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TSX MAG

Product Information

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TSX MAG Encoders – Product Information

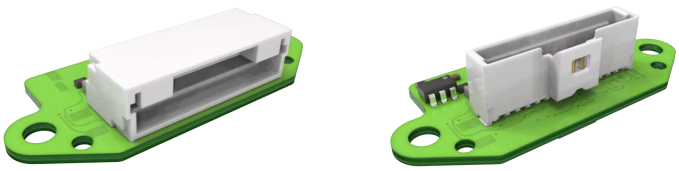

Figure 1 Left: TSX MAG with axial cable outlet
Right: TSX MAG with radial cable outlet

The versatile «TSX MAG» (Through Shaft Configurable) encoder expands the maxon product portfolio as off-axis encoder variant. The magnet encoder utilizes an interpolated angle measuring system with Hall sensors to generate incremental square wave signals. It features two differential channels (A, A/, B, B/) with up to 2560 impulses per turn. For the use with EC motors (BLDC, brushless DC), additional commutation signals are generated.

The «TSX MAG» with axial or radial connector is currently used in combination with motors of the series «EC frameless DT» (Dynamic Torque) and the EC-i motors with a size of 40 mm and 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.

1 TECHNICAL DATA

1.1 Preconditions for operation

Preconditions for trouble-free operation

- *When combined with EC frameless DT motors, the rotor and stator are delivered separately.*
    - They must remain paired with the same product number.
    - Incorrect pairing will cause noisy or unstable operation.
- *The encoder must be supplied with voltage before the motor is rotated. Thereby, take a power-up time of up to 2.5 ms into account.*
- *The encoder already reacts to small and medium magnetic fields (amplitude > 1.5 mT). For best performance, no magnetic fields must be present in the encoder's immediate vicinity.*
- *Voltage ripples (V_{pp}) in the supply voltage (V_{cc}) with an amplitude ≥ 0.2 V affect the repeatability of the encoder.*

1.2 Absolute maximum rating

Parameter	Conditions	Min	Max	Unit
Supply voltage (V_{cc})		–0.3	+7	V
Voltage at signal output (V_{signal})	Incremental signals	–0.3	+7	V
	Hall signals		+26.4	
Operating temperature (T_{amb})		–40	+105	°C
Storage temperature (T_{store})		–40	+105	°C
Humidity	condensation not permitted		95	%rH

1.3 General data

Parameter	Conditions	Min	Typ	Max	Unit
Supply voltage (V_{cc})		+4.5	+5	+5.5	V
Supply current (I_{dd})	no load	12	18	19	mA
Power-on time				2.5	ms

1.4 Incremental interface

Parameter	Conditions		Min	Typ	Max	Unit
Number of channels	ChA, ChB		2	—		
Impulses per turn [a]	7 pp Target	7, 14, 21, ..., 1792cpt	7	—	1792	cpt
	8 pp Target	8, 16, 24, ..., 2048cpt	8	—	2048	
	10 pp Target	10, 20, 30, ..., 2560cpt	10	—	2560	
Pulse frequency (f_{pulse})	Max. output pulse frequency		—	500	—	kHz
Signal output current (I_{signal})	Incremental output: Termination resistor differential A-A/, B-B/, R_{DIFF} = 100 Ω		–50	±20	+50	mA
Signal voltage high (V_{high})	I_{signal} <20 mA		2			V
Signal voltage low (V_{low})	I_{signal} <20 mA				0.5	V
Transition time (t_{trans})	Rise time/fall time ChA/ChB R_{DIFF} = 100 Ω, CD = 50 pF		7	11	20	ns

[a] Factory configurable

1.5 Commutation interface (open collector)

Parameter	Conditions	Min	Typ	Max	Unit
Number of channels	H1, H2, H3		3		—
Pulse frequency (f_{pulse})	Max. output pulse frequency		20		kHz
Signal output current (I_{signal})				+50	mA
Signal voltage high (V_{high})	I_{signal} <50 mA, relative to V_{CC}	V_{CC}–0.5			V
Signal voltage low (V_{low})	I_{signal} <50 mA			0.5	V
Transition time (t_{trans})	Rise time H1/H2/H3 (10…90%) R_{pu} = 3.3 kΩ			≤0.5	µs
	Fall time H1/H2/H3 (90…10%) R_{pu} = 3.3 kΩ			≤0.1	

1.6 Angle measurement

Conditions: All values at T=25°C, n=5000 rpm, V_{cc}=5 V unless otherwise specified.

Definitions *See ➔Page 9.*

Parameter	Conditions	Min	Typ	Max	Unit
Counting direction of absolute signals (Dir)	Motor shaft movement for phasing “A leads B”, as seen from the shaft end [a]	—	CW	—	—
Counting direction of commutation signals	Motor shaft movement for phasing “H1 leads H2 leads H3”, as seen from the shaft end [a]	—	CW	—	—
State length (L_{state}), incremental signal	N=2560 cpt	80	90	100	°e
Minimum state duration (t_{state}), incremental		—	62.5	—	ns
Integral Nonlinearity (INL) [b]	7pp, target, all pulse counts per revolution	—	1	—	°m
	8pp, target, all pulse counts per revolution	—		—	
	10pp, target, all pulse counts per revolution	—		—	
Differential Nonlinearity (DNL) [d]		—	—	0.2	LSB
Repeatability (Jitter), incremental [c]	Interpolation factor i=64 (7pp, 8pp, 10pp)	—	—	0.25	LSB
	Interpolation factor i=128 (7pp, 8pp, 10pp)	—	—	0.5	
	Interpolation factor i=256 (7pp, 8pp, 10pp)	—	—	1	
Repeatability (Jitter) [c]		—	0.05	—	°m
Phase delay A to B (Phase θ), incremental [c]	All number of impulses	80	90	100	°e
Angle hysteresis (Hyst)			0.7		°m
Delay of digital signal path	Typical latency of digital signal processing	—	8	—	µs

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Parameter	Conditions	Min	Typ	Max	Unit
Filter time constant	$T=0.38/F_{cutoff}$ $F_{cutoff}=1500$ Hz	—	0.253	—	ms
Maximum commutation angle error (maxCAE) [c]		—	7.5	13	°e

[b] Measurement results from laboratory characterizations with target pole pair numbers ≥ 7pp. Encoder mounted in housing or rotor and stator mounted on both sides in compliance with the tolerances according to ➔separate document «EC frameless DT Installation Manual».

[c] Measurement derive from laboratory characterizations. Rotor and stator supported on both ends subject to tolerances according to ➔separate document «EC frameless DT Installation Manual»

[d] Guaranteed by 100% testing.

1.7 Mechanical data

The following data refers to the TSX-MAG in combination with EC-i motors. Installation on the EC frameless motors are described in the ➔ separate document «EC frameless DT Installation Instructions».

Parameter	Conditions	Value	Unit
Dimension (D x L) (➔Figure 2)	TSX MAG	ø40 x 11.7	mm
Inertia torque (J_t)	motor shaft ø6, ø8mm	7.6, 7.4	g cm²

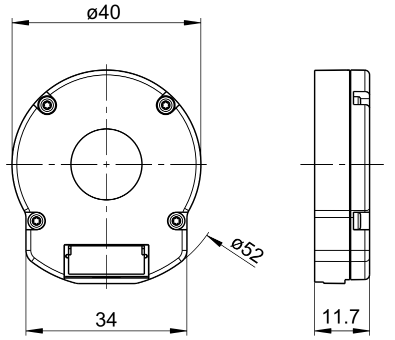


Figure 2 TSX 40 MAG closed housing - dimension drawing

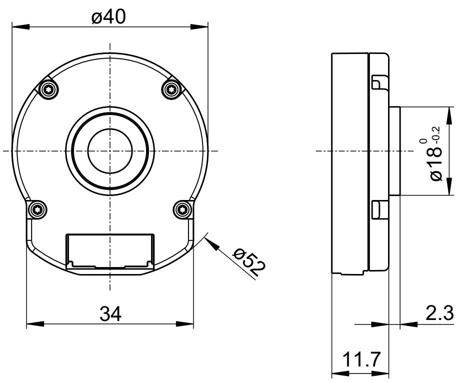


Figure 3 TSX 40 MAG open housing - dimension drawing

1.8 Angle alignment

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

For the block commutation (signals H1, H2, H3) this means that the rising edge of the commutation signal H1 is synchronous to the mean value of the angle "zero" of the pole pairs of the EC (BLDC) motor used.

The incremental signals are also synchronized to this edge to make phase-synchronous sinusoidal commutation (Field-oriented Control; FOC) possible after determining the zero angle from the block commutation signals.

Figure 4 shows the incremental signals A, B and the Hall signals H1, H2, H3 of a TSX MAG encoder (N= 20 cpt), recorded in sense of rotation CW at V_{CC}=5 V, n=2500 rpm, 120 Ω load, 10 kΩ pull-up resistance, T=25°C

Signals: C1 = ChA; C2 = ChB; C4 = H1; C5 = H2; C6 = H3; 500 µs/div; 5 V/div

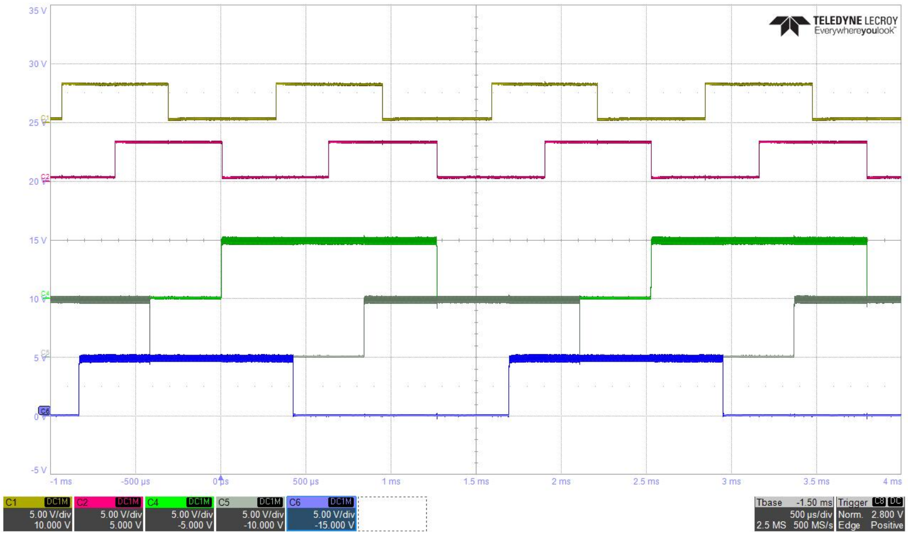


Figure 4 Oscilloscope capture of incremental signals

Figure 5 shows the Hall signals H1, H2, H3 of a TSX MAG encoder and the back EMF of the EC frameless DT50 motor, recorded in sense of rotation CW at V_{CC}=5 V, n=2500 rpm, 120 Ω load, 10 kΩ pull-up resistance, T=25°C

Signals: C1 = U; C2 = V; C3 = W; 20V/div; C4 = H1; C5 = H2; C6 = H3; 500 µs/div; 5 V/div

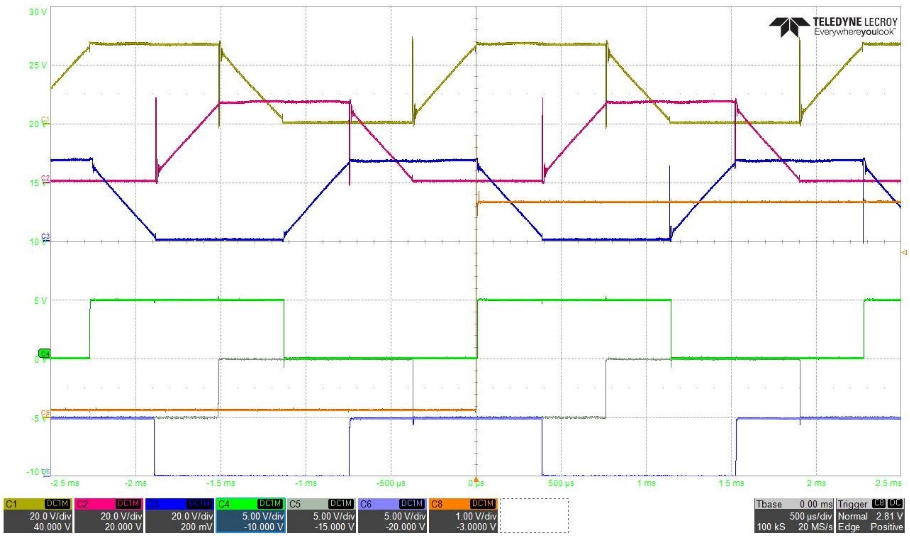


Figure 5 Hall signals and back EMF

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 = 3434 K (25…85°C) R_0 = 10 kΩ ±1% T_0 = 298.15 K

Figure 6 presents the measured and calculated resistance values as a function of temperature. The results correspond to the theoretical values.

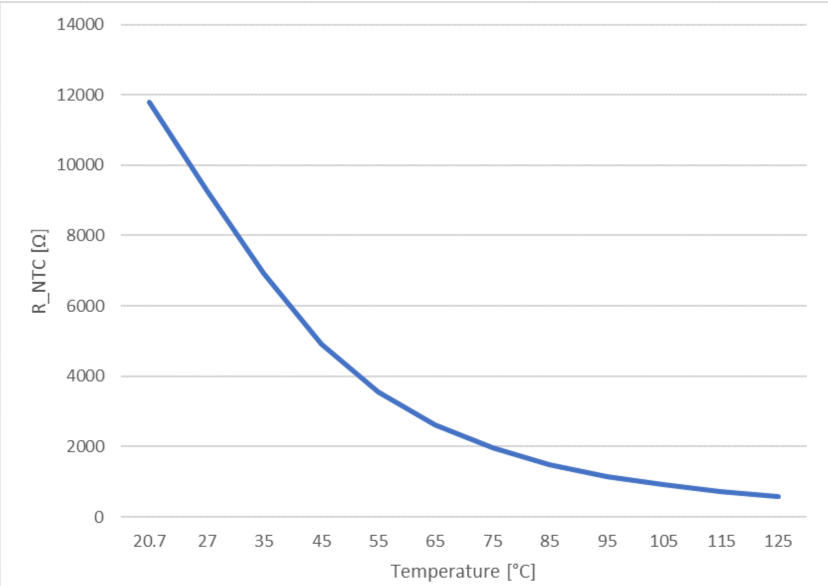
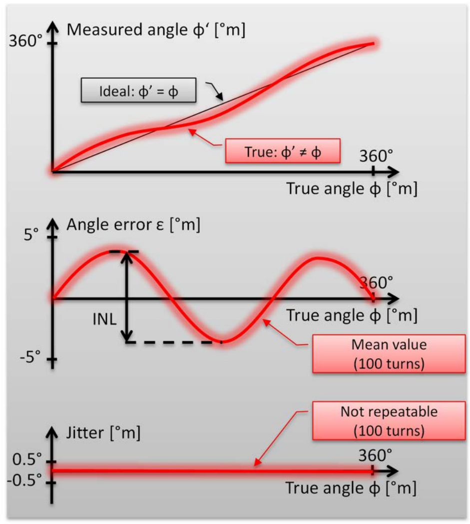
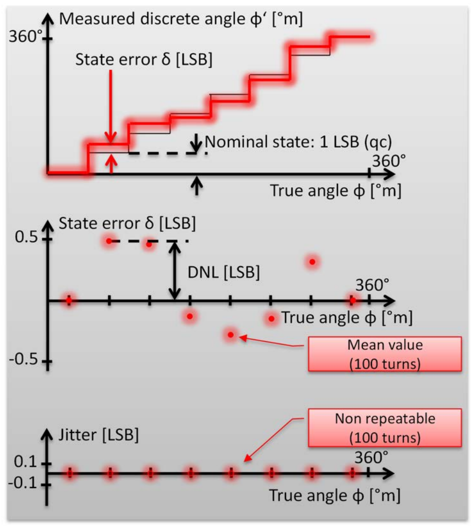
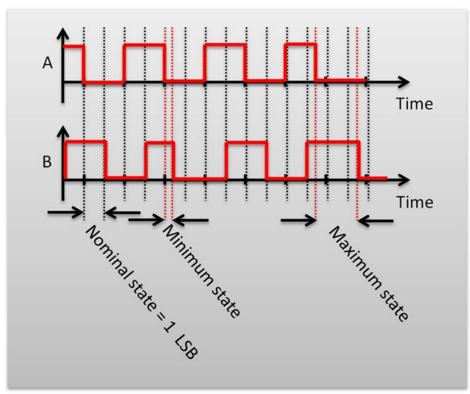


Figure 6 Resistances of the thermistor

2 DEFINITIONS

Metric	Definition	Illustration
Angle Error [°m]	Difference of measured and true angular shaft position at each position.	
Average Angle Error [°m]	Average of Angle Error at each position, over a given number of turns.	
Integral Nonlinearity (INL) [°m]	Peak-to-peak value of Average Angle Error.	
Jitter (Repeatability) [°m] or [LSB]	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.	
Least Significant Bit [LSB]	Minimum measurable difference between two angle values at given resolution (= quadcount, = State).	
State Error [LSB]	Difference between actual state length and average state length.	
Average State Error [LSB]	Average of State Error over a number of turns for each state of a turn.	
Differential Nonlinearity [DNL]	Maximum positive or negative Average State Error.	
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.	

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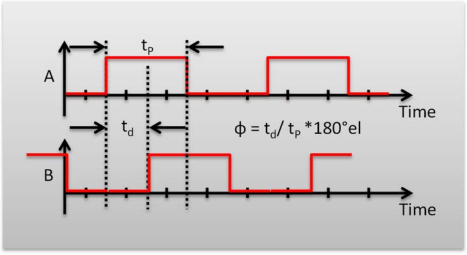
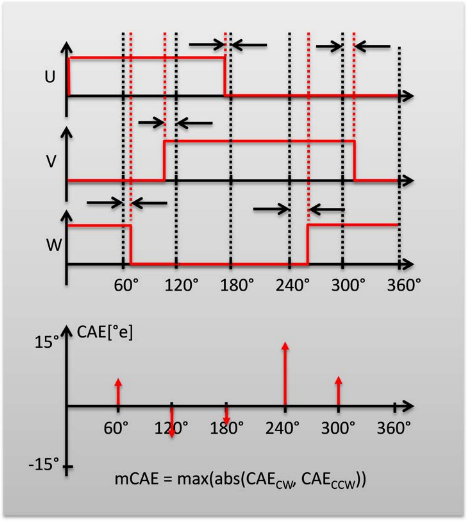
Metric	Definition	Illustration
Phase delay θ [°e]	Time difference of rising edge A to B relative to duration of positive level of A.	
Maximum commutation angle error (maxCAE) [°e]	Minimum positive or negative deviation of the individual switching points of the commutation signals (reference signals), determined over a certain number of turns.	

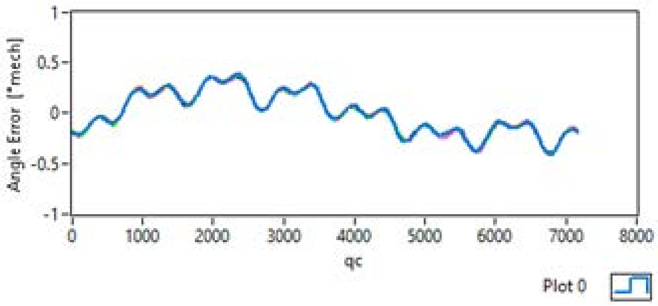
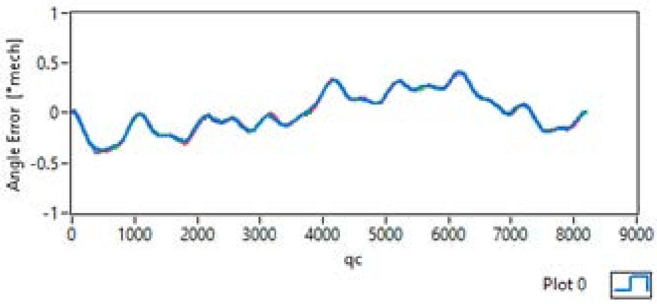
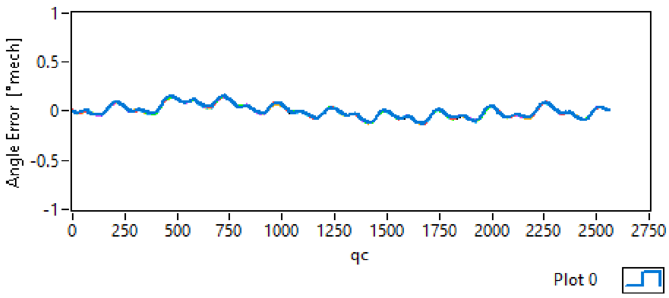
Table 1 Definitions

3 TYPICAL MEASUREMENT RESULTS

3.1 Angle error per turn

The average angle error [°m] and the repeatability (Jitter) [°m] are independent of the chosen resolution. The metrics given in LSB are resolution-dependent.

Below graphs show angle error measurements on a TSX MAG encoder configured in three different resolutions under the following conditions:
Measurement of 20 turns at V_{CC}=5 V, n=4000 rpm, T=25°C, rotor and stator supported on both ends subject to tolerances according to ➔separate document «EC frameless DT Installation Manual».

Target number of pole pairs	Resolution	Graph	Analysis	
7pp	(7*256) 1792	 	INL Jitter DNL Min State Max State	0.77°m 0.05°m = 0.99LSB 0.06 LSB 0.94 LSB 1.06 LSB
8pp	(8*256) 2048	 	INL Jitter DNL Min State Max State	0.79°m 0.04°m = 0.98LSB 0.07 LSB 0.93 LSB 1.06 LSB
10pp	(10*64) 640	 	INL Jitter DNL Min State Max State	0.28°m 0.03°m = 0.21LSB 0.035 LSB 0.97 LSB 1.04 LSB

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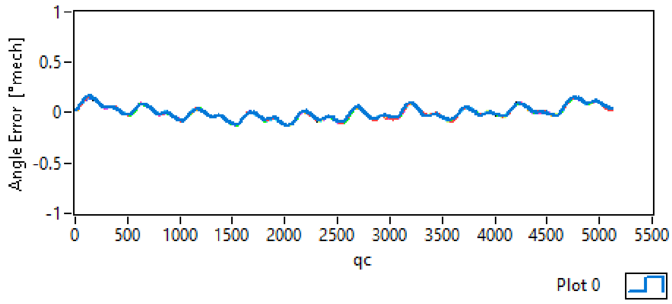
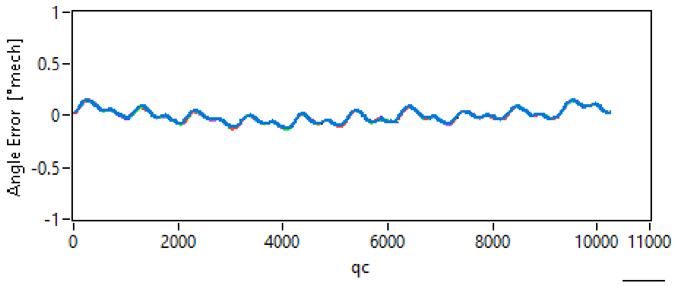
Target number of pole pairs	Resolution	Graph	Analysis	
10pp	(10*128) 1280		INL Jitter DNL Min State Max State	0.28°m 0.03°m = 0.45LSB 0.04 1LSB 0.97 LSB 1.04 LSB
10pp	(10*256) 2560		INL Jitter DNL Min State Max State	0.28°m 0.03°m = 0.87LSB 0.061 LSB 0.95 LSB 1.06 LSB

Table 2 Typical Measurement Results

3.2 Temperature dependence

Basically, INL, DNL, and Min State are temperature-independent.

Figure 7 shows the temperature dependence of ten different EC frameless DT50 with TSX MAG encoder under the following conditions:
V_{cc}=5 V, 4000 rpm, 2560 cpt, rotor and stator supported on both ends subject to tolerances according to ➔separate document «EC frameless DT Installation Manual».

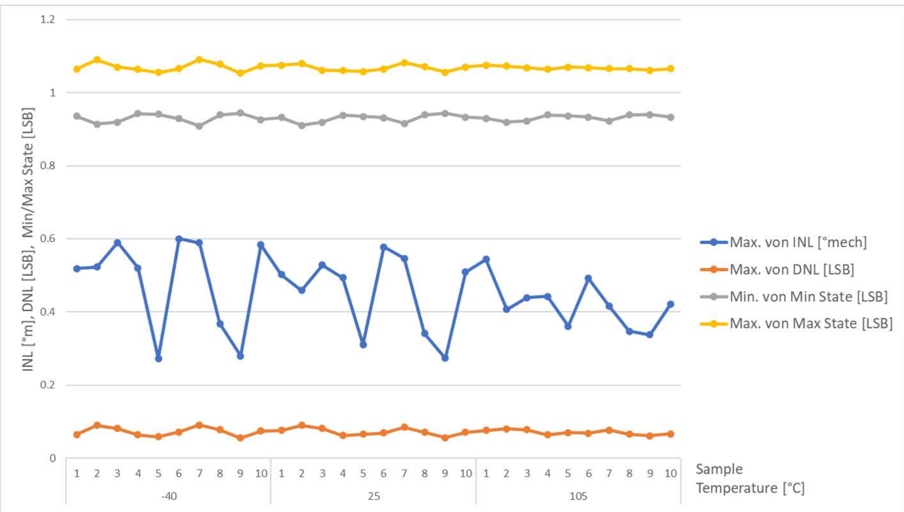


Figure 7 Temperature Dependence

3.3 Speed and resolution dependence

INL [°m] and DNL [LSB] show no speed or resolution dependence. Min/Max State have a slight resolution dependence. Jitter [LSB] is proportional to the number of impulses.

Figure 8 shows the speed and resolution dependence of an EC frameless DT50 with TSX MAG encoder under the following conditions:
V_{cc}=5 V, 3000…4000 rpm, 640/1280/2560 cpt, rotor and stator supported on both ends subject to tolerances according to ➔separate document «EC frameless DT Installation Manual».

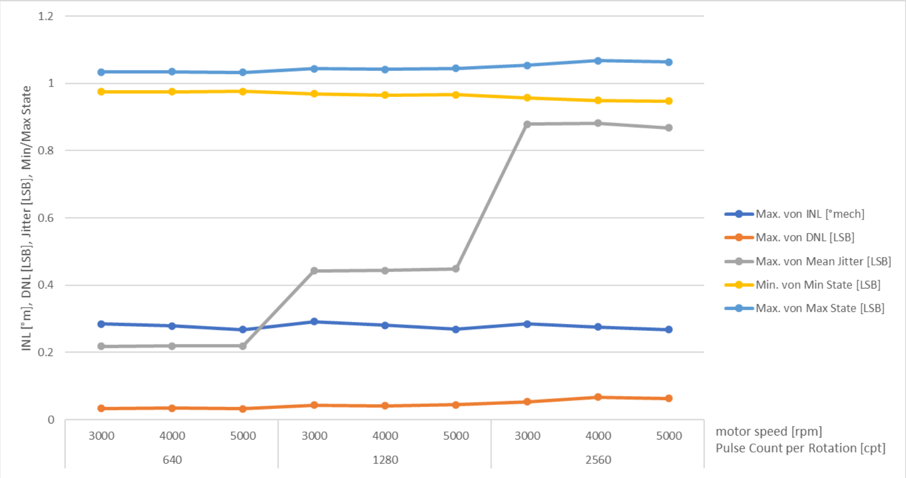


Figure 8 Speed and resolution dependence

3.4 Compliance to regulations

Parameter	Description
Electrostatic discharge immunity (DIN EN 61000-4-2)	Direct discharge on conductive surfaces – ±8 kV.
Vibration strength (DIN EN 60068-2-64)	Mounted encoder and stator – ≤3.45 g (sinusoidal, 10…1000 Hz; T_{amb} 25°C)
Mean Time To Failure (MTTF)	6'275'958 hrs (MIL-HDBK-217F, Ground Benign GB, 25°C, In accordance with circuit diagram and nominal power)
Compatibility UL	See conditions listed below

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 MAG 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. The voltage supply must guarantee that, even in case of defect of 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 the voltages and the encoder or such conductors must use UL-listed isolations.

4 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).*

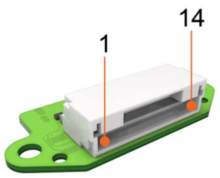


Figure 9 Encoder connector with radial cable outlet

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	internal signal	Channel I complement (1 index impulse per pole pair)
8	internal signal	Channel I (1 index impulse per pole pair)
9	H1	Hall sensor 1
10	H2	Hall sensor 2
11	H3	Hall sensor 3
12	—	not connected
13	NTC+	Connection thermistor +
14	NTC−	Connection thermistor −

Table 4 Pin assignment – Encoder connector with radial cable outlet

TSX MAG encoder connector with radial cable outlet		
Connector	JST (SM14B-NSHSS-TB)	
Suitable cable	TSX MAG 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; JST (NSHR-14V-S)
	Contacts	Crimp contact, 28-32 AWG; JST (SSHL-003T-P0.2)

Table 5 Encoder connector with radial cable outlet

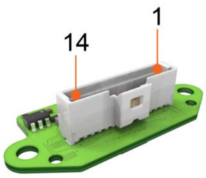


Figure 10 Encoder connector with axial cable outlet

Pin	Signal	Description
1	NTC−	Connection thermistor −
2	NTC+	Connection thermistor +
3	—	not connected
4	H3	Hall sensor 3
5	H2	Hall sensor 2
6	H1	Hall sensor 1
7	internal signal	Channel I (1 index impulse per pole pair)
8	internal signal	Channel I complement (1 index impulse per pole pair)
9	B	Channel B
10	B\	Channel B\ complement
11	A	Channel A
12	A\	Channel A\ complement
13	GND	Ground
14	Vcc	Power supply voltage

Table 6 Pin assignment – Encoder connector with axial cable outlet

TSX MAG encoder connector with axial cable outlet		
Connector	Molex Pico-Clasp (501331-1407)	
Suitable cable	TSX MAG 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

5 OUTPUT CIRCUITRY

The following figure shows the conceptual output schematics.

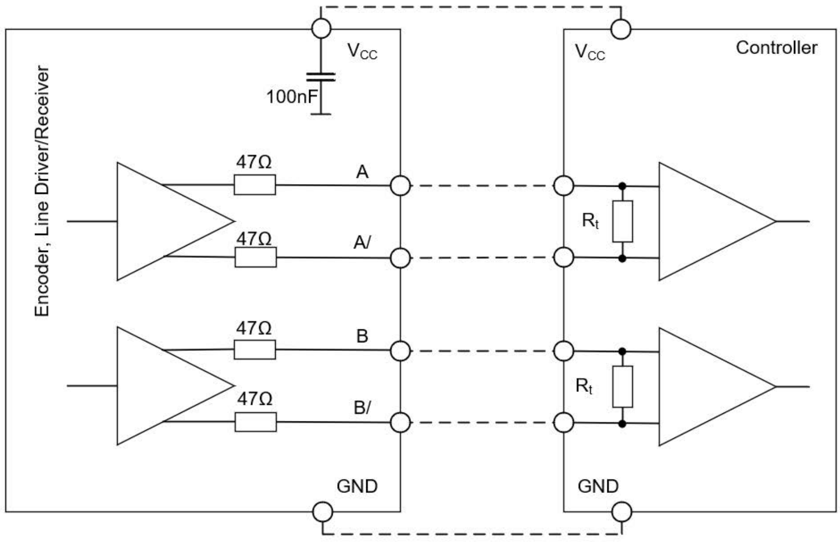


Figure 11 Output Circuitry incremental interface

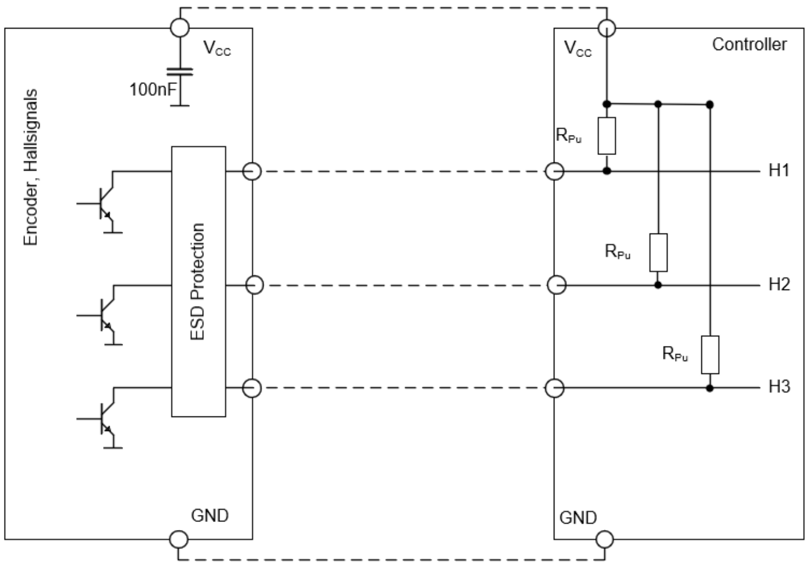


Figure 12 Output Circuitry commutation interface

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