ESC201 Introduction to Electronics Lab 6 Handout for Lab Experiments
Characteristics of MOSFET and MOSFET-based Circuits

Aim: In this lab, you will observe the DC characteristics of MOSFET and MOSFET-based inverters**.** You will also extract the MOSFET parameters, e.g., threshold voltage (V_T) and transconductance parameter (K_n).
The simplest model for the current I_D of the NMOS will be $I_D = 0$ for $V_{GS}<V_T$, and for $V_{GS}>V_T$, current in saturation is $I_D = 0.5K_n(V_{GS}–V_T)^2$, and current in linear region is $I_D = K_n[V_{GS}–V_T – V_{DS}/2]V_{DS}$.
You will be using the IC CD4007 (shown in Fig. P1a) which contains multiple n- and p-channel MOSFETs. The way an IC is mounted on a breadboard is shown in Fig. P1b so that no two pins of the IC are connected.

Precautions: MOSFETs are highly susceptible to damage through electrostatic discharge. Touch the ground wire of power supply to discharge static electricity from your body before handling MOSFET.
For most of the applications with CD4007, it is extremely important to connect pin 14 to the most positive supply of the circuit and pin 7 to the most negative supply of the circuit (or the ground) as shown in Fig. P1b.

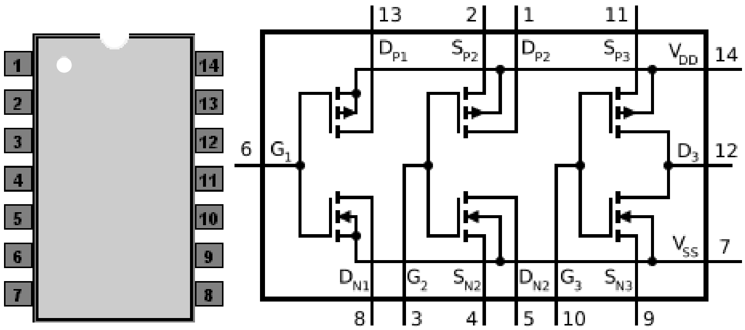

Figure P1a: CD4007 Pin Diagram

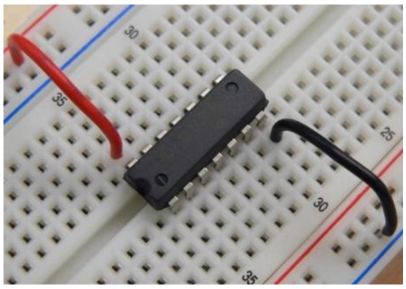

Figure P1b: CD4007 on Breadboard

Experiment 1: Observing the Output Characteristic of NMOS (*3 × 4 = 12 marks*)

- Wire the circuit shown in Fig. E1a with R_D = 1 kΩ. The pin numbers for CD4007 are given in the figure.
- Using the FG, apply an ac triangular pulse of 1 kHz frequency with peak-to-peak voltage from 0 V to 5 V.

Use the offset and amplitude knob of the FG to obtain the signal (you may need to check it using the DSO).

- Observe and trigger the waveforms properly in Normal mode before changing the display to XY mode.
- Rotate the potentiometer knob to vary V_{GS} and observe different I_D vs. V_{DS} characteristics for different V_{GS}.
- You can measure the corresponding value of V_{GS} using the DMM.
- The maximum range of V_{DS} for the circuit shown in Fig. E1a will lie on the load line as shown in Fig. E1b.

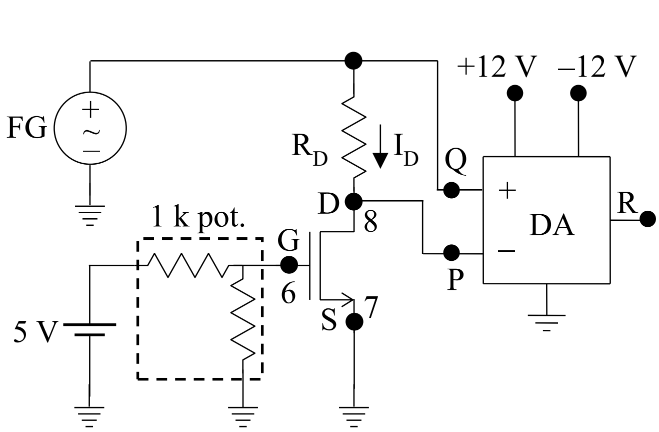

Figure E1a

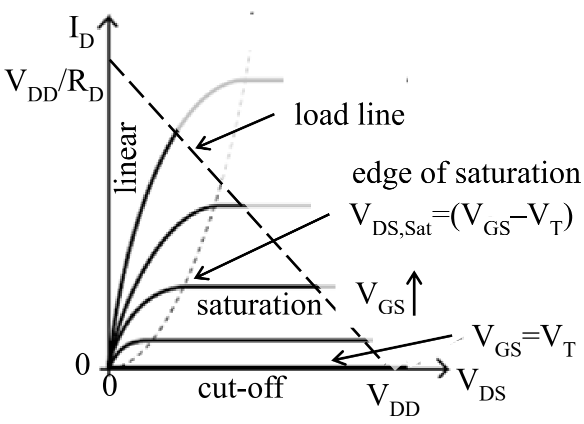

Figure E1b: Output Characteristic of NMOS

1. For R_D = 1 kΩ, observe, measure and plot the I_D vs V_{DS} characteristics for V_{GS} = 0 V, 2.5 V, 5 V. Find approximately the threshold voltage (V_T) by observing when I_D becomes almost negligible while changing V_{GS} using the 1k pot, and then, measuring the corresponding value of V_{GS} using the DMM.
2. Set V_{GS} = 2.5 V by rotating the potentiometer knob and find the value of $V_{DS,Sat}$ at the edge of saturation and the corresponding value of $I_{D,Sat}$ in the saturation region (but close to the edge of saturation). From the results obtained, find the threshold voltage (V_T) and transconductance parameter (K_n) of the NMOS.
3. Find the maximum value of V_{DS} for V_{GS} = 2.5 V and 5 V. Also, find I_D in each case when V_{DS} has its maximum value. Plot the line from the obtained (I_D, V_{DS}) data and find the intercept to both I and V axes.
4. Put R_D = 100 Ω and repeat step 3 above. Observe, measure and write down the changes along with a plot. Note that the current-to-voltage conversion will be different because of a different resistance value used.

Experiment 2: Observing the Load-line for NMOS Inverter (*3 × 2 = 6 marks*)

- Set up the circuit shown in Fig. E2a with R_D = 1 kΩ. The pin numbers for CD4007 are given in the figure.
- Using the FG, apply an ac triangular pulse of 1 kHz frequency with peak-to-peak voltage from 0 V to 5 V. Use the offset and amplitude knob of the FG to obtain the signal (you may need to check it using the DSO).
- Connect CH-1 to the drain terminal of the NMOS and CH-2 to the output of the DA.
- Observe and trigger the waveforms properly in Normal mode before changing the display to XY mode.

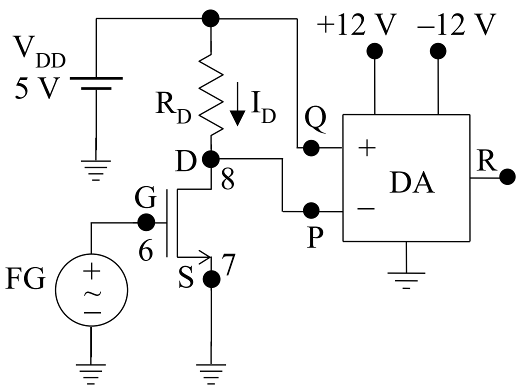

Figure E2a

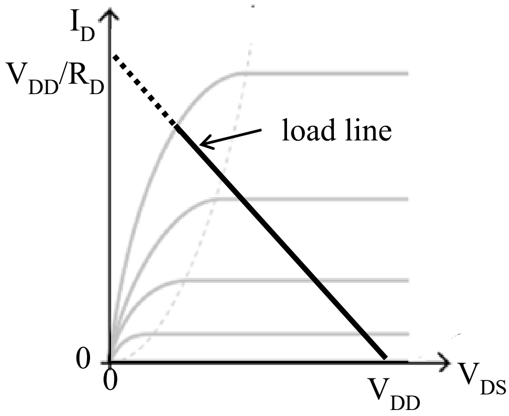

Figure E2b: Load-line for NMOS Inverter

1. For R_D = 1 kΩ, observe the load-line on the DSO. Find two points on the load line, measure the current and voltage values at those two points. Plot the entire load line and find the intercept to both I and V axes. Compare your result with that obtained in part 3 of experiment 1 above and comment.
2. Put R_D = 100 Ω and repeat the step above. Observe, measure and write down the changes in the load line along with the plot of it. Compare your result with that in part 4 of experiment 1 above and comment.

Experiment 3: Observing the Transfer Characteristic of NMOS (*3 × 2 = 6 marks*)

- Set up the circuit of Fig. E2a with R_D = 100 Ω. The pin numbers for CD4007 are given in the figure.
- Using the FG, apply an ac triangular pulse of 1 kHz frequency with peak-to-peak voltage from 0 V to 5 V. Use the offset and amplitude knob of the FG to obtain the signal (you may need to check it using the DSO).
- Observe and trigger the waveforms properly in Normal mode before changing the display to XY mode.

1. Observe, measure and plot the I_D vs V_{GS} characteristics. Using the cursor, measure the value of the current I_D for V_{GS} = 0. Also, measure the value of threshold voltage (V_T) from the I_D vs V_{GS} characteristics.
2. Check if the NMOS is in the saturation region (i.e., the quadratic part of I_D vs V_{GS} characteristic) or not for V_{GS} = 2.5 V. Measure the current I_D for V_{GS} = 2.5 V, and calculate the value of the transconductance parameter K_n. Compare these results with those obtained in part 2 of experiment 1, and comment.

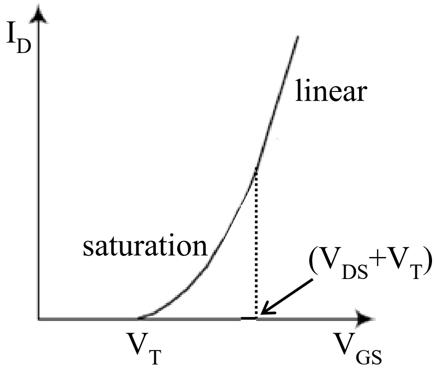

Figure E3: Transfer Characteristic of NMOS

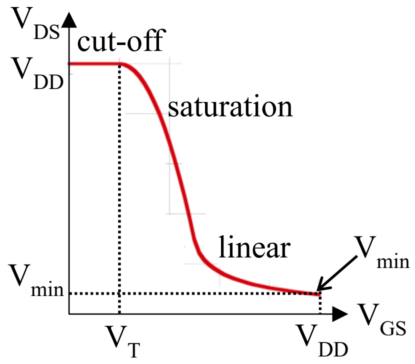

Figure E4: VTC of NMOS Inverter

Experiment 4: Observing the VTC of an NMOS based Circuit (*3 × 2 = 6 marks*)

- Set up the circuit of Fig. E2a with R_D = 1 kΩ. The pin numbers for CD4007 are given in the figure.
- Connect CH-1 to the FG output (connected to the gate of the NMOS) to observe V_{GS} and CH-2 to the drain of the NMOS to observe V_{DS}.
- Using the FG, apply an ac triangular pulse of 100 Hz frequency and peak-to-peak voltage from 0 V to 5 V. Use the offset and amplitude knob of the FG to obtain the signal (you may check it using the DSO CH-1).
- Observe and trigger the waveforms properly in Normal mode before changing the display to XY mode.

1. For R_D = 1 kΩ, observe, measure and plot the VTC (similar to that shown in Fig. E4). Also, measure the output voltage (V_{min}) for V_{GS} = 5 V, and write it down. From the data, calculate the value of the threshold voltage V_T and the transconductance parameter K_n. Compare these results with those obtained before.
2. Now, change the frequency of the input signal from 100 Hz to 100 kHz in multiples of 10, and observe how the VTC is changing and plot them. Note down if there is any hysteresis in the VTC, and comment.

Experiment 5: Functionality of the NMOS based Circuit (*2 × 5 = 10 marks*)

Now, set up the circuit of Fig. E2a with R_D = 10 kΩ. Using the FG, apply an ac triangular pulse of 100 Hz frequency and peak-to-peak voltage from 0 V to 5 V.

1. Observe, measure and plot the VTC. Note down the changes you observe in the VTC from that obtained in previous part. Measure the value of the output voltage (V_{min}) for V_{GS} = 5 V and note it down.
2. Calculate the value of V_{GS} at the edge of saturation for the NMOS (use the K_n and V_T values which you found earlier for this calculation). Find the gain of the circuit from the VTC near the edge of saturation (i.e., near the value of V_{GS} that you calculated). Choose two points on the VTC near the edge of saturation and measure accurately the voltages at these two points on the VTC using cursor. You may need to zoom in and adjust the scale. From these two points, calculate the slope which will give the gain at that point.

Now, using the FG, apply an ac square pulse of 1 kHz frequency with peak-to-peak voltage from 0 V to 5V and duty cycle of 50%. Use the offset and amplitude knob of the FG to obtain the signal.

3. Check the functionality of the NMOS circuit by observing both the input and the output waveforms on the DSO in the Normal mode. Measure and plot both the input and the output waveforms.
4. Now connect CH-1 to the output of the DA and observe I_D. Measure and plot the waveforms for both V_{DS} and I_D (after proper conversion from voltage to current).
5. Using the Multiply option from the Math function, find the instantaneous power as well as the average power dissipated across the NMOS, and write it down.