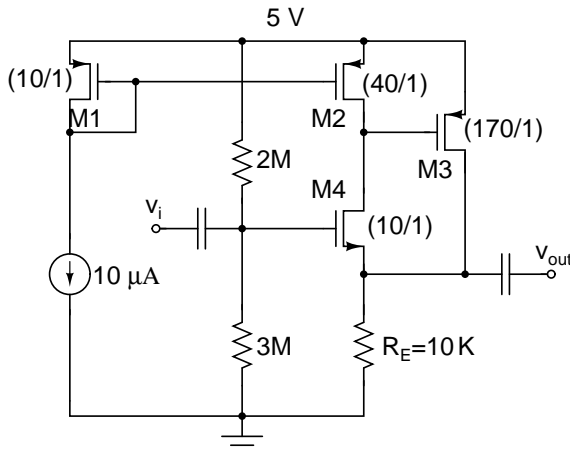# EE5310/EE3002: Analog Circuits
Tutorial 5
Due on 21st Oct. 2014

Problem 1

The circuit of Fig. 1 shows an amplifier.

V_{Tn}=0.7V, $\mu_n C_{ox}$=200μA/V^2

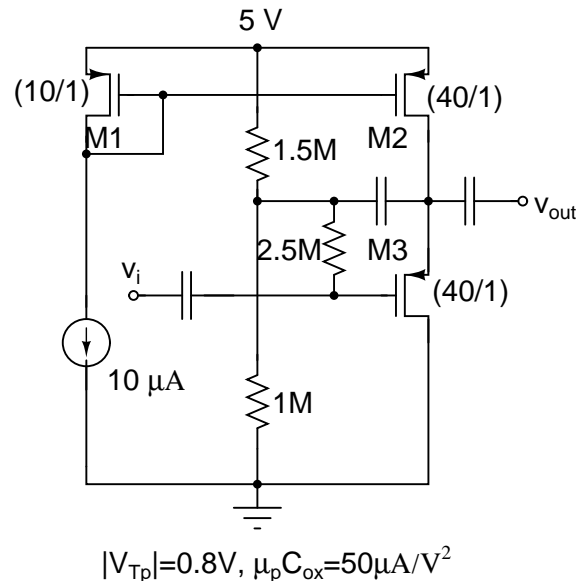$|V_{Tp}|$=0.8V, $\mu_p C_{ox}$=50μA/V^2

Figure 1: Problem 1

- Determine the operating points of all the devices in the circuit. For this part, assume $\lambda = 0$ for all devices.

- All transistors have finite output impedance, such that for any transistor, $g_m r_o = 100$. Draw the small signal equivalent circuit of the amplifier. Determine the small signal gain from v_i to v_{out} and the input and output resistances of the amplifier.

- Determine the amplitude of the largest sinusoid that can be applied at the input, so that the output is also a sinusoid, devoid of clipping effects. As usual, assume that the coupling capacitors are infinite.

Problem 2

The circuit of Fig. 2 shows a common-drain amplifier.

- Determine the operating points of all the devices in the circuit. For this part, assume $\lambda = 0$ for all devices.

- All transistors have finite output impedance, such that for any transistor, $g_m r_o = 100$. Draw the small signal equivalent circuit of the amplifier. Determine the small signal gain from v_i to v_{out} and the input and output resistances of the amplifier.
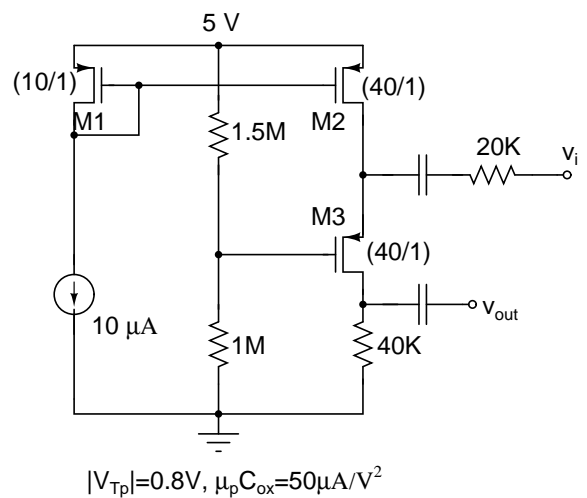

$|V_{Tp}|$=0.8V, $\mu_p C_{ox}$=50μA/V^2

Figure 2: Problem 2

- Determine the amplitude of the largest sinusoid that can be applied at the input, so that the output is also a sinusoid, devoid of clipping effects. As usual, assume that the coupling capacitors are infinite.

Problem 3

The circuit of Fig. 3 shows an amplifier.

$|V_{Tp}|$=0.8V, $\mu_p C_{ox}$=50μA/V^2

Figure 3: Problem 3

- Determine the operating points of all the devices in the circuit. For this part, assume $\lambda = 0$ for all devices.

- All transistors have finite output impedance, such that for any transistor, $g_m r_o = 100$. Draw the small signal equivalent circuit of the amplifier. Determine the small signal gain from v_i to v_{out} and the input and output resistances of the amplifier.

- Determine the amplitude of the largest sinusoid that can be applied at the input, so that the output is also a sinusoid, devoid of clipping effects. As usual, assume that the coupling capacitors are infinite.

Problem 4

In the circuit of Fig. 4, assume that all devices operate in saturation.
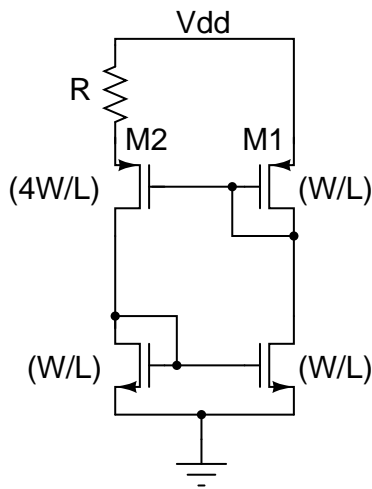
Figure 4: Problem 4

- Determine the operating points of all the devices in the circuit. Assume $\lambda = 0$ for all devices. The answers should be in terms of $|V_{TP}|, V_{TN}, \mu_n C_{ox}, \mu_p C_{ox}, R, V_{dd} \& (W/L)$.

- What is the transconductance of M1 ? How does it depend on the device thresholds, $\mu_n C_{ox}$ and $\mu_p C_{ox}$? What do you think the practical utility of this circuit is ?

- Determine the minimum Vdd required to ensure that all devices are in saturation.

Problem 5

The circuit of Fig. 5 shows an amplifier.

- Determine the operating points of all the devices in the circuit. For this part, assume $\lambda = 0$ for all devices.

- All transistors have finite output impedance, such that for any transistor, $g_m r_o = 100$. Draw the small signal equivalent circuit of the amplifier. Determine the input and output resistances of the amplifier. What kind of controlled source is this ? Determine the relevant "transfer" parameter of the source.

$|V_{Tp}|$=0.8V, $\mu_p C_{ox}$=50μA/V^2

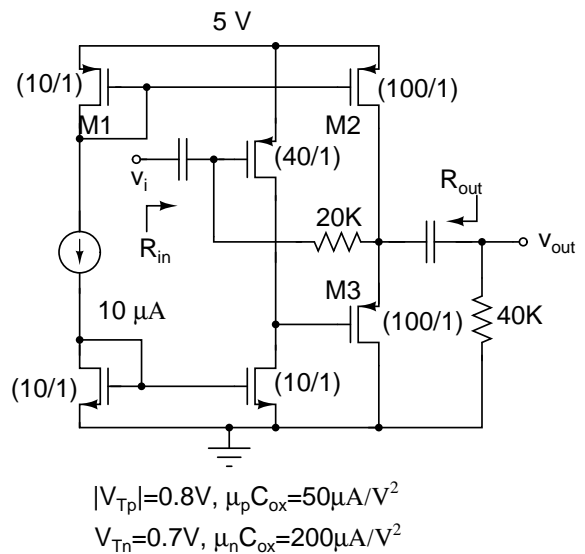V_{Tn}=0.7V, $\mu_n C_{ox}$=200μA/V^2

Figure 5: Problem 5

- Determine the amplitude of the largest sinusoid current at the input, so that the output is also a sinusoid, devoid of clipping effects. As usual, assume that the coupling capacitors are infinite.

Problem 6

In the circuit of Fig. 6, determine the voltages at Va and Vb. Neglect λ. For the transistors, use same the device parameters as in Problem 1.
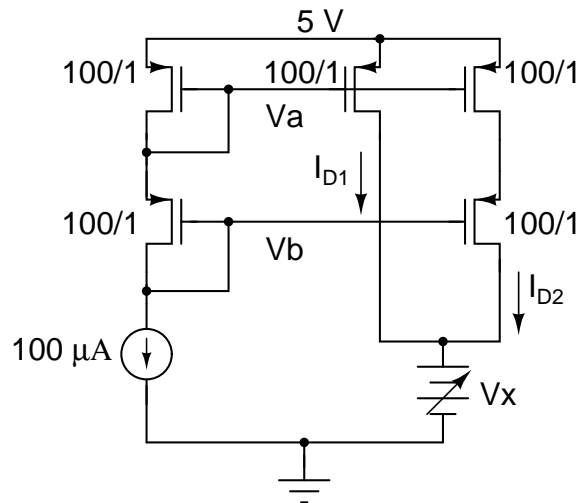
Figure 6: Problem 6

- Assume that $\lambda = 0$. Plot I_{D1} and I_{D2} in the voltage source Vx is varied in the range 0-to-$V_b + |V_{TP}|$.

- Repeat the above for $\lambda = 0.1\,V^{-1}$.

For the following problems, use the data below:

$\mu_n C_{ox} = 300\,\mu\text{A}/V^2$, $\mu_p C_{ox} = 75\,\mu\text{A}/V^2$, $V_{Tn} = V_{Tp} = 0.6\,\text{V}$; $\lambda_p = \lambda_n = k_\lambda/L$, where $k_\lambda = 0.12/(\text{V}\,\mu\text{m})$
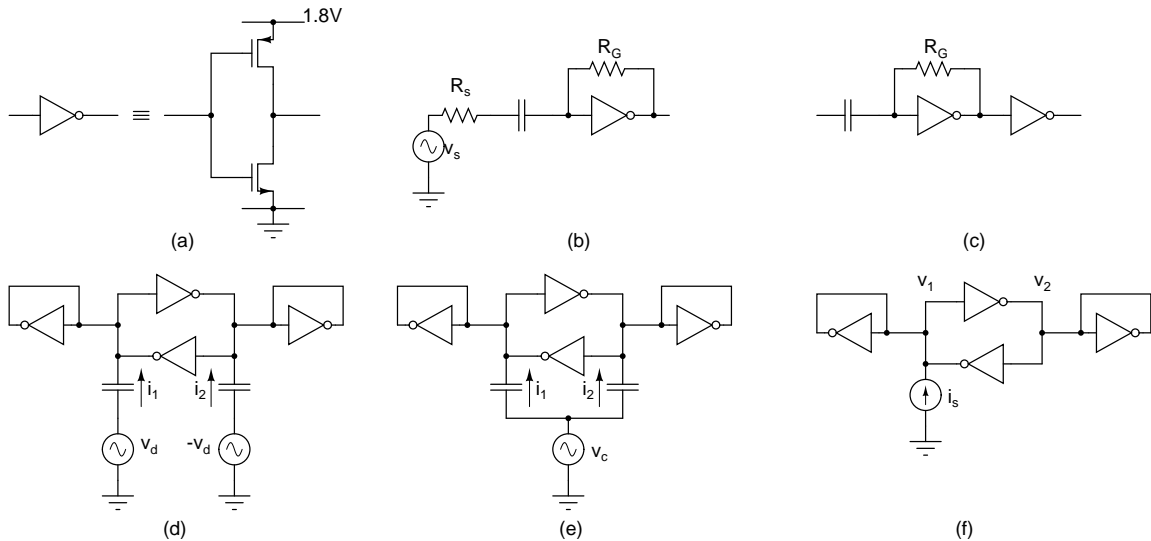

Figure 1: Circuits for Problems 7 to 13 (All capacitors are large enough to be shorts at the signal frequency.)

7. Design the inverter (determine the transistor widths) in Fig. 1(a) to have a self bias voltage of 0.9 V and a quiescent current of 54 μA when self biased. Use $L = 0.18\,\mu$m for all transistors. Ignore λ for operating point calculations. What is the dc gain of this inverter? (Use this inverter for the rest of the problems).

   What aspects of the inverter change if the all transistor lengths are quadrupled?

8. What is the constraint on R_G such that it doesn't affect the gain of the self biased inverter (Fig. 1(b))? Under this constraint, what are the maximum and minimum output voltages such that both transistors are in saturation?

9. The two inverters in Fig. 1(c) are identical. R_G satisfies the constraint above. What is the quiescent output voltage? What is the amplitude of the input sinusoid such that the output just reaches the swing limits calculated above?

10. What additions do you need to make to this circuit so that the small sinusoidal input can be converted to a square, (almost) digital waveform?

11. Assume that the threshold voltage of the nMOS transistor in the second inverter in Fig. 1(b) differs from the nominal value by ΔV_{Tn}. Find the value of ΔV_{Tn} for which the quiescent output voltage is half way towards the output swing limit.

12. Fig. 1(d, e) show a circuit driven by out of phase and in phase (small) signals. Calculate (symbolically) the small signal currents i_1 and i_2 in in the two cases. Denote the transconductance and output conductance of each inverter by g_m and g_o respectively. Comment on the magnitude of the currents in the two cases.

13. Based on the above results, calculate the small signal voltages v_1 and v_2 in Fig. 1(f). What might be the utility of this circuit?