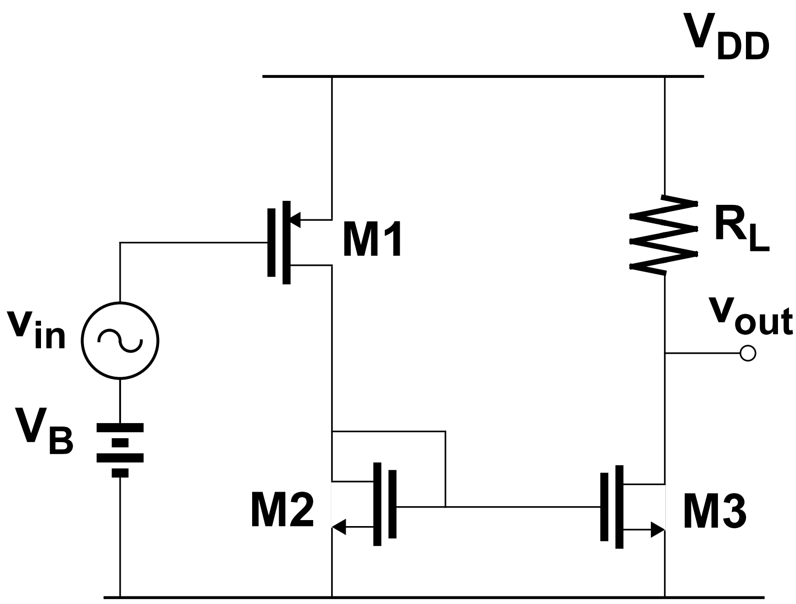


Figure 1b

(i) Draw the small-signal equivalent circuit for the gain stage shown in Figure 1a.
(ii) Derive an expression for the small-signal voltage gain (v_{out}/v_{in}) in terms of the small-signal parameters and R_L.
(iii) What is the largest value of gain in dB that can be achieved by increasing R_L?
Assume V_{DD}=3V, V_B = 1.7V, V_{tp}= -0.8V. K_p'=50µA/V^2, W_1=20µm, L_1=1µm, R_L<<$1/g_{ds1}$.
(iv) In Figure 1b, M3 has twice the width of M2 but the same length. Give an expression for the small-signal voltage gain (v_{out}/v_{in}) of this circuit in terms of the small-signal parameters and R_L .

Question 2

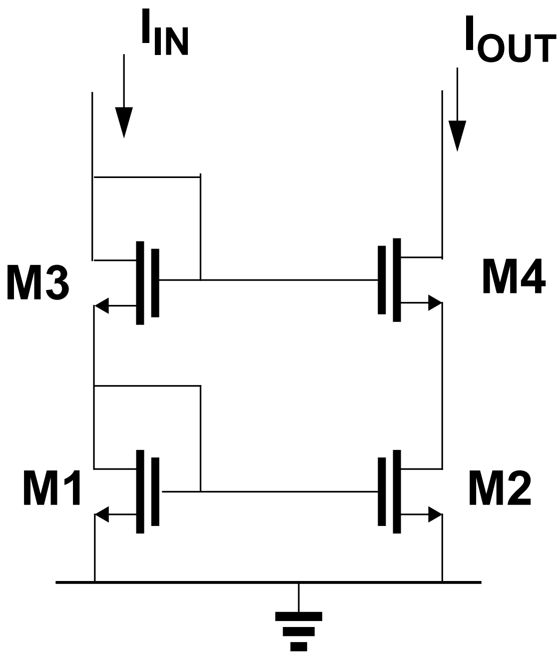


Figure 2

Figure 2 shows a cascoded current mirror.
Assume I_{IN}=I_{OUT}=100µA, K_n'=200µA/V^2, V_{tn}=750mV, λ_n = 0.04V^{-1}.
All transistors have W/L=16/1.

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

(ii) Derive an expression for the small-signal output resistance.
Assume g_{m1}, g_{m2}, g_{m3}, g_{m4} >> g_{ds1}, g_{ds2}, g_{ds3}, g_{ds4}.

(iii) What is the change in current if the voltage at the output node varies by 10mV?
Assume all transistors are 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 such that M2 remains in saturation?

Question 3

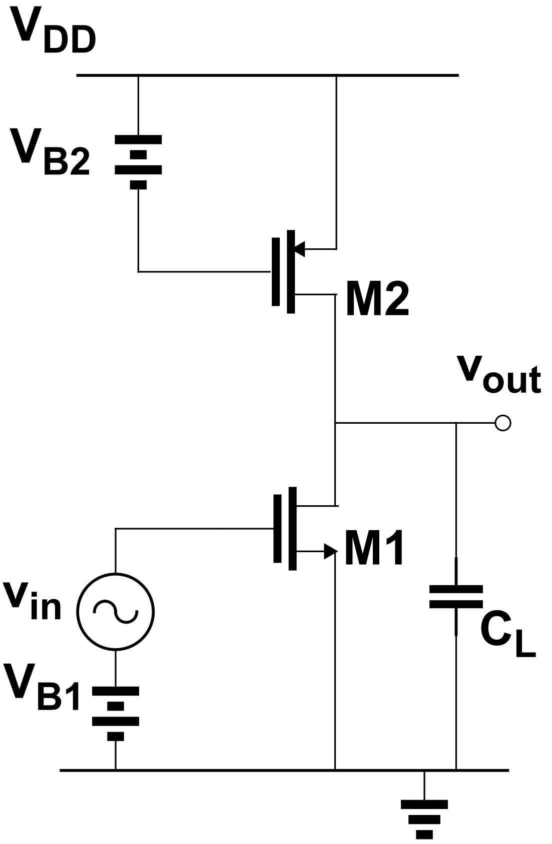


Figure 3a

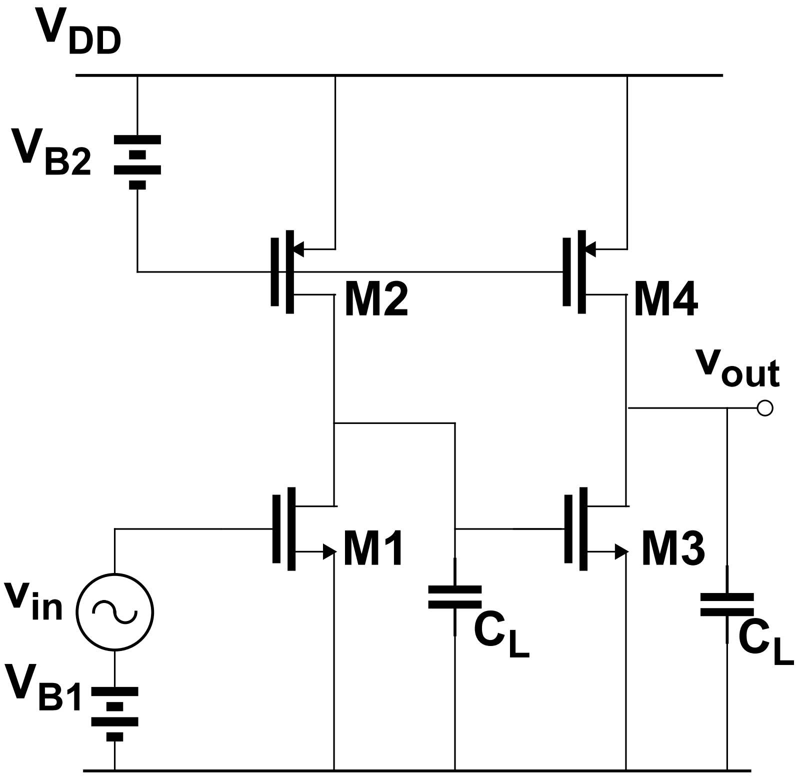


Figure 3b

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

(ii) Ignoring all capacitances except C_L, derive an expression for the high frequency transfer function (v_{out}/v_{in}).

(iii) Draw a Bode diagram of the gain. Indicate the values of the dc gain in dB, the pole frequency and the high-frequency roll-off if
V_{B1}=1.1V, V_{tn}=0.7V, V_{tp}=-0.7V, $\lambda_n=\lambda_p$=0.02V^{-1}, C_L=1pF.
Assume both transistors are in saturation with a drain current of 200μA.

(iv) The circuit shown in Figure 3a is cascaded with an identical stage with an identical load capacitance as shown in Figure 3b . Draw the Bode diagram of the gain of the cascaded circuit, indicating the values of the dc gain in dB, the pole frequency and the high-frequency roll-off.

Question 4

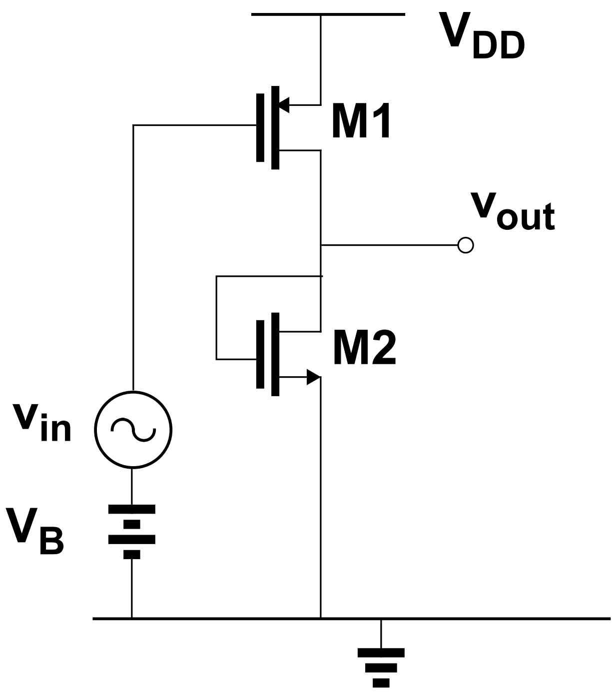


Figure 4

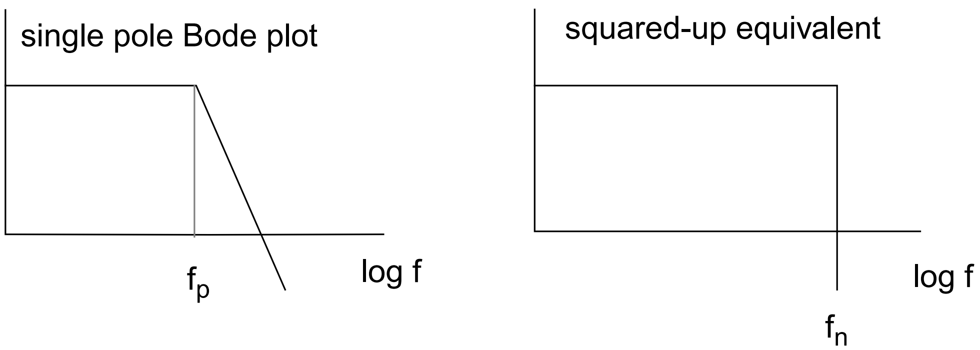
Assume M1 and M2 are operating in saturation.

(i) What is the low-frequency small signal voltage gain (v_{out}/v_{in}) of the circuit shown in Figure 4? Assume that $g_{m1}, g_{m2} >> g_{ds1}, g_{ds2}$.

(ii) What is the input-referred thermal noise voltage in terms of the small signal parameters of M1 and M2, Boltzmann's constant k and temperature T?

(iii) If a capacitor C_L is connected between the output node and ground what is the total integrated thermal noise at the output node?

You may assume the following:



For the area underneath the curves to be the same then $f_n=(\pi/2)*f_p$

(iv) It is desired to limit the bandwidth such that a signal-to noise ratio of 60dB is achieved at the output, when the input is a 1mVrms sine wave with a frequency much lower than the frequency of the pole at the output node. Using the result of (iii) calculate the minimum value of C_L required.
For this calculation take $|V_{GS1}|$ = 1V, V_{GS2} = 2.8V, V_{tn} = 0.8V, V_{tp} = -0.8V.
The drain current of M1 is 100μA.
Assume Boltzmann's constant k=1.38X10^{-23}J/^{o}K, temperature T=300^{o}K