

**Week 9 Notes:**

**Review for Test 2 Quadrature encoding  
Geared DC Motors and Motor Drivers<  
Scope Displays**

**CAM8302E**

**Fall 2018**

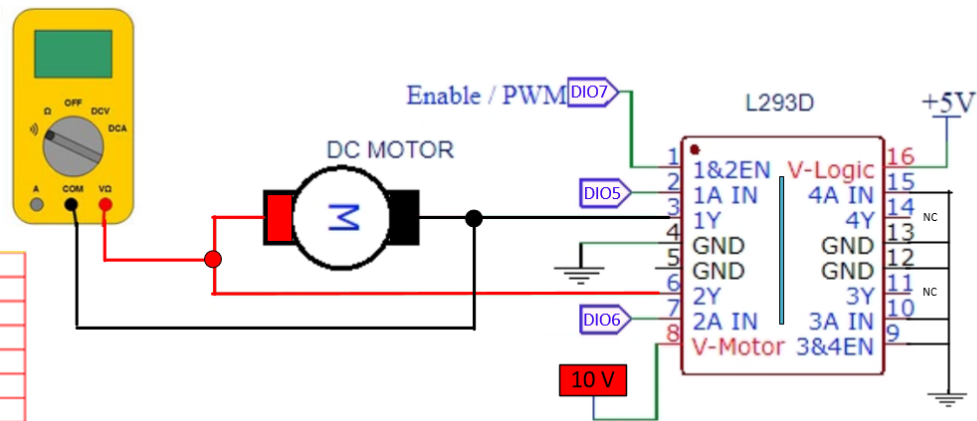
**Motor Control IC** – Control motor speed using PWM. The motor operating mode, CW,CCW, brake and free run or coast are controlled Mode using IN1 and IN2.

The **output voltage** to the motor is lower than the input supply voltage on pin 8 by approximately 1.4 to 1.8 volts due to the two internal BJT CE voltage drops.

The **signal on pin 1 (Enable)** input is required to enable the motor drivers it can also be used to PWM the motor voltage to reduce the average DC voltage to the motor.

The **dual H-bridge motor driver** can handle about 600 mA per side, on the L293D version there are internal diodes that protect the circuit from the inductive spike that occurs when the motor turn off. The motor controller reverses the motor voltage when switched from CW to counter clockwise.

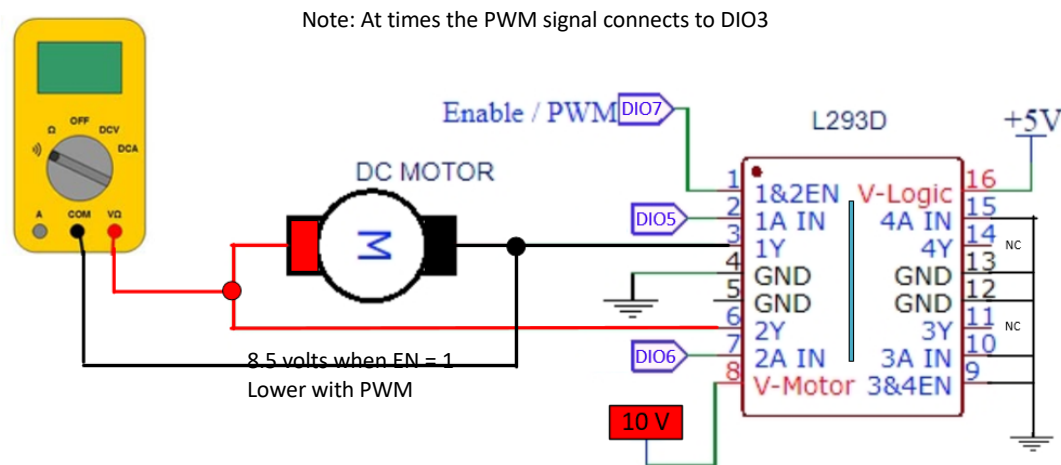
EN	myDAQ IO 7	IN1	myDAQ IO 5	IN2	myDAQ IO 6	Motor Function
L	X	X				Free Run Motor Stop
H	L	L				Fast Motor Stop (Braking)
H	L	H				Clockwise
H	H	L				Counter-ClockWise
H	H	H				Fast Motor Stop (Braking)



The speed of the DC motor will be controlled using a PWM signal applied to pin 1 of the L293D motor controller.

With the Enable pin at a logic high the motor terminals receive the maximum voltage. For example with a motor supply of 10 volts DC the motor voltage will equal about 8.5 volts. The drop is due to the voltage drop across the two internal BJT transistor collector emitter junctions.

The IN1 and IN2 pins determine the operation of the motor: CW, CCW, coast or brake.



## L293D Motor Control IC description – Control speed using PWM, Mode using IN1 and IN2

### L293x Quadruple Half-H Drivers

#### 1 Features

- Wide Supply-Voltage Range: 4.5 V to 36 V
- Separate Input-Logic Supply
- Internal ESD Protection
- High-Noise-Immunity Inputs
- Output Current 1 A Per Channel (600 mA for L293D)
- Peak Output Current 2 A Per Channel (1.2 A for L293D)
- Output Clamp Diodes for Inductive Transient Suppression (L293D)

#### 2 Applications

- Stepper Motor Drivers
- DC Motor Drivers
- Latching Relay Drivers

#### 6.5 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>OH</sub>	L293: I <sub>OH</sub> = -1 A	V <sub>CC2</sub> - 1.8	V <sub>CC2</sub> - 1.4		V
	L293D: I <sub>OH</sub> = - 0.6 A				
V <sub>OL</sub>	L293: I <sub>OL</sub> = 1 A		1.2	1.8	V
	L293D: I <sub>OL</sub> = 0.6 A				

#### 3 Description

The L293 and L293D devices are quadruple high-current half-H drivers. The L293 is designed to provide bidirectional drive currents of up to 1 A at voltages from 4.5 V to 36 V. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. Both devices are designed to drive inductive loads such as relays, solenoids, DC and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN.

The L293 and L293D are characterized for operation from 0°C to 70°C.

## Motor Control IC – Control speed using PWM, Mode using IN1 and IN2

### 10 Power Supply Recommendations

$V_{CC1}$  is  $5\text{ V} \pm 0.5\text{ V}$  and  $V_{CC2}$  can be same supply as  $V_{CC1}$  or a higher voltage supply with peak voltage up to 36 V. Bypass capacitors of  $0.1\text{ }\mu\text{F}$  or greater should be used at  $V_{CC1}$  and  $V_{CC2}$  pins. There are no power up or power down supply sequence order requirements.

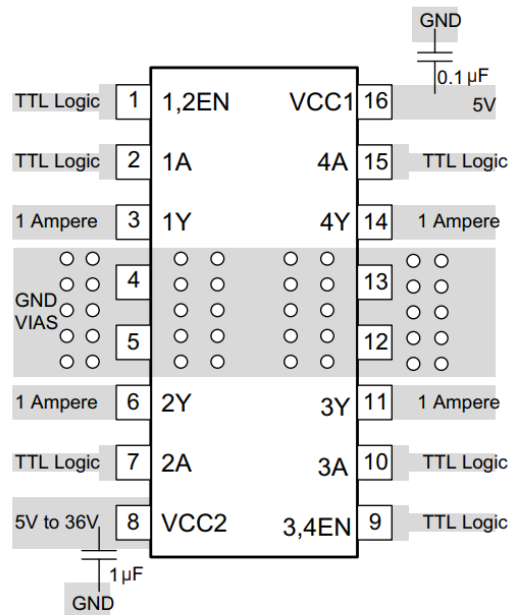


Figure 13. Layout Diagram

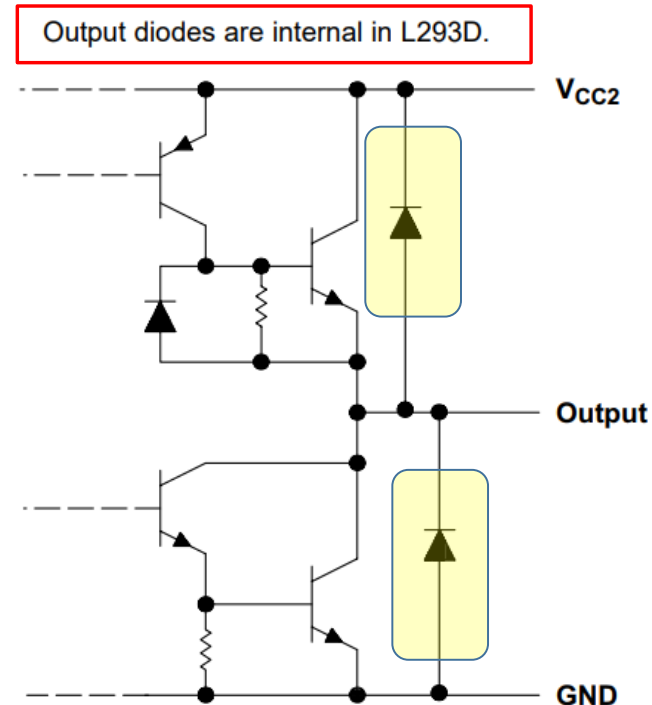


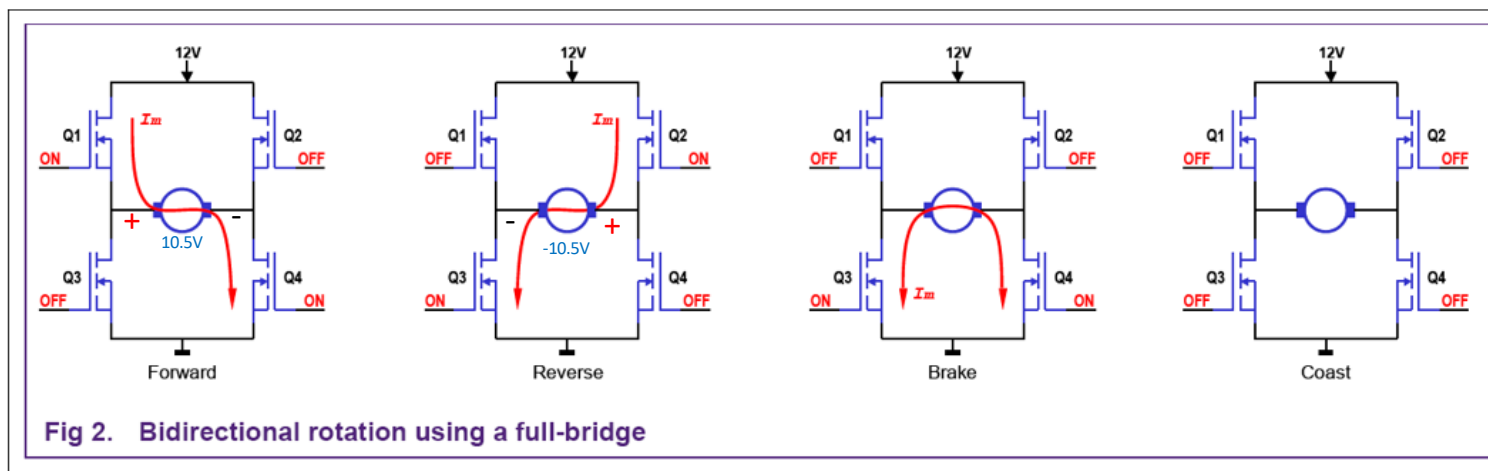
Figure 5. Schematic of Outputs for the L293D

- Output Clamp Diodes for Inductive Transient Suppression (L293D)

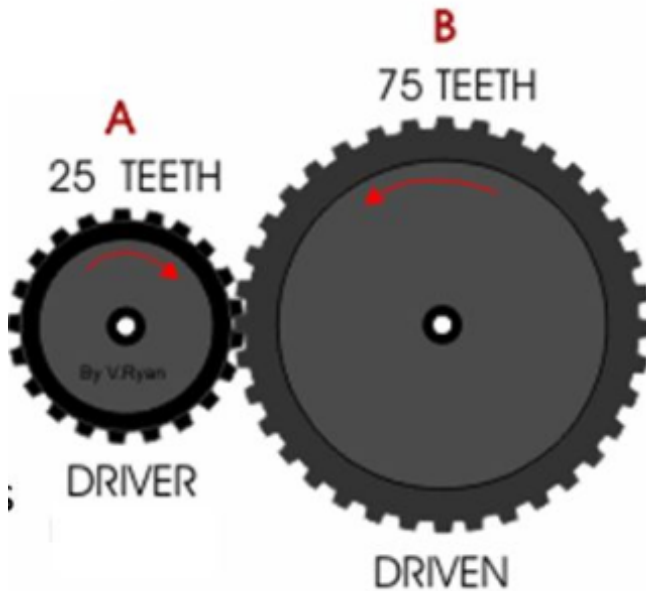
In free run mode (coast) all four transistors are turned off and the motor coasts to a stop.

In brake mode the motor leads are shorted to ground or the supply. The motor acts as a generator and stops quickly.

**Note:** This diagrams shows the concepts of the four modes of operation of the motor control IC, the actual L293 uses BJT transistors not MOSFETS as shown in the image below.



## Gear Ratios - Calculations



Adding gears are used to:

- 1) Increase or decrease speed.
- 2) Increase or decrease torque
- 3) Change direction

Gear Ratio = Driven Gear # teeth/ Drive gear # teeth.

$$\text{Gear Ratio} = 75/25 = 3:1$$

Assume the drive gear is rotating a 360 RPM with a torque of 2.0 Newton meters (Nm).

Determine the speed and torque of the driven gear?

To convert to REV/SECOND from REV/MIN divide by 60.

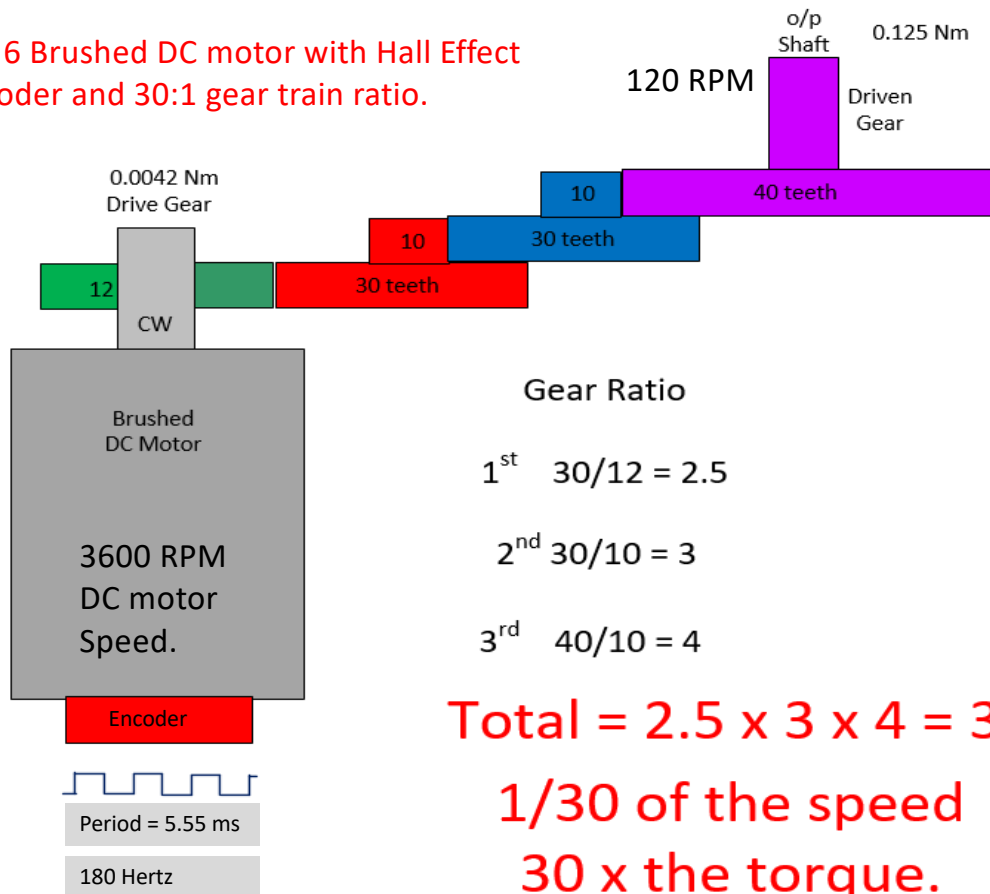
\_\_\_\_\_ Nm (torque)

\_\_\_\_\_ RPMs

\_\_\_\_\_ RPSs

Time/Revolution = \_\_\_\_\_

Lab 6 Brushed DC motor with Hall Effect encoder and 30:1 gear train ratio.



Gear Ratio

1<sup>st</sup>  $30/12 = 2.5$

2<sup>nd</sup>  $30/10 = 3$

3<sup>rd</sup>  $40/10 = 4$

**Total =  $2.5 \times 3 \times 4 = 30$**

**1/30 of the speed**  
**30 x the torque.**

Gears inside the lab DC brushed motor. In this example the applied DC voltage is at about 12.0 volts.

Gear train ratio of 30:1

When the DC motor turns at 3600 RPMs

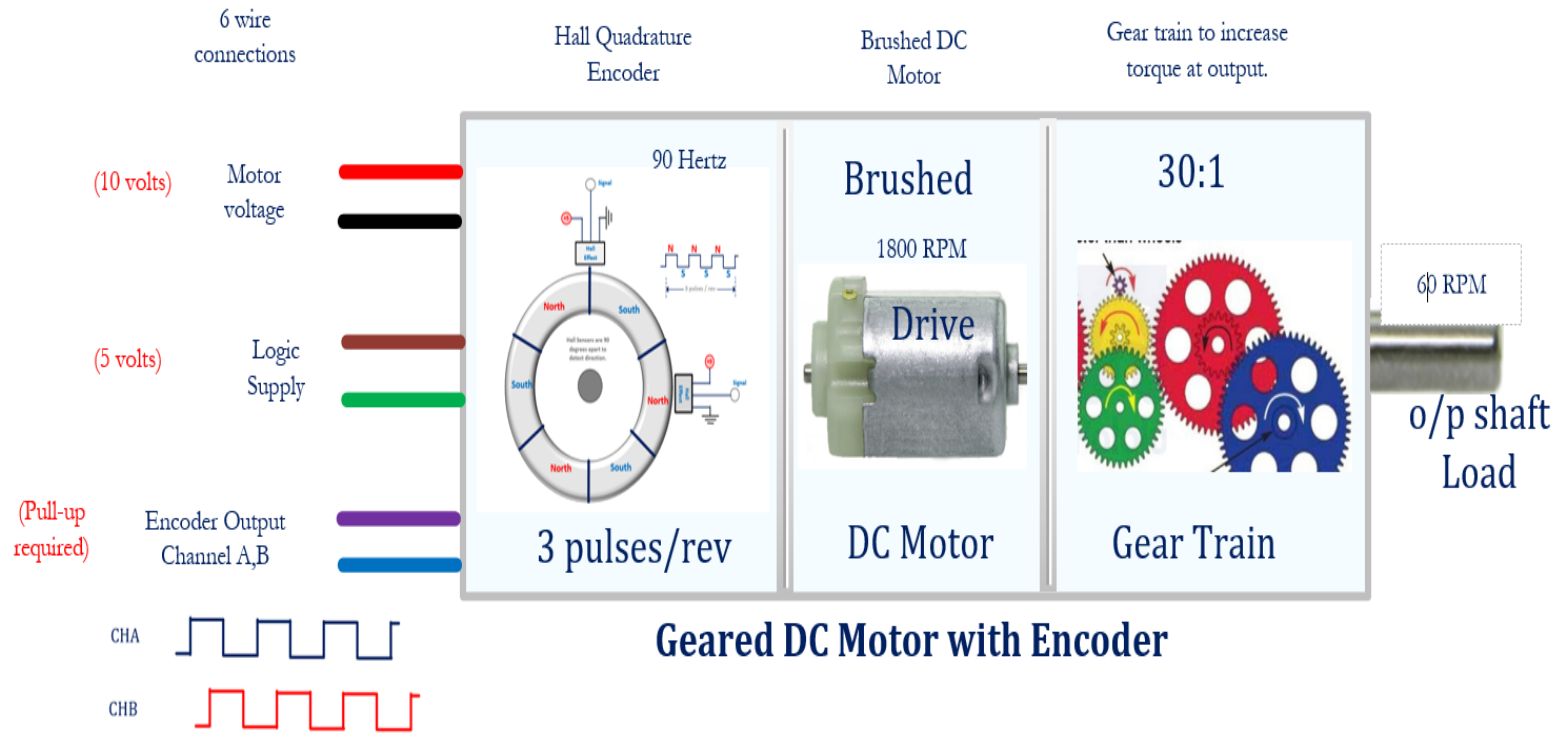
The output shaft turns at: 120 RPMs  
 2 revolutions/ second  
 1 revolution every 500 ms.

The Encoder produces 3 pulses for each revolution of the DC motor.

1 revolution of DC motor = 16.65 ms

$1/16.65 \text{ ms} = 60 \text{ REV/SEC (DC motor)}$

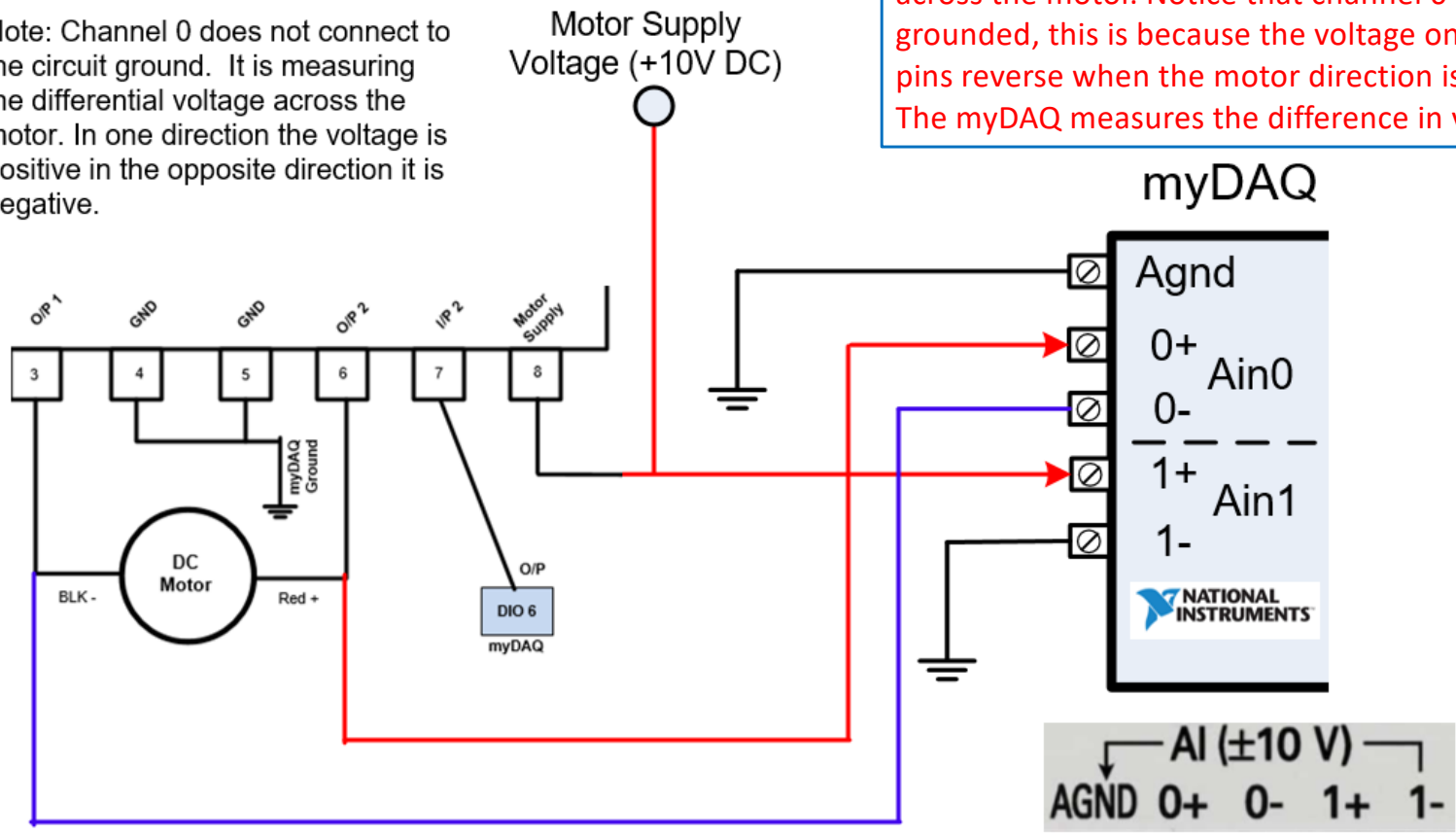
# Brushed DC Motor with Gear Train and Hall Effect Encoder

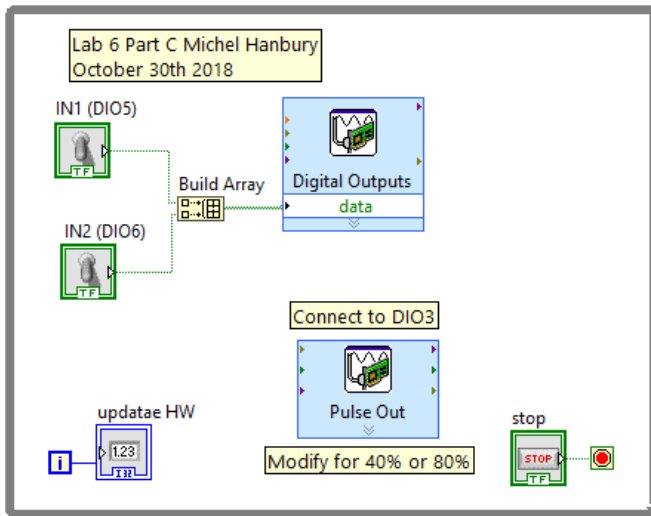




Note: Channel 0 does not connect to the circuit ground. It is measuring the differential voltage across the motor. In one direction the voltage is positive in the opposite direction it is negative.

Motor connections when measuring the voltage across the motor. Notice that channel 0 is not grounded, this is because the voltage on these two pins reverse when the motor direction is changed. The myDAQ measures the difference in voltage.





### Pulse Output Setup

Settings

Signal Output Range

High Time: 4m

Low Time: 6m

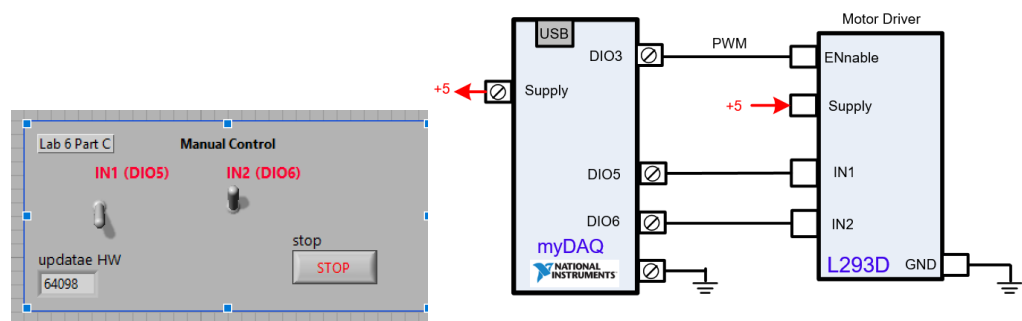
Scaled Units: Seconds

Idle State: Low

Initial Delay (s): 0

Output Terminal: PFI3

## PWM control of the DC motor speed Lab 6 Part C.

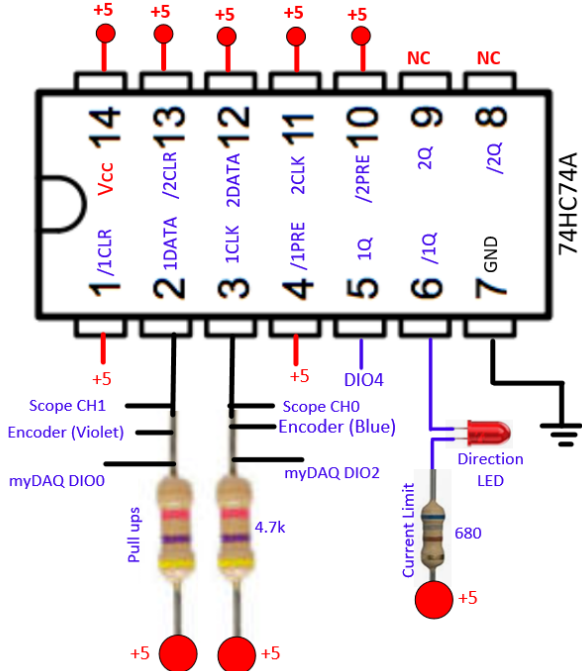


Part C: of lab 6 is used to control the average DC voltage to the motor using PWM. In this example the PWM is 40%. The PWM signal is at a frequency of 100 Hertz.

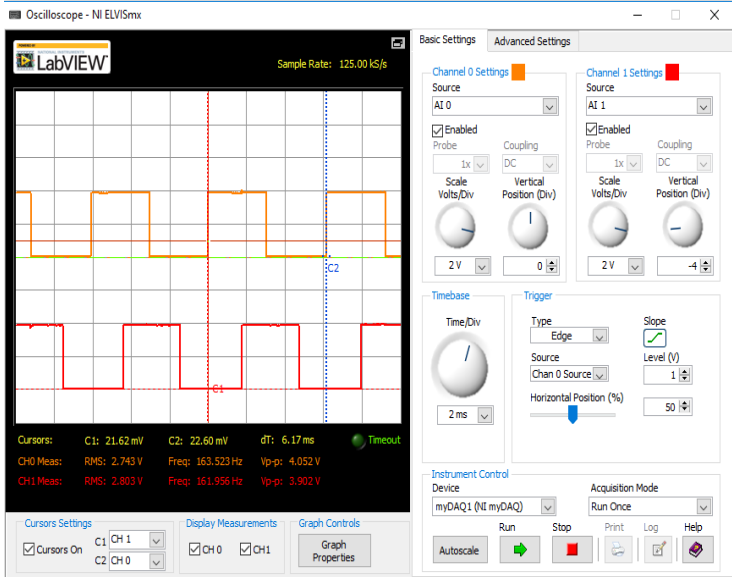
When this part of the lab is running the DIO3 pin on the myDAQ produces the PWM using the counter/timer. The DIO3 signal will connect to the EN pin on the motor controller.

# 74HC74A D-type flip-flop

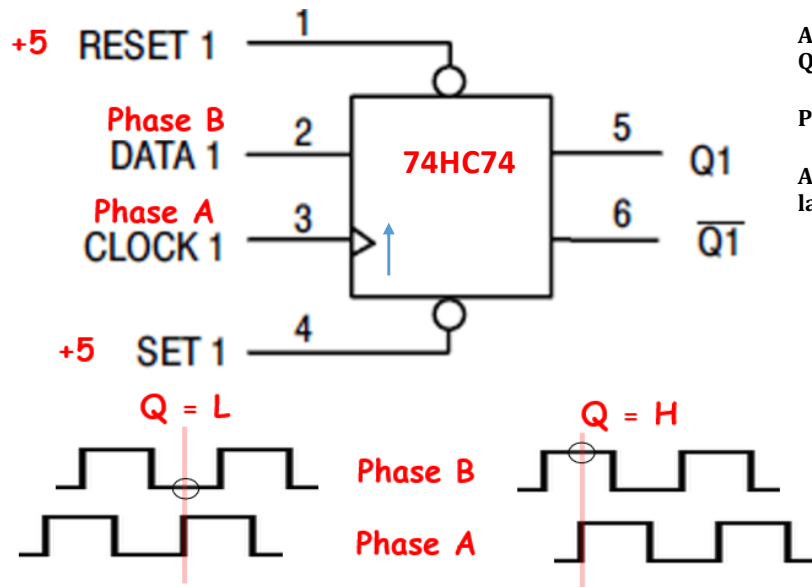
When the Data input is high and the clock goes through a rising edge the Q output will go high and the not Q or /Q output will go low.



Clock input	Data input	Q output	not Q output
Rising edge	High	High	Low
Rising edge	Low	Low	High
Low, high or falling edge	Low	no change to o/p	no change to o/p
Low, high or falling edge	High	no change to o/p	no change to o/p



# Direction Detection Using Encoder

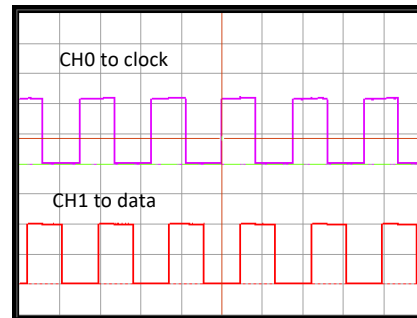


A 74HC74 IC is used to decode direction and produce a logic low or high output on Q to provide direction information to other parts of the control circuit.

Pin 1 and 4 are tied to a high level to override the clear and set signals.

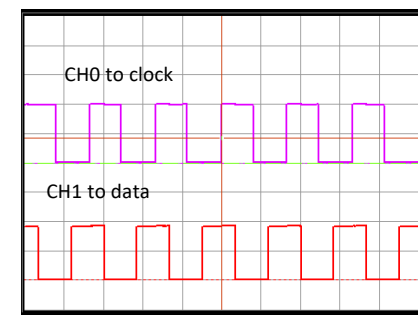
As a positive going edge occurs on pin 3 (the clock) the signal at pin 2 will be latched to the output Q1.

Counter Clockwise



Q Output Low **Direction**

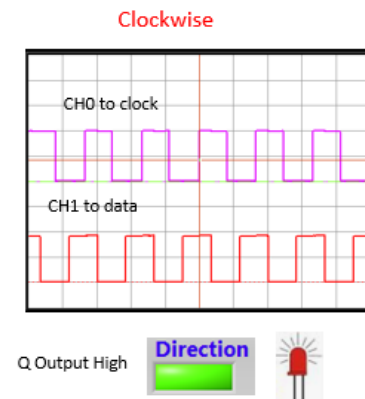
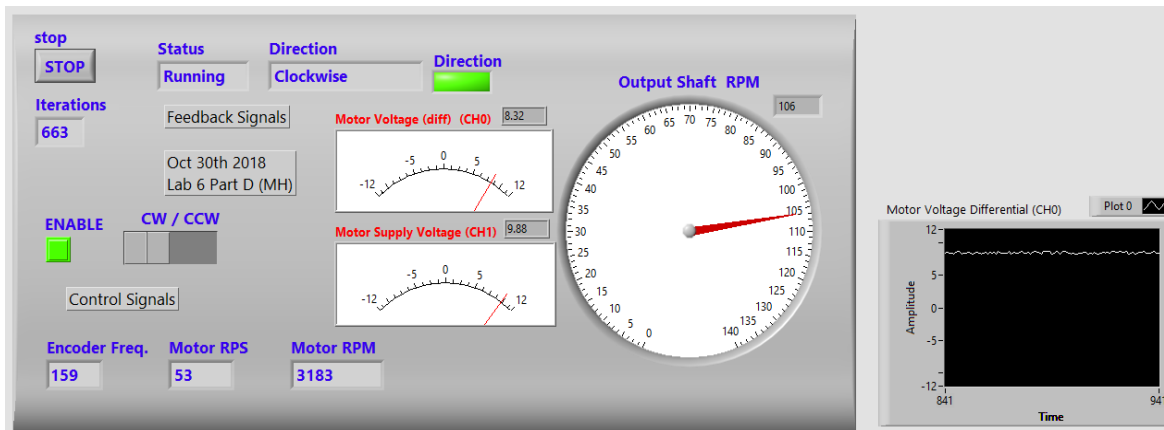
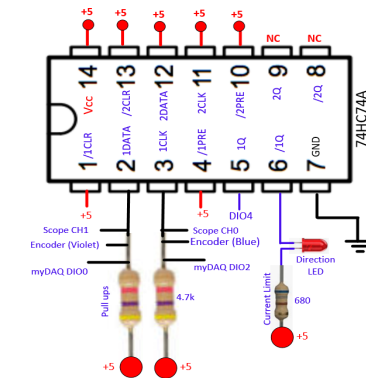
Clockwise



Q Output High **Direction**

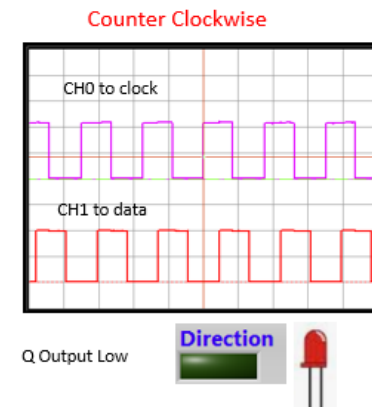
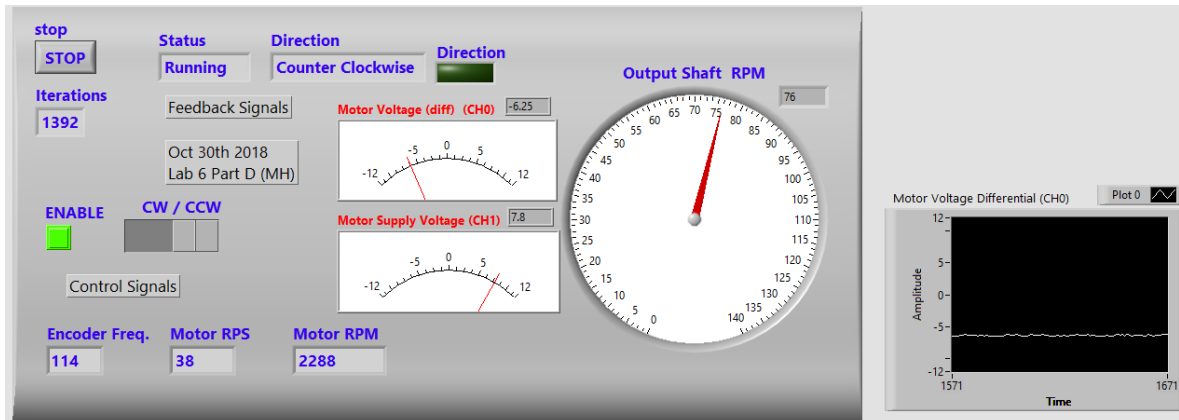
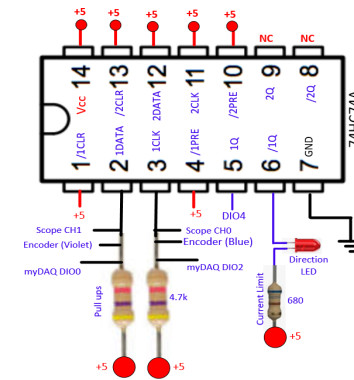
In this screen capture of Lab 6 Part D:

The motor is turning clockwise, the supply voltage is 10 VDC.  
 The voltage across the motor terminals is at 8.3 volts.  
 The encoder frequency equals 159 Hz or at a period of 6.3 ms.  
 The REV/SEC of the DC motor equals  $159 \text{ Hz} / 3 \text{ (3 pulses/REV)} = 53 \text{ Hz}$   
 The motor RPM = DC motor freq. x 60 sec/min. = 3180 RPM.  
 The output shaft RPM =  $3180 \text{ RPM} / 30 \text{ gear ratio} = 106 \text{ RPM}$   
 $106 \text{ RPM} / 60 = 1.8 \text{ REV/SEC}$  or 560 ms per revolution.



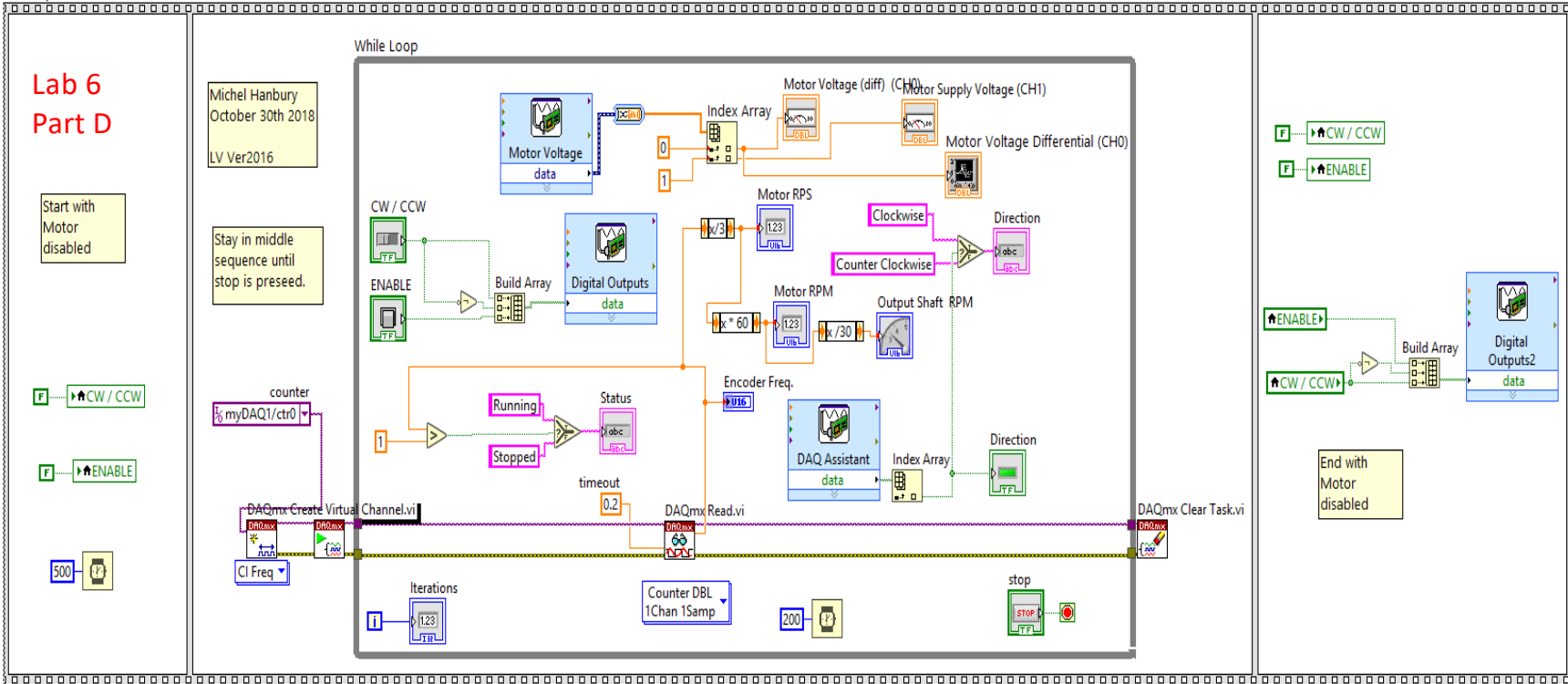
In this screen capture of Lab 6 Part D:

The motor is turning counter clockwise, the supply voltage is 7.8 VDC.  
 The voltage across the motor terminals is at -6.25 volts.  
 The encoder frequency equals 114 Hz or at a period of 8.8 ms.  
 The REV/SEC of the DC motor equals  $114 \text{ Hz} / 3 = 38 \text{ Hz}$  (3 pulses/REV)  
 The motor RPM = DC motor freq. x 60 sec/min. = 2280 RPM.  
 The output shaft RPM = 2280 RPM/30 gear ratio = 76 RPM  
 76 RPM/60 = 1.3 REV/SEC or 770 ms per revolution.

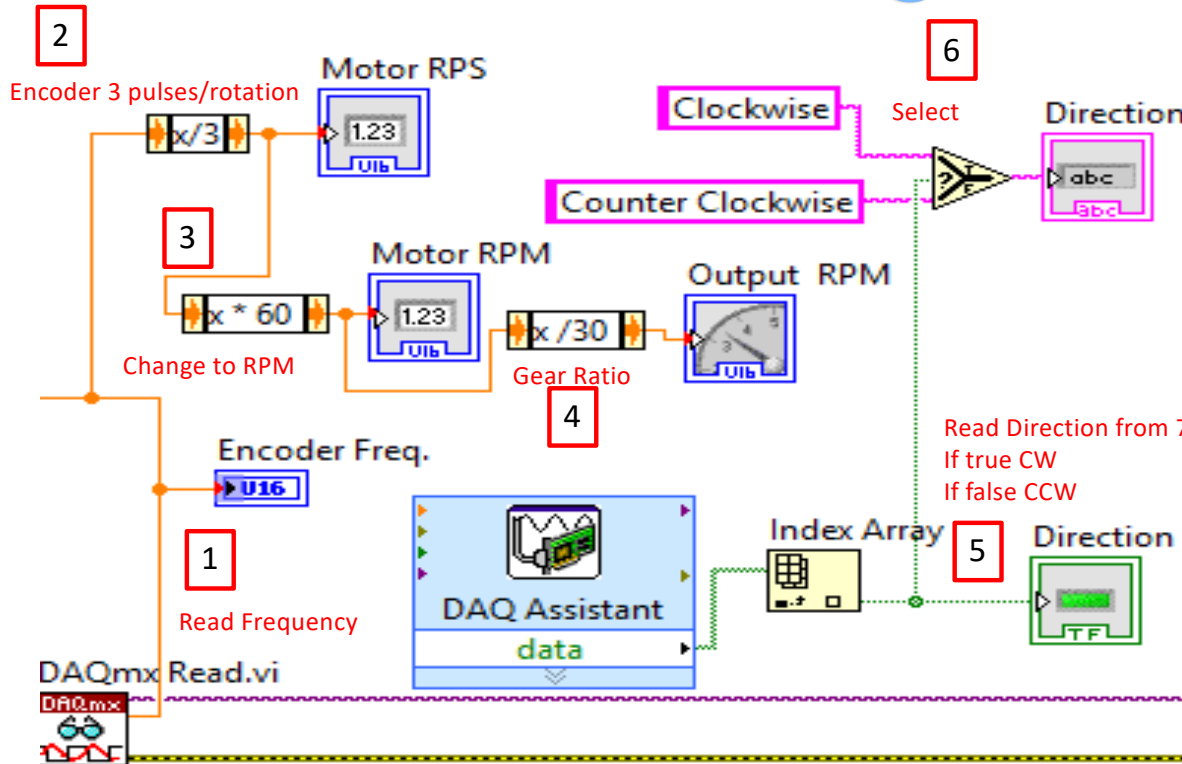


A flat sequence structure controls the sequence of execution of a LabVIEW program. In this example the left box is executed for 0.5 seconds, the second box executes until the user presses stop button on the front panel. The box on the right is executed after the front panel stop button is pressed causing the motor to stop.

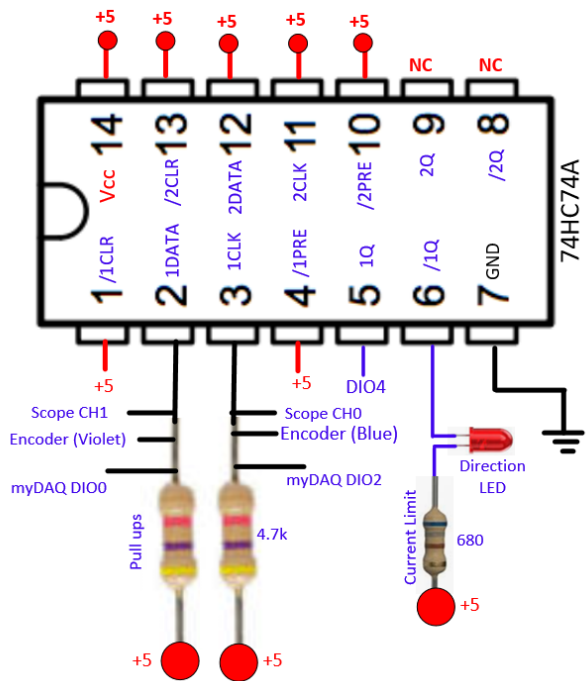
Flat Sequence Structure



# LabVIEW Block Diagram Lab 6 Part D

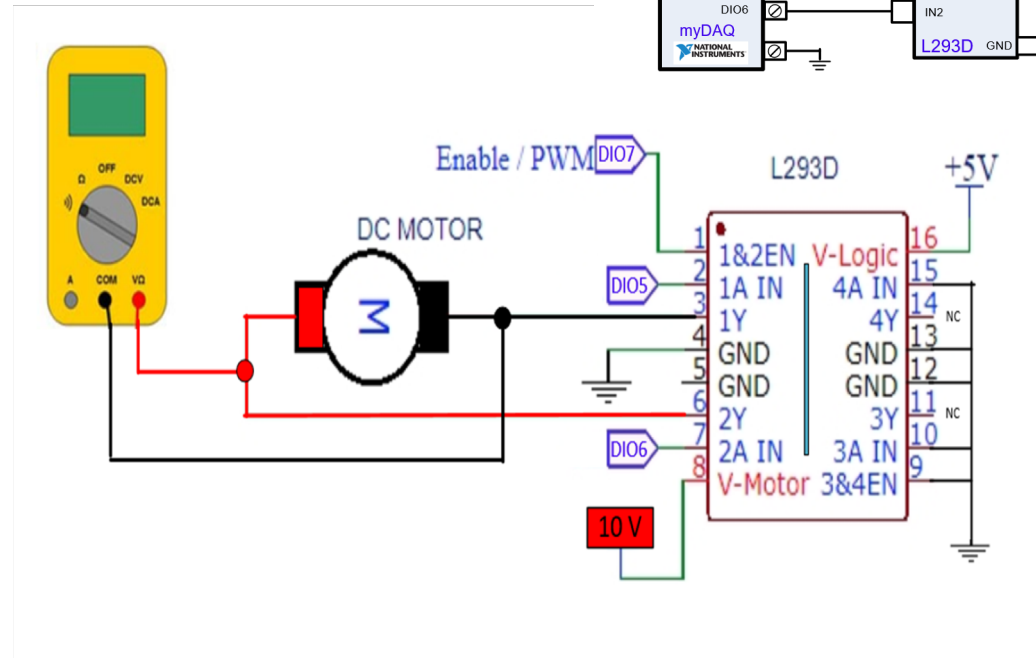
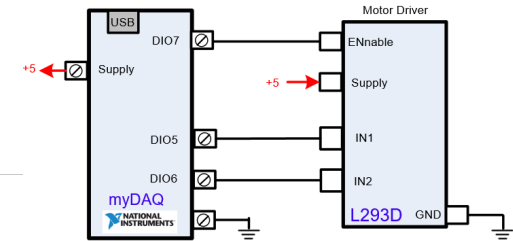


- 1) The Frequency from the encoder is read using the timer frequency read function.
- 2) The DC motor produces 3 pulses / rotation so that is first divided.
- 3) The value from step 2 is multiplied by 60 to obtain a value in RPM.
- 4) The signal is divided by the gear train ratio to obtain the RPM speed at the output.
- 5) Read the data from the Q output of the 74HC74 latch.
- 6) Display a text value of the direction.



The enable pin on the L293D motor control will change for the different parts of Lab 6.

Part A,B,D: connect to DIO7 (H/L)  
 Part C: connect to DIO3 (PWM)



Configuration    Triggering    Advanced Timing

Channel Settings

- + X Details >>
- Pulse Output
- PulseOutput

Click the Add Channels button (+) to add more channels to

Pulse Output Setup

Settings

Signal Output Range

High Time: 8m  
Low Time: 2m

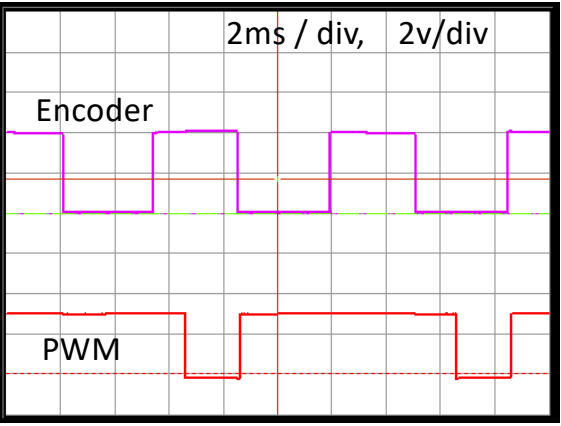
Scaled Units: Seconds

Idle State: Low  
Initial Delay (s): 0

Output Terminal: PFI3

AVG DC Volts to motor when EN = High = 8.5 V, when EN = 0 AVG DC = 0 volts  
Encoder = 6ms when EN = 1  
motor = 3333 RPM when EN = 1

80% PWM freq. = 100 Hz  
Average DC voltage = 8.1 (3120 RPM)



Channel Settings

- + X Details >>
- Pulse Output
- PulseOutput

Click the Add Channels button (+) to add more channels to

Pulse Output Setup

Settings

Signal Output Range

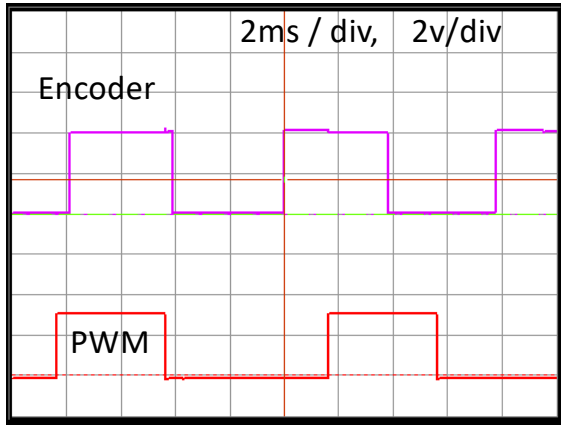
High Time: 4m  
Low Time: 6m

Scaled Units: Seconds

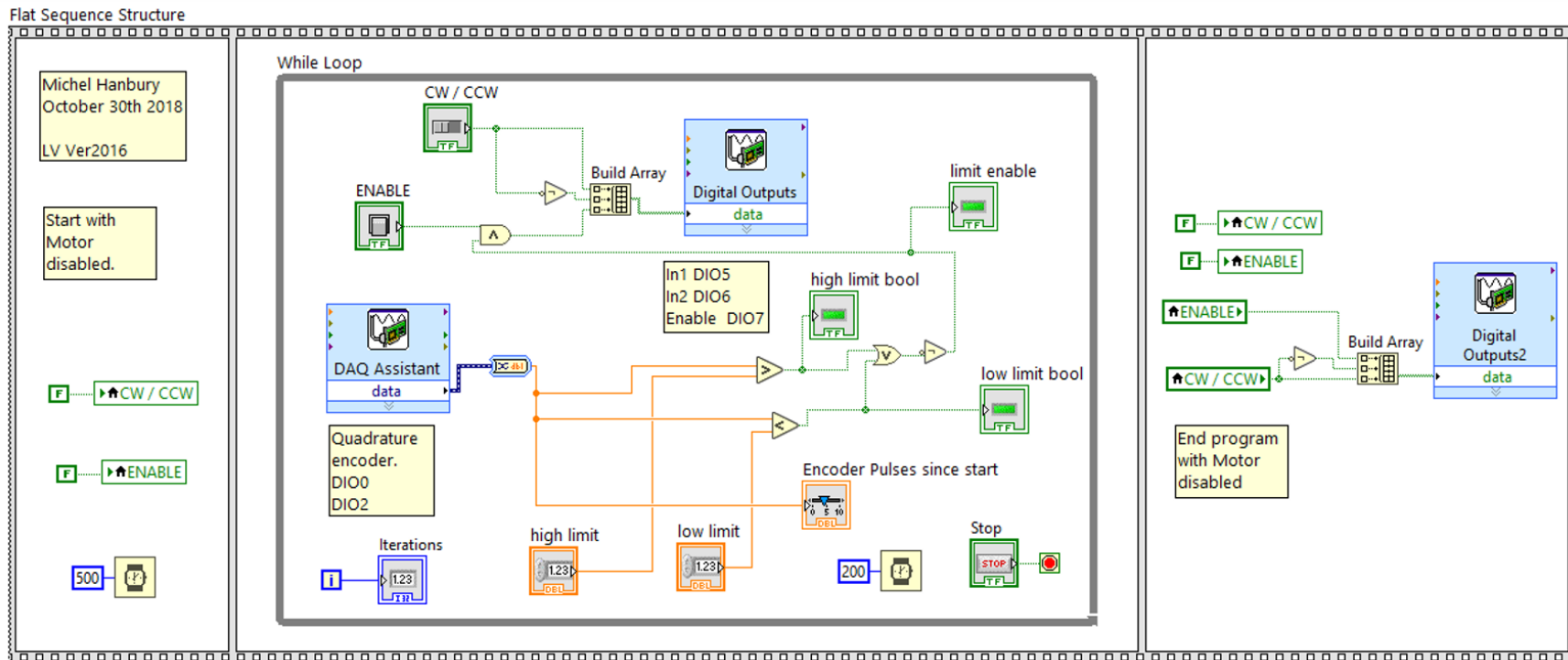
Idle State: Low  
Initial Delay (s): 0

Output Terminal: PFI3

40% PWM  
Average DC voltage = 6.7 (2564 RPM)



A flat sequence structure controls the sequence of execution of a LabVIEW program. In this example the left box is executed for 0.5 seconds, the second box executes until the user presses the front panel stop. The box on the right is executed and then the program stops running. The output of the Quadrature DAQ assist is output degrees of revolution. For each rotation of 360 degrees of the output shaft the motor turns one revolution and produces 90 encoder pulses.



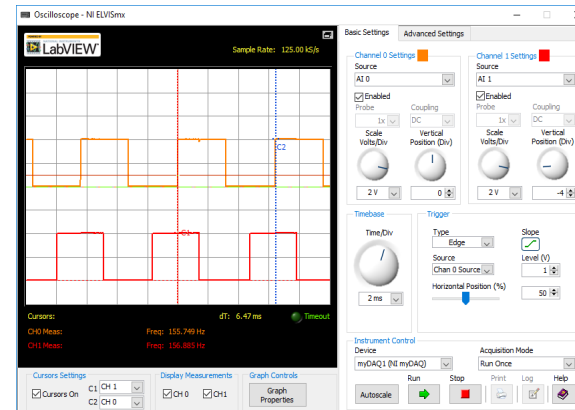
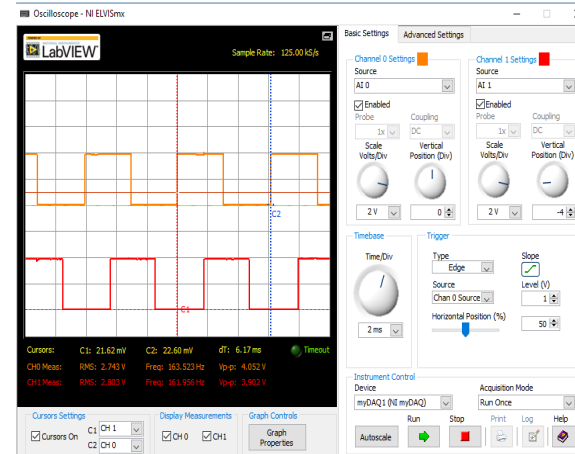
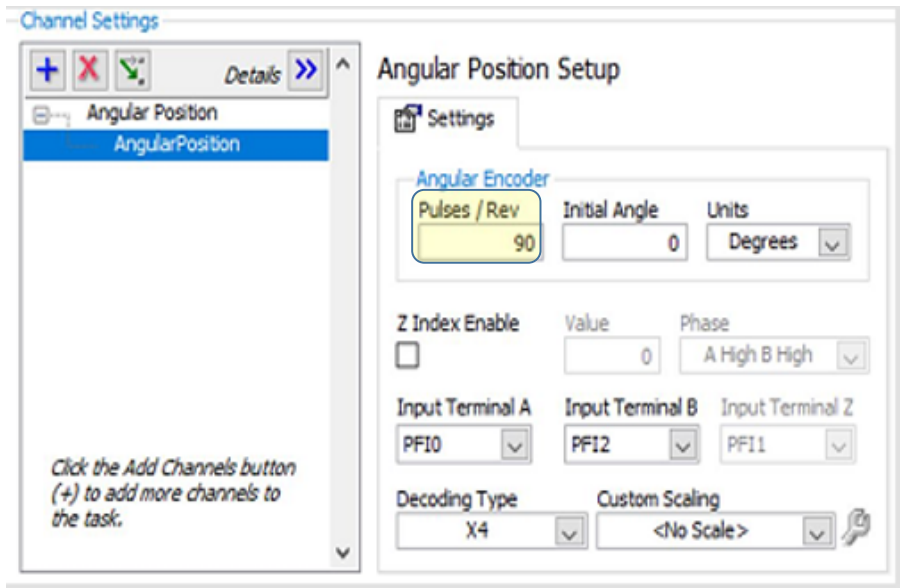
Lab 6 Part B – measuring angular rotation. Increases in one direction, decreases in the opposite. Stops when a minimum and maximum value is reached.

The interface displays the following information:

- STOP** button
- Iterations**: 39
- ENABLE** indicator: lit green
- CW / CCW** direction indicators: three buttons, the rightmost is lit grey
- Control Signals** label
- Quadrature Encoder** section:
  - Date: Oct 30th 2018
  - Lab: Lab 6 (MH)
  - Sub-section: Lab 6 Part B
  - Information: 1 Rev of output shaft equals 90 pulse (360 degrees).
- Encoder Pulses since start** scale: -5000 to 5000, with a blue arrow pointing to approximately 3300.
- Limit Settings**:
  - high limit: 3600
  - low limit: -3600
  - limit enable: lit green
  - low limit bool: lit green
  - high limit bool: lit green

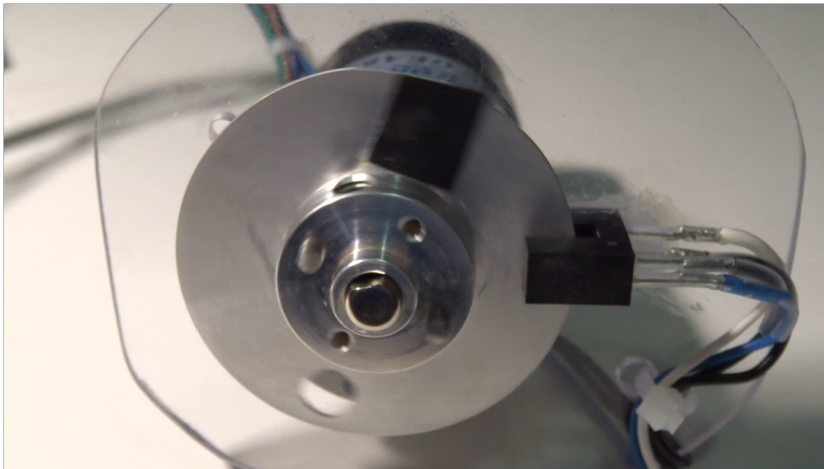
## Quadrature Encoder:

The myDAQ has a DAQ assist to measure the signals from a quadrature encoder. The two signals connect to DIO0 and DIO2 inputs. The angular encoder produces 90 pulses per revolution of the motor output shaft.

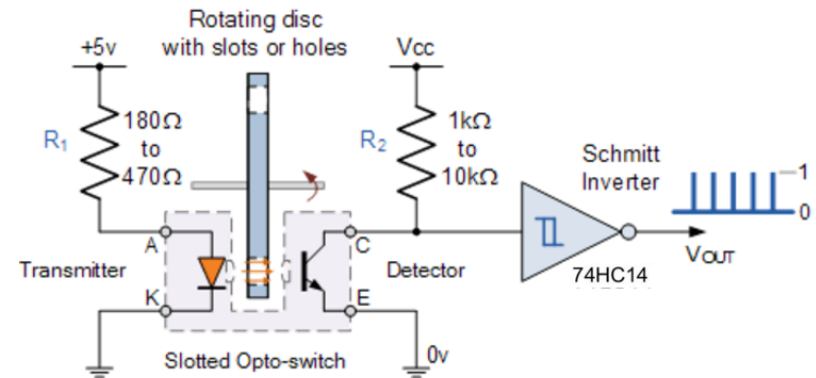


# Motor Speed with Optical Sensor (video)

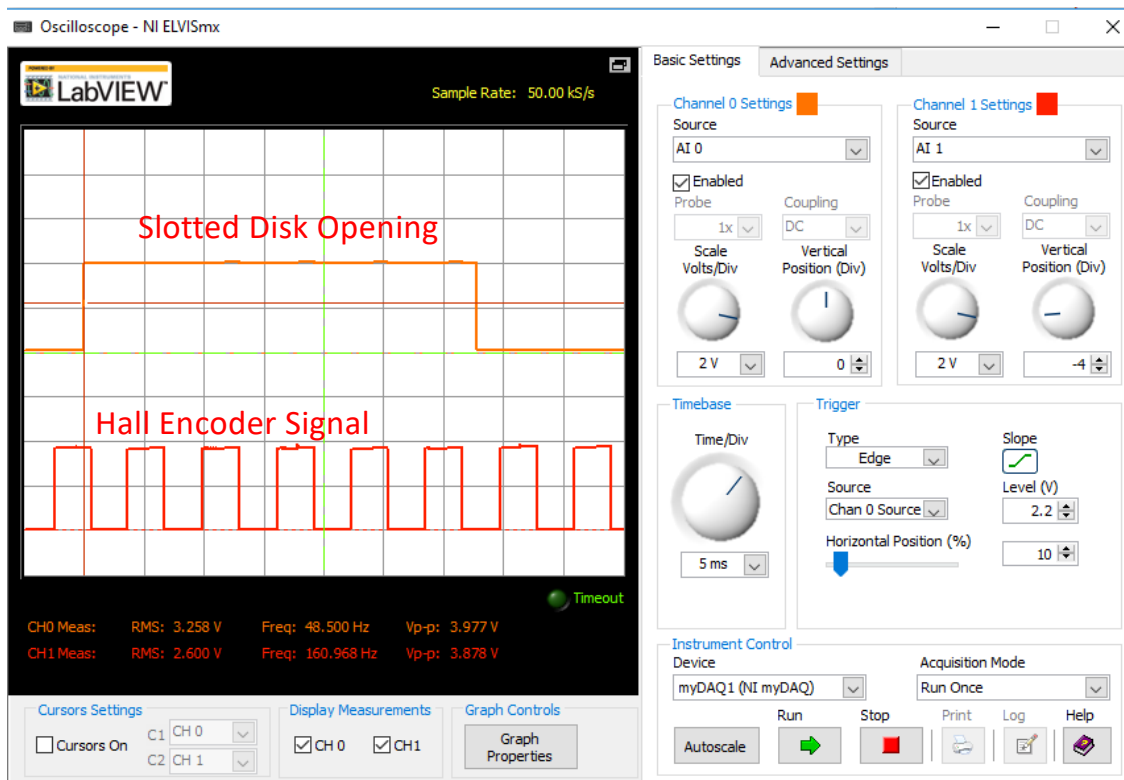
In this example an optical slotted switch measures the rotation speed of the output shaft. 1 hole is drilled into the aluminum plate. As the motor is rotated the optical switch gap is blocked or opened. The rotation causes 1 pulse per revolution.



The output signal is shown on the next slide. As the hole in the disk passes the optical sensor a logic high is produced at the output of the Schmitt trigger.



# Encoder and Optical Sensor



Encoder freq. 161 Hz.

There are 3 pulses per revolution.

$$1/161 = 6.2 \text{ ms.}$$

$$\text{Motor rotates at } 6.2 \text{ ms} \times 3 = 18.6 \text{ ms.}$$

$$1/18.6 \text{ ms} = 54 \text{ Hertz.}$$

$$54 \text{ Hz} \times 60 = 3226 \text{ Hz (DC motor).}$$

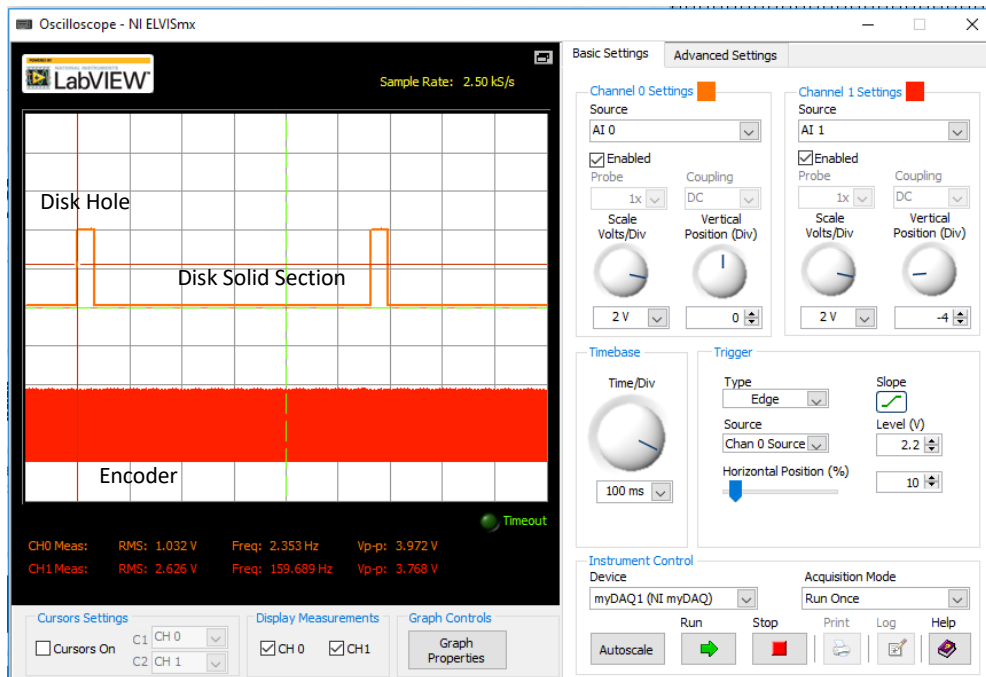
Gear Ratio is 30:1

Divide RPM by 30 equals 108 RPM

Divide by 60 equals 1.8 rev/second.

$$1/1.8 \text{ Hz} = 0.56 \text{ seconds.}$$

# Encoder and Optical Sensor



Period of the output shaft is 560 ms.

Therefore the motor output shaft is turning at 1.8 rev/second.

The DC motor is turning at 54 rev/second or 3214 RPM.

$$1/54 = 18.5 \text{ ms}$$

There are 3 pulses per DC motor revolution.

$$18.5 \text{ ms}/3 = 6.2 \text{ ms.}$$

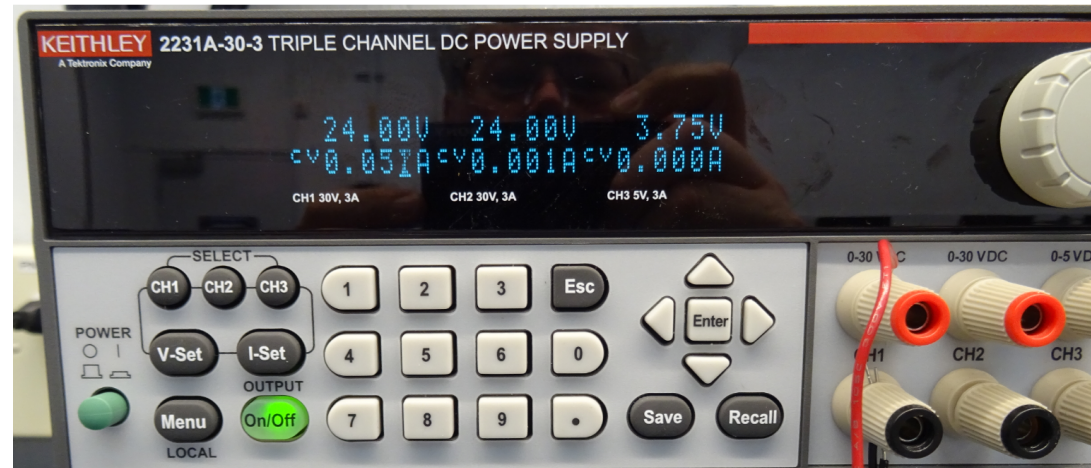
o/ shaft rotation period = 560 ms.

o/ shaft rotation frequency = 1.8 rev/sec.

When setting up the lab power supply you should configure the current limit to a value of about 1.5 times the value you expect the typical current to be when your circuit is operating normally.

If the current is not exceeded the letters “CV” (Constant voltage) will appear near the circuit current reading.

If your circuit has a problem or it is trying to draw more current than the maximum you have set the letters “CC” (constant current) will appear near the circuit current reading. You may also notice that the DC voltage drops when in “CC” mode.



# Scope Configuration Video (no audio)

The screenshot displays the LabVIEW scope configuration interface. The main window shows a scope plot with two channels: CH0 (orange) and CH1 (red). Both channels show a square wave signal. The plot includes two cursors: C1 (red vertical line) and C2 (blue vertical line). The sample rate is 125.00 kS/s. The time base is set to 2 ms. The frequency measurements are 155.316 Hz for CH0 and 102.558 Hz for CH1. The interface is divided into Basic Settings and Advanced Settings tabs. The Basic Settings tab is active, showing Channel 0 and Channel 1 settings, Timebase, Trigger, and Instrument Control. The Channel 0 settings include Source (AI 0), Enabled (checked), Probe (1x), Coupling (DC), Scale (2 V), and Vertical Position (0). The Channel 1 settings include Source (AI 1), Enabled (checked), Probe (1x), Coupling (DC), Scale (2 V), and Vertical Position (-4). The Timebase is set to 2 ms. The Trigger is set to Edge, Slope (rising), Source (Chan 1 Source), Level (1 V), and Horizontal Position (10%). The Instrument Control shows the Device (myDAQ1 (NI myDAQ)) and Acquisition Mode (Run Once). The Run button is highlighted with a green arrow.

LabVIEW Sample Rate: 125.00 kS/s

Channel 0 Settings: Source: AI 0, Enabled: , Probe: 1x, Coupling: DC, Scale: 2 V, Vertical Position: 0

Channel 1 Settings: Source: AI 1, Enabled: , Probe: 1x, Coupling: DC, Scale: 2 V, Vertical Position: -4

Timebase: Time/Div: 2 ms

Trigger: Type: Edge, Slope: , Source: Chan 1 Source, Level (V): 1, Horizontal Position (%): 10

Instrument Control: Device: myDAQ1 (NI myDAQ), Acquisition Mode: Run Once

Cursors: dT: 2.02 ms, Timeout:

CH0 Meas: Freq: 155.316 Hz

CH1 Meas: Freq: 102.558 Hz

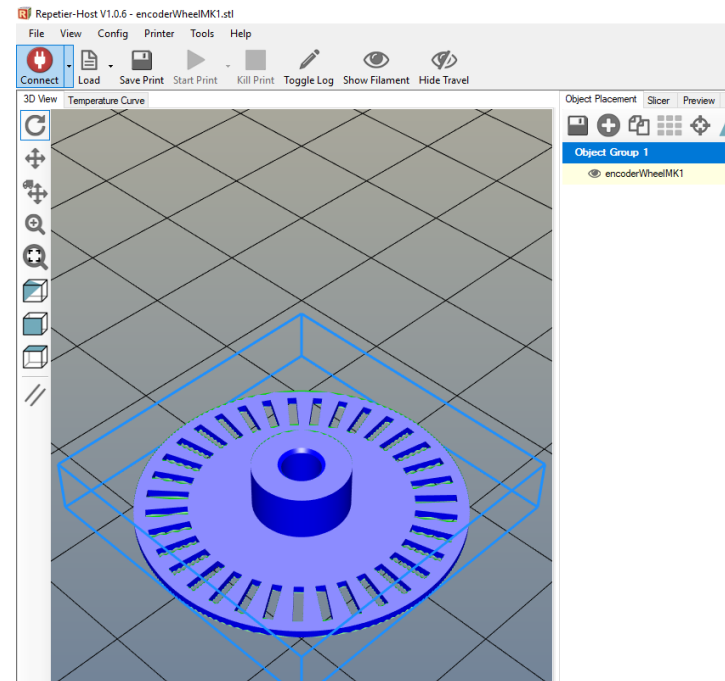
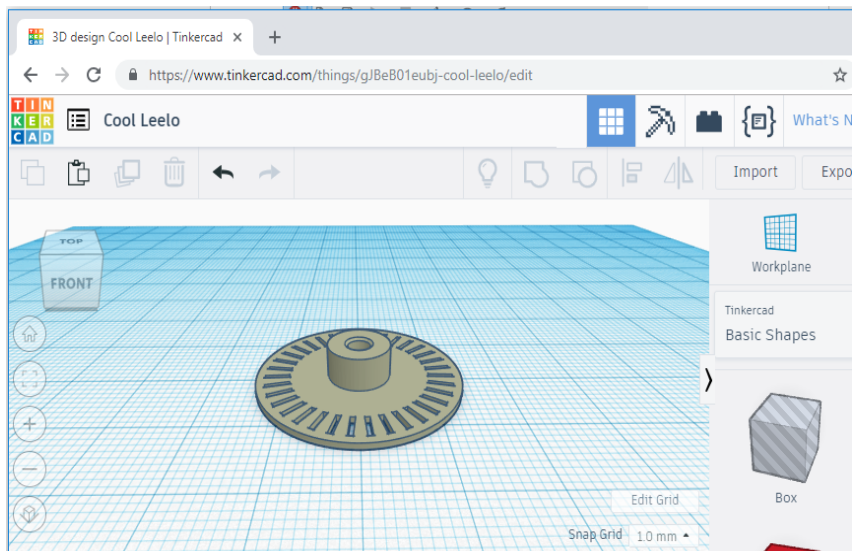
Cursors Settings:  Cursors On, C1: CH 1, C2: CH 0

Display Measurements:  CH 0,  CH 1

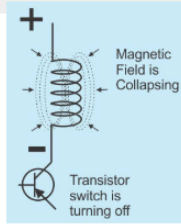
Graph Controls: Graph Properties

# Slotted Wheel 3D Printed.

A slotted wheel along with slotted optical sensor can be used to measure output shaft speed.



## Something Has to Give



Inside an electronic circuit, this voltage will appear on the terminals of the relay, and from there be applied to the rest of the circuit.

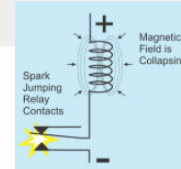
This voltage is going to be passed through the circuit to whatever is stopping the current.

**Notes: Suppressing spikes when using inductive loads. Page 1**

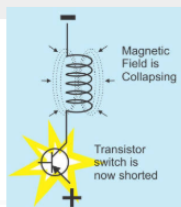
## Sparks

The voltage in the electromotive force causes electrical current to jump gap in the switch contacts that originally turned off the current. This sudden short-term surge of current will also produce electromagnetic interference (EMI), interfering with other parts of the circuit and possibly this EMI will be transmitted to nearby electronics.

Mechanical switches get little sparks jumping the contacts.



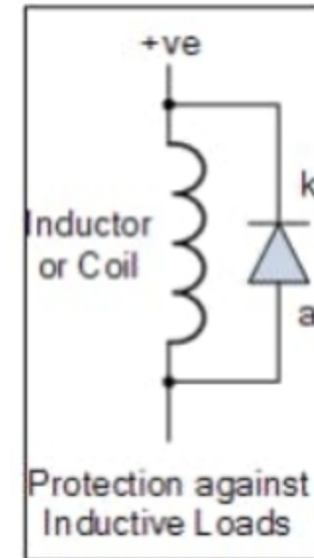
## Holes



This jumping-the-gap is hard on semiconductors; their fragile junctions are no match for the high voltage of the relay's electromotive force.

Semiconductors get little sparks too, which punch holes through the junctions.

**What Can Be Done About This Voltage Spike?**

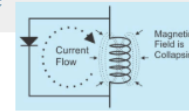


## What Can Be Done About This Voltage Spike?

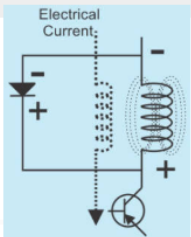
The flyback diode keeps the electrons moving by shunting them back into the relay coil. Because the electrons keep moving, the collapse of the magnetic field is slowed down, and the generated voltage will be much lower. Switch contacts and semiconductor junctions can easily handle these lower voltages.

The flyback diode, as a snubber, keeps the current flowing through the coil...

By shunting the current back into the coil, the diode shorts out the voltage spike.



## Doesn't the Diode Normally Short Out The Whole Circuit?



The diode, as installed, is reverse biased. It will not conduct when the relay is turned on. There is no short circuit and no energy is wasted.

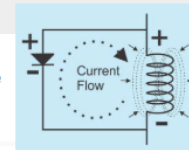
Normally, when external voltage is applied to the coil, the flyback diode is reverse biased and will not conduct any current.

**Notes: Suppressing spikes when using inductive loads. Page 2.**

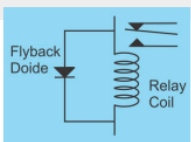
## The Flyback Diode is Forward Biased Only While the Relay is Being Turned Off

When turned on, the relay is a load to the power supply and does conduct; the diode is reverse biased and does not conduct. When first turned off, the relay is a generator of voltage; for a short time the voltage on the relay contacts is reversed and the flyback diode does conduct.

During the brief turn-off time of the relay, when external voltage is removed, the diode is forward biased to keep the transient voltage spike to a minimum.

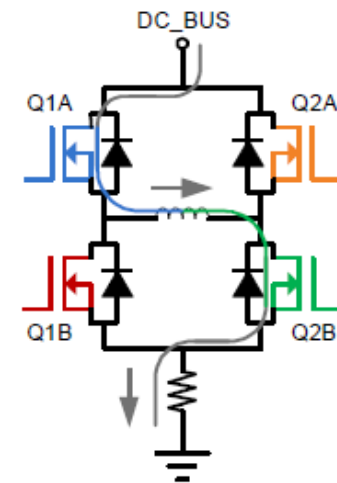


## The Flyback Diode Protects the Circuit



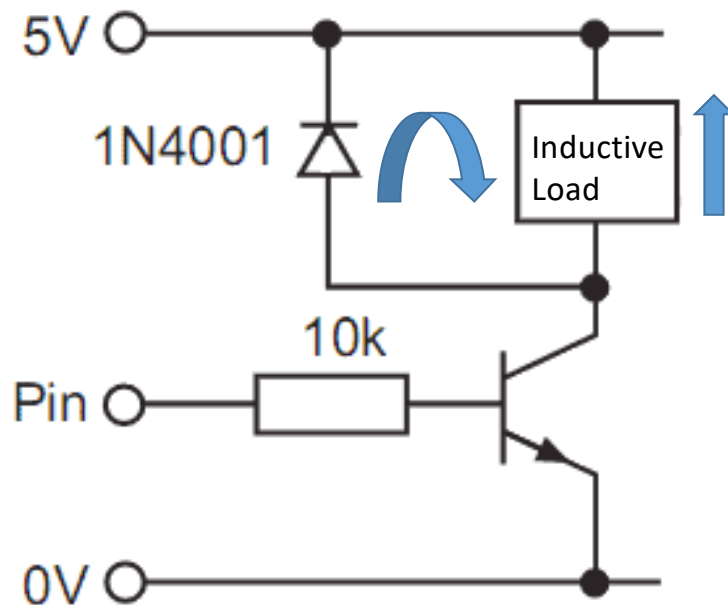
The flyback diode is a snubber, reducing the impact of the voltage produced by the collapsing magnetic field of the relay coil.

The reason manufacturers install these diodes next to DC relays is because at turn-off time, as the magnetic field is flying back, the flyback diode protects the circuit, and its components from the relay's damaging voltage spike.



Flyback, Flywheel, Transient Suppression Diode.

Back EMF – Back Electromotive Force.

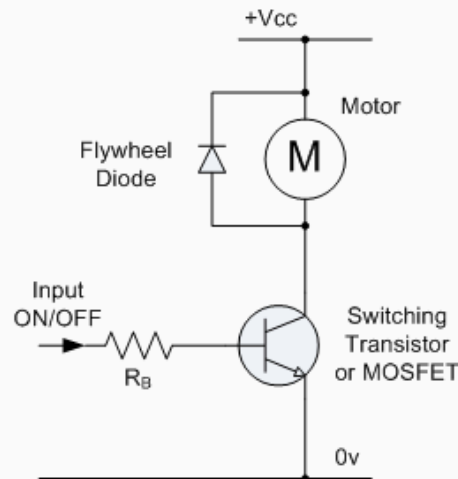


When inductive loads such as relays, solenoids and motors are switched off the stored energy in the magnetic field around the inductor collapses. The collapsing field produces a current in the opposite direction than when the coil is energized. Without the diode a high voltage spike may damage electronic circuits used to drive the coil. Adding the diode provides a path for the current to flow through the diode and through the load, preventing damage to the electronic circuits. During normal operation the diode is reverse biased.

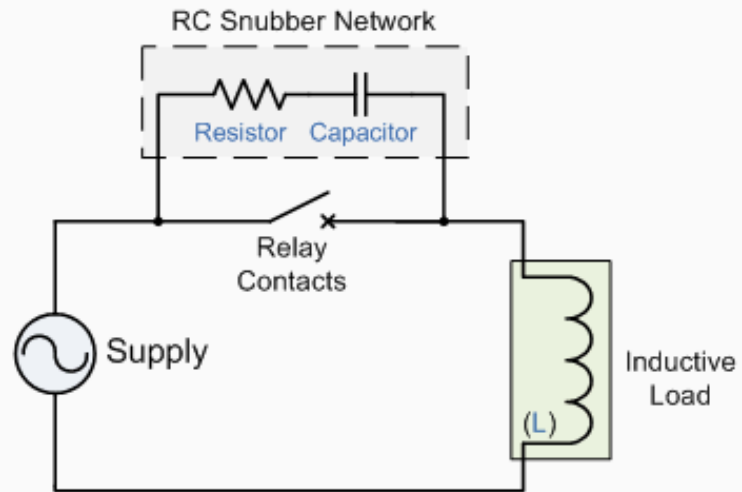
## DC Motor Switching and Control

Small DC motors can be switched "On" or "Off" by means of relays, transistors or mosfet circuits. The simplest form of motor control is "Linear" control. This type of circuit uses a bipolar **Transistor as a Switch** (A Darlington transistor may also be used were a higher current rating is required) to control the motor from a single power supply. By varying the amount of base current flowing into the transistor the speed of the motor can be controlled for example, if the transistor is turned on "half way", then only half of the supply voltage goes to the motor. If the transistor is turned "fully ON", then all of the supply voltage goes to the motor and it rotates faster. Then for the linear type of control, power is delivered constantly as shown below.

This circuit shows the connections for a **Uni-directional** (one direction only) motor control circuit. A continuous logic "1" or logic "0" is applied to the input of the circuit to turn the motor "ON" or "OFF" respectively and a flywheel diode is connected across the motor terminals to protect the transistor from any back emf generated by the motor when the transistor turns "OFF". As well as the basic "ON/OFF" control the same circuit can also be used to control the motors rotational speed. By repeatedly switching the motor current "ON" and "OFF" the speed of the motor can be varied between stand still (0 rpm) and full speed (100%). This is achieved by varying the proportion of "ON" time ( $t_{on}$ ) to the "OFF" time ( $t_{off}$ ) and this is called "**Pulse Width Speed Control**".



## Relay Snubber Circuit



The snubber circuit reduces the peak voltages when an inductive load is removed. If the control is a switch it reduces the spark across the switch. If the control is an electronic circuit (transistor) the snubber prevents damage to the electronics.