

# iC-MH16

## 12-BIT ANGULAR HALL ENCODER



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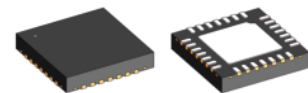
### FEATURES

- ◆ Real-time system for full resolution at up to 200 000 rpm
- ◆ Integrated Hall sensors with automatic offset compensation
- ◆ 4x sensor arrangement for fault-tolerant adjustment
- ◆ Amplitude control for optimum operating point
- ◆ FlexCount<sup>®</sup> interpolator with 1 to 1024 CPR, resolution up to 4 096 / 0.08 °
- ◆ UVW commutation signals with 1 to 16 CPR, for motors of up to 16 pole pairs
- ◆ Programmable resolution, hysteresis, edge spacing, zero position and rotating direction
- ◆ Up to 16 MHz incremental edge rate
- ◆ RS422-compatible AB encoder signals with index Z
- ◆ BiSS/SSI interface for data output and configuration
- ◆ Integrated Zapping ROM for default setup and OEM data
- ◆ Errors signaled via pin and serial interface
- ◆ Single 5V supply with reversed-polarity monitoring and sub-system switching
- ◆ Extended temperature range from -40 to +125 °C

### APPLICATIONS

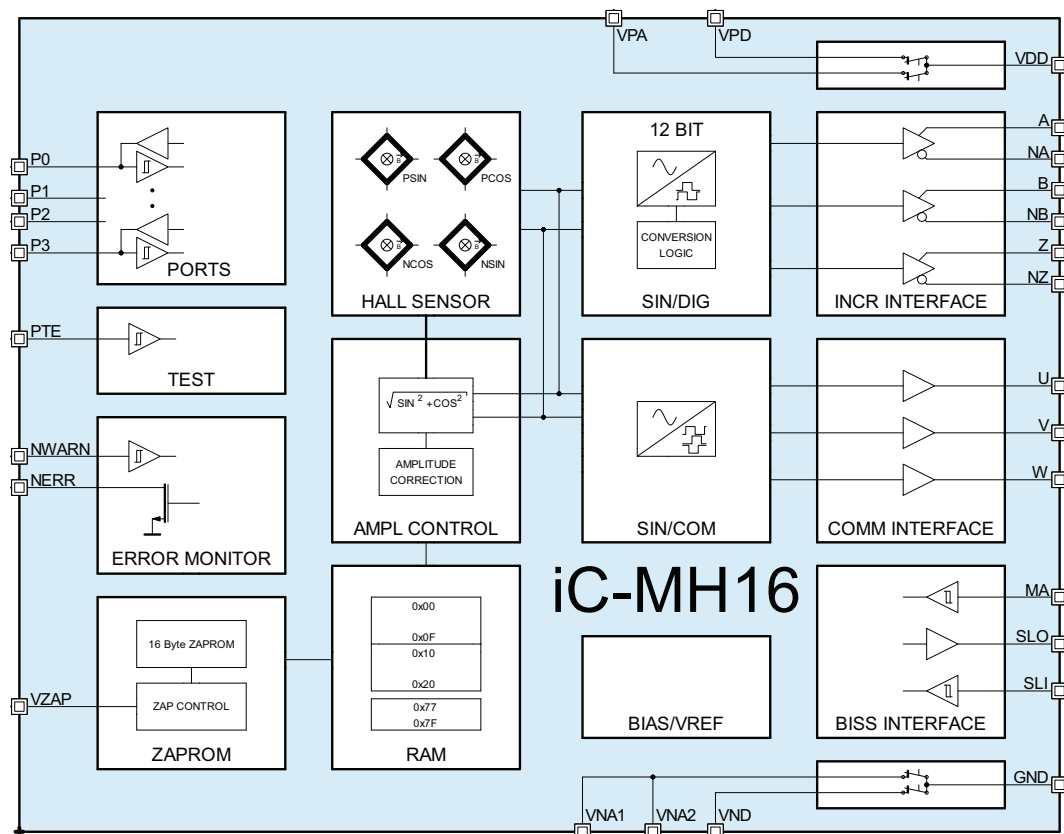
- ◆ Digital angular sensor technology, 0–360 °
- ◆ Incremental angular encoder
- ◆ Absolute angular encoder
- ◆ Brushless motors
- ◆ Motor feedback
- ◆ Rotational speed control

### PACKAGES



QFN28  
5 mm x 5 mm x 0.9 mm  
RoHS compliant

### BLOCK DIAGRAM



# iC-MH16

## 12-BIT ANGULAR HALL ENCODER



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### DESCRIPTION

The iC-MH16 12-bit angular encoder is a position sensor with integrated Hall sensors for scanning a permanent magnet. The signal conditioning unit generates constant-amplitude sine and cosine voltages that can be used for angle calculation. The resolution can be programmed up to a maximum of 4 096 angular increments per rotation; the zero position is adjustable.

The incremental interface with pins A, B and Z provides quadrature signals with an edge rate of up to 16 MHz. Interpolation is performed with maximum resolution at speeds up to 200 000 rpm.

The RS422-compatible outputs of the incremental interface are programmable for output current and slew rate.

The commutation interface with the signals U, V and W provides 120 ° phase-shifted signals for block commutation of EC motors with up to 16 pole pairs.

The integrated serial interface also allows the position data to be read out to several networked sensors. The integrated memory can be written embedded in the data protocol.

In conjunction with a rotating permanent magnet, the iC-MH16 module forms an one-chip encoder including protection against reversed power supply voltage. The entire configuration can be stored in the internal parameter ROM with zapping diodes. The integrated programming algorithm assumes writing of the ROM structure.

The iC-MH16 is a multi-function device that contains integrated BiSS C interface components. The BiSS C process is protected by patent DE 10310622 B4, owned by iC-Haus GmbH, and its use requires the execution of a license (free of charge).  
**Download the license at [www.biss-interface.com/bua](http://www.biss-interface.com/bua)**

# iC-MH16

## 12-BIT ANGULAR HALL ENCODER



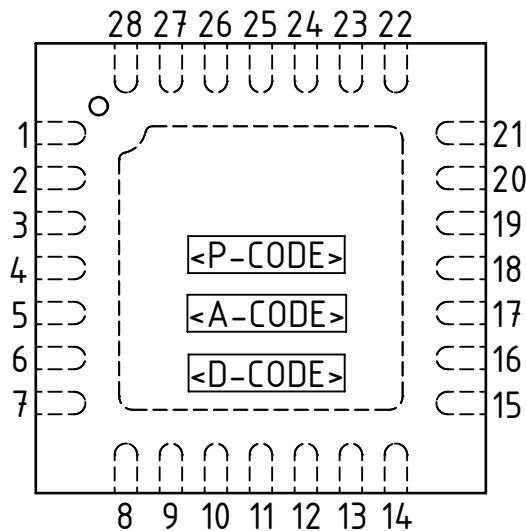
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### PACKAGING INFORMATION

#### PIN CONFIGURATION

QFN28 5 mm x 5 mm x 0.9 mm

(according to JEDEC Standard MO-220)



#### PIN FUNCTIONS

##### No. Name Function

- 1 PTE<sup>1)</sup> Test Enable Pin
- 2 NERR Error output(active low)

#### PIN FUNCTIONS

##### No. Name Function

- 3 VPA +5 V Supply Voltage (analog)
- 4 VNA1 Ground (analog)
- 5 SLI<sup>1)</sup> Serial Interface, Data Input
- 6 MA Serial Interface, Clock Input
- 7 SLO Serial Interface, Data Output
- 8 VND Ground (digital)
- 9 U Commutation U
- 10 V Commutation V
- 11 W Commutation W
- 12 VZAP Zener Zapping Programming Voltage
- 13 VNA2 Ground (analog)
- 14 nc not connected
- 15 A Incremental A
- 16 B Incremental B
- 17 Z Index Z
- 18 GND Ground (line)
- 19 VDD +5 V Supply Voltage (line)
- 20 NA Incremental NA
- 21 NB Incremental NB
- 22 NZ Incremental NZ
- 23 NWARN Warning input (active low)
- 24 P0 Bidirectional Port No. 0
- 25 P1 Bidirectional Port No. 1
- 26 P2 Bidirectional Port No. 2
- 27 P3 Bidirectional Port No. 3
- 28 VPD +5 V Supply Voltage (digital)
- BP<sup>2)</sup> Backside Paddle

<sup>1)</sup> If not used, the pin must be connect to common ground (VNA1, VNA2, VND).

<sup>2)</sup> The backside paddle has to be connected to common ground (VNA1, VNA2, VND) on the PCB. Current flow across the paddle should be avoided.

#### IC top marking:

<P-CODE> = product code

<A-CODE> = assembly code (subject to changes)

<D-CODE> = date code (subject to changes)

Orientation of the top marking is subject to alteration.

# iC-MH16

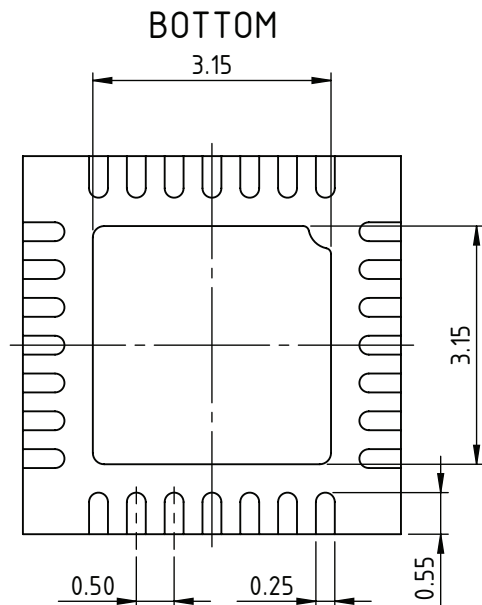
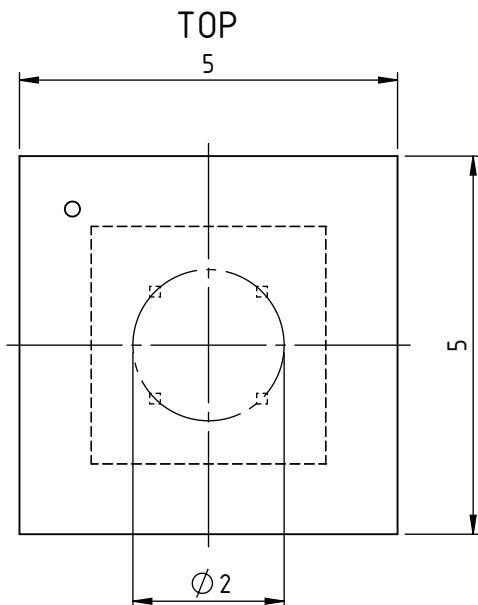
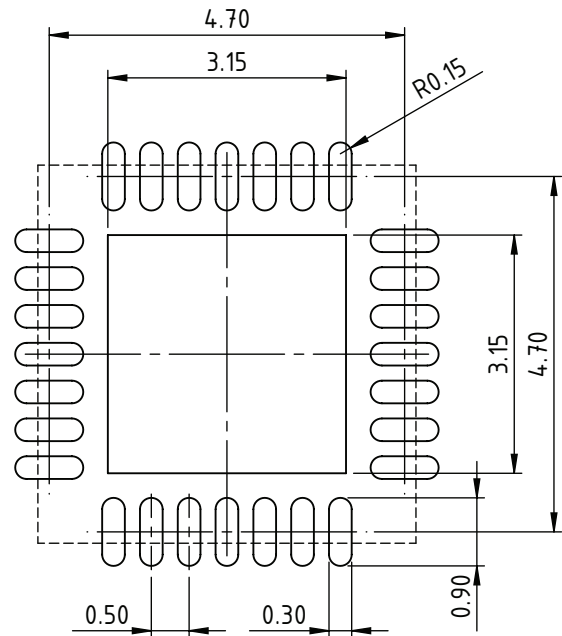
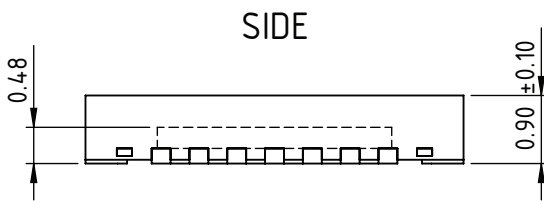
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### PACKAGE DIMENSIONS QFN28-5x5

### RECOMMENDED PCB-FOOTPRINT



All dimensions given in mm.

Tolerances of form and position according to JEDEC MO-220.

Tolerance of sensor pattern: ±0.10mm / ±1° (with respect to center of backside pad).

dra\_qfn28-5x5-2\_mh8\_pack\_1, 10:1

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### ABSOLUTE MAXIMUM RATINGS

These ratings do not imply operating conditions; functional operation is not guaranteed. Beyond these ratings device damage may occur.

Item No.	Symbol	Parameter	Conditions	Min.   Max.		Unit
				Min.	Max.	
G001	V()	Voltage at VDD, GND, A, B, Z, NA, NB, NZ, U, V, W, MA, SLI, SLO		-6	6	V
G002	V(VZAP)	Zapping voltage		-0.3	8	V
G003	V()	Voltage at NERR, NWARN, P0, P1, P2, P3, PTE		-0.3	6	V
G004	I()	Current in VDD		-10	20	mA
G005	I()	Current in GND		-20	200	mA
G006	I()	Current in A, B, Z, NA, NB, NZ, SLO, U, V, W		-100	100	mA
G007	I()	Current in MA, SLI, NERR, PTE		-10	10	mA
G008	Vd()	ESD Susceptibility at all pins	HBM, 100 pF discharged over 1.5 kΩ		2	kV
G009	Ts	Storage Temperature		-40	150	°C
G010	Tj	Junction Temperature		-40	150	°C

### THERMAL DATA

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

Item No.	Symbol	Parameter	Conditions	Min.   Typ.   Max.			Unit
				Min.	Typ.	Max.	
T01	Ta	Operating Ambient Temperature Range		-40		125	°C
T02	Rthja	Thermal Resistance Chip to Ambient	surface mounted to PCB, <i>thermal pad</i> linked to cooling area of approx. 2 cm <sup>2</sup>		40		K/W

All voltages are referenced to pin VNA1 unless otherwise stated.

All currents flowing into the device pins are positive; all currents flowing out of the device pins are negative.

## ELECTRICAL CHARACTERISTICS

Operating conditions:

VDD = 5 V ±10 %, EP = VNA1 = VNA2 = VND, Tj = -40...125 °C, IBM adjusted to 200 µA, 4 mm NdFeB magnet, unless otherwise noted

Item No.	Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>General</b>							
001	V(VDD)	Permissible Supply Voltage		4.5		5.5	V
002	I(VDD)	Supply Current in VDD	PRM = 0x0, without load, fmag = 0 rpm PRM = 0x1, without load, fmag = 0 rpm	10 7	20 15	30 20	mA mA
003	fi(VDD)	Supply Current in VDD Rotating Speed Dependence	PRM = 0x0, without load, fmag = 0...3.3 kHz		1.4		mA/kHz
006	Vc(j)hi	Clamp-Voltage hi at P0, P1, P2, P3, PTE, NERR, NWARN	Vc(j)hi = V() – VPD, I() = 1 mA	0.4		1.5	V
007	Vc(j)lo	Clamp-Voltage lo	I() = -1 mA	-1.5		-0.3	V
<b>Hall Sensors and Signal Conditioning</b>							
101	Hext	Permissible Magnetic Field Strength	at chip surface	20		100	kA/m
102	fmag	Operating Magnetic Field Frequency				3.33	kHz
103	rpm	Rotating Speed of Magnet				200 000	rpm
104	dsens	Diameter of Hall Sensor Array			2		mm
105	xdis	Permissible Lateral Displacement of Magnet Axis to Center of Hall Sensors				0.2	mm
106	xpac	Displacement Chip Center to Package Center	package QFN28	-0.15		0.15	mm
107	φpac	Angular Alignment of Chip vs. Package	package QFN28	-3		+3	Deg
108	hpac	Displacement of Chip Surface to Package Surface	package QFN28		0.4		mm
109	Vos	Trimming Range of Output Offset Voltage	VOSS or VOSC = 0x7F			-55	mV
110	Vos	Trimming Range of Output Offset Voltage	VOSS or VOSC = 0x3F	55			mV
111	Vopt	Optimal Differential Output Voltage	Vopt = Vpp(PSIN) – Vpp(NSIN), ENAC = 0x0, see Figure 7		4		Vpp
112	Vratio	Amplitude Ratio	Vratio = Vpp(PSIN) / Vpp(PCOS), GCC = 0x3F	1.09			
113	Vratio	Amplitude Ratio	Vratio = Vpp(PSIN) / Vpp(PCOS), GCC = 0x40			0.92	
<b>Signal Level Control</b>							
201	Vpp	Differential Peak-to-Peak Output Amplitude	Vpp = Vpk(Px) – Vpk(Nx), ENAC = 0x1, see Figure 7	3.2		4.8	Vpp
202	ton	Controller Settling Time	to ±10 % of final amplitude			300	µs
203	Vt(j)lo	MINERR Amplitude Error Threshold	see Item No. 201	1.0		2.8	Vpp
204	Vt(j)hi	MAXERR Amplitude Error Threshold	see Item No. 201	4.8		5.8	Vpp
<b>Bandgap Reference</b>							
401	Vbg	Bandgap Reference Voltage		1.18	1.25	1.32	V
402	Vref	Reference Voltage		45	50	55	%VPA
403	libm	Bias Current	CIBM = 0x0 CIBM = 0xF bias current adjusted	-370 -220	-200	-100 -180	µA µA µA
404	VPDon	Turn-on Threshold VPD, System on	V(VPD) – V(VND), increasing voltage	3.65	4.0	4.3	V
405	VPDoff	Turn-off Threshold VPD, System reset	V(VPD) – V(VND), decreasing voltage	3	3.5	3.8	V
406	VPDhys	Hysteresis System on/reset		0.3			V

## ELECTRICAL CHARACTERISTICS

Operating conditions:

VDD = 5 V ±10 %, EP = VNA1 = VNA2 = VND, Tj = -40...125 °C, IBM adjusted to 200 µA, 4 mm NdFeB magnet, unless otherwise noted

Item No.	Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
407	Vosr	Reference Voltage Offset Compensation		470	500	530	mV
<b>Clock Generation</b>							
501	f()sys	System Clock	bias current adjusted	0.8	1.0	1.2	MHz
502	f()sdc	Sine/Digital Converter Clock	bias current adjusted	13.65	16	19	MHz
<b>Sine/Digital Converter</b>							
601	RESsdc	Sine/Digital Converter Resolution			12		bit
602	AAabs	Absolute Angular Accuracy	Vpp() = 4 V, adjusted	-0.35		0.35	Deg
603	AArel	Relative Angular Accuracy	with reference to an output period at A, B. CFGRES = 0x0FF, ENF = 0x1, PRM = 0x0, GAING = 0x0, Vpp(SIN/COS) = 4 Vpp. see Figure 20		± 10		%
604	f()ab	Output Frequency at A, B	CFGMTD = 0x0, CFGRES = 0x3FF CFGMTD = 0x1, CFGRES = 0x3FF CFGMTD = 0x2, CFGRES = 0x3FF CFGMTD = 0x3, CFGRES = 0x3FF		4.0 2.0 0.5 0.125		MHz MHz MHz MHz
<b>Serial Interface, Digital Outputs MA, SLO, SLI</b>							
701	Vs(SLO)hi	Saturation Voltage hi	Vs(SLO)hi = V(VDD) – V(), I(SLO) = -4 mA			0.4	V
702	Vs(SLO)lo	Saturation Voltage lo	I(SLO)lo = 4 mA, with reference to GND			0.4	V
703	Isc(SLO)hi	Short-Circuit Current hi	V(SLO) = V(VDD), 25 °C	-60		-18	mA
704	Isc(SLO)lo	Short-Circuit Current lo	V(SLO) = V(GND), 25 °C	18		60	mA
705	tr(SLO)	Rise-Time	CL = 50 pF, rise 10 % to 90 %			60	ns
706	tf(SLO)	Fall-Time	CL = 50 pF, fall 90 % to 10 %			60	ns
707	Vt()hi	Threshold Voltage hi at MA, SLI	with reference to VND			2	V
708	Vt()lo	Threshold Voltage lo at MA, SLI	with reference to VND	0.8			V
709	Vt()hys	Threshold Hysteresis at MA, SLI		140	250		mV
710	Ipu(MA)	Pull-up Current	V() = 0...VPD – 1 V	-60	-30	-6	µA
711	Ipd(SLI)	Pull-down Current	V() = 1 V...VPD	6	30	60	µA
712	f(MA)	Permissible MA Clock Frequency				10	MHz
713	Iik(SLO)tri	Tristate Leakage Current	reversed supply	-20		20	µA
<b>Ports P0, P1, P2, P3 and Test PTE</b>							
801	Vs()hi	Saturation Voltage hi at P0, P1, P2, P3	Vs()hi = V(VPD) – V(), I() = -4 mA			0.4	V
802	Vs()lo	Saturation Voltage lo at P0, P1, P2, P3	I() = 4 mA, with reference to VND			0.4	V
803	tr()	Rise-Time at P0, P1, P2, P3	CL = 50 pF, rise 10 % to 90 %			60	ns
804	tf()	Fall-Time at P0, P1, P2, P3	CL = 50 pF, fall 90 % to 10 %			60	ns
805	Vt()hi	Threshold Voltage hi	with reference to VND			2	V
806	Vt()lo	Threshold Voltage lo	with reference to VND	0.8			V
807	Vt()hys	Hysteresis	Vt()hys = Vt()hi – Vt()lo	140	250		mV
808	Ipd()	Pull-down Current	V() = 1 V...VPD	6	30	60	µA
<b>Error Monitor NERR, NWARN</b>							
901	Vs()lo	Saturation Voltage lo at NERR	I() = 4 mA, with reference to VND			0.4	V
902	Vt()hi	Input Threshold Voltage hi	with reference to VND			2	V
903	Vt()lo	Input Threshold Voltage lo	with reference to VND	0.8			V
904	Vt()hys	Input Hysteresis	Vt()hys = Vt()hi – Vt()lo	140	250		mV
905	Ipu()	Pull-up Current Source at NERR	V(NERR) = 0...VPD – 1 V	-800	-300	-80	µA
906	Isc()lo	Short-Circuit Current lo at NERR	V(NERR) = V(VPD), Tj = 25 °C		50	80	mA
907	tf()hilo	Delay Time at NERR	CL = 50 pF			60	ns
908	Ipu()	Pull-up Current at NWARN	V() = 0...VPD – 1 V	-60	-30	-6	µA

### ELECTRICAL CHARACTERISTICS

Operating conditions:

VDD = 5 V ±10 %, EP = VNA1 = VNA2 = VND, Tj = -40...125 °C, IBM adjusted to 200 µA, 4 mm NdFeB magnet, unless otherwise noted

Item No.	Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
<b>Zapping VZAP</b>							
A01	Vt()hi	Input Threshold Voltage hi	with reference to VND			2	V
A02	Vt()lo	Threshold Voltage lo	with reference to VND	0.8			V
A03	Vt()hys	Hysteresis	Vt()hys = Vt()hi – Vt()lo	140	250		mV
A06	V()zap	Zapping Voltage	PROG = '1'	6.9	7.0	7.1	V
A09	Rpd()	Pull-Down Resistor		30		55	kΩ
<b>Incr Interface Line Driver Outputs A, B, Z, NA, NB, NZ</b>							
P01	Vs()hi	Saturation Voltage hi	Vs() = VDD – V(); CFGDR(1:0) = 0x00, I() = -4 mA CFGDR(1:0) = 0x01, I() = -50 mA CFGDR(1:0) = 0x10, I() = -50 mA CFGDR(1:0) = 0x11, I() = -20 mA			200 700 700 400	mV mV mV mV
P02	Vs()lo	Saturation Voltage lo	with reference to GND; CFGDR(1:0) = 0x00, I() = -4 mA CFGDR(1:0) = 0x01, I() = -50 mA CFGDR(1:0) = 0x10, I() = -50 mA CFGDR(1:0) = 0x11, I() = -20 mA			200 700 700 400	mV mV mV mV
P03	Isc()hi	Short-Circuit Current hi	V() = GND; CFGDR(1:0) = 0x00 CFGDR(1:0) = 0x01 CFGDR(1:0) = 0x10 CFGDR(1:0) = 0x11	-12 -125 -125 -60		-4 -50 -50 -20	mA mA mA mA
P04	Isc()lo	Short-Circuit Current lo	V() = VDD; CFGDR(1:0) = 0x00 CFGDR(1:0) = 0x01 CFGDR(1:0) = 0x10 CFGDR(1:0) = 0x11	4 50 50 20		12 125 125 60	mA mA mA mA
P05	Iik()tri	Tristate Leakage Current	TRIH(1:0) = 0x11 or reversed supply	-20		20	µA
P06	tr()	Rise-Time lo to hi	RL = 100 Ω to GND; CFGDR(1:0) = 0x00 CFGDR(1:0) = 0x01 CFGDR(1:0) = 0x10 CFGDR(1:0) = 0x11	5 5 50 5		20 20 350 40	ns ns ns ns
P07	tf()	Fall-Time hi to lo	RL = 100 Ω to VDD; CFGDR(1:0) = 0x00 CFGDR(1:0) = 0x01 CFGDR(1:0) = 0x10 CFGDR(1:0) = 0x11	5 5 50 5		20 20 350 40	ns ns ns ns
<b>Comm Interface Outputs U, V, W</b>							
Q01	Vs()hi	Saturation Voltage hi	Vs() = VDD – V(); I() = -12 mA			400	mV
Q02	Vs()lo	Saturation Voltage lo	with reference to GND; I() = -12 mA			400	mV
Q03	Isc()hi	Short-Circuit Current hi	V() = GND	-60		-20	mA
Q04	Isc()lo	Short-Circuit Current lo	V() = VDD	20		60	mA
Q05	Iik()tri	Tristate Leakage Current	reversed supply voltage	-20		20	µA
Q06	tr()	Rise Time	RL = 100 Ω to VDD	5		40	ns
Q07	tf()	Fall Time	RL = 100 Ω to GND	5		40	ns
<b>Reverse Polarity Protection VPA, VPD, VNA1, VNA2, VND</b>							
R01	Vs()	Saturation Voltage at VPA, VPD	Vs() = VDD – V(); I() = -10 ... 0 mA			450	mV
R02	Vs()	Saturation Voltage at VNA1, VNA2, VND	Vs() = GND – V(); I() = -10 ... 0 mA			450	mV



### OPERATING REQUIREMENTS: Serial Interface

Operating conditions: VDD = 5 V ±10 %, Ta = -40...125 °C, IBM calibrated to 200 μA;  
 Logic levels referenced to VND: lo = 0...0.45 V, hi = 2.4 V...VPD

Item No.	Symbol	Parameter	Conditions			Unit
				Min.	Max.	
<b>SSI Protocol (ENSSI = 1)</b>						
I001	$T_{MAS}$	Permissible Clock Period	$t_{tos}$ according to Table 30	250	$2x t_{tos}$	ns
I002	$t_{MASH}$	Clock Signal hi Level Duration		25	$t_{tos}$	ns
I003	$t_{MASI}$	Clock Signal lo Level Duration		25	$t_{tos}$	ns
<b>BiSS C Protocol</b>						
I004	$T_{MAS}$	Permissible Clock Period	$t_{tos}$ according to Table 30	100	$2x t_{tos}$	ns
I005	$t_{MASH}$	Clock Signal hi Level Duration		25	$t_{tos}$	ns
I006	$t_{MASI}$	Clock Signal lo Level Duration		25	$t_{tos}$	ns

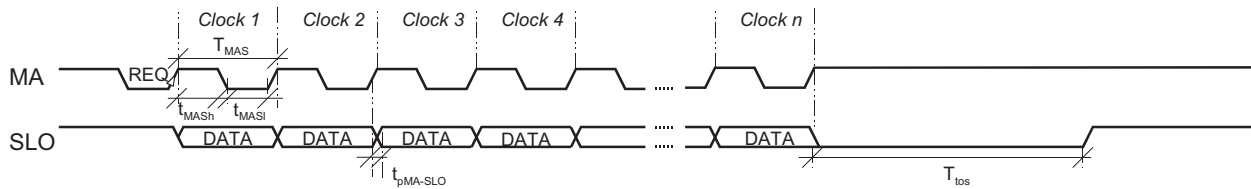


Figure 1: Timing diagram in SSI protocol.

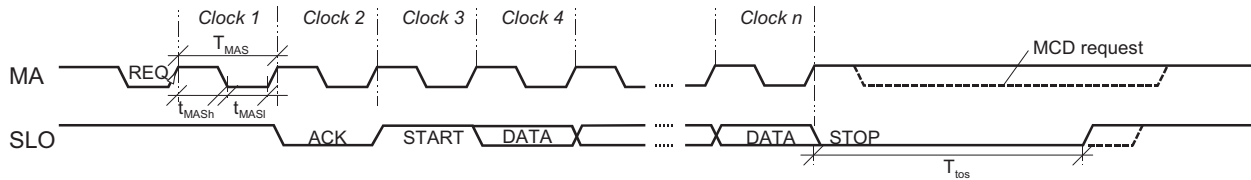


Figure 2: Timing diagram in BiSS C protocol.

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### REGISTERS

#### OVERVIEW

Addr	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
<b>Hall Signal Conditioning</b>									
0x00	z	GAING(1:0)		GAINF(5:0)					
0x01	z	ENAC	GCC(6:0)						
0x02	z	ENF	VOSS(6:0)						
0x03	z	PRM	VOSC(6:0)						
0x04	z	DCS	DPU	-	ENADAP	CIBM(3:0)			
<b>RS422 Driver</b>									
0x05	z	ENSSI	CFGPROT	CFGMTD(1:0)		TRIHL(1:0)		CFGDR(1:0)	
<b>Sine/Digital Converter</b>									
0x06	z	CFGRES(7:0)							
0x07	z	CFGHYS(1:0)	CFGDIR	CFGSU	CFGAB(1:0)		CFGRES(9:8)		
0x08	z	CFGZPOS(7:0)							
0x09	z	CFGCOM(3:0)			CFGZPOS(11:7)				
0x0A	z	OEMA			HARMCAL(4:0)				
0x0B	z	OEMB							
0x0C	z	OEMC							
0x0D	z	OEMD							
<b>Test Settings</b>									
0x0E	p	TEST(7:0)							
0x0F	p	ENHC	res.	res.	res.	res.	res.	PROGZAP	
<b>ZAP Diodes (read only)</b>									
0x10 .. 0x20		ZAP diodes for addresses 0x00..0x0D and 0x7D..0x7F							
<b>not used</b>									
0x21 .. 0x41		'invalid addresses'							
<b>Profile Identification (read only)</b>									
0x42		Profile - 0x2C							
0x43		Profile - 0x0				R_ST			
<b>not used</b>									
0x44 .. 0x74		'invalid address'							
<b>Ports</b>									
0x75		DIR3	DIR2	DIR1	DIR0	P3	P2	P1	P0
<b>Status Messages (read only; messages will be reset to default values during reading)</b>									
0x76		GAIN							
0x77		PROGERR	ERRSDATA	ERRAMIN	ERRAMAX	ERREXT	WARNEXT	res.	PROGOK

OVERVIEW								
Addr	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
<b>Identification (0x78 bis 0x7B read-only)</b>								
0x78				Device ID - 0x4D ('M')				
0x79				Device ID - 0x48 ('H')				
0x7A				Revision - 0x67 ('g')				
0x7B				Revision - 0x34 ('4')				
0x7C							CFGTOS	
0x7D	z				Manufacturer Revision - 0x00			
0x7E	z				Manufacturer ID - 0x00			
0x7F	z				Manufacturer ID - 0x00			

z: Register value programmable by zapping

p: Register value write protected; can only be changed while V(VZAP)> Vt()hi

Table 5: Register layout

<b>Hall Signal Processing</b> .....	Page 13	<b>Sine/Digital Converter</b> .....	Page 19
GAING:	Hall signal amplification range	CFGRES:	Resolution of sine digital converter
GAINF:	Hall signal amplification (1–20, log. scale)	CFGZPOS:	Zero point for position
GCC:	Amplification calibration cosine	CFGAB:	Configuration of incremental output
ENF:	Enable filter	CFGSU:	Behavior during startup
ENAC:	Activation of amplitude control	CFGMTD:	Frequency at AB
VOSS:	Offset calibration sine	CFGDIR:	Rotating direction reversal
VOSC:	Offset calibration cosine	CFGHYS:	Hysteresis sine/digital converter
PRM:	Energy-saving mode	CFGCOM:	No. of pole pairs for commutation signals
CIBM:	Calibration of bias current	DCS:	Disable commutation synchronization
DPU	Deactivation of NERR pull-up		
<b>RS422 Driver</b> .....	Page 21	<b>Test</b>	
CFGDR:	Driver property	TEST:	Test mode
TRIHL:	Tristate high-side/low-side driver	ENHC:	Enable high current during ZAP diode read
CFGPROT:	Write/read protection memory	PROGZAP:	Activation of programming routine
ENSSI:	Activation of SSI mode		

### SENSOR PRINCIPLE

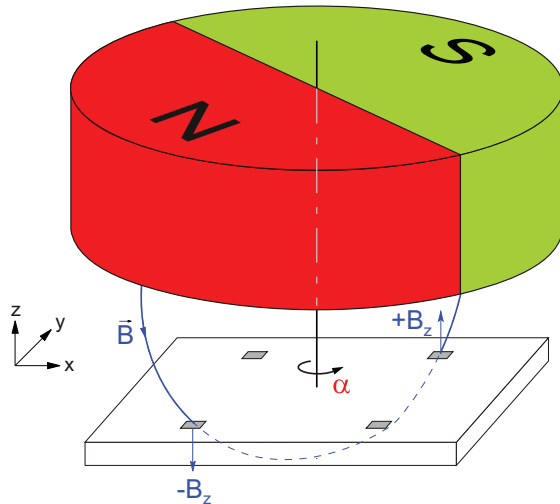


Figure 3: Sensor principle

In conjunction with a rotating permanent magnet, the iC-MH16 module can be used to create a complete encoder system. A diametrically magnetized, cylindrical permanent magnet made of neodymium iron boron (NdFeB) or samarium cobalt (SmCo) provides optimum sensor signals. The diameter of the magnet should be in the range of 3 to 6 mm.

The iC-MH16 has four Hall sensors designed for angle determination and to convert the magnetic field into a measurable Hall voltage. Only the z-component of the magnetic field is evaluated, with the field lines passing through two opposing Hall sensors in the opposite direction. Figure 3 shows an example of field vectors. The arrangement of the Hall sensors is chosen so that a large permissible magnet to iC-MH16 mounting tolerance is achieved. Two Hall sensors combined provide a differential Hall signal. When the magnet is rotated around the longitudinal axis, sine and cosine output voltages are produced which are used to determine the magnet rotation angle.

### POSITION OF THE HALL SENSORS AND THE ANALOG SENSOR SIGNAL

The Hall sensors are placed in the center of the QFN28 package at a 90° angle to one another and arranged in a circle with a diameter of 2 mm as shown in Figure 4.

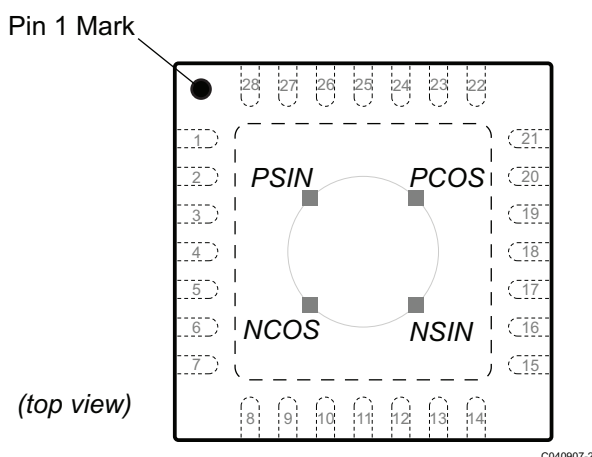


Figure 4: Position of the Hall sensors

In order to calculate the angle position of a diametrically polarized magnet placed above the device a difference in signal is formed between opposite pairs of Hall sensors, resulting in the sine being  $V_{SIN} = V_{PSIN} - V_{NSIN}$  and the cosine  $V_{COS} = V_{PCOS} - V_{NCOS}$ . The zero angle position of the magnet is reached when the resulting cosine voltage value is at a maximum and the sine voltage value is at zero.

This is the case when the south pole of the magnet is exactly above the PCOS sensor and the north pole is above sensor NCOS, as shown in Figure 5. Sensors PSIN and NSIN are placed along the pole boundary so that neither of them generate a Hall signal.

When a magnetic south pole comes close to the surface of the package the resulting magnetic field has a positive component in the +z direction (i.e. from the top of the package) and the individual Hall sensors each generate their own positive signal voltages.

When the magnet is rotated counterclockwise the poles then also cover the PSIN and NSIN sensors, resulting in the sine and cosine signals shown in Figure 6 being produced.

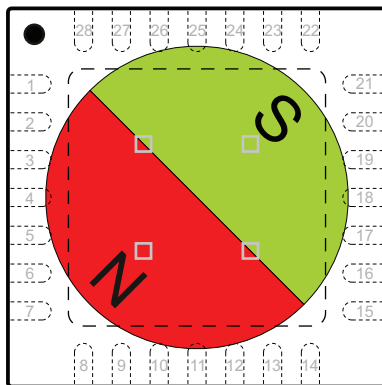


Figure 5: Zero position of the magnet

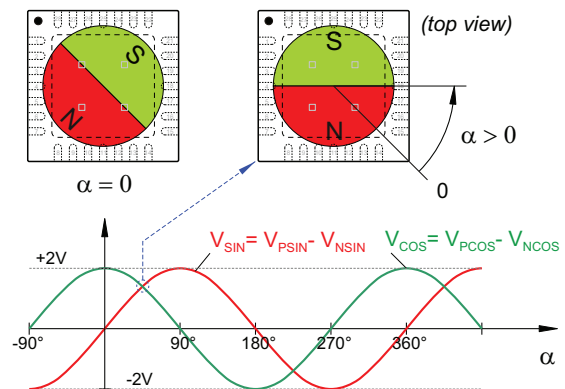


Figure 6: Pattern of the analog sensor signals with the angle of rotation

### HALL SIGNAL PROCESSING

The iC-MH16 module has a signal calibration function for compensating signal and adjustment errors. The Hall signals are amplified in two stages. With the first amplifier stage the field strength within which the Hall sensor is operated is roughly selected. The first amplifier stage can be programmed in the following ranges:

GAING(1:0)		Addr. 0x00; bit 7:6
0x0	5-fold	
0x1	10-fold	
0x2	20-fold	

Table 6: Range selection for Hall signal amplification

The operating range can be specified in advance in accordance with the temperature coefficient and the magnet distance. The integrated amplitude control can vary the signal amplitude between 1 and 20 via the GAINF amplification factor. Should the signal amplitude reach the range limits, a different signal amplification must be selected via GAING.

GAINF(5:0)		Addr. 0x00; bit 5:0
0x00...0x02	1.098	
0x03	1.150	
...	$\exp\left(\frac{\ln(20)}{64} \cdot \text{GAINF}\right)$	
0x3E...0x3F	18.213	

Table 7: Hall signal amplification

The second amplifier stage can be varied in an additional range. With the amplitude control (ENAC = 0x0) deactivated, the amplification setting in the GAINF register is used. With the amplitude control (ENAC = 0x1) activated, the GAINF register bits have no effect.

GCC(6:0)		Addr. 0x01; bit 6:0
0x00	1.000	
0x01	1.0015	
...	$\exp\left(\frac{\ln(20)}{2048} \cdot \text{GCC}\right)$	
0x3F	1.0965	
0x40	0.9106	
...	$\exp\left(-\frac{\ln(20)}{2048} \cdot (128 - \text{GCC})\right)$	
0x7F	0.9985	

Table 8: Amplification calibration cosine

The GCC register is used to correct the sensitivity of the sine channel in relation to the cosine channel. The cosine amplitude can be corrected within a range of approximately  $\pm 10\%$ .

ENAC		Addr. 0x01; bit 7
0x0	amplitude control deactivated	
0x1	amplitude control active	

Table 9: Activation of amplitude control

The integrated amplitude control can be activated with the ENAC bit. In this case the differential signal amplitude is automatically adjusted to 4 Vpp and the setting of GAINF has no effect here.

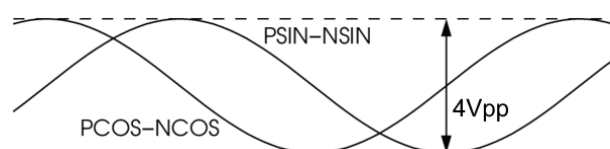


Figure 7: Definition of differential amplitude

After switch-on the amplification is increased until the setpoint amplitude is reached. The amplification is automatically corrected in case of a change in the input amplitude by increasing the distance between the magnet and the sensor, in case of a change in the supply voltage or a temperature change. The sine signals are therefore always converted into high-resolution quadrature signals at the optimum amplitude.

<b>VOSS(6:0)</b>		Addr. 0x02; bit 6:0
<b>VOSC(6:0)</b>		Addr. 0x03; bit 6:0
0x00	0 mV	
0x01	1 mV	
...	...	
0x3F	63 mV	
0x40	0 mV	
0x41	-1 mV	
...	...	
0x7F	-63 mV	

Table 10: Offset calibration for sine and cosine

An offset in the sine or cosine signal can be corrected by the VOSS and VOSC registers. The output voltage can be shifted by  $\pm 63$  mV to compensate for the offset.

<b>HARM-CAL</b>			Addr. 0x0A; bit 4:0
Value	Correction	Angle Error Correction	
0x00	0 LSB	0°	
0x01	1 LSB	0.05°	
...	...	...	
0x0F	15 LSB	0.75°	
0x10	0 LSB	0°	
0x11	-1 LSB	-0.05°	
...	...	...	
0x1F	-15 LSB	-0.75°	

Table 11: Harmonic calibration

After calibration of offset and gain a residual error with four times period remains. This error can be reduced with the calibration parameter HARM-CAL. The mode of operation is shown in Figure 8.

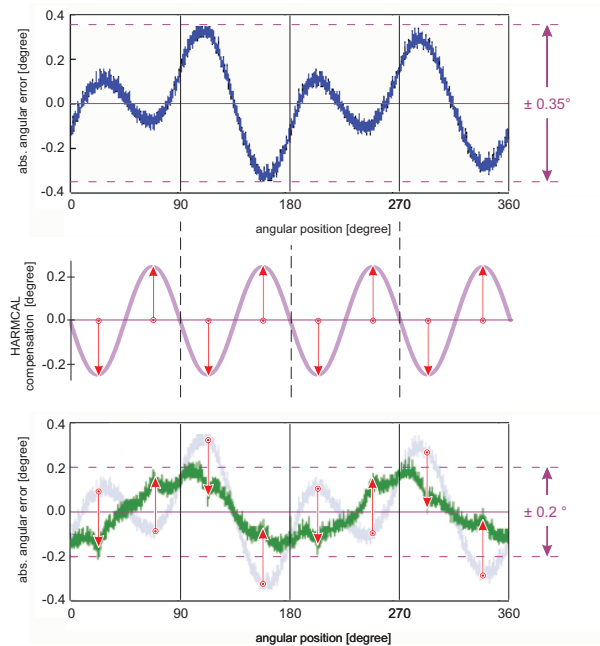


Figure 8: Harmonic calibration

<b>ENF</b>		Addr. 0x02; bit 7
Code	Description	
0x0	16 kHz cutoff frequency	
0x1	3 kHz cutoff frequency	

Table 12: Filter

The amplifier cutoff frequency can be programmed with the parameter ENF.

<b>PRM</b>		Addr. 0x03; bit 7
Code	Description	
0x0	Energy-saving mode deactivated	
0x1	Energy-saving mode active	

Table 13: Energy-saving mode

In the energy-saving mode the current consumption of the Hall sensors can be quartered. This also reduces the maximum rotating frequency by a factor of 4.

<b>CIBM(3:0)</b>		Addr. 0x04; bit 3:0
Code	Description	
0x0	-40 %	
...	...	
0x8	0 %	
0x9	+5 %	
...	...	
0xF	+35 %	

Table 14: Calibration of bias current

The bias current is factory calibrated to 200  $\mu$ A. The calibration can be verified in test mode (TEST = 0x43) by measuring the current from Pin B to Pin VNA.

### TEST MODES FOR SIGNAL CALIBRATION

For signal calibration iC-MH16 has several test settings which make internal reference values and the amplified Hall voltages of the individual sensors accessible at external pins A, B, Z and NA for measurement purposes. This allows observing of the offset (VOSS, VOSS), gain (GAING, GAINF) and amplitude ratio of the cosine to the sine signal (GCC) on the oscilloscope.

Test mode is triggered by connecting pin VZAP to VPD and setting the TEST register (address 0x0E) accordingly. The individual test modes are listed in the following table:

Output signals in test mode					
Mode	TEST	Pin A	Pin B	Pin Z	Pin NA
Normal	0x00	A	B	Z	U
Analog SIN	0x20	HPSP	HPSN	HNSP	HNSN
Analog COS	0x21	HPCP	HPCN	HNCP	HNCN
Analog OUT	0x22	PSIN	NSIN	PCOS	NCOS
Analog REF	0x43	VREF	IBM	VBG	VOSR
Digital CLK	0xC0	CLKD			

Table 15: Test modes and available output signals

The output voltages are provided as differential signals with an average voltage of 2.5 V. The gain is determined by register values GAING and GAINF and should be set so that output amplitudes from the sine and cosine signals of about 1 V are visible.

#### Test modes Analog SIN and Analog COS

In these test modes it is possible to measure the signals from the individual Hall sensors independent of one another. The name of the signal is derived from the sensor name and position. **HPSP**, for example, is the (amplified GAING and GAINF) Hall voltage of sensor **PSIN** at the positive signal path; similarly, **HNCN** is the Hall voltage of sensor **NCOS** at the negative signal path. The effective Hall voltage is accrued from the differential voltage between the positive and negative signal paths of the respective sensor.

#### Test mode Analog OUT

In this test mode the sensor signals are available at the outputs as they are seen internally by the interpolator. The interpolation accuracy which can be achieved is determined by the quality of signals  $V_{sin}$  and  $V_{cos}$  and can be influenced in this particular test mode by the calibration of the offset, gain and amplitude ratio.

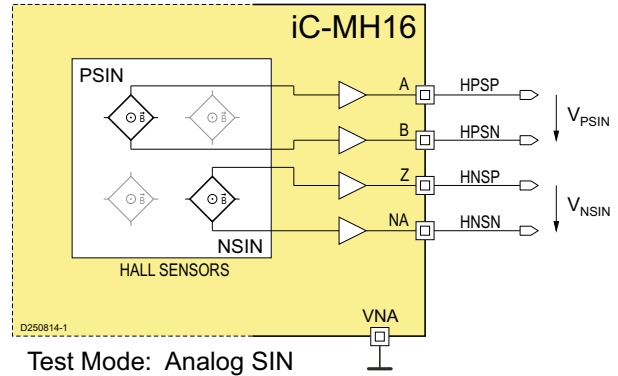


Figure 9: Output signals of the sine Hall sensors in test mode Analog SIN

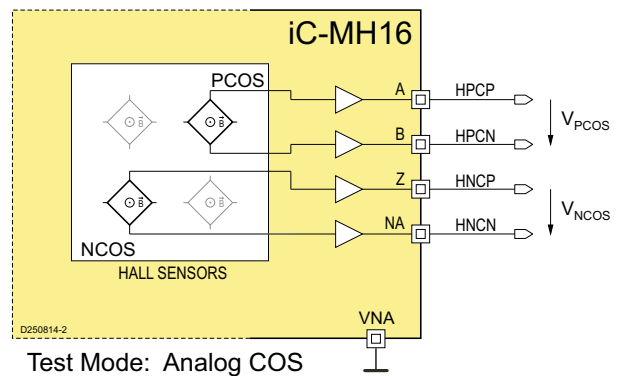


Figure 10: Output signals of the cosine Hall sensors in test mode Analog COS

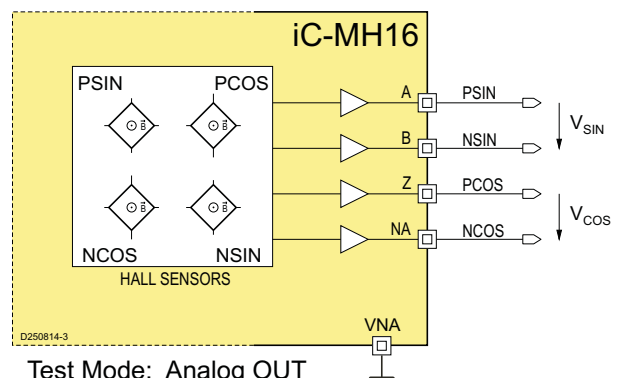


Figure 11: Differential sine and cosine signals in test mode Analog OUT

#### Test mode Analog REF

In this mode various internal reference voltages are provided. VREF is equivalent 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 (1.24 V), with VOSR (0.5 V) used to gener-

# iC-MH16

## 12-BIT ANGULAR HALL ENCODER



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ate the range of the offset settings. Bias current IBM determines the internal current setting of the analog circuitry. In order to compensate for variations in this current and thus discrepancies in the characteristics of the individual iC-MH16 devices (due to fluctuations in production, for example), this can be set within a range of -40 % to +35 % using register parameter CIBM. The nominal value of 200  $\mu$ A is measured as a short-circuit current at pin B to ground.

### Test mode Digital CLK

IF due to external circuitry IBM can not be measured directly it is possible to use clock signal CLKD instead. In this case it should be calibrated to a nominal of 1 MHz via register value CIBM.

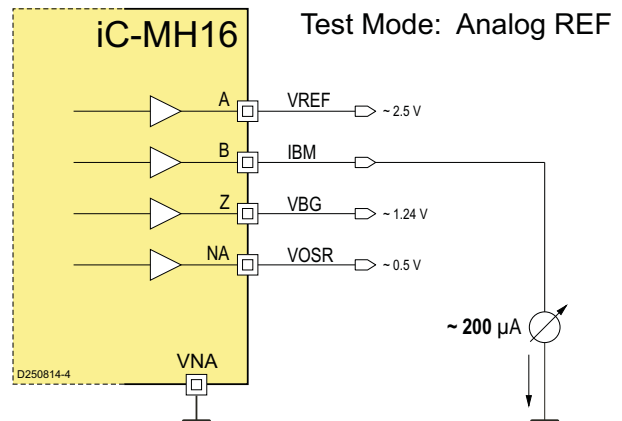


Figure 12: Setting bias current IBM in test mode Analog REF

## CALIBRATION PROCEDURE

The calibration procedure described in the following applies to the optional setting of the internal analog sine and cosine signals and the mechanical adjustment of the magnet and iC-MH16 in relation to one another.

### BIAS setting

The BIAS setting compensates for possible manufacturing tolerances in the iC-MH16 devices. A magnetic field does not need to be present for this setting which can thus be made either prior to or during the assembly of magnet and iC-MH16.

If the optional setup process is not used, register CIBM should be set to an average value of 0x8 (which is equivalent to a change of 0 %). As described in the previous section, by altering the value in register CIBM in test mode Analog REF current IBM is set to 200  $\mu$ A or, alternatively, in test mode Digital CLK signal CLKD is set to 1 MHz.

### Mechanical adjustment

In test modes Analog SIN and Analog COS, iC-MH16 can be adjusted in relation to the magnet. The Hall signals of the individual Hall sensors can be observed while the magnet rotates.

In test mode Analog SIN the output signals of the sine Hall sensors which are diagonally opposite to each other are visible at pins A, B, Z and NA. iC-MH16 and the magnet are then adjusted in such a way that differential signals VPSIN and VNSIN have the same amplitude and a phase shift of 180°. The same applies to test mode Analog COS, where differential signals VPCOS and VNCOS are calibrated in the same manner.

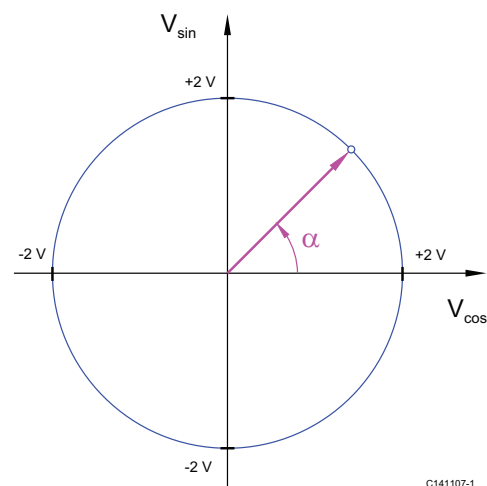


Figure 13: Ideal Lissajous curve

### Calibration using analog signals

In test mode Analog OUT as shown in Figure 6 the internal signals which are transmitted to the sine/digital converter can be tapped with high impedance. With the help of a rotating magnet and an oscilloscope it is possible to portray the differential signals VSIN and VCOS as an x-y graph (Lissajous curve). In an ideal setup the sine and cosine analog values describe a perfect circle, as illustrated by Figure 13.

At room temperature and with the amplitude control switched off (ENAC = 0x0) a rough GAING setting is selected so that at an average fine gain of GAINF = 0x20 (a gain factor of ca. 4.5) the Hall signal amplitudes are as close to 1 V as possible. The amplitude can then be set more accurately by varying GAINF. Variations in the gain factor have no effect on the angle in between VSIN



and VCOS (refer to Figure 14). The angle information fed to the interpolator is maintained.

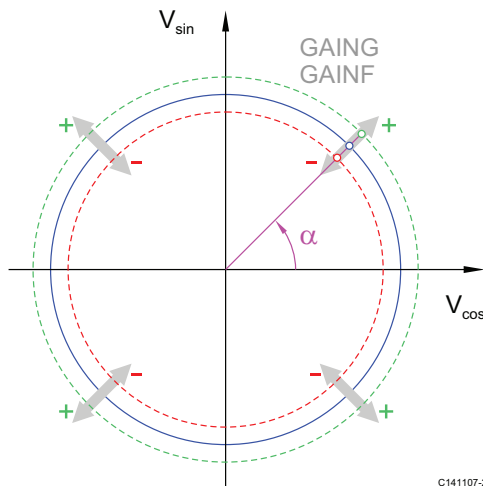


Figure 14: Effect of gain settings GAING and GAINF

Deviations of the observed Lissajous curve from the ideal circle can be corrected by varying the amplitude offset (register VOSS, VOSC) and amplitude ratio (register GCC). Changes in these parameters are described in the following figures 15 to 17.

Each of these settings have a different effect on the interpolated angle value. A change in the sine offset thus has a maximum effect on the angle value at  $0^\circ$  and  $180^\circ$ , with no alterations whatsoever taking place at angles of  $90^\circ$  and  $270^\circ$ . When varying the cosine offset exactly the opposite can be achieved as these angle pairs can be set independent of each other. Setting the cosine/sine amplitude ratio does not change these angles ( $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  and  $270^\circ$ ); however, in-between values of  $45^\circ$ ,  $135^\circ$ ,  $225^\circ$  and  $315^\circ$  can still be influenced by this parameter.

Once calibration has been carried out a signal such as the one illustrated in Figure 13 should be seen.

In the final stage of the process the amplitude control can be switched back on ( $ENAC = 0x1$ ) to compensate for deviations in the signal amplitude caused by variations in the magnetic field due to changes in distance and temperature.

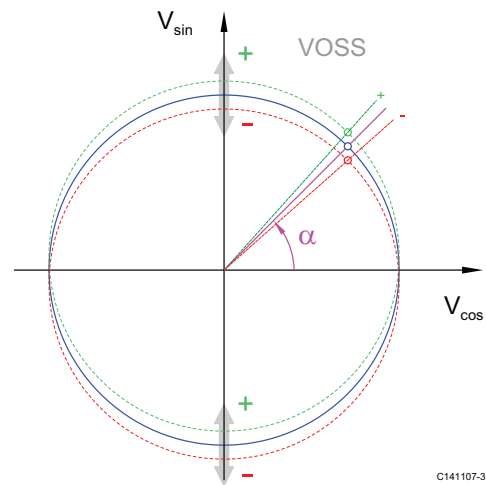


Figure 15: Effect of the sine offset setting

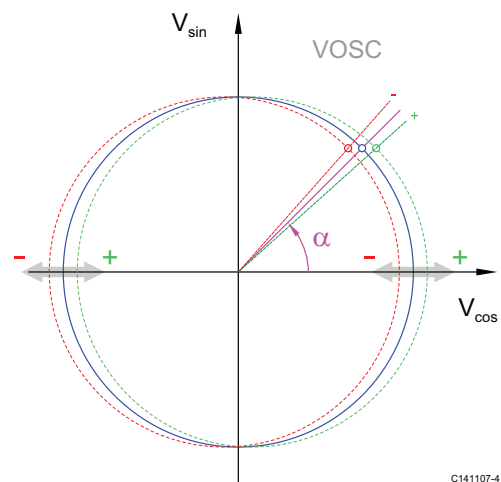


Figure 16: Effect of the cosine offset setting

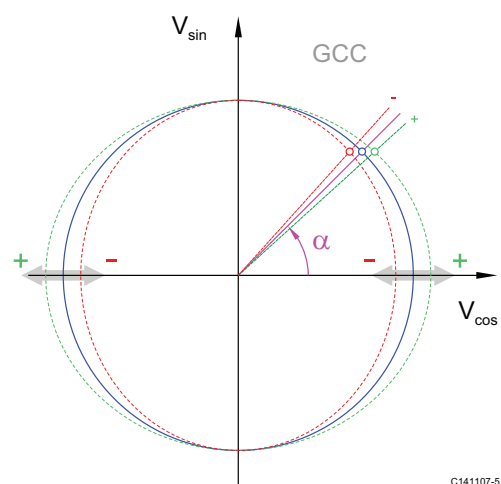


Figure 17: Effect of the amplitude ratio

### Calibration using incremental signals

If test mode cannot be used, signals can also be calibrated using the incremental signals or the values read out via the serial interface. In order to achieve a clear relationship in between the calibration parameters which have an effect on the analog sensor signals and the digital sensor values derived from these, the position of the zero pulse should be set to  $ZPOS = 0x00$  and the rotating direction should be set to  $CFGDIR = 0x00$ , so that the digital signal starting point matches that of the analog signals. Set  $CFGAB = 0x00$ . To achieve good calibration results it is essential that the magnet is rotated at a constant angular speed.

**Note:** For this calibration procedure "PER" refers to one mechanical period (360°).

**Step 1:** Set  $CFGRES = 0x00$  (4 edges per 360° rotation). Adjust  $VOSS$  so that the duty cycle of signal A is at 50%. Then adjust  $VOSC$  so that the duty cycle of signal B is also at 50%. Most modern oscilloscopes offer a measurement function for this.

**Step 2:** Set  $CFGRES = 0x01$  (8 edges per 360° rotation). Adjust  $GCC$  so that the distance in between two adjacent edges of signal A and B is exactly  $PER/8$ . Please refer to Figure 18.

**Step 3:** Set  $CFGRES = 0x03$  (16 edges per 360° rotation). Adjust  $HARMCAL$  so that the duration of the Z Pulse is exactly  $PER/16$ . Please refer to Figure 19.

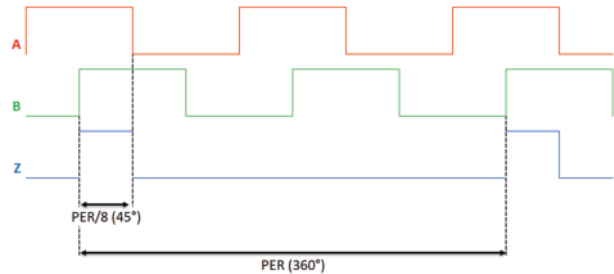


Figure 18: Calibration using incremental signals when rotating clockwise according to Figure 6

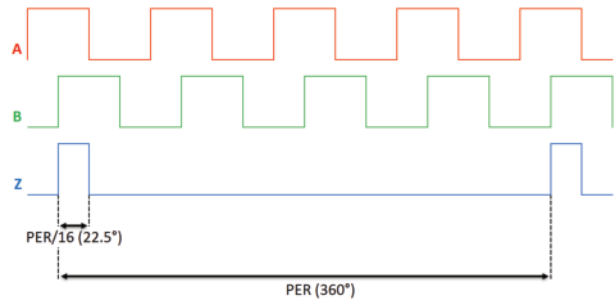


Figure 19: Calibration using incremental signals Calibration using incremental signals when rotating clockwise according to Figure 6

### SINE/DIGITAL CONVERTER

The iC-MH16 module integrates a high-resolution sine/digital converter. In the highest output resolution with an interpolation factor of 1024, 4096 edges per rotation are generated and 4096 angular steps can be differentiated. Even in the highest resolution, the absolute position can be calculated in real time at the maximum speed depending on CFGMTD. After programming a register at address 0x06 and 0x07, a module reset is triggered internally and the absolute position is recalculated.

The resolution of the incremental output signals is programmed with CFGRES. The output of the 12-bit sine/digital converter is available in a resolution correspondent to CFGRES via the serial interface.

CFGRES(7:0)	Addr. 0x06; bit 7:0
CFGRES(9:8)	Addr. 0x07; bit 1:0
0x000	1
0x001	2
...	...
0x07E	127
0x07F	128
...	...
0x0FE	255
0x0FF	256
...	...
0x1FE	511
0x1FF	512
...	...
0x3FE	1023
0x3FF	1024

Table 16: Programming interpolation factor

If the magnet is mounted on top of the chip and turned counter clockwise, then cosine is leading sine and the digital output value increases. For incremental output, A is assigned to sine and B is assigned to cosine.

CFGAB(1:0)	Addr. 0x07; bit 3:2
0x0	A and B not inverted
0x1	A normal, B inverted
0x2	A inverted, B normal
0x3	A and B inverted

Table 17: Inversion of AB signals

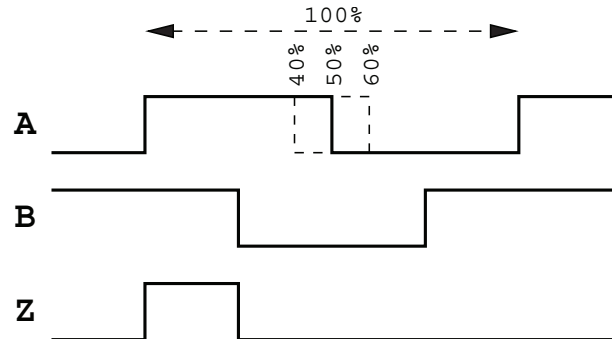


Figure 20: ABZ signals and relative accuracy

The incremental signals can be inverted again independent of the output drivers. As a result, other phase angles of A and B relative to the index pulse Z can be generated. The standard is A and B high level for the zero point, i.e. Z is equal to high.

Figure 20 shows the position of the incremental signals around the zero point. The relative accuracy of the edges to each other at a resolution setting of 10 bit is better than 10%. This means that, based on a period at A or B, the edge occurs in a window between 40% and 60%.

CFGHYS(1:0)	Addr. 0x07; bit 7:6
0x0	0°
0x1	0.17°
0x2	0.35°
0x3	0.7°

Table 18: Programming angular hysteresis

With rotating direction reversal, an angular hysteresis prevents multiple switching of the incremental signals at the reversing point. The angular hysteresis corresponds to a slip which exists between the two rotating directions. However, if a switching point is approached from the same direction, then the edge is always generated at the same position on the output. The following Figure shows the generated quadrature signals for a resolution of 360 edges per rotation (interpolation factor 90) with hysteresis.

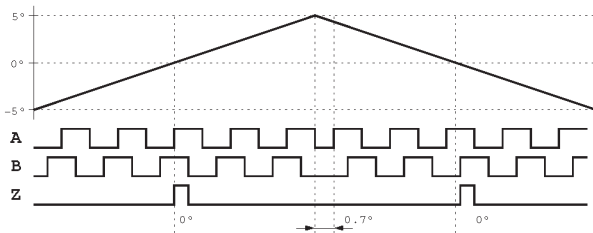


Figure 21: Quadrature signals for rotating direction reversal with hysteresis (CFGDIR = 0)

At the reversal point at  $+10^\circ$ , first the corresponding edge is generated at A. As soon as the angular hysteresis has been exceeded in the other direction, the return edge is generated at A again first. This means that all edges are shifted by the same value in the rotating direction.

CFGZPOS(7:0)	Addr. 0x08; bit 7:0
CFGZPOS(11:8)	Addr. 0x09; bit 3:0
0x0	$0^\circ$
0x1	$0.08^\circ$
0x2	$0.16^\circ$
...	$\frac{360}{4096} \cdot \text{CFGZPos}$
0xFF	$359.9^\circ$

Table 19: Programming zero position

The zero position can be set in  $0.08^\circ$  steps. It is valid for the quadrature and commutation signals. An 12-bit register is provided for this purpose, which can shift the Z-pulse over an angle of  $360^\circ$ .

CFGMTD(1:0)	Addr. 0x05; bit 5:4
0x0	52.6 ns
0x1	105.3 ns
0x2	421.1 ns
0x3	1.68 $\mu\text{s}$
Note:	For $f_{\text{sdC}} = 19 \text{ MHz}$ and highest resolution

Table 20: Minimum edge spacing

CFGMTD(1:0)	Addr. 0x05; bit 5:4
0x0	200 000 rpm
0x1	100 000 rpm
0x2	25 000 rpm
0x3	6 250 rpm
Note:	For $f_{\text{sdC}} = 13.65 \text{ MHz}$ and highest resolution

Table 21: Maximum RPM

The CFGMTD register defines the time in which two consecutive position events can be output at the highest resolution. The default is a maximum output frequency of 500 kHz on A. This means that at the highest resolution, speeds of 25 000 rpms can still be shown correctly.

In the setting with an edge spacing of 62.5 ns, the edges can be generated even at the highest resolution and the maximum speed. However, the counter connected to the module must be able to correctly process all edges in this case. The  $2 \mu\text{s}$  setting can be used for slower counters. However it should be noted that the maximum rotation speed is reduced in this case.

CFGDIR	Addr. 0x07; bit 5
	Increasing position values
0x0	Counterclockwise (Normal)
0x1	Clockwise (Inverted)

Table 22: Rotating direction reversal

The rotating direction can easily be changed with the bit CFGDIR. When set to CCW (counter-clockwise, CFGDIR = 0x0) the resulting angular position values will increase if rotation of the magnet is performed as shown in Figure 6. To obtain increasing angular position values in the CW (clockwise) direction, CFGDIR has to be set to 0x1.

The internal analog sine and cosine signal that are available in test mode are not affected by the setting of CFGDIR. They will always appear as shown in Figure 6.

CFGSU	Addr. 0x07; bit 4
0x0	ABZ output "111" during startup
0x1	AB instantly counting to actual position

Table 23: Configuration of output startup

Depending on the application, a counter might not tolerate generated pulses while the module is being switched on. On power on the current angular position is determined first. During this phase, the quadrature outputs are constantly set to "111". In the setting CFGSU = 0x1, edges are generated at the output until the absolute position is reached. This allows detection of the absolute position with an incremental interface.

The converter for the generation of the commutation signals can be configured for up to 16 pole pair motors. Three rectangular signals with a phase shift of  $120^\circ$  are generated. With a two pole pair setting, the commutation sequence is generated twice per rotation.

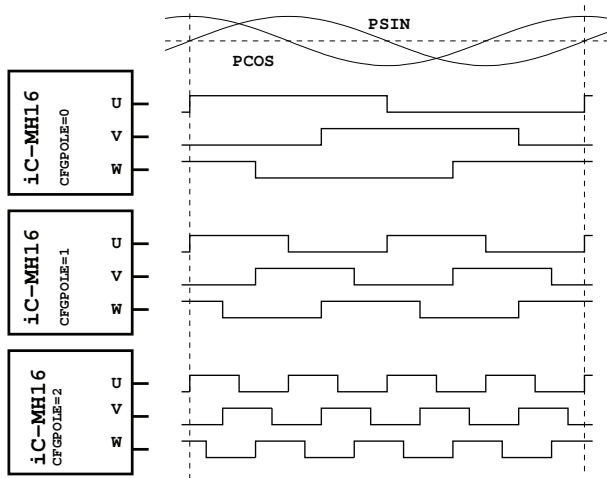


Figure 22: UVW signals for different settings of CFG-COM

CFGCOM(1:0)		Addr. 0x9; bit 7:4
0x0	1 pole pair commutation	
0x1	2 pole pair commutation	
...	...	
0xF	16 pole pair commutation	

Table 24: Commutation

The commutation signals, which have a much shorter latency than the ABZ signals, are synchronized to the

sine/digital converter. For an autonomous and torque optimized motor commutation it is recommended, to deactivate the synchronization with the parameter DCS.

DCS		Addr. 0x5; bit 7
0x0	Commutation signal synchronization enabled	
0x1	Commutation signal synchronization disabled	

Table 25: Synchronization of commutation signals

After changing the direction of rotation, the commutation signal that appears within  $0.7^\circ$  after the reversal point is shifted; the distance between two consecutive transitions is max.  $0.7^\circ$  shorter. No systematical errors occur at constant direction.

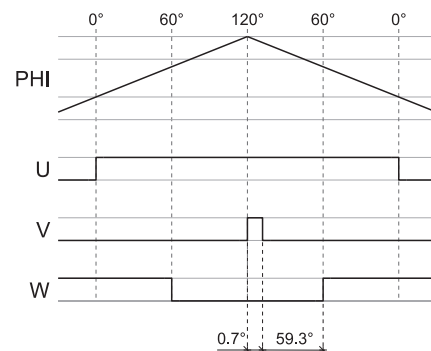


Figure 23: Hysteresis for UVW signals

## OUTPUT DRIVERS

Three RS422-compatible output drivers for the incremental signals **A - NA**, **B - NB** and **Z - NZ** are available.

The configuration of the RS422 driver can be adjusted in the CFGDR register.

CFGDR(1:0)		Addr. 0x05; bit 1:0
0x0	10 MHz 4 mA (default)	
0x1	10 MHz 60 mA	
0x2	300 kHz 60 mA	
0x3	3 MHz 20 mA	

Table 26: Driver property for incremental signals

Highest transmission speed is available in setting 0x00 and 0x01. The driver capability is at least 4 mA, however it is not designed for a  $100\Omega$  line. This mode is ideal for short distance connection to a digital input. With the setting CFGDR = 0x01 the same transmission

speed is available and the driver power is sufficient for the connection to short distance line. Steep edges on the output signals enables a high transmission rate. A lower slew rate is offered by the setting CFGDR = 0x10, which is excellent for longer lines in an electromagnetically sensitive environment. Use of the setting CFGDR = 0x11 is advisable at medium transmission rates.

The following driver output types are available:

TRIHL		Addr. 0x05; bit 3:2
0x0	Push, pull output stage	
0x1	Highside driver	
0x2	Lowside driver	
0x3	Tristate	

Table 27: Tristate Register for incremental signals

### REVERSE POLARITY PROTECTION

The line drivers in iC-MH16 are short-circuit-proof and protected against reverse polarity. A defective connecting cable within the module or an incorrectly connected wire damages neither iC-MH16 nor the devices protected against reverse polarity by VPA, VPD and VNA1, VNA2, VND. The following pins are also protected against reverse polarity: A, B, Z, NA, NB, NZ, U, V, W, MA, SLI and SLO.

Boundary conditions: Pins VNA1, VNA2, VND may only be charged to VPA, VPD. The maximum voltage difference between the pins must not exceed 6 V.

If the reverse polarity feature is not required, pins VPA and VPD have to be connected directly to VDD while VNA1, VNA2 and VND have to be connected to GND.

### SERIAL INTERFACE: BiSS C protocol

The serial interface operates in BiSS C protocol mode and enables sensor data to be output in uninterrupted cycles (data channel SCD). At the same time parameters can be exchanged via bidirectional register communication (data channel CD).

The sensor data produced by iC-MH16 contains the binary coded angle value (ST) with 12 bits, two status bits (nE and nW) and 6 CRC bits (CRC). In case of lower

resolution the angle data is left aligned and filled-up with zero. The low-active error bit nE 0x0 indicates an error which can be further identified by reading the status register. The following bit nW corresponds to the state of the NWARN pad. The status bits are latched, until readout via single cycle data. The 6 CRC bits are calculated over ST(11:0), nE and nW with the polynomial 0x43, the start value zero and inverted transmitted.

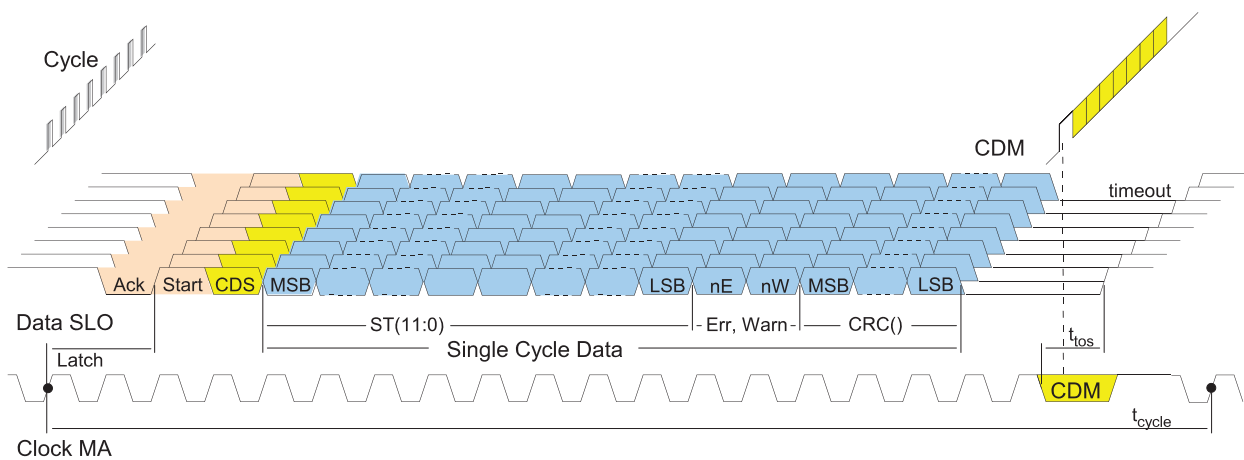


Figure 24: Example line signals (BiSS C)

Single Cycle Data Channel: SCD		
Bits	Typ	Label
12	DATA	Angle data ST(11:0) (singleturn position)
1	ERROR	Error bit nE (low active)
1	ERROR	Warning bit nW (low active)
6	CRC	Polynomial 0x43 $x^6 + x^1 + x^0$ (inverted bit output)

Table 28: BiSS data channels

CFGTOS Adr 0x7C, bit 0			
Code	Clock	Timeout $t_{tos}$	fclk(MA) min*
0x0	19-20	ca. 20 $\mu$ s	50 kHz
0x1	3-4	ca. 3.5 $\mu$ s	300 kHz
ENADAP Adr 0x04, bit 4			
0x0	see CFGTOS	see BiSS specification	50 kHz
0x1	adaptive with $T_{CLK} = \frac{1.33}{f(sys)}$	see BiSS specification	50 kHz
Notes	A ref. clock count is equal to f(sys) (see El. Char., Item No. 501).		

Table 30: Timeout configuration

### Interface Parameters With BiSS C Protocol


ENSSI Adr. 0x05; bit 7		
Code	Protocol	Information
0x0 0x1	BiSS C SSI	 <a href="http://www.biss-interface.com">www.biss-interface.com</a>

Table 29: Protocol version

### Short BiSS Timeout

If the adaptive timeout is not used, iC-MH16 has a short BiSS timeout function regardless of register protection settings according to the description of the BiSS C protocol (see Page 19, Table 2, El. Char., Item No. 6). The timeout can be programmed to a shorter value with the CFGTOS bit. However, this setting is reset to the default value 20  $\mu$ s again following a reset.

### Register Communication

iC-MH16 uses standard BiSS C register mapping with one bank for addresses 0x00 to 0x3F; Bank select is not implemented.

The register range 0x00 to 0x0F is equivalent to the settings with which the IC can be parameterized. The settings directly affect the corresponding switching parts. The range 0x10 to 0x20 is read-only and reflects the contents of the integrated zapping diodes. Following programming the data can be verified via these addresses. After the supply voltage is connected, the contents of the zapping diodes are copied to the RAM area 0x00 to 0x0D and 0x7D to 0x7F. Then the settings can be overwritten via the serial interface. Overwriting is not possible if the CFGPROT bit is set.

With the profile ID, the data format can be requested for the following sensor data cycles in the module. A read operation at address 0x42 results in 0x2C, which is the equivalent to 12-bit single-cycle data. The address 0x43 contains the number of significant singleturn bits R\_ST depending on the resolution. The registers 0x7D to 0x7F are reserved for the manufacturer and can be provided with an ID so that the manufacturer can identify its modules.

The port register at address 0x75 allows read and write access to the ports P0 to P3. The reset value is 0x00.

Px	Addr. 0x75; bit 3:0	0x0
0x0	low	
0x1	high	

Table 31: Port Value

DIRx	Addr. 0x75; bit 7:4	0x0
0x0	input	
0x1	output	

Table 32: Port Direction

The gain register at address 0x76 contains the actual value of the amplitude control. This value multiplied with GAING results in the overall gain.

GAIN(7:0)	Addr. 0x76; bit 7:0
0x00..0x08	1,098
...	$\exp\left(\frac{\ln(20)}{256} \cdot GAIN\right)$
0xF8..0xFF	18,213

Table 33: Hall signal amplification

The status register at address 0x77 provides information on the status of the module. The information resets after reading.

### Internal Reset Function

A write access at RAM address 0x04 to 0x09 triggers an internal reset.

## SERIAL INTERFACE: SSI protocol

In the SSI mode the absolute position is output with 13 bits according to the SSI standard. (The data is transmitted as Gray code with trailing zeros.)

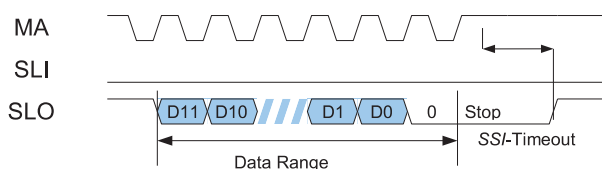


Figure 25: SSI protocol, data GRAY-coded

ENSSI	Addr. 0x05; bit 7
0x0	BiSS C
0x1	SSI

Table 34: Protocol version

Register transfer is not possible in SSI-Mode. The BiSS mode must be forced by applying  $V(VZAP) = V()ZAP$  before changing the value of bit ENSSI to avoid an aborted register communication.

## ERROR HANDLING

Errors in the module are stored in the status message register 0x77 and signaled via the error message output NERR(only ERRAMAX, ERRAMIN and PROGERR). This open-drain output signals an error if the output is pulled against VND. If the error condition no longer

exists, then the pin is released again after a waiting time of approximately 1 ms. If the integrated pull-up resistor is deactivated with DPU = 0x1, then an external resistor must be provided. With DPU = 0x0 it brings the pin up to the high level again.



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DPU		Addr. 0x04; bit 6
0x0		Pull-up activated
0x1		Pull-up deactivated

Table 35: Activation of NERR pull-up

The status register provides information on the status of the module. There are 5 different errors that can be signaled. Following unsuccessful programming of the zapping diodes, the bit PROGERR is set. If an attempt is made to read the current position via the serial inter-

face during the start-up phase, an error is signaled with ERRSDATA, as the actual position is not yet known. The ERRAMAX bit is output to signal that the amplitude is too high, while the ERRAMIN bit signals an amplitude which is too low, caused for example by an excessive magnet to chip surface distance. If the NERR pin is pulled against VND externally, this is also signaled via the serial interface. The ERREXT bit is then equal to 0x1. The error bits are reset after the status register is read out at the address 0x77. The error bit in the data word is then also read in the next cycle as 0x0.

### OTP PROGRAMMING

CFGPROT		Addr. 0x05; bit 6
0x0		no protection
0x1		write/read protection

Table 36: Write/read protection of configuration

ENHC		Addr. 0x0F; bit 7
0x0		Default setting
0x1		ZAP diode testing: Use a higher current for reading the ZAP diodes memory (0x10-0x1F)

Table 37: Enable High Current

With CFGPROT = 0x0, the registers at the addresses 0x00..0x0F, 0x75 and 0x78..0x7F are readable and writable. The addresses 0x10..0x1F, 0x42..0x43 and 0x76..0x77 are read-only. With CFGPROT = 0x1, all registers except the addresses 0x75 and 0x7C are write-protected; the addresses 0x42..0x42 and 0x75..0x7F are readable, while all others are read-protected.

than 6.5V and the test register TEST (2:0) is not set. Following programming, the register is reset internally again. In the process, the bit PROGOK is set in the status register (address 0x77) when programming is successful, and the bit PROGERR if it is not.

The ZAP memory can be tested by reading the register range 0x10-0x20. This test can be done with a higher readout current (bit ENHC = 0x1) to simulate deteriorated working conditions.

For reliable ROM writing, a low impedance connection path as shown in Figure 26 must be established for the VZAP blocking capacitor (about 100 nF) between pin VZAP and pin VNA2 to ensure stable VZAP voltage during programming. A further capacitor of 10 µF which may be located externally (e.g. on the programming board) is recommended for additional blocking purpose.

A typical PCB layout may look like the one shown in Figure 27.

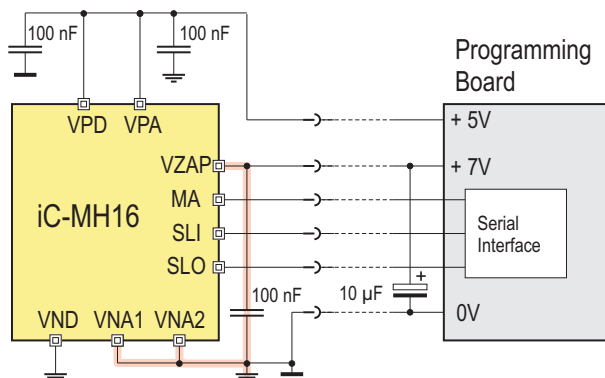


Figure 26: Programming within system

An internal programming algorithm for the ZAP diodes is started by setting the bit PROGZAP. This process can only be successful if the voltage at VZAP is greater

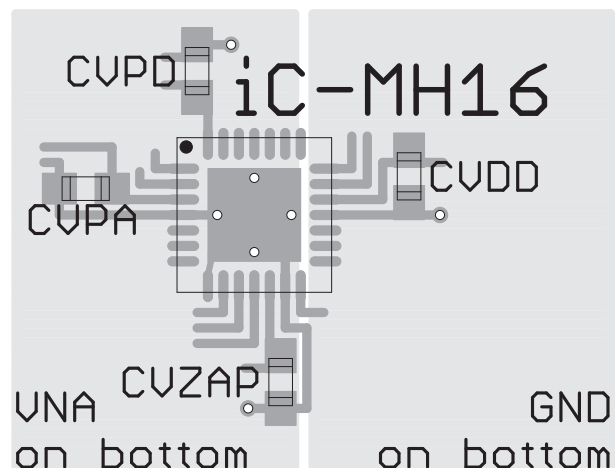


Figure 27: Example PCB layout showing low impedance connection of capacitors to supply voltages (VPA, VPD, VZAP) and common ground

**DESIGN REVIEW: Notes on chip functions**

<b>iC-MH16 Z</b>		
No.	Function, Parameter/Code	Description and Application Hints
1	Commutation signals at U, V, W	May show spurious glitches in non-synchronized mode (parameter DCS = 1) .

Table 38: Notes on chip functions regarding iC-MH16 chip release Z.

<b>iC-MH16 Z2</b>		
No.	Function, Parameter/Code	Description and Application Hints
1	Commutation signals at U, V, W	Glitch-free performance in non-synchronized mode (parameter DCS = 1).

Table 39: Notes on chip functions regarding iC-MH16 chip release Z2.

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### REVISION HISTORY

Rel.	Rel. Date*	Chapter	Modification	Page
A1	2015-05-13	All	Initial Release	all

Rel.	Rel. Date*	Chapter	Modification	Page
B1	2017-10-27	BLOCK DIAGRAM	Colour of block diagram changed to blue	1
		DESCRIPTION	BiSS User Agreement "BUA" added	2
		ELECTRICAL CHARACTERISTICS	Item 002 with additional test condition PRM=0x1 added	6
		REGISTERS	Names OEMA, OEMB, OEMC, OEMD assigned to registers at 0x0A to 0x0D	10
		REGISTERS	Register 0x7B: Revision changed to 0x34 ('4') for design version Z2	11
		SENSOR PRINCIPLE	Fig. 3 with colours reassigned to magnet polarity (red = north pole)	12
		POSITION OF THE HALL SENSORS AND THE ANALOG SENSOR SIGNAL	Fig. 5, Fig. 6: colors reassigned to magnet polarity (red = north pole)	13
		HALL SIGNAL PROCESSING	Table 6 and Table 9: Decimal entries replaced by hexadecimal numbers	13
		CALIBRATION PROCEDURE	Section "Calibration using incremental signals" revised, Figures 18 and 19 updated	18
		SINE/DIGITAL CONVERTER	Tables 20, 21, 22: Decimal entries replaced by hexadecimal numbers	20
		ERROR HANDLING	Table 35: Decimal entries replaced by hexadecimal numbers	25
		OTP PROGRAMMING	Fig. 26 "Programming within system" and Fig. 27 "Example PCB layout.." introduced	25
		Revision History	Revision History introduced	27
		DESIGN REVIEW: Notes on chip functions	Design review for chip designs Z and Z2 introduced	26

Rel.	Rel. Date*	Chapter	Modification	Page
C1	2019-02-13	All	"Preliminary" tag removed on all pages	
		PACKAGES	Recommended connections of PTE and SLI pins added as footnote Text layout of top marking description changed	3

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Type	Package	Options	Order Designation
iC-MH16	QFN28-5x5		iC-MH16 QFN28-5x5

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