**The University of Alabama at Birmingham**

**School of Engineering**

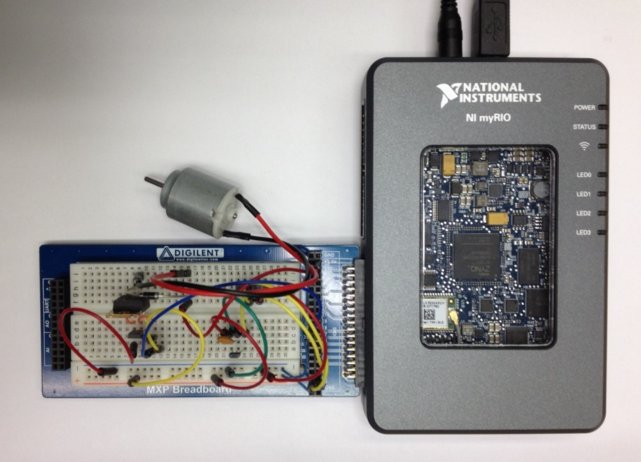
**Department of Mechanical Engineering**

**in collaboration with**

**Center for Advanced Automotive Technology and**

**National Instruments Corporation**

***Hall-effect sensor concept design and applications for measuring wheel rotational speed***



***Prepared By:***

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## Objective

1. Understand the basics of the Hall Effect Principle and sensor design
2. Understand automotive applications of Hall Effect Sensors
3. Understand the process of measuring wheel rotational kinematics parameters by implementing a Hall Sensor
4. Understand integration of electrical, and mechanical components, and software to achieve a user-friendly and intelligent Virtual Interface.
5. Understand signal processing and transformation.

In this lab, you will alter the breadboard circuit via LabView to magnetically turn the DC motor on and off. The digital switch will be a Hall-Effect sensor that does not require human input to control the motor, rather detection of a magnetic field will provide either an “ON” command or an “OFF” command.

## Safety

* Do not touch any wires connected to a power source; doing so will result in an electric shock and possible injuries
* Disconnect all power sources when touching and moving wires.
* Do not touch any electrical component if hands are wet and or damped.
* If the circuits shorts, do not attempt to fix it; notify the instructor immediately.

## Equipment

|  |  |
| --- | --- |
| **Direct Current Motor** |  |
| **General Purpose Rectifier**  **1N4001** |  |
| **ZVN2110A n-channel enhancement-mode**  **MOSFET** |  |
| **ZVP2110A p-channel enhancement-mode**  **MOSFET** |  |
| **IRF510 n-channel enhancement-mode power**  **MOSFET** |  |
| **Breadboard** | C:\Users\marker\Pictures\breadboard.png |
| **Jump wires, M-F (4x)** | C:\Users\marker\Pictures\jumpwires.png |
| **US18 Hall-Effect Latch** |  |
| **Ceramic Disk Capacitor, marking “104”** | C:\Documents and Settings\Tony\My Documents\Mechatronic Labs\capacitor.jpg |
| **Rectangular Magnet** |  |

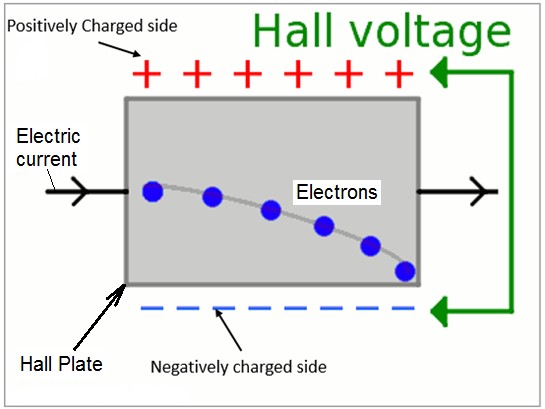
## Hall-Effect Sensors

### Introduction to the Hall Effect Principle

Hall Effect Sensors work on a principle called the Hall Effect. The Hall Effect is an extension of the Lorentz force - a phenomenon in which an electron is deflected from its straight path when it passes through a magnetic field that acts perpendicular to its direction of motion.



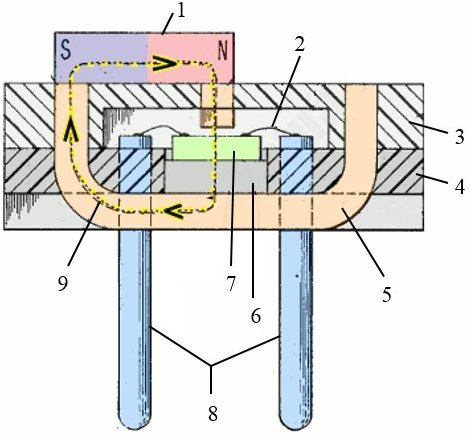
When an electric current flows through a semiconductive material (also known as a Hall plate), the electrons follow a straight path through that material. When the plate is placed inside a magnetic field, the electrons become deflected, as shown in Figure 1.1. This causes electrons to gather on one side of the material, resulting in a potential difference across the plate. This potential difference is referred to as the Hall voltage, and it is directly proportional to the magnitude of the electric current and the magnitude of the magnetic field.

****

**Figure 1.1: Diagram of the Lorentz force acting to produce the Hall Voltage (modified [2])**

### Hall Effect Sensor

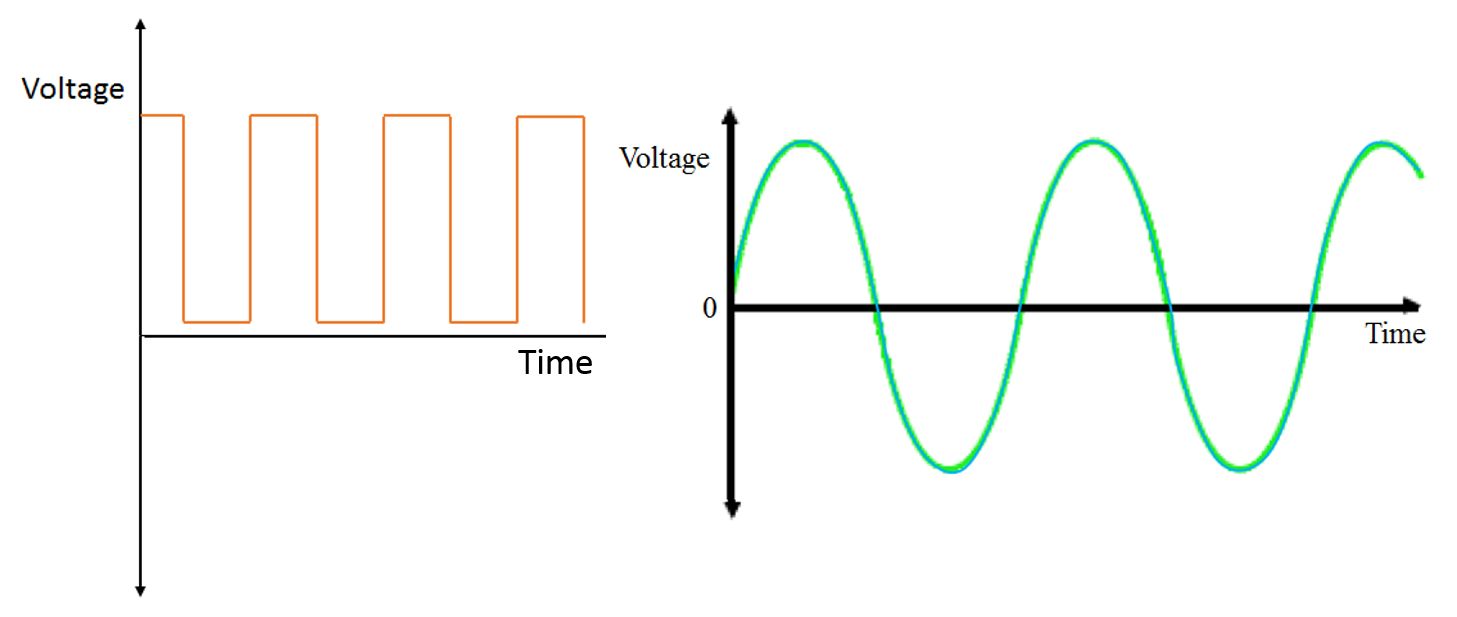
This section will describe a typical Hall Effect sensor and will highlight its basic components. Hall Effect sensors are implemented in circuits. The simplest circuit consists of a voltage source (battery) connected to a resistor and some type of device that does work when current flows through the closed circuit. The Hall Effect sensor will take the place of the device that does work. Most Hall Effect sensors already have a built-in circuit, and these sensors are referred to as Hall Effect IC sensors, where IC stands for Integrated Circuit. Integrated circuits are collections of hundreds to even millions of tiny electrical components (e.g. resistors, transistors, capacitors, etc.) that are etched onto a semiconductor wafer. Based on the configuration of the IC, Hall Effect sensors can act in different ways, allowing for broader application of these sensors. Below is a diagram of a typical Hall Effect sensor with explanations of the individual parts.



**Figure 1.2: Cross-section of a typical Hall Effect sensor [2]**

Number **1** shows a magnet that is placed near the Hall Effect sensor. The magnet is not part of the sensor; however, it is included to show how the Hall Effect sensor operates. Number **2** is a pair of lead wires that connects the hall chip (green block that is numbered **7**) to the terminal pins (terminals pins are colored a light shade of blue and are labeled **8** on the diagram). The hall chip is the part of the sensor that reacts to the magnetic field. The terminal pins connect the Hall Effect sensor to a circuit. Numbers **3** and **4** are separate plastic material plates that are sandwiched together to form the shell of the Hall Effect sensor. Number **6** is an iron carrier plate that the hall chip is mounted onto. The iron carrier plate carries the charge through the soft iron flux connector which, in turn, travels back to the magnet and then to the hall chip, completing the circuit. The flux connector is number **5** and colored orange; it serves as one of the most important parts of the Hall Effect sensor components. This is because the flux connector allows the magnetic flux from the magnetic field to flow around a continuous loop through the Hall chip. Number **9** is the path the magnetic flux flows inside the Hall Effect sensor.

The Hall Effect sensor is a form of transducer (a device that transfers physical data like stress, strain, or brightness into an electrical signal, usually a voltage) that measures the Hall voltage across two surfaces. The Hall Sensor is similar to a magnetic sensor in that it reacts to a magnetic field, but the difference lies in the way the two sensors output the generated voltage. The magnetic sensor outputs an alternating current (AC) signal that varies in voltage and speed, while the Hall sensor produces a constant voltage signal that can change quickly from the max value to a value close to zero and back again, resulting in a digital signal. This is also known as a square wave. An example of this is shown in the following plots in Figure 1.3.



**Figure 1.3: Hall Sensor voltage vs time (Left); Magnetic sensor voltage vs time (Right).**

A Hall Effect sensor can be “on” or “off” depending on how it is integrated into a circuit and how the sensor itself is wired. When the Hall Effect sensor is “on”, it produces a constant output voltage, but when the sensor is “off”, it produces a near zero voltage. The polarity of the magnet controls this “on” and “off” state. This leads to four different categories of Hall Effect sensors: unipolar switch, bipolar switch, latching switch and omnipolar switch.

Unipolar Hall Effect sensor, also known as a unipolar switch, will turn on and remain on as long as the south end of the magnetic is present. Once the south end of the magnet (south polarity) is removed from the unipolar switch, the unipolar switch will turn off. This allows the unipolar switch to operate with either a static magnetic field or a dynamic magnetic field. One thing to note is a unipolar switch will not react to the north side of a magnet (north polarity) – only the south polarity will be able to operate a unipolar switch.

Bipolar Hall Effect Sensor, also known as either a bipolar sensor or bipolar switch, behaves differently from the unipolar switch. Bipolar switches respond to both the north and south polarity of a magnet. When the south polarity comes close to the bipolar switch, it causes the bipolar switch to output its max voltage. The bipolar switch continues to output that signal until the north polarity of the magnetic comes near, causing the bipolar switch to output a low, non-zero voltage. Bipolar switches are often used as a sensitive switch, where the sensor responds strongly to a signal. An example of this is the touch screen on smart phones.

Latch Hall Effect Sensor, also known as a latch switch or just latch, is similar to a bipolar switch. The difference is that latches are not as sensitive as bipolar switches. This allows for latches to be able respond to signals in a more controlled manner, allowing for tighter control of the signal.

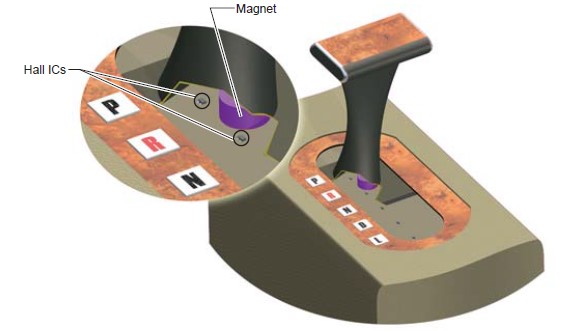
Omnipolar Hall Effect Sensor, also known as an omnipolar switch, responds to both the north and south polarity of a magnetic field. When the omnipolar switch experiences either a north or south polarity, it will stay on and output a constant signal, similar to the unipolar switch. When the magnetic field is removed, the omnipolar switch reverts to its off state, outputting a low or zero signal.

## Automotive Applications of Hall Effect Sensors

There are many uses and automotive applications of Hall Effect Sensors. This section will cover various applications of Hall Effect sensors, ranging from proximity sensors to sensors that measure the rotational velocity of shafts.

### 2.1 Automatic Transmission

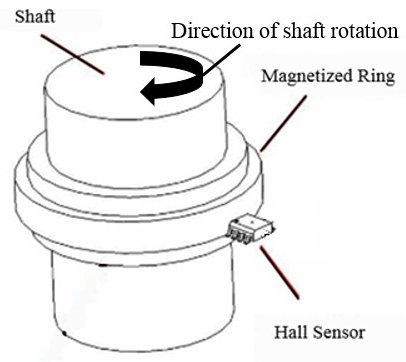
An example of a Hall Effect sensor behaving as a proximity sensor is the gear selector in an automatic transmission vehicle as seen in Figure 2.1 [3]. This is achieved by integrating a Hall Effect sensor at each desired location. A Hall Effect sensor is placed at each symbol P, R, N D, etc., and a magnet is installed in the gear selector handle that allows the Hall Effect Sensor IC to react with the magnet when they are in close proximity. Gear selectors can be operated with either a Unipolar switch or an Omnipolar switch.



**Figure 2.1: Gear selector [3]**

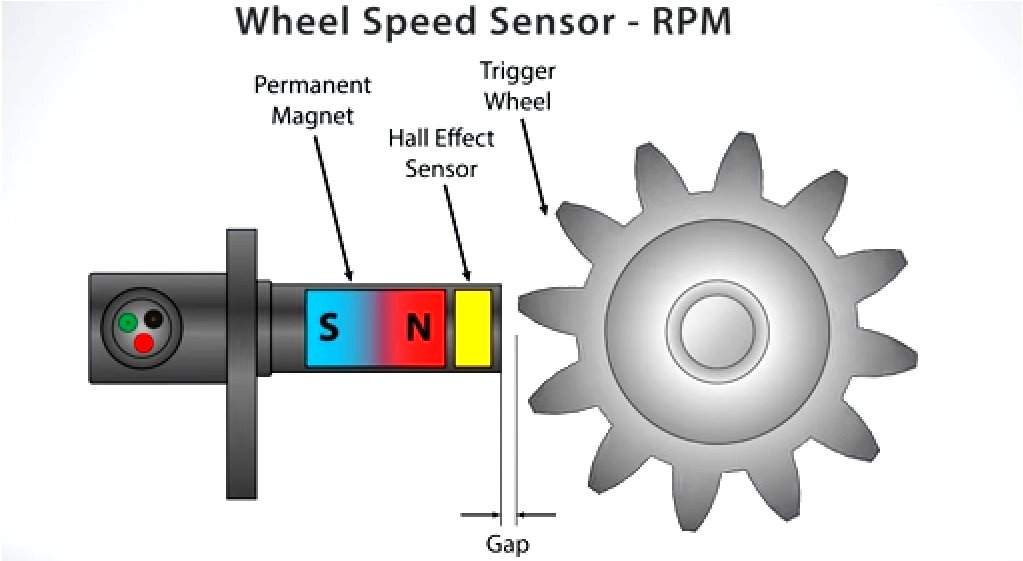
### 2.2 Applications at Engines and Wheels

A rotational velocity sensor is a device that measures the angular velocity of a shaft. For this purpose, a digital output bipolar sensor reacts to a magnetic field which is created by a rotating magnetized ring driven by the shaft. Figure 2.3 [4] shows an example of measuring the angular velocity of a shaft. The frequency developed by the rotation of the shaft is proportional to the rotational speed.



**Figure 2.3: Rotating shaft with Hall Effect sensor [4]**

Another way to measure the angular velocity of a shaft is to use a gear attached to the shaft, as in Figure 2.4 [5]. As the shaft rotates, the toothed gear passes by the Hall Effect Sensor. The sensor reacts every time the tooth of the gear passes by and thus outputs a voltage. The voltage developed is referred to as the pulse coming from the sensor. When the tooth completely passes by, the voltage drops to zero. The number of pulses from the sensor are counted over a certain amount of time, and this frequency is utilized to compute the RPM of the shaft.



**Figure 2.4: Hall Effect sensor implemented in a wheel sensor [5]**

## Hall Effect Experiment

The objective of the experiment is to learn how to control an electric motor by applying the Hall Effect principle and to gain knowledge on creating a virtual interface that allows for the student to control the electric motor with a Hall Effect sensor. This is done by bringing the magnet toward the Hall Effect sensor. When this is done, the motor will turn “On” until the magnet is removed from the Hall Effect sensor. When the magnet is removed, the electric motor will turn “Off”. The sections below will describe the process of setting up a virtual interface.

### 3.1 Part 1 of the Lab: Building the Virtual Interface

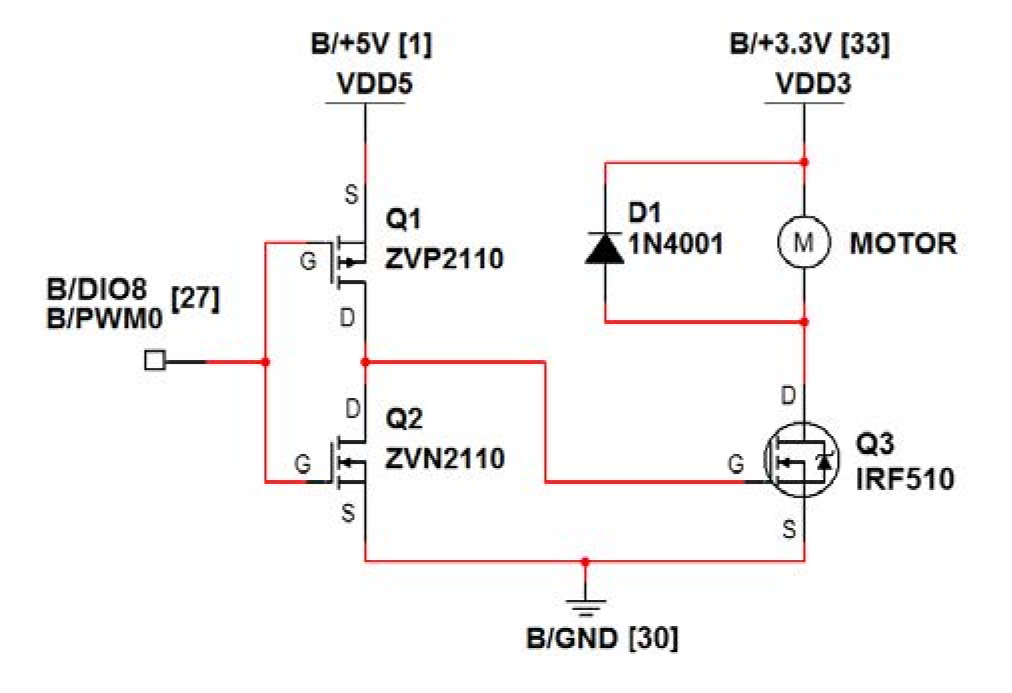
Refer to the schematic diagram and recommended breadboard layout shown in Figure 3.1.

**The interface circuit requires 6 connections to NI MyRIO MXP Connector B. These connections are already in place. You do not need to connect anything. Simply familiarize yourself with the connections listed below.** You may refer to the schematic diagram in Fig. 3.1 and recommended breadboard layout.

|  |  |
| --- | --- |
| What is being connected | Pin and Port on My Rio |
| 5-volt power supply | B/+5V (pin 1) |
| 3.3-volt power supply | B/+3.3V (pin 33) |
| Ground | B/GND (pin 30) |
| Motor control | B/DIO8 (pin 27) |
| Hall-effect sensor (not directly connected to MyRio) | 5-volt power supply, Ground, B/DIO1 (Pin 13) |
| Ceramic capacitor | 5-volt power supply, Ground [In Parallel with Sensor] |

**Important! Pin 13 refers to the port on myRIO but you will not connect the sensor directly to myRIO.**

Note: Although this diagram shows circuit components connected directly to the myRIO port, the circuits in this lab will be built on a breadboard and connected to a built-in port that is then plugged into the XMP Port B in myRIO. In other words, the real case will have one level of separation between the circuit components and myRIO pins, but the diagram still illustrates the same principles. The input on the diagram of Figure 3.1 will be the magnet field that is created when a magnet is brought toward the Hall Effect sensor. This will result with the output of the myRio device to be the Hall Voltage that is developed from the Hall Effect sensor. This voltage will activate the circuit providing power to the electric motor.



**DIO**

**1**

**/pin13**

**Ground**

**Input**

**Output**

**+5**

**V**

**0.1**

**μF**

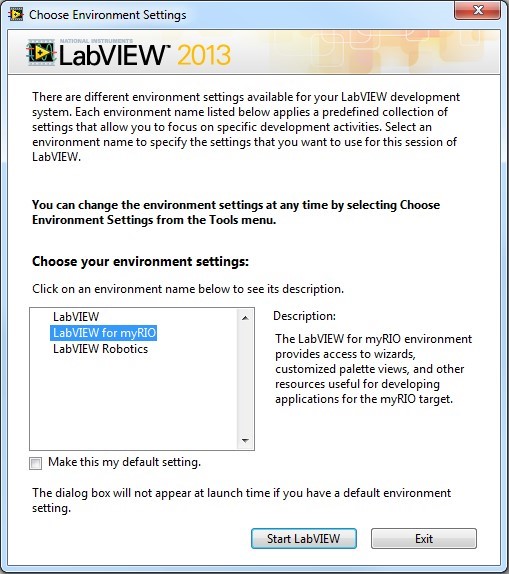
**US 18**

**Figure 3.1: Interface circuit diagram**

### 3.2 Part 2 of the Lab: Building the Virtual Interface

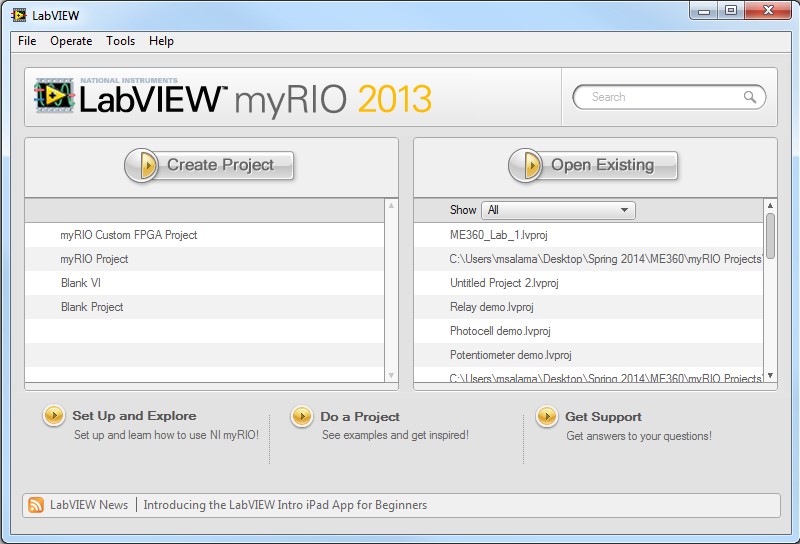
**Step 1: Open LabVIEW:** on the desktop, double click on LabVIEW icon to start LabVIEW.

**Step 2: Create a New Project:** by choosing “LabVIEW for MyRIO” and then click “Start LabVIEW”. See Figure 3.2.



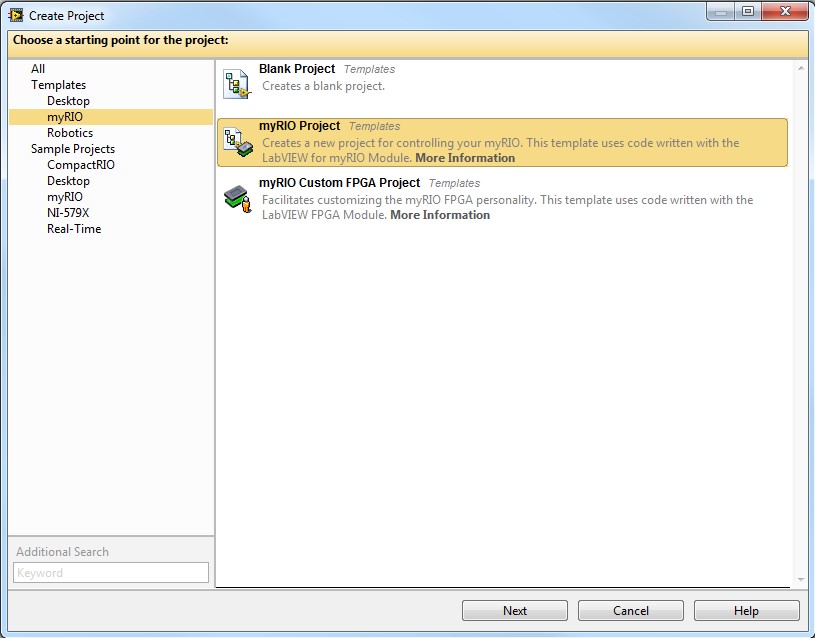
**Figure 3.2: Choose Environment Settings**

Another window will pop up. Click on “Create Project”. See Figure 3.3.



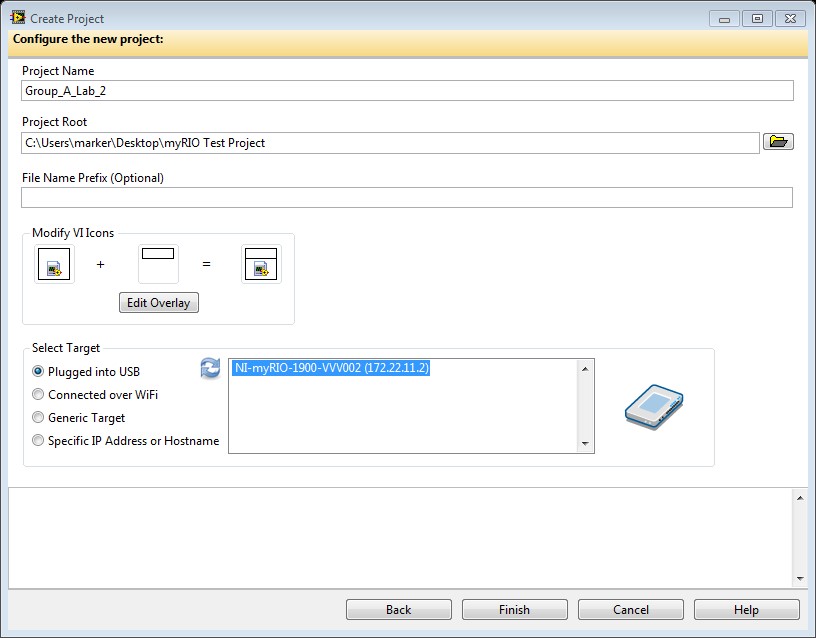
**Figure 3.3: Create Project**

The “Create Project” window will pop up. Click on “MyRIO” on the left side list menu and then click “MyRIO Project” on the right side list menu. Click “Next”. See Figure 3.4.



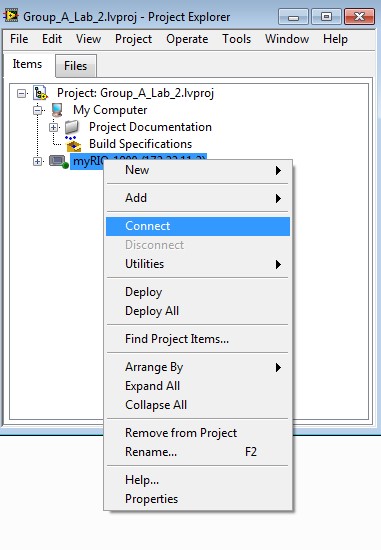
**Figure 3.4: Create Project**

Another window will appear. Change the Project Name to your Group Letter and Lab name as “Group\_Letter\_Lab Name”. You will save your VI (project root) to the Lab Name under your group folder. For example: Group A will save their work (project root) to “Group A”>>”Hall-Effect Lab”. Then click “Finish”. See Figure 3.5.



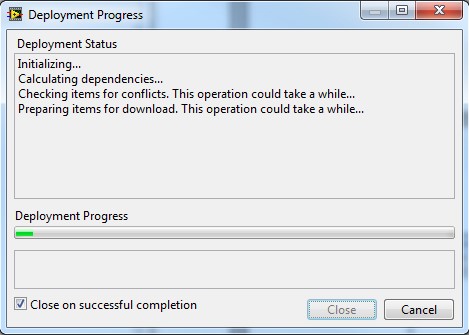
**Figure 3.5: Create Project**

Once you click “Finish”, the “Project Explorer” window will appear. Right click on “MyRIO-1900 (172.22.11.xx)” and “Connect”. A green light on the MyRIO icon will be ON. See Figure 3.6.



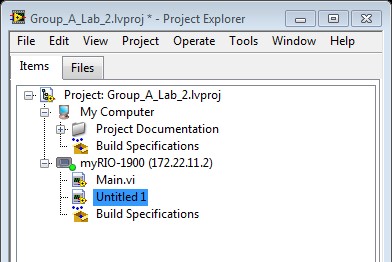
**Figure 3.6: Project Explorer**

Once you click “Connect”, a “Deployment Progress” will show you the deployment status. Click “Close” when it is finished, or it may close automatically if the check box is selected. See Figure 3.7.



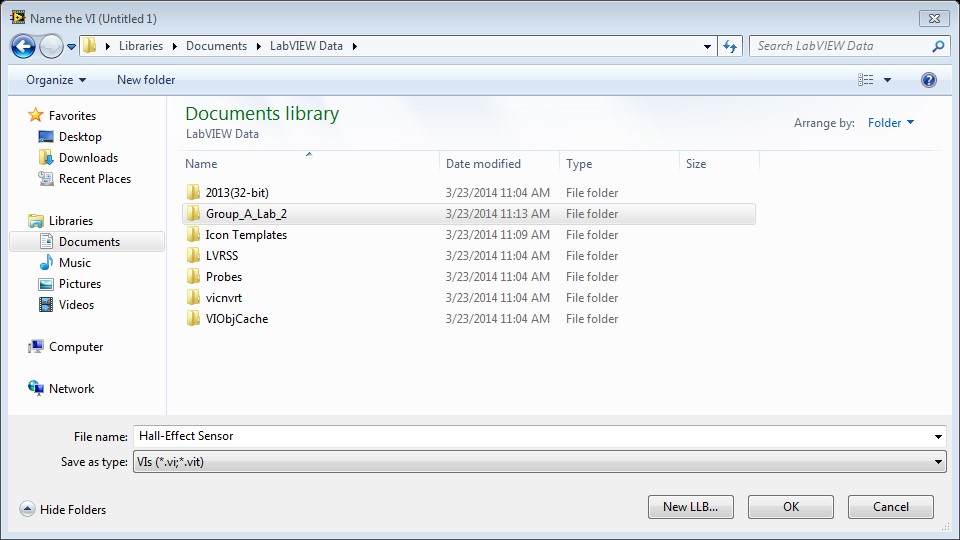
**Figure 3.7: Deployment Progress Window**

Again, right click on “MyRIO-1900 (172.22.11.xx)” and click “New>>VI”. A new VI “Untitled 1” will be added to your project. See Figure 3.8.



**Figure 3.8: Create a new VI**

Right click on “Untitled 1” and save it as “Hall-Effect Sensor”. Make sure that the “File Directory” is your “Project Folder” under the name Group\_Letter>> Hall Effect Lab. See Figure 3.9.



**Figure 3.9: Rename the VI**

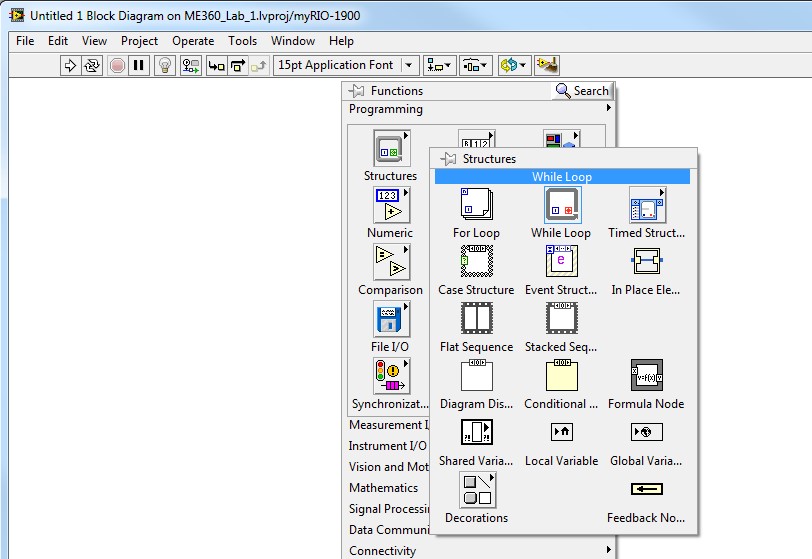
Click “OK”.

If needed, double-click on the slideshow below to refer back to the LabVIEW class lectures “LV\_myRIO Intro\_UAB”.

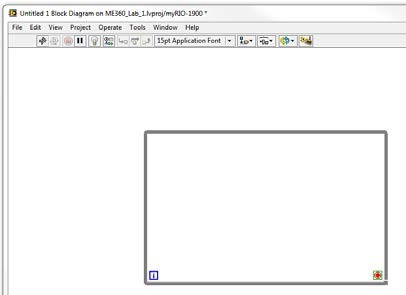


**Step 3: Build the VI:** In the Block Diagram window, right click to show the “Functions” palette. Hover the cursor over “Structures” A new window will pop open, and then click on “While Loop”. See Figure 3.10.

**Figure 3.10: While Loop (1)**



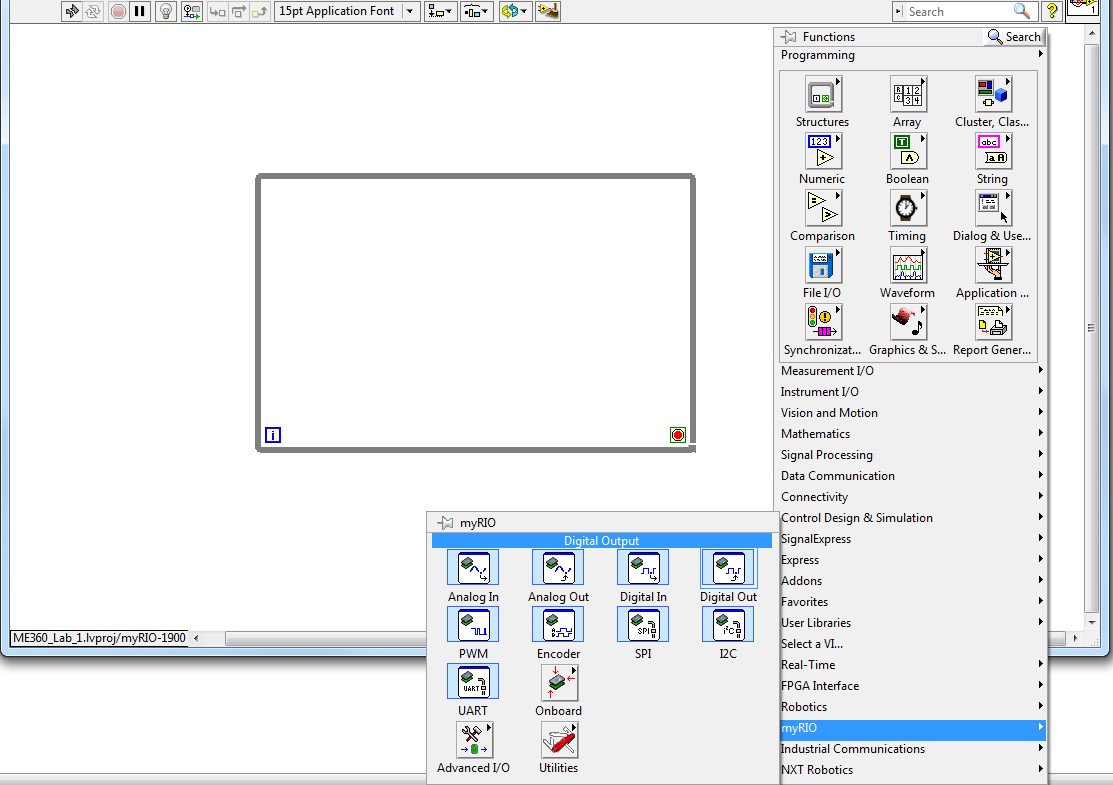
Your cursor will now change into a drawing tool. Hold the mouse and draw the square for your “While Loop”. You will want it to be relatively large since you will be placing several virtual components inside. Release the mouse when you’re ready to set it in place. See Figure 3.11.



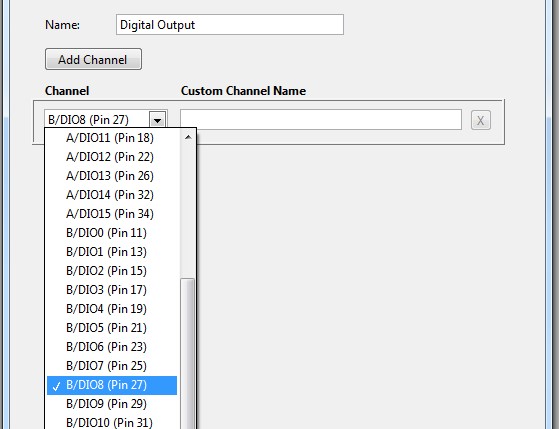
**Figure 3.11: While Loop**

Right click to show the “Functions” palette. Hover the cursor over “myRIO” near the bottom of the menu. Then select the “Digital Output” block. This will represent the output signal to the DC motor. See Figure 3.12. Place the icon somewhere inside of the while loop.

**Figure 3.12: myRIO Digital Output block**



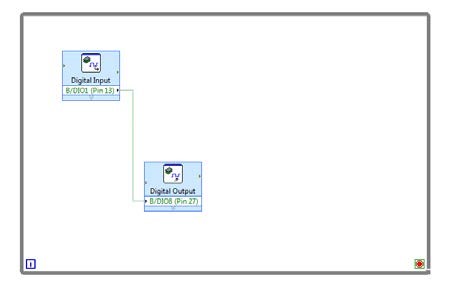
Another window will appear as shown in Figure 3.13. In the dropdown menu labeled “Channel,” select B/DIO8(Pin 27). This means you are selecting digital output to Pin 27 which is digital input/output number 8 on port B of the myRIO. You can see that the breadboard holding the entire circuit is connected to port B.



**Figure 3.13: Configure Digital Output Window**

In this lab, the input signal that tells the myRIO whether the DC motor should be on or off comes from the Hall-effect sensor. Follow the same procedure as Part 2 for creating Digital Output, shown in Figure 3.12 and Figure 3.13, but instead of selecting “Digital Out” select “Digital In”. When you see the menu that has the drop-down menu of Channels, select “B/DIO1 (Pin 13)”. Remember, you connected the Hall effect sensor to the DIO1 pin on the breadboard of the myRIO.

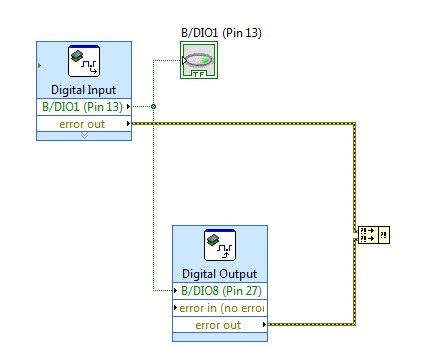
Next you will need to connect the signal from Digital Input (DIO1) to the Digital Output (DIO8). Click and drag the cursor from the black arrow right next to the word “Pin 13” on the Digital Input icon to the back of the black arrow next to “B/DIO8 (Pin 27)” on the Digital Output icon. This creates your input to output connection, shown by a green line. See Figure 3.14.



**Figure 3.14: Create Digital Input**

**Input Indicator:** Right click on the box that says “B/DIO1 (Pin 13)” on the Digital Input icon and go to Create>>Indicator. Make sure this indicator is connected between the Digital Input and Digital Outputs.

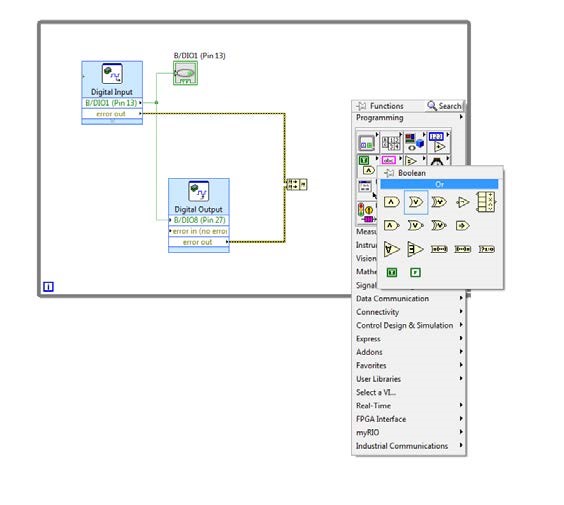
**Merge Errors:** There needs to be a junction merging the error output signals for the Digital Input and Output so the same operations will occur for either one. There is a “Merge Errors” function, that can be found by right-clicking again and going to “Dialog and User Interface”. Pull the paths of both the digital input and output “error out” boxes to the left side of the merge errorsicon as shown in Figure 3.15.



**Figure 3.15: Merge Errors and Front Panel Indicator**

**Stopping Conditions:** All while loops must have a stopping condition or they continue forever. In LabVIEW the stop controller is the red octagon in the bottom corner of the while loop. We need to connect the “error out” from Digital Input/Outputs to the stopping condition of the while loop. We also need to give the user an option to stop the loop from the front panel. Creating these alternatives will be done using an “Or” Boolean operator. The “Or” operator means that if either *x* or *y* are true then execute the next step.

Right click anywhere in the window, “Functions” palette will pop up, hover over “Boolean” and select “Or”. Place the icon somewhere to the right of the “Digital Output” block. See Figure 3.16.

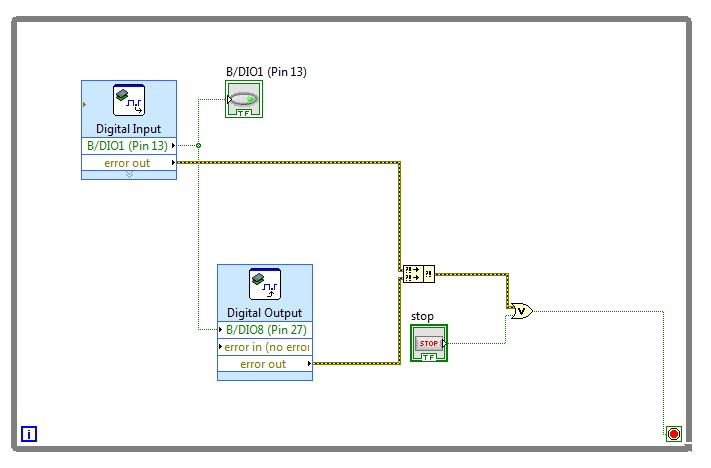


**Figure 3.16: While Loop Stopping Condition**

An “Or” Boolean operator takes two inputs (x and y) and gives one output. If either of the inputs are true, then the output is true. If neither input is true, then nothing happens. In order for this to correctly work, the stop condition for the y input needs to be set first.

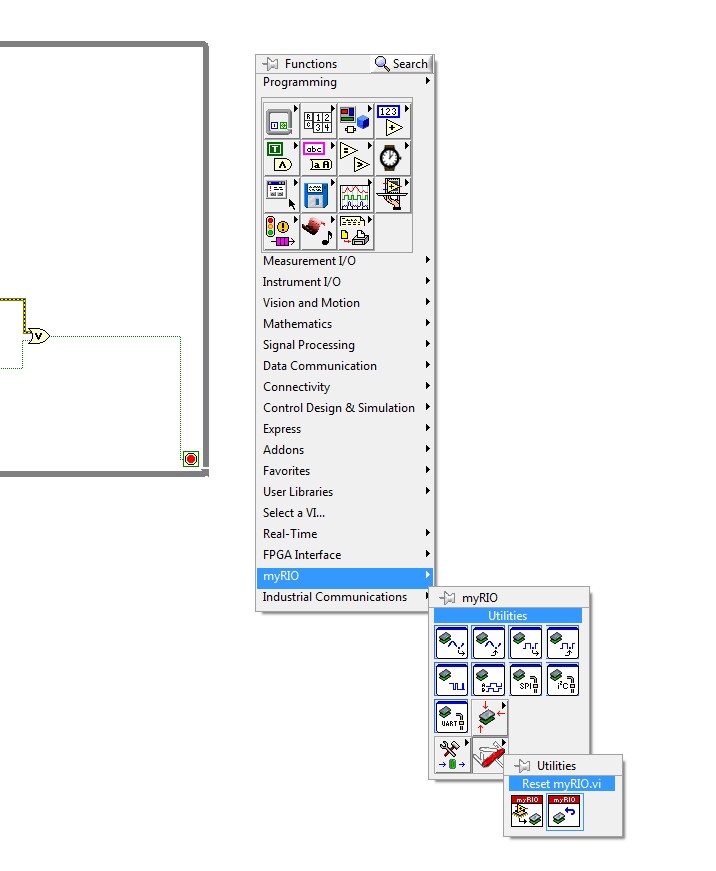
* For the y output: right click on the red button in the bottom right hand corner of the loop. Go to Create >> Control. Delete the control’s connection to the red button, and connect it to the bottom left tip of the “Or” icon. Finally, click on the right tip of the “Or” arrow and drag to the red button, which represents the loop’s stopping condition.
* For the x output: At the top left corner of the “Or” icon, click, hold, and drag the cursor to the output of the Merge Errors block. This makes Digital Input/Output errors the *x* input for the Boolean “Or” statement.

See Figure 3.17. If the new icon doesn’t look like the picture below, you may need to select the control from the red stop conditional, disconnect it, and then connect it to the “Or” Boolean operator.



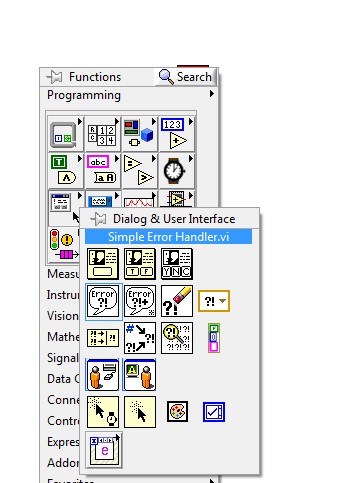
**Figure 3.17: While Loop Stopping Condition**

The myRIO input and output pins need to reset each time the program is stopped or an error occurs. Otherwise, they will continue to transmit the same signal as when the program was running. To add the reset capability, right click in the block diagram, select Functions >> myRIO >> Utilities >> Reset myRIO.vi as shown below in Figure 3.18.



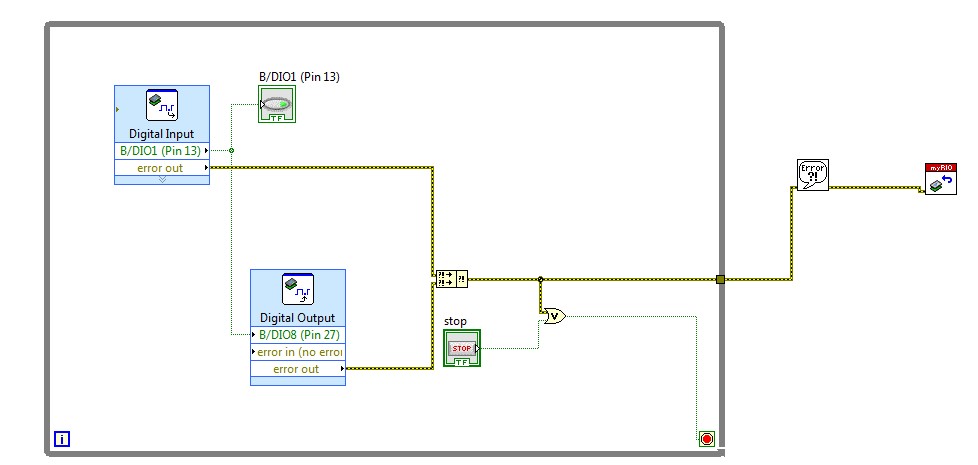
**Figure 3.18: Reset myRIO**

It would be good to also have an error message appear if any error with the digital output should occur. To add this, right click, select Functions >> Programming >> Dialog & User Interface >> Simple Error Handler.vi. see Figure 3.19.



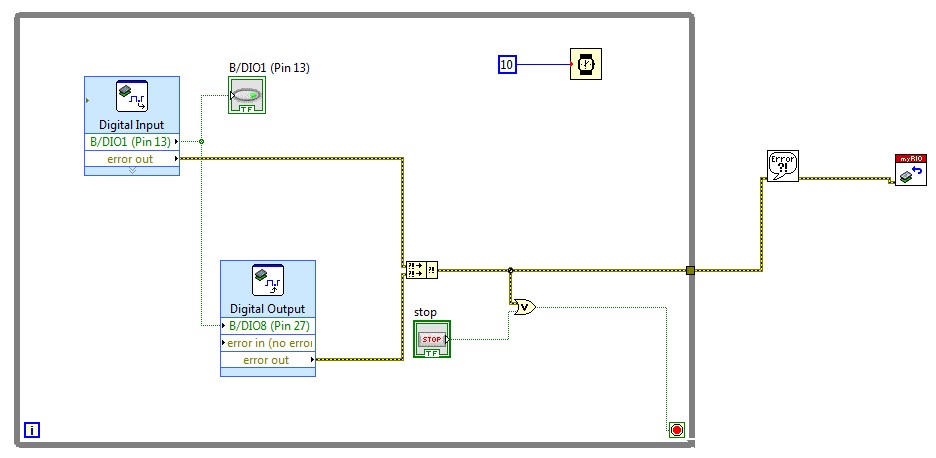
**Figure 3.19: Simple Error Handler**

Connect both the “Simple Error Handler” icon and the “Reset myRIO.vi” to the connecting line between the “Merge Errors” icon and the “Or” Boolean operator. Keep the Error Handler and Reset icons outside of the while loop. If they’re inside the while loop then the program will keep executing them over and over. See Figure 3.20.



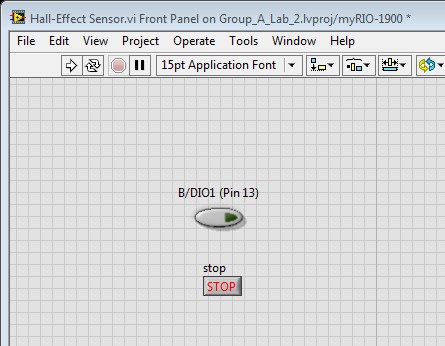
**Figure 3.20: Error Handling Blocks**

Adding a timer in the loop will let the VI wait for a specified time between loop iterations. In this lab we will use 10 milliseconds. Right-click, hover the cursor over “timing,” and click on the watch icon that says “Wait (ms)”. Place the watch inside the loop. To tell it how many milliseconds to wait, you should right click, go to “Numeric” and then click “Numeric Constant”. Type 10, and then move it near the “wait” block (the watch). Finally drag a line between the new numeric constant and the left side of the “Wait” block. Do not connect it to the right side because that means a different kind of input. See Figure 3.21.



**Figure 3.21: Wait Timer**

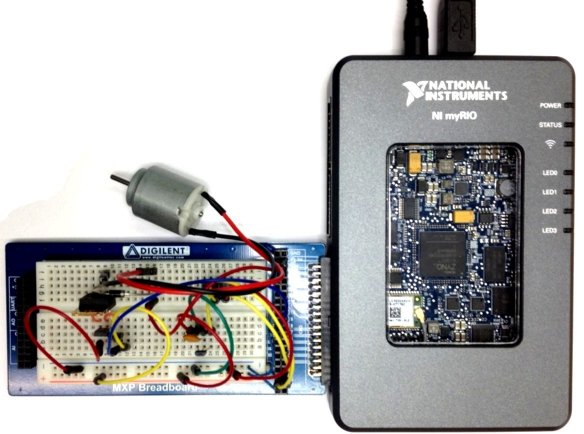
**Step 3: Check the Front Panel:** Look at the front panel and make sure that you have the following icons. If not, there is something missing from your block diagram. Also, feel free to change the appearances of elements by right-clicking on them and choosing different options.



**Figure 3.22: Front Panel**

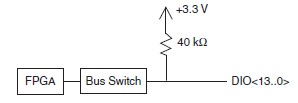
**Step 4: Save:** Save this VI that you just finished under File >> Save, and make sure it is saved as “Hall Effect sensor”.

**Step 5: Test the VI:** Now, run the VI by clicking the white arrow at the top as shown in Figure 3.22 and bring a magnet close to the Hall-effect sensor. See if the motor turns on and off as you bring the magnet near the Hall Effect sensor and take it away. At the same time, check the Front Panel to see B/DIO State if it is High (H) or Low (L).



**Figure 3.23: Test the Hall-effect sensor**

NI MyRIO-1900 has 3.3 V general purpose (Digital Input Output) DIO lines on the MXP and MSP connectors. MXP connectors A and B have 16 DIO lines per connector. On the MXP connectors, each DIO line from 0 to 13 has a 40 kΩ pull-up resistor to 3.3 V, and DIO lines 14 and 15 have 2.2 kΩ pull-up resistors to 3.3 V. MSP connector C has eight DIO lines. Each MSP DIO line has a 40 kΩ pull-down resistor to ground. See Figure 3.24.



**Figure 3.24: Pull-up Resistor to MXP Connector**

You should notice that the DIO State is On, “High”, or “H” when the motor is not rotating as in Figure 23.

# References

[1] Keim, Robert (2015). Understanding and Applying the Hall Effect. *All about Circuits.* Retrieved from <http://www.allaboutcircuits.com/technical-articles/understanding-and-applying-the-hall-effect/>

[2] Woodford, Chris. (2009). Hall-Effect Sensors. *Explain That Stuff.* Retrieved from: <http://www.explainthatstuff.com/hall-effect-sensors.html>

[3] Allegro Micro Systems. Unipolar Switch Hall-Effect IC Basics. Retrieved from: <http://www.allegromicro.com/ja-JP/Design-Center/Technical-Documents/Hall-Effect-Sensor-IC-Publications/Unipolar-Hall-Effect-Sensor-IC-Basics.aspx>

[4] Melexis (2013, August 13). 360ο Through Shaft Position Sensor Solution. *Entrepreneurial Engineer*. Retrieved from: <https://www.eeweb.com/blog/melexis/360-through-shaft-position-sensor-solution>

[5] [Dejan Nedelkovski]. (2015,December 30). *What is Hall Effect and How Hall Effect Sensors Work.* [Video File]. Retrieved from: https://www.youtube.com/watch?v=wpAA3qeOYiI

**Assignment:**

1. Save your LabVIEW project in the L-Drive under Group\_Letter> Hall-Effect Lab. The project should contain your Hall-Effect Sensor VI.
2. Write a Lab report including the following points:
   1. What is the Hall-Effect?
   2. How do Hall-Effect sensors work?
   3. Discuss the Hall-Effect sensors and automotive applications of the sensor
   4. Briefly discuss what was done in the lab, the final result, and how the final result was achieved.
   5. Do a literature search and describe additional applications of Hall Effect sensors in automotive vehicles (include minimum two real world examples of Hall-Effect sensors applications).