Physics 3150, Laboratory 8
Schmitt triggers, Basic Digital Logic, and
Data Acquisition with LabView Signal Express

March 21 and 23, 2016
Last revised March 7, 2016, by Ed Eyler

Notes:

(1) For this lab, please keep your circuit self-contained on a breadboard, so that it can easily be connected to a computer-based general-purpose data acquisition system in Part III.

(2) If you already know how to use LabView, feel free to use it as a more powerful alternative to Signal Express. The reason for using Signal Express is that it provides a way to perform basic I/O and data plotting without the need to learn a programming language at all.

Purpose:

1. To use positive feedback with a comparator IC to construct a Schmitt trigger, converting an analog signal to a binary digital signal in a reproducible and noise-immune way.
2. To perform basic data acquisition tasks using a PC with National Instruments LabView Signal Express software, attached to a general-purpose data acquisition system.
3. To examine a few basic logical operations using a NAND gate in the TTL or HCT logic families.

References:

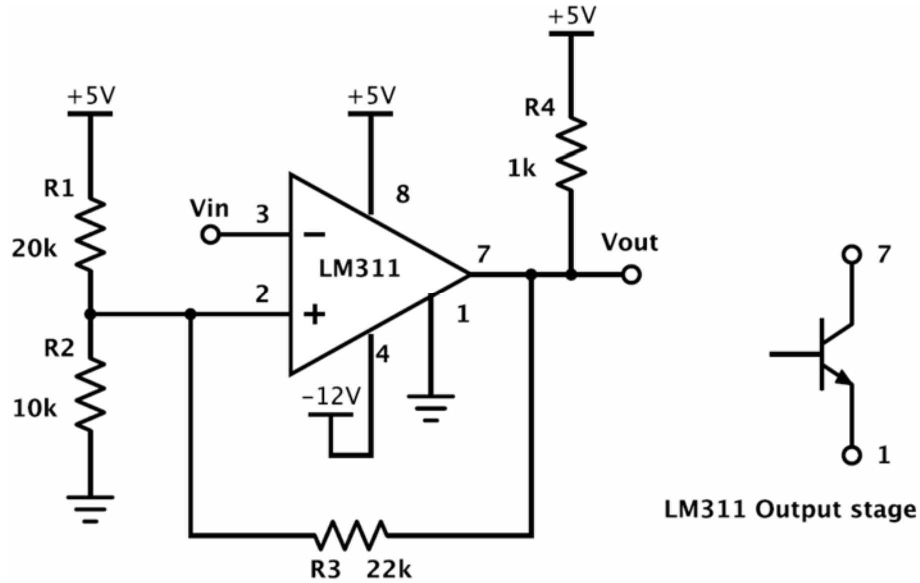
Chapter 8 of Eggleston and Chapters 6 and 7 of Meyer; also, *Getting Started with LabView Signal Express*, from National Instruments (available on the lab computers and also in the Resources section of the course web page).

Equipment:

1. LM311 comparators.
2. Digital oscilloscope.
3. Breadboard with power supplies, logic indicator LEDs, and a basic function generator.
4. A selection of 1/4W or 1/2W resistors.
5. A computer with LabView Signal Express installed, connected to a National Instruments USB data acquisition system ((USB-6008 or USB-6211).
6. A 74LS00 or 74HCT00 NAND gate.

I. Schmitt Trigger with an LM311 Comparator

Build the following comparator circuit using the specialized LM311 chip, which is designed to operate with a saturated output that is always either "high" or "low":



Note the unusual pin assignments and the unusual output stage, consisting of an npn transistor whose base is driven by the internal circuitry. You have access to the collector (pin 7) and the emitter (pin 1), allowing you to select the high and low output voltages. In this example, the output switches between +5 V and ground, even though the comparator is powered with -12 V and +5 V so that it can tolerate negative input voltages.

1) Initially, omit feeback resistor R3 so that the value of V_{in} at which the comparator switches is set by voltage divider R1-R2. Drive the circuit with a slow sine wave (about 100 Hz) from the buit-in function generator on the breadboard, and observe the input and output on your scope. How rapidly does the output switch from low to high?

2) Still omitting R3, make the amplitude of the input smaller and smaller, until it is barely large enough to switch the comparator. Note that the output now switches erratically — the pulse width is unstable, and worse, multiple pulses can frequently occur.

3) To convert noisy input signals into clean digital signals without "bouncing", we can introduce *positive* feedback to produce a circuit with *hysteresis.* The threshold voltages at V_{in} are different for turning the output on or off, suppressing spurious switching due to noisy signals. By adding feedback resistor R3, turn your comparator circuit into a *Schmitt trigger*. Measure the resulting upwards-going and downwards-going thresholds V_{Hi} and V_{Low} at the V_{in} terminal.

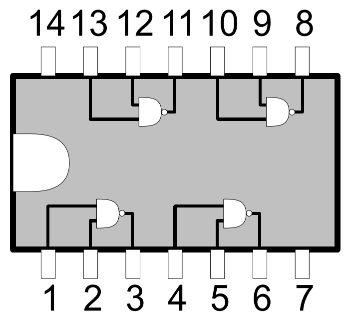
4) To provide a signal source for Parts II and III of this lab, set the input sine wave to a 4–5 V peak-to-peak amplitude, and verify that a clearn pulse train appears at the comparator output.

Questions:

1) Why does the output of the comparator go unstable near the threshold?
2) How much output current can this circuit supply when in the "high" state while still maintaining the minimum output voltage specified by the TTL logic level standard?
3) Calculate V_{Hi} and V_{Low} (see p. OPA-16 of the lecture notes) and compare with your measured values.

II. Basic logic circuits with NAND gates

Any logic gate can be contructed with NAND gates. Here you will use a basic NAND gate to switch a pulse train on and off, then use multiple NAND gates to create the AND and OR logic functions. You should use a 74LS00 or 74HCT00 quad NAND gate, each of which has the folloing pin diagram:



Power must be provided by connecting +5V to pin 14 and ground to pin 7. This configuration for power pins is quite common on logic chips but is not universal, so always check the data sheet when you aren't sure. Note that if you want an input to be high, it should be explicitly tied to V_{CC} (or V_{DD} for CMOS), either directly or through a resistor. Some logic inputs float to the high state when disconnected, but this is not reliable, and it's not even true for most CMOS logic families. Unconnected inputs can be a major source of confusing behavior in digital circuits.

1) To start, connect the pulse train from the comparator output used in Part I to one input of a NAND gate, and connect the other to a logic switch (i.e. one that switches between TTL logic levels). You should be able to verify with your scope that the logic switch can be used to gate the pulse train on and off, and that the pulse train is inverted when present at the output.

2) Next, combine two NAND gates to form an AND gate. Verify that its truth table is correct by connecting the output to a logic level indicator LED (be sure to set it for TTL logic levels), and using a pair of logic switches for the two inputs. Now connect the same pulse train and logic switch signals as for the original NAND gate, and explain the differences you observe.

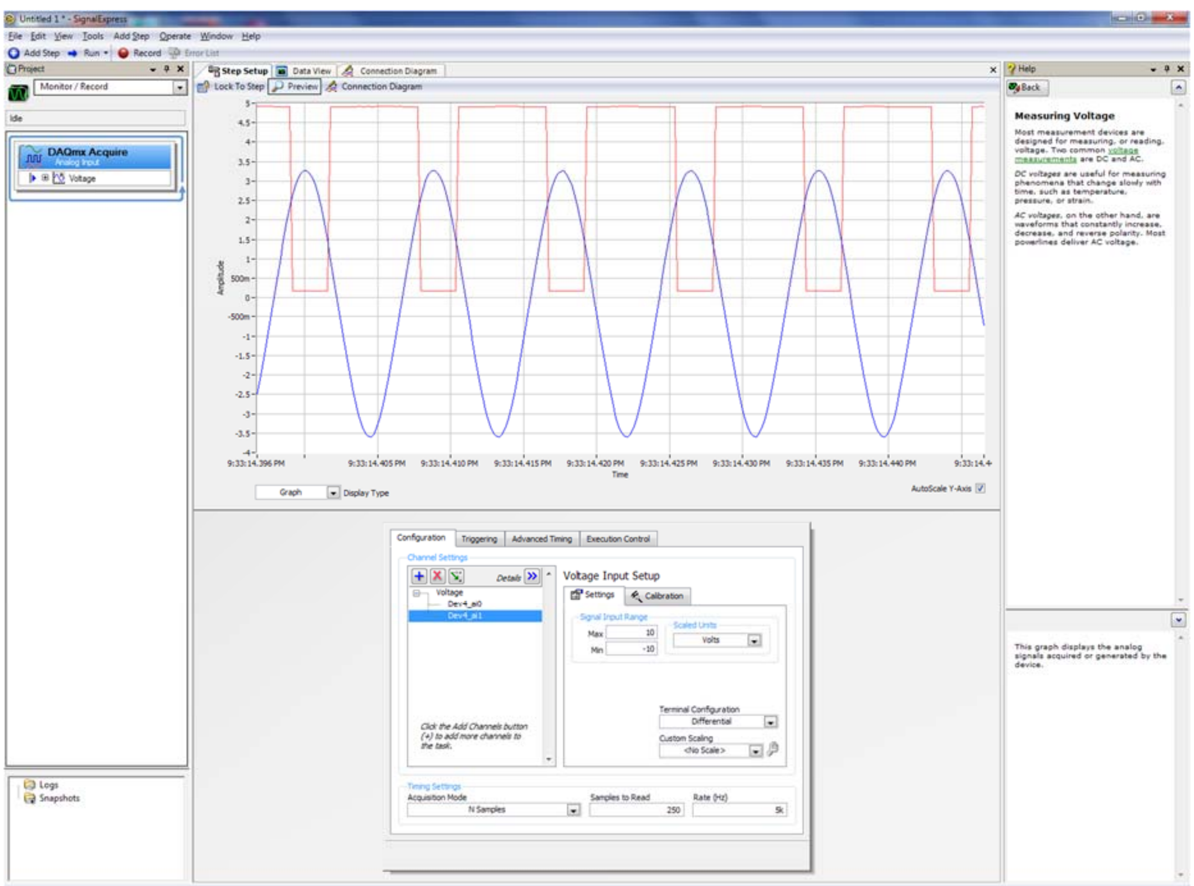
3) Finally, use two or more NAND gates to create an OR gate, and verify its truth table with the switches and LED.

III. Acquisition of analog data with NI Signal Express

Here we will use a PC-based general-purpose data acquisition to sample the analog input voltage for your comparator circuit along with its digital ouput, plotting the data on the computer screen and later saving it to a file. We also briefly examine the analog output capability of the data acquisition system.

First we need to connect some signals to the computer data acquisition system so there's something to look at. To provide this, use the input and output signals from the Schmitt trigger circuit you constructed in Part I of this lab. Connect the sine wave from the function generator to the terminals labeled for differential analog input on Channel 0. Specifically, connect the ground of your circuit to the AI0- terminal and the signal to AI0+. The input impedance of most data acquisition cards is at least 10 MΩ when power is on (in the present case, it's much higher), so you don't have to worry about perturbing the circuit when you connect it. Now connect the comparator output to Channel 1, at terminals AI1- and AI1+. Note that several additional analog input channels are also available on additional interface connectors.

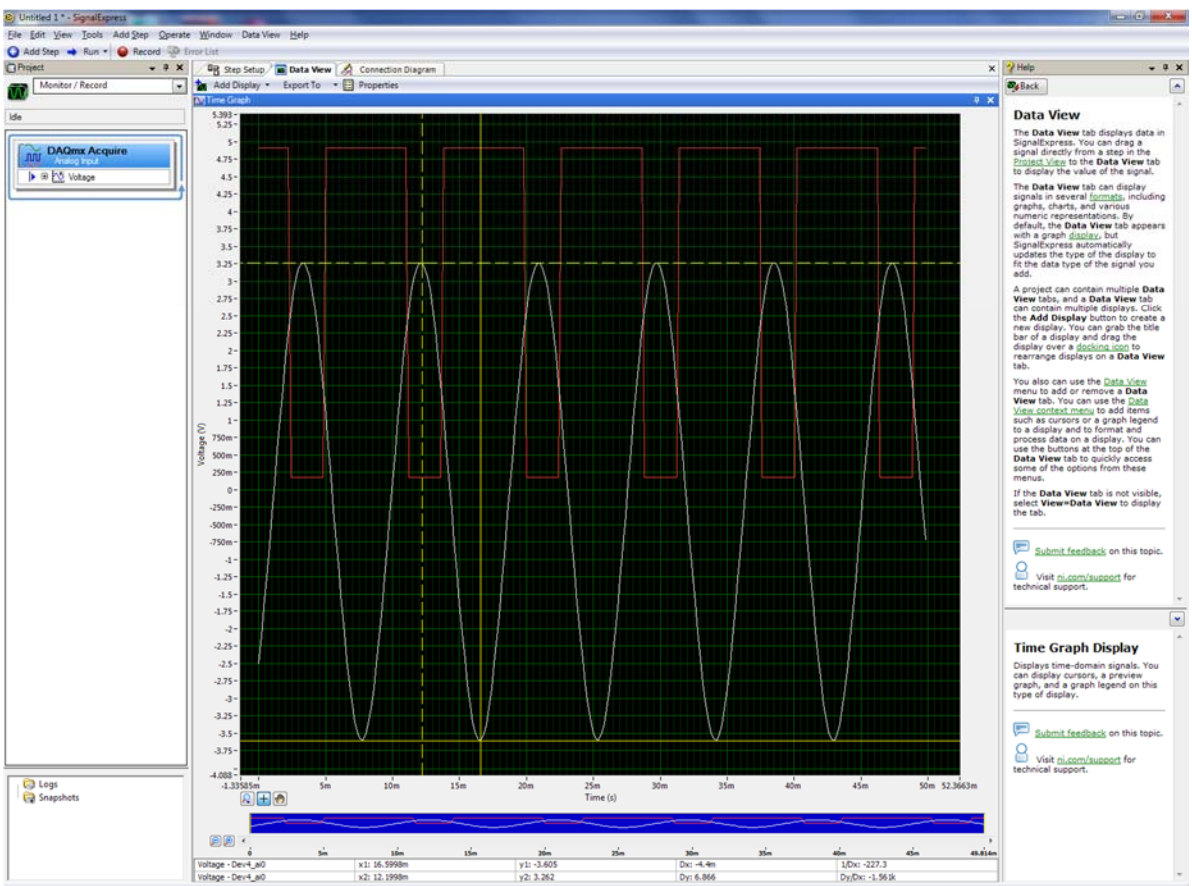
Start the Signal Express Program and open an empty project. To configure the program for analog input, select "Add Step" from the menu bar, then "Acquire Signals/DAQmx Acquire/Analog Input/Voltage" from the pop-up menu box. You should then see a box listing all of the available channels for the DAQ device. Select "ai0", the shorthand name for analog input channel 0, and click on "OK". Close the "Channel View" window at the bottom of the screen, if present Your Signal Express window should now look like the image below, except that the graph area will be empty. At the upper left you can see an icon for the Analog Input step you



have added (presently the only step in the sequence), and in the lower window you can configure the properties. Make sure that the Input Range is set for -10 V to 10 V (the maximum) and that the Terminal Configuration is set to Differential. Finally, change the Timing Settings to acquire "N Samples" and specify 250 samples at a sampling rate of 5k (i.e., 5 kHz).

Next test your setup by clicking "Run Once," which is available by clicking on the arrow next to the "Run" button on the main menu bar. You should now see the sine wave displayed in the preview graph in the top half of the "Step Setup" window. Next, add a second input channel by selecting the "+" button on the "Configure" tab, then selecting "Voltage/ai1," then test your setup again. Once you have succeeded at sampling data from both channels, select the "Data View" tab near the top of the screen to provide a much more flexible data viewing environment. To link your signals to this large graph, left-click on the "Voltage" signal label in the "DAQmx Acquire" step in the Project window, and while holding down the mouse button, drag the signals into the graph, which should then resemble the screen image below. When multiple signals are available as in this example, the graph window will display them together if they are compatible, or open a new graph window if they use incommensurate units (such as time vs. frequency). Note that each time the "Run Once" button is pressed, a new data set is acquired and graphed.

To examine your data in more detail, you can zoom the graph, and you can also obtain a set of cursors by right-clicking on the graph and selecting "Visible Items/Cursors". To save a record of your results, right-click on the graph and select the "Export" option, then save your data to an Excel spreadsheet. In your lab writeup, include a plot of the oscillator waveform prepared from this saved data.



IIIA. (Optional, not fully supported on NI USB-6008) Analog output using NI Signal Express

Here we will add steps to the Signal Express sequence to create and output an analog waveform, and then read and display it together with the unrelated output waveform from your circuit. Unfortunately, if you have the low-cost NI-USB6008 device, only single-point output will possible rather than a full hardware-timed waveform output. This section is included largely to provide guidance in case you need the analog output capability as part of a later final project.

Before a waveform can be output via the digital-to-analog converters (DACs) on the data acquisition card, it is necessary to define the waveform. Do this by selecting “Add Step” and then “Create Signals/Create Analog Signal”. Select a sawtooth wave with an amplitude of 2 V and a frequency of 200 Hz. Specify 250 samples at a sample rate of 5k.

Now add yet another step: “Generate Signals/DAQmx Generate/Analog Output/Voltage”. Select channel “AO0” in the pop-up window and press “OK”. If you have an NI-USB6211 or similar interface unit, set the configuration for “Continuous samples” and check the box just to the right of “Generation mode” to specify that the timings from the input waveform are to be used. If you have an NI-USB6008 this hardware-timed waveform output mode is not supported, and you will instead have to settle for a single-sample output with a manually specified constant voltage value. Finally, disconnect your external signal from input terminals AI0, then connect the analog output at terminal AO0 to AI0+, and the analog ground to AI0-. Differential input Channel 1 can remain connected to your comparator output.

To set the overall sequence, drag the “DAQmx Acquire” step in the Project View window so that it comes last. Now select the “Execution Control” tab for this step, and select “Start this step after Previous Generation Step”. Finally, press “Run Once” and make sure things look reasonable, then switch to the “Data View” window and export your results to a spreadsheet.