CDA 3201L Lab #3

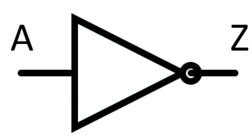
Ring Oscillator with 3 NAND

Welcome to CDA3201L Lab #3! The purpose of this lab is to introduce you to the use of the oscilloscope tool in the Analog Discovery II device. You've likely used some kind of debugger while writing a program in C or Python – an oscilloscope can help you debug your circuits in much the same way. These devices can be especially helpful when working with large, complex circuits to check voltage levels or the timing of different signals. For example, you can take a "snapshot" of a signal based on a specific event. You can zoom in to see different parts of the signal in more detail, take measurements, and even transfer the captured waveforms to a PC for further processing or graphing.

<u>To prepare for Lab #3, carefully read and work with your lab partner to complete the prelab BEFORE you come to lab.</u>

<u>Prelab/ assignment questions</u>

An inverter is a logic gate that takes a single input and has one output. The inverter will flip the input signal; that is, if the input is a logic low, the output will be high, and if the input is logic high, the output will be low. The diagram and truth table for the inverter are shown here:



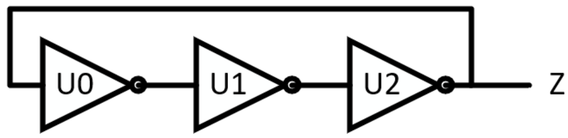
A	Z
0	1
1	0

For 5V logic, the "high" level is about 5V, and the "low" level is about 0V. So, if the input is 0V, the output will be about 5V. If the input is 5V, the output will be about 0V. <u>The change is not instantaneous</u> – there is a brief switching delay. This is listed in the datasheet as $\mathbf{t_{PLH}}$ or $\mathbf{t_{PHL}}$, which stands for "propagation time from low to high" or "propagation time from high to low". The same holds true for logic gates besides inverters – NAND, NOR, etc.; they all take time to transition when a change in the input causes a change in the output. The delay also depends on what is connected to the output and environmental conditions. Datasheets will list the "test conditions" such as C_L (capacitive load), temperature, and supply voltage.

PQ-1 (3 pts): Check your datasheet for the 74LS00 Quad NAND – what is the typical (Typ) propagation delay for these gates? What is the maximum (Max) delay? Be sure to include units!

Understanding these delays is critical to designing functional logic circuits. We will go into more detail later this semester. For now, we will just be measuring these properties using an oscilloscope and a special circuit that makes these delays more obvious, called a *ring oscillator*.

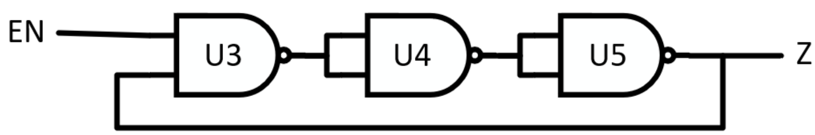
A *ring oscillator* is a kind of circuit whose output constantly changes between two states: LOW and HIGH. A diagram of a simple ring oscillator comprised of 3 inverters is shown below:



Let's assume the output of U2 is initially LOW (Z = 0), and walk through the events that happen next. The output of U2 is fed back into the input of U0. The output of U0 will be HIGH, and is fed into U1. The output of U1 will be LOW. Finally, this is fed into U2, and the circuit output will be HIGH (Z = 1). If we assume **t_{PLH} = t_{PHL} = 10 ns**, signal propagation will take 3 x 10 = 30 ns.

PQ-2 (3 pts): Continue the exercise – what is the sequence of events when the output of U2 is HIGH? How much time (in total) will have passed since Z = 0?

Note that this only works with an odd number of inverters (3, 5, 7, …), otherwise it will not oscillate. We would like to measure its *period of oscillation* or, alternatively, its *frequency* (recall that period and frequency are inverses). That is where the oscilloscope comes in. As you know, NAND gates can be used to make inverters. To build the ring oscillator, you will need to use three NAND gates, connected in the following manner:



This circuit also has an EN or **enable** signal which can be used to turn the oscillation on or off.

PQ-3 (3 pts): Show that when EN = 1, it enables the ring oscillator, and when EN = 0, the output does not oscillate.

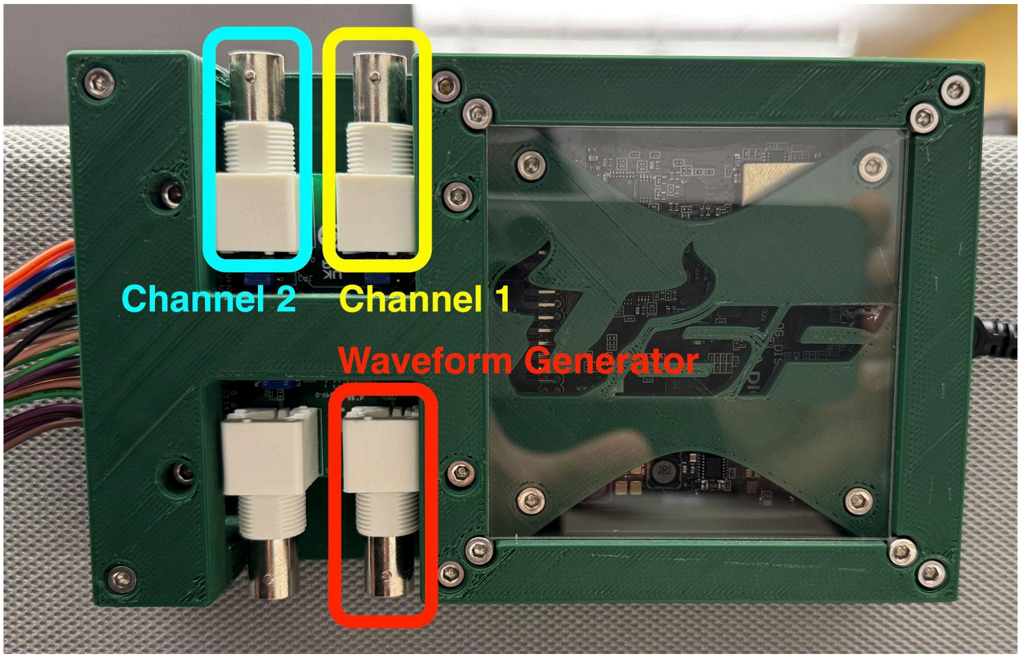
PQ-4 (3 pts): In general, what will the period of oscillation be, as a function of the number of gates (G) and gate delay (t_p)? (Hint: think about your answer to PQ-2!)

To prepare for your lab, use the provided datasheet to plan out which pins on the 74LS00 package need to be connected to realize the NAND-gate ring oscillator on your breadboard. Have a TA check this before you begin constructing your circuit.

What if there are no separate function generators available?

You can use the function generators inside the Discovery 2 devices.

https://www.instructables.com/Waveform-Generator-With-the-Analog-Discovery-2/



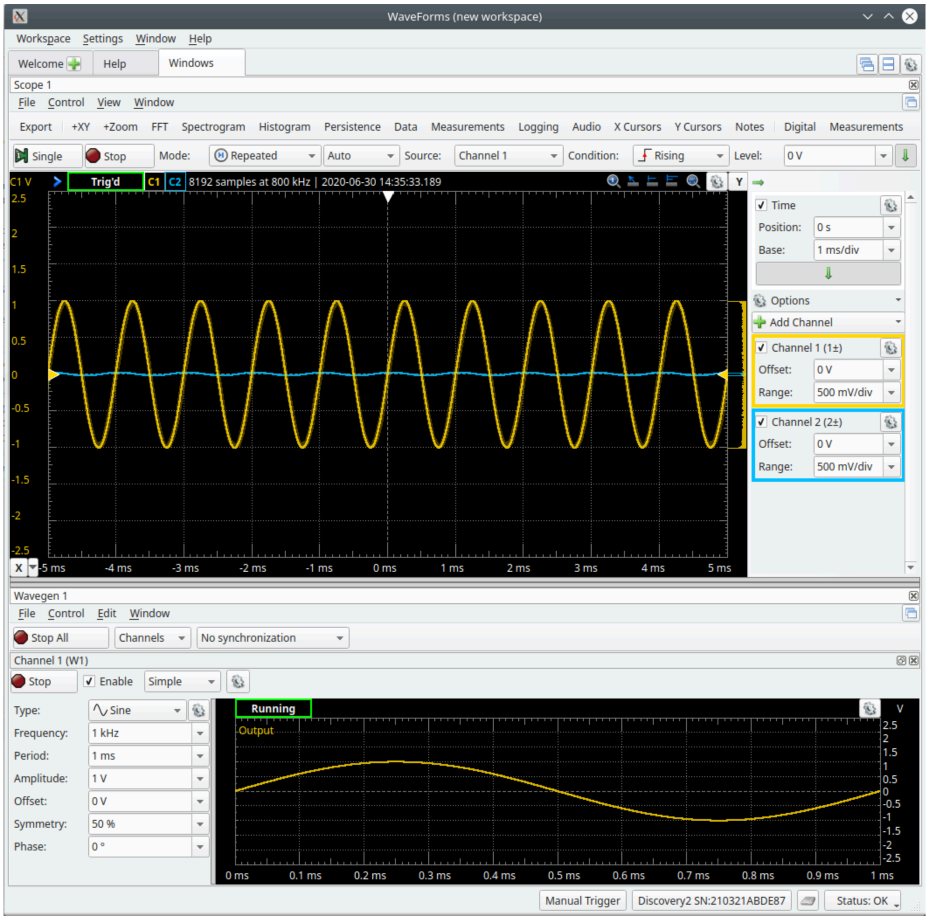
Experimental Portion of the Lab

Instructions

TAs will walk you through the basic use of the oscilloscopes tool in the Analog Discovery II device, including some basic operation instructions (copied below for your reference). These instructions are adapted from:
https://www.instructables.com/Using-the-Oscilloscope-With-the-Analog-Discovery-2/

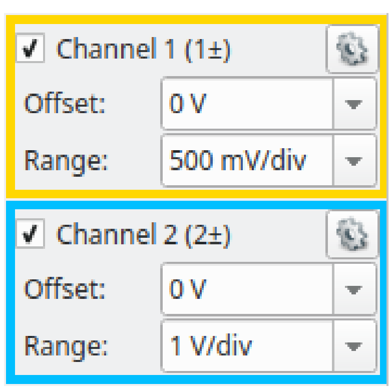
1. Log on to the lab computer and open the WaveForms software by Digilent (this should be on your Desktop). Once you open Waveforms, click on the "Scope" button at the Welcome tab. The oscilloscope window should open.

2. Use the function generator to output a 1kHz sinewave at 1V amplitude and then also Run the Scope tool with its default settings. Connect the scope probe (Channel 1) to the function generator. You should now have something like the following on your screen.



A typical Oscilloscope has 3 main control sections: **Vertical, Horizontal, and Trigger**. These controls section will be discussed in the following sections.

3. The **vertical** section controls the y-axis of the displayed incoming voltage signal. There is one set of controls for every input channel. In our case since this is a 2-channel oscilloscope there are 2 sets of controls. The main vertical controls are 'Offset' and 'Range' which contribute to how the incoming waveform is displayed on the vertical/y-axis.



The key points about the vertical/y-axis are:

- There are 2 vertical channels: channel 1 in yellow and channel 2 in blue.
- The channels can be turned on and off using the checkbox next to the Channel name.
- It is the voltage axis. The higher the incoming voltage, the farther from the ‘ground’ (0 Volt level) the graph moves for a given ‘Range’ setting.
- Voltage can be positive or negative relative to ‘ground’. Positive input voltages moves the graph point above the ‘ground’; negative input voltage moves it below the ‘ground’.

<u>Vertical Position</u>

Each input channel has a ‘ground’ (0 Volt level) indicator on the left edge of the screen. Below is an image showing the vertical position of channel 1 which should now be in the vertical center of the display.

The ‘Offset’ dropdown box or clicking and dragging the indicator will move this position indicator up and down on the display which in turn will also move the incoming voltage waveform up and down on the display.

Note: All the controls on the Scope have no effect on the incoming voltage. They only affect the way the waveform is displayed on the screen.

<u>Volts per Division</u>

A typical oscilloscope will have 8-10 vertical divisions on the display. You can change the graph’s y-axis scale (usually expressed in volts per division or VOLTS/DIV) using the Range dropdown box to control how the incoming voltage waveform is scaled when it is displayed on the graph.

The displayed waveform (currently 2V peak to peak) should currently span approximately 4 vertical divisions of the oscilloscope’s screen if the range is currently set to 500mV/div. When you multiply the number of vertical divisions the waveform spans (~4) by the VOLTS/DIV setting (500mV/div) you arrive at that peak-to-peak voltage (2Vp-p).

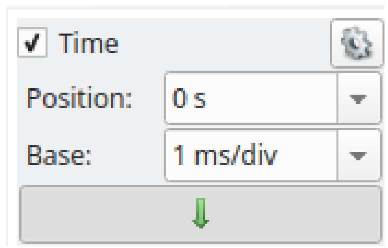
<u>Adjust Vertical</u>

Adjust the following Channel 1 vertical controls to see how they affect the Scopes graph display.

- Make a change to the ‘Offset’ dropdown box to other values and see the result. It should move the waveform and the ‘ground’ indicator up and down on the screen. You can also try clicking and dragging on the indicator to see the results. Return the position back to the center of the display by setting the offset to 0V.

- Make a change to the ‘Range’ dropdown box and see the result. It should scale the magnitude of the waveform on the screen. Return the ‘Range’ back to 500mV/div.

4. The **horizontal** section controls the x-axis, which is generally used as the time-axis. There is only one common set of controls for all the input channels. The horizontal controls are ‘Position’ and ‘Base’ which all contribute to how the incoming waveform is displayed on the horizontal/x-axis.

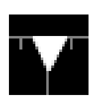


The key points about the x-axis are:

- The x-axis is generally a time axis. In that mode, the point on the screen sweeps across at a constant user-selectable speed, covering equal distances across the screen at equal times.
- If there is no input signal, you will see a horizontal line at y = 0, usually in the center of the display.
- Changing the ‘Base’ or ‘Sec/div’ changes the scale of the x-axis on the graph display.
- Time is scaled in units of seconds/division (Sec/div). To rescale the time axis, use the ‘Base’ control dropbox.

Horizontal Position

The current horizontal position is indicated on the top edge of the graph, typically in the center of the display which represents 0 seconds. This mark indicates where the current captured waveform was triggered. Below is an image showing the horizontal position of the display.



The ‘Position’ dropdown box or clicking and dragging the indicator will move this position indicator left and right on the display which in turn will also move the incoming voltage waveform left and right on the display.

Seconds per Division

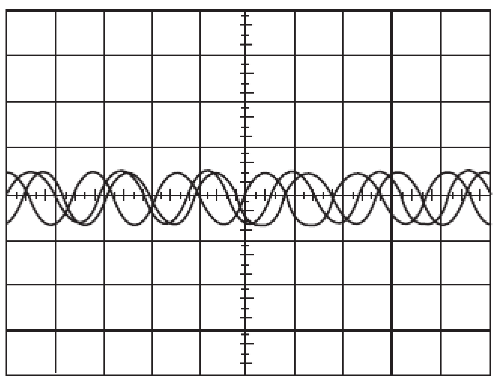
A typical oscilloscope will have 10 horizontal divisions on the display. You can change the graph’s x-axis scale (expressed in seconds per division or Sec/div) using the ‘Base’ dropdown box to control how the time-base of the incoming voltage waveform is scaled when it is displayed on the graph.

Adjust Horizontal

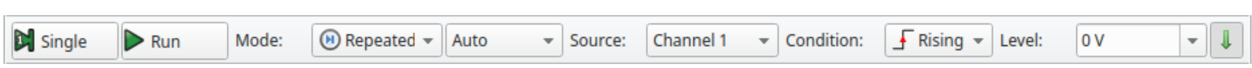
Adjust the horizontal controls to see how they affect the Scopes graph display.

- Make a change to the 'Position' dropdown box to other values to see the result. It should move the waveform and the position indicator left and right on the screen. You can also try clicking and grabbing the indicator to see the result. Return the position back to the center of the display by setting the 'Position' back to 0s.
- Make a change to the 'Base' dropdown box to see the result. It should scale the time base of how the waveform is displayed on the screen. Return the 'Base' back to 1ms/div.

5. An oscilloscope's **trigger** function synchronizes the horizontal sweep at the correct point of the signal, essential for clear signal characterization. Trigger controls allow you to stabilize repetitive waveforms and capture single-shot waveforms. The trigger makes repetitive waveforms appear static on the oscilloscope display by repeatedly displaying the same portion of the input signal. Imagine the jumble on the screen that would result if each sweep started at a different place on the signal, as illustrated in the figure below.



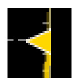
Trigger Controls



Along the Trigger controls toolbar, you have the following controls:

- **Single** - When the 'Single' button is pushed the acquisition will wait for a trigger signal to occur and then capture a single acquisition from the inputs, automatically stopping after the acquisition is complete.

- **Run/Stop** - When the ‘Run’ button is pushed the acquisition will wait for a trigger signal to occur and then capture an acquisition from the inputs. Once the first acquisition is finished it will then wait for another trigger signal to start the next one. This will happen indefinitely until the ‘Stop’ button is pushed.
- **Mode:** - These are more advanced settings that will not be used in this course. For our purposes they should be set to both ‘Repeated’ and ‘Auto’.
- **Source:** - This sets which signal you wish to use to trigger the acquisition. For this course we will only use Channel 1 as the trigger source.
- **Condition:** - This sets what type of edge you would like to trigger on: Either Rising, Falling or Both. For this course we will only use the Rising edge.
- **Level:** - This control sets at what voltage the incoming signal (ie. Channel 1) needs to pass through to activate a trigger. You can also adjust this level by clicking and dragging on the trigger level indicator on the right side of the graph display.



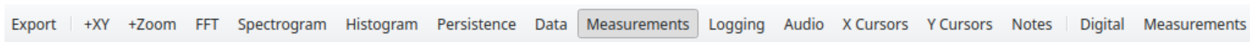
Adjust the trigger controls to see how the effect the Scopes graph display.

- Adjust the triggers ‘Level’ by clicking and dragging the trigger level indicator up and down and see the results. Notice, if you move the trigger level above or below the peaks of the waveform what happens? The signal is no longer triggered. Use the ‘Level’ in the trigger toolbar to reset the trigger level back to 0V.

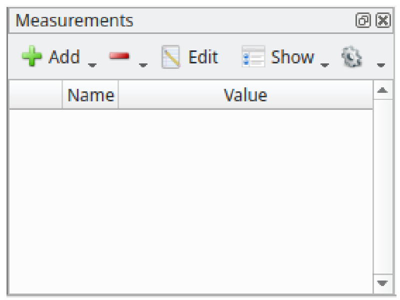
Note: The waveform will trigger on the edge (Rising or Falling) that is selected under ‘Condition’ where the trigger level indicator intersects the horizontal ‘Position’ indicator

Performing Measurements with Scope in Analog Discovery II

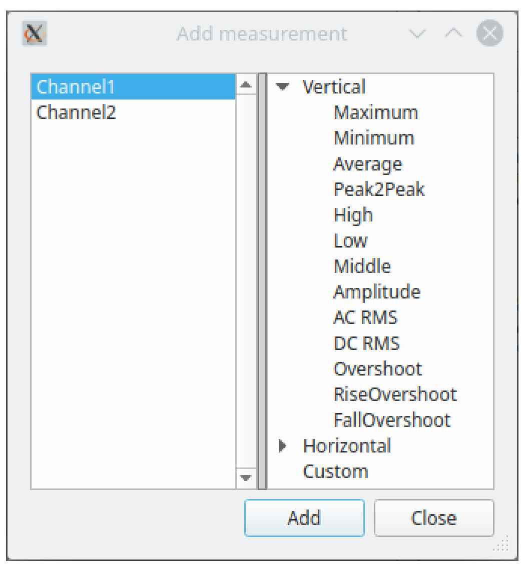
Another important function in the Scopes tool is the Measurements toolbar at the top of the display. Let's have a look at how it works.



After selecting the Measurements tab a window will open up on the side of the graph display as shown below. You can then add measurements that will be automatically calculated from the waveform that is captured on the Scopes graph.



To add a measurement, use the Add dropdown and select 'Define Measurement'. Which will give you an Add measurement selection box like shown below.



Here you can select which channel you would like to make the measurement on as well as the type of measurement.

- Vertical: Create a peak-to-peak voltage measurement for Channel 1 using the steps outlined above. Once created you should see that a measurement is being made on the incoming Channel 1 waveform with a reading about 2V.
- Horizontal: Create a period measurement for Channel 1 using the steps outlined above. Once created you should see that a measurement is being made on the incoming Channel 1 waveform. You can add as many measurements as you like.

Cursor-based measurements

You can also measure the time/voltage using cursors. ***This approach will be used in our lab.*** From the top menu under Scope 1, select "View", then "X Cursors". This action will open the cursor panel. You can "Normal" cursors, and "Delta" cursors to measure the time difference between (i.e., delay) the points on your waveform.

You can also try to do the same for the voltage values of the signal, with y cursors lying on the y-axis, by selecting "Y Cursors" from the "View" menu.

Assignment

Now, you are ready to construct your NAND-gate-based ring oscillator circuit from the prelab. Implement this circuit on your breadboard using a single 74LS00 Quad NAND chip. **Use a 5MHz square wave at 5V amplitude to test your circuit.** Use the oscilloscope tool in the Analog Discovery II device to measure the period of oscillation. In your report, include the following: 1) the period (measured with cursors), 2) computed frequency, 3) measured frequency, 4) a screenshot of the Scope screen showing the cursors and frequency, and 5) answers to the PQs from the prelab. **Is the measured period what you expected? Discuss your findings in the report. Please follow the guidelines under the Canvas module "Report Guidelines" for preparing your report.**