Experiment 1 Report

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19 January 2023
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Abstract

This experiment demonstrates the CD4007UB integrated circuit and its functionality. The CD4007UB is a dual complimentary pair plus inverter chip, containing 3 pMOSFET transistors and 3 nMOSFET transistors. This experiment tests the chip by determining the voltage transfer characteristic of the inverter in the chip to properly examine its properties and various voltage thresholds. The experiment later uses the CD4007UB to create a digital ring oscillator to measure the propagation delay of the inverters.

The experiment found that the transfer characteristic appeared as expected, with voltage properties being within reason for the chip design. When oriented as a ring oscillator, the performance remained good, with oscillation frequency and propagation delay being within the limits set by the manufacturer as stated on the product datasheet.

Task 1

Objective

This section will demonstrate basic measurement techniques and functions learned in ECE 20007, using the lab instruments provided, including an oscilloscope, waveform generator, digital multimeter (DMM), and variable DC power supply.

Procedure

For testing purposes, the function:

$$2\sin(2\pi 750t) \tag{1}$$

was generated with the waveform generator.

The waveform generator was connected to one channel of an oscilloscope, and adjusted so that the signal was stable and reasonably sized within the window.

On the oscilloscope,

- The window was resized horizontally such that more periods of the wave were visible.
- The trigger level was modified between -4V and 4V.
- The horizontal and vertical offsets of the signal were modified.

After recording findings, the DC power supply was set to 3.3V. The AC and DC RMS values were measured through the DMM.

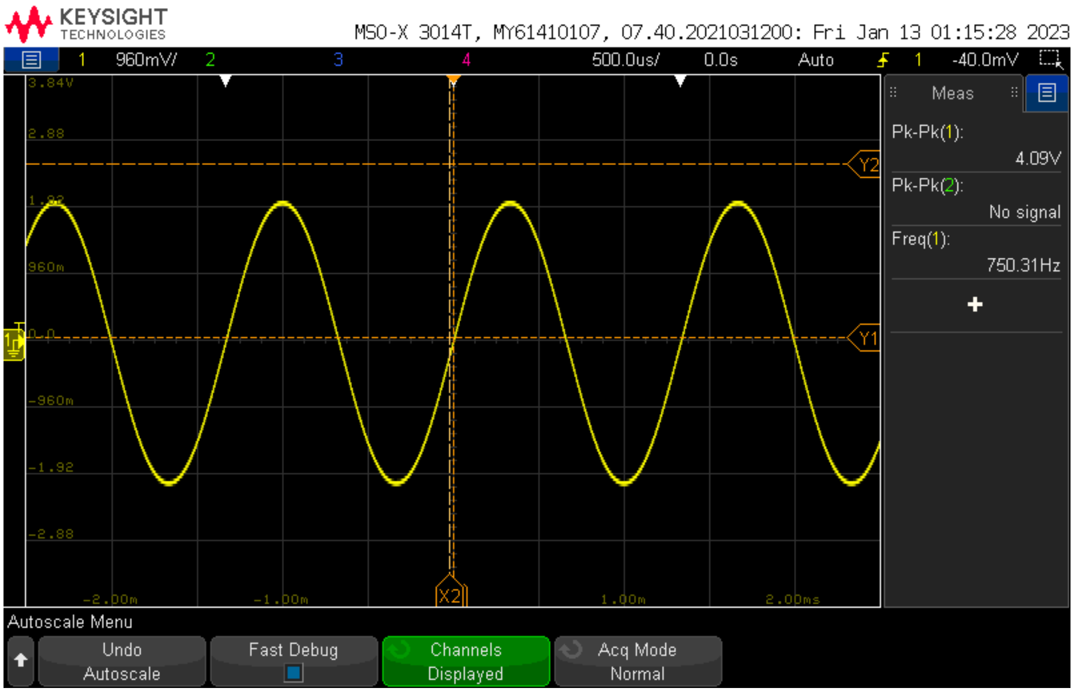
Results / Calculations

Each control serves a different function for manipulating the signal viewed on the oscilloscope.

The horizontal scale adjustment knob determines the scale of time on the oscilloscope's horizontal axis. This can vary widely, depending on what signal is being passed to the oscilloscope's input channel. An analogy for what this control does is that it "squishes" or "stretches" the view of the signal being measured.

The trigger level is a set voltage that the oscilloscope looks for when measuring signals to create stability in the image shown. The level of the trigger determines at what voltage and time the signal lines up with.

Below is a screenshot containing the signal displayed in normal mode.



The offsets control the position of the signal in the viewing window. The vertical offset can move the signal up or down on the graph, where ground is shown with a marker on the vertical axis to the left of the signal. The horizontal offset moves the signal in time as shown. The signal appears to move left or right, indicating a change in time measurements, being slightly ahead or behind where the original location was.

For using the DMM and DC power supply, the DC RMS and AC RMS values were measured to be:

$$DC_{RMS} = 3.3005V \tag{2}$$

$$AC_{RMS} = 0.003V \tag{3}$$

Knowing the nominal value for the DC_{RMS} being 3.3V, the following error calculation can be achieved:

$$\%_{err} = \frac{|V_{meas} - V_{ideal}|}{V_{ideal}} = \frac{|DC_{RMS,meas} - DC_{RMS,nominal}|}{DC_{RMS,nominal}} = \frac{|3.305V - 3.3V|}{3.3V} = 0.15\% \tag{4}$$

Conclusions

This task explored the techniques and adjustments that can be made when measuring a circuit or signal, and how such measurements can impact the readability and usefulness of the tools used. On the oscilloscope, signals can be manipulated in many ways to make them more readable and measurable to a user. The DMM has multiple modes that can be used to measure different types of signals, differentiated by being AC or DC values.

Task 2

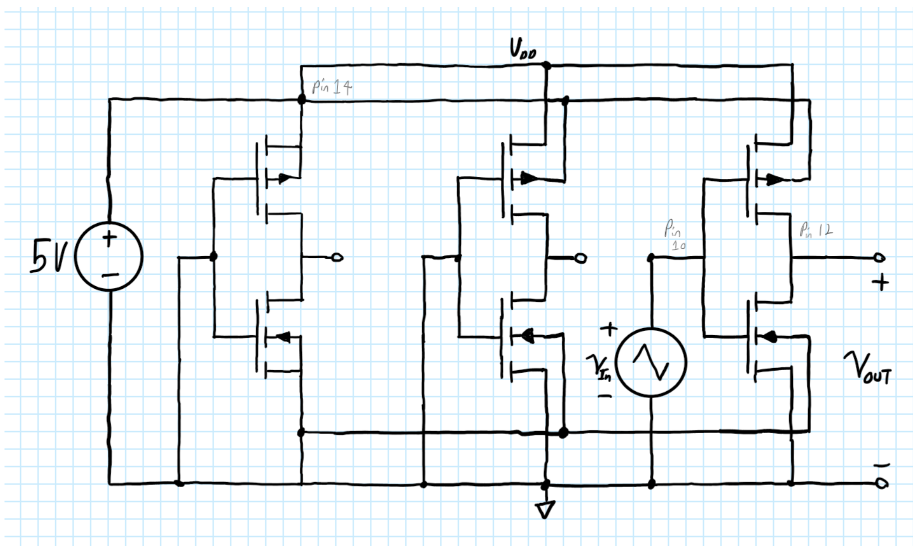
Objective

This section will explore a CMOS inverter and its voltage transfer characteristic.

Procedure

Steps 1 - 5

The following circuit was built:



using the CD4007UB integrated circuit, and measuring v_{in} at the function generator and v_{out} at pin 12 and ground.
V_{DD} was set to 5V DC, and v_{in} was a 500 Hz 0V to 5V triangle wave.

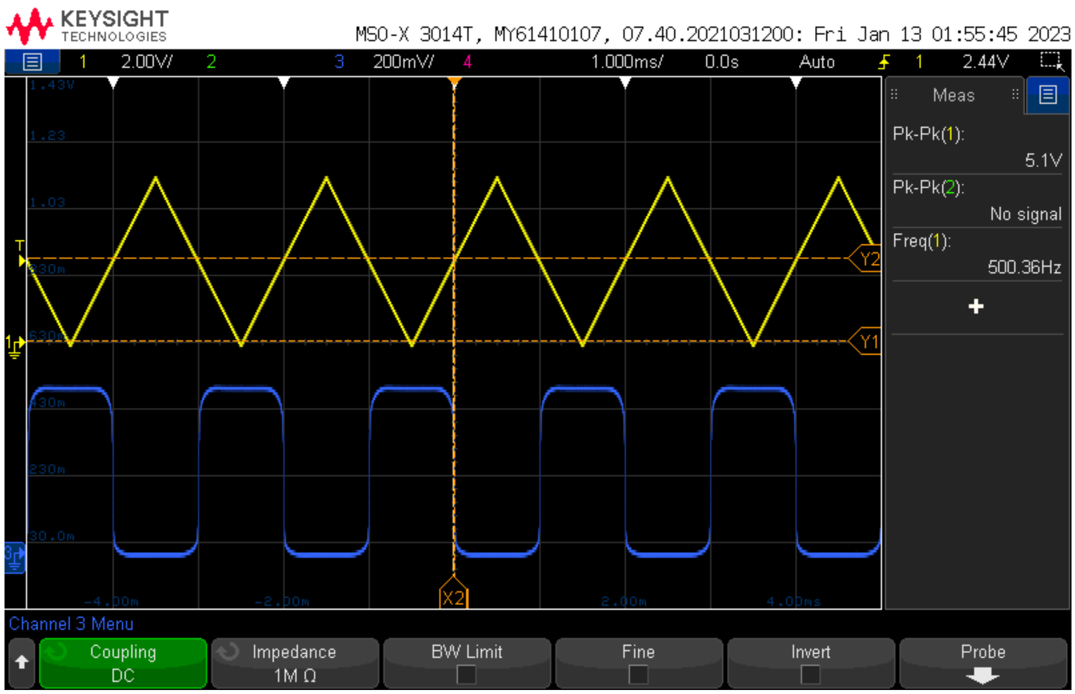
Step 6

The oscilloscope display was captured showing v_{in} and v_{out} as signals. The oscilloscope display was then changed to be in XY mode, such that v_{in} represented the horizontal axis, and v_{out} represented the vertical axis.

Results / Calculations

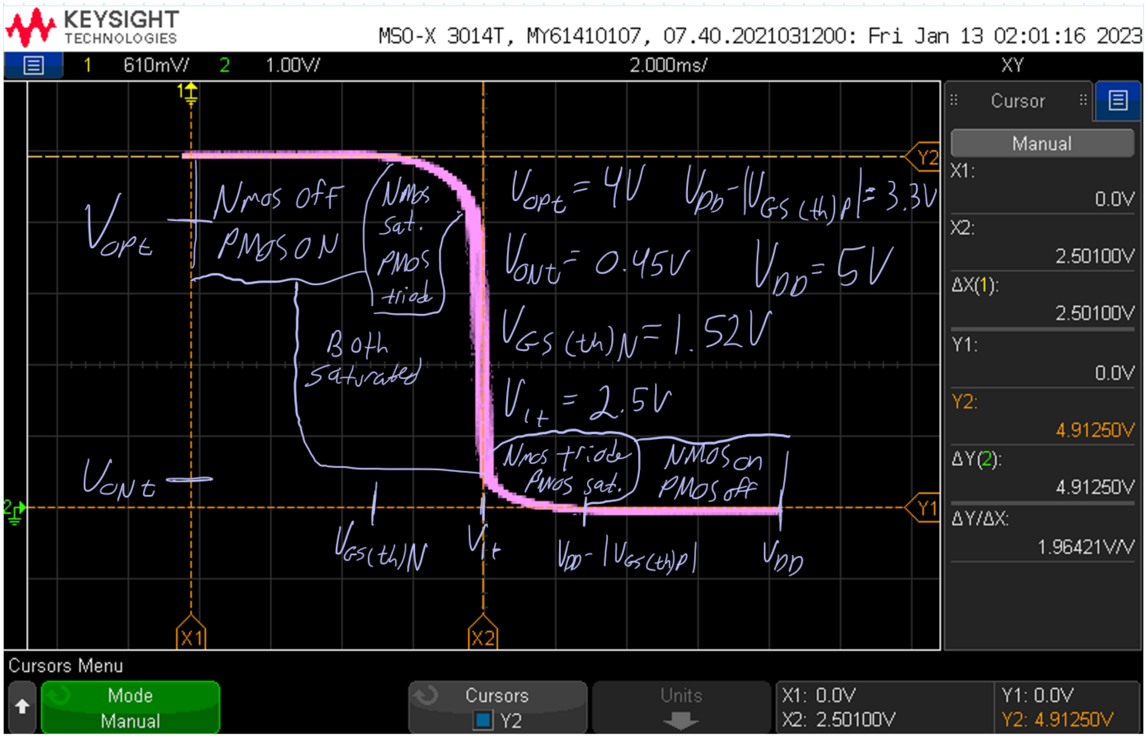
Step 6

The following screenshot shows v_{in} and v_{out} displayed as 2 channels in normal time mode.



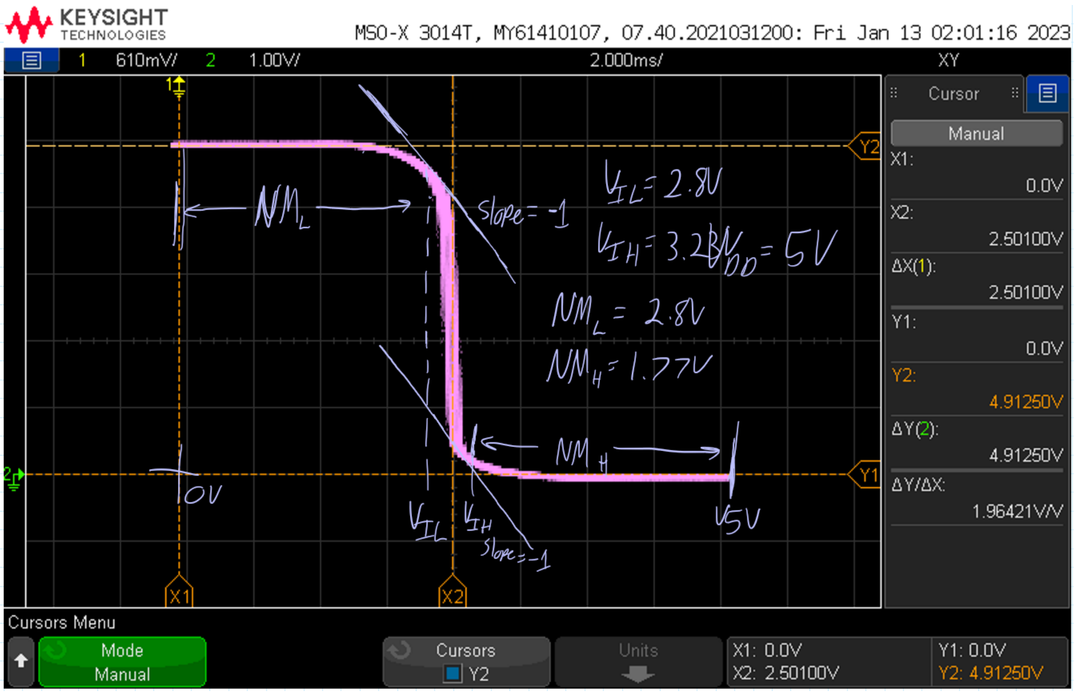
Step 7

The below graph represents the transfer characteristic v_{out} vs. v_{in}, with points labeled to represent what mode the transistor is in, and which voltages correlate with those descriptions.



Step 8

The below graph depicts the transfer characteristic v_{out} vs. v_{in}, with noise margins and their voltages labeled.



The noise margins defined on the datasheet for the CD4007UB transistor chip show that the worst-case margins are $V_{IL} = 4.5$V, and $V_{IH} = 0.5$V.

Conclusions

In this section, a simple inverter circuit was demonstrated with a CD4007UB integrated circuit containing three complimentary pairs of NMOS and PMOS transistors. The transfer characteristic was found, and various intrinsic properties of this characteristic were determined and shown to be within limits and reasonable values.

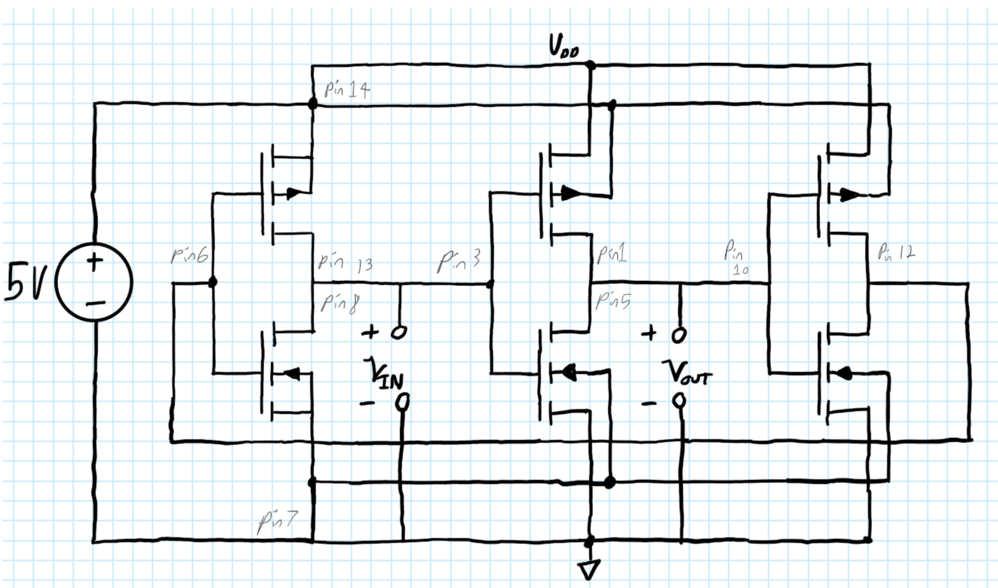
Task 3

Objective

The objective of this task is to create a ring oscillator by daisy-chaining 3 inverters in a loop, and to find its oscillation frequency and propagation delay of the inverter circuit.

Procedure

The circuit below was built using a CD4007UB chip by wiring the three inverters together in a loop.

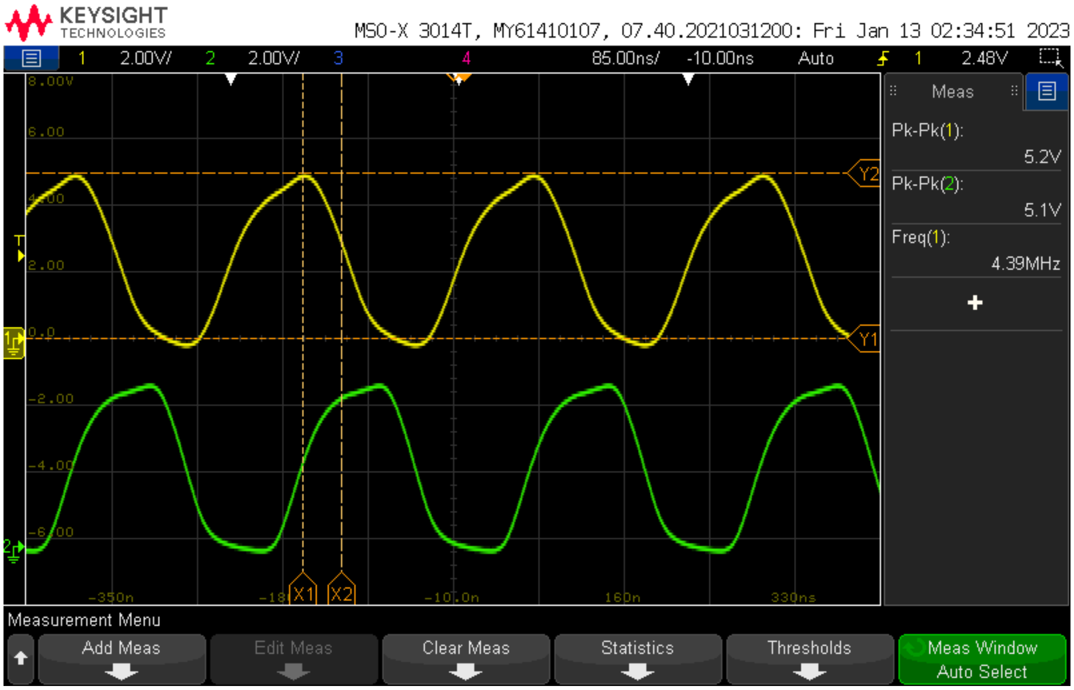


The circuit is then measured with an oscilloscope at v_{in} and v_{out} to measure oscillation frequency and propagation delay.

Results / Calculations

The circuit was built, and oscillation began on its own, without the aid of a kick start with a resistor and V_{DD}.

The following is the oscilloscope display showing v_{in} and v_{out}.

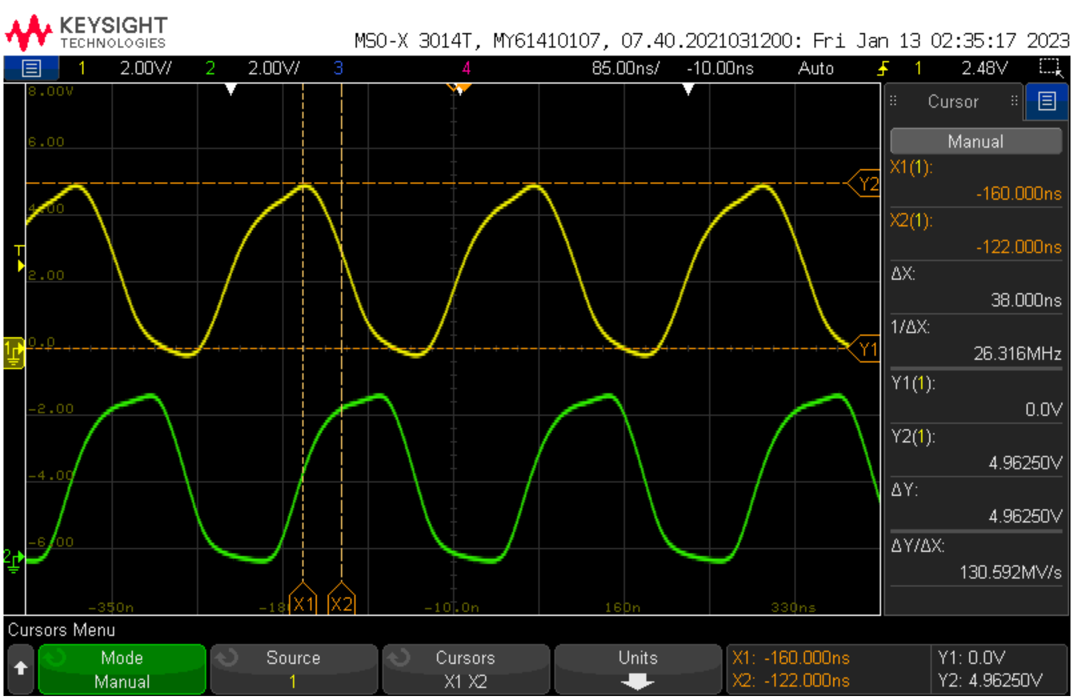


The display shows the oscillation frequency f_{osc} to be 4.39 MHz. The ideal oscillation frequency is:

$$f_{osc} \approx \frac{1}{3} * (t_{PLH} + t_{PHL}) \tag{5}$$

Where t_{PLH} and t_{PHL} are the propagation delay from low to high states, and high to low states respectively, measured by comparing v_{in} to v_{out} and measuring the delay between the two.

Below is an oscilloscope screen capture showing the propagation delay with the cursors.



The measured propagation delay is 38 ns, which when used to calculate ideal oscillation frequency is:

$$f_{osc} = \frac{1}{3} * (t_{PLH} + t_{PHL}) = \frac{1}{3} * (38ns + 38ns) = \frac{1}{3} * (0.000000076) = 4.38MHz \tag{6}$$

With an error of:

$$\%err = \frac{4.39MHz - 4.38MHz}{4.38MHz} = 0.22\%error \tag{7}$$

While this error value can be calculated, the original equation for f_{osc} was an approximation, and thus cannot be treated as the true ideal value, however, our value was very close to the approximation.

Conclusions

In this task, a ring oscillator was built and demonstrated using a CD4007UB triple complimentary pair circuit arranged as three inverters in a loop. The oscillation frequency was measured and verified through the use of propagation delay.