## MOS transistor characteristics

This week we look at some MOS transistor characteristics and circuits. Most of the measurements will be done with our usual lab equipment, but we will also use the parameter analyzer to map out a set of NMOS curves. Your lab kit has a CD4007 chip, which has 3 NMOS and 3 PMOS transistors integrated into a single package. The chip is set up to make CMOS inverters, but it is easy enough to use the individual transistors. You also have an IRF540 power NMOS transistor, which can carry large currents.

### Prior to Lab

1. Look over the data sheets for the CD4007 chip and the IRF540 NMOS transistor. Pay particular attention to the pin arrangement so that you know how to locate the source, gate, and drain leads.
2. Look over the instructions for measuring an NMOS transistor with the parameter analyzer. As we did with the diodes and BJTs, we will have to take turns using the analyzer to measure the MOSFETs. Every group should get at least 15 minutes on the machine.

### CD4007 MOS array

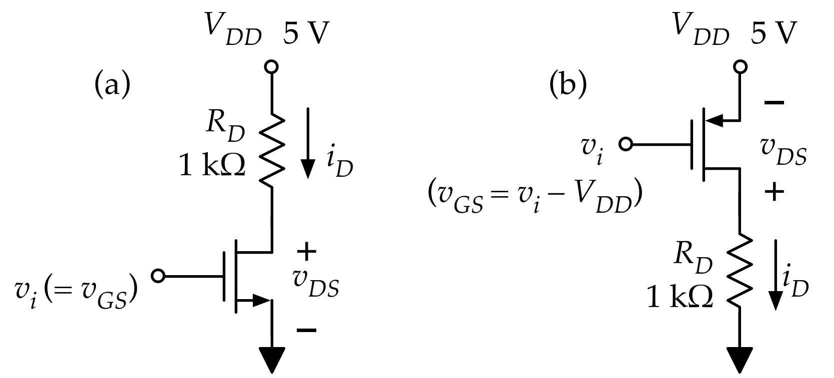
Note the connections for the transistors in the 4007 array. There are two *substrate* or *body* connections. VSS is the substrate connection for the NMOS transistors. For now, make sure that VSS (pin 7, which is also the source connection for NMOS A) is connected to the most negative voltage in the circuit. (Typically this will be ground.) VDD is the substrate connection for the PMOS transistors, therefore VDD (pin 14, which is also the source connection for PMOS A) should be connected to the most positive voltage in the circuit, which is usually a DC power supply.

Final note: Often we denote the positive power supply in a MOSFET circuit as VDD. Don't confuse the name of the positive power supply with the name of pin 14 of the 4007 chip. It is true that we will usually connect pin 14 to the positive supply, but you should make certain that you understand the distinction between the two.

## A. MOSFET $I_D$-$V_{DS}$ and $I_D$-$V_{GS}$ characteristics with the parameter analyzer

Since you will need to know $V_T$ *and* $K = [\ \mu C_{ox} W/(2L)\ ]$for the various transistors and you may not get to use the analyzer until later in the period, perform some quick measurements to determine those parameters for one NMOS and one PMOS from the DC4007 array. Use the circuit shown in Fig. 1(a) for an NMOS transistor and the the circuit of Fig. 1(b) for a PMOS device. In each case, measure the drain current (by measuring the voltage across $R_D$ and using Ohm's Law) for $v_i$ = 2 V and for $v_i$ = 3 V. Use the "square-root of $i_D$ versus $v_{GS}$" technique to determine ether slope of the line (= $K^{0.5}$) and the $x$-axis intercept (= $V_T$).

Figure 1.

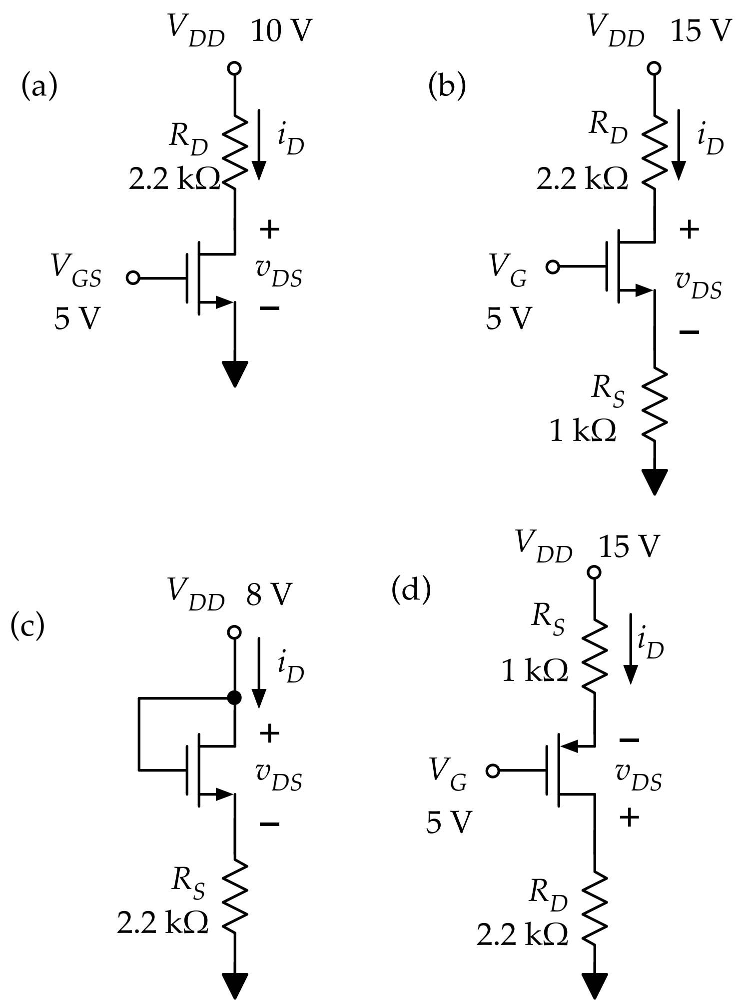



Then, during your turn with the parameter analyzer, measure a set of $i_D$–$v_{DS}$ curves for one NMOS transistor and one PMOS from the CD4007 array and also for the IRF540 power NMOS Then, using the same transistors, obtain plots of $i_D^{1/2}$ vs $v_{GS}$ and use that to determine $V_T$ and $K$ for the transistor. Take photos of the curves to include in your report.

### B. DC MOS circuits

Build each of the circuits shown in Fig. 2 below, using the measured NMOS or PMOS transistor from the 4007 array. (Use the same devices that you measured using the "quick and dirty" method from part A.) Use the multi-meter to measure $i_D$, $v_{GS}$ and $v_{DS}$ in each circuit. (Measure the voltage across the drain resistor and use Ohm's law to determine the current.) Use what we have learned in class to calculate the expected values of the currents and voltages in each case.

Figure 2.



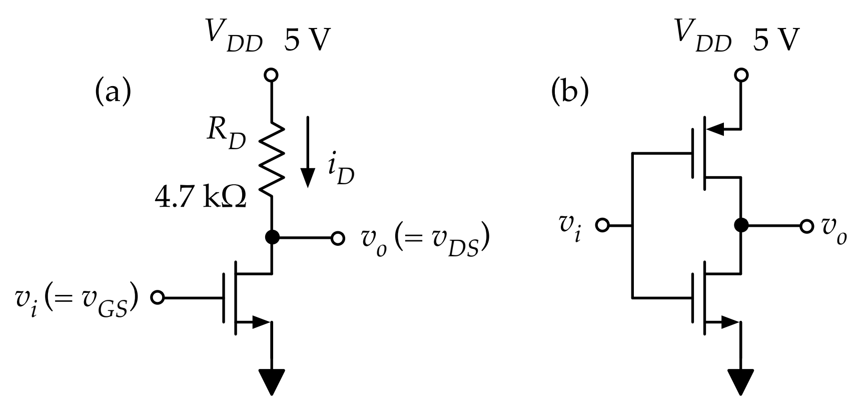
## C. MOS inverters

Inverters are the basis for all digital and many analog MOS circuits. Measure the transfer characteristics ($v_o$ vs. $v_o$) of the two inverter circuits shown in Fig. 3. The first is a simple, resistively-loaded NMOS inverter. The second is the ubiquitous CMOS inverter. Use transistors from the CDD4007 array to build the circuits.

Use a DC voltage at the input and vary the value from 0 to 5 V in 0.2 V (or smaller) steps. Measure the output voltage at each value of the input. Use the collected data to make plots of the transfer characteristic for each circuit. Include the plots in your report.

Note: You can save some time by building both circuits and performing the measurements on the circuits simultaneously.

Figure 3.




Note: The parameter analyzer could be used to do these measurements, also. To use it, you would have to program the SMUs yourself, but it is not a difficult exercise. If you choose, you can measure the transfer characteristic curves with the analyzer rather than obtaining them by hand at the lab bench.

## D. MOSFET as a switch

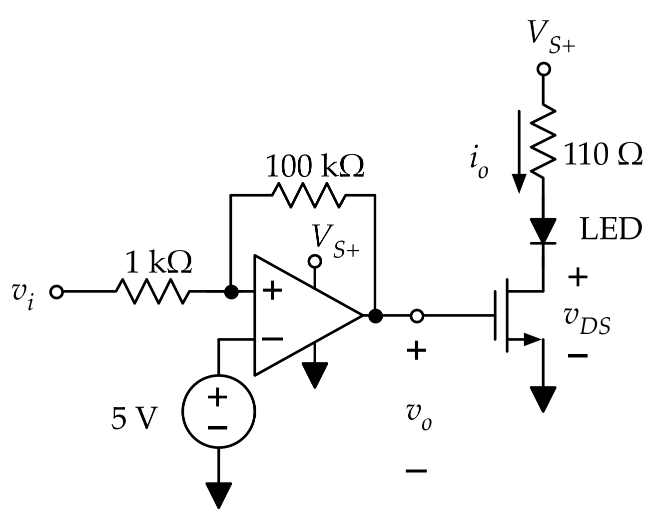
Recall that op-amps have limited output current capability, typically around about 20 mA. A MOSFET can be used to increase the current delivered to a load. same thing can be done with a power NMOS transistor.

Build a simple non-inverting comparator with an NMOS output switch as shown in Fig. 4. Use the LMC660 with a single 10-V supply to power the op-amp for the comparator. (The negative supply terminal is tied to ground.) Use the IRF540 power NMOS for the switching element, and make the 110-Ω resistor by using three 330-Ω resistors in parallel. (This keeps things from getting too hot.)

Make the op-amp output go high (by making the input high). This causes the NMOS to turn on, and it should be operating "hard" in the linear mode ($v_{DS}$ small). Measure the comparator output voltage, the LED current, and the drain-source voltage of the transistor. (Keep it simple — measure the resistor voltage and calculate the current using Ohm's Law.)

Connect the function generator to the comparator input, and set it to produce to a square wave that has 0 V for the lower limit and 10 V for the upper limit. Set the frequency at 10 Hz or lower. (So the you can see the LED blinking.) Observe $v_{DS}$ of the transistor on the oscilloscope. Save a clear copy of the trace for your report.

Figure 4.



### E. NMOS amplifier

Using the inverter circuit of Fig. 3(a), as a simple amplifier. For the input, use the function generator, set to produce a sine wave at a frequency of 1 kHz. Set the amplitude to 0 (i.e. no sine wave) initially. Increase $V_{DD}$ to 10 V.

Attach the multimeter – set to DC volts – to measure $v_{DS}$. Then adjust the *DC offset* of the function generator to make the *DC* value of $v_{DS}$ = 5 V. Then increase the amplitude of the sine wave to 0.25 $V_{RMS}$. The output should now have an AC component as well – an inverted and amplified version of the input.

Use the oscilloscope to view the input and output waveforms together. Save a good copy of the traces for your report.

Use the multimeter on the AC setting to measure the amplitudes of the input and output sinusoids, and calculate the magnitude of the voltage gain.

### Reporting

Prepare and submit a report after you have finished the lab. A template is available. Each lab group is required to submit a report (i.e. one report for two people). Be sure to include all of the *I-V* curves for the MOSFETs, the calculations for part B, and all of the measurements for parts B – E.