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| ELEC 402 – October 24, 2021 |
| Project 3 Report |
| Martin Chua - 35713411 |

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Diagram, schematic

Description automatically generated



1. **Resistive load inverter**

At one extreme, V­in is high, transistor is off and no current flows because MOS is in cut-off region, VOH = VDD. At the other extreme, Vin = VOH = VDD substituted into IOUT = Iload g IR = I­DS(lin), and the transistor operates in linear region. Using the useful formula for linear current:

Now we can also just straight up plug-in everything (taken from question):

* Vin = VGS = VOH = VDD = 1.2 V
* VDS = Vout = VOL = 0.1 V
* L = 0.1 µm
* RL = 10 kΩ
* µn = 270 cm2V-1s-1
* Cox = 1.0E-6 F/cm2
* EC = 6 V/µm
* VT = 0.4 V

Equating for W and throwing into wolfram:

1. **Saturated-enhancement-load inverter**

With this layout, we know the top pull-up transistor is the load and bottom pull-down transistor is the inverter. We know the load is always in saturation and the inverter should be linear because we want Vout = VOL = 0.1 V. Using the useful formulas for linear (left) and saturated (right) current, we can equate the two and get:

Using the following substitutions (inverter):

* Vin = VGS = VOH = VDD = 1.2 V
* VDS = Vout = VOL = 0.1 V
* L = 0.1 µm
* µn = 270 cm2V-1s-1
* Cox = 1.0E-6 F/cm2
* EC = 6 V/µm
* VT = 0.4 V

Using the following substitutions (load):

* Vin = VOH = VDD = 1.2 V
* VGS = 1.2 – 0.1 = 1.1 V
* vsat = 8E6 cm/s
* Wload = 0.1 µm
* L = 0.1 µm
* Cox = 1.0E-6 F/cm2
* EC = 6 V/µm
* VT = 0.4 V

Note that although the left side units cancel out nicely due to the cm2/cm2, we need to convert the right-side units from cm (1E-2) to µm (1E-6) after the Coxvsat cancellation as there is still a cm unit left, done by multiplying the right side with 1E-4.

Equating for Winverter and throwing into wolfram:

1. **Linear-Enhancement-Load inverter**

To overcome low VOH, in the saturated-enhancement-load inverter, instead of VDD for both gate and drain of the load transistor, it is separated with VGG = 1.6 V and VDD = 1.2 V. Its linear region of operation is then VGG > VDD + VTL(VDD). Again, we equate currents but this time, the right side is not in saturation, but linear operation as well:

Using the following substitutions (inverter):

* Vin = VGS = VOH = VDD = 1.2 V
* VDS = Vout = VOL = 0.1 V
* L = 0.1 µm
* µn = 270 cm2V-1s-1
* Cox = 1.0E-6 F/cm2
* EC = 6 V/µm
* VT = 0.4 V

Using the following substitutions (load):

* Vin = VDS = VOH = VDD = 1.2 V
* Vout = VOL = 0.1 V
* VGS = 1.6 – 0.1 = 1.5 V
* L = 0.1 µm
* µn = 270 cm2V-1s-1
* Cox = 1.0E-6 F/cm2
* EC = 6 V/µm
* VT = 0.4 V

Note that the difference this time between linear-enhancement and saturated-enhancement is VGS of the load pull-up transistor. Also note that Vin for the linear region inverter pull-down transistor remains at 1.2 V. Here we equate VDS as the same for both transistors as we’re treating it as output, VOL.

Equating for Winverter and throwing into wolfram (no need to simplify if wolfram does it all 😊):

1. Results explanation

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| Resistive Load | Saturated-Enhancement-Load | Linear-Enhancement-Load |
| 0.634 µm | 0.174 µm | 0.140 µm |

Table 1. Calculated widths for each inverter

The resistive load inverter appears to have the highest width, followed by Saturated-Enhancement, then Linear-Enhancement. The resistor in digital design is probably worse than using a MOSFET due to area which in turn means a slower and larger circuit area. The Saturated-Enhancement load inverter replaces the resistor with a MOSFET, where the max input voltage is limited by VDD – VT., which has tradeoffs such a lower saturation operation threshold. The Linear-Enhancement load inverter introduces a higher V­GG, which means that biasing the gate voltage to exactly VT above drain voltage allows linear operation and increases the saturation operation threshold.

Diagram, schematic

Description automatically generated

Diagram

Description automatically generated

Graphical user interface, text, application

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Text

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1. A picture containing chart

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