

Allegro Motor Driving with Angular Sensor IC

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Introduction

This application note will describe how to use Allegro’s motor driver and angle sensor solutions to enable precise driving and reliable monitoring of brushless DC (BLDC) motors. This application note shows an example of a BLDC motor control and provides a procedure to drive it with the A3930 or AMT49413 (three-phase BLDC motor driver IC) in conjunction with the A1333/A1339 (high-speed angle sensor IC). This application note also shows some BLDC basics, what equipment will be needed, and where to find detailed information on the demo boards of the parts used and the A1333/A1339 programming applications.

A cylindrical diametrically magnetized magnet attached to the shaft of a motor provides access to a precise motor shaft angle from the A1333/A1339 angle sensor with a refresh rate as fast as 1 μ s. In order to keep a BLDC motor spinning at maximum efficiency, precise timing is key, and the 1 μ s update rate and 10 μ s latency of the A1333/A1339 helps achieve motor efficiency requirements. Regardless of the motor driving scheme (speed, torque, or position control), a tailored commutation circuitry must be implemented and requires information of the shaft position to operate efficiently.

Allegro has developed a whole family of parts with fast output refresh rates. The A1333 and A1339 feature UVW, ABI, PWM, and SPI outputs for maximum flexibility. The A1339 also includes a low power mode and a turns counter for applications that require absolute position of the motor with very low current draw.

See the Allegro website for more details:

<https://allegromicro.com/en/products/sense/linear-and-angular-position/angular-position-sensor-ics>

Motor Description and Driving Review

Brushless DC motors (BLDC) are externally commutated motors that are renowned for their reliability and low cost. They exhibit high zero-speed torque and can be used as stepper motors.

BLDC motors rely on creating a rotary magnetic field that will drag the shaft’s permanent magnet and turn the rotor by alternately energizing the windings present in the motor.

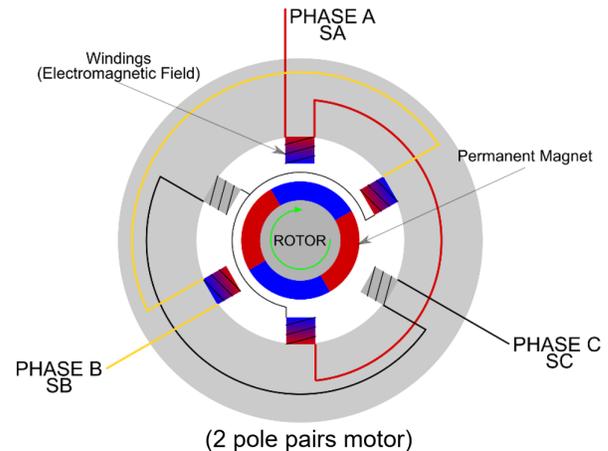


Figure 1: Working Principle of Brushless DC Motor

From an electrical standpoint, the motor is a three-phase device that has a star (or delta) built-in circuitry. The two motor structures are equivalent in the way they are driven, and this application note hence applies to both cases. Arrows in Figure 2 below illustrate the flow of the current across phase wires, which match up to the high or low voltages or high-impedance measurements at the motor drive MOSFET outputs.

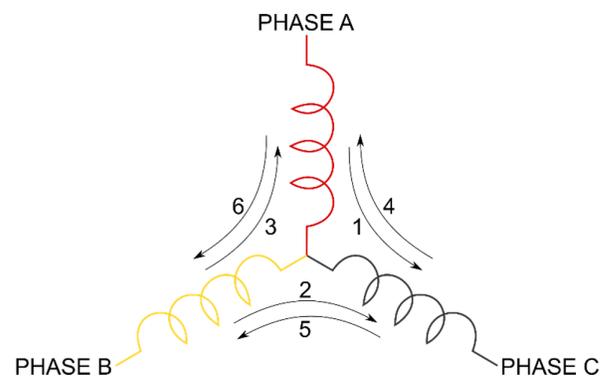


Figure 2: Star Equivalent Electrical Circuit

To have the motor spin forward, namely clockwise when looking at the shaft, a precise commutation scheme must be applied to the three phase pins. The waveform shape depends on the behavior expected from the motor. Trapezoidal driving (such as proposed by the A3930 or AMT49413) is simple and allows high speed and torque. For detailed

information about this motor driver and the associated demo board, see the Allegro website:

<https://allegromicro.com/en/products/motor-drivers/bldc-drivers/a3930-1>

The principle presented herein applies to all driving schemes. Figure 3 presents the driving pattern that must be reproduced for trapezoidal driving.

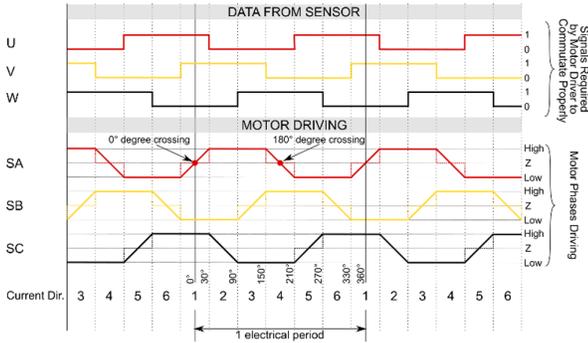


Figure 3: Waveforms of Trapezoidal Driving

Trapezoidal motor drivers drive phase A (SA), phase B (SB), and phase C (SC) as a function of U, V, and W sensor signals (output of the A1339) deduced from the angle. Driving and sensing signals are paired: U triggers High/Low on phase SA, V triggers High/Low on phase SB, and W triggers High/Low on phase SC.

Signals U, V, W are normally generated by three Hall switches (sometimes called Ha, Hb, and Hc) properly positioned inside the motor. In this application note, the Hall switches are replaced by a properly programmed angle sensor located outside the motor and on the shaft axis. A single A1333/A1339 angle sensor is able to generate the three signals U, V, W.

The shaft motion is related to the frequency of the driving sequence and the number of windings. An electrical period does not generally coincide with a mechanical revolution. To easily deal with electrical and mechanical motor representations, it is convenient to represent both revolutions over time as angles: electrical angle θ_{el} (phase of the electrical signal) and mechanical angle θ_{mec} (mechanical angle of the shaft with respect to a reference).

Equations 1 through 3 are a set of useful equations to select between representations of the number of pole pairs in the permanent rotor magnet N_{PP} (pole pairs). The rotation speed ω can be deduced from the electrical frequency f_{el} .

Equation 1:

$$\theta_{mec} = \frac{\theta_{el}}{N_{PP}}$$

Equation 2:

$$\omega_{[rad/s]} = \frac{2\pi f_{el}}{N_{PP}}$$

Equation 3:

$$n_{[rpm]} = \frac{60 f_{el}}{N_{PP}}$$

For example, a motor made of four poles (two pole pairs) that has an electrical period of 100 Hz (on every phases) turns at $n = 100 \times 60 / 2 = 3000$ rpm.

Implementation of Angle Sensor

Using an angle sensor enables one to achieve two major functions with a single sensor, namely control and position monitoring. Thus, the need of a resolver or encoder vanishes. The mounting effort is limited to a single sensor and a magnet. This is important in advanced driving schemes where precise switching angles are required like field-oriented control (FOC) or position monitoring with a precision of 1° and below. Compared to three switches, this solution requires fewer cables from inside the motor (five less in total: 5 V, Ha, Hb, Hc, GND), since the angle sensor can be directly integrated on the same PCB as the motor driver.

The magnet can be mounted at end of shaft. This configuration is depicted in Figure 4. A side-shaft magnet can also be used but will not be covered here. The AAS33001 and AAS33051 have the capability to perform side-shaft sensing after being linearized over one full rotation.

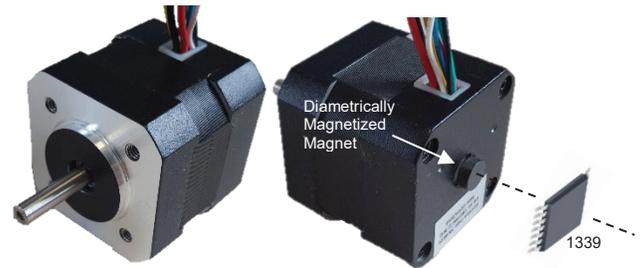


Figure 4: Motor with End of Shaft Magnet and Position of the Angle Sensor (face down)

The angle sensor must provide the U, V, W edges at precise mechanical locations to have efficient driving.

Thus, the angle sensor needs to be properly programmed in function of the motor characteristics:

- UVW output protocol
- Number of poles
- Zero degree angular reference

The sensor programming procedure is now described in the following paragraphs. A flow chart of the procedure is also provided in Figure 18. The procedure aims to have the exact same waveforms as Figure 3 with the motor rotating clockwise. If the motor is expected to turn counterclockwise, it suffices to toggle the direction pin DIR of the motor driver afterwards.

STEP 1: Configure the Sensor

The programming application, ASEK20 daughter and granddaughter PCB schematics, and a user manual for the A1333 or A1339 can be found on Allegro’s software registration site.

<https://registration.allegromicro.com/login>

Once registered, download the programming application and supporting documentation. Also, the A1333/A1339 ASEK20, daughter and granddaughter board available from Allegro can be used if an application-specific PCB is not available. The SPI interface

can be used from the ASEK20 programming box by using jumper wires from the daughter board to the application-specific PCB developed. Contact an Allegro salesperson, FAE, or distributor with questions.

The sensor must be set up in the U, V, W mode and receive the number of poles featured by the motor. Programming can be done by accessing the 0x19 register and setting its value as depicted in the following figure. Moreover, the rotation direction should also be changed in the 0x1C register to achieve clockwise rotation (angle values should be increasing when the shaft rotates clockwise regardless of sensor orientation). Note that the Allegro A1339 Samples Programmer software can be used for programming and provides a dedicated output tab where the settings can be entered without searching for the location in the EEPROM tab. To read back the value just written, the sensor should be turned off and on. The A1333 Programmer is slightly different and does not have the output tab.

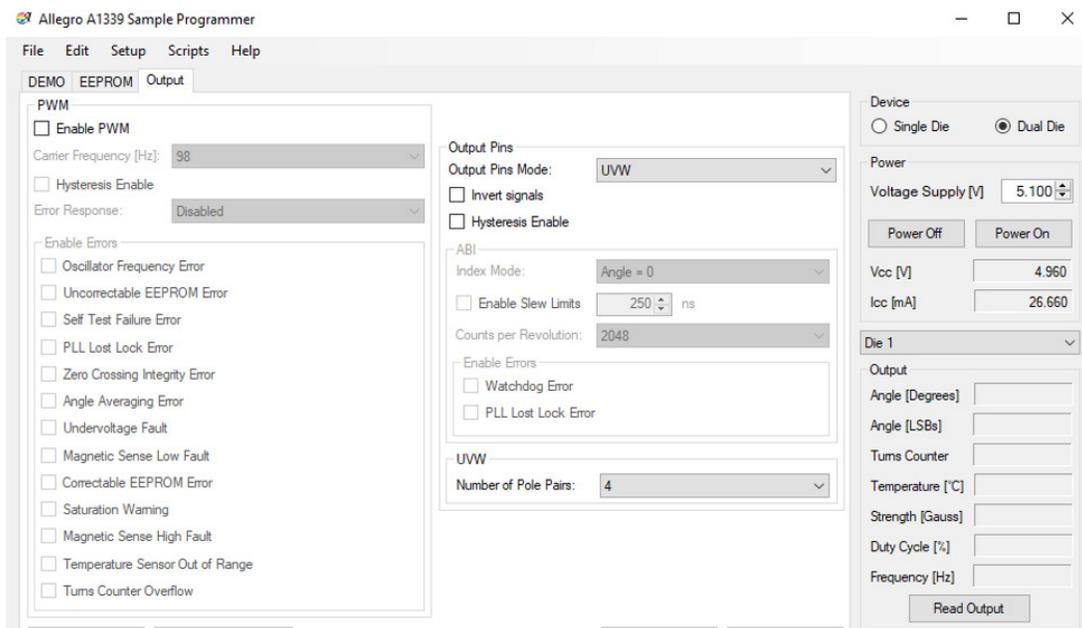


Figure 5 (A)

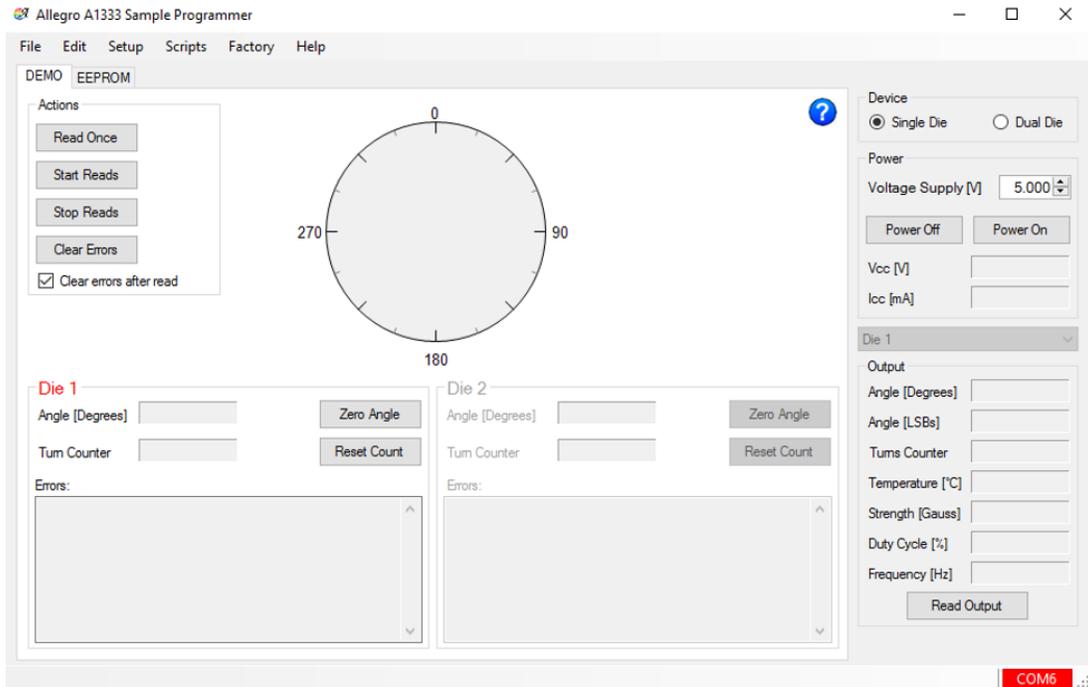


Figure 5 (B)

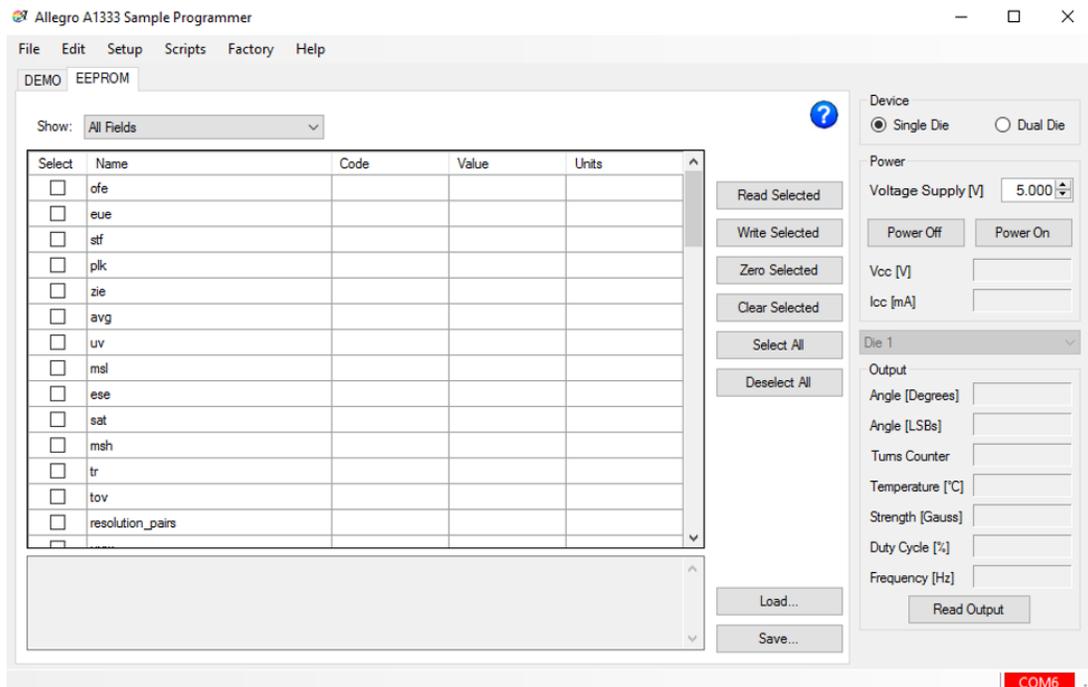


Figure 5 (C)

Figure 5: (a) GUI programming of EEPROM registers using dedicated tab, (b) main programming tool screen with zero angle button, (c) example of the EEPROM tab available in both programming tools

Extra care should be taken to ensure the correct pole pairs are programmed or else the motor will not operate correctly. Figure 7 shows that the value programmed to EEPROM for number of pole pairs is the actual pole pairs physically in the motor minus 1. The example in the figure shows that for a four pole-pair motor, a value of 3 should be placed in the EEPROM.

Program UVW output protocol on the 1339
 Register 0x19 bit 4

<input checked="" type="checkbox"/>	uvw	1	UVW
-------------------------------------	-----	---	-----

1=UVW output enabled

Program Number of poles on the 1339
 Register 0x19 bit 3:0

<input checked="" type="checkbox"/>	resolution_pairs	3	3
-------------------------------------	------------------	---	---

Value=Number of pole pairs -1
Example: resolution pairs=3 for 4 pole pairs motor.

Program Clockwise rotation on the 1339
 Register 0x1C bit 18

<input checked="" type="checkbox"/>	ro	0	false
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Figure 6: Sensor Trimming (a) Accessing Registers

The angle sensor is now able to generate correctly shaped U, V, W signals. Their phases must be adjusted so that their transitions occur at proper mechanical positions.

STEP 2: Identification of Phase Order

The technique to identify the phases (regardless of color coding) is called D-axis alignment or DC alignment and consists of aligning the shaft with one of the phase windings.

The first wire can be selected freely and assigned the label SA.

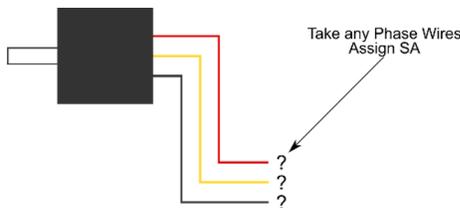


Figure 7: Identification of Phase Order (1)

The shaft shall be aligned with phase A by applying voltage to SA and connecting the other phases to ground with enough voltage and current to make the motor turn and align to Phase A (see Figure 8). Some motors have high cogging torque that make it more difficult to determine alignment. This can be tested by purposely misaligning manually and reapplying voltage to Phase A to see it turn back. Note that it is advised to limit the generator's current to avoid damaging the motor. This DC alignment results in the shaft turning to the closest windings of phase SA. The resulting position corresponds to a zero crossing of the Phase A signal, or equivalently to an electrical angle of 0° or 180° in Figure 3.

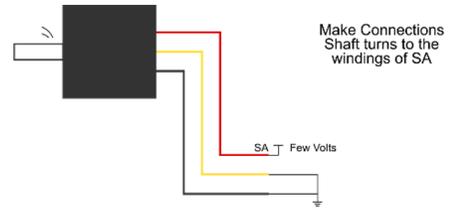


Figure 8: Identification of Phase Order (2)

Phase B and C can now be identified by performing a DC alignment on one of the unknown wires. This leads to the shaft turning clockwise if true phase B was supplied and counterclockwise if true phase C was supplied (see Figure 9).

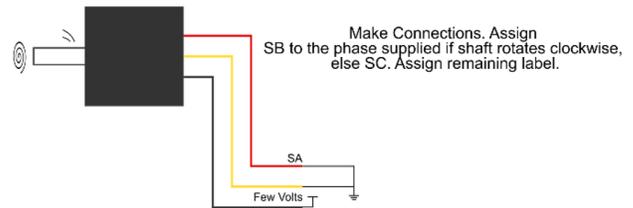


Figure 9: Identification of Phase Order (3)

Now phases SA, SB, and SC have been identified.

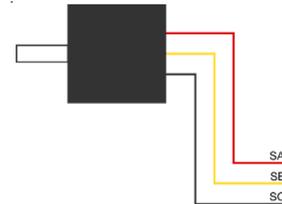


Figure 10: Identification of Phase Order (4)

STEP 3: Pairing Sensor Output with Motor Driver

The motor driver IC now needs the synchronization signals U, V, W from the A1333/A1339 angle sensor as shown below in Figure 11 and in the datasheet.

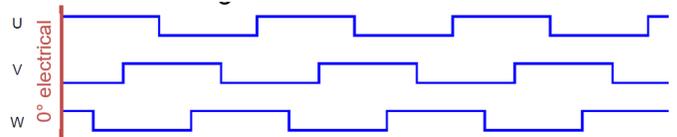


Figure 11: A1339 Datasheet Extract

These waveforms shall be connected to their respective phases: U paired to SA, V to SB, and W to SC.

The commutation table of the A3930 or AMT49413 is reported in Figure 12 (extracted from datasheet). Note that the direction pin must be high (DIR = 1) on the motor driver; otherwise, input/output responses will not match Figure 3.

Table 2. Commutation Truth Table*

Device	H1	H2	H3	DIR	SA	SB	SC
Both	1	0	1	1	High	Z	Low
Both	1	0	0	1	Z	High	Low
Both	1	1	0	1	Low	High	Z
Both	0	1	0	1	Low	Z	High
Both	0	1	1	1	Z	Low	High
Both	0	0	1	1	High	Low	Z

Figure 12: Truth Table of Motor Driver IC, Extract from A3930 Datasheet

From the truth table, it can be deduced that H1 controls SC, H2 controls SA, and H3 controls SB, because phases enter in a low or high state at their respective Hx transitions. Since U goes with SA, V with SB, and W with SC, the following correspondence table can be built:

U	↔	SA	↔	H2
V	↔	SB	↔	H3
W	↔	SC	↔	H1

Figure 13: U, V, W wiring to H1, H2, H3

The sensor outputs (U, V, W) can now be connected to the motor driver inputs (H1, H2, H3) according to the table above. In the example presented here, U shall be connected to H2, V to H3, and W to H1. The order of the UVW sequence should be verified on an oscilloscope and should look like the plot shown in Figure 14.

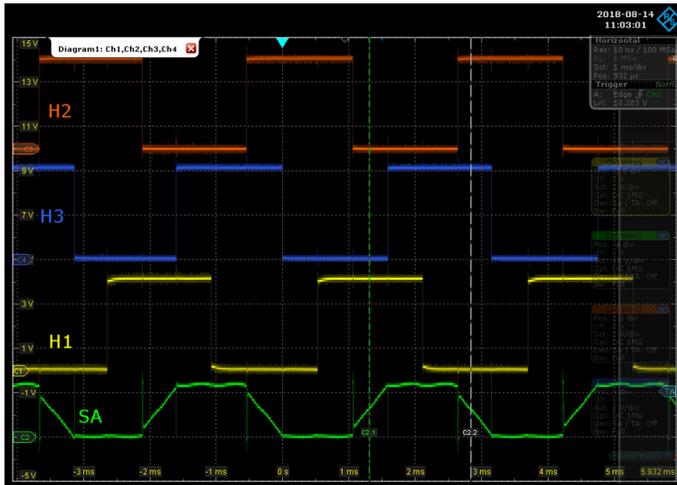


Figure 14: Shows the A1333 UVW output along with a phase voltage plot from a real motor. The UVW output is shown in order according to Figure 13 so that the commutation logic can be followed.

Some applications have more challenging mechanical constraints. Stray fields from high-current phase wires, strong rotor magnets, and stator coils can interfere with the integrity of the UVW signals. Proper shielding, phase wire positioning, and magnet proximity are important factors in getting proper motor commutation. These factors can yield to inefficient motor operation (high current), vibrating a few commutation steps in each direction (not spinning as expected), and some cases a locked, buzzing rotor.

Figure 15 shows the locked buzzing motor situation. The plot shows that the motor is vibrating enough to toggle Hall 1, but not rotate.

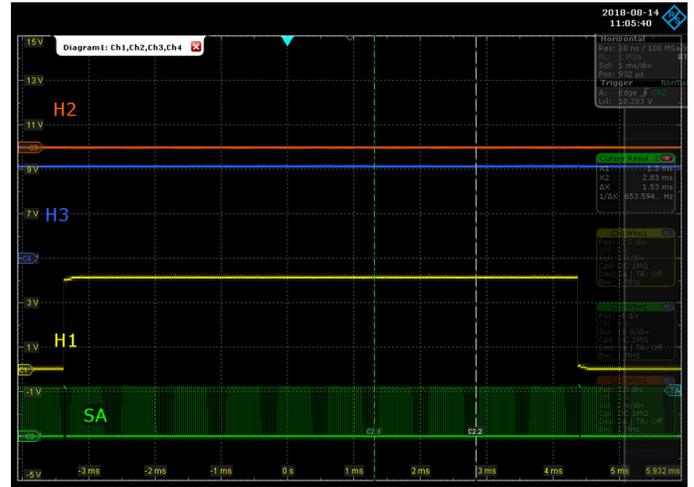


Figure 15: Shows the UVW output when the sensor was placed in an area with excessive EMC interference.

STEP 4: Trim Sensor

Now that phases have been identified, the shaft must be rotated back to the zero position through a DC alignment on Phase A (see Figure 8). The zero reference angle on the A1339 can be programmed to the EEPROM according to the following steps:

1. Read the angle (corresponding to the DC alignment of phase A).
2. Modify the zero offset angle in EEPROM location 0x1C (see Figure 16) or use the “zero angle” button on the demo tab so that the current position corresponds to 0° mechanical angle.
3. U high-to-low transition shall occur 30° electrical after the zero-crossing of phase SA (as depicted in Figure 3) for windings to efficiently attract the permanent magnet. Consequently, the output of the sensor shall be phase-shifted to match this condition as depicted in Figure 17. This phase shift is denoted ϕ and depends on the motor driver IC. The angle offset set before shall be decreased by a value ϕ / N_{PP} or $(\phi + 180) / N_{PP}$, depending on which crossing the motor is DC-aligned with (0° or 180° degrees crossing) and winding directions (clockwise or counter-clockwise). In the AMT49413/A1339 case (see Figure 17), $\phi = 150^\circ$, so the zero-crossing value should be decreased by $\phi / N_{PP} = 150 / 4 = 37.5^\circ$ or $(\phi + 180) / N_{PP} = 82.5^\circ$.

Program Zero-degree angular reference on the 1339		
Register 0x1C bit 11:0		
<input checked="" type="checkbox"/>	zero_offset	712 62.578 Degrees

Figure 16: Programming of Offset Angle to Set Phase Shift

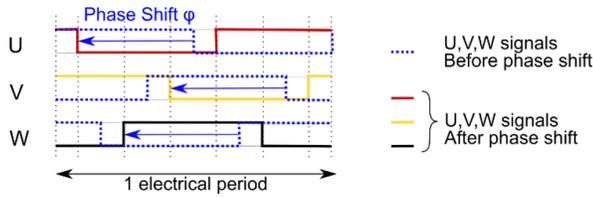


Figure 17: U, V, W Phase Adjustment

The motor can now be spun. To change the direction, the value of the DIR pin must be toggled.

STEP 5: Fine Adjustment

To account for motors fabrication variability, the angle offset can be changed slightly to achieve best efficiency.

To do so, change the zero offset in a range of a few electrical degrees. For example, $\pm 5^\circ$ electrical angle corresponds to $\pm(5^\circ / N_{PP})$ mechanical angles from the sensor perspective. Find the angle that minimizes the current consumption while the motor spins at constant rpm.

Procedure Summary

Figure 18 summarizes the steps that must be undertaken to drive a motor with AMT49413 motor driver IC in conjunction with A1339 angle sensor.

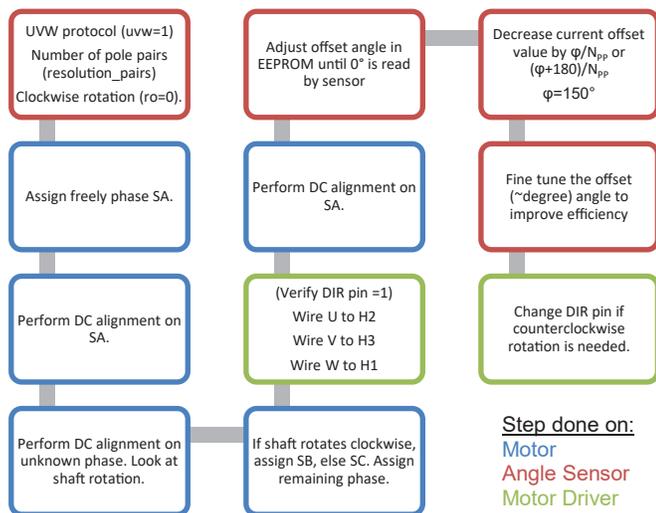


Figure 18: PROCEDURE Flow Chart

Conclusion

BLDC motors are driven with a precise timing to achieve optimal efficiency. In many systems, the procedure shown in this application note allows this to happen with the use of fewer parts and less complexity. With the features included in this class of advanced angle sensors, these signals that were typically generated with three discrete latches can be replaced by a single angle sensor. The pair of devices from this application note helps simplify applications by eliminating the precisely located Hall latches and the separate PCB mounted inside a motor. It also reduces the wiring costs and motor manufacturing complexity since the sensor is located outside the motor. The major advantages that using angle sensors for motor commutation provide is that it allows for precise position monitoring and efficient motor driving capabilities in a single IC package. With the other outputs available on these angle sensors, a precise high-speed angle measurement of the motor shaft can be provided to a microcontroller for actuator-type applications that require the position to be known. This advanced driving scheme can be implemented thanks to the precise angle tracking and to the high-speed refresh rate offered by circular vertical Hall technology implemented in the A1339 and its related parts (A1333, AAS33001, AAS33051).

The motor driver used for this note (A3930/AMT49413) has built-in trapezoidal commutation logic for simple implementation of motor drive control. With just a few simple inputs and a PWM signal that can be driven by a microcontroller, this set of drivers can vary speed, brake, coast, and change direction.

Revision History

Number	Date	Description
–	December 17, 2018	Initial release
1	August 1, 2019	Minor editorial updates
2	July 5, 2024	Fixed broken links (pages 1 and 2)

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