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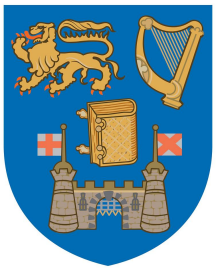

JS Engineering: 3C2 Digital Circuits

D2: The MOS/CMOS Inverter

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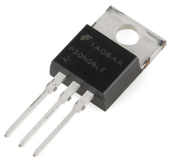


Contents

1 Abstract

Lab D2 introduces the concept of MOS transistor simulation in the MultiSim 13.0 environment, and theory associated with the static and dynamic characteristics which show the effect of performance in various environments in the modern world of technology.

2 Introduction

The aim for this lab is to show and understand the differences between *n-channel* and *p-channel* MOS transistors, to test various properties of MOS, and also to demonstrate the performance of CMOS inverters. These states are modelled and examined during this laboratory through adjusting and viewing the properties associated with these states within circuit design.

3 Theory

3.1 What is a MOSFET?

MOSFETs are used in modern day technology to control electronics, similarly to a BJT. However a BJT controls by current, while a MOSFET is a voltage-controlled device that acts like a variable resistor, where voltage applied changes how the device conducts within the circuit. MOSFETs have a very high impedance, therefore it's extremely easy to drive on low current.

3.2 How does a MOSFET work?

A MOSFET is a voltage controlled field effect transistor that has its gate electrode highly insulated from the semiconductor in the transistor by a very thin layer of insulating material. The insulated metal gate acts similarly to how a capacitor's plate which causes an extremely high input resistance due to isolation. However, when a voltage is applied to the gate, the width of the *drain-source* channel changes, and the device conducts freely.

3.3 Abbreviations

- MOSFET
  - MOSFET stands for *Metal-Oxide Semiconductor Field Effect Transistor*, and is used to amplify signals or act as a switch in an electronic circuit. Their main advantage is the low current required (1mA) in order to activate, while delivering a much higher current load (10-50A).
- N-channel
  - An n-channel MOS transistor is classified as a semiconductor device where the electrons control the current flowing through it by utilising three terminal substrates: *gate*, *drain* and *source*. These terminals allow for three different modes of operation that affect the output differently, whose modes are *cut-off*, *triode*, and *saturation*. The n-channel generally has a lower resistance than a p-type MOS transistor.
- P-channel
  - A p-type MOS transistor pertains to the same properties in terms of operation as a n-type MOS transistor, where the differences lie in its substrate composition, where the charge characteristics are holes instead of electrons.

- Gate
  - The gate is the terminal controlled by the voltage supplied to the MOS transistor.
- Drain
  - The drain is where the charge carriers can exit the channel.
- Source
  - The source is where the charge carriers can enter the channel.
- V_{GS}
  - This is the voltage that exists between the gate and source terminals.
- V_T
  - This is the threshold voltage of the transistor, other scripts such as O or I imply its threshold on the out- or input.
- V_I
  - This is the input voltage, other subscripts such as L or H determine the logic level implied.
- V_O
  - This is the output voltage, other subscripts such as L or H determine the logic level implied.
- V_{DD}
  - This is the positive power supply voltage that the circuit utilises to drive charge carriers.
- V_{ILMAX}
  - Max input voltage in order to recognise a logic LO.
- V_{IHMIN}
  - Minimum input voltage in order to recognise a logic HI
- V_{OL}
  - Output level to be recognised as a logical LO
- V_{OH}
  - Output level to be recognised as a logical HI
- R_d
  - Resistive load applied to the drain of the MOS transistor.
- t_{PHL}

  - The propagation delay that exists for an input changing from a logic high to a logic low.

- t_{PLH}
  - The propagation delay that exists for an input changing from a logic low to a logic high.

- t_f
  - The time taken for the voltage to cross the transistor junction in forward active mode.

- t_r
  - The time taken for the voltage to cross the transistor junction in reverse active mode.

4 MOS Transistor Characteristics

Using MultiSim 13.0, the following schematic should be drawn and connected up.

4.1 Procedure

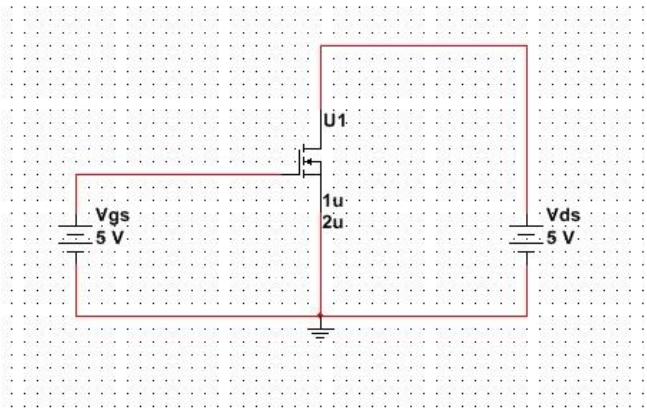


Figure 1: Drain Current v Gate-Source Voltage

- Create a new page and insert a N-MOS transistor with the following values onto the design schematic sheet. Ensure to save them to the user database for easy access.
  - Length: $1 \cdot 10^{-4}$m
  - Width: $2 \cdot 10^{-4}$m
  - V_{TO}: 1V
  - K_n: $2 \cdot 10^{-5}$A/V^2
- Later on for a P-MOS transistor, the following values should be used instead, which should be also saved in the user database to save time.
  - Length: $1 \cdot 10^{-4}$m
  - Width: $2 \cdot 10^{-4}$m

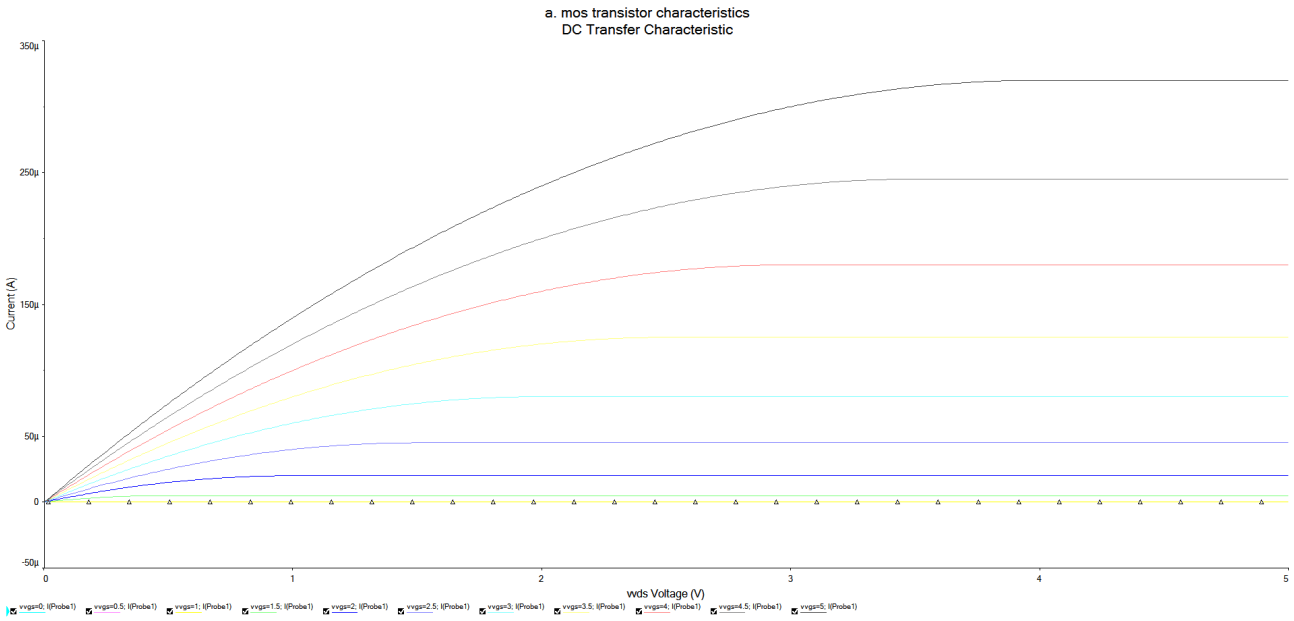
  - V_{TO}: -1V
  - K_p: $2 \cdot 10^{-5}$A/V^2

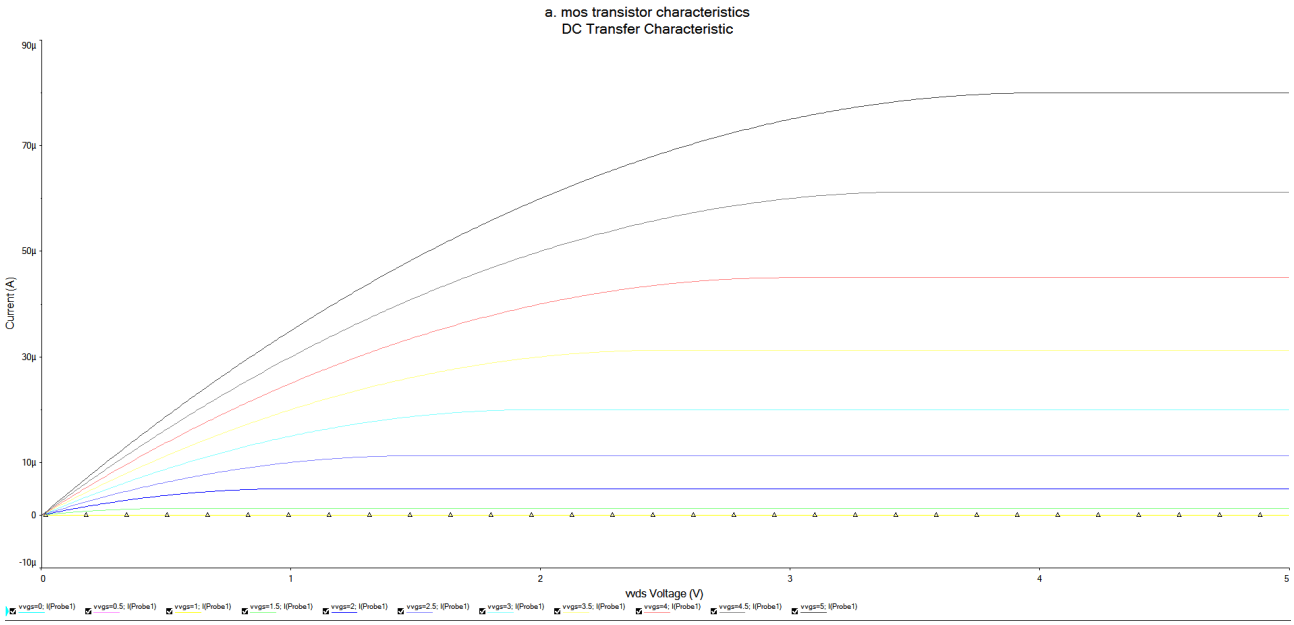
- Set up the schematic as shown in the diagram
- Ensure the components are wired up correctly, including the ground.
- Place a probe looking towards the drain of the MOS transistor
- Perform a sweep using V_{DS} as source 1, and V_{GS} as source 2.
- Also make sure that I(Probe1) has been added to the list of selected variables for analysis for generating a plot of I_D v V_{GS}
- On sweeping this, change the value of the MOS transistor width to 4μm and rerun the analysis.

4.2 Results

	N-Channel	P-Channel
Length	0.0001m	0.0001m
Width	0.0001m	0.0001m
V_{TO}	1V	-1V
K_p, K_n	$2 \cdot 10^{-5}$ A/V^2	$1 \cdot 10^{-5}$ A/V^2

Table 1: Reference Values





4.3 Discussion

5 Resistively Loaded MOS Transistor Inverter

5.1 Procedure

- Using the previously designed circuit, add the extra components to their respective positions by following the schematic provided.
- When setting up a DC sweep, ensure that V_{DS} is set to be source 1 instead of V_{GS} where the probe is with respect to voltage, and not current.
- When repeating the exercise, modify the resistor value R_D to be 100kΩ
- Measure the logic values of V_{ILMAX}, V_{IHMIN}, V_{OL}, and V_{OH} to be shown in the table below.

5.2 Results

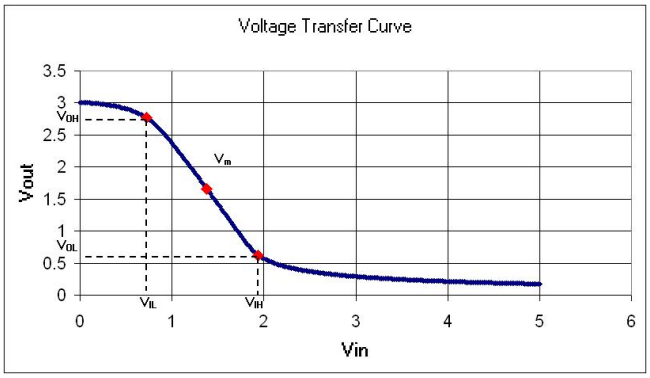


Figure 2: Voltage Transfer Characteristics

Using the formula below, where $V_{GS} = V_{DD}$,

$$V_O = V_L = \left(V_{DD} - V_T + \frac{1}{2K_n R_D}\right) \pm \sqrt{\left(V_{DD} - V_T + \frac{1}{2K_n R_D}\right)^2 - \frac{V_{DD}}{K_n R_D}}$$

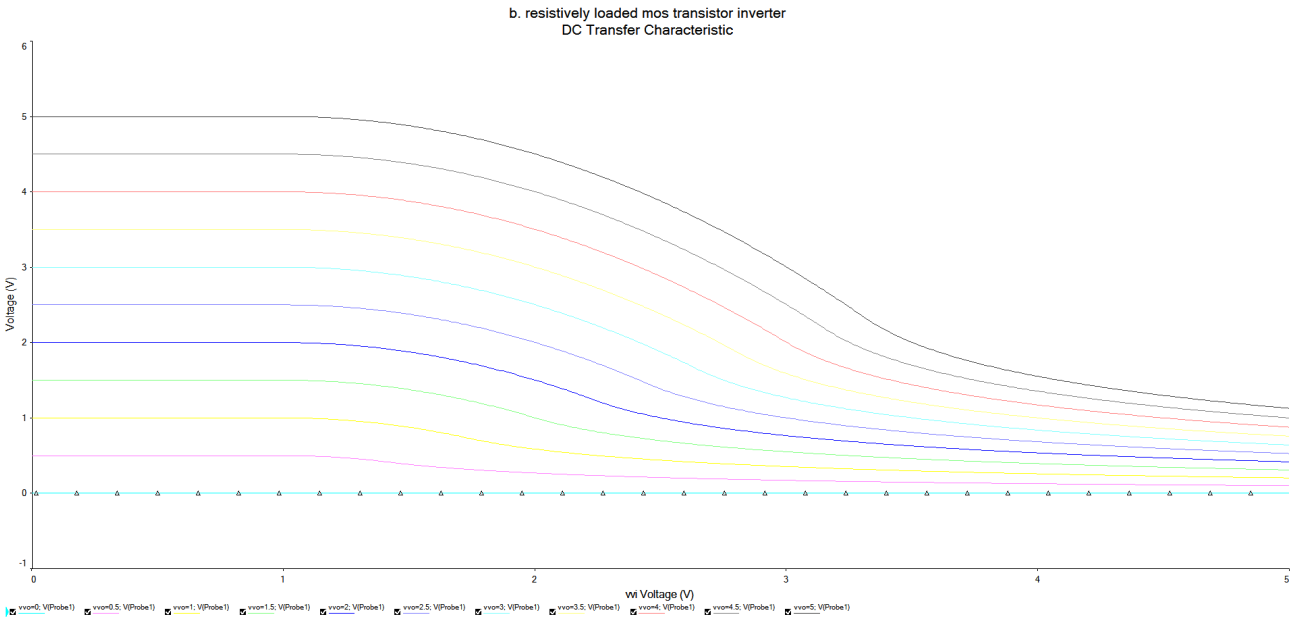
We find that 100kΩ resistor has a V_O of 7.44V or 0.305V, and the 25kΩ resistor has a V_O of 8.87V or 1.127V.

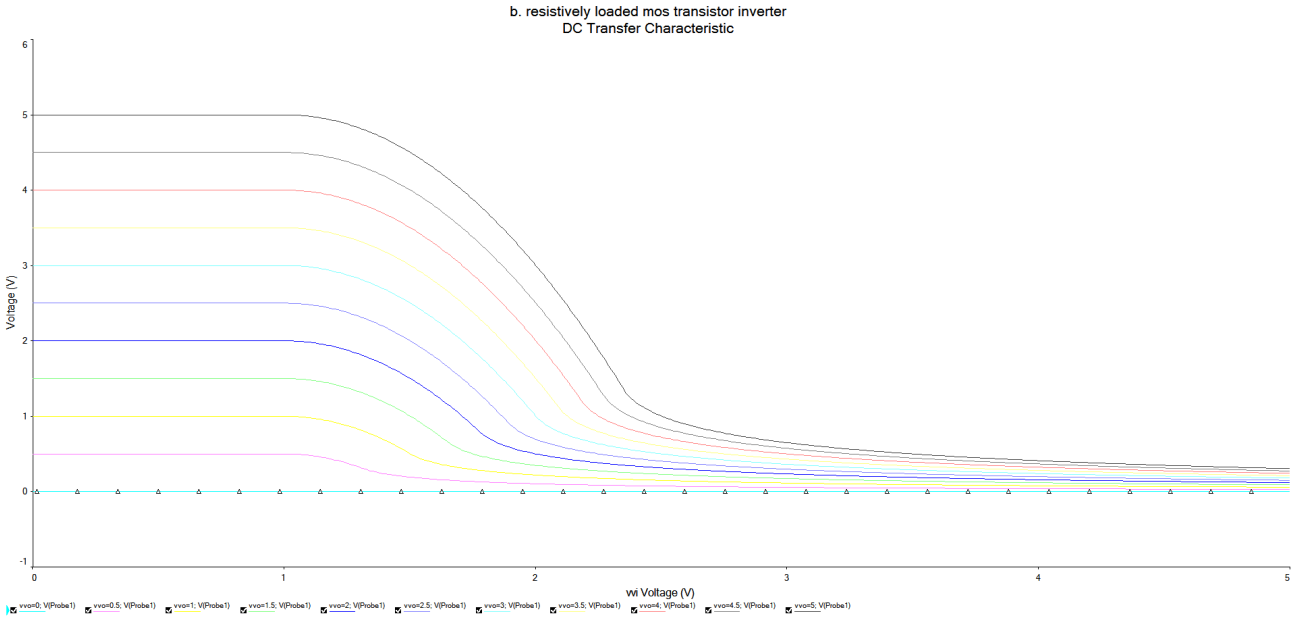
V_{ilmax}	1.51V
V_{oh}	5.05V
V_{ihmin}	2.42V
V_{ol}	1.29V

Table 2: 25kΩ Resistor

V_{ilmax}	1.26V
V_{oh}	4.93V
V_{ihmin}	1.17V
V_{ol}	645mV

Table 3: 100kΩ Resistor





5.3 Discussion

6 CMOS Inverter

6.1 Static Characteristics

6.1.1 Procedure

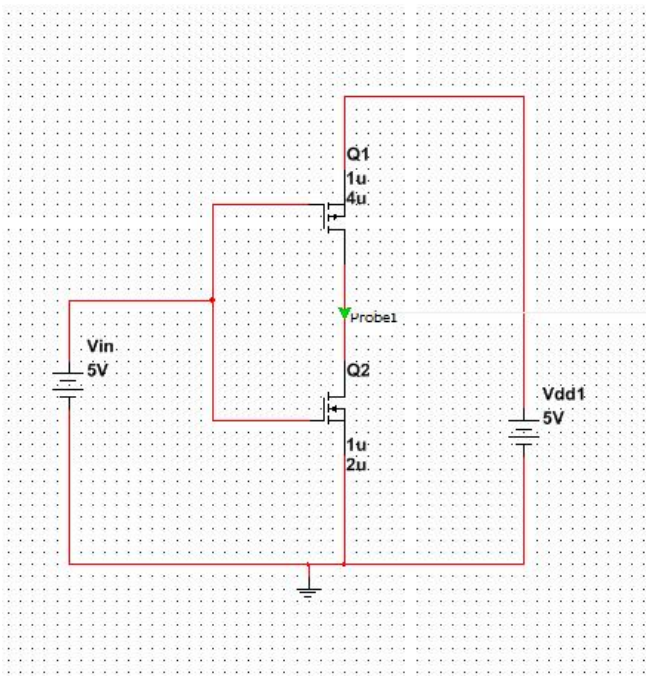


Figure 3: Drain Current v Gate-Source Voltage

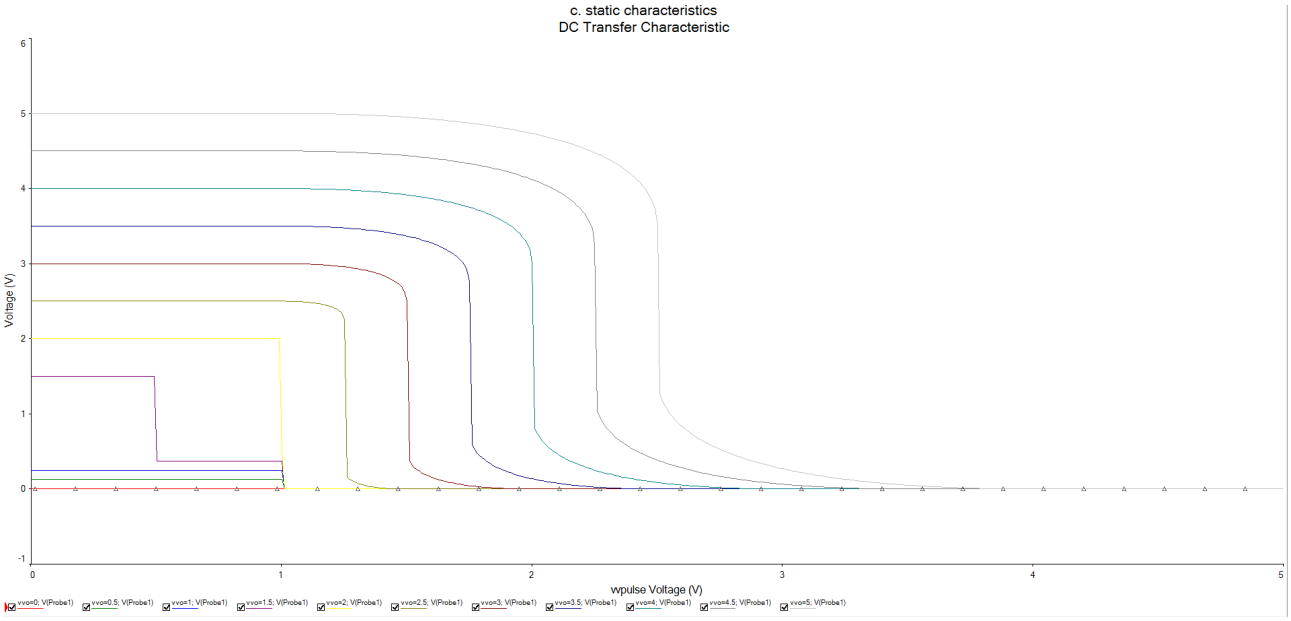
- Create a new schematic and set up everything as shown in the diagram provided using the correct components.

- Ensure the MOS transistors are facing the correct way, where in the case that they aren't, the can be flipped accordingly through right clicking on the component and selecting an option from the menu.
- Set up a DC sweep for V_{in} from 0-5V using an output probe of voltage as V_O.
- Simulate the graph and use the cursors to obtain V_{ILMAX}, V_{IHMIN}, V_{OLMAX}, and V_{OHMIN} at the points where the slope is tending to -1 in the appropriate regions of curvature.

6.1.2 Results

V_{ilmax}	2.4V
V_{ihmin}	2.6V
V_{olmax}	0.8V
V_{ohmin}	4.2V

Table 4: Static Characteristics



6.1.3 Discussion

6.2 Dynamic Characteristics

6.2.1 Procedure

- Using the schematic created in the previous part, modify the circuitry to include a capacitive dynamic condition in its configuration.
- Using pulse voltage instead of a gate source this time, ensure the values from the image below are used.
- Set up a transient analysis accordingly with a start time of 0, and end time of 2E-006, and a maximum time step of 4E-006.
- Obtain the values for t_{phl}, t_{plh}, t_f, and t_r as follows:

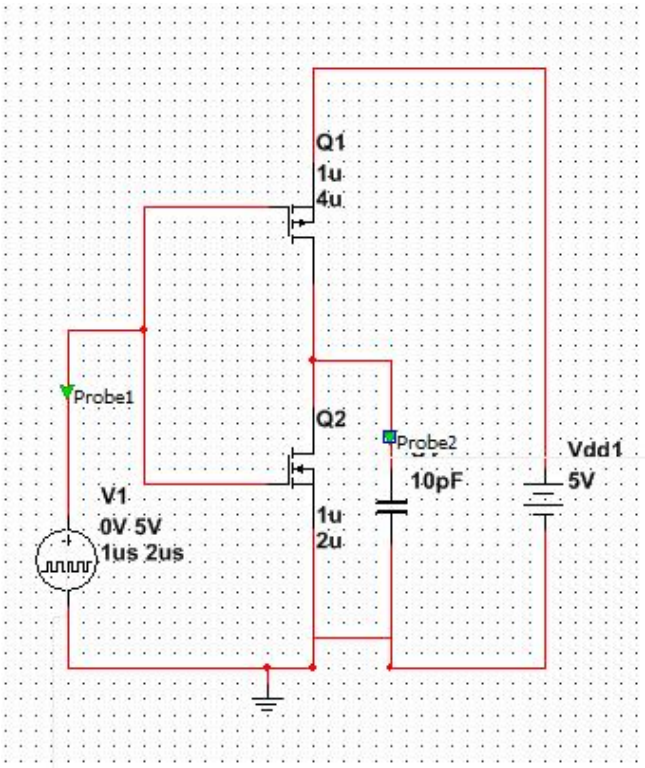


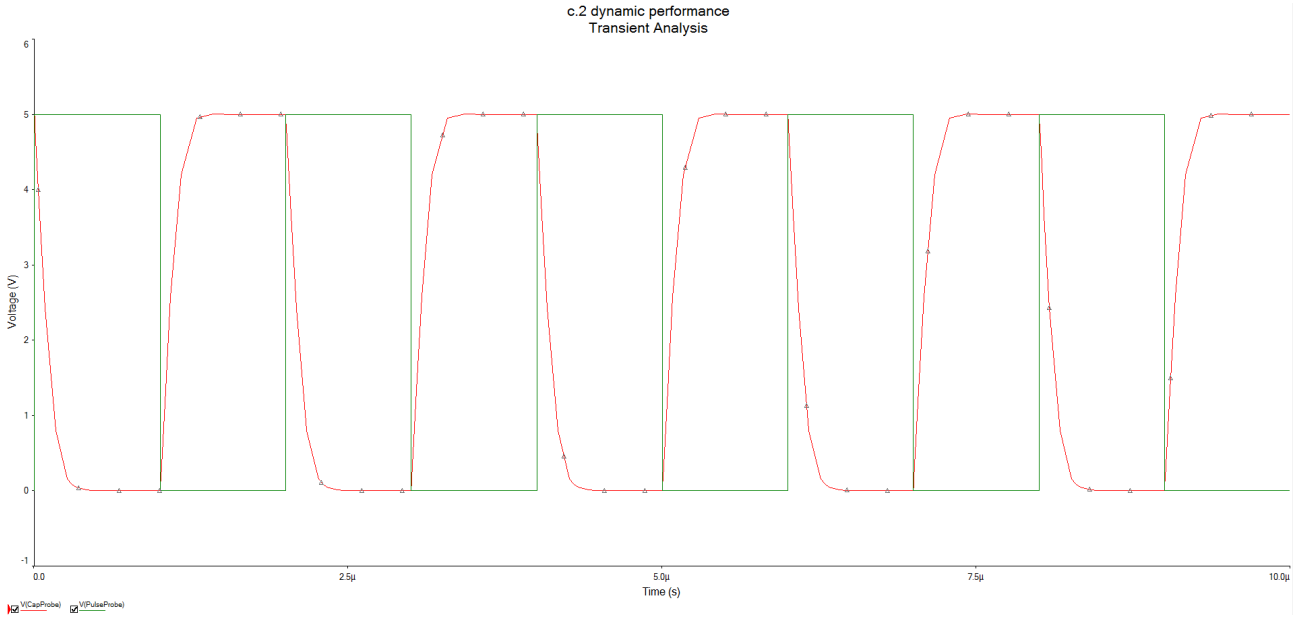
Figure 4: Drain Current v Gate-Source Voltage

- t_{phl}: Input-output propagation delay at 50% for a HI-LO transition
- t_{plh}: Input-output propagation delay at 50% for a LO-HI transition
- t_f: Fall time over the 90%-10% HI-LO transition
- t_r: Rise time over the 10%-90% LO-HI transition

6.2.2 Results

t_{PHL}	0.07μs
t_{PLH}	81.1ns
t_f	187.1ns
t_r	1.1μs

Table 5: Static Characteristics



6.2.3 Discussion

6.3 Discussion

- What are the limitations on the accuracy of your results?
  - Human error and eye-balling results as an approximation were major contributions to error in results as the error wasn't entirely standard overall and the results of approximation varied per person's judgement.
- How do the values of parameters compare with those obtained in the lectures?
  - The values obtained were somewhat similar to values in lectures. There are discrepancies in values though as those in lectures are always in an ideal and theoretical environment.
- What are the advantages or disadvantages of circuit simulations such as the one carried out in the experiment?
  - A great advantage of such a programme would be the ability to streamline and improve the design of the circuit without too much hassle and time involved in comparison to creating and testing it out in real life. Although these are great advantages of Multisim, a disadvantage would be that this is always in an ideal world. As we live in a world that is not always ideal, there might be some environmental factors such as temperature that would tamper with actual values.
- What are the benefits or drawbacks of circuit simulation and of MultiSim in general as applied to the design of electronic circuits?
  - The simulator needs to be user friendly with the graphics. It needs to be able to work efficiently and calculate the values needed at the time needed. A large library of components needs to be available to use in the simulation. All modules are accurate and up to date with the current technology.
- What are the essential elements of good circuit simulation and simulators?

  - The simulator needs to be user friendly with the graphics. It needs to be able to work efficiently and calculate the values needed at the time needed. A large library of components needs to be available to use in the simulation. All modules are accurate and up to date with the current technology

- What is the roll of the Electronic Engineer in this regard?
  - The role in this regard would be to understand how to use the software package in an efficient and educated manner. In order to do this however, a strong understanding of circuitry is required and the limits of the circuit itself.

7 Bibliography

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