Electrical & Computer Engineering Department
ECE 2100
Experiment No. 11

Introduction to MOSFET Transistors

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rev,4/6/03

Bring your textbook to lab.

Minimum required points = 46
Recommend parts (all) = 66 pts (100%)

Objectives

1. Take the curves of a MOSFET.
2. Measure resistance in the ohmic region.
3. Build and test a CMOS circuit as a switch and as an amplifier.

Check out from stockroom:

- Wire kit & 10x scope probes

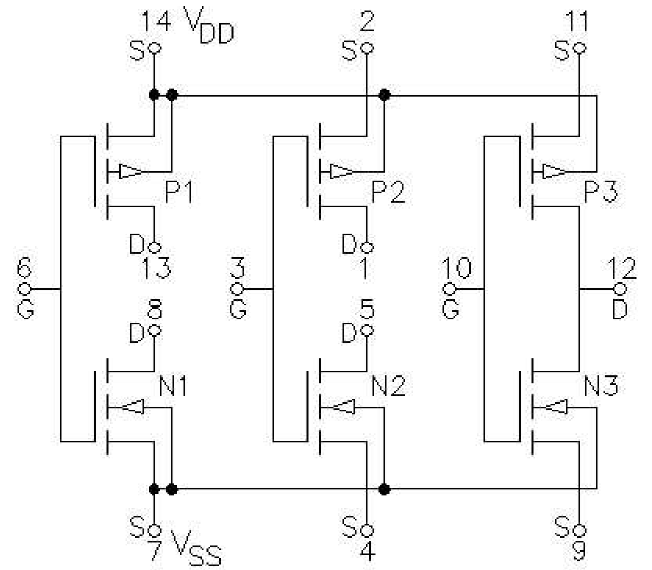
Parts:

- two 10 MΩ, resistors
- two 0.1 µF (104) capacitors
- CA3600 MOSFET array (Read box at right before handling)

General

The CA3600 MOSFET array contains three n-channel and three p-channel Transistors, labeled N1 through N3 and P1 through P3. Notice that the substrate (body) of all the n-channel parts is hooked to pin 7 and the substrate of all the p-channel parts is hooked to pin 14.

MMOS and CMOS parts are very susceptible to Electro-Static Damage (ESD), especially the gate terminals. The CA3600 includes protection for all of its gate terminals as shown on the next page. This type of protection is common in nearly all MOS and CMOS parts, but is rarely shown on the part schematic. Despite the protection, these parts should still be handled with care.

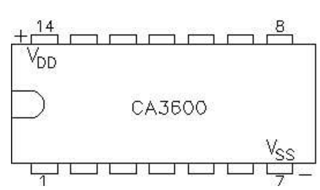


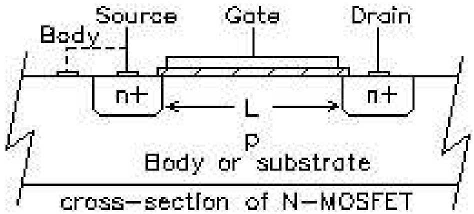
CA3600 MOSFET Array

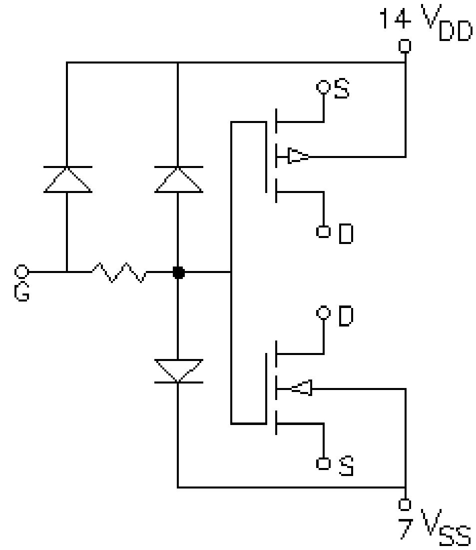
The CA3600 part that you use in this lab is expensive and easily damaged, so be careful with it.

- Don't subject it to high voltages or static electricity. Store it in an anti-static bag or in anti-static foam.
- Momentarily touch a metal part of the workbench to discharge yourself before handling the part or touching the leads.
- Never let voltage on any pin be more positive than pin 14 or more negative than pin 7. The circuit may "latch up"— possibly causing permanent damage.
- Always connect pin 7 (substrate for n-channel transistors) to your negative supply voltage and pin 14 (substrate for p-channel transistors) to your positive supply voltage. (See Fig 5.9, p.365.)
- Connect or turn-on the supply voltages (pins 7 & 14) before any other voltages in your circuit.
- For added safety, ground any unused inputs.

In general, these precautions apply to all MOS and CMOS parts.







If you look at the construction of MOSFET parts, you'll see that each source and each drain forms a diode to the substrate. To avoid damaging the part, no pin can be more positive than pin 14 (connected to the p-channel substrate) and no pin can be more negative than pin 7 (connected to the n-channel substrate). The upshot is:

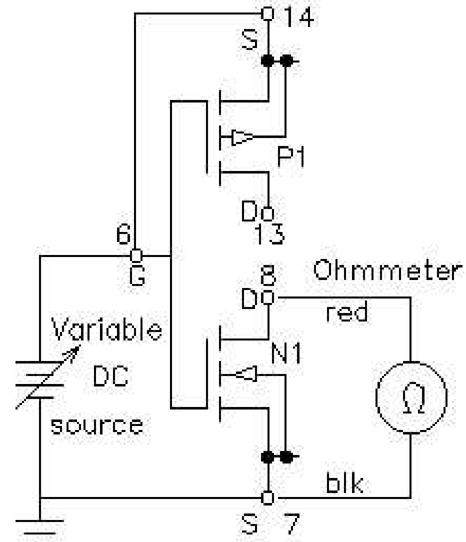
- Always hook pins 14 & 7 to the power supply, no matter which MOSFETs you are actually using.
- Always turn on the power supply ***before*** turning on any other voltages or signal sources.
- Always turn off other voltages or signal sources ***before*** turning off the power. **WARNING:** This last this last point is very easy to forget and will probably cost you a part before you learn. Each and every time you turn off the power, you must turn off or disconnect the signal generator first.

Experiment 1, Curves from Curve Tracer (14 pts, Recommended)
You may do Experiment 2 and/or 3 first if there's a wait at the curve tracer. Just leave enough room in you lab book for two printouts from the curve tracer and a few lines of writing.

Look at the characteristic curves for a MOSFET shown in Fig. 5.11, on page 367 in your textbook. I want you to get a set of curves like those from the curve tracer for one of the n-channel devices in your CA3600. The curve tracer doesn't have a socket for a DIP package, so you'll have to put the part in your proto board and use some wires to connect to the curve tracer. I suggest that you measure transistor N1 since it's source is already connected to the substrate internally. If you use N2, connect pin 7 to pin 4. If you use N3, connect pin 7 to pin 9. This insures that the substrate is connected to the most negative point in the circuit.

Note: sample curves are shown on the last page of the lab. On the curve tracer menu, select N-FET as the part. The drain voltage should cover the range from 0 to +10 volts. Set the drain current range to 20 mA, although the current itself should never go higher than 15 mA. Set the gate voltage to 1.0 volt steps. Try 5 steps first. Take a set of curves and then add as many steps as you can, trying not to let the drain current go above 15 mA. Print out the best set of curves you can get. Label each curve with the gate voltage that produced it. Start from the top and work down. Say you used 9 steps at 1.0 V per step. You'd label the top curve with V_{GS} = 9 V. The next one down would be V_{GS} = 8 V, etc.. The last couple of curves will probably be flat lines at the bottom of the graph. Look at Fig. 5.11, on page 367 in your textbook. Estimate the threshold voltage V_t from your curves.

Now reduce the drain voltage range to 1 V, the drain current range to 10 mA, and increase the steps to 10. This should effectively “zoom in” to the ohmic region at the lower, left corner of the first set of curves, as shown in Fig. 5.4, page 359. Adjust the ranges as necessary to get good curves, then print. Label each curve with the gate voltage that produced it. Start from the top and work down like before. Do your curves look like those in the book? Make your answer part of your conclusion.

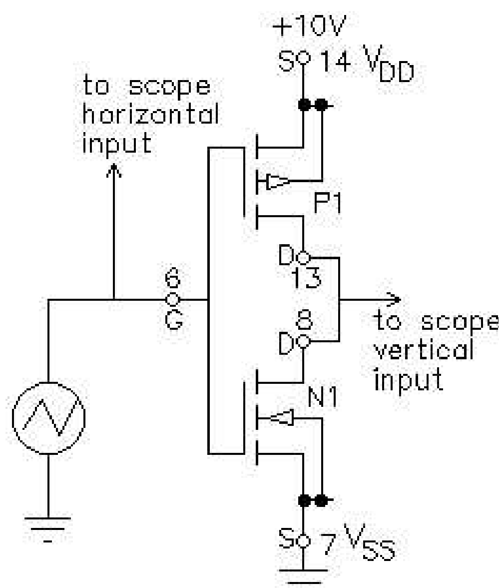


Experiment 2, Ohmic Measurements (25 pts, Recommended)

Wire the circuit shown. Use the same transistor for this experiment as for experiment 1. I recommend N1. That will save you the source-to-pin-7 connection. I want you to vary the DC voltage between 0 V and 12 V, measure the resistance (r_{DS}) of the MOSFET with an ohmmeter in at least 5 places and record the values. If you’re in a hurry you can skip to the next section. The next two paragraphs don’t involve measurements and may be done later, but leave a blank page in your notebook.

Make a plot of $1/r_{DS}$ vs V_{GS}. Draw carefully and to scale, use a spreadsheet if you want. It should come out to a fairly straight line. Draw your best straight-line approximation to the data or make the spreadsheet do a linear fit. Look at Eq. 5.13, page 368. The zero-crossing point of your straight line will be the threshold voltage V_t. Record this value. Find the slope of your straight line, that should be $k_{n'}W/L$. Record that too.

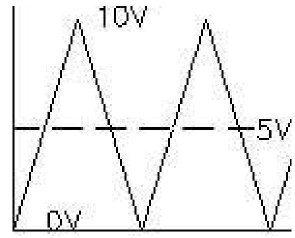
Voltage-controlled amplifier design: Next you’ll design an op-amp amplifier which uses the MOSFET as one of the resistors so that the gain can be controlled by the MOSFET gate voltage. Draw a noninverting op-amp amplifier wherein you replace one resistor with your n-channel MOSFET to create a variable-gain amplifier Try for a linear relationship between V_{GS} and the gain.. Select components so that your gain can be varied from 10 to 100 by varying the V_{GS} voltage. Show all necessary components and values on your drawing. Find the values of V_{GS} that will give you a gain of 10 and of 100 or better yet, use a spreadsheet to plot the gain as a function of V_{GS}. This is now an interesting circuit. It can be used a multiplier or as an AM modulator.



Experiment 3, CMOS circuit (27 pts, Recommended)

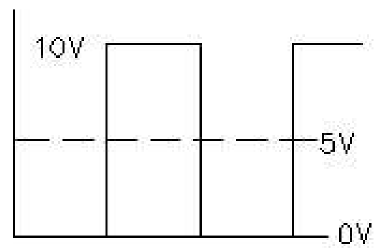
CMOS stands for “complimentary MOS” and means that the circuit uses both p-channel and n-channel devices.

CMOS Inverter Transfer curve: The objective here is to get a curve like that shown in Fig. 5.58, page 430 in your text. First build the circuit, **but don’t make the connections to pins 6 and 14 yet**. The way in which the external voltages are applied to the CMOS chip is important in order to avoid "latchup", a phenomena that sometimes occurs in CMOS integrated circuits. Turn on your power supply and set the output to zero volts, then connect it to pin 14. Now turn up the voltage to +10 V.

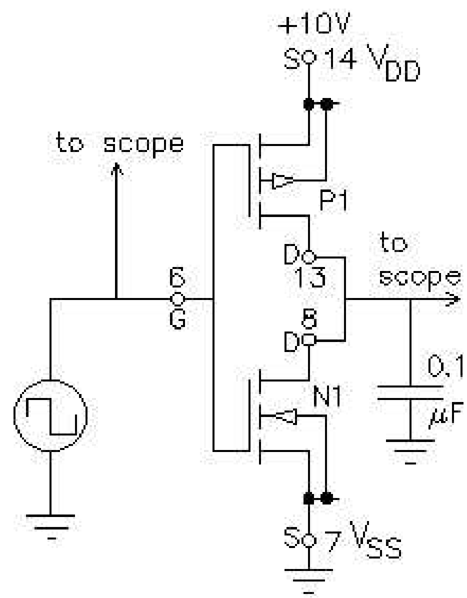


Before connecting the signal generator, adjust it to give a 0 to +10 volt triangular output at about 1 kHz, see drawing. (If you're using the HP, set it for 5Vpp with a 2.5V DC offset, remember its doubling trick.). After you set and check the signal, turn the output off, connect it to the input at pin 6, and then turn the output on again. Set the scope to display "x-y" (Look right above the Time/Div knob, press Main/Delayed --> then XY under the screen.) Adjust the display on the oscilloscope to get the voltage transfer curve of your CMOS inverter (see Fig. 5.58, page 430 in the text).

Observe and accurately sketch the voltage transfer curve in your lab book, or make a print of the scope screen. You want your sketch to be accurate enough to get the measure th e A, B, C, & D points on the curve (see Fig. 5.58, page 430 in the text). Turn off the signal generator output, then turn off the power supply. Reset the oscilloscope to the normal time base mode.



Square Wave Response: Build the circuit shown but do not yet actually connect the power supply or the signal generator. Do things in the following order will avoid latchup and prevent damage to the ESD protection diodes. Turn off the voltage supply, connect it to pin 14, then turn it on. Before connecting the signal generator set it to give a 0 to +10 volt square wave at about 1 kHz (use the DC offset like you did with the triangle wave), then connect it to the input, pin 6.



Adjust the scope to display the input and output waveforms. Does this circuit work as an inverter? Does the output waveform have rise and fall times like Fig. 5.59b, page 432, in the text? Measure t_{PHL} and t_{PLH} as shown in the figure. (If you can't quite read this figure, refer to Fig. 1.35, page 46)

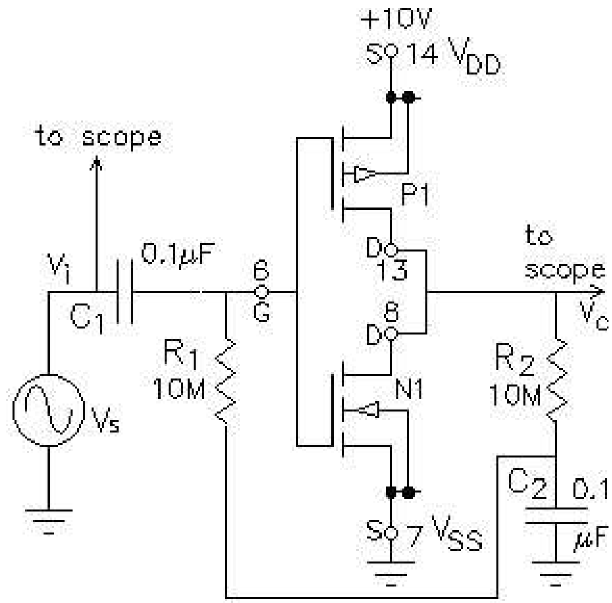
Sketch the output voltage in your lab book.

The capacitor was added to the circuit to simulate a capacitive load, like the input to another CMOS device. This capacitor is rather large, but then, the frequency is rather low. Disconnect the capacitor. Was this circuit badly affected by load capacitance IE did the square wave get lots better when you removed the cap? Will capacitive loading limit the switching speed in digital circuits?

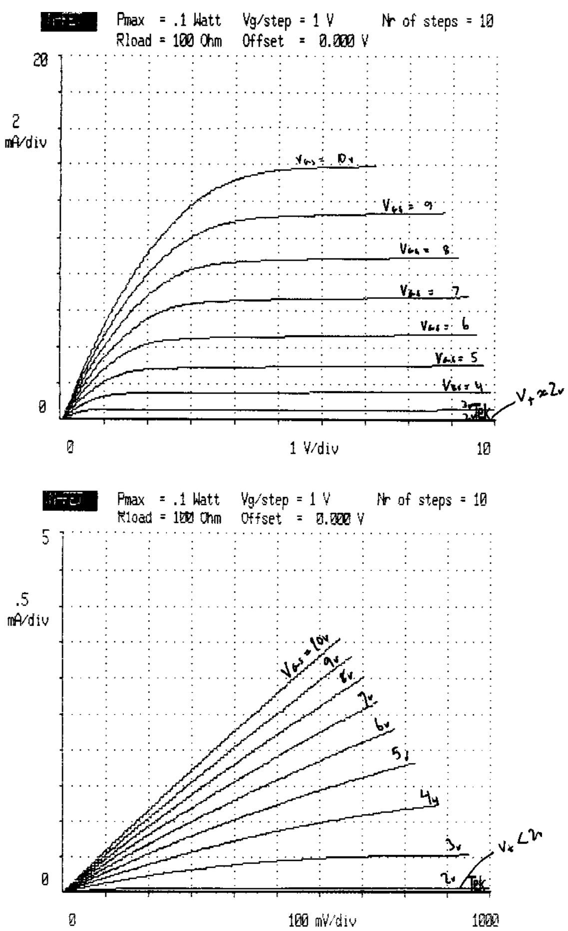
Optional: Measure the rise and fall times (10% to 90%, and 90% to 10%, see Fig. 1.35, page 46 in your book). Replace the capacitor for this measurement.

Turn off the signal generator, turn off the power supply, and then disconnect both.

Small-signal amplifier: Rewire the circuit as shown. Set the signal generator to give a 0.1 Vpp sine wave at about 1 KHz, then connect the power supply and signal generator in the same order as last time.



If the output signal is distorted, reduce the input voltage until the distortion is no longer visible. (You may have to make an attenuation circuit like you did in earlier labs to use with the HP). Measure and record v_i and v_o (Vpp). Calculate and record the small signal voltage gain $A_v = v_o/v_i$.



Representative Curves