Programming AksIM-2 encoders
with EncoLink communication protocol

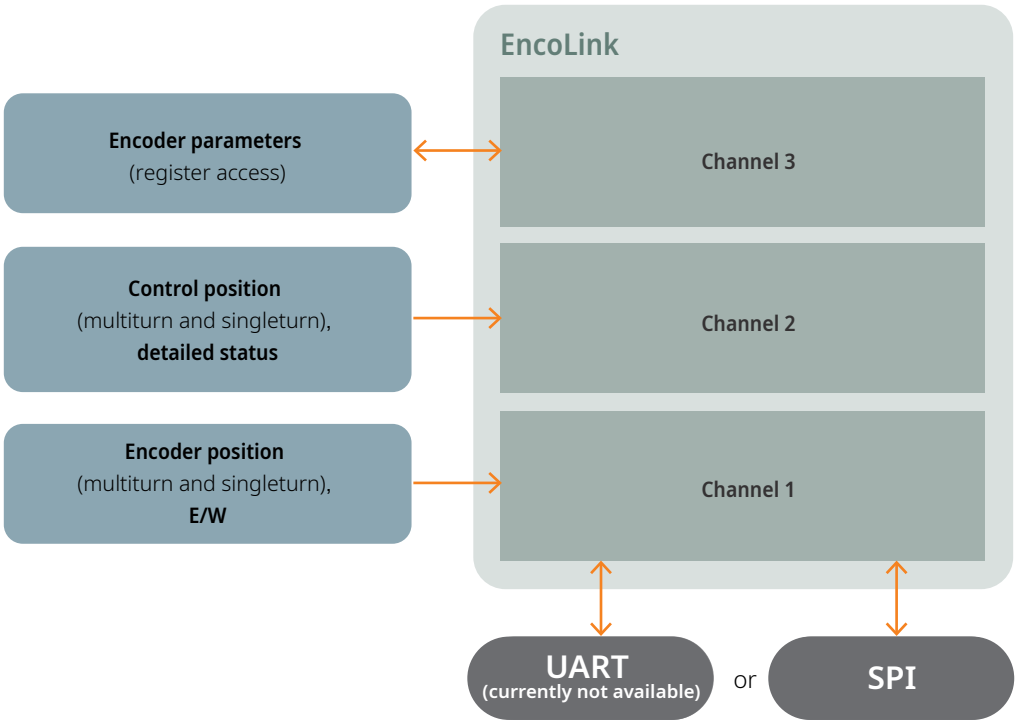
EncoLink is a communication protocol that can be implemented on different physical channels, UART and SPI. It is a multilayer communication protocol that provides position, CRC and error/warning bits in the first channel, control position and detailed status in the second channel and register access in the third channel. The user can read all data simultaneously, the first channel with the highest bandwidth and the third channel with the lowest bandwidth.

User implementation: The user can choose one of two options:

- Channel 1 only. Only the encoder position is available, with general Error and Warning bits. For SPI, the MOSI line can be tied to GND (unused) and for UART, an empty request (0x00, 0x00) is sent.
- Full 3-channel access. RLS provides source code of EncoLink master libraries. The end user does not need to write custom code to implement full encoder functionality.

Related product

AksIM-2 off-axis absolute magnetic encoder

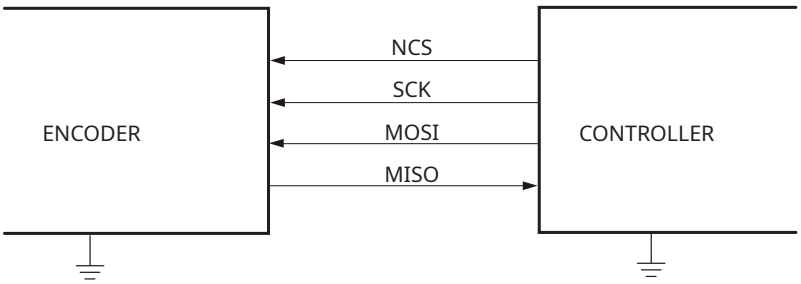


EncoLink over SPI bus

The Serial Peripheral Interface (SPI) bus is a bidirectional, synchronous, four wire serial communication interface, typically used for short-range communications. It operates in full duplex mode, where the master (controller) selects the slave with the NCS line, generates a clock signal on the SCK line, sends commands over the MOSI line, and receives data over the MISO line.

Electrical connection

All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant. Maximum current sourced or sunk from signal lines should not exceed 20 mA. Single-ended signals should be as short as possible, especially if high frequencies are used.
Signal termination: 100 Ω resistors are added in series with all SPI signals.

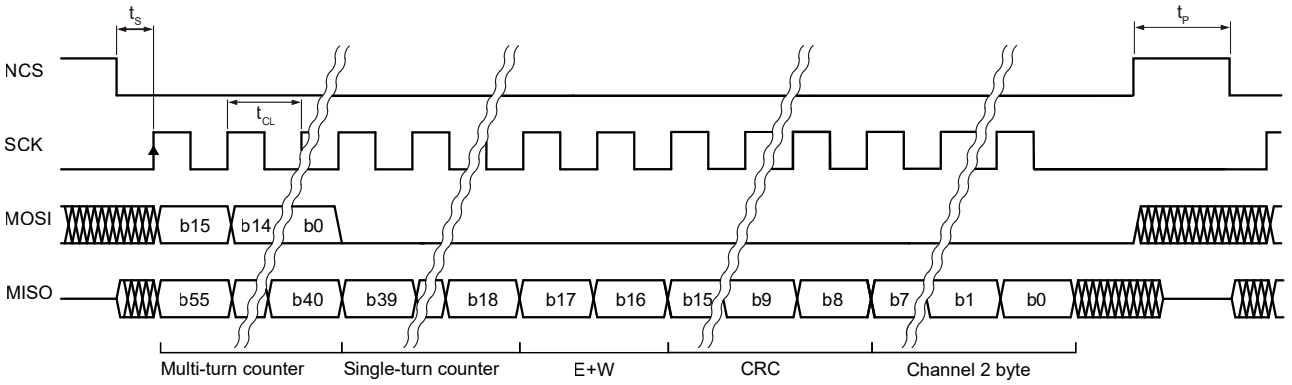


Signal	Description
NCS	Active low. NCS line is used for synchronisation between master and slave devices. During communication it must be held low. Idle is high. When NCS is high, MISO line is in high-Z mode. This allows connection of multiple slaves in parallel, sharing all lines except NCS.
SCK	Serial clock. Shifts out the data on rising edge. Data is stable and valid on falling edge.
MOSI	Master output ⟶ Slave input. Command from the controller to encoder.
MISO	Master input ⟵ Slave output. Data is output on rising edge on SCK after NCS low. When NCS is high, MISO line is in high-Z mode.

Pinout

Pin	SPI
1	+5 V
2	GND
3	-
4	-
5	SCK
6	NCS
7	MISO
8	MOSI

SPI timing diagram



Controller starts the communication by setting the NCS signal low. At the same time the encoder position is latched. A delay of t_S is required to allow the encoder to prepare the data which is then shifted to MISO output on rising edges of clock signal SCK. Encoder Position and General Status (active low) data is transmitted, followed by CRC (inverted) of the first part of the data packet. Last byte (after CRC) is used by the EncoLink library to transfer data from protocol layers 2 and 3.
The command is sent into the encoder over the MOSI line on first 16 rising edges of SCK. Command bytes are prepared by the EncoLink library.

Communication parameters

Parameter	Symbol	Min	Max
Clock period	t_{CL}	250 ns	
Clock frequency	f_{CL}		4 MHz
Time after NCS low to first SCK rising edge	t_S	5 µs	
Pause time	t_P	5 µs	
SPI settings	CPOL= 0 (clock idle is low)		
	CPHA = 1 (data is output on clock rising edge and sampled on clock falling edge)		

Encoder position data structure

Transmitted data (2 bytes): Command [b15:b8], Data [b7:b0] (from EncoLink library)
Received data: see table below

For multiturn		
2B	**b55 : b40**	Multiturn counter (if specified in part number) – Left aligned, MSB first.
	b39 : b18	Encoder position + zero padding bits – Left aligned, MSB first.
3B	**b17**	Error – If low, the position data is not valid.
	b16	Warning - If low, the position data is valid, but some operating conditions are close to limits.
1B	**b15 : b8**	Inverted CRC, 0x97 polynomial
1B	**b7 : b0**	Channel 2 byte (for EncoLink Library)

For singleturn		
	b39 : b18	Encoder position + zero padding bits – Left aligned, MSB first.
3B	**b17**	Error – If low, the position data is not valid.
	b16	Warning - If low, the position data is valid, but some operating conditions are close to limits.
1B	**b15 : b8**	Inverted CRC, 0x97 polynomial
1B	**b7 : b0**	Channel 2 byte (for EncoLink Library)

CRC calculation example is in application note document CRCD01, available for download at **RLS media center**.

When EncoLink library is in use, it will transmit 2 bytes on MOSI line and receive additional 1 byte at the end of position data over MISO line. See “Channel 2 byte” in the timing diagram for details.

Encoder programming

Encoder supports setting zero position, running self-calibration function, reading air gap and other configuration and operating parameters. Those functions are available over Channels 2 and 3 with use of EncoLink libraries. **Contact RLS** for C source code of the EncoLink SPI Master library.

EncoLink memory map on AksIM-2 encoders

Register map

Address	Data type	Access	Min - Max	Unit	Description
Identification					
0x0064	20× U8	R	x	–	Encoder part number
0x005C	8× U8	R	x	–	Encoder serial number
0x0100	16× U8	R	x	–	Encoder extended serial number
0x002F	U16	R	2	–	FW major version
0x0031	U16	R	9	–	FW minor version
0x0033	U16	R	x	–	FW Comm driver version
0x0035	U16	R	x	–	FW revision number
Runtime status					
0x002C	U16	R	–	–	Encoder status (persistent)
0x004E	U16	R	–	–	Signal level
0x004C	S16	R	–	°C	Sensor temperature
0x0050	S16	R	–	RPM	Rotational speed
Configuration					
0x0000	U32	R/W	0 - Counts-1	Counts	Position offset
0x0004	U32	R/W	0 - 240	–	Position filter value
0x0008	U32	R/W	0 - 1000	RPM	Position filter speed
0x0014	U32	R/W	0 - 65535	Turns	Multiturn counter preset
0x0018	U8	R/W	1 - 64	Segments	Multiturn error arc length
0x1800	S16	R/W	-999 - +999	Counts	Error map
0x0049	U8	W	–	–	Command input (see below for list)
0x002E	U8	R/W	–	–	Write lock
Self-calibration config, status and results					
0x0019	U16	R/W	180 - 360	Deg	Set partial arc length for self-calibration
0x0021	U8	R/W	1 - 40	Sec	Set duration of self-calibration
0x0052	U8	R	–	–	Self-calibration status
0x001B	U16	R	0 - 200	µm	Ring eccentricity shift from rotation axis center
0x001D	U16	R	0 - 360	Deg	Ring eccentricity angle (phase)
0x001F	S16	R	-500 - +500	µm	Readhead radial shift (positive = outside)

List of commands

Char	Hex	Description
r	0x72	Reset configuration to factory settings
c	0x63	Save current configuration to non-volatile memory
m	0x6D	Preset multiturn counter from register 0x0014
b	0x62	Clear persistent status in register 0x002C
A	0x41	Start self-calibration procedure

Encoder operating parameters

Encoder status

Detailed status bits represent current operational state of the encoder.

Detailed status (part 1)	
b15	Error - Multiturn counter mismatch. Encoder was rotated for more than ±90° during power off. Cycle the power to clear this error.
b14	Error - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
b13	Warning - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
b12	Error - Magnetic sensor. Cycle power to the encoder.
b11	Error - Sensor reading error, probably caused by electrical interference, ground loop or RFI.
b10	Error - Encoder not configured properly.
General status	
b9	Error. If bit is set, position is not valid.
b8	Warning. If bit is set, encoder is near operational limits. Position is valid. Resolution and / or accuracy might be lower than specified.
Error and Warning bits can be set at the same time; in this case Error bit has priority. The colour of the LED on the readhead housing indicates the value of the General status bits: ● Red = Error, ● Orange = Warning, ● Green = Normal operation, ○ No light = no power supply. The warning or error status is more closely defined by the Detailed status bits.	
Detailed status (part 2)	
b7	Warning - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
b6	Warning - Signal amplitude low. The distance between the readhead and the ring is too large.
b5	Error - Signal lost. The readhead is out of alignment with the ring or the ring is damaged.
b4	Warning - Temperature. The readhead temperature is out of specified range.
b3	Error - Power supply error. The readhead power supply voltage is out of specified range.
b2	Error - System error. Malfunction inside the circuitry or inconsistent calibration data is detected. To reset the System error bit try to cycle the power supply while the rise time is shorter than 20 ms.
b1	Error - Magnetic pattern error. A stray magnetic field is present or metal particles are present between the readhead and the ring or radial positioning between the readhead and the ring is out of tolerances.
b0	Error - Acceleration error. The position data changed too fast. A stray magnetic field is present or metal particles are present between the readhead and the ring.

Persistent encoder status

This is similar to “Encoder status”, but with the added functionality that all detailed statuses are accumulated. Any error or warning that appears in Detailed Status during operation of encoder is copied into Persistent detailed status. Even if the value in Detailed Status has very short duration, the past statuses can be read from this Persistent register. It keeps the value as long as the power is present. Clearing is possible either by a power cycle or by writing the command ‘b’ to the Command register.

Sensor temperature

Temperature of the sensor in °C. This value is typically 10 °C to 15 °C higher than ambient. Tolerance of the readout is ±5 °C.

Signal level

The signal level information can be used to calculate the ride height (distance between rubber on the ring and sensor on the readhead).

Encoder size	K	N
022, 029	–95.49	977
039, 049	–83.56	865
053, 064, 080	–71.62	748

The value is proportional to the distance between the sensor and the ring.
To calculate the real distance, use the following formula:
Ride height = K × Ln (SignalLevel) + N
Calculated ride height has tolerance of ±20 µm.
K and N are selected depending on the encoder size.

AksIM-2 programming

The AksIM readhead can be programmed with a position offset (zero position of the encoder), a multiturn counter (optional) and multiturn power-on error detection arc length. In addition, the readhead can be self-calibrated or reset to the factory settings. The numbers written in the registers only become effective once they have been stored in the non-volatile memory. An exception Multiturn counter value which is effective immediately.

Position offset (encoder zero position)

The position offset is written as a positive number, in encoder counts.
After changing the zero position to a larger value, an acceleration error or a multiturn error may occur. After each setting of a new position offset, the value of the multiturn counter (if present) must be checked or adjusted.
To save the settings permanently, execute the command to save the programmed data in a non-volatile memory: Write ASCII 'c' (0x63) to address 0x0049

> Saving the parameters in the non-volatile memory takes 80 ms. During this time, the encoder position is not calculated. With the multiturn counter option, the counter is only valid if the rotational speed does not exceed ±300 rpm during the saving process.

Multiturn counter

Multiturn counter preset is only available for the multiturn variants of the AksIM encoders.
First, the new multiturn counter value must be written to register 0x0014. Programming a multiturn counter greater than 65535 (unsigned) is discarded. At this point, the new multiturn counter is not yet active. To validate it, the user must execute the command to preset the multiturn counter: Write ASCII 'm' (0x6D) to address 0x0049.

Self-calibration

The self-calibration of the AksIM is suitable after mounting the readhead. It improves the accuracy of the encoder, which depends on the mounting precision. It can be triggered by sending the Self-Cal-Start command (0x41) to the Command register (address 0x0049). No communication via the SPI interface is possible during the process; the encoder does not respond to incoming clock cycles. The completion of the process is indicated by the LED flashing rapidly for 3 seconds. If the self-calibration was successful, the LED flashes green, otherwise red. The SPI interface is then active again. The status of the self-calibration can be read from a register 0x0052. It consists of a two-bit counter and two status bits. The counter is incremented at the end of each self-calibration. Error bits indicate the success or the reasons for failure.

Before the self-calibration process, the status should be read from register 0x0052. The controller must remember the current self-calibration counter (bits 1:0). After sending the self-calibration command, the LED must be observed for completion. If the LED is not visible, the readhead should be polled via the SPI interface until communication with the readhead is re-established, or wait 10 seconds, which is the longest possible time for completion. The self-calibration status register should then be read again. When the self-calibration counter has increased by 1 (compared to the previously read value), the self-calibration function is complete. If the self-calibration was successful, both status bits (b3, b2) are zero. Additional data from the self-calibration is available from firmware 2.5. This includes the measurement of the ring eccentricity and the positioning of the readhead.

Speed and direction of rotation during self-calibration are not important and may be inconsistent. The only requirement is that the shaft makes at least one complete revolution within 10 seconds of the command being sent. If the default setting of 10 seconds is not sufficient, this period can be extended to up to 40 seconds using register 0x0021 (available for encoders with firmware 2.9 and higher). If the mechanics do not allow 360° rotation, the length of the calibration arc can be reduced to at least 180°. The new arc length must be set before the self-calibration function is executed. The performance of the self-calibration procedure is optimal at 360° rotation and is reduced if the arc length is reduced.

Self-calibration status register at address 0x0052

Bit	Meaning
b7	Reserved
b6	Calibration was successfully performed, error map is in use.
b5	No correction needed (mechanical installation is perfect).
b4	Arc length parameter (0x19) out of range.
b3	Calculated parameters out of range. Mechanical installation is not inside tolerances.
b2	Timeout. Encoder ring did not make a complete turn during 10 seconds.
b1 : b0	Counter

After successful competition of the self-calibration procedure the results are automatically saved into the non-volatile memory. All numeric results from the calibration are stored in the volatile memory and are cleared on the power cycle. To verify if encoder was already calibrated, read the Self-calibration status byte and verify that bit b6 (0x40) is set.

Saving configuration parameters

Sending a programming command byte ‘c’ triggers the procedure to save all configuration parameters of the encoder in the non-volatile memory. These parameters also include the position offset.
Execute the command to save the data: Write ASCII ‘c’ (0x63) to address 0x0049.

> Saving the parameters in the non-volatile memory takes 80 ms. During this time, the encoder position is not calculated. With the multiturn counter option, the counter is only valid if the rotational speed does not exceed ±300 rpm during the saving process.

Reset to factory defaults

Resetting to the factory defaults will set all programmed parameters to the default values. This includes the zero position, the calibration results and others.
Execute the command to reset the encoder: Write ASCII ‘r’ (0x72) to address 0x0049.

> Saving the parameters in the non-volatile memory takes 80 ms. During this time, the encoder position is not calculated. With the multiturn counter option, the counter is only valid if the rotational speed does not exceed ±300 rpm during the saving process.

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Document issues

Issue	Date	Page	Description
4	17. 4. 2024	2	Asynchronous serial communication removed
		4, 5	SPI communication amended
		6, 7	AksIM-2 pogramming added