PWM and Motors

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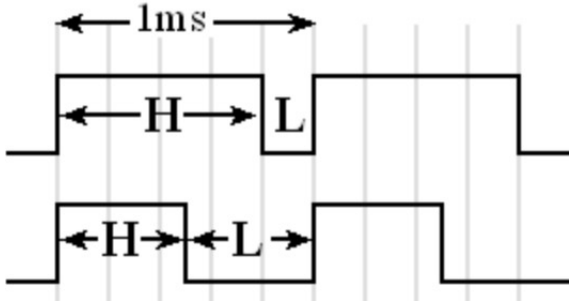
Outline

- Introducing PWM
- How to generate PWM signals
- Applications of PWM Signals
- Three Motors
- Servo Motor
- DC Motor

Introducing PWM

- PWM (pulse width modulation) is used to vary the **delivered power** in a variable manner.
- The basic idea of PWM is to create a digital output wave of **fixed frequency**, but allow the microcontroller to **vary** its **duty cycle**, which varies from 0 to 1 or 0-100%
- The **duty cycle** is defined as the fraction of time the signal is high:

$$duty\ cycle = \frac{High}{High + Low}$$



PWM and Delivered Power

- Choice of frequency: needs to be high enough so that the DC motor does not start/stop with each individual pulse; the LED shows steady light instead of blinking.
- Calculate delivered power.
  Delivered Power = Duty Cycle × P
  = (High/(High+Low)) × VI
- The delivered power of a PWM signal is linearly related to its duty cycle and is independent of its frequency.

How to Generate PWM Signals

- Using a hardware timer
  - Systick
- Use a PWM Module
  - PWM modules are available on some microcontroller.
  - Only dedicated I/O pins can be used to output PWM signals.

Generating PWM Signals Using a Timer

- Use SysTick timer to generate two timing:
  Duty cycle vs. Non-Duty cycle.
- Declare two variables to keep track of the reload values
  of duty cycle and non-duty cycle: L & H
- SysTick handler: toggle output between duty cycle and non-duty cycle

```
86 unsigned long H,L;
87 void SysTick_Handler(void){
88   if(GPIO_PORTA_DATA_R&0x20){    // toggle output
89     GPIO_PORTA_DATA_R &= ~0x20; // make PA5 low
90     NVIC_ST_RELOAD_R = L-1;     // reload value for low phase
91   } else{
92     GPIO_PORTA_DATA_R |= 0x20;  // make PA5 high
93     NVIC_ST_RELOAD_R = H-1;     // reload value for high phase
94   }
95 }
```

Applications for PWM Signals

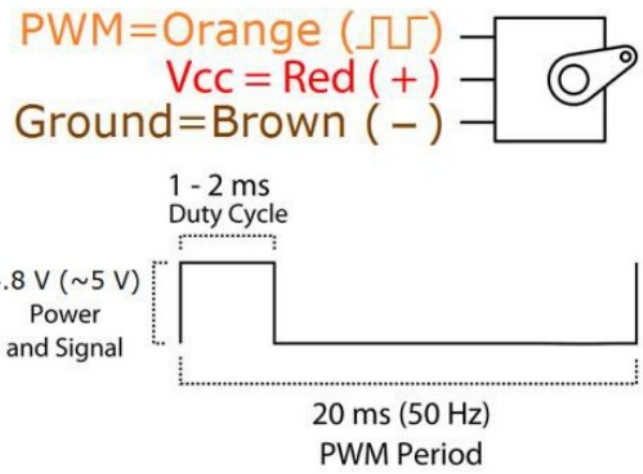
- Use PWM signal to control servo movement: duty cycle determines turning angle.
- Use PWM signal to control a DC motor: duty cycle controls the speed of a DC motor.
- Use PWM signal to control an LED: duty cycle control the brightness of an LED.

Motors

- DC Motors
  - Fast, continuous rotation motors – Used for anything that needs to spin at a high RPM e.g. car wheels, fans, etc.
- Stepper Motors
  - Slow, precise rotation, easy set up & control. Suited for 3D printers and similar devices where position is fundamental.
- Servo Motors
  - Fast, high torque, accurate rotation within a limited angle. Suited for robotic arms/legs or rudder control, etc.

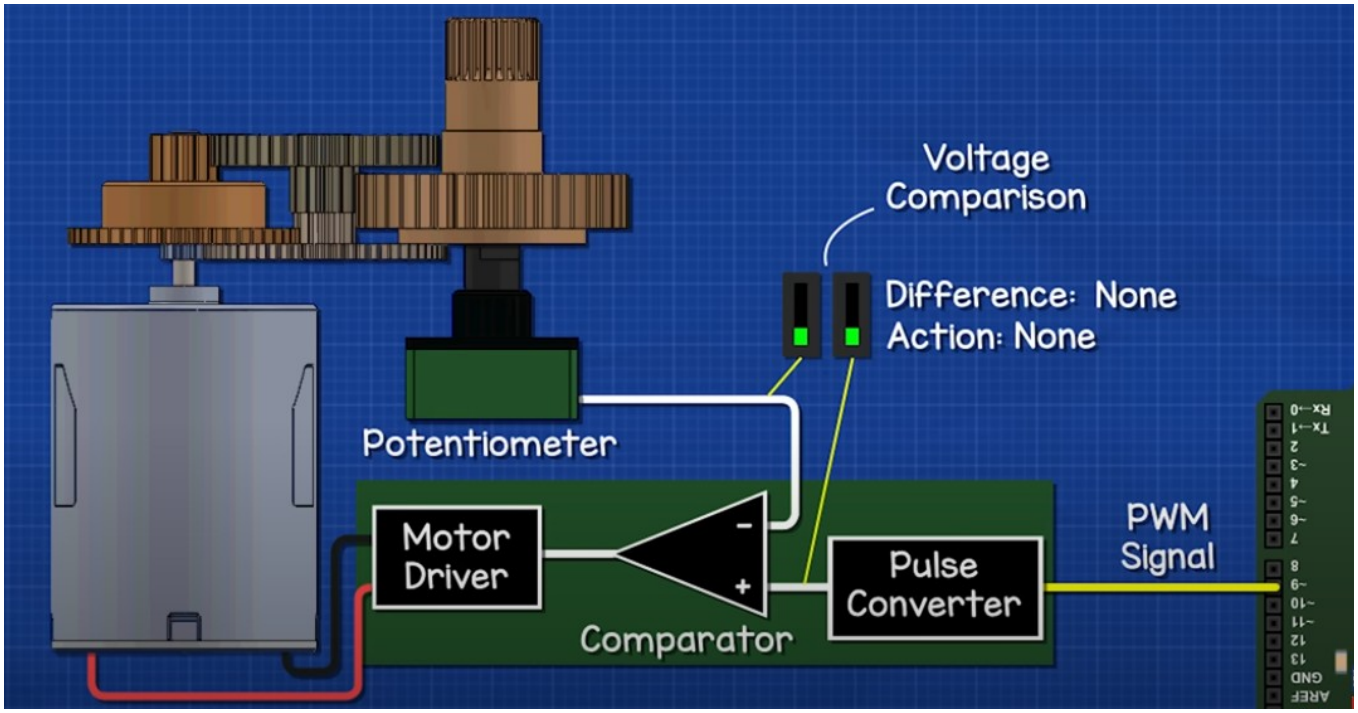
Servo Motor SG90

- Control Using a PWM Signal of 50Hz or 20ms period
- Can rotate approximately 180 degree (90 in each direction)
- Duty Cycle determines angular position: in-between 0.5ms-2.5ms or 2.5%-12.5%
- Higher duty cycle moves to motor to CCW, lower duty cycle moves the servo CW
- Voltage: 4.8 - 6V.



Angle	Duty Cycle
Center	1.5ms
CW 45 degree	1.0ms
CCW 45 degree	2.0ms
CW 90 degree	0.5ms
CCW 90 degree	2.5ms

How Servo Motor Works



Watch a video here .

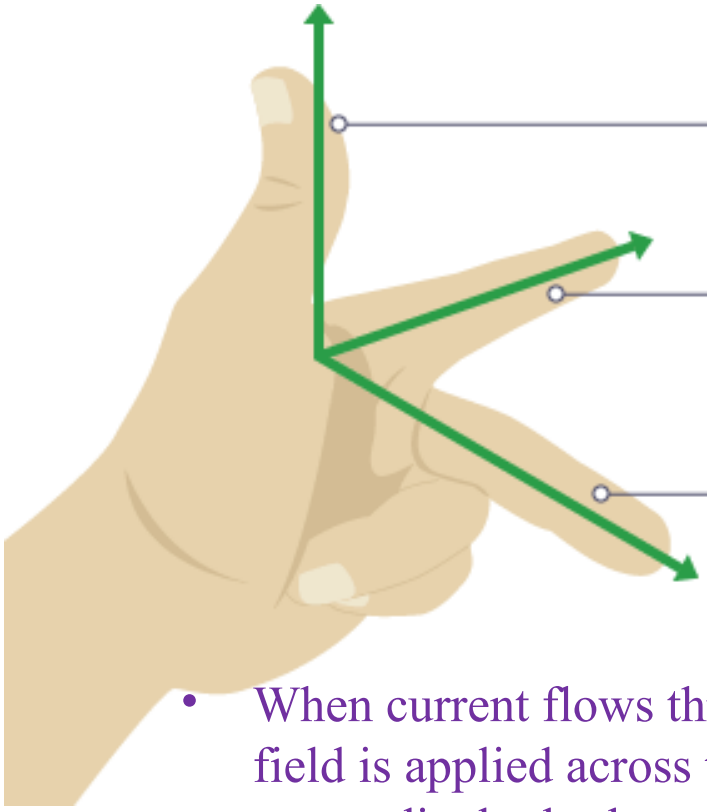
- A servo motor consists of a DC motor and motor driver, a comparator, a pulse converter, a potentiometer and multiple gears.
- The potentiometer connects to the final gear of the motor.
- The PWM signal is converted to a voltage by a pulse converter and passes through a comparator and then to a motor driver.
- The comparator is used to compare the potentiometer output with the pulse converter output.
- The motor will turn until the difference of the two outputs are close to zero.

DC Motors

- Two wire (power & ground) analog motors with continuous rotation.
- When power is supplied, it will start spinning until that power is removed.
- The motor's RPM is proportional to the voltage input: It is how fast (angular velocity) the output shaft will rotate when nothing is connected to it.
- The speed of DC motors is controlled using pulse width modulation (PWM), a technique of rapidly pulsing the power on and off.
- The duty cycle of PWM determines the speed of the motor:
  - Ex: if the power is cycled at 50% (half on, half off), then the motor will spin at half the speed of 100% (fully on).

The Lorentz Force and Fleming's Left Hand Rule

The **Lorentz Force** is the **force** on a charged particle due to electric and magnetic fields.

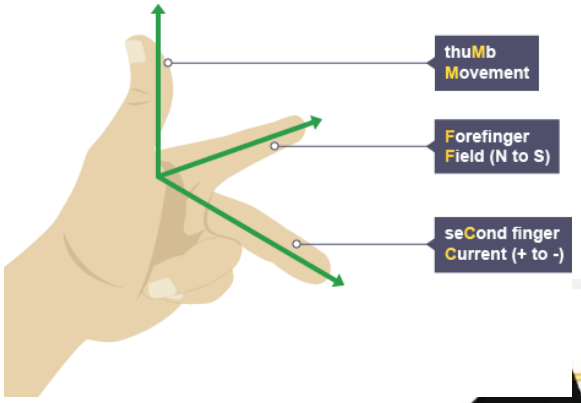


thuMb Movement — thumb points along the direction of the force experienced by the charged particle.

Forefinger Field (N to S) — forefinger points along the direction of the field a positively charged particle is moving through.

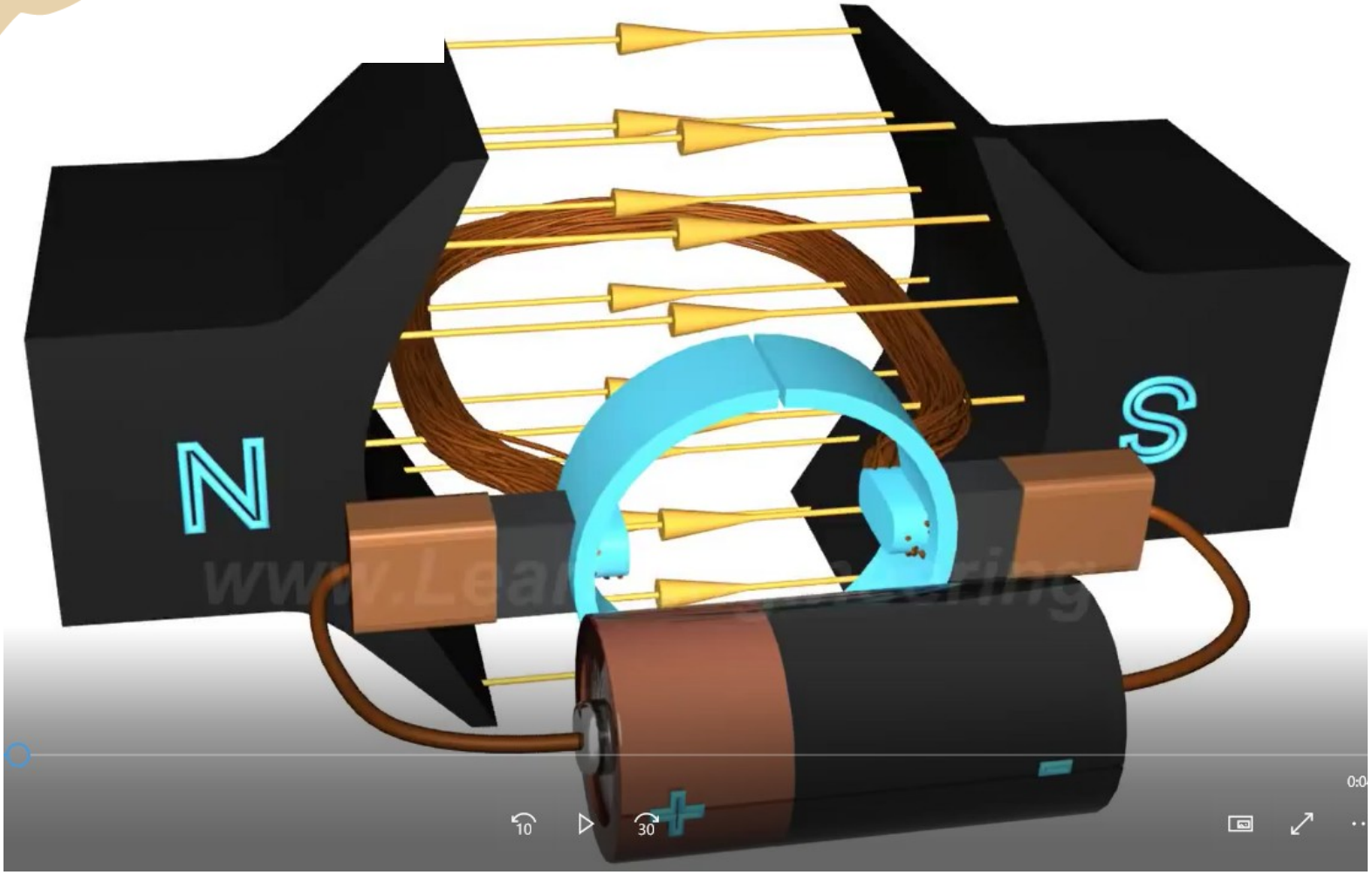
seCond finger Current (+ to -) — middle finger in the direction of current flow from positive to negative.

- When current flows through a conducting wire, and an external magnetic field is applied across that flow, the conducting wire experiences a force perpendicular both to that field and to the direction of the current flow.
- The direction of the force experienced by the particle is given by Fleming's Left Hand Rule.



How DC Motor Works

youtube video here.



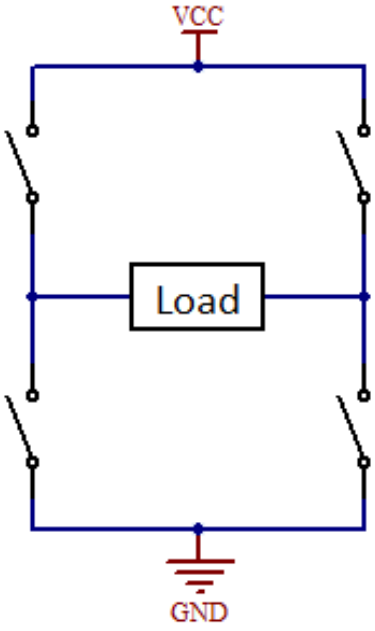
Control DC Motor with PWM

- Apply PWM wave to the DC Motor: power is applied to the motor when the signal is high, and no power is applied when the signal is low.
- Choose a frequency high enough so the DC motor does not start/stop with each individual pulse.
- The average value of a PWM signal is linearly related to its duty cycle and is independent of its frequency.
- PWM is a very effective mechanism, allowing the microcontroller to adjust delivered power.
  Delivered Power = Duty Cycle × P
  = (High/(High+Low)) × VI

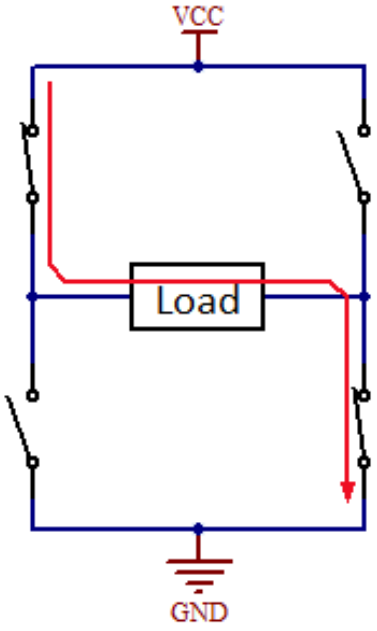
H-Bridge

- An *H bridge* is an electronic circuit that enables a voltage to be applied across a load in either direction. These circuits are often used in robotics and other applications to allow DC motors to run forwards or backwards.

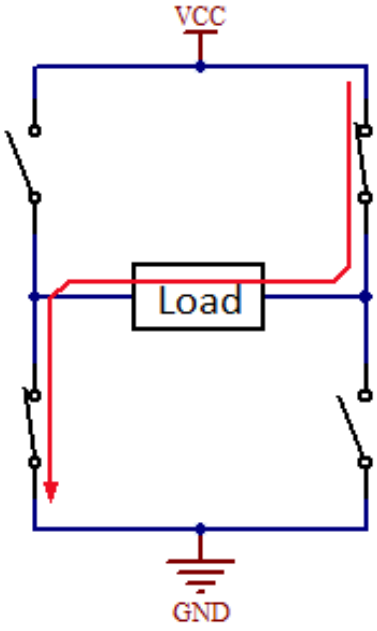
H bridge topology



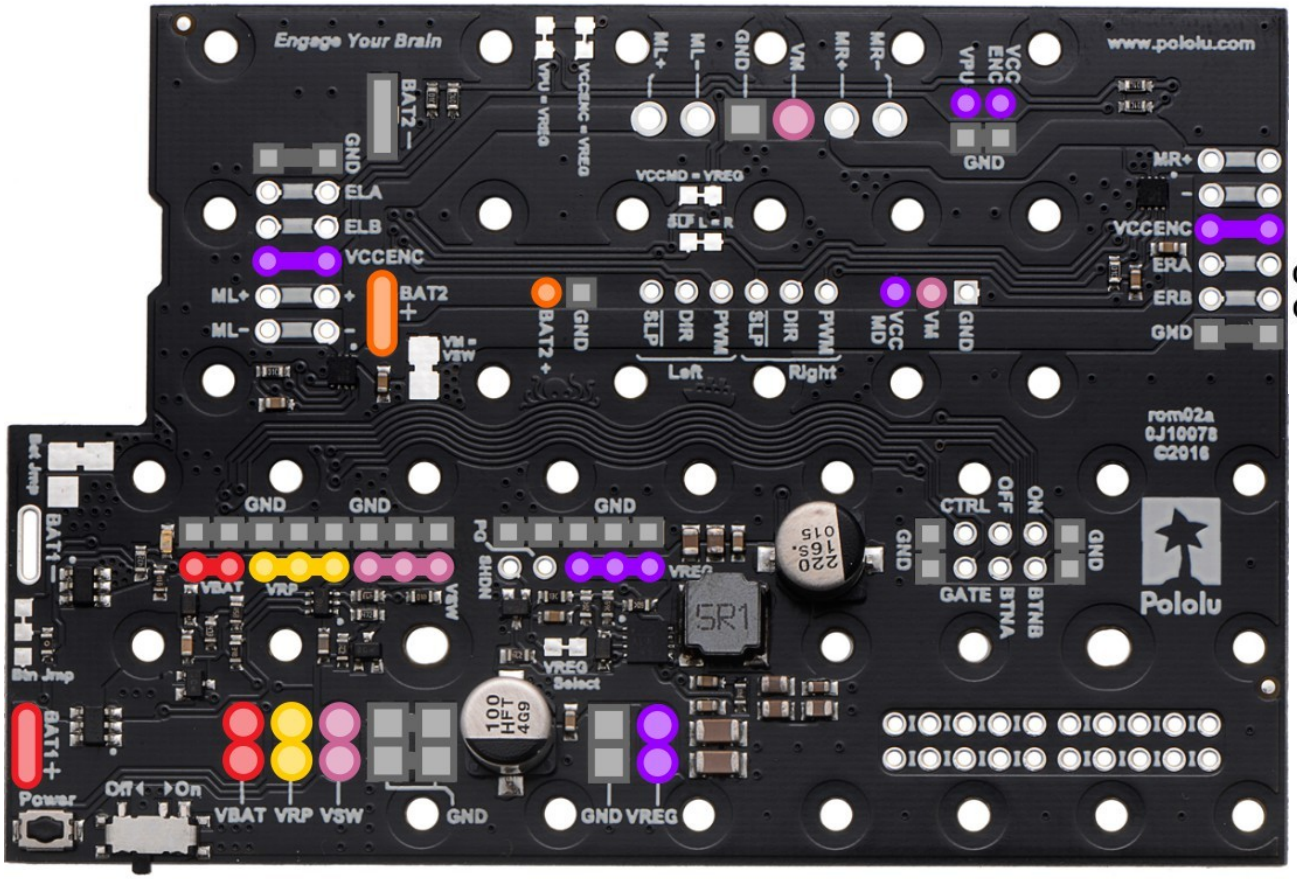
Connecting the load in one direction

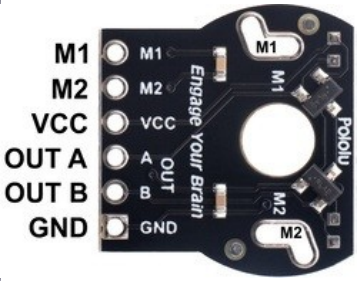


Connecting the load in the other direction



Power Board For Romi Chassis

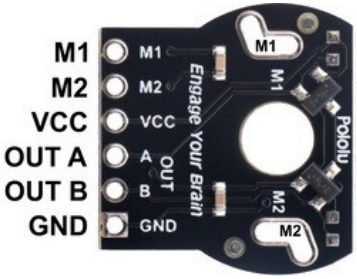




VCC is connected to VCCENC, which is connected to VREG (5v) regulated power supply.

- **VBAT** (BAT1+)
- **VRP** (after reverse protection)
- **VSW** (after switch)
- **VREG** (regulator output)
- **BAT2+**
- **Ground** (0 V)

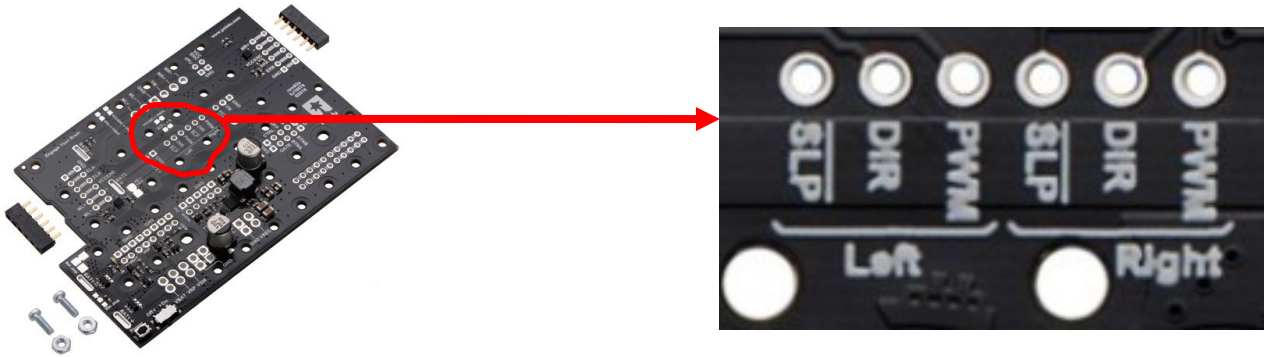
Motor Encoder



Encoder Pins	Description
M1	Drives motor forward, used when DIR pin on power board is 1
M2	Drives motor backward, used when DIR pin on power board is 0
VCC	Intended for 4.5V, can be used in a range of 3V-6V
OUT A*	Generate square wave
OUT B*	Generate square wave
GND	GND

- ❑ VCC is connected to VCCENC, which is connected to VREG (5v) regulated power supply.
- ❑ OUT A and OUT B are used to determine speed and direction based on phase difference

Power Board

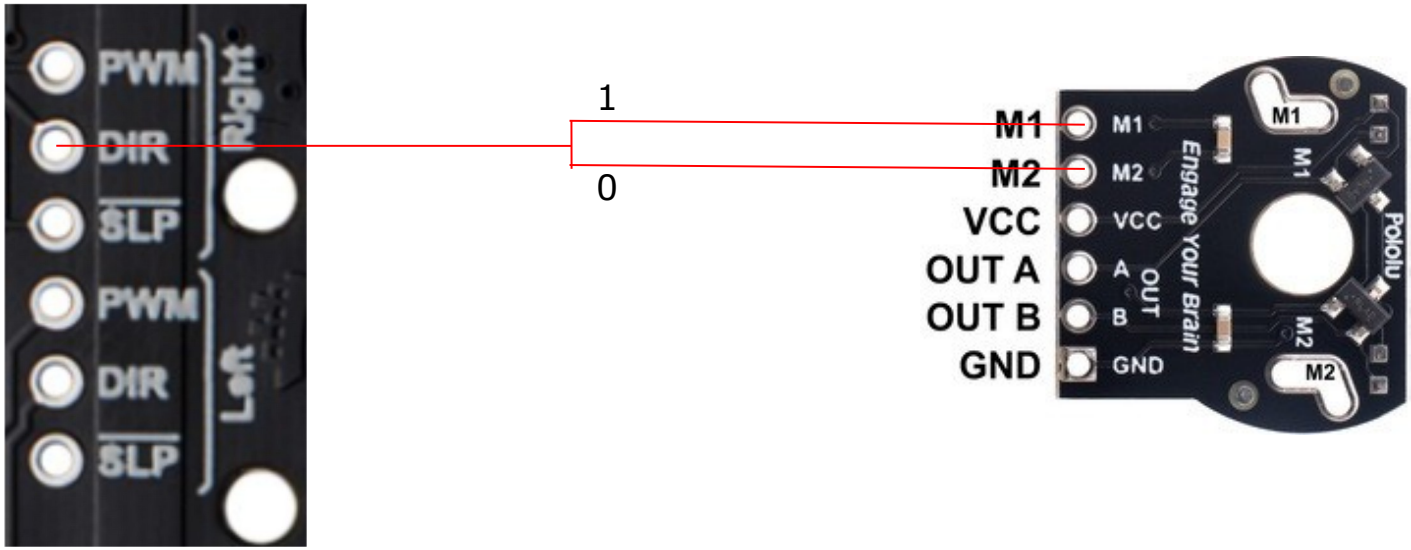


Pins	Description
SLP	Puts motor driver into low power mode when driven low. Both SLP pins are pulled high through 10 kΩ pull-up resistors on the board so that the drivers are awake by default. In most applications, these pins can be left disconnected.
DIR	Controls motor direction High/1 = Forward Low/0 = Backward
PWM	Controls motor speed, when PWM is 0 it will short the motor to GND preventing movement

The following simplified truth table shows how each driver operates:

DIR	PWM	$\overline{\text{SLEEP}}$	Motor +	Motor −	operating mode
0	PWM	1	PWM	L	forward/brake at speed *PWM %*
1	PWM	1	L	PWM	reverse/brake at speed *PWM %*
X	0	1	L	L	brake low (outputs shorted to ground)
X	X	0	Z	Z	coast (outputs floating/disconnected)

Board and Encoder Connection



- The DIR pin controls the H-Bridge, dictating the current flow direction through the motor. When DIR is 1, the motor is driven forward via the M1 connection. When DIR is 0, the motor is driven backward via the M2 connection.
- The H-Bridge output connects to motor terminals M1 and M2, which are also linked to the encoder for speed and direction sensing

References

- Motor driver and power board: https://www.pololu.com/product/3543
- Servo motor SG90 Datasheet: http://www.ee.ic.ac.uk/pcheung/teaching/DE1_EE/stores/sg90_datasheet.pdf
- How DC motor works: https://www.youtube.com/watch?v=LAtPHANEfQo
- How servo motor work: https://www.youtube.com/watch?v=1WnGv-DPexc
- Example Projects:

  Servo_Motor, Systick_PWM_Car.