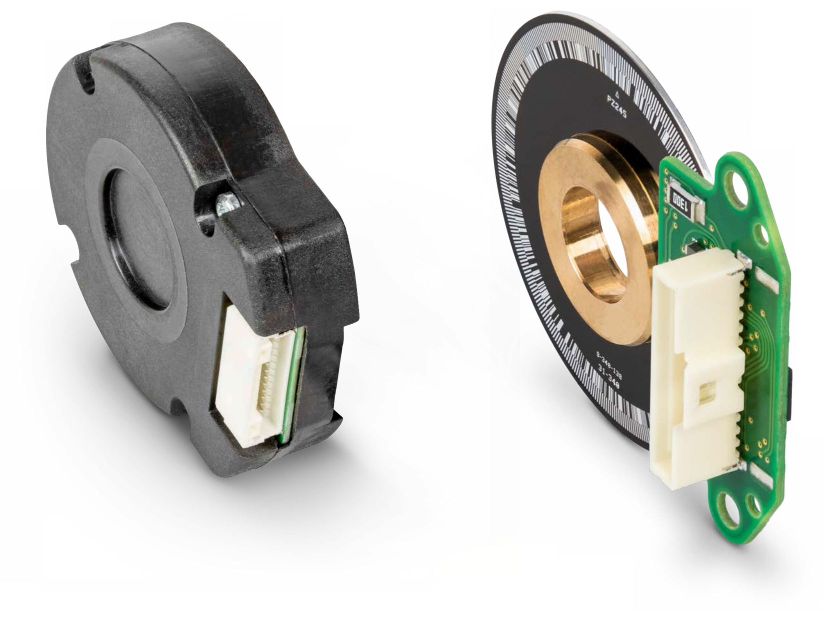
maxon

TSX RIO

Product Information



TSX RIO Encoder
Product Information
mmag | Ausgabe 2025-09 | DocID 9121490-05

maxon

TABLE OF CONTENTS

1 TECHNICAL DATA 4

1.1 Preconditions for operation 4
1.2 Absolute maximum rating 4
1.3 General data 4
1.4 Incremental interface 5
1.5 Absolute interface 5
1.6 Angle measurement 6
1.7 Mechanical data 6
1.8 Angle alignment 7
1.9 Thermistor (NTC) 8

2 ABSOLUTE ENCODER 9

2.1 SSI-mode 9
2.2 BiSS-C-mode 10

3 DEFINITIONS 11

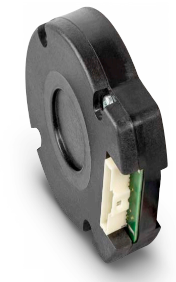
4 TYPICAL MEASUREMENT RESULTS 13

4.1 Angle error per turn 13
4.2 Jitter 14
4.3 Temperature dependence 15
4.4 Speed and resolution dependence 16
4.5 Compliance to regulations 17

5 PIN ASSIGNMENT 18

6 OUTPUT CIRCUITRY 20

TSX RIO Encoders – Product Information



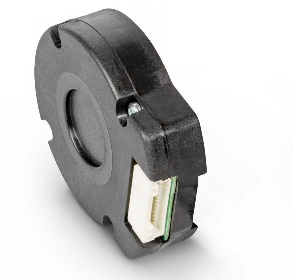


Figure 1 Left: TSX 40 RIO with axial cable outlet
Right: TSX 40 RIO with radial cable outlet

The high-resolution «TSX 40 RIO» (Through Shaft (X) Configurable) encoder expands the maxon product portfolio as an optical axis-remote encoder variant. The TSX-RIO encoders have 3 differential channels (A, A/, B, B/, I, I/) with up to 524'288 impulses per turn (or 21Bit). Incremental square-wave signals and absolute angle values with up to 21 bits (SSI or BiSS-C) are available optionally or in combination.

The «TSX 40 RIO» with axial or radial connector is currently available in combination with the brushless EC-i motors of ø 40 mm and ø 52 mm. For maxon controllers, matching adapter cables are available.

Note
The listed data are for informational purposes only. None of the stated values or information may be used as an indicator of guaranteed performance.

maxon

1 TECHNICAL DATA

1.1 Preconditions for operation

Preconditions for trouble-free operation

- *The encoder must be supplied with voltage before the motor is rotated. Thereby, take a power-up time of up to 14 ms into account.*
- *The encoder can be disturbed by PWM signals from the commutation of the motor. For best performance, the motor housing must be connected to GND.*
- *Voltage ripples (V_{pp}) in the supply voltage (V_{cc}) with an amplitude ≥0.6 V affect the repeatability of the encoder.*
- *The encoder housing is not protected against dust. For free operation, it must be ensured that no particles > 30 µm can penetrate the encoder housing.*
- *At maximum operational temperature, limit the torque on the shaft if the shaft is suddenly blocked by a mechanical hard stop. This condition can occur when TSX RIO is combined with high-torque, low-inertia motors. The motor EC-i40 70 W (496656) is especially susceptible. At 105 °C, limit the maximum torque of this motor to 520 mNm when it is driven into a hard stop.*

1.2 Absolute maximum rating

Exceeding these values can damage the device.

Parameter	Conditions	Min	Max	Unit
Supply voltage (V_{cc})		-0.3	+6	V
Voltage at signal output (V_{signal})	Incremental signals	-0.3	+6	V
Operating temperature (T_{amb})		-40	+105	°C
Storage temperature (T_{store})		-40	+105	°C

1.3 General data

Parameter	Conditions	Min	Type	Max	Unit
Supply voltage (V_{cc})		+4.5	+5	+5.5	V
Supply current (I_{dd})	no load	50		120	mA
Power-on time			14		ms
maximum electrical speed	Limited by input frequency, with interpolation = 1 (340 cpt)			42’000	rpm
	up to 8’000 cpt		42’000		
	8’000 ... 8’192 cpt		32’000		
	8’193 ... 16’384 cpt		16’000		
	16’385 ... 32’768 cpt		8’000		
	32’769 ... 65’536 cpt		4’000		
	65’537 ... 131’070 cpt *[a]*		2’000		
	131’071 ... 262’140 cpt *[a]*		1’000		
	262’141 ... 524’288 cpt *[a]*		500		

[a] over 65’536 cpt the encoder parameters cannot be guaranteed

1.4 Incremental interface

Parameter	Conditions	Min	Type	Max	Unit
Number of channels	ChA, ChB, ChI		3		–
Impulses per turn *[b]*	1 … 524288 cpt	1		524'288	cpt
Pulse frequency (f_{pulse})	Max. output pulse frequency			6.67	MHz
Signal output current (I_{signal})	Incremental output: Termination resistor differential A-A/, B-B/, I-I/, R_{DIFF} = 100Ω	-50	±20	+50	mA
Signal voltage high (V_{high})	I_{signal} <75mA	2.5			V
Signal voltage low (V_{low})	I_{signal} <75mA			0.5	V
Transition time (t_{trans})	Rise time/fall time ChA/B/I R_{DIFF} = 54Ω, CD = 50pF	7	15	20	ns

[b] Factory configurable

1.5 Absolute interface

Parameter	Conditions	Min	Type	Max	Unit
Steps per rotation (ST)	SSI/ BiSS-mode 21 Bit			2'097'152	—
Signal output current (I_{signal})	Absolute interface load resistor differential DATA-DATA/, R_{diff}=100Ω	-50	±20	+50	mA
Signal voltage high (V_{high})	I_{signal} <100mA	2.5			V
Signal voltage low (V_{low})	I_{signal} <100mA			0.5	V
Transition time (t_{trans})	To rise-/ fall time ChA/B/I R_{DIFF} = 54Ω, CD = 50pF	7	15	20	ns
CLK signal frequency (f_{Clk})	SSI-mode			3.3	MHz
	BiSS-mode	0.08		10	MHz
Timeout (t_{out})	SSI-mode, fixed slave timeout	16	20	24	µs
	BiSS-mode, adaptive slave timeout t_{init} measured as first 1.5×T_{Clk} each frame	0.075	t_{init}+0.2	24	µs
Busytime (t_{busy})	BiSS mode		2×T_{Clk}		µs
Input voltage CLK, CLK/ (V_{in})	SSI/ BiSS-mode	-7		12	V
Input resistance differential CLK-CLK/ (R_T)			130		Ω
Propagation Delay (t_{PD})				60	ns
REQ Signal low Level Duration (t_{RQ})		50			ns
Duration (t_{State})	SSI	25		t_{out}	ns
	BiSS	20		t_{out}	ns

maxon

1.6 Angle measurement

Conditions: All values at T=25°C, (n=4'000 rpm, V_{cc}=5 V, unless otherwise specified.)

Definitions: **See** ➔Page 11.

Parameter	Conditions	Min	Type	Max	Unit
Counting direction of incremental signals (Dir)	Motor shaft movement for phasing “A leads B”, as seen from the shaft end		CW		
Counting direction of absolute signals	Motor shaft movement for increasing angular values, as seen from the shaft end		CW		
State length (L_{state}), incremental signal			90		°e
Minimum state duration (t_{state}), incremental		37.5			ns
Integral Nonlinearity (INL) *[c]*	all pulse counts per revolution		0.15	0.3	°m
Differential Nonlinearity (DNL) *[c]*	N = 4096cpt		0.1		LSB
	N = 16384cpt		0.4		
	N = 32768cpt		0.8		
Repeatability (Jitter), incremental *[c]*	N = 4096cpt		0.15		LSB
	N = 16384cpt		0.4		
	N = 32768cpt		1		
Repeatability (Jitter) *[c]*	All number of impulses		0.003		°m
Phase delay A to B (Phase θ), incremental	All number of impulses	85	90	95	°e
Noise free resolution, ±3σ noise level *[c]*	Maximum number of bits unaffected by peak-to-peak noise	18		19	Bit
Angle hysteresis (H_{yst})			1.406		°e
Delay of digital signal path	Typical latency of digital signal processing			2	µs

[c] Measurement results from laboratory characterizations

1.7 Mechanical data

Parameter	Conditions	Value	Unit
Dimension (D × L) (➔Figure 2)	TSX 40 RIO	ø 40×11.7	mm
Interia torque (J_t)	motor shaft ø6, ø8mm	3.6, 3.5	g cm²

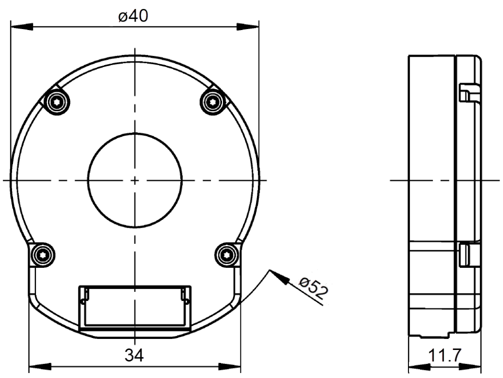


Figure 2 TSX 40 RIO on EC-i - dimension drawing

1.8 Angle alignment

To enable sinus commutation, the encoder's zero angle is adjusted to the phase position of the back EMF per pole pair of the underlying motor.

The incremental signals are also synchronized to this edge allowing phase-synchronous sinusoidal commutation ("field-oriented control, FOC") when used with a motor providing commutation signals.

Figure 3 shows the incremental index signal of a TSX RIO encoder (N= 4096 cpt), and the back EMF of the EC-i50 motor, recorded in direction of rotation CW at V_{CC} = 5 V, n=2'500 min^{-1}, 1 k||4.7 kΩ load, T = 25°C

Signals: C1 = U; C2 = V; C3 = W; 20V/div; C4 = INC Index;1V/div; 1ms/div

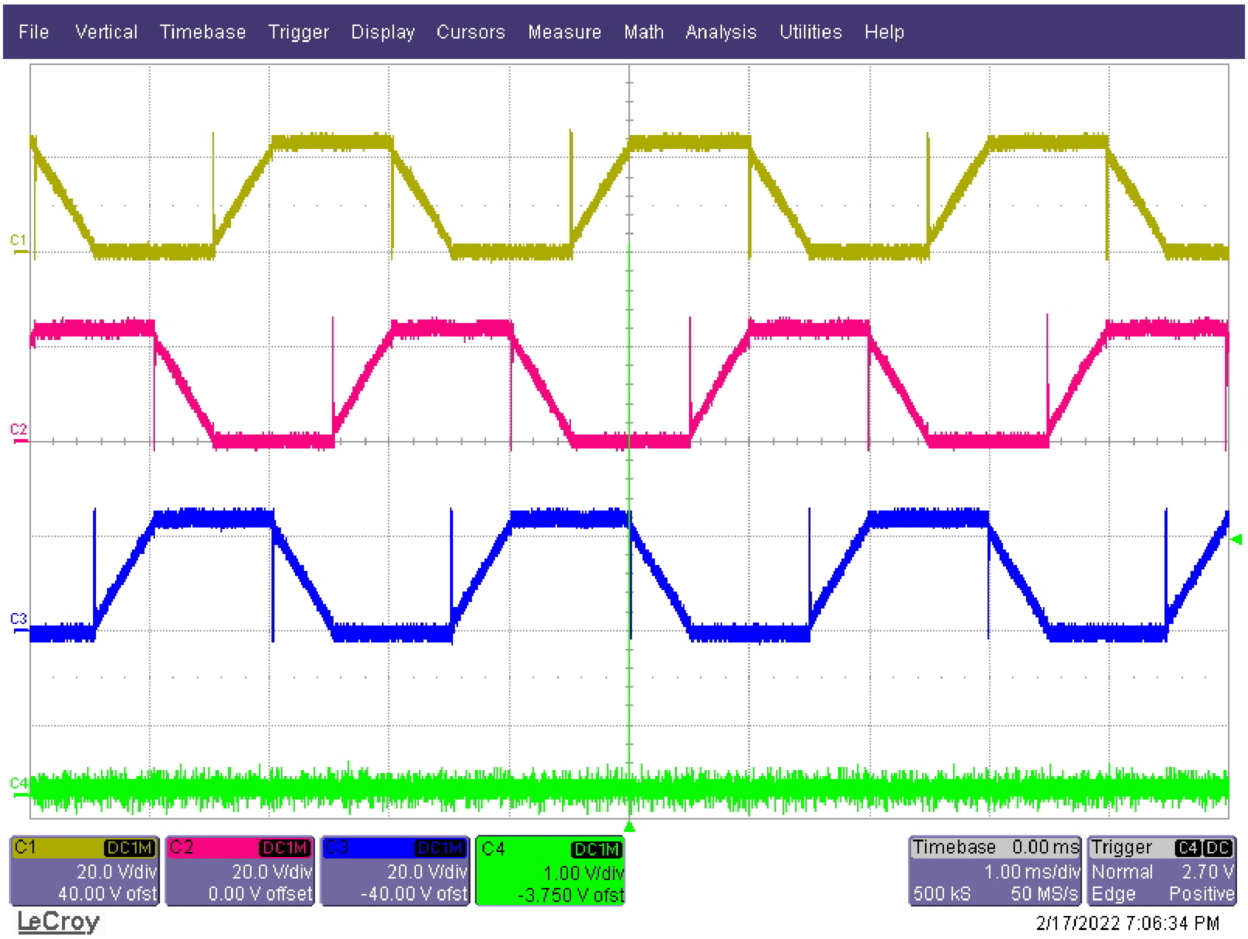


Figure 3 Oscilloscope capture of incremental signals (INC Index and back-EMF)

1.9 Thermistor (NTC)

A thermistor is installed on the encoder for temperature monitoring. The resistance value of the NTC depending on the temperature can be described with the following formula:

$$R = R_0 \cdot e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

The following values apply:

B = 3'434 K (25…85°C) R_0 = 10 kΩ ±1% T_0 = 298.15 K

Figure 4 presents the measured and calculated resistance values as a function of temperature. The results correspond to the theoretical values.

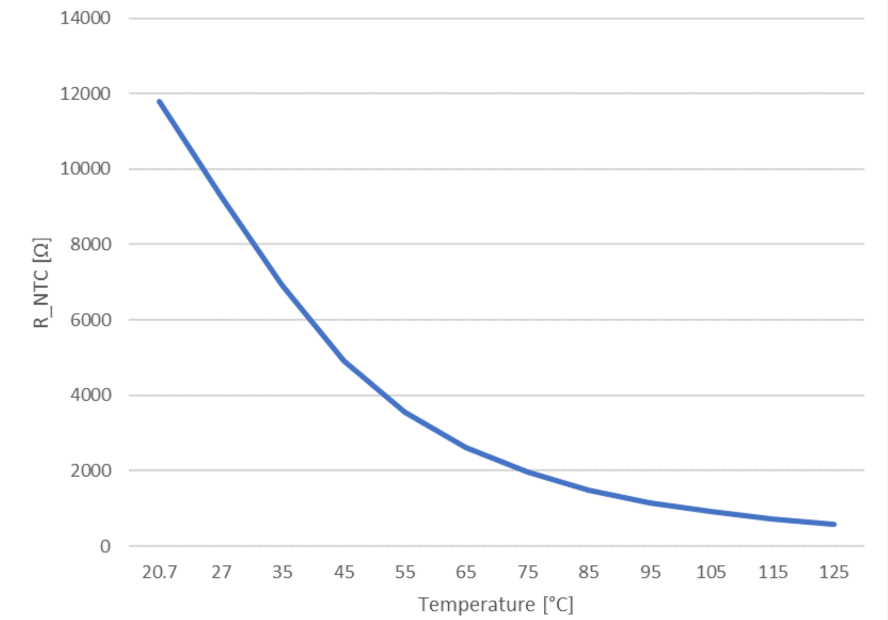


Figure 4 Resistances of the thermistor (R_{NTC} = f(T))

2 ABSOLUTE ENCODER

The "TSX RIO" encoder series provides the functionality of a single-turn absolute encoder. Two protocol variants are factory configurable, SSI and BiSS-C.

2.1 SSI-mode

- The waiting time after reading the last bit must be longer than the timeout (t_{out}).
- Data frame: 0 multiturn bits, 24 singleturn bits (MSB first, gray coded, unused bits are set to zero from right to left), 2 error/warning bits, 0 LC bit, 6 CRC bits (polynomial: 0b1000011, inverted mode, binary).
- EPOS Studio Settings: 0 Special Leading Bits, Data=0 Multiturn Bits, 0 Position, Data=24 Singleturn Bits, 19 Position, 8 Special Trailing Bits, see ➔Figure 5

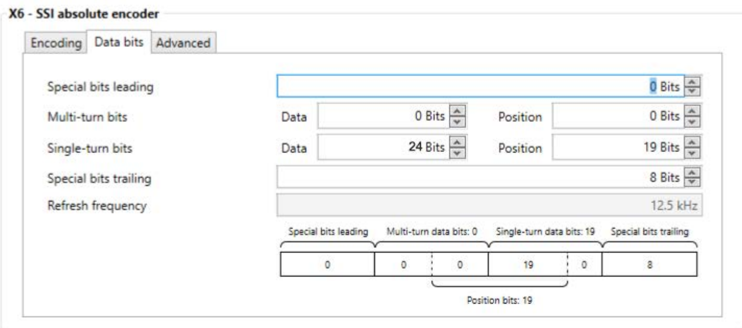


Figure 5 EPOS Studio settings in SSI mode

- A complete reading cycle can be calculated as follows:

$$t_{frame} = t_{RQ} + 32 \times \frac{1}{f_{clk}} + t_{out}$$

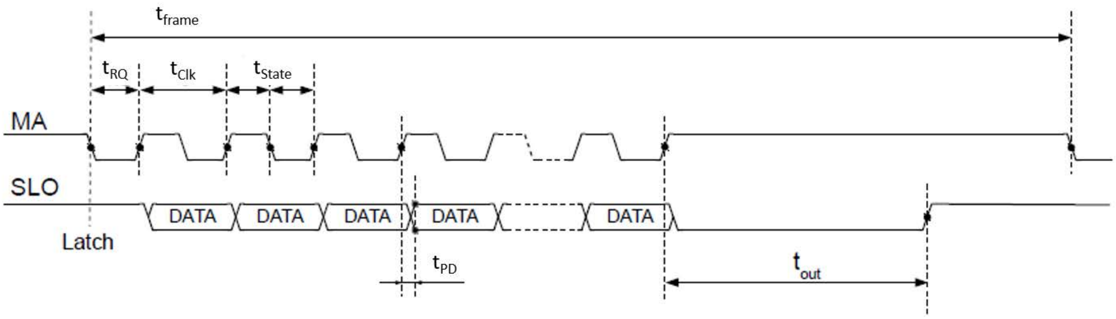


Figure 6 Timing diagram of the TSX RIO in SSI mode

2.2 BiSS-C-mode

- The waiting time after reading the last bit must be longer than the timeout (t_{out}).
- Data frame: n= start sequence {}, 24 singleturn bits (MSB first, binary, unused bits are set to zero from right to left), 2 error/warning bits, 0 LC bit, 6 CRC bits (polynomial: 0b1000011, inverted mode, binary).
- A complete reading cycle can be calculated as follows:

$$t_{frame} = t_{busy} + 32 \times \frac{1}{f_{clk}} + t_{out}$$

- The maximum frame repetition rate is 124 kHz.

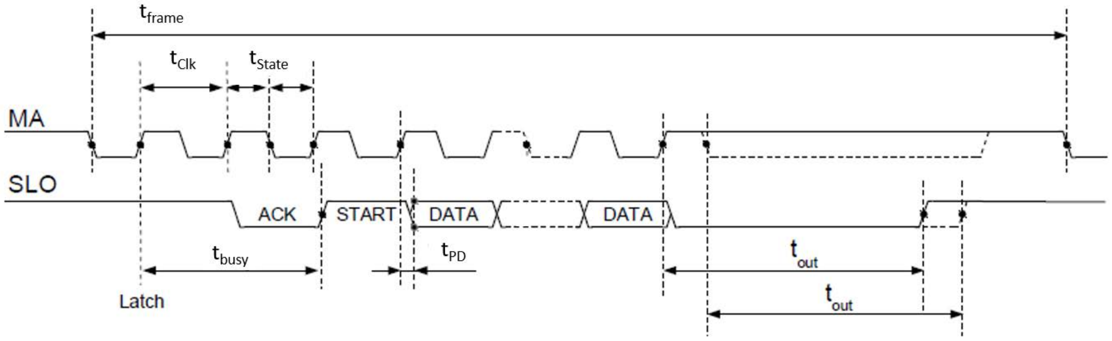
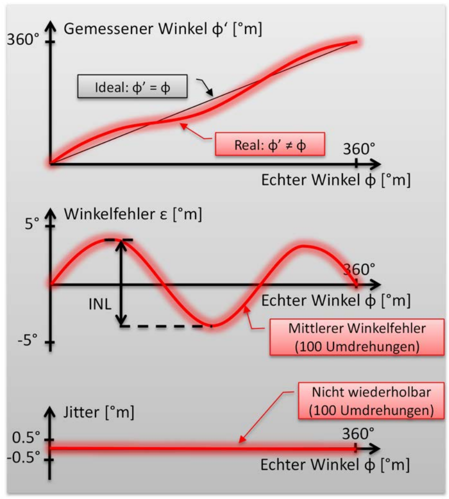
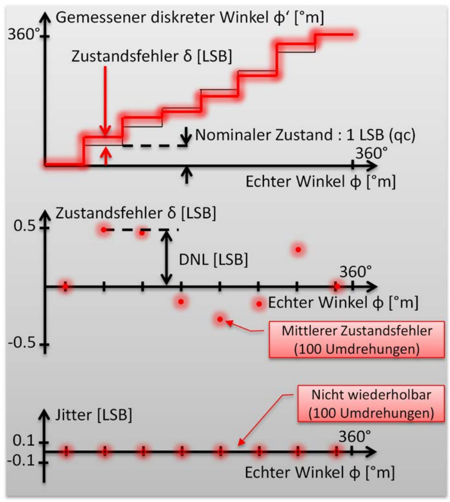


Figure 7 Timing diagram of the TSX RIO in BiSS-C mode

3 DEFINITIONS

<table>
<tr><th>Metric</th><th>Definition</th><th>Illustration</th></tr>
<tr><td>Angle error [°m]</td><td>Difference of measured and true angular shaft position at each position.</td><td rowspan="5">
</td></tr>
<tr><td>Average angle error [°m]</td><td>Average of Angle Error at each position, over a given number of turns.</td></tr>
<tr><td>Integral nonlinearity (INL) [°m]</td><td>Peak-to-peak value of Average Angle Error.</td></tr>
<tr><td>Jitter (repeatability) [°m] or [LSB]</td><td>Six standard deviations of Angle Error per turn (at each position, over a given number of turns).
Jitter [°m] is typically independent of the resolution and defines the maximum useful positioning repeatability.
Jitter [LSB] is resolution-dependent. At given Jitter [°m], the value is roughly proportional to resolution.</td></tr>
<tr><td>Noise free resolution</td><td>Maximum number of bits unaffected by peak-to-peak noise</td></tr>
<tr><td>Least significant bit [LSB]</td><td>Minimum measurable difference between two angle values at given resolution (= quadcount, = State).</td><td rowspan="5">
</td></tr>
<tr><td>State error [LSB]</td><td>Difference between actual state length and average state length.</td></tr>
<tr><td>Average state error [LSB]</td><td>Average of State Error over a number of turns for each state of a turn.</td></tr>
<tr><td>Differential nonlinearity [DNL]</td><td>Maximum positive or negative Average State Error.</td></tr>
<tr><td></td><td></td></tr>
</table>

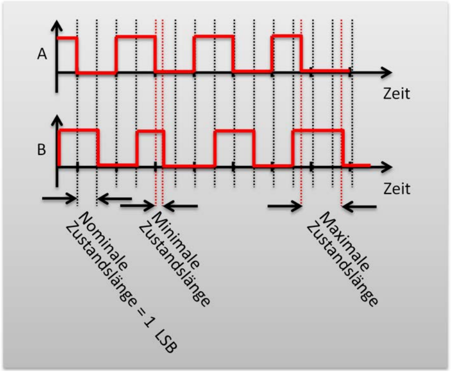
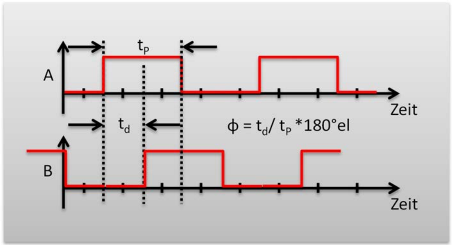
Metric	Definition	Illustration
Minimum state length [°e]	Minimum measured state length within a number of turns relative to pulse length.	
Maximum state length [°e]	Maximum measured state length within a number of turns relative to pulse length.	
Minimum state duration [ns]	By chip limited minimum time separation between two A/B transitions.	
Phase delay θ [°e]	Time difference of rising edge A to B relative to duration of positive level of A.	

Table 1 Definitions

4 TYPICAL MEASUREMENT RESULTS

4.1 Angle error per turn

Below graphs show angle error measurements of a TSX RIO encoder configured at different resolutions under the following conditions:
Measurement of 15 turns at V_{cc}=5 V, n=4'000 min^{-1}, T=25°C, incremental signals.

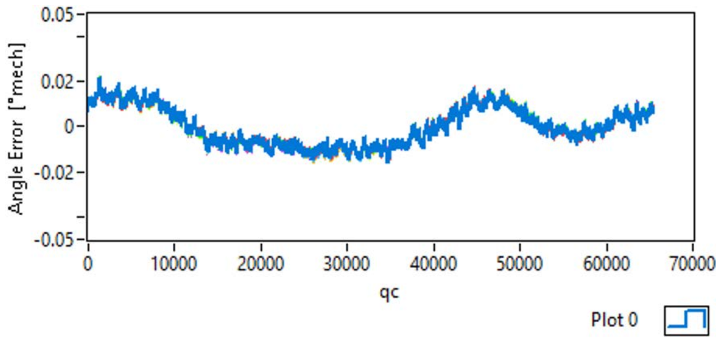
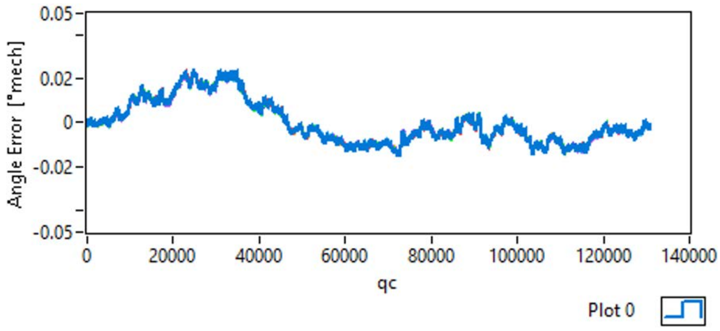
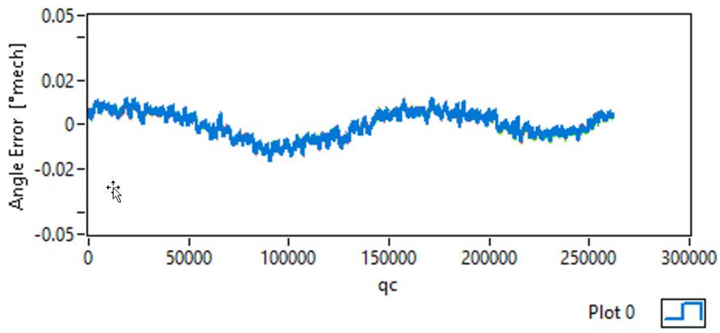
Motor	Resolution	Graph	Analysis	
1	16’384 cpt		INL Jitter DNL Min State Max State	0.038°m 0.0022°m = 0.4LSB 0.25 LSB 0.75 LSB 1.25 LSB
2	32’768 cpt		INL Jitter DNL Min State Max State	0.039°m 0.0016°m = 0.6LSB 0.32 LSB 0.7 LSB 1.3 LSB
3	65’536 cpt		INL Jitter DNL Min State Max State	0.028°m 0.0017°m = 1.3LSB 0.75 LSB 0.25 LSB 1.75 LSB

Table 2 Angle error per turn

maxon

4.2 Jitter

Figure 8 shows the random portion of the angular error measured at a position at standstill. Six standard deviations (sigma) of the value sequence can typically reach 8 LSB.

Conditions: VCC=5V, n=0min-1, T=25°C, 100 Ω load, resolution 22 bits* (1LSB = 8.58e-5°m).

- ** The maximum resolution is 22.4 bits. Due to the high noise level, the function on maxon controllers is only guaranteed up to 21 bits.*

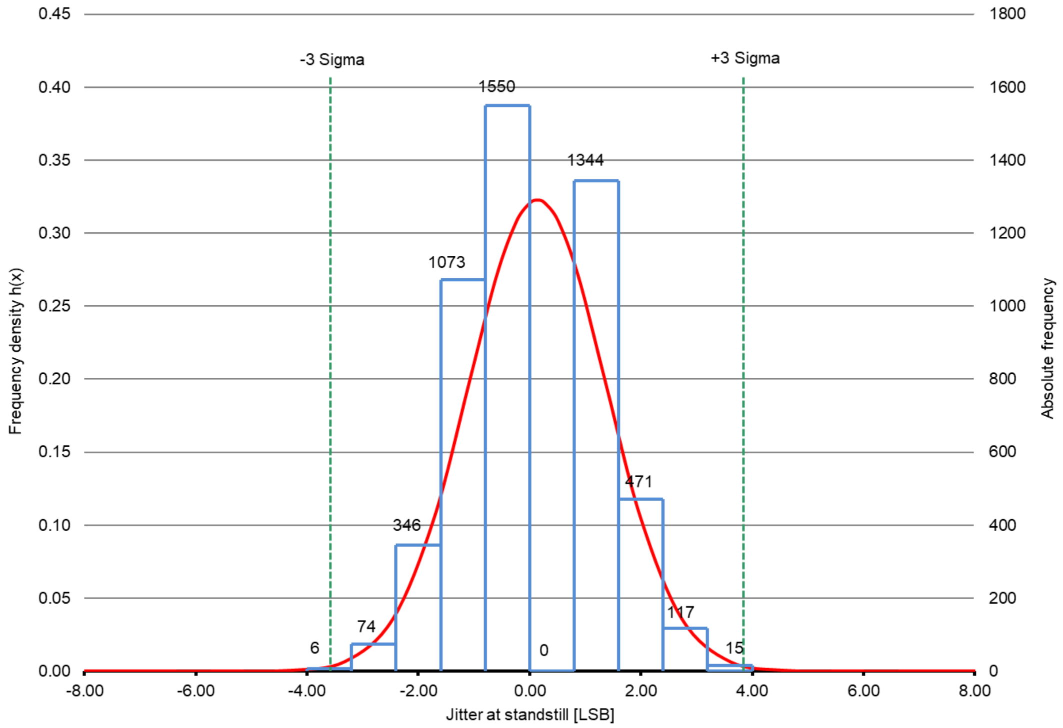


Figure 8 Jitter at stand-still

4.3 Temperature dependence

INL is essentially independent of temperature. The DNL increases slightly with increasing temperatures.

Figure 9 shows the temperature dependence of five EC-i40 with TSX-RIO under the following conditions: V_{cc}=5 V, 6‘000 min^{-1}, 32'768 cpt,

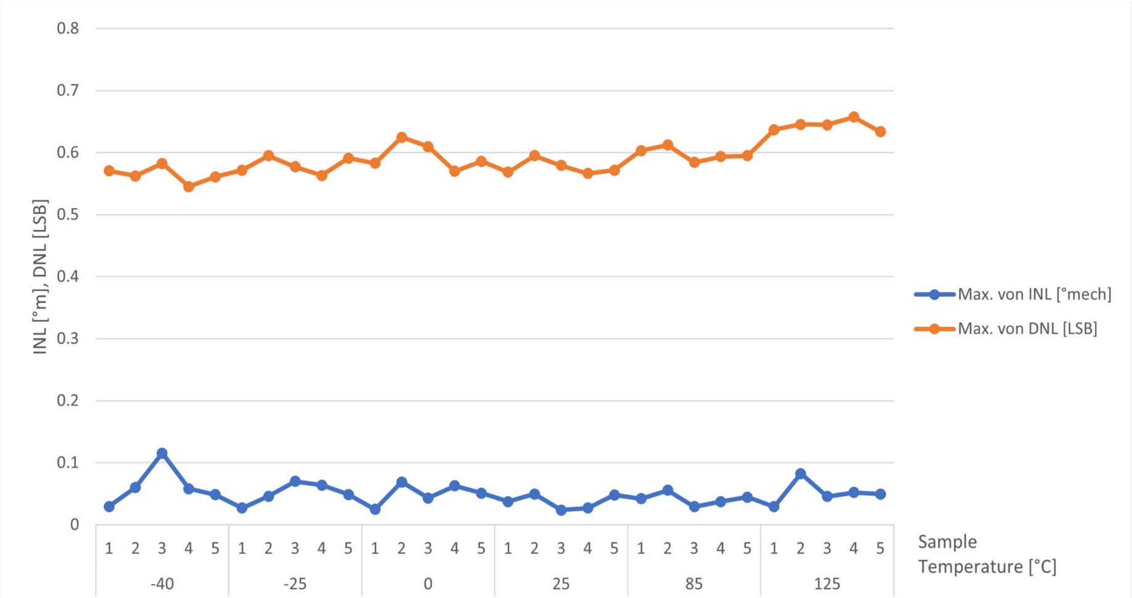


Figure 9 Temperature dependence

The noise is temperature-dependent. Both at -40°C and at 105°C, higher values are to be expected than at room temperature. At the limit temperatures, a noise-free resolution of 18 bits can be expected.

Figure 10 shows the temperature dependence of a TSX-RIO encoder.

Conditions: V_{CC}=5V, n=0min^{-1}, 120Ω load, resolution 22Bit *

- ** The maximum resolution is 22.4 bits. Due to the high noise level, the function on maxon controllers is only guaranteed up to 21 bits.*

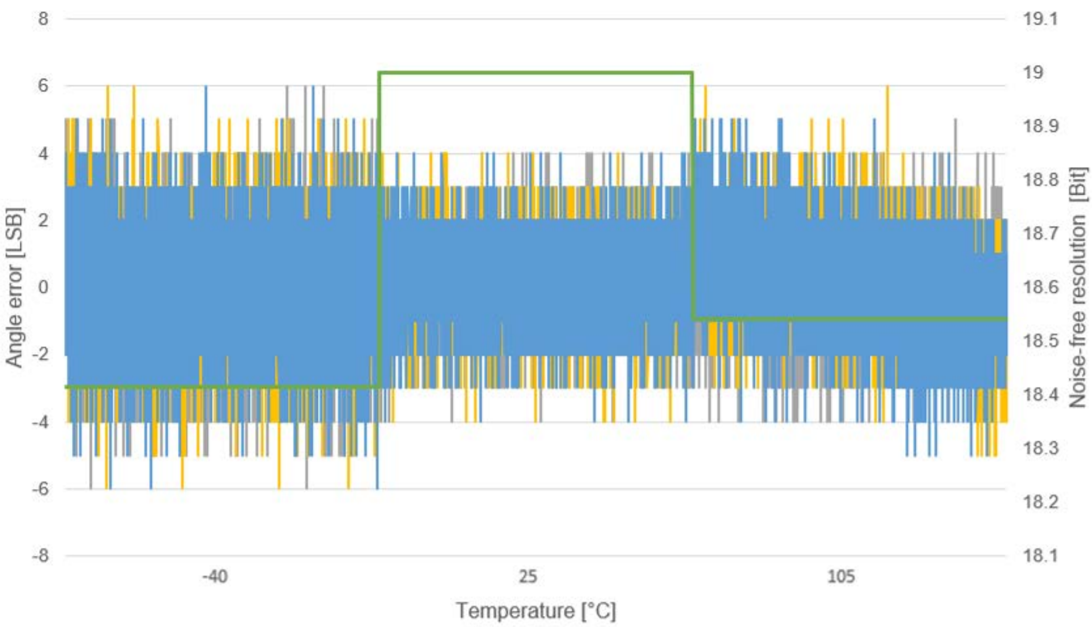


Figure 10 Temperature dependence Jitter

maxon

4.4 Speed and resolution dependence

The INL [°m] shows no dependence on speed or resolution. The DNL [LSB] increases with increasing pulse frequency. It is related to the minimum state duration.

Figure 11 shows five EC-i40 units under the following conditions:

Conditions: Vcc=5 V, 5'000...8'000 min-1, 340/ 4096/ 8192/ 16384/ 32768 cpt.

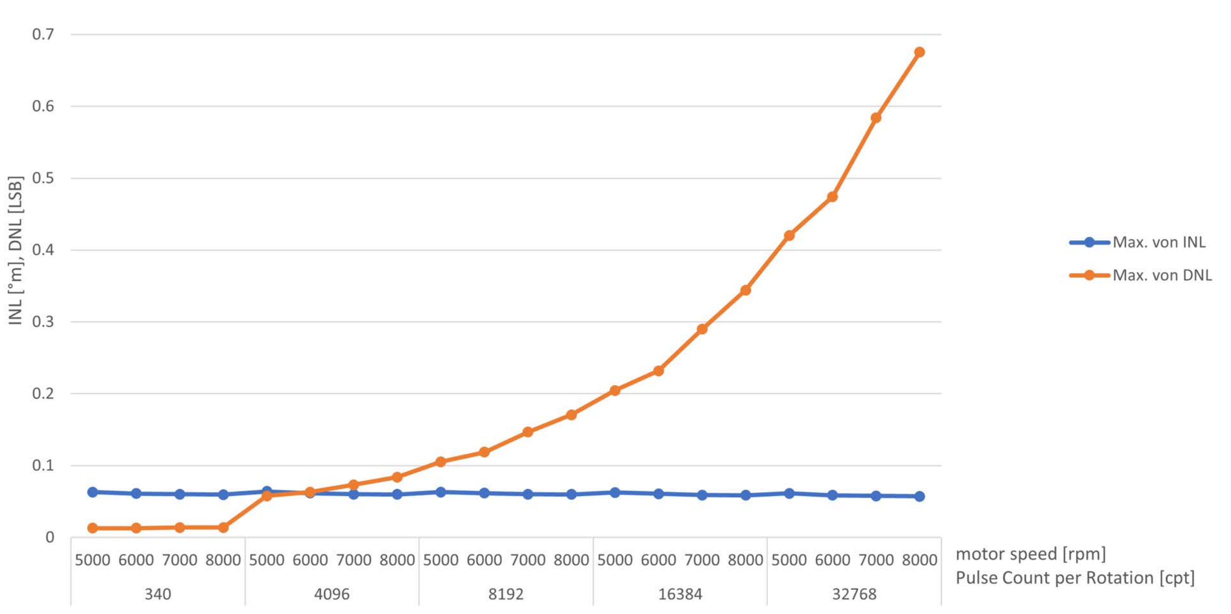


Figure 11 Speed and resolution dependence of INL and DNL

4.5 Compliance to regulations

Parameter	Description
Electrostatic discharge immunity (DIN EN 61000-4-2)	Direct discharge on motor housing and connectors – ±8 kV
Reliability (Mean Time To Failure, MTTF)	4'238'050 hrs (483.8 years) (MIL-HDBK-217F, Ground Benign GB, 25°C, In accordance with circuit diagram and nominal power)
Compatibility UL	See conditions listed below
Compliant BiSS device	BiSS INTERFACE CERTIFIED Compliant BiSS Device www.BiSS-interface.com

Table 3 Compliance to regulations

The following conditions are fulfilled by the product or must be fulfilled in the customer's overall system in order to have a drive unit equipped with an TSX RIO encoder certified according to UL:

- As per UL 840 chapter 8:
  The encoder is considered as “low voltage equipment” because it has a supply voltage below 50 V and all electrically conducting parts are separated by at least 0.2 mm from the next adjacent metal part that is or could be electrically connected to an outside potential.
- As per UL 746C chapter 3.34 section b:
  The maximum power consumption of the device is less than 15 W under regular conditions. The voltage supply must guarantee that, even in case of defect at the encoder, the maximum power consumption is limited to 15 W (for example by current limiting circuitry).
- A surrounding system with circuitry operating at voltages between 50 V and 125 V must either guarantee an isolation distance of at least 1.6 mm between all parts at these voltages and the encoder or such conductors must use UL-listed isolations.

5 PIN ASSIGNMENT

Maximum permitted Supply Voltage
- *Make sure that supply power is within stated range.*
- *Supply voltages exceeding the stated range—or wrong polarity—will destroy the unit.*
- *Connect the unit only when supply voltage is switched off (V_{cc}=0).*

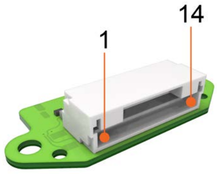


Figure 12 Encoder connector with radial cable outlet

Pin	Signal	Description
1	Vcc	Power supply voltage
2	GND	Ground
3	A\	Channel A\ complement
4	A	Channel A
5	B\	Channel B\ complement
6	B	Channel B
7	I\	Channel I\ complement
8	I	Channel I
9	CLK+/MA+	Absolute encoder clock
10	CLK-/MA-	Absolute encoder clock complement
11	DATA+/SLO+	Absolute encoder data
12	DATA-/SLO-	Absolute encoder data complement
13	NTC+	Connection thermistor +
14	NTC−	Connection thermistor -

Table 4 Pin assignment – encoder connector with radial cable outlet

<table>
<tr><th colspan="3">TSX RIO encoder connector with radial cable outlet</th></tr>
<tr><td>Connector</td><td colspan="2">JST SM14B-NSHSS-TB</td></tr>
<tr><td>Suitable cable</td><td colspan="2">TSX RIO radial to EPOS4 / ESCON, (➔Further information in separate document «Product Information TSX Cable»), L=300 mm</td></tr>
<tr><td rowspan="2">Suitable plugs</td><td>Housing</td><td>Connector housing, 1.0 mm pitch, 14-pole;
JST (NSHR-14V-S)</td></tr>
<tr><td>Contacts</td><td>Crimp contact, 28-32 AWG; JST (SSHL-003T-P0.2)</td></tr>
</table>

Table 5 Encoder connector with radial cable outlet

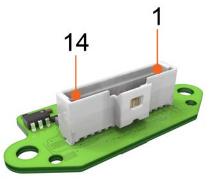


Figure 13 Encoder connector with axial cable outlet

Pin	Signal	Description
1	NTC−	Connection thermistor −
2	NTC+	Connection thermistor +
3	DATA-/SLO-	Absolute encoder data complement
4	DATA+/SLO+	Absolute encoder data
5	CLK-/MA-	Absolute encoder clock complement
6	CLK+/MA+	Absolute encoder clock
7	I	Channel I
8	I\	Channel I\ complement
9	B	Channel B
10	B\	Channel B\ complement
11	A	Channel A
12	A\	Channel A\ complement
13	GND	Ground
14	Vcc	Supply voltage

Table 6 Pin assignment – encoder connector with axial cable outlet

TSX RIO encoder connector with axial cable outlet		
Connector	Molex Pico-Clasp (501331-1407)	
Suitable cable	TSX RIO axial to EPOS4 / ESCON (➔Further information in separate document «Product Information TSX Cable»), L=300 mm	
Suitable plugs	Housing	Connector housing, 1.0 mm pitch 1.0 mm, 14-pole; Molex Pico-Clasp (5013301400)
	Contacts	Crimp contact, 28-32 AWG; Molex (5013340100)

Table 7 Encoder connector with axial cable outlet

6 OUTPUT CIRCUITRY

The following figure shows the conceptual output schematics.

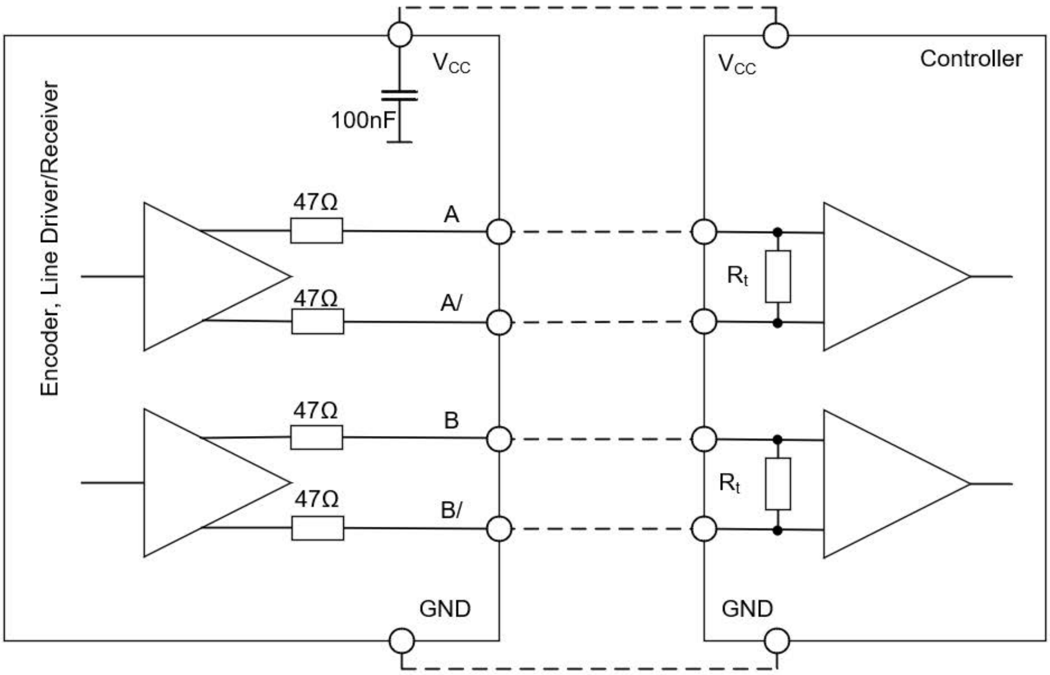


Figure 14 Output Circuitry incremental interface

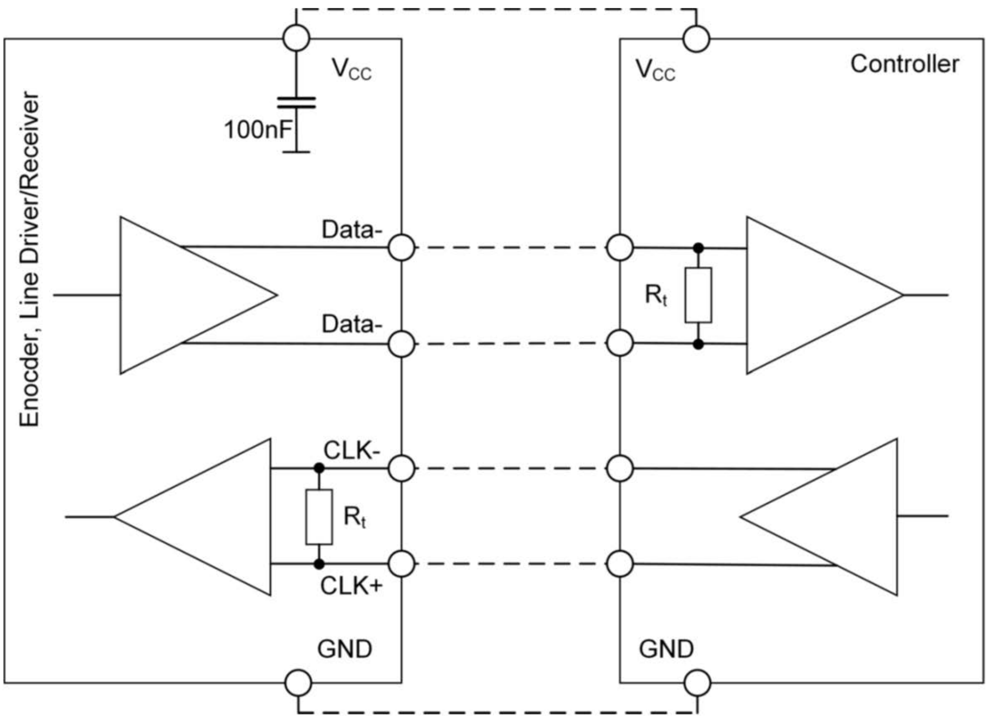


Figure 15 Output circuitry absolute interface