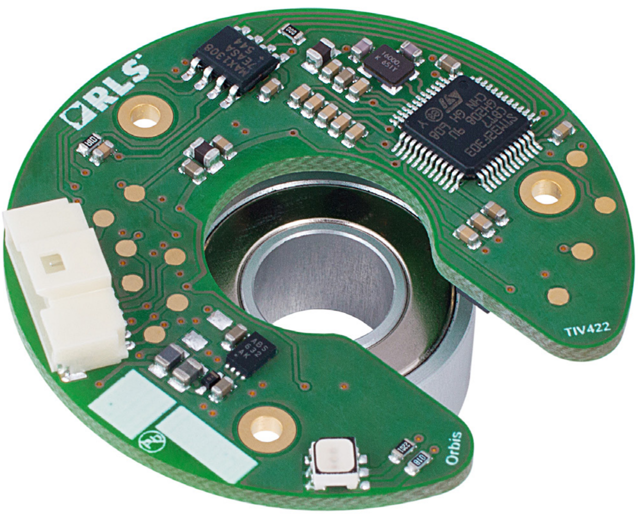
Data sheet
BRD01_03
Issue 3, 12th March 2018

Orbis™ true absolute rotary encoder



Orbis™ is a true absolute rotary encoder suitable for applications where a typical OnAxis encoder cannot be mounted at the end of the rotating shaft due to space constraints or if hollow shaft is required.

The encoder comprises a diametrically magnetized permanent ring magnet and a printed circuit board. Geometric arrangement of RLS' proprietary Hall sensors on a PCB enables generation of one period of sine and cosine signals per mechanical magnet revolution. Moreover, it also enables cancellation of third harmonic component that becomes non-negligible at low magnet ride height.

An adaptive filtering function ensures high resolution at low rotation speeds and low angle phase delay at high rotational speeds. Orbis™ also features an additional built-in self-calibration algorithm that improves encoder's accuracy after installation.

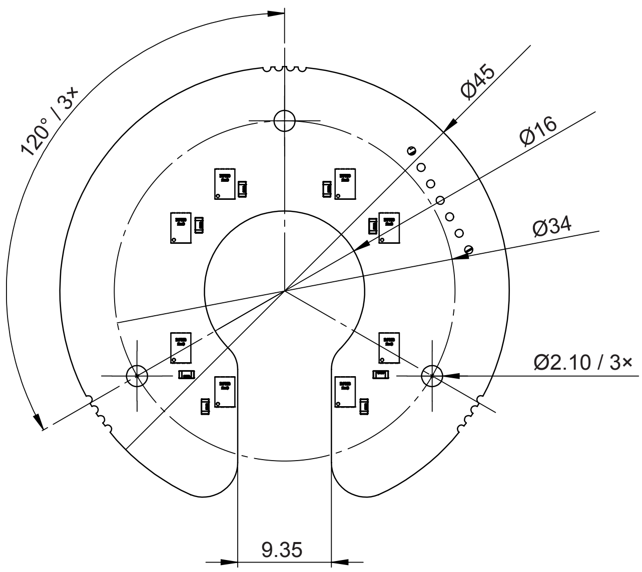
Orbis™ through-hole measuring principle allows customisation with various board and magnet sizes to suit your application.

- **True absolute encoder**
- **14 bit resolution**
- **Multi-turn counter option**
- **Through-hole design enables its mounting anywhere along the shaft**
- **Self-calibration after assembly**
- **Buit-in self-diagnostics**
- **Status LED**
- **SPI, SSI, BiSS-C, PWM, and asynchronous serial communication**
- **Wide installation tolerances**

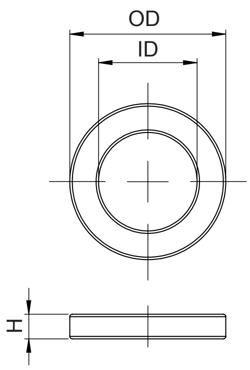
Dimensions

Dimensions and tolerances in mm.

Encoder readhead



Permanent magnets

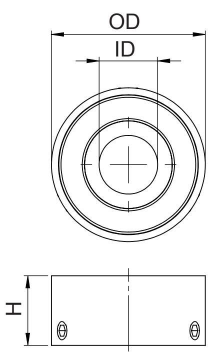


Available magnets:

ID	OD	H
12	19	3
16	24	3.5

ID tolerances are ±0.05.

Magnetic actuators

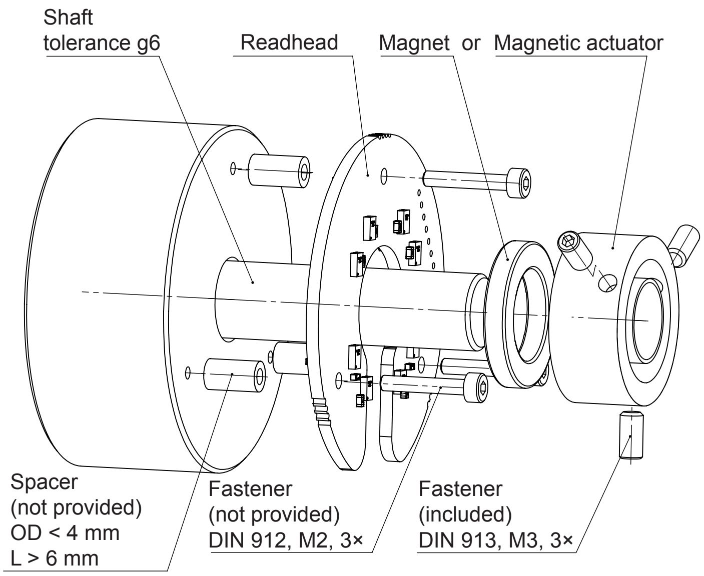


Available actuators:

ID	OD	H
6	21	9.5
8	21	9.5
10	22	9.5
12	27	10
15	27	10

ID tolerances are H7.

Installation drawing



Technical specifications

System data		
Reading type	Axial reading	
Resolution	14 bit	
Maximum speed	10,000 rpm	
Accuracy	±0.25° (optimal installation)	
Accuracy thermal drift	±0.01°/°C	
Repeatability	±2 LSB (counts)	
Digital hysteresis	±2 LSB (counts)	
Position update rate	50 kHz	
Electrical data		
Supply voltage	4.5 V to 5.5 V (at the connector)	
Set-up time	Single-turn 15 ms Multi-turn 35 ms	
Power consumption	65 mA typical (no output load)	
Connection	Molex 501568-1107 or soldering pads (through holes)	
Output load	PWM, SPI	Max. ±20 mA at 3.3 V
	RS422	Max. ±100 mA at 5 V
ESD protection	HBM, max. ±2 kV	
Mechanical data		
Available magnet sizes (ID)	12 mm, 16 mm	
Available magnetic actuator sizes (ID)	6 mm, 8 mm, 10 mm, 12 mm, 15 mm	
Readhead outer diameter	45 mm	
Readhead inner diameter	16 mm	
Mass	Readhead: 5.3 g	
	Magnetic actuators (ID): 6 mm: 6.0 g ; 8 mm: 5.5 g ; 10 mm: 5.7 g ; 12 mm: 8.7 g ; 15 mm: 7.1 g	
	Magnets (ID): 12 mm: 3.8 g ; 16 mm: 6.4 g	
Magnet material	Neodymium with Ni-Cu-Ni protective layer	
Actuator material	Anodised aluminium	
Environmental data		
Temperature	Operating 0 °C to +85 °C Storage -40 °C to +105 °C	
Humidity	0 % to 70 % non-condensing	
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 diagnostic use. 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. Fast red flashes indicate the readhead can not start.

LED	Status
Green	Normal operation; position data is valid.
Orange	Warning; position is valid, but some operating conditions are close to limits.
Red	Error; position data is not valid.
No light	No power supply.

Multi-turn counter

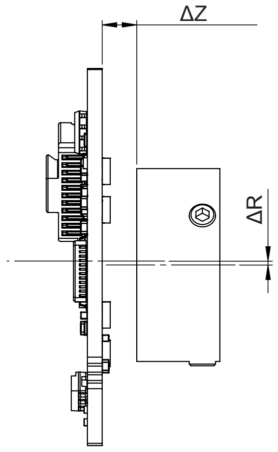
Multi-turn counter is available on the following communication interfaces: BiSS, SSI, SPI and Asynchronous serial communication. Multiturn option is chosen with *Resolution* in part number on page 15. Multi-turn counter is 16 bit (0 to 65535 counts). Counting is available only when the encoder is powered on, but the counter state is stored in a non-volatile memory at power off and is restored at power up. The number of non-volatile memory write-in cycles is limited to 10^7. Maximum permissible rotation during power-down is ±90°. If rotation is bigger, encoder will signal an error to indicate invalid multiturn counter value. Power cycle is needed to reset this condition.

Installation instructions

Installation tolerances

Precise magnet and readhead installation is key to achieve good overall accuracy.

	Magnet with 12 mm ID	Magnet with 16 mm ID
Axial (ΔZ) displacement (ride height)	4 mm nominal ±1 mm	5.5 mm nominal ±1 mm
Radial (ΔR) displacement	0.3 mm	0.3 mm



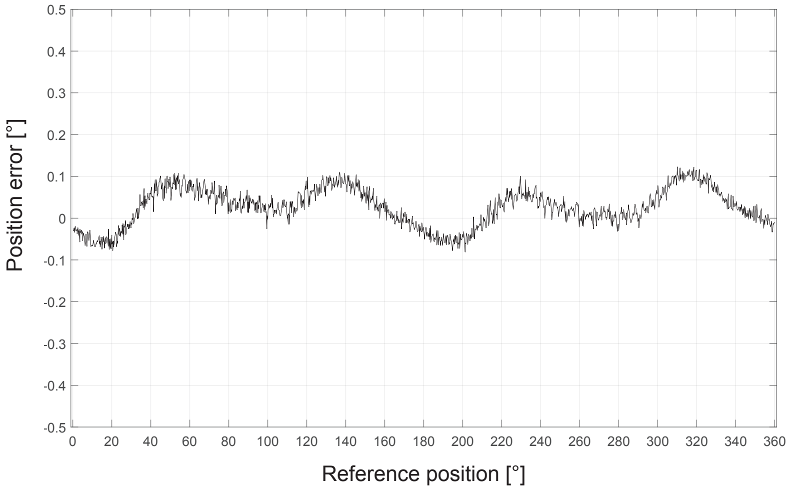
Axial position adjustment (ride height)

Any non-magnetic and non-conductive tool with nominal ride height thickness can be used to check the correct ride height setting mechanically. The integrated LED can be used as a coarse indicator. When correct ride height is achieved, the LED glows green and does not change colour when the magnet rotates.

Accuracy of encoder system

Best accuracy plot after good installation and self-calibration of Orbis encoder is shown in the graph on the right.

Precise centering of the magnet on the shaft is key to achieve good overall accuracy.



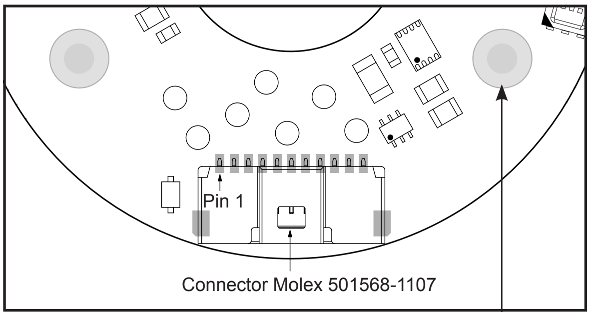
External magnetic field

Principle of operation of any magnetic encoder is sensing changes in the magnetic field of the magnetic actuator. External magnetic fields, generated by permanent magnets, electric motors, coils, magnetic brakes, etc. may influence the encoder operation.
The accuracy of Orbis is degraded in case of magnetic field gradients in axial direction.

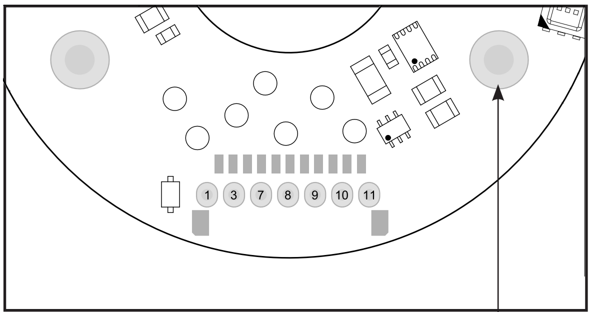
Electrical connections

Pin	Wire Colour	Asynchronous serial	PWM	SSI	BiSS-C	SPI
1	Brown	5 V supply				
2						
3	White	0 V (GND)				
4						
5	Pink	-	-	-	-	-
6	Grey	-	-	-	-	-
7	Red	RX data in+	Status	Clock+	MA+	SCK
8	Blue	RX data in–	-	Clock–	MA–	NCS
9	Cable Shield	Cable Shield	Cable Shield	Cable Shield	Cable Shield	Cable Shield
10	Green	TX data out+	PWM Out	Data+	SLO+	MISO
11	Yellow	TX data out–	-	Data–	SLO–	MOSI

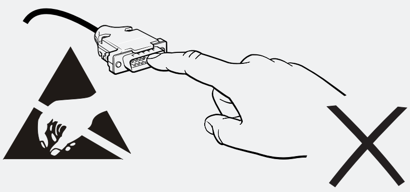
Pinout



With Molex connector



With soldering pads
(through holes)



WARNING!

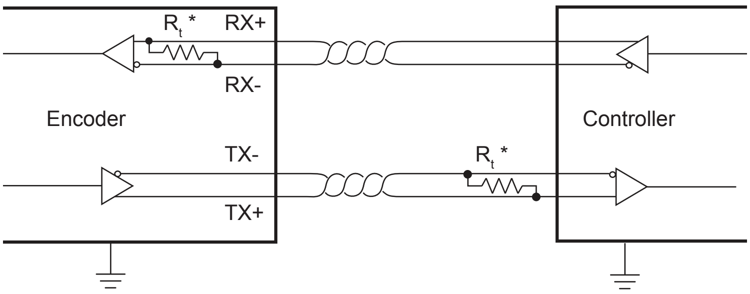
ESD protection
Readhead is ESD sensitive - handle with care. Do not touch electronic circuit, wires or sensor area without proper ESD protection or outside of ESD controlled environment.

Communication interfaces

Asynchronous serial communication interface

Asynchronous serial communication is supported by a universal asynchronous receiver/transmitter commonly known as UART. It comprises two unidirectional communications channels, forming a full-duplex bidirectional data link. Every channel consists of a two wire differential twisted-pair connection conforming to the RS422 signalling standard.

Electrical connection



Line signals	
RX+	RX data in +
RX–	RX data in –
TX+	TX data out +
TX–	TX data out –

* The Command and Data signals are 5 V RS422 compatible differential pairs with RC termination inside the readhead.

Communication parameters

Character length	8 bits
Parity	None
Stop bits	1
Flow control	None
Bit order	LSB first (standard)

Communication speed is set with the *Communication interface variant* in the part number:

Communication interface variant	A	B	C	D	E	F
Value [kbps]	115.2	128	230.4	256	500	1000

Command set

Command "1" (0x31) – position request	
Response	1 byte ASCII "1" 2 bytes (4 for multi-turn) hex – see Encoder position data structure
Command "d" (0x64) – position request + detailed status	
Response	1 byte ASCII "d" 2 bytes (4 for multi-turn) hex – see Encoder position data structure 1 byte hex – see Detailed status data structure
Command "s" (0x73) – position request + speed	
Response	1 byte ASCII "s" 2 bytes (4 for multi-turn) hex – see Encoder position data structure 2 bytes hex – speed (in revolutions per second multiplied by 10)
Command "t" (0x74) – position request + temperature	
Response	1 byte ASCII "t" 2 bytes (4 for multi-turn) hex – see Encoder position data structure 2 bytes hex – temperature (temperature of the readhead in °C multiplied by 10)
Command "v" (0x76) – serial number	
Response	1 byte ASCII "v" 6 bytes ASCII – serial number

Encoder position data structure

Encoder position		
	b31 : b16	Multi-turn counter (if specified in part number) - Left aligned, MSB first.
	b15 : b2	Encoder position – Left aligned, MSB first.
General status		
	b1	Error - If low, the position data is not valid. The last valid position is sent out.
	b0	Warning - If low, the position data is valid, but some operating conditions are close to limits.
	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. LED is flashing (duty cycle 50 %, frequency 2.5 Hz), when the encoder is in idle state. If the controller requests the data every 200 ms or more often, the duty cycle of the LED is 100 % (always on).	
Detailed status		
	b7	Signal amplitude too high. The readhead is too close to the magnet or an external magnetic field is present.
	b6	Signal amplitude low. The distance between the readhead and the ring is too large.
	b5	The readhead temperature is out of specified range.
	b4	Speed too high.
	b3 : b0	Reserved.

PWM - Pulse width modulation interface

The PWM interface transmits the information about the absolute angle position over the pulse width modulated PWM Out signal. An additional digital Status signal indicates the encoder's error condition.

Electrical connection
The Status and PWM Out signals are 3.3 V TTL compatible. These signals have weak ESD protection. Handle with care. Maximum current sourced from or sunk into signal lines should not exceed 20 mA.

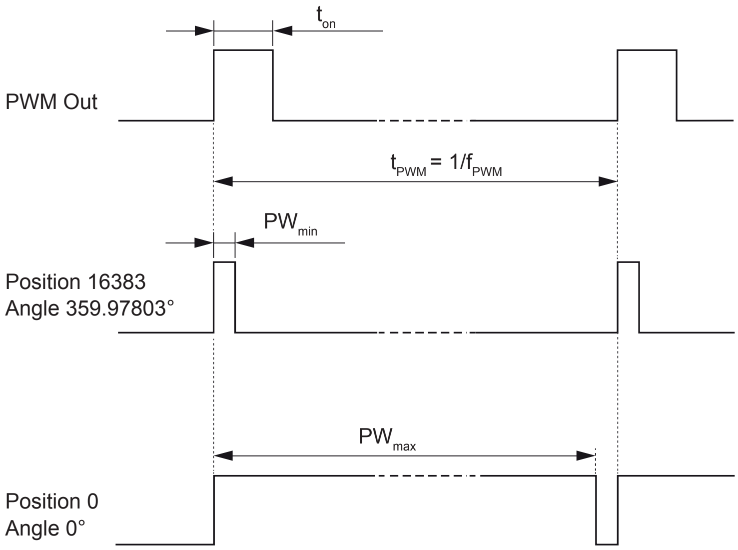
Status signal
The Status signal indicates the current status of the encoder. The Status signal is high for normal operation and valid position information. The low state of the Status signal indicates an error state of the encoder which can be caused by:

- Operation outside the installation tolerances
- 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 modulated output with 14-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.

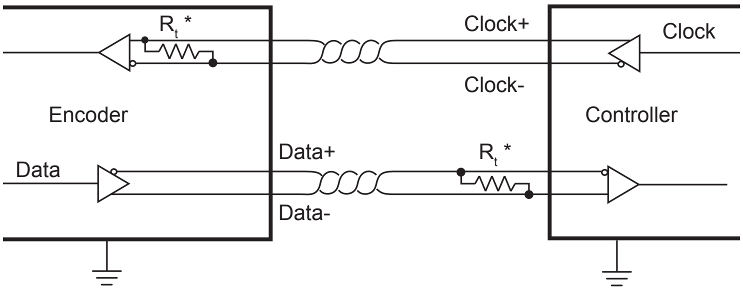
		Communication interface variant				
Parameter	**Symbol**	**A**	**D**	**E**	**Unit**	**Note**
PWM frequency	f_{PWM}	122.07	549.32	1098.63	Hz	
Signal period	t_{PWM}	8192	1820.44	910.22	µs	
Minimum pulse width	PW_{min}	0.5	0.111	0.0556	µs	Position 0 (Angle 0°)
Maximum pulse width	PW_{max}	8191.5	1820.33	910.17	µs	Position 16383
Min. counter frequency	f_{CNTR}	2	9	18	MHz	
Resolution		14	14	14	Bit	

$$\textit{Position}\ \text{[counts]} = \frac{(t_{on} - PW_{min}) \times 16383}{PW_{max} - PW_{min}}$$

SSI - Synchronous serial interface

The encoder position, in 14 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.

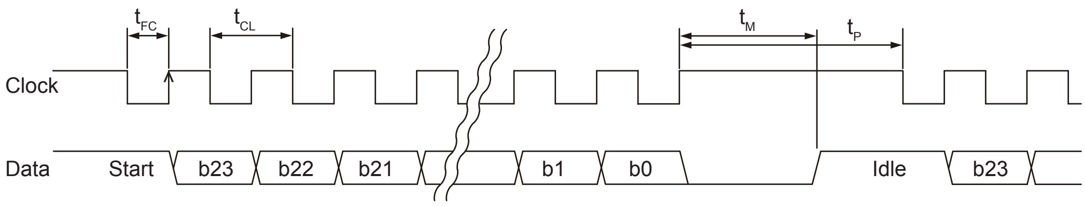
Electrical connection



Line signals	
Clock+	Clock non-inverted signal
Clock–	Clock inverted signal
Data+	Data non-inverted signal
Data–	Data inverted signal

* The Clock and Data lines are 5 V RS422 compatible differential pairs. The termination resistor on the Clock line is integrated inside the encoder. On the controller's side of Data line it should be added by the user or enabled in the controller.

SSI timing diagram



The controller requests the position and status data of the encoder by sending a pulse train to the Clock input. The Clock signal always starts from high. The first falling edge of the Clock latches the last position data available and on the first rising edge of the Clock the most significant bit (MSB) of the position is transmitted to the Data output. The Data output should then be read on the following falling or rising edge. On subsequent rising edges of the Clock signal the next bits are transmitted.

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

While reading the data, the half of a Clock 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.

Communication parameters

Parameter	Symbol	Min	Typ	Max
Clock period	t_{CL}	2 µs (400 ns *)		15 µs
Clock frequency	f_{CL}	70 kHz		500 kHz (2.5 MHz *)
Delay first clock	t_{FC}	1.25 µs		14 µs
Transfer timeout	t_M		14 µs	
Pause time	t_P	20 µs		

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

Structure of data packet

Bit	b39 : b24	b23 : b10	b9 : b8	b7 : b0
Data length	16 bits	14 bits	2 bits	8 bits
Meaning	Multi-turn counter (if specified in part number)	Encoder position	General status	Detailed status

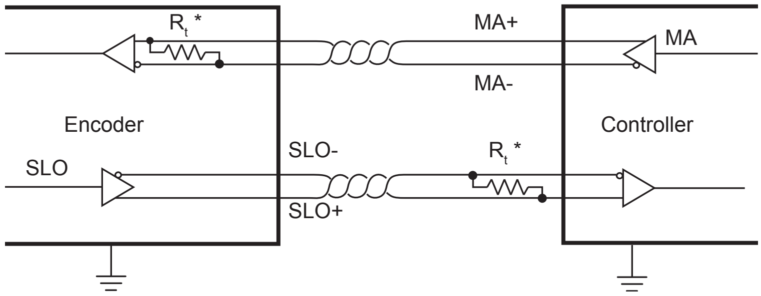
Encoder position		
	b39 : b24	Multi-turn counter (if specified in part number) - Left aligned, MSB first.
	b23 : b10	Encoder position – Left aligned, MSB first.
General status		
	b9	Error - If high, the position data is not valid. The last valid position is sent out.
	b8	Warning - If high, the position data is valid, but some operating conditions are close to limits.
	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. LED is flashing (duty cycle 50 %, frequency 2.5 Hz), when the encoder is in idle state. If the controller requests the data every 200 ms or more often, the duty cycle of the LED is 100 % (always on).	
Detailed status		
	b7	Signal amplitude too high. The readhead is too close to the magnet or an external magnetic field is present.
	b6	Signal amplitude low. The distance between the readhead and the ring is too large.
	b5	The readhead temperature is out of specified range.
	b4	Speed too high.
	b3 : b0	Reserved.

BiSS-C interface

The encoder position, in 14 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.

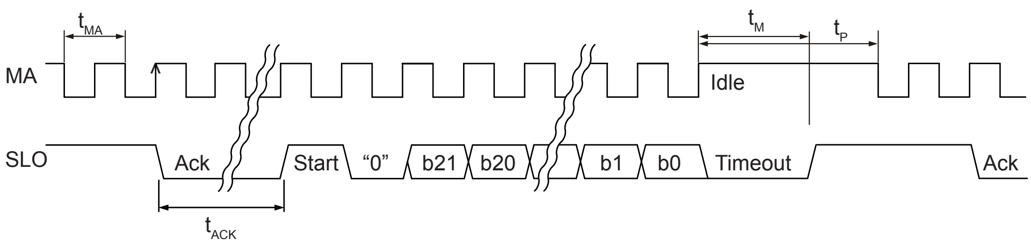
Electrical connection



Line signals	
MA+	Clock non-inverted signal
MA–	Clock inverted signal
SLO+	Data non-inverted signal
SLO–	Data inverted signal

* The MA and SLO lines are 5 V RS422 compatible differential pairs. The termination resistor on the MA line is integrated inside the encoder. On the controller's side of SLO line it should be added by the user or enabled in the controller.

BiSS-C timing diagram (single-turn)



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.
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, left aligned, MSB first.

Communication parameters

Parameter	Symbol	Min	Typ	Max
MA period	t_{MA}	200 ns		14 µs
MA frequency	f_{MA}	70 kHz		5 MHz
ACK length	t_{ACK}		5 bits	
Transfer timeout	t_M		14 µs	
Pause time	t_P	20 µs		

Structure of data packet

Bit	b37 : b22	b21 : b8	b7 : b6	b5 : b0
Data length	16 bits	14 bits	2 bits	6 bits
Meaning	Multi-turn counter (if specified in part number)	Encoder position	General status	CRC

Encoder position		
	b37 : b22	Multi-turn counter (if specified in part number) - Left aligned, MSB first.
	b21 : b8	Encoder position – Left aligned, MSB first.
General status		
	b7	Error - If low, the position data is not valid. Bits b21 - b8 are replaced with error status bits.
	b6	Warning - If low, the position data is valid, but some operating conditions are close to limits.
		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. LED is flashing (duty cycle 50 %, frequency 2.5 Hz), when the encoder is in idle state. If the controller requests the data every 200 ms or more often, the duty cycle of the LED is 100 % (always on).
CRC (inverted)		
	b5 : b0	Polynomial for CRC calculation of position, error and warning data is: x6 + x1 + 1. Represented also as 0x43.

CRC calculation example is in Appendix 2 on page 18.

Error status		
	b21 : b16	Reserved
	b15	Signal amplitude too high. The readhead is too close to the magnet or an external magnetic field is present.
	b14	Signal amplitude low. The distance between the readhead and the ring is too large.
	b13	The readhead temperature is out of specified range.
	b12	Speed too high.
	b11 : b8	Reserved.

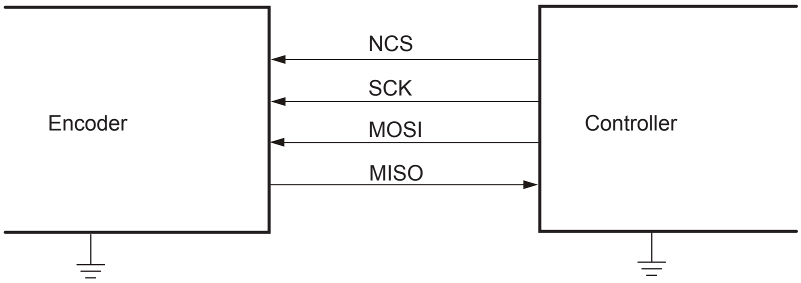
For more information regarding BiSS protocol see **www.biss-interface.com**.

SPI - Serial peripheral interface (slave mode)

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

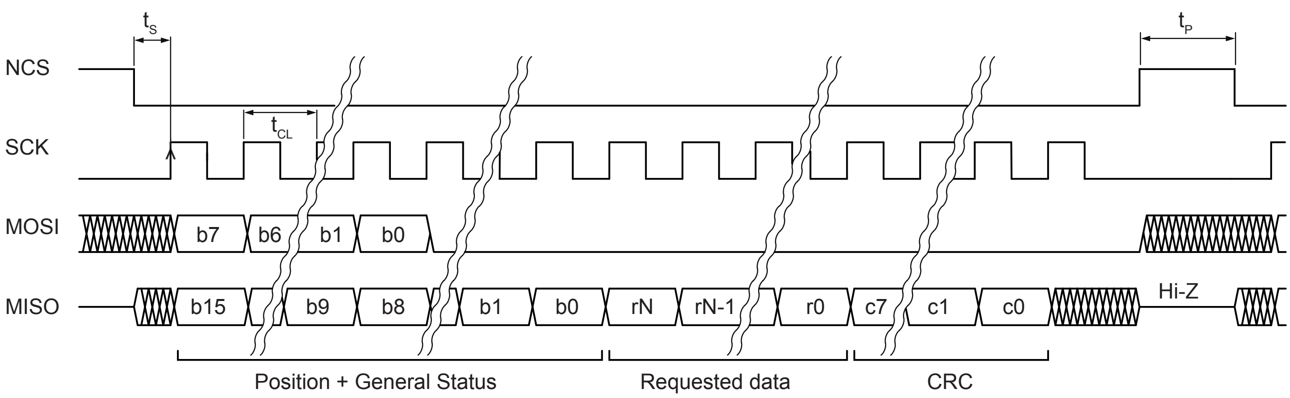
Electrical connection

All data signals are 3.3 V TTL. Inputs are 5 V tolerant. Maximum current sourced or sunk from signal lines should not exceed 20 mA.



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 paralell, sharing all lines except NCS.
SCK	Serial clock. Shifts out the data on rising 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.

SPI timing diagram (single-turn)



Controller starts the communication by setting the NCS signal low. The last available position data is latched at the same time. A delay of t_s is required for the encoder to prepare the data which is shifted to MISO output on rising edges of clock signal SCK. The command is received on 8 consecutive rising edges of SCK. 16 bits of Position and General Status (active low) data are sent out regardless of the received command. The following Requested data length as well as the content depends on the command. The last eight bits contain CRC (inverted) of the complete data packet.

Communication parameters

Parameter	Symbol	Min	Typ	Max
Clock period	t_{CL}	250 ns		
Clock frequency	f_{CL}			4 MHz
Time after NCS low to first SCK rising edge	t_S	1.25 µs		
Pause time	t_P	5 µs		

Structure of data packet

Bit	b31 : b16	b15 : b2	b1 : b0	rN : r0	c7 : c0
Data length	16 bits	14 bits	2 bits	Variable	8 bits
Meaning	Multi-turn counter (if specified in part number)	Encoder position	General status	Requested data	CRC

Encoder position - for all commands		
	b31 : b16	Multi-turn counter (if specified in part number) - Left aligned, MSB first.
	b15 : b2	Encoder position - Left aligned, MSB first.
General status - for all commands		
	b1	Error - If low, position data is not valid. Last valid position is sent out.
	b0	Warning - If low, position data is valid, but some operating conditions are close to limits.
	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. LED is flashing (duty cycle 50 %, frequency 2.5 Hz), when the encoder is in idle state. If the controller request the data every 20 ms or more often, the duty cycle of the LED is 100% (always on).	
Requested data - Command "v" (0x76) - serial number request		
	r47 - r0	6 bytes (48 bits) of ASCII serial number.
Requested data - Command "s" (0x73) - speed request		
	r15 - r0	16 bits, signed. Number represents speed in revolutions per second multiplied by 10.
Requested data - Command "t" (0x74) - temperature request		
	r15 - r0	16 bits, signed. Number represents temperature of the readhead in °C multiplied by 10.
Requested data - Command "d" (0x64) - detailed status request		
	r7	Signal amplitude too high. Readhead is too close to the magnet or an external magnetic field is present.
	r6	Signal amplitude low. Distance between the readhead and the magnet is too large.
	r5	Readhead temperature is out of range.
	r4	Speed is too high.
	r3 - r0	Reserved.
CRC (inverted)		
	c7 : c0	Polynomial for CRC calculation of the sent data is: x8 + x7 + x4 + x2 + x1 + 1. Represented also as 0x97.

CRC calculation example is in Appendix 1 on page 17.

If command byte does not match any of listed commands, encoder will send only Position, Status, CRC data. If additional data is not required, MOSI line of the encoder can be tied to GND.

Readhead part numbering

BR10 SF A 14B 16 C D 00

Communication interface
DC - BiSS-C, RS422
PW - Pulse width modulation (PWM), TTL
SC - Synchronous serial (SSI), RS422
SF - Asynchronous serial, RS422
SP - SPI slave, TTL

Communication interface variant
See table next to the description of the chosen communication interface for detailed information
For **DC**: **D -** BiSS-C, 5 ACK bits, bidirectional
For **PW**: Base frequency in Hz:

A	D	E
122.07	549.32	1098.63

For **SC**: **B -** Start bit and idle data line 1 (standard)
For **SF**: Link speed in kbps:

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

For **SP**: **C -** Standard, full duplex

Resolution
14B - 14 bits per revolution
14M - 14 bits per revolution + 16 bit multiturn counter (for **DC, SC, SF** and **SP** only)

Magnet type compatibility
12 - BM120A190A1ABx00 or actuator BA060..BA100
16 - BM160B240A1ABx00 or actuator BA120..BA150

Operating temperature range
B - 0 °C to +60 °C (NRND)
C - 0 °C to +85 °C

Connector option
H - Soldering pads with through holes
D - Molex 501568-1107

Special requirements
00 - No special requirements (standard)

Available combinations ("x" indicates all valid combinations)
BR10SFx14xxxCx00
BR10PWx14BxxCx00
BR10SCB14xxxCx00
BR10DCD14xxxCx00
BR10SPC14xxxCx00

Magnet part numbering

BM 120 A 190 A 1 A B A 00

Series
BM - Orbis magnet

Inner diameter
120 - 12 mm
160 - 16 mm

Thickness
A - 3 mm
B - 3.5 mm

Outer diameter
190 - 19 mm
240 - 24 mm

Material
A - NdFeB

Grade
1 - Grade 1 tested magnet

Surface finishing
A - NiCuNi

Temperature range
B - -40 °C to +120 °C

Packaging
A - Individual packaging
B - Bulk packaging

Special requirements
00 - No special requirements

Available combinations
BM120A190A1ABA00
BM160B240A1ABA00

Magnetic actuator part numbering

BA 060 AB 01 A A 00

Series
BA - Orbis magnetic actuator

Shaft diameter
060 - 6 mm
080 - 8 mm
100 - 10 mm
120 - 12 mm
150 - 15 mm

Form
AA - With 1 mounting fastener (NRND)
AB - With 3 fasteners (standard)

Magnet type
01 - BM120A190A1ABA00
02 - BM160B240A1ABA00

Material
A - Anodized aluminium

Packaging
A - Individual packaging
B - Bulk packaging

Special requirements
00 - No special requirements

Available combinations
BA060AB01AA00
BA080AB01AA00
BA100AB01AA00
BA120AB02AA00
BA150AB02AA00

Accessories part numbering

ACC012 Cable, 1 m length, Molex 11-pin connector, flying leads

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. ACK, Start and CDS bits are not included in the CRC calculation.

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

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Document issues

Issue	Date	Page	Corrections made
1	4. 10. 2017	-	New document
2	8. 11. 2017	2	Installation drawing amended
		3	Technical specifications amended
		4	Multi-turn counter amended
		6	Asynchronous serial communication parameters amended
		15	Readhead part numbering amended
3	12. 3. 2018	3	Permanent magnets tolerances amended