Due in the "EE 105 box" near 125 Cory Hall by 5pm on Monday 10/15/2012.

Read Chapter 6 in B. Razavi: Fundamentals of Microelectronics

Use the following parameters in all problems, unless otherwise specified:
$\mu_n C_{ox} = 200\,\mu\text{A}/\text{V}^2$, $\mu_p C_{ox} = 100\,\mu\text{A}/\text{V}^2$, $V_{TH_n} = -V_{TH_p} = 400\,\text{mV}$, $\gamma_n = \gamma_p = 0$ (no body effect).

1. Answer the Excercise after Example 6.2 in B. Razavi: Fundamentals of Microelectronics.

2. Answer the Excercise after Example 6.5 in B. Razavi: Fundamentals of Microelectronics.

3. Answer the Excercise after Example 6.7 in B. Razavi: Fundamentals of Microelectronics.

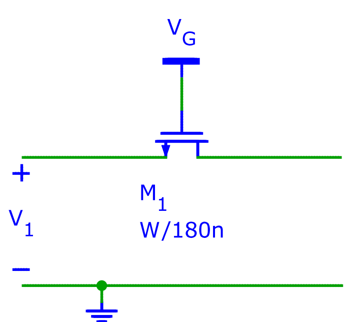
4. Answer the Excercise after Example 6.8 in B. Razavi: Fundamentals of Microelectronics.

5. Answer the Excercise after Example 6.10 in B. Razavi: Fundamentals of Microelectronics.

6. Answer the Excercise after Example 6.11 in B. Razavi: Fundamentals of Microelectronics.

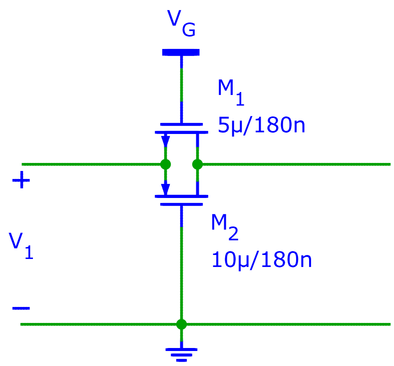
7. Answer the Excercise after Example 6.14 in B. Razavi: Fundamentals of Microelectronics.

8. The circuit below shows using a MOSFET as a switch. Varying V_G modulates the resistance R_{sd} between the source and drain of M_1. Determine the minimum value of W for which $R_{sd} \leq 1\,\text{k}\Omega$ with $V_1 = 0 \ldots 2\,\text{V}$, $V_G = 3\,\text{V}$ and $I_D = 0$. Note that for $V_G = 0\,\text{V}$ the value of $R_{sd} \to \infty$.



9. A pair of MOSFETs are used as a switch as shown below. Plot (remember how from an earlier assignment) R_{sd} for M_1 and M_2 individually and the combination of both devices (use the same axes) as a function of $V_1 = 0 \ldots V_G$ for $V_G = 0.6\,\mathrm{V}$. Repeat with $V_G = 1.8\,\mathrm{V}$. Assume $R_{sd} \to \infty$ for $|V_{GS}| < |V_{TH}|$.

   The CMOS switch (consisting of NMOS and PMOS transistors in parallel) operates at lower supply voltages than a single switch. For low supplies (e.g. $V_G = 0.6\,\mathrm{V}$) it is difficult or impossible ($V_G < V_{TH}$) to turn on the switch. Good to know when a design calls for switches.



10. Problem 6.13 in B. Razavi: Fundamentals of Microelectronics.

11. Problem 6.18 in B. Razavi: Fundamentals of Microelectronics.

12. Problem 6.21 in B. Razavi: Fundamentals of Microelectronics.

13. The ratio of transconductance to bias current g_m/I_D is an important "figure of merit" of transistors: higher is better (more g_m for given current and power dissipation).

    a) Determine the value of g_m/I_C for a BJT at room temperature.
    b) Determine the value of g_m/I_D for a MOSFET as a function of $V_{GS} - V_{TH}$.
    c) Plot (you know how!) g_m/I_D as a function of $V_{GS} - V_{TH} = 10 \ldots 200\,\mathrm{mV}$ and (in the same plot) g_m/I_C as a function of V_{BE}.
    d) Apparently for small $V_{GS} - V_{TH}$ the MOSFET has higher g_m/I_D than the BJT. That's not actually the case: in reality, the "square law" equation applies only for MOSFETs in "strong inversion" when $V_{GS} - V_{TH}$ is larger than about 200 mV. For small $V_{GS} - V_{TH}$, the MOSFET is in "weak inversion" and the relationship for I_D (in saturation) changes to

       $$I_D = I_s e^{V_{GS}/nV_t}$$

       In this expression, V_t is the thermal voltage and n is a device dependent parameter, typically $n = 1.2 \ldots 1.5$. Calculate g_m/I_D for a MOSFET in weak inversion with $n = 1.2$. Add this trace to your plot (same axes). The actual g_m/I_D is the lower of the values predicted by the formula for weak and strong inversion.
       In conclusion, MOSFETs have lower g_m/I_D, i.e. are less current efficient than BJTs. In some circuits—e.g. RF power amplifiers—this translates into lower power dissipation. But this is not the case for all circuit applications. For example, microprocessors built from MOS transistors dissipate usually less power than similar computers built from BJTs since more power efficient digital circuit topologies can be built from MOS transistors. It's important to understand the differences between MOS and BJTs and use the best one depending on the application.

14. Determine the bias currents I_1 and I_2 for the followers below such that the small signal gains $v_{oq}/v_{iq} \geq 0.99$ and $v_{om}/v_{im} \geq 0.99$ for $V_{oq} = V_{om} = 0\,\text{V}$. Choose W such that $V_{GS} - V_{TH} = 100\,\text{mV}$.

   a) Which amplifier—MOS or BJT—has lower power dissipation?
   b) Calculate the small-signal input resistance for both amplifiers. Which one is preferable based on input resistance?