Class #24: Digital Electronics,
Interfacing Hardware and Software

Purpose: In this experiment we will begin to address the use of software to control and extract data from a simple circuit. We also begin working with the digital functionality provided by Analog Discovery. The overall goal is, essentially, to consider what we need to do so we can interface hardware and software.

Background: Before doing this experiment, students should be able to
- Review online background materials.
- Build and operate simple circuits on a Protoboard.
- Measure the voltages and determine the currents using a math channel in simple Protoboard circuits using Analog Discovery
- Analyze simple circuits consisting of combinations of resistors, especially voltage dividers.
- Do a transient (time dependent) simulation of circuits using LTspice
- Generate a truth table for a logic gate
- Review the background for the previous experiments.

Learning Outcomes: Students will be able to
- Set up Analog Discovery Static I/O channels as switchable sources to output ones and zeros and as an input to monitor ones and zeros.
- Test logic gates using Analog Discovery Digital I/O capabilities
- Set up and test a photocell circuit to monitor light levels.
- Set up Analog Discovery Patterns to output a PWM signal.

Resources Required:
- Analog Discovery and Parts Kit
- Some additional logic gates

Helpful links for this experiment can be found on the course website under Class #24.

Pre-Lab

Required Reading: Before beginning the lab, read over and be generally acquainted with this document and the other **required reading** materials.
Hand-Drawn Circuit Diagrams: Before beginning the lab, hand-drawn circuit diagrams must be prepared for <u>all</u> circuits either to be analyzed using LTspice or physically built and characterized using Analog Discovery.
Due: At the beginning of Class #26

Background Preparation

The Analog Discovery Board is an excellent example of a product of a design process generally known as Software/Hardware co-design which can be defined as the simultaneous design of both hardware and software to implement a desired function. In this experiment, we will explore some of the features of Analog Discovery and analog and digital electronics that can play a role in the powerful combination of software and hardware. Look up Software/Hardware co-design and see if you can find an understandable reference, which can be a challenge. This experiment will primarily provide the tools for the Matlab experiment in Class #25, but you may also find what you learn to be quite useful in your final project and your present and future study of embedded systems. In this experiment, you will explore one approach to use digital I/O to produce pulse width modulated signals. When you set up Analog Discovery for this purpose, you should notice that there are many other options available, but we will choose the simplest approach.

Part A – Static Digital Logic I/O with Analog Discovery

Begin by exploring three of the 16 digital Input-Output (I/O) channels, specifically, channels 0, 1, 2. On your Protoboard, build a circuit consisting of three LEDs, each in series with a 1kΩ resistor, as shown at the right in Figure A-1. Connect the black ground wire to the circuit ground. For each of the three resistors, connect the corresponding wire from digital channels 0, 1 & 2, respectively. For now, you do not have to build the circuit at the left in this figure. Note that it is relatively easy to confuse the digital wires so make sure you have the correct ones by having another student and/or a TA or instructor look at your circuit. Note that the 1kΩ resistor can be replaced with any value from 100Ω to 1kΩ, depending on how bright you want the LED to be. 1kΩ works fine and minimizes the power used in this experiment, so that is what you should use for this experiment. For the other resistor values are provided for future reference.
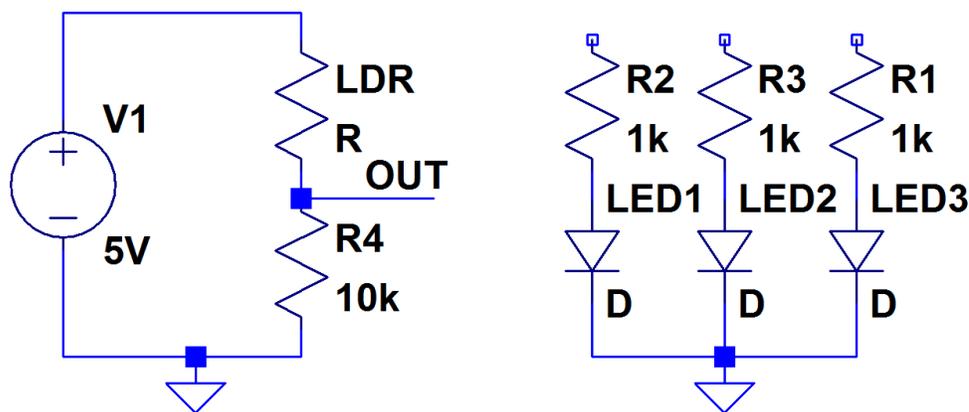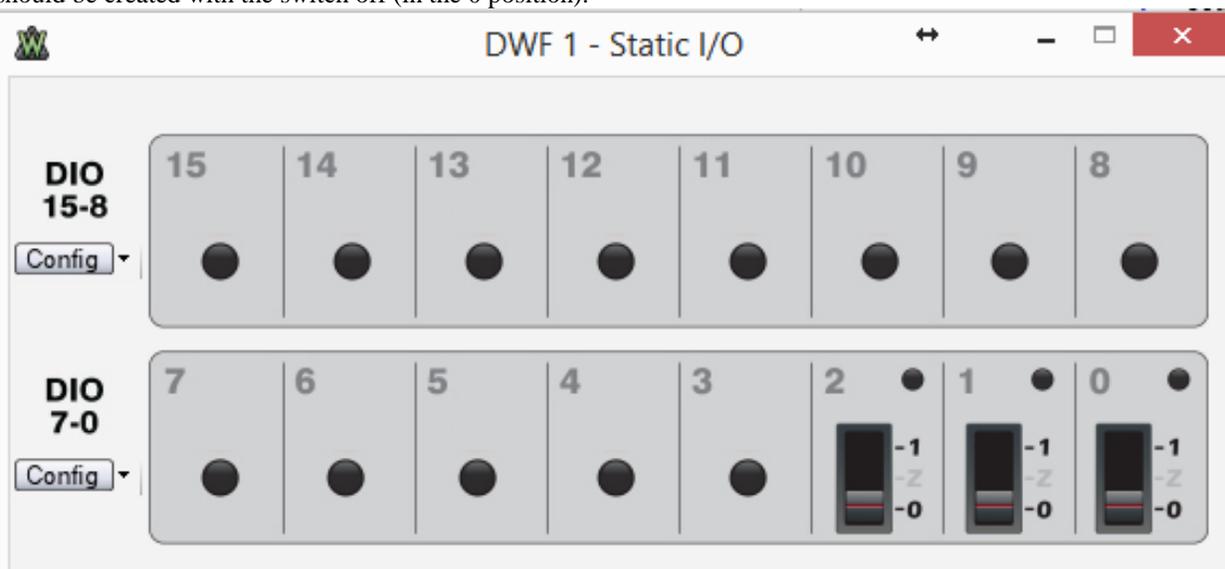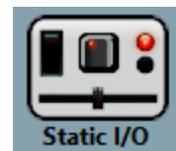

Figure A-1

Next, turn on the Static I/O feature of Analog Discovery. This will bring up a new window that will look something like one of the figures in Figure A-2. It is likely that your window will not show the three switches for channels 0, 1, 2. For the original version of Waveforms, to change the corresponding block to a slider switch, right click on the block and select push/pull switch. For Waveforms 2015, use the drop-down menu by the block number to select *Switch* and then *Push/Pull*. Note that it is possible for each of the 16 digital connections to perform either as an input or an output. We will use these three as outputs and not use the other 13, at least not for now. The switches should be created with the switch off (in the 0 position).
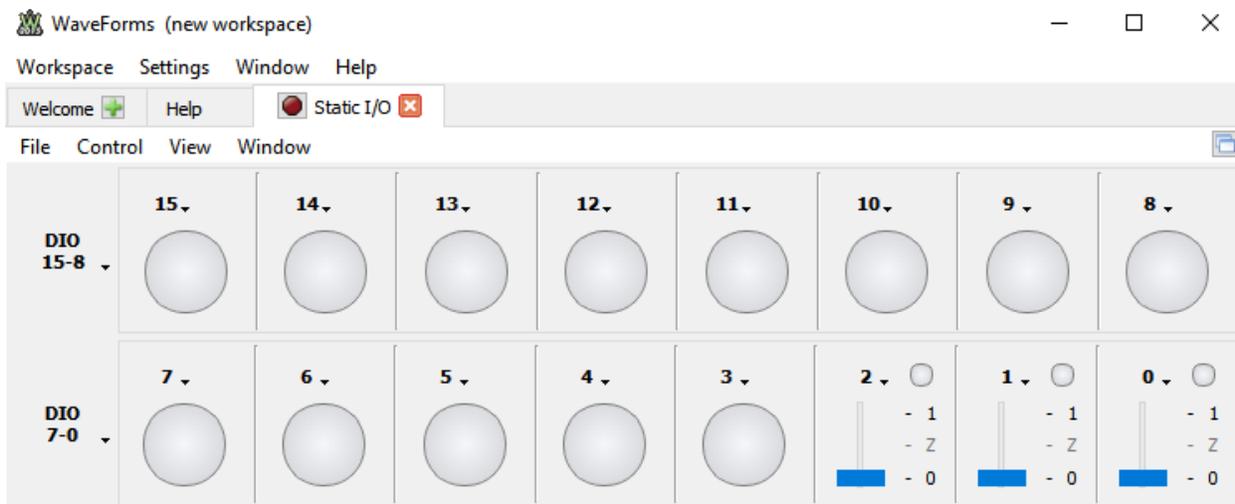
Figure A-2

1. For each of the three switches, turn them on and then off in sequence (i.e. Switch to 1 and then to 0). What do you observe? If nothing, you may have your LEDs in backwards. You should be able to turn the LEDs on and off. *You will probably also observe flickering images from the digital channels you are not using. This shows the sensitivity of digital electronics to noise. To remove the flicker, you can ground each channel that is set up as an input, but that is not necessary here. You may want to try one channel just to be sure that this works. Try connecting a channel to ground through a 1kΩ resistor too.*

2. Use a multi-meter or Analog Discovery (The Logger works) to measure the voltage output by Digital Channel 0 when it is turned on. *If you use the Logger, be sure to set the voltage scale to something like 1V/div rather than letting it run in Auto mode. We did this very early in the semester, so you may not recall that the little gear icon for each Logger measurement allows you to set the scale.* Also measure the voltage with the LED removed (open circuit voltage). You only have to do this for one channel, because all should work the same. What do you observe? Explain your observation to a TA or Instructor: _____. *Hint: What do you think the output impedance (AKA Thevenin Resistance) of Channel 0 is when you are using it as a voltage source, as you are here?*

3. Now also connect the output from Channel 0 directly to Channel 8, 1 to 9 and 2 to 10. What do you observe? What is the circle in each block supposed to represent? *Note that for the next question, you still need to be measuring the voltage with your multi-meter or Analog Discovery.*

4. Does connecting to the digital input channels change the voltage measured? From the voltage you measure, determine whether the input impedance of Digital Channel 8 is large or small.

Part B – Photocell Light Sensor Circuit

The circuit on the left in Figure A-1 can be used to sense the level of light in a room. The photocell changes resistance with light level, as we saw in Class #17 with the Optical Theremin Project. The resistance goes down with increasing light, so the voltage across the fixed 10kΩ resistor will increase with increasing light. For an accurate measurement of light level, the sensor must be calibrated. However, if we only wish to know when light is at is maximum or minimum level, we just have to measure the voltage for those two conditions. Once the max and min levels of light are known, the measurement of light level can be used to control one or more of the Analog Discovery digital outputs.

5. Set up the circuit in Figure A-1, power it with the 5V DC power supply from Analog Discovery. Be sure to also connect the ground where shown. Set up analog Channel 2 to measure the voltage across the fixed resistor. The Logger also works well for this measurement. Record the measured voltage when the room is fully illuminated and when the sensor is covered by something that blocks room light (e.g. a dark hat or coat will work). Demonstrate your circuit to a TA or instructor: _____

Part C – Truth Tables for TTL Logic Gates

We will now consider three basic logical elements: a two input NOR gate, a three input NAND gate and an INVERTER (NOT gate). While the stated goal for Part C is to find the truth tables for three common gates, the real motivation is to get some experience with commercial TTL logic gates. It is necessary to know how to use them in a circuit before the decision is made to add such gates any future projects. *Note: For the following activity, it is only necessary to determine the truth table for the 7410, 3 input NAND gate. The other two gates are optional.*

Wire the circuits in Figure C-1 on your protoboard. Do not forget to tie pin 14 to +Vcc (+5V) and pin 7 to 0V (Ground) on each chip. Also, like other chips, be careful when you read the identifying numbers. The protoboard, with and without connections to Analog Discovery, is also shown in Figures C-2 and C-3. *Note that the chip numbers are no written consecutively on the chips in the two figures. For example, the 7402 is actually labeled SN74LS02N. Usually, there are additional letters providing other information, but we only need the numbers for our purposes here.*
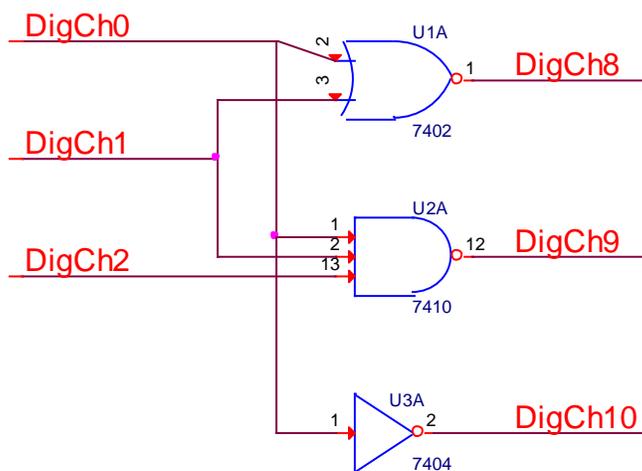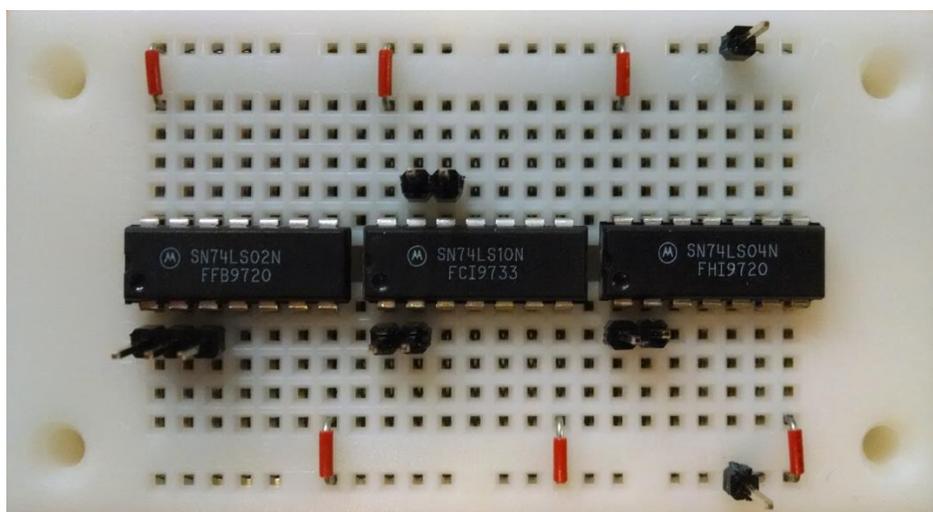

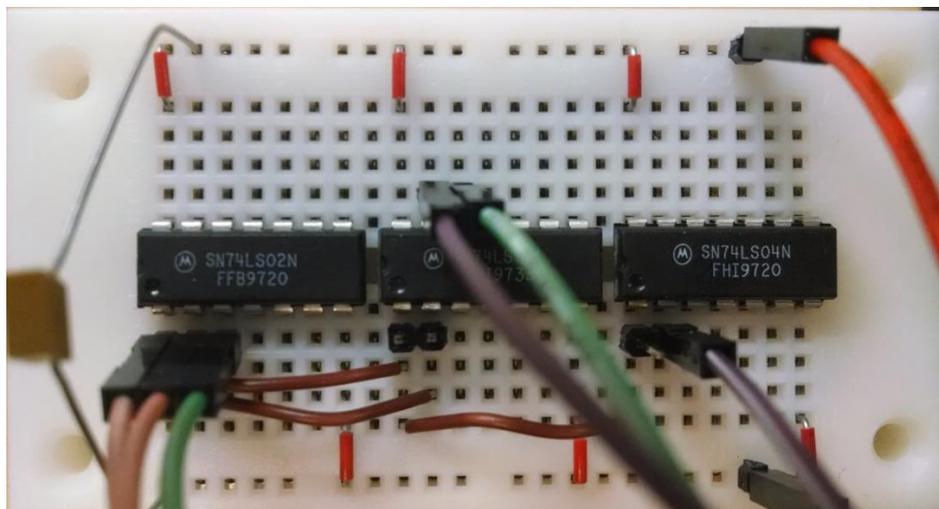**Figure C-1**

Figure C-2

Figure C-3

For the first measurements, we use the Digital Static I/O feature of Analog Discovery. Enable Static I/O and be sure that all 16 channels are configured Bit I/O (menus on the left) and channels 8-15 are LED (for measurements, the LED is on when the voltage is HIGH and off when it is LOW) and channels 0-7 are Push/Pull Switch (for output voltages, when the switch is up, the output is HIGH and its little LED in the upper right hand corner will turn on or when the switch is down, the output is LOW and its LED will turn off). We will use the outputs from Digital Channels 0, 1, 2 to provide inputs to the gates and inputs to 8, 9, 10 to measure the outputs from the gates.
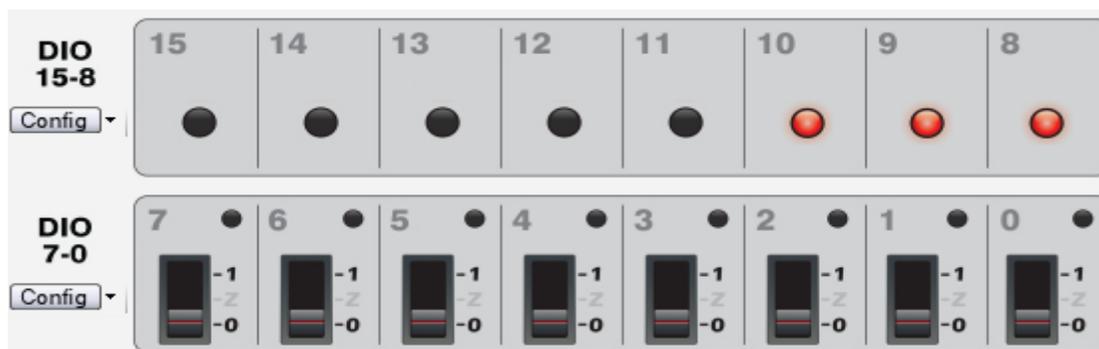.

Figure A-4.

Consider all possible combinations of inputs to generate a truth table for each device. The NOT gate has only one input. Therefore, we need only need to observe the output when the input is HIGH and LOW.

6. Record the truth table for the NOT gate
    a. First set channel 0 to HIGH and record the status of channel 10.
    b. Then set channel 0 to LOW and record the status of channel 10.
    c. Does the gate invert the input?
    d. Take a picture (screen capture) of one of the input/output combinations.
    e. Record the truth table for this gate. Include the picture and truth table in your report.
7. Now you will repeat this process for the other two gates.
    a. The NOR gate has two inputs, so we must observe the output at pin 1 (Digital I/O channel 8) for all possible combinations of binary inputs at pins 2 and 3: (LOW, LOW), (LOW, HIGH), (HIGH, LOW) and (HIGH, HIGH).
    b. Take a picture (screen capture) of one of the input/output trace combinations.
    c. Record the truth table on the plot. Include the picture and truth table in your report.
    d. The NAND gate has three inputs. How many combinations of HIGH and LOW are required to fully test this gate? Show your completed truth table to a TA or Instructor: _____

  e. Record the input and output for this gate in a truth table and a sample screen capture of one input/output combination, as well. <u>Include the picture and truth table in your report.</u>

Part D – Pulse Width Modulation from Digital Output

We have previously seen that we can generate a PWM (Pulse Width Modulated) signal using the analog function generators (Wavegen). One of the limitations of that approach is that there are only two function generators, so we can only produce two PWM signals. The sixteen Digital I/O Channels can also be used to produce PWM signals, which has two big advantages: 1) Many more channels and 2) Can be controlled by and a key part of a fully digital system and, thus, generally more flexibly, if not necessarily more easily, programmed. The time-varying digital source from Analog Discovery is called Patterns. Its primary purpose is to generate digital signal patterns that can be used to test digital circuitry. It can also be used to generate lots of PWM signals. Here we will only generate one signal as a proof of principle. For this experiment, the circuit we will use is in Figure A-1.

  8. Reconstruct one of the resistor, LED combinations and connect the top of the resistor to Digital Channel 0. Ground the other end of the LED. Open Patterns and make sure that it is set to run in continuous mode. Change the display to Manual and Show: 20ms/div from: 0s, as shown in Figure D-1. This time scale is chosen because the goal will be to create a 100Hz square wave with a specified duty cycle.
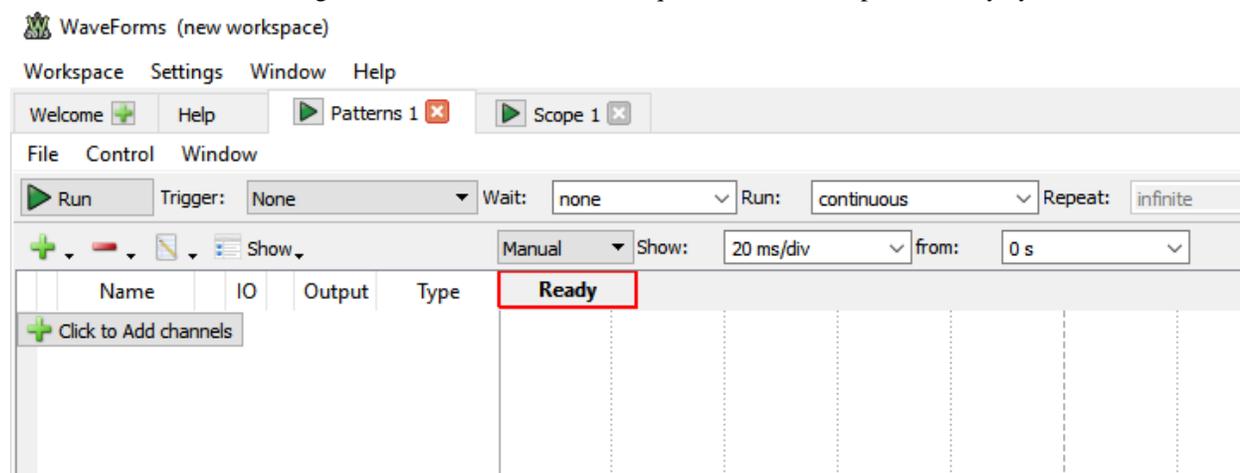
Figure D-1

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  9. Click to add a channel. Add a Signal and Add DIO 0. For Output choose Push-Pull (PP) and for Type choose Clock. Your display will not look like Figure D-2 because you still have to select the frequency. To do this, click on the little pencil icon to the left of PP and you will see the window shown in Figure D-3. Set the frequency to 100Hz. Then your Patterns window should look like Figure D-2.
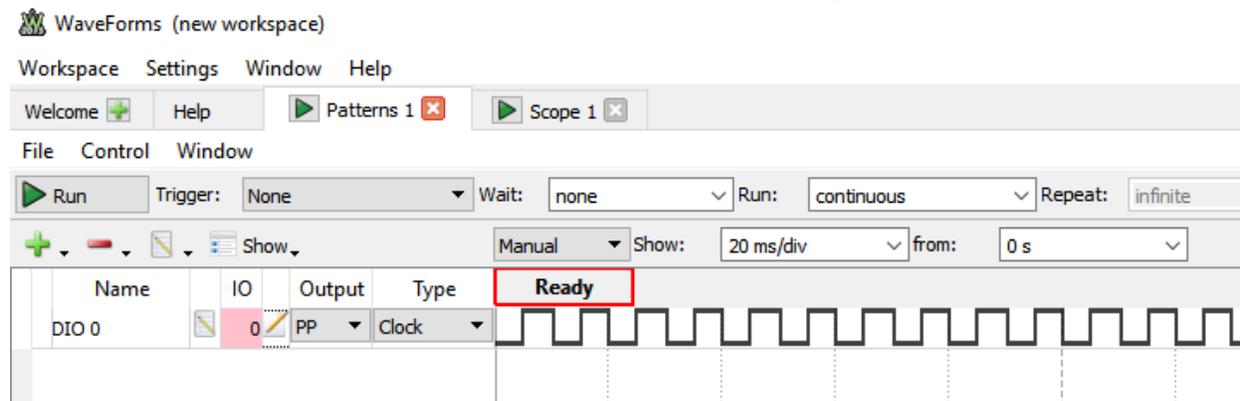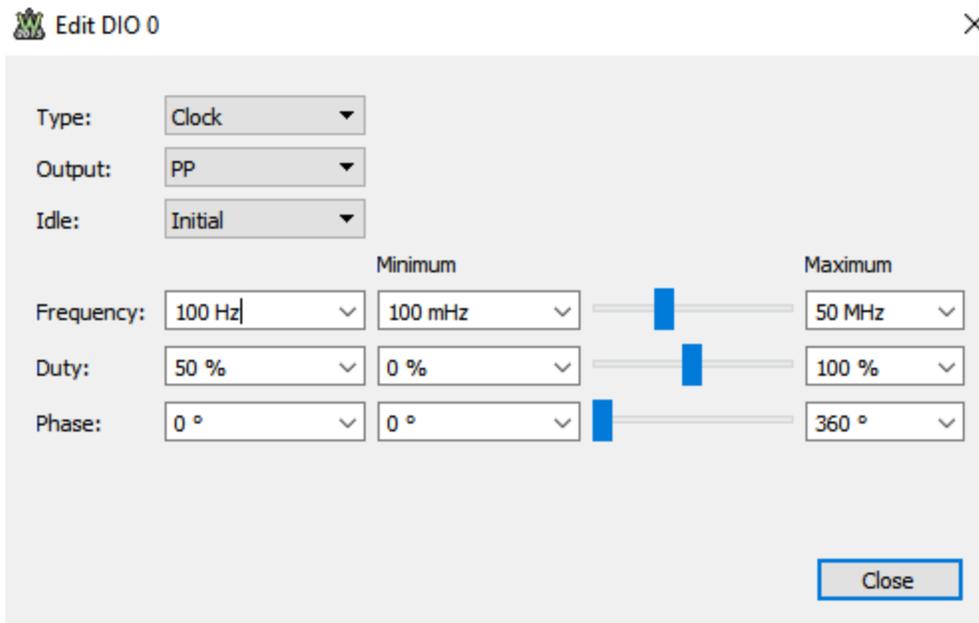
Figure D-2

Figure D-3

10. Run Patterns and your LED should light up. Open the Edit DIO 0 window again and change the Duty cycle up and down and observe the LED brightness. What do you observe? Connect Analog Input Channel 1 or 2 from your oscilloscope to the output from Digital Channel 0, as you did for the Static I/O above. Measure the voltage as a function of time with and without the LED connected, again as you did for the Static I/O. Save the scope images in your report and discuss whether or not the signals you measure are consistent with the Static I/O measurements above. Also discuss any disadvantages you can identify in the use of a Digital I/O channel as a PWM source rather than one of the two function generators. Demonstrate your PWM control to a TA or instructor: _____

Part E – Task List
- Test and describe the static digital output capabilities of Analog Discovery
- Show that the simple voltage divider made with a fixed resistor and a photocell can produce a signal that changes with light level
- Generate truth tables for the three TTL logic gates
- Generate PWM output from a digital I/O channel and compare the signals measured to the static output task above. Also, compare the voltage signals to what you can produce using one of the function generators.

Part F – Reflection

Take a moment to reflect on what you have learned in this experiment, then discuss what you have learned. In particular, discuss the static and dynamic Digital I/O capabilities of Analog Discovery, the use of a photocell to measure light level and generation of truth tables for logic gates using Analog Discovery. Discuss anything that still confuses you and/or anything else you would like to know about these topics and any other experiments or simulations you think might be worth doing. Discuss how well your final circuit design worked and any problems you may have had. Include the reflections in your report.

Part G – Extra

Obtain an XOR gate from your instructor or TA, design, build and test a circuit in which you use four Static I/O channels as a signal to be transmitted and four channels as a key to encode and decode the signal. This should only be done if there is time. This task is mostly included to show how some of the digital electronics you have seen can be used in a practical and powerful application. Demonstrate your working system to a TA or instructor: _____