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

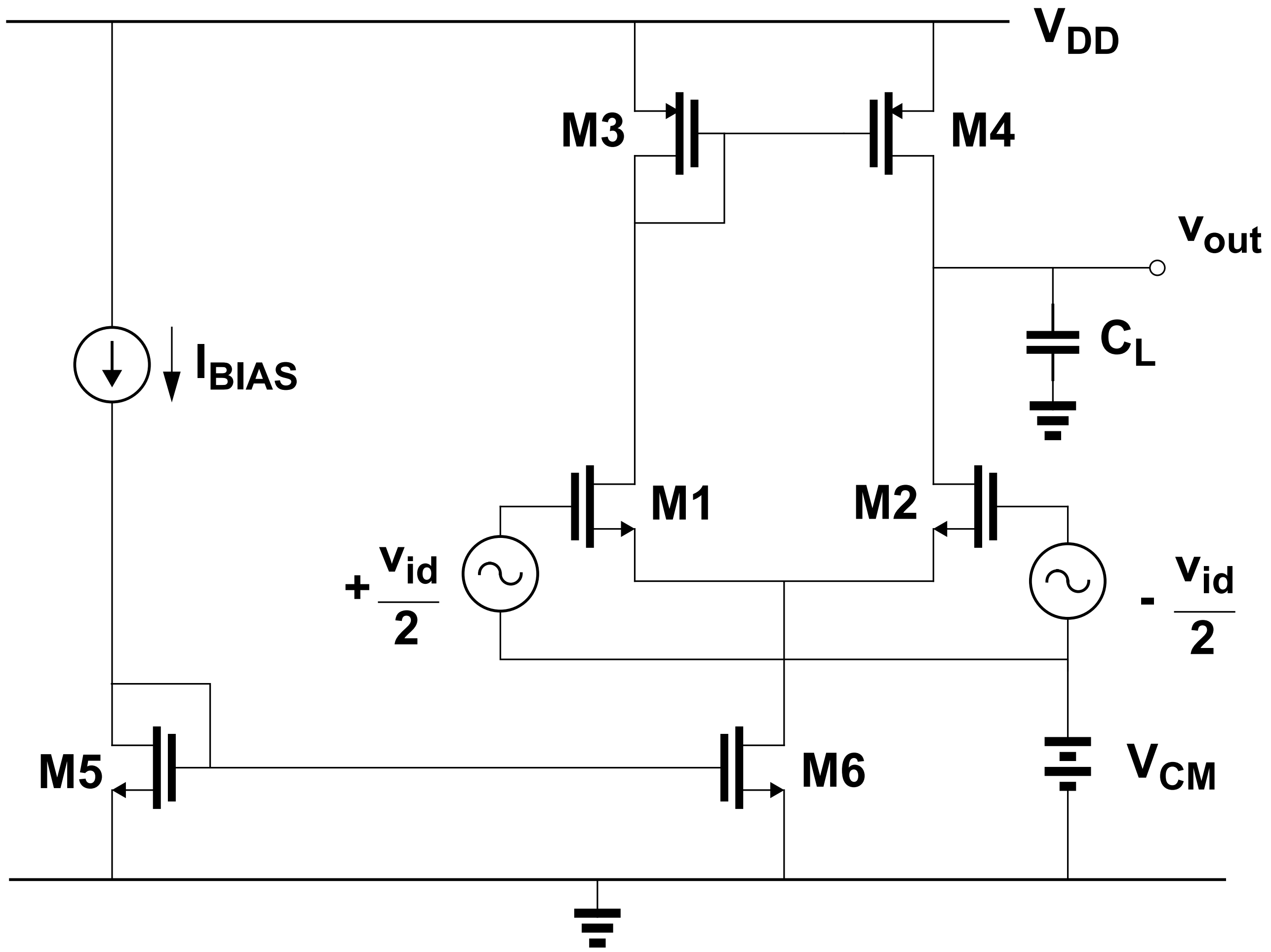


Figure 1

Figure 1 shows a differential to single-ended amplifier.
I_{BIAS} = 400μA, K_n'=200μA/V^2, K_p'=50μA/V^2, V_{tn}=0.8V, V_{tp}=-0.8V, $\lambda_n=\lambda_p$=0.04/L V^{-1}. (L in μm)
Transistor dimensions in μm are:
M1, M2, M3, M4: 32/1
M5, M6: 64/4

(i) What is the low-frequency small-signal gain (v_{out}/v_{id}) of this amplifier ? You may assume the common source of M1,M2 is at ac ground.
(ii) What is the common-mode input range of this amplifier?
(iii) Calculate the low-frequency small-signal gain.
(iv) Calculate the frequency of the pole at the output node if C_L has a value of 10pF. What is the unity gain frequency?

Question 2

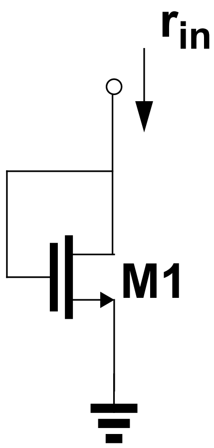


Figure 2

(i) Figure 2 shows a diode-connected nmos. Show that, assuming the transistor is on and g_{m1}>>g_{ds1}, the small-signal resistance looking into the gate-drain node of M1 is given by

$$r_{in} = \frac{1}{g_{m1}}$$

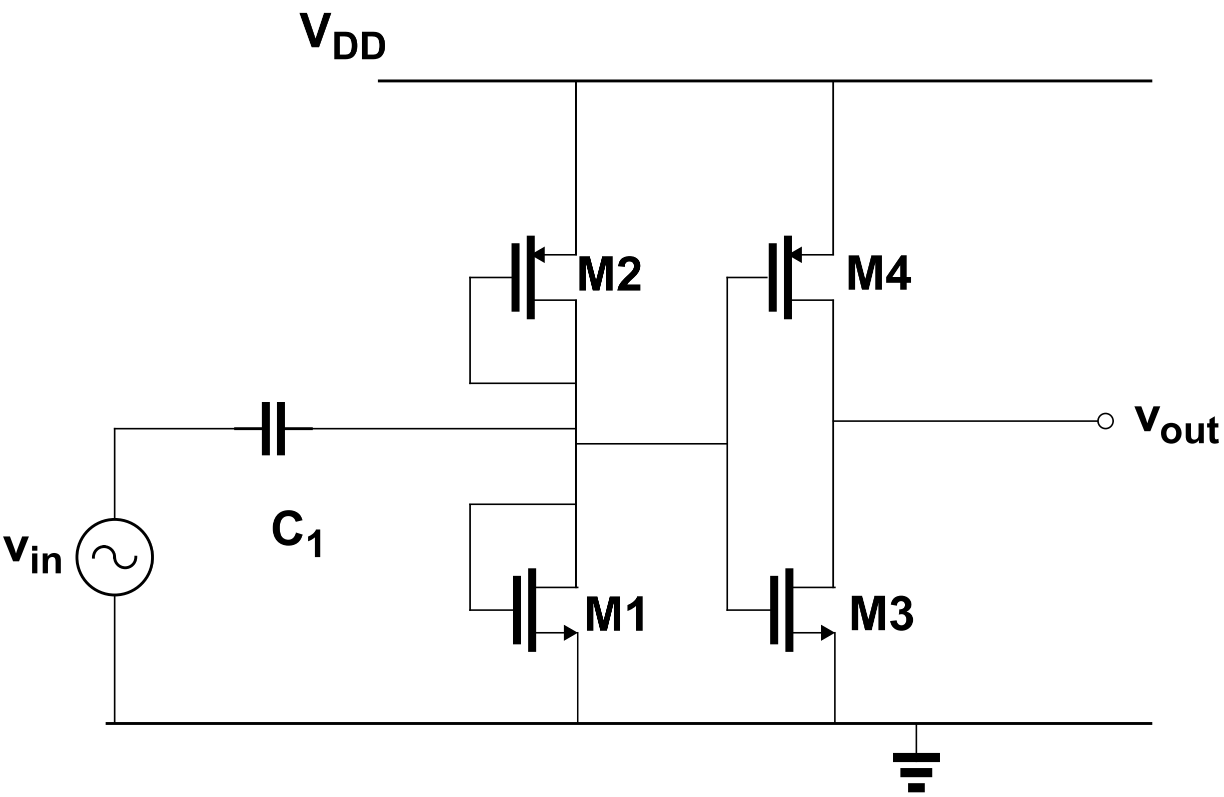


Figure 3

Figure 3 shows a small-signal v_{in} ac-coupled onto an inverter stage.
M1 and M3 have equal dimensions. M2 and M4 have equal dimensions. Assume g_m>>g_{ds} for each transistor.

(ii) Draw the small-signal equivalent circuit for the circuit shown in Figure 3. (The result of (i) may be used).
(iii) Derive an expression for the high frequency transfer function of v_{out}/v_{in}
(iv) Calculate the gain at high frequencies. You may assume that at these frequencies C_1 acts as a short circuit.
V_{tn}=0.7V, V_{tp}=-0.7V, K_n'=200µA/V^2, K_p'=50µA/V^2, $\lambda_n=\lambda_p$=0.04/L V^{-1}. (L in µm)
All nmos transistors have W/L = 10µm/1µm. All pmos transistors have W/L = 40µm/1µm.

Question 3

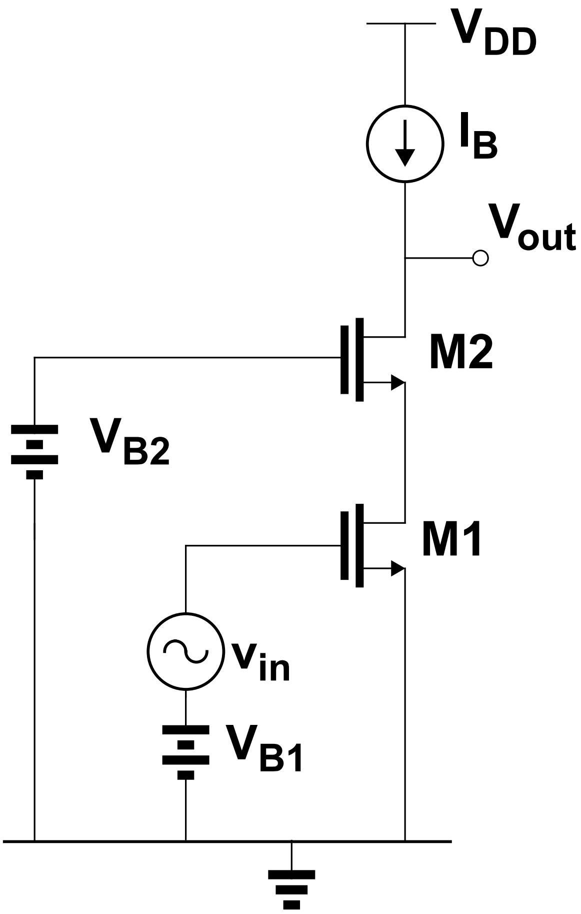


Figure 4(a)

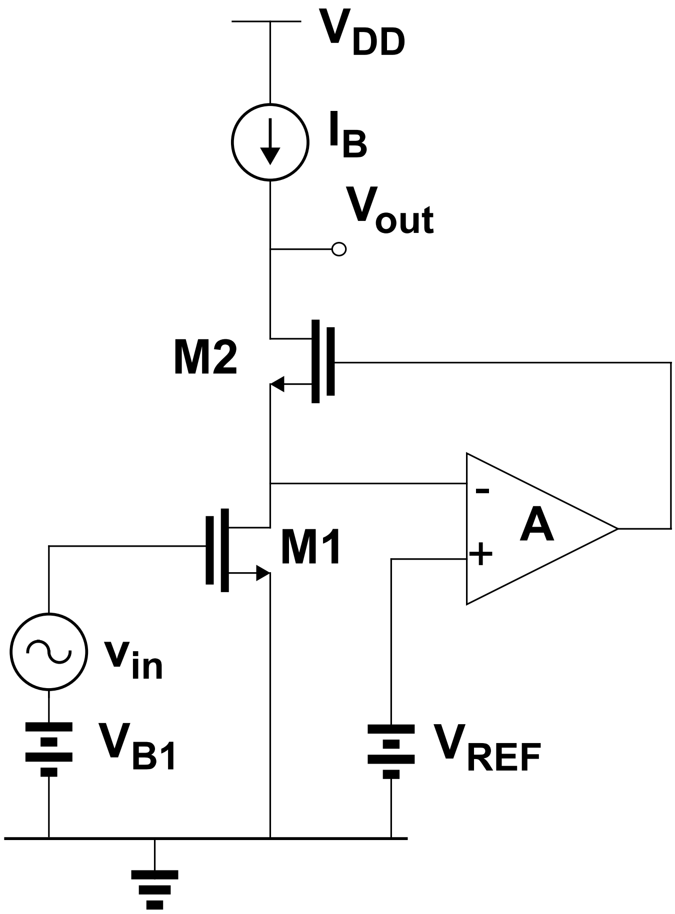


Figure 4(b)

Figures 4(a) and 4(b) show cascoded gain stages.
Assume all devices have equal dimensions and $g_m >> g_{ds}$
V_{B1}= 1.2V, V_t=0.7V

(i) For the circuit in Figure 4(a) what is the minimum value of V_{B2} such that M1 is in saturation? With this value of V_{B2} what is then the minimum voltage at the output node such that M2 is in saturation?
(ii) Draw the small-signal equivalent circuit for the gain stage shown in Figure 4(a)
(iii) Derive an expression for the small-signal voltage gain (v_{out}/v_{in}) for the circuit shown in Figure 4(a). Simplify the expression assuming $g_m >> g_{ds}$.
(iv) In Figure 4(b) the gain of the stage has been enhanced by the use of a regulated cascode. Derive an expression for the small-signal voltage gain (v_{out}/v_{in}) of this circuit.

Question 4

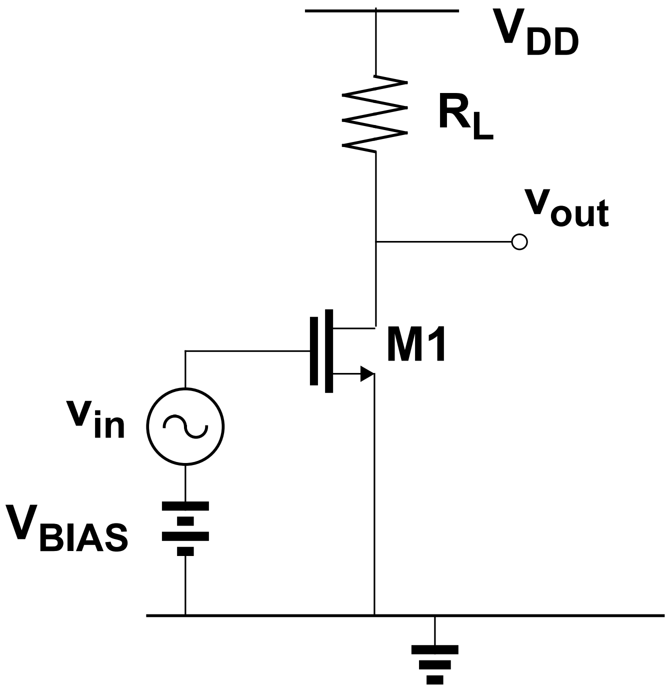


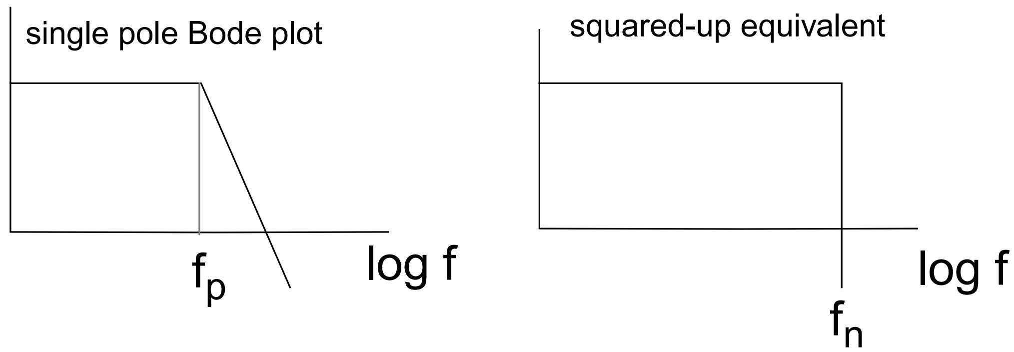
Figure 5

Assume M1 is operating in saturation and that $g_{ds1} << 1/R_L$.
Only thermal noise sources need be considered.

(i) Draw the small-signal model for the circuit shown in Figure 5.
What is the small-signal voltage gain (v_{out}/v_{in})?

(ii) What is the input-referred thermal noise voltage in terms of R_L, the small-signal parameters of M1, 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) Using the result of (iii) calculate the signal-to noise ratio at the output if the input signal v_{in} is a $10mV_{rms}$ sine wave with a frequency much lower than the frequency of the pole at the output node.
For this calculation take V_{GS1}=1V, V_{tn} = 0.75V, λ_n=0.04/L V^{-1}, R_L=5kΩ, C_L=1pF.
The drain current of M1 is 100μA.
Assume Boltzmann's constant k=1.38X10^{-23}J/^{o}K, temperature T=300^{o}K.