EE5310/EE3002: Analog Circuits
Tutorial 3
Due on 18th Sep. 2014

Problem 1

The MOSFET in Fig. 1 has $V_T = 0.7\,V$, and $\mu_n C_{ox} = 500\,\mu A/V^2$. The drain current in the device is 1 mA.

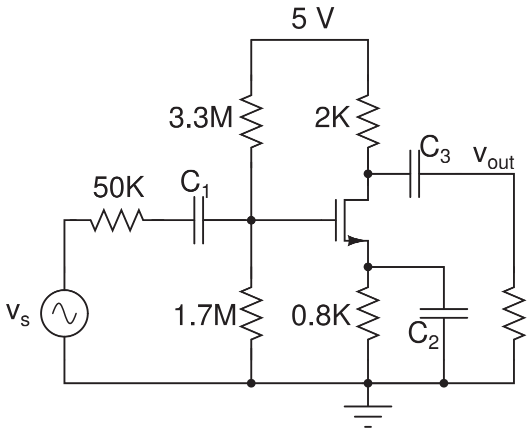


Figure 1: Problem 1

- Determine the small signal gain from v_s to v_{out}.
- Determine the (W/L) of the device and the quiescent V_{GS} and V_{DS}.
- The lowest frequency contained in v_s is 100 rad/s. Determine the minimum values of C_1, C_2 and C_3 required so that the natural frequencies associated with their charging/discharging is atleast 10 times smaller than the smallest input frequency.
- Determine the voltage swing limits at v_{out}. What is the amplitude of the largest sinusoidal input signal that can be applied before the output begins to clip ?
- The supply voltage is changed to 5.5 V. Determine the small signal gain of the amplifier.
- Due to a change in temperature, V_T increases by 100 mV. What is the new small signal gain of the amplifier ?

Problem 2

The MOSFETs in Fig. 2 have $V_T = 0.7\,V$, and $\mu_n C_{ox} = 500\,\mu A/V^2$. Like in Problem 1, the drain current in M2 is 1 mA, and has the same (W/L) as in that problem.

- Determine the small signal gain from v_s to v_{out}.
- Determine the (W/L) of M1 and the quiescent V_{GS} and V_{DS}.

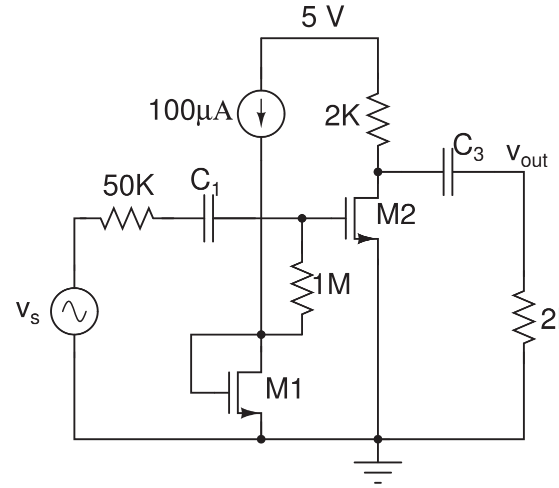


Figure 2: Problem 2

- The lowest frequency contained in v_s is 100 rad/s. Determine the minimum values of C_1 and C_3 required so that the natural frequencies associated with their charging/discharging is atleast 10 times smaller than the smallest input frequency.
- Determine the voltage swing limits at v_{out}. What is the approximate amplitude of the largest sinusoidal input signal that can be applied before the output begins to clip ?
- The supply voltage is changed to 5.5 V. Determine the small signal gain of the amplifier. How does this compare with the results of Problem 1 ? Why ?
- What is the small signal gain of the amplifier if (a) $V_{T,M1} = 0.8\,V$,$V_{T,M2} = 0.7\,V$ (b) $V_{T,M1} = 0.7\,V$,$V_{T,M2} = 0.8\,V$ and (c) $V_{T,M1} = 0.8\,V$,$V_{T,M2} = 0.8\,V$? How does this compare with the results of Problem 1 ? Why ?

Problem 3

The MOSFETs in Fig. 3 have $V_T = 0.7\,V$, and $\mu_n C_{ox} = 500\,\mu A/V^2$. Like in Problem 1, the drain current in M2 is 1 mA, and has the same (W/L) as in that problem.

- Determine the small signal gain from v_s to v_{out}.
- Determine the (W/L) of M1 and the quiescent V_{GS} and V_{DS}.
- The lowest frequency contained in v_s is 100 rad/s. Determine the minimum values of C_1 and C_3 required so that the natural frequencies associated with their charging/discharging is atleast 10 times smaller than the smallest input frequency.

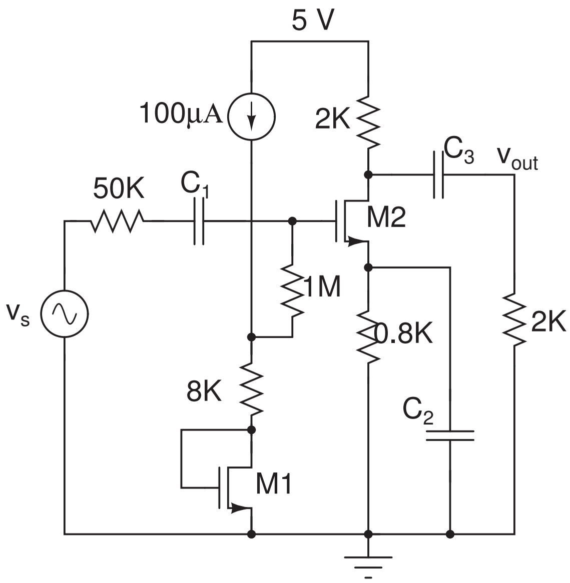


Figure 3: Problem 3

- Determine the voltage swing limits at v_{out}. What is the amplitude of the largest sinusoidal input signal that can be applied before the output begins to clip ?
- The supply voltage is changed to 5.5 V. Determine the small signal gain of the amplifier. How does this compare with the results of Problem 1 & 2 ? Why ?
- What is the small signal gain of the amplifier if (a) $V_{T,M1} = 0.8\,V$,$V_{T,M2} = 0.7\,V$ (b) $V_{T,M1} = 0.7\,V$,$V_{T,M2} = 0.8\,V$ and (c) $V_{T,M1} = 0.8\,V$,$V_{T,M2} = 0.8\,V$? How does this compare with the results of Problem 1 & 2 ? Why ?

Problem 4

This problem illustrates the effects of battery internal resistance on the small signal performance of an amplifier. The MOSFETs in Fig. 4 have $V_T = 0.7\,V$, and $\mu_n C_{ox} = 500\,\mu A/V^2$. Like in Problem 1, the drain current in M2 is to be 1 mA. R_b represents the internal resistance of the battery. To determine the operating point, neglect the drop across R_b due to the current flowing through the gate-bias resistors. For the first three parts, set $Cb = 0$.

- For $R_b = 0$, determine the (W/L) of the FET and the quiescent V_{GS} and V_{DS}. Determine the small signal y-parameters of the two port enclosed in the box. What do you observe about y_{12} ? Why ? Is there *any* AC negative feedback around M2 ?
- Repeat the above exercise for $R_b = 500\,\Omega$. Comment on the results.
- To avoid degradation in performance due to the DC drop across R_b, a student deliberately increases the battery voltage to 5.5 V, so that the device operating point is identical to that in the first part of this problem. Determine the small signal y-parameters of the two port enclosed in the box. What do you observe about y_{12} ? Why ? Is there *any* AC negative feedback around M2 ?

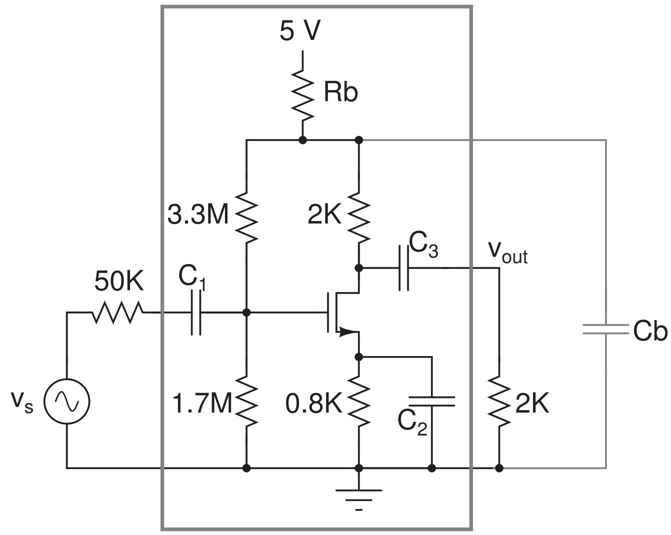
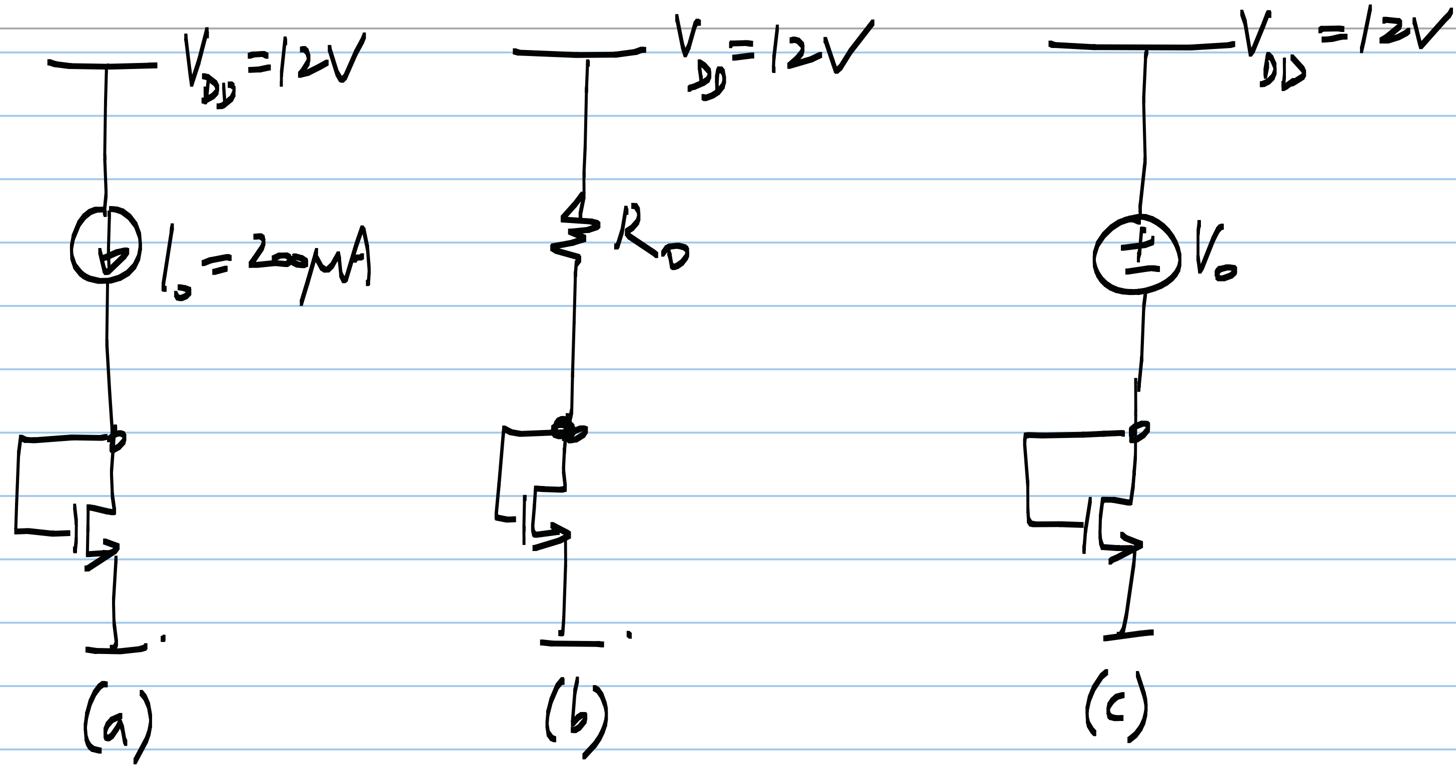


Figure 4: Problem 4

- Based on the observations above, the student adds a **huge** capacitor Cb between the battery output and ground. Does this solve the problem(s) faced in part 3 above? Why ?

Note Title 9/8/2012

P.5 $\mu C_{ox} = 100 \mu A/V^2$; $\frac{W}{L} = 1$; $V_T = 1V$



* Determine R_o & V_o such that the transistor is in the same operating point as in (a)

* Determine the effect of change in V_{DD} (by ΔV_{DD}) and change in V_T (by ΔV_T) on the transistor's drain current in the three cases.

[Evaluate the sensitivity symbolically before evaluating it numerically]

P. 6. While assembling the circuit in the first problem of this problem set, I forgot to solder C_2. What will be V_o/V_s in this case? Relate the answer to the seventh problem of problem set #2.

7) In the circuit shown below, it is known that both M1 & M2 operate in saturation. Further, k and W/L for both transistors is the same. The threshold voltage of M2 is *slightly* larger than that of M1, by an amount ΔV_T. Determine I_2. Assume $\Delta V_1 \ll V_1$.

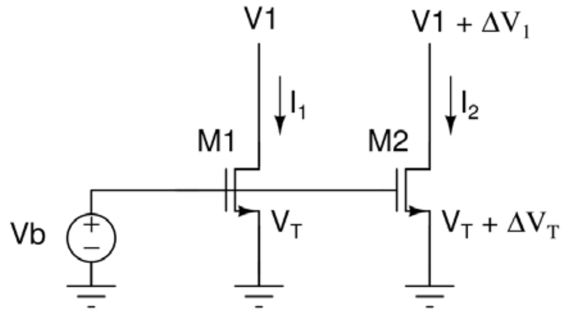


Figure 7: Circuit for Problem 7

8) The small signal equivalent circuit of an amplifier is shown below. M1 is assumed to be in saturation, with transconductance g_m and output conductance g_o. Determine the Norton equivalent looking in at A, as well as the Thevenin equivalent looking in at B. What happens to these equivalents when $g_m \rightarrow \infty$?

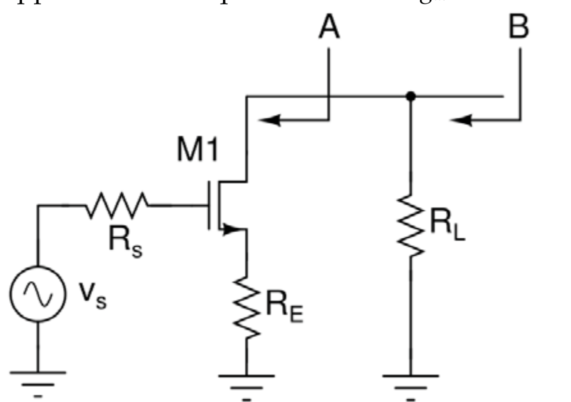
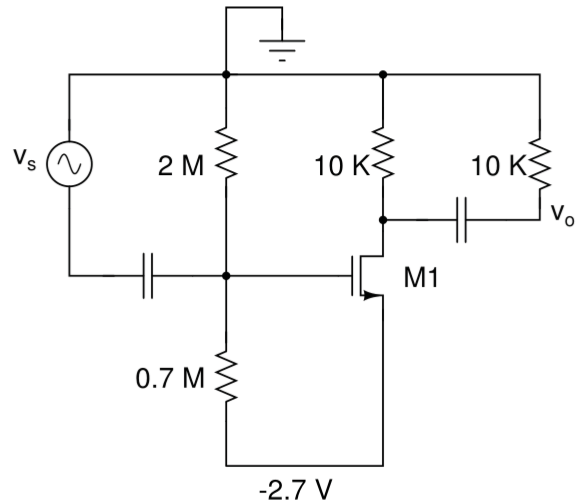


Figure 8: Circuit for Problem 8

9) Determine the quiescent operating point and small signal gain of the amplifier shown below. What is the maximum permissible amplitude of the sinewave input so that clipping of the output is avoided?



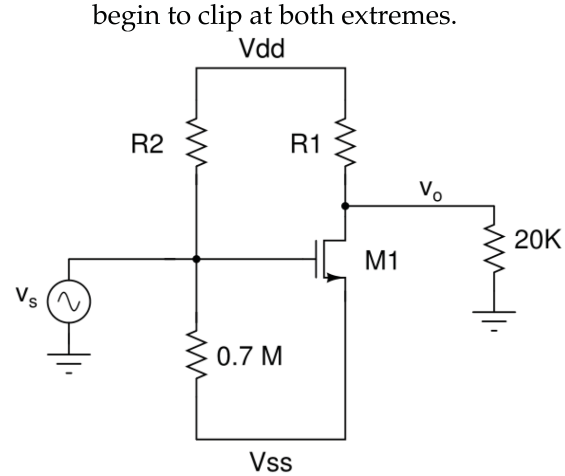
$V_T = 0.5$ V

$\mu_n C_{ox}(W/L) = 5000\ \mu A/V^2$

Figure 9: Circuit for Problem 9

10) The input to the amplifier shown below is a sinusoid of amplitude A. Determine R1, R2, A, Vdd and Vss in the circuit to achieve the following:

- There must be no quiescent current flowing through the load and source.
- The incremental gain must be -4.
- The output sinewave must begin to just begin to clip at both extremes.



$V_T = 0.5$ V

$\mu_n C_{ox}(W/L) = 5000\ \mu A/V^2$

Figure 10: Circuit for Problem 10