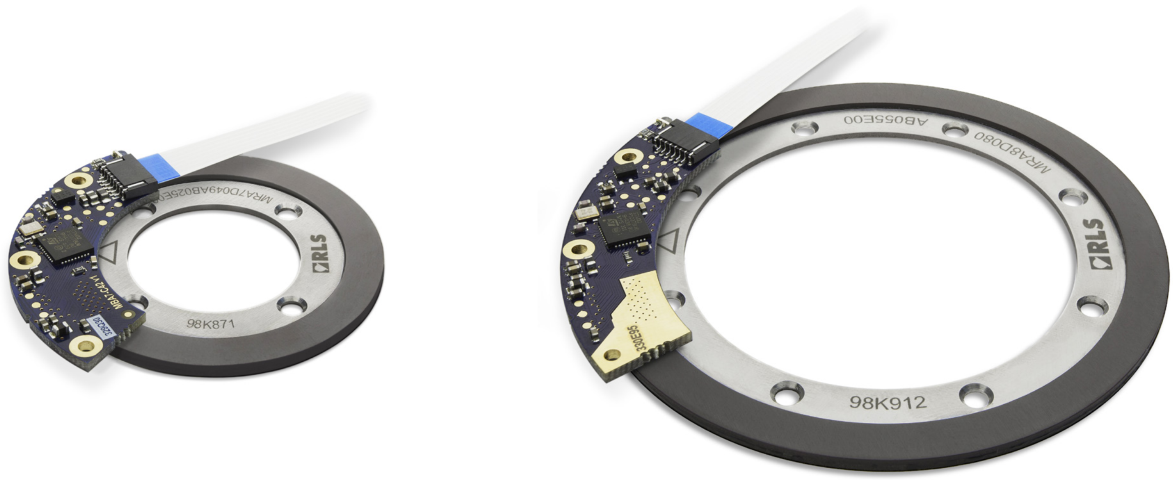
Data sheet
MBAD01_08
Issue 8, 20th June 2016

AksIM™ rotary absolute encoder module



AksIM™ is a non-contact high performance off-axis absolute rotary encoder designed for integration into space-constrained applications. A hollow ring, true absolute functionality and high speed operation make this encoder suitable for many applications.

The AksIM™ board level encoder is specifically designed for integration into applications where there is no space for the classic AksIM™ readhead with T-shaped housing. An external case (provided by the customer) must serve as environmental protection of the encoder.

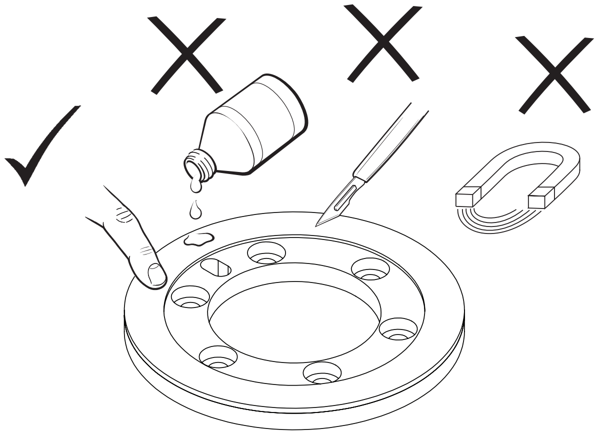
The board level encoder system consists of an axially magnetised ring and a readhead board.

The encoder has a built-in advanced self-monitoring function, continually checking several internal parameters. Error reporting, warnings and other status signals are available on all digital interfaces and are visualised with the on-board LED.

The encoder system is suitable for use in industrial and medical applications. A typical application is a robotic arm joint with a cable feed running through the ring or a precision gearbox where the ring is attached onto the main transmission shaft. Custom readhead board design service for OEM integration is also available.

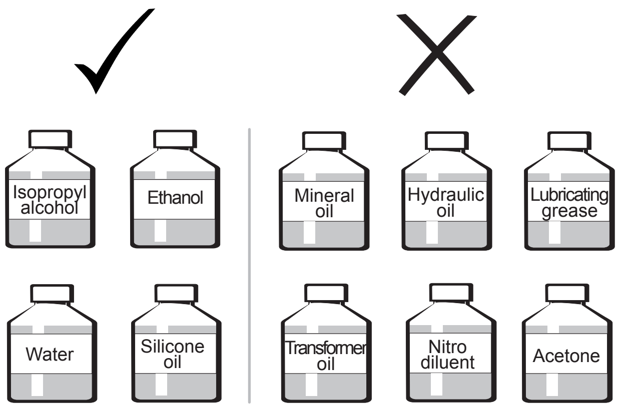
- **True absolute system**
- **Custom magnetic sensor ASIC**
- **No hysteresis**
- **Resolutions up to 20 bits**
- **Multiturn counter option**
- **High speed operation**
- **Low profile, non-contact**
- **Built-in self-monitoring**
- **Integrated status LED**
- **SSI, SPI, PWM, BiSS, I²C, asynchronous serial communication interfaces**
- **Corrosion resistant magnetic ring**

Storage and handling



> **WARNING:** Magnetic rings should not be exposed to magnetic field densities higher than 50 mT on its surface. Magnetic fields higher than 50 mT can damage the ring.

Chemical resistance



Readhead

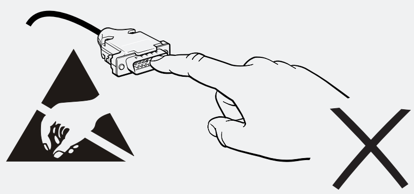
The MBA readhead with cable is resistant to a range of greases and oils commonly found in industry.
If the encoder is to be used in the area without air, it is recommended to use silicone-based oils or demineralised water.
Before any long-term immersion into any liquid or gas, please consult your local sales representative.
Encoder is not vacuum compatible.

Magnetic ring

The magnetized rubber on the ring does not withstand the following chemicals: mineral oils, hydraulic oils, most of transformer oils, lubricating grease, nitro diluent, acetone etc.
The following have been tested and are not recommended:

- ISO VG 46 (SAE MS1004 type HM)
- Nytro 10 XN
- MIDEL 7131
- Shell Diala S3 ZX-I.

The rings are resistant to isopropyl-alcohol, ethanol, water and some silicone-based oils.



WARNING!

ESD protection
Readhead is ESD sensitive - handle with care. Do not touch electronic circuit, wires or sensor area without proper ESD protection or outside of ESD controlled environment.

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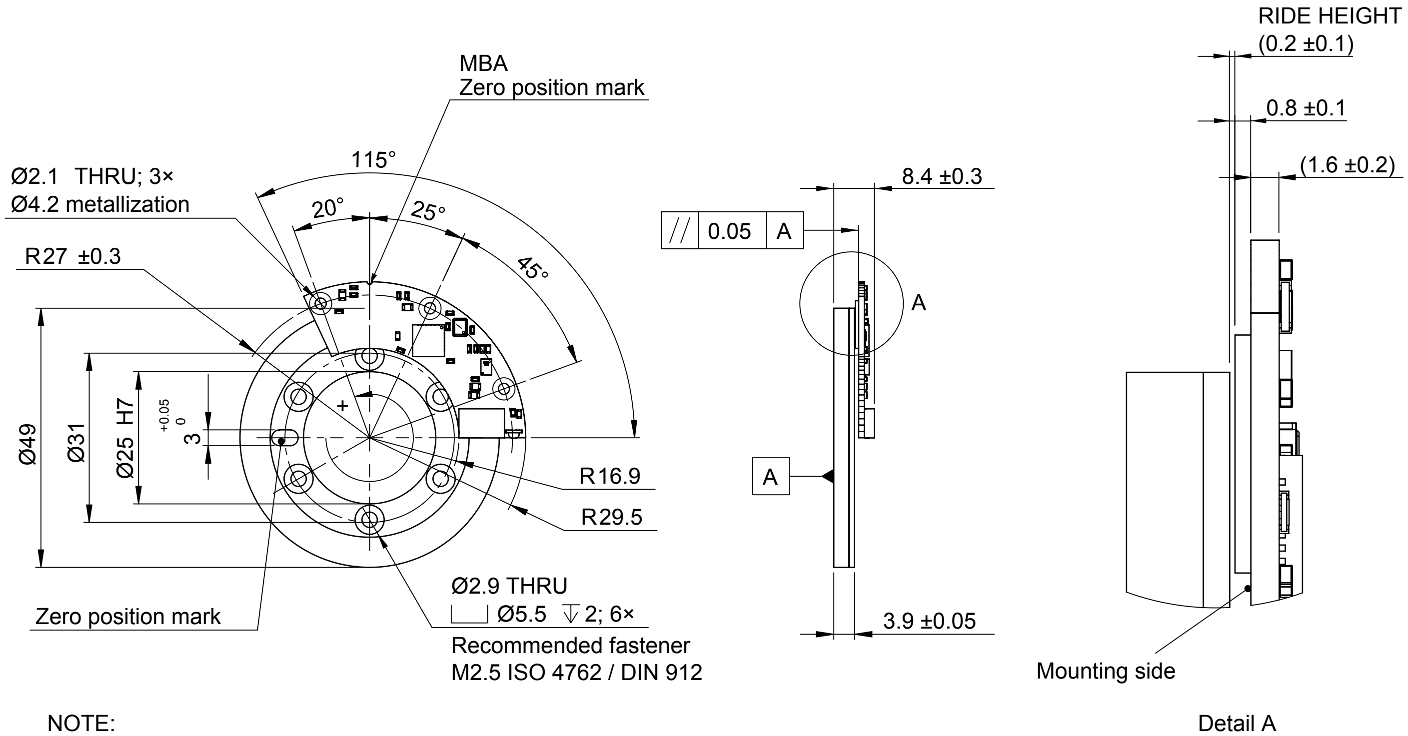
Dimensions

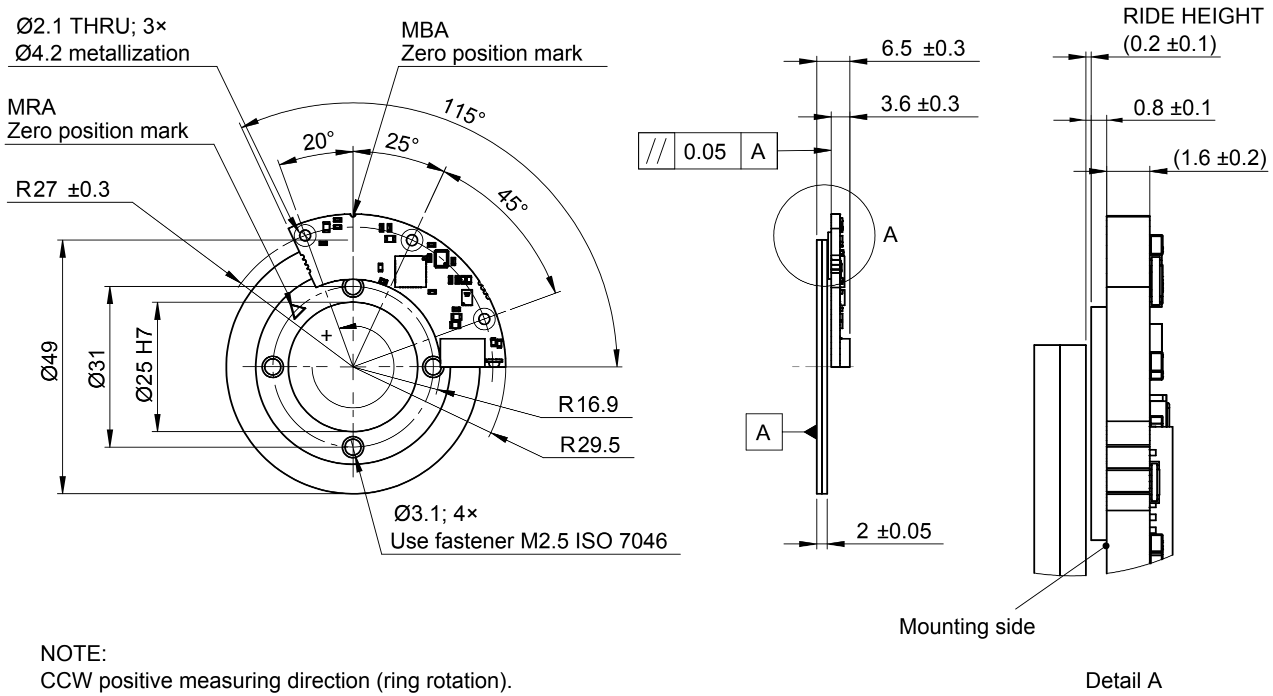
Dimensions and tolerances in mm.

MBA7 with MRA7D049AA025B00 ring



NOTE:
CCW positive measuring direction.

MBA7 with MRA7D049AB025E00 ring



NOTE:
CCW positive measuring direction (ring rotation).

Data sheet
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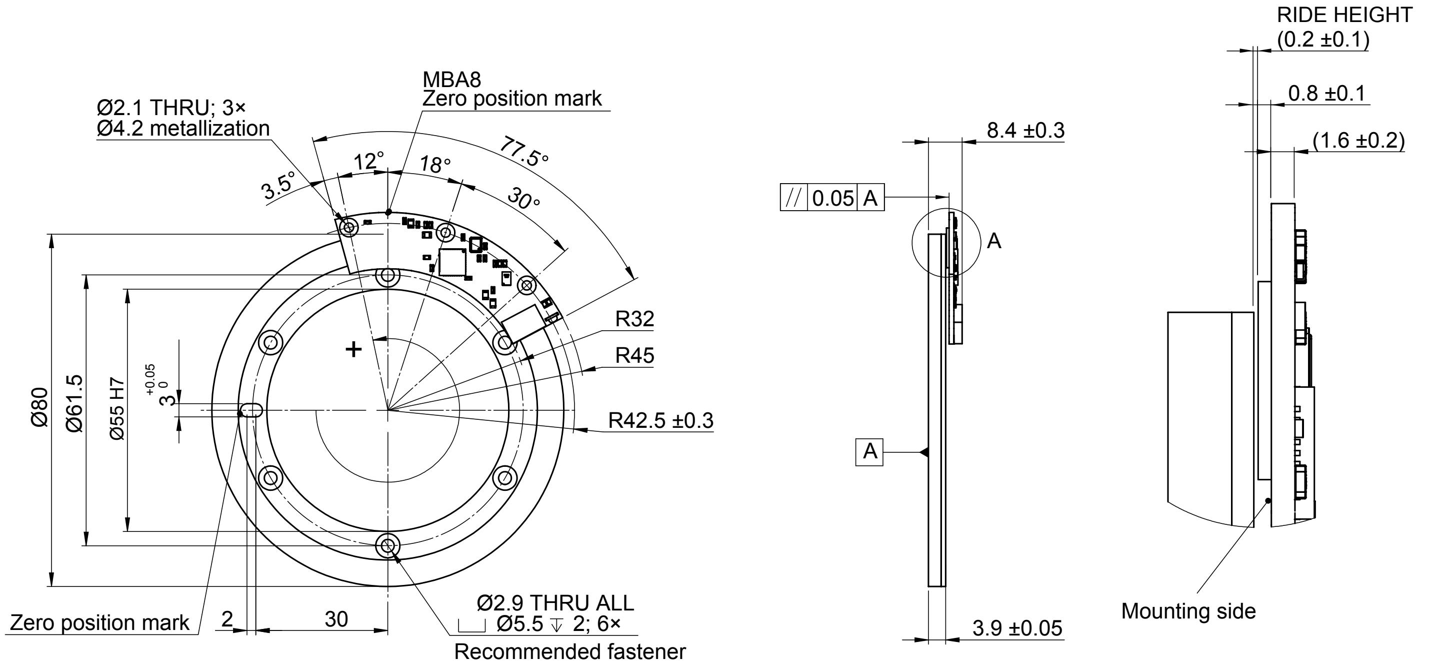
Dimensions continued

Dimensions and tolerances in mm.

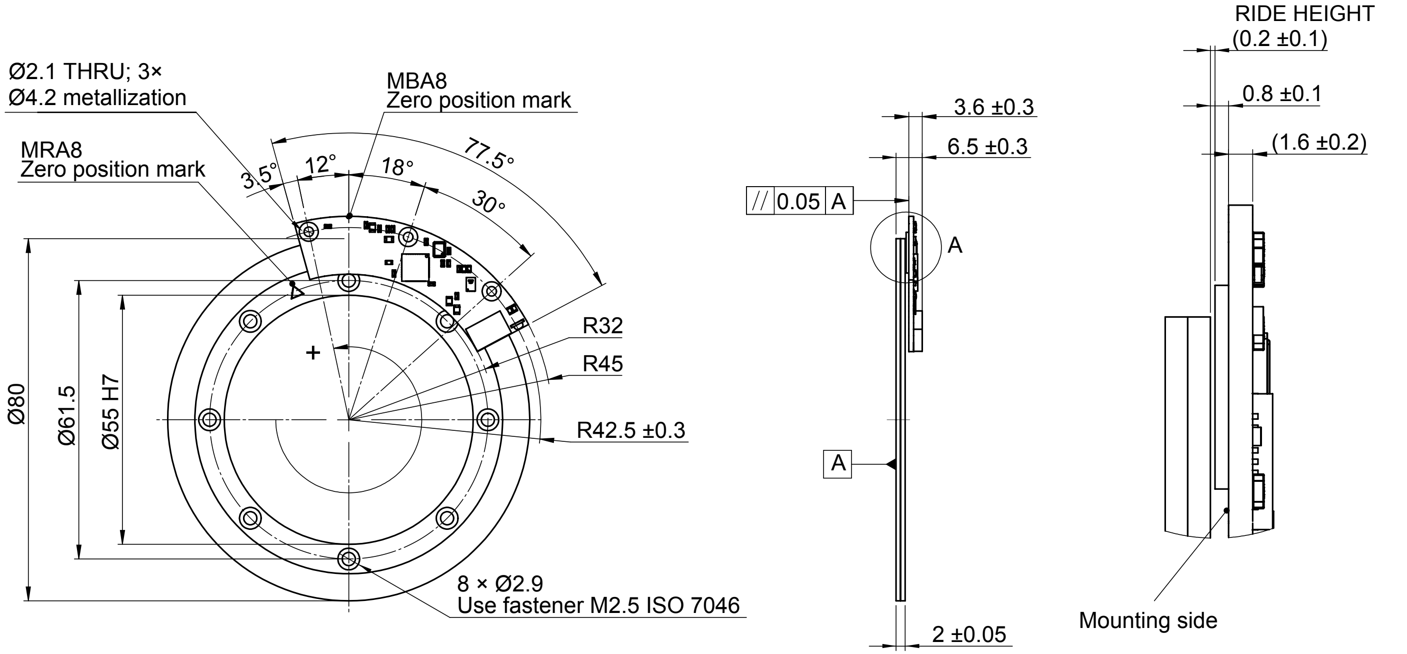
MBA8 with MRA8D080AA055B00 ring



NOTE:
CCW positive measuring direction.

Detail A

MBA8 with MRA8D080AB055E00 ring



NOTE:
CCW positive measuring direction (ring rotating).

Detail A

Technical specifications

System data		
Reading type	Axial reading	
Resolution	From 15 bit to 20 bit and 16 bit multiturn counter option (see chapter Available resolutions on page 8)	
Maximum speed	> 10,000 rpm	
Encoder accuracy	±0.05° (before installation - errors caused by mounting inaccuracy of the readhead, ring and drive shaft are not included)	
Final system accuracy	Typ. ±0.1° (within defined installation tolerances - see chapter Installation instructions on page 6)	
Hysteresis	Less than unit of resolution	
Repeatability	Better than unit of resolution	
Electrical data		
Supply voltage	4 V to 6 V (3.3 V option available upon request)	
Set-up time	10 ms (first data ready after switch-on)	
Power consumption	Typ. 115 mA, max. 150 mA	
Connection	FFC connector, 6 pins, 1 mm pitch Mating connector: standard FFC, 6 way, 1 mm pitch (can be ordered under: ACC006)	
Output load	Max. ±20 mA	
ESD protection	HBM, Class 2, max. 2 kV	
Mechanical data		
Available ring sizes (outer diameter)	49 mm (ring MRA7)	
	80 mm (ring MRA8)	
Ring material type	EN 1.4005 / AISI416 or EN 1.4104 / AISI430F with glued rubber filled with ferrite particles	
Readhead thickness	4.3 mm	
System thickness	With MRA7D049AA025B00 or MRA8D080AA055B00	8.4 ± 0.3 mm
	With MRA7D049AB025E00 or MRA8D080AB055E00	6.5 ± 0.3 mm
Mass	Readheads: MBA7 2.6 g, MBA8 2.9 g; Rings: MRA7D049AA025B00 32 g, MRA7D049AB025E00 15 g, MRA8D080AA055B00 64 g, MRA8D080AB055E00 26 g	
Inertia	MRA7D049AA025B00 13.1 kg×mm², MRA7D049AB025E00 5.5 kg×mm², MRA8D080AA055B00 79.1 kg×mm², MRA8D080AB055E00 31.2 kg×mm²	
Environmental data		
Temperature	Operating	–30 °C to +70 °C
	Storage	–40 °C to +100 °C
Humidity	0 % to 70 % non-condensing	
Environmental protection	None (conformal coating available upon request)	
External magnetic field	Max. ±3 mT (DC or AC) on top side of readhead	

Status indicator LED

The LED provides visual feedback of signal strength, error condition and is used for set-up and diagnostics.
Flashing LED indicates the encoder is powered but communication has not been established. When communication is running at a rate of minimum 5 readings per second LED is constantly lit. Repeatable two short red flashes indicate the readhead can not start.

LED	Status
Green	Normal operation; position data is valid
Orange	Warning; position is valid, but the resolution and/or accuracy might be out of specification. Some operating conditions are outside limits.
Red	Error; position data is not valid
No light	No power supply

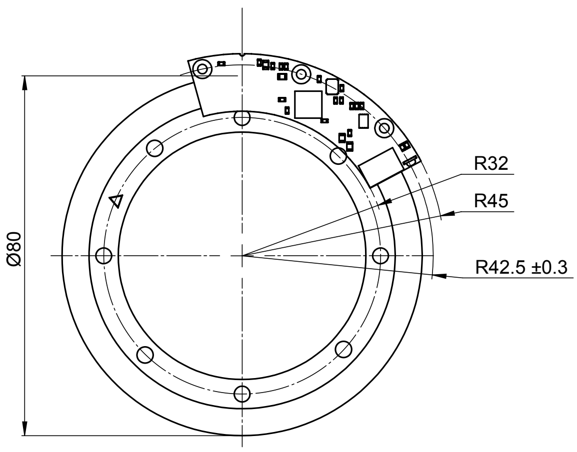
Installation instructions

Axial position adjustment (ride height)
The nominal gap between the gold mounting areas on the PCB mounting side and the rubber band on the ring is 0.8 mm ±0.1 mm.
We recommend using gold plated surfaces on the bottom of the PCB as a reference for mounting the readhead. If the top side of the readhead is used, user must adjust the ride height carefully due to wide PCB thickness tolerances.
Any nonmagnetic tool with 0.2 mm thickness can be used to mechanically check the ride height between the sensor and the ring.
The integrated LED can be used as an indicator. When the correct ride height is achieved, the LED glows green and does not change colour when the ring rotates.
Center point of the ring and center point of the readhead arc must be coaxial. Allowed tolerances are listed in the table below.

Installation tolerances (readhead to ring)

Axial (Z) displacement (ride height)	0.2 mm nominal ±0.1 mm
PCB to ring distance*	0.8 mm ±0.1 mm
Radial (Y) displacement	±0.3 mm
Off center (X) displacement	±0.5 mm
Nonparalell mounting	±0.05 mm

* The nominal gap between the gold mounting areas on the PCB mounting side and the rubber band on the ring.



Installation tolerances (ring to shaft)

Ring/shaft fit on MRA7	Worst case accuracy
H7/g6	±0.08°
H7/f7	±0.11°

Ring/shaft fit on MRA8	Worst case accuracy
H7/g6	±0.07°
H7/f7	±0.10°

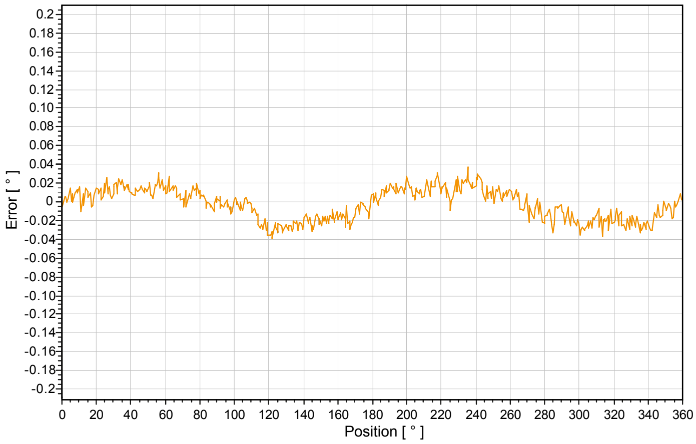
Accuracy of the encoder system

Precise centering of the ring is key to achieving good overall accuracy.

By minimising the eccentricity of the ring installation (using a gauge) and using a drive shaft with precision bearings, the error can typically be reduced to ±0.05° on MRA8 rings or ±0.06° on MRA7 rings.

A typical accuracy plot after good installation of MRA8 is shown in the graph on the right.

For highest accuracy options contact RLS.



External magnetic field

Principle of operation of any magnetic encoder is sensing changes in the magnetic field of the magnetised ring. External magnetic fields, generated by permanent magnets, electric motors, coils, magnetic brakes, etc. may influence the operation of the encoder. When magnetic field is between 0 mT and 3 mT perpendicularly to the readhead it might affect accuracy. When bigger than 3 mT it temporarily causes the encoder to malfunction. Fields stronger than 50 mT can permanently damage the ring.

Unwanted magnetic fields must be blocked at the source. When this is not possible, encoder can be shielded with ferromagnetic metal plate. The ring can also be used for partial shielding. It is recommended to mount the bottom side of the ring towards the source of the leaking magnetic field and readhead pointing away.

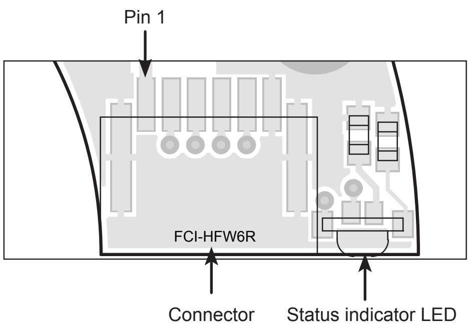
Electrical connections

FFC connector, 6 pins, 1 mm pitch, contacts on bottom side. All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant.

Pin	Asynchronous serial	SPI slave simple	SPI slave advanced	I²C slave	SSI	BiSS	PWM
1	5 V supply	5 V supply	5 V supply	5 V supply	5 V supply	5 V supply	5 V supply
2	-	Status	-	-	-	-	OK
3	-	MISO	MISO	-	Data *	SLO *	Warning
4	TX data out	SCK	SCK	SCL	Clock *	MA *	PWM out
5	RX data in	$\overline{\text{CS}}$	$\overline{\text{CS}}$	SDA	-	-	-
6	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)	0 V (GND)

* Single-ended signals. No line driver.

Pinout



Communication interfaces

Asynchronous serial RS422		
	Baud rate	115.2 kbps, 128 kbps, 230.4 kbps, 256 kbps, 500 kbps, 1 Mbps
	Data format	8 bits, no parity, 1 stop bit
	Update rate	On demand or continuous
	Resolution	See table below
	Latency	200 µs
PWM		
	Base frequency	122.07 Hz, 244.14 Hz, 325.52 Hz, 488.28 Hz, 976.56 Hz
	Update rate	Same as Base frequency
	Resolution	16 bits
	Latency	200 µs
SSI*		
	Maximum clock frequency	500 kHz standard 2.5 MHz with *Delay First Clock* function on the controller
	Update rate	5 kHz
	Resolution	See table below
	Latency	200 µs to 400 µs
	Timeout (monoflop time)	20 µs
BiSS		
	Maximum clock frequency	5 MHz
	Maximum request rate	31 kHz (28 kHz multiturn counter option)
	Bandwidth	2.5 kHz
	Resolution	See table below
	Latency	<10 µs
	Timeout (monoflop time)	20 µs
SPI slave*		
	Maximum clock frequency	3 MHz
	Update rate	5 kHz
	Resolution	16 bits fixed (option S) or up to 20 bits (option A) - see table below
	Latency	200 µs to 400 µs
I²C slave*		
	Maximum clock frequency	400 kHz
	Update rate	5 kHz
	Resolution	See table below
	Latency	200 µs to 400 µs

* Slave type interfaces might not be suitable for high-speed closed control loops because of the variable latency time.
See "Latency" chapter on page 23 for detailed information.

Available resolutions

Resolution	Ring MRA7	Ring MRA8
Binary	15 bits per revolution 16 bits per revolution 17 bits per revolution 18 bits per revolution * 19 bits per revolution *	16 bits per revolution 17 bits per revolution 18 bits per revolution 19 bits per revolution * 20 bits per revolution *

* High resolution options may contain noise on the output. These resolutions are suitable for smoother operation of the control loops or averaging to get fine position. Noise margin increases exponentially with increasing ride height between the ring and readhead.

Multiturn counter

On selected digital interfaces additional 16 bit counter is available to count number of shaft turns (±32,768 turns). Counting is available only when encoder is powered. During initialization process after switch on multiturn counter is reset to zero. Currently available only via BiSS interface. Please see part numbering on page 24 for ordering information.

Asynchronous serial communication interface

Encoder identification, position data and temperature are available with request-response type of communication over the asynchronous serial link. There are two unidirectional communication channels, forming a full-duplex bidirectional data link. Data is transmitted MSB first; big-endian order.

Electrical connection

All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant. Signal lines are single-ended. For connections to RS422 compatible controllers please use an external line driver (see Accessories section on page 24).

Communication parameters

Character length	8 bits
Parity	None
Stop bits	1
Repetition rate	5 kHz max. Transmission time lowers this frequency.
Position latency	Fixed at 200 µs between the position acquisition and first start bit sent out. Transmission time is not included here and should be added to calculate the loop time.

Link speed is selectable by the *Communication interface variant* in the part number:

Communication interface variant	A	B	C	D	E	F
Link speed	115.2 kbps	128 kbps	230.4 kbps	256 kbps	500 kbps	1 Mbps

Command set

Command "v" (0x76) - version request	
	Response - version info and serial number 5 bytes ASCII identification string ("AksIM") 1 byte ASCII space character 8 bytes ASCII serial number 16 bytes ASCII part number 1 byte binary firmware version 1 byte binary communication interface version (5) 1 byte binary ASIC revision 3 bytes ASCII resolution identifier
Command "1" (0x31) - single position data request	
	Response - position and status, transmitted once 1 byte header 0xEA 3 bytes binary absolute position, big-endian, left aligned 2 bytes encoder status – see below 1 byte constant footer 0xEF
	The next request should not be sent sooner than 250 µs after the end of the previous response from the readhead to allow refreshing of the position data. If request is sent sooner, data will arrive at the end of the refresh cycle.
Command "2" (0x32) - continuous position data request	
	Response - position and status, transmitted continuously 1 byte constant header 0xEA 3 bytes binary absolute position, big-endian, left aligned 2 bytes encoder status – see below 1 byte constant footer 0xEF
Command "3" (0x33) - request for continuous position data with reduced length	
	Response - position and status, transmitted continuously 3 bytes binary absolute position, big-endian, left aligned 1 byte detailed encoder status – see below
Command "0" (0x30) - stop	
	Stop continuous transmission
Command "4" (0x34) - single position data request including velocity information	
	Response - position, status, and velocity transmitted once 1 byte header 0xEA 3 bytes binary absolute position, big-endian, left aligned, unsigned 2 bytes encoder status - see below 3 bytes binary velocity information, right aligned, signed 1 byte constant footer 0xEF
	Velocity resolution: Number of counts per 1 microsecond multiplied by 65536. Counts per second (CPS) = velocity × 10^6 / 2^{16} Degrees per second (DPS) = CPS × 360 / 2^{20} (at 20-bit resolution)
	The next request should not be sent sooner than 250 µs after the end of the previous response from the readhead to allow refreshing of the position data. If request is sent sooner, data will arrive at the end of the refresh cycle.
Command "t" (0x74) - temperature request	
	Response - temperature of the encoder 1 byte signed binary number - temperature of the sensor in °C
	Accuracy of the readings is ±3 °C This function is available with firmware version 30 and higher (see command "v" for firmware version).

Structure of data packet

Encoder status (two bytes):		
	b15 : b10	Reserved, always zero
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		
	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.

PWM - Pulse width modulation interface

The PWM communication interface consists of two digital signals: the Status signal and the PWM Out signal. It is 3.3 V TTL compatible.

Electrical connection
The Status and PWM Out signals are 3.3 V TTL compatible.

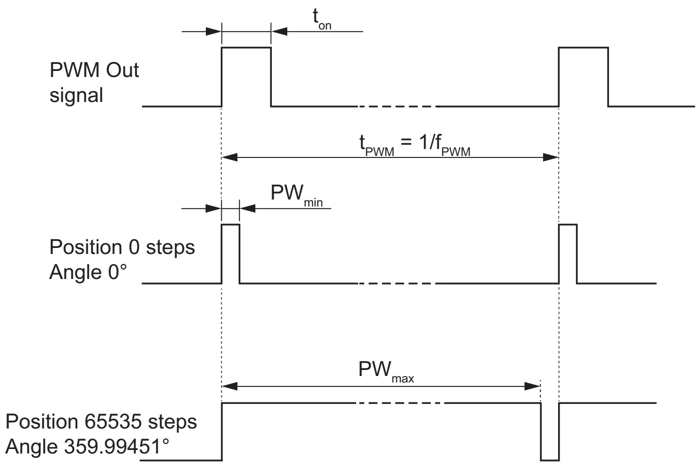
Status signal
The Status signal indicates the current status of the encoder. The Status signal is high with normal operation and valid position information. The low state of the Status signal indicates an error state of the encoder which can be caused by:

- Operation outside the installation tolerances
- Invalid or damaged magnetisation of the ring
- Sensor malfunction
- System error
- No power supply

When the Status signal is low, the PWM Out signal is low and no pulses are output.
The encoder position is latched on the rising edge of the PWM Out signal. The Status signal should also be checked at the rising edge of the PWM Out signal. If the Status signal changes during the PWM period, it does not affect the currently transmitted position information.

PWM Out signal
The PWM Out is a pulse width modulation output with 16-bit resolution whose duty cycle is proportional to the measured position. The change of the pulse width by PW_{min} corresponds to a change in position by one count (change in angle for 360° / 65536 ≈ 0.00549°).

PWM Out signal timing diagram



Communication parameters
Communication interface variant in the part number defines the PWM frequency and all other dependent parameters.

Parameter	Symbol	Communication interface variant A	B	C	D	E	Unit	Note
PWM frequency	f_{PWM}	122.07	244.14	325.52	488.28	976.56	Hz	
Signal period	t_{PWM}	8,192.00	4,096.00	3,072.00	2,048.00	1,024.00	µs	
Minimum pulse width	PW_{min}	0.1250	0.0625	0.0469	0.0313	0.0156	µs	Position 0 (Angle 0°)
Maximum pulse width	PW_{max}	8,191.88	4,095.94	3,071.95	2,047.97	1,023.98	µs	Positions 65534 and 65535 *
Min. counter frequency	f_{CNTR}	8	16	21	32	64	MHz	Receiving counter frequency
Resolution		16 Bit	16 Bit	16 Bit	16 Bit	16 Bit		Fixed; resolution in part number must be set as "16B"

* Note that positions 65534 and 65535 (Angle 359.98901° and 359.99451°) result in the same pulse width PW_{max}.

$$\textit{Position}\ [\text{counts}] = \frac{t_{on} \times 65536}{t_{PWM}} - 1 \qquad \textit{Position}\ [°] = \frac{(t_{on} - PW_{min}) \times 360°}{t_{PWM}}$$

SSI - Synchronous serial interface

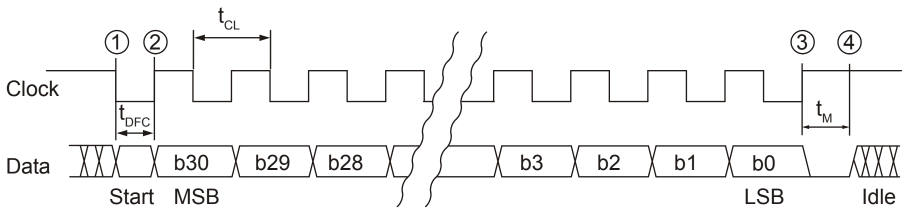
The encoder position, in up to 20 bit natural binary code, and the encoder status are available through the SSI protocol. The position data is left aligned. After the position data there are two general status bits followed by the detailed status information.

Electrical connection

All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant. Signal lines are single-ended. For connections to RS422 compatible controllers please use an external line driver (see Accessories section on page 24).

The power supply must be applied at least 10 ms before the clock sequence is being sent to the encoder.
Clock line must be high during encoder power-up (or connected to the 10k pull-up resistor).

SSI timing diagram

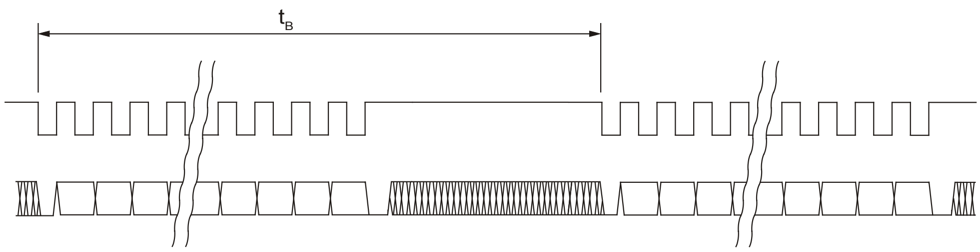


The controller interrogates the readhead for its position and status data by sending a pulse train to the Clock input. The Clock signal always starts from high. The first falling edge ① latches the last position data available and on the first rising edge ② the most significant bit (MSB) of the position is transmitted to the Data output. The Data output should then be latched on the following falling edge. On subsequent rising edges of the Clock signal the next bits are transmitted. If time between ① and ② is extended for additional 1 µs, then maximum clock frequency limit is 2.5 MHz instead of 500 kHz. This function is called "Delay First Clock" and must be supported by the controller to which the encoder is connected.

After the transmission of the last bit ③ the Data output goes to low. When the t_M time expires the Data output is undefined ④. The Clock signal must remain high for at least t_M before the next reading can take place.

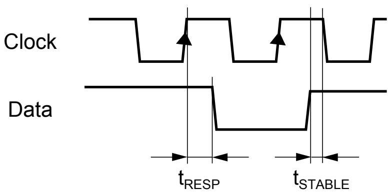
While reading the data the period t_{CL} must always be less than t_M. However, reading the encoder position can be terminated at any time by setting the Clock signal to high for the duration of t_M.

To allow updating of the position data at least t_B should pass between two subsequent readings. If the reading request arrives earlier than t_B after the previous reading, the encoder position will not be updated.



Maximum frequency

The readhead needs 170 ns to respond to incoming clocks (t_{RESP}). Change on Data signal is delayed for 170 ns after the rising edge on Clock line. The data signal must be stable for at least 10 % of clock period length before the value is latched.



Communication parameters

Parameter	Symbol	Min	Typ	Max
Delay first clock	t_{DFC}	1 µs		10 µs
Clock period	t_{CL}	2 µs		20 µs
Clock frequency	f_{CL}	50 kHz		500 kHz (2.5 MHz *)
Monoflop time	t_M		20 µs	
Repetition rate	t_B	200 µs		
Readhead response delay	t_{RESP}		170 ns	

* With *Delay First Clock* function on the controller.

Start bit and idle line value are defined by the *Communication interface variant.*

Communication interface variant	Line state selection	Usage
A	Start bit = 0; idle line = 0	Not recommended for new design
B	Start bit = 1; idle line = 1	Standard

Structure of data packet

Bit	b30 : b11	b10 : b9	b8 : b1	b0
Data length	20 bits	2 bits	8 bits	1 bit
Meaning	Encoder position	General status	Detailed status	Reserved

Encoder position	
b30 : b11	Encoder position – Left aligned, MSB first, LSB last. If the encoder resolution is lower than 20 bits, the last few bits of the encoder position, which are not used, are set to zero.
General status	
b10	Error bit. If set, the position is not valid.
b9	Warning bit. If set, the encoder operational is close to its limits. The position is still valid, but the resolution and/or accuracy might be out of specification.
	The Error and Warning bits can be set at the same time, in this case the 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	
b8	Warning - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
b7	Warning - Signal amplitude low. The distance between the readhead and the ring is too large.
b6	Error - Signal lost. The readhead is out of alignment with the ring or the ring is damaged.
b5	Warning - Temperature. The readhead temperature is out of specified range.
b4	Error - Power supply error. The readhead power supply voltage is out of specified range.
b3	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.
b2	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.
b1	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.
b0	Reserved, always zero.

BiSS-C interface

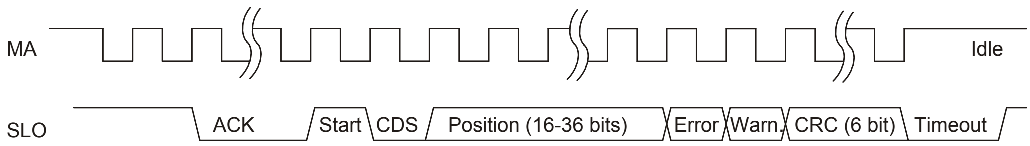
The encoder position, in up to 20 bit natural binary code, and the encoder status are available through the BiSS-C protocol. The position data is left aligned. After the position data there are two status bits (active low) followed by CRC (inverted).

BiSS is implemented for point-to-point operation; multiple slaves are not supported.
Communication is unidirectional, the readhead is not user programmable and custom parameters can not be stored into the readhead.

Electrical connection

All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant. Signal lines are single-ended. For connections to RS422 compatible controllers please use an external line driver (see Accessories section on page 24).

BiSS-C timing diagram



MA is idle high. Communication is initiated with first falling edge.
The encoder responds by setting SLO low on the second rising edge on MA. ACK length is 12 bits.
When the encoder is ready for the next request cycle it indicates this to the master by setting SLO high.
The absolute position and CRC data is in binary format and sent MSB first.
Multicycle data is not implemented, therefore CDS bit is always zero.

Status bits

Type	Value 0	Value 1	Possible reason for failure
Error	Position data is invalid.	OK	Error bit is active low. If low, the position is not valid.
Warning	Position data is valid.	OK	Warning bit is active low. If low, the encoder operation is close to its limits. The position is still valid but the resolution and/or accuracy might be out of specification.

Communication parameters

Communication interface variant in the part number defines the functionality of the encoder.

Communication interface variant	Parameter	Value
H	MA frequency	Max. 5 MHz

Parameter	Symbol	Worst case
Latency		<10 μs
Bandwidth *		2.5 kHz
Maximum request rate		31 kHz (28 kHz Multiturn counter option)
Timeout		20 μs
Readhead response delay	t_{RESP}	170 ns

* Bandwidth parameter is mechanical bandwidth. AksIM samples at 5 kHz therefore any mechanical changes that are appearing faster than 2.5 kHz are not detectable on the output (Nyquist theorem). If request for position comes faster than sampling frequency, AksIM encoder recalculates the position at the time of request based on current ring velocity.

Data packet description

Data packet length depends on the resolution and can be from 24 to 44 bits long. It consists of 16 bits for the multiturn counter (if selected) and 15 to 20 bits of Position selected by (resolution), followed by 2 Status bits and 6 CRC bits (see table below).

Resolution	Multiturn counter	Position	Status		CRC (inverted)
			Error	Warning	
15B	0 bits	15 bits	1 bit	1 bit	6 bits
16B		16 bits			
17B		17 bits			
18B		18 bits			
19B		19 bits			
20B		20 bits			
15M	16 bits	15 bits	1 bit	1 bit	6 bits
16M		16 bits			
17M		17 bits			
18M		18 bits			
19M		19 bits			
20M		20 bits			

Example: 18 bits of position + 2 status bits + 6 bits CRC = 26 bits long data packet.

Polynomial for CRC calculation of position, error and warning data is: $x^6 + x^1 + 1$. Represented also as 0x43.
It is inverted and transmitted MSB first.
Example of calculation routine for 6-bit CRC can be found in Appendix 2 of this document.

For more information regarding BiSS protocol see **www.biss-interface.com**.

SPI - Serial peripheral interface (slave mode)

The SPI interface is designed for communication with nearby devices.

Electrical connection

All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant.

Signal	Description
$\overline{CS}$	Active low. $\overline{CS}$ line is used for synchronisation between master and slave devices. During communication it must be held low. Idle is high. Rising edge on $\overline{CS}$ signal resets the SPI interface.
SCK	Clocks out the data on rising edge. Max frequency 3 MHz at 1.5 m cable length.
MISO	Data is output on rising edge on SCK after $\overline{CS}$ low. Data is valid on the falling edge of SCK signal. During $\overline{CS}$=1 MISO line is in high-Z mode.
Status	Indicates normal operation (only available with S option).

Communication parameters

Communication interface variant in the part number defines the SPI interface type and all dependent parameters.

Communication interface variant	Description	Parameter	Value
S	SPI slave - simple mode	Resolution	Fixed - resolution in part number must be set as "16B"
		Status	Error status available on a separate wire
		Data length	16 bit data packet - position only
A	SPI slave - advanced mode	Resolution	Selectable (see part numbering)
		Status	All status bits are available through the SPI
		Data length	40 bit data packet - position, status, CRC
T	SPI slave - advanced mode with timestamp	Resolution	Selectable (see part numbering)
		Status	All status bits are available through the SPI
		Data length	56 bit data packet - position, status, timestamp, CRC

Parameter	Symbol	Min	Typ	Max	Note
Clock frequency	f_{CLK}	1 Hz		3 MHz	Max frequency with 1.5 m cable
Time after $\overline{CS}$ low to first CLK rising edge	t_S	2 µs			
Time after last CLK falling edge to $\overline{CS}$ high	t_H	1 µs			
$\overline{CS}$ high time	t_R	8 µs			Time to complete SPI reset
Read repetition rate	f_{REP}			5 kHz	If higher, the same position data might be transmitted twice

SPI slave - simple mode (variant S)

Structure of data packet

Data packet is 16 bits long. MSB first. Left aligned. Position only, no status bits. Only 16-bit resolution available. Repetition of reading is maximum 5000 times per second. If higher, it is possible to read the same position data twice.

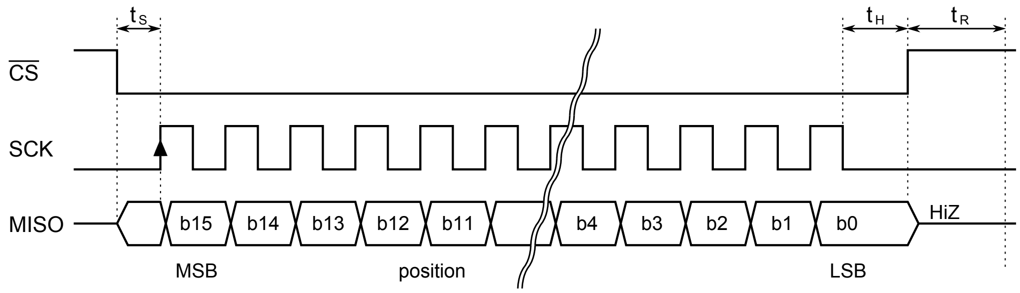
Status signal

The Status signal indicates the current status of the encoder. The Status signal is high with normal operation and valid position information. The low state of the Status signal indicates an error state of the encoder which can be caused by:

- Operation outside the installation tolerances
- Invalid or corrupted magnetisation of the ring
- Sensor malfunction
- System error
- No power supply

When the Status signal is low, the data read through the SPI interface is invalid. The Status signal should be checked at the first rising edge of the SCK signal. If the Status signal changes during the data transmission, it does not affect the currently transmitted position information.

SPI slave timing diagram (variant S)



SPI slave - advanced mode (variant A)

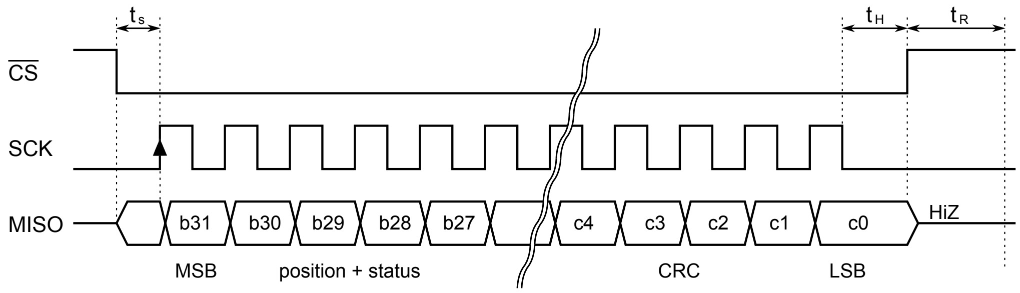
Structure of data packet
Data packet is 40 bits long. MSB first. Position data is left aligned.
Repetition of reading is maximum 5000 times per second. If higher, it is possible to read the same position data twice.

Bit	b31 : b12	b11 : b10	b9 : b2	b1 : b0	c7 : c0
Data length	20 bits	2 bits	8 bits	2 bits	8 bits
Meaning	Encoder position	General status	Detailed status	Reserved always 1	CRC

Encoder position	
b31 : b12	Encoder position, left aligned, MSB first. If the encoder resolution is lower than 20 bits, the last few bits of the encoder position, which are not used, are set to zero.
General status	
b11	Error. If bit is set, position is not valid.
b10	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 color 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	
b9	Warning - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
b8	Warning - Signal amplitude low. The distance between the readhead and the ring is too large.
b7	Error - Signal lost. The readhead is out of alignment with the ring or the ring is damaged.
b6	Warning - Temperature. The readhead temperature is out of specified range.
b5	Error - Power supply error. The readhead power supply voltage is out of specified range.
b4	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.
b3	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.
b2	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.
CRC	
c7 : c0	CRC check with polynomial 0x97 - see Appendix 1 of this document.

Status signal
The Status signal is not available in Advanced mode.

SPI slave timing diagram (variant A)



SPI slave - advanced mode with timestamp (variant T)

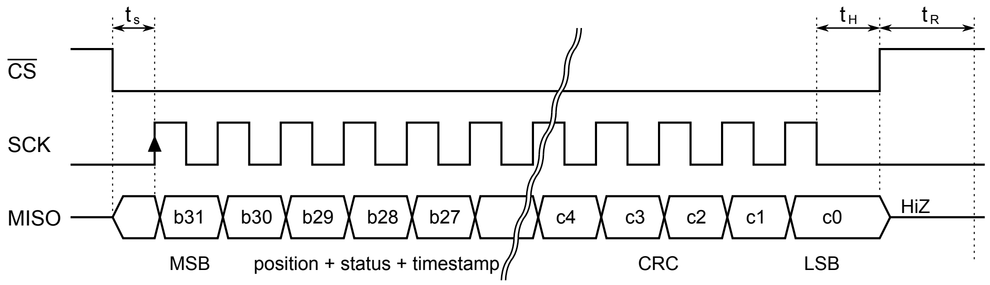
Structure of data packet
Data packet is 56 bits long. MSB first. Position data is left aligned.
Repetition of reading is maximum 5000 times per second. If higher, it is possible to read the same position data twice.

Bit	b31 : b12	b11 : b10	b9 : b2	b1 : b0	t15 : t0	c7 : c0
Data length	20 bits	2 bits	8 bits	2 bits	16 bits	8 bits
Meaning	Encoder position	General status	Detailed status	Reserved always 1	Timestamp	CRC

Encoder position		
	b31 : b12	Encoder position, left aligned, MSB first. If the encoder resolution is lower than 20 bits, the last few bits of the encoder position, which are not used, are set to zero.
General status		
	b11	Error. If bit is set, position is not valid.
	b10	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 color 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		
	b9	Warning - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
	b8	Warning - Signal amplitude low. The distance between the readhead and the ring is too large.
	b7	Error - Signal lost. The readhead is out of alignment with the ring or the ring is damaged.
	b6	Warning - Temperature. The readhead temperature is out of specified range.
	b5	Error - Power supply error. The readhead power supply voltage is out of specified range.
	b4	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.
	b3	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.
	b2	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.
Timestamp		
	t15 : t0	Time between latch of mechanical position and $\overline{CS}$ falling edge in μsec.
CRC		
	c7 : c0	CRC check with polynomial 0x97 - see Appendix 1 of this document.

Status signal
The Status signal is not available in this mode.

SPI slave timing diagram (variant T)



I²C / TWI interface

Inter-integrated circuit interface or Two-wire interface on AksIM encoders supports read-only access of position data including status bits and CRC for data transmission verification. Interface supports standard and fast speed modes. Encoder works as a slave unit on a multi-drop bus. Slave address is factory preset to 0x18 and can be reprogrammed by user.

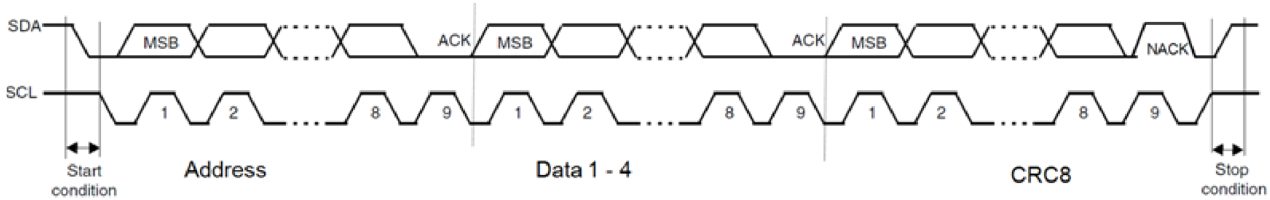
Electrical connection
All data signals are 3.3 V LVTTL. Inputs are 5 V tolerant. Pull-up resistors must be installed externally.

Signal	Description
SCL	Master clock. Max clock frequency is 400 kHz in fast mode.
SDA	Slave out. MSB first.

Parameter	Symbol	Min	Typ	Max	Note
Clock frequency	f_{CLK}	100 kHz		400 kHz	Master clock frequency.
Read repetition rate	f_{REP}		5 kHz		Time to update a new position. If higher, the same position data might be transmitted twice

Output type variant must be selected as “A”.

I²C Timing diagram (slave transmitter)



Start condition is generated by the master for starting the communication.
ACK (acknowledge): if address is correct, slave generates ACK.
When each data is received, master sends ACK.
At the end of transaction master sends NACK (not acknowledge) and stop condition.

Structure of data packet
Complete data packet is 32 bits long + 8 bits of CRC. MSB first. Position data is left aligned.
Repetition of reading is maximum 5000 times per second. If higher, it is possible to read the same position data twice.

Address is 7 bits long + Read / Write bit. (Read – LSB is set, Write – LSB is reset). Factory preset address is 0x18.
Data section consists of 4 bytes and CRC is 1 byte long.
Data byte 1 = MSB bits of position
Data byte 2 = Middle bits of position
Data byte 3 = LSB bits of position + MSB bits of status
Data byte 4 = LSB bits of status + reserved bits
After each data ACK must be sent.
CRC calculation is performed on all 4 data bytes. Polynomial for CRC calculation is 0x97. For details how to calculate CRC please see Appendix 1 of this document.

If status and CRC data are not needed, master can terminate the communication after every byte with NACK and Stop condition. For example if only 16 bits of position are needed, Master should send Start condition, Address, read first two bytes of data and generate NACK and Stop.

Number of bits in different sections of data packet:

<table>
<tr><th rowspan="2">Resolution</th><th rowspan="2">Position</th><th rowspan="2">Reserved0*</th><th colspan="3">Status</th><th rowspan="2">Reserved1*</th><th rowspan="2">CRC</th></tr>
<tr><th>Error</th><th>Warning</th><th>Status</th></tr>
<tr><td>16B</td><td>16 bits</td><td>4</td><td rowspan="5">1 bit</td><td rowspan="5">1 bit</td><td rowspan="5">8 bits</td><td rowspan="5">2 bits</td><td rowspan="5">8 bits</td></tr>
<tr><td>17B</td><td>17 bits</td><td>3</td></tr>
<tr><td>18B</td><td>18 bits</td><td>2</td></tr>
<tr><td>19B</td><td>19 bits</td><td>1</td></tr>
<tr><td>20B</td><td>20 bits</td><td>/</td></tr>
</table>

* Reserved0 bits are always 0. Reserved1 bits are always 1.

Encoder position		
	b31 : b12	Encoder position, left aligned, MSB first. If the encoder resolution is lower than 20 bits, the last few bits of the encoder position, which are not used, are set to zero.
General status		
	b11	Error. If bit is set, position is not valid.
	b10	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 color 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		
	b9	Warning - Signal amplitude too high. The readhead is too close to the ring or an external magnetic field is present.
	b8	Warning - Signal amplitude low. The distance between the readhead and the ring is too large.
	b7	Error - Signal lost. The readhead is out of alignment with the ring or the ring is damaged.
	b6	Warning - Temperature. The readhead temperature is out of specified range.
	b5	Error - Power supply error. The readhead power supply voltage is out of specified range.
	b4	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.
	b3	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.
	b2	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.
CRC		
	c7 : c0	CRC check with polynomial 0x97 - see Appendix 1 of this document.

Changing slave address
Address of the AksIM encoder on the I^{2}C bus can be changed by writing special sequence to it.
After transmit sequence is complete encoder will store new address into non-volatile memory and immediately switch to the new address. This process should not be repeated more than 1000 times. After writing new address the I^{2}C bus must be idle for 10 ms.

I^{2}C new address sequence (slave receiver)

Slave			A		A		A			
Master	S	Address		'a' (0x61)		New address		'a' (0x61)	NA	P

S – Start condition
A – Acknowledge
'a' – Header and footer for changing address
NA – Not Acknowledge
P – Stop condition

Latency on Asynchronous serial communication

Readhead has its internal cycle of acquiring position that is running at 5 kHz (±10 %). One cycle takes 200 μs. This does not depend on the request frequency.
Controller sends the request. If the request arrives into the readhead just after new cycle has started, it will take 200 μs for the new position to be ready. It is transmitted to controller, always at the end of the cycle. In this case there will be 200 μs of delay between request and answer (transmission time is not taken into account).
If the request arrives into the readhead just before the end of the cycle, the position is just ready and response will be transmitted instantly. Position was acquired 200 μs ago at the beginning of the cycle.

Second mode is continuous transmission after every cycle. In this mode there is no need to query the encoder for position but it sends it immediately when it is ready.
When the controller receives the first bit of the data position it is 200 μs old. This time is constant (±10 %). The additional delay is due to time needed to complete the data transmission. This varies depending on the selected bit-rate.

(Per special request timing information and/or speed can be provided in the same data packet as position.)

Latency on other slave type interfaces (SSI, SPI slave)

All interfaces transmit the last valid data available.
Internal cycle of the encoder is 200 μs. This is the delay from the time when the mechanical position is latched by the sensor to when the data is ready to be transmitted over the interface.
If the request comes right after the data is ready, latency will be 200 μs.
If request comes just before the new data will be calculated, then latency is 400 μs.

For example:
At t = 0 μs the physical position is latched but position data is not yet calculated. It will be available at 200 μs.
If the request comes at t = 1 μs – 199 μs, the last available data will be sent - the one from previous cycle when position was latched at t = –200 μs.

Latency on BiSS interface

BiSS uses a different approach and calculation so the request rate can be higher than 5 kHz. Typically, request rate can be up to 30 kHz. Position is latched at the first falling edge on the MA (clock) line and calculated instantly, therefore latency is shorter than 10 μs.

Readhead part numbering

MBA 7 SG A 16B C 42 C 00

Series
MBA - Magnetic board AksIM

MRA ring compatibility
7 - For use with MRA7 ring
8 - For use with MRA8 ring

Communication interface
DD - BiSS-C, no line driver
FC - I^2C / Two-wire interface
PW - Pulse width modulation (PWM)
SD - Synchronous serial interface (SSI), no line driver
SG - Asynchronous serial
SP - SPI slave, LVTTL

Communication interface variant
See table next to the description of the chosen communication interface for detailed information
For **DD**: **H -** BiSS-C, low latency, 12 ACK bits, max. 5 MHz
For **FC**: **A -** Standard
For **PW**: Base frequency in Hz (16 bit resolution only):

A	B	C	D	E
122	244	325	488	976

For **SD**: **A -** Start bit and idle data line 0 (NRND)
B - Start bit and idle data line 1 (standard)
For **SG**: Link speed in kbps:

A	B	C	D	E	F
115.2	128	230.4	256	500	1000

For **SP**: **A -** SPI slave advanced
S - SPI slave simple
T - SPI slave advanced with timestamp

Resolution
For **PWx** and **SPS**:
16B - 16 bits per revolution
For **DDH**, **FCA, SDx, SGx, SPA** and **SPT**:
15B - 15 bits per revolution (for **MBA7** readhead only)
16B - 16 bits per revolution
17B - 17 bits per revolution
18B - 18 bits per revolution
19B - 19 bits per revolution
20B - 20 bits per revolution (for **MBA8** readhead only)

Multiturn counter options (for **DDH** only)
15M - 15 bits per revolution + 16 bits multiturn counter (for **MBA7** readhead only)
16M - 16 bits per revolution + 16 bits multiturn counter
17M - 17 bits per revolution + 16 bits multiturn counter
18M - 18 bits per revolution + 16 bits multiturn counter
19M- 19 bits per revolution + 16 bits multiturn counter
20M - 20 bits per revolution + 16 bits multiturn counter (for **MBA8** readhead only)

Housing
C - Partial arc, axial installation (standard)

Ring main diameter
42 - 42 mm (for MBA7 readhead only)
73 - 73 mm (for MBA8 readhead only)

Connector option
C - FFC connector, 1 mm pitch, 6 way, bottom contacts

Special requirements
00 - No special requirements (standard)

Ring part numbering

MRA 7 D 049 A A 025 B 00

Series
MRA - Magnetic ring AksIM

MRA ring type
7 - For use with MBA7 readhead
8 - For use with MBA8 readhead

Accuracy grade
D - ±0.1°

Outer diameter
For **MRA7** ring type:
049 - 49 mm
For **MRA8** ring type:
080 - 80 mm

Material
A - Stainless steel with glued rubber bonded ferrite

Cross section
A - 3.9 mm thick
B - 2 mm thick, lightweight

Inner diameter
For **MRA7** ring type:
025 - 25 mm
For **MRA8** ring type:
055 - 55 mm

Zero position
B - Marked by additional hole in metal hub
E - Engraved

Special requirements
00 - No special requirements (standard)

Currently available ring options:
MRA7D049AA025B00
MRA7D049AB025E00
MRA8D080AA055B00
MRA8D080AB055E00

Accessories

ACC006	FFC flat cable, 152 mm length, 6 way, 1 mm pitch
ACC009	6-pin, 1 mm pitch FFC to DSUB 9-pin adapter with RS422 line driver for BiSS and SSI
ACC010	ACC009 without housing

Appendix 1 - 8-bit CRC calculation with 0x97 polynome

Some of the communication interfaces offer a CRC value to check the correctness of the data read from the encoder. This chapter gives an example of the CRC calculation on the receiver side. The CRC calculation must always be done over the complete set of data including all the reserved bits. The polynomial for the CRC calculation is $P(x) = x^8 + x^7 + x^4 + x^2 + x^1 + 1$, also represented as 0x97.

Code example:

```
//poly = 0x97
static u8 tableCRC [256] = {
                0x00, 0x97, 0xB9, 0x2E, 0xE5, 0x72, 0x5C, 0xCB, 0x5D, 0xCA, 0xE4, 0x73, 0xB8, 0x2F, 0x01, 0x96,
                0xBA, 0x2D, 0x03, 0x94, 0x5F, 0xC8, 0xE6, 0x71, 0xE7, 0x70, 0x5E, 0xC9, 0x02, 0x95, 0xBB, 0x2C,
                0xE3, 0x74, 0x5A, 0xCD, 0x06, 0x91, 0xBF, 0x28, 0xBE, 0x29, 0x07, 0x90, 0x5B, 0xCC, 0xE2, 0x75,
                0x59, 0xCE, 0xE0, 0x77, 0xBC, 0x2B, 0x05, 0x92, 0x04, 0x93, 0xBD, 0x2A, 0xE1, 0x76, 0x58, 0xCF,
                0x51, 0xC6, 0xE8, 0x7F, 0xB4, 0x23, 0x0D, 0x9A, 0x0C, 0x9B, 0xB5, 0x22, 0xE9, 0x7E, 0x50, 0xC7,
                0xEB, 0x7C, 0x52, 0xC5, 0x0E, 0x99, 0xB7, 0x20, 0xB6, 0x21, 0x0F, 0x98, 0x53, 0xC4, 0xEA, 0x7D,
                0xB2, 0x25, 0x0B, 0x9C, 0x57, 0xC0, 0xEE, 0x79, 0xEF, 0x78, 0x56, 0xC1, 0x0A, 0x9D, 0xB3, 0x24,
                0x08, 0x9F, 0xB1, 0x26, 0xED, 0x7A, 0x54, 0xC3, 0x55, 0xC2, 0xEC, 0x7B, 0xB0, 0x27, 0x09, 0x9E,
                0xA2, 0x35, 0x1B, 0x8C, 0x47, 0xD0, 0xFE, 0x69, 0xFF, 0x68, 0x46, 0xD1, 0x1A, 0x8D, 0xA3, 0x34,
                0x18, 0x8F, 0xA1, 0x36, 0xFD, 0x6A, 0x44, 0xD3, 0x45, 0xD2, 0xFC, 0x6B, 0xA0, 0x37, 0x19, 0x8E,
                0x41, 0xD6, 0xF8, 0x6F, 0xA4, 0x33, 0x1D, 0x8A, 0x1C, 0x8B, 0xA5, 0x32, 0xF9, 0x6E, 0x40, 0xD7,
                0xFB, 0x6C, 0x42, 0xD5, 0x1E, 0x89, 0xA7, 0x30, 0xA6, 0x31, 0x1F, 0x88, 0x43, 0xD4, 0xFA, 0x6D,
                0xF3, 0x64, 0x4A, 0xDD, 0x16, 0x81, 0xAF, 0x38, 0xAE, 0x39, 0x17, 0x80, 0x4B, 0xDC, 0xF2, 0x65,
                0x49, 0xDE, 0xF0, 0x67, 0xAC, 0x3B, 0x15, 0x82, 0x14, 0x83, 0xAD, 0x3A, 0xF1, 0x66, 0x48, 0xDF,
                0x10, 0x87, 0xA9, 0x3E, 0xF5, 0x62, 0x4C, 0xDB, 0x4D, 0xDA, 0xF4, 0x63, 0xA8, 0x3F, 0x11, 0x86,
                0xAA, 0x3D, 0x13, 0x84, 0x4F, 0xD8, 0xF6, 0x61, 0xF7, 0x60, 0x4E, 0xD9, 0x12, 0x85, 0xAB, 0x3C};

// use this function to calculate CRC from 32-bit number

u8 crc8_4B(u32 bb)
 {
 u8 crc;
 u32 t;
 t = (bb >> 24) & 0x000000FF;
 crc = ((bb >> 16) & 0x000000FF);
 t = crc ^ tableCRC[t];
 crc = ((bb >> 8) & 0x000000FF);
 t = crc ^ tableCRC[t];
 crc = (bb & 0x000000FF);
 t = crc ^ tableCRC[t];
 crc = tableCRC[t];
 return crc;
 }

// use this function to calculate CRC from fixed length buffer

u8 CRC_Buffer(u8 NumOfBytes)  // parameter = how many bytes from buffer to use to calculate CRC
 {
 u32 t;
 u8 icrc;
 NumOfBytes -= 1;
 icrc = 1;
 t = Buffer[0];
 while (NumOfBytes--)
   {
   t = Buffer[icrc++] ^ tableCRC[t];
   }
 crc = tableCRC[t];
 return crc;
 }

example:

u8 Buffer[BufferLength];

crc_value = u8 CRC_Buffer(BufferLength);
```

Recommended literature:

- Painless guide to CRC error detection algorithm; Ross N. Williams.
- Cyclic Redundancy Code (CRC) Polynomial Selection For Embedded Networks; P. Koopman, T. Chakravarty

Appendix 2 - 6-bit CRC calculation with 0x43 polynome for BiSS

BiSS communication offers a CRC value to check the correctness of the data read from the encoder. This chapter gives an example of the CRC calculation on the receiver side. The CRC calculation must always be done over the complete set of data. The polynomial for the CRC calculation is $P(x) = x^6 + x^1 + 1$, also represented as 0x43.
Following code example must be modified to fit actual data length. Position data, error and warning bits must all be included into calculation in the same order as in the BiSS data packet.

Code example:

```
u8 tableCRC6[64] = {
        0x00, 0x03, 0x06, 0x05, 0x0C, 0x0F, 0x0A, 0x09,
        0x18, 0x1B, 0x1E, 0x1D, 0x14, 0x17, 0x12, 0x11,
        0x30, 0x33, 0x36, 0x35, 0x3C, 0x3F, 0x3A, 0x39,
        0x28, 0x2B, 0x2E, 0x2D, 0x24, 0x27, 0x22, 0x21,
        0x23, 0x20, 0x25, 0x26, 0x2F, 0x2C, 0x29, 0x2A,
        0x3B, 0x38, 0x3D, 0x3E, 0x37, 0x34, 0x31, 0x32,
        0x13, 0x10, 0x15, 0x16, 0x1F, 0x1C, 0x19, 0x1A,
        0x0B, 0x08, 0x0D, 0x0E, 0x07, 0x04, 0x01, 0x02};

u8 crcBiSS(u32 bb)
 {
 u8 crc;
 u32 t;
 t = (bb >> 30) & 0x00000003;
 crc = ((bb >> 24) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = ((bb >> 18) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = ((bb >> 12) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = ((bb >> 6) & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = (bb & 0x0000003F);
 t = crc ^ tableCRC6[t];
 crc = tableCRC6[t];
 return crc;
 }
```

Recommended literature:

- Painless guide to CRC error detection algorithm; Ross N. Williams.
- Cyclic Redundancy Code (CRC) Polynomial Selection For Embedded Networks; P. Koopman, T. Chakravarty

Head office

RLS merilna tehnika d.o.o.
Poslovna cona Žeje pri Komendi
Pod vrbami 2
SI-1218 Komenda
Slovenia

T +386 1 5272100
F +386 1 5272129
E mail@rls.si
www.rls.si

Document issues

Issue	Date	Page	Corrections made
7	26. 2. 2016	2	Storage and handling - magnetic ring and readhead added
		3, 4	Ride height amended
		5	External magnetic field data amended
		6	Flashing LED information added
		8 - 23	Latency changed from 250 µs to 200 µs Update rate changed from 4 kHz to 5 kHz
		8, 15, 24	BiSS output variant G removed, BiSS maximum request rate amended
		10	Command "v" amended, command 4 added, command 3 description amended
		14	SSI output type variant usage added
		15	Bandwidth description added, communication parameters tables amended
		17, 20, 24	SPI variant T added
		25, 26	Appendix 1 and 2 amended
8	20. 6. 2016	5, 8, 16, 24	Multiturn counter function added and BiSS interface amended