

## **Week 8 Notes:**

# **Quadrature encoding Geared DC Motors and Motor Drivers**

**CAM8302E**

**Fall 2018**

# Slide Index – Week 8

Slides	Topic
<input type="checkbox"/> 3	Geared DC Motor with Encoder
<input type="checkbox"/> 4	Hall Sensor Review
<input type="checkbox"/> 6	Quadrature Encoding
<input type="checkbox"/> 10	74HC74 D-Type FF
<input type="checkbox"/> 15	Encoder with Optical Sensor
<input type="checkbox"/> 16	Measuring Torque
<input type="checkbox"/> 17	Gear Trains
<input type="checkbox"/> 21	Basic DC Brushed Motors
<input type="checkbox"/> 23	H-Bridge
<input type="checkbox"/> 28	Lab 6 Front Panel
<input type="checkbox"/> 31	Lab 6 Block Diagram

# Geared DC Motor with Encoder

The motor used in the lab has a gear ratio of 30:1. The rotor of the DC motor turns 30 times for each revolution of the output shaft. The torque will increase by a factor of 30, the speed at the output is reduced by a factor of 30. The direction of the DC brushed motor is controlled by changing the voltage polarity to the positive and negative motor terminals. The link below is a short video showing the operation of the motor quadrature encoder.



[http://www.youtube.com/watch?v=4YLTHjbZVP0&list=PLZedxz6zGNJwsdKPOZJ\\_9BFq6VRrxDypK](http://www.youtube.com/watch?v=4YLTHjbZVP0&list=PLZedxz6zGNJwsdKPOZJ_9BFq6VRrxDypK)

Built in Hall Effect Sensors are separated by 90 degrees. The two sensors produce two pulses. The two combined signals produce 4 (quad) edges. They are used to measure direction and speed. There are three sections in the circular magnet. Each with a north and south pole.



# Geared DC Motor with Encoder



12V, 150RPM 30:1 Gear  
Motor w / Encoder

Product Code : RB-Cyt-82

**CAD \$27.33**



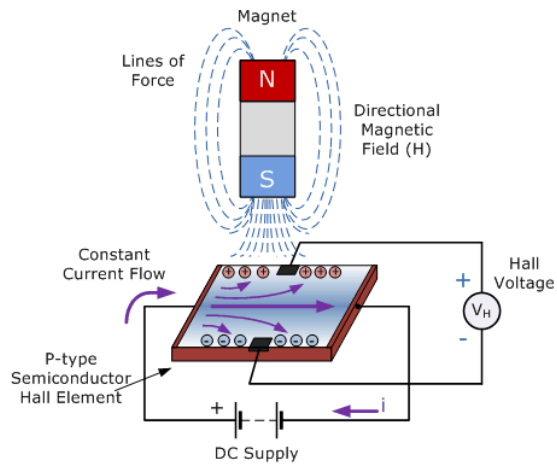
From robotshop.ca

12 volts DC 103 RPM 0.127 N.m torque 30:1 gear ratio

型番	[V]	[rpm]	[mN·m]
SPG20-50K	12	130	58.8
SPG30-20K	12	185	78.4
SPG30-30K	12	103	127.4
SPG30-60K	12	58	254.8
SPG30-150K	12	26	588
SPG30-200K	12	17	784
SPG30-300K	12	12	1176
SPG50-20K	12	170	196
SPG50-60K	12	56	588
SPG50-100K	12	34	980
SPG50-180K	12	17	1960

# Non Contact Hall Effect Sensor

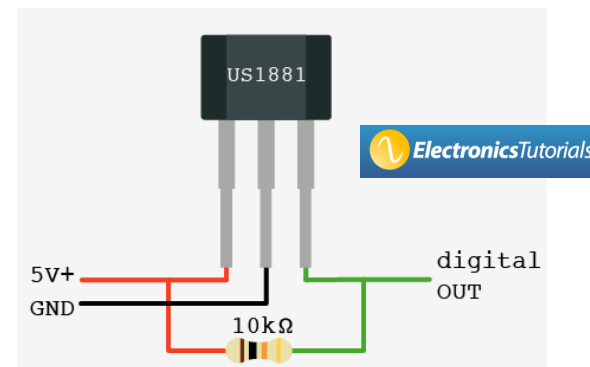
## Hall Effect Sensor Principals



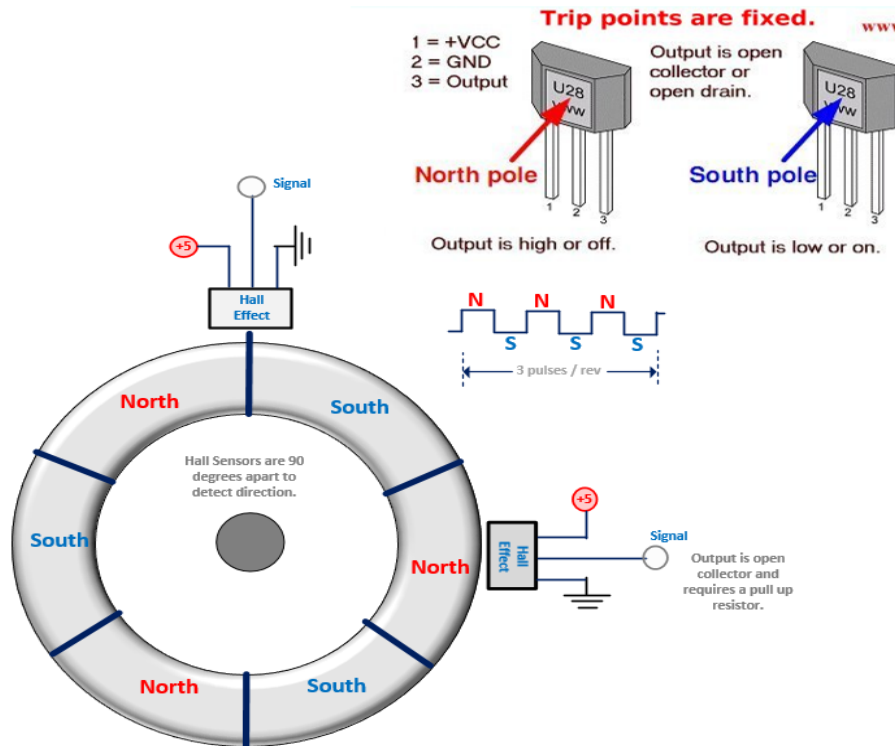
**Hall Effect Sensors** consist basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself. When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab. This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.

As these electrons and holes move side wards a potential difference is produced between the two sides of the semiconductor material by the build-up of these charge carriers. Then the movement of electrons through the semiconductor material is affected by the presence of an external magnetic field which is at right angles to it and this effect is greater in a flat rectangular shaped material.

**Magnetic Field causes a small voltage perpendicular to current flow in the wire. The Hall sensor used in the motor encoder has a latched output. A south pole cause a low output, a north pole causes a high output. The Hall sensor has three terminals. Ground, +5, and an open collector output which is pulled high using a 10k pull up resistor. Without the pull up resistor the signal is always a logic low.**



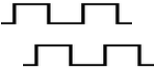
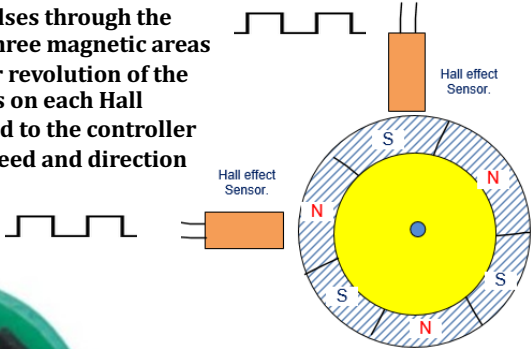
# Direction Detection Using Encoder



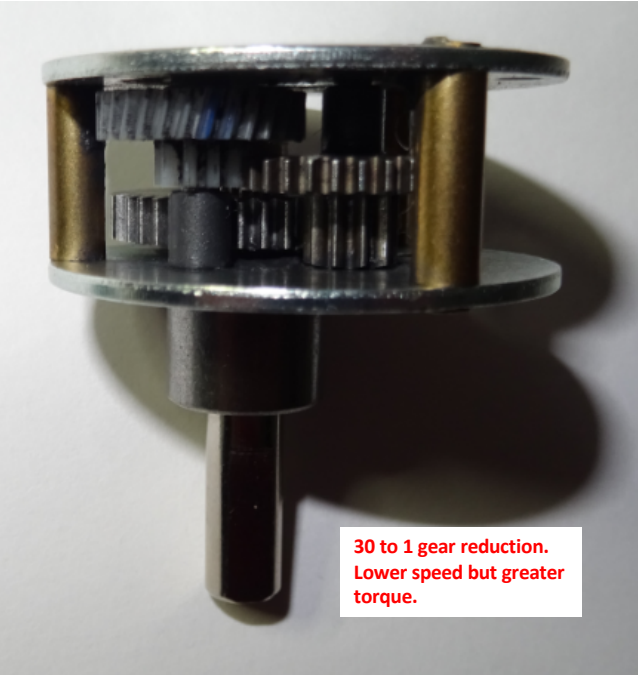
A Magnetic Field causes a small voltage to be produced perpendicular to current flow in the wire. The Hall sensor used in the motor encoder has a latched output. A south pole cause a low output, a north pole causes a high output. The Hall sensor has three terminals. Ground, +5, and an open collector output which is pulled high using a 10k pull up resistor. Without the pull up resistor the signal is always a logic low.

# Direction Detection Using Encoder

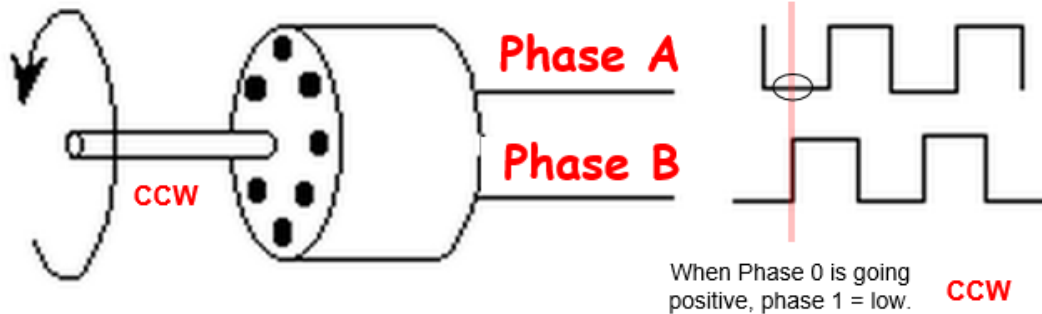
A rotating magnet creates pulses through the Hall sensor. Since there are three magnetic areas there will be three pulses per revolution of the motor. There are three pulses on each Hall sensor. When both are applied to the controller they can determine motor speed and direction



Hall effect sensors are separated by 90 degrees. The two pulses create 4 edges. (quadrature o/p). The motor has 6 terminals. Two to supply the logic voltage for the Hall sensor. Two wires for the DC motor supply and two wire for the quadrature encoder output.

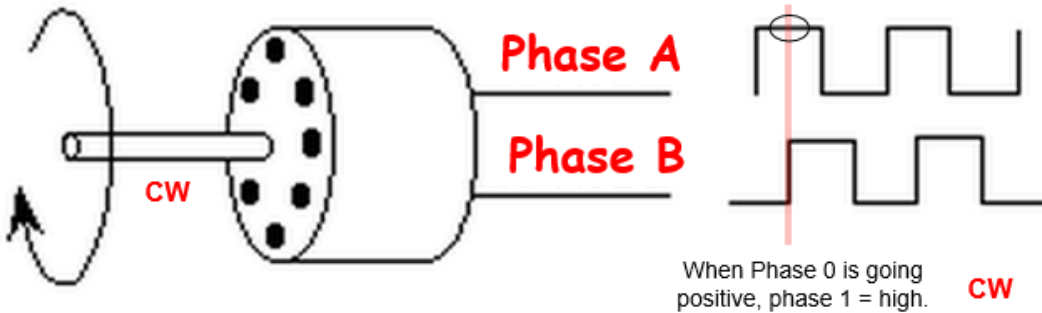


# Direction Detection Using Encoder



These two timing diagrams demonstrate the differences in the A and B signals as the motor rotates clockwise the counter clockwise.

The motor in the upper diagram is rotating CCW. Assume the B signal is the clock input of our circuit. As the B signal goes through a positive transition the logic level of the A signal is low.

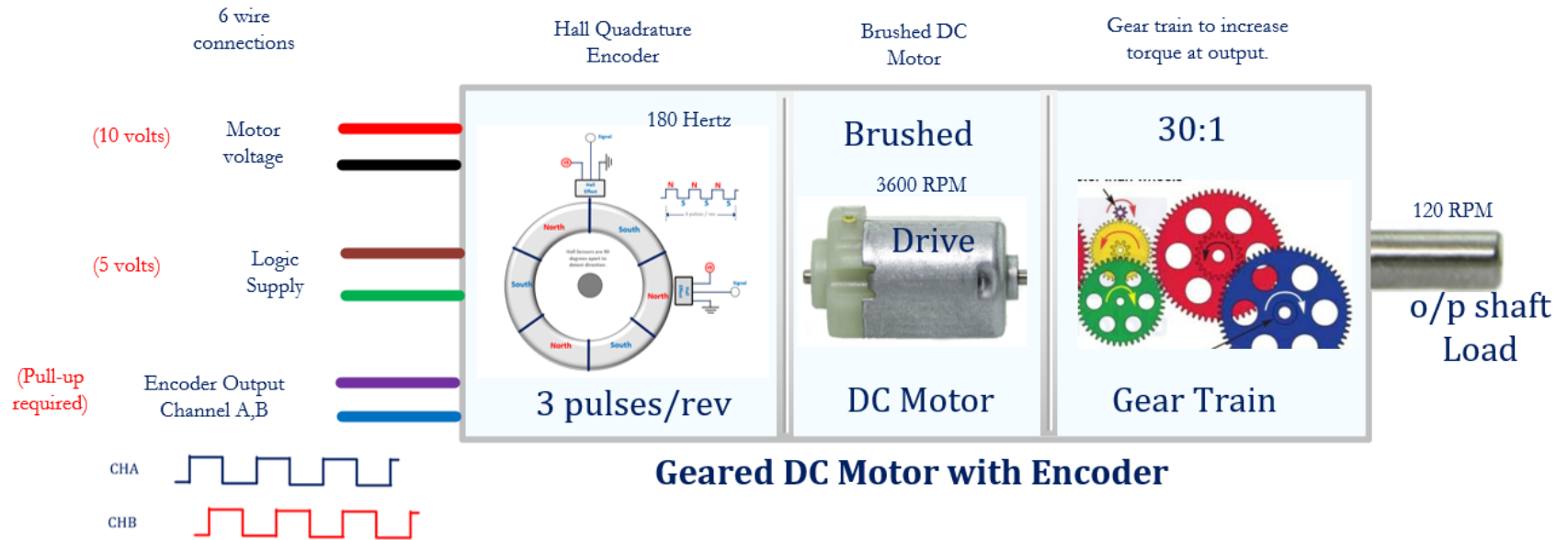


The motor in the lower diagram is rotating CW. Assume the B signal is the clock input of our circuit. As the B signal goes through a positive transition the logic level of the A signal is high.

The reason the signals produce the pulses in this pattern is that the sensors are placed 90 degrees apart from each other.



# Gear Train of lab DC motor.



# Quadrature Encoder (4 edges)

## Decode a quadrature encoder in software

Sid Levingston, Gentec-EO, Lake Oswego, OR

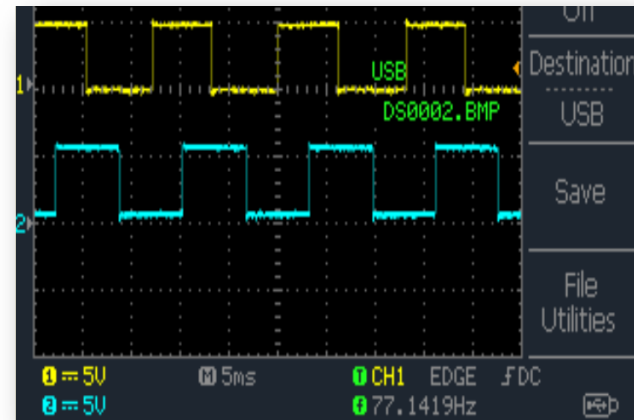
Quadrature encoders work in many applications to determine displacement and direction of mechanical travel. They vary in design, but they all do the same thing: supply a set of square waves 90° out of phase. **Figure 1** shows the typical output signals.

The encoder rotates clockwise when Channel A leads Channel B. If Channel B leads Channel A, the encoder is rotating counter clockwise. By counting the pulses and the direction of ro-

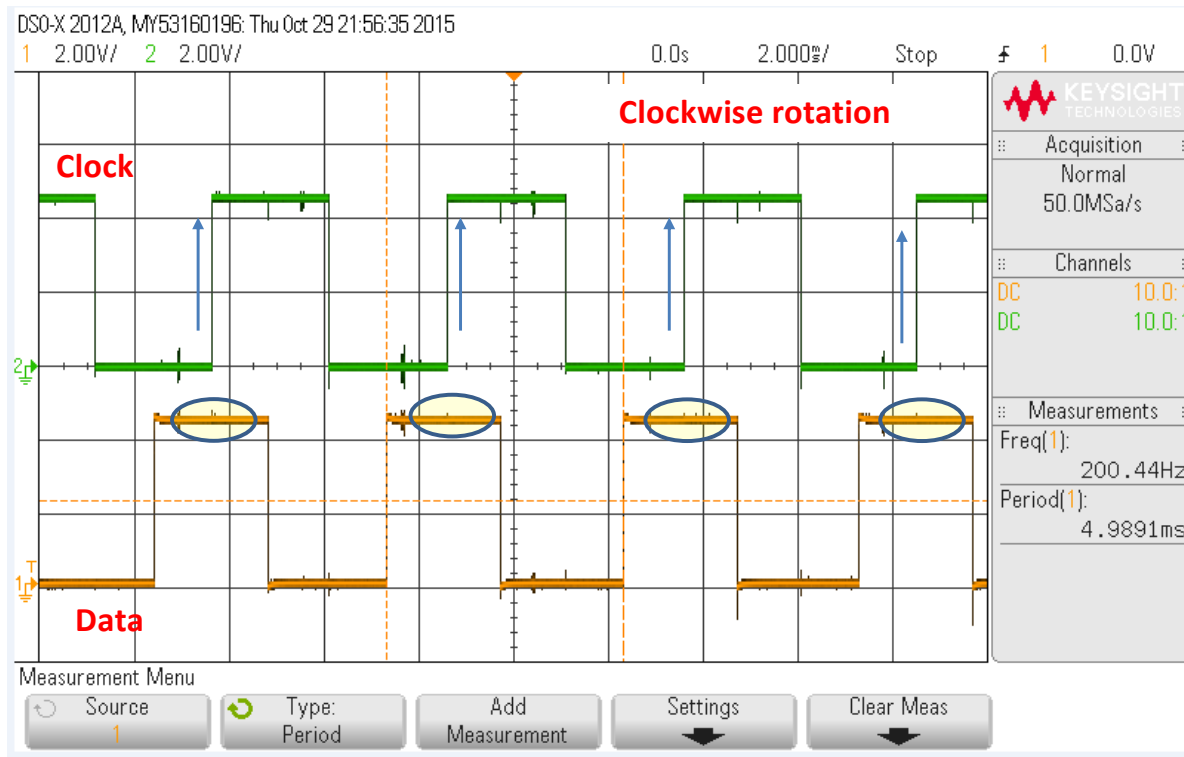
tation, you can find the position of the encoder. Although ICs can decode quadrature encoders, you can easily and less expensively have the processor decode the signal. The signals from Channel A and Channel B go through a Schmitt trigger if necessary, but many encoders and processors include this trigger internally. The signals are then applied to two I/O pins on the processor that support edge-triggered inter-

48 EDN | JANUARY 20, 2011

The Hall Effect Sensor is able to detect a magnetic field and produce output pulses as the motor rotates. The Hall sensors are 90 degrees apart. The encoder is used to measure speed and direction.

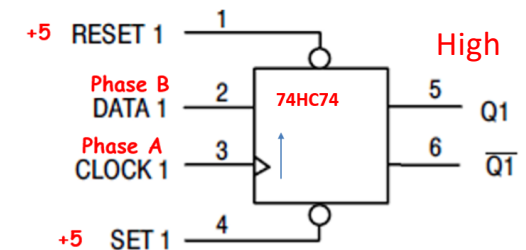


# Encoder Signals Clockwise

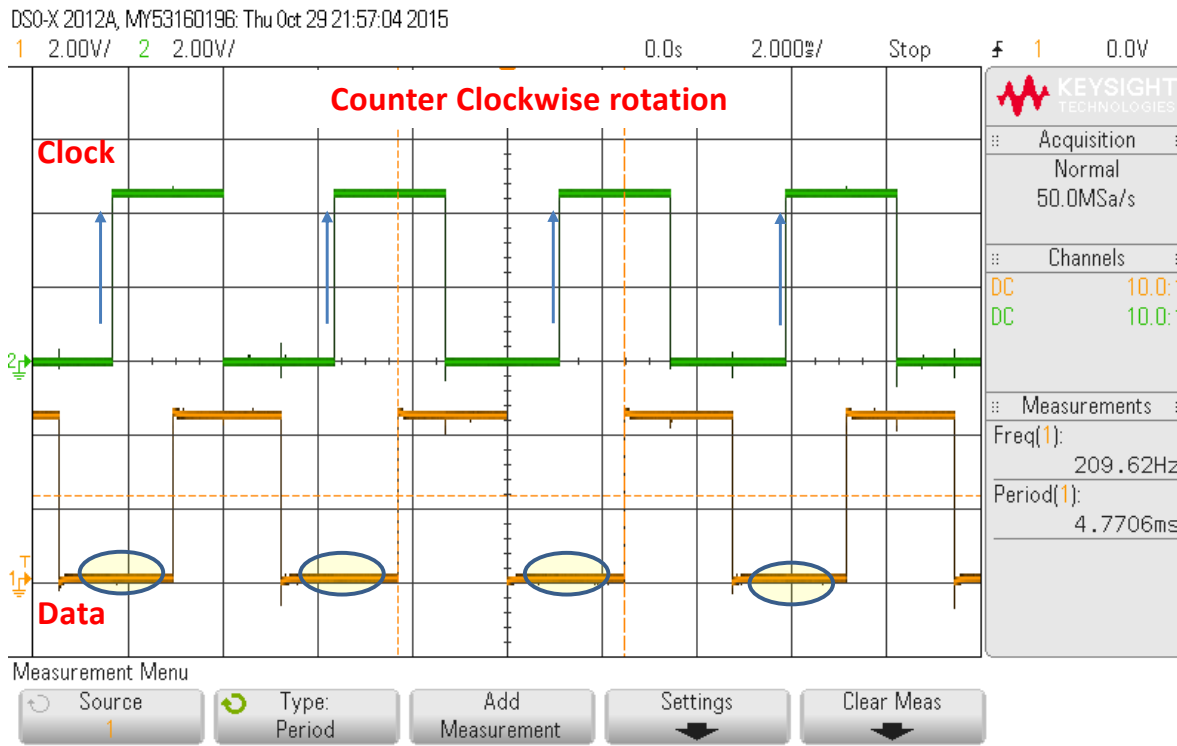


The input to the HC74 is positive edge sensitive and is connected to the clock of the quadrature encoder.

In this case as the rising edge occurs the data is high, therefore the output o Q1 will be high.

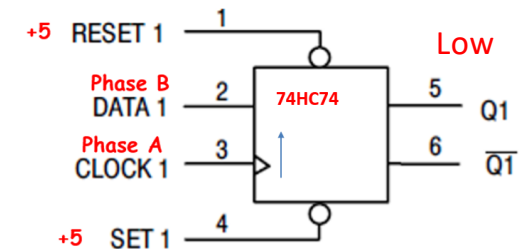


# Encoder Signals CCW

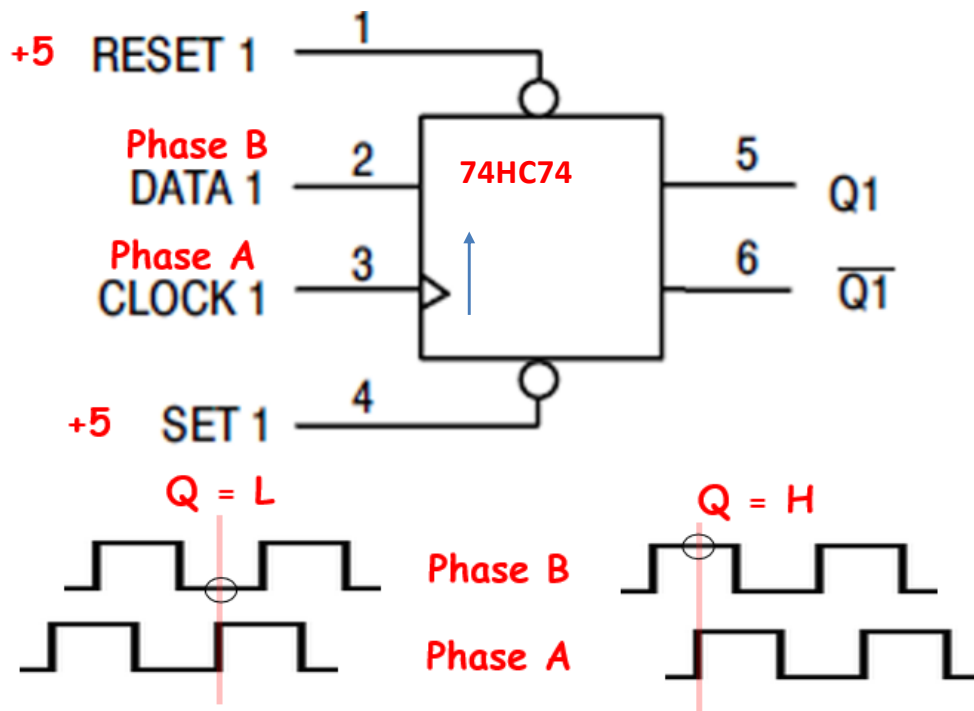


The input to the HC74 is positive edge sensitive and is connected to the clock of the quadrature encoder.

In this case as the rising edge occurs the data is low, therefore the output o Q1 will be low.



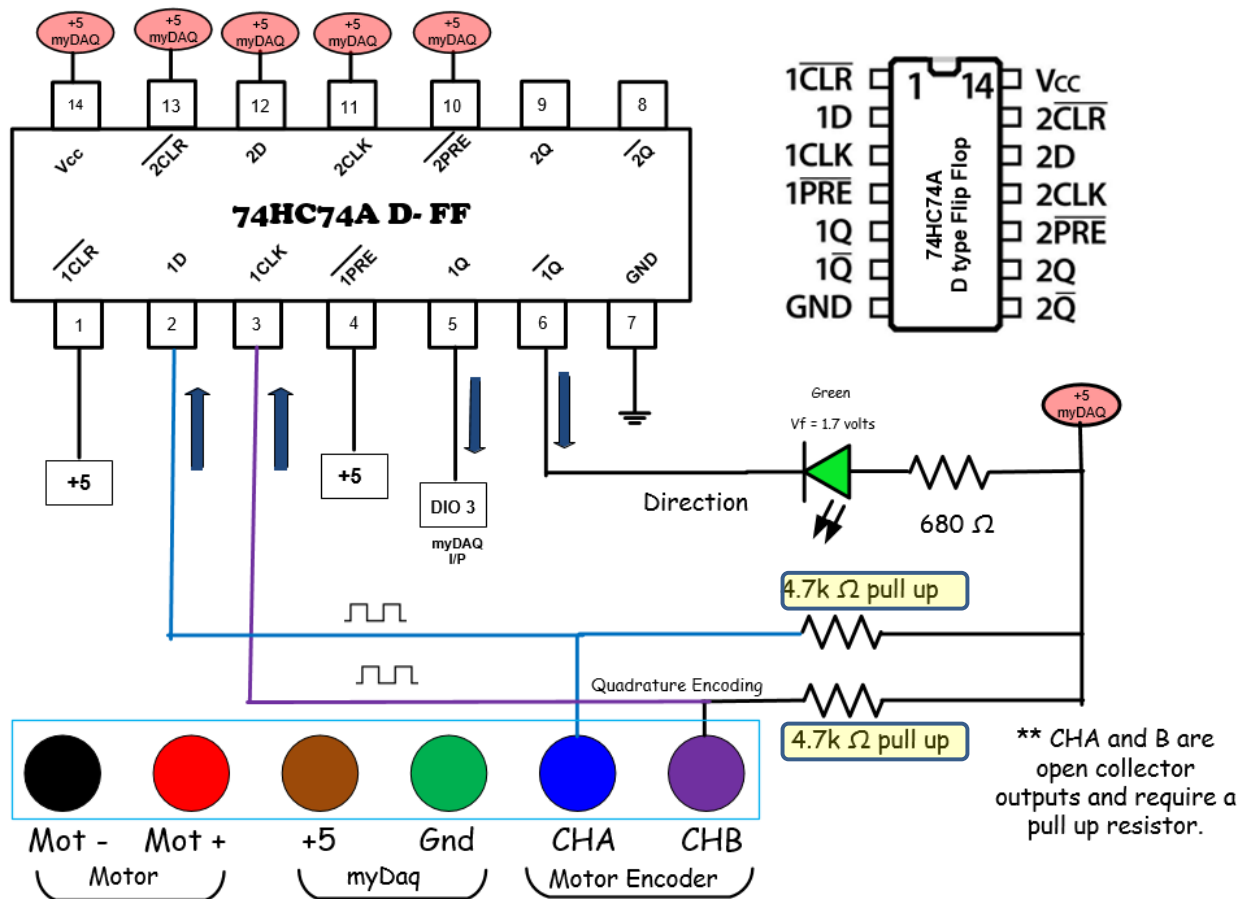
# Direction Detection Using Encoder



A 74HC74 IC is used to decode direction and produce a logic low or high output on Q1 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.

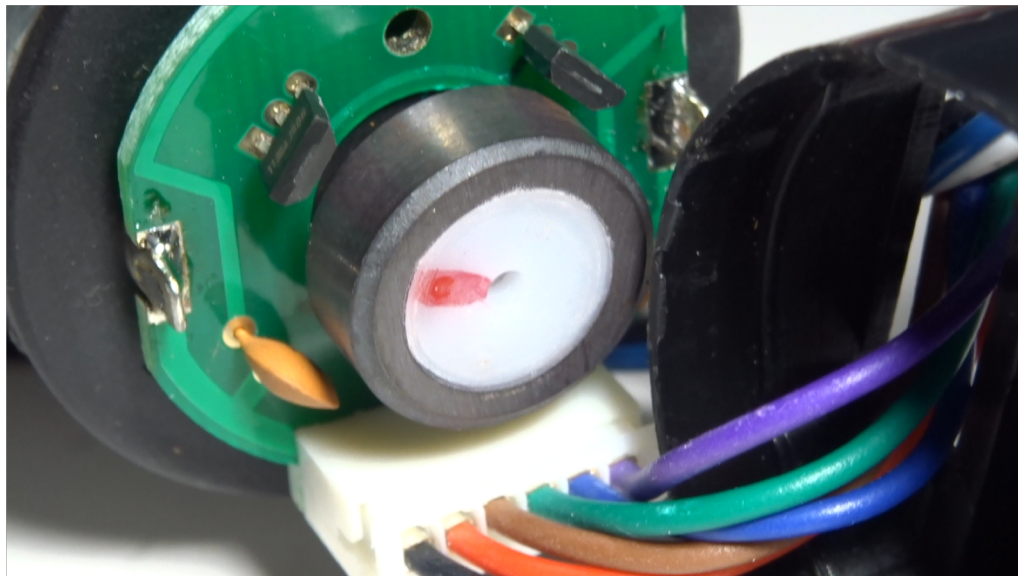


This circuit is used to detect the direction of rotation of the DC motor.

One of the output signals connects to an LED, the other connects to an input on the myDAQ, this will be used to indicate direction on the front panel.

Your circuit will not work as expected without the pull-up resistors.

# myDAQ Motor Speed LabVIEW Front Panel (video)



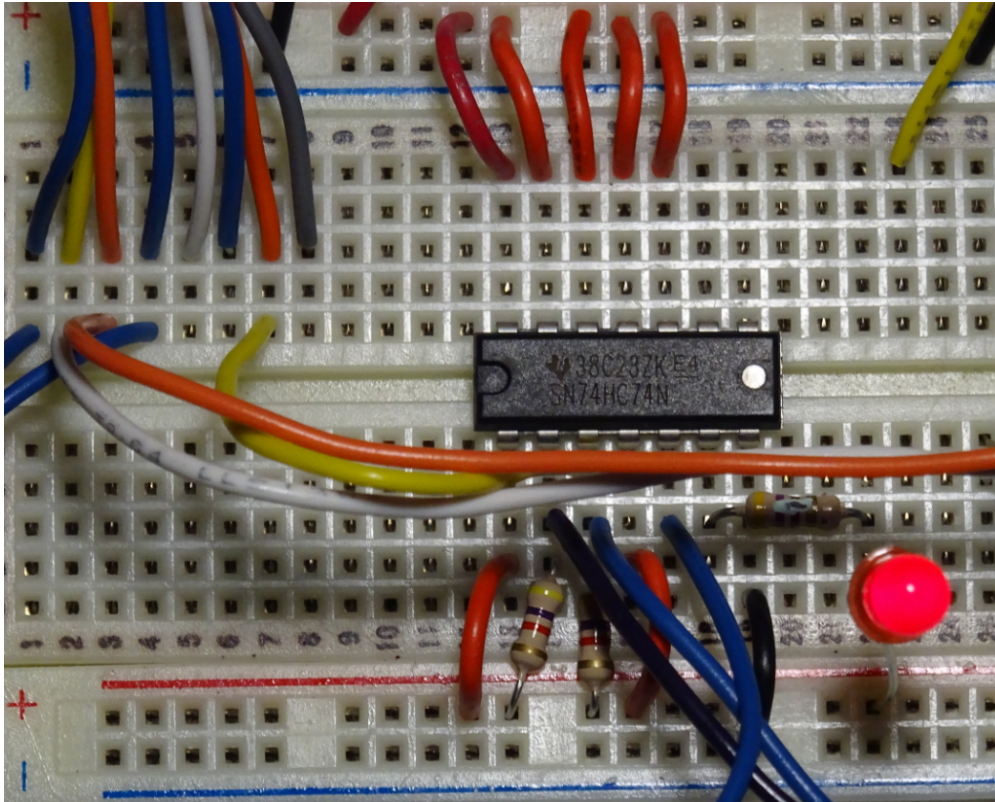
**Video of the DC motor Encoder.**

**The magnet wheel is comprised of three magnets with 3 north and south poles.**

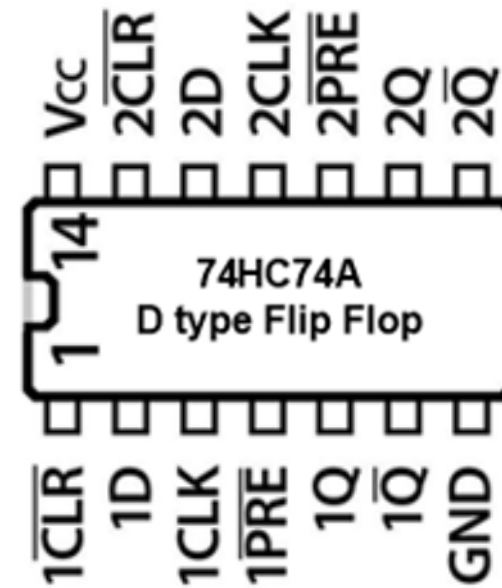
**As the motor rotates 3 pulses occur on each Hall sensor output.**

**The motor is rotated CW and CCW.**

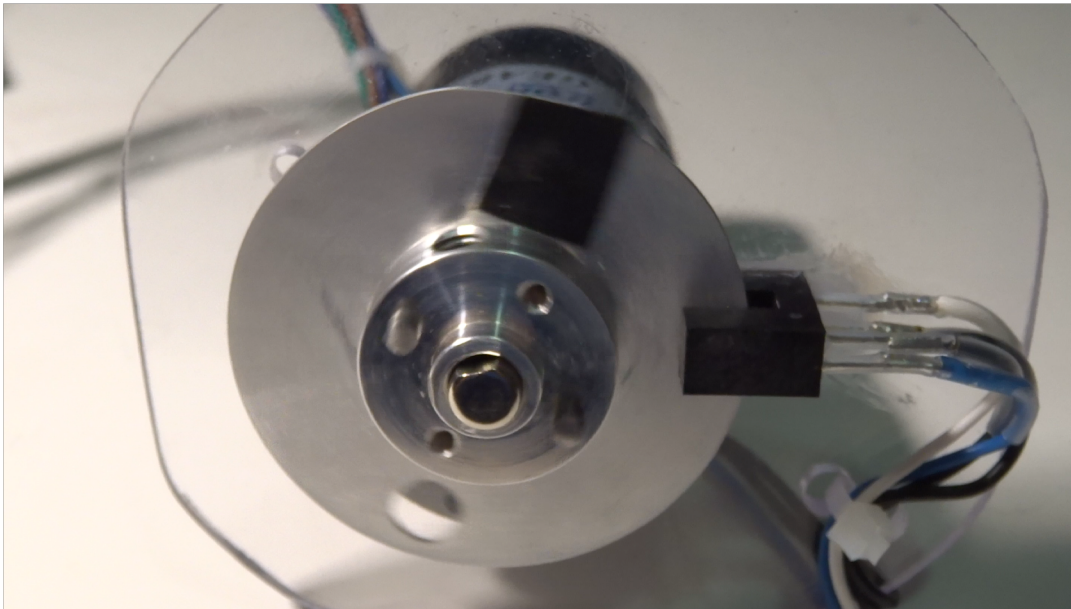
# 74HC74 D-Flip Flop



CAM8302E F2018



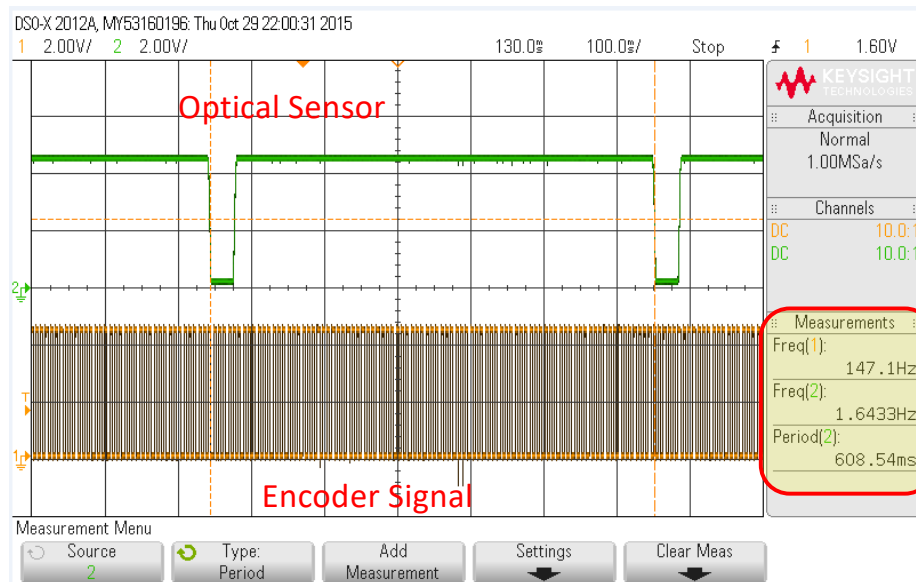
# Motor Speed with Optical Sensor (video)



**In this example an optical switch measures the rotation speed of the output shaft. 1 hole is drilled into the aluminum plate. As the motor 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.**

# Encoder and Optical Sensor



Encoder pulses per second = 147.

There are 3 pulses per revolution.

$$147/3 = 49.$$

Motor rotates at 49 rev/sec.

$$\times 60 = 2940 \text{ RPM.}$$

Gear Ratio is 30:1

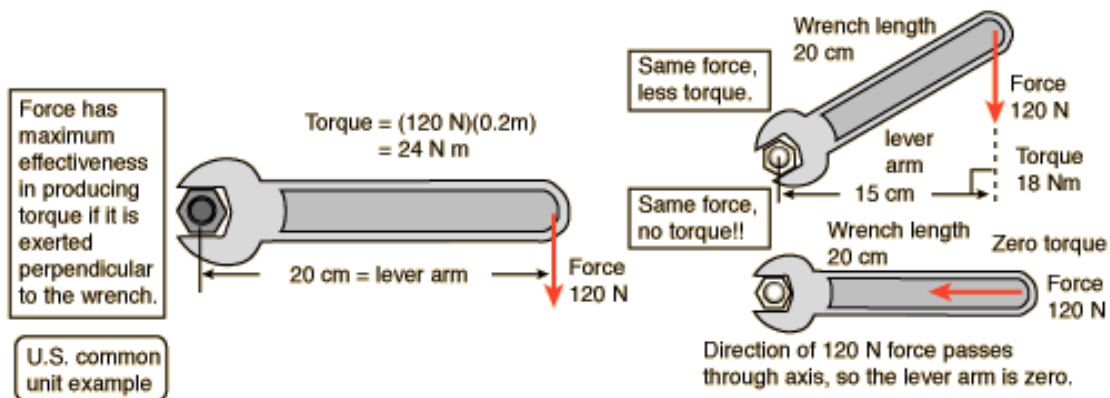
Divide RPM by 30 equals 98 RPM.

Divide by 60 equals 1.64 rev/second.

Rotation frequency = 1.64 seconds.

Rotation period = 608 ms.

# Torque (Rotational Force)



Three examples of torque exerted on a wrench of length 20 cm.

## What is Torque?

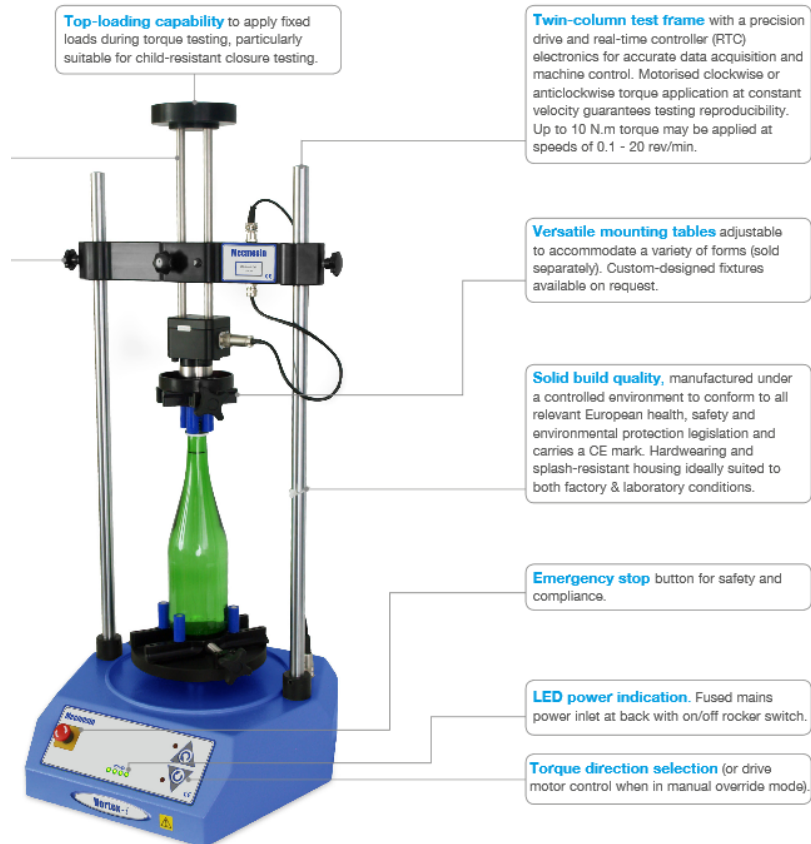
According to Webster:

- A twisting or wrenching effect, or moment, exerted by a force acting at a distance on a body, equal to the force multiplied by the perpendicular distance between the line of action of the force, and the center of rotation at which it is exerted.
- A force, which tends to produce rotation. The measurement of torque is based on the fundamental law of the lever.

- Torque is expressed in commonly used units of measurement such as:

- in. lbs. = inch pounds
- in. ozs. = inch ounces
- ft. lbs. = foot pounds
- Nm = Newton meter
- cNm = Centi Newton meter





This instrument is used to measure the turning torque on bottle caps.

The range is from 0 to 10 N.m.

The torque for the nuts on a car wheel is between 75 to 100 foot-pounds, or about 135 newton-meter.

This is about 1000 time greater than the motor used in the lab. The lab motor has a maximum torque of about 0.1 foot-pounds or 0.127 Nm.



# Geared Motor – Force

## Specifications:

- Rated voltage: 12VDC
- Tested voltage range: 9V to 15V
- Speed at free run, 12V: 103rpm
- Current at free run, 12V: 410mA
- Stall Current, 12V: 1800mA
- Stall torque, 12V: ~1.3kg-cm (127.4mN.m)
- Weight: 160g
- Gear ratio: 30:1
- Shaft: 6mm diameter x 15.5mm length



<a href="#">newton meter [N*m]:</a>	.127
<a href="#">newton centimeter [N*cm]:</a>	12.7
<a href="#">newton millimeter [N*mm]:</a>	127
<a href="#">kilonewton meter [kN*m]:</a>	0.000127
<a href="#">dyne meter [dyn*m]:</a>	12700
<a href="#">dyne centimeter [dyn*cm]:</a>	1270000
<a href="#">dyne millimeter [dyn*mm]:</a>	12700000
<a href="#">kilogram-force meter [kgf*m]:</a>	0.012950396
<a href="#">kilogram-force centimeter [kgf*cm]:</a>	1.29503959
<a href="#">kilogram-force millimeter [kgf*mm]:</a>	12.950395905
<a href="#">gram-force meter [gf*m]:</a>	12.950395905
<a href="#">gram-force centimeter [gf*cm]:</a>	1295.039590482
<a href="#">gram-force millimeter [gf*mm]:</a>	12950.39590482
<a href="#">ounce-force foot [ozf*ft]:</a>	1.498726248
<a href="#">ounce-force inch [ozf*in]:</a>	17.984714975
<a href="#">pound-force foot [lbf*ft]:</a>	0.093670389
<a href="#">pound-force inch [lbf*in]:</a>	1.124044673

# Gears and Drive Trains

Gears and gear trains are used to:

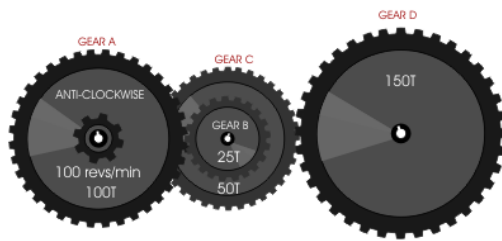
- 1) Increase or decrease speed
- 2) Increase or decrease torque

Torque is a turning or twisting force measured in Newton . metre (Nm).

A gear train is a group of gears used to achieve the desired torque or speed.

**Gear Ratio** – Ratio between the driving device and the final output.

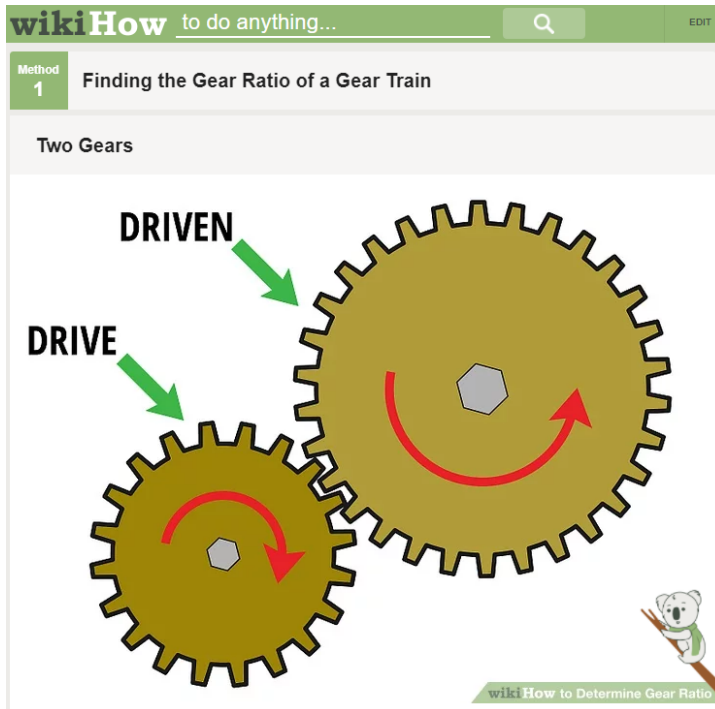
Example a motor rotates at 30 rev/second, the output shaft rotates at 1 rev/second, the gear ratio is 30:1.



What is the revs/min at gear D and what is its direction?

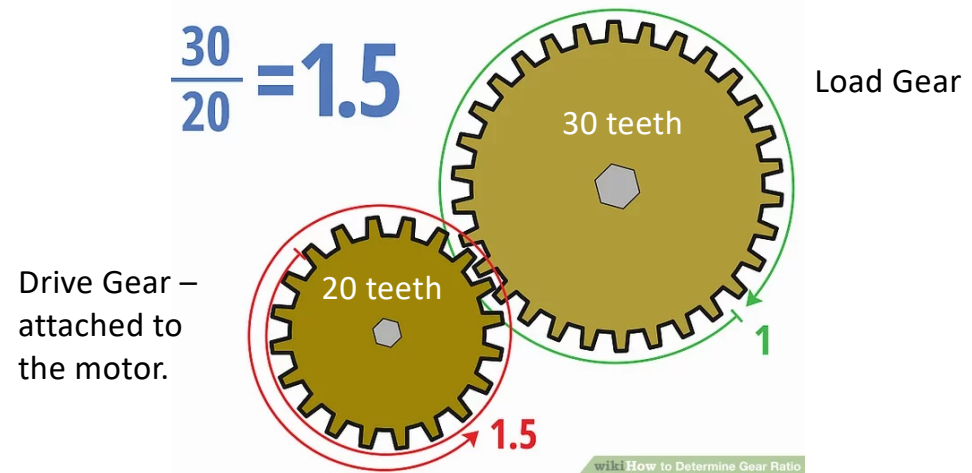
<http://www.technologystudent.com/gears1/gears8.htm>

# Gears and Drive Trains



The load gear turns slower than the drive gear but has greater torque. The direction is reversed.

If the drive gear turns at 100 RPM with a torque of 5 N.m the driven gear will turn 66 RPM and have a torque of 7.5 N.m



$$\text{Gear Ratio} = \text{Driven Gear} / \text{Drive Gear} = 30 / 20 = 1.5$$

# Gears and Drive Trains

**1 Start with a two-gear train.** To be able to determine a gear ratio, you must have at least two gears engaged with each other — this is called a "gear train." Usually, the first gear is a "drive gear" attached to the motor shaft and the second is a "driven gear" attached to the load shaft. There may also be any number of gears between these two to transmit power from the drive gear to the driven gear: these are called "idler gears."

- For now, let's look at a gear train with only two gears in it. To be able to find a gear ratio, these gears have to be interacting with each other — in other words, their teeth need to be meshed and one should be turning the other. For example purposes, let's say that you have one small drive gear (gear 1) turning a larger driven gear (gear 2).

**2 Count the number of teeth on the drive gear.** One simple way to find the gear ratio between two interlocking gears is to compare the number of teeth (the little peg-like protrusions at the edge of the wheel) that they both have. Start by determining how many teeth are on the drive gear. You can do this by counting manually or, sometimes, by checking for this information labeled on the gear itself.

- For example purposes, let's say that the smaller drive gear in our system has **20 teeth**.

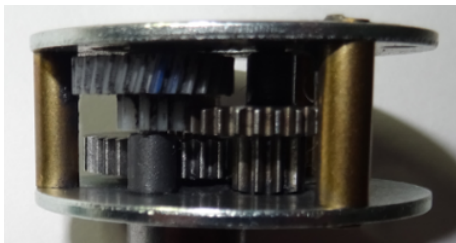
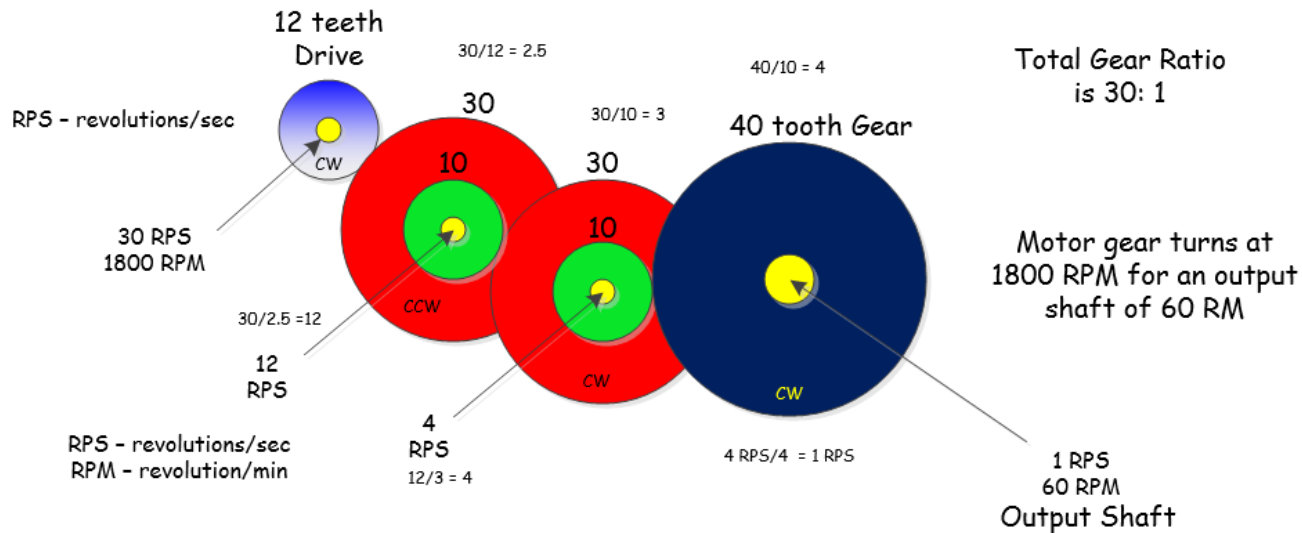
**3 Count the number of teeth on the driven gear.** Next, determine how many teeth are on the driven gear exactly as you did before for the drive gear.

- Let's say that, in our example, the driven gear has **30 teeth**.

**4 Divide one teeth count by the other.** Now that you know how many teeth are on each gear, you can find the gear ratio relatively simply. Divide the driven gear teeth by the drive gear teeth. Depending on your assignment, you may write your answer as a decimal, a fraction, or in ratio form (i.e.,  $x : y$ ).

- In our example, dividing the 30 teeth of the driven gear by the 20 teeth of the drive gear gets us  $30/20 = 1.5$ . We can also write this as **3/2** or **1.5 : 1**, etc.
- What this gear ratio means is that the smaller driver gear must turn one and a half times to get the larger driven gear to make one complete turn. This makes sense — since the driven gear is bigger, it will turn more slowly.<sup>[2]</sup>

# Compound Gears and Drive Trains

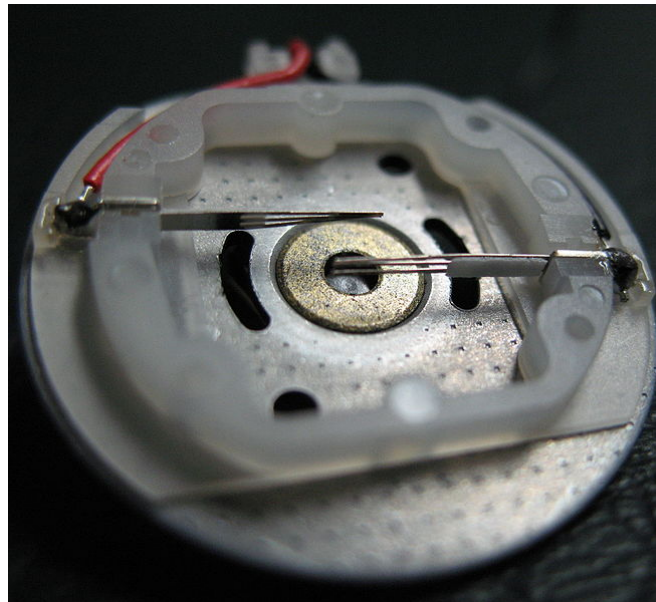


The gear set to the left is from the motor used in the lab. At 12 VDC the output shaft rotates at 103 RPM with a maximum torque of 0.127 Nm. The motor has a gear ratio of 30:1. If the output shaft is turning at 103 RPMs the motor is rotating at 3090 RPM or 51.5 RPS. The hall sensors will produce pulses at a rate of 154.5 Hz. Total gear ratio =  $2.5 \times 3 \times 4 = 30$

# Basic Brushed DC Motors

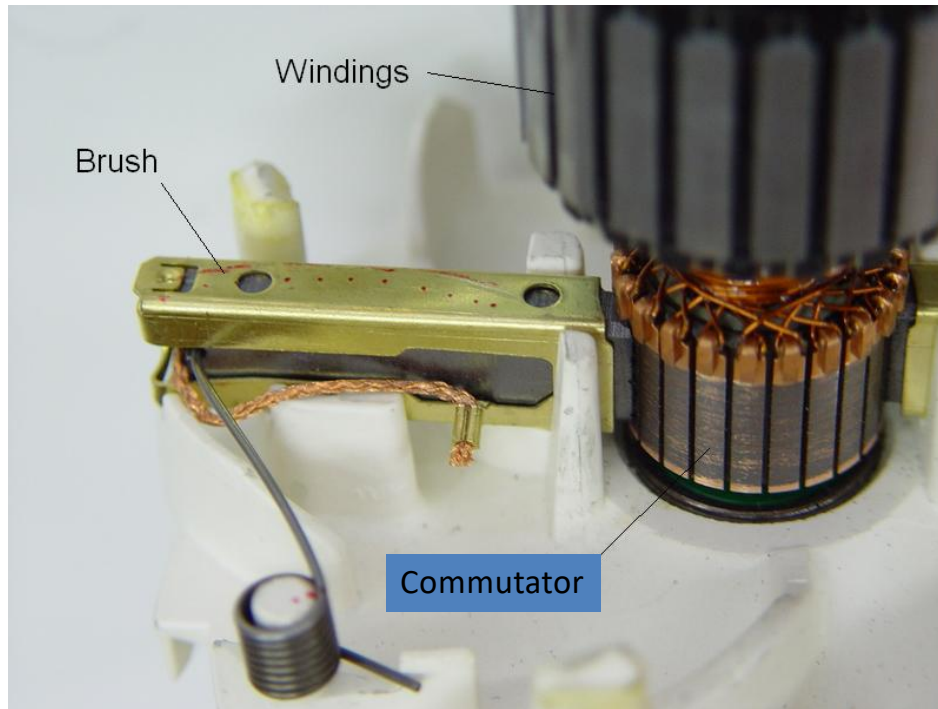


DC Motor -- Wired Rotor



Brushes on the stator of a small DC Motor

# Basic DC Brushed Motors



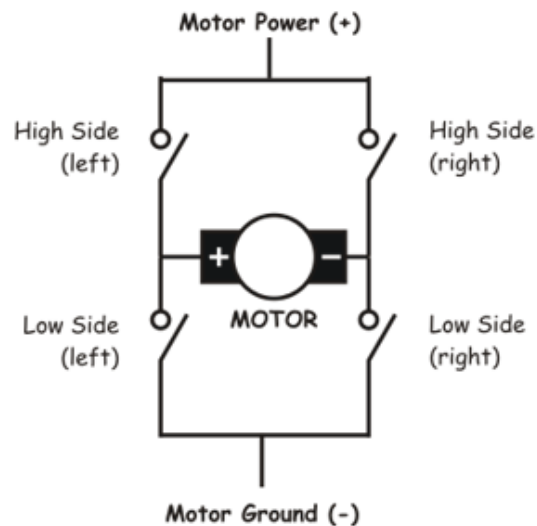
## DC Motor Components

This picture shows the details of one of the two brushes touching the commutator of the rotor. The commutator provides a path for current to flow through the coils of wire attached to the rotor.

# Simple H-Bridge

## H-Bridge Manual Operation:

A group of four switches are used to control the direction of a DC motor. The circuit reverses which pins on the motor receive the positive and negative signals.



## Clock Wise Operation

High Left, Low Right Closed  
Positive on left of motor, Negative on right of motor.

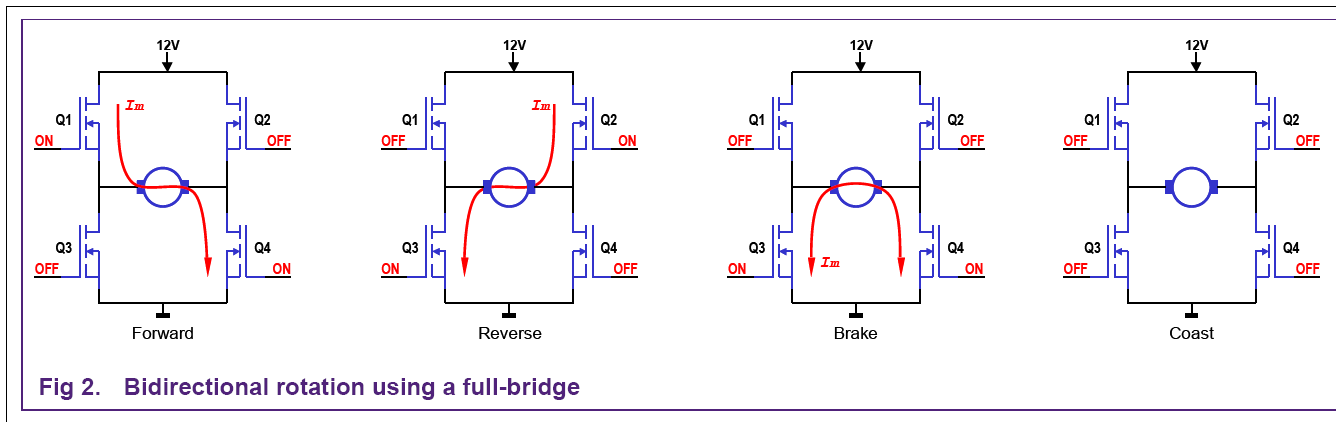
## Counter Clock Wise

High Right, Low Left Closed  
Positive on right of motor, Negative on left of motor.

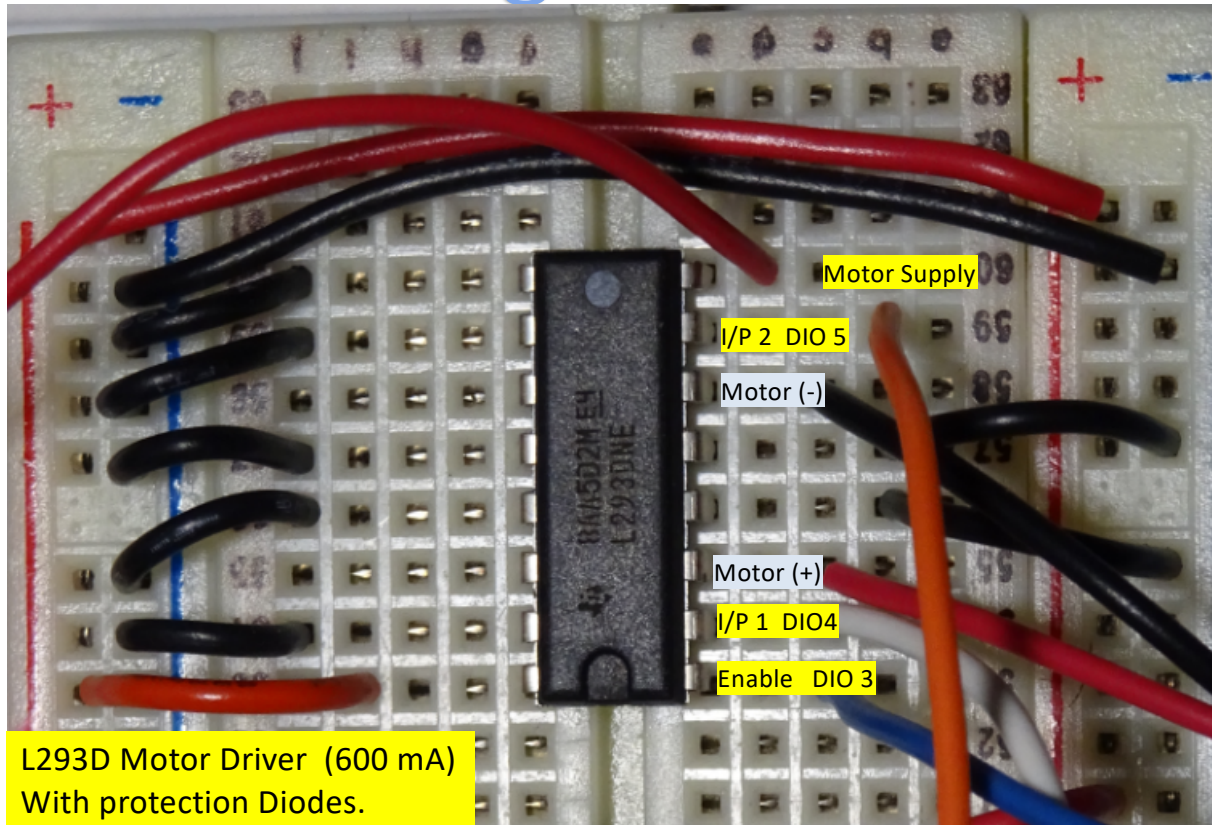
# DC Motor Control H-Bridge

## L293, L298 H-Bridge Operation:

A group of four transistors (MOSFETS) are used to control the direction of a DC motor. The circuit reverses which pins on the motor receive the positive and negative signals. Logic is built into the driver IC to prevent a short circuit.



# L293D H-Bridge Motor Controller



L293D Motor Driver (600 mA)  
With protection Diodes.

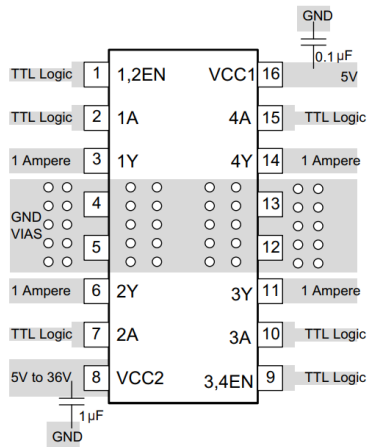
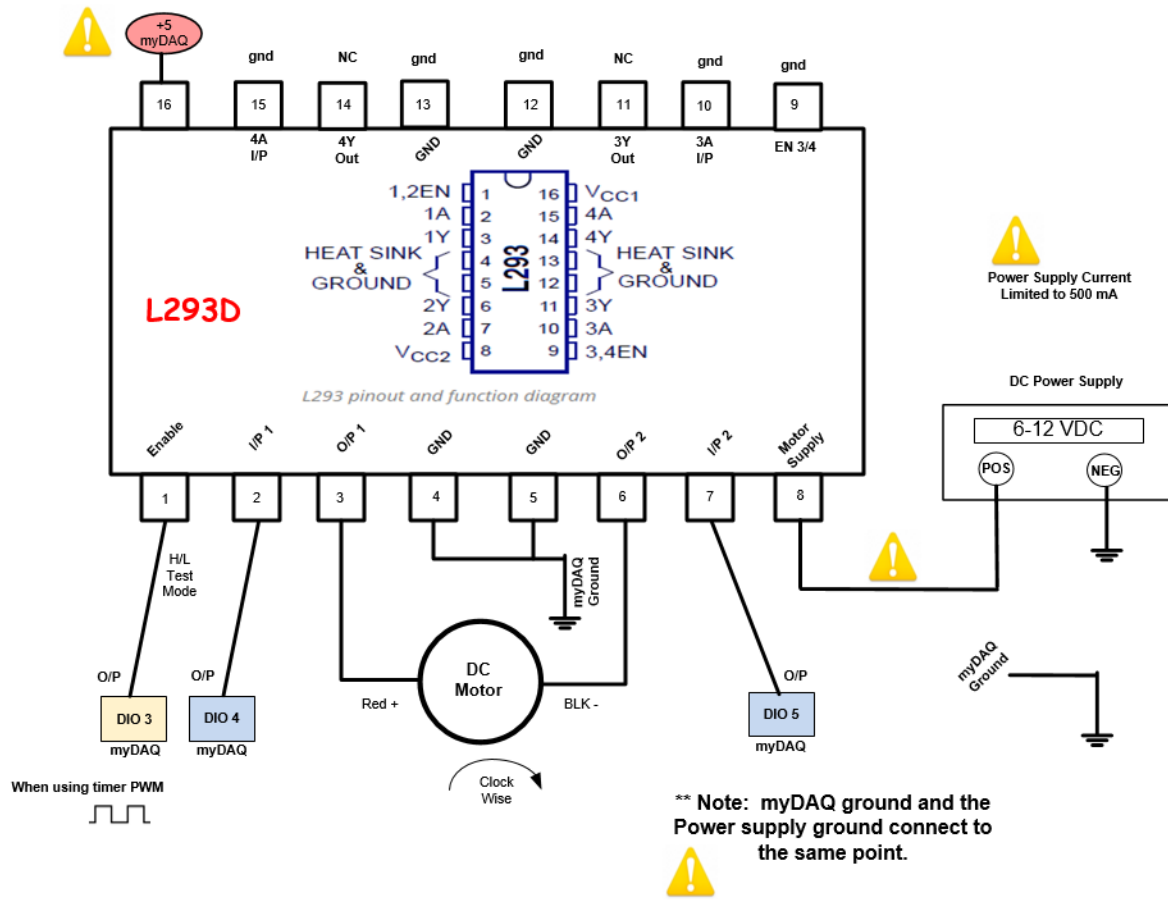
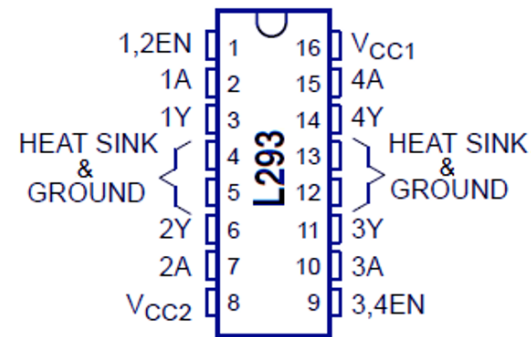


Figure 13. Layout Diagram



# Motor Controller Function Table

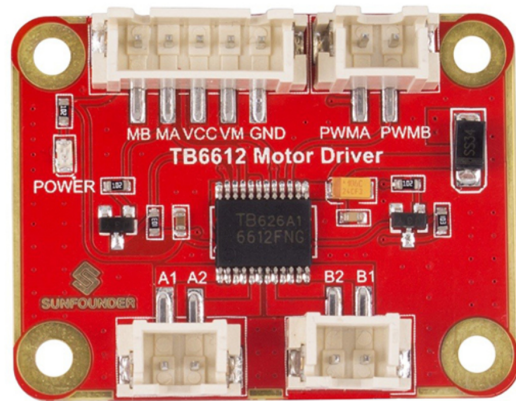
EN (EIO0) Pin 1	IN1 (EIO1) Pin 2	IN2 (EIO2) Pin 7	Motor Function
L	X	X	Free Run Motor Stop
H	L	L	Fast Motor Stop (Braking)
H	L	H	Clockwise
H	H	L	Counter-ClockWise
H	H	H	Fast Motor Stop (Braking)



*L293 pinout and function diagram*

The three control pins determine the motor direction, clockwise or counter-clockwise. The control signals also control whether the motor brakes or free runs to a stop. If the motor control IC is enabled and both inputs are at the same level the motor will stop quickly (brake). If the IC is disabled the motor free runs to a stop.

# TB6612 Motor Driver



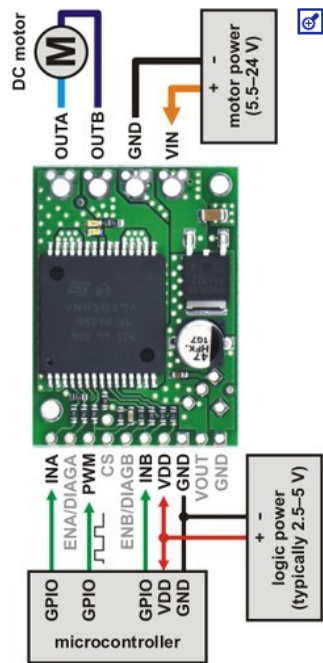
Now, for a quick overview of how to control each of the channels. If you are using an Arduino, don't worry about this too much as the library takes care of all of this for you. If you are using a different control platform, pay attention. When the outputs are set to High/Low your motor will run. When they are set to Low/High the motor will run in the opposite direction. In both cases, the speed is controlled by the PWM input.

In1	In2	PWM	Out1	Out2	Mode
H	H	H/L	L	L	Short brake
L	H	H	L	H	CCW
L	H	L	L	L	Short brake
H	L	H	H	L	CW
H	L	L	L	L	Short brake
L	L	H	OFF	OFF	Stop

Pin Label	Function	Power/Input/Output	Notes
VM	Motor Voltage	Power	This is where you provide power for the motors (2.2V to 13.5V)
VCC	Logic Voltage	Power	This is the voltage to power the chip and talk to the microcontroller (2.7V to 5.5V)
GND	Ground	Power	Common Ground for both motor voltage and logic voltage (all GND pins are connected)
STBY	Standby	Input	Allows the H-bridges to work when high (has a pulldown resistor so it must actively pulled high)
AIN1/BIN1	Input 1 for channels A/B	Input	One of the two inputs that determines the direction.
AIN2/BIN2	Input 2 for channels A/B	Input	One of the two inputs that determines the direction.
PWMA/PWMB	PWM input for channels A/B	Input	PWM input that controls the speed
A01/B01	Output 1 for channels A/B	Output	One of the two outputs to connect the motor
A02/B02	Output 2 for channels A/B	Output	One of the two outputs to connect the motor

# VNH5019 Motor Controller

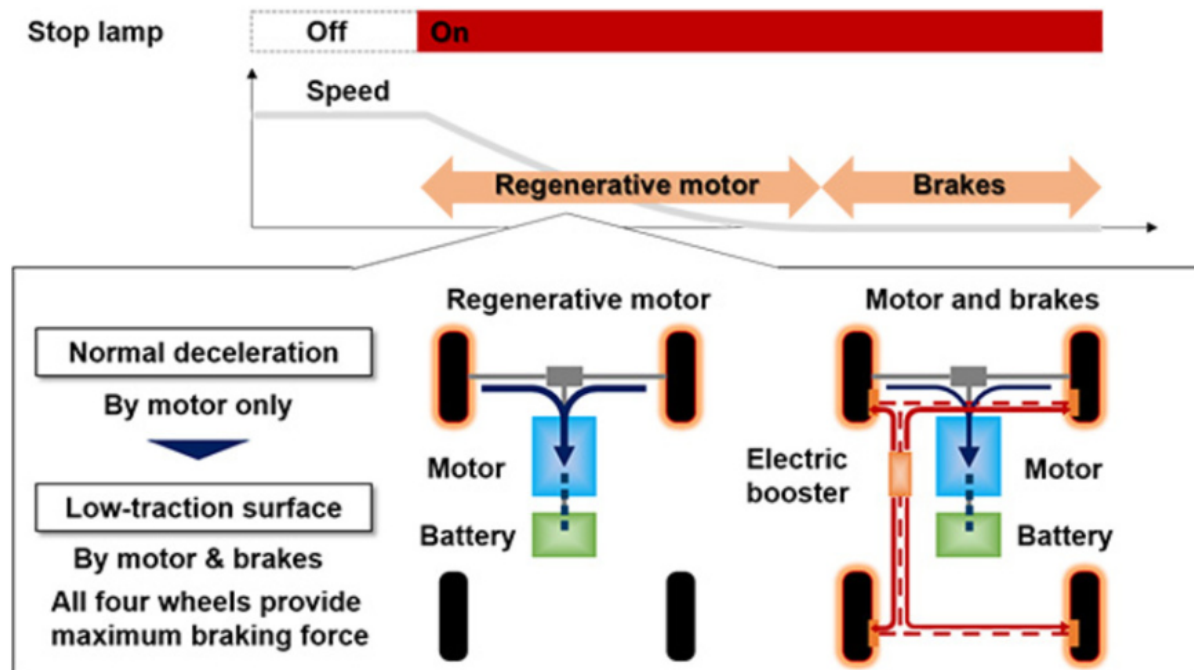
12 Ampere DC motor Drive.



Minimal wiring diagram for connecting a microcontroller to a VNH5019 motor driver carrier.

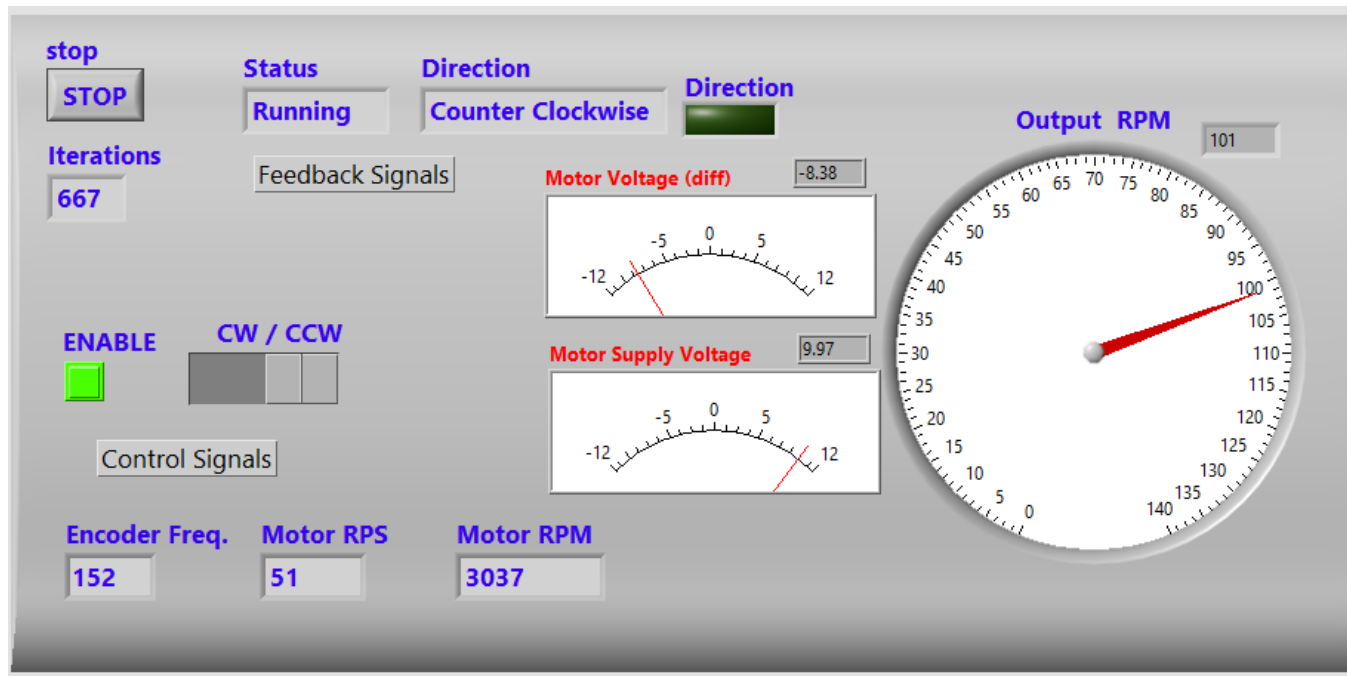
PIN	Default State	Description
VIN		The connection point for the positive side of the 5.5 – 24 V motor power supply. Since the overvoltage protection can be as low as 24 V, we do not recommend using 24V batteries for VIN.
VDD		The connection point for the positive side of the logic power supply (typically 2.5 – 5 V). The only function of this pin is to power the internal pull-ups on the two enable lines, ENA and ENB.
VOUT		This pin gives you access to the motor power supply after the reverse-voltage protection MOSFET (see the board schematic below). It can be used to supply reverse-protected power to other components in the system, but it should not be used for high currents. This pin should only be used as an output.
GND		Ground connection points for logic and motor power supplies. <u>The control source and the motor driver must share a common ground.</u>
OUTA		Output of half-bridge A (connects to one terminal of a DC motor).
OUTB		Output of half-bridge B (connects to the other terminal of a DC motor).
PWM	LOW	Pulse width modulation input: a PWM signal on this pin corresponds to a PWM output on the motor outputs.
INA	FLOAT	Motor direction input A ("clockwise" input).
INB	FLOAT	Motor direction input B ("counterclockwise" input).
CS		Current sense output. The pin voltage is roughly 140 mV per amp of output current when the CS_DIS pin is low or disconnected. The current sense reading is more accurate at higher currents. The CS pin is designed for PWM frequencies of 5 kHz or higher. If you use a PWM frequency lower than 5 kHz and want to measure the current, we recommend adding an extra capacitor between the CS pin and GND to smooth out the signal. For example, if you use a PWM frequency of 490 Hz and want to measure the current, you should add a 1 µF capacitor (or larger) between CS and GND. (Note that while the CS voltage can potentially exceed 3.3 V at high currents, the current sense circuit should be safe for use with many 3.3V analog inputs. Most MCUs have integrated protection diodes that will clamp the input voltage to a safe value, and since the CS circuit has a 10 kΩ resistor in series with the output, only a few hundred microamps at most will flow through that diode.)
ENA/DIAGA	HIGH	Combination enable input/diagnostic output for half-bridge A. When the driver is functioning normally, this pin acts as an enable input, with a logical high enabling half-bridge A and a logical low disabling half-bridge A. When a driver fault occurs, the IC drives this pin low and half-bridge A is disabled. This pin is connected to VDD through a pull-up resistor on the board.
ENB/DIAGB	HIGH	Combination enable input/diagnostic output for half-bridge B. See the description of ENA/DIAGA.
CS_DIS	LOW	Disables the current sense output, CS, when high. Can be left disconnected in most applications.

# Regenerative Braking in Electric Cars

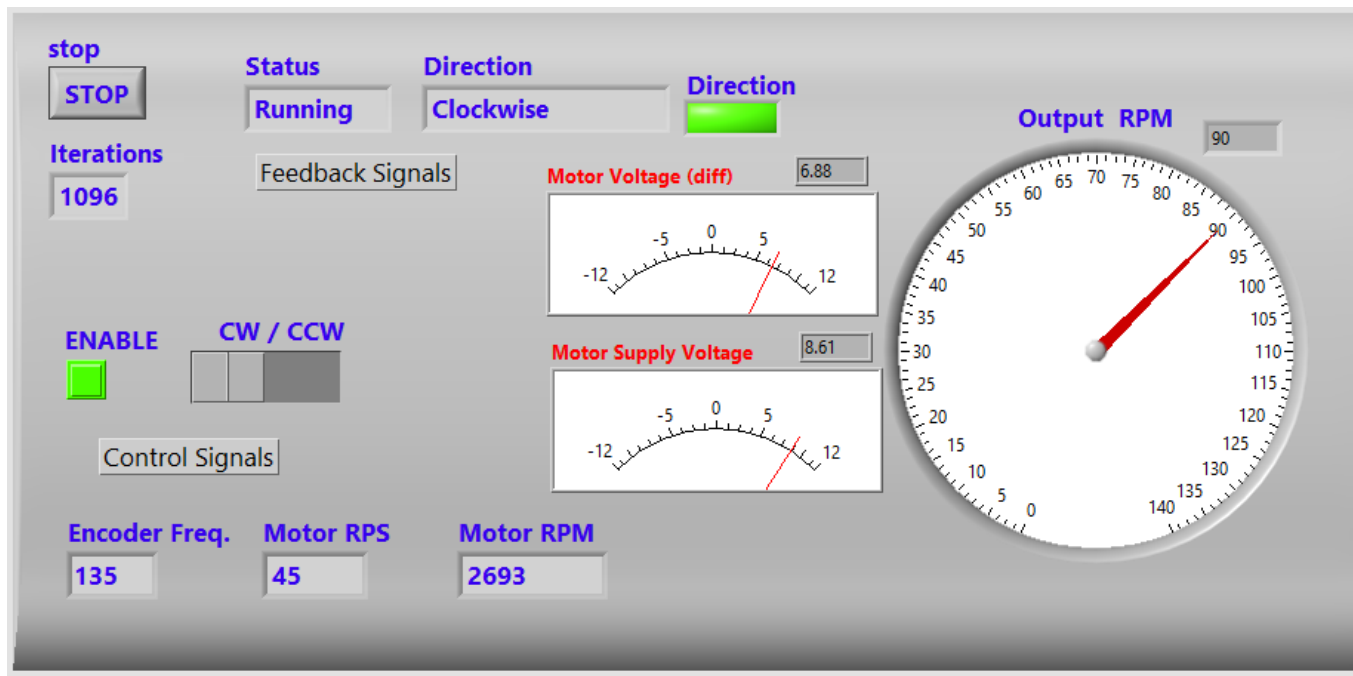


e-Pedal: Easy driving using only the accelerator pedal

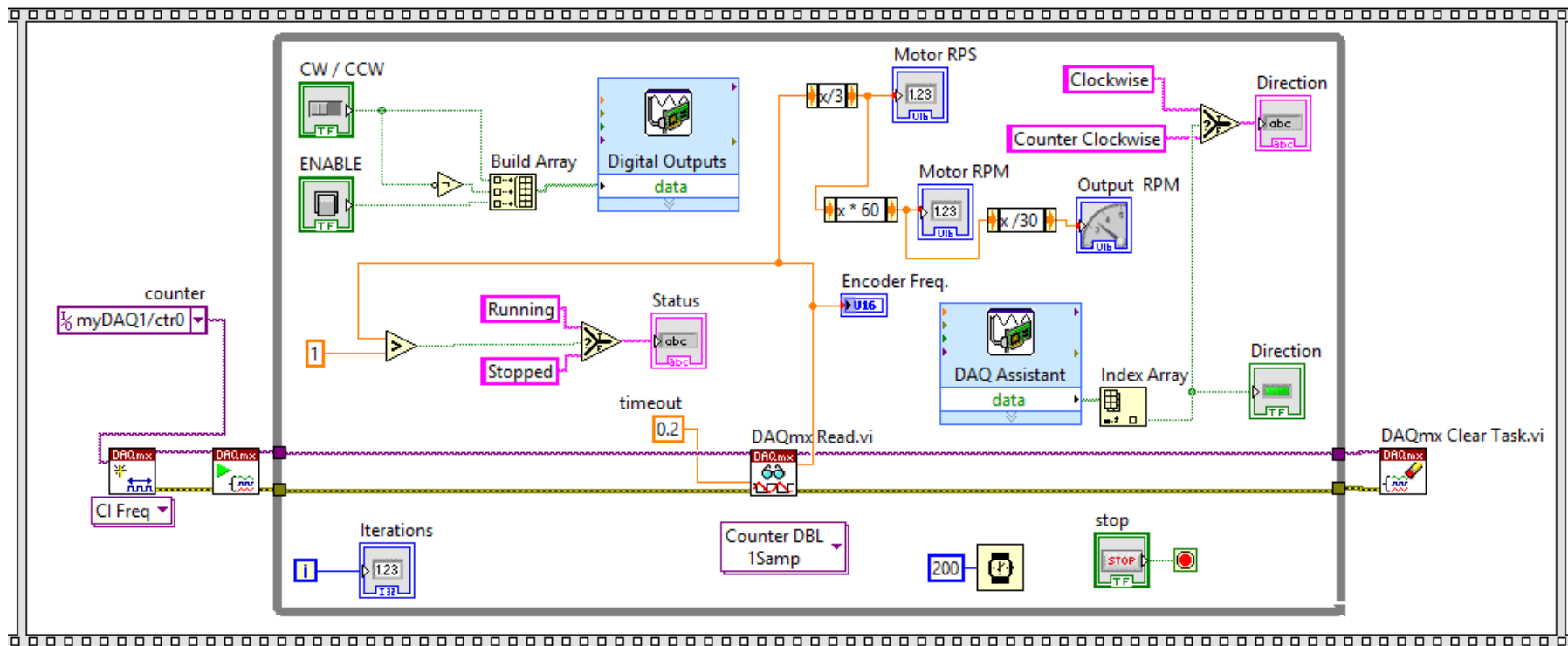
# myDAQ Motor Speed LabVIEW Front Panel



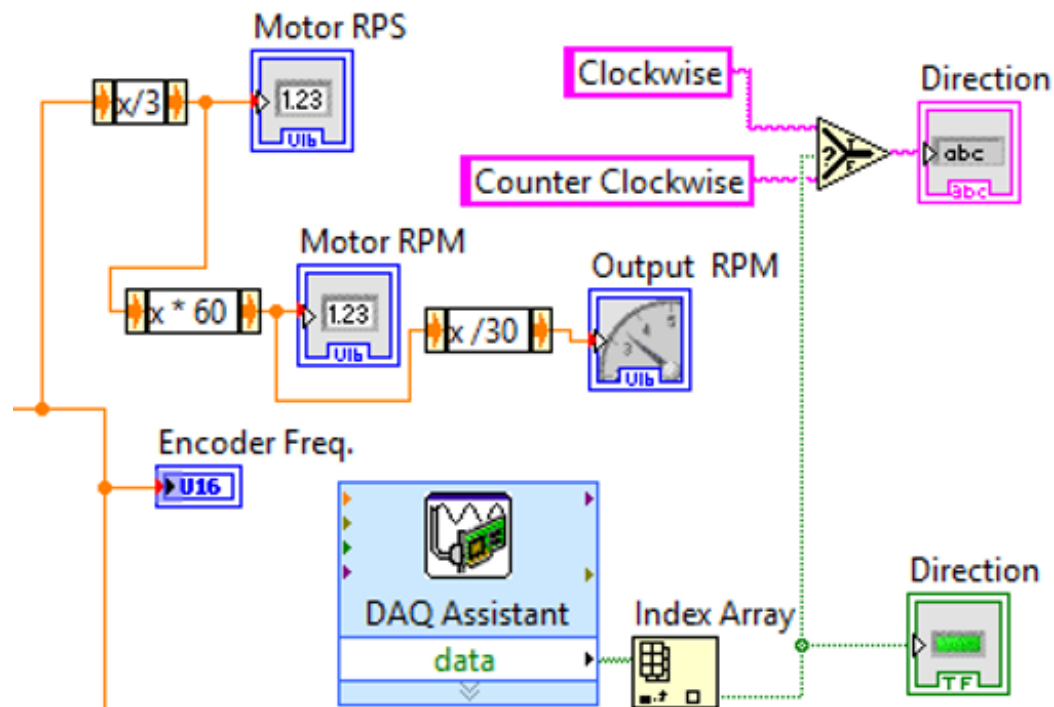
# myDAQ Motor Speed LabVIEW Front Panel



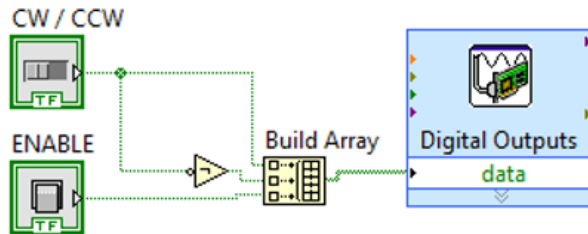
# Motor Direction and speed Feedback



# Motor Direction and speed Feedback



## L293 Control Signals



This section of the VI controls the direction of the motor and enables and disables the driver.

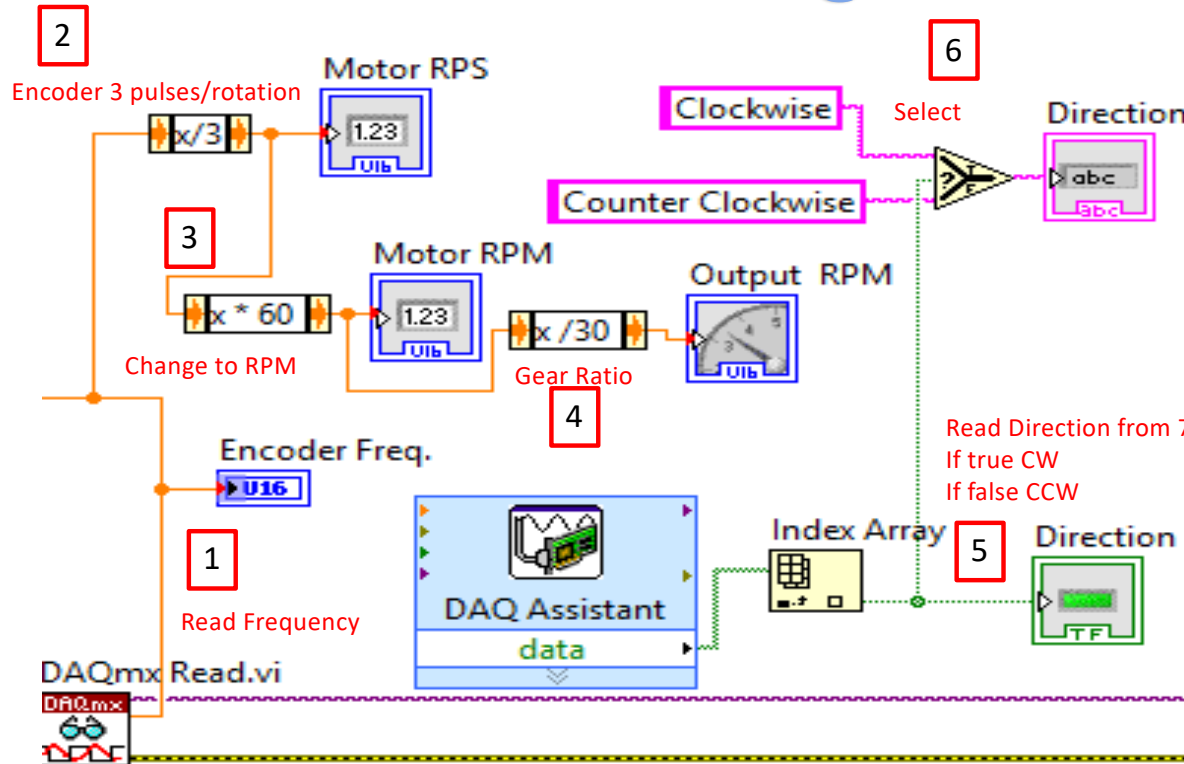
The signals connect to IN1 and IN2 on the L293 motor controller.

### Channel Settings

	Order	Physical Channel
Digital Output		
In1	0	myDAQ1/port0/line5
in2	1	myDAQ1/port0/line6
EN	2	myDAQ1/port0/line7

EN (EIO0) Pin 1	IN1 (EIO1) Pin 2	IN2 (EIO2) Pin 7	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)

# LabVIEW Block Diagram Lab 6



- 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.