Tiny Hall-effect Latches for Miniature BLDC Motor Designs

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This application note introduces the DRV5011 Hall latch sensor, and how it is used in motor commutation for small motor designs. Brushless DC (BLDC) motors are electrically commutated by pulsing current through the stator windings in a very specific sequence, which allows the motor to spin with the highest amount of torque possible. Commutation is achieved by using solid-state, Hall-effect sensor integrated circuits (ICs) to measure the constantly rotating magnetic fields with high accuracy. Additionally, as seen in Figure 1, a motor controller and motor driver monitor the speed and position of the rotor as the motor is spinning, and control this sequencing in real time. By sequencing current through the motor windings, the attraction and repulsion between the stator field and the permanent magnets of the rotor produce torque. To keep the motor spinning with maximum torque and efficiency, the magnetic field of the stator constantly changes position as the rotor field tries to approach it.

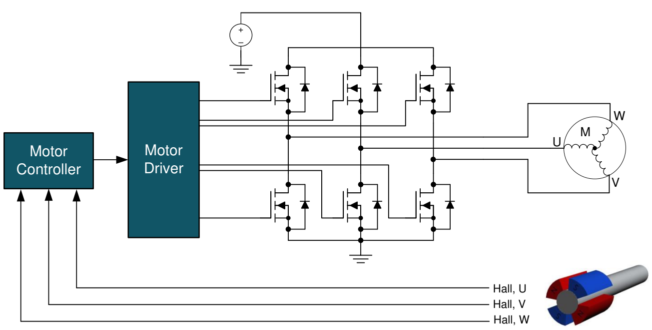

Figure 1. Closed-Loop System for BLDC Motor Control

In order to energize the correct stator winding while the motor is spinning, the rotor position must be known. This is the purpose of the three Hall-effect latch sensors that are typically used. With the latches physically spaced 120° from each other, these sensors detect the alternating north and south magnetic fields to produce either a high- or a low-output signal to indicate which magnetic pole is in position. As seen in Figure 2, this switching of the three Hall-effect sensors (from high-to-low or from low-to-high) provides rotor position information every 60° in a six-step commutation scheme.

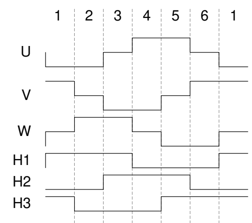

Figure 2. PWM Winding States (High, Low, Off) for U, V, or W in Relation to Hall Sensor Outputs for H1, H2, and H3

In six-step commutation, the Hall sensors generate a unique, three-digit signature for each of the six stages, and allows the motor controller to energize the U, V, W windings accordingly. As they are easy to implement, low-cost sensors are the most commonly used method for determining rotor position in BLDC motors due to their ease of use. Because Hall-effect sensors are critical for the determination of the rotor position, the bandwidth performance (the ability of the device to react to a fast-changing magnetic field) and sensitivity (the ability of the device to detect small magnetic fields) are especially important. Additionally, the physical size of the sensor is paramount when designing BLDC motors that may be 12,7mm (0.5 inches) in diameter or less. The most common package types used today are TO-92 (through-hole package) and SOT-23, but newer, smaller form factors, such as the X2SON and WCSP, are necessary for the development of tiny, BLDC motors. SOT-23, X2SON, and DSBGA (also called WCSP) are all surface-mount packages. The smallest is WCSP, which is essentially bare silicon die with a ball grid array.

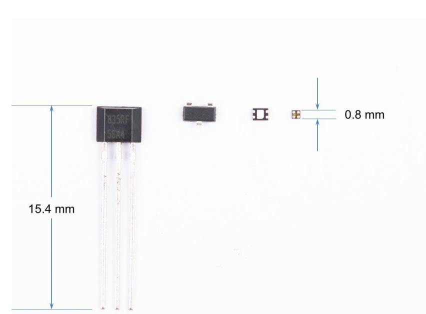

Figure 3. TO-92, SOT-23, X2SON, and WCSP Package Types

Battery-powered, handheld drills used in the medical field and in dentistry are a great example of this. Smaller motors reduce the overall weight of the system, reducing fatigue and stress on the end user, while maintaining the same torque and battery life. For this reason, smaller Hall sensors become extremely advantageous, as these can be placed strategically inside the motor casing without impacting the overall diameter of the motor design. To illustrate this point, consider the below package types — TO-92 and X2SON. The traditional TO-92 package (Figure 4) is most logically placed around the circumference of the rotor. For inner-rotor motor designs, this is typically not an issue, because the stator has enough room for the Hall sensors (stator not shown). The drawback with this approach is that it can lead to larger-diameter motor designs.

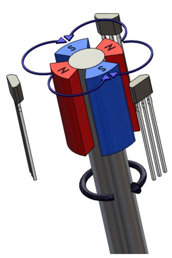

Figure 4. Rotor Position Using TO-92 Hall Sensor

In slotless BLDC motors, space is not available within the motor windings. Hall sensors are optimally placed directly above the motor, on a PCB centered axially on the rotor shaft (Figure 5). In this configuration, it can be seen that this package type does not impede the development of even smaller motor designs.

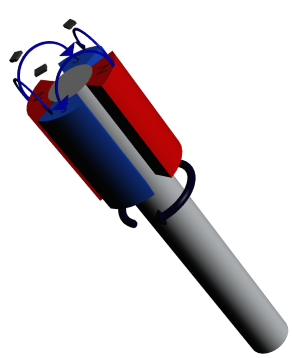

Figure 5. Rotor Position Using Surface Mount Hall Sensor

The DRV5011 is a digital Hall-effect sensor designed specifically for motors and other rotary systems. The device has an efficient, low-voltage architecture that operates from 2.5 V to 5.5 V. The device is offered in the standard SOT-23, as well as low-profile X2SON and DSBGA (WCSP) packages. The DSBGA package represents a 58% reduction in size when compared to the X2SON. The digital output of the device is a push-pull driver that requires no external pullup resistor, which enables even more compact systems. When a south magnetic pole is near the top of the package and the magnetic threshold operating point, BOP, is exceeded, the device drives a low voltage. The output stays low until a north pole is applied and the magnetic threshold release point, BRP, is crossed, which causes the output to drive a high voltage. Alternating north and south poles are required to toggle the output.

Table 1. Package Comparisons

Package	Body Size
SOT-23 (3-pin)	2.92 mm x 1.3 mm
X2SON (4-pin)	1.1 mm x 1.4 mm
DSBGA (WCSP) (4-pin)	0.8 mm x 0.8 mm

Alternate Device Recommendations

Depending on the necessary system requirements, there may be optional devices that provide the needed performance and functionality. For applications where space is not as constrained, the DRV5015 offers a good, high-bandwidth solution available in SOT-23. Also, the DRV5015 provides the highest sensitivity solution in TI's product portfolio, and enables the use of smaller permanent motor magnets. Another popular product is the DRV5013, available in SOT-23 and TO-92. The DRV5013 is a high-voltage solution that can operate up to 38V VCC. Table 2 shows the high-bandwidth (up to 30 kHz) Hall latches that are useful for high-RPM motor applications.

Table 2. Device Recommendations

Device	Optimized Feature	Performance Benefit
DRV5011	Tiny DSBGA package	Allows smaller motor designs
DRV5015	High sensitivity (BOP of 0.7 mT typical)	Smaller magnets can be used enabling even smaller motor designs
DRV5013	High voltage (38V VCC)	No sub-regulation needed to operate device

Table 3. Related Documentation and Information

Training Videos	Comprehensive training videos on Hall-effect sensors
Application Note	Incremental rotary encoder design considerations
DRV5011	Smallest latch in the industry

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