Experiment 2. Integrated Circuits; Electrical Properties and Specifications

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1. Objectives

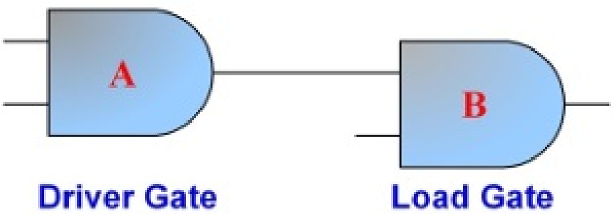
- Reading data sheets and extracting required parameters.
- Understanding the significance of some major input and output electrical specifications.
- Understanding the limitations of driving various loads.
- Develop experiments to measure and verify some of these specs.

2. Materials Required

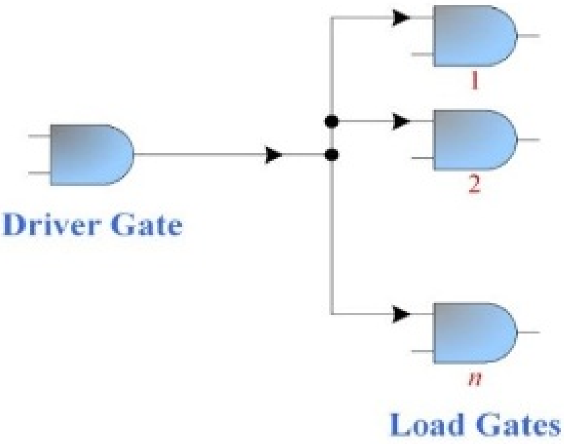
- IC – 7404
- Potentiometers / Variable resistors
- Wires
- Wire stripper
- Prototyping board with power and ground connections
- IC Tester
- Multi-meters

3. Background

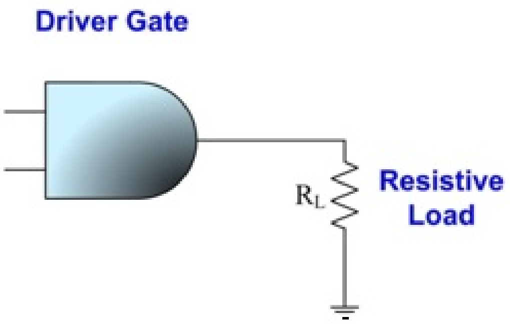
- If the *output* of some gate `A` is connected to the *input* of another gate `B`, gate `A` is said to be the driver gate, while gate `B` is said to be the load gate. Equivalently, we say:
  - `A` drives `B`, or
  - `B` loads `A`

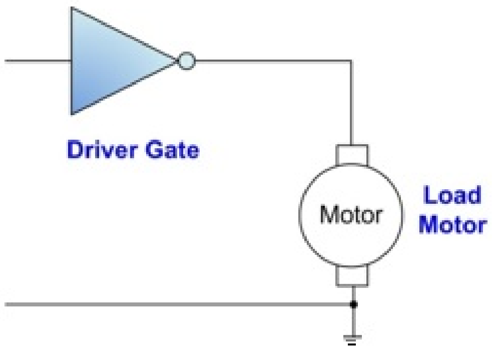


- A single driver gate may have more than one load gate.



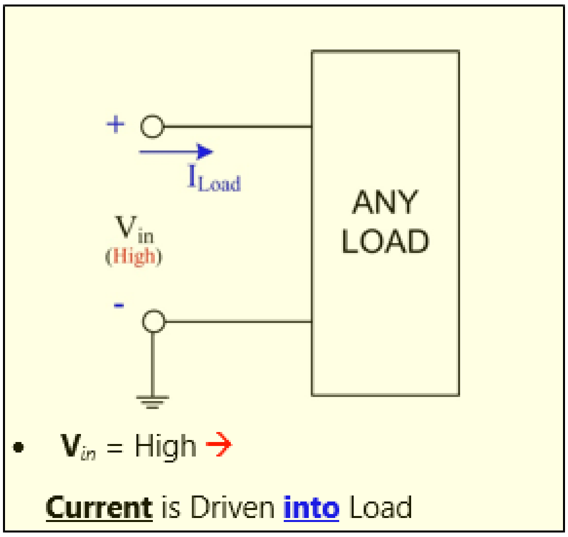
- The *load* does not necessarily have to consist of similar gate(s). The load may be a combination of a variety of other devices, e.g. a purely resistive load, a servo motor, etc.

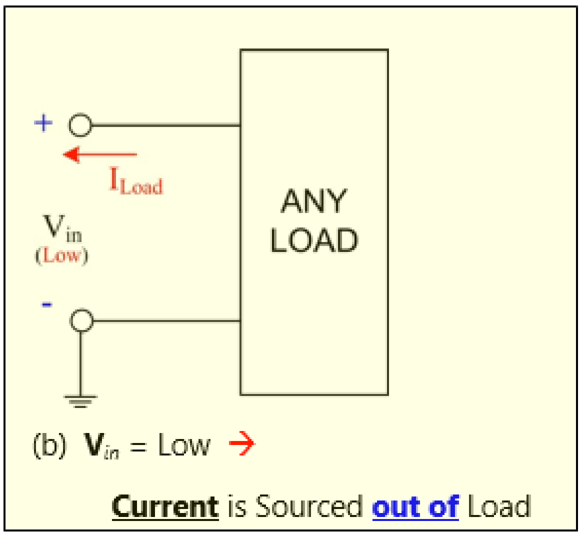




3.1. Requirements for Proper Load Driving

- To drive a given load, the driver must be capable of providing the load with the proper values of:

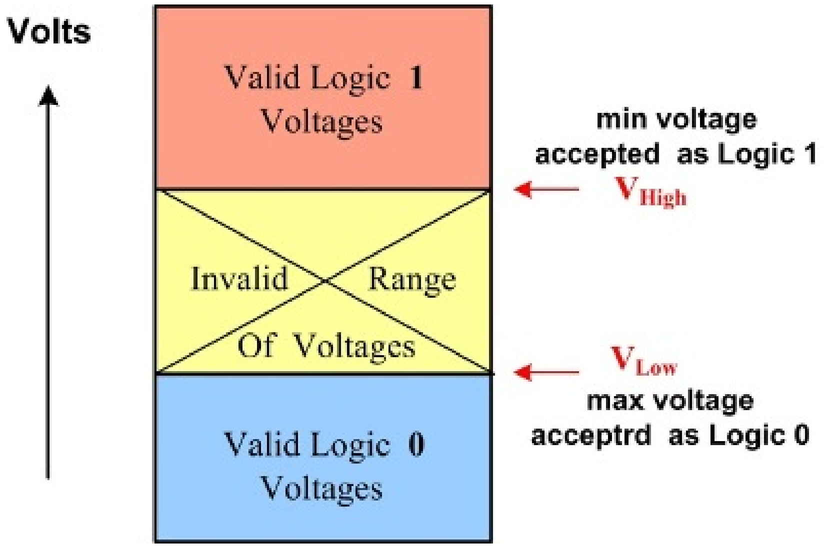




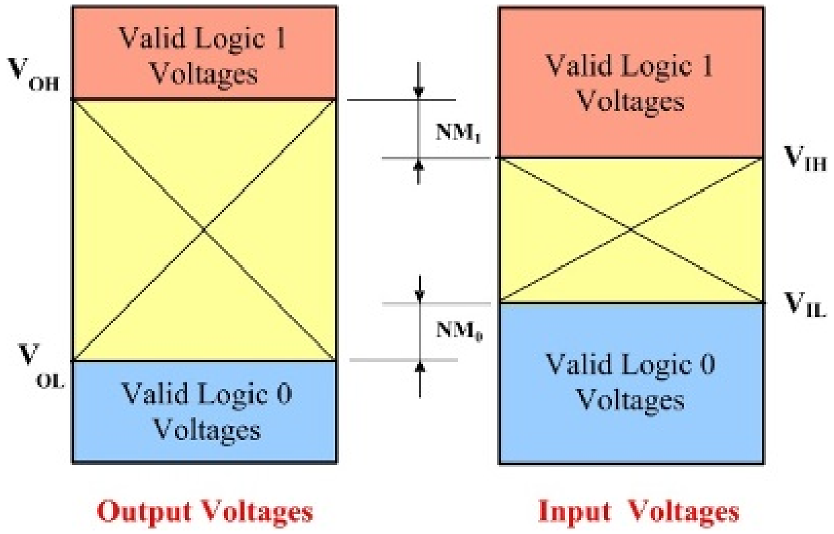
1. Input voltage (*high* and *low*), and
2. Current (*in* and *out*)

3.2. Voltage Requirements

- Using electric signals to represent logic values, a logic `0` value is allocated a range of low voltages while a logic `1` value is allocated a range of high voltages:



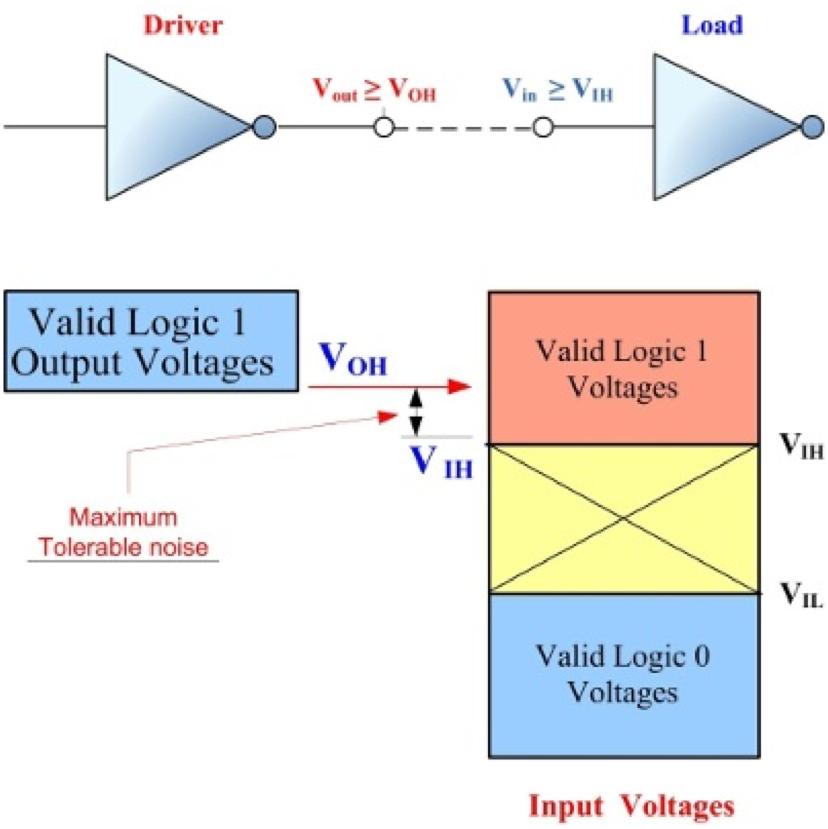
- If both the driver and load are IC gates, the driver output voltage V_{high} and V_{low} values and the load input voltage V_{high} and V_{low} values are different and are designated as V_{OH} and V_{OL} for outputs and as V_{IH} and V_{IL} for inputs.



- Worst case *driver high output voltage* (V_{OH}) should be within the range of acceptable *input* logic `1` voltages, i.e.

$$V_{OH} \geq V_{IH}$$

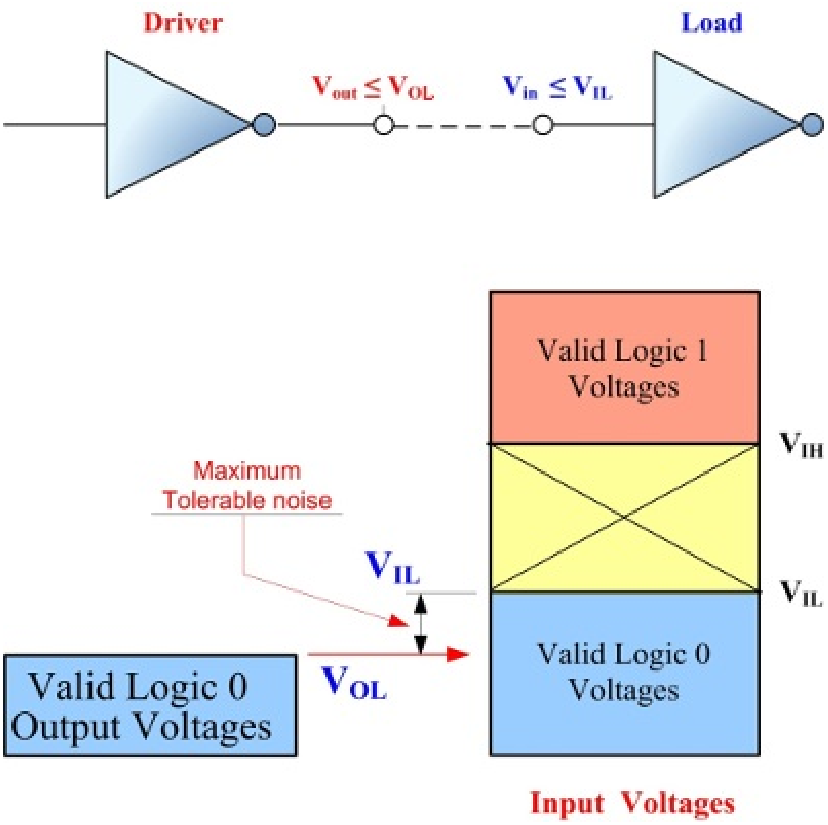
Typically, $V_{OH} = V_{IH} + NM_1$, where NM_1 is the maximum tolerable noise voltage that can be *subtracted* from the driver high output voltage with the load gate still functioning properly.



- Worst case *driver low output voltage* (V_{OL}) should be within the range of acceptable *input* logic `0` voltages, i.e.

  $$V_{OL} \leq V_{IL}.$$

  Typically, $V_{IL} = V_{OL} + NM_0$, where NM_0 is the maximum tolerable noise voltage that can be *added* to the driver low output voltage with the load gate still functioning properly.



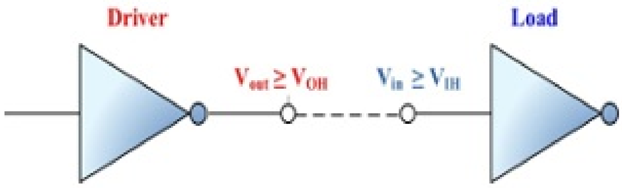
3.3. Current Requirements

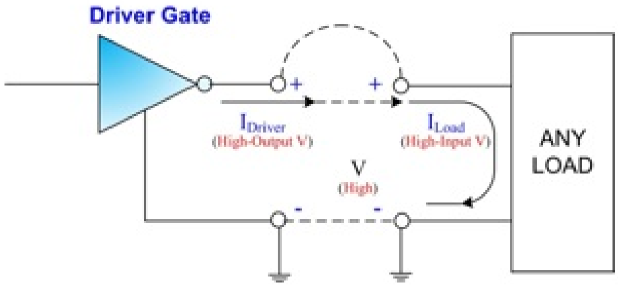
- When the *driver output* is high ($V_{out} \geq V_{OH}$), the maximum current that can be *delivered by* the driver is known as I_{OH}.

  If the current drawn from the driver exceeds I_{OH}, the output voltage ay drop below the minimum acceptable logic `1` voltage of V_{OH}.

Thus, for proper operation:

$$I_{OH} \geq I_{Load}$$



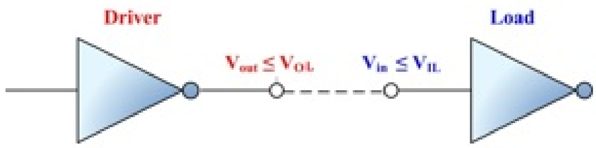


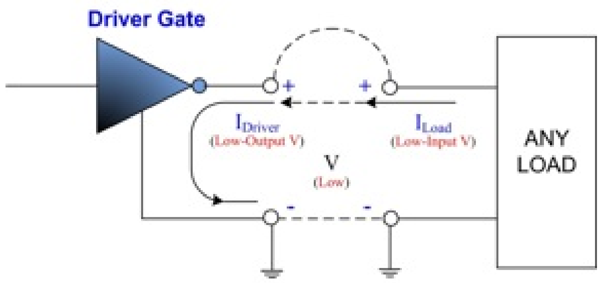
- When the *driver output* is low ($V_{out} \leq V_{OL}$), the maximum current that can be *sunk into* the driver from the load is designated as I_{OL}.

  If more current than I_{OL} is sunk into the driver, the output voltage may exceed the maximum acceptable logic `0` voltage of V_{OL}.

  Thus, for proper operation:

$$I_{OL} \geq I_{Load}$$





Exercise

Check out the SN7404 [1] or the SN5404 [2] IC that you will use in this lab, read its corresponding data sheet, and answer the following:

1. What is the difference between the 7400 and the 5400 series?
2. Define the following electrical parameters in your own words, and extract their values from the data sheet of the specific IC type you will be using:

Parameter	Definition	Value
V_{IL}		
V_{IH}		
V_{OL}		
V_{OH}		
I_{IL}		
I_{IH}		

Parameter	Definition	Value
I_{OS}		

4. Tasks

In this experiment, we characterize some major electrical characteristics of IC input and output pins. The IC used in the experiment is a hex inverter 54/7404.

The tasks are broken down into two parts:

1. Determination of the current drive capability of the output of an IC driver, i.e. measuring I_{OH}, and I_{OL}.
2. Determination of some major voltage specifications of an IC:
   - Output specifications (V_{OH} and V_{OL})
   - Input specifications (V_{IH} and V_{IL})

4.1. Current Drive Capability (I_{OH} and I_{OL})

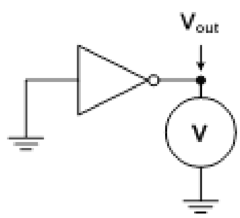
In this part, we characterize the drive capability (I_{OH} and I_{OL}) of output pin drivers of the SN7404 IC.

Strategy

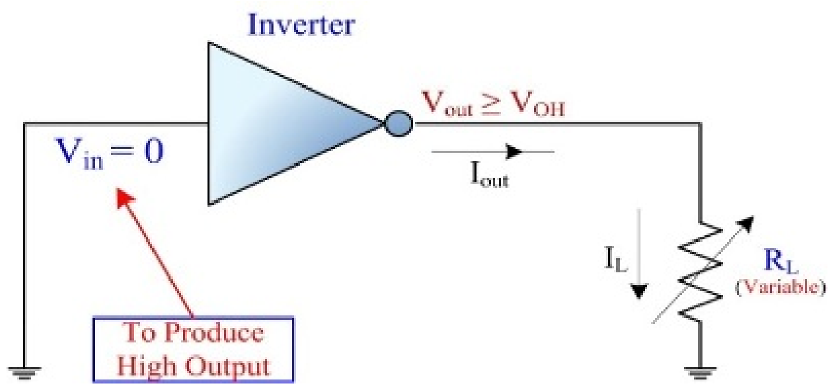
1. Plot the output voltage of one of the hex inverters versus the output load current in two cases:
   a. V_{out} = Logic `1` = High Voltage, i.e. $V_{out} \geq V_{OH}$
   b. V_{out} = Logic `0` = Low Voltage, i.e. $V_{out} \leq V_{OL}$
2. Together we will develop, in a step-by-step manner, the circuit needed to test case 1 (a).
3. Independently, you will develop the circuit needed to test case 1 (b).

4.1.1. Plotting V_{out} vs. I_{out} with V_{out} = High ($V_{out} \geq V_{OH}$)

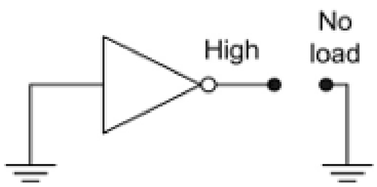
- First, for an inverter of the SN7404 IC, make sure that V_{out} = High, i.e. force V_{in} = Low.
- This way, when connecting V_{out} to the load, the current will be sourced out of the driver.



- We need to draw different values of load current from the driver and see how this affects the output voltage value.



- For the highest impedance [3] load (open circuit), there will be no load (no current drawn, i.e. $I_{out} = 0$), and V_{out} assumes its highest value.

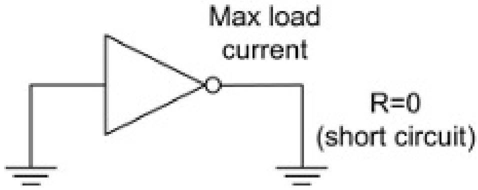


- The lowest impedance load (short circuit) yields the largest load current, and V_{out} assumes its lowest value ($V_{out} = 0$).

  In this case, $V_{out} = 0$ in spite of the fact that the inverter input $V_{in} = 0$.

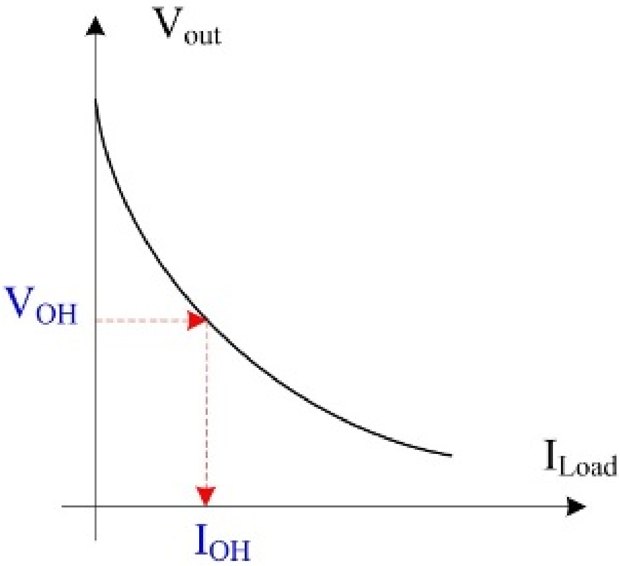
  Thus,

  - V_{out} = highest value when $I_{out} = 0$ (no load condition, i.e. open circuit)
  - V_{out} = lowest value = 0 when I_{out} = maximum (short circuit)



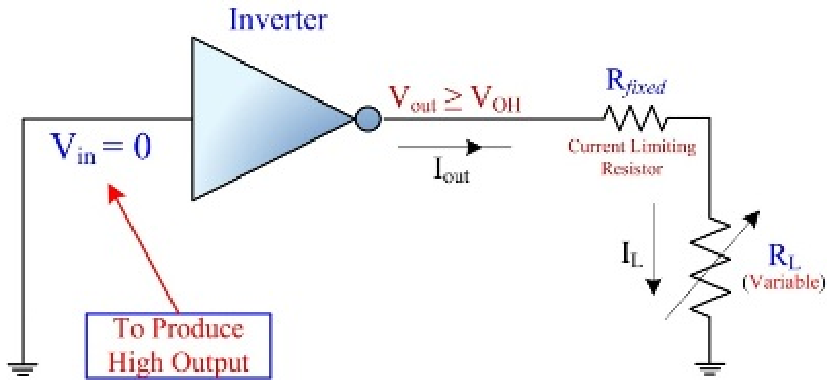
Conclusions

- As the load current I_{out} increases, V_{out} goes down.
- V_{out} must have acceptable logic `1` voltage for proper inverter operation, i.e. $V_{out} \geq V_{OH}$.
- Thus, the load current I_{out} must not exceed the value that brings V_{out} down to V_{OH} (i.e. at $V_{out} = V_{OH}$) → $I_{Load} = I_{OH}$.



Test Circuit

- The above circuit may inadvertently cause the variable load resistor to be `0` ($R_L = 0$). Thus, the driver inverter output is short circuited to ground causing huge currents that may damage the IC.
- To avoid such damaging large current, a fixed resistor, R_{fixed}, is connected in series with the variable resistor.



Estimating a Reasonable Value for R_{fixed}

- Maximum output current when V_{out} = High ($V_{out} \geq V_{OH}$) is I_{OH}.
- The I_{OS} current is damaging if sustained for more than a very short duration (about 1 second).
- Let's select the maximum allowed output current $I_{out}(max)$ to be such that:

$$I_{OH} < I_{out}(max) < I_{OS}$$

- Assume that $I_{out}(max) = I_{OS}/2$. Then,

$$R_{fixed} = V_{out}(max) / I_{out}(max) = 2\ V_{out}(\text{no load}) / I_{OS}$$

Steps

1. Vary the variable resistor from its maximum value to its lowest value in steps, each time recording V_{out} and the corresponding I_{out}.
2. Plot V_{out} vs. I_{out}. Determine the value of I_{out} corresponding to the spec. value of V_{OH}.
3. Compare your suggested I_{OH} value with the spec. value. Which value is lower? Why?

Questions

1. Is the value you selected for I_{OH} different from that specified by the manufacturer?
2. If yes, what are some of the factors that the manufacturer might have taken into account in defining his specified values of I_{OH}?

4.1.2. Plotting V_{out} vs. I_{out} with V_{out} = Low ($V_{out} \leq V_{OL}$)

Follow the same steps in the previous section. Use the following hints as a guide.

1. Make sure the inverter output is low.
2. Make sure that I_{out} direction is into the driver (inverter) output, not out of it.
3. Make sure that your circuit allows varying I_{out} versus output voltage V_{out}.
4. Make sure that your circuit protects the inverter output from passing excessive currents, i.e. the max current should be limited to an acceptable value (> I_{OL}).

Steps

1. Vary the variable resistor from its maximum value to its lowest value in steps, each time recording V_{out} and the corresponding I_{out}.
2. Plot V_{out} vs. I_{out}. Determine the value of I_{out} corresponding to the spec value of V_{OL}.

3. Compare your suggested I_{OL} value with the spec. value? Which value is lower? Why?

Questions

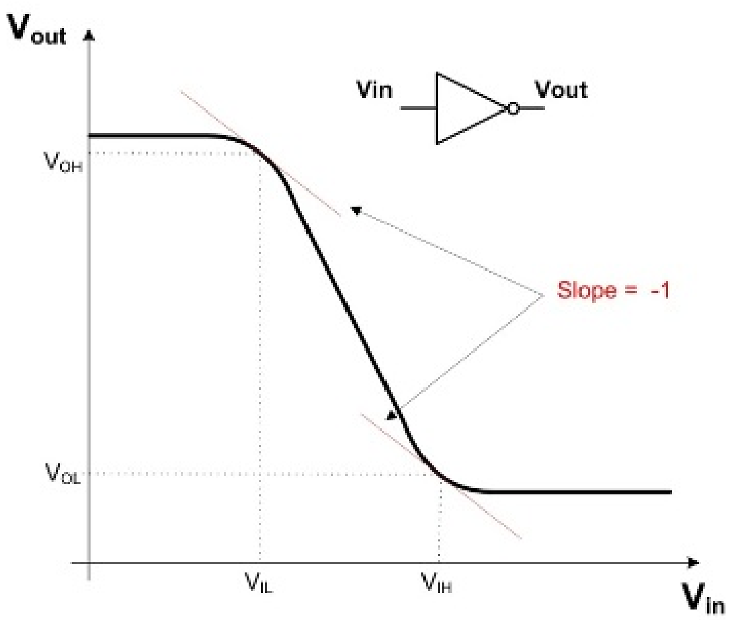
1. Is the value you selected for I_{OL} different from that specified by the manufacturer?
2. If yes, what are some of the factors that the manufacturer might have taken into account in defining his specified values of I_{OL}?
3. What is meant by the output drive? What are the parameters that define the driving-ability of an IC output pin?

4.2. Major Voltage Specifications (V_{OH}, V_{OL}, V_{IL}, and V_{IH})

In this part, we determine V_{OH}, V_{OL}, V_{IL} and V_{IH} for one of the hex inverters available in the SN7404 IC.

Strategy

Determination of these voltage quantities will be done through plotting the voltage transfer characteristics of the inverter.



Inverter Voltage Transfer C/Cs.

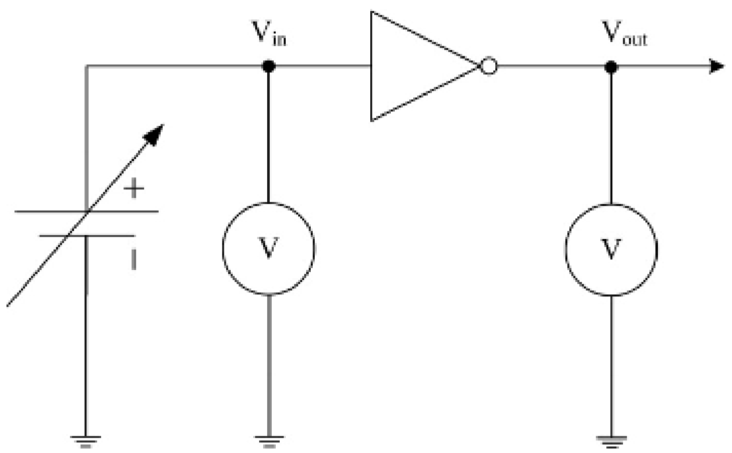
4.2.1. The Test Circuit

In this section, we are going to incrementally build the test circuit, justifying each revision as we go.

Revision 1

- Variable voltage source
- $V_{in} = V_{SRC}$
- V_{in} is varied by varying the input voltage source from 0 to V_{CC}.
- For each V_{in} value, measure and record the corresponding V_{out}.

Merits: Directly connecting the voltage source to the IC input is not recommended as the absolute maximum rating of the input may accidentally be exceeded causing device permanent damage.



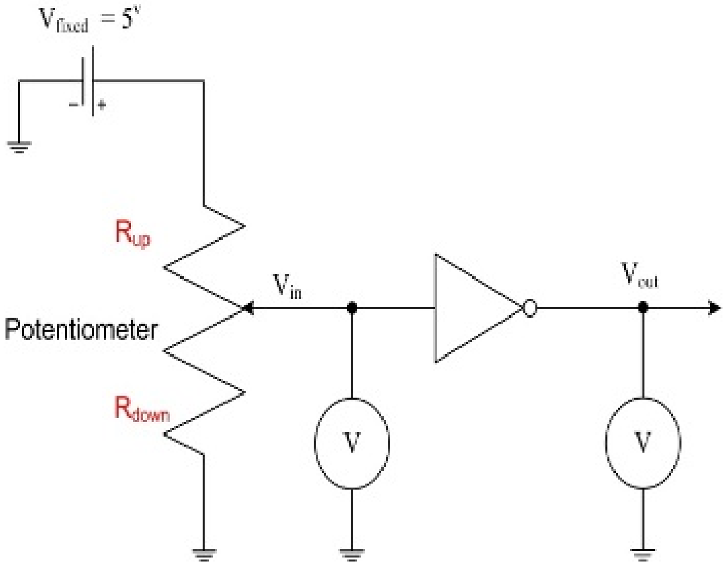
Revision 2

- A potentiometer acts as a voltage divider where both R_{up} and R_{down} vary as we vary the rotating position of the third tapping terminal such that:

  $$R_{up} + R_{down} = R_{Pot}$$

  where R_{Pot} = Total potentiometer resistance.
- If the input impedance of the inverter is much higher than R_{Pot}, then:

  $$V_{in} = V_{fixed} / (1 + R_{up} / R_{down})$$
- V_{in} is varied by varying the potentiometer knob.
- For each V_{in} value, measure and record the corresponding V_{out}.



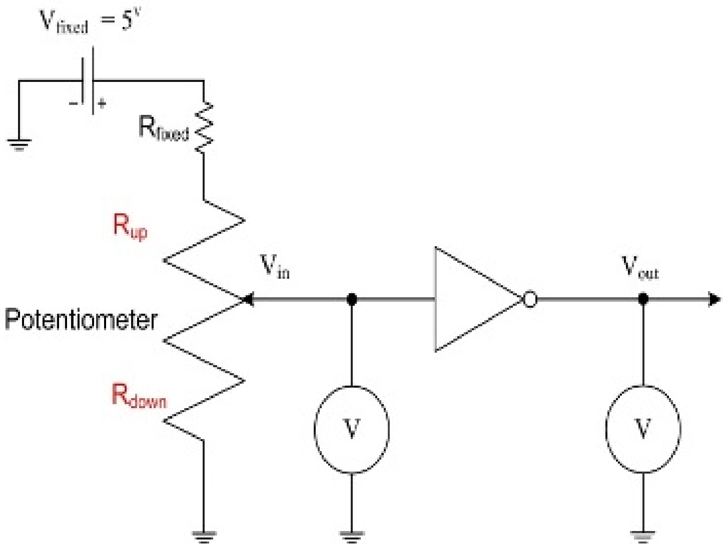
Merits: If $R_{up} \approx 0$, direct connection of the voltage source to the IC input may cause an input voltage overshoot and is not recommended.

Revision 3

- The lowest V_{in} in this case is when $R_{down} = R_{Pot}(min) \approx 0$, leading to: $V_{in}(min) \approx 0$.
- The highest V_{in} in this case is when $R_{down} = R_{Pot}$ and is given by:

  $$V_{in}(max) = V_{fixed} / (1 + R_{fixed} / R_{Pot})$$
- For $V_{in}(max) \approx V_{fixed}$, the value of R_{fixed} should be selected such that:

  $$R_{fixed} << R_{Pot} \rightarrow R_{fixed} \leq 0.1\ R_{Pot}$$



Steps

1. Vary the potentiometer rotary switch knob, and read V_{in} and the corresponding V_{out} values.
2. Plot V_{out} vs. V_{in}.

Questions

1. Are the values you selected for V_{OH}, V_{OL}, V_{IL}, and V_{IH} different from those specified by the manufacturer?
2. If yes, what are some of the factors that the manufacturer might have taken into account in defining the specified values of V_{OH}, V_{OL}, V_{IL}, and V_{IH}?

5. Grading Sheet

Task	Points
Plot and discuss V_{out} vs. I_{out} with V_{out} = High	25
Plot and discuss V_{out} vs. I_{out} with V_{out} = Low	25
Plot V_{out} vs. V_{in}	25
Lab notebook and discussion	25

1. SN7404, SN74LS04, or SN74S04.
2. SN5404, SN54LS04, or SN54S04.
3. resistance

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