

# H-BRIDGE MOTOR CONTROL CIRCUIT

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# 1 Motor Manufacturer Specifications

## 1.1 RS-775126000E7 Motor

PG27 RS775-125 Motor with Encoder

The test motor was purchased here: [www.andymark.com](http://www.andymark.com) (PG27 RS775-125 Motor with Encoder)

### Product Overview

This motor is the same motor included in our PG27 Gearmotor, and is being sold with the intention of replacing the motor without having to purchase the gearbox as well. This motor comes with the pinion gear and encoder attached and also includes the 2 mounting screws.

The back shaft of this motor features our Hall Effect Encoder, which can be removed if your application needs the long back shaft.

This motor, without the encoder, is am-2766, and is similar to am-2194, (same motor slightly shorter shaft). Both of these base motors are called out in the FIRST Robotics Competition manual as being legal for use in 2022.

Encoder Pinout:

- Pin 1: 5V DC
- Pin 2: Ground
- Pin 3: Channel A Output
- Pin 4: Channel B Output

### Specifications

- Back Shaft Diameter: 0.2 in.
- Back Shaft Length: 0.45 in.
- No Load RPM: 5700 RPM
- Pulses Per Revolution: 7
- Shaft Diameter: 0.125 in.
- Stall Current: 15-20 AMPs
- Stall Torque: 35 oz-in
- Teeth: 11
- Voltage: 12 Volts DC
- Wattage: 44
- Weight: 0.86 lbs.

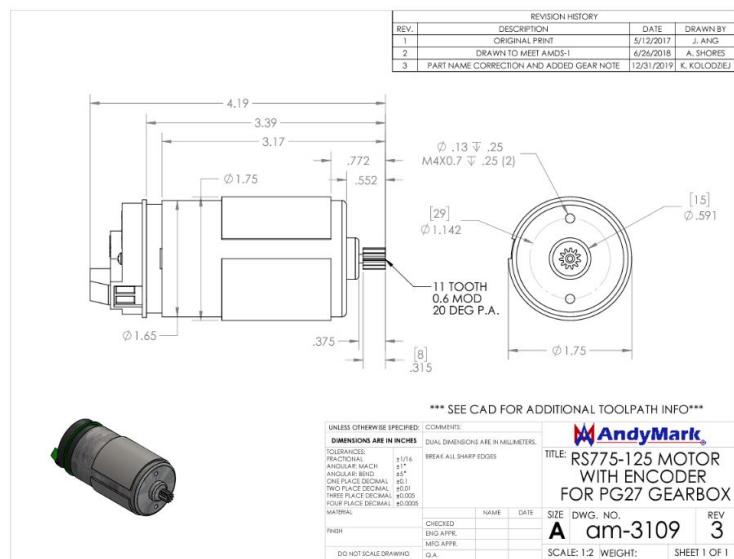


Figure 1: RS-775126000E7 Dimensions

Motor dimensions pdf can be downloaded here: [www.andymark.com](http://www.andymark.com) (layout prints PG27 RS775-125 Motor with Encoder)

## 1.2 TS-25GA370H-20 Motor

Encoder Metal Gearmotor 12V DC High Speed 300RPM Gear Motor with Encoder for Arduino and 3D Printers

The test motor was purchased here: [www.amazon.com \(Encoder Metal Gearmotor 12V DC High Speed 300RPM Gear Motor with Encoder for Arduino and 3D Printers\)](http://www.amazon.com/Encoder-Metal-Gearmotor-12V-DC-High-Speed-300RPM-Gear-Motor-with-Encoder-for-Arduino-and-3D-Printers)

**Product type:** DC Gear motor with two-channel Hall effect encoder

- Rated Voltage: 12V
- No-Load Speed: 300RPM
- No-Load Current:  $\leq 0.15A$
- Rated Torque: 0.5kg.cm
- Single Output 240 Pulses Per Revolution
- Gear Reduction Ratio: 1/20
- Each Loop Output Pulses: 12PPR  $20 \times 12 = 240$ PPR

Wiring Diagram

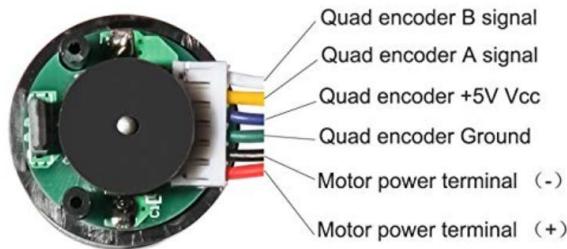


Figure 2: TS-25GA370H-20 Wiring

**Motor Dimensions:**

- Main Body: 66 x 25mm / 2.6in x 0.99in (L\*D)
- Out Shaft: 11 x 4mm / 0.433 x 0.1575in (L\*D) with 10 x 0.5mm / 0.39 \* 0.017inches flat cut off

Dimensional drawing



Figure 3: TS-25GA370H-20 Dimensions

## 2 RS-775126000E7

### 2.1 RS-775126000E7 Initial Test Data

Table 1: RS-775126000E7 Initial Test Data

DC Voltage	DC Current	Power	RPM	Encod Freq	Resolution
12V	680mA	8.16W	5,500 RPM	641.0hz	51.48°
11V	660mA	7.26W	5,037 RPM	602.4hz	50.17°
10V	630mA	6.30W	4,545 RPM	537.6hz	50.73°
9V	620mA	5.58W	4,064 RPM	480.8hz	50.72°
8V	600mA	4.80W	3,600 RPM	434.8hz	49.68°
7V	580mA	4.06W	3,155 RPM	370.4hz	51.107°
6V	510mA	3.06W	2,728 RPM	310.6hz	52.70°
5V	496mA	2.48W	2,200 RPM	252.5hz	52.28°
4V	470mA	1.88W	1,700 RPM	201.6hz	50.60°
3V	460mA	1.38W	1,196 RPM	139.7hz	51.37 °
2V	434mA	868mW	701.0 RPM	82.64hz	50.90°
1V	430mA	430mW	222.0 RPM	23.58hz	56.68°
Average Measured Resolution					51.53°

### 2.2 Step Resolution Using Measured Values

#### 2.2.1 Resolution at 12VDC

Measured Frequency = 641.0hz or cycles per second

Measured RPM = 5,500RPM or revolutions per minute

Convert RPM to revolutions per second

$$RPS = \frac{RPM}{60} = \frac{5,500}{60} = 91.667 RPS$$

Set cycles per second equal to revolutions per second and solve for the resolution per clock cycle.

$$\frac{641 \text{cycles}}{\text{Second}} = \frac{91.667 \text{revolutions}}{\text{Second}}$$

$$641 \text{cycles} = 91.667 \text{revolutions}$$

$$1 \text{cycle} = \frac{91.667 \text{revolutions}}{641} = 0.143 \text{revolutions}$$

Convert revolutions to degrees

$$1 \text{rev} = 360^\circ$$

$$1 \text{cycle} = \frac{91.667 \text{revolutions}}{641} = 0.143 \times 360^\circ = 51.48^\circ$$

Final Formula for converting measured RPM and Frequency to Step Resolution:

$$\text{Step Resolution} = \left( \frac{\text{RPM}}{\text{Frequency}} \times 6 \right)^\circ \quad (1)$$

## 2.3 Step Resolution Using Manufacturers Data

The manufacturer specification states "Pulses Per Revolution: 7".

$$7 \text{ counts} = 1\text{rev}$$

Convert revolutions to degrees

$$7 \text{ counts} = 360^\circ$$

Solve for resolution per count or step

$$1 \text{ count} = \frac{360^\circ}{7} = 51.43^\circ$$

$$\text{Manufacturer Step Resolution} = 51.43^\circ \text{ per step} \quad (2)$$

The manufacturer step resolution of  $51.43^\circ$  per step is consistent with the average measured step resolution of  $51.53^\circ$ .

## 2.4 RS-775126000E7 Encoder Waveforms

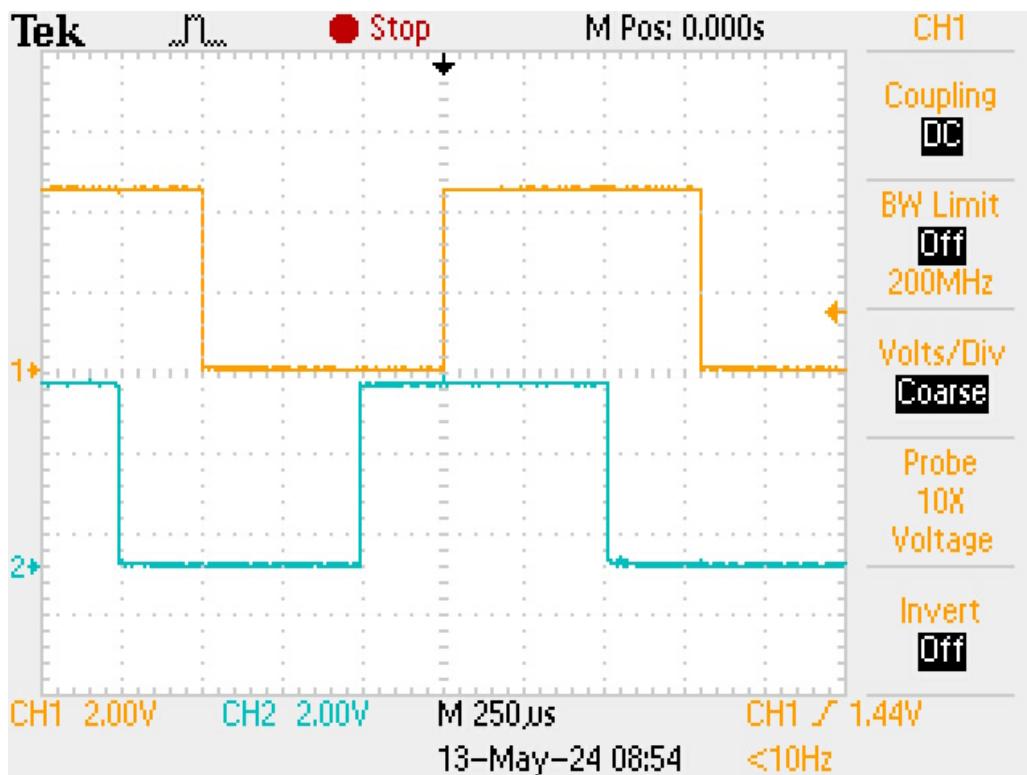


Figure 4: RS-775126000E7 Encoder Waveforms

### 3 TS-25GA370H-20

#### 3.1 TS-25GA370H-20 Initial Test Data

Table 2: TS-25GA370H-20 Initial Test Data

<b>DC Voltage</b>	<b>DC Current</b>	<b>Power</b>	<b>RPM</b>	<b>Encod Freq</b>	<b>Resolution</b>
12V	78.2mA	938mW	276.5 RPM	1.111Khz	1.493°
11V	66.6mA	733mW	254.7 RPM	1.064Khz	1.436°
10V	61.5mA	615mW	231.1 RPM	980.4hz	1.414°
9V	56.4mA	508mW	210.1 RPM	862.1hz	1.462°
8V	51.0mA	408mW	185.3 RPM	757.6hz	1.468°
7V	47.3mA	331mW	161.4 RPM	657.9hz	1.472°
6V	43.6mA	262mW	138 RPM	574.7hz	1.441°
5V	40.1mA	201mW	114 RPM	480.0hz	1.425°
4V	36.4mA	145.6mW	90.1 RPM	373.1hz	1.449°
3V	32.2mA	96.6mW	67.5 RPM	285.7hz	1.418°
2V	28.8mA	57.6mW	44.3 RPM	177.3hz	1.499°
1V	22.0mA	22.0mW	19.3 RPM	79.37hz	1.459°
Average Measured Resolution					1.435°

##### 3.1.1 Resolution at 12VDC

Measured Frequency = 1.111Khz or cycles per second

Measured RPM = 276.5RPM or revolutions per minute

Convert RPM to revolutions per second

$$RPS = \frac{RPM}{60} = \frac{276.5}{60} = 4.608RPS$$

Set cycles per second equal to revolutions per second and solve for the resolution per clock cycle.

$$\frac{1.111Kcycles}{Second} = \frac{4.608revolutions}{Second}$$

$$1.111Kcycles = 4.608revolutions$$

$$1cycle = \frac{4.608revolutions}{1.111K} = 4.148 \times 10^{-3}revolutions$$

Convert revolutions to degrees

$$1rev = 360^\circ \text{ & } 1cycle = 4.148 \times 10^{-3}revolutions$$

$$1cycle = 4.148 \times 10^{-3} \times 360^\circ = 1.493^\circ$$

Final Formula for converting measured RPM and Frequency to Step Resolution:

$$Step\ Resolution = \left( \frac{RPM}{Frequency} \times 6 \right)^\circ \quad (3)$$

### 3.2 Step Resolution Using Manufacturers Data

The manufacturer specification states "Single Output 240 Pulses Per Revolution".

$$240 \text{ counts} = 1\text{rev}$$

Convert revolutions to degrees

$$240 \text{ counts} = 360^\circ$$

Solve for resolution per count or step

$$1 \text{ count} = \frac{360^\circ}{240} = 1.5^\circ$$

$$TS25GA370H20 \text{ Manufacturer Step Resolution} = 1.5^\circ \text{ per step} \quad (4)$$

The manufacturer step resolution of  $1.5^\circ$  per step is consistent with the average measured step resolution of  $1.435^\circ$ .

### 3.3 TS-25GA370H-20 Encoder Waveforms

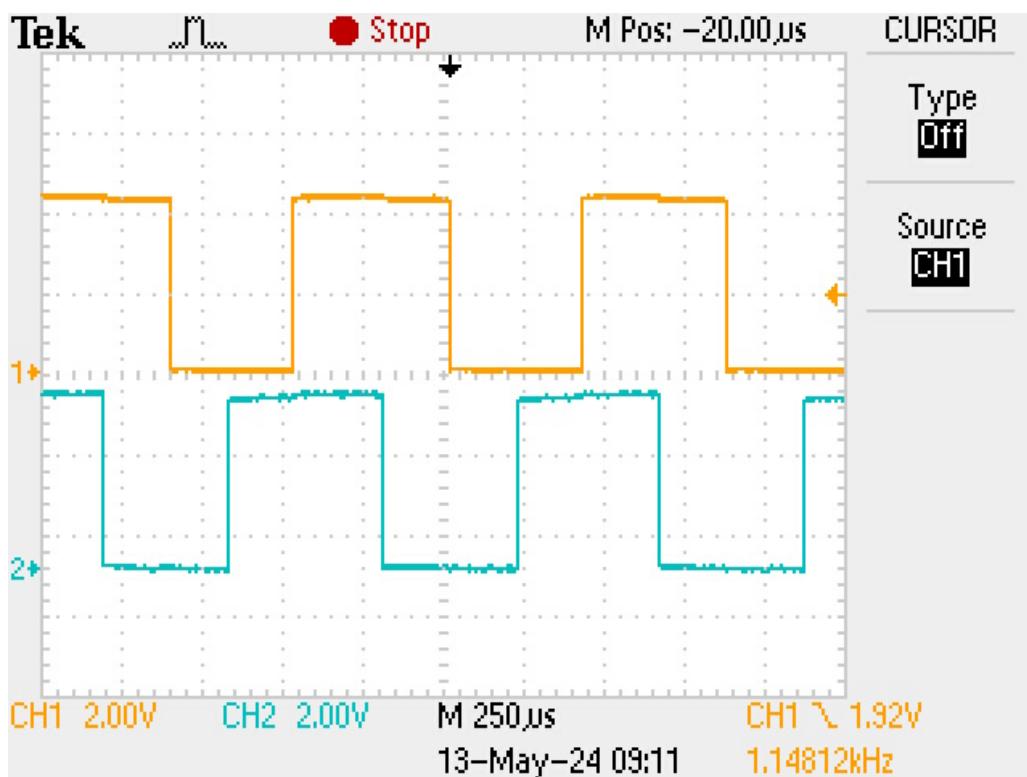


Figure 5: TS-25GA370H-20 Encoder Waveforms

## 4 Discrete H-Bridge Development

### 4.1 Switching Ground (N-Channel MosFET)

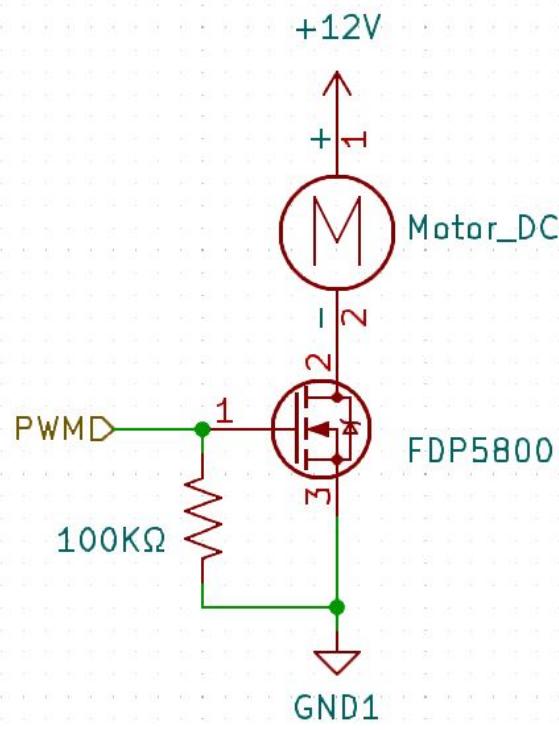


Figure 6: PWM Test Circuit (N-Channel MosFET)

Table 3: N-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
5Khz	4V	0V	99%	5454 RPM	284 RPM
5Khz	4V	0V	90%	4792 RPM	270 RPM
5Khz	4V	0V	80%	4365 RPM	234 RPM
5Khz	4V	0V	70%	3887 RPM	178 RPM
5Khz	4V	0V	60%	3220 RPM	113 RPM
5Khz	4V	0V	50%	2420 RPM	55 RPM
5Khz	4V	0V	40%	1400 RPM	22 RPM

## 4.2 Opto-Isolation, Switching 12V (P-Channel MosFET)

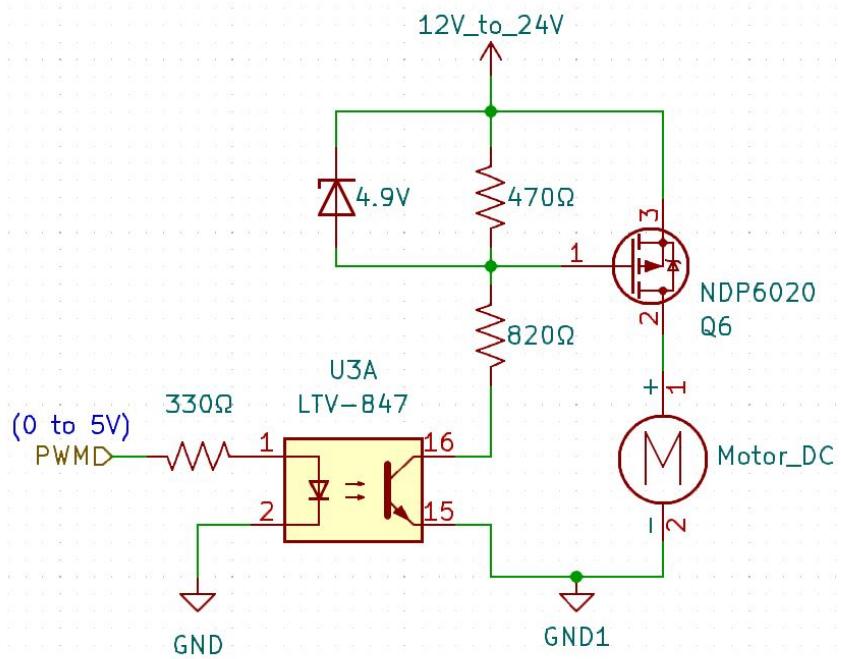


Figure 7: PWM Test Circuit (Opto-Isolated P-Channel MosFET)

Table 4: Opto-Isolated, P-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
5Khz	5V	0V	99%	5547 RPM	283 RPM
5Khz	5V	0V	90%	5471 RPM	283 RPM
5Khz	5V	0V	80%	4921 RPM	276RPM
5Khz	5V	0V	70%	4615 RPM	249 RPM
5Khz	5V	0V	60%	4226 RPM	203 RPM
5Khz	5V	0V	50%	3728 RPM	142 RPM
5Khz	5V	0V	40%	3072 RPM	82 RPM
5Khz	5V	0V	30%	2177 RPM	32 RPM
5Khz	5V	0V	20%	1010 RPM	0 RPM

### 4.3 Opto-Isolation, Switching 12V (N-Channel MosFET)

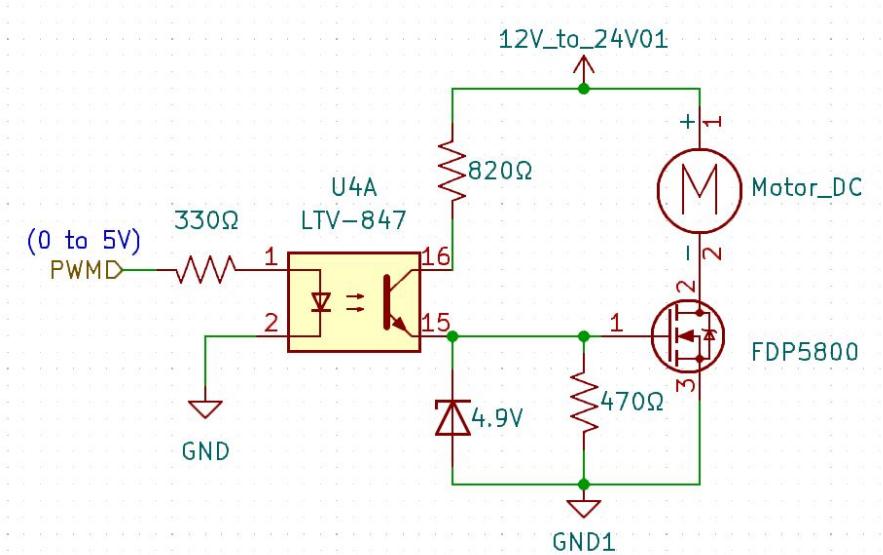


Figure 8: PWM Test Circuit (Opto-Isolated N-Channel MosFET)

Table 5: Opto-Isolated N-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
5Khz	5V	0V	99%	5525 RPM	280 RPM
5Khz	5V	0V	90%	5520 RPM	280 RPM
5Khz	5V	0V	80%	4720 RPM	268 RPM
5Khz	5V	0V	70%	4335 RPM	233 RPM
5Khz	5V	0V	60%	3909 RPM	179 RPM
5Khz	5V	0V	50%	3395 RPM	113 RPM
5Khz	5V	0V	40%	2669 RPM	55 RPM
5Khz	5V	0V	30%	1688 RPM	18 RPM
5Khz	5V	0V	20%	380 RPM	0 RPM

#### 4.4 Opto-Isolation, Switching 12V (N-Channel and P-Channel MosFETs)

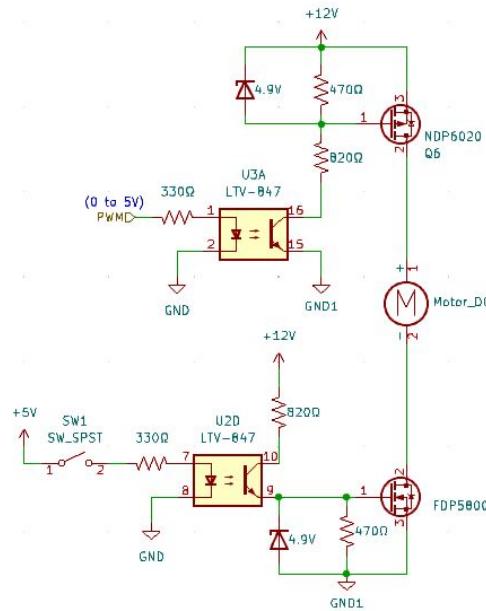


Figure 9: PWM Test Circuit (Opto-Isolated N-Channel and P-Channel MosFETs)

Table 6: Opto-Isolated N-Channel and P-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
2Khz	5V	0V	99%	5563 RPM	275 RPM
2Khz	5V	0V	90%	5264 RPM	272 RPM
2Khz	5V	0V	80%	4939 RPM	260 RPM
2Khz	5V	0V	70%	4800 RPM	232 RPM
2Khz	5V	0V	60%	4508 RPM	186 RPM
2Khz	5V	0V	50%	4033 RPM	128 RPM
2Khz	5V	0V	40%	3396 RPM	73 RPM
2Khz	5V	0V	30%	2467 RPM	31 RPM
2Khz	5V	0V	20%	980 RPM	0 RPM

## 4.5 H-Bridge

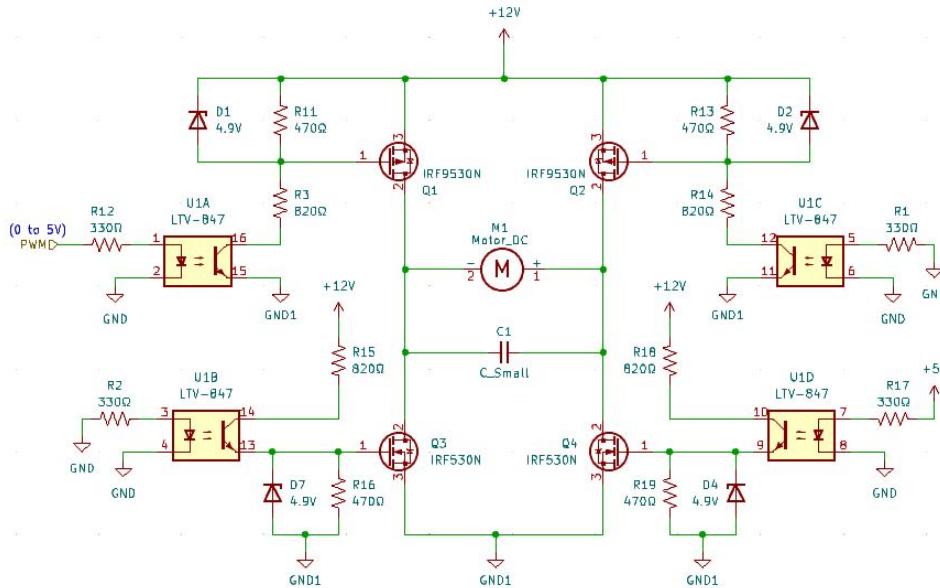


Figure 10: Clockwise Test Circuit

### 4.5.1 Clockwise Test

See Figure 10 verified. With U1B and U1C inputs tied to ground (GND), Q2 and Q3 will be off. With U1D's input tied high, Q4 is on. Applying PWM to U1A provides speed control to the motor via Q1. This configuration will provide speed and direction control "clockwise" or forward.

### 4.5.2 Counter-Clockwise Test

Re-configuring or swapping inputs U1A with U1C and U1B with U1D. The motor turns in the opposite orientation "Counter-Clockwise" or reverse.

Table 7: RS-775126000E7 Discrete H-Bridge PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	CW Forward	CCW Reverse
2Khz	5V	0V	99%	5645 RPM	5525 RPM
2Khz	5V	0V	90%	4941 RPM	4891 RPM
2Khz	5V	0V	80%	4965 RPM	4799 RPM
2Khz	5V	0V	70%	4630 RPM	4530 RPM
2Khz	5V	0V	60%	4310 RPM	4155 RPM
2Khz	5V	0V	50%	3760 RPM	3643 RPM
2Khz	5V	0V	40%	3000 RPM	2795 RPM
2Khz	5V	0V	30%	1922 RPM	1535 RPM
2Khz	5V	0V	20%	480 RPM	0 RPM

Table 8: TS-25GA370H-20 Discrete H-Bridge PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	CW Forward	CCW Reverse
2Khz	5V	0V	99%	288 RPM	290 RPM
2Khz	5V	0V	90%	284 RPM	282 RPM
2Khz	5V	0V	80%	268 RPM	262 RPM
2Khz	5V	0V	70%	238 RPM	226 RPM
2Khz	5V	0V	60%	191 RPM	174 RPM
2Khz	5V	0V	50%	132 RPM	113 RPM
2Khz	5V	0V	40%	70 RPM	57 RPM
2Khz	5V	0V	30%	32 RPM	23 RPM
2Khz	5V	0V	20%	0 RPM	0 RPM

## 4.6 Control Logic and H-Bridge

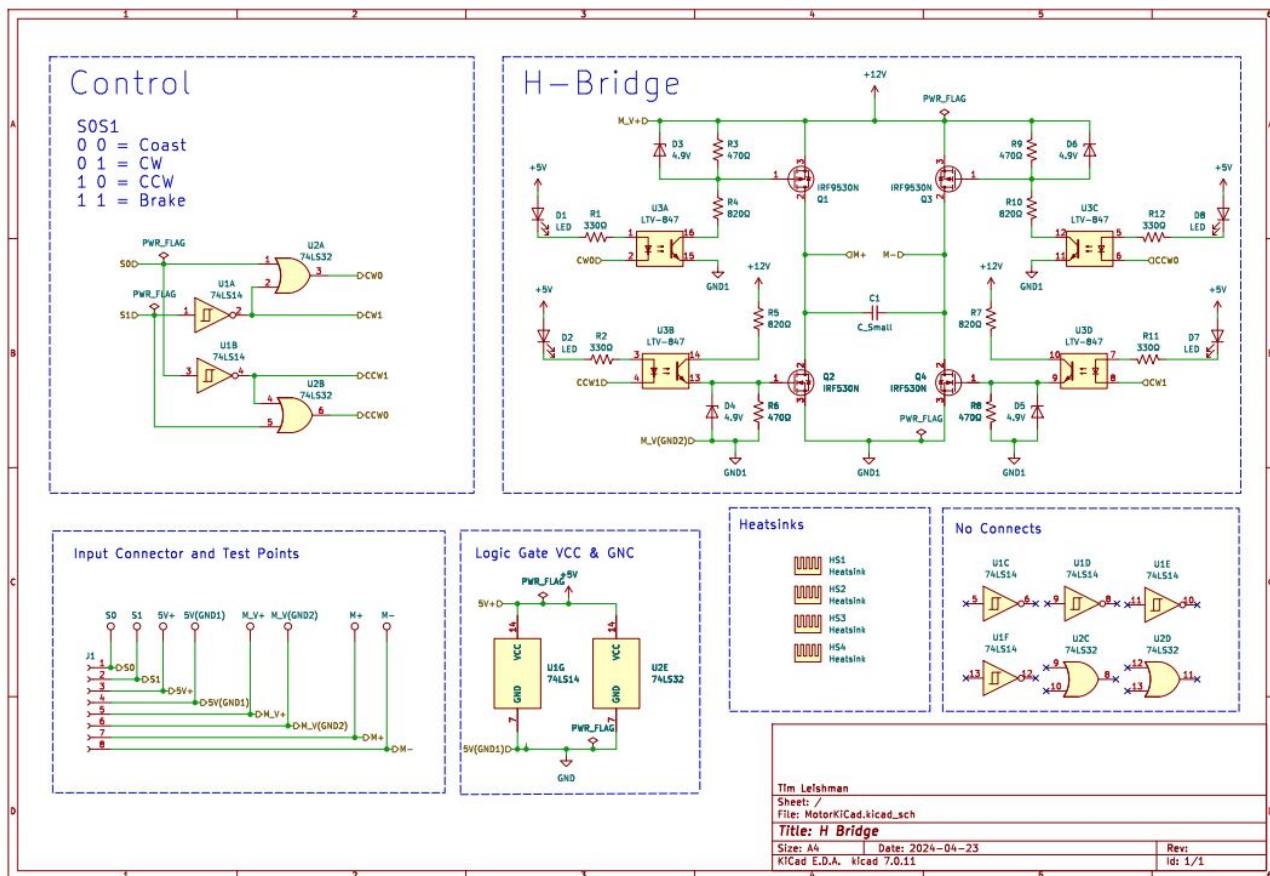


Figure 11: H-Bridge and Control Logic Schematic

The control inputs S0 and S1 will provide TTL voltage level inputs to control the H-Bridge.

### SO & S1 = 0

When both SO and S1 are both equal to 0V, the H-Bridge will be disabled and the motor will be in Coast mode.

### SO = 0 & S1 = 1

When SO is equal to 0V and S1 is equal to a TTL High ( $\approx 5V$ ) the H-Bridge turn on Q1 and Q4 and the motor will move full speed in a "Clockwise" direction.

### SO = 1 & S1 = 0

When SO is equal to a TTL High ( $\approx 5V$ ) and S1 is equal to 0V the H-Bridge turn on Q2 and Q3 and the motor will move full speed in a "Counter Clockwise" direction.

### SO = 1 & S1 = 1

When SO and S1 are both equal to a TTL High ( $\approx 5V$ ) the H-Bridge turn on Q2 and Q4 and the motor will be in Brake mode.

## 4.7 H-Bridge PCB



Figure 12: H-Bridge PCB KiCAD

## 4.8 H-Bridge PCB Build and Test

There were no issues with the assembly of the PCB. The H-Bridge PCB operated as expected. The rotational speed was measured at approximately 5,500 RPM in both directions using the RS-775126000E7 motor.



Figure 13: H-Bridge PCB Clockwise test



Figure 14: H-Bridge PCB Counter Clockwise test

## 4.9 Problems with the H-Bridge PCB

The H-Bridge PCB can operate in both clockwise and counterclockwise modes along with coast and brake. However, the circuit cannot control speed. An external circuit was used to provide PWM for the motor speed control. Additionally, the



Figure 15: H-Bridge PCB Brake test

H-Bridge circuit requires both motor voltage and TTL voltage inputs. A 5V regulator could be implemented to minimize the number of voltage inputs required to operate the PCB.

## 5 TL494 with H-Bridge Development

## 5.1 TL494 Data Sheet Description

The TL494 device incorporates all the functions required in the construction of a pulse-width modulation (PWM) control circuit on a single chip. - [TL494 Data Sheet](#)

The supply voltage for the TL494 is a minimum of 7V to a maximum of 40V.

## 5.2 Voltage Level Adj. and PWM Circuit

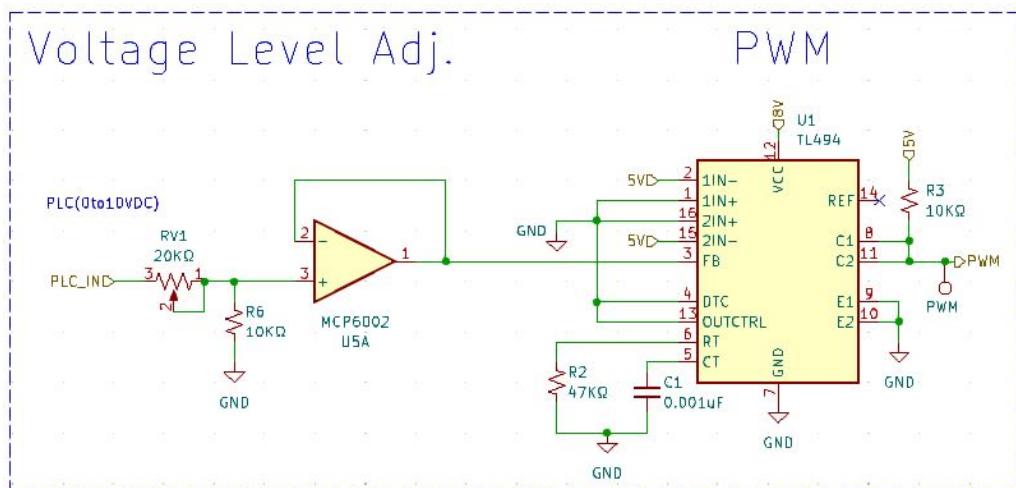


Figure 16: Voltage Level Adjust and PWM Circuit

The MCP6002 U5A is a rail-to-rail operational amplifier - [MCP6002 Data Sheet](#). U5A is configured as a buffer between the analog voltage in "PLC\_IN" and the FB (Feedback) input of the TL494. The FB input pin of the TL494 will have a maximum threshold voltage of 4.5VDC and the PLC analog input will have a maximum voltage of 10VDC. The MCP6002 U5A having a rail voltage of 5VDC will prevent the FB input from ever going above 5VDC. RV1 and R6 will provide a voltage divider allowing for calibration of the TL494 PWM and can be adjusted for either a PLC (0 to 10V) input or a 0 to 5V input depending on the application.

R2 and C1 determine the frequency of the PWM waveform.

$$F_{OSC} = \frac{1}{R_T \times C_T}$$

$$F_{OSC} = \frac{1}{47K\Omega \times 0.001\mu F}$$

$$F_{OSC} = \frac{1}{47K\Omega \times 0.001\mu F}$$

$$F_{OSC} = 21.28Khz$$

### 5.2.1 RV1 Calibration Procedure

1. For PLC input, set the input voltage to 5V. For a 5V input, set the input voltage to 2.5V.
2. Adjust RV1 until the PWM waveform is at 50% duty cycle.

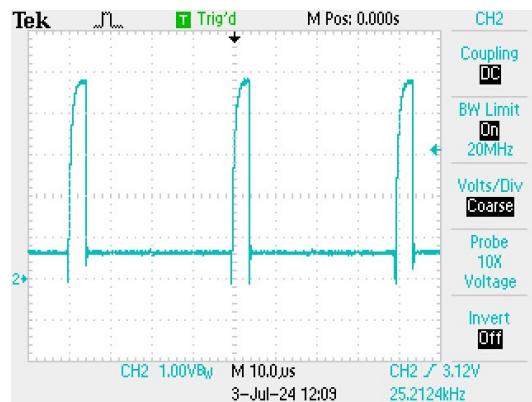


Figure 17: PWM with TL494 Feedback Voltage set to 0V

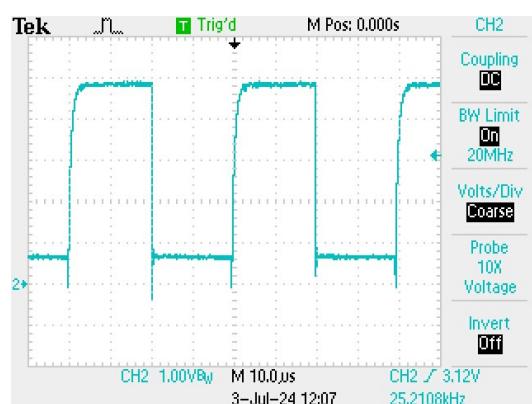


Figure 18: PWM with TL494 Feedback Voltage set to mid-voltage



Figure 19: PWM with TL494 Feedback Voltage set to max-voltage

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Use this section to thank your data sources including citations to the data, weblinks, etc.