Logic Level Conversion and Digital Waveform Measurements

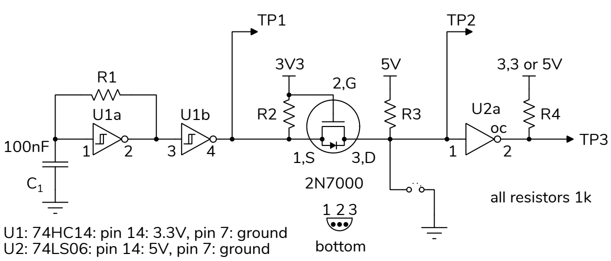
Version 2: View inverted waveforms on TP1 and TP3 (not TP2).

Introduction

In this lab you will build an oscillator, two logic-level converters, and make measurements using an oscilloscope.

The oscillator uses a Schmitt trigger inverter. This type of inverter uses feedback to increase the input threshold when the output is high and decrease it when the output is low. This is called “hysteresis” and one application is to prevent noise from causing multiple undesired changes in the output when a signal crosses the input switching threshold.

The following schematic shows the circuit you will be measuring at the test points TP1, TP2 and TP3:



The Schmitt trigger inverter U1a is configured as an oscillator. When the output of the inverter is high, the capacitor charges up through a 1k resistor until it crosses the upper switching threshold (V_{T+}). Then the output switches off and discharges the capacitor through the resistor until the input crosses the lower switching threshold (V_{T-}).

This oscillator’s frequency depends on the switching thresholds and supply voltage, and so its accuracy and stability are much worse than for quartz-crystal, ceramic, or MEMs oscillators. However, this oscillator has no start-up delay and the circuit components can be integrated into an IC. Thus this type of oscillator is used when start-up time and cost are more important than frequency accuracy.

Voltages used in logic circuits are a compromise between power consumption and noise immunity. ICs made with bipolar transistors typically use 5 V logic levels. ICs made with CMOS transistors often use 3.3 V IO logic levels. When both types of devices are used in the same circuit it’s necessary to convert between different logic levels.

The lecture describes simple techniques, such a voltage dividers, diode clamps and MOSFET switches to convert between logic levels. In this lab you will build and test the two logic level conversion circuits shown in the schematic above.

U1 is a 74HC14 hex Schmidt trigger using CMOS gates and has a supply voltage and logic levels of 0 and 3.3 V.

U2 is a 74LS06 hex open-collector inverter using bipolar transistor (“TTL”) gates and has a supply voltage and logic levels of 0 and 5 V.

The circuit between U1 and U2 uses a 2N7000 N-channel MOSFET to convert the 3.3V output of U1 to a 5 V input for U2:

- When the source is low, the gate-source voltage (V_{GS}) is 3.3 V, the transistor conducts and the drain terminal is pulled low.
- When source is high, V_{GS} is 0 V, the transistor is off and the drain terminal is pulled up to 5 V.

The interesting feature of this circuit it that pulling the drain terminal low pulls the source low through the “body diode”[1]. This allows bidirectional logic level conversion between two open-collector outputs. For example, a sensor with a 5 V I2C interface and a microcontroller with 3.3 V IO.

The 74LS06 has open-collector outputs that can be pulled up to any voltage up to 30 V. The output can sink up to 40 mA, enough to drive small loads directly or as a driver for higher-power semiconductors. Since V_{IH} is 2 V it can be driven from a 3.3 V CMOS logic output. This IC can thus convert 3.3 V or 5 V logic levels to any other logic level.

[1]MOSFETs are actually 4-terminal devices. For an n-channel transistor the control voltage is applied between the gate and the P substrate. In most packages the P substrate is connected to the source. This results in a PN “body” diode from source to drain as shown above and in some MOSFET schematic symbols.

Components

You will need the following from your ELEX 2117 parts kit:

- 74HC14 hex Schmitt trigger input inverter
- 74LS06 hex open-collector inverter
- 2N7000 n-channel MOSFET
- 4×1 kΩ resistors (from your ELEX 1117 parts kit)
- 100 nF capacitor
- your breadboard, some hookup wire and M-F jumpers
- a USB flash drive

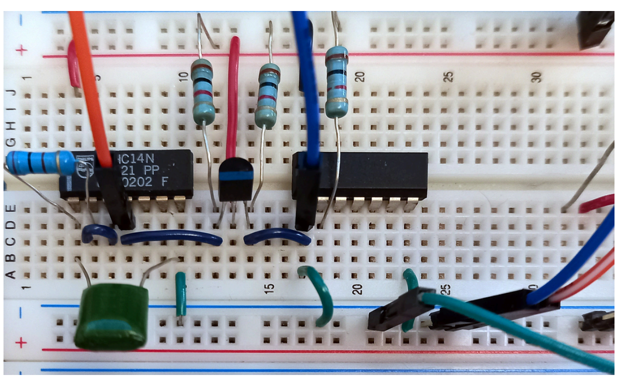
You will need to use the lab 'scopes to make the measurements and a USB flash drive to save 'scope screen captures.

Procedure

Test Circuit

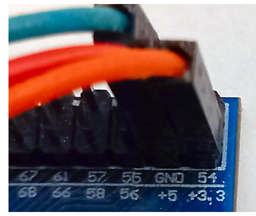
Assemble the circuit shown above using components from your ELEX 1117 and 2117 parts kits. Consult the 74HC14 and 74LS06 datasheets on the course web site for pin-outs and specifications. If you have time, connect unused IC inputs to V_{CC} or ground.

The photo below shows an example of how the circuit could be built[2]. Note the two supply rails (one for 5 V and one for 3.3 V).



[2]Unused logic inputs should be tied high (for TTL) or low. However the U1 Schmitt trigger inputs and U2 TTL inputs are less sensitive to noise than CMOS logic inputs and may be left disconnected (floating) for this lab if necessary.

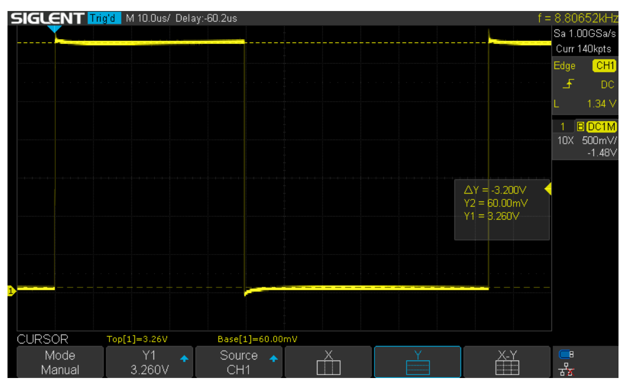
Use the 5 V and 3.3 V supplies from the CPLD board (the ground, 3.3 V and 5 V pins are on the pin headers at the upper right of the board):



WARNING: Do not connect the 5 V and 3.3 V supplies together. This may destroy your CPLD.

The CPLD gets its 5 V supply from a USB port. Although the nominal USB supply voltage is 5 V±5%, a device may see as little as 4.0 V under some conditions.

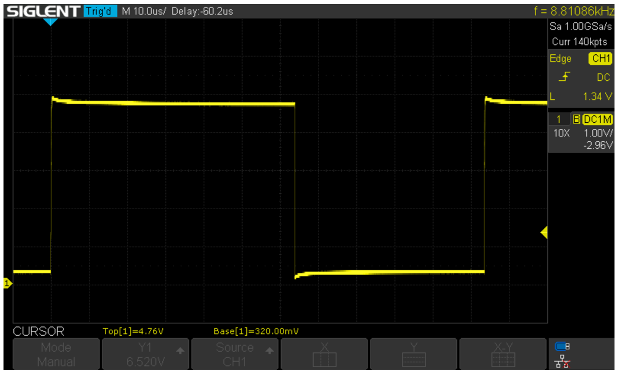
Connect the scope to test point 1 (TP1). Press the 1 button to bring up the Channel 1 menu and set the Probe to 10X if your probe is set to 10X. Enabling the BW (bandwidth) limit to 20M (MHz) will reduce noise and increase measurement accuracy for this lab. Press the Auto Setup button. You should see a 3.3 V clock signal:



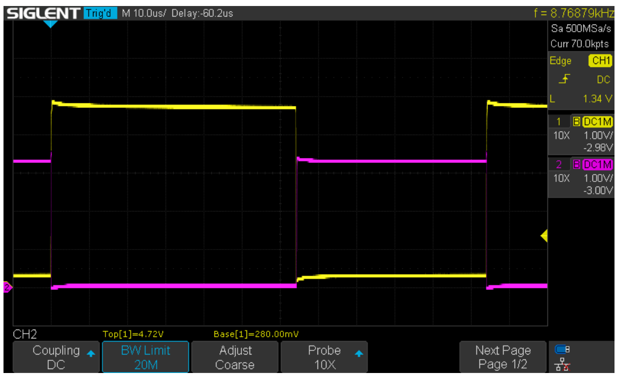
Connect the transistor's drain (TP2, U2 pin 1) to ground [3], observe the effect on TP1 (U1 pin 4) and record your observations for your report.

Remove the ground and check the waveform on TP3. You should see a 5 V square wave:

[3]Do this briefly; U2 does not have open-collector outputs but should tolerate its output being short-circuited briefly.



Connect probes to TP1 and TP3 simultaneously. You should see TP1 inverted and at 5V on TP3:



Switch the pull-up resistor to 3.3 V and observe the effect on the output. Record the results for your report.

Plug a USB flash drive into the USB port on the front of the 'scope and press the Print button. A message should be displayed with the name of the screen capture file as it's being saved to your drive[4].

Oscilloscope Measurement Methods

Three ways to make measurements on digital 'scopes are:

- using measurement functions,
- marking the waveform feature(s) of interest using cursors, and
- estimating from the graticule markings.

Measurement functions are the most convenient and accurate but can give incorrect results if the waveforms don't match what the function expects. In this case, *cursors* allow you mark the specific times or voltages that you want to measure from or to. If accuracy is not required, the fastest measurements can made by *estimating* values from graticule markings and the display scale. This is computed by estimating the number of vertical or horizontal divisions and multiplying by the vertical or horizontal scale.

You will practice these three methods in this lab. You can read the user manual for the 'scope if necessary.

[4]Record the test point and the name of each capture file for your report.

Measurements

Switching Thresholds

Connect the channel 1 probe to pin 1 of U1, the Schmidt trigger input.

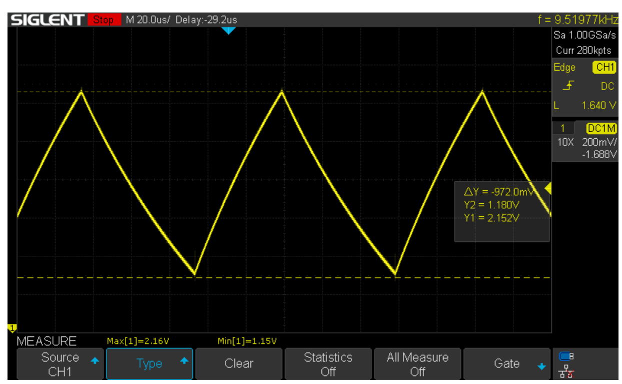
Adjust the vertical scale and Position knobs to expand the waveform so that it is vertically centered and takes up most of the screen.

Adjust the trigger level (move the yellow triangle on the right of the screen) so it's in the range of the Channel 1 voltage swing.

Press the Cursors button, select Y cursors and Channel 1 as the source and use the Adjust knob to adjust the cursors to the maximum and minimum voltages. Press the knob to switch between the cursors.

Press the Measure button and the soft key Type. Enable two measurements: Max and Min using the Adjust knob and pressing it to enable or disable individual measurements.

Your screen might look like:

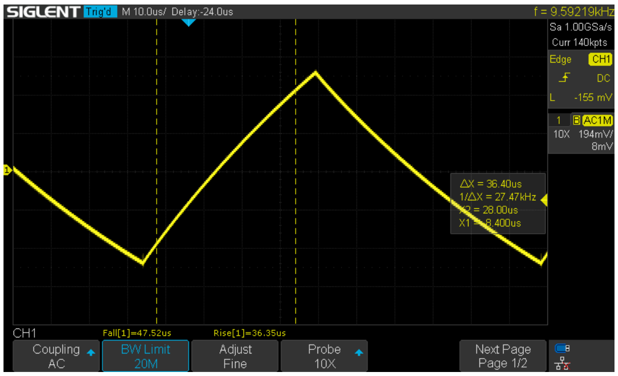


Make sure both the cursor and measurement values are displayed and take a screen capture for your report.

Rise and Fall Times

Adjust the vertical scale and Position knobs and the horizontal scale and Position knobs to expand the waveform so that it is vertically centered and takes up exactly 5 vertical divisions.

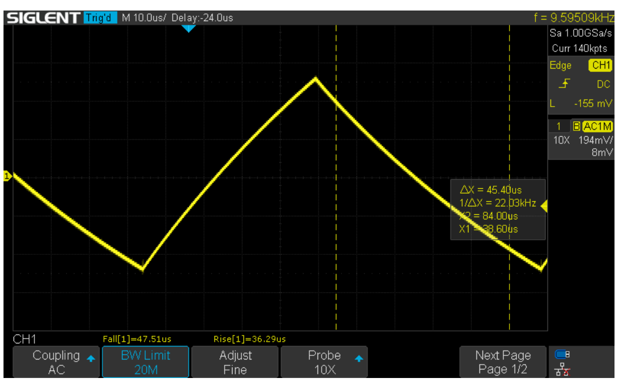
Switch to X cursors and adjust them so that they intersect the waveform at half a division from the minimum (10%) and half a division from the maximum (90%):



The Δ value shown for the cursors is the rise time: the time from 10% to 90% of the maximum voltage.

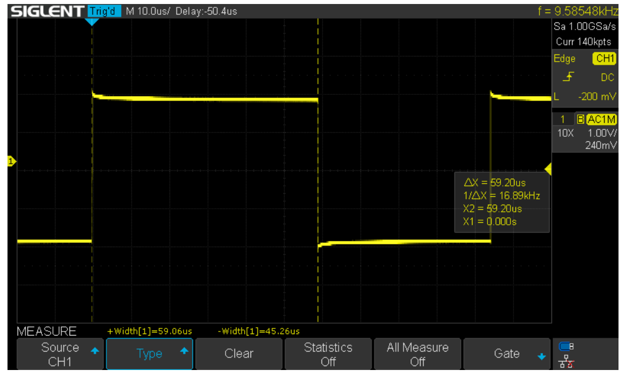
Change the measurements to the Rise and Fall times. Take a screen capture for your report, making sure both the cursor and measurement values are visible.

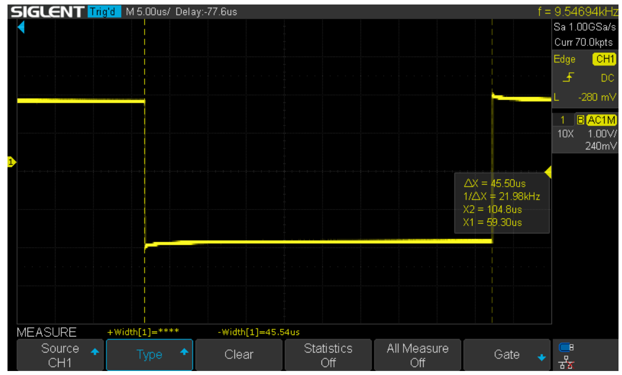
Repeat the cursor measurement of the fall time and take a screen capture for your report:



Pulse Widths

Move the Channel 1 probe to TP1. Adjust the horizontal scale and position to show the positive or negative pulse. Change to the +Width and -Width measurements of the positive and negative pulse widths. Use X cursors and adjust to measure the two pulse widths as shown below.





Take a screen capture for your report, again ensuring both cursor and measurement data are visible.

Report

Show your working circuit to the instructor to get a mark for completing the lab.

Your report should include the following:

- A description of what happens at TP1 when you ground TP2.
- A description of what happens when you switch the pull-up on TP3 from 5 V to 3.3 V.
- A screen capture of the waveforms at TP1 and TP2 showing the voltage levels over one or two periods of the waveform.
- A screen capture showing the cursor and 'scope measurement results for the threshold voltages.
- Screen captures showing the cursor and 'scope measurement results for the rise and fall times.
- Screen captures showing the cursor and 'scope measurement results for the pulse widths.

Do *not* use your phone camera to record the lab 'scope screen! Instead, plug your USB flash drive into the USB Flash Drive socket on the 'scope and use the Print button.