Optical encoder integration for BLDC-motor feedback

By Dr. David Lin

THE MAJORITY OF WASTED electrical energy in the industry comes from oversized motors and fixed speed drive systems. Thus energy efficient motion control system should adapt in the future to the actual load demand from the application. BLDC-Motors meet this requirement through electronic commutation and variable speed control. Commutating the motor pole winding at the optimal rotor position is essential for reducing electrical losses when managing variable speed and load situations. The following article discusses different Hall sensor arrangement and technology trends in integration.

Reliable feedback of the rotor position is important for the performance of the total motion control system. It allows a precise commutation of the stator windings and minimizes electrical losses in the motor. Typically the 120˚ in phase shifted UVW signals are used to activate commutation in the BLDC-motor driver. Different options are available today to generate the UVW signals.

This could be using Hall sensors or switches which are built into the windings or mounted on a small PCB; calculation by software with data based on the back-EMF from the stator winding; attaching an optical or magnetic encoder to the motor axis; or the integration of advanced single-chip optical or magnetic encoder ICs into the motor housing.

Hall sensors or switches are widely used in BLDC-motors due to their low component cost. The sensorless approach requires effective algorithm to calculate UVW from the measured back-EMF. Also a fast microprocessor or DSP is needed to reduce execution time and minimize the additional latency time introduced. The limitation with sensorless UVW generation can be seen on fast load changes, at low speed and out of sync operation. Sensing the absolute rotor position in hardware is regarded as the most reliable option. Attaching an optical or magnetic encoder unit to the BLDC motor is advantageous when very high precision dynamic positioning is required and if the application is not cost sensitive.

Hall sensor for commutation

Using three discrete Hall sensors/switches in a BLDC motor generates UVW signals based on the sensor mounting position, either in the stator windings, or assembled on a small PCB at 0˚, 120˚ and 240˚locations opposite the rotors permanent magnets. In some cases a magnetic pole ring attached to the axis can be used. Figure 1 shows on the left side the mechanical position of the three Hall sensors/switches and the resulting UVW signals generated. The position accuracy of the UVW signals in relation to the actual rotor position depends on the mounting tolerances and matching of the Hall sensors/switches sensitivity and stability. Since the magnetic field will vary quite a lot over temperature, rotor speed and operating life time (permanent magnet ageing) a position error can add-up easily to +/-3˚ or more.

Another approach uses four integrated Hall sensors and signal conditioning to generate a sine/cosine signal, where the

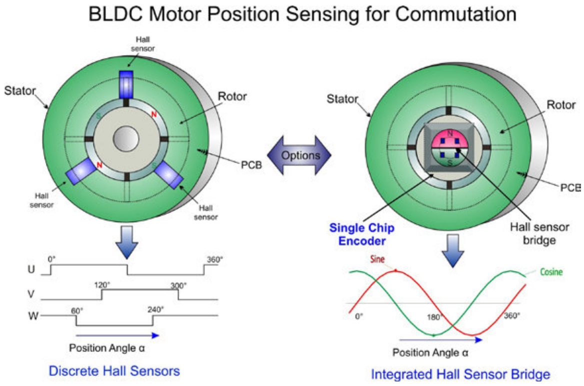
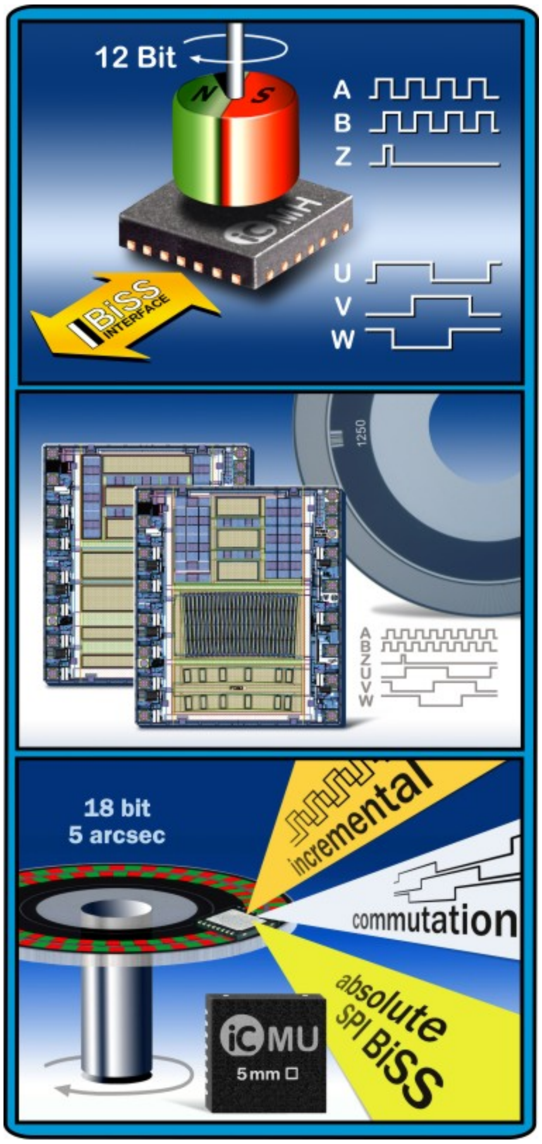
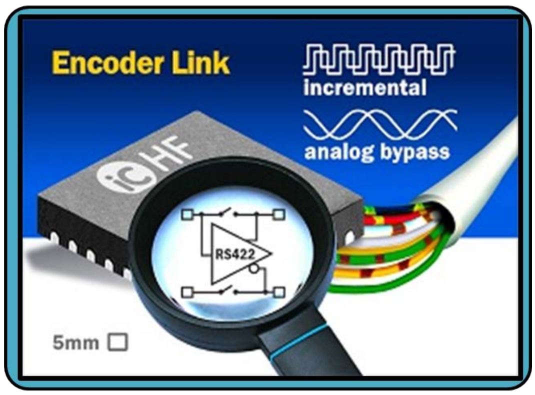


Fig. 1: Options of BLDC motor position sensing for commutation.



Product Selector Magnetic/Optical Motor Encoder iCs



Product Selector Line Driver iCs

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angular position within a 360˚ turn is continuously available. Figure 1 shows this Hall arrangement on the right side. A small permanent magnet 4-6mm in diameter is attached to the rotor axis and generates a rotating field which is picked-up by the integrated Hall bridge. The sensor arrangement allows the generation of a differential sine/cosine signal which is insensitive to common mode magnetic fields. The sine/cosine signals can then be converted by a sine-to- digital converter to an absolute position. This interpolation is done by calculating the arctangent of the sine value divided by the cosine value. It delivers an absolute position of the rotor with a configurable resolution of 6-12 bit.

Today's advances in mixed-signal integration allow the Hall array plus all sine/cosine signal conditioning and interpolation for the absolute position to be on one encoder IC. Instead of the three discrete Hall sensor/switches, a single 5x5mm package can be assembled on the same PCB (see figure 1).

From the absolute position also incremental ABZ signals can be generated to monitor fast position changes with a very low latency. Figure 2 shows the up/down coded AB-signals for incremental operation. When the direction of the motor is reversing the AB-signals shift its phase. The Z-signal marks the zero position of the rotor and allows in a simple manner to count from the ABZ-signals the absolute position in the motor control or motion control system.

With a sine/cosine to UVW interpolation unit the commutation signals can be generated for two, four or multiple pole BLDC-motor types. In this case each commutation signal is shifted by 60˚ in phase. It can be used to control directly the BLDC-driver unit for block commutation. It can also be used by the motor controller to generate a sine wave commutation. An integrated single chip magnetic encoder has usually multiple output options to be used by the motor controller or a superior motion controller. But advances go far behind just the resolution.

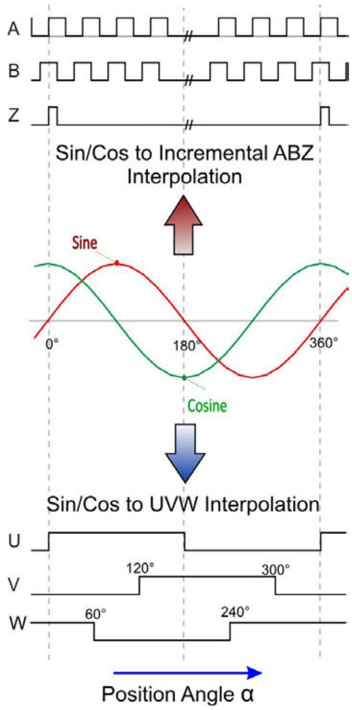

Fig. 2: Generating UVW and ABZ from Sine/Cosine.

Advances through single-chip encoder integration

The advances in single-chip encoder integration have taken them to a complete "system on-chip" with multiple output options for the BLDC-motor. Figure 3 shows the BLDC-motor feedback options for the iC-MH8 as one example. On top of the UVW signals other output options are provided, such as absolute position via the SSI/BiSS interface, ABZ incremental and analogue sine/cosine signals.

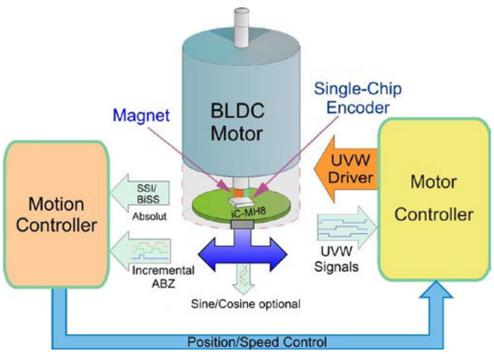

Fig. 3: Motor control with absolute magnetic encoder with outputs options.

The chip includes a Hall array, analogue signal conditioning, digital sine/cosine interpolation, error monitoring, automatic gain controls, multiple encoder output formats, UVW motor commutation outputs, digital configuration, line driver capability, and in-system programmability.

The signals from the Hall bridge are conditioned and amplified by a PGA with auto gain control to compensate for different operation condition, like temperature, supply voltage or magnetic field changes due to temperature or ageing. The on-chip sine/cosine signals are amplified to 1 Vpp and provided through a differential analogue output driver for external monitoring or independent interpolation. They also drive the 12-bit real-time Sine-to-Digital converter/interpolator with a very low latency time of less than 1µs.

12-bit provides a resolution of better the 0.1˚. An absolute position can be readout through the serial SSI (Synchronous Serial Interface) or BiSS-Interface (Bi-directional Synchronous Serial Interface) by the motion controller. The open standard SSI/BiSS provides a high speed serial interface also for configuration at the production line. If needed, integrated RS422 line driver support also longer cable length to the motor or motion controller. The ABZ-signals are updated at a 2MHz frequency and have a latency time of less the 1µs. The zero position can be programmed in 256 steps (1.4˚) for the incremental and 192 steps (1.8°) for the UVW interface.

Important is also the ability to setup and adjust the analogue signal conditioning. This allows for a higher quality encoder output signal. Selecting the BLDC motor commutation pole setting enables the device to be used with various BLDC motor types. The adjustable settings reside in the onboard RAM of the encoder chip and can be programmed into the onboard nonvolatile PROM read-on at power-up.

Optical integration also possible

Magnetic encoder ICs can be better for very harsh, dusty and rigorous environments. However optical single-chip encoder ICs with commutation outputs have become available through optical system integration as well. The performance can be higher, but comparisons indicate more and more a head on head race between the two technologies. Figure 4 shows two single chip optical encoders with incremental and UVW outputs. Here the resolution is defined by the code disc and uses three optical sensors for the UVW generation. The number of pole pairs of the motor is defined the code wheel design. An array of four photodiodes can provide up to 20,000 counts per revolution at a code disc diameter of 33.2 mm, for instance. Special packaging such as optoQFN is required for this optical solution.

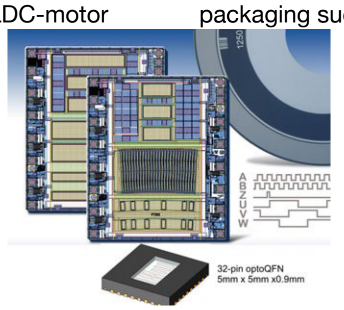

Fig. 4: Optical single-chip motor encoder ICs with UVW commutation.

Today's mixed signal integration capabilities can provide single-chip encoder ICs offering reliable, highly flexible and configurable magnetic encoder feedback options with 12 bit resolution. This can compete with traditional Hall sensors/switches at the system level with higher performance integrated into the motor housing. On optical encoder ICs with integrated UVW-output options follow also the trend toward a single chip solution. These trends support the increasing performance required to improve energy efficiency in electronically commutating motors through best in class motor feedback solutions.