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EMS22 NON-CONTACTING ROTARY ENCODERS TECHNICAL NOTE

Background

Technological advancements in the semiconductor industry have created a broad use of electronically controlled systems. This developing technology promotes the need for sensors that provide digital output and can handle harsh environments with a wide range of temperatures, moisture and particles. Non-contacting magnetic encoders provide an excellent option for many rotary sensor applications with a variety of encoder output modes including absolute, direction/step, Pulse Width Modulation (PWM), and quadrature. The Bourns® Model EMS22 is a non-contacting magnetic rotary encoder with a Hall Effect sensor that offers options for each of these four output types to meet broad application needs. This application note will present the design versatility of the Bourns® EMS22 non-contacting rotary magnetic encoder, and will provide helpful details on its output form and characteristics in PWM, direction/step, quadrature, and absolute modes.

Introduction to Rotary Non-Contacting Encoders

A traditional rotary encoder is used to produce a digital output signal related to the angular position of its shaft. Encoders are an optional replacement for potentiometers in many existing applications because they eliminate the need for an Analog-to-Digital Converter (ADC) on the circuit board. Rotary encoders are also used in designs that require precision position sensing, high resolution, or fast data acquisition. The Bourns® EMS22 non-contacting rotary magnetic encoder incorporates an austriamicrosystems® AS5040 Hall Effect Sensor. This non-contacting Hall Effect technology extends the rotational life of the Bourns® EMS22 device over encoders using contacting technology. The Bourns® Model EMS22 non-contacting encoder is available with several output options to meet a wide variety of application specifications.

For many system manufacturers, there is a need to utilize components that can operate in PWM output mode. Servo motors and interfaces that require fast data acquisition often use PWM input. The Bourns® Model EMS22 non-contacting encoder has PWM capability, which provides the advantage of better noise immunity compared to traditional analog readings. The direction/step output mode provides better resolution for incremental counting and indexing output. Quadrature mode is the most common operation of encoders and typically indicates direction and magnitude to an external interface circuit. Direction/step and quadrature modes provide incremental output with an index. Absolute mode is used in high-speed operation and also where the exact position of an object is necessary. The reading provided in absolute mode is not affected by interruption of power since each angular position corresponds to a predefined unique code. Table 1 lists examples of applications for each output option of the Bourns® Model EMS22 non-contacting rotary magnetic encoder.

Table 1 | Rotary Encoder Applications

PWM Model EMS22P	Direction/Step Model EMS22D	Quadrature Model EMS22Q	Absolute Model EMS22A
Servo Motors	Marine Applications	Automotive	Audio and Broadcast
Robotics	Office Equipment	Material Handling Equipment	Medical

PWM Output

While the output of the encoder is based on the shaft position, or measured angle, the specifications and operation for each output option are distinct. PWM signals have a duty cycle that is proportional to the measured angle. Table 2 contains the parameters of a PWM signal, and Figure 1 illustrates pulses of minimum and maximum width.

Table 2 | PWM Signal Parameters

Parameter	Symbol	Typical	Unit	Note
PWM frequency	f_{PWM}	0.9756	kHz	Signal period: 1025 µs
MIN pulse width	PW_{MIN}	1	µs	Position: 0 Angle: 0 degrees
MAX pulse width	PW_{MAX}	1024	µs	Position: 1023 Angle: 359.65 degrees
Time on	t_{on}	1 to 1024	µs	$t_{on} + t_{off} = 1025$ µs
Time off	t_{off}	1 to 1024	µs	$t_{on} + t_{off} = 1025$ µs

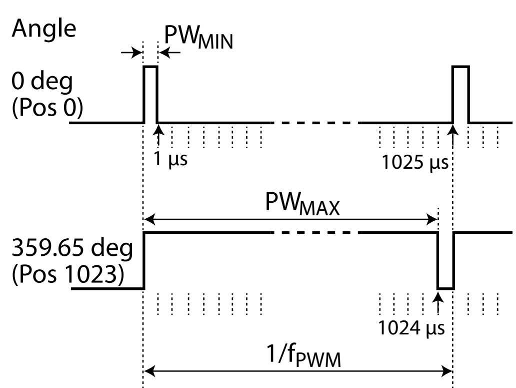

Figure 1 | Minimum and Maximum Pulse Width of PWM Signals (source: austriamicrosystems AG)

The position can be calculated based on the following formula:

$$Position = \frac{t_{on} * 1025}{(t_{on} + t_{off})} - 1$$

The PWM frequency is internally trimmed to an accuracy of ± 5 % (± 10 % over a full temperature range). In order to compensate for variation from part to part or over a given temperature range, the complete duty cycle can be measured. The measuring error is then eliminated because the position ratio is calculated based on the actual f_{PWM}.

Incremental Outputs

Output signals indicating the position and index of the shaft are provided by the Bourns® EMS22 non-contacting encoder when operating in quadrature or direction/step modes. With the Bourns® Model EMS22Q device, the phase shift between channel A and B indicates the direction of magnet movement. Channel A leads channel B by 90 electrical degrees when rotation is clockwise, and channel B leads channel A during counterclockwise rotation. The Bourns® Model EMS22D device is available with incremental resolution programmed from 64 to 512, and the 'Least Significant Bit' (LSB) of this resolution is available on the 'Pulse' output pin. The 'Direction' (Dir) output provides information about the rotational direction of the shaft (1 = clockwise; 0 = counterclockwise; top view), which is updated with every LSB change. The index pulse indicates the zero position. By default, it is one angular step (1 LSB) wide, and is available for up to three LSBs. In both modes, the resolution and the index output are user selectable. Table 3 shows the pin assignments for incremental output modes.

Table 3 | Incremental Output Pin Assignments

Output Type	Model	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6
A/B Quadrature	EMS22Q	A	B	GND	Index	V_{CC}*	CS**
Direction/Step	EMS22D	Pulse	Direction	GND	Index	V_{CC}*	CS**

** Can be 5 VDC or 3.3 VDC depending on the version*

***Active low chip select pin; if not used connect pin 6 to GND*

Hysteresis for Incremental Outputs

To avoid flickering on incremental outputs when the magnet is stationary, the Bourns® EMS22 non-contacting magnetic encoder introduces hysteresis. The incremental outputs have a hysteresis of 2 LSB in the case of rotational direction change. Regardless of the programmed incremental resolution, the hysteresis of 2 LSB always corresponds to the highest resolution of 10 bits. In absolute terms, the hysteresis is set to 0.704 degrees for all resolutions. For constant rotational directions, every change in magnet position is indicated at the incremental outputs.

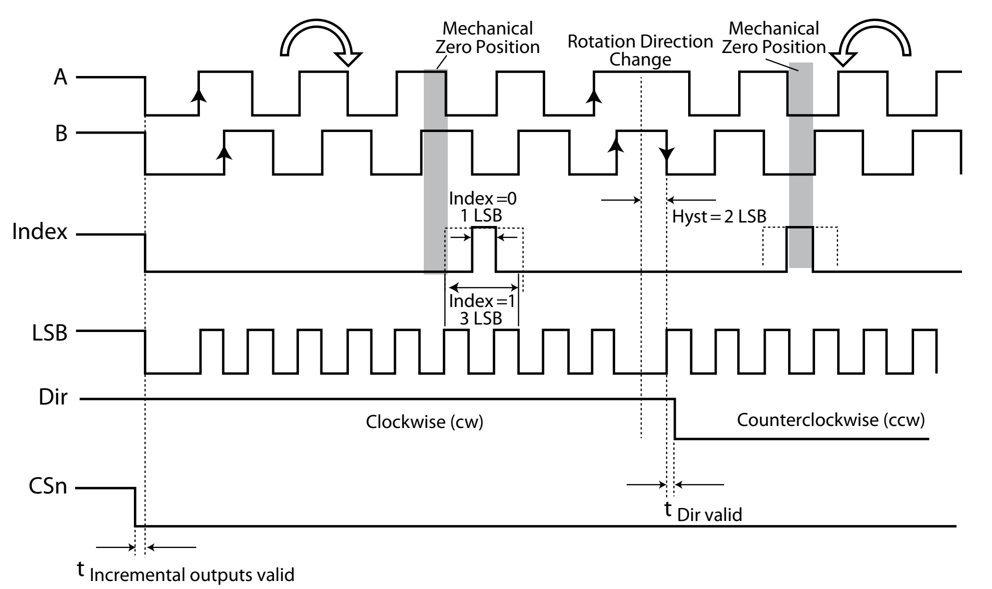

Figure 2 *Incremental Mode Output Signals (source: austriamicrosystems AG)*

Table 4 *Incremental Output Operating Conditions*

Parameter	Symbol	Max	Unit	Note
Incremental outputs valid after power-up	$t_{\text{incremental outputs valid}}$	500	ns	Time between first falling edge of CSn after power-up and valid incremental outputs
Directional indication valid	$t_{\text{dir valid}}$	500	ns	Time between rising or falling edge of LSB output and valid directional indication

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Hysteresis for Incremental Outputs *(Continued)*

Hysteresis can be illustrated with the example shown in Figure 3. If the magnet turns clockwise from position "x + 3" to "x + 4", the incremental output would indicate this position accordingly. A change of the magnet's rotational direction back to position "x + 3" means that the incremental output remains unchanged for the duration of 2 LSB, until position "x + 2" is reached. For subsequent changes in this direction, the incremental outputs will again be updated with every change of the magnet position.

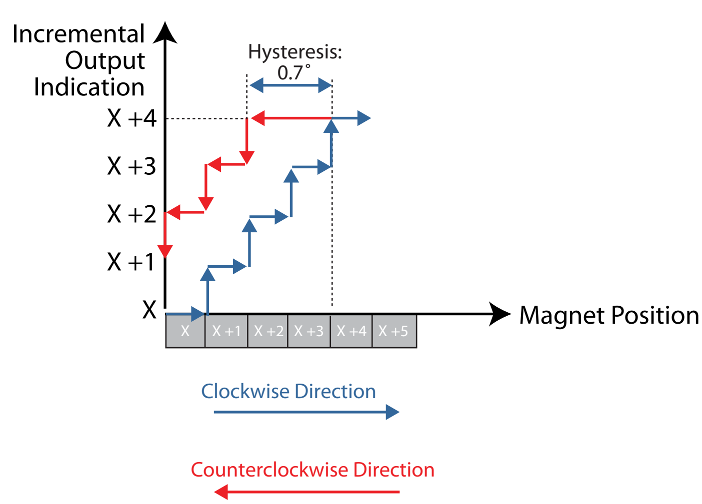

Figure 3 *Hysteresis with Magnet Rotation (source: austriamicrosystems AG)*

Incremental Power-up Lock Option

After power-up, the incremental outputs optionally can be locked or unlocked, depending on the status of the Chip Select (CS) pin. CS has an internal pull-up resistor, making it high or open at power-up by default. In this mode, the incremental outputs (A, B, Index) will remain at logic high state until CS goes low or a low pulse is applied at CS. This mode allows intentional disabling of the incremental outputs until, for example, the system microcontrollers are ready to receive data.

An external resistor, Rext (Rext ≤ 5 kΩ), can be connected between CS and GND to pull CS low. If CS is low at power-up, the incremental outputs A, B, and Index will be high until the internal offset compensation is finished. To shorten the waiting time at power-up, this unique state, A = B = Index = high, may be used as an indicator for the external controller. Instead of waiting for the specified maximum power-up time, the controller can start requesting data as soon as the state A = B = Index = high is no longer valid.

High-Speed Operation

The Bourns® EMS22 encoder is suitable for use in high-speed operation. The encoder samples the angular value at a rate of 10.42 k samples per second. As a result, the incremental and the absolute outputs are updated every 96 µs. Two popular modes in high-speed operation are serial communication and PWM.

Incremental and Absolute Modes with Serial Communication

With the given sampling rate of 10.42 kHz, the number of samples (n) per turn for a magnet rotating at high-speed can be calculated with the following formula:

$$n = \frac{60}{rpm * 96\ \mu s}$$

Regardless of the rotational speed, the absolute angular value is always sampled at the highest resolution of 10 bits. In absolute mode with serial communication, 610 RPM is the maximum rotational speed, and 1024 readings per revolution can be obtained. In practice, there is no upper speed limit. Rather as the speed increases, the number of samples per revolution is reduced. For a given number of samples per revolution (n), the corresponding maximum speed can be calculated with the following formula:

$$rpm = \frac{60}{n * 96\ \mu s}$$

When the magnet is stationary, the sampling rate is free of error. In direction/step mode, the maximum error caused by the sampling rate of the ADCs is 0/+96 µs. This error has a peak of 1 LSB = 0.35 ° at 610 RPM, and at higher speeds the error is reduced due to interpolation. The output delay remains at 192 µs to allow the DSP two sampling periods (2 x 96 µs) to synthesize and redistribute any missing pulses.

Absolute Mode with PWM

Absolute mode with PWM follows the same formula as serial communication. Since the PWM output is refreshed at a rate of 1.025 ms, the number of samples (n) per turn for a magnet rotating at high-speed can be calculated with the following formula:

$$n = \frac{60}{rpm * 1.025\ ms}$$

The Bourns® Model EMS22P encoder in absolute mode has a maximum speed of 57 RPM with 1024 readings per revolution. When operating above the maximum speed, the absolute position is still read, though it will be delayed.

UNDERSTANDING AND UTILIZING OUTPUT FORMS AND CHARACTERISTICS

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Versatile Solutions

Bourns has been a leader in sensors and controls for decades, and its experience has contributed to a versatile product offering in the Bourns® Model EMS22 non-contacting encoder. With the capability of PWM, absolute, and incremental mode operation, it can be used in numerous applications. Popular requirements in incremental operation are addressed with the introduction of hysteresis and the production of no missing pulses when operating up to several thousand RPMs. The Bourns® Model EMS22 non-contacting encoder has a built-in interpolator to ensure that there are no missing pulses at the incremental outputs for rotational speeds up to 10,000 RPM at 10 bit resolution (512 pulses per revolution). Table 5 summarizes the exceptional sampling up to thousands of RPMs for absolute and incremental output modes. Versatility is provided by the ability to lock the outputs with the CS pin at power-up for optimal interface with microcontrollers.

Table 5 | Bourns® EMS22 Non-Contacting Encoder Revolution Specifications

Absolute Output Mode Model EMS22A	Incremental Output Mode Models EMS22Q & EMS22D
610 RPM = 1024 samples / turn	No missing pulses @ 10 bit resolution (512 PPR): Max. speed = 10,000 RPM
1220 RPM = 512 samples / turn	
2441 RPM = 256 samples / turn	
Etc.	

Complementing its high-speed performance, the rugged construction of the Bourns® EMS22 non-contacting rotary magnetic encoder makes it suitable for reliable operation in harsh environments with particles. It is sealed to IP65 standards, with the option to meet IP67 standards. The non-contacting Hall Effect technology provides increased product life and performance compared to contacting technology. Additional benefits of the Bourns® EMS22 non-contacting encoder include its cost-effectiveness, small package, low circuit complexity, and resolution range. Design engineers with constraints in these areas of their design can take advantage of such features. Bourns offers excellent customer service, including access to the company's Field Application Engineers to assist in incorporating the appropriate Bourns® device based on system specifications.

For more information about the Bourns® EMS22 non-contacting rotary magnetic encoders, please visit
www.bourns.com

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