

# iC-MU Series MAGNETIC OFF-AXIS POSITION ENCODERS



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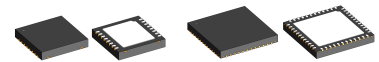
## FEATURES

- ◆ Integrated Hall sensors for two-track scanning
- ◆ Hall sensors optimized for 1.28 mm (iC-MU128), 1.50 mm (iC-MU150) or 2.00 mm (iC-MU200) pole width (master track)
- ◆ **iC-MU200 QFN48-7x7 AEC-Q100 qualified (Grade 1)**
- ◆ Signal conditioning for offset, amplitude, and phase
- ◆ Sine/digital real-time conversion with 12-bit resolution (14-bit filtered)
- ◆ 16, 32, or 64 pole pairs per measurement distance
- ◆ 2-track nonius absolute value calculation up to 18, 19 or 20 bits for 16, 32 or 64 master pole pairs
- ◆ Enlargement of measurement distance with second iC-MU Series
- ◆ Synchronization of external multiturm systems
- ◆ Configuration from an external EEPROM using a multimaster I2C interface
- ◆ Microcontroller-compatible serial interface (SPI, BiSS, SSI)
- ◆ Incremental quadrature signals with an index (ABZ)
- ◆ FlexCount®: scalable resolution from 1 up to 65536 CPR
- ◆ Commutation signals for motors from 1 up to 16 pole pairs (UVW)

## APPLICATIONS

- ◆ Rotative absolute encoders
- ◆ Linear absolute scales
- ◆ Singleturn and multiturm encoders
- ◆ Motor feedback encoders
- ◆ BLDC motor commutation
- ◆ Hollow shaft encoders
- ◆ Multi-axis measurement systems

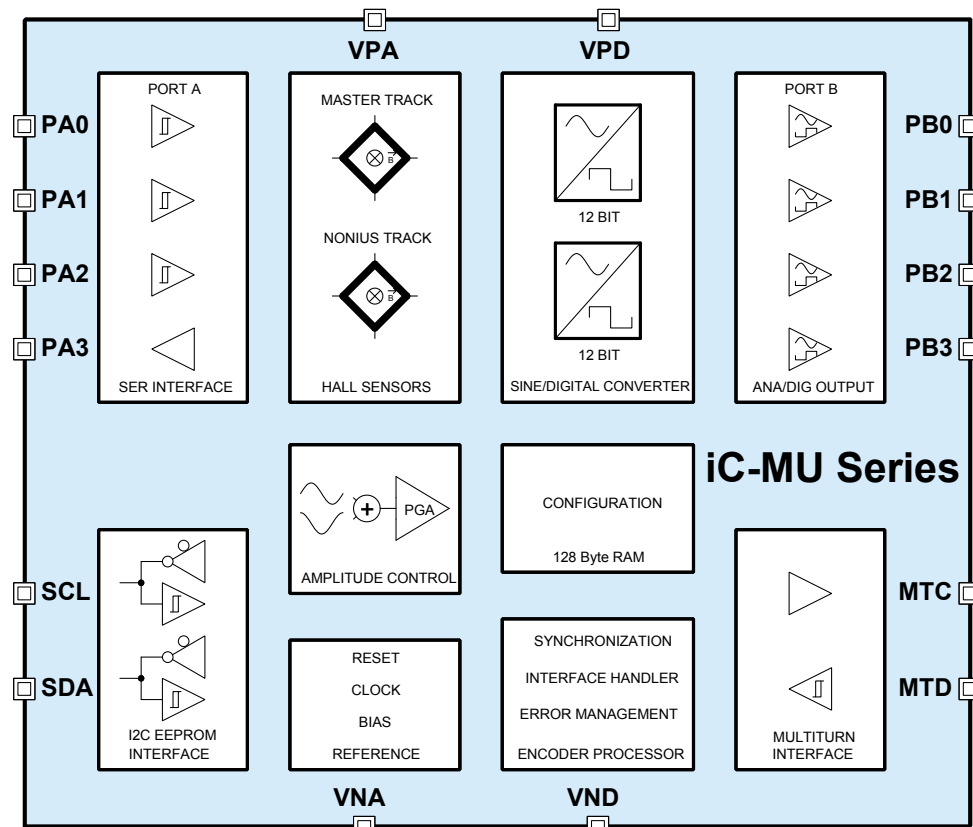
## PACKAGES



**DFN16**  
5 mm x 5 mm x 0.9 mm  
RoHS compliant

**QFN48**  
7 mm x 7 mm x 0.9 mm  
RoHS compliant

## BLOCK DIAGRAM



## DESCRIPTION

The iC-MU Series family includes the iC-MU128, iC-MU150, and iC-MU200 chips and is used for magnetic off-axis position scanning with integrated Hall sensors. By scanning two separate channels i.e. the master and Nonius track the device can log an absolute position within one mechanical revolution. The chip conditions the sensor signals and compensates for typical signal errors.

The internal 12-bit (14-bit filtered) sine/digital converters generate two position words that supply high-precision position data within one sine-period. The integrated Nonius calculation engine calculates the absolute position within one mechanical revolution and synchronizes this with the master track position word. Position data can be transmitted serially, incrementally, or analog through two ports in various modes of operation. Commutation signals for brushless DC (BLDC) motors with up to 16 pole pairs are derived from the absolute position and supplied through a 3-pin interface.

During startup the device loads a CRC-protected configuration from an external EEPROM.

After the device has been reset an optional external multiturn is read in and synchronized with the inter-

nal position data. During operation the position is cyclically checked.

**Note:** Parameters defined in the datasheet represent supplier's attentive tests and validations, but - by principle - do not imply any warranty or guarantee as to their accuracy, completeness or correctness under all application conditions. In particular, setup conditions, register settings and power-up have to be thoroughly validated by the user within his specific application environment and requirements (system responsibility).

The performance of iC-MU Series in application is impacted by system conditions like quality of the magnetic target and its adjustment, field strength and stray fields, temperature and mechanical stress and initial calibration.

iC-MU Series is realized in two alternative leadless plastic packages DFN16-5x5 and QFN48-7x7 (iC-MU200 is only available in QFN48-7x7). The DFN package occupies less board space and picks up less package stress on board. The larger QFN package shows slightly lower Rth suited for increased operation temperature and sets higher demands for system conditions.



This datasheet is valid for iC-MU128, iC-MU150 and iC-MU200 hardware revision X1 or newer. For earlier chip hardware revisions please refer to the corresponding prior datasheet for the specific chip.

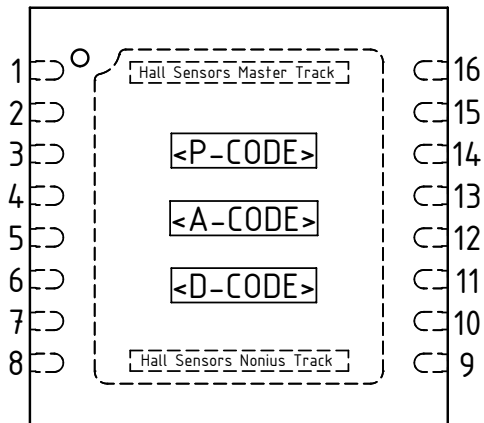
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## PACKAGING INFORMATION

### PIN CONFIGURATION DFN16-5x5 (topview)



### PIN FUNCTIONS

#### No. Name Function

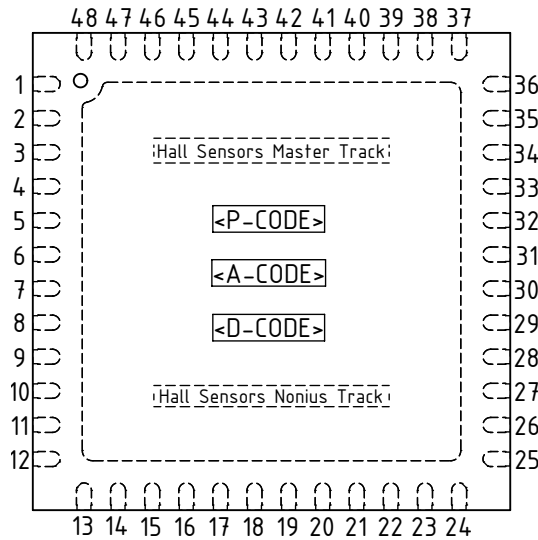
1	SCL	EEPROM interface, clock
2	SDA	EEPROM interface, data
3	VPA	+4.5V...+5.5V analog supply voltage
4	VNA <sup>1)</sup>	Analog Ground
5	PB0	Port B, Pin 0: Digital I/O, analog output
6	PB1	Port B, Pin 1: Digital I/O, analog output
7	PB2	Port B, Pin 2: Digital I/O, analog output
8	PB3	Port B, Pin 3: Digital I/O, analog output
9	PA3	Port A, Pin 3: Digital I/O
10	PA2	Port A, Pin 2: Digital I/O
11	PA1	Port A, Pin 1: Digital I/O
12	PA0	Port A, Pin 0: Digital I/O
13	VND <sup>1)</sup>	Digital ground
14	VPD	+4.5V...+5.5V digital supply voltage
15	MTD	Multiturn interface, data input
16	MTC	Multiturn interface, clock output
	BP <sup>2)</sup>	Backside Pad

IC top marking: <P-CODE> = product code, <A-CODE> = assembly code (subject to changes), <D-CODE> = date code (subject to changes)  
Only the Pin 1 mark on the front or reverse is determinative for package orientation (<P-CODE>, <A-CODE>, <D-CODE> are subject to change).  
Pin 1 mark on backside pad may differ from drawing.

1) Analog (VNA) and digital grounds (VND) have to be connected low ohmic on the PCB

2) The backside pad on the underside of the package should be appropriately connected to VNA/VND for better heat dissipation (ground plane)

## PIN CONFIGURATION QFN48-7x7 (topview)



## PIN FUNCTIONS

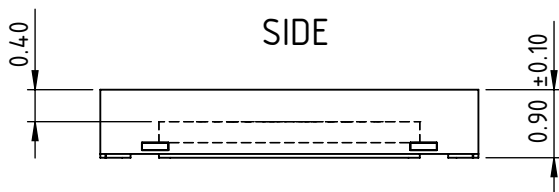
No.	Name	Function
1-2	n.c.	not connected
3	SCL	EEPROM interface, clock
4	SDA	EEPROM interface, data
5	VPA	+4.5 V... +5.5 V analog supply voltage
6	VNA <sup>1)</sup>	Analog Ground
7	PB0	Port B, Pin 0: Digital I/O, analog output
8	PB1	Port B, Pin 1: Digital I/O, analog output
9	PB2	Port B, Pin 2: Digital I/O, analog output
10	PB3	Port B, Pin 3: Digital I/O, analog output
11-26	n.c.	not connected
27	PA3	Port A, Pin 3: Digital I/O
28	PA2	Port A, Pin 2: Digital I/O
29	PA1	Port A, Pin 1: Digital I/O
30	PA0	Port A, Pin 0: Digital I/O
31	VND <sup>1)</sup>	Digital ground
32	VPD	+4.5 V... +5.5 V digital supply voltage
33	MTD	Multiturn interface, data input
34	MTC	Multiturn interface, clock output
35-48	n.c.	not connected
	BP <sup>2)</sup>	Backside Pad

IC top marking: <P-CODE> = product code, <A-CODE> = assembly code (subject to changes), <D-CODE> = date code (subject to changes)  
 Only the Pin 1 mark on the front or reverse is determinative for package orientation (<P-CODE>, <A-CODE>, <D-CODE> are subject to change)  
 Pin 1 mark on backside pad may differ from drawing.  
 Please also see Design Review item No. 4

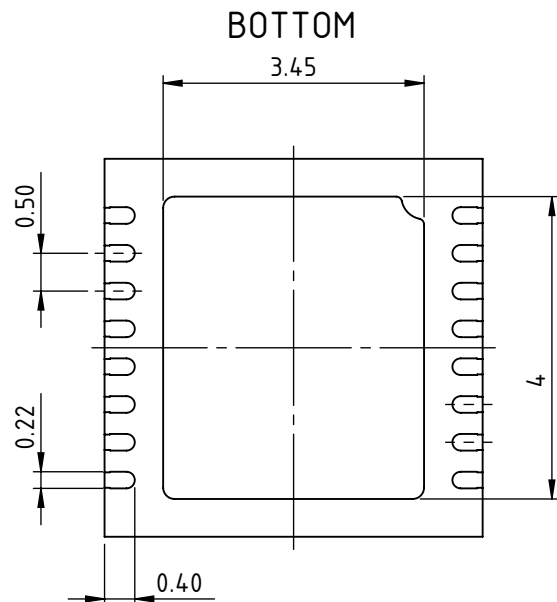
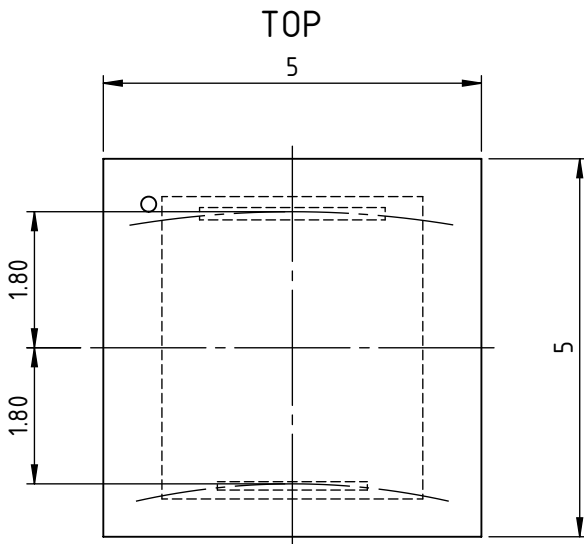
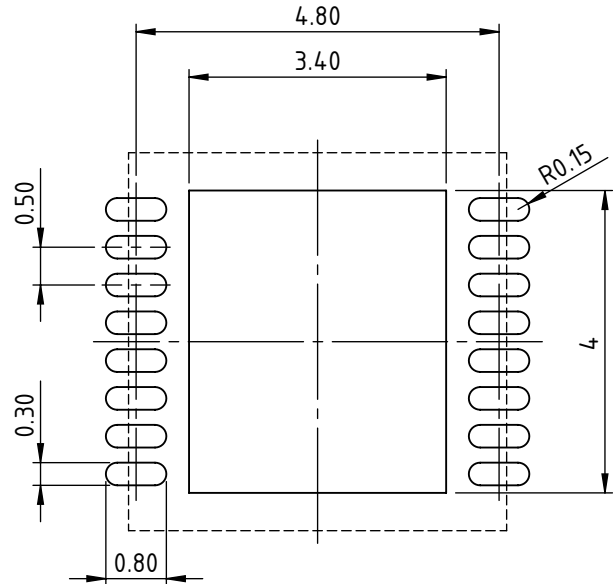
1) Analog (VNA) and digital grounds (VND) have to be connected low ohmic on the PCB

2) The backside pad on the underside of the package should be appropriately connected to VNA/VND for better heat dissipation (ground plane)

**PACKAGE DIMENSIONS DFN16-5x5**



**RECOMMENDED PCB-FOOTPRINT**

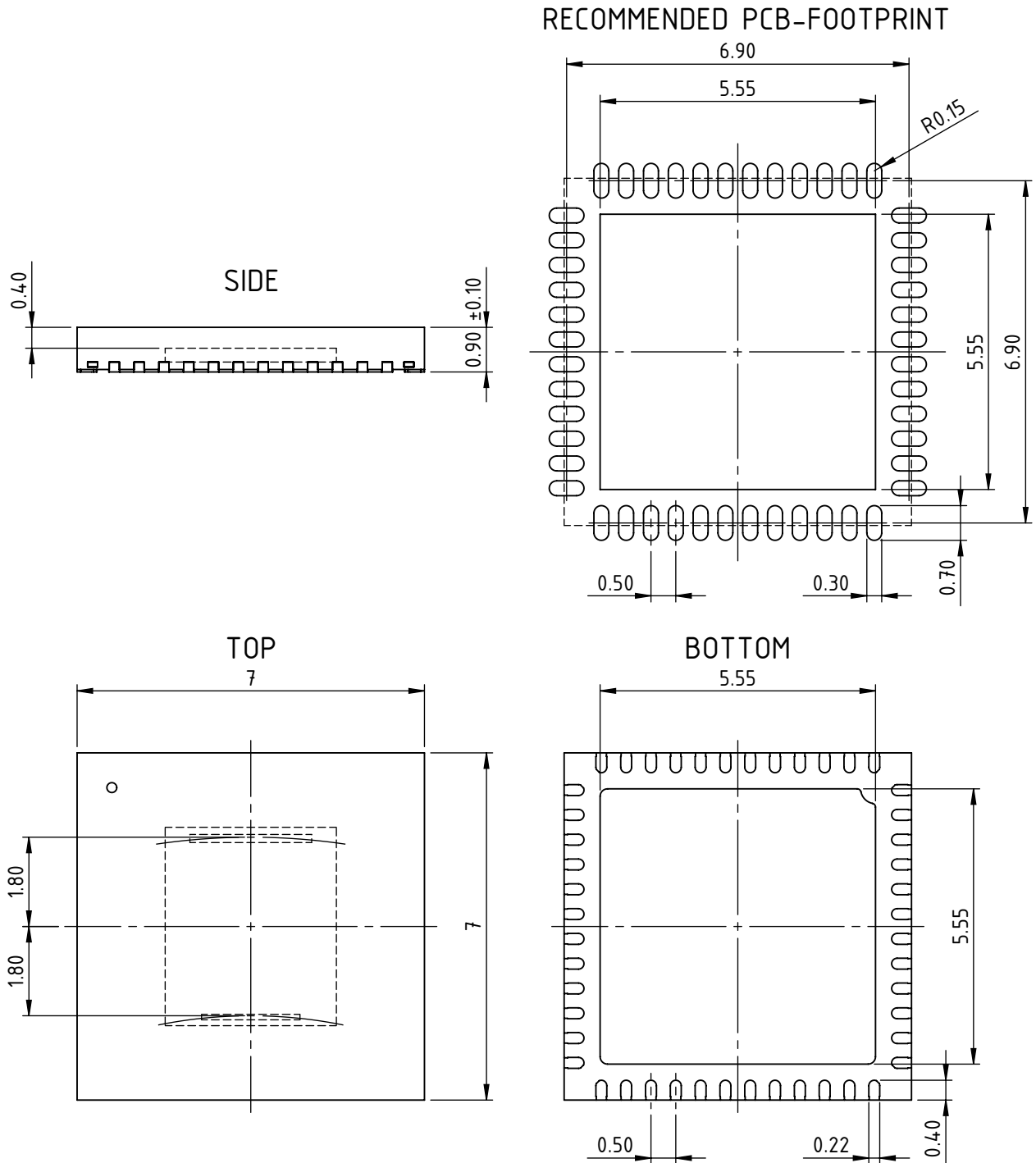


All dimensions given in mm. Tolerances of form and position according to JEDEC MO-229.  
Positional tolerance of sensor pattern:  $\pm 0.10\text{mm}$  /  $\pm 1^\circ$  (with respect to center of backside pad).

drb\_dfn16-5x5-2\_mu\_1\_pack\_1, 10:1

Pin 1 mark on backside pad may differ from drawing.

**PACKAGE DIMENSIONS QFN48-7x7, iC-MU128, iC-MU150**



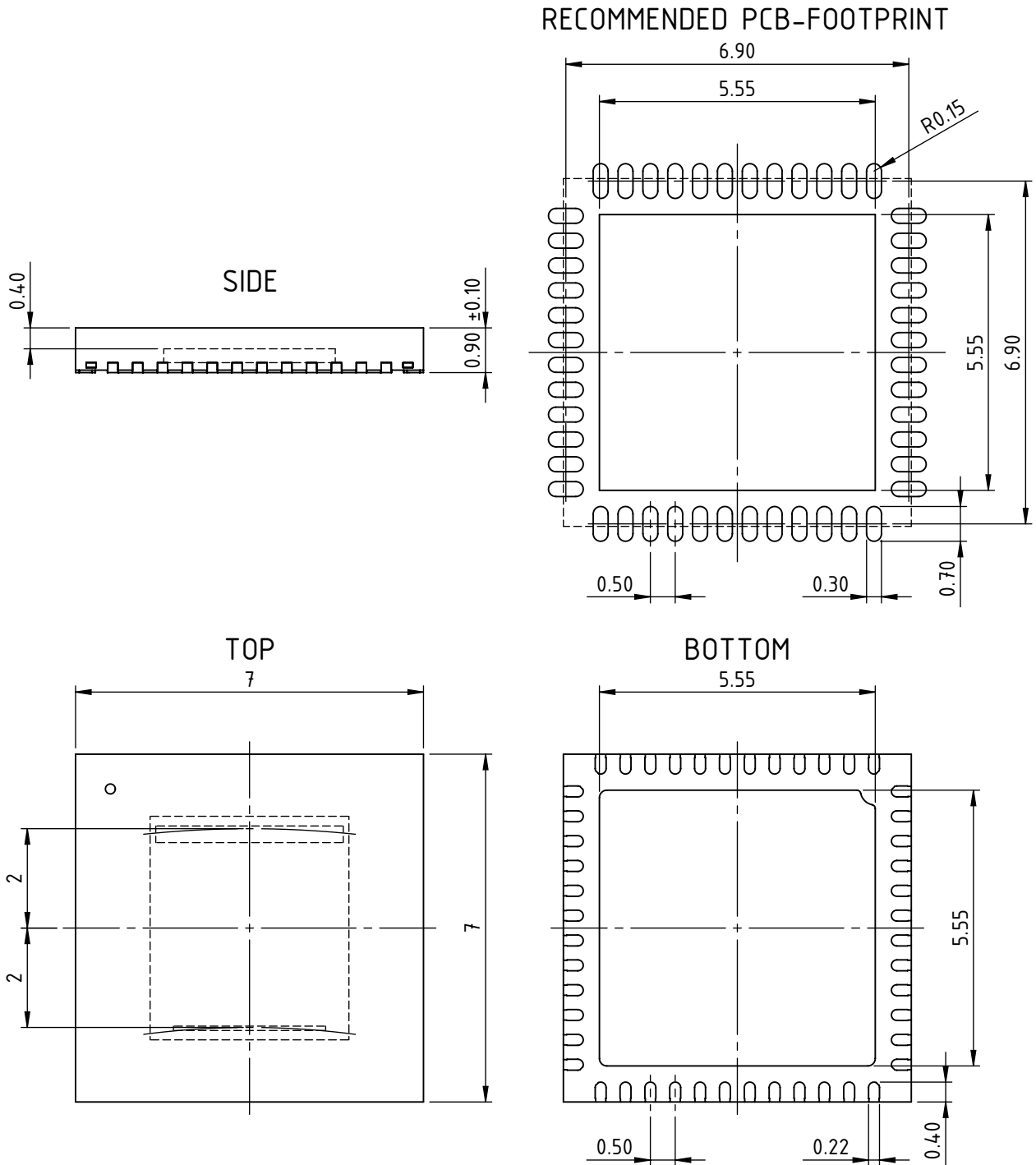
All dimensions given in mm. Tolerances of form and position according to JEDEC MO-220.  
Positional tolerance of sensor pattern:  $\pm 0.10\text{mm}$  /  $\pm 1^\circ$  (with respect to center of backside pad).

drb\_qfn48-7x7-2\_mu\_y2\_pack\_1, 8:1

Please also see Design Review item No. 4.

Pin 1 mark on backside pad may differ from drawing.

**PACKAGE DIMENSIONS QFN48-7x7, iC-MU200**



All dimensions given in mm. Tolerances of form and position according to JEDEC MO-220.  
Positional tolerance of sensor pattern:  $\pm 0.10\text{mm}$  /  $\pm 1^\circ$  (with respect to center of backside pad).

dra\_qfn48-7x7-2\_mu200\_0\_pack\_1, 8:1

Please also see Design Review item No. 4.

Pin 1 mark on backside pad may differ from drawing.

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## ABSOLUTE MAXIMUM RATINGS

Maximum ratings do not constitute permissible operating conditions; functionality is not guaranteed. Exceeding the maximum ratings can damage the device

Item No.	Symbol	Parameter	Conditions	Limits		Unit
				Min.	Max.	
G001	V()	Voltage at VPA, VPD		-0.3	6	V
G002	I()	Current in VPA		-10	20	mA
G003	I()	Current in VPD		-10	100	mA
G004	V()	Voltage at all pins except VPD		-0.3	VPD+0.3	V
G005	I()	Current in all I/O pins	DC current Pulse width < 10 µs	-10 -100	10 100	mA mA
G006	Vd()	ESD Susceptibility at all pins	HBM, 100 pF discharged through 1.5 kΩ		2	kV
G007	Ptot	Permissible Power Dissipation			400	mW
G008	Tj	Chip-Temperature		-40	150	°C
G009	Ts	Storage Temperature Range		-40	150	°C

## THERMAL DATA

Operating conditions: VPA = VPD = 5V ±10%

Item No.	Symbol	Parameter	Conditions	Limits			Unit
				Min.	Typ.	Max.	
T01	Ta*	Operating Ambient Temperature Range	DFN16-5x5 - iC-MU128, iC-MU150	-40		110	°C
			QFN48-7x7 - iC-MU128, iC-MU150	-40		115	°C
			QFN48-7x7 - iC-MU200	-40		125	°C
T02	Rthja	Thermal Resistance Chip to Ambient DFN16	DFN16-5x5 on PCB according to JESD51		40		K/W
T03	Rthja	Thermal Resistance Chip to Ambient QFN48	QFN48-7x7 on PCB according to JESD51		30		K/W

\*) Please also see Design Review item No. 4.

# iC-MU Series MAGNETIC OFF-AXIS POSITION ENCODERS



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## ELECTRICAL CHARACTERISTICS

Operating conditions: VPD = VPA = 5 V ±10%, iC-MU128 and iC-MU150: Tj = -40... 125°C, iC-MU200: Tj = -40... 140°C<sup>1</sup>, IBP calibrated to 200 µA, reference is VNA = VND, unless otherwise stated

Item No.	Symbol	Parameter	Conditions	Min. Typ. Max.			Unit
				Min.	Typ.	Max.	
<b>Total Device</b>							
101	V(VPA, VPD)	Permissible Supply Voltage	VPA = VPD	4.5	5	5.5	V
103	I(VPA)	Analog Supply Current in VPA		8	13	16	mA
104	I(VPD)	Digital Supply Current in VPD		12	22	45	mA
105	Vc()hi	Clamp Voltage hi at all pins	Vc()hi = V() - V(VPD), I() = +1 mA Pins SDA, SCL, PA0, MTD all other pins	0.3 0.3		1.8 1.6	V V
106	Vc()lo	Clamp Voltage lo at all pins	I() = -1 mA	-1.6		-0.3	V
107	ton()	Power-Up Time	VPD > 4 V, EEPROM Data valid after first I <sup>2</sup> C read in		20		ms
108	ΔV/Δt	Power-Up Slew Rate at VPA = VPD	V() = 3.0 V → 4.5 V	50			V/s
109	CVPA, CVPD	Required Backup Capacitors at VPA, VPD	placed near by pin, recommended low ESR		100		nF
<b>Hall Sensors</b>							
201	Hext	Operating Magnetic Field Strength	at surface of chip	15		100	kA/m
202	f()	Operating Magnetic Field Frequency				7	kHz
203	rpm	Permissible rotation of pole wheel with FRQ_CNV=lo	16 pole pairs 32 pole pairs 64 pole pairs (note: for incremental part see table 78)			24000 12000 6000	rpm rpm rpm
204	vmax	Permissible movement speed	MU128 MU150, MU200			17 20	m/s m/s
205	hpac	Sensor-to-Package-Surface Distance			400		µm
<b>Assembly Tolerances</b>							
301	TOLrad	Permissible Radial Displacement				0.5	mm
302	TOLtan	Permissible Tangential Displacement				0.5	mm
303	WOBrad	Permissible Eccentricity of Code Disc	MPC = 0x4 MPC = 0x5, 0x6			0.06 0.1	mm mm
<b>Bias Current Source, Reference Voltage, Power On Reset, Clock Oscillator</b>							
401	Vbg	Bandgap Voltage	TEST = 0x1F	1.18	1.24	1.36	V
402	Vref	Reference Voltage	TEST = 0x1F	45	50	55	%VPA
403	IBM	Reference Current	CIBM = 0x0 CIBM = 0xF IBM calibrated	-370 -220	-200	-100 -180	µA µA µA
404	VPDon	Turn-on Threshold VPD (power on release)	increasing voltage at V(VPD)	3.65	3.9	4.3	V
405	VPDoff	Turn-off Threshold VPD (power down reset)	decreasing voltage at V(VPD)	3	3.5	3.8	V
406	VPDhys	Hysteresis	VPDhys = VPDon - VPDoff	0.3			V
407	fosc	Clock Frequency	TEST=0x26, fosc = 64*f(HCLK), IBM aligned	22	26	32	MHz
408	tchk	Max. Time For Internal Cyclic Checks	NCHK_NON = 0x0, CHK_MT = 0x1, NCHK_CRC = 0x0, MODE_MT = 0xF (18 bit), SBL_MT = 0x3 (4 bit), ESSI_MT = 0x1 (Error bit)			6	ms
<b>Signal Conditioning Master and Nonius Track (x = M, N)</b>							
501	GC	Adjustable Gain Range	GC_x = 0x0 GC_x = 0x1 GC_x = 0x2 GC_x = 0x3		4.4 7.7 12.4 20.6		

<sup>1</sup> reliability figures according to FIT and Mission Profile

## ELECTRICAL CHARACTERISTICS

Operating conditions: VPD = VPA = 5 V ±10%, iC-MU128 and iC-MU150: Tj = -40...125°C, iC-MU200: Tj = -40...140°C<sup>1</sup>, IBP calibrated to 200 µA, reference is VNA = VND, unless otherwise stated

Item No.	Symbol	Parameter	Conditions				Unit
				Min.	Typ.	Max.	
502	GF	Adjustable Fine Gain Range	GF_x = 0x00 GF_x = 0x20 GF_x = 0x3F		1 4.4 19		
503	GX	Adjustable Gain(SIN)/Gain(COS)	GX_x = 0x00 GX_x = 0x3F GX_x = 0x7F	9	0 10 -9	-8.5	% % %
504	VOS	Adjustable Offset Calibration	VOS_x = 0x3F VOS_x = 0x7F	60	70 -70	-60	mV mV
505	PHM	Adjustable Phase Calibration Master Track	PH_M = 0x3F, PHR_M = 0 for MU128 PH_M = 0x7F, PHR_M = 0 for MU128 PH_M = 0x3F, PHR_M = 1 for MU128 PH_M = 0x7F, PHR_M = 1 for MU128 PH_M = 0x3F, PHR_M = 0 for MU150, MU200 PH_M = 0x7F, PHR_M = 0 for MU150, MU200 PH_M = 0x3F, PHR_M = 1 for MU150, MU200 PH_M = 0x7F, PHR_M = 1 for MU150, MU200	6 12 8 15.5	7 -7 14 -14 10 -10 18 -18	-6 -12 -8 -15.5	° ° ° ° ° ° ° °
506	PHN	Adjustable Phase Calibration Nonius Track	PH_N = 0x3F, PHR_N = 0 PH_N = 0x7F, PHR_N = 0 PH_N = 0x3F, PHR_N = 1 PH_N = 0x7F, PHR_N = 1	11.25 20.5	13 -13 23 -23	-11.25 -20.5	° ° ° °
507	Vampl	Signal Level Controller	chip internally, Vampl = Vpp(PSINx)+Vpp(NSINx), ENAC = 1	3.2	4	4.8	Vpp
508	Vae()lo	Signal Monitoring Threshold lo	Vae()lo = Vpp(PSINx)+Vpp(NSINx)	1.2		2.8	Vpp
509	Vae()hi	Signal Monitoring Threshold hi	Vae()hi = Vpp(PSINx)+VPP(NSINx)	4.9		7.0	Vpp
510	t()ana	Latency of analog signal path			11		µs
<b>Sine-To-Digital Conversion</b>							
601	AAabs	Absolute Angular Accuracy	ideal input signals, reference to 12 Bit of sine period			2	LSB
602	AArel	Relative Angular Accuracy	FILT = 0x2 FILT = 0x6 ideal input signals, reference to 12 Bit of sine period, f = 1 KHz			2 1/4	LSB LSB
<b>Nonius Calculation</b>							
701	Pnon	Permissible Track deviation Master vs. Nonius	16 periods, MPC = 0x4 32 periods, MPC = 0x5 64 periods, MPC = 0x6 referenced to 360° of Master sine period			10 5 2.5	DEG DEG DEG
<b>Digital Output Port PA1..3, MTC, SCL, SDA</b>							
801	Vs()hi	Saturation Voltage hi Pins PA1..3, MTC	Vs()hi = V(VPD) - V(), I() = -4 mA			0.4	V
802	Vs()lo	Saturation Voltage lo	I() = 4 mA versus VND			0.4	V
803	Isc()hi	Short-Circuit Current hi Pins PA1..3, MTC	V() = V(VND), 25 °C	-90	-50		mA
804	Isc()lo	Short-Circuit Current lo	V() = V(VPD), 25 °C		50	90	mA
805	tr()	Rise Time	CL = 50 pF			60	ns
806	tf()	Fall Time	CL = 50 pF			60	ns
807	Iik(PA3)	Leakage Current at PA3	MODEA=0, PA0 = hi	-5		5	µA
808	fclk(SCL)	Frequency at SCL	normal mode during start-up		80 70		kHz kHz
<b>Digital Input Port PA0..2, MTD, SCL, SDA</b>							
901	Vt()hi	Threshold Voltage hi				2	V
902	Vt()lo	Threshold Voltage lo		0.8			V
903	Vt()hys	Hysteresis	Vt()hys = Vt()hi - Vt()lo	150			mV
904	Ipu()	Pull-Up Current Pins PA0..2, MTD	V() = 0 V ... V(VPD)-1 V	-60	-30	-6	µA
905	Ipu()	Pull-Up Current Pins SCL, SDA	V() = 0 V ... V(VPD)-1 V	-800	-300	-80	µA

<sup>1</sup> reliability figures according to FIT and Mission Profile

# iC-MU Series MAGNETIC OFF-AXIS POSITION ENCODERS



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## ELECTRICAL CHARACTERISTICS

Operating conditions: VPD = VPA = 5 V ±10%, iC-MU128 and iC-MU150: Tj = -40...125°C, iC-MU200: Tj = -40...140°C<sup>1</sup>, IBP calibrated to 200 µA, reference is VNA = VND, unless otherwise stated

Item No.	Symbol	Parameter	Conditions				Unit
				Min.	Typ.	Max.	
906	f()	Permissible Input Frequency				10	MHz
<b>Analog/Digital Output Port PB0..2</b>							
A01	I() <sub>buf</sub>	Analog Driver Current		-1		1	mA
A02	fg() <sub>ana</sub>	Analog Bandwidth			100		kHz
A03	Isc() <sub>hi,ana</sub>	Analog Short-Circuit Current hi	V() = V(VND)			-1.4	mA
A04	Isc() <sub>lo,ana</sub>	Analog Short-Circuit Current lo	V() = V(VPD)	1.5			mA
A05	Rout() <sub>ana</sub>	Output Resistor, Analog Mode	I() = 1 mA			500	Ω
A06	Vs() <sub>hi,dig</sub>	Digital Saturation Voltage hi	Vs() = V(VPD) - V(), I() = -4 mA			0.5	V
A07	Vs() <sub>lo,dig</sub>	Digital Saturation Voltage lo	I() = 4 mA			0.5	V
A08	Isc() <sub>hi,dig</sub>	Short-Circuit Current hi	V() = V(VPD)	-60	-35		mA
A09	Isc() <sub>lo,dig</sub>	Short-Circuit Current lo	V() = V(VND)		45	70	mA
A10	tr()	Rise Time	CL = 50 pF			50	ns
A11	tf()	Fall Time	CL = 50 pF			50	ns
A12	I <sub>lk</sub> ()	Leakage Current	MODEB = 0x7	-5		5	µA
<b>Analog/Digital Output Port PB3</b>							
B01	I() <sub>buf</sub>	Analog Driver Current		-1		1	mA
B02	fg() <sub>ana</sub>	Analog Bandwidth			100		kHz
B03	Isc() <sub>hi,ana</sub>	Analog Short-Circuit Current hi	V() = V(VND)			-1.5	mA
B04	Isc() <sub>lo,ana</sub>	Analog Short-Circuit Current lo	V() = V(VPD)	1.5			mA
B05	Rout() <sub>ana</sub>	Output Resistor, Analog Mode	I() = 1 mA			500	Ω
B06	Vs() <sub>lo,dig</sub>	Digital Saturation Voltage lo	I() = 4 mA			0.5	V
B07	Isc() <sub>lo,dig</sub>	Short-Circuit Current lo	V() = V(VND)		45	70	mA
B08	tr()	Rise Time	CL = 50 pF			50	ns
B09	tf()	Fall Time	CL = 50 pF			50	ns
B10	I <sub>pu</sub> (PB3)	Pull-Up Current	V() = 0 V...V(VPD) - 1 V, MODEB = 0x0..0x3	-60	-30	-6	µA
B11	I <sub>lk</sub> ()	Leakage Current	MODEB = 0x7	-5		5	µA

<sup>1</sup> reliability figures according to FIT and Mission Profile

## OPERATING REQUIREMENTS: Multiturn Interface, I2C Interface

Item No.	Symbol	Parameter	Conditions	Min.   Max.		Unit
				Min.	Max.	
<b>Multiturn Interface (Figure 1)</b>						
I001	$t_{MTC}$	Clock Period		6.4		$\mu\text{s}$
I002	$t_{sMD}$	Setup Time: Data valid before MTC hi $\rightarrow$ lo		50		ns
I003	$t_{hMD}$	Hold Time: Data stable after MTC hi $\rightarrow$ lo		50		ns
I004	$t_{tos}$	Timeout		20		$\mu\text{s}$
I005	$t_{cycle}$	Cycle Time	CHK_MT=1	1	5	ms
<b>EEPROM and I2C Interface</b>						
I006	$t_{s(SDA)}$	Setup Delay SDA to Rising Edge SDA		700		ns

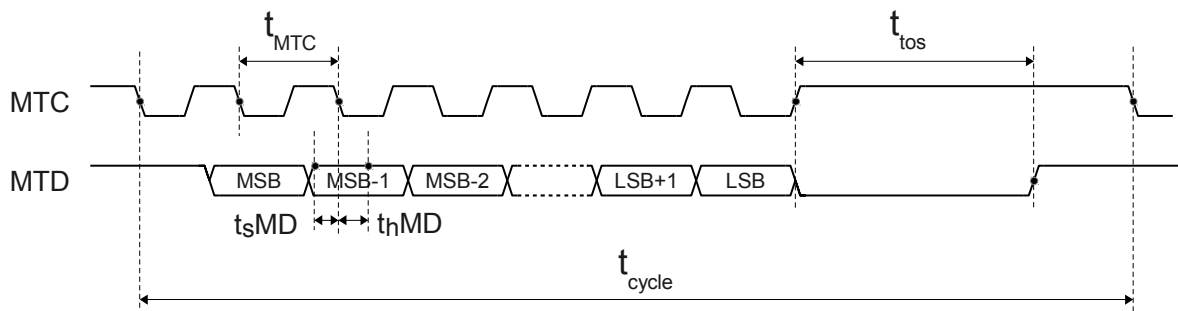


Figure 1: Timing multiturn interface, MODE\_MT  $\neq$  0

**OPERATING REQUIREMENTS: I/O Interface**

Item No.	Symbol	Parameter	Conditions	Min.   Max.		Unit
				Min.	Max.	
<b>SPI-Interface (Figure 2)</b>						
I101	$t_{C1}$	Permissible Clock Period	see Elec. Char. No.: 906	1/f()		ns
I102	$t_{W1}$	Wait Time: between NCS lo $\rightarrow$ hi and NCS hi $\rightarrow$ lo		500		ns
I103	$t_{S1}$	Setup Time: NCS lo before SCLK lo $\rightarrow$ hi		50		ns
I104	$t_{P1}$	Propagation Delay: MISO stable after NCS hi $\rightarrow$ lo			50	ns
I105	$t_{P2}$	Propagation Delay: MISO high impedance after NCS lo $\rightarrow$ hi	MODEA = 0x00	30		ns
I106	$t_{H1}$	Hold Time: NCS lo after SCLK lo $\rightarrow$ hi	valid for SPI mode 3	30		ns
I107	$t_{H3}$	Hold Time: NCS lo after SCLK hi $\rightarrow$ lo	valid for SPI mode 0	50		ns
I108	$t_{S2}$	Setup Time: MOSI stable before SCLK lo $\rightarrow$ hi		30		ns
I109	$t_{H2}$	Hold Time: MOSI stable after SCLK lo $\rightarrow$ hi		30		ns
I110	$t_{P3}$	Propagation Delay: MISO stable after MOSI change	mode: repeating MOSI on MISO		50	ns
I111	$t_{P4}$	Propagation Delay: MISO stable after SCLK hi $\rightarrow$ lo	mode: sending data MISO	30		ns
I112	$t_{W2}$	Wait Time: SCLK stable after NCS lo $\rightarrow$ hi		500		ns
I113	$t_{L1}$	Clock Signal lo Level Duration		25		ns
I114	$t_{L2}$	Clock Signal hi Level Duration		25		ns
<b>BiSS-Interface (Figure 3, Figure 4)</b>						
I115	$t_{out}$	Slave Timeout	NTOA = 0, adaptive, typ. $t_{init}$	1.5 $\cdot$ $t_{MAS}$	1.5 $\cdot$ $t_{MAS} +$ 8/f <sub>osc</sub>	ns
			NTOA = 1, fixed	16000	24000	ns
I116	$t_{MAS}$	Permissible Clock Period	NTOA = 0, adaptive, typ. $t_{init}$	100		ns
			NTOA = 1, fixed	100		ns
I117	$t_{MASH}$	Clock Signal Hi Level Duration	NTOA = 0, adaptive, typ. $t_{init}$	50	$t_{out}$	ns
			NTOA = 1, fixed	50	$t_{out}$	ns
I118	$t_{MASI}$	Clock Signal Lo Level Duration	NTOA = 0, adaptive, typ. $t_{init}$	50		ns
			NTOA = 1, fixed	50		ns
I119	$t_{P3}$	Propagation Delay		30		ns
<b>SSI-Interface (Figure 5), (Figure 6)</b>						
I120	$t_{out}$	Timeout	NTOA = 1	16000	24000	ns
			NTOA = 0, adaptive, (not recommended)	1.5 $\cdot$ $t_{MAS}$	1.5 $\cdot$ $t_{MAS} +$ 8/f <sub>osc</sub>	ns
I121	$t_{MAS}$	Permissible Clock Period		250		ns
I122	$t_{MASH}$	Clock Signal Hi Level Duration		125	$t_{out}$	ns
I123	$t_{MASI}$	Clock Signal Lo Level Duration		125		ns
I124	$t_{P3}$	Propagation Delay		30		ns

## Timing SPI

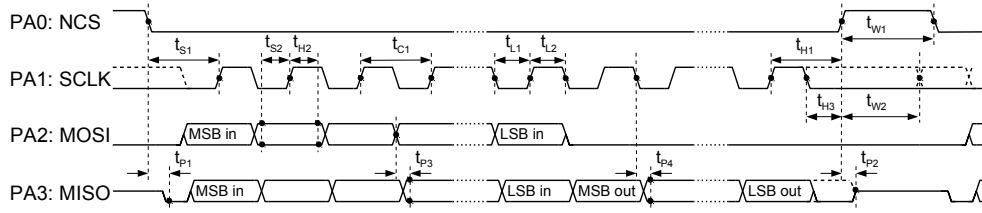


Figure 2: Timing SPI interface

## Timing BiSS

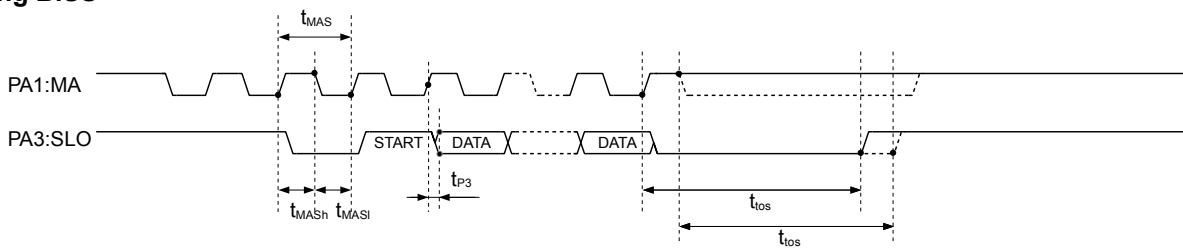


Figure 3: Timing BiSS interface

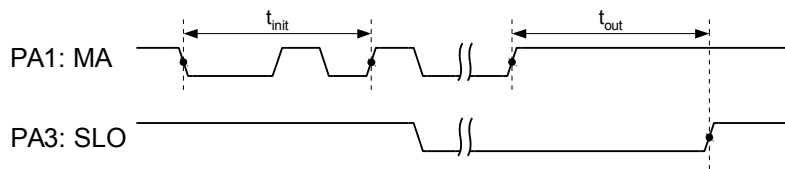


Figure 4: Timeout BiSS interface adaptive (NTOA = 0)

## Timing SSI

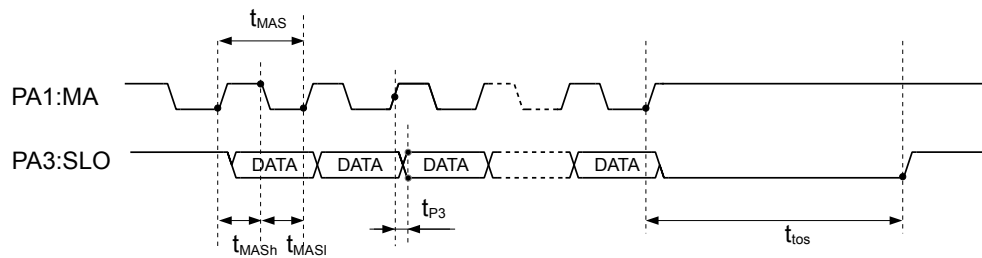


Figure 5: Timing SSI interface (NTOA = 1)

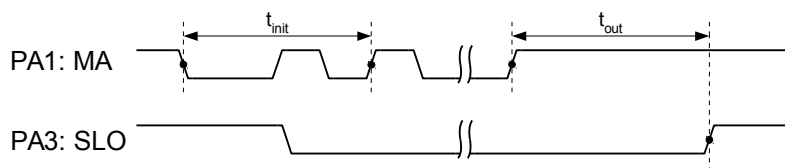


Figure 6: Timeout SSI interface adaptive

## PRINCIPLE OF MEASUREMENT

An absolute position measuring system consists of a magnetized code carrier and an iC-MU Series chip which integrates Hall sensors for signal scanning, signal conditioning, and interpolation in one single device. iC-MU Series can be used in rotative and linear measurement systems.

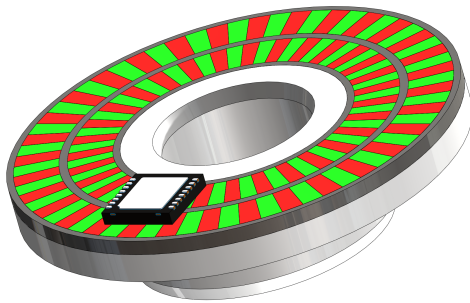


Figure 7: Rotative position measurement system



Figure 8: Linear position measurement system

### Rotative measuring system

The magnetic code carrier consists of two magnetic encoder tracks. The outer track comprises 16, 32, or 64 magnetic pole pairs and is used for high-precision position definition. This is called the master track. The second inside track has one pole pair less than the outer track and is thus referred to as the Nonius track. This track is used to calculate an absolute position within one revolution of the pole disc. To this end, the difference in angle between the two tracks is calculated.

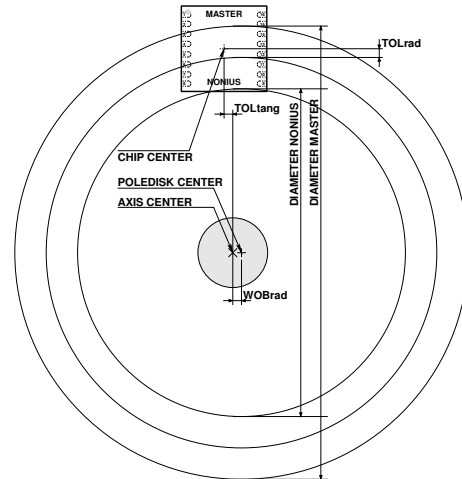


Figure 9: Definition of system measurements

The Hall sensors of iC-MU Series span one pole pair of the code carrier. The pole width of the master track is defined by the distance of the Hall sensors and is 1.28 mm (iC-MU), 1.50 mm (iC-MU150) or 2.00 mm (iC-MU200). Accordingly, the Hall sensors generate a periodic sine and cosine signal with a cycle length of 2.56 mm (iC-MU128), 3.00 mm (iC-MU150) or 4.00 mm (iC-MU200). The scanning diameter can be computed from the number of pole pairs.

The distance between the Hall sensors of the Nonius track and the master track is 3.6 mm (iC-MU128 and iC-MU150) or 4.0 mm (iC-MU200).

### Linear measuring system

With a linear Nonius system the pole width of the master track is also 1.28 mm (iC-MU128), 1.50 mm (iC-MU150) or 2.00 mm (iC-MU200). The pole width of the Nonius track is defined by the number of pole pairs with

$$p_{\text{Nonius}} = p_{\text{master}} * \frac{\text{number of poles}_{\text{master}}}{\text{number of poles}_{\text{Nonius}}}$$

## CONFIGURATION PARAMETERS

### Analog parameters (valid for all channels)

CIBM: Bias current settings (p. 23)  
ENAC: Amplitude control unit activation (p. 24)

### Signal conditioning

GC\_M: Master gain range selection (p. 23)  
GF\_M: Master gain (p. 23)  
GX\_M: Master cosine signal gain adjustment (p. 23)  
VOSS\_M: Master sine offset adjustment (p. 24)  
VOSC\_M: Master cosine offset adjustment (p. 24)  
PH\_M: Master phase adjustment (p. 25)  
PHR\_M: Master phase adjustment range (p. 25)  
GC\_N: Nonius gain range selection (p. 23)  
GF\_N: Nonius gain (p. 23)  
GX\_N: Nonius cosine signal gain adjustment (p. 23)  
VOSS\_N: Nonius sine offset adjustment (p. 24)  
VOSC\_N: Nonius cosine offset adjustment (p. 24)  
PH\_N: Nonius phase adjustment (p. 25)  
PHR\_N: Nonius phase adjustment range (p. 25)

### Digital parameters

TEST: Adjustment modes/iC-Haus test modes (p. 26)  
CRC16: EEPROM configuration data checksum (p. 27)  
CRC8: EEPROM offset and preset data checksum (p. 28)  
NCHK\_CRC: Cyclic check of CRC16 and CRC8 (p. 28)  
BANKSEL: Serial Access: Bank register (p. 53)  
RPL: Register Access Control (p. 57)  
RPL\_RESET: Serial Access: Register for reset register access restriction (p. 57)  
EVENT\_COUNT: Serial Access: Event counter (p. 62)  
HARD\_REV: serial address: revision code (p. 56)

### Configurable I/O interface

MODEA: I/O port A configuration (p. 31)  
MODEB: I/O port B configuration (p. 31)  
NTOA: Adaptive Timeout (p.34)  
PA0\_CONF: Configurable commands to pin PA0 (p. 64)  
ROT\_ALL: Code direction (p. 33)  
OUT\_MSB: Output shift register configuration: MSB used bits (p. 33)  
OUT\_LSB: Output shift register configuration: LSB used bits (p. 33)  
OUT\_ZERO: Output shift register configuration: number of zeros inserted after the used bits and before an error/warning (p. 33)  
MODE\_ST: Data output (p. 32)  
GSSI: Gray/binary data format (p. 36)  
RSSI: Ring operation (p. 36)

### Multiturn interface

MODE\_MT: Multiturn mode (p. 45)  
SBL\_MT: Multiturn synchronization bit length (p. 45)  
CHK\_MT: Cyclic check of the multiturn value (p. 46)  
GET\_MT: MT interface daisy chain (p. 48)  
ROT\_MT: Code direction external multiturn (p. 46)  
ESSI\_MT: Error Bit external multiturn (p. 46)  
SPO\_MT: Offset external multiturn (p. 46)

### Converter and Nonius calculation

FILT: Digital filter settings (p. 42)  
MPC: Master period count (p. 42)  
LIN: Linear scanning (p. 43)  
SPO\_x: Offset of Nonius to master (x=BASE,0-14) (p. 43)  
NCHK\_NON: Cyclic check of the Nonius value (low active) (p. 44)

### Incremental output ABZ, STEP/DIR and CW/CCW

RESABZ: Incremental interface resolution ABZ,STEP-DIR,CW/CCW (p. 49)  
LENZ: Index pulse length (p. 50)  
INV\_A: A/STEP/CW signal inversion (p. 50)  
INV\_B: B/DIR/CCW signal inversion (p. 50)  
INV\_Z: Z/NCLR signal inversion (p. 50)  
SS\_AB: System AB step size (p. 51)  
FRQAB: AB output frequency (p. 51)  
CHYS\_AB: Converter hysteresis (p. 51)  
ENIF\_AUTO: Incremental interface enable (p. 51)

### UVW commutation signals

PPUVW: Number of commutation signal pole pairs (p. 52)  
PP60UVW: Commutation signal phase position (p. 52)  
OFF\_UVW: Commutation signal start angle (p. 52)  
OFF\_COM: serial address: absolute position offset for UVW calculation engine changed by Nonius (p. 52)

### Status/command registers and error monitoring

CMD\_MU: serial address: command register (p. 61)  
STATUS0: serial address: status register 0 (p. 59)  
STATUS1: serial address: status register 1 (p. 59)  
CFGEW: Error and warning bit configuration (p. 60)  
EMTD: Minimum error message duration (p. 60)  
ACC\_STAT: Output configuration status register (p. 59)  
ACRM\_RES: Automatic reset with master track amplitude errors (p. 44)

**BiSS-ID/Profile-ID**

DEV\_ID: Device ID (p. 22)  
MFG\_ID: Manufacturer ID (p. 22)  
EDSBANK: EDSBANK (p. 22)  
PROFILE\_ID: Profile ID (p. 22)  
SERIAL: Serial number (p. 22)

**Preset function**

ROT\_POS: Code direction for ABZ calculation engine and serial absolute interface(p. 33)  
OFF\_ABZ: Offset Absolute position offset for ABZ calculation engine (p. 65)  
OFF\_POS: serial address: absolute position offset for ABZ calculation engine changed by Nonius/multiturn (p. 65)  
PRES\_POS: Preset position for ABZ section (p. 65)

## REGISTER ASSIGNMENT (EEPROM)

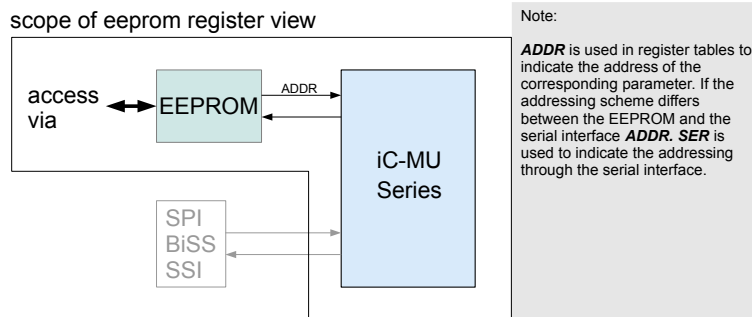


Figure 10: Scope of register mapping EEPROM

### Register assignment (EEPROM)

OVERVIEW								
Addr	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
<b>Signal Conditioning</b>								
0x00	GC_M(1:0)		GF_M(5:0)					
0x01	GX_M(6:0)							
0x02	VOSS_M(6:0)							
0x03	VOSC_M(6:0)							
0x04	PHR_M	PH_M(6:0)						
0x05	ENAC	CIBM(3:0)						
0x06	GC_N(1:0)		GF_N(5:0)					
0x07	GX_N(6:0)							
0x08	VOSS_N(6:0)							
0x09	VOSC_N(6:0)							
0x0A	PHR_N	PH_N(6:0)						
<b>Digital Parameters</b>								
0x0B	MODEB(2:0)			NTOA	MODEA(2:0)			
0x0C	CFGEW(7:0)							
0x0D	ACC_STAT	NCHK_CRC	NCHK_NON	ACRM_RES	EMTD(2:0)			
0x0E	ESSI_MT(1:0)		ROT_MT	LIN	FILT(2:0)			
0x0F	SPO_MT(3:0)				MPC(3:0)			
0x10	GET_MT	CHK_MT	SBL_MT(1:0)		MODE_MT(3:0)			
0x11	OUT_ZERO(2:0)			OUT_MSB(4:0)				
0x12	GSSI	RSSI	MODE_ST(1:0)		OUT_LSB(3:0)			
0x13	RESABZ(7:0)							
0x14	RESABZ(15:8)							
0x15	ROT_ALL	SS_AB(1:0)		ENIF_AUTO	FRQAB(2:0)			
0x16	LENZ(1:0)		CHYS_AB(1:0)	PP60UVW	INV_A	INV_B	INV_Z	
0x17	RPL(1:0)		PPUVW(5:0)					
<b>TEST</b>								
0x18	TEST(7:0)							
<b>TRACK-OFFSET</b>								
0x19	SPO_0(3:0)			SPO_BASE(3:0)				
0x1A	SPO_2(3:0)			SPO_1(3:0)				

OVERVIEW									
Addr	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
0x1B		SPO_4(3:0)				SPO_3(3:0)			
0x1C		SPO_6(3:0)				SPO_5(3:0)			
0x1D		SPO_8(3:0)				SPO_7(3:0)			
0x1E		SPO_10(3:0)				SPO_9(3:0)			
0x1F		SPO_12(3:0)				SPO_11(3:0)			
0x20		SPO_14(3:0)				SPO_13(3:0)			
CRC16									
0x21		CRC16(15:8)							
0x22		CRC16(7:0)							
OFFSET/PRESET									
0x23		OFF_ABZ(3:0)							ROT_POS
0x24		OFF_ABZ(11:4)							
0x25		OFF_ABZ(19:12)							
0x26		OFF_ABZ(27:20)							
0x27		OFF_ABZ(35:28)							
0x28		OFF_UVW(3:0)							
0x29		OFF_UVW(11:4)							
0x2A		PRES_POS(3:0)							
0x2B		PRES_POS(11:4)							
0x2C		PRES_POS(19:12)							
0x2D		PRES_POS(27:20)							
0x2E		PRES_POS(35:28)							
CRC8									
0x2F		CRC8(7:0)							
PA0_CONF									
0x30		PA0_CONF(7:0)							
BiSS Profile and Serial number									
0x31		EDSBANK(7:0) = 0x01							
0x32		PROFILE_ID(15:8)							
0x33		PROFILE_ID(7:0)							
0x34		SERIAL(31:24)							
0x35		SERIAL(23:16)							
0x36		SERIAL(15:8)							
0x37		SERIAL(7:0)							
Device Identification									
0x38		DEV_ID(47:40)							
0x39		DEV_ID(39:32)							
0x3A		DEV_ID(31:24)							
0x3B		DEV_ID(23:16)							
0x3C		DEV_ID(15:8)							
0x3D		DEV_ID(7:0)							
0x3E		MFG_ID(15:8)							
0x3F		MFG_ID(7:0)							
Notes:	Register assignment for serial access through SPI/BiSS s.p. 53								

Table 1: Register assignment (EEPROM)

## Special BiSS registers



Further information about the BiSS interface can be found at [biss-interface.com](http://biss-interface.com).

<b>DEV_ID(7:0)</b>	Addr. 0x3D; bit 7:0
	Addr. SER:0x7D; bit 7:0
<b>DEV_ID(15:8)</b>	Addr. 0x3C; bit 7:0
	Addr. SER:0x7C; bit 7:0
<b>DEV_ID(23:16)</b>	Addr. 0x3B; bit 7:0
	Addr. SER:0x7B; bit 7:0
<b>DEV_ID(31:24)</b>	Addr. 0x3A; bit 7:0
	Addr. SER:0x7A; bit 7:0
<b>DEV_ID(39:32)</b>	Addr. 0x39; bit 7:0
	Addr. SER:0x79; bit 7:0
<b>DEV_ID(47:40)</b>	Addr. 0x38; bit 7:0
	Addr. SER:0x78; bit 7:0
Code	Description
0x000000000000	DEV_ID
...	
0xFFFFFFFFFFFF	

Table 2: Device ID

<b>MFG_ID(7:0)</b>	Addr. 0x3F; bit 7:0
	Addr. SER:0x7F; bit 7:0
<b>MFG_ID(15:8)</b>	Addr. 0x3E; bit 7:0
	Addr. SER:0x7E; bit 7:0
Code	Description
0x0000	MFG_ID
...	
0xFFFF	

Table 3: BiSS Manufacturer ID

<b>EDSBANK(7:0)</b>	Addr. 0x31; bit 7:0
<b>EDSBANK(7:0)</b>	Addr. SER:0x41; bit 7:0
Code	Description
0x00	no EDS
0x01	
...	
0xFE	EDSBANK pointer to first EDS bank
0xFF	
Note:	recommended value 0x02, in this case an additional sensor like iC-PVL can use BANK 1 for configuration

Table 4: EDSBANK: Start of EDS-part

<b>PROFILE_ID(7:0)</b>	Addr. 0x33; bit 7:0
	Addr. SER:0x43; bit 7:0
<b>PROFILE_ID(15:8)</b>	Addr. 0x32; bit 7:0
	Addr. SER:0x42; bit 7:0
Code	Description
0x0000	PROFILE_ID
...	
0xFFFF	

Table 5: Profile ID

<b>SERIAL(7:0)</b>	Addr. 0x37; bit 7:0
	Addr. SER:0x47; bit 7:0
<b>SERIAL(15:8)</b>	Addr. 0x36; bit 7:0
	Addr. SER:0x46; bit 7:0
<b>SERIAL(23:16)</b>	Addr. 0x35; bit 7:0
	Addr. SER:0x45; bit 7:0
<b>SERIAL(31:24)</b>	Addr. 0x34; bit 7:0
	Addr. SER:0x44; bit 7:0
Code	Description
0x00000000	SERIAL
...	
0xFFFFFFFF	

Table 6: Serial number

## SIGNAL CONDITIONING FOR MASTER AND NONIUS CHANNELS: x = M,N

### Bias current source

The calibration of the bias current source in test mode  $TEST=0x1F$  is prerequisite for adherence to the given electrical characteristics and also instrumental in the determination of the chip timing (e.g. SCL clock frequency). For the calibration the current out of pin PB2 into VNA must be measured, and register bits CIBM changed until the current is calibrated to 200  $\mu$ A.

CIBM(3:0) Addr. 0x05; bit 3:0	
Code	Description
0x0	-40 %
...	...
0x8	0 %
0x9	+5 %
...	...
0xF	+35 %

Table 7: Calibrating the bias current

### Gain settings

iC-MU Series has signal conditioning features that can compensate for signal and adjustment errors. The Hall signals are amplified in two stages. The gain of both amplification stages is automatically controlled when the bit ENAC is set to '1'. The register bits GC\_x and GF\_x have no effect. In the case of a deactivated automatic gain control (ENAC='0') the gain must be set manually. First, the approximate field strength range must be selected in which the Hall sensor is to be operated. The first amplifier stage can be programmed in the following ranges:

GC_M(1:0) Addr. 0x00; bit 7:6	
GC_N(1:0) Addr. 0x06; bit 7:6	
Code	Coarse gain
0x0	4.4
0x1	7.8
0x2	12.4
0x3	20.7

Table 8: Selection of the Hall signal amplification range

The second amplifier stage can be varied within a wide range.

GF_M(5:0) Addr. 0x00; bit 5:0	
GF_N(5:0) Addr. 0x06; bit 5:0	
Code	Fine gain
0x00	1.000
0x01	1.048
...	$\exp(\frac{\ln(20)}{64} \cdot GF_x)$
0x3F	19.08

Table 9: Hall signal amplification

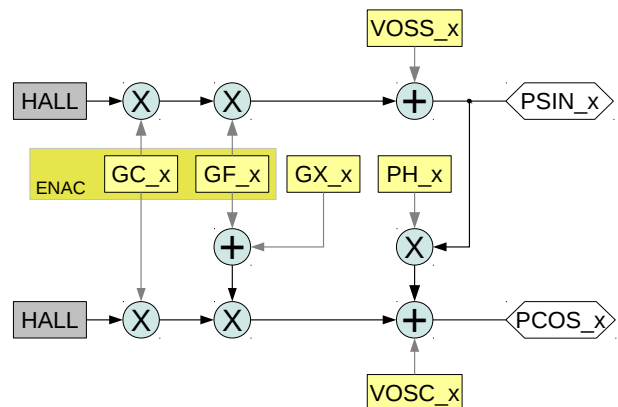


Figure 11: Conditioning of hall voltages

Register GX\_x enables the sensitivity of the sine channel in relation to the cosine channel to be corrected. The amplitude of the cosine channel is adapted to the amplitude of the sine channel. The cosine amplitude can be corrected within a range of approx.  $\pm 10\%$ .

GX_M(6:0) Addr. 0x01; bit 6:0	
GX_N(6:0) Addr. 0x07; bit 6:0	
Code	Description
0x00	1.000
0x01	1.0015
...	$\exp(\frac{\ln(20)}{2048} \cdot GX_x)$
0x3F	1.0965
0x40	0.9106
...	$\exp(-\frac{\ln(20)}{2048} \cdot (128 - GX_x))$
0x7F	0.9985

Table 10: Cosine gain adjustment

The integrated amplitude control unit can be activated using bit ENAC. In this case the differential signal amplitude is regulated to 2 Vpp; the values of GF\_x have no effect here.

ENAC		Addr. 0x05; bit 7
Code	Description	
0	Amplitude control not active ( <i>constant</i> )	
1	Amplitude control active ( $\sin^2 + \cos^2$ )	

Table 11: Amplitude control unit activation

The current gain set by the amplitude control unit can be read with the parameters ACGAIN\_M and ACGAIN\_N for the gain range, AFGAIN\_M and AFGAIN\_N for the gain factor (ref. Table 12 and 13). AFGAIN\_M and AFGAIN\_N shows coarse steps of the gain factor, but the amplitude control unit uses a finer resolution to control the gain factor.

ACGAIN_M(1:0)		Addr. SER:0x2B; bit 4:3	R
ACGAIN_N(1:0)		Addr. SER:0x2F; bit 4:3	R
Code	Gain range		
0x0	4.4		
0x1	7.8		
0x2	12.4		
0x3	20.7		

Table 12: Current gain range of amplitude control unit

AFGAIN_M(2:0)		Addr. SER:0x2B; bit 2:0	R
AFGAIN_N(2:0)		Addr. SER:0x2F; bit 2:0	R
Code	Description		
0x0	1.00		
0x1	1.45		
...	$\exp(\frac{\ln(20)}{8}) \cdot AFGAIN\_x$		
0x7	13.75		

Table 13: Current gain factor of amplitude control unit

After startup the gain is increased until the set amplitude is obtained. If the input amplitude is altered by the distance between the magnet and sensor being varied, or if there is a change in the supply voltage or temperature, the gain is automatically adjusted. The conversion of the sine signals into high-resolution quadrature signals thus always takes place at optimum amplitude.

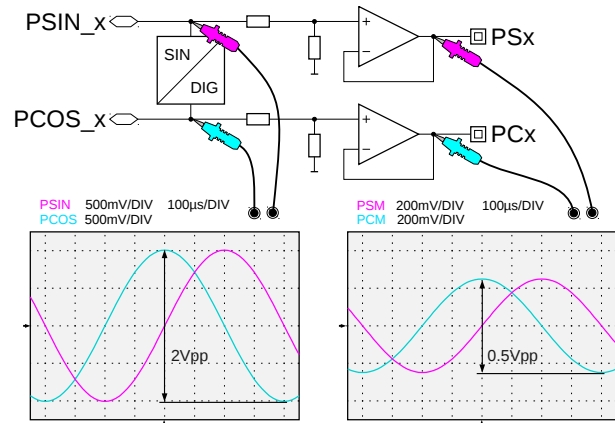


Figure 12: Definition of peak-peak amplitude

### Offset compensation

If there is an offset in the sine or cosine signal, possibly caused by a magnet not being precisely adjusted, for instance, this can be corrected by registers VOSS\_x and VOSC\_x. The output voltage can be shifted in each case by  $\pm 63$  mV in order to compensate for the offset.

VOSS_M(6:0)		Addr. 0x02; bit 6:0
VOSS_N(6:0)		Addr. 0x08; bit 6:0
VOSC_M(6:0)		Addr. 0x03; bit 6:0
VOSC_N(6:0)		Addr. 0x09; bit 6:0
Code	Description	
0x00	0 mV	
0x01	1 mV	
...	...	
0x3F	63 mV	
0x40	0 mV	
0x41	-1 mV	
...	...	
0x7F	-63 mV	

Table 14: Sine and cosine offset adjustment

### Phase adjustment

The phase between sine and cosine is adjusted by PHR\_x and PH\_x (6:0). The compensation range for the master track is with range selector PHR\_M= 0 approx.  $\pm 6^\circ$  (MU128) and  $\pm 8^\circ$  (MU150, MU200) and in extended phase adjustment range PHR\_M=1  $\pm 12^\circ$  (MU128) and  $\pm 16^\circ$  (MU150, MU200). The compensation range for the Nonius track of all MU Series devices is approx.  $\pm 12^\circ$  (PHR\_N=0) and  $\pm 20^\circ$  (PHR\_N=1), respectively.

PHR_M Addr. 0x04; bit 7		
PH_M(6:0) Addr. 0x04; bit 6:0		
PH_M(6:0)	PHR_M=0	PHR_M=1
0x00	0°	0°
...	+6° * PH_M/63	+12° * PH_M/63
0x3F	+6°	+12°
0x40	0°	0°
...	-6° * (PH_M-64)/63	-12° * (PH_M-64)/63
0x7F	-6°	-12°

Table 15: Master track phase adjustment MU128

PHR_N Addr. 0x0A; bit 7		
PH_N(6:0) Addr. 0x0A; bit 6:0		
PH_N(6:0)	PHR_N=0	PHR_N=1
0x00	0°	0°
...	+12° * PH_N/63	+20° * PH_N/63
0x3F	+12°	+20°
0x40	0°	0°
...	-12° * (PH_N-64)/63	-20° * (PH_N-64)/63
0x7F	-12°	-20°

Table 17: Nonius track phase adjustment MU128, MU150 and MU200

PHR_M Addr. 0x04; bit 7		
PH_M(6:0) Addr. 0x04; bit 6:0		
PH_M(6:0)	PHR_M=0	PHR_M=1
0x00	0°	0°
...	+8° * PH_M/63	+16° * PH_M/63
0x3F	+8°	+16°
0x40	0°	0°
...	-8° * (PH_M-64)/63	-16° * (PH_M-64)/63
0x7F	-8°	-16°

Table 16: Master track phase adjustment MU150, MU200

## ANALOG SIGNAL CONDITIONING FLOW: x = M,N

For the purpose of signal conditioning iC-MU Series has several settings that make internal reference values and the amplified Hall voltages of the individual sensors accessible at the outer pins of PORT B for measurement. This allows the settings of the amplifier (GC\_x, GF\_x), the amplitude ratio of cosine to sine signal (GX\_x), and the offset (VOSS\_x, VOSC\_x) and phase (PH\_x) of the master (x = M) and Nonius tracks (x = N) to be directly observed on the oscilloscope.

### Note:

The analog and the track offset SPON correction should be done by using the automatic calibration functions of the GUI software (or DLL) available for iC-MU Series. All necessary steps are described in the iC-MU Series application note AN3: [http://www.ichaus.de/MU\\_AN3\\_appnote\\_en](http://www.ichaus.de/MU_AN3_appnote_en)

Test mode can be programmed using register TEST (address 0x18). The individual test modes are listed in Table 18 and 19.

### Note:

MODEB must be set to 0x0 before selecting a test mode. In test mode 0x1F (Analog REF) I2C communication is disabled.

Test Mode output signals					
Mode	TEST	Pin PB0	Pin PB1	Pin PB2	Pin MTC
Normal	0x00				
Analog REF	0x1F	VREF	VBG	IBM	-
Digital CLK	0x26	-	-	-	CLK

Table 18: Test modes for signal conditioning

### 1. Conditioning the BIAS current

First of all, the internal bias is set. The BIAS current is adjustable in the range of -40 % to +35% to compensate variations of this current and thus differences in characteristics between different iC-MU Series (e.g. due to manufacturing variations). The nominal value of 200 µA is measured as a short-circuit current at pin PB2 referenced to VNA in test mode 0x1F.

Additionally various internal reference voltages are available for measuring in this test mode. VREF corresponds to half the supply voltage (typically 2.5 V) and is used as a reference voltage for the hall sensor signals. VBG is the internal bandgap reference (1.25 V)

Alternatively the frequency at Pin MTC can be adjusted to 405 kHz ( $\frac{f_{osc}}{64}$ , see elec. char. no.: 407) using register value CIBM in test mode 0x26, if an analog measuring of the current is not possible.

Test mode output signals					
Mode	TEST	Pin PB0	Pin PB1	Pin PB2	Pin PB3
Normal	0x00				
Analog Master	0x01	PSM	NSM	PCM	NCM
Analog CNV_M	0x03	PSIN_M	NSIN_M	PCOS_M	NCOS_M
Analog Nonius	0x11	PSN	NSN	PCN	NCN
Analog CNV_N	0x13	PSIN_N	NSIN_N	PCOS_N	NCOS_N

Table 19: Test modes and available output signals

The output signals of the signal path are available as differential signals with a mean voltage of half the supply voltage and can be selected for output according to Table 19.

**Note:**

Pins MTC and MTD must be unconnected when using analog test modes.

**2. Positioning of the sensor**

Next, the sensor should be adjusted in relation to the magnetic code carrier. The value of MPC (Table 51) has to be selected according to the magnetic code carrier. The register values for VOSS\_x, VOSC\_x, GX\_x and PH\_x are set to 0. The chip position will now be displaced radially to the magnetic code carrier until the phase shift between the sine and cosine is 90°.

Depending on the mounting of the system it may be necessary to displace iC-MU Series tangentially to the magnetic code carrier to adjust the amplitude between the sine and cosine signals.

A fine adjustment of the analog signals is made with the registers described in the chapter SIGNAL CONDI-

TIONING FOR MASTER AND NONIUS CHANNELS page 23.

The adjustment should be made in the order:

1. phase
2. amplitude
3. offset

**3.a Test modes analog master and analog Nonius**

In these test modes the amplified, conditioned signals are presented to port B. These signals can be charged with a maximum of 1 mA and should not exceed a differential voltage of 0.5 Vpp.

**3.b Test mode CNV\_x**

In this test mode the sensor signals are present at port B as they are internally for further processing on the interpolator. The achievable interpolation accuracy is determined by the quality of signals PSIN\_x/NSIN\_x and PCOS\_x/NCOS\_x and can be influenced in this test mode by adjustment of the gain, amplitude ratio, offset, and phase. The signals must be tapped at high impedance.

**4. Track offset SPON**

After the analog adjustment of the master and Nonius track the absolute system must be electrically calibrated, see page 43 ff.

## EEPROM AND I2C INTERFACE

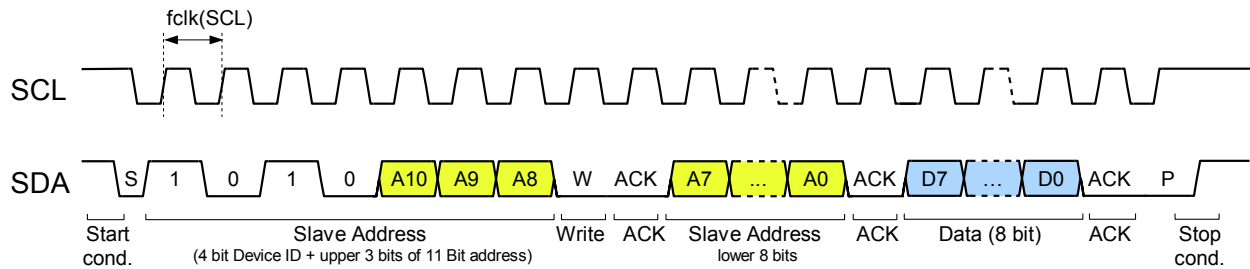


Figure 13: I<sup>2</sup>C slave addressing for writing a single byte to the EEPROM.

### Basic interface features

I2C Master Performance	
Protocol	Standard I <sup>2</sup> C
Clock Rate (Output)	70/80 kHz max. (refer to Elec.Char. 808)
Addressing	11 bit: 8 bit register address plus 3 bit block selection
Multi-Master Capability	Yes

Table 20: I<sup>2</sup>C interface performance

The multimaster-I2C interface enables read and write access to a serial EEPROM. The basic EEPROM requirements are summarized in Table 21.

### EEPROM device requirements

EEPROM Device Requirements	
Supply Voltage	2.5 V to 5.5 V (respectively according to VPA/VPD)
Power-On Threshold	< 3.6 V (due to Elec.Char. 404)
Addressing	11 bit address max.
Device Address	0x50 ('1010 000' w/o R/W bit), 0xA0 ('1010 0000' with R/W = 0)
Page Buffer	Not required
Size Min.	1 Kbit (128x8 bit), type 24C01, for configuration data
Size Max.	16 Kbit (8x 256x8 bit), type 24C16 Size limited due to 11-bit slave addressing.

Table 21: EEPROM Device Requirements

It is not relevant if the EEPROM's internal page buffer is 8 or 16 bytes. EEPROMs beyond 16 Kbit can not be used as those require a 2 byte address.

**ATTENTION:** EEPROMs which consider block selection bits as "don't care" should not be used. This can be the case with 8-pin devices, as well as with 5-pin devices not featuring A2, A1, A0 pins.

Be aware of potential conflicts:

If a user tries to access memory beyond the 2 Kbit range, the iC-MU Series configuration data will be overwritten.

If further I<sup>2</sup>C slave devices are operated on the same bus, higher device addresses may be occupied.

### CRC checksums

The configuration data in the EEPROM in address range 0x00 to 0x20 and 0x30 to 0x3F is secured with a 16 bit CRC (CRC16). The start value for the CRC16 calculation is 1.

<b>CRC16(7:0)</b>	Addr. 0x22; bit 7:0
<b>CRC16(15:8)</b>	Addr. 0x21; bit 7:0
<b>CRC16(7:0)*</b>	Addr. SER: 0x80; bit 7:0
<b>CRC16(15:8)*</b>	Addr. SER: 0x81; bit 7:0
Code	Meaning
...	CRC formed with CRC polynomial 0x11021**)
Notes:	*) Access only via SPI interface **) $x^{16} + x^{12} + x^5 + 1$ , start value 0x1 This is equivalent to CRC-CCITT/CRC-16

Table 22: EEPROM data checksum

The offset and preset position for the iC-MU Series preset sequence is not part of the configuration data area. The data is located in address range 0x23 to 0x2E of the EEPROM and is secured separately with a 8-bit CRC (CRC8). The start value for the CRC8 calculation is 1.

<b>CRC8(7:0)</b> Addr. 0x2F; bit 7:0	
<b>CRC8(7:0)*</b> Addr. SER: 0x82; bit 7:0	
Code	Meaning
...	CRC formed with CRC polynomial 0x197**)
Notes:	*) Access only via SPI interface **) $x^8 + x^7 + x^4 + x^2 + x^1 + 1$ , start value 0x1

Table 23: Offset/preset data checksum

iC-MU Series calculates CRC8 and CRC16 automatically when writing the configuration to the EEPROM. However, an example of a CRC calculation routine is given in Tab. 25. The serial interface allows to access the CRC8 and CRC16 values only in SPI mode. CRC16 and CRC8 are checked on startup. A cyclic check during operation can be configured with NCHK\_CRC. With the command CRC\_VER (s. Tab. 102) a CRC check can be explicitly requested. An error is reported by status bit CRC\_ERR.

<b>NCHK_CRC</b> Addr. 0x0D; bit 6	
Code	Meaning
0	cyclical CRC check of CRC16 and CRC8
1	no cyclical CRC check

Table 24: Cyclic CRC check

```

unsigned char ucDataStream = 0;
int iCRC_CRC8Poly = 0x97;
unsigned char ucCRC8;
int i = 0;

ucCRC8 = 1; // start value !!!
for (iReg = 35; iReg<47; iReg ++ )
{
    ucDataStream = ucGetValue(iReg);
    for (i=0; i<=7; i++) {
        if ((ucCRC8 & 0x80) != (ucDataStream & 0x80))
            ucCRC8 = (ucCRC8 << 1) ^ iCRC_CRC8Poly;
        else
            ucCRC8 = (ucCRC8 << 1);
            ucDataStream = ucDataStream << 1;
    }
}
    
```

Table 25: Example of CRC calculation routine using CRC8

## STARTUP BEHAVIOR

After switching on the power (power-on reset) iC-MU Series reads the configuration data from the EEPROM. If an error occurs during the EEPROM data readout (a CRC error or communication fault with the EEPROM), the current read-in is aborted and restarted. Following a third faulty attempt the read-in process is terminated and the internal iC-MU Series configuration register initialized as in Tab. 27. The addresses are referenced to the register allocation for an register access through the serial interface s. p. 53.

**Note:** After the third faulty attempt to read-in the configuration data from the EEPROM the default value of MODEA is set to BiSS or SPI depending on the logic level at pin PA0 (PA0=0 → BiSS, PA0=1 → SPI<sub>TRI</sub>).

**Note:** After startup of iC-MU Series it is best practice to check the status register for fault conditions. In case of an active STUP, CRC\_ERR or EPR\_ERR flag, a SOFT\_RESET command should be sent to restart the system and thus to maximize system availability.

Pin PA0	I/O Interface	Data length
0	BiSS	32 bits (24 bits + 2 bits E/W + 6 bits CRC)
1	SPI	24 bits

Table 26: Default interface depending on PA0

The amplitude control is started after the read-in of the EEPROM. To determine the absolute position a Nonius calculation is started. An external multiturn is read-in if configured. If there is an error the multiturn read-in is repeated until no multiturn error occurs. The status bit MT\_ERR is set in this case, register communication is possible. The ABZ/UVW-converter is only started if there was no CRC\_ERR, EPR\_ERR, MT\_ERR or MT\_CTR error during startup. The startup behaviour is described in Figure 14.

Default values			
Bank	Addr. (serial access)	value	Meaning
0	0x05	0x88	Amplitude control active (ENAC=1), CIBM = 0%
0	0x0B	0x02	PA0=0 → BiSS interface (MODEA=0x2), ABZ Incremental (MODEB=0x0)
0		0x00	PA0=1 → SPI interface (MODEA=0x0), ABZ Incremental (MODEB=0x0)
0	0x0E	0x06	FILTER activated
0	0x0F	0x05	32 pole pairs master track
0	0x10	0x00	no Multiturn, Nonius check active
0	0x11	0xA5	5 bit Nonius information, 5 Zeros added
0	0x12	0x00	output with max. resolution
0	0x13	0xFF	resolution 16384 edges
0	0x14	0x0F	
0	0x15	0x13	up to 12000 rpm (SS_AB=0x1), 266ns minimum edge distance
0	0x16	0x10	90° Index, 0.175° Hysteresis
0	0x17	0x02	1 pole pair commutation
-	0x74	HARD_REV	s. Tab. 92
-	0x78	0x4D	≈ M
-	0x79	0x55	≈ U
-	0x7E	0x69	≈ i
-	0x7F	0x43	≈ C
Notes:	all other registers are preset with 0 Register assignment for register access through serial interface s.p. 53		

Table 27: Default configuration without the EEPROM

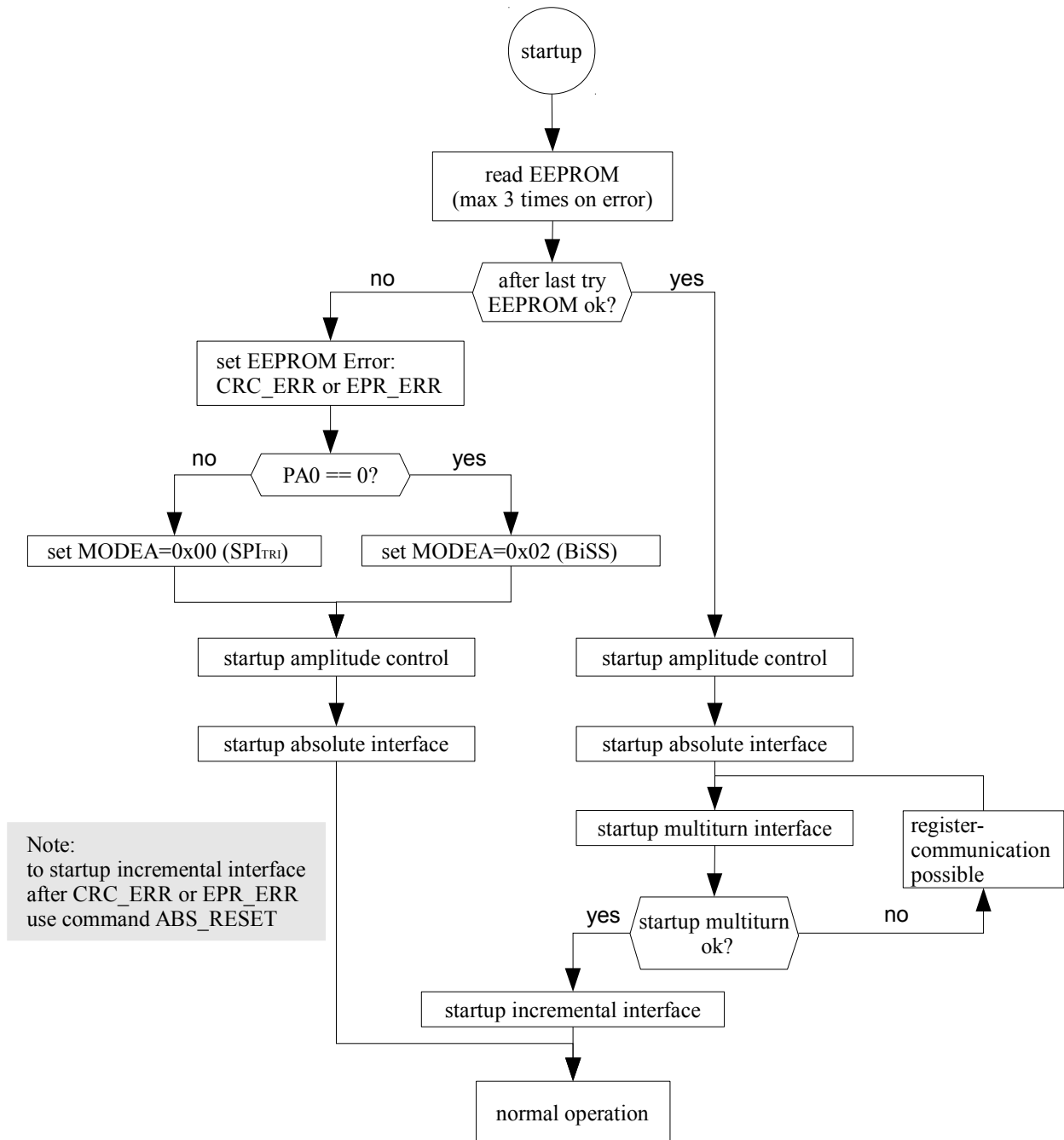


Figure 14: Startup behavior

## CONFIGURABLE I/O INTERFACE

### Setting the interfaces

iC-MU Series has several configurable output modes which can be set using parameters MODEA and MODEB. The pins at port A are set with MODEA. The choice of a serial interface at port A has also effect on the output of error and warning bits in the serial protocol see Table 31.

#### Note:

With an empty EEPROM or after the third faulty attempt to read-in the configuration data from the EEPROM the default value of MODEA is set to BiSS or SPI depending on the logic level at pin PA0 (PA0=0 → BiSS, PA0=1 → SPI<sub>TRI</sub>).

MODEA(2:0) Addr. 0x0B; bit 2:0					
Code	PA0	PA1	PA2	PA3	Function
0x0	NCS	SCLK	MOSI	MISO	SPI <sub>TRI</sub>
0x1	NCS	SCLK	MOSI	MISO	SPI
0x2	NPRES	MA	SLI	SLO	BiSS
0x3	NPRES	A	B	Z	ABZ *)
0x4	NPRES	MA	SLI	SLO	SSI **)
0x5	NPRES	MA	SLI	SLO	SSI+ERRL
0x6	NPRES	MA	SLI	SLO	SSI+ERRH
0x7	NPRES	MA	SLI	SLO	ExtSSI

Note: \*) to save this configuration in the EEPROM see command SWITCH page 61 ff.  
 \*\*) MT sensor communication not possible (GET\_MT = 0)

Table 28: Port A configuration

The pins at port B are set with MODEB.

MODEB(2:0) Addr. 0x0B; bit 6:4					
Code	PB0	PB1	PB2	PB3	Function
0x0	A	B	Z	NER*	ABZ
0x1	U	V	W	NER*	UVW
0x2	STEP	DIR	NCLR	NER*	Step/Direction
0x3	CW	CCW	NCLR	NER*	CW/CCW Incremental
0x4	PSN	NSN	PCN	NCN	SIN/COS Nonius**
0x5	PSM	NSM	PCM	NCM	SIN/COS Master**
0x6	-	-	-	-	reserved
0x7	-	-	-	-	tristate

Note: \*) Pin PB3 (signal NER) is an open-collector output  
 \*\*) PSx, NSx, PCx, NCx vs. GND  $V_{pk}() = 250\text{ mV}$ ,  $V_{CM}() = V_{PA}/2$

Table 29: Port B configuration

#### Note:

It is not possible to select ABZ at port A and ABZ, Step/Direction or CW/CCW at port B simultaneously.

In operating modes ABZ, UVW, step/direction, and CW/CCW the position is output incrementally. In setting SIN/COS Master the master track analog signal is switched directly to the analog drivers. The signals of the Nonius track are available on the drivers with setting SIN/COS Nonius.

## Serial interface: Configuring the data format and data length

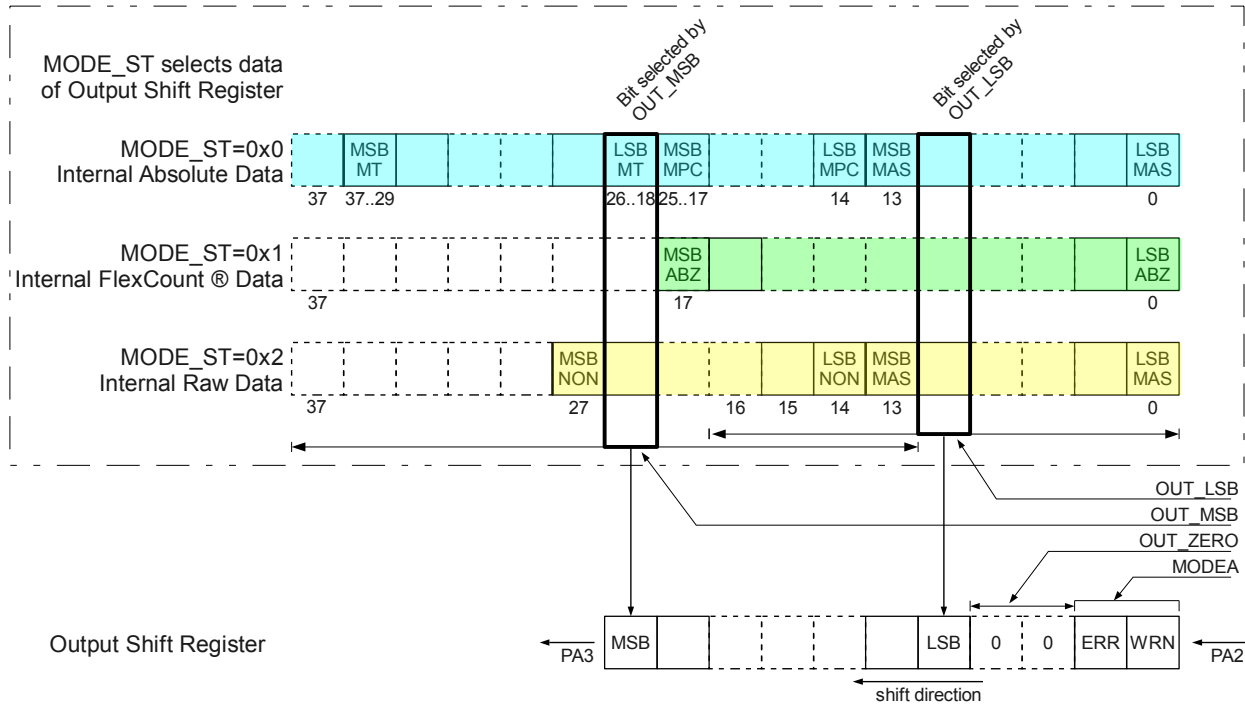


Figure 15: Determining the output data length

The structure of the output shift register is shown in Figure 15. The abbreviation MT stands for the multiturn data, MPC is short for the number of master periods in bit, ABZ for the data whose resolution is specified by the parameter RESABZ (Table 71), NON for the data of the Nonius track and MAS for the data of the master track. The numbering of the user data starts at the LSB with zero. OUT\_MSB and OUT\_LSB determine which part of the user data is output by the output shift register.

MODE\_ST selects the type of user data to be output through the output shift register.

MODE_ST(1:0) Addr. 0x12; bit 5:4	
Code	Description
0x0	output absolute position
0x1	output position in user resolution*) (FlexCount®)
0x2	output raw-data of Master- and Nonius track**)
0x3	reserved
Note:	*) resolution defined by RESABZ (Table 71) **) MPC must be ≠ 12

Table 30: Selection of output data

The number of output bits is determined by parameters OUT\_MSB, OUT\_LSB, OUT\_ZERO and the error/warning bits (see Figure 15 and Table 31):

$data\_length = 14 + OUT\_MSB - OUT\_LSB + OUT\_ZERO +$   
optional ERR/WRN (depending on MODEA)

There is an exception for the calculation of the output data length. If parameter MPC=12, OUT\_LSB = 0 and OUT\_MSB > 0x02 the number of output bits is given by:

$data\_length\_2 = OUT\_MSB + OUT\_ZERO + ERR/WRN$  (depending on MODEA) - 2

MODEA(2:0) Addr. 0x0B; bit 2:0				
Function	Error		Warning	
	low active	high active	low active	high active
SPI	-	-	-	-
BiSS	✓	-	✓	-
SSI	-	-	-	-
SSI+ERRL	✓	-	-	-
SSI+ERRH	-	✓	-	-
ExtSSI	✓	-	✓	-

Table 31: MODEA: error/warning-bit within serial protocols

OUT\_MSB configures the bit of the user data which is output as MSB at pin PA3.

OUT_MSB(4:0) Addr. 0x11; bit 4:0	
Code	Description
0x00	MSB = bit 13
0x01	MSB = bit 14
...	...
0x18	MSB = bit 37

Table 32: Selection of shift register MSB

OUT\_LSB determines the LSB of the user data being output through the output shift register.

OUT_LSB(3:0) Addr. 0x12; bit 3:0		
Code	Condition	Description
0x0	MPC = 12, OUT_MSB > 0x02 MPC ≠ 12	LSB = bit 16 LSB = bit 0
0x1	-	LSB = bit 1
0x2	-	LSB = bit 2
...	...	...
0xD	-	LSB = bit 13
0xE	OUT_MSB > 0x00	LSB = bit 14
0xF	OUT_MSB > 0x01	LSB = bit 15

Table 33: Selection of shift register LSB

With OUT\_ZERO additional zeros to be inserted between the user data and the error/warning bit can be configured. Parameter OUT\_ZERO can be used to achieve multiples of 8 bits when sensor data is output through the SPI interface.

OUT_ZERO(2:0) Addr. 0x11; bit 7:5	
Code	Description
0x0	no additional '0' bit
0x1	1 additional '0' bit
...	...
0x7	7 additional '0' bits

Table 34: Selection of additional ZEROS

The code direction of the position data can be inverted with the parameters ROT\_ALL, ROT\_POS and the commands ROT\_POS and ROT\_POS\_E2P (see P.61). Parameter ROT\_ALL affects the output of the position

data of the serial interface in MODE\_ST = 0x0 and 0x1, the incremental outputs (ABZ) and the UVW-interface. Parameter ROT\_POS is EXOR-gated with parameter ROT\_ALL and affects only the output of the position data of the serial interface in MODE\_ST = 0x0 and 0x1 and the incremental outputs (ABZ).

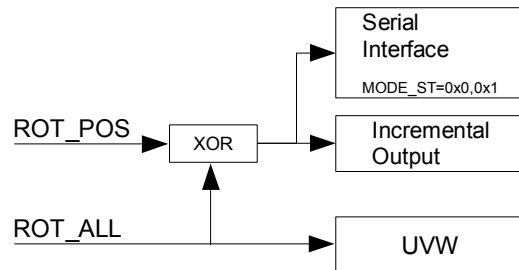


Figure 16: Effect of ROT\_ALL and ROT\_POS on position data code direction

ROT_ALL Addr. 0x15; bit 7	
Code	Description
0	no inversion of code direction
1	inversion of code direction
Notes:	no effect in MODE_ST = 2 (raw-data) for the data output of the serial interface ROT_POS can change the code direction in MODE_ST = 0x0 and 0x1, incremental outputs

Table 35: Inversion of code direction for the serial interface in MODE\_ST = 0x0 and 0x1, incremental outputs and UVW-interface

ROT_POS Addr. 0x23; bit 0		
ROT_POS Addr. SER:0x1E; bit 0		
Code	ROT_ALL = 0	ROT_ALL = 1
0	no inversion of code direction	inversion of code direction
1	inversion of code direction	no inversion of code direction
Note:	no effect in MODE_ST = 2 (raw-data) for the data output of the serial interface and on UVW-interface	

Table 36: Resulting inversion of code direction for the serial interface in MODE\_ST = 0x0 and 0x1, incremental outputs

## BiSS C interface

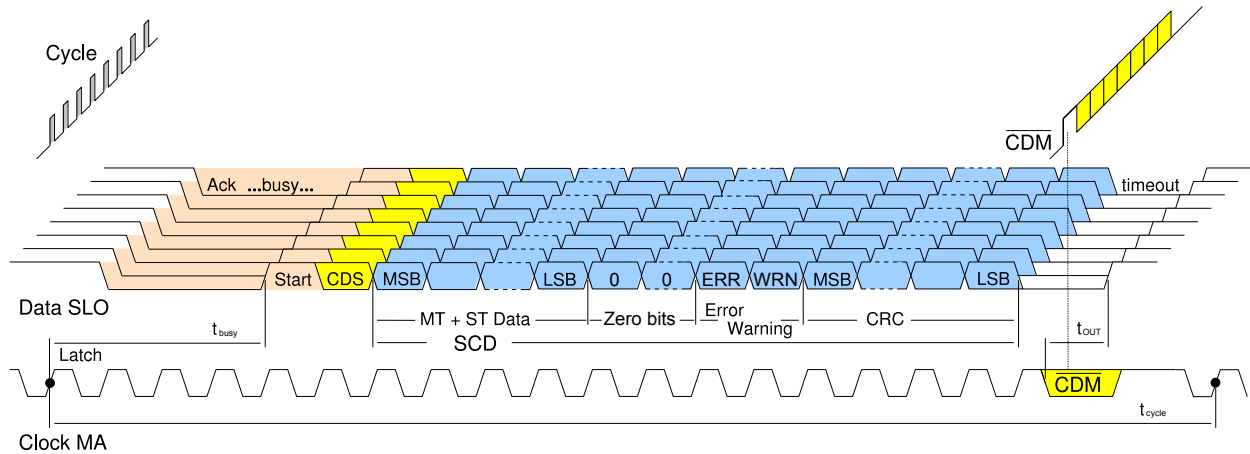


Figure 17: Example of BiSS line signals

MODEA	
Code	Description
0x2	BiSS-C

Table 37: MODEA: BiSS

The BiSS C interface serial bit stream is binary coded. The error and warning bit is low active. Transmission of sensor and register data is implemented. iC-MU Series needs no processing time up to 5 MHz BiSS clock speed, therefore  $t_{busy}$  is one master clock cycle. The processing time  $t_{busy}$  can be maximum two clock cycles for a BiSS clock speed faster than 5 MHz.

NTOA Addr. 0x0B; bit 3		
Code	Description	Timeout *)
0	Adaptive	$t_{init}$
1	Fixed	20 $\mu$ s
Note:	*) see I115, P. 15	

Table 38: Communication Timeout

A communication frame ends when the MA pin clock cycles stop. After the last edge on MA the communication timeout begins. With NTOA set to 0 the timeout is adaptive. The timeout period  $t_{out}$  is calculated based

on the first MA edges as shown in Figure 4. By setting NTOA to 1 a fixed timeout of 20  $\mu$ s terminates the communication frame.

In BiSS protocol iC-MU Series uses fixed CRC polynomials, see Table 39. The single cycle data (SCD), i.e. the primary data which is newly generated and completely transmitted in each cycle, contains the position data (optional multiturn + singleturn) and the error and warning bit. The CRC value is output inverted.

data-channel*)	CRC HEX Code	Polynomial
SCD (sensor)	0x43	$x^6+x^1+x^0$
CDM, CDS (register)	0x13	$x^4+x^1+x^0$
Note:	*) explanation s. BiSS-C specification	

Table 39: BiSS CRC polynomials

BiSS protocol commands are not supported by iC-MU Series.



Further information about the BiSS interface can be found at [biss-interface.com](http://biss-interface.com).

## SSI interface

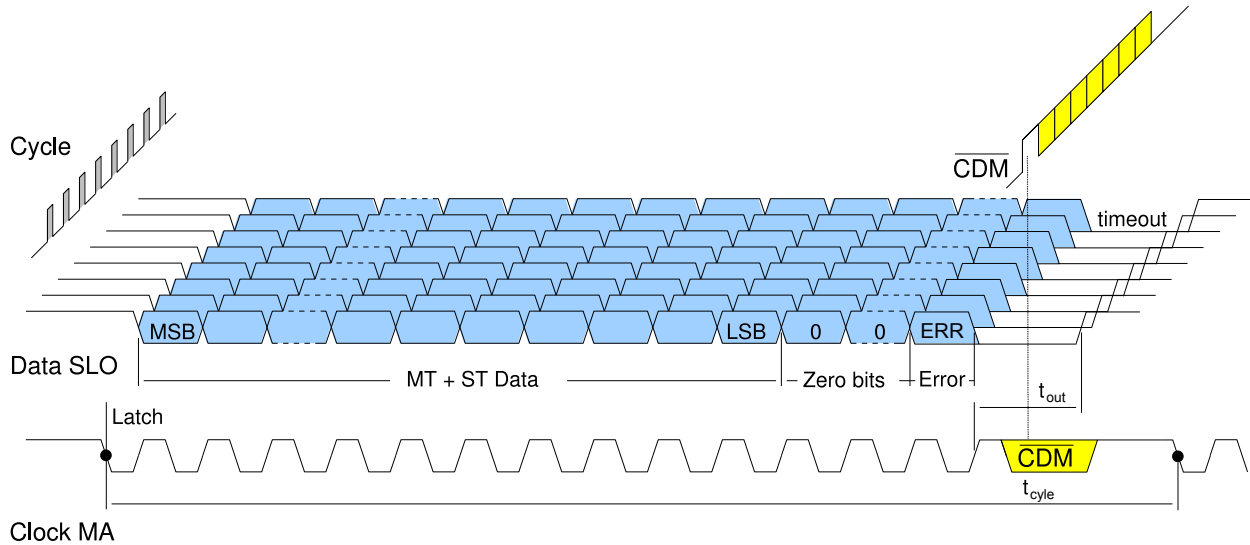


Figure 18: Example of SSI line signals (MODEA=0x5/0x6) with optional unidirectional register communication

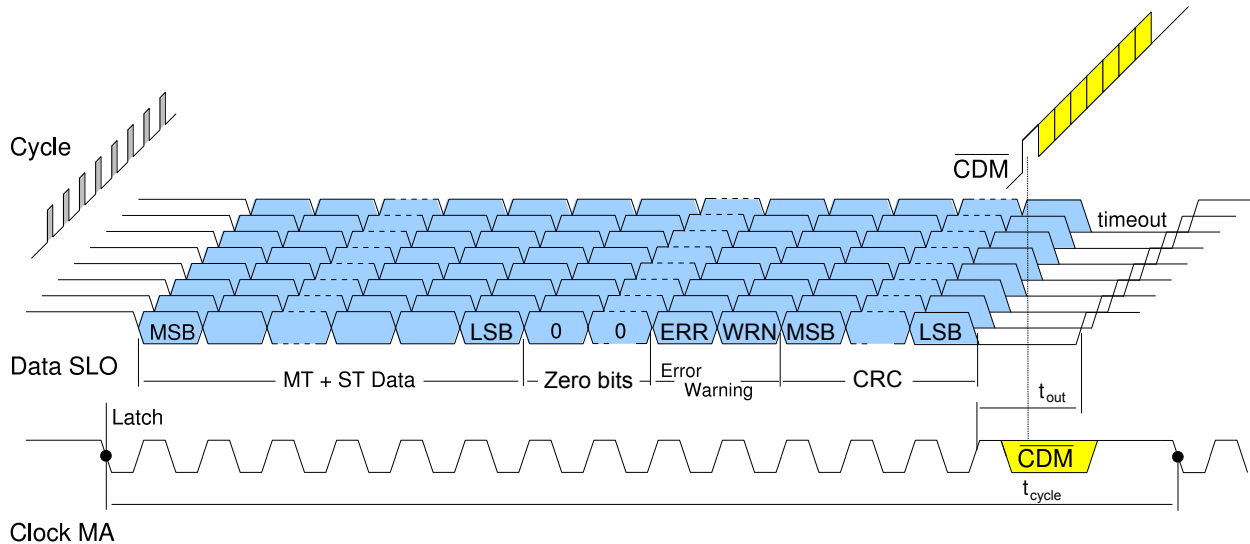


Figure 19: Example of extended SSI line signals (MODEA=0x7, ExtSSI)

MODEA	
Code	Description
0x4	Standard SSI, no error-bit
0x5	Standard SSI, error-bit low active
0x6	Standard SSI, error-bit high active
0x7	extended SSI, data-package like BiSS-C

Table 40: MODEA: SSI

In standard SSI mode singleturn data and, optionally, multiturn data, an error, and a stop zero can be transmitted. In extended SSI mode (ExtSSI) the multiturn data (optional), singleturn data, error, warning, and CRC can be read out. All data is sent with the MSB first and is equivalent to the data package that is output through BiSS.

The SSI interface of iC-MU Series can handle sensor data communication and unidirectional register communication (Advanced SSI protocol see Figure 18).

NTOA		
Addr. 0x0B; bit 3		
Code	Description	Timeout *)
0	Adaptive	$t_{init}$
1	Fixed	20 $\mu$ s
Note:	*) see I115, P. 15	

Table 41: Communication Timeout

It is possible to select the adaptive or the fixed timeout in SSI mode. However in order to meet the requirements of the standard SSI protocol the fixed timeout of 20  $\mu$ s should be chosen by setting NTOA to 1.

In SSI mode the sensor data can be output in binary or Gray code.

GSSI <sup>1</sup>	
Addr. 0x12; bit 7	
Code	Data format
0	binary coded
1	Gray coded

Table 42: Data format (for MT and ST data)

SSI interface ring operation can be activated for the repeated output of position data in SSI protocol. In this mode position data output is repeated cycle by cycle separated by a zero-bit until the internal timeout  $t_{out}$  (p. 16) is reached. After  $t_{out}$  has elapsed a new request can be made for position data. By checking the repeated position data for equality, SSI ring operation mode enables any possible transmission errors to be detected. If RSSI is deactivated zeros are subsequently output after the position data output.

RSSI	
Addr. 0x12; bit 6	
Code	Ring operation
0	normal output
1	Ring operation

Table 43: Ring operation

<sup>1</sup> Please refer to the design review on p. 67.

## SPI interface: general description

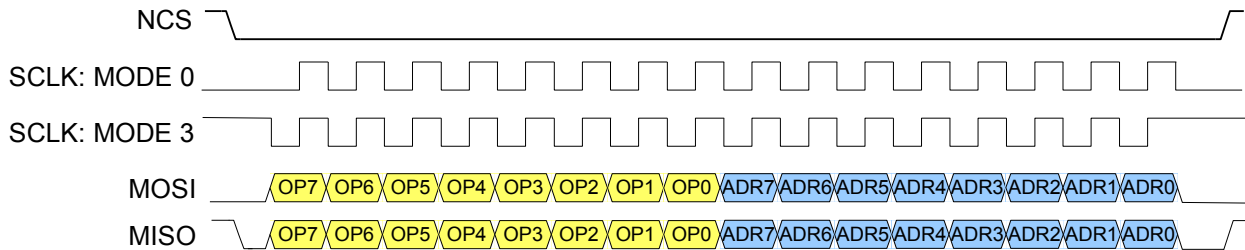


Figure 20: SPI transmission SPI-Mode 0 and 3, using opcode Read REGISTER(single) as an example

MODEA	
Code	Description
0x0	SPI <sub>TRI</sub>
0x1	SPI

Table 44: MODEA: SPI

In mode SPI<sub>TRI</sub> MISO (Pin PA3) is set to tristate if the slave is not selected by the master, i.e. NCS=1. This function is used for a parallel SPI bus configuration (Figure 21). In mode SPI the idle state of MISO (Pin PA3) is high if the slave is not selected by the master.

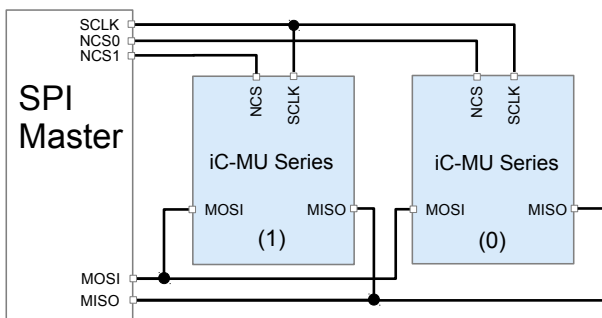


Figure 21: Example configuration SPI bus with 2 parallel Slaves

SPI modes 0 and 3 are supported, i.e. idle level of SCLK 0 or 1, acceptance of data on a rising edge. Data is sent in packages of 8 bits and with the MSB first (see Figure 20). Each data transmission starts with the master sending an opcode (Table 45) to the slave.

The following describes the typical sequence of an SPI data transmission, taking the command **Read REGISTER (single)** as an example (see Figure 20):

1. The master initializes a transmission with a falling edge at NCS.

2. iC-MU Series passes the level on from MOSI to MISO.
3. The master transmits the opcode OP and address ADR via MOSI; iC-MU Series immediately outputs OP and ADR via MISO.
4. The master terminates the command with a rising edge at NCS.
5. iC-MU Series switches its MISO output to 1 (MODEA=0x1) or tristate (MODEA=0x0).

OPCODE	
Code	Description
0xB0	ACTIVATE
0xA6	SDAD-transmission (sensor data)
0xF5	SDAD Status (no latch)
0x97	Read REGISTER(single) <sup>2</sup>
0xD2	Write REGISTER (single) <sup>2</sup>
0xAD	REGISTER status/data

Table 45: SPI OPCODEs

For the setup to be compatible with SPI protocol, when setting the sensor data length for the command "SDAD transmission" with parameters OUT\_MSB, OUT\_LSB, and OUT\_ZERO, it must be ensured that the output data length is a multiple of 8 bits.

## SPI interface: Command ACTIVATE

Each iC-MU Series has one RACTIVE and one PACTIVE register. These registers are used pairwise to configure the register data channel and the sensor/actuator data channel of a slave.

Using the **ACTIVATE** command, the register and sensor data channels of the connected slaves can be switched on and off. The command causes all slaves

<sup>2</sup> Please refer to the design review on p. 67.

to switch their RACTIVE and PACTIVE registers between MOSI and MISO and set them to 0 (slaves in daisy chain connection, Figure 24). The register and sensor/actuator data channels can be switched on and off with data bytes following the OPCODE.

After startup of iC-MU Series RACTIVE and PACTIVE is set to 1.

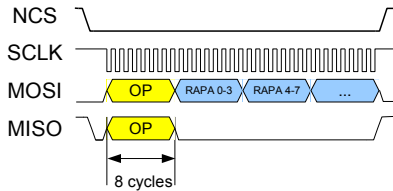


Figure 22: Set ACTIVATE: RACTIVE/PACTIVE (several slaves)

The **ACTIVATE** command resets the bits FAIL, VALID, BUSY, and DISMISS in the SPI-STATUS byte (see Table 49).

RACTIVE	
Code	Description
0	Register communication deactivated
1	Register communication activated*)
Note	*) default after startup

Table 46: RACTIVE

If RACTIVE is not set, on commands **Read REGISTER (single)**, **Write REGISTER (single)**, **REGISTER status/data** the ERROR bit is set in the SPI-STATUS byte (see Table 49) to indicate that the command has not been executed. At MISO the slave immediately outputs the data transmitted by the master via MOSI.

PACTIVE	
Code	Description
0	Sensor data channel deactivated
1	Sensor data channel activated*)
Note	*) default after startup

Table 47: PACTIVE

If PACTIVE is not set, on commands **SDAD status** and **SDAD transmission** the ERROR bit is set in the SPI-STATUS byte (see Table 49) to indicate that the command has not been executed. At MISO the slave immediately outputs the data transmitted by the master via MOSI.

If only one slave is connected up with one register and one sensor data channel, it must be ensured that the RACTIVE and PACTIVE bits come last in the data byte.

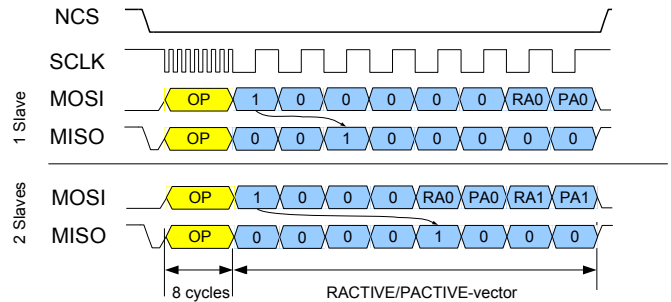


Figure 23: Set ACTIVATE: RACTIVE/PACTIVE (Example with one and two slaves (daisy chain))

An example for a daisy chain wiring of 2 SPI slaves is given in Figure 24. In order to do register communication (**Read REGISTER (single)**, **Write REGISTER (single)**, **REGISTER status/data**) with e.g. slave (1) the register communication has to be enabled explicitly for this slave and disabled for slave (0) with command **ACTIVATE** and parameter **RACTIVE**.

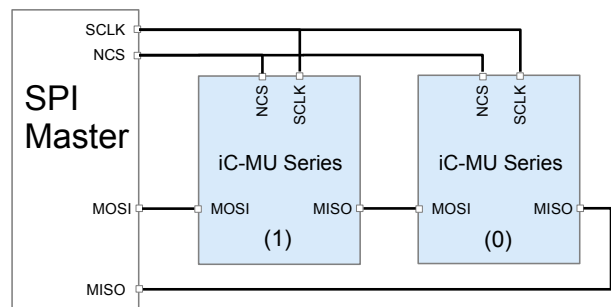


Figure 24: Example configuration with 2 Slaves (daisy chain)

### SPI interface: Command SDAD transmission

iC-MU Series latches the absolute position on the first rising edge at SCLK, when NCS is at zero (REQ/LATCH). Because iC-MU Series can output the sensor data (SD) immediately, the master can transmit the **SDAD transmission** command directly. The sensor data shift register (the size of which is 8 to 40 bits in multiples of 8 using iC-MU Series) is switched and clocked out between MOSI and MISO.

If invalid data is sampled in the shift register, the ERROR bit is set in the SPI-STATUS byte (see Table 49) and the output data bytes are set to zero.

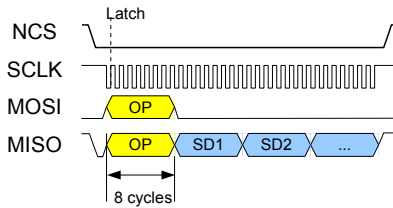


Figure 25: SDAD transmission: read SD

### SPI interface: Command SDAD status

If the master does not know the processing time of the connected slaves, it can request sensor data using the command **SDAD status**. The command causes:

1. All slaves activated via PACTIVE to switch their SVALID register between MOSI and MISO.
2. The next request for sensor data started with the first rising edge at SCLK of the next SPI communication is ignored by the slave.

The end of conversion is signaled by SVALID (SV). Using this command, the master can poll to the end of conversion. The sensor data is read out via the command **SDAD transmission**.

SVALID	
Code	Description
0	Sensor data invalid
1	Sensor data valid

Table 48: SVALID

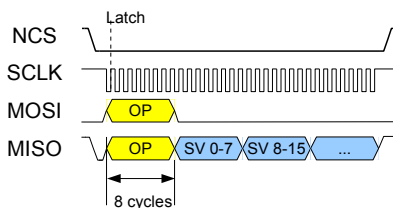


Figure 26: SDAD status

If only one slave is connected, the corresponding SVALID bit (SV0) is placed at bit position 7 in the SVALID byte.

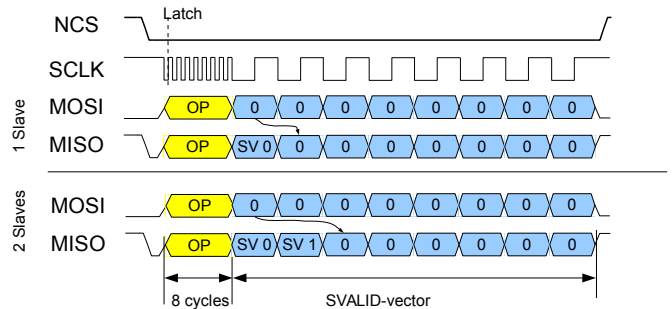


Figure 27: SDAD status (Example with one and two slaves)

Figure 28 shows the interaction of the two commands **SDAD Status** and **SDAD transmission**. It is not necessary to start each sensor data communication with the command **SDAD Status** (1). iC-MU Series has no processing time and can therefore directly output valid sensor data. Because of that the command sequence can start with **SDAD-transmission** (2). Following this, the command **REGISTER status/data** should be executed to detect an unsuccessful SPI communication.

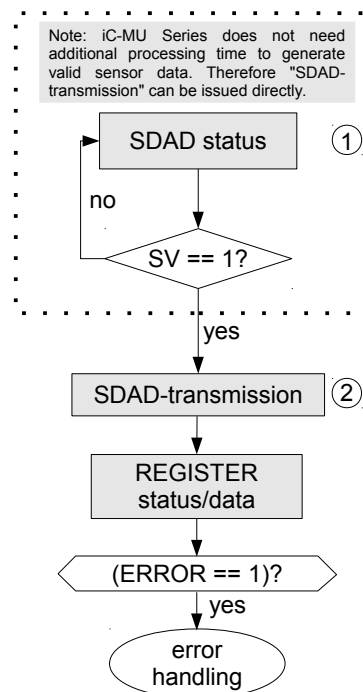


Figure 28: Example sequence of the commands SDAD Status/SDAD-transmission

### SPI interface: Command Read REGISTER (single)

This command enables register data to be read out from the slave byte by byte.

The master first transmits the **Read REGISTER (single)** command and then address ADR. The slave immediately outputs the command and address at MISO.

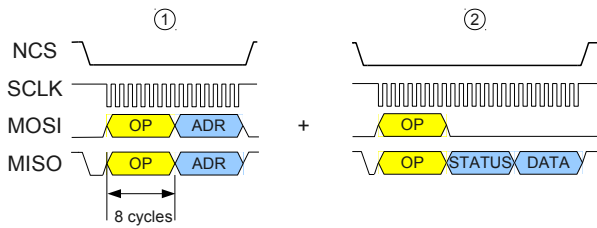


Figure 29: Read REGISTER (single): set the read address (1) + command REGISTER status/data to read-out data (2)

Following this, using the **REGISTER status/data** command (see page 40) the master can poll until the validity of the DATA following the SPI-STATUS byte is signaled via SPI-STATUS.

**SPI interface: Command Write REGISTER (single)**  
This command enables data to be written to the slave byte by byte.

The master first transmits the **Write REGISTER (single)** command and then address ADR and the data (DATA). The slave immediately outputs the command, address, and data at MISO.

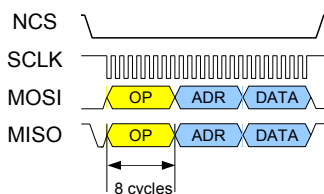


Figure 30: Write REGISTER (single); set write address and data

Using the **REGISTER status/data** command, the master can poll to the end of the register communication (signaled via the SPI-STATUS byte).

**SPI interface: Command REGISTER status/data**

The **REGISTER status/data** command can be used to request the status of the last register communication and/or the last data transmission. The SPI-STATUS byte contains the information summarized in Table 49.

SPI-STATUS		
Bit	Name	Description of the status report
<b>Status bits of the SDAD and register communication</b>		
7	ERROR	Opcode not implemented, Sensor data was invalid on readout
6..4	-	Reserved
<b>Status bits of the register communication only</b>		
3	DISMISS	Address rejected
2	FAIL	Data request has failed
1	BUSY	Slave is busy with a request
0	VALID	DATA is valid
Note	Display logic: 1 = true, 0 = false	

Table 49: Communication status byte

All SPI status bits are updated with each register access. The exception to the rule is the ERROR bit; this bit indicates whether an error occurred during the last SPI-communication with the slave.

The master transmits the **REGISTER status/data** opcode. The slave immediately passes the opcode on to MISO. The slave then transmits the SPI-STATUS byte and a DATA byte.

Following the commands **Read REGISTER (single)** and **Write REGISTER (single)**, the validity of the DATA byte is signaled with the VALID status bit.

The requested data byte is returned via DATA following the **Read REGISTER (single)** command. Following the **Write REGISTER (single)** command, the data to be written is repeated in the DATA byte. With all other opcodes, the DATA byte is not defined.

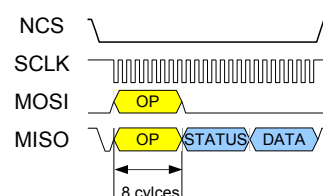


Figure 31: REGISTER status/data

Figure 32 shows the interaction of the commands **REGISTER read/write** and **REGISTER status/data**.

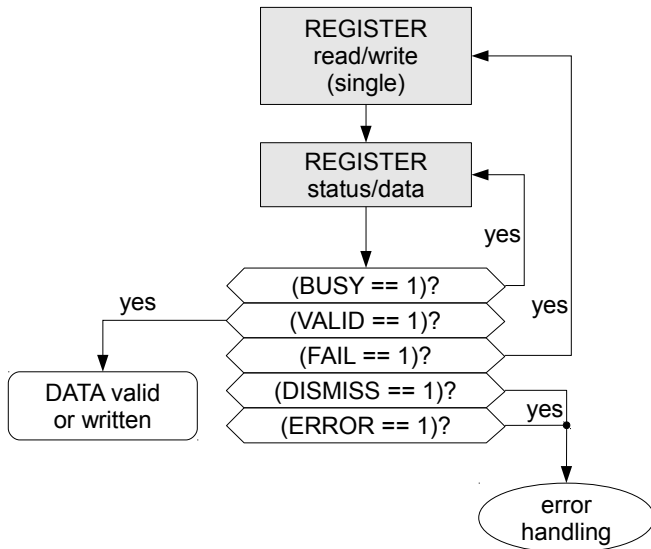


Figure 32: Example sequence of commands REGISTER read/write and REGISTER status/data

## CONVERTER AND NONIUS CALCULATION

### Converter principle

The system consist of two real-time tracking converters, each with a resolution of 12 bits for the master track and Nonius track. Above the maximal permissible input frequency the status bits FRQ\_CNV is set. The tracking converter can't follow the input signal any more. With a filter setting of type FILT1 and higher an increased resolution of 14 bits is available.

A digital filter can be configured with FILT to reduce the noise of the digital output signals. Using this the digital angle values of the tracking converter can be filtered.

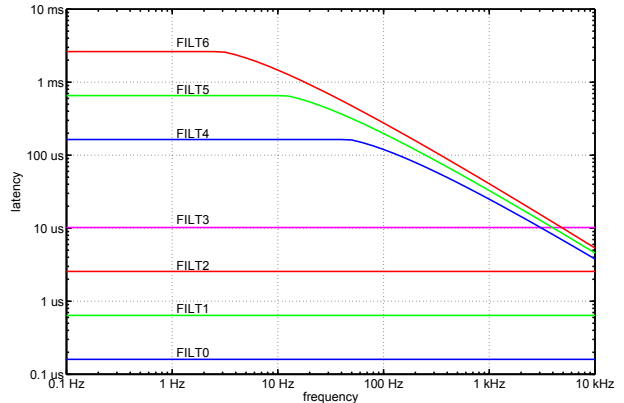


Figure 34: Filter latency

FILT Addr. 0x0E; bit 2:0				
Code	Type	noise sup-pression	latency	Interpol. MAS / NON
0x0	FILT0	0 dB	< 1 μs	12 bit
0x1	FILT1	15 dB	< 1 μs	14 bit
0x2	FILT2	21 dB	2.5 μs	14 bit
0x3	FILT3	27 dB	10 μs	14 bit
0x4	FILT4	39 dB	164 μs $f_{sin} < 50 \text{ Hz}$ 25 μs $f_{sin} < 1 \text{ kHz}$	14 bit
0x5	FILT5	45 dB	650 μs $f_{sin} < 12 \text{ Hz}$ 33 μs $f_{sin} < 1 \text{ kHz}$	14 bit
0x6	FILT6	51 dB	2.6 ms $f_{sin} < 3 \text{ Hz}$ 41 μs $f_{sin} < 1 \text{ kHz}$	14 bit
Note	Influences on the max. rotation speed with incremental output signals are shown in table 78			

Table 50: Digital filter features

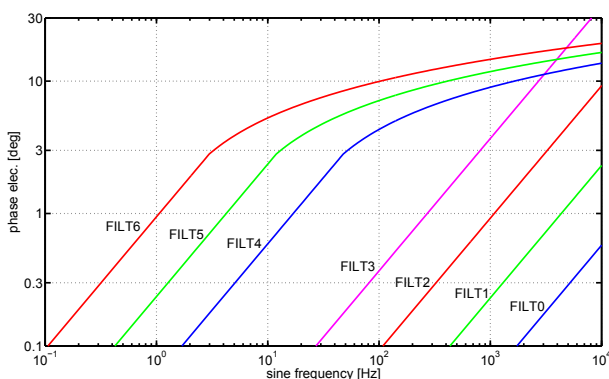


Figure 33: Phase relationship of the filters

### Synchronization mode

Table 51 lists the configurable master period counts and the resulting bit lengths for Nonius synchronization, and the synchronization bit length used. The parameter MPC defines thus the Nonius system and has to be chosen according to the magnetic code carrier. If MPC is switched during operation, command ABS\_RESET must be executed and the track offset values must be calibrated again.

MPC(3:0) Addr. 0x0F; bit 3:0					
Code	Master period count	Nonius period count	bit length	syn-chroniza-tion bit length	Maximum absolute resolution [bit]
0x4	16	15	4	8	18
0x5	32	31	5	7	19
0x6	64	63	6	6	20
for MU Series as Nonius-Multiturn *)					
0x7	128	127	7	5	21
0x8	256	255	8	4	22
0x9	512	511	9	3	23
0xA	1024	1023	10	2	24
0xB	2048	2047	11	1	25
0xC	4096	4095	12	0	26
Note	*) see page 47				

Table 51: Master period count and the resulting bit lengths

LIN selects the hall sensor arrangement to linear or rotative for axial or radial/linear scanning (see table 52).

LIN Addr. 0x0E; bit 4		
Code	Hall sensor arrangement	Type of target magnetization
0	Rotative	Axial
1	Linear	Radial or Linear

Table 52: Selection of linear/rotative hall sensors

An offset between the Nonius track and the master track within one revolution can be adjusted with SPO\_BASE and SPO\_x (x=0-14) .

The following formula describes how the error curve based on the raw data from the master and Nonius track can be calculated.  $2^{MPC}$  is the number of sine periods of the measuring distance.

$$TOL_{SPON} = RAW_{MASTER} - RAW_{NONIUS} * \frac{2^{MPC}}{2^{MPC} - 1}$$

The maximum tolerable phase deviation for a 2-track Nonius system is shown in Table 53. For the tolerable phase deviation of a 3-track Nonius system please refer to Table 67 page 47.

Periods/revolution		Permissible Max. Phase Deviation [given in degree per signal period of 360°] Master ↔ Nonius
Master	Nonius	
16	15	+/- 9.84°
32	31	+/- 4.92°
64	63	+/- 2.46°

Table 53: Tolerable phase deviation for the master versus the Nonius track of a 2 track Nonius system (with reference to 360°, electrical)

**Note:** The lower the maximum permissible phase deviation, the higher the demands on the mechanical system design and the quality of the magnetic target.

An offset correction curve can be specified with SPO\_BASE and SPO\_x (x = 0-14). SPO\_BASE is the start-value. SPO\_0 to SPO\_14 can be interpreted as slope-values. A change in the slope of the offset function can be made each 22.5°. The slope value SPO\_15 is computed automatically by iC-MU Series. To do this the following condition must be met:

$$\sum_{x=0}^{14} SPO\_x = \{-7 \dots 7\}$$

The offset value between two slopes (e.g. SPO\_0 and SPO\_1) is interpolated. The computed offset is added

to the converted result of the Nonius track prior to synchronization and is used to calibrate the Nonius to the master track. An offset value is chosen by the absolute position given by the Nonius difference (master-Nonius).

SPO_BASE(3:0) Addr. 0x19; bit 3:0	
SPO_BASE(3:0) Addr. SER:0x52; bit 3:0	
Code	Starting point referred to 1 revolution
0x0	0 * (22.5° / 2 <sup>MPC</sup> )
...	...
0x7	7 * (22.5° / 2 <sup>MPC</sup> )
0x8	-8 * (22.5° / 2 <sup>MPC</sup> )
0x9	-7 * (22.5° / 2 <sup>MPC</sup> )
...	...
0xF	-1 * (22.5° / 2 <sup>MPC</sup> )

Table 54: Nonius track offset start value

<b>SPO_0(3:0)</b>	Addr. 0x19; bit 7:4	Addr. SER: 0x52
<b>SPO_1(3:0)</b>	Addr. 0x1A; bit 3:0	Addr. SER: 0x53
<b>SPO_2(3:0)</b>	Addr. 0x1A; bit 7:4	Addr. SER: 0x53
<b>SPO_3(3:0)</b>	Addr. 0x1B; bit 3:0	Addr. SER: 0x54
<b>SPO_4(3:0)</b>	Addr. 0x1B; bit 7:4	Addr. SER: 0x54
<b>SPO_5(3:0)</b>	Addr. 0x1C; bit 3:0	Addr. SER: 0x55
<b>SPO_6(3:0)</b>	Addr. 0x1C; bit 7:4	Addr. SER: 0x55
<b>SPO_7(3:0)</b>	Addr. 0x1D; bit 3:0	Addr. SER: 0x56
<b>SPO_8(3:0)</b>	Addr. 0x1D; bit 7:4	Addr. SER: 0x56
<b>SPO_9(3:0)</b>	Addr. 0x1E; bit 3:0	Addr. SER: 0x57
<b>SPO_10(3:0)</b>	Addr. 0x1E; bit 7:4	Addr. SER: 0x57
<b>SPO_11(3:0)</b>	Addr. 0x1F; bit 3:0	Addr. SER: 0x58
<b>SPO_12(3:0)</b>	Addr. 0x1F; bit 7:4	Addr. SER: 0x58
<b>SPO_13(3:0)</b>	Addr. 0x20; bit 3:0	Addr. SER: 0x59
<b>SPO_14(3:0)</b>	Addr. 0x20; bit 7:4	Addr. SER: 0x59
Code	Slope referred to 1 revolution	
0x0	0 * (22.5° / 2 <sup>MPC</sup> )	
...	...	
0x7	7 * (22.5° / 2 <sup>MPC</sup> )	
0x8	-8 * (22.5° / 2 <sup>MPC</sup> )	
0x9	-7 * (22.5° / 2 <sup>MPC</sup> )	
...	...	
0xF	-1 * (22.5° / 2 <sup>MPC</sup> )	
Note	$\sum_{x=0}^{14} SPO\_x = \{-7 \dots 7\} * (22.5° / 2^{MPC})$	

Table 55: Nonius track offset slopes

SPO_15(3:0) Addr. SER:0x5A; bit 3:0	
Code	Slope
0x0	-
...	is automatically computed: $-\sum_{x=0}^{14} SPO\_x$
0xF	-
Note	internal register, not readable via serial interface

Table 56: Nonius track offset slope (is automatically computed)

The principle is shown in Figure 35. The red curve corresponds to the error curve of the Nonius difference absolute within 360°. By taking the blue marked SPO\_x curve it is shown, that the Nonius difference can be changed in a way that the resulting green curve is in the valid synchronization range. It can be seen that an error within 22.5° (in the Figure between 67.5° and 90°) can not be corrected. For SPO\_0 the range of a possible slope change is exemplary shown.

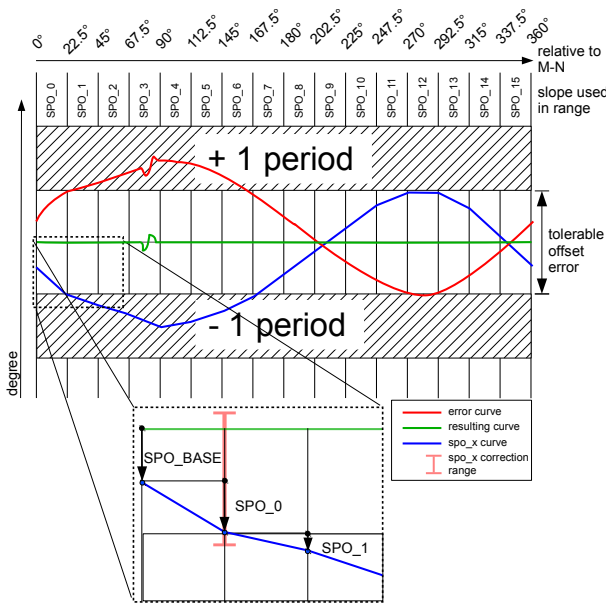


Figure 35: Nonius track offset calibration

Following the first Nonius synchronization the number of exceeded periods is counted and output. Using NCHK\_NON the system can be configured to check the internal period counter against the period given by the code disc at regular intervals. Command NON\_VER explicitly requests Nonius verification. If an error is found during verification of the Nonius, bit NON\_CTR is set in status register STATUS1.

Figure 36 describes the principle of Nonius synchronization with verification, with  $\varphi$  representing the respective digitized angle of the relevant track.

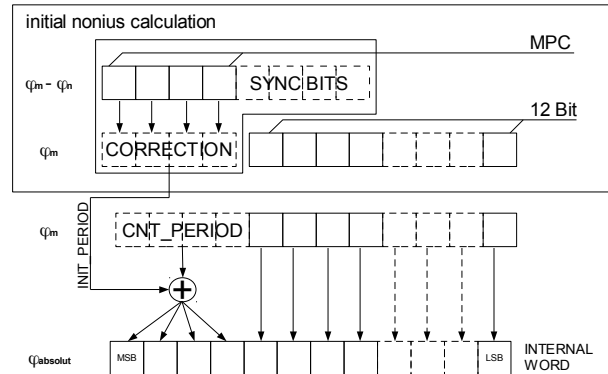


Figure 36: Principle of Nonius synchronization

NCHK_NON		Addr. 0x0D; bit 5
Code	Description	
0	automatic period verification	
1	no automatic period verification	
Notes:	For max. duration of the internal cyclic checks see elec. char. no. 408	

Table 57: Automatic Nonius period verification

The Nonius data and incremental interface can be automatically reset with ACRM\_RES if the master amplitude is too low. The incremental section is reset as soon as the amplitude control unit indicates that the master amplitude is too low (AM\_MIN occurs, see Table 96). The ABZ-interface shows position 0 as default. When the master amplitude is again in its set range, a new Nonius calculation is carried out and the incremental section is restarted.

ACRM_RES		Addr. 0x0D; bit 4
Code	Description	
0	no automatic reset	
1	automatic reset active	

Table 58: Automatic Reset triggered by AM\_MIN

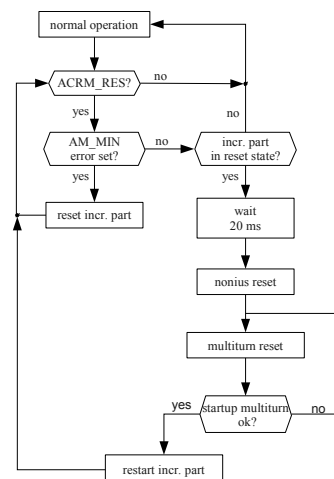


Figure 37: Automatic reset ACRM\_RES

## MT INTERFACE

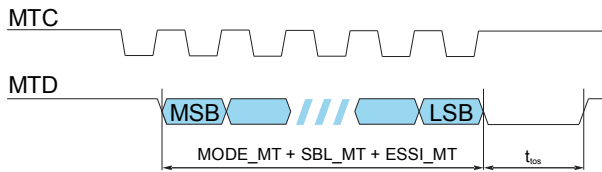


Figure 38: Example of multiturn SSI line signals

### Configuration of the Multiturn interface

iC-MU Series can read in and synchronize binary data from an external SSI sensor through the serial multiturn interface. On startup the first data value read in determines the start value of the internal multiturn counter. After startup the multiturn counter counts the ST cycles. If there is an error reading the external multiturn during startup, the read-in will be repeated.

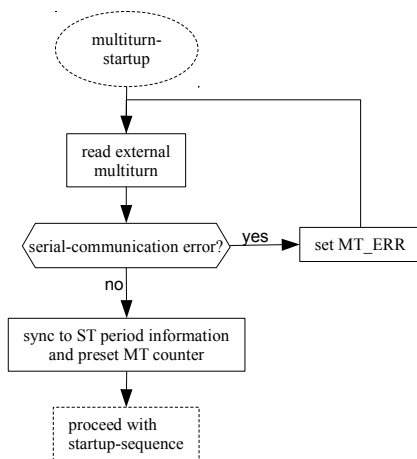


Figure 39: Error handling during startup

If the MT interface is not used ( $MODE\_MT = 0x0$ ), the internal 24-bit MT counter can extend the singleturn information to include the counted ST cycles. To access the internal MT counter increase parameter  $OUT\_MSB$  accordingly.

For exclusive multiturn systems a 4, 8, 12, 16 or 18-bit multiturn data value can be read in ( $MODE\_MT = 0xB-0xE$ ).

There is also the possibility to interpret a part of the external multiturn data value as singleturn data ( $MODE\_MT = 0x1-0xA$ ). This influences the incremental output signals, UVW commutation signals and data output in  $MODE\_ST = 0x01$  (FlexCount®). For further information see **Construction of a Multiturn system with two iC-MU Series** p. 47.

MODE_MT(3:0) Addr. 0x10; bit 3:0			
Code	Function	Code	Function
0x0	no external data	0x8	4 *) + 12 bits
0x1	1 *) bit	0x9	5 *) + 12 bits
0x2	2 *) bits	0xA	6 *) + 12 bits
0x3	3 *) bits	0xB	4 bits
0x4	4 *) bits	0xC	8 bits
0x5	5 *) bits	0xD	12 bits
0x6	6 *) bits	0xE	16 bits
0x7	3 *) + 12 bits	0xF	18 bits
Notes:	*) data interpreted as ST If $MPC \geq 0x07$ than $MODE\_MT$ has to be set to 0x0 or 0xD		

Table 59: MT interface operating mode

For synchronization a synchronization bit length must be set with  $SBL\_MT$ . Synchronization takes place between the external multiturn data read in and the ST period information counted internally (see Fig. 41). Synchronization can take place automatically within the relevant phase tolerances.

SBL_MT(1:0) Addr. 0x10; bit 5:4		
Code	MT synchronization bit length	synchronization tolerance (ST-resolution)
0x0	1 bit	$\pm 90^\circ$
0x1	2 bits	$\pm 90^\circ$
0x2	3 bits	$\pm 135^\circ$
0x3	4 bits	$\pm 157.5^\circ$

Table 60: MT synchronization bit length

Figure 40 shows the principle of a 2 bit MT synchronization for ideal signals (without indication of synchronization tolerance limits).

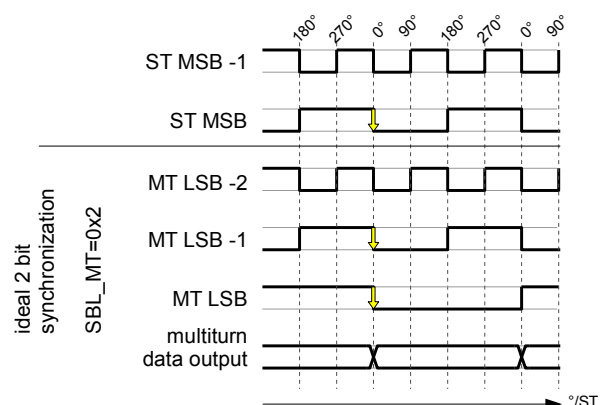


Figure 40: Principle of 2 bit MT synchronization

The code direction of the read multiturn data can be inverted using parameter ROT\_MT.

ROT_MT		Addr. 0x0E; bit 5
Code	Function	
0	no inversion of code direction	
1	inversion of code direction	

Table 61: Inverted code direction of external multiturn

The parameter ESSI\_MT configures the evaluation of an optional error-bit send by the external multiturn device.

ESSI_MT		Addr. 0x0E; bit 7:6
Code	Function	
0x0	no error bit	
0x1	1 error-bit low active	
0x2	reserved	
0x3	1 error-bit high active	

Table 62: Evaluation of an error-bit of the external multiturn

The SSI parity and warning bit are not supported by iC-MU Series and need to be deactivated in the external multiturn sensor.

The total data length of the external read multiturn data word is determined by:

$$\text{data\_length\_ext\_mt} = \text{Bits}(\text{MODE\_MT}) + \text{Bits}(\text{SBL\_MT}) + \text{Bits}(\text{ESSI\_MT})$$

The parameter SPO\_MT allows to balance an existing static offset between the singleturn and the multiturn. The offset is added before the synchronization of the read multiturn data (see Figure 41).

SPO_MT		Addr. 0x0F; bit 7:4
Code	Function	
0x0	multiturn offset	
...		
0xF		

Table 63: Offset of external multiturn

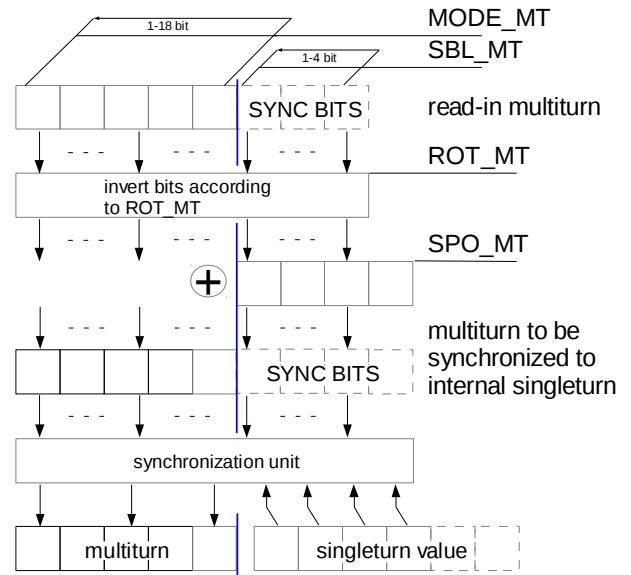


Figure 41: Parameters to configure external multiturn

CHK\_MT can be used to verify the counted multiturn at regular intervals. Verification can also be requested using command MT\_VER. A multiturn verification error (comparison of the internal MT counter with the external multiturn data) is reported on status bit MT\_CTR.

CHK_MT		Addr. 0x10; bit 6
Code	Function	
0	no verification	
1	periodical verification	

Table 64: Multiturn verification

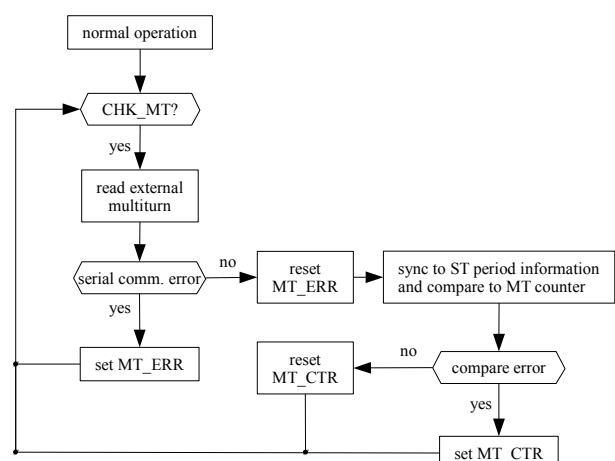


Figure 42: Error handling in normal operation with cyclic verification of the period counter

## Construction of a Multiturn system with two iC-MU Series

A 3 track Nonius system can be build using two iC-MU Series chips of the same type. The singleturn iC-MU Series (1) can be configured to interpret 3, 4, 5, or 6 bits of the read multiturn data as singleturn data (ST) (see Table 59). The output through the incremental interface, the UVW interface and the serial interface in MODE\_ST = 0x1 (FlexCount) of iC-MU Series (1) is then absolute with this additional information.

The construction of such a system is shown as an example in Figure 43 and the configuration in Table 65.

Master Periods	128	256	512	1024
iC-MU Series (1): singleturn				
Parameter	Value	Value	Value	Value
MPC	0x04	0x04	0x05	0x05
MODE_MT	0x03	0x04	0x04	0x05
SBL_MT	0x03	0x03	0x03	0x03
ROT_MT	0x01	0x01	0x01	0x01
NCHK_NON	0x00	0x00	0x00	0x00
CHK_MT	0x01	0x01	0x01	0x01
ESSI_MT	0x01	0x01	0x01	0x01
LIN	0x01	0x01	0x01	0x01
OUT_LSB	0x00	0x00	0x00	0x00
OUT_MSB	0x07	0x08	0x09	0x0A
iC-MU Series (2): multiturn				
Parameter	Value	Value	Value	Value
MPC	0x07	0x08	0x09	0x0A
MODE_MT	0x00	0x00	0x00	0x00
MODE_ST	0x00	0x00	0x00	0x00
ROT	0x00	0x00	0x00	0x00
NCHK_NON	0x00	0x00	0x00	0x00
GSSI	0x00	0x00	0x00	0x00
MODEA	0x05	0x05	0x05	0x05
LIN	0x01	0x01	0x01	0x01
OUT_LSB	0x0E	0x0E	0x0F	0x0F
OUT_MSB	0x07	0x08	0x09	0x0A
OUT_ZERO	0x00	0x00	0x00	0x00

Table 65: Configuration example for the 3-track Nonius systems of 128, 256, 512 and 1024 master periods

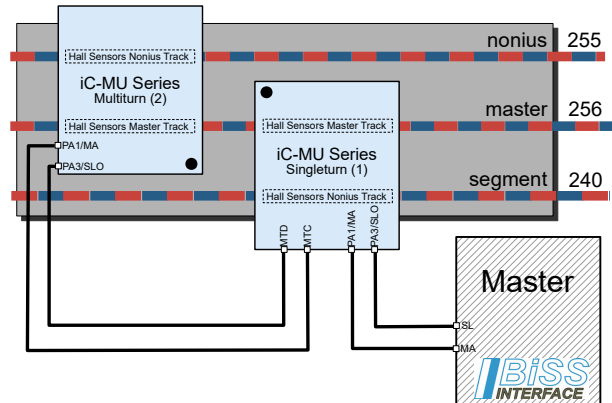


Figure 43: 3-track Nonius with 2 iC-MU Series

Table 66 shows the possible settings for a 3-track Nonius systems with 2 iC-MU Series and the resulting periods/revolution of the tracks. The maximum phase deviation of the tracks is summarized in Table 67.

MPC (2)	(1)	Periods/revolution			ST Periods [Bit]	
		Master	Segm.	Nonius	from MT(2)	from ST(1)
0x7	0x4	128	120	127	3	4
0x8	0x4	256	240	255	4	4
0x9	0x5	512	496	511	4	5
0xA	0x5	1024	992	1023	5	5
0xB	0x6	2048	2016	2047	5	6
0xC	0x6	4096	4032	4095	6	6

Table 66: Settings for a 3-track Nonius system using 2 iC-MU Series

Periods/revolution			Permissible Max. phase deviation [given in degree per signal period of 360°]	
Master	Segm.	Nonius	Master ↔ Segm. (1)	Master ↔ Non.* (2)
128	120	127	+/-9.84°	+/-19.68°
256	240	255	+/-9.84°	+/-9.84°
512	496	511	+/-4.92°	+/-9.84°
1024	992	1023	+/-4.92°	+/-4.92°
2048	2016	2047	+/-2.46°	+/-4.92°
4096	4032	4095	+/-2.46°	+/-2.46°
Note	*) with SBL_MT=0x3			

Table 67: Tolerable phase deviation for the master versus the Nonius or segment track of a 3-track Nonius system (with reference to 360°, electrical)

**Note:** The lower the maximum permissible phase deviation, the higher the demands on the mechanical system design and the quality of the magnetic target.

Figure 44 shows the principle of the synchronization of the data from iC-MU Series (2) to iC-MU Series (1).

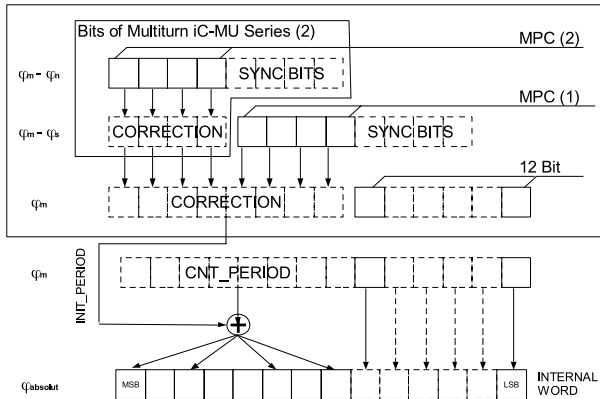


Figure 44: Principle of the synchronization of a 3-track Nonius system using 2 iC-MU Series without further multitrurn data

To facilitate the initial configuration of an iC-MU Series as a SSI multitrurn device the command SWITCH can be used (see page 61). The singleturn iC-MU Series (1) in Figure 43 has to enable the direct communication to the multitrurn sensor by setting GET\_MT to 1. The configuration of iC-MU Series (2) can take place using the BiSS protocol. After the configuration of the external multitrurn MODEA\_NEW and RPL\_NEW are used to set the target configuration of MODEA and RPL. After that the command SWITCH is executed. By reading STATUS1 it is possible to control if there was an error while executing the command. After the next startup or after the execution of the command SOFT\_RESET iC-MU Series starts with the interface configured with MODEA\_NEW and RPL\_NEW.

### MT Interface Daisy Chain

The MT interface daisy chain mode gives direct access to an external multitrurn sensor for calibration purposes.

MODEA	
Code	Function
0x2	BiSS
0x5	SSI+ERRL
0x6	SSI+ERRH
0x7	ExtSSI

Table 68: MT Interface Daisy Chain: Possible MODEA configuration

Making use of the BiSS Interface bus capabilities, iC-MU Series can connect the external multitrurn sensor to the BiSS master controller in modes MODEA = 0x02 (BiSS) and MODEA = 0x05-0x07 (SSI with Error bit and ExtSSI; additional condition RSSI = 1) when GET\_MT is enabled.

To this end input pin MA (PA1) receiving the BiSS master's clock signal is fed through to output pin MTC and the input pin MTD is activated in place of the input pin SLI (PA2). Upon enabling this mode the single cycle timeout (see Fig. 3) must have elapsed and an additional init command carried out by the BiSS master, before it can run the first register communication.

**Note:**  
Additional condition RSSI = 1 when using GET\_MT and MODEA = 0x05, 0x06 or 0x07.  
**Hint:**  
First set GET\_MT then RSSI to activate direct communication to Multitrurn Sensor in SSI modes.

Example: external multitrurn sensor built with iC-MU Series is connected to the MT interface of a first iC-MU Series, preparing the singleturn data. With GET\_MT enabled, the external multitrurn can then be addressed via BiSS ID 0 and the singleturn via BiSS ID 1. This temporal chain operation simplifies device configuration during encoder manufacturing.

GET_MT	
Addr. 0x10; bit 7	
Code	Function
0	Disabled
1	MT interface daisy chain

Table 69: Direct BiSS communication enable for MT sensor via I/O Interface

## INCREMENTAL OUTPUT ABZ, STEP/DIRECTION AND CW/CCW

MODEA	
Code	Description
0x3	ABZ
MODEB	
Code	Description
0x0	ABZ
0x2	Step/Direction
0x3	CW/CCW Incremental
Note:	It is not possible to select an incremental interface on MODEA and MODEB simultaneously

Table 70: MODEA/MODEB: ABZ, step/direction and CW/CCW

The resolution of incremental signals ABZ can be programmed for each singleturn cycle within a range of 4 to 262,144 edges using the internal FlexCount®. The number of master periods which is equivalent to a singleturn cycle is defined by the settings in register MPC (Table 51).

RESABZ(7:0)	Addr. 0x13; bit 7:0	
RESABZ(15:0)	Addr. 0x14; bit 7:0	
Code	Resolution	Interpolation factor
0x0000	4	1
0x0001	8	2
...	...	...
0xFFFF	262,144	65,536
Note:	For non-binary resolutions above 32,768 (0x2000) the relative error increases	

Table 71: FlexCount®- Resolution

In linear application the min. increment of the incremental output (FlexCount) can be calculated as follows:

$$\frac{MPC * \text{magnetic period}}{\text{max. resolution FlexCount}} = \text{min. increment linear}$$

Example calculation for iC-MU150 and MPC = 0x5:

$$\frac{32 * 3.00\text{mm}}{262144} = 366.2\text{nm}$$

### Note:

In linear applications the minimum increment of 156 nm (iC-MU128), 183 nm (iC-MU150) and 244 nm (iC-MU200) can be read via the serial interfaces for MODE\_ST = 0x0 (output absolute position) independent of the selected MPC.

Figure 45 shows the ABZ, step/direction, and CW/CCW signals. The length of a signal A or B cycle is defined by  $\varphi_{360AB}$  as a range between two rising edges of an A or B signal.

$\varphi_{\text{hys}}$  represents the hysteresis which must be exceeded before further edges are generated at the incremental interface.

Minimum edge distance  $t_{\text{mtd}}$  is the minimum time which must have elapsed before another event can be output at the incremental interface.

The length of the Z pulse with setting ZLEN = 0x00 is defined by  $\varphi_{z90}$ .

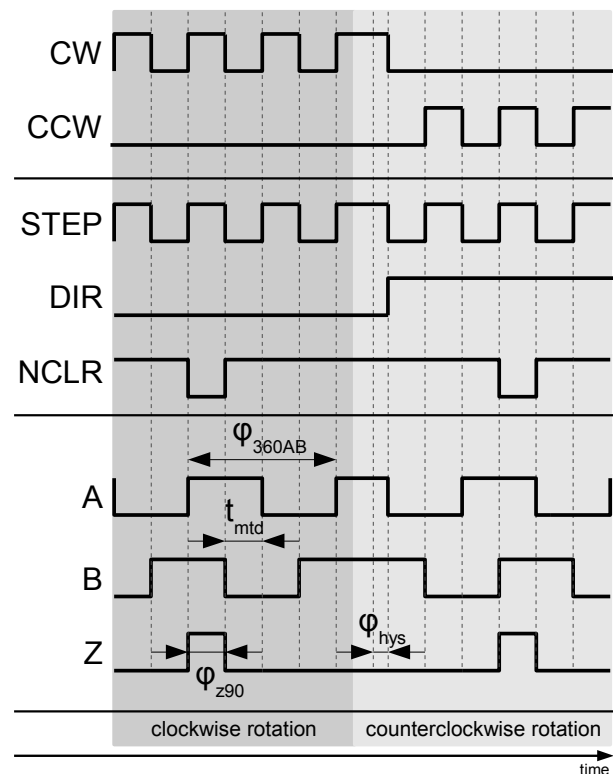


Figure 45: Definition of the ABZ, STEP/DIR, and CW/CCW signals

The phase position of the incremental output signals can be inverted using the relevant configuration bit INV\_x (x = A,B,Z).

INV_A		Addr. 0x16; bit 2
Code	A/STEP/CW-Signal	
0	normal	
1	inversion	

Table 72: Inversion A-Signal

INV_B		Addr. 0x16; bit 1
Code	B/DIR/CCW-Signal	
0	normal	
1	inversion	

Table 73: Inversion B-Signal

INV_Z		Addr. 0x16; bit 0
Code	Z/NCLR-Signal	
0	normal	
1	inversion	

Table 74: Inversion Z-Signal

Index pulse Z can be programmed in four lengths. The position of the index pulse in relation to the A/B signals is shown in Figure 46.

LENZ(1:0)		Addr. 0x16; bit 7:6
Code	Z-pulse length	
0x0	90°	
0x1	180°	
0x2	270°	
0x3	360°	

Table 75: Index pulse length

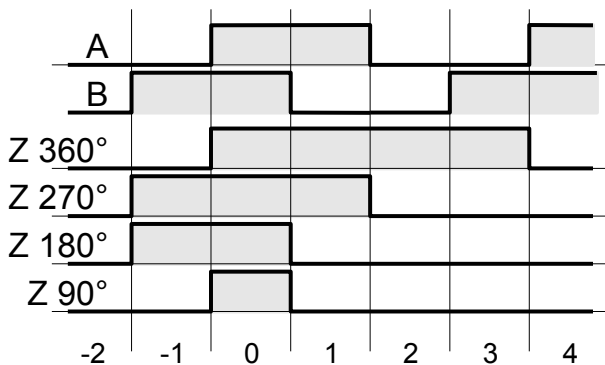


Figure 46: Index pulse length settings

The position data code direction of the incremental output signals ABZ, STEP/DIRECTION and CW/CCW can be inverted with the parameters ROT\_ALL and ROT\_POS. Both parameters are EXOR-gated and together comprise the internal code direction signal for the incremental output signals (Figure 47).

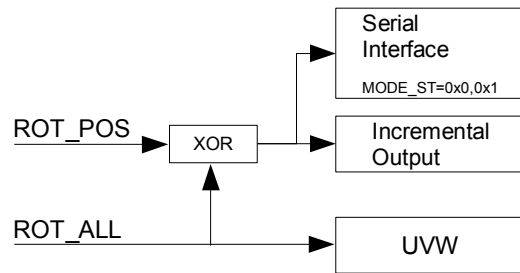


Figure 47: Effect of ROT\_ALL and ROT\_POS on position data code direction

**Note:**

**Parameter ROT\_ALL** affects the output of the data word through the serial interface in MODE\_ST = 0x0 and 0x1, the incremental outputs and the UVW-interface.

**Parameter ROT\_POS** affects the output of the data word through the serial interface in MODE\_ST = 0x0 and 0x1 and the incremental outputs.

For the description of the commands ROT\_POS and ROT\_POS\_E2P see P.61.

ROT_ALL		Addr. 0x15; bit 7
Code	Description	
0	no inversion of code direction	
1	inversion of code direction	
Notes:	no effect in MODE_ST = 2 (raw-data) for the data output of the serial interface ROT_POS can change the code direction in MODE_ST = 0x0 and 0x1, incremental outputs	

Table 76: Inversion of the code direction for the serial interface in MODE\_ST = 0x0 and 0x1, incremental outputs and UVW-interface

ROT_POS		Addr. 0x23; bit 0
ROT_POS		Addr. SER:0x1E; bit 0
Code	ROT_ALL = 0	ROT_ALL = 1
0	no inversion of code direction	inversion of code direction
1	inversion of code direction	no inversion of code direction
Note:	no effect in MODE_ST = 2 (raw-data) for the data output of the serial interface and on UVW-interface	

Table 77: Resulting inversion of code direction for the serial interface in MODE\_ST = 0x0 and 0x1, incremental outputs

Parameter SS\_AB must be configured depending on the maximum speed. With a filter setting of FILT = 0x00 (Table 50), correspondingly higher SS\_AB step size values must be programmed. The maximum possible resolution of the incremental count signal is limited by

the selected step size. The FRQ\_ABZ status bit is set in the case of an unacceptable high speed.

SS_AB(1:0) Addr. 0x15; bit 5:4					
Code	max res.	FILT	max. rotation speed *)		
			MPC = 0x4 (16/15)	MPC = 0x5 (32/31)	MPC = 0x6 (64/63)
0x0	2 <sup>18</sup>	0x0 ≥ 0x1	don't use 6000 rpm	don't use 6000 rpm	1500 rpm 6000 rpm
0x1	2 <sup>17</sup>	0x0 ≥ 0x1	don't use 12000 rpm	3000 rpm 12000 rpm	3000 rpm 6000 rpm
0x2	2 <sup>16</sup>	0x0 ≥ 0x1	6000 rpm 24000 rpm	6000 rpm 12000 rpm	6000 rpm 6000 rpm
0x3	2 <sup>15</sup>	0x0 ≥ 0x1	12000 rpm 24000 rpm	12000 rpm 12000 rpm	6000 rpm 6000 rpm
Note:	*) FRQAB = 0x0				

Table 78: System AB step size and limitation of rotation frequency

The minimum edge distance  $t_{mtd}$  of the ABZ, STEP/DIR or CW/CCW interface can be limited by setting the maximum output frequency with FRQAB. It can be used to adjust the output frequency to a frequency limit given by an external ABZ, STEP/DIR or CW/CCW counter device.

FRQAB(2:0) Addr. 0x15; bit 2:0		
Code	Output frequency AB	Edge distance $t_{mtd}$
0x0	6.25 MHz	40 ns
0x1	3.13 MHz	80 ns
0x2	1.56 MHz	160 ns
0x3	781.25 kHz	320 ns
0x4	390.63 kHz	640 ns
0x5	195.31 kHz	1.28 $\mu$ s
0x6	48.83 kHz	5.12 $\mu$ s
0x7	12.2 kHz	20.48 $\mu$ s

Table 79: AB output frequency

The incremental counter has an integrated hysteresis which prevents multiple switching of the incremental signals at the reversing point. Hysteresis  $\varphi_{hys}$  must first be exceeded before edges can again be generated at A or B. This hysteresis can be set within a range of 0° to 0.35° according to Table 80 and is referenced to 360° of a singleturn cycle.

CHYS_AB(1:0) Addr. 0x16; bit 5:4		
Code	Hysteresis	parameter SS_AB
0x0	0.0014°	0x0
0x0	0.0041°	0x1
0x0	0.0096°	0x2
0x0	0.021°	0x3
0x1	0.175°	d.c.
0x2	0.35°	d.c.
0x3	0.7°	d.c.
Note:	d.c.: don't care	

Table 80: Hysteresis with an inverted direction of rotation

The parameter ENIF\_AUTO selects whether at startup the incremental interface is enabled after the converter has found its operating point or if the counting to the absolute singleturn angle can be seen at the incremental interface.

ENIF_AUTO Addr. 0x15; bit 3	
Code	Description
0	counting to operating point visible
1	counting to operating point not visible

Table 81: Incremental interface enable

See the chapter on the preset function (p. 65) to set the offset for ABZ output.

## UVW COMMUTATION SIGNALS

MODEB	
Code	Description
0x1	UVW

Table 82: MODEB: UVW

iC-MU Series can generate commutation signals for BLDC motors from 1 up to 16 pole pairs. The hysteresis is set fixed to 0.0879° referenced to a mechanical revolution.

Figure 48 shows the commutation sequence for a motor with 6 pole pairs. Here, a commutation sequence spanning an angle of  $\varphi_{360UVW}$  repeats itself 6 times within one mechanical revolution of the motor. The phase shift between the commutation signals is 120°.

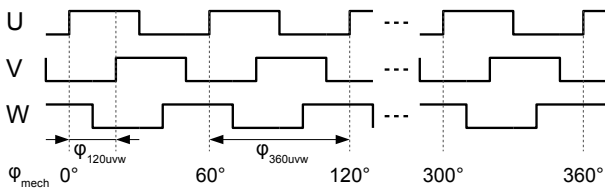


Figure 48: commutation signals UVW

Using parameter PPUVW the number of commutation sequences per mechanical revolution can be set.

PPUVW(5:0) Addr. 0x17; bit 5:0			
Code	number of pole pairs	Code	number of pole pairs
0x02	1 pole pair	0x1A	9 pole pairs
0x05	2 pole pairs	0x1D	10 pole pairs
0x08	3 pole pairs	0x20	11 pole pairs
0x0B	4 pole pairs	0x23	12 pole pairs
0x0E	5 pole pairs	0x26	13 pole pairs
0x11	6 pole pairs	0x29	14 pole pairs
0x14	7 pole pairs	0x2C	15 pole pairs
0x17	8 pole pairs	0x2F	16 pole pairs

Table 83: Number of commutation signal pole pairs

The sequence of the commutation signals can be selected by  $\varphi_{120UVW}$  as in Figure 48 or with a distance of 60° between two neighboring rising edges referenced to one UVW cycle using parameter PP60UVW.

PP60UVW Addr. 0x16; bit 3	
Code	Phase UVW signals
0	120° phase shift
1	60° phase shift

Table 84: Commutation signal phase length

Register OFF\_UVW is used to set the start angle and compensate for the offset between the winding of the BLDC and the Hall sensor signals. This angle can be set with 12 bits.

### Note:

After startup or the commands SOFT\_RESET and ABS\_RESET the OFF\_UVW values are amended to include the Nonius data, with a configured multi-turn updated with the multiturn data, and stored as OFF\_COM in the internal RAM.

Code	Offset UVW signals
0x000	0.00° mech
0x001	0.09° mech
...	$\frac{360.0^\circ \text{ mech}}{4096} \cdot \text{OFF\_UVW}$
0xFFFF	359.9° mech

Table 85: Commutation signal start angle

OFF_COM(3:0) Addr. SER:0x23; bit 7:4		R
OFF_COM(11:4) Addr. SER:0x24; bit 7:0		R
Code	Description	
0x000	start angle commutation signal (automatically computed)	
...		
0xFFFF		

Table 86: Commutation signal start angle amended by the Nonius/MT

The code direction of the UVW-signals can be inverted with parameter ROT\_ALL.

### Note:

Parameter ROT\_ALL affects the output of the data word of the serial interface in MODE\_ST=0x0 and 0x1, the incremental outputs (ABZ) and the UVW-interface.

ROT_ALL Addr. 0x15; bit 7	
Code	Description
0	no inversion of code direction
1	inversion of code direction

Table 87: Inverted code direction

## REGISTER ACCESS THROUGH SERIAL INTERFACE (SPI AND BISS)

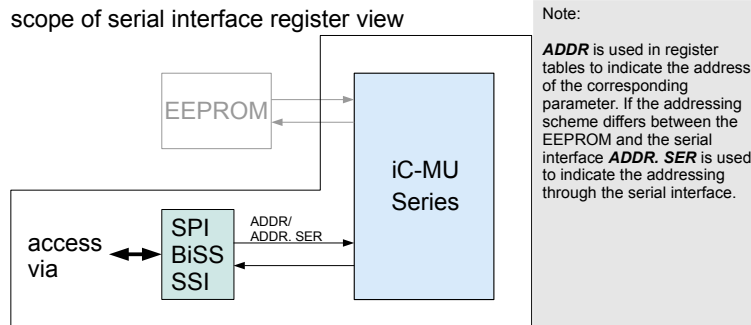


Figure 49: Scope of register mapping serial interface

The distribution of addresses in iC-MU Series corresponds to the document BiSS C Protocol Description which can be downloaded at [www.biss-interface.com](http://www.biss-interface.com).

The address translation for the addressable memory areas via the bank register to the EEPROM addresses is shown in Table 89.

iC-MU Series supports an addressing scheme using banks. Therefore the internal address space is divided into banks of 64 bytes each. The address sections visible via the I/O interface recognizes a "dynamic" section (addresses 0x00 to 0x3F) and a "static" section which is permanently visible (addresses 0x40 to 0x7F). The static address section is always visible independent of the bank currently selected. Figure 50 illustrates how the banks selected by BANKSEL are addressed.

Code	Bank	Memory location during operation	Mode
CONF	0	internal register	iC-MU Series configuration data
EDS	1	E2P: 0x040-0x07F	Electronic Data Sheet
...	...	...	
4	E2P: 0x100-0x13F		
USER	5	E2P: 0x140-0x17F	OEM data, free user area
...	...	...	
31	E2P: 0x7C0-0x7FF		

BANKSEL(4:0) Addr. SER:0x40; bit 4:0	
Code	Description
0x0	Selection of the memory bank
...	
0x1F	

Table 89: Address translation Addr Ser: 0x00-0x3F

Table 88: Register to select a memory bank

The abbreviation *Addr. SER* used in the register tables of the specification of the iC-MU Series stands for the addressing of this register through the serial interface.

After startup the BANKSEL register is set to 0.

**Note:** Burst mode is not supported by iC-MU Series for write access to the registers. Data has to be written byte-by-byte.

CONF: Bank 0, Addresses 0x00-0x3F								
Addr. SER	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0x00	GC_M(1:0)		GF_M(5:0)					
0x01	GX_M(6:0)							
0x02	VOSS_M(6:0)							
0x03	VOSC_M(6:0)							
0x04	PHR_M	PH_M(6:0)						
0x05	ENAC	CIBM(3:0)						
0x06	GC_N(1:0)		GF_N(5:0)					
0x07	GX_N(6:0)							

CONF: Bank 0, Addresses 0x00-0x3F									
Addr. SER	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
0x08	VOSS_N(6:0)								
0x09	VOSC_N(6:0)								
0x0A	PHR_N	PH_N(6:0)							
0x0B	MODEB(2:0)				NTOA	MODEA(2:0)			
0x0C	CFGEW(7:0)								
0x0D	ACC_STAT	NCHK_CRC	NCHK_NON	ACRM_RES	EMTD(2:0)				
0x0E	ESSI_MT(1:0)		ROT_MT	LIN	FILT(2:0)				
0x0F	SPO_MT(3:0)				MPC(3:0)				
0x10	GET_MT	CHK_MT	SBL_MT(1:0)		MODE_MT(3:0)				
0x11	OUT_ZERO(2:0)			OUT_MSB(4:0)					
0x12	GSSI	RSSI	MODE_ST(1:0)		OUT_LSB(3:0)				
0x13	RESABZ(7:0)								
0x14	RESABZ(15:8)								
0x15	ROT_ALL	SS_AB(1:0)		ENIF_AUTO	FRQAB(2:0)				
0x16	LENZ(1:0)		CHYS_AB(1:0)		PP60UVW	INV_A	INV_B	INV_Z	
0x17	RPL(1:0)		PPUVW(5:0)						
0x18	TEST(7:0)								
0x19	RESERVED								
...									
0x1D	RESERVED								
0x1E	OFF_ABZ(3:0)				RESERVED			ROT_POS	
0x1F	OFF_ABZ(11:4)								
0x20	OFF_POS*(19:12)								
0x21	OFF_POS*(27:20)								
0x22	OFF_POS*(35:28)								
0x23	OFF_COM**(3:0)				RESERVED				
0x24	OFF_COM**(11:4)								
0x25	PA0_CONF(7:0)								
0x26	RESERVED								
...									
0x2A	RESERVED								
0x2B	RESERVED			ACGAIN_M(1:0)		AFGAIN_M(2:0)			
0x2C	RESERVED								
...									
0x2E	RESERVED								
0x2F	RESERVED			ACGAIN_N(1:0)		AFGAIN_N(2:0)			
0x30	RESERVED								
...									
0x3F	RESERVED								
Note:	* OFF_ABZ value amended to include Nonius/multiturn information ** OFF_UVW value amended to include Nonius information								

Table 90: Register mapping bank 0, addresses 0x00-0x3F (access via serial interface)

OFF\_POS\* are the offset values (OFF\_ABZ) automatically changed by the period information of the initial Nonius calculation and if configured by the external multiturn data. OFF\_POS can thus be seen as a start value for the internally counted ST period and MT data.

Static part: Addresses 0x40-0xBF									
Addr. SER	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
0x40				BANKSEL(4:0)					
0x41	EDSBANK(7:0)								
0x42	PROFILE_ID(15:8)								
0x43	PROFILE_ID(7:0)								
0x44	SERIAL(31:24)								
0x45	SERIAL(23:16)								
0x46	SERIAL(15:8)								
0x47	SERIAL(7:0)								
0x48	OFF_ABZ(19:12)								
0x49	OFF_ABZ(27:20)								
0x4A	OFF_ABZ(35:28)								
0x4B	OFF_UVW(3:0)						RESERVED		
0x4C					OFF_UVW(11:4)				
0x4D	PRES_POS(3:0)						RESERVED		
0x4E	PRES_POS(11:4)								
0x4F	PRES_POS(19:12)								
0x50	PRES_POS(27:20)								
0x51	PRES_POS(35:28)								
0x52	SPO_0(3:0)				SPO_BASE(3:0)				
0x53	SPO_2(3:0)				SPO_1(3:0)				
0x54	SPO_4(3:0)				SPO_3(3:0)				
0x55	SPO_6(3:0)				SPO_5(3:0)				
0x56	SPO_8(3:0)				SPO_7(3:0)				
0x57	SPO_10(3:0)				SPO_9(3:0)				
0x58	SPO_12(3:0)				SPO_11(3:0)				
0x59	SPO_14(3:0)				SPO_13(3:0)				
0x5A	RPL_RESET(7:0)								
0x5B	I2C_DEV_START(7:0)								
0x5C	I2C_RAM_START(7:0)								
0x5D	I2C_RAM_END(7:0)								
0x5E	I2C_DEVID(7:0)								
0x5F	I2C_RETRY(7:0)								
0x60 ... 0x6F	USER_EXCHANGE_REGISTERS								
0x70 0x71 0x72	RESERVED								
0x73	EVENT_COUNT(7:0)								
0x74	HARD_REV(7:0)								
0x75	CMD_MU(7:0)								
0x76	STATUS0(7:0)								
0x77	STATUS1(7:0)								
0x78	DEV_ID(47:40)								
0x79	DEV_ID(39:32)								

Static part: Addresses 0x40-0xBF								
Addr. SER	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0x7A	DEV_ID(31:24)							
0x7B	DEV_ID(23:16)							
0x7C	DEV_ID(15:8)							
0x7D	DEV_ID(7:0)							
0x7E	MFG_ID(15:8)							
0x7F	MFG_ID(7:0)							
0x80*	CRC16(7:0)							
0x81*	CRC16(15:8)							
0x82*	CRC8(7:0)							
0x83*	RESERVED							
...								
0xAF*								

\*) Access on address space SER > 0x7F only via SPI interface possible

Table 91: Register mapping bank 0-31, addresses 0x40-0xBF (access via serial interface)

The current iC-MU Series chip type and hardware revision can be read out through HARD\_REV. The upper nibble indicates the chip type (iC-MU128 = 0b0000, iC-MU150 = 0b0001, iC-MU200 = 0b0010), and the lower nibble indicates the hardware revision.

HARD_REV(7:0) Addr. SER: 0x74; bit 7:0	
Code	Chip Type and Revision
0x0A	iC-MU128 X1
0x15	iC-MU150 X1
0x24	iC-MU200 X1

Table 92: HARD\_REV



For earlier hardware revisions see the respective iC-MU, iC-MU150 or iC-MU200 datasheet.

## Address sections/Register protection level

Register access can be restricted via RPL (see Table 93). RPL = 0x2/0x3 selects a shipping mode with limited access which can be set back to RPL = 0x0. To set back RPL the content of Bank: 0, Addr. SER: 0x17 has to be written to RPL\_RESET.

RPL(1:0) Addr. 0x17; bit 7:6		
Code	Mode	Access restriction
0x0	Configuration mode - no restrictions	RP0
0x1	Shipping mode - command I2C_COM not available, reset not possible	RP1
0x2	Shipping mode - command I2C_COM available, reset to RP0 possible	RP1
0x3	Shipping mode - command I2C_COM not available, reset to RP0 possible	RP1

Table 93: Register access control

RPL_RESET(7:0) Addr. SER:0x5A; bit 7:0	
Code	Description
0x00	Set back value for RPL
...	
0xFF	

Table 94: Set back value for RPL

Sections CONF, EDS and USER are protected at different levels in shipping mode for read and write access (see Figure 50).

RPL(1:0) Addr. 0x17; bit 7:6			
RPL*	Section		
	CONF	EDS	USER
RP0	r/w	r/w	r/w
RP1	n/a	r	r/w
Note	*) RPL: Register Protection Level n/a: iC-MU Series denies access to those register addresses r: Registers are readable w: Registers are writeable		

Table 95: Register Read/Write Protection Levels

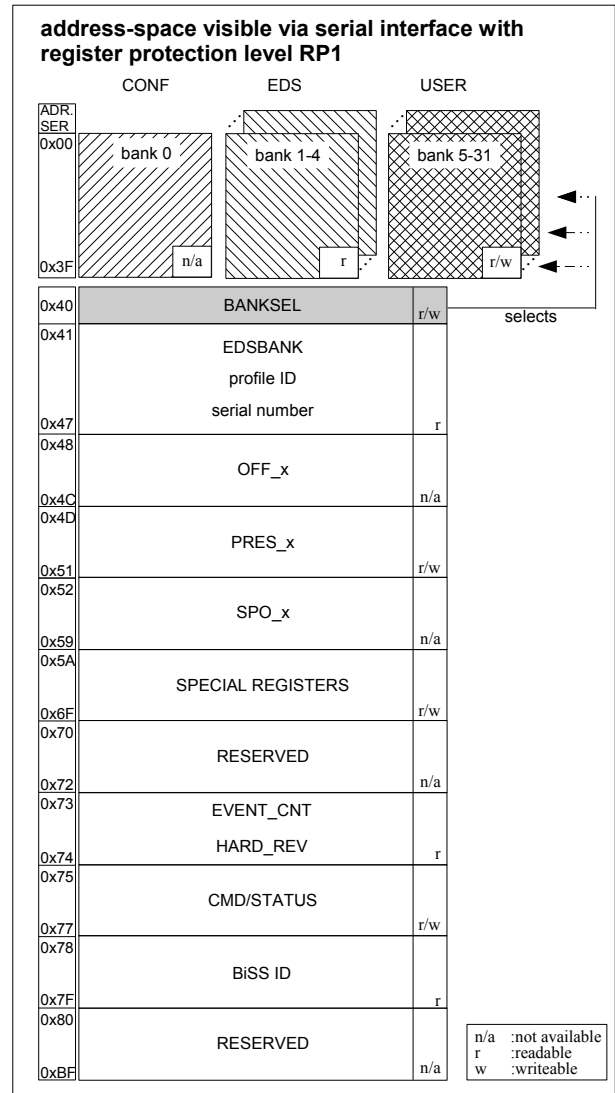


Figure 50: Principle of bank-wise memory addressing and access restrictions with register protection level RP1

## Overview Register access: memory mapping, Register protection levels

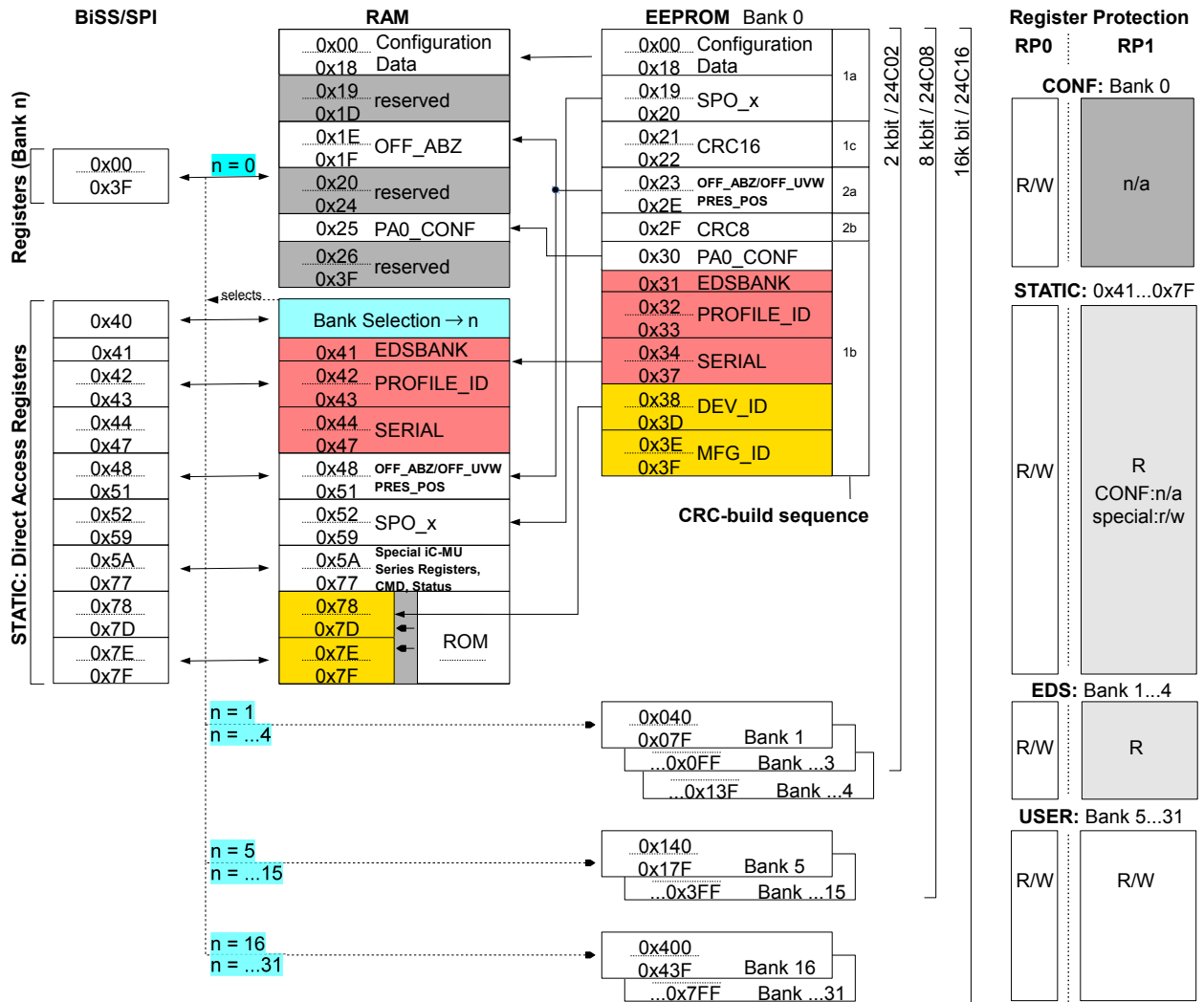


Figure 51: Register access with memory mapping

## STATUS REGISTER AND ERROR MONITORING

### Status register

Various Status-information can be read out via status bytes STATUS0 and STATUS1.

STATUS0(7:0)		Addr. SER: 0x76; bit 7:0	R
Bit	Name	Description of status message	
4	STUP	Startup iC-MU Series	
3	AN_MAX	Signal error*: clipping (Nonius track)	
2	AN_MIN	Signal error*: poor level (Nonius track)	
1	AM_MAX	Signal error*: clipping (master track)	
0	AM_MIN	Signal error*: poor level (master track)	
	Notes	Error indication logic: 1 = true, 0 = false, * for signal thresholds see elec. char. no. 508 and 509	

Table 96: Status register 0

Status bit **STUP** indicates that one or multiple of the following conditions apply during the startup routine:

- An I2C communication or CRC error occurred (ABZ/UVW engine is stopped, reset with ABS\_RESET)
- The amplitude of the master track is too low and ACRM\_RES = 1 (ABZ/UVW engine is stopped, reset when the master track amplitude is sufficient again)
- The multiturn interface is active and communication fails or the SSI error bit is active

STATUS1(7:0)		Addr. SER: 0x77; bit 7:0	R
Bit	Name	Description of status message	
7	CRC_ERR	Invalid check sum internal RAM	
6	EPR_ERR	I2C communication error: - No EEPROM - I2C communication error	
5	MT_ERR	Multiturn communication error: - MTD line not 1 when trying to read MT data - MTD line is not 0 right after the last clock pulse - SSI error bit active on MT interface*	
4	MT_CTR	Multiturn data consistency error: counted multiturn ↔ external MT data	
3	NON_CTR	Period counter consistency error: counted period ↔ calculated Nonius position	
2	FRQ_ABZ	Excessive signal frequency for ABZ-converter	
1	FRQ_CNV	Excessive signal frequency for internal 12-bit converter	
0	CMD_EXE	Command execution in progress	
	Notes	Error indication logic: 1 = true, 0 = false * ESSI_MT = 0x1 or 0x3	

Table 97: Status register 1

ACC\_STAT configures, if the status registers show the actual or the accumulated status information.

If the accumulated status is configured, the status bits are maintained until the status register is read out or

the command ABS\_RESET or SOFT\_RESET are executed. This is valid except for EPR\_ERR, STUP and CMD\_EXE. These bits are set in the status register independent of the ACC\_STAT configuration while the status information is active. The status register can be accessed independently of the internal operating state.

ACC_STAT		Addr. 0x0D; bit 7
Code	Description	
0	Output of actual status information	
1	Output of accumulated status information	

Table 98: Output configuration of status register

### Note:

A read access to the reserved addresses SER: 0x3D and 0x3E also clears the accumulated status information STATUS0 and STATUS1 if ACC\_STAT is set to 1.

### Error and warning bit configuration

The output and the polarity of the error and warning bit within the different serial protocols (MODEA Table 28) can be found in Table 99. Messages are allocated to the error and warning bit by parameter CFGEW according to Table 100.

MODEA(2:0)	Addr. 0x0B; bit 2:0				
	Function	Error		Warning	
		low active	high active	low active	high active
SPI	-	-	-	-	-
BiSS	x	-	-	x	-
SSI	-	-	-	-	-
SSI+ERRL	x	-	-	-	-
SSI+ERRH	-	x	-	-	-
ExtSSI	x	-	-	x	-

Table 99: MODEA: error/warning-bit within serial protocols

<b>CFGEW(7:0)</b> Addr. 0x0C; bit 7:0	
Bit	Visibility for error bit
7	MT_ERR/MT_CTR
6	NON_CTR
5	Ax_MAX and Ax_MIN
4	EPR_ERR
3	CRC_ERR
2	CMD_EXE
Bit	Visibility for warning bit
1	FRQ_CNV/FRQ_ABZ
0	Ax_MAX and Ax_MIN
Notes	x = M, N Encoding: 0 = message enabled, 1 = message disabled

Table 100: Error and warning bit configuration

If an error pin is configured using parameter MODEB (Table 29), an internal error (see status register, ACC\_STAT configuration and error bit configuration with CFGEW) is reported by pulling the NER pin (PB3) against VND. In that case pin PB3 is an open-collector output. With devices featuring open-drain alarm outputs a wired-or bus logic can be installed. The minimum message time for I/O pin NER can be set by EMTD.

<b>EMTD(2:0)</b> Addr. 0x0D; bit 2:0			
Code	min. disp. time	Code	min. disp. time
0x0	0 ms	0x4	50 ms
0x1	12.5 ms	0x5	62.5 ms
0x2	25 ms	0x6	75 ms
0x3	37.5 ms	0x7	87.5 ms

Table 101: Minimum error display time

## COMMAND REGISTER

The CMD\_MU register is used to execute defined commands received via the serial interface. As long as the command is queued the CMD\_MU register keeps the respective command code. Once the command is accepted and execution started, CMD\_MU is set to 0x00.

CMD_MU(7:0)		Addr. SER: 0x75; bit 7:0	W
Code	Command	Explanation	
0x00	reserved	no function	
0x01	WRITE_ALL	Write internal configuration and Offset values to EEPROM	
0x02	WRITE_OFF	Write internal Offset values to EEPROM	
0x03	ABS_RESET	Reset of Absolute value (including ABZ-part), takes typ. 10 ms	
0x04	NON_VER	Verification of actual position by doing a Nonius calculation	
0x05	MT_RESET	New read in and synchronization of multiturn value	
0x06	MT_VER	Read in of multiturn and verification of counted multiturn value	
0x07	SOFT_RESET	startup with read in of EEPROM	
0x08	SOFT_PRES	Set output to preset	
0x09	SOFT_E2P_PRES	Set output to preset and save offset values to EEPROM	
0x0A	I2C_COM	start I2C communication	
0x0B	EVENT_COUNT	increment event counter by 1	
0x0C	SWITCH	Writes all configurations parameters without offsets to EEPROM. MODEA/RPL will be exchanged with MODEA_NEW/RPL_NEW during write operation	
0x0D	CRC_VER	Verification of CRC16 and CRC8	
0x0E	CRC_CALC	Recalculate internal CRC16 and CRC8 values	
0x0F	SET_MTC	Set MTC-Pin *)	
0x10	RES_MTC	Reset MTC-Pin *)	
0x11	reserved	no function	
0x12	MODEA_SPI	set serial interface to SPI (MODEA = 0x0)	
0x13	ROT_POS	invert code direction for Incremental Output Signals and Serial Interface	
0x14	ROT_POS_E2P	invert code direction for Incremental Output Signals and Serial Interface and save this configuration to EEPROM	
0x15 ...0xFF	reserved	no function	
Note:	*) MODE_MT=0x00		

Table 102: Implemented commands

**WRITE\_ALL** stores the internal configuration and offset/preset values to the EEPROM. CRC16 and CRC8 are automatically updated.

**WRITE\_OFF** only stores the offset/preset data area to the EEPROM. CRC8 is automatically updated.

Command **ABS\_RESET** initiates a recalculation of the absolute position. A new Nonius calculation is started. If a multiturn is configured, it is read in and synchronized. Offset values OFF\_ABZ/OFF\_UVW are updated to include the ST period and MT information and are stored as OFF\_POS and OFF\_COM. The ABZ/UVW converter is restarted.

Command **NON\_VER** initiates a Nonius calculation and the computed value is compared to the current counted

period. If there is a discrepancy, error bit NON\_CTR is set in status register STATUS1.

With command **MT\_RESET** an external multiturn is read in anew and synchronized. Offset values OFF\_ABZ and OFF\_UVW are changed to include the newly read-in multiturn data and stored as OFF\_POS and OFF\_COM.

### Attention:

The ABZ/UVW converter is not restarted automatically with the command **MT\_RESET**. If part of the multiturn data is used for the singleturn information, **ABS\_RESET** has to be executed additionally.

With command **MT\_VER** an external multiturn is read in and the counted multiturn value is verified. If there is

a discrepancy, error bit MT\_CTR is set in status register STATUS1.

With command **SOFT\_RESET** internal finite state machines and counters are reset. The EEPROM is read in anew. A redefinition of the absolute value is initiated (see **ABS\_RESET**)

**Attention:**

After issuing the SOFT\_RESET command no further communication attempt with iC-MU Series is permitted for at least 50ms.

Command **SOFT\_PRES** initiates a preset sequence (cf. page 65) with preset values PRES\_POS. The internal offset values OFF\_ABZ are changed to set the output value to the value given by PRES\_POS. The internal CRC8 is automatically updated.

Command **SOFT\_E2P\_PRES** initiates a preset sequence (cf. page 65) with preset values PRES\_POS. The altered offset values OFF\_ABZ are stored in the EEPROM. CRC8 is automatically updated.

Command **I2C\_COM** initiates communication with a I2C device (RPL=0x00 and 0x02). Prior to this the following parameters must be configured:

- I2C\_DEVID
- I2C\_RAM\_START
- I2C\_RAM\_END
- I2C\_DEV\_START

The device ID is written to I2C\_DEVID (see Table 103). If an error occurs while communicating with an external I2C device up to 3 new communication attempts are started by iC-MU Series.

I2C\_RAM\_START defines the start address in the internal RAM which in case of a

- write access: marks the begin of the data area that holds the data to be written
- read access: marks the begin of the data area where the data read from the I2C device is written to

According to this I2C\_RAM\_END defines the end address of the data area in the internal RAM. The number of bytes NUM\_BYTES to be read/written is determined as I2C\_RAM\_END - I2C\_RAM\_START + 1 (if the I2C\_RAM\_END and I2C\_RAM\_START address are identical 1 byte is read/written).

I2C\_DEV\_START defines the start address of the I2C device from which NUM\_BYTES bytes should be read-/written.

The USER\_EXCHANGE\_REGISTERS (see Table 90) can be used for the data-exchange with the I2C device.

I2C_DEVID(7:0) Addr. SER:0x5E; bit 7:0	
Code	Meaning
0xA0	write EEPROM
0xA1	read EEPROM
0xC0	write to iC-PVL (status/commands)
0xC1	read from iC-PVL (status/commands)
Note:	I2C_DEVID needs to include the I2C read/write bit.

Table 103: Examples of I2C Device IDs

I2C_RAM_START Addr. SER: 0x5C; bit 7:0	
Code	Description
0x00	I2C-RAM start address
...	
0xFF	

Table 104: I2C-RAM start address

I2C_RAM_END Addr. SER: 0x5D; bit 7:0	
Code	Description
0x00	I2C-RAM end address
...	
0xFF	

Table 105: I2C-RAM end address

I2C_DEV_START Addr. SER: 0x5B; bit 7:0	
Code	Description
0x00	I2C device start address
...	
0xFF	

Table 106: I2C device start address

With command **EVENT\_COUNT** the value of register EVENT\_COUNT is incremented by 1.

EVENT_COUNT(7:0) Addr. SER:0x73; bit 7:0	
Code	Description
0x0	Event counter
...	
0xFF	

Table 107: Event counter

The command **SWITCH** makes it possible to write configurations of MODEA and RPL into the EEPROM which inhibit further register communications (e.g. MODEA=ABZ).

**Note:** RPL must be set to 0x0 before starting the command.

MODEA\_NEW and RPL\_NEW are used to set the target configuration of MODEA and RPL (e.g. ABZ, no RPL). On executing the command SWITCH MODEA and RPL are set to the target values and the configuration without the offsets is written to the EEPROM. Finally MODEA and RPL are set back to the original values. This makes it possible to control the success of the EEPROM write process by reading STATUS1 (EPR\_ERR should not be set).

**Note:** CRC\_ERR is set after command execution if there is the cyclic CRC check configured by NCHK\_CRC=0 and the target values of MODEA and RPL differ from the originals values.

iC-MU Series starts with the interface and register protection level configured with MODEA\_NEW and RPL\_NEW after the next startup or after the execution of command SOFT\_RESET.

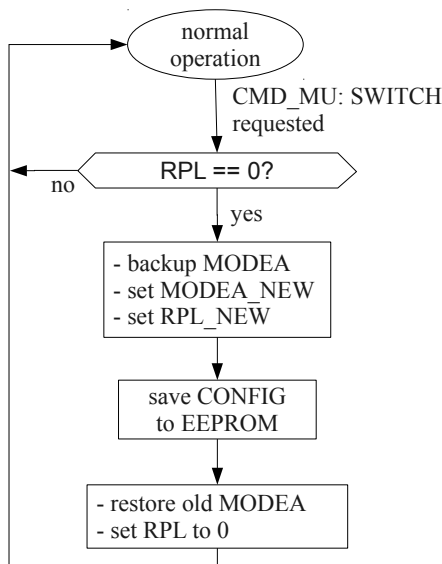


Figure 52: Event sequence of command SWITCH

**Note:** The SWITCH command should always be executed as the last command after all other configurations have been finished and stored to the EEPROM. Otherwise the values set by RPL\_NEW and MODEA\_NEW will be overwritten again by the actual RPL and MODEA values, defeating the purpose of the SWITCH command.

If the SWITCH command is used with an empty EEPROM, the WRITE\_OFF command needs to be executed in addition to properly initialize the OFFSET/PRESET area CRC8.

MODEA_NEW		Addr. SER: 0x60; bit 2:0			
Code	PA0	PA1	PA2	PA3	Function
0x0	NCS	SCLK	MOSI	MISO	SPI <sub>TR1</sub>
0x1	NCS	SCLK	MOSI	MISO	SPI
0x2	NPRES	MA	SLI	SLO	BiSS
0x3	NPRES	A	B	Z	ABZ
0x4	NPRES	MA	SLI	SLO	SSI
0x5	NPRES	MA	SLI	SLO	SSI+ERRL
0x6	NPRES	MA	SLI	SLO	SSI+ERRH
0x7	NPRES	MA	SLI	SLO	ExtSSI

Table 108: Target value of MODEA for the command SWITCH

RPL_NEW		Addr. SER: 0x60; bit 7:6	
Code	Registerprotection	Command I2C_COM	Reset to RP0 possible
0x0	RP0	x	x
0x1	RP1	-	-
0x2	RP1	x	x
0x3	RP1	-	x

Table 109: Target value for RPL for the command SWITCH

Command **CRC\_VER** starts a verification of CRC16 and CRC8. In case of an crc error, the CRC\_ERR status bit is set.

Command **CRC\_CALC** starts a recalculation of CRC16 and CRC8. CRC16 and CRC8 are saved internally in iC-MU Series and are used for later CRC verifications.

The command **SET\_MTC** sets pin MTC to logic level 1. **RES\_MTC** resets pin MTC to logic level 0. iC-MU Series saves the actual logic level of pin MTD to MTD\_STATUS before it sets or resets pin MTC. To use these commands MODE\_MT has to be set to 0x0, i.e. no external multiturm is configured.

MTD_STATUS		Addr. SER: 0x60; bit 0
Code	Description	
0	MTD Pin was 0, before setting/resetting MTC	
1	MTD Pin was 1, before setting/resetting MTC	

Table 110: Status of pin MTD before command execution SET\_MTC and RES\_MTC

**MODEA\_SPI** forces the serial interface to use the SPI protocol by setting MODEA = 0x0 (see P.31).

**ROT\_POS** inverts the code direction of the serial interface in MODE\_ST = 0x0 and 0x1 and the incremental output ABZ, Step/Direction and CW/CCW by setting/resetting bit ROT\_POS (see P.33).

**ROT\_POS\_E2P** inverts the code direction of the serial interface in `MODE_ST = 0x0` and `0x1` and the incremental output ABZ, Step/Direction and CW/CCW by setting/resetting bit `ROT_POS` (see P.33). `ROT_POS` is stored in the EEPROM and CRC8 is automatically updated.

### Configurable NPRES Pin

A configurable NPRES pin can be used at pin PA0 if `MODEA` is set to `0x2-0x7`. This pin can be used to execute a command configured by `PA0_CONF` on a falling edge of NPRES.

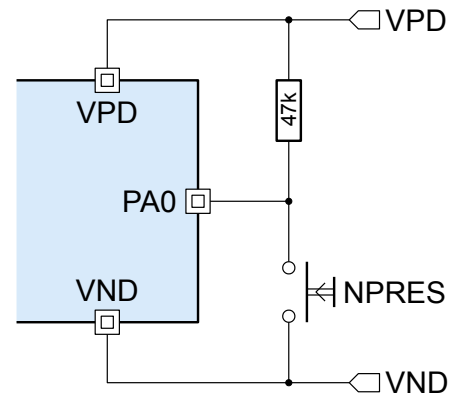


Figure 53: External circuitry for NPRES functionality

<b>PA0_CONF(7:0)</b> Addr. 0x30; bit 7:0	
<b>PA0_CONF(7:0)</b> Addr. SER: 0x25; bit 7:0 Bank 0	
Code	Command
0x00	no function
0x01	WRITE_ALL
0x02	WRITE_OFF
0x03	ABS_RESET
0x04	NON_VER
0x05	MT_RESET
0x06	MT_VER
0x07	SOFT_RESET
0x08	SOFT_PRES
0x09	SOFT_E2P_PRES
0x0A	I2C_COM
0x0B	EVENT_COUNT
0x0C	SWITCH
0x0D	CRC_VER
0x0E	CRC_CALC
0x0F	SET_MTC
0x10	RES_MTC
0x11	no function
0x12	MODEA_SPI
0x13	ROT_POS
0x14	ROT_POS_E2P
...0xFF	no function

Table 111: Command to be executed on falling edge of NPRES

## POSITION OFFSET VALUES AND PRESET FUNCTION

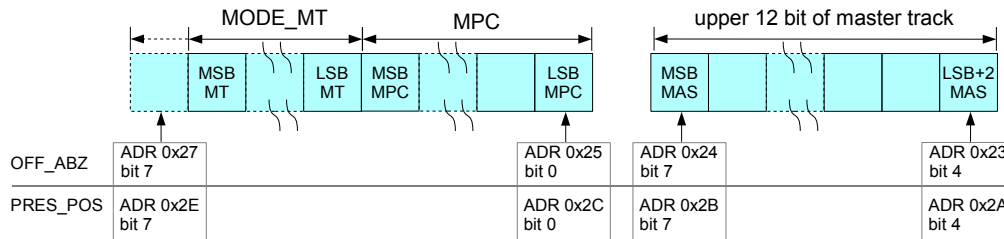


Figure 54: Position of the parameters OFF\_ABZ and PRES\_POS with respect to configured multiturn (MODE\_MT), periods (MPC) and converter resolution

OFF\_ABZ holds the position offset values stored in the EEPROM. After startup or the commands SOFT\_RESET and ABS\_RESET the OFF\_ABZ values are amended to include the nonius data and the multiturn data (in case an external multiturn is configured) and stored as OFF\_POS in the internal RAM. Value OFF\_POS is subtracted with each conversion from the internally synchronized result. OFF\_ABZ is not affected by the RESABZ parameter.

### Preset function

The preset function corrects the output position value of the ABZ, SPI, or BiSS interface to the setpoint given by PRES\_POS. Correction is initiated by writing command SOFT\_PRESET or SOFT\_E2P\_PRESET to the command register (see page 61), or, if one of these commands is configured with PA0\_CONF as NPRES command at PA0 pin, by a falling edge at PA0. See Table 28 for configuration of NPRES and Table 111 for PA0\_CONF.

<b>OFF_ABZ(3:0)</b>	Addr. 0x23; bit 7:4	
<b>OFF_ABZ(11:4)</b>	Addr. 0x24; bit 7:0	
<b>OFF_ABZ(19:12)</b>	Addr. 0x25; bit 7:0	
<b>OFF_ABZ(27:20)</b>	Addr. 0x26; bit 7:0	
<b>OFF_ABZ(35:28)</b>	Addr. 0x27; bit 7:0	
<b>OFF_ABZ(3:0)</b>	Addr. SER:0x1E; bit 7:4	Bank0
<b>OFF_ABZ(11:4)</b>	Addr. SER:0x1F; bit 7:0	Bank0
<b>OFF_ABZ(19:12)</b>	Addr. SER:0x48; bit 7:0	
<b>OFF_ABZ(27:20)</b>	Addr. SER:0x49; bit 7:0	
<b>OFF_ABZ(35:28)</b>	Addr. SER:0x4A; bit 7:0	
Code	Description	
0x00000000	Offset position relative to absolute position	
...		
0xFFFFFFFF		

Table 112: Output offset position, relative to absolute position

<b>OFF_POS(19:12)</b>	Addr. SER:0x20; bit 7:0	Bank0, R
<b>OFF_POS(27:20)</b>	Addr. SER:0x21; bit 7:0	Bank0, R
<b>OFF_POS(35:28)</b>	Addr. SER:0x22; bit 7:0	Bank0, R
Code	Description	
0x00000000	Offset (is automatically computed)	
...		
0xFFFFFFFF		

Table 113: Output position offset amended by the Nonius/MT

When the preset function is started, the ABZ converter is stopped. The current position is then determined. The correction factor for output (OFF\_POS) is calculated taking PRES\_POS into account and stored in the internal RAM. Offset values OFF\_ABZ are computed and if the command SOFT\_E2P\_PRESET is used written to the external EEPROM. The ABZ converter is then restarted.

<b>PRES_POS(3:0)</b>	Addr. 0x2A; bit 7:4
<b>PRES_POS(11:4)</b>	Addr. 0x2B; bit 7:0
<b>PRES_POS(19:12)</b>	Addr. 0x2C; bit 7:0
<b>PRES_POS(27:20)</b>	Addr. 0x2D; bit 7:0
<b>PRES_POS(35:28)</b>	Addr. 0x2E; bit 7:0
<b>PRES_POS(3:0)</b>	Addr. SER:0x4D; bit 7:4
<b>PRES_POS(11:4)</b>	Addr. SER:0x4E; bit 7:0
<b>PRES_POS(19:12)</b>	Addr. SER:0x4F; bit 7:0
<b>PRES_POS(27:20)</b>	Addr. SER:0x50; bit 7:0
<b>PRES_POS(35:28)</b>	Addr. SER:0x51; bit 7:0
Code	Description
0x00000000	Preset position
...	
0xFFFFFFFF	

Table 114: Output position preset

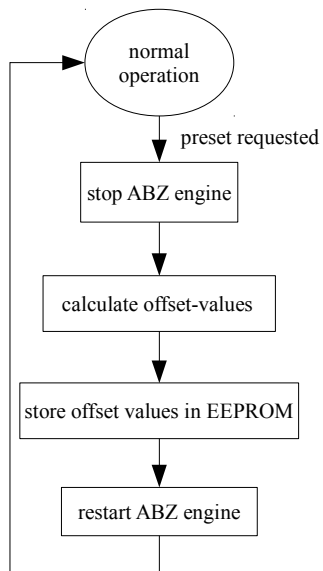


Figure 55: Preset sequence using command  
SOFT\_E2P\_PRES

## DESIGN REVIEW: Notes On Chip Functions

iC-MU128 X1 iC-MU150 X1 iC-MU200 X1		
No.	Function, Parameter/Code	Description and Application Notes
1	SPI interface (MODEA = 0x0, 0x1), <b>Read/Write REGISTER(single)</b> with access to EEPROM	SPI command sequence as in Figure 32. The end of a <b>Read/Write REGISTER(single)</b> command to an EEPROM address can be detected by checking the status bit BUSY. <b>Register Status/Data</b> and SPI-STATUS change from 0x02 (Busy) to 0x00. The status bits VALID/FAIL are without functionality. A successful I <sup>2</sup> C communication between iC-MU and the EEPROM can be checked via STATUS1 flag EPR_ERR = 0.
2	SSI interface Gray coded MODEA = 0x4; GSSI = 0x1; OUT_ZERO = 0x0	The level of the SSI output pin (signal SLO) can be "1" or "0" during timeout $t_{out}$ (see Figure 5). Therefore, a SSI timeout may not be detected by a SSI master in all cases. To obtain a reliable SSI timeout set parameter OUT_ZERO = 0x1 (includes a zero bit after position data) and send an additional clock pulse.
3	SSI interface Gray coded with error bit MODEA = 0x5 or 0x6; GSSI = 0x1; OUT_ZERO = 0x0	Conversion of the SSI position data into Gray code requires following procedure: By setting parameter OUT_ZERO = 0x1 (includes a zero bit after position data) and sending an additional clock pulse and subsequently ignoring the additional ZERO bit, the singleturn data is converted correctly into Gray code.
4	Restrictions on Nonius phase margin / analog offset	Especially for the low Rth and thus larger QFN48-7x7 package the specific mechanical properties and package stress on board can cause increased analogue offset within the Nonius track (in particular with lower quality targets with 64/63 pole pairs; parameter MPC = 0x6). A significantly reduced Nonius phase margin would be indicated by the iC-MU Series as a NON_CTR error. A NON_CTR error can cause an incorrect absolute position when the system is restarted. iC-MU128 and iC-MU150 fit into the smaller DFN16-5x5 package with its advantages regarding required board space and lower mechanical package stress on board. Especially for the alternative lower Rth QFN48-7x7 packages sufficient Nonius phase margin requires - besides good quality magnetic targets and mechanical adjustment - thorough initial calibration at room temperature or a reduced operating temperature range. Safe operation can be determined e.g. by measuring the Nonius curve over the whole operating temperature range. For further information please request Application Note MU AN16 at support@ichaus.de.

Table 115: Notes on chip functions regarding iC-MU128, iC-MU150, iC-MU200 chip revision X1



For design reviews of earlier iC-MU Series chip hardware revisions, please refer to the corresponding prior datasheet for the specific chip.

# iC-MU Series MAGNETIC OFF-AXIS POSITION ENCODERS



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## REVISION HISTORY

Rel.	Rel. Date <sup>3</sup>	Chapter	Modification	Page
A1	2025-06-18	all	Initial release for iC-MU128, iC-MU150, iC-MU200 chip hardware revision X1 or newer. For earlier revision history please refer to the corresponding prior datasheet for the specific chip	all
		all	Consolidation of all iC-MU Series variants in one data sheet. Wording adapted accordingly. Minor wording and formatting improvements throughout the document	all
		ELECTRICAL CHARACTERISTICS	Updated Elec. Char. 104 I(VPD) min 12, typ 22, max 45 mA	11
		ELECTRICAL CHARACTERISTICS	Elec. Char. 105 Vc(hi) max 1.8 V at pins SDA, SCL, PA0, MTD	11
		ELECTRICAL CHARACTERISTICS	Elec. Char. 204 v <sub>max</sub> - consolidated ratings for all chip versions	11
		ELECTRICAL CHARACTERISTICS	Elec. Char. 509 V <sub>ae</sub> (hi) max 7.0 V	12
		ELECTRICAL CHARACTERISTICS	Elec. Char. 505 PHM - consolidated ratings for all chip versions, iC-MU128 now also supports extended phase adjustment range	12
		OPERATING REQUIREMENTS	Added I006 s(SDA) for clarification, no change in properties compared to prior chip hardware revisions	14
		OPERATING REQUIREMENTS	Updated I116, I117, I118.	15
		MT INTERFACE	Removed note on recommended bus idle time with GET_MT = 1	48
		DESIGN REVIEW: Notes On Chip Functions	Updated for iC-MU, iC-MU150 and iC-MU200 chip hardware revision X1.	67
		ORDERING INFORMATION	Updated to include all iC-MU Series variants	69

Rel.	Rel. Date <sup>3</sup>	Chapter	Modification	Page
A2	2025-08-29	PACKAGING INFORMATION	Added remark: Pin 1 mark on backside pad may differ from drawing.	5
		PACKAGE DIMENSIONS	Added separate drawing of the iC-MU200, QFN48-7x7 package to reflect the different Hall sensor distance.	9

Rel.	Rel. Date <sup>3</sup>	Chapter	Modification	Page
B1	2025-10-07	FEATURES	Added iC-MU200 QFN48-7x7 AEC-Q100 qualified (Grade 1)	1
		THERMAL DATA	Corrected T <sub>a</sub> to -40°C...125°C for iC-MU200	10
		ELECTRICAL CHARACTERISTICS	Corrected T <sub>j</sub> to -40°C...140°C for iC-MU200, added footnote "Reliability figures according to FIT and Mission Profile"	11

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<sup>3</sup> Release Date format: YYYY-MM-DD

# iC-MU Series MAGNETIC OFF-AXIS POSITION ENCODERS



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## ORDERING INFORMATION

Type	Package	Order Designation
iC-MU128	16-pin DFN 5 x 5 mm	iC-MU128 DFN16-5x5
iC-MU128	48-pin QFN 7 x 7 mm	iC-MU128 QFN48-7x7
iC-MU150	16-pin DFN 5 x 5 mm	iC-MU150 DFN16-5x5
iC-MU150	48-pin QFN 7 x 7 mm	iC-MU150 QFN48-7x7
iC-MU200	48-pin QFN 7 x 7 mm	iC-MU200 QFN48-7x7

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