Boost Performance in Motion Control Applications with Single-chip Encoders

When designing systems with motion control, the speed or position feedback can be accomplished with readily available rotary and linear encoder devices. These devices offer standard mechanical and electrical interfaces that most systems and motion controllers can easily interface to.
Typical options for an encoder are standard packaged and modular encoders. These devices are utilized by many motion control designs and are available in standard configurations. These off the shelf solutions are the norm for most motion control applications, but may offer limited configuration to the end user. An alternative and application oriented approach is to utilize higher integration and smart sensor technology within a Single-chip encoder based design. These offer a highly flexible and configurable option for those applications that need the ability to fine tune the encoder output for enhancing the overall system performance.
The following White Paper describes the benefits of utilizing Single-chip encoder devices to aide in increasing overall system performance in motion control applications.

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1) Increasing Performance in Motion Control Applications

In motion control applications, enhancing the motion feedback path is one way to increase system performance. In many applications, a rotary or linear encoder provides this feedback so as to report speed and position data to the motion controller in real-time [1].

Examples of increasing a system's motion control performance may come in the following forms:

- Enhancing position accuracy
- Higher operating speeds
- Increasing system efficiency
- Increasing reliability and repeatability

Examples of implementing such performance criteria may come in the following forms:

- System and sub-assembly calibration
- Real-time configuration adjustments
- Reducing mechanical tolerances
- Adding mechanical alignment adjustments
- Preventative maintenance adjustments

While implementing many of these items to boost system performance is desirable, the ability to do so may not always be possible for a new or existing design. Furthermore, implementing such changes can impact system design complexity, manufacturability, form factor, cost, and time to market. However, by focusing on the motion controls encoder feedback, let's discuss an encoder design approach that can actually reduce these factors or eliminate them altogether.

2) The Single-chip Encoder Approach

As an example, consider the standard motor assembly of Figure-1. Here a standard off the shelf encoder has been mounted to a Brushless DC (BLDC) motor in order to provide position feedback for the motion control application. Once the motor assembly has been connected to the application drive system, there are a limited amount of mechanical and electronic adjustments that can be made to the encoder itself to alter its output and configuration for system performance gains. In most cases, this is perfectly acceptable, but for those systems that demand higher performance, there must be more control of the encoder configuration to meet the design goals.

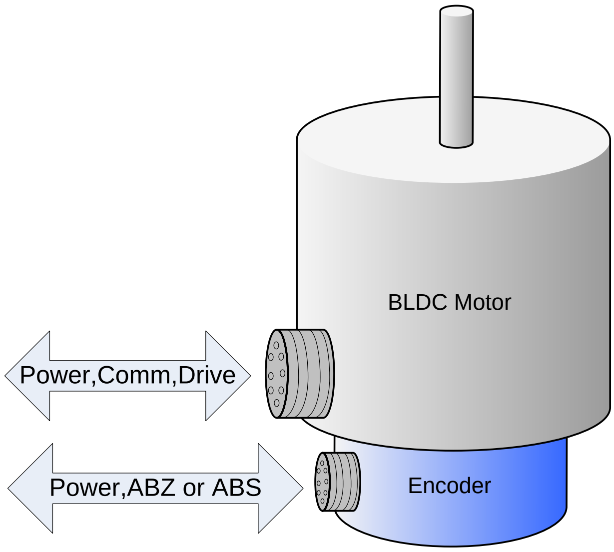


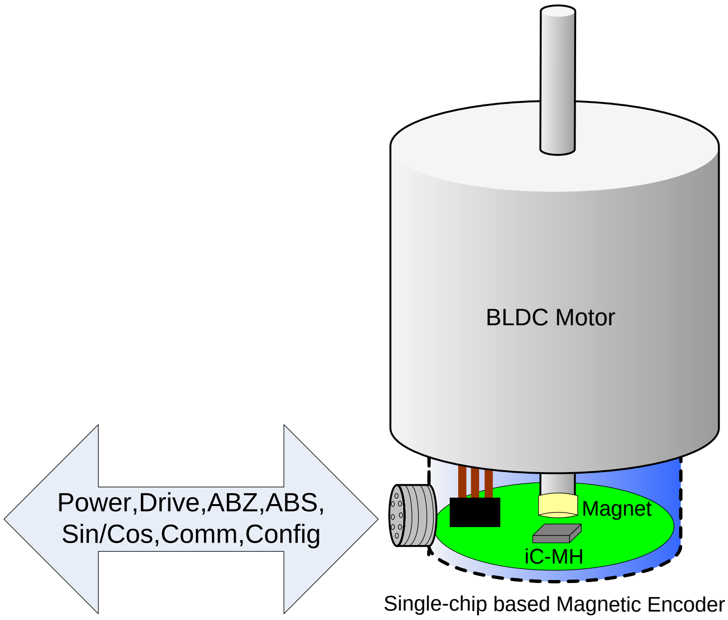
Figure-1: BLDC Motor assembly with attached packaged encoder device

Now let's introduce an alternative Single-chip encoder solution as shown in Figure-2. In this approach, an encoder IC (integrated circuit) or 'chip' is used over an off the shelf packaged solution. When designing at the chip level, a circuit board and mechanical packaging design is required. While the mechanical design may be straightforward, designing a circuit board may at first seem like an intimidating task. However, given the high integration of the Single-chip encoder, only the encoder chip itself plus a few supporting discrete components are all that's required. Furthermore, reference circuit board designs and layouts are usually available from the encoder IC manufacturer.

As shown in Figure-2, now the packaged encoder solution has been replaced with the Single-chip encoder design, and in this case, the Single-chip encoder is an iC-MH magnetic encoder IC. With this type of design, there is now the ability to adjust the encoder configuration over a digital interface. By doing so, this gives the ability to adjust various parameters and further enhance the motion control feedback in order to boost the performance of the system.

Besides the Single-chip encoder IC, it is worth mentioning the other notable design changes when migrating from the design in Figure-1 to Figure-2.

Note: Comm=Commutation, ABZ=Incremental Output, ABS=Absolute Position Output



Figur-2: BLDC Motor assembly with attached Single-chip encoder based design

As mentioned previously, the circuit board design contains the encoder IC and its supporting components. The circuit board can also contain other application specific circuitry or interfaces if so required [2]. For example, the BLDC motor wiring has now been routed through the encoder circuit board to allow for a single cable to go back to the controller providing a simplified wiring solution. Additionally, the BLDC drive circuitry could have been added to the circuit board as well if so desired. Also shown, the means for the encoder chip to sense motor shaft rotation is done via a diametrically magnetized cylinder magnet. This magnet is attached to the through shaft of the BLDC motor allowing direct motor position and speed to be detected. Also of interest is the lack of motor commutation hall sensors from the BLDC motor. Given that the encoder chip has the ability to generate motor commutation signals itself, this now eliminates the need for these extra signals from the motor. Most notable in this Single-chip encoder design is the increase in encoder signals now available to the motion control system. With the Single-chip encoder design, it is possible to have incremental outputs [3], Sine/Cosine analog outputs [4], and a digital serial interface for configuration and absolute position data reading. With all of these signals and configuration capability for the design, now the encoder itself can be a programmable solution to allow for adjustments to aide in increasing system performance. With the design concept of Figure-2 in mind, let’s now explore the Single-chip encoder design in more detail with the goal of boosting system performance.

Note: Comm=Commutation, ABZ=Incremental Output, ABS=Absolute Position Output Sin/Cos=Analog Sine and Cosine outputs, Config=Encoder Configuration

3) Single-chip Encoder Types and Options

Two types of Single-chip encoder devices are magnetic and optical encoder IC's as shown in Figure-3. Selecting the right one for the specific application can have a serious impact on system performance. For example, while the magnetic encoder IC can be better for very harsh environments [5], and is a simpler assembly, its resolution and accuracy will usually be less than that of a comparable optical encoder IC. This is the case when comparing the iC-MH8 magnetic encoder IC to the iC-LNG optical encoder IC. That being said, it is important to understand the requirements for the application and the operating environment it will be used in. As an example, consider the Single-chip encoder IC selection guide of Figure-4. By comparing the many features of each encoder IC, this will help to find the optimum solution for the application to allow a solid foundation for adding system performance enhancements.

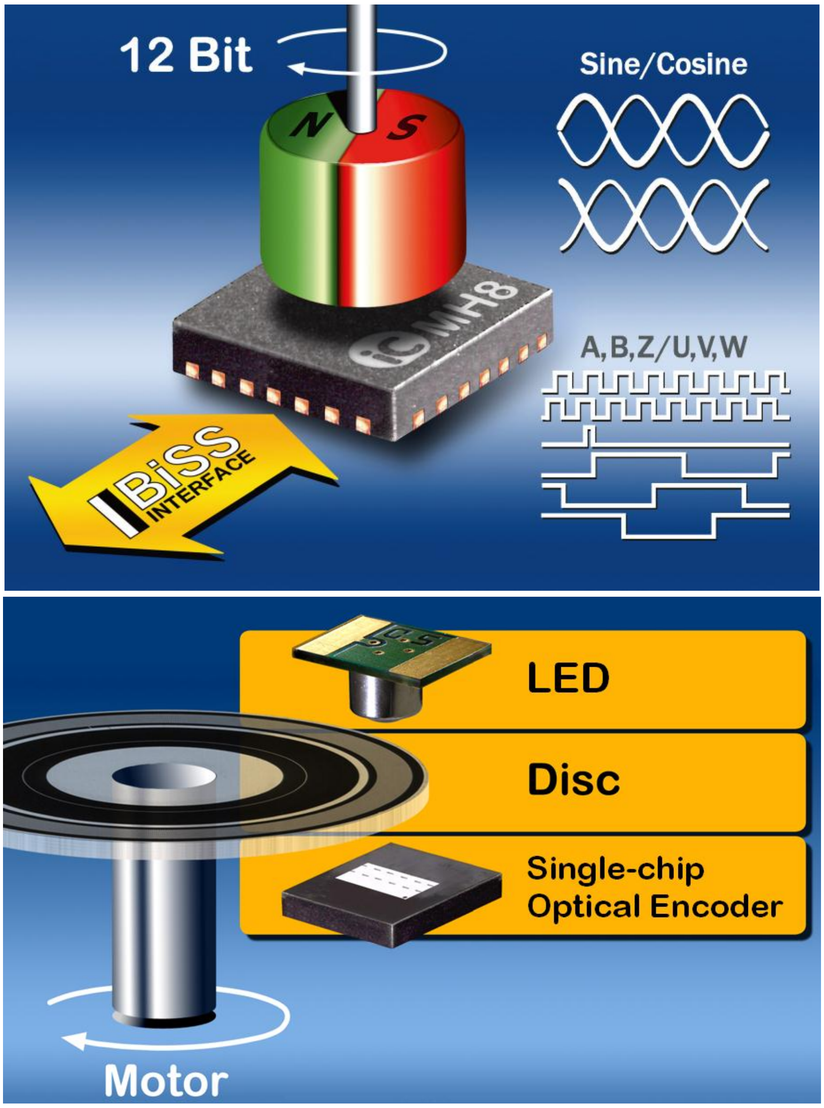


Figure-3: Single-chip magnetic encoder IC with magnet and Single-chip optical encoder IC with LED and disc

Parameter	Single-Chip Optical Incremental Encoder IC's			Single-Chip Magnetic Encoder IC's		
	iC-LTA	iC-PT33xx	iC-PT26xx	iC-MH	iC-MH8	iC-MU*
Resolution	Variable+	1000...2500 CPR	250...1250 CPR	12 bit	12 bit	18 bit
Commutation signals	UVW	UVW	UVW	Diff. UVW	Diff. UVW	UVW
Integrated UVW driver	No	No	No	Yes	Yes	No
Pole pairs supported	Variable	Variable	Variable	1 and 2	1, 2 and 4	1 to 16
Max. motor speed [RPM]	typ. 24,000+	typ. 12,000	typ. 24,000	120,000	120,000	24,000
ABZ output	Yes	Yes	Yes	Yes	Yes	Yes
SSI/BiSS Interface	No	No	No	Yes	Yes	Yes
Sine/cosine	No	No	No	No	Yes	Yes
SPI Interface	No	No	No	No	No	Yes

+ defined by code disc

* in qualification

Parameter	Single-Chip Absolute Optical Encoder IC's		
	iC-LNG	iC-LNB	iC-LG, iC-LGC
Resolution	16 bit	16...18 bit	9...20 bit
Commutation signals	MCU calculation	MCU calculation	MCU calculation
Integrated UVW driver	No	No	No
Pole pair supported	Variable	Variable	Variable
Motor position update	100 ns	500 ns	4 µs
ABZ output	Yes	Yes	No
Serial output	Shift register	Shift reg., SSI	SSI, BiSS
Sine/cosine	512/1024 CPR	1024 CPR	512/.../4096 CPR
Parallel output	14 bit	16 bit	15 bit
Controller interface	SPI	SPI	8-bit MCU

Figure-4: Selection guide for Single-chip encoder IC's

Output Format

As shown in Figure-5, Single-chip encoders like the iC-LNG offer many different output formats with many being available for use simultaneously. As shown, these consist of standard AB quadrature outputs with Z index pulse, Sine/Cosine analog outputs, Absolute position serial interface, and an Absolute position parallel interface.

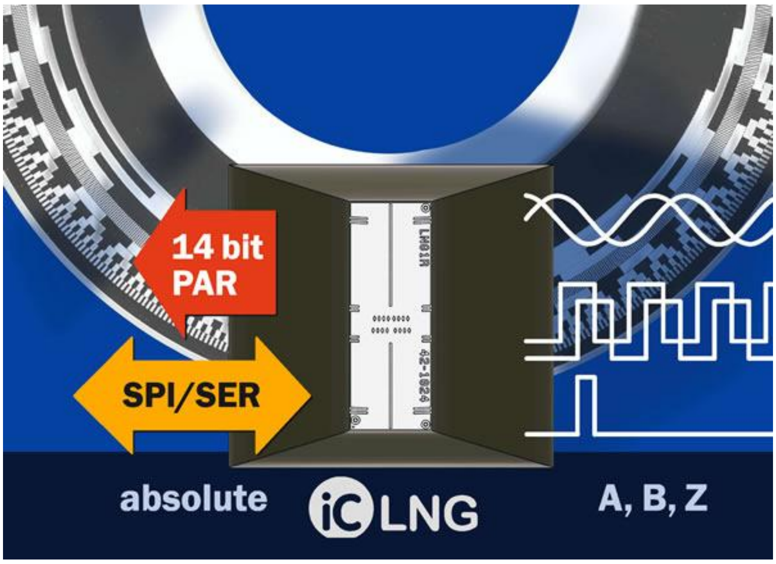
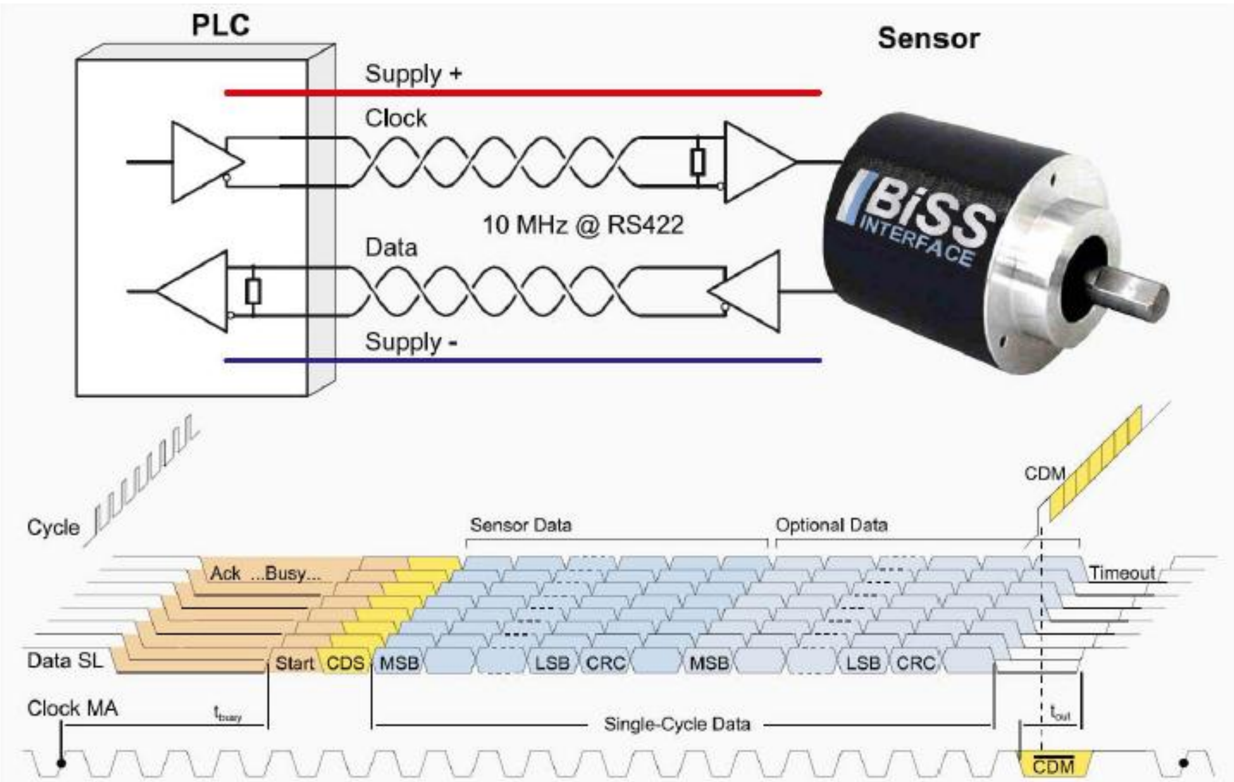


Figure-5: iC-LNG Optical Absolute Encoder IC showing the many available encoder output formats

For some encoder devices like the iC-MH8, there is an open-source serial interface called BiSS (Bi-directional Synchronous Serial Interface), which allows for a high speed serial interface for configuration and absolute position reading. As shown in Figure-6, this interface only requires clock and data for reading absolute position data and also for the reading and writing of encoder configuration data. Reading the position data is similar to SSI, but reading and writing the configuration data is uniquely handled through the two master and slave bits CDS and CDM as shown. BiSS itself provides the ability to use an SSI encoder interface, but at a much higher throughput and with built-in features such as cyclical redundancy checks for data integrity purposes. More information on BiSS can be found at the BiSS website [6].



Point-to-point: Sensor-to-PLC communication with two data words and bidirectional control data: master to slave by CDM, slave to master by CDS. The BiSS master adjusts automatically to line and measurement delays each cycle.

Figure-6: BiSS serial interface - Point to point connection

4) Single-chip Encoder Features for Boosting Performance

Advances in Single-chip encoder devices have taken them beyond raw sensors on a chip. These devices now have many built-in features making them complete integrated devices and true encoder systems on a chip. As shown in Figure-7, some of these features include analog signal conditioning, digital Sine/Cosine interpolation, error monitoring, automatic gain controls, multiple encoder output formats, BLDC motor commutation outputs, digital configuration, line driver capability, and in-system programmability.

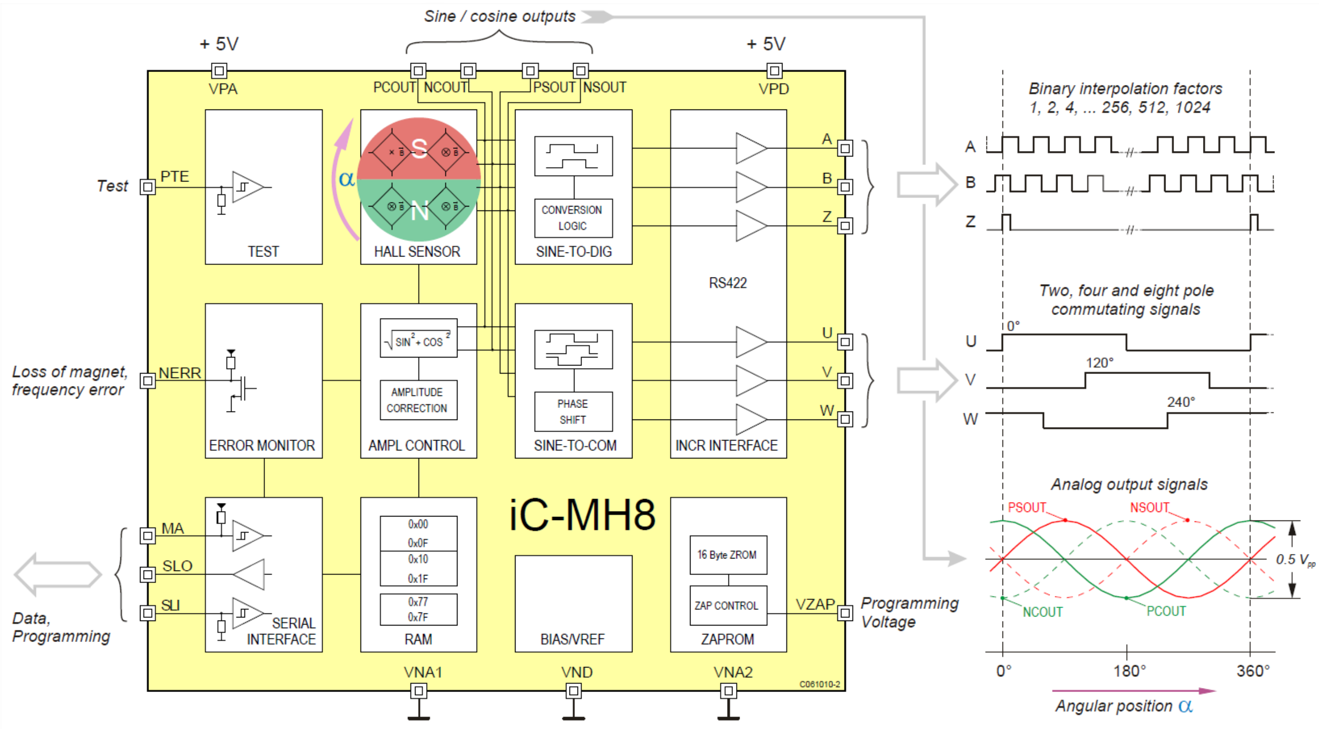


Figure-7: iC-MH8 Magnetic Encoder IC Block Diagram

It is important to note that while having all these features in one encoder device offers a very flexible solution, as important is the ability to adjust these features to meet the application requirements. For example, having the ability to setup and adjust the analog signal conditioning allows for a higher quality encoder output signal. Or, selecting the BLDC motor commutation pole setting allows the device to be used with various BLDC motors. All of these adjustable settings reside in the onboard RAM of the encoder chip, but are also programmed into the onboard nonvolatile PROM as well to allow these settings to be read and used on power-up. With all these features, it becomes clear that a highly configurable Single-chip encoder device can help achieve an increase in system performance.

With such a configurable device it is important to also have a simple means to configure it. While the configuration can be programmed over a serial interface, encoder IC's like the iC-MH also have a PC GUI tool that allows simple and real-time interaction and programming of the device. A PC adapter plug is used to interface to the encoder IC on the circuit board and then this adapter connects to the PC over a USB connection. This PC GUI shown in Figure-8 allows for an in-system configuration and programming tool which is key for the Single-chip encoder design.

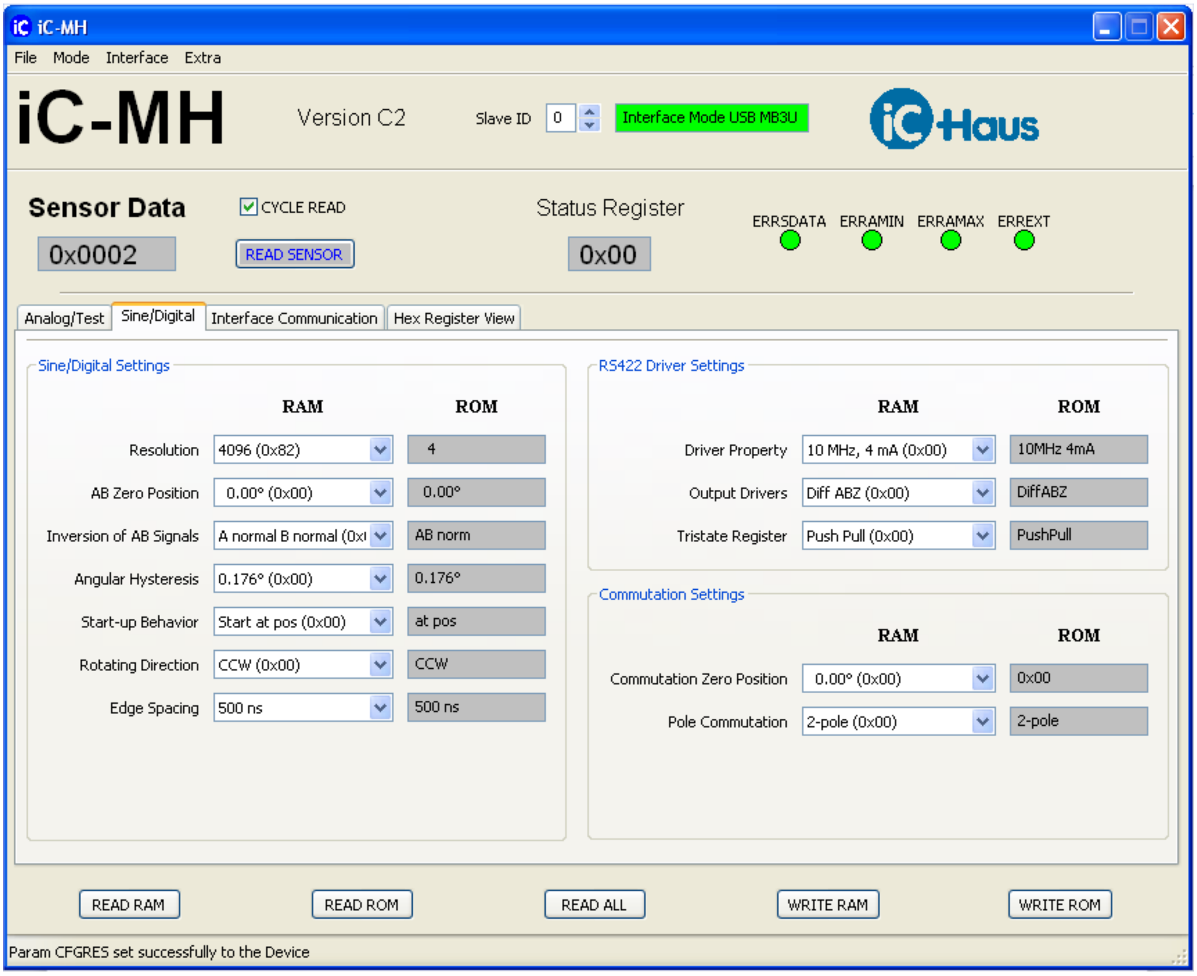


Figure-8: iC-MH Magnetic Encoder IC PC Configuration GUI

Besides configurability, many of these features can also add flexibility and open new design approaches for motion control systems to boost system performance. Let's consider the following features that can contribute to boosting system performance in motion control applications.

Resolution

Looking back at the designs shown in Figure-1 and Figure-2, when a boost in performance is required by a motion controller, a first item that comes to mind is the resolution of the encoder. If the encoder outputs 100 CPR (quadrature cycles per revolution) or 400 PPR(pulses per revolution or quadrature edges), changing this to a higher value like 1000 CPR or 4000 PPR yields a 10x increase in resolution. From an angular perspective this jumps the angular resolution from 0.9 degrees to 0.09 degrees per rotation for the motion control system. When doing this, one point to keep in mind is the underlying motion controller processing bandwidth and response time [3]. With 10x more pulses coming into the controller or embedded microprocessor, the hardware and firmware design must be able to handle this increase in interrupts and data processing.

Once these design considerations have been taken into account, adjusting resolution in-system is where the Single-chip encoder solution shines. In many cases, adjusting the resolution requires replacing the encoder device itself, however for a select few magnetic and optical encoders this can be adjusted digitally without changing the encoder IC or the source magnet/disc. For example, the iC-LNB optical encoder IC has a built-in FlexCount module which allows changing the resolution to any desired PPR from 1-65,536 PPR without changing the code disc itself. This allows a single Single-chip encoder IC to provide multiple different resolution settings for the application.

Form Factor

One benefit of the Single-chip encoder is the ability to create a solution in a very small form factor. For example, the iC-MH magnetic encoder IC has a 5x5 mm² package size which allows the encoder circuit board to be very compact in size. Having the flexibility of a small form factor, this allows monitoring of speed and position in confined areas. This potentially allows an encoder solution to be used where one could not be used prior. By adding this feedback to a system that may have ran open loop before, boosting performance and efficiency is possible instead of over driving an open loop system.

Encoder Sensor Input

The encoder output is only as good as its input. For a magnetic encoder this is the diametrically magnetized magnet and for an optical encoder the LED and code disc. An increase in performance can simply be realized by evaluating and then improving the input elements of the encoder. For the magnetic encoder IC, this could be in the form of selecting a higher quality magnet, reducing the air gap from encoder IC to magnet, and optimizing the mechanical design for concentricity. For the optical encoder IC, this could be in the form of selecting a higher quality LED as well as also reducing the air gap and optimizing the mechanical design. In both cases the goal is to provide the highest quality input signal to the encoder IC. By doing so this provides the building blocks for enhancing performance of the encoder feedback.

Accuracy Calibration

Calibration of encoder accuracy can be achieved by testing to a standard and then adjusting the encoder mechanical alignment and the internal encoder IC parameters accordingly. For the mechanical alignment, the small form factor of the Single-chip encoder design allows the ability to design in various mechanical adjustments over a packaged encoder solution. Having the ability to fine tune the physical location of the encoder IC to the magnet or code disc allows for the best possible input signal to the encoder IC.

While the mechanical adjustment can be an optional addition for the application, utilizing the Single-chip encoder's digital configuration is definitely worth pursuing. Given that the Single-chip encoder allows configuration of its internal parameters over a digital serial interface, this allows calibration to occur for a more accurate encoder solution. With the highest possible accuracy achieved for the encoder, not only does system performance increase with this accuracy increase, but motor control efficiency can increase with a higher quality encoder feedback.

Achieving this calibration is not always a straightforward task. In some cases, comparing the encoder under test to a known encoder standard is a possiblity. Then a custom data acquisiton and PC program can be used to show accuracy and error plot measurements. This can require a large effort upfront if designed from scratch. There are however readily available systems to aide in encoder calibration. As shown in Figure-9, the SinCosYzer is an off the shelf data acquisition system specifically meant for this task. By simply inputting the encoder Sine and Cosine output signals, many different measurements are displayed to assist with calibration. Most notably are the Lissajous curve, error curve, and accuracy in bits and degrees. As these settings are shown in real-time, adjusting the Single-chip encoder's configuration on the fly is possible; which is simply done via the encoder chips PC GUI shown in Figure-8. These configuration changes inside the encoder chip come by the way of the internal signal conditioning of amplitude, offset, and even phase adjustments of the Sine and Cosine encoder signals.

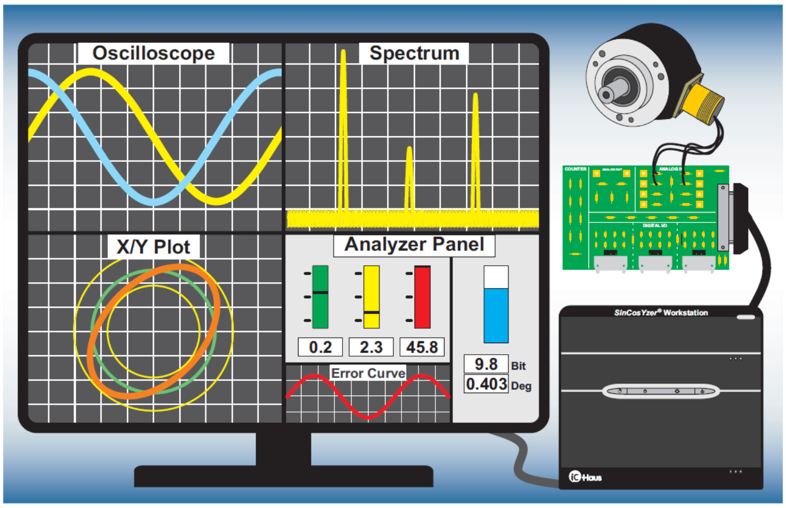


Figure-9: SinCosYzer encoder calibration tool

Encoder Signal Position Adjustment

Digitally adjusting the zero position of the encoder signals provides another way to boost system performance. Referencing the encoder signals shown in Figure-10, the iC-MH magnetic encoder chip's index or Z position can be digitally adjusted in 1.4 degree steps. The motor commutation zero position or rising edge of the U pulse can also be adjusted in 1.4 degree steps. By digitally adjusting the zero position for an application, this provides flexibility for defining a home position in the application. By digitally adjusting the zero position for motor commutation, performance gains can be seen in motor drive efficiency. Unlike hall sensors that sense the position of the BLDC magnet poles and are fixed in place, the Single-chip encoder can generate these motor commutation signals and then allow fine tuning of them to enhance the performance of the motor drive itself. As both the index and motor commutation signal positions are fully adjustable and programmable on the Single-chip encoder, a more flexible solution is realized to enhance motion control performance.

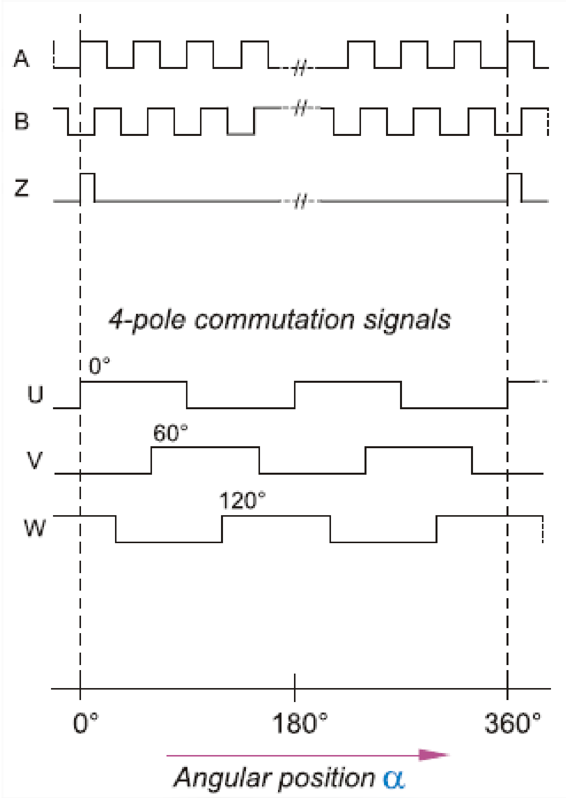


Figure-10: iC-MH ABZ and BLDC UVW motor commutation signals

5) Summary

Single-chip encoder IC's offer a highly flexible and configurable encoder feedback option in comparison to standard packaged and modular encoders. For those motion control applications that require the ability to fine tune and optimize the encoder feedback, Single-chip encoder devices offer a highly flexible and cost-effective alternative. Additionally, with a Single-chip encoder based design, there is now the ability to adjust the encoder configuration over a digital interface. By doing so, this gives the ability to adjust various parameters and further enhance the motion control feedback in order to boost the overall performance of the system.

6) Literature

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